



Projects

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Many of the MIT Media Lab research projects described in the following pages are conducted under the auspices of sponsor-supported, interdisciplinary Media Lab centers, joint research programs, special interest groups (SIGs), and initiatives. They include:

Advancing Wellbeing

In contributing to the digital revolution, the Media Lab helped fuel a society where increasing numbers of people are obese, sedentary, and glued to screens. Our online culture has promoted meaningfulness in terms of online fame and numbers of viewers, and converted time previously spent building face-to-face relationships into interactions online with people who may not be who they say they are. What we have helped to create, willingly or not, often diminishes the social-emotional relationships and activities that promote physical, mental, and social health. Moreover, our workplace culture escalates stress, provides unlimited caffeine, distributes nutrition-free food, holds back-to-back sedentary meetings, and encourages overnight hackathons and unhealthy sleep behavior. Without being dystopian about technology, this effort aims to spawn a series of projects that leverage the many talents and strengths in the Media Lab in order to reshape technology and our workplace to enhance health and wellbeing.

With support from the Robert Wood Johnson Foundation (RWJF), Cisco, Deloitte, LKK Health Products Group, and Steelcase, the Media Lab's Advancing Wellbeing initiative addresses the role of technology in shaping our health, and explores new approaches and solutions to wellbeing. The program is built around education and student mentoring; prototyping tools and technologies that support physical, mental, social, and emotional wellbeing; and community initiatives that will originate at the Media Lab, but be designed to scale. Thanks to the Carson Reynolds Memorial Fund for generously funding the video lectures and making them freely accessible around the planet.

Autism & Communication Technology Initiative

The Autism & Communication Technology Initiative utilizes the unique features of the Media Lab to foster the development of innovative technologies that can enhance and accelerate the pace of autism research and therapy. Researchers are especially invested in creating technologies that promote communication and independent living by enabling non-autistic people to understand the ways autistic people are trying to communicate; improving autistic people's ability to use receptive and expressive language along with other means of functional, non-verbal expression; and providing telemetric support that reduces reliance on caregivers' physical proximity, yet still enables enriching and natural connectivity as wanted and needed.

CE 2.0

Most of us are awash in consumer electronics (CE) devices: from cellphones to TVs to dishwashers. They provide us with information, entertainment, and communications, and assist us in accomplishing our daily tasks. Unfortunately, most are not as helpful as they could and should be; for the most part, they are dumb, unaware of us or our situations, and often difficult to use. In addition, most CE devices cannot communicate with our other devices, even when such communication and collaboration would be of great help. The Consumer Electronics 2.0 initiative (CE 2.0) is a collaboration between the Media Lab and its sponsor companies to formulate the principles for a new generation of consumer electronics that are highly connected, seamlessly interoperable, situation-aware, and radically simpler to use. Our goal is to show that as computing and communication capability seep into more of our everyday devices, these devices do not have to become more confusing and complex, but rather can become more intelligent in a cooperative and user-friendly way.

Center for Civic Media

Communities need information to make decisions and take action: to provide aid to neighbors in need, to purchase an environmentally sustainable product and shun a wasteful one, to choose leaders on local and global scales. Communities are also rich repositories of information and knowledge, and often develop their own innovative tools and practices for information sharing. Existing systems to inform communities are changing rapidly, and new ecosystems are emerging where old distinctions like writer/audience and journalist/amateur have collapsed. The Civic Media group is a partnership between the MIT Media Lab and Comparative Media Studies at MIT. Together, we work to understand these new ecosystems and to build tools and systems that help communities collect and share information and connect that information to action. We work closely with communities to understand their needs and strengths, and to develop useful tools together using collaborative design principles. We particularly focus on tools that can help amplify the voices of communities often excluded from the digital public sphere and connect them with new audiences, as well as on systems that help us understand media ecologies, augment civic participation, and foster digital inclusion.

Center for Extreme Bionics

Half of the world's population currently suffers from some form of physical or neurological disability. At some point in our lives, it is all too likely that a family member or friend will be struck by a limiting or incapacitating condition, from dementia, to the loss of a limb, to a debilitating disease such as Parkinson's. Today we acknowledge—and even "accept"—serious physical and mental impairments as inherent to the human condition. But must these conditions be accepted as "normal"? What if, instead, through the invention and deployment of novel technologies, we could control biological processes within the body in order to repair or even eradicate them? What if there were no such thing as human disability? These questions drive the work of Media Lab faculty members Hugh Herr and Ed Boyden, and MIT Institute Professor Robert Langer, and what has led them and the MIT Media Lab to propose the establishment of a new Center for Extreme Bionics. This dynamic new interdisciplinary organization will draw on the existing strengths of research in synthetic neurobiology, biomechatronics, and biomaterials, combined with enhanced capabilities for design development and prototyping.

Community Biotechnology

Humanity's capacity to engineer the living world is a collective concern that requires collective engagement. While synthetic biology has expanded the breadth of technical participation to include a host of engineering disciplines, the next generation of innovators in biotechnology will include diverse communities across cultural, socioeconomic, artistic, and creative domains. The Community Biotechnology initiative is developing tools and technologies to enable the broadest possible participation in biotechnology. Our projects include the creation of low-cost enabling hardware, infrastructure for sharing, and new interfaces for artistic expression with biology.

Digital Currency Initiative

The Internet enabled people to easily call each other without a phone company, send a document without a mail carrier, or publish an article without a newspaper. As a result, more than 2.9 billion people depend on a decentralized communications protocol—the Internet—to more efficiently communicate with one another. Similarly, cryptocurrencies like bitcoin enable permission-less innovation for entrepreneurs and technologists to build world-changing applications that answer the demand for global transactions that has been created by global communication. The Digital Currency Initiative strives to be a neutral leader of world-class research to push the boundaries of knowledge around cryptocurrency and its underlying distributed ledger technology. We seek to clarify the real-world impact of these technologies, inspired by their potential for public good and mindful of the risks and ethical questions attached to them. We act in support of the MIT and open-source cryptocurrency communities and yet are open to collaborating with all sectors of society.

Ethics and Governance of Artificial Intelligence

The development, application, and capabilities of AI-based systems are evolving rapidly, leaving largely unanswered a broad range of important short- and long-term questions related to the social impact, governance, and ethical implications of these technologies and practices. The Berkman Klein Center and the MIT Media Lab, as anchor institutions of the Ethics and Governance of Artificial Intelligence Fund, are conducting evidence-based research to provide guidance to decision-makers in the private and public sectors, and to engage in impact-oriented pilot projects to bolster the use of AI for the public good, while also building an institutional knowledge base on the ethics and governance of AI, fostering human capacity, and strengthening interfaces with industry and policy-makers.

Knowledge Futures Group

The MIT Knowledge Futures Group (KFG), a new joint venture of the MIT Media Lab and the MIT Press, develops and deploys technologies that form part of a new open knowledge ecosystem. The partnership is the first of its kind between a leading publisher and a world-class research lab that promotes and builds change-creating technologies.

ML Learning

Thirty years ago, Media Lab founding faculty member Seymour Papert laid the foundation for a new theory of learning through construction. He created tools for children to be designers and creators, rather than just consumers of technology, positing that learning happens best when people are actively constructing knowledge through creative experimentation and the design of sharable objects. Today, the ML Learning Initiative is built on similar principles and aims to bring the collective creativity to bear on the future of learning.

The ML Learning initiative explores new approaches to learning. We study learning across many dimensions, ranging from neurons to nations, from early childhood to lifelong scholarship, and from human creativity to machine intelligence. The program is built around a cohort of learning innovators from across

the diverse Media Lab groups. We are designing tools and technologies that change how, when, where, and what we learn; and developing new solutions to enable and enhance learning everywhere, including at the Media Lab itself. In addition to creating tools and models, the initiative provides non-profit and for-profit mechanisms to help promising innovations to scale.

Open Agriculture (OpenAg)

The MIT Media Lab Open Agriculture (OpenAG) initiative is on a mission to create healthier, more engaging, and more inventive future food systems. We believe the precursor to a healthier and more sustainable food system will be the creation of an open-source ecosystem of food technologies that enable and promote transparency, networked experimentation, education, and hyper-local production. The OpenAG Initiative brings together partners from industry, government, and academia to develop an open source "food tech"? research collective for the creation of the global agricultural hardware, software, and data commons. Together we will build collaborative tools and open technology platforms for the exploration of future food systems.

Open Ocean

The ocean is vast. It covers more than 70% of the surface of our planet and holds 97% of the water on Earth. The ocean is exciting. We swim, surf, dive, and play in it. We romanticize pirates, dream of merfolk, and love to be frightened of sea monsters. The ocean is critical. We rely on the sea for food, energy, and environmental protection. And yet, the ocean remains mysterious. Only 15% of the seafloor has been mapped by modern methods, and perhaps 5% has ever been seen by human eyes. The Open Ocean initiative works at the intersection of science, technology, art, and society to design and deploy new ways to understand the ocean and connect people to it in novel ways, empowering a global community of explorers. Together, we will discover the unknown, the extremes, and the wonder of the sea—because the ocean is for everyone.

Space Exploration

The public grand opening of Space draws near. Much as biology has witnessed an explosion of DIY biohacking in recent years, the dropping costs of space launches and cubesats enable a new mode of engagement in Low Earth Orbit (LEO) and beyond. What was once an exclusive, expensive and narrowly serious pursuit begins to thaw. With the dawn of "New Space," a burgeoning group of private, commercial space companies excites a new philosophy of involvement with space technology. Space will be hackable. Space will be playful. Space will be accessible to the space enthusiast—through the reach of their DIY instruments, experiments, sensors and satellites, and eventually through space tourism. This opportunity to design our interplanetary lives beckons to us. Our mission is to design a life worth living up there. We aim to drive innovation at the frontiers of space exploration, from the holy grail of "life in space" to widespread societal involvement in "open space." Humanity stands on the cusp of interplanetary civilization and space is our next, grand frontier. While many organizations already tackle, quite effectively, the engineering and scientific challenges, the Media Lab is distinct in its freedom to imagine bold visions that venture beyond the rational constraints of most academic grants. We'll prototype provocative space architectures, new communication networks, and astro-bacteria wearables. We'll open-source payload designs and repurpose existing satellites—and deploy! Our collective creativity strives to bring science fiction to life. Space may not be our final frontier, but should be our next.

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Fadel Adib: Signal Kinetics

Extending human and computer abilities in sensing, communication, and actuation through signals and networks

1. **Health Sensing using Wireless Signals**

Fadel Adib

Today's health sensors (which monitor breathing, heartbeats, steps, etc.) require their users to wear them on their bodies. In contrast, our technologies can monitor human health without requiring the user to wear any device on his/her body. To do so, we capture and analyze wireless signals reflected off the human body; we then use these reflected signals to extract breathing and heartbeats without any physical contact with the human body. We are currently exploring techniques to remotely sense additional health metrics like blood pressure, oxygen saturation, and glucose levels. Monitoring these health metrics can render ICU (intensive care unit) vital sign monitors completely noninvasive and enable continuous monitoring of diabetes patients.

2. **In-Vivo Networking: Powering and communicating with tiny battery-free devices inside the body**

Fadel Adib, Zhihong Luo, Yunfei Ma, Giovanni Traverso (MIT Koch Institute, Harvard Medical School, Brigham & Women's Hospital) Christoph Steiger (MIT Koch Institute, Harvard Medical School, Brigham & Women's Hospital)

In-Vivo Networking (IVN) is the new technology that can wirelessly power and communicate with tiny devices implanted deep within the human body. Such devices could be used to deliver drugs, monitor conditions inside the body, or treat disease by stimulating the brain with electricity or light.

The implants are powered by radio frequency waves, which are safe for humans. In tests in animals, we showed that the waves can power devices located 10 centimeters deep in tissue, from a distance of one meter.

3. **Programming Wireless Networks (Computer Networks)**

Fadel Adib

Wireless networks—consisting of WiFi, LTE, RFIDs, and millimeter-wave devices—have become integral parts of our everyday lives. Our research explores how we can make these networks faster, more robust, and seamlessly mobile. It also explores how we can use these networks for purposes other than communication, such as localization, sensing, and control.

4. **RFind: Extreme localization for billions of items**

Fadel Adib, Yunfei Ma, Nicholas Selby

Presenting RFind, a new technology that allows us to locate almost any object with extreme accuracy by transforming low-cost, battery-free wireless stickers into powerful radars. At a high level, our technology operates by measuring the time it takes the signal to travel from the wireless sticker to an access point. By taking into account the speed of propagation of light, we can then map the time to an exact location (with sub-centimeter precision) in 3D space.

5. **RFIQ: Food quality and safety detection using wireless stickers**

Fadel Adib, Unsoo Ha, Junshan Leng, Yunfei Ma

We have developed a wireless system that leverages the inexpensive RFID tags already on hundreds of billions of products to sense potential food contamination. Our system, called RFIQ (Radio Frequency IQ), aims at democratizing food quality and safety, bringing it to the hands of consumers.

6. **RFly: Drones that find missing objects using battery-free RFIDs**

Fadel Adib, Yunfei Ma, Nicholas Selby

Can drones find missing items? Every year, companies lose billions of dollars due to misplaced items and faulty inventory records in their warehouses. Consider that the smallest Walmart warehouse is larger than 17 football fields, making it impossible to keep track of all items in the warehouse.

To overcome this challenge, we introduce RFly, a drone-based wireless system that can scan and locate items in warehouses. The system leverages cheap, battery-free RFID (Radio Frequency Identifier) stickers, which are attached to every item in the warehouse similar to barcodes. These RFIDs power up and respond with a unique identifier when commanded by a wireless device called a reader. To scan a warehouse, a drone operator dispatches a small, inexpensive, and safe drone which flies throughout a warehouse, cataloging and localizing all the RFIDs in a warehouse. The video below shows how the system operates.

7. **Seeing Through Walls**

Fadel Adib

Our group develops technologies that can see through walls and perform motion capture through occlusions. To do so, we rely on wireless signals, like WiFi. These signals traverse walls and reflect off humans behind the wall before returning to a wireless receiver. We design and develop new algorithms and software-hardware systems that can extract these signals and analyze them to capture human motion from behind a wall.

8. **TurboTrack: 3D Backscatter Localization for Fine-Grained Robotics**

Fadel Adib, Zhihong Luo, Yunfei Ma

TurboTrack is a 3D localization system for fine-grained robotic tasks, with unique capability to localize backscatter nodes with sub-centimeter accuracy without any constraints on their locations or mobility. We showed that TurboTrack can work in multiple collaborative applications with robotic arms and nanodrones including indoor tracking, packaging, assembly, and handover.

This research is partially funded by the National Science Foundation (NSF) and a Google Faculty Research Award.

9. **Wireless Communication from Underwater to the Air**

Fadel Adib, Junsu Jang, Francesco Tonolini

Did you know that submarines today still cannot wirelessly communicate with airplanes? For decades, communicating between underwater and the air has remained an unsolved problem. Underwater, submarines use acoustic signals (or SONAR) to communicate; in the air, airplanes use radio signals like cellular or WiFi. But neither of these signals can work across both water and air.

We present TARF (Translational Acoustic-RF communication), the first technology that enables communication between underwater and the air. A TARF transmitter sends standard sound (or SONAR signals). Sound travels as pressure waves; when these waves hit the surface, they cause it to vibrate. To pick up these vibrations, a TARF receiver in the air uses a very sensitive radar. The radar transmits a signal which reflects off the water surface and comes back. As the water surface vibrates, it causes small changes to the received radar signal, enabling a TARF receiver to sense the tiny vibrations caused by the underwater acoustic transmitter.

The video below explains how TARF works and some of its applications.

V. Michael Bove: Object-Based Media

Changing storytelling, communication, and everyday life through sensing, understanding, and new interface technologies

10. **3D Telepresence Chair**

Daniel Novy

An autostereoscopic (no glasses) 3D display engine is combined with a "Pepper's Ghost" setup to create an office chair that appears to contain a remote meeting participant. The system geometry is also suitable for other applications, such as tabletop or automotive heads-up displays.

11. **4K/8K Comics**

V. Michael Bove, Daniel Novy

4K/8K Comics applies the affordances of ultra-high-resolution screens to traditional print media such as comic books, graphic novels, and other sequential art forms. The comic panel becomes the entry point to the corresponding moment in the film adaptation, while scenes from the film indicate the source frames of the graphic novel. The relationships among comics, films, social media, parodies, and other support materials can be navigated using native touch screens, gestures, or novel wireless control devices. Big data techniques are used to sift, store, and explore vast catalogs of long-running titles, enabling sharing and remixing among friends, fans, and collectors.

12. **8K Time Machine**

V. Michael Bove, Hisayuki Ohmata (NHK), Yukiko Oshio (NHK)

Archived TV programs evoke earlier times. This application combines a video and music archive with an immersive screen and a simple user interface suitable for everyone, from children to the elderly, to create a "Time Machine" effect. The only key for exploring is the user's age. People can enjoy over 1,300 TV programs from the last seven decades without having to do tedious text searches. This catalogue intuitively guides the user with an image array (64 different videos on one screen at the same time) that simplifies navigation and makes it immediate, rather than referencing it to previous screens.

13. **Aerial Light-Field Display**

V. Michael Bove, Daniel Novy, Henry Holtzman (Samsung NExD Lab)

Suitable for anywhere a "Pepper's Ghost" display could be deployed, this display adds 3D with motion parallax, as well as optically relaying the image into free space such that gestural and haptic interfaces can be used to interact with it. The current version is able to display a person at approximately full-size.

14. **AirTap**

V. Michael Bove, Ali Shtarbanov

We demonstrate a method for augmenting existing visual interfaces, including 3D and conventional displays, with haptic feedback capabilities, by utilizing a large number of closely spaced vortex-ring generators mounted along the periphery of the display. We present our first prototype of a multimodal interactive interface platform with 16 independently-controlled air-vortex ring generators with one angular degree of freedom each. Our system has applications as an interactive interface, as a research tool, as an automotive control interface, and as a platform for creative expressions.

15. **ArtBoat**

Laura Perovich

ArtBoat is a tool for communities to make collaborative light paintings in public spaces and reimagine the future of their cities. Visit our project website at artboatcommunity.com.

ArtBoat consists of a remote control boat with light strips that change color in response to a custom light design board. During ArtBoat events, community members can drive remote controlled boats, control the color of lights on the boats, or take long exposure photographs to make collaborative light graffiti that explores how art can help communities claim public spaces.

Our first ArtBoat community event was on July 29, 2018 at Magazine Beach Park in Cambridge, MA. Thanks to our Magazine Beach host Cathie Zusy, our photographers Jorge Valdez (IG: jorgelvma), Ron Hoffmann (IG: archiscapes.us), Neil Gaikwad (IG: Neil Gaikwad Photography), Garance Malivel, and Jimmy Day, our boat facilitators, and our participants. Our second ArtBoat event was on September 22, 2018 at Herter Park Amphitheater in Boston, MA, as part of the 15th anniversary Revels RiverSing!

If you'd like to join our mailing list to find out about future ArtBoat events, email artboat@lauraperovich.com or fill out this form.

ArtBoat is a sister project of SeeBoat. It is an open source project licensed under GPLv2 and Creative Commons.

16. **Atmopragmascope**

Everett Lawson

We are surrounded by displays and technologies whose mechanisms are hidden from view. This work is an exploration of revealing the underlying mechanisms of not only how we generate and parse visual information but how it can be delivered. The design process and its outcomes are derivatives, in part, of the mechanics of the eye which guide our estimation of a "fair curve." Working within the parameters of 19th-century tools and techniques, I adopted the perspective of research modalities relevant for a time in which the eye and low-level visual mechanisms for discerning thresholds, edges, and shapes were the dominant tools in the creation of experimentation. Modern design and engineering tools—while enabling increasingly complex and sophisticated research—can also obfuscate the fundamentals of form and function. By minimizing the influence of technological aides, we give our vision in the act of creation, the articulation of this machine intended to give form to the fundamental algorithms inherent in early biological visual processing.

Process album:

<https://photos.app.goo.gl/ybEyqelWtOugMXd73>

17. **BigBarChart**

V. Michael Bove, Laura Perovich

BigBarChart is an immersive, 3D bar chart that provides a new physical way for people to interact with data. It takes data beyond visualizations to map out a new area--data experiences--that are multisensory, embodied, and aesthetic interactions. BigBarChart is made up of a number of bars that extend up to 10 feet to create an immersive experience. Bars change height and color in response to interactions that are direct (a person entering the room), tangible (pushing down on a bar to get meta information), or digital (controlling bars and performing statistical analyses through a tablet). BigBarChart helps both scientists and the general public understand information from a new perspective. Early prototypes are available.

18. **Bottles&Boxes: Packaging with Sensors**

V. Michael Bove, Daniel Novy

We have added inexpensive, low-power, wireless sensors to product packages to detect user interactions with products. Thus, a bottle can register when and how often its contents are dispensed (and generate side effects, like causing a music player to play music when the bottle is picked up, or generating an automatic refill order when near-emptiness is detected). A box can understand usage patterns of its contents. Consumers can vote for their favorites among several alternatives simply by handling them more often.

19. **Calliope**

V. Michael Bove, Edwina Portocarrero, Ye Wang

Calliope was designed by building on the lessons learnt from the NeverEnding Drawing Machine. Rather than a static system that lives indoors, Calliope was inspired by the portability of "en plein air" painting and the pochade box that made it possible. Thinking of "the world as your palette," Calliope is a portable, paper-based platform for interactive, networked story making which allows physical editing of shared digital media at a distance. With Calliope, we shrank the size and cost by using a system of mirrors and the availability of pocket projectors. We were also interested in exploring the difference between a system that allowed "from many to many" collaboration to a more intimate "one to one" design. Like the Never-Ending Drawing Machine, Calliope is composed of networked "creation-stations" that seamlessly blend analog and digital media which uses the page-turning book format to synchronize networked co-creation.

When using the Never-Ending Drawing Machine, we noticed people had trouble pressing the "big red button" since their hands were mostly busy. Calliope substituted the button for a pedal to be pressed. Unlike the Never-Ending Drawing Machine, Calliope uses human-readable tags, designed as dominoes, which can be drawn directly onto the paper with a marker by the user.

One of the most valuable outcomes of blending analog and digital media, was the ability to save every version, allowing to then explore the process of creation. The NEDM though did not have a way that the user could access this without having to interface with the computer's file system. For Calliope, we designed a tag which, upon placing it over the desired page, lets you see all the versions that came before the last one. Furthermore, Calliope now can record audio! When the "rooster" tag is placed, one can record onto that page and play back, extending the palette to the aural realms. The intention remains: to offer opportunities for cross-cultural and cross-generational collaboration among peers with expertise in different media.

20. **Consumer Holo-Video**

V. Michael Bove, Bianca Datta, Sunny Jolly, Nickolaos Savidis, Daniel Smalley (BYU)

The goal of this project, building upon work begun by Stephen Benton and the Spatial Imaging group, is to enable consumer devices such as tablets, phones, or glasses to display holographic video images in real time, suitable for entertainment, engineering, telepresence, or medical imaging. Our research addresses real-time scene capture and transmission, computational strategies, display technologies, interaction models, and applications.

21. **Cosmetic Light**

Nina Lutz, Vik Parthiban

From skin to light: an artistic dialog between cosmetics, lasers, and lighting between the human and microscopic scale.

Cosmetics essentially diffract and scatter light in a way that makes the wearer appear different to the naked eye. In this project we propose an illumination grammar between cosmetic projects and coherent light lasers, as a suggestion for alternative interior lighting as well as artistic effect and expression. From skin to light, we explore these artistic archetypes.

22. **Cosmetics-Empowered Identities**

V. Michael Bove, Nina Lutz

What if we could leverage technology and modern cosmetics for good? To empower people to explore identities? To give anyone, regardless of skill level, the tools to bend, express, and explore various gender identities and traits?

The goal of this project is to create a tool that will allow a user to add more feminine, masculine, or androgynous traits to themselves with cosmetics. After interacting with renders and the tool's preferences, the user will receive a list of cosmetics and then follow along with the tool in real time while they apply their makeup.

This tool is meant to be accessible, to be free and open source technology, and made for users of all skin tones, shapes, and preferences. To allow anyone to express their identities.

This work is ongoing and will have regular updates, beta releases, and user surveys coming soon.

23. **design(human)design**

Philippa Mothersill

design(human)design is a tool that builds on insights about the design process inspired by research carried out at IDEO Cambridge. The idea is that there are a few design "variables" that designers play with, and that they often like to provoke their creativity with "random but purposeful" inspirations—which present the designer with a random selection of design variables to act as a "structured serendipitous" creative prompt.

design(human)design comprises a deck of cards that act as a creative game to prompt new design ideas. The deck consists of sets of cards containing examples of each of the design variables, e.g. an object, an app, a book, etc., for the artifact design variable. Designers randomly select a card from each of the variable sets and create their design inspired by the MadLibs-style prompt sentence construct. Blank cards for each of the variables are also included so that designers can add their own examples.

To make the complete and selective randomization and personalization of the variables even easier, an interactive design(human)design website was created at designhumandesign.media.mit.edu. The list of design variables are contained in a Google Spreadsheet that again can be added to by designers to customise their prompts.

24. **Designing Robots in Mixed Reality**

Vik Parthiban, Andrew Spielberg, MIT CSAIL

This is a joint proposal from graduate students Vik Parthiban (Media Lab) and Andrew Spielberg (MIT CSAIL, Distributed Robotics Laboratory).

With the release of the Magic Leap Creator and Leap Motion NorthStar platform for new mixed-reality and augmented-reality applications, we propose a new computer-aided design (CAD) tool for simulating and deploying robots. Our goal is to better understand locomotion in 3D space and diagnose character movement under multiple constraints.

We will develop the "Magic Leap Design and Control Toolbox," a suite of new interactive algorithms and implementations to directly build structures within the environment using captured information about the world. A new system for gesturing the desired path or degrees of freedom of an object will automatically translate the gestures into robot and character control inputs. The system will be based on algorithms that synthesize natural gestural control based on the desired motion.

25. **Dressed in Data**

V. Michael Bove, Laura Perovich

This project steps beyond data visualizations to create data experiences. It aims to engage not only the analytic mind, but also the artistic and emotional self. In this project, chemicals found in people's bodies and homes are turned into a series of fashions. Quantities, properties, and sources of chemicals are represented through various parameters of the fashion, such as fabric color, textures, and sizes. Wearing these outfits allows people to live the data—to experience tangibly the findings from their homes and bodies. This is the first project in a series of works that seek to create aesthetic data experiences that prompt researchers and laypeople to engage with information in new ways.

26. **DUSK**

V. Michael Bove, Bianca Datta

DUSK was created as part of the Media Lab's Advancing Wellbeing initiative (supported by the Robert Wood Johnson Foundation) to create private, restful spaces for people in the workplace. DUSK promotes a vision of a new type of "nap pod," where workers are encouraged to use the structure on a daily basis for regular breaks and meditation. The user is provided with the much-needed privacy to take a phone call, focus, or rest inside the pod for short periods during the day. The inside can be silent, or filled with binaural beats audio; pitch black, or illuminated by a sunlamp; whatever works for users to get the rest and relaxation needed to continue to be healthy and productive. DUSK is created with a parametric press-fit design, making it scalable and suitable for fabrication customizable on a per-user basis.

27. **Emotive Materials**

V. Michael Bove, Bianca Datta

The design process is no longer limited to one group of individuals, as number, level, and cost make tools ever more accessible. As we move towards tools that allow us to create our own materials, having a set of rules with which to evaluate, interpret, and design them will become increasingly important. One way of approaching this problem is by unpacking the ways in which materials create meaning. This project explores the more emotive aspects of materials, such as haptic responses to, cognitive evaluation of, and emotive perception of materials to understand how materials communicate meaning. The development of an effective methodology aims to lower the barriers of fabrication of engaging objects. By incorporating qualities that were not previously quantifiable, we aim to encourage a more interactive design process that allows for the production of experiences tailored to individual preference, and a framework for conversations around material issues.

28. **EmotiveModeler: An Emotive
Form Design CAD Tool**

V. Michael Bove, Philippa Mothersill

Whether or not we're experts in the design language of objects, we have an unconscious understanding of the emotional character of their forms. EmotiveModeler integrates knowledge about our emotive perception of shapes into a CAD tool that uses descriptive adjectives as an input to aid both expert and novice designers in creating objects that can communicate emotive character.

29. **Everything Tells a Story**

V. Michael Bove

Following upon work begun in the Graspables project, we are exploring what happens when a wide range of everyday consumer products can sense, interpret into human terms (using pattern recognition methods), and retain memories, such that users can construct a narrative with the aid of the recollections of the "diaries" of their sporting equipment, luggage, furniture, toys, and other items.

Emily Salvador

Motivation

The need for inexpensive, reliable 3D, 360-degree display technologies grows as augmented reality applications continue to increase in popularity. There is room for innovation in the field, as many volumetric displays have moving components, are prohibitively expensive, aren't 360-degree, or some combination of those factors. By creating a 360-degree autostereoscopic display that is cost-effective and reliable, we could expand the audience who would benefit from collaborative, interactive experiences. Additionally, while augmented reality headsets are increasingly popular, a volumetric display readily encourages accessible, collaborative interaction without separating users by wearable technology. This technology could impact a variety of industries and demographics as the connected media landscape continues to expand.

Approach - Hardware

This system is comprised on three main components. First, a 4K monitor displays properly distorted, lenticularized content using a custom shader. That light-field information is then partitioned by a refracting medium, either a radial lenticular array or a holographic optical element. After the rays of light from the pixels bend through the refracting medium, the rays then bounce off the conical mirror, producing the proper image for each viewing angle.

Hardware - Radial Lenticular

The radial lenticular design is dictated by several parameters which all trade-off with one another. For the design of this lenticular, I plan to focus on maximizing the resolution and size of the image rendered in the cone, while also maintaining a reasonable number of viewing angles. Variables that can be changed include the number of cameras (which corresponds to the number of discreet viewing zones), the number of views per lenticular slice, and the number of times a particular sequence of views should repeat. Those variables dictate the minimum viewing radius size, the angular size of each lenticular slice, the angle of influence for each viewing zone and the size of the image rendered in the cone. It is important to consider what a user can reasonably see reflected in the cone, before the rays no longer bounce back to the user.

Resolution is one over the number of views per each lenticular wedge. As the user moves radially around the display, the rendered views that are opposite the user (i.e. on the other side of the radial mirror) cannot be seen. Because of this assertion that the user doesn't need to see all of the potential views from a static position, radial lenticulars operate differently than linear lenticulars. With a linear lenticular, every view that will be displayed needs to exist under every lenticular lens for the effect to work. For example, if there are 8 potential images lenticularized, there would be a slice of each of those 8 views underneath each lenticular lens. However, with this setup, it is not

necessary to produce every view under every lenticular lens because each lenticular lens only needs to display the views that the user could potentially see from that lens. Because of that, there is a rolling priority system for which views to display under each lenticular lens. If the user is standing directly in front of where a viewing zone is located for a particular image, the lenticular lenses closest to the user should have that view centrally located under the lenticular. The lenticulars that are adjacent to that area should still have information that can reach the user, however the views have to shift to accommodate the off-axis position. In that way, there is a rolling priority system, where the generated view that is closer to the user will appear centrally under the lenticular lens and incrementally move off-center and eventually disappear as the user moves radially around the display.

Hardware - Interactivity

For hardware integration for interactivity, I plan to use Intel Realsense cameras, microphones and arduino powered LEDs that all communicate with Unity. There is a plugin to use Intel Realsense in the unity environment, along with libraries that allow for more detailed signal processing and pose analysis. I will use serial messaging in unity to send message to the arduino that will control the LEDs that will wrap around the housing of the device. The LEDs will be used to indicate important signals to users. Those signals include that the system can see the user and whether the user appears to be engaging as well as can signal when the program is performing a request that requires time. Additionally, I will use unity to receive and process microphone inputs.

Software - Custom Shader

Unity has built in support for creating complex shaders that can be applied real-time. In Unity, I will write a shader that appropriately partitions the views based on the number of cameras in the scene, the number of views per each lenticular lens, and the number of times each sequence of views should repeat. Before the views can be lenticularized the media from the camera must be rotated around the display to match where it will physically appear on the reflected cone. If you don't do this step, all of the views will be rendered on top of each other, resulting in an incorrect result. By rotating the views to their appropriate

location, the imagery you should see when standing on the left of the display will appear on the left and same for all other

directions. After the views have been rotated to the appropriate location, each of the camera's views are sliced and reordered within the shader to produce the lenticularized result.

Software - Interactivity

Intel Realsense and similar depth sensing devices like Kinect and Leap Motion provide SDKs that allow developers to readily stream depth and color data into Unity. The Intel Realsense data can be further processed and interpreted using software like Nuitrack to do skeleton tracking which exposes body pose and joint positions. This can be used to allow the system to know when a user is close enough to the display or standing a particular place. This is good for gesture tracking as well. The color data from the Intel Realsense camera can be processed in OpenCV which has a Unity SDK. With OpenCV, the color data can be analyzed for object detection, face detection and recognition and face pose analysis. This allows the system to recognize objects, people and face pose (which could be used to interpret affective state). Face and gaze detection could be used in lieu of trigger words like "OK Google" and "Alexa" as presumably the users have intent to interact with the system if they're looking at the character/sensors.

The sound recordings are used to detect volume, pitch and speech. The speech is analyzed using a cloud-based service, which then streams the input and a response back to unity to influence how the character animates and responds. The speech analysis could be used to interpret special assigned words to trigger activities, games or special animations or content in the display. The response generated by the cloud-service can be used to animate the characters mouth if the character audibly responds to users. The coupling of depth/RGB data and audio allow for more nuanced understanding of a user's intent and affective state. In combination, this could be used to drive sympathetic animations from the character. Because the RGB data allows for face recognition, the character can potentially store information about users to be retrieved whenever that user interacts with the system.

Software - Procedural Character

I chose an animated dog character as the embodied representative for several key affordances. The face and body of this character have already been rigged and those parameters are accessible in Unity. The design of the character is ideal for this system and for expressing emotion because the head size is large relative to the body and the facial features of the character are contrasted which will read better with this device. Additionally, because this character is familiar and has recognizable physical embodiments of emotion, the user will more readily understand key animation poses. For example, if the character is happy, it will wag its tail and stick out its tongue, but if it's nervous or upset, it will put its head and ears down. Based on the signals received and processed from the Intel Realsense camera and microphone, the dog character will animate. Those inputs will impact the character's emotional pose, LookAt() behavior and special animation sequences.

Evaluation

The ultimate goal of this project is to produce a low-cost, reliable, 3D, 360-degree autostereoscopic display. I will visually inspect the hardware/software implementation to determine if the desired 360-degree display is produced and measure the specifications of this display to other closely related devices. I will evaluate our software/hardware implementation by creating test patterns to discretize each individual view zone. Additionally, we will perform user studies to verify that the interaction system is intuitive and engaging.

User Study

The questions I'd like to answer about this project lie at the intersection of the affordances of the display itself and the media users can interact with. Because I'm designing a procedural character for this display, I want to explore believability and engagement through the user study as well as whether placing a character in-situ in a space impacts user experience. The nearest neighbor devices for the study will be an AR headset and a 2D monitor. In this individual-use user study, participants will engage in activities that evaluate the character's ability to engage. The participants will complete a close ended warm-up task both meant to acclimate and provide a concrete objective. After the warm-up task is completed (e.g. playing catch), the participants will be asked to engage in a more exploratory capacity with the character on each of the displays. The activity will involve engaging the character's LookAt() behavior, object detection, face-pose detection, speech recognition, and visual accessories (like the LED light-strip). The order in which the participants use each display will be randomized to avoid conflating intuitive use with prior experience with the activity they're asked to compete.

If this device were to become commercially viable, it would have to be accessible for a wide variety of ages and expertise level. Because of that, I will look for a diverse group of participants with varying degrees of prior experience with technologies like video games, AR/VR, and voice assistants. As I design and implement features for my project, I will carefully prioritize scope that builds towards the user-study experience.

Future Work

If the radial lenticular works optimally, it would be amazing to explore a portable version of this novel volumetric display. Because the optical elements of this device have no moving parts and are lightweight, this display would be a great candidate for portability. It'd be fascinating to expand on the AI character's capabilities by adding context aware infrastructure that changes how the character responds depending on localized metadata curation.

Ethically, this technology has the potential to make volumetric displays incredibly accessible at scale, because both the mylar cone and radial lenticular would cost less than one dollar to fabricate when productized. This would severely reduce cost on a market where displays typically cost thousands of dollars per unit.

31. **Guided-Wave Light Modulator for Holographic Video**

V. Michael Bove, Bianca Datta, Sunny Jolly, Nickolaos Savidis, Daniel Smalley (BYU)

We are developing inexpensive, efficient, high-bandwidth light modulators based on lithium niobate guided-wave technology. These full-color modulators support hundreds of thousands of pixels per scan line, making them suitable for fixed or wearable holographic displays.

32. **Hover**

Pedro Colon-Hernandez

We designed, implemented, and tested a proof of concept, wrist-based wearable object identification system which allows users to "hover" their hands over objects of interest and gain access to contextual information that is tied to them, through an intelligent personal assistant. The system uses a fusion of sensors to be able to perform the identification of an object under a variety of conditions. Among these sensors, there is a camera (operating in the visible and infrared spectrum), a small solid-state radar, and multi-spectral light spectroscopy sensors. Users can interact with contextual information tied to an object through conversations with an intelligent assistant to permit a hands-free, non-obtrusive, and discreet experience. The system explores audio interfacing with augmented reality content without the hassle of phones or head-mounted devices.

33. **Infinity-by-Nine**

V. Michael Bove, Daniel Novy

We are expanding the home-video viewing experience by generating imagery to extend the TV screen and give the impression that the scene wraps completely around the viewer. Optical flow, color analysis, and heuristics extrapolate beyond the screen edge, where projectors provide the viewer's perceptual vision with low-detail dynamic patterns that are perceptually consistent with the video imagery and increase the sense of immersive presence and participation. We perform this processing in real time using standard microprocessors and GPUs.

34. **Large User Interface with Gesture and Voice Feedback**

Vik Parthiban, Ashley Lee, Allen Lee

LUI is a new human-computer interface for interactive media on large screens and AR/VR platforms. It utilizes voice and gestures to naturally control UI elements such as maps, photos, and YouTube. This operating system removes the boundary introduced by remotes and controllers and hopes to be a standard for large screens and heads-up displays in self-driving cars. The user can imagine "opening the hand" to separate the display into multiple windows, or asking Google to pull up your favorite photo or places to eat nearby.

For more information, contact graduate researcher Vik Parthiban at vparth@mit.edu.

Advisors

V. Michael Bove, Director, Object-Based Media group

John Underkoffler, CEO, Oblong Industries; Scientific advisor, Minority Report and Iron Man interface

35. **ListenTree: Audio-Haptic Display in the Natural Environment**

V. Michael Bove, Joseph A. Paradiso, Gershon Dublon, Edwina Portocarrero

ListenTree is an audio-haptic display embedded in the natural environment. Visitors to our installation notice a faint sound emerging from a tree. By resting their heads against the tree, they are able to hear sound through bone conduction. To create this effect, an audio exciter transducer is weatherproofed and attached to the tree's roots, transforming it into a living speaker, channeling audio through its branches, and providing vibrotactile feedback. In one deployment, we used ListenTree to display live sound from an outdoor ecological monitoring sensor network, bringing a faraway wetland into the urban landscape. Our intervention is motivated by a need for forms of display that fade into the background, inviting attention rather than requiring it. We consume most digital information through devices that alienate us from our surroundings; ListenTree points to a future where digital information might become enmeshed in material.

36. **Live Objects**

V. Michael Bove, Arata Miyamoto, Valerio Panzica La Manna

A Live Object is a small device that can stream media content wirelessly to nearby mobile devices without an Internet connection. Live Objects are associated with real objects in the environment, such as an art piece in a museum, a statue in a public space, or a product in a store. Users exploring a space can discover nearby Live Objects and view content associated with them, as well as leave comments for future visitors. The mobile device retains a record of the media viewed (and links to additional content), while the objects can retain a record of who viewed them. Future extensions will look into making the system more social, exploring game applications such as media "scavenger hunts" built on top of the platform, and incorporating other types of media such as live and historical data from sensors associated with the objects.

37. **Living Materials Library**

V. Michael Bove, Neri Oxman, Bianca Datta, Sunanda Sharma

The control of living systems as part of design interfaces is of interest to both the scientific and design communities due to the ability of living organisms to sense and respond to their environments. They may, for example, detect and break down harmful environmental agents, or create beneficial products when environmental levels dropped below a certain threshold. However, it is also important for these systems to be reversible, so that the biological components are only active when their functionality is necessary, and the system can remain dormant otherwise.

The Living Material Library is an exploration of tunable hybrid systems. Our work in this area demonstrates the means through which intrinsic material properties may be functionally changed through environmental factors and, in turn, serve as dynamic substrates for living systems. Nearly all organisms have highly developed sensing capabilities, and have been shown to behaviorally respond to changes in substrate properties. By creating a tunable and reversible material system, we explore how cell behavior such as adhesion, patterning, and differentiation may be influenced via an active interface.

In this iteration, we propose a reversible material system that allows for control of living interactions (much like a light switch). We are particularly interested in fluid material systems (such as electrorheological fluids) that transition from a liquid-like to a solid-like state when exposed to electric fields and currents.

This endeavor brings to light the complex relationship between dynamic materials and living systems. While other methods of cell intervention often rely on light, chemicals, or temperature, here we explore substrate material properties as inputs for organisms. Our library may allow for more directed inquiry into processes such as collective cell durotaxis, general mechanotaxis, and active sensing. This marks an initial foray into establishing candidate design methods for responsive applications.

38. **Micronauts**

Caroline Rozendo

Microbes are the foundation upon which life on Earth depends: they set the boundaries of habitability for all plants and animals and create half of the oxygen we breathe. Ocean-dwelling microbes regulate the global climate and could hold the secrets to the origin of life. Put simply, we wouldn't be here without microbes, yet most people don't realize how ubiquitous and important they are.

The Micronauts project builds an emotional bridge over this gap. Microscopic creatures are, by definition, typically hidden from view, and the challenge of seeing them and perceiving their importance prevents emotional involvement and investment. Through an immersive experience built around scientific discoveries, visitors—"Micronauts"—will venture into the dynamic world of ocean microbes. A responsive, large floor projection will illuminate the frantic business of the microorganisms, as they go about their daily business of finding food, reproducing, transforming chemicals, and breathing metals.

The Micronauts journey was exhibited for the first time during the 2018 National Ocean Exploration Forum—All Hands on Deck on November 8 + 9 at the MIT Media Lab.

39. **ModeSense**

V. Michael Bove, Ali Shtarbanov

ModeSense is a full stack system that enables indoor environments to become aware of what is happening in them, and then enables the environment to locally inform (offline) all nearby phones and other electronic devices about the most appropriate operating mode in the present time and space. We have developed an ultra-low cost, \$5 device that can be installed in conference rooms, lecture halls, movie theaters, homes, and cars, which can dynamically determine the contexts in those areas and then locally broadcast the corresponding mode. Any phones in those areas are then aware of the mode in which they ought to be at that time, and can change their behavior accordingly.

40. **Narratarium**

V. Michael Bove, Catherine Havasi, Kasia Hayden, Daniel Novy, Jie Qi

Narratarium augments printed and oral stories and creative play by projecting immersive images and sounds. We are using natural language processing to listen to and understand stories being told, and analysis tools to recognize activity among sensor-equipped objects such as toys, then thematically augmenting the environment using video and sound. New work addresses the creation and representation of audiovisual content for immersive story experiences and the association of such content with viewer context.

41. **Networked Playscapes: Dig Deep**

V. Michael Bove, Edwina Portocarrero

Networked Playscapes re-imagines outdoor play by merging the flexibility of the digital world with the tangible, sensorial properties of physical play to create hybrid interactions for the urban environment.

Dig Deep takes the classic sandbox found in children's playgrounds and merges it with the common fantasy of "digging your way to the other side of the world" to create a networked interaction in tune with child cosmogony.

42. **Open Water Data**

Laura Perovich, Sara Wylie (Northeastern University), Roseann Bongiovanni (GreenRoots), and ECO (GreenRoots)

The Open Water Data project explores data physicalization as a path to community engagement and action on important environmental issues. For our 2018 installation Chemicals in the Creek, we released glowing lanterns representing water quality permit violations from local facilities onto the river as part of a performance of local environmental challenges that informed a community conversation on these issues.

See our website for pictures from the events and more information about the project: datalanterns.com.

This project is a collaboration between the MIT Media Lab (Laura Perovich), Northeastern University (Sara Wylie), and GreenRoots (Roseann Bongiovanni and ECO).

43. **PerForm**

Caroline Rozendo, Jaleesa Trapp, Irmandy Wicaksono, Rhunzou Ye

"Music is not limited to the world of sound. There exists a music of the visual world."
—Oskar Fischinger, 1951.

Almost 70 years ago, when the German-American animator and film-maker Oskar Fischinger created musically inspired animations and works of art, he touched on the intuitive associations our minds make between all the different sensory stimuli received from the environment.

While the psychology of perception has been widely explored in the context of visual technology, visual-auditory associations remain mostly underexplored in the field. There is strong evidence, though, that our brains forge relationships between shapes and seemingly correspondent sounds.

PerForm explores one possibility of how the associations between visual and auditory perception can be used in interaction design. We developed a physical interface that users can transform by bending to create geometric shapes or symbols. Those shapes can then be played as percussion instruments of different sound frequencies, directly related to the shape created.

This deformable interface is responsive to shaking, enabling users to manipulate it as a percussion instrument. For the future, we envision the possibility of enabling the creation of more complex shapes, which would enable specific modes of interaction—piano, winds, and metals, for example.

44. **Pigments and Lumens**

V. Michael Bove, Nina Lutz, Samantha Seaman - Design and Fabrication Assistance
CAMIT - Funded in part by a Director's Grant from the Council for the Arts at MIT
Additional thanks to: Bianca Datta - Microscope photography Furless Cosmetics - Donating pigments for experiments

This pedagogy of experiments seeks to accurately model and manufacture a new form of lighting fixtures.

These new fixtures are made of polyester resin and a particle distribution called a colloid. Unlike traditional light bulb models, rather than having illumination come from individual lighting fixtures that are wired to a common electric source, we are using one lighting source in the form of a laser to illuminate each fixture.

By using controlled resin casting alongside numerical simulation of structured colloids, we can program and evaluate different substances held in distribution with a 9 dimensionality lighting model. This allows us to understand the type of lighting output that can be achieved with various materials and shapes, as well as predict the aesthetic properties that these lighting sources may allow us. From various colors to different glittery reflects, this framework allows both technical and artistic framework.

45. **Pillow-Talk**

V. Michael Bove, Edwina Portocarrero

Pillow-Talk is a set of connected objects intended to assist in the capture and recall digitally stored dreams and memories via natural and tangible interfaces. It consists of two devices, one of which is a pillow embedded with a voice recorder that is activated upon squeezing together several conductive patches at the corner of the pillow. This interaction minimizes the steps necessary to record a fresh memory of a dream immediately upon awakening. After the dream is recorded into the pillow, the audio file is transmitted wirelessly to a jar containing shimmering LEDs to display the "capture" of a new memory, and electronics in the jar can play back the recordings through a small speaker under its lid when it is opened.

46. **PlusMinus**

V. Michael Bove, Kevin Esvelt, Iyad Rahwan, Danielle Wood, Ethan Zuckerman, Hildreth England
Ride-sharing, social media, artificial intelligence. These are examples of socially-beneficial, net-positive technologies that have shown us the dark side of a move-fast, break-things ethos. In visible or invisible ways, these technologies have also had unexpectedly—and disproportionately—negative impacts on some of society's most vulnerable citizens.

PlusMinus provides both a structure for Media Lab researchers to work with members and other outside collaborators on impact and equity issues, and a force for changing our internal culture to bring these considerations more consciously into our design and evaluation processes. As part of the Media Lab's continuing investigation into complex, adaptive systems, PlusMinus is...

Equipping future technologists with the space, community, and skills to reflect on, critique, and inclusively design technologies for equitable, positive social impact before, during and after they're deployed.

Examining—in collaboration with member companies and sponsors—how to radically re-cast design processes both inside the Lab and outside it, to improve our collective understanding of the pluses and minuses of the technologies shaping our lives.

We envision a community of PIs, research staff, and students who concentrate their research on PlusMinus issues—exploring how the benefits of their research might be distributed equitably across society if projects were to be scaled up, how to evaluate ongoing research for early hints of possible trouble, and how to mitigate negative impacts should they appear.

47. **Printed Wearable Holographic Display**

V. Michael Bove, Bianca Datta, Sunny Jolly, Nikolaos Savidis, Daniel Smalley (BYU)

Holographic displays offer many advantages, including comfort and maximum realism. In this project we adapt our guided-wave light-modulator technology to see-through lenses to create a wearable 3D display suitable for augmented or virtual reality applications. As part of this work we also are developing a femtosecond-laser-based process that can fabricate the entire device by "printing."

48. **Programmable Synthetic Hallucinations**

V. Michael Bove, Daniel Novy

We are creating consumer-grade appliances and authoring methodologies that will allow hallucinatory phenomena to be programmed and utilized for information display and narrative storytelling.

49. **QuietSense: Distributed Context-Awareness System for WiFi Enabled Mobile Devices**

V. Michael Bove, Ali Shtarbanov

What if our mobile devices could sense and then adapt to the spatial, temporal, and social context of their local environments? Imagine if your smartphone was smart enough to know that it should not be ringing loudly when you are in an important meeting, or that it should not be in silent mode when you are trying to find where you have misplaced it at home. We have created an inexpensive secure system that delivers this goal by embedding contextual information into the environment rather than the phone. In that way, all mobile devices at a given location can detect the broadcasted contextual information using WiFi and change their behavior accordingly, without requiring any handshake or internet connection. By leveraging the latest and most inexpensive WiFi modules on the market, and by building our own embedded firmware, server-side software, and mobile app, we are able to deploy this system in a secure and massively scalable way.

50. **SeeBoat (Thermal Fishing Bob): In-Place Environmental Data Visualization**

V. Michael Bove, Laura Perovich, Don Blair, Sara Wylie (Northeastern University)

Two of the most important traits of environmental hazards today are their invisibility and the fact that they are experienced by communities, not just individuals. Yet we don't have a good way to make hazards like chemical pollution visible and intuitive. SeeBoat and the thermal fishing bob seek to visceralize rather than simply visualize data by creating a physical data experience that makes water pollution data present in communities.

SeeBoat is a remote control boat with sensors (temperature, turbidity, conductivity, pH) that measure local water quality and LEDs that display the data on site by changing color in real time. Data is also logged to be physically displayed elsewhere and can be further recorded using long-exposure photos. Making environmental data experiential and interactive will help both communities and researchers better understand pollution and its implications.

The Thermal Fishing Bob is an early version of this tool that has a spherical form factor and focuses on measuring water temperature as a marker for combined sewer overflows (CSOs) that may pollute rivers.

This project began in partnership with Sara Wylie (Northeastern University) in Spring 2015. Early work included Thermal Fishing Bob workshops, design iteration, prototyping, system testing with users in the Mystic River and Charles River, long exposure photography events, and further concept development. In Spring of 2017, Perovich and Wylie began a collaboration with Roseann Bongiovanni of GreenRoots, an environmental justice community group in Chelsea, MA, to test and iterate on the devices so they best suit the environmental and social context in the local community. As part of this process, Perovich continued to develop the technical side of the project to create SeeBoat, a remote control boat based system, including sensors for turbidity, conductivity, pH, radio based data communication, and designs for and early implementation of an Android app for collecting and viewing quantitative sensor data. Perovich, Wylie, and Bongiovanni are also pursuing related routes of research and community engagement around open access environmental data, the politics of space, community based data installations, and evaluating individual and group learning through extended participatory action research projects.

A publication describing their first year of collaboration can be found in their paper:

Laura J. Perovich, Sara Wylie, Roseann Bongiovanni (2018) Pokémon Go, pH, and projectors: Applying transformation design and participatory action research to an environmental justice collaboration in Chelsea, MA, *Cogent Arts & Humanities*, 5:1, 1-22, <https://www.tandfonline.com/doi/pdf/10.1080/23311983.2018.1483874>.

In July of 2018, the team began to collaborate with high school students and staff at the Microsoft Garage Makerspace to test the ease of fabrication of SeeBoat in a more general audience and to continue development of the SeeBoat Android app for numeric data display.

Thanks to ECO, David Ortiz, Adela Gonzalez, Leo Martinez, GreenRoots staff, Don Blair, Catherine D'Ignazio, the Boston University Law Clinic, and Dr. Sharon Harlan for their support and input on this project. Thanks to MIT undergraduates Sophia Struckman, Rod Bayliss, Robert Henning, and Claudia Chen who contributed to the technical aspect of these workshops and citizen science tool development, photographers Jorge Valdez and Shirin Adhami, the Wylie Lab at Northeastern University, Dr. V. Michael Bove and members of the Object-Based Media group at the MIT Media Lab, the MIT Arts Scholars, the Public Lab community, Mare Librum, the MIT Sailing Pavilion, and the Council for the Arts at MIT.

51. **ShAir: A Platform for Mobile Content Sharing**
V. Michael Bove, Yosuke Bando, Henry Holtzman, Arata Miyamoto
ShAir is a platform for instantly and easily creating local content-shareable spaces without requiring an Internet connection or location information. ShAir-enabled devices can opportunistically communicate with other mobile devices and optional pervasive storage devices such as WiFi SD cards whenever they enter radio range of one another. Digital content can hop through devices in the background without user intervention. Applications that can be built on top of the platform include ad-hoc photo/video/music sharing and distribution, opportunistic social networking and games, digital business card exchange during meetings and conferences, and local news article-sharing on trains and buses.
52. **Slam Force Net**
V. Michael Bove, Daniel Novy
A basketball net incorporates segments of conductive fiber whose resistance changes with degree of stretch. By measuring this resistance over time, hardware associated with this net can calculate force and speed of a basketball traveling through the net. Applications include training, toys that indicate the force and speed on a display, dunk competitions, and augmented-reality effects on television broadcasts. This net is far less expensive and more robust than other approaches to measuring data about the ball (e.g., photosensors or ultrasonic sensors) and the only physical change required for the hoop or backboard is electrical connections to the net. Another application of the material is a flat net that can measure velocity of a ball hit or pitched into it (as in baseball or tennis); it can measure position as well (e.g., for determining whether a practice baseball pitch would have been a strike).
53. **Smell Narratives**
V. Michael Bove, Carol Rozendo
We are adding an olfactory dimension to storytelling in order to create more immersive and evocative experiences. Smell Narratives allows the authoring of a "smell track," involving individual or proportionally mixed fragrance components.
54. **SurroundVision**
V. Michael Bove, Santiago Eloy Alfaro
Adding augmented reality to the living-room TV, we are exploring the technical and creative implications of using a mobile phone or tablet (and possibly also dedicated devices like toys) as a controllable "second screen" for enhancing television viewing. Thus, a viewer could use the phone to look beyond the edges of the television to see the audience for a studio-based program, to pan around a sporting event, to take snapshots for a scavenger hunt, or to simulate binoculars to zoom in on a part of the scene. Recent developments include the creation of a mobile device app for Apple products and user studies involving several genres of broadcast television programming.
55. **The 8K Data Manipulator**
Pedro Colon-Hernandez
The 8K Data Manipulator is a Unity game engine application which harnesses the gesture recognition and limb tracking available through Microsoft Kinect and combines it with the multitouch capability of our 8K display. Using either gesture at a distance or close-up touch, a user can rotate, zoom, and slice a very large graphical dataset. The 8K Data Manipulator is currently being used to visualize seismic data; however, it is capable of loading an arbitrary point cloud or volume, supporting medical, terrestrial, biochemical, social network, design, and other applications.
56. **Where's Pedro?**
Pedro Colon-Hernandez
An 85-inch television screen combined with 8K resolution provides a tool through which multiple users can perform quick, highly detailed, visual analysis of a dataset to identify anomalies. In order to test this, we developed a fully 3D application similar to the popular picture game Where's Waldo. In the Where's Waldo game, users must find a person (Waldo) within a densely-populated picture. In the developed application, users utilize touch and gestures to navigate a large 3D city in which a person of a varying size is placed randomly. The application serves as a proof of concept that multiple users can interact with one large, high resolution dataset to visually find anomalies.

Edward Boyden: Synthetic Neurobiology

Revealing insights into the human condition and repairing brain disorders via novel tools for mapping and fixing brain computations

57. **8K Brain Tour**

V. Michael Bove, Edward Boyden, Shoh Asano, Yosuke Bando, Takahito Ito, Mika Kanaya

We present an 8K (7680 x 4320 pixels) visualization system for terabyte-scale, three-dimensional microscopy images of a brain slice that can facilitate neuroscience research. High resolution, large format (85" or 188 cm x 106 cm) rendering allows the viewer to dive into the massive dataset of 700 billion voxels capturing thousands of neurons and to investigate nanoscale and macroscale structures of the neurons simultaneously.

58. **Cognitive Integration: The Nature of the Mind**

Edward Boyden, Kevin Slavin, Joscha Bach, Adam Marblestone

While we have learned much about human behavior and neurobiology, there is arguably no field that studies the mind itself. We want to overcome the fragmentation of the cognitive sciences. We aim to create models and concepts that bridge between methodologies, and can support theory-driven research. Among the most interesting questions: How do our minds construct the dynamic simulation environment that we subjectively inhabit, and how can this be realized in a neural substrate? How can neuronal representations be compositional? What determines the experiential qualities of cognitive processes? What makes us human?

59. **Implosion Fabrication**

Edward Boyden, Fei Chen, Daniel Oran, Paul Tillberg
Shrinking problems in 3D printing

Although a range of materials can now be fabricated using additive manufacturing techniques, these usually involve assembly of a series of stacked layers, which restricts three-dimensional (3D) geometry. Oran et al. developed a method to print a range of materials, including metals and semiconductors, inside a gel scaffold (see the Perspective by Long and Williams). When the hydrogels were dehydrated, they shrunk 10-fold, which pushed the feature sizes down to the nanoscale.

Lithographic nanofabrication is often limited to successive fabrication of two-dimensional (2D) layers. We present a strategy for the direct assembly of 3D nanomaterials consisting of metals, semiconductors, and biomolecules arranged in virtually any 3D geometry. We used hydrogels as scaffolds for volumetric deposition of materials at defined points in space. We then optically patterned these scaffolds in three dimensions, attached one or more functional materials, and then shrank and dehydrated them in a controlled way to achieve nanoscale feature sizes in a solid substrate. We demonstrate that our process, Implosion Fabrication (ImpFab), can directly write highly conductive, 3D silver nanostructures within an acrylic scaffold via volumetric silver deposition. Using ImpFab, we achieve resolutions in the tens of nanometers and complex, non-self-supporting 3D geometries of interest for optical metamaterials.

60. **Optogenetics: Molecules Enabling Neural Control by Light**

Edward Boyden

We have pioneered the development of fully genetically encoded reagents that, when targeted to specific cells, enable their physiology to be controlled via light. These reagents, known as optogenetic tools, enable temporally precise control of neural electrical activity, cellular signaling, and other high-speed physiological processes using light. Such tools are in widespread use in neuroscience and bioengineering, for the study of how specific neurons contribute to cognition, emotion, and movement, and to brain disorder states, or to the remedy thereof. These tools are also being evaluated as components of prototype optical neural control prosthetics for ultraprecise treatment of intractable brain disorders. Derived from the natural world, these tools highlight the power of ecological diversity, in yielding technologies for analyzing biological complexity and addressing human health. We distribute these tools as freely as possible, and routinely host visitors to learn optogenetics.

61. **Prototype Strategies for Treating Brain Disorders**

Edward Boyden

New technologies for recording neural activity, controlling neural activity, or building brain circuits, may be capable someday of serving in therapeutic roles for improving the health of human patients - enabling the restoration of lost senses, the control of aberrant or pathological neural dynamics, and the augmentation of cognition and empathy, through prosthetic means. High throughput molecular and physiological analysis methods may also open up new diagnostic possibilities. We are inventing new noninvasive methods for targetedly controlling brain dynamics in living human subjects, and also exploring novel ways of reading activity from the brain in noninvasive fashion. We are assessing, often in collaborations with other groups, the translational possibilities opened up by our technologies, exploring the safety and efficacy of our technologies in multiple animal models, in order to discover potential applications of our tools to various clinically relevant scenarios. New kinds of "brain co-processor" may be possible which can work efficaciously with the brain to augment its computational abilities, e.g. in the context of cognitive, emotional, sensory, or motor disability.

62. **SensorKnits: Architecting textile sensors with machine knitting**

Hiroshi Ishii, Joseph A. Paradiso, Don Derek Haddad, Daniel Oran, Jifei Ou

Digital machine knitting is a highly programmable manufacturing process that has been utilized to produce apparel, accessories, and footwear. Our research presents three classes of textile sensors exploiting the resistive, piezoresistive, and capacitive properties of various textile structures enabled by machine knitting with conductive yarn.

63. **Tools for mapping the molecular architecture and wiring of the brain**

Edward Boyden

Complex biological systems such as brain circuits are extended 3-D structures made out of nanoscale building blocks such as proteins, RNAs, and lipids, which are often organized with nanoscale precision. This presents a fundamental tension in biology — to understand a biological system like a brain circuit, you might need to map a large diversity of nanoscale building blocks, across an extended spatial expanse. We are developing a new suite of tools that enable the mapping of the location and identity of the molecular building blocks of complex biological systems such as the brain, aiming to map out the architecture of such systems with enough precision to understand how the structures of biological systems lead to function and dysfunction. One of the technologies we are developing, expansion microscopy (ExM), enables large 3D objects to be imaged with nanoscale precision, by physically expanding preserved biological systems (in contrast to all previous microscopies, that magnify light from the sample via lenses). We are working to improve expansion microscopy further, and are working, often in interdisciplinary collaborations, on a suite of new labeling and analysis techniques that exploit the biochemical freedom enabled by the expanded state. We are also applying expansion microscopy to the scalable mapping of complex biological systems, including brain circuits. Such brain circuit maps may be detailed enough to enable detailed computer simulations of neural circuits. Finally, we are extending and applying such tools to the early detection and understanding of complex diseases such as cancers and autoimmune diseases, and to the analysis of aging.

64. **Tools for Recording High-Speed Brain Dynamics**

Edward Boyden

The brain is a three-dimensional, densely-wired circuit that computes via large sets of widely distributed neurons interacting at fast timescales. In order to understand the brain, ideally it would be possible to observe the electrical activity, and other intra- and intercellular signaling pathways, of many neurons—and ideally entire brains—with as great a degree of precision as possible, so as to understand the neural codes and dynamics that are produced by the circuits of the brain. Our lab and our collaborators are developing a number of innovations—such as new fluorescent reporters of cellular signals such as voltage, and new robotic and nanotechnological probes—to enable such analyses of neural circuit dynamics. These tools will hopefully enable pictures of how neurons work together to implement brain computations, and how these computations go awry in brain disorder states. Such neural observation strategies may also serve as detailed biomarkers of brain disorders or indicators of potential drug side effects. These technologies may, in conjunction with optogenetics, enable closed-loop neural control technologies, which can introduce information into the brain as a function of brain state ("brain co-processors"), enabling new kinds of circuit characterization tool as well as new kinds of advanced brain-repair prosthetic. To build these tools, we are developing supporting approaches such as robots and molecular strategies for multidimensional directed evolution of protein-based tools in mammalian cells.

65. **Understanding Normal and Pathological Brain Computations**

Edward Boyden

We are providing our tools to the community, and also using them within our lab, to analyze how specific brain mechanisms (molecular, cellular, circuit-level) give rise to behaviors and pathological states. These studies may yield fundamental insights into how best to go about treating brain disorders.

Cynthia Breazeal: Personal Robots

Building socially engaging robots and interactive technologies to help people live healthier lives, connect with others, and learn better

66. **AI + Ethics Curriculum for Middle School**

Cynthia Breazeal, Hae Won Park, Blakeley H. Payne

How do we raise conscientious consumers and designers of AI?

Children today live in the age of artificial intelligence. On average, US children tend to receive their first smartphone at age 10, and by age 12 over half of all children have their own social media account. Additionally, it's estimated that by 2022, there will be 58 million new jobs in the area of artificial intelligence. Thus, it's important that the youth of today are both conscientious consumers and designers of AI.

This project seeks to develop an open source curriculum for middle school students on the topic of artificial intelligence. Through a series of lessons and activities, students learn technical concepts—such as how to train a simple classifier—and the ethical implications those technical concepts entail, such as algorithmic bias.

67. **Artificial Listener with Social Intelligence**

Cynthia Breazeal, Jin Joo Lee, Dr. David DeSteno, Dr. Fei Sha

A social robot modifies its behavior to change what you think about it!

68. **Assessing Children's Relationships with Social Robots**

Cynthia Breazeal, Jacqueline M Kory Westlund, Hae Won Park, Randi Williams

Social robots are increasingly being developed for long-term interactions with children in domains such as healthcare, education, therapy, and entertainment. In prior research, we have seen that children treat robots as more than mere artifacts, e.g., ascribing them mental states, psychological attributes, and moral standing. Thus, while children's relationships with robots may not be like the relationships they have with their parents, pets, imaginary friends, or smart devices, they will form relationships of some kind. As such, we need to deeply understand how children's relationships with robots develop through time, and find ways to characterize and measure these relationships. However, there are few validated assessments for measuring young children's long-term relationships. Thus, we have adapted or created a variety of assessments for use in this context for children aged 5-6 years.

Four of these assessments are presented in the associated paper.

This paper shows that children can appropriately respond to these assessments with reasonably high internal reliability, and that these assessments are able to capture child-robot relationship adjustments over a long-term interaction.

69. **Cognimates: Collaborative creative learning with embodied intelligent agents**

Cynthia Breazeal, Stefania Druga, Sarah T. Vu, Tammy Qiu, Eesh Likith

Cognimates is a platform where parents and children (7-10 years old) participate in creative programming activities in which they learn how to build games, program robots, and train their own AI models. Some of the activities are mediated by embodied intelligent agents which help learners scaffold learning and better collaborate. Learn more about our research, projects, and learning guides.

Conversational agents and connected toys are becoming common in homes. Increasing exposure to "intelligent" technology raises important questions about the ways that children understand it and how they could learn with and from it. Embodied intelligent agents, such as social robots, afford longer-term engagement in the home for children and their families.

Building on the prior experience in the Personal Robots group of designing social robots for nurturing children's curiosity and learning, we built a platform where children and parents can learn to program with embodied intelligent agents which in turn become learning companions (Cognimates). The goal is to enable learners to interact with a social robot but also program it, train it to remember and learn things over time, and have reflective conversations with their peers prompted by it.

Why, how, and when can embodied intelligent agents support children and parents to learn via reflective teaching? What are the new intergenerational learning pathways that Cognimates could facilitate? How can these future learning companions be integrated into various learning applications and what are the generalizable design considerations? In this research project we are addressing these questions by allowing children and parents to use a visual programming interface to control and customize an embodied intelligent agent.

Demo video

70. **Curious Learning:
Understanding Learning
Behaviors for Early Literacy**

Cynthia Breazeal, Pedro Reynolds-Cuellar, Nikhita Singh, Tinsley Galyean, Eric Glickman-Tondreau, Stephanie Gottwald, Robin Morris, Maryanne Wolf

Early literacy plays an important role in a child's future. However, the reality is that over 57 million children have no access to a school and another 100 million attend such inadequate schools that they will remain functionally non-literate.

Curious Learning is an open platform that addresses the deployment and learning challenges faced by under-resourced communities, particularly their limited access to literacy instruction.

We are developing a system of early literacy apps, games, toys, and robots that will triage how children are learning, diagnose literacy deficits, and deploy dosages of content to encourage app play using a mentoring algorithm that recommends an appropriate activity given a child's progress. Currently, over 200 Android-based tablets have been sent to children around the world; these devices are instrumented to provide a very detailed picture of how kids are using these technologies. We are using this big data to discover usage and learning models that will inform future educational development. The open-source software enables any Android device to be transformed into a literacy mentor. This platform is presently deployed in Ethiopia, Uganda, India, South Africa, and rural United States.

The open-source tablet software enables data collection across the deployment sites. By employing a data-driven approach to understanding learning behaviors across cultures and contexts, this project seeks to design and develop a personalized, adaptive learning platform.

71. **Designing social robots for
older adults**

Cynthia Breazeal, Anastasia Ostrowski, Hae Won Park, Nikhita Singh

Most countries are projected to see their 65 and older population surpass the number of people under the age of 15 by 2050. The limitations of current aging assisting solutions, the increased social and emotional toll on caregivers, and the inability of institutions to create structural solutions in a timely manner calls for a paradigm shift in the way we approach aging.

As these new meanings of age, aged, and aging are re-negotiated at a personal and collective level, the main goal of this research initiative is to study aging adults' daily living assistance, social and emotional needs, and intergenerational connection while exploring the optimized modalities for embodied agents to successfully deliver these interactions. We see embodied agents as a method to enable older adults to age-in-place, supporting them in ways such as promoting social connectedness, tracking vitals, coaching in emotional wellness, and assisting with medical adherence.

Our work is rooted in partnering with the community through co-design and participatory design methods to inform robot design by empowering older adults to engage in our research. We prioritize developing robot interactions that can be tested long-term in older adults' homes to better inform how social robots can shape aging-in-place.

If you are 60 years of age or older and interested in participating in future study opportunities, please contact Anastasia Ostrowski (akostrow@media.mit.edu).

72. **Emotionally Aware Robot
Teammates**

Cynthia Breazeal, Sigurdur Orn Adalgeirsson, Nick DePalma, Jin Joo Lee, Dr. Malte Jung, Dr. Pamela Hinds

Emotionally supportive robots improve overall team functioning!

73. **Engagement with Voice-User
Interface Agents**

Cynthia Breazeal, Anastasia Ostrowski, Hae Won Park

Voice-user interfaces (VUIs), such as Amazon Echo and Google Home, are increasingly becoming present in domestic environments. Users attribute agency and personality traits to these AI agents. Due to the social attributes of these technologies, users try to understand the agents' characteristics based on social norms. These factors affect user experience quality and overall engagement, which, when considering first experiences, can impact continuous usage and engagement with VUI technology.

Our work examines users' first impressions and interactions with VUI agents, such as Google Home, Amazon Echo, and Jibo, with varying brands and modalities. Using personality and experience questionnaires, we seek to understand how VUI modalities, form, and personality affect engagement with VUIs.

74. **Huggable: A Social Robot for Pediatric Care**
Cynthia Breazeal, Sooyeon Jeong, Boston Children's Hospital, Northeastern University, Fardad Faridi, Jetta Company
 The Huggable is a new type of robotic companion for health care, education, and social communication applications. The Huggable is much more than a fun, interactive robotic companion; it functions as an essential team member of a triadic interaction. Therefore, the Huggable is not meant to replace any particular person in a social network, but rather to enhance it.
 Children and their parents may undergo challenging experiences when admitted for inpatient care at pediatric hospitals. While most hospitals make efforts to provide socio-emotional support for patients and their families during care, gaps still exist between human resource supply and demand. The Huggable project aims to close this gap by creating a social robot able to mitigate stress, anxiety, and pain in pediatric patients by engaging them in playful interactions. In collaboration with Boston Children's Hospital and Northeastern University, we are currently running an experimental study to compare the effects of the Huggable robot to a virtual character on a screen and a plush teddy bear. We demonstrated preliminarily that children are more eager to emotionally connect with and be physically activated by a robot than a virtual character, illustrating the potential of social robots to provide socio-emotional support during inpatient pediatric care.
75. **Human-Robot Trust**
Cynthia Breazeal, Jin Joo Lee, Dr. David Desteno, Dr. Robert H. Frank, Dr. David Pizarro, Dr. Jolie Wormwood, Dr. Leah Dickens
 Unconventional mixing of research fields introduces a new method to study human behavior using social robots.
76. **Intentional Inference of Emotions**
Cynthia Breazeal, Jin Joo Lee, Dr. Fei Sha
 Emotion recognition modeled as a goal-directed process!
77. **Jibo Social Robotic Research Platform**
Cynthia Breazeal, Jon Ferguson, Hae Won Park, Samuel Spaulding
 The Jibo Research Platform is an in-the-field deployable Social Robotics experimentation and data collection infrastructure. Built upon the world's first commercial social robot for the home, it extends Jibo's design, hardware, and data security for research purposes.
78. **P2PSTORY: Dataset of Children as Storytellers and Listeners in Peer-to-Peer Interactions**
Cynthia Breazeal, Ishaan Grover, Jin Joo Lee, Nikhita Singh
 Understanding social-emotional behaviors in storytelling interactions plays a critical role in the development of interactive and educational technologies for children. A challenge when designing for such interactions using technologies like social robots, virtual agents, and tablets is understanding the social-emotional behaviors pertinent to the storytelling context—especially when emulating a natural peer-to-peer relationship between the child and the technology. We present P2PSTORY, a dataset of young children (5-6 years old) engaging in natural peer-to-peer storytelling interactions with fellow classmates. The dataset contains 58 recorded storytelling sessions along with a diverse set of behavioral annotations as well as developmental and demographic profiles of each child participant.
 The CHI 2018 paper presenting this dataset can be found here:
 Nikhita Singh, Jin Joo Lee, Ishaan Grover, and Cynthia Breazeal (2018). P2PSTORY: Dataset of Children Storytelling and Listening in Peer-to-Peer Interactions. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems.

See below for instructions on how to access the dataset.

79. **Personalized Interaction for Language Learning**

Cynthia Breazeal, Huili Chen, Hae Won Park, Samuel Spaulding

The process by which children learn native languages is markedly different from the process of learning a second, or non-native, language. Children are typically immersed in their native languages. They receive input from the adults and other children surrounding them, based on immediate need and interaction, during every waking hour.

Second language learners are exposed to input from the new language in very different ways, most commonly in a classroom setting. The second language learner relies heavily on memory skills with sparse interaction, in contrast to the first language learner that can rely on environmental reinforcement and social interaction to learn words.

Social robots have the potential to drastically improve on this paradigm, making the second-language learning experience more like the experience of learning a native language by engaging the child in a rich, interactive exposure to the target language, especially aspects not typically covered by traditional technological solutions, such as prosody, fundamental phonetics, common linguistic structures, etc.

Our project explores how to design child-robot interactions that encourage child-driven language learning, that adapt and personalize each child's learning experience. We incorporate game design and machine learning into the child-robot interaction design. The child and robot play through a suite of educational games together. Using real-time sensor data and gameplay features, the robot constructs a model of each child's learning and emotional trajectory, then uses these models to inform its own decision making during the game. Thus, the robot's behaviors become personalized to individual children based on their learning style, personality and knowledge/emotional states during gameplay.

80. **Personalized Robot Storytelling Companion**

Cynthia Breazeal, Huili Chen, Ishaan Grover, Hae Won Park, Pedro Reynolds-Cuellar, Nikhita Singh, Samuel Spaulding, Randi Williams, Stephanie Gottwald (Tufts), Goren Gordon (Tel Aviv), Susan Engel (Williams College)

Could a social robot collaboratively exchange stories with children as a peer and help improve their linguistic and storytelling skills? Tega uses machine learning algorithms to learn actions that improve children's storytelling and keep them engaged. We are also interested in how Tega can personalize its interaction with each child over multiple encounters, because every child learns and engages differently.

In Spring 2017, Tega went to twelve preschool classrooms in the Greater Boston area for three months, pioneering the field of long-term human-robot interaction. Using Q-learning, a policy was trained to tell stories optimized for each child's engagement and linguistic skill progression. Tega monitored children's affect signals and asked dialogic questions during storytelling to gauge their engagement. Tega also invited children to tell it stories, which Tega used to assess each child's linguistic skill development. Our results show robot's interaction policy indeed personalized to each child. At the end of the sessions, the policy significantly differed from one child to the other. Children who interacted and built relationships with a personalized robot showed higher engagement, learned and retained more vocabularies, and used more complex syntax structure in their speech compared to where they had started.

81. **Predicting Trust Between People**

Cynthia Breazeal, Rosalind W. Picard, Jin Joo Lee, Dr. David DeSteno, Dr. W Bradley Knox, Dr. Jolie B. Wormwood
Machine learning model outperforms human judgement

Our computational trust model is capable of predicting—above human accuracy—the degree of trust a person has toward a stranger by observing the nonverbal behaviors expressed in their social interaction. We used machine learning algorithms, specifically hidden Markov models (HMMs), to model the temporal relationship between specific nonverbal behaviors. By interpreting its resulting learned structure, we discovered that the sequence of low and high trusting behaviors a person emits provides further information of their trust orientation toward their partner. These discoveries shaped the feature engineering process that enabled a support vector machine (SVM) model to achieve a prediction performance more accurate than human judgment.

82. **Realtime Detection of Social Cues**

Cynthia Breazeal, Mirko Gelsomini, Jin Joo Lee, Hae Won Park, Tonghui Zhu
Realtime detection of social cues in children's voices

In everyday conversation, people use what are known as backchannels to signal to someone that they are still listening, paying attention, and engaged. As listeners, we smile, nod, and say "uh-huh" to convey attentiveness, and we do this naturally with little thought. We give this feedback not randomly but at certain moments in the conversation because speakers give off social cues that signal upcoming backchanneling opportunities.

83. **Relational AI**

Cynthia Breazeal, Rosalind W. Picard, Jacqueline M Kory Westlund, Paul L. Harris, Harvard Graduate School of Education
Creating long-term interpersonal interaction and shared experiences with social robots

Many of our current projects explore the use of social robots as a technology to support young children's early language development. In this project, instead of focusing on how to make social robots effective as an educational tools, we ask why they are effective. Based on our prior work, we hypothesize that a key aspect of why social robots can benefit children's learning is their nature as a relational technology—that is, a technology that can build long-term, social-emotional relationships with users.

Thus, in this project, our goals are twofold. First, we aim to understand how children conceptualize social robots as relational agents in learning contexts, and how children relate to these robots through time. Second, we explore the core nature of autonomous relational technologies, that is, relational AI. We will examine how adding features of relational AI to a social robot impacts longitudinal child-robot learning interactions, including children's learning, engagement, and relationships.

As part of this project, we are taking a second look at work we have done so far, this time through the lens of children's relationships. We are creating assessments for measuring young children's relationships. We are developing a computational relational AI model, which we will test during a longitudinal study with a social robot.

Read more about children's relationships with robots here!

84. **Robot Mindset and Curiosity**

Cynthia Breazeal, Safinah Arshad Ali, Anastasia Ostrowski, Hae Won Park, Goren Gordon (Tel Aviv)

Young Learner's Companion
Developing robots' growth mindset and pro-curious behavior and fostering the same in young learners via long-term interaction

A growth mindset and curiosity have significant impact on children's academic and social achievements. We are developing and evaluating a novel expressive cognitive-affective architecture that synergistically integrates models of curiosity, understanding of mindsets, and expressive social behaviors to advance the state-of-the-art of robot companions. In doing so, we aim to contribute major advancements in the design of AI algorithms for artificial curiosity, artificial mindset, and their verbal and non-verbal expressiveness in a social robot companion for children. In our longitudinal study, we aim to evaluate the robot companion's ability to sustain engagement and promote children's curiosity and growth mindset for improved learning outcomes in an educational play context.

85. **Talking Machines:
Democratizing the design of
voice-based agents for the
home**

Cynthia Breazeal, Anastasia Ostrowski, Hae Won Park, Nikhita Singh

Embodied voice-based agents, such as Amazon's Echo, Google Home, and Jibo, are becoming increasingly present in the home environment. For most, these agents represent their first experience of living with artificial intelligence in such private and personal spaces.

However, little is known about people's desires, preferences, and boundaries for these technologies. This projects seeks to answer questions surrounding this space: How do we live with voice-based agents in the home? How do different generations interact with voice-based agents? How should these technologies be designed to incorporate people's preferences, desires, and boundaries? What tools can be used to understand this space?

This work presents insights from a long-term exploration with over 70 children, adults, and older adults over a one-year period to interact with, discover, experience, reflect upon, and design voice-based agents. In addition, design tools and learnings from the experience have been developed into an open-source design kit to enable designers and researchers to explore these ideas with the broader population.

For more information, please contact Nikhita Singh (nikhita@media.mit.edu) and Anastasia Ostrowski (akostrow@media.mit.edu).

86. **Text-to-Motion: Automatic
Sequencing of Animative Robot
Motions**

Cynthia Breazeal, Hae Won Park

Text-to-Motion generates a sequence of contingent robot animations to accompany the sentiment analyzed from an input sentence and its spoken audio. We trained a linear classifier to transfer learn our corpus of animated robot speech from DeepMoji network, a long short-term memory (LSTM) network with an attention model trained on billion tweets.

87. **The Role of Social Robots in
Fostering Human Empathy**

Cynthia Breazeal, Pedro Reynolds-Cuellar

Empathy is a core human skill. From early stages of our lives, being able to understand and behave with empathy is fundamental to our social experience. Research in the field of social robotics suggests that given a set of behaviors from a social robot, a child can perceive this agent as empathic. In this project, we explore a novel approach to modeling empathy in children using a social robot. Two social robots were programmed to have conversations containing interactions depicting empathic and non-empathic behaviors. Children were provided with opportunities to act on these interactions as well as to comment on the robot's behavior afterward.

88. **Tools to Investigate Societal
Impacts of Robots and AI**

Cynthia Breazeal, Anastasia Ostrowski, Hae Won Park

Artificial intelligence (AI) agents in an embodied form, such as Jibo, Amazon Alexa, and Google Home, are increasingly becoming part of our daily lives and our homes. While there have been numerous studies in lab settings documenting short-term individual interactions with intelligent agents, we are at a point where we need to be exploring the larger impact of these technologies in the world, living with real people over longer periods of time.

From a design research perspective, understanding and developing robots and AI that intersect with society is a "wicked problem," a problem with many components that cannot be solved without interdisciplinary approaches. Design research within interdisciplinary applications has sought to develop approaches, methods, tools, and techniques to investigate the impact of technologies and inform future development. This work focuses on developing tools for exploring robots' and AI's impact on daily lives to better inform the development of these technologies by elucidating academia's and industry's requirements of tools for this domain.

For more information, please contact Anastasia Ostrowski (akostrow@media.mit.edu).

Canan Dagdeviren: Conformable Decoders

Converting the patterns of nature and the human body into beneficial signals and energy

89. **A Protocol to Characterize pH Sensing Materials and Systems**

Canan Dagdeviren, Mohamed Tarek, Atieh Sadraei

Although significant progress is being made in identifying pH sensing materials and device configurations, a standard protocol for benchmarking performance of next-generation pH devices is still lacking. In particular, key properties of characterization systems, such as inherent component contributions, time plots for extended-gate field-effect transistor (EGFET) measurements, and the input resistance (R_{in}), often go unreported in studies of pH sensing systems. These properties strongly influence the characterization system and can lead to mistaken attribution of properties to the device. In this project, a series of essential characterization tests and parameters are reported to evaluate pH systems, such as the zinc oxide (ZnO) EGFET, in a standardized protocol. This EGFET ZnO sensor has a sensitivity of -58.1 mV pH^{-1} , drift range from 2.5 to $14.2 \mu\text{A h}^{-1}$, and response time of 136 s . By using a ZnO sensing electrode, it is demonstrated that i) intrinsic contributions of reference electrode and commercial transistor (for EGFET) are not negligible; ii) time plots for EGFET configuration and defining a critical point at the onset of drift are essential for accurate sensitivity, response time, and drift reporting; and iii) the results of the pH sensing system are strongly dependent on the input resistance of the used characterization instruments.

90. **Conformal Piezoelectric Mechanical Energy Harvesters: Mechanically Invisible Human Dynamos**

Canan Dagdeviren, Atieh Sadraei

Nearly all classes of wearable and implantable biomedical devices depend on battery power for continuous operation. However, the life span of batteries is limited, rarely exceeding a few hours for wearables and a few years for implants. Consequently, battery replacements and, often times, surgical procedures are required to change the depleted batteries of implants, exposing people to high risks of surgical complications and/or high financial costs. This project seeks to develop conformal piezoelectric patches integrated to personal garments to extract energy from body movements such as motion of arms, fingers, and legs. The completion of this project could improve quality life for people and potentially provide environmentally friendly power.

91. **Flexible piezoelectric devices for gastrointestinal motility sensing**

Canan Dagdeviren, Zijun Wei

Improvements in ingestible electronics with the capacity to sense physiological and pathophysiological states have transformed the standard of care for patients. Yet, despite advances in device development, significant risks associated with solid, non-flexible gastrointestinal transiting systems remain. Here, we report the design and use of an ingestible, flexible piezoelectric device that senses mechanical deformation within the gastric cavity. We demonstrate the capabilities of the sensor in both in vitro and ex vivo simulated gastric models, quantify its key behaviours in the gastrointestinal tract using computational modelling and validate its functionality in awake and ambulating swine. Our proof-of-concept device may lead to the development of ingestible piezoelectric devices that might safely sense mechanical variations and harvest mechanical energy inside the gastrointestinal tract for the diagnosis and treatment of motility disorders, as well as for monitoring ingestion in bariatric applications.

92. **Miniaturized Neural System for Chronic, Local Intracerebral Drug Delivery (MiNDS)**

Canan Dagdeviren

Recent advances in medications for neurodegenerative disorders are expanding opportunities for improving the debilitating symptoms suffered by patients. Existing pharmacologic treatments, however, often rely on systemic drug administration, which result in broad drug distribution and consequent increased risk for toxicity. Given that many key neural circuitries have sub-cubic millimeter volumes and cell-specific characteristics, small-volume drug administration into affected brain areas with minimal diffusion and leakage is essential. We report the development of an implantable, remotely controllable, miniaturized neural drug delivery system permitting dynamic adjustment of therapy with pinpoint spatial accuracy. We demonstrate that this device can chemically modulate local neuronal activity in small-animal (rodent) and large-animal (nonhuman primate) models, while simultaneously allowing the recording of neural activity to enable feedback control.

Caroline Rozendo, Jaleesa Trapp, Irmandy Wicaksono, Rhunzou Ye

"Music is not limited to the world of sound. There exists a music of the visual world."

— Oskar Fischinger, 1951.

Almost 70 years ago, when the German-American animator and film-maker Oskar Fischinger created musically inspired animations and works of art, he touched on the intuitive associations our minds make between all the different sensory stimuli received from the environment.

While the psychology of perception has been widely explored in the context of visual technology, visual-auditory associations remain mostly underexplored in the field. There is strong evidence, though, that our brains forge relationships between shapes and seemingly correspondent sounds.

PerForm explores one possibility of how the associations between visual and auditory perception can be used in interaction design. We developed a physical interface that users can transform by bending to create geometric shapes or symbols. Those shapes can then be played as percussion instruments of different sound frequencies, directly related to the shape created.

This deformable interface is responsive to shaking, enabling users to manipulate it as a percussion instrument. For the future, we envision the possibility of enabling the creation of more complex shapes, which would enable specific modes of interaction—piano, winds, and metals, for example.

Kevin Esvelt: Sculpting Evolution

Exploring evolutionary and ecological engineering

94. **Brainstorm: Anima Mundi**

Jeantine Lunshof, Eswar Iyer (Wyss Institute, Harvard University), Mark Skylar-Scott (Harvard John A. Paulson School of Engineering and Applied Sciences)

We'd like to introduce you to a very special neuroscience project that we are currently conducting in the setting of a traditional fine arts museum.

Join the conversation on the Responsive Science Brainstorm project site.

Responsive Science uses the PubPub platform, which allows for direct interaction. PubPub was developed at MIT Media Lab.

95. **City as Classroom, City as Laboratory**

Devora Najjar, Avery Normandin

Often, we neglect to see the city as living, complex, and dynamic. Shrouded by its masses of concrete and steel, however, lie unique ecosystems and uncharacterized phenomena awaiting exploration and inquiry. Now more than ever, as urban populations boom and city boundaries expand, there exists a pressing need to understand urban ecology, the environmental impact of cities and their development, and the importance of designing in concert with nature. Yet, in spite of this, curricula for youth focused on ecology canonically instruct solely on topics which apply exclusively to natural, undeveloped systems—even in metropolitan schools where access to "nature" is difficult or a privilege. Our failure to use cities as educational resources must be addressed.

City as Classroom, City as Laboratory is a series of six educational workshops for youth in the Greater Boston area, ages 8 to 14. Throughout the sessions, students make use of "urban wilds" in order to become enveloped in the hybrid ecology of the growing city. This curriculum utilizes hands-on approaches for culturing ecological identity such that students are able to recognize and appreciate the complex ecological processes ongoing in urban contexts, and thus understand cities as novel ecosystems.

The goal of this educational framework is to inspire urban youth to champion future endeavors related to the environmental and political spheres (in efforts related to conservation, wildlife protection, sustainability, infrastructure development) and to see the city as a forum for intervention.

The curriculum is designed to be neuroinclusive and sensory-friendly—thus, we encourage participation by neurodivergent individuals.

Participation is of free of charge, and all materials are provided. This program is sponsored by the MIT Media Lab, MIT School of Architecture and Planning, Empowered Brain Institute, and National Geographic.

The first session of this series will be offered this summer on the following dates:

City as Classroom Summer 2018—July 8, 15, 22, and 29; August 5 and 12.

To register, please visit this link.

For questions, please contact Avery Normandin (ave@media.mit.edu)

96. **Computer-Assisted Transgenesis**

Kevin Esvelt, Erika Alden DeBenedictis, Cody Gilleland, Jianghong Min

This is a new platform to automate experiments in genetic engineering and bring large-scale moonshot projects within reach. Too often, lab experiments are limited in scale by human fatigue and costs associated with manual labor. In particular, the process of delivering genetic materials via manual microinjection remains a long-standing bottleneck. We are developing a computer-assisted microinjection platform to streamline the production of transgenic organisms. Briefly, organisms are immobilized in a gel and microinjections are performed using precision robotics using computer vision algorithms. This platform demonstrated high-throughput gene editing in an animal model (*C. elegans*) for the first time. We will use this technology to refine and create safeguards for our gene drive technology.

97. **Daisy Drives**

Kevin Esvelt, Joanna Buchthal, Charleston Noble, John Min, Jason Olejarz, Alejandro Chavez, Andrea L. Smidler, Erika A. DeBenedictis, George M. Church, and Martin A. Nowak.

Who should decide whether, when, and how to alter the environment? It's a hard question, especially when the decision will impact people in many different communities or nations. Daisy drive systems may help by empowering local communities to make decisions concerning their local environments without imposing them on anyone else.

The problem with current CRISPR-based gene drive systems is that they can spread indefinitely—potentially affecting every population of the target species throughout the world. It's unclear how such "global" drives can be safely tested, much less whether nations will ever agree to use them. To return power to the hands of local communities, we devised a new form of drive system called a "daisy drive" that can only affect local environments. The trick was to teach DNA to count. We hope that daisy drives will simplify decision-making and promote responsible use by allowing local communities to decide how to solve their own ecological problems.

98. **Ecology, Evolution, and Engineering for Empowered Brains**

Devora Najjar, Avery Normandin, Pedro Reynolds-Cuellar, Joshua Van Zak
EEEB Spring 2019: Urban Oceans

March 24, April 7 and 21, May 19, June 2

To register, please visit this link.

Sponsored and run by members of the MIT Media Lab and the Empowered Brain Institute, Ecology, Evolution, and Engineering for Empowered Brains is an eight-week, sensory-friendly series of related educational workshops for neurodiverse individuals (ages 8 - 14) which aims to hone skills in understanding, interpreting, and protecting the natural environment. Through creative, hands-on teaching exercises and field visits, participants become comfortable with basic ecological principles, as well as emerging technologies used to sculpt ecological and evolutionary processes. We discuss contemporary issues related to conservation and highlight engineering strategies with which to address these obstacles. Through project-based learning, students will have the opportunity to develop understanding by experimentation—or play—and workshops will emphasize immersion, rather than memorization. Wholly, we seek to foster a safe and creative learning space in which students are able to develop the necessary technical literacy to become future leaders in the myriad realms of environmental science.

For questions, please contact Avery Normandin (ave@media.mit.edu).

99. **Engineering Microbial Ecosystems**

Kevin Esvelt, Erika Alden DeBenedictis, Avery Normandin, Devora Najjar

We are developing methods of controlling the genetic and cellular composition of microbial communities in the gut. Stably colonized microbes could be engineered to sense disease, resist pathogen invasion, and release appropriate therapeutics in situ.

100. **Field Experimentation in
Boston's Intertidal Zone**

Devora Najjar, Avery Normandin

The Intertidal Experimentation Workshop will take place September 29 and 30 (9am to 2pm) at the MIT Media Lab, open to students ages 8-14. To register, please visit [this link](#).

Field Exploration in Boston's Intertidal Zone is a two-day, hands-on educational workshop for neurodiverse youth in the Greater Boston area, in which participants will use the city of Boston as a classroom, laboratory, and creative playground. Together, scientists, engineers, and artists will take to the field as explorers in order to answer questions related to ecology, biology, chemistry, art, and more.

Workshop sessions will take place from 9am to 2pm on September 29 and 30, 2018. We will gather at the MIT Media Lab (75 Amherst Street, Cambridge) prior to traveling to field sites located within Greater Boston.

Day I. Introduction to Intertidal Ecology and Experimental Design.

Day I of this workshop will take place at the MIT Media Lab, where students will learn about the ecology of rocky intertidal zones as well as experimental design. Students will additionally work collaboratively in small groups to develop hypotheses about the phenomena occurring in Boston's urban intertidal zones which they will subsequently test on-site during Day II.

Day II. Data Collection, Interpretation, and Presentation.

On Day II, following the field investigation, students will regroup at the Media Lab to get a crash course on data interpretation and visualization. Thereafter, they will present their work to classmates as well as parents and community members through text, graphics, and more.

Participation is free of charge, and all materials and meals are provided. For questions, or opportunities for involvement, please contact Avery Normandin (ave@media.mit.edu).

Why Urban Oceans?

Presently, over 40% of the world's population lives within 100 kilometers of the coastline, often in seaside megalopolises. While it is known that urban-adjacent marine ecosystems are subjected to unique stressors—namely unparalleled amounts of pollution stemming from urban runoff—efforts related to ocean conservation, as well as marine ecological investigation, most frequently concern the open sea, beyond the immediate reaches of urban ecosystems.

To better inform regulatory actions related to urban ocean protection, we must understand the unique qualities of these ecological bodies—the seas of cities—particularly as global changes (climate change, rapid urbanization) increase strain on these fragile systems.

In parallel, given technological-driven paradigmatic shifts in our ability to characterize the unknown world, we are driven to generate innovative and novel platforms for education in the environmental sciences: experiential, instructional excursions which will empower and inspire urban populations to spearhead efforts to sculpt the future of their territories.

Ideally, these sorts of experiences will cater to all individuals, regardless of gender, race, or cognitive differences.

A Workshop for Neuroinclusivity

"Citizen science" (or Open Science) movements have generated robust momentum for allowing communities to delineate the natural world—or speculate on its future—in hands-on and creative ways. As part of a larger effort to cultivate a future generation of environmentally engaged and justice-focused citizen scientists—and in line with the outreach efforts of the Media Lab's Open Ocean Initiative—we have developed Field Experimentation in Boston's Intertidal Zone: a two-day pilot workshop for Boston-area neurodivergent (e.g., autistic, dyslexic, dyspraxic, ADD, ADHD) youth, in which participants will learn about the ecology of rocky and intertidal systems, develop a hypothesis surrounding these bodies, and subsequently execute a field investigation to test this hypothesis. Students will have the option of approaching fieldwork as a scientist (or engineer), an artist, or a writer (poet, journalist).

We envision that use of easy-to-access, public sites for the pilot workshop will further democratize the potential to recapitulate similar endeavors in ecological exploration and immersive learning.

101. **PlusMinus**

V. Michael Bove, Kevin Esvelt, Iyad Rahwan, Danielle Wood, Ethan Zuckerman, Hildreth England
Ride-sharing, social media, artificial intelligence. These are examples of socially-beneficial, net-positive technologies that have shown us the dark side of a move-fast, break-things ethos. In visible or invisible ways, these technologies have also had unexpectedly—and disproportionately—negative impacts on some of society's most vulnerable citizens.

PlusMinus provides both a structure for Media Lab researchers to work with members and other outside collaborators on impact and equity issues, and a force for changing our internal culture to bring these considerations more consciously into our design and evaluation processes. As part of the Media Lab's continuing investigation into complex, adaptive systems, PlusMinus is...

Equipping future technologists with the space, community, and skills to reflect on, critique, and inclusively design technologies for equitable, positive social impact before, during and after they're deployed.

Examining—in collaboration with member companies and sponsors—how to radically re-cast design processes both inside the Lab and outside it, to improve our collective understanding of the pluses and minuses of the technologies shaping our lives.

We envision a community of PIs, research staff, and students who concentrate their research on PlusMinus issues—exploring how the benefits of their research might be distributed equitably across society if projects were to be scaled up, how to evaluate ongoing research for early hints of possible trouble, and how to mitigate negative impacts should they appear.

102. **Preventing Tick-Borne Disease by Permanently Immunizing Mice**

Kevin Esvelt, Joanna Buchthal, Joanna Buchthal, Devora Najjar

Lyme disease is the most common vector-borne infection in North America. People are infected when bitten by ticks; ticks are typically infected when they bite white-footed mice, the primary "reservoir" of the disease. We are exploring the possibility of permanently immunizing mouse populations to block transmission by making and releasing mice that produce protective mouse antibodies from birth and pass immunity on to their pups. The project has been guided by representatives in offshore island communities from inception. Communities will choose which type of antibodies, pick uninhabited islands to serve as field trial sites, select independent monitors, and ultimately decide whether to volunteer their own islands for the next stage. If successful, prevention could be expanded to the mainland using local or global gene drive systems. Whether or not communities decide to proceed, we hope the process will become a model for responsive science worldwide.

103. **Reducing Suffering in Laboratory Animals**

Kevin Esvelt, Devora Najjar,

The world uses an estimated 20 million mice in laboratory research experiments each year. These experiments are monitored and regulated to protect animal welfare whenever possible. However, analgesics cannot completely eliminate suffering, and many studies cannot use opiates or anti-inflammatory drugs because they would interfere with the biological process being studied. The benefits of animal research may outweigh the cost in animal suffering, but it would be better to perform these experiments without animal suffering. This project seeks to develop strains of mice that experience far less pain and suffering than current animals, but that are equally suited to laboratory and medical research. If successful, widespread adoption of these mice could drastically reduce animal suffering in laboratories worldwide.

104. **Responsive Science**

Devora Najjar, Avery Normandin

Responsive Science is a way of conducting research that invites openness and community involvement from the earliest stages of each project. Real-time interaction between scientists, citizens, and broader communities allows questions and concerns to be identified before experiments are performed, fosters open discussion, and encourages research studies and new technologies to be redesigned in response to societal feedback.

105. **Studying the Evolution of Gene Drive Systems**

Kevin Esvelt, Cody Gilleland, Jianghong Min

How will gene drive systems evolve once released into the wild? Can they be reliably overwritten and blocked by immunizing reversal drives? Might they spread into related species? These are difficult questions because wild populations are so much larger than laboratory colonies, meaning critical evolutionary events would never be observed in the lab. We seek to develop nematode worms as a model system to help answer these questions. Nematodes are genetically tractable, reproduce twice each week, and are readily grown in populations numbering in the billions. This allows us to study drive systems intended for other organisms in nematodes. Synthetic site targeting, split drives, and ecological confinement will prevent spread into wild nematodes. Because nematodes are easy to culture and count using Foldscope microscopes, we intend to work with educators to enable students, museum-goers, and citizen scientists to participate in gene drive research.

106. **Understanding Molecular
Evolution**

Kevin Esvelt, Erika Alden DeBenedictis

Humanity has harnessed evolution to sculpt domesticated animals, crops, and molecules, but the process remains a black box. Which combinations of evolutionary parameters will enable us to discover the best solutions? We plan to answer this question by performing massively parallel directed evolution experiments. Our system will use phage-assisted continuous evolution (PACE), a method of building synthetic ecosystems in which billions of fast-replicating viruses compete to optimize a molecular function of our choice. We are developing methods of running many experiments in parallel, each with real-time fitness monitoring and customized evolutionary conditions such as mutation rate, selection stringency, and evolutionary goal-switching. We will use these methods to systematically characterize the relationship between evolutionary parameters and outcomes.

Hugh Herr: Biomechatronics

Enhancing human physical capability

107. **3D Neuromuscular Model of the Human Ankle-Foot Complex**

Hugh Herr, David Hill

During the gait cycle, the human ankle complex serves as a primary power generator while simultaneously stabilizing the entire limb. These actions are controlled by an intricate interplay of several lower leg muscles that cannot be fully uncovered using experimental methods alone. A combination of experiments and mathematical modeling may be used to estimate aspects of neuromusculoskeletal functions that control human gait. In this research, a three-dimensional neuromuscular model of the human ankle-foot complex based on biplanar fluoroscopy gait analysis is presented. Driven by kinematics, kinetics, and electromyography (EMG), the model seeks to solve the redundancy problem, individual muscle-tendon contributions to net joint torque, in ankle and subtalar joint actuation during overground gait. An optimization approach was employed to calculate sets of morphological parameters that simultaneously maximize the neuromuscular model's metabolic efficiency and fit to experimental joint torques. Optimal morphological parameter sets produce estimates of force contributions and states for individual muscles.

108. **Agonist-antagonist Myoneural Interface (AMI)**

Hugh Herr, Matthew Carty, Tyler Clites, Lisa Freed, Shriya Srinivasan

Humans can accurately sense the position, speed, and torque of their limbs, even with their eyes shut. This sense, known as proprioception, allows humans to precisely control their body movements.

Today's conventional prosthetic limbs do not provide feedback to the nervous system. Because of this, people with amputated limbs cannot feel the position, speed, and torque of their prosthetic joints without looking at them, making it difficult to control their movement. In order to create a more complete prosthetic control experience, researchers at the Center for Extreme Bionics at the MIT Media Lab invented the agonist-antagonist myoneural interface (AMI). The AMI is a method to restore proprioception to persons with amputation.

109. **Analysis of Residual Limb Changes using Digital Image Correlation and Finite Element Modelling**

Hugh Herr, Kevin Mattheus Moerman, Dana Solav

Local changes in the volume, shape, and mechanical properties of the residual limb can be caused by adjacent joint motion, muscle activation, hydration, atrophy, and more. These changes affect socket fit quality and might cause inefficient load distribution, discomfort, and dermatological problems. Analyzing these effects is an important step in considering their influence on socket fit, and in accounting for their contribution within the socket design process.

In this study, a 360° 3D digital image correlation (3D-DIC) system was developed for the full-field deformation measurements of the residuum. A multi-camera rig was designed for capturing synchronized image sets as well as force measurements from a hand-held indenter. Custom camera calibration and data-processing procedures were specifically designed to transform image data into 3D point clouds, and automatically merge data obtained from multiple views into continuous surfaces. Moreover, a specially developed data-analysis procedure was applied for correlating pairs of largely deformed images of speckled surfaces, from which displacements, deformation gradients, and strains were calculated. Characterization of the full-field deformations using 3D-DIC provides insight into the patterns and sources of the phenomena.

In addition, local and subject-specific soft tissue mechanical properties were obtained by analyzing surface deformation and force measurement during indentation using inverse FE analysis. These data can be used to accurately describe the residuum's biomechanical behavior. Consequently, prosthetic socket designs that take into account these effects can be considered.

110. **An Osseointegrated Prosthesis with Bi-Directional Neural Communication**

Hugh Herr, Matthew Carney, Tyler Clites, Lisa Freed, Tsung-Han Hsieh, Tony Shu, Seong Ho Yeon, Matthew J Carty, MD (BWH), Rickard Branemark, MD, PhD, MS (UCSF)

Recent advancements in orthopedic implants have made way for a new generation of bionic limbs that attach directly to the skeleton. Leveraging these "osseointegrated" implants to pass wires out of the body enables robust, long-term communication with residual muscles and the nervous system. We are exploring the ways in which the improved neural communication afforded by osseointegration can impact the experience of controlling a limb prosthesis.

111. **Artificial Gastrocnemius**

Hugh Herr

Human walking neuromechanical models show how each muscle works during normal, level-ground walking. They are mainly modeled with clutches and linear springs, and are able to capture dominant normal walking behavior. This suggests to us to use a series-elastic clutch at the knee joint for below-knee amputees. We have developed the powered ankle prosthesis, which generates enough force to enable a user to walk "normally." However, amputees still have problems at the knee joint due to the lack of gastrocnemius, which works as an ankle-knee flexor and a plantar flexor. We hypothesize that metabolic cost and EMG patterns of an amputee with our powered ankle and virtual gastrocnemius will dramatically improve.

112. **Automated and Data-Driven Computational Design of Subject-Specific Prosthetic Sockets**

Hugh Herr, Lisa Freed, Kevin Mattheus Moerman, Bryan Ranger, Dana Solav

Complications of prosthetic leg use in persons with lower extremity amputation often occur at the prosthetic socket, and includes delayed wound healing, recurrent skin ulcerations, and pressure damage to soft tissues. Such complications can result in limited mobility, which further contributes to conditions such as obesity, musculoskeletal pathologies, and cardiovascular disease. Conventional prosthetic socket fabrication is an artisanal process requiring substantial human hours, financial cost and patient involvement for evaluation. Computer aided design (CAD) and computer aided manufacturing (CAM) methods have been explored as an alternative. However, these tools have not reached full clinical efficacy and do not inform the design in a data-driven sense since the actual design process remains a manual and experience-based procedure. The long-term goal of our research is to develop a fully-quantitative process for prosthetic socket design and production that requires minimal patient involvement and can be delivered at affordable price points.

A pre-print for our novel patient-specific and data-driven computational framework for the automated design of biomechanical interfaces is presented here. Optimization of the design of biomechanical interfaces is complex since it is affected by the interplay of the geometry and mechanical properties of both the tissue and the interface. The proposed framework is presented for the application of transtibial amputee prostheses where the interface is formed by a prosthetic liner and socket. Conventional socket design and manufacturing is largely artisan, non-standard, and insufficiently data-driven, leading to discrepancies between the quality of sockets produced by different prosthetists. Furthermore, current prosthetic liners are often not patient-specific. The proposed framework involves: A) non-invasive imaging to record patient geometry, B) indentation to assess tissue mechanical properties, C) data-driven and automated creation of patient-specific designs, D) patient-specific finite element analysis (FEA) and design evaluation, and finally E) computer aided manufacturing. Uniquely, the FEA procedure controls both the design and mechanical properties of the devices, and simulates, not only the loading during use, but also the pre-load induced by the donning of both the liner and the socket independently. Through FEA evaluation, detailed information on internal and external tissue loading, which are directly responsible for discomfort and injury, are available. Further, these provide quantitative evidence on the implications of design choices, e.g. : 1) alterations in the design can be used to locally enhance or reduce tissue loading, 2) compliant features can aid in relieving local surface pressure. The proposed methods form a patient-specific, data-driven and repeatable design framework for biomechanical interfaces, and by enabling FEA-based optimization reduces the requirement for repeated patient involvement in the currently manual and iterative design process.

113. **Biomimetic Active Prosthesis for Above-Knee Amputees**

Hugh Herr, Matthew Carney, Luke Mooney

Using biologically inspired design principles, a biomimetic robotic knee prosthesis is proposed that uses a clutchable series-elastic actuator. In this design, a clutch is placed in parallel to a combined motor and spring. This architecture permits the mechanism to provide biomimetic walking dynamics while requiring minimal electromechanical energy from the prosthesis. The overarching goal for this project is to design a new generation of robotic knee prostheses capable of generating significant energy during level-ground walking, that can be stored in a battery and used to power a robotic ankle prosthesis and other net-positive locomotion modes (e.g., stair ascent).

114. **Biplanar Fluoroscopy Gait Analysis**

Hugh Herr, David Hill, Kevin Mattheus Moerman, Dana Solav, Susan E. D'Andrea

Biplanar fluoroscopy (BiFlo) enables three-dimensional bone kinematics analysis using x-ray videos and bone geometry from segmented CT. Hindered by a small capture volume relative to traditional optical motion capture (MOCAP), BiFlo applications to human movement are generally limited to single-joint motions with constrained range. Here, a hybrid procedure is developed for multi-joint gait analysis using BiFlo and MOCAP in tandem. Kinematic analysis of bones surrounding the knee, ankle, and foot was performed. Results show that this hybrid protocol effectively measures knee and ankle kinematics in all three body planes. Additionally, sagittal plane kinematics for select foot bone segments (proximal phalanges, metatarsals, and midfoot) was realized. The proposed procedure offers a novel approach to human gait analysis that eliminates errors originated by soft tissue artifacts, and is especially useful for ankle joint analysis, whose complexities are often simplified in MOCAP studies.

115. **Computational Biomechanics**
- Hugh Herr, Kevin Mattheus Moerman, Bryan Ranger, Dana Solav**
- This research track focuses on the use of computational (and experimental) techniques to understand the biomechanical behavior of human tissue as well as the musculoskeletal system. This knowledge feeds into novel methods for computational modeling based design of biomechatronic devices which in turn aim to restore or improve the human body. These devices include prosthetic and orthotic devices, and exoskeletons.
116. **Control of Muscle-Actuated Systems via Electrical Stimulation**
- Hugh Herr**
- Motivated by applications in rehabilitation and robotics, we are developing methodologies to control muscle-actuated systems via electrical stimulation. As a demonstration of such potential, we are developing centimeter-scale robotic systems that utilize muscle for actuation and glucose as a primary source of fuel. This is an interesting control problem because muscles: a) are mechanical state-dependent actuators; b) exhibit strong nonlinearities; and c) have slow time-varying properties due to fatigue-recuperation, growth-atrophy, and damage-healing cycles. We are investigating a variety of adaptive and robust control techniques to enable us to achieve trajectory tracking, as well as mechanical power-output control under sustained oscillatory conditions. To implement and test our algorithms, we developed an experimental capability that allows us to characterize and control muscle in real time, while imposing a wide variety of dynamical boundary conditions.
117. **Effect of a Powered Ankle on Shock Absorption and Interfacial Pressure**
- Hugh Herr, David Hill**
- Lower-extremity amputees face a series of potentially serious post-operative complications. Among these are increased risk of further amputations, excessive stress on the unaffected and residual limbs, and discomfort at the human-prosthesis interface. Currently, conventional, passive prostheses have made strides towards alleviating the risk of experiencing complications, but we believe that the limit of "dumb" elastic prostheses has been reached; in order to make further strides we must integrate "smart" technology in the form of sensors and actuators into lower-limb prostheses. This project compares the elements of shock absorption and socket pressure between passive and active ankle-foot prostheses. It is an attempt to quantitatively evaluate the patient's comfort.
118. **FitSocket: Measurement for Attaching Objects to People**
- Hugh Herr, Neri Oxman, Jean-Francois Duval, Arthur J Petron**
- A better understanding of the biomechanics of human tissue allows for better attachment of load-bearing objects to people. Think of shoes, ski boots, car seats, orthotics, and more. We are focusing on prosthetic sockets, the cup-shaped devices that attach an amputated limb to a lower-limb prosthesis, which currently are made through unscientific, artisanal methods that do not have repeatable quality and comfort from one individual to the next. The FitSocket project aims to identify the correlation between leg tissue properties and the design of a comfortable socket. The FitSocket is a robotic socket measurement device that directly measures tissue properties. With these data, we can rapid-prototype test sockets and socket molds in order to make rigid, spatially variable stiffness, and spatially/temporally variable stiffness sockets.
119. **FlexSEA: Flexible, Scalable Electronics Architecture for Wearable Robotics Applications**
- Hugh Herr, Jean-Francois Duval**
- This project aims to enable fast prototyping of a multi-axis and multi-joint active prosthesis by developing a new modular electronics system. This system provides the required hardware and software to do precise motion control, data acquisition, and networking. Scalability is achieved through the use of a fast industrial communication protocol between the modules, and by a standardization of the peripherals' interfaces: it is possible to add functionalities to the system simply by plugging in additional cards. Hardware and software encapsulation are used to provide high-performance, real-time control of the actuators, while keeping the high-level algorithmic development and prototyping simple, fast, and easy.
120. **High Power Bionic Joints for Dynamic Gait Actions**
- Matthew Carney, Jean-Francois Duval, Tsung-Han Hsieh, Tony Shu, Seong Ho Yeon**
- The design of next-generation bionic ankles and knees aims to improve bionic actuators on all metrics: range of motion, power density, bandwidth, mass, while adopting a futuristic aesthetic. We are pushing the limits of materials and magnetics, combined with new control topologies to enforce a new paradigm in both autonomous and volitional controlled powered prostheses.
121. **Human Walking Model Predicts Joint Mechanics, Electromyography, and Mechanical Economy**
- Hugh Herr, Matt Furtney, Stanford Research Institute**
- We are studying the mechanical behavior of leg muscles and tendons during human walking in order to motivate the design of power-efficient robotic legs. The Endo-Herr walking model uses only three actuators (leg muscles) to power locomotion. It uses springs and clutches in place of other essential tendons and muscles to store energy and transfer energy from one joint to another during walking. Since mechanical clutches require much less energy than electric motors, this model can be used to design highly efficient robotic legs and exoskeletons. Current work includes analysis of the model at variable walking speeds and informing design specifications for a collaborative "SuperFlex" exosuit project.

122. **Load-Bearing Exoskeleton for Augmentation of Human Running**

Hugh Herr

Augmentation of human locomotion has proved an elusive goal. Natural human walking is extremely efficient, and the complex articulation of the human leg poses significant engineering difficulties. We present a wearable exoskeleton designed to reduce the metabolic cost of jogging. The exoskeleton places a stiff fiberglass spring in parallel with the complete leg during stance phase, then removes it so that the knee may bend during leg swing. The result is a bouncing gait with reduced reliance on the musculature of the knee and ankle.

123. **Mechatronic Systems**

Matthew Carney, Jiun-Yih Kuan, Ken A. Pasch, Emily Rogers, Tony Shu, Roman Stolyarov, Matt Weber, Seong Ho Yeon

Mechanical, electrical, and dynamic control systems recreate biological behavior with synthetic hardware.

124. **MultiDIC: a MATLAB Toolbox for Multi-View 3D Digital Image Correlation**

Hugh Herr, Kevin Mattheus Moerman, Dana Solav

Three-dimensional Digital Image Correlation (3D-DIC) is a non-contact optical-numerical technique for evaluating the dynamic mechanical behavior at the surface of structures and materials, including biological tissues. 3D-DIC can be used to extract shape and full-field displacements and strains with high resolution, at various length scales. While various commercial and academic 3D-DIC software exist, the field lacks 3D-DIC packages which offer straightforward calibration and data-merging solutions for multi-view analysis, which is particularly desirable in biomedical applications. To address these limitations, we present MultiDIC, an open-source MATLAB toolbox, featuring the first 3D-DIC software specifically dedicated to multi-view setups. MultiDIC integrates robust two-dimensional subset-based DIC software with specially tailored calibration procedures, to reconstruct the dynamic behavior of surfaces from multiple stereo-pairs. MultiDIC contains novel algorithms to automatically merge meshes from multiple stereo-pairs, and to compute and visualize 3D shape and full-field motion, deformation, and strain. User interfaces provide capabilities to perform 3D-DIC analyses without interacting with MATLAB syntax, while standalone functions also allow proficient MATLAB users to write custom scripts for specific experimental requirements. This paper discusses the challenges underlying multi-view 3D-DIC, details the proposed solutions, and describes the algorithms implemented in MultiDIC. The performance of MultiDIC is tested using a low-cost experimental system featuring a 360-deg 12-camera setup. The software and system are evaluated using measurement of a cylindrical object with known geometry subjected to rigid body motion and measurement of the lower limb of a human subject. The findings confirm that shape, motion, and full-field deformations and strains can be accurately measured, and demonstrate the feasibility of MultiDIC in multi-view in-vivo biomedical applications.

125. **Neural Interfaces**

Hugh Herr, Tyler Clites, Lisa Freed, Benjamin Maimon, Ron Riso, Shriya Srinivasan, Cameron Taylor, Seong Ho Yeon, Matthew J. Carty, MD (BWH), Rickard Branemark, MD, PhD (UCSF)
Nerve-Muscle Graft Chamber and micro-channel arrays for interface to peripheral nerves for prosthesis control.

This research effort consists of two sub-projects with the goal to develop a small implantable device for achieving bi-directional communication with the amputated nerves in a prosthesis user's residuum. The nerve-muscle graft chamber (NMGC) is a small implanted device which contains one or more electrically isolated chambers (ca. 20mm l x 4mm h x 4mm w) that can be filled with muscle or cutaneous tissue. The electrical activities of the components of a compound peripheral nerve that in the intact limb sub-served different motor functions can be separated by mechanically dividing the nerve and placing each isolated nerve segment into apposition with a small piece of muscle tissue in each of the separate chambers of the NMGC. For example, the muscle filled chambers can be ganged together in a modular design so that a single implanted device containing three chambers would interface to motor nerve fascicles that provide prosthesis command signals for three different motor functions. For a mixed peripheral nerve that is known to contain cutaneous fascicles as well as motor fascicles, an additional compartment could be added that contains cutaneous tissue. This would be done to provide an appropriate target for regenerating cutaneous nerve fibers to prevent the cutaneous axons from competing with regenerating motor nerve fibers and errantly taking up residence in the muscle tissues. Also, by provide cutaneous target tissue, regenerating sensory afferent nerve fiber are less likely to result in the formation of potentially painful neuromas.

The second sub-project aims to develop a micro-channel array into which peripheral nerve fibers will grow into. Because the micro-channels are on the order of 100 to 200 μm I.D., only a small number of nerve fibers will be present in an individual micro-channel. This can potentially provide greater separation of axons by their functionality. Such separation by function is important when seeking to provide cutaneous and proprioceptive feedback by means of direct electrical activation of the sensory components of the interfaced peripheral nerves.

126. **Neural Interface Technology for Advanced Prosthetic Limbs**

Edward Boyden, Hugh Herr, Tyler Clites, Lisa Freed, Benjamin Maimon, Ron Riso, Shriya Srinivasan, Cameron Taylor, Seong Ho Yeon, Matthew J. Carty, MD (BWH), Rickard Branemark, MD, PhD (UCSF)

Recent advances in artificial limbs have resulted in the provision of powered ankle and knee function for lower extremity amputees and powered elbow, wrist, and finger joints for upper extremity prostheses. Researchers still struggle, however, with how to provide prosthesis users with full volitional and simultaneous control of the powered joints. This project seeks to develop means to allow amputees to control their powered prostheses by activating the peripheral nerves present in their residual limb. Such neural control can be more natural than currently used myoelectric control, since the same functions previously served by particular motor fascicles can be directed to the corresponding prosthesis actuators for simultaneous joint control, as in normal limbs. Future plans include the capability to electrically activate the sensory components of residual limb nerves to provide amputees with tactile feedback and an awareness of joint position from their prostheses.

127. **Powered Ankle-Foot Prosthesis**

Hugh Herr, Matthew Carney

The human ankle provides a significant amount of net positive work during the stance period of walking, especially at moderate to fast walking speeds. Conversely, conventional ankle-foot prostheses are completely passive during stance, and consequently, cannot provide net positive work. Clinical studies indicate that transtibial amputees using conventional prostheses experience many problems during locomotion, including a high gait metabolism, a low gait speed, and gait asymmetry. Researchers believe the main cause for the observed locomotion is due to the inability of conventional prostheses to provide net positive work during stance. The objective of this project is to develop a powered ankle-foot prosthesis that is capable of providing net positive work during the stance period of walking. To this end, we are investigating the mechanical design and control system architectures for the prosthesis. We are also conducting a clinical evaluation of the proposed prosthesis on different amputee participants.

128. **Revolutionizing Amputation Surgery for the Restoration of Natural Neural Sensation and Mobility**

Hugh Herr, Tyler Clites, Lisa Freed, Shriya Srinivasan, Matthew J Carty, MD (BWH)

Lower-extremity amputation surgery has not seen significant change since the Civil War. This research is focused on the development of novel amputation paradigms that leverage native biological end organs to interpret efferent motor commands and to provide meaningful neural feedback from an artificial limb. Surgical replication of natural agonist-antagonist muscle pairings within the residuum allow us to use biomimetic constructs to communicate joint state and torque from the prosthesis directly to the peripheral nervous system. We hypothesize that these architectures will facilitate control of advanced prosthetic systems to improve gait and reduce metabolic cost of transport.

129. **Sensor-Fusions for an EMG Controlled Robotic Prosthesis**

Hugh Herr

Current unmotorized prostheses do not provide adequate energy return during late stance to improve level-ground locomotion. Robotic prostheses can provide power during late-stance to improve metabolic economy in an amputee during level-ground walking. This project seeks to improve the types of terrain a robotic ankle can successfully navigate by using command signals taken from the intact and residual limbs of an amputee. By combining these command signals with sensors attached to the robotic ankle, it might be possible to further understand the role of physiological signals in the terrain adaptation of robotic ankles.

130. **Terrain-Adaptive Lower Limb Prosthesis**

Hugh Herr, Roman Stolyarov

Although there have been great advances in the control of lower extremity prostheses, transitioning between terrains such as ramps or stairs remains a major challenge for the field. The mobility of leg amputees is thus limited, impacting their quality of life and independence. This projects aims to solve this problem by designing, implementing, and integrating a combined terrain-adaptive and volitional controller for powered lower limb prostheses. The controller will be able to predict terrain changes using data from both intrinsic sensors and electromyography (EMG) signals from the user; adapt the ankle position before footfall in a biologically accurate manner; and provide a torque profile consistent with biological ankle kinetics during stance. The result will allow amputees to traverse and transition among flat ground, stairs, and slopes of varying grade with lower energy and pain, greater balance, and without manually changing the walking mode of their prosthesis.

131. **Tethered Exoskeleton System for Understanding and Augmenting Human Movements**

Hugh Herr, Jiun-Yih Kuan, Michael Nawrot, Ken A. Pasch

This project explores the effects of hardware intervention on human gait. Our current system works in parallel with a subject's biological legs to provide an unprecedented level of gait enhancement, without causing discomfort or inhibiting natural motion. Multiple controller designs are being developed to explore the effects of intervention on the metabolic cost of transport, as well as gait pathologies and adaptation. This system provides a powerful tool in the analysis of human locomotion that will lead to potential innovations in mobility, rehabilitation, and athletics.

132. **Tethered Robotic System for Understanding Human Movements**

Hugh Herr, Jiun-Yih Kuan, Ken A. Pasch

This project aims to build a powerful system as a scientific tool for bridging the gap in the literature by determining the dynamic biomechanics of the lower-limb joints and metabolic effects of physical interventions during natural locomotion. This system is meant for use in applying forces to the human body and measuring force, displacement, and other physiological properties simultaneously, helping investigate controllability and efficacy of mechanical devices physically interacting with a human subject.

133. **Transdermal Optogenetic Peripheral Nerve Stimulation**

Edward Boyden, Hugh Herr, Lisa Freed, Benjamin Maimon, Shriya Srinivasan

Optogenetic techniques have recently been applied to peripheral nerves as a scientific tool with the translatable goal of alleviating a variety of disorders, including chronic pain, muscle fatigue, glucose-related pathologies, and others. When compared to the electrical stimulation of peripheral nerves, there are numerous advantages: the ability to target molecularly defined subtypes, access to opsins engendering neural inhibition, and optical recruitment of motor axons in a fashion that mimics natural recruitment, which eliminates the fatigue roadblock inherent to functional electrical stimulation. The ability to control peripheral nerves situated under deep tissue structures with transdermal, optical signals would be of enormous benefit, integrating all of the advantages conferred by optogenetics while averting the drawbacks associated with implantable devices, such as mechanical failure, device tissue heating, and a chronic foreign body response.

We work to develop novel molecular and optical methods in an effort to enable this transdermal optogenetic peripheral nerve control. A further example of a potential clinical application involves optogenetically targeting the vagus nerve, a peripheral cranial nerve implicated in numerous ailments, including epilepsy, migraines, obesity, hypertension, fibromyalgia, Crohn's disease, asthma, depression, and obsessive-compulsive disorder. An efficient method of stimulating the vagus nerve with minimal side-effects and high target specificity, such as described here, may have profound implications to the study of various illnesses and disabilities.

134. **Ultrasound Imaging for Transtibial Prosthetic Interface Design**

Hugh Herr, Kevin Mattheus Moerman, Bryan Ranger, Brian W. Anthony

In the United States, there are an estimated 1.7 million people living with amputation, with that number expected to double by 2050. Complications of prosthetic leg use in persons with lower extremity amputation (LEA) include delayed wound healing, recurrent skin ulcerations, and pressure damage to soft tissues. This can result in limited mobility, which further contributes to conditions such as obesity, musculoskeletal pathologies (e.g., osteoarthritis, osteopenia, and osteoporosis), as well as cardiovascular disease. Traditionally, fabrication of prosthetic sockets remains a fundamentally artisanal process with limited input of quantitative data. Even with advances in computer-aided design and manufacturing (CAD/CAM), prosthetists often modify sockets using non-quantitative craft processes requiring substantial human hours and financial cost. The goal of this research is to develop and validate musculoskeletal ultrasound imaging techniques for creating predictive biomechanical models of residual limbs that will reduce the barrier for and cost of computer aided design (CAD)-driven prosthetic socket design in the US and in low-and middle-income countries.

135. **Volitional Control of a Powered Ankle-Foot Prosthesis**

Hugh Herr, Oliver A Kannape

This project focuses on giving transtibial amputees volitional control over their prostheses by combining electromyographic (EMG) activity from the amputees' residual limb muscles with intrinsic controllers on the prosthesis. The aim is to generalize biomimetic behavior of the prosthesis, making it independent of walking terrains and transitions.

Cesar A. Hidalgo: Collective Learning

Transforming data into knowledge

136. **DataUSA**

Cesar A. Hidalgo, DataWheel, Deloitte

DataUSA is the most comprehensive site visualizing public data for the United States. Through interactive profiles, DataUSA makes available data from a variety of public sources, including the American Community Survey, the Bureau of Economic Analysis, the Bureau of Labor and Statistics, the Department of Education (IPEDS), and the county health records from the University of Wisconsin in Madison.

137. **DataViva**

Cesar A. Hidalgo, FapeMIG, DataWheel

DataViva made available data for the entire economy of Brazil, including exports and imports for each municipality and product, and occupation data for every municipality, industry, and occupation.

You can experience dataviva at legacy.dataviva.info

138. **DIVE**

Cesar A. Hidalgo, Kevin Zeng Hu

DIVE is a web-based data exploration system that lets non-technical users create stories from their data without writing code. DIVE combines semantic data ingestion, recommendation-based visualization and analysis, and dynamic story sharing into a unified workflow.

Links

Public version: dive.media.mit.edu

Demo video: dive.media.mit.edu/video

Front-end repository: github.com/MacroConnections/dive-frontend

Back-end repository: github.com/MacroConnections/dive-backend

139. **FOLD**

Matthew Carroll, Cesar A. Hidalgo, Ethan Zuckerman, Alexis Hope, Kevin Zeng Hu, Joe Goldbeck, Nathalie Huynh

Some readers require greater context to understand complex stories. FOLD (fold.cm) is an open publishing platform with a unique structure that lets writers link media cards to the text of their stories. Media cards can contain videos, maps, tweets, music, interactive visualizations, and more.

FOLD is used by journalists, educators, and storytellers around the world.

140. **GIFGIF**

Cesar A. Hidalgo, Andrew Lippman, Kevin Zeng Hu, Travis Rich

An animated GIF is a magical thing. It has the power to compactly convey emotion, empathy, and context in a subtle way that text or emoticons often miss. GIFGIF is a project to combine that magic with quantitative methods. Our goal is to create a tool that lets people explore the world of GIFs by the emotions they evoke, rather than by manually entered tags. A web site with 200,000 users maps the GIFs to an emotion space and lets you peruse them interactively.

141. **How the medium shapes the message: Printing and the rise of the arts and sciences**

Cesar A. Hidalgo, Cristian Ignacio Jara Figueroa, Amy Yu

Communication technologies, from printing to social media, affect our historical records by changing the way ideas are spread and recorded. Yet, finding statistical evidence of this fact has been challenging. Here we combine a common causal inference technique (instrumental variable estimation) with a dataset on nearly forty thousand biographies from Wikipedia (Pantheon 2.0) to study the effect of the introduction of printing in European cities on Wikipedia's digital biographical records. By using a city's distance to Mainz as an instrument for the adoption of the movable type press, we show that European cities that adopted printing earlier were more likely to become the birthplace of a famous scientist or artist during the years following the invention of printing. We bring these findings to recent communication technologies by showing that the number of radios and televisions in a country correlates with the number of globally famous performing artists and sports players born in that country, even after controlling for GDP, population, and including country and year fixed effects. These findings support the hypothesis that the introduction of communication technologies can bias historical records in the direction of the content that is best suited for each technology.

142. **Immersion**

Cesar A. Hidalgo, Deepak Jagdish, Daniel Smilkov

The current interface of emails is designed around time and messages, pushing people to focus on what is more recent rather than important. Immersion is a design experiment that centers the email interface on people and the networks that people form.

143. **Inequality and the impact of industrial structures**

Cesar A. Hidalgo, Manuel Aristaran, Dominik Hartmann, Cristian Ignacio Jara Figueroa, Miguel Guevara

Decades ago development scholars argued that the productive structure of a country (i. e. the mix of industries operating in the country) constrains its ability to generate and distribute income. They were correct! It was recently shown that the mix of products that a country exports is predictive of its future pattern of diversification and economic growth. But what is the link between a country's productive structure and its ability to distribute income? Here, we combine methods from econometrics, network science, and economic complexity, together with data on income inequality and world trade, to show that countries exporting complex products have lower levels of income inequality than countries exporting simpler products. Using multivariate regression analysis, we show that economic complexity is a significant and negative predictor of income inequality and that this relationship is robust to controlling for aggregate measures of income, institutions, export concentration, and human capital. Moreover, we introduce a measure that associates a product to a level of income inequality equal to the average GINI of the countries exporting that product (weighted by the share the product represents in that country's export basket). The Product-GINI index, or PGI, can provide important insights on the constraints to inequality imposed by a country's productive structure. Finally, we integrate our results to the Observatory of Economic Complexity, an online resource that allows its users to visualize the structural transformation of over 150 countries and their associated changes in income inequality during 1963–2008.

144. **Meet me in the middle: The reunification of the German research and innovation system**

Cesar A. Hidalgo, Bogang Jun, Flavio L. Portas Pinheiro

In 1990 Germany began the reunification of two separate research systems. Yet, the institutional unification of these system does not necessarily imply their actual unification. Here we study the evolution of the network of co-authorships between East and West German scholars between 1974 and 2014 to identify the fields that integrated more successfully, and also, the factors predicting re-unification success. We find that the unification of the German research network was fast during the 1990s, but then stagnated at an intermediate level of integration. Next, we study the integration of the twenty largest academic fields (by number of publications prior to reunification) and find an inverted U-shaped between a field's East or West "dominance" (a measure of the concentration of the scholarly output of a field in East or West Germany prior to 1990) and the field's subsequent level of integration. We check for the robustness of these results by running Monte Carlo simulations, and a differences-in-difference analysis. Both methods confirm that fields that were dominated by either West or East Germany prior to the reunification integrated less than those whose output was balanced among East and West. Finally, we explore the origins of this inverted U-shape relationship by comparing the mixing patterns, and show that this inverted U-shaped relationship can be explained as a consequence of a tendency of scholars from the most productive regions to collaborate preferentially with scholars from other top regions. These results shed light on the mechanisms governing the reintegration of networks in the content of scholarly communities that were separated by institutions.

145. **Opus**

Cesar A. Hidalgo

Opus is an online tool exploring the work and trajectory of scholars. Through a suite of interactive visualizations, Opus help users explore the academic impact of a scholar's publications, discover her network of collaborators, and identify her peers.

146. **Pantheon**
Cesar A. Hidalgo, Kevin Zeng Hu, Cristian Ignacio Jara Figueroa, Amy Yu, Shahar Ronan
 What if we could look at the entire history of humanity at once?
 Pantheon aims to create a data-driven view of history by collecting, visualizing, and analyzing data on the biographies of historical characters. We are particularly interested in what this data can teach us about the production of knowledge across history, the relation between accomplishment and fame, and information wanes from history.
147. **Participie**
Sanjay Guruprasad, Ali Almossawi
 Participie was a design experiment on direct participation for constrained choices (like budgets).
148. **PubPub**
Cesar A. Hidalgo, Andrew Lippman, Kevin Zeng Hu, Travis Rich, Thariq Shihpar
 PubPub reinvents publication to align with the way the web was designed: collaborative, evolving, and open. PubPub uses a graphical format that is deliberately simple and allows illustrations and text that are programs as well as static PDFs. The intention is to create an author-driven, distributed alternative to academic journals that is tuned to the dynamic nature of many of our modern experiments and discoveries. It is optimized for public discussion and academic journals, and is being used for both. It is equally useful for a newsroom to develop a story that is intended for both print and online distribution.
149. **Railroad Access and Diffusion of Industries: Evidence from Sweden during the Second Industrial Revolution**
Cesar A. Hidalgo, Cristian Ignacio Jara Figueroa
 Industrial diversification is a path-dependent process that leverages knowledge, skills, and new technologies. Because such resources are difficult to move, geography plays a crucial role in determining the future economic activities of countries, regions, and cities. Yet most of the evidence on the geographic diffusion of economic activities is restricted to the last 60 years and relies on correlations.
 This paper analyzes the geographic diffusion of economic activities for Swedish towns between 1850 and 1950, using the evolution of the railroad network as a way to address endogeneity. We use the straight line between Sweden's 10 largest towns as an instrument for train adoption. Our instrumental variable estimates show that regions are more likely to diversify into sectors that are present in their train neighbors, suggesting that the impact of connectivity goes beyond access to markets: connectivity also promotes diffusion of economic activities, even at early stages of development.
150. **Streetchange**
Cesar A. Hidalgo, Ramesh Raskar, Nikhil Naik
 Computer vision uncovers predictors of physical urban change
151. **StreetScore**
Cesar A. Hidalgo, Ramesh Raskar, Nikhil Naik, Jade Philipoom
 StreetScore is a machine learning algorithm that predicts the perceived safety of a streetscape. StreetScore was trained using 2,920 images of streetscapes from New York and Boston and their rankings for perceived safety obtained from a crowdsourced survey. To predict an image's score, StreetScore decomposes this image into features and assigns the image a score based on the associations between features and scores learned from the training dataset. We use StreetScore to create a collection of map visualizations of perceived safety of street views from cities in the United States. StreetScore allows us to scale up the evaluation of streetscapes by several orders of magnitude when compared to a crowdsourced survey. StreetScore can empower research groups working on connecting urban perception with social and economic outcomes by providing high-resolution data on urban perception.
152. **The laws of forgetting II: How death and exogenous events shape our collective memory**
Cesar A. Hidalgo, Cristian Esteban Candia Vallejos, Cristian Ignacio Jara Figueroa, Carlos Rodriguez-Sickert
 In order to understand how exogenous shocks, like death, impact memorability by remembering, we use a data-set of biographies from Wikipedia for all individuals who have more than 15 different language editions. Here, we focus on different external shocks that are able to trigger remembering, such as Death, Nobel Prize, Academy Awards (Oscars), Ballon d'Or, Golden Globes, and Grammy's. All of these events show an exogenous-critical non-trivial herd behavior, as described by Crane and Sornette 2008.
153. **The Observatory of Economic Complexity (OEC)**
Cesar A. Hidalgo, Alexander Simoes
 The Observatory of Economic Complexity (OEC) is the world's leading data visualization tool for international trade data. The OEC makes more than 50 years of international trade data available through dozens of millions of interactive visualizations.
 Visit the OEC at: <http://atlas.media.mit.edu>

154. **The role of industry, occupation, and location-specific knowledge in the survival of new firms**

Cesar A. Hidalgo, Cristian Ignacio Jara Figueroa, Bogang Jun, Edward Glaeser

How do regions acquire the knowledge they need to diversify their economic activities? How does the migration of workers among firms and industries contribute to the diffusion of that knowledge? Here we measure the industry-, occupation-, and location-specific knowledge carried by workers from one establishment to the next, using a dataset summarizing the individual work history for an entire country. We study pioneer firms—firms operating in an industry that was not present in a region—because the success of pioneers is the basic unit of regional economic diversification. We find that the growth and survival of pioneers increase significantly when their first hires are workers with experience in a related industry and with work experience in the same location, but not with past experience in a related occupation. We compare these results with new firms that are not pioneers and find that industry-specific knowledge is significantly more important for pioneer than for non-pioneer firms. To address endogeneity we use Bartik instruments, which leverage national fluctuations in the demand for an activity as shocks for local labor supply. The instrumental variable estimates support the finding that industry-specific knowledge is a predictor of the survival and growth of pioneer firms. These findings expand our understanding of the micromechanisms underlying regional economic diversification.

155. **The Universal Decay of Collective Memory and Attention**

Cesar A. Hidalgo, Cristian Esteban Candia Vallejos, Cristian Ignacio Jara Figueroa, Carlos Rodriguez-Sickert, Laszlo Barabasi

Collective memory and attention are sustained by two channels: oral communication (communicative memory) and the physical recording of information (cultural memory). Here, we use data on the citation of academic articles and patents, and on the online attention received by songs, movies, and biographies, to describe the temporal decay of the attention received by cultural products. We show that, once we isolate the temporal dimension of the decay, the attention received by cultural products decays following a universal biexponential function. We explain this universality by proposing a mathematical model based on communicative and cultural memory, which fits the data better than previously proposed log-normal and exponential models. Our results reveal that biographies remain in our communicative memory the longest (20–30 years) and music the shortest (about 5.6 years). These findings show that the average attention received by cultural products decays following a universal biexponential function.

156. **What is the Optimal Way to Diversify an Economy?**

Cesar A. Hidalgo, Aamena Alshamsi, Flavio L. Portas Pinheiro

One of the eternal challenges of economic development is how to identify the economic activities that a country, city, or region should target. During recent years, a large body of research has shown that countries, regions, and cities, are more likely to enter economic activities that are related to the ones they already have. For instance, a region specialized in the exports of frozen fish and crustaceans can more easily start exporting fresh fish than heavy machinery. This research has illuminated a new chapter in the economic development literature, but has left an important question unanswered: what is the right strategy for countries wanting to diversify their economies?

157. **When bullying meets (video) game theory: A novel framework to understand elementary school environments**

Cesar A. Hidalgo, Cristian Esteban Candia Vallejos, Victor Landaeta-Torres, Carlos Rodriguez-Sickert, Tamara Yaikin, Cecilia Monge, Jorge Fábrega, Ignacio Toledo, Camilo Rodriguez Beltran, Jorge Varela

Social learning has shown that people are more likely to learn from those who are seen as prestigious, talented, or who share demographic attributes with learners. In order to demonstrate that, many experiments and data-based studies have been conducted in many different systems; however, classroom environments have been understudied, because of different complications in both designing experiments and collecting data.

Combining both new technologies that are able to capture children's attention, e.g. video games, as well as experimental game theory, which provides us a formal framework to capture children's revealed preferences—a school classroom can provide an ideal environment for controlled social dilemma experiments, whose results can be contrasted against real-life indicators of school-life.

The connection between cooperation inside a classroom and social relationships is central in our framework. Here, we navigate the social network structure by running a non-anonymous dyadic cooperative (video) game (Fig. 1), in 50 different public primary school classrooms, between grades 3-5, allowing us to map cooperation networks for each classroom.

From the video game decisions, we build a weighted cooperation network for each classroom. The resulting network structure is able to capture different properties of the classroom, such as academic performance and social co-existence (Fig. 2). First, we find that positions in the social network have a significant power to identify, in an early stage, children who are susceptible to becoming the victims of bullying, and children who have a high probability to be bullies (Fig. 2A). Second, we find a positive and statistically significant relationship between network centrality—measured as the sum of the outcome on the video game—and student's academic performance (measured as GPA, even controlling for others socio-behavioral characteristics that are correlated with GPA (Fig. 2 B)).

These results don't just help us to understand the elementary school environment, but also open new avenues for the role of networks in the education system, with a huge potential impact in education public policy. These results are useful inputs for decision makers and physiologists to prevent bullying and improve learning.

Hiroshi Ishii: Tangible Media

Seamlessly coupling the worlds of bits and atoms by giving dynamic physical form to digital information and computation

158. **aeroMorph**

Hiroshi Ishii, Chin-Yi Cheng, Felix Heibeck, Jifei Ou, Nikolaos Vlavianos, Melina Skouras, Nikolaos Vlavianos, Jannik Peters

The project investigates how to make origami structure with inflatables with various materials. We introduce a universal bending mechanism that creates programmable shape-changing behaviors with paper, plastics, and fabrics. We developed a software tool that generates this bending mechanism for a given geometry, simulates its transformation, and exports the compound geometry as digital fabrication files. A custom heat-sealing head that can be mounted on usual three-axis CNC machines to precisely fabricate the designed transforming material is presented. We envision this technology could be used for designing interactive wearables and toys, and for the packaging industry.

Visit <http://tangible.media.mit.edu/project/aeromorph/>.

Honorable Mention Paper Award, UIST 2016

159. **AnimaStage**

Hiroshi Ishii, Daniel Leithinger, Ken Nakagaki, Udayan Umapathi

We present AnimaStage: a hands-on animated craft platform based on an actuated stage. Utilizing a pin-based shape display, users can animate their crafts made from various materials. Through this system, we intend to lower the barrier for artists and designers to create actuated objects and to contribute to interaction design using shape-changing interfaces for inter-material interactions.

We introduce a three-phase design process for AnimaStage with examples of animated crafts. We implemented the system with several control modalities that allow users to manipulate the motion of the crafts so that they could easily explore their desired motion through an iterative process. Dynamic landscapes can also be rendered to complement the animated crafts. We conducted a user study to observe the subject and process by which people make crafts using AnimaStage. We invited participants with different backgrounds to design and create crafts using multiple materials and craft techniques. A variety of outcomes and application spaces were found in this study.

Project Page

160. **AUFLIP**

Daniel Visan Levine

How can people learn advanced motor skills such as front flips and tennis swings without starting from a young age? The answer, following the work of Masters et. al., we believe, is implicitly. Implicit learning is associated with higher retention and knowledge transfer, but that is unable to be explicitly articulated as a set of rules. To achieve implicit learning is difficult, but may be taught using obscured feedback—that is, feedback that does not directly describe the result of an action.

With AUFLIP, we sought to provide auditory feedback to help newcomers learn front flips. We created a wearable system with a simplified model of a front flip that compares a user's time to peak rotation against their ideal time. As the user approaches their ideal performance, the system begins playing a chord, only completing the chord if the user manages to rotate at their ideal peak time. We tested this system by integrating it into an environment where professional coaches teach novices how to perform front flips; we found preliminary results suggesting that users wearing the device exhibited implicit learning.

161. **Auto-Inflatables**

Amos Golan, Ken Nakagaki, Jifei Ou, Penelope Eugenia Webb

162. **ChainFORM**

Hiroshi Ishii, Joseph A. Paradiso, Artem Dementyev, Ken Nakagaki

ChainFORM is a modular hardware system for designing linear shape-changing interfaces. Each module is developed based on a servo motor with added flexible circuit board, and is capable of touch detection, visual output, angular sensing, and motor actuation. Moreover, because each module can communicate with other modules linearly, it allows users and designers to adjust and customize the length of the interface. Using the functionality of the hardware system, we propose a wide range of applications, including line-based shape changing display, reconfigurable stylus, rapid prototyping tool for actuated crafts, and customizable haptic glove. We conducted a technical evaluation and a user study to explore capabilities and potential requirements for future improvement.

163. **Cillia: 3D-Printed Micro Pillar Structures for Surface Texture, Actuation and Sensing**

Hiroshi Ishii, Gershon Dublon, Jifei Ou, Felix Heibeck, Chin-Yi Chen, Liang Zhou

In nature, hair has numerous functions such as providing warmth, adhesion, locomotion, sensing, and a sense of touch, as well as its well-known aesthetic qualities. This work presents a computational method of 3D printing hair structures. It allows us to design and generate hair geometry at 50 micrometer resolution and assign various functionalities to the hair. The ability to fabricate customized hair structures enables us to create superfine surface texture, mechanical adhesion properties, new passive actuators, and touch sensors on a 3D printed artifact. We also present several applications to show how the 3D-printed hair can be used for designing everyday interactive objects.

164. **Circuit Robots: Mass Manufacturing of Self-Actuating Robots**

Joseph A. Paradiso, Artem Dementyev, Jifei Ou, Jie Qi
Integrating sensors and actuators using flexible electronics

Currently, the manufacturing of self-actuating and self-sensing robots requires non-standard manufacturing techniques and assembly steps to integrate electrical and mechanical systems. In this work, we developed a novel manufacturing technique, where such robots can be produced at a flexible electronics factory. We developed the technique using standard industrial machines, processes, and materials. Using a lamination process, we were able to integrate air pouches or shape memory alloy (SMA) inside a polyamide-based flexible circuit to produce bending actuators. The bend angle of the actuators is sensed with a chain of inertial measurement units integrated on the actuator. Air-pouch actuators can produce a force of a 2.24N, and a maximum bend angle of 74 degrees. To demonstrate, we manufactured a five-legged robot with the developed actuators and bend sensors, with all the supporting electronics (e.g., microcontrollers, radio) directly integrated into the flexible printed circuit. Such robots are flat and lightweight (15 grams) and thus conveniently compact for transportation and storage. We believe that our technique can allow inexpensive and fast prototyping and deployment of self-actuating and self-sensing robots.

165. **CONJURE**

Hiroshi Ishii, Daniel Visan Levine, Kallirroi Retzepi, Woodbury Shortridge, Jesper Alkestrup

A recent focus of our lab has been making use of Tangible Displays and Body Object Space to develop new assistive technologies. As a test case, we prototyped the Mario side-scrolling game for visually impaired users, using body movement analogies to control Mario in the game. Mario and 2D side scrollers present a particularly interesting case, as they keep the main character location in the center of the display and move the world around the character. The shape display itself provides spatial audio of enemy positions. We make use of the AUFLIP sensor platform to pick up body movements—walking and jumping, causing Mario to do the same in-game. This enables users to keep their hands engaged to understand the game landscape, while using their body to control Mario at the same time.

166. **HydroMorph**

Hiroshi Ishii, Ken Nakagaki, Thariq Shhipar, Anthony Stuart, Chantline Akiyama, Yin Shuang, Jim Peraino, Pasquale Totaro

HydroMorph is an interactive display based on shapes formed by a stream of water. Inspired by the membrane formed when a water stream hits a smooth surface (e.g., a spoon), we developed a system that dynamically controls the shape of a water membrane. This project explores a design space of interactions around water shapes, and proposes a set of user scenarios in applications across scales, from the faucet to the fountain. Through this work, we look to enrich our interaction with water, an everyday material, with the added dimension of transformation.

167. **Inflated Appetite**

Hiroshi Ishii, Jifei Ou, Wen Wang, Lining Yao, Chin-Yi Cheng

As part of human evolution and revolution, food is among the earliest forms of human interaction, but it has remained essentially unchanged from ancient to modern times. What if we introduced engineered and programmable food materials? With that change, food can change its role from passive to active. Food can "communicate" using its inherent behaviors combined with engineering accuracy. Food becomes media and interface. During an MIT winter course we initiated and taught, we encouraged students to design pneumatic food. Students successfully implemented inflatable sugar and cheese products. To inflate food, we use both an engineering approach and a biological approach; to solidify the inflated food, we introduce both heat via the oven, and coldness with liquid nitrogen.

168. **inFORM**

Hiroshi Ishii, Daniel Leithinger, Alex Olwal

Shape displays can be used to render both 3D physical content and user interface elements. We propose to use shape displays in three different ways to mediate interaction: facilitate, providing dynamic physical affordances through shape change; restrict, guiding users through dynamic physical constraints; and manipulate, actuating passive physical objects on the interface surface. We demonstrate this on a new, high-resolution shape display.

169. **jamSheets: Interacting with Thin Stiffness-Changing Material**

Hiroshi Ishii, Jifei Ou, Lining Yao, Juergen Steimle, Ryuma Niiyama, Daniel Tauber

This project introduces layer jamming as an enabling technology for designing deformable, stiffness-tunable, thin sheet interfaces. Interfaces that exhibit tunable stiffness properties can yield dynamic haptic feedback and shape deformation capabilities. In contrast to particle jamming, layer jamming allows for constructing thin and lightweight form factors of an interface. We propose five-layer structure designs and an approach that composites multiple materials to control the deformability of the interfaces. We also present methods to embed different types of sensing and pneumatic actuation layers on the layer-jamming unit. Through three application prototypes we demonstrate the benefits of using layer jamming in interface design. Finally, we provide a survey of materials that have proven successful for layer jamming.

170. **kinetiX**

Hiroshi Ishii, Jifei Ou, Jannik Peters, Nikolaos Vlavianos, Zhao Ma, Sen Dai

kinetiX is a transformable material featuring a design that resembles a cellular structure. It consists of rigid plates or rods and elastic hinges. These modular elements can be combined in a wide variety of ways and assembled into multifarious forms.

This project describes a group of auxetic-inspired material structures that can transform into various shapes upon compression. While the majority of the studies of auxetic materials focus on their mechanical properties and topological variations, our work proposes a parametric design approach that gives auxetic structures the ability to deform beyond shrinking or expanding. To do so, we see the auxetic structure as a parametric four-bar linkage. We developed four cellular-based material structure units composed of rigid plates and elastic/rotary hinges. Different compositions of these units lead to a variety of tunable shape-changing possibilities, such as uniform scaling, shearing, bending and rotating. By tessellating those transformations together, we can create various higher level transformations for design. The simulation is validated by the 3D printed structures.

We hope this work will inspire research in metamaterials design, shape-changing materials, and transformable architecture.

171. **LeakyPhones**

Hiroshi Ishii, Tal Achituv, Amos Golan

LeakyPhones is a public/private headset that was designed to encourage face-to-face interactions, curiosity, and healthier social skills by letting users "peek" into each other's music just by looking at one another.

Gaze is an important social signal in human interaction. Though its interpretation may vary across cultures, it is generally agreed that eye contact indicates interest and the point of attention in a conversation. Despite this, many common personal computing technologies, such as our smartphones and headphones, require significant visual and auditory attention thereby inhibiting our ability to interact with others. LeakyPhones offers a new approach for addressing this challenge.

172. **LineFORM**

Hiroshi Ishii, Ken Nakagaki

We propose a novel shape-changing interface that consists of a single line. Lines have several interesting characteristics from the perspective of interaction design: abstractness of data representation; a variety of inherent interactions/affordances; and constraints such as boundaries or borderlines. By using such aspects of lines together with added transformation capability, we present various applications in different scenarios: shape-changing cords, mobiles, body constraints, and data manipulation to investigate the design space of line-based shape-changing interfaces.

173. **Liquid Resin Fabrication in Microgravity**

Amos Golan

The future of human life outside of Earth will heavily depend on the ability to fabricate and manufacture things. Yet fabrication in space poses numerous difficulties. Some of these challenges include storage space in vehicles, availability of raw materials, lack of machines, and shortage of manpower.

Other challenges in fabricating objects in space are simply a result of the different physical environment; the lack of gravity introduces unexpected material behaviour, as other forces aside from gravity become dominant. Surface tension, for example, becomes very dominant in determining the shape of liquid materials and adhesion between liquids and other materials also plays a more dominant role.

Because of the reasons stated above, 3D printing in space was conceptually limited to fused deposition modeling (FDM) technologies, which are less susceptible to problems resulting from the harsh conditions. Liquid- or powder-based printing technologies are assumed to be very problematic for space fabrication because of liquid behavior in microgravity conditions. On the other hand, FDM technologies have a lot of limitations such as the inability to create transparent structures or layerless shapes with defined smooth curvatures.

In this experiment, we would like to harness surface tension's dominance in liquid behavior under zero gravity conditions to create various controllable and accurate, layerless and transparent geometries using UV-curable resin. The resin will be hardened using a high-power UV light source.

We will focus on rapid fabrication (in under 17 seconds) of the following shapes:

Shapes that are hard to make on Earth without special machinery, e.g., perfect lenses.

Shapes and materials that could be necessary in the space environment and are hard to make with existing methods available in space, such as ball bearings.

174. **Materiable**

Hiroshi Ishii, Daniel Leithinger, Ken Nakagaki, Luke Vink, Daniel Windham, Jared Counts, Daniel Leithinger, Sean Follmer

Shape-changing interfaces give physical shape to digital data so that users can feel and manipulate data with their hands and body. Combining techniques from haptics with the field of shape-changing interfaces, we propose a technique to build a perceptive model of material properties by taking advantage of the shape display's ability to dynamically render flexibility, elasticity, and viscosity in response to the direct manipulation of any computationally rendered physical shape. Using a computer-generated relationship between the manipulated pins and nearby pins in the shape display, we can create human proprioception of various material properties. Our results show that users can identify varying material properties in our simulations through direct manipulation, and that this perception is gathered mainly from their physical relationship (touch) with the shape display and its dynamic movements.

175. **MirrorFugue**

Hiroshi Ishii, Xiao Xiao

MirrorFugue is an installation for a player piano that evokes the impression that the "reflection" of a disembodied pianist is playing the physically moving keys. Live music emanates from a grand piano, whose keys move under the supple touch of a pianist's hands reflected on the lacquered surface of the instrument. The pianist's face is displayed on the music stand, with subtle expressions projecting the emotions of the music. MirrorFugue recreates the feeling of a live performance, but no one is actually there. The pianist is an illusion of light and mirrors, a ghost both present and absent. Viewing MirrorFugue evokes the sense of walking into a memory, where the pianist plays without awareness of the viewer's presence; or, it is as if viewers were ghosts in another's dream, able to sit down in place of the performing pianist and play along.

176. **Pneuduino**

Hiroshi Ishii, Felix Heibeck, Jifei Ou, Lining Yao

Pneuduino is a hardware platform for kids, students, artists, designers, and researchers who are interested in controlling air flow and pressure for their projects. The Pneuduino toolkit is currently used in workshops with high school or college students. While each workshop has a different focus, they all introduce concepts of air as actuator and sensor as well as different fabrication methods to create transforming artifacts. Air is one of the most abundant resources on earth. By adding computation ability to air, we can create new types of materials that enable us to design robots that are soft, furniture that is adaptive, clothing that is intelligent, and art pieces that are breathing.

177. **Pneumatic Shape-Changing Interfaces**

Hiroshi Ishii, Jifei Ou, Lining Yao

An enabling technology to build shape-changing interfaces through pneumatically driven, soft-composite materials. The composite materials integrate the capabilities of both input sensing and active shape output. We explore four applications: a multi-shape mobile device, table-top shape-changing tangibles, dynamically programmable texture for gaming, and a shape-shifting lighting apparatus.

178. **Printflatables: Printing Human-scale, Functional and Dynamic Inflatable Objects**
- Hiroshi Ishii, Pattie Maes, Yasuaki Kakehi, Jifei Ou, Harpreet Sareen, Udayan Umapathi, Patrick Shin, MIT Mechanical Engineering**
- Printflatables is a design and fabrication system for human-scale, functional and dynamic inflatable objects. The user begins with specifying an intended 3D model which is decomposed to two dimensional fabrication geometry. This forms the input for a numerically controlled contact iron that seals layers of thermoplastic fabric.
- In this project, we showcase the system design in detail, the pneumatic primitives that this technique enables and merits of being able to make large, functional and dynamic pneumatic artifacts. We demonstrate the design output through multiple objects which could motivate fabrication of inflatable media and pressure-based interfaces.
- Project Website
179. **Programmable Droplets**
- Hiroshi Ishii, Udayan Umapathi, Patrick Shin (undergraduate researcher), Sam Gen Chin (undergraduate researcher), Dimitris Koutentakis (undergraduate researcher), Carolyn E. Will (undergraduate researcher), Rui Qing (Center for Bits and Atoms)**
- State-of-the art liquid handling systems are generally pump-driven systems connected with valves and tubes. These systems are manually assembled, expensive, and unreliable. With the growth of the genomic and drug industries, we are moving toward increasingly complex biological processes requiring very small volume liquid manipulation capability.
- Manually assembled mechanical systems do not scale to parallel manipulation of large amounts of small volume liquids. However, the electronics industry has demonstrated how to build robust integrated systems for information manipulation. With this as our motivation, we look toward electronics and integrated circuits to bring miniaturization, complexity, and integration to enable the next generation of biology.
180. **Radical Atoms**
- Hiroshi Ishii, Leonardo A. Bonanni, Jean-Baptiste (JB) Labrune, Daniel Leithinger, Xiao Xiao**
- Radical Atoms is our vision of interactions with future materials. Radical Atoms goes beyond Tangible Bits by assuming a hypothetical generation of materials that can change form and appearance dynamically, becoming as reconfigurable as pixels on a screen. Radical Atoms is a computationally transformable and reconfigurable material that is bidirectionally coupled with an underlying digital model (bits) so that dynamic changes of physical form can be reflected in digital states in real time, and vice versa.
181. **SensorKnits: Architecting textile sensors with machine knitting**
- Hiroshi Ishii, Joseph A. Paradiso, Don Derek Haddad, Daniel Oran, Jifei Ou**
- Digital machine knitting is a highly programmable manufacturing process that has been utilized to produce apparel, accessories, and footwear. Our research presents three classes of textile sensors exploiting the resistive, piezoresistive, and capacitive properties of various textile structures enabled by machine knitting with conductive yarn.
182. **TRANSFORM**
- Hiroshi Ishii, Daniel Leithinger, LEXUS International**
- TRANSFORM fuses technology and design to celebrate its transformation from still furniture to a dynamic machine driven by a stream of data and energy. TRANSFORM aims to inspire viewers with unexpected transformations and the aesthetics of the complex machine in motion. First exhibited at LEXUS DESIGN AMAZING MILAN (April 2014), the work comprises three dynamic shape displays that move over one thousand pins up and down in real time to transform the tabletop into a dynamic tangible display. The kinetic energy of the viewers, captured by a sensor, drives the wave motion represented by the dynamic pins. The motion design is inspired by dynamic interactions among wind, water, and sand in nature, Escher's representations of perpetual motion, and the attributes of sand castles built at the seashore. TRANSFORM tells of the conflict between nature and machine, and its reconciliation, through the ever-changing tabletop landscape.
183. **TRANSFORM: Adaptive and Dynamic Furniture**
- Hiroshi Ishii, Viirj Kan, Daniel Leithinger, Ken Nakagaki, Luke Vink**
- Introducing TRANSFORM, a shape-changing desk. TRANSFORM is an exploration of how shape display technology can be integrated into our everyday lives as interactive, transforming furniture. These interfaces not only serve as traditional computing devices, but also support a variety of physical activities. By creating shapes on demand or by moving objects around, TRANSFORM changes the ergonomics and aesthetic dimensions of furniture, supporting a variety of use cases at home and work: it holds and moves objects like fruit, game tokens, office supplies, and tablets, creates dividers on demand, and generates interactive sculptures to convey messages and audio.

Joseph M. Jacobson: Molecular Machines

Engineering at the limits of complexity with molecular-scale parts

184. **Affinity: Deep learning API for molecular geometry**

Joseph M. Jacobson, Maksym Korablyov, Kfir Schreiber, Andrew Gritsevskiy, Isaac Wolverton, Aditi Harini, Manvitha Ponapatti

Affinity is a high-level machine learning API (Application Programming Interface) dedicated exclusively to molecular geometry. Affinity is written in TensorFlow; a small proportion of high-performance code is in low-level C++. Depending on the application it can be configured as multi-CPU, multi-CPU single GPU, or multi-GPU system. Affinity has its own web page at affinity.mit.edu

185. **DeepPPI**

Kfir Schreiber

Protein-protein interactions (PPIs) are an essential part of many biological pathways in living organisms. With use cases such as regulation of gene expression, enzymatic catalyzation, and muscle contraction, understanding PPIs is a critical step toward a better understanding of life itself. Moreover, aberrant human PPIs may lead to multiple diseases, such as Alzheimer's, Creutzfeldt–Jakob, and cancer. Despite the undisputed importance of PPIs, only a small portion of the human interactome is known.

The PPI mapping problem is composed of two subproblems: the Interaction Problem—identifying the two or more proteins involved in a particular interaction; and the Position Problem—recognizing the residues within the interacting proteins that are crucial for the interaction (also known as hot spots or interacting residues). Current experimental techniques for PPI mapping, like Yeast 2 Hybrid or Alanine scans, are limited in scale, tedious, and expensive, therefore establishing the need for a fast, efficient, and accurate computational system.

DeepPPI is a Deep Learning algorithm that uses known PPIs to identify reoccurring patterns in the human interactome. These underlying patterns can be used, in turn, to predict both the existence of a new interaction and the interacting residues within the relevant proteins. Through this project, we hope to answer a fundamental biological question: How does nature, via evolution, create new protein-protein interactions? Additionally, we believe that DeepPPI will serve as a large-scale computational alternative to Alanine Scans and other experimental methods, contributing to the study of diseases and development of new therapeutics.

186. **Evolutron: Deep Learning for Protein Design**

Joseph M. Jacobson, Thrasyvoulos Karydis, Kfir Schreiber, Aditya Koshla

Technological advances in the past decade have allowed us to take a close look at the proteomes of living organisms. As a result, more than 120,000 solved protein structures are readily available, and we are still on an exponential growth curve. By looking at the proteomes of current living organisms, we are essentially taking snapshots of the successful results in this evolutionary process of continuous adaptation to the environment. Could we process the information available to us from nature to design new proteins, without the need for millions of years of Darwinian evolution?

To answer this question, we are developing an integrated Deep Learning framework for the evolutionary analysis, search, and design of proteins, which we call Evolutron. Evolutron is based on a hierarchical decomposition of proteins into a set of functional motif embeddings. Two of our strongest motivations for this work are gene therapy and drug discovery. In both cases, protein analysis and design play a fundamental role in the implementation of safe and effective therapeutics.

187. **Opening wider genomic access with a flexible CRISPR enzyme**

Joseph M. Jacobson, Pranam Chatterjee, Noah Jakimo

The CRISPR-Cas9 system has proven to be a versatile tool for genome editing, with numerous implications in medicine, agriculture, bioenergy, food security, and beyond. The range of targetable DNA sequences is limited, however, by the need for a short sequence of DNA beside the target site, called the PAM. In total, there are only a handful of CRISPR enzymes with a short enough PAM sequence to be able to target a large portion of the total DNA in a genome. In this study, we identify a natural Cas9 enzyme from the bacterial genome of *Streptococcus canis* that has a PAM sequence with only a single G as its PAM sequence (5'-NNG-3'), allowing flexible targeting of up to 50% of all DNA sequences in living organisms. This new molecular tool potentially grants unprecedented access to correct disease-related mutations, enhance agricultural methods, and expand research efforts.

188. **Synthetic Genome Engineering**

Joseph M. Jacobson, Pranam Chatterjee, Noah Jakimo

We are currently developing novel DNA editing technologies to broaden the scope of genome engineering. Our strategy is based on identifying and engineering endonucleases from diverse living systems, along with targeting with synthetic molecules. Together these components confer greater stability, minimize off-target DNA cleavage, and eliminate sequence restrictions for precision genetic manipulations within cells.

Kent Larson: City Science

Looking beyond smart cities

189. **Aalto Campus-As-a-Service Simulations**

Kent Larson, Luis Alberto Alonso Pastor, Ronan Doorley
How can we get more value from the same buildings?

Cities contain many different resources and spaces and typically, these resources operate as products with a single function and a single owner and/or renter. However, the owner's demand for space often varies daily or seasonally, meaning that many buildings tend to be underutilized and are often vacant or partially vacant for large portions of each day.

Meanwhile, the "sharing economy" has been one of the most significant economic shifts in the last 10 years, with companies like Uber and Airbnb experiencing explosive growth. Along these lines, Aalto University—a member of the MIT Media Lab City Science network—has developed the concept of City-as-a-Service, where building space and other resources are shared among institutions, businesses, and citizens in a community. Aalto has already begun experimenting with School-as-a-Service, as a prototype of City-as-a-Service on their campus in Espoo.

190. **Andorra | Dynamic Urban Planning**

Kent Larson, Luis Alberto Alonso Pastor, Juanita Devis, Ronan Doorley, Arnaud Grignard, Yan Leng, Ariel Noyman, Carson Smuts, J. Ira Winder, Yan Zhang, Dalma Földesi, Jung In Seo, Ariel Noyman, Yasushi Sakai, Mikita Samsonau, Poseidon Ho, Carson Smuts

[View the main City Science Andorra project profile.](#)

Research in dynamic tools, mix users (citizens, workers) amenities, services, and land use, with the goal of promoting sustainable development.

191. **Andorra | Energy + Environment**

Kent Larson, Luis Alberto Alonso Pastor, Juanita Devis, Arnaud Grignard, Carson Smuts, Núria Macià (Fundació ActuaTech), Juanita Devis, Marcel Corominas (Andorradrones), Guillem Santacreu (Government of Andorra), Esteve Bardolet (Government of Andorra), Aleix Dorca (University of Andorra), Marc Unzueta (University of Barcelona), Marc Pons (OBSA), Marc Vilella (OBSA), Oriol Travesset (OBSA), Jordi Martin (University of Girona), Xavier Forne (FEDA), Josep Ribes (ActuaTech), Oriol Lordan (University of Barcelona), Cristina Yáñez (UdA), Francesco Pilla, Anna Penzo, Tossaporn Saengja, Ronald Dooley, Yan Leng, Anna Sinelnikova, Brian Wheatman, Alejandro Noriega

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192. **Andorra | Innovation**

Kent Larson, Luis Alberto Alonso Pastor, Juanita Devis, Ronan Doorley, Arnaud Grignard, Ariel Noyman, Carson Smuts, Marcel Corominas (Andorradrones), Guillem Santacreu (Govern d'Andorra), Esteve Bardolet (Govern d'Andorra), Aleix Dorca (Universitat d'Andorra), Marc Unzueta (Universitat Politècnica de Catalunya), Jordi Guerrero (Parc Científic i Tecnològic de la Universitat de Girona), Oriol Lordan (Universitat Politècnica de Catalunya), Cristina Yáñez (Universitat d'Andorra), Xavier Forné (FEDA), Núria Macià (Fundació ActuaTECH), Cristina Yáñez (Universitat d'Andorra), Lara Martínez (Universitat d'Andorra), David Mas (Departament de Patrimoni Cultural d'Andorra), Abel Fortó García (Departament de Patrimoni Cultural d'Andorra), Sara Ubach Balagué (Departament de Patrimoni Cultural d'Andorra), Dalma Földesi, Núria Macià, Guillem Francisco Giné, Marc Vilella

[View the main City Science Andorra project profile.](#)

The MIT Media Lab's City Science research group, the University of Andorra, and national and international companies are collaborating in order to bring an innovative ecosystem into the capital of Andorra. This innovation district aims to engage local citizens, researchers, and R&D from the companies in order to build together an Andorran living lab, an "innovation district" where national and international companies can test and deploy their products and ideas and cultivate human capital.

Current Projects

Andorra Innovation Space

Andorra Cultural Heritage

Drones patterns and flows, collaboration living lab

Young Future

193. **Andorra | Tourism**

Kent Larson, Luis Alberto Alonso Pastor, Juanita Devis, Ronan Doorley, Arnaud Grignard, Nina Lutz, Ariel Noyman, J. Ira Winder, Naichun Chen, Yan Leng, Alejandro Noriega, Joseph Cunningham, Reijul Sachdev, Claire Tsao, David Sukhin, Tanya Ivonchik, Wei Hou Wu, Ryan Zang, Núria Macià (Fundació ActuaTech), Marc Vilella (OBSA), Nina Lutz

View the main City Science Andorra project profile.

With more than eight million visitors a year, tourism represents almost 30% of the economy of Andorra. By gathering and analyzing data from social media, call detail records, and wifi, we can understand the country's dynamics of tourism and commerce as well as design interventions that can improve the experience for tourists, encouraging them to visit Andorra more frequently, stay longer, and increase spending.

Current Projects

Event Analysis

Social Network

Location Recommendation system

EVENT ANALYSIS

Based on the analysis of call detail records and social media, the goal of this project is to understand the tourist behaviors in Andorra. After mining those anonymized data, we have been able to learn different patterns and behaviors of the tourism in Andorra thanks to an agent-based model developed in order to represent the flow of people. This simulation is also coupled with an interactive table called CityMatrix.

194. **Cities Network
(UNPUBLISHED)**

Kent Larson

We propose that fundamentally new strategies must be found for creating the places where people live and work, and the mobility systems that connect these places, in order to meet the profound challenges of the future.

Building on current work at the Media Lab, City Science researchers will initially focus on the following project themes. Additional project themes will be added in response to the priorities of corporate members, MIT researchers, and the City Science advisory board. These six initial themes represent a cross section of the interdisciplinary research that will be undertaken to address the major challenges associated with global urbanization.

The world is experiencing a period of extreme urbanization. In China alone, 300 million rural inhabitants will move to urban areas over the next 15 years. This will require building an infrastructure equivalent to the one housing the entire population of the United States in a matter of a few decades.

In the future, cities will account for nearly 90% of global population growth, 80% of wealth creation, and 60% of total energy consumption. Developing better strategies for the creation of new cities, is therefore, a global imperative.

Our need to improve our understanding of cities, however, is pressed not only by the social relevance of urban environments, but also by the availability of new strategies for city-scale interventions that are enabled by emerging technologies. Leveraging advances in data analysis, sensor technologies, and urban experiments, City Science will provide new insights into creating a data-driven approach to urban design and planning. To build the cities that the world needs, we need a scientific understanding of cities that considers our built environments and the people who inhabit them. Our future cities will desperately need such understanding.

Ariel Noyman
Cloud-Based Urban Data Platform

cityIO (input/output) is a cloud- and database-driven platform which allows remote participation, database augmentation, and high-end complex visualization. cityIO operates anywhere, on multiple platforms and devices, using client-side apps or web-based interfaces. The cityIO platform is built for scale and to serve large volumes of end-users in real time, in order to augment multi-participant discussions and decision-making processes. Utilizing the mass adaptation of mobile and hand-held devices, cityIO promotes an equal and decentralized discussion for multiparty stakeholders. cityIO offers a suite of augmented reality data-visualization tools that utilize server-side data and analysis. cityIO allows client-side interactions in multiple forms:

AUGMENTED REALITY URBAN SIMULATION

cityIO is intended to reduce complexity in design and planning tools and to support data-driven environments for planners, designers, and decision makers. cityIO uses modern simulation tools and employs cutting-edge AR applications in order to offer an immersive user experience for both planning professionals and the general public. These simulations can augment indoor and outdoor environments, physical models, and technical drawings.

REMOTE AND DECENTRALIZED PUBLIC PARTICIPATION

Using self-explanatory web and mobile apps with high-end visualization and user interfaces, cityIO offers cities, municipalities, and planning authorities the ability to better communicate complex planning processes and to aggregate the public's opinion in real time. cityIO's scalable server side allows multiple users to collaborate, participate, and voice their opinions on design and planning initiatives.

CITYIO HAMBURG

cityIO Hamburg augments cityMatrix table. This deployment allows design in the urban context of the Rothenburgsort neighborhood.

Kent Larson, Luis Alberto Alonso Pastor, Arnaud Grignard, Yan Zhang, Alex Aubuchon, Kevin A Lyons

An Urban Decision-Support System Augmented by Artificial Intelligence

The decision-making process in urban design and urban planning is outdated. Currently, urban decision-making is mostly a top-down process, with community participation only in its late stages. Furthermore, many design decisions are subjective, rather than based on quantifiable performance and data. Current tools for urban planning do not allow both expert and non-expert stakeholders to explore a range of complex scenarios rapidly with real-time feedback.

CityMatrix was an effort towards evidence-based, democratic decision-making. Its contributions lie in the application of Machine Learning as a versatile, quick, accurate, and low-cost approach to enable real-time feedback of complex urban simulations and the implementation of the optimization searching algorithms to provide open-ended decision-making suggestions. The goals of CityMatrix were:

Designing an intuitive Tangible User Interface (TUI) to improve the accessibility of the decision-making process for non-experts.

Creating real-time feedback on multi-objective urban performances to help users evaluate their decisions, thus to enable rapid, collaborative decision-making.

Constructing a suggestion-making system that frees stakeholders from excessive, quantitative considerations and allows them to focus on the qualitative aspects of the city, thus helping them define and achieve their goals more efficiently.

CityMatrix was augmented by Artificial Intelligence (AI) techniques including Machine Learning simulation predictions and optimization search algorithms. The hypothesis explored in this work was that the decision quality could be improved by the organic combination of both strengths of human intelligence and machine intelligence.

The system was pilot-tested and evaluated by comparing the problem-solving results of volunteers, with or without AI suggestions. Both quantitative and qualitative analytic results showed that CityMatrix is a promising tool that helps both professional and non-professional users understand the city better to make more collaborative and better-informed decisions.

197. **City Science Collaboration Guadalajara**
- Kent Larson, Luis Alberto Alonso Pastor, Margaret Church, Arnaud Grignard**
 The University of Guadalajara, referred to as UdeG, is a university network composed of 15 campuses within the state of Jalisco and one online system. The University offers undergraduate and graduate studies to around 130,000 students. UdeG strives to understand urban performance metrics using evidence-based decision making tools, facilitated through a collaboration with the MIT Media Lab City Science Group.
198. **City Science Lab Aalto**
- Kent Larson, Luis Alberto Alonso Pastor, Arnaud Grignard, Ariel Noyman**
 Aalto University, Finland, and the MIT Media Lab's City Science group are co-developing a version of the MIT CityScope platform for urban analysis, efficient resource utilization, and spatial programming for campus development, using Otaniemi as a testbed. Aalto joins a network of City Science collaborators which includes Tongji University (Shanghai), Taipei Tech (Taiwan), HafenCity University (Hamburg), and ActuaTech (Andorra).
199. **City Science Lab Andorra**
- Kent Larson, Luis Alberto Alonso Pastor, Juanita Devis, Ronan Doorley, Arnaud Grignard, Michael Lin, Ariel Noyman, Carson Smuts, Phil Tinn, Yan Zhang, Núria Macià (Fundació ActuaTech), Marc Vilella (OBSA), Marc Pons (OBSA), Guillem Francisco Giné (OBSA), Cristina Yañez (UdA)**
 Andorra and the City Science research group at the MIT Media Lab are taking on the challenge of turning Andorra into an "Internationally Recognized Intelligent Country." The Andorra Living Lab project combines different research topics (tourism, innovation, energy and environment, mobility, dynamic urban planning) for the future urban challenges of the country. We are collaborating on a unique initiative providing Andorrans with the research, knowledge, methods, and tools to carry out such transformation.
 Learn more below about City Science Andorra research below.
200. **City Science Lab Hamburg**
- Kent Larson, Ariel Noyman**
 Read more about this project [here](#)
 MIT City Science is working with HafenCity University to develop CityScope for the neighborhood of Rothenburgsort in Hamburg, Germany. The goal is to create an interactive stakeholder engagement tool that also serves as the platform for joint research of modules for city simulation. Researchers are developing modules for walkability, neighborhood connectivity, energy efficiency, and economic activity, among others.
201. **City Science Lab Shanghai**
- Kent Larson, Luis Alberto Alonso Pastor, Margaret Church, Ronan Doorley, Arnaud Grignard, Michael Lin, Ariel Noyman, Yasushi Sakai, Phil Tinn, Yan Zhang**
 Tongji University, Shanghai, and the MIT Media Lab's City Science group are co-developing a version of the MIT CityScope platform for urban analysis, efficient resource utilization, and spatial programming. The MIT CityScope is a tangible, augmented reality platform used to visualize complex urban relationships, simulate the impact of multiple urban interventions, and support decision-making in a dynamic, iterative, evidence-based process.
202. **City Science Lab Toronto**
- Hossein Rahnama**
 City Science Lab Toronto was established in cooperation with Ryerson University in Toronto, Canada. It started in 2018 and is the newest city in the City Science Network. The lab will be embedded in the Faculty of Communications and Design and will be part of the University's Paradox Initiative. The two groups plan to build and work on the development and simulation of urban interventions, such as micro-units for young people, shared work and collaboration spaces, educational facilities, financial services innovations, and new mobility and parking systems. This information will be analyzed and visualized using different platforms including the CityScope. The two groups plan to define new parameters which may include financial modeling, design of innovation flow, public health, new mobility systems, and/or energy networks. A number of large financial institutions, telecommunications companies, and hospitality groups are the founding corporate supporters of the initiative. The lab's director is Professor Hossein Rahnama, who is also a visiting faculty member at the MIT Media Lab.
203. **City Science Network**
- Kent Larson, Luis Alberto Alonso Pastor, Margaret Church, Ronan Doorley, Arnaud Grignard, Mary Heckbert, Michael Lin, Ariel Noyman, Yasushi Sakai, Phil Tinn, Yan Zhang**

204. **CityScope Boston BRT**

Kent Larson, Ryan C. C. Chin, Ariel Noyman, Phil Tinn, J. Ira Winder

The Mobility Futures Collaborative in the MIT Department of Urban Studies and Planning (DUSP) and the Changing Places group at the MIT Media Lab have developed new interactive tools aimed to better communicate the possible impacts of new transit systems. The Media Lab and DUSP have partnered with the Barr Foundation to test these tools in a series of community engagement workshops to examine the impacts of Bus Rapid Transit (BRT) systems in greater Boston. These tools include the CityScope — an interactive platform that utilizes physical models (built from LEGO bricks) and 3-D projection — to enable community members to engage in neighborhood and street-level decisions including alternative bus corridor designs and station-level variations (such as pre-pay boarding). The second tool, CoAXs is a new interactive platform for collaborative transit planning that builds on open-source urban analytics tools such as Conveyal Transport Analyst

205. **CityScope Cooper Hewitt**

Kent Larson, Gabriela Advincula, Luis Alberto Alonso Pastor, Guadalupe Babio Fernandez, Alexandra Berke, Margaret Church, Arnaud Grignard, Maitane Iruretagoyena, Ariel Noyman, Yasushi Sakai, Carson Smuts, Yan Zhang

We are at the dawn of a mobility revolution, where autonomous vehicles will replace cars controlled by humans. We can imagine this developing along two possible divergent paths with very different implications for cities. Will we create an ownership society with private, driverless cars? Or a world of lightweight, shared social mobility robots available to all? In this CityScope project, extreme versions of these two futures are presented. In one, streets are dominated by machines and density leads to congestion and anxiety. The other is a more vibrant city where humans recapture streets and density increases equity and creative interactions. We propose that new mobility systems must be explored to meet the profound challenges of the future and to enable dynamic and evolving places that respond to the complexities of life.

206. **CityScope PlayGround: MIT East Campus**

Kent Larson, Ariel Noyman, J. Ira Winder

This project depicts the design, deployment and operation of a Tangible Regulation Platform, a physical-technological apparatus made for the distillation of regulations. The platform is set to exemplify the effects of regulations on a designated territory, allowing planners, designers, stakeholders and community members a common ground for discussion and decision making. An accessible and self-explanatory tool, this platform illustrates the relationship between urban form and regulations, offering a seamless and transparent process of regulation-based urban design. Lastly, projecting on the foreseen future of law and urbanism, this project proposes an alternative data and performance-based approach for the making of new regulations. Beyond excelling the processes of design under regulations, this platform and other new tools are offered to help facilitate a discussion on the way future regulations will be devised, improving both the design processes and their final outcome.

207. **CityScope Volpe**

Luis Alberto Alonso Pastor, Arnaud Grignard, Ariel Noyman, Yan Zhang, Markus F. ElKatsha, Dalma Foldesi, Jung In Seo

CityScope Volpe is demonstrating most of the urban planning, analysis, and prediction features developed for the CityScope project. The site, a 14-acre parcel on the northern part of MIT/Kendall Square area of Cambridge, has been acquired and is being developed by MIT. City Science researchers designed and built a CityScope urban performance tool that is aiming to predict the outcomes of multiple planning and development scenarios.

208. **Deep Urban Interaction**

Yan Zhang

Analyze and visualize urban interaction with computer vision and deep neural net.

209. **Dynamic Traffic Prediction in Andorra: a Bayesian Network Approach**

Kent Larson, Luis Alberto Alonso Pastor, Ronan Doorley, Arnaud Grignard
Data Fusion for Dynamic Traffic Prediction

Traffic congestion has huge negative impacts on the productivity, health and personal lives of city dwellers. To manage this problem effectively, transportation engineers need to predict traffic congestion throughout the road network at all hours of the day. Prediction of traffic typically involves travel surveys that are expensive, time consuming and do not capture temporal variation in travel demand. However, anonymised location data from mobile phones present an alternative source of data which is passively collected, widely available and naturally captures temporal trends. On the other hand, these data contain other biases and so if we use these data for transportation models, we must take care to correct for these biases using more reliable data. As part of the City Science collaboration with Andorra, we used a Bayesian network to build a calibrated transportation model for the country based on geolocated telecoms data and validated using a small sample of traffic counts.

210. **Escape Pod**

Kent Larson, Chrisoula Kapelonis, Nina Lutz, Lucas Cassiano Pereira Silva, Carson Smuts

The esc-Pod (or Escape Pod) is an exploratory platform for researchers investigating moments of refuge within our bustling work lives. The core of the esc-Pod consists of actuated work and rest surfaces. This allows for moments of productivity and relaxation to occur within a single space. The outer skin provides variable transparency, enabling a spectrum of visibility settings according to privacy requirements. The inner skin provides an infrastructure for the modulation of spatial experiences. Each panel is a pixel, connecting itself to the skin network, and can embody an array of senses.

211. **FindingPlaces**

Kent Larson, Ariel Noyman
What is FindingPlaces?

In reaction to the sudden arrival of tens of thousands of refugees in the city of Hamburg (DE) in 2015, the Lord Mayor requested the CityScienceLab (CSL) at HafenCity University to facilitate a public discussion and decision-making process on locations for refugee accommodation in Hamburg neighborhoods. With highly sensitive socio-political implications, this project demanded a well-designed technological and procedural approach. CSL employed an innovative Human-Computer Interaction tool, CityScope, to facilitate public participation and urban decision-making. A workshop process was also designed to help multiple participants and stakeholders interact effectively. Running from May to July 2016, the FindingPlaces (FP) project enabled about 400 participants to identify 160 locations accepted by Hamburg's citizens, out of which 44 passed legal confirmation by the authorities. Overall, on a qualitative level, the project facilitated surprisingly constructive and collaborative interaction, raising awareness and a sense of ownership among participants.

212. **Hackable Bike**

Yasushi Sakai

To explore future mobility modes, the City Science group is working with Media Lab member company Panasonic to explore the use and potential adaptations of the popular MamaChari bikes. Like other mobility modes, the MamaChari bikes have developed and adapted over the past decades. Bikes for women first became popular during Japan's economic boom in the 1980s when many households benefited from one income, and women were encouraged to stay home and take care of their children. Women used bikes to quickly navigate their cities and make frequent trips to shops and schools, kids in tow. Even as women gradually entered the workforce in the 1990s and 2000s, the stereotype of the Japanese biking woman remained. By 2008, electric assist bikes were introduced to the market, and again they targeted women with children as the primary users. Today MamaChari bikes are stable, secure and ubiquitous in Japan, yet they have yet to enter other global markets.

The City Science group strives to understand current uses of the MamaChari and adapt the bike for new and future uses globally. Ideation workshops were completed in February and May 2018.

Learn more about the first workshop here: <https://www.media.mit.edu/posts/mamachari/>

213. **Human-Machine Cooperation (HMC) for Lightweight Autonomous Robots**

Yi-Cheng Jiang, Michael Lin, Yago Lizaribar Carrillo, Lucas Cassiano Pereira Silva, Phil Tinn, Jerry Wei Hua Yao, Chang-Qi Zhang, Narindra Peaks, Nick Meyer
Facilitating coexistence, trust-building, and collaboration among people and machines.

New modes of 21st century urban transportation are becoming increasingly lightweight, electrified, connected, shared, and autonomous. Cohabitation of humans and machines is an increasingly important question, and one which requires careful attention and design. We strive to enable new forms of human-machine co-existence, trust, and collaboration.

This work focuses on enabling:

Intuitive and effective two-way communication between vehicles and pedestrians;

Street safety and traffic-yielding mechanisms; and

Behavior change related to the adoption of active mobility mode, or electric assist.

214. **KinderCity**

Laya Anasu

KinderCity is a pilot project that attempts to understand the intangibles of city perception. It attempts to understand how people, across ages, children and adults, perceive places and spaces that are playful, creative and inspiring.

215. **Last Mile Logistics**

Kent Larson, J. Ira Winder

Developed by Ira Winder with the MIT Centre for Transportation and Logistics, the model seeks to use real population data and create a simulation to optimize delivery cost and coverage. This could be modified and applied to many disciplines, industries, and population types. The platform has the user place stores on a Tactile Matrix, a type of tangible interface, and displays the output of their potential delivery coverage and cost. This optimization game of sorts is a whole new approach to maximizing delivery potential. The interactive interface and layers of finely granulated and detailed data allow the user to make meaningful interventions and see the intertwining of many rich data sets.

Photos by James Li. Video by Nina Lutz.

216. **MoCho: Mobility choices and societal impacts**

Ronan Doorley, Ariel Noyman, Yasushi Sakai

MoCho (short for "Mobility Choices") is a CityScope module focused on mobility choices and societal impacts. This tool helps predict the choices of mobility modes made at the individual level throughout the entire Boston Metro area.

>>> Check out a live demo of MoCho predictions here <<<

217. **Persuasive Electric Vehicle (PEV)**

Kent Larson, Abhishek Agarwal, Tai-Yu Chen, Yi-Cheng Jiang, Michael Lin, Inigo Martinez Lopez, Phil Tinn, Chang-Qi Zhang

**An Alternative Autonomous Revolution
System design for emerging urban contexts and societal aspirations**

The Persuasive Electric Vehicle (PEV) aims to solve urban mobility challenges with a healthy, convenient, sustainable alternative to cars. The PEV is a low-cost, agile, shared-use autonomous bike that can be either an electrically assisted tricycle for passenger commuting or an autonomous carrier for package delivery.

The PEV uses standard bicycle components and is lightweight (<50kg) yet robust. Its sensors are easy to reconfigure and it has a 250W mid-drive electric motor and 10Ah battery pack that provides 25 miles of travel per charge and a top speed of 20 miles per hour.

Our vision for the PEV: a rider summons the PEV through a phone app, and the nearest available PEV arrives autonomously to meet the rider. Upon completing the trip, the PEV simply moves on to its next passenger or package pickup. The PEV can be autonomous, operated by the rider, or provide the rider with an electric assist. PEV's operate in bike lanes, avoiding the congestion and adding incentives to make more bikeable cities.

218. **Receptive Skins: The Breathing Wall**

Kent Larson, Chrisoula Kapelonis

In architecture, the building skin is the primary interface for mediating the environment of the external with the internal. But today, this mediation is mechanical, deterministic, and static—often seeing the human as a generalizable and problematic input. With advances in material science however, there is great potential to disrupt these traditional manufactured environments of architecture and turn them into responsive mediated environments. What this thesis aims to explore is this idea of the receptive skin—a sensate and dynamic multi-material interface for environmental mediation. This suggests that by departing from the view that buildings are static artifacts, we may instead begin to see buildings as organic, living entities.

Through the development of a working prototype, this project explores how such an interface may manifest itself, through dynamic material composites, instead of mechanical and electronic means. The final prototype is a "proof of concept," a built example of this novel design methodology, which unites material performance with sensate technologies, as a way to enable new interactions between building and environment.

219. **Reversed Urbanism**

Kent Larson, Luis Alberto Alonso Pastor, Ronan Doorley, Arnaud Grignard, Esteban Moro Egido, Ariel Noyman, Zhekun Xiong (MIT SA+P), Nuria Macia (Acuta Andorra)
Predicting Urban Performance through Behavioral Patterns in Temporal Telecom Data

This study explores a novel method to analyze diverse behavioral patterns in large urban populations and to associate them with discrete urban features. This work utilizes machine learning and anonymized telecom data to understand which fragments of the city has greater potential to attract dense and diverse populations over longer periods of time. Finally, this work suggests a road map for building spatial prediction tools in an effort to improve city-design and planning processes.

[Click here for an interactive visualization of this study](#)

Advisors: Kent Larson and Esteban Moro

Thanks to Andorra Telecom, ActuaTech, Núria Macià.

Data was obtained by Andorra Telecom as part of MIT Media Lab City Science and the State of Andorra collaboration.

220. **Service Deployment Simulation and Optimization for Mixed-Use Delivery Fleets**

Michael Lin, Phil Tinn, Fernando Sanchez, Richard Chew, Philip Lee
Forecasting the supply of fleets to meet emerging travel demands and service needs in cities

The availability of vehicles is a critical factor behind successful shared-use mobility services. Proper management of supply-demand dynamics is paramount for achieving viability in a new mobility service, as achieving scale often requires a large capital investment. Under-supplying the fleet would result in low service availability and user dissatisfaction; over-supplying results in inefficient use of capital. In addition, as a new shared mobility platform diversifies its service across both passenger and freight delivery, its required scale of operation and investment becomes more difficult to estimate.

In this fleet deployment and optimization research, the City Science group aims to create an accessible simulation tool to enable cities to forecast the size of deployment of new shared mobility services using the Persuasive Electric Vehicle delivering passengers and packages as an initial test case. The simulation tool also provides a platform for testing fleet rebalancing and service-hub strategies.

221. **Spatial Flux: Body and Architecture in Space**

Chrisoula Kapelonis, Carson Smuts

Structurally, zero gravity means that we do not have to contend with architecture's greatest arch-nemesis, gravity. This opens up a new world of possibilities where we can deploy structures that no longer have to counteract/resist gravitational force. We would like to explore new forms of rapid inflatable prototyping. Most importantly, this prototype explores surfaces utilizing materials that would normally fail on Earth, yet flourish in zero gravity.

This year the MIT Media Lab's City Science group had an opportunity to think of architecture at the scale of the body that was literally out of this world. These are the results.

222. **TerMITes**

Lucas Cassiano Pereira Silva, Carson Smuts

TerMITes are wireless environmental sensors that capture data to help us better understand our environments and human behavior. The sensor data is time-stamped and place-tagged, but otherwise hardware agnostic. TerMITes support multi-modal sensor attachments using common protocols and can be attached to objects in the home such as doors, windows, drawers, cabinets, tables, and chairs to register object usage. TerMITes directly log on to the Internet via low-power Wi-Fi for ease of connection and automatically upload to a centralized database. TerMITes bridge existing methods for qualitative inquiry about our experiences in various planes to quantitative recording based on sensor input. TerMITes are currently used to gather data on humidity, presence detection, ambient light, motion, carbon dioxide, and temperature.

223. **Theme | Changing Places**

Kent Larson, Carlos Aizpurua Azconobieta, Luis Alberto Alonso Pastor, Oier Arino Zaldúa, Mohammad Hadhrawi, Hasier Larrea

Changing Places researchers are developing scalable strategies for creating hyper-efficient, technology-enabled spaces that can help make living more affordable, productive, enjoyable, and creative for urban dwellers.

224. **Theme | CityScope**

Kent Larson, Luis Alberto Alonso Pastor, Guadalupe Babio Fernandez, Ronan Doorley, Arnaud Grignard, Ariel Noyman, Yasushi Sakai, Yan Zhang

City Science researchers are developing a slew of tangible and digital platforms dedicated to solving spatial design and urban planning challenges. The tools range from simulations that quantify the impact of disruptive interventions in cities to communicable collaboration applications. We develop and deploy these tools around the world and maintain open source repositories for the majority of deployments.

"CityScope" is a concept for shared, interactive computation for urban planning.

All current CityScope development, tools, and software are open source here.

225. **Theme | Mobility On-Demand**

Kent Larson, Abhishek Agarwal, Tai-Yu Chen, Yi-Cheng Jiang, Michael Lin, Yago Lizaribar Carrillo, Lucas Cassiano Pereira Silva, Phil Tinn, Jerry Wei Hua Yao, Chang-Qi Zhang

Urban populations around the world are rapidly growing. To improve livability, urban residents must reduce dependency on fossil fuels and private cars, while needing efficient equitable access to inexpensive and reliable transportation.

Urbanization has outpaced transportation innovation as we know it, and urban transportation issues are far more complex and diverse than they appear when viewed from a car seat. The private sector frequently offers self-driving and electric cars as a catch-all solution; additionally, the sharing/on-demand model with connected vehicles has become mainstream, human-scaled, and increasingly electrified, from cars (ZipCar, Car2Go) to bicycles (Hubway, MoBike).

The Mobility Revolution's autonomous vehicles and car sharing have created open questions about the needed participation of the public sector, questionable suitability of automobiles in the emerging urban context, and unintended negative externalities like sprawl or autonomous congestions.

226. **Torque**

Yi-Cheng Jiang, Michael Lin, Phil Tinn, Chang-Qi Zhang

**Open-Source Autonomous Platform for Educational and Service Design Applications
How can new technologies respond to society's diverse industrial, socio-economic, and educational needs?**

Despite AI and robotics being widely trumpeted as keys to the new Industrial Revolution, access to their development remains largely restricted to companies and institutions that are rich in capital and/or data, potentially further deepening the socio-economic disparity observed across continents. As a likely result, these new technologies generate limited positive externalities. For instance, are automobiles really the most critical area in need of self-driving technology? Where else might AI and robotics be applied to lead to increased urban livability, socioeconomic equity, and the vibrancy of local businesses?

Building upon the architecture of MIT's open-source race car platform, the City Science group introduces a new open-ended and heavy-duty self-driving platform. Torque is intended to be used by educators and makers and is ideal for hackathons and classroom instruction. Torque will soon allow rapid prototyping of usage scenarios and services for various contexts and needs.

227. **Urban Tattoo**

Tai-Yu Chen, Michael Lin, Phil Tinn

**Scalable Urban Infrastructure for Human-Machine Cohabitation
New infrastructure to help sustain public-sector participation and operation, and maximize public interest and safety.**

Advancements in autonomous technology have led automobile makers and tech companies to focus on reinventing the automobile—increasing computational capability and enhancing sensor systems. But due to strict road-safety regulations, this vehicle-centric, inside-out approach may take years to materialize, and when it does, restricting "autonomy" to selected vehicles will limit autonomy's impact on street safety and accessibility.

To address current issues, The City Science group focuses on ways to offload often-heavy computational requirements from the vehicle through affordable interventions to street infrastructure by creating human-machine readable traffic signs and urban markers.

With the support of a new genre of smart urban infrastructure, we believe this "autonomy-lite" approach will soon allow lightweight autonomous vehicles to be widely deployed and navigate smoothly in most urban environments.

Andrew Lippman: Viral Communications

Creating scalable technologies that evolve with user inventiveness

228. 8K Time into Space

Andrew Lippman, Hisayuki Ohmata

8K Time into Space is a user interface for a video exploration system with an 8K display. 8K is an ultra high-definition video system and it can present a huge amount of visual content on one display. In our system, video thumbnails with shifted playback time in chronological order are spaced out like tiles. The time range of a scene that a viewer wants to check can be adjusted with a touch interface, and resolution of the thumbnails is changed depending of the range. 8K Time into Space aims to provide responsive and intuitive experiences for video consumption.

229. As You Need It

Andrew Lippman, Yasmine (Jasmin) Rubinovitz

Video or broadcast news is viewed in a far wider set of circumstances than it ever has been before. It is composed with the assumption of a complete, situated viewing, but in fact it is often grabbed on-the-fly as a momentary experience. As You Need It is a semantic summarizer that deconstructs a multi-part segment for presentation as "chunks of importance." We are learning if a story can be cut down to a useful update that takes less time than a traffic light, or as much time as a given user has. This project uses and contributes to another group project, SuperGlue.

230. Boycott!

Andrew Lippman, David Anderton-Yang

A web browser extension that reveals less well-known aspects of corporate public behavior such as environmental respect and political bias. When one engages in a search, we place an image next to the link to a corporate site that graphically reveals relevant information. It might be a donkey versus an elephant, or a measure of "greenness." We seed the system with public information and allow users to contribute to the database.

Data collected can be further explored and mapped out using data visualizations, allowing perception of network distributions and polarizations.

231. Broadercasting

Andrew Lippman, Hisham Bedri, Mike Hao Jiang

Ditch the truck. Live, collaborative broadcasting through mixed reality.

232. Captions++

Andrew Lippman, Tomer Weller

Modern web presentations such as Youtube feature videos with commentary appended at the bottom. In our new imagining of Videotext, we put the two together: comments appear as active bubbles along the playback time line. We thereby associate the commentary with the place in the video to which it refers. It gains context. This project is in the early test stage and is presented for discussion and further development in summer 2016.

233. CivicLink

Andrew Lippman, Oceane Boulais, Britney Johnson, Sam Posner,

CivicLink is a self-hosted platform geared towards internal community organizers that aims to leverage community physical co-presence. CivicLink provides a calendar, event listings, and discussion forums for an organization. There is also moderation support to facilitate discussion and action. The project aims to connect CivicLinks to other Civic Links on topics that community moderators choose to meet about and notifies users through extensible notification programming on user device[s].

234. DbDb

Andrew Lippman, Travis Rich

DbDb (pronounced DubDub) is a collaborative, visually based analysis and simulation platform. We promote open distribution of experimental data by allowing researchers to present a graphical representation of their data and processing techniques that collaborators can build on and augment. This helps test the reproducibility of results and allows others to learn and apply their own techniques. Our intention is for the research community as a whole to benefit from a growing body of open, analytical techniques. DbDb provides an interface for archiving data, executing code, and visualizing a tree of forked analyses. It is part of the Viral initiative on open, author-driven publishing, collaboration, and analysis. It is intended to be linked to PubMed, the main project.

235. **Election ARG**

Andrew Lippman, Agnes Cameron, Mike Hao Jiang, Sam Posner

Only 40% of the eligible population votes in the typical US midterm election, and among young people turnout is even lower. In this experiment, we develop a game that encourages people to influence their friends to physically go to the polls. The system is reminiscent of Fifty Nifty, where people competed to amass points by both calling representatives and spreading the message to others. In addition to awarding points, vote.lol aims to motivate players by allowing them influence over the outcome of a shared narrative that develops in real-time before (and during) the election. Interactive stories with real-world game mechanics are characteristic of alternate reality games (ARGs), which have received scholarly attention for their potential to instigate viral communications among players who self-organize to solve complex problems. The purpose of this study is to test whether ARG techniques can motivate gamers to solve the intractable problem of getting their peers to vote.

236. **FiftyNifty**

Andrew Lippman, Britney Johnson, Leopold Mebazaa, Travis Rich, Yasmine (Jasmin) Rubinovitz, Penelope Eugenia Webb

This is a grassroots challenge to get friends to participate in democracy by making calls to congresspeople in all 50 states. Live phone calls are the best way to directly express your opinion on an issue to your elected officials. Your mission is to pass message this along to friends who will make calls and also pass the message/link along to others who will do the same. It's a social chain letter and a call to action for a better participatory democracy. We help you make your call and you pass on an invitation for your friends to do the same. Your invite can stress your opinion on a given issue.

The winners are the first ten chains to reach 50 states and accumulate the most challenge points. You get 250 points for making a call, 125 points for a call that your friend makes, 65 points for the call their friend makes, on and on. Everyone on the chain earns points. Points count for your first call to each of your two senators and your representative. You get a bonus for a "grand slam" —a network that reaches all 435 representatives and 100 senators.

There is a leaderboard and a network view so you can track how you are doing. You can also see how much of the country your chain is covering.

237. **GIFGIF**

Cesar A. Hidalgo, Andrew Lippman, Kevin Zeng Hu, Travis Rich

An animated GIF is a magical thing. It has the power to compactly convey emotion, empathy, and context in a subtle way that text or emoticons often miss. GIFGIF is a project to combine that magic with quantitative methods. Our goal is to create a tool that lets people explore the world of GIFs by the emotions they evoke, rather than by manually entered tags. A web site with 200,000 users maps the GIFs to an emotion space and lets you peruse them interactively.

238. **Holonews**

Andrew Lippman, Hisham Bedri, Michael Draskovitch

News reporting today suffers from sensationalism. News agencies are constantly fighting for attention and clicks, leading to headlines and photos that exaggerate a single perspective.

What if you could get a full perspective on certain news topics by exploring the news in AR? The spatial nature of AR allows a user to gain a more complete perspective on a story. Having a constant holographic widget on your desk also allows you to follow developing stories, such as a foreign conflict. In addition, the interactive nature of AR means that users can explore the news in a delightful way.

239. **Investigating Provenance in Pacific Island Fisheries**

Oceane Boulais

Fisheries in the Pacific Islands operate in an opaque market where an auditing tool built on a distributed ledger would be beneficial to the local economy by providing an immutable "stamp" that could leverage semi-trusted, third party auditors and vet fisheries for:

labor conditions on-board

types of fish caught (Skipjack, Yellowfin, Bigeye)

sustainability of fishing method (fish aggregating device (FAD), seine net fishing, longline)

240. **IoT Recorder**

Andrew Lippman, Thariq Shihpar

The physical world is increasingly coming online. We have things that measure, sense, and broadcast to the rest of the world. We call this the Internet of Things (IoT). But our cameras are blind to this new layer of metadata on reality. The IoT recorder is a camera that understands what IoT devices it sees and what data they are streaming, thus creating a rich information "caption-track" for the videos it records. Using this meta-data, we intend to explore how this enables new video applications, starting with cooking.

241. **Let's see a game!**

Andrew Lippman, Hisham Bedri, Mike Hao Jiang

In "Let's see a game!" we expose the different perspectives in TV sports & news in order to build broadcasting systems that unify rather than divide. We use the galvanizing impact of sports and live events as a forum, and then we add production and viewing opportunities to distinguish fact from opinion and to challenge the basis of those opinions.

In 1951, when the Dartmouth football team played against Princeton, there was deep disagreement between the two schools as to what had happened during the game. In "They Saw a Game: A Case Study," the psychologists Albert Hastorf and Hadley Cantril found that when the same motion picture of the game was shown to a sample of undergraduates at each school, each individual perceived a different game, and their versions of the game was just as "real" as other versions were to other people.

However, little is known about whether and how broadcasting media are adding fuel to the fire. In order to study the relationship between storytelling/perspectives and opinion formation, we built the following two applications: "Let's see a game!" and "Let's watch news!"

In the first step, we built an interactive application that exposes different perspectives in sports broadcasting. The application plays two broadcasts of the same game, created for each team's home audience. The user can tune into an audio channel by moving the slider. Additional buttons allow the user to take other actions.

242. **MedRec**

Agnes Cameron, Nchinda Nchinda, Kallirroi Retzepi

Increasingly in the US, people have to take responsibility for their health information. Simultaneously, medical providers must make patient data available. MedRec fully decentralizes access rights via an Ethereum blockchain, thereby giving patients control over record distribution. Our model is the World Wide Web: MedRec is a network. Patients and providers operate nodes that authorize others to retrieve data. It is a basis for a generally useful permissioning system.

There is no website or central repository of permissions. Instead, patients and medical records originators establish a relationship and based on that, the patient creates smart contracts that other members of the network can use to authorize access to a record database. The parameters of contracts are kept in a blockchain that is maintained by all member providers/originators who at the same time use those contracts to provide access to their database. The patient/user contracts themselves are held by the patients in a wallet that resides on their device[s] as an app. This app is secure and recoverable in case the physical device is lost or damaged.

For a full overview, technical documentation, and updates, visit the project's website.

243. **News Graph**

Andrew Lippman, Yasmine (Jasmin) Rubinovitz

This project aims to show a different picture of the data behind the news, looking at how we analyze, represent, and interact with it. Video content is constantly created and added to the public archives, but there is never time to watch it all. News Graph explores a new method for interacting with news media. By analyzing the words that are said, extracting entities that appear, and finding the connections between them, we are able to map connections between video segments. Each connection represents two entities that were mentioned in the same video segment, and a video segment can be mapped to a number of connections.

244. **PubPub**

Cesar A. Hidalgo, Andrew Lippman, Kevin Zeng Hu, Travis Rich, Thariq Shihpar

PubPub reinvents publication to align with the way the web was designed: collaborative, evolving, and open. PubPub uses a graphical format that is deliberately simple and allows illustrations and text that are programs as well as static PDFs. The intention is to create an author-driven, distributed alternative to academic journals that is tuned to the dynamic nature of many of our modern experiments and discoveries. It is optimized for public discussion and academic journals, and is being used for both. It is equally useful for a newsroom to develop a story that is intended for both print and online distribution.

245. **Radio Days**

Andrew Lippman, David Anderton-Yang, Hisham Bedri, Kallirroi Retzepi

Following the 2016 election, the entirety of the nation became conscious of its polarization. According to a study by the National Bureau of Economic Research*, polarization has increased among Americans since 1990. The study observes, however, that in 8 of the 9 measures of polarization, older individuals (70+ age group) show higher rates of increase in polarization than other age groups. This age group also utilizes social media less than other age-groups. Could it be that social media is not the root cause of polarization?

In order to explore this further, we looked at polarization through talk radio, which is commonly thought to have political influence.

246. **RelatiVotey**

Andrew Lippman, Harry Minsky, Research Intern

Many people think their vote doesn't count—that a single vote would not change an election's outcome—and they stay home on Election Day. However, your vote is a public statement of beliefs, amplified because many people in your voting district may agree with you, but do not (and in many cases cannot) vote. Your vote gives a voice to those many others.

For example, congressional elections affect everyone in the district, regardless of whether they are eligible to vote. The same senators represent everyone in your state. The same ballot questions affect everyone in your community.

Using data we've gathered from the United States Census Bureau, we have calculated just how many people you're representing with your vote. We directly compare the number of votes in recent congressional elections (by district) to the total population of the district.

When you vote, you're not only voting for your own best interest, but you're also voting for the best interest of those around you.

Visit <https://www.relativotey.org> and recognize your relative voting power!

247. **SuperGlue**

Andrew Lippman, David Anderton-Yang, Mike Hao Jiang, Tomer Weller

SuperGlue is a core news research initiative that is a "digestion system" and metadata generator for mass media. An evolving set of analysis modules annotate 14 DirecTV live news broadcast channels as well as web pages and tweets. The video is archived and synchronized with the analysis. Currently, the system provides named-entity extraction, audio expression markers, face detectors, scene/edit point locators, excitement trackers, and thumbnail summarization. We use this to organize material for presentation, analysis, and summarization. SuperGlue supports other news-related experiments.

SuperGlue is a framework for media digestion and metadata generation. The digestion work flow also has applications for media more broadly including conversational ecommerce.

248. **Theme | Decentralized Systems**

Andrew Lippman

Blockchains have spawned new ways of looking at security, trust, and consensus. These are now design variables that allow diverse communities to develop networks with permanence and agreement that have no central authority. We explore trust as a variable, building blockchain-based systems that separate transactions and currency from the utility of a shared, inedible ledger.

249. **Theme | Ultimate Media**

Andrew Lippman

We concentrate on media that informs, unifies, and defines society such as news, sports, and public events. These are characterized by simultaneity, synchronicity, immersion, multiple perspectives, and new ways of framing discussions as stories. We design structures that allow for civic participation in media creation and distribution yet retain the editorial imperative to create a shared reality based on trust and truth.

250. **Theme | Viral Political Action**

Andrew Lippman

Friends don't let friends vote alone.

We construct bottom-up ways to get people civically engaged, specifically to vote. The idea is independent, culturally and community-based ways to reinforce participation. We replace centrally radiated messaging and mobilization with local, iterative, and potentially orthogonal cues that diffuse through a population. Experiments this term address voting as a teachable moment where people might openly accept new information, discuss it, and encourage others to join. While issues may be increasingly national (in any nation) discussion and action remains local; the challenge is to energize it and by doing so engender critical thought about issues and people. Our projects will be tested in the US mid-terms in November and can shed new light on decentralized mobilization of ideas in all areas.

251. **This Is How**

Andrew Lippman, Tomer Weller

This Is How is a platform for connecting makers with small businesses through stories. Small businesses share their stories in the form of video bytes in which they explain what they do and why, what their requirements and constraints are, and what kinds of issues they have. Makers can then annotate the video, ask further questions, and propose solutions for issues. The video is passed through SuperGlue for annotation and to categorize and find commonalities among requests.

252. **votoMosaic**

Andrew Lippman, Kallirroi Retzeppi

A tapestry where each pixel represents a pledge by an individual to vote. Anyone can participate and watch the growing and changing image that emerges as others agree to vote. The tapestry evolves and will encourage repeated attention. This tests local reinforcement to support actions.

<https://votomosaic.media.mit.edu/>

253. **VR Codes**

Andrew Lippman

VR Codes are dynamic data invisibly hidden in television and graphic displays. They allow the display to present simultaneously visual information in an unimpeded way, and real-time data to a camera. Our intention is to make social displays that many can use at once; using VR codes, users can draw data from a display and control its use on a mobile device. We think of VR Codes as analogous to QR codes for video, and envision a future where every display in the environment contains latent information embedded in VR codes.

254. **Wall of Now**

Andrew Lippman, Tomer Weller

Wall of Now is a multi-dimensional media browser of recent news items. It attempts to address our need to know everything by presenting a deliberately overwhelming amount of media, while simplifying the categorization of the content into single entities. Every column in the wall represents a different type of entity: people, countries, states, companies, and organizations. Each column contains the top-trending stories of that type in the last 24 hours. Pressing on an entity will reveal a stream of video that relates to that specific entity. The Wall of Now is a single-view experience that challenges previous perceptions of screen space utilization towards a future of extremely large, high-resolution displays.

255. **What's America Listening To?**

Andrew Lippman, David Anderton-Yang, Hisham Bedri, Kallirroi Retzepi

Tod Machover: Opera of the Future

Extending expression, learning, and health through innovations in musical composition, performance, and participation

256. **Aether Muse**

Charles Holbrow

Aether Muse proposes an extension for live internet streams of musical audio/video performance. We explore how a two-way data connection between distributed audience listening can enhance the connection between a musician and their audience. By generating synchronized visualization for client watching the performance in the browser, musicians gain a new means to communicate with their fans and grow their audiences.

This project also showcases "tcchh," a custom digital audio effect for warping and stretching a live audio signal.

257. **Ambisonic Surround-Sound Audio Compression**

Tod Machover, Charles Holbrow

Traditional music production and studio engineering depends on dynamic range compression audio signal processors that precisely and dynamically control the gain of an audio signal in the time domain. This project expands on the traditional dynamic range compression model by adding a spatial dimension. Ambisonic Compression allows audio engineers to dynamically control the spatial properties of a three-dimensional sound field, opening new possibilities for surround-sound design and spatial music performance.

258. **Breathing Window**

Tod Machover, Rebecca Kleinberger

Breathing Window is a tool for non-verbal dialogue that reflects on your own breathing while also offering a window on another person's respiration. This prototype is an example of shared human experiences (SHEs) crafted to improve the quality of human understanding and interactions. Our work on SHEs focuses on first encounters with strangers. We meet strangers every day, and without prior background knowledge of the individual we often form opinions based on prejudices and differences. In this work, we bring respiration to the foreground as one common experience of all living creatures.

259. **...but not simpler...**

Tod Machover

This collection of Tod Machover's music focuses on chamber and orchestral music composed during the last decade, both with and without electronic enhancement. Machover's music is a fascinating blend of expressive and lyrical melody combined with a sophisticated ear for textural complexity. The resulting music is always a treat for the ears—colorful, vibrant, and rhythmically propulsive. The largest composition on this disc is the piano concerto *Jeux Deux*, scored for large orchestra (the work was commissioned and first performed by the Boston Symphony Orchestra), with the soloist performing on a "hyperpiano"—a concert grand piano which interacts with sensors and computer programs in order to expand its technical possibilities. Machover produces cutting-edge music with a heart!

260. **Chronosonogy: Sonic Sensory Time Shifting**

Alexandra Rieger

Chronosonogy was born through extending the neuroscience research of Teki Et Al, which reveals "Distinct Neural Substrates of Duration-Based and Beat-Based Auditory Timing" and Fassnidge Et Al's work examining "Visual Interference of Auditory Signal Detection."

Our perception of time is impacted by combining factors of visual-auditory override and imaginary notes sensations. Chronosonogy is both an experience and a newly discovered time-shifting phenomenon that activates a neurological quirk situated in fronto-temporal-parietal regions of our brains.

261. **City Symphonies: Massive Musical Collaboration**

Tod Machover, Benjamin Bloomberg, Charles Holbrow, Rebecca Kleinberger, David Nunez, Simone Ovsey, Sarah Platte, Peter A. Torpey, Akito Oshiro van Troyer, Garrett Parrish

The City Symphony project by the Opera of the Future group brings creative musical participation to everyone while encouraging collaboration between artists and amateurs, with symphony orchestras (and many other organizations) as the principal galvanizers. City Symphonies invite the citizens of a particular place to listen to the world around them, to discover the "music" in that place, and to work together to create a sonic portrait of that city that reveals its essential qualities and most important issues and questions to audiences locally and around the world. Going beyond crowd-sourcing, City Symphonies propose a new model of collaboration, where people of all ages and backgrounds work together to make beautiful, meaningful music that none of them—including the highest-level professionals—could have made alone.

Tod Machover and Opera of the Future launched the City Symphony project in 2012, and since then have created collaborative symphonies with the cities of Toronto (Toronto Symphony Orchestra, 2013), Edinburgh (Edinburgh International Festival, Royal Scottish National Orchestra, 2013), Perth (Perth International Festival, West Australian Symphony Orchestra, 2014), Lucerne (Lucerne Festival, Lucerne Festival Academy Orchestra, 2015), and Detroit (Detroit Symphony Orchestra with Knight Foundation, 2015). Machover and his research group collaborated with these cities to explore new relationships between author/audience, composition/improvisation, music/noise, and online/onsite while emphasizing the potential of each locale to inspire its citizens to engage with their community through music in a profound way. One of the most rewarding aspects of the City Symphonies project is that the processes employed to achieve the final work are designed to grow naturally out of each particular city and context. For this reason, the five City Symphonies realized to date by Tod Machover and the MIT Media Lab have differed widely in terms of use of imagery/video, interactive performance elements, incorporation of local musicians, and the balance of acoustic/electronic sounds.

262. **Cognitarium 2.0**

Alexandra Rieger

Cognitarium 2.0 is a planetarium for the mind. Enter a world of 40 Hz sounds, multicolored lights and mind-entraining frequencies. Cognitarium 2.0 combines early groundbreaking research in gamma frequencies, multi sensory music and cognition research, to leap into the future of cognitive health and cross-modal experiences. This edition of the Cognitarium is a collaboration combining creative cognition research by Alexandra Rieger, lighting physics and control from Ben Bloomberg, the gamma drones of David Su, and 40 Hz sculpted sound as defined by Tod Machover.

263. **Death and the Powers: Redefining Opera**

Tod Machover, Benjamin Bloomberg, Elena Jessop, Simone Ovsey, Peter A. Torpey, Akito Oshiro van Troyer

Death and the Powers is a groundbreaking opera that brings a variety of technological, conceptual, and aesthetic innovations to the theatrical world. It is a one-act, full-evening work that tells the story of Simon Powers, a successful and powerful businessman and inventor, reaching the end of his life and facing the question of his legacy. He is now conducting his final experiment, passing from one form of existence to another in an effort to project himself into the future. Simon Powers is himself now a System. His family, friends, and associates must decide what this means, whether or not he is actually alive, how it affects them, and whether to follow.

Death and the Powers was composed by Tod Machover and developed at the MIT Media Lab along with Diane Paulus (director) and Alex McDowell (production designer). The opera uses the techniques of tomorrow to address age-old human concerns of life and legacy. The unique performance environment, including autonomous robots, expressive scenery, new Hyperinstruments, and human actors, blurs the line between animate and inanimate. The opera premiered in Monte Carlo in Fall 2010, with additional performances in Boston and Chicago in 2011 and a new production with a global, interactive simulcast in Dallas in February 2014. The DVD of the Dallas performance of Powers was released in April 2015.

264. **Diastrophisms**

Nicole L'Huillier, Yasushi Sakai, Thomas Sanchez Lengeling

Diastrophisms is a sound installation with a modular system that sends images through rhythmic patterns. It is built on a set of debris from the Alto Rio building that was destroyed by the 27F earthquake in 2010 in Chile. With Diastrophisms we were looking for a poetical, critical and political crossing between technology and matter, in order to raise questions about the relationship between human beings and nature, and to consider the construction of memory in a community by questioning the notion of monument, as well as to imagine new forms of communication in times of crisis.

Work by: Nicole L'Huillier, Thomas Sanchez Lengeling, and Yasushi Sakai

Exhibited at Siggraph Art Gallery 2018, curated by Andres Burbano. A paper about this work was published in Leonardo Journal for the special edition of Siggraph 2018 Art Papers and Art Gallery Exhibition. The paper was written by Nicole L'Huillier and Valentina Montero.

Diastrophisms was also exhibited as "Diastrofismos" at the Media Arts Bienal, Santiago de Chile, 2017, curated by Valentina Montero.

265. **Disembodied Performance**

Tod Machover, Elena Jessop, Peter A. Torpey

Early in the opera "Death and the Powers," the main character, Simon Powers, is subsumed into a technological environment of his own creation. The set comes alive through robotic, visual, and sonic elements that allow the actor to extend his range and influence across the stage in unique and dynamic ways. This environment assumes the behavior and expression of the absent Simon; to distill the essence of this character, we recover performance parameters in real time from physiological sensors, voice, and vision systems. Gesture and performance parameters are then mapped to a visual language that allows the off-stage actor to express emotion and interact with others on stage. To accomplish this, we developed a suite of innovative analysis, mapping, and rendering software systems.

266. **Emotionally Intelligent Playback**

Hane Lee, David Su

Emotionally Intelligent Music Playback opens possibilities to various emotional trajectories through a piece of music. The listener can navigate through emotional territories via a touchscreen interface. The system transitions seamlessly to corresponding emotional interpretations extracted from various existing renditions of the same composition.

267. **Empathy and the Future of Experience**

Tod Machover, Benjamin Bloomberg, Charles Holbrow, Rebecca Kleinberger, David Nunez, Simone Ovsey, Sarah Platte, Peter A. Torpey, Akito Oshiro van Troyer, Meejin Yoon and the Empathy and Experience class

Nothing is more important in today's troubled world than the process of eliminating prejudice and misunderstanding, and replacing them with communication and empathy. We explore the possibility of creating public experiences to dramatically increase individual and community awareness of the power of empathy on an unprecedented scale. We draw on numerous precedents from the Opera of the Future group that have proposed concepts and technologies to inspire and intensify human connectedness (such as Sleep No More, Death and the Powers, Vocal Vibrations, City Symphonies, and Hyperinstruments) and from worldwide instances of transformative shared human experience (such as the Overview Effect, Human Libraries, Immersive Theatre, and non-sectarian spiritual traditions). The objective is to create a model of a multisensory, participatory, spatially radical installation that will break down barriers between people of immensely different backgrounds, providing instantaneous understanding of—as well as long-term commitment to—empathic communication.

268. **Eternal**

Charles Holbrow

The web enables massive realtime communication and collaboration, but most media on the web does not take advantage of these features. Media on the internet typically uses the web only as a distribution medium.

If we are going to make next-generation internet media, we need to think about how to integrate the unique properties of the web into the media itself. This involves rethinking the role and design of web servers so they facilitate realtime interaction instead of serving requests.

Models for internet-enabled interaction and collaboration like forums, chatroom, live documents, metrics and A/B testing, are not designed with interactive media in mind.

This project is our very first exploration using custom web server technology and a new interaction model to facilitate online collaboration.

269. **Fablur**

Tod Machover, Rebecca Kleinberger, Alisha Panjwani

Fablur explores the limit of the self in its relationship to others through the medium of clothing. The augmented gown uses a rear dome projection system on the surface of the fabric. The system comprises laser projectors and mirror structures talking wirelessly with a computer, within which is contained both content and warp projection mapping software. This novel technological interface presents both a performative element and a seamless integration in a woman's life experience. This wearable project questions the boundary between the self and others, the boundary between the individual and society, and the boundary between the body and nature.

270. **Fensadense**

Tod Machover, Benjamin Bloomberg, Peter A. Torpey, Lucerne Festival

Fensadense is a new work for 10-piece ensemble composed by Tod Machover, commissioned for the Lucerne Festival in summer 2015. The project represents the next generation of hyperinstruments, involving the measurement of relative qualities of many performers where previous systems only looked at a single performer. Off-the-shelf components were used to collect data about movement and muscle tension of each musician. The data was analyzed using the Hyperproduction platform to create meaningful production control for lighting and sound systems based on the connection of the performers, with a focus on qualities such as momentum, connection, and tension of the ensemble as a whole. The project premiered at the Lucerne Festival, and a spring European tour just concluded this May 2016.

Fensadense site created by our former UROPer, Garrett Parrish.

[Listen to a complete recording of the Lucerne performance here.](#)

271. **Freedom Is in the Ear of the Beholder**

Hane Lee

"The sense of freedom...entails not simply the absence of frustration but the absence of obstacles to possible choices and activities—absence of obstructions on roads along which a man can decide to walk."

—Isaiah Berlin

How do we evoke a sense of freedom through sound?

Freedom Is in the Ear of the Beholder (FreeEar) approaches the question in two parts: first, raising awareness of physical space around the listener through an immersive soundscape; second, giving agency to the listener by devising a correlation between the listener's movement and the soundscape.

The first part consists of spatialized layers of music. Each layer is given a different depth and movement. The layers, combined, aim to create a scope of active sound that reminds the listener of the plethora of physical space—absence of inhibition—around them and of the opportunities for movement.

The second part, currently in development, will be detection of the listener's motion using sensors and drawing its influence on the soundscape. The listener can explore the realized space with a stronger sensation of agency.

272. **Gamma Instrument**

Alexandra Rieger

The Gamma Instrument is a small-format interactive device hovering between the realms of musical instrument and medical instrument. A capacitive hand-following interface allows one to create abstract gamma sounds while surrounded by an orbit of gamma-frequency lights. Creating musical tones on the device could heighten gamma entrainment as it mimics higher-level cognition and gamma-band processing noted in musicians. This device is part of a larger exploration of 40 Hz frequencies and Alzheimer's prevention/reduction within the context of the Aging Brain Initiative at MIT. The tabletop multi-sensory experience brings aspects of the Cognitarium to an interactive and portable platform.

273. **Gammalan**

David Su

Gammalan is an interactive musical experience that uses music information retrieval techniques in conjunction with game design principles to engage audiences in creative behavior that combines the power of familiar songs with neural entrainment on multiple temporal scales.

A preliminary system analyzes and processes existing recordings, manipulating properties such as rhythm and harmony, while introducing synthesized frequencies in a musically informed manner. The recordings are then presented in an exploratory 3D game-like environment that encourages active and playful engagement with the recorded music.

274. **Gamma MOON: Musical
Omnisensory Orbital
Neuroinstrument**

Alexandra Rieger

Introducing the newest edition of the gamma musical/medical instruments - the Gamma MOON (Musical Omnisensory Orbital Neuroinstrument). This instrument features a capacitive interface which delivers multisensory gamma stimulation through audio, visual, haptic and tactile feedback. In collaboration with the Aging Brain Alzheimer's Initiative at MIT, the Gamma MOON pilots a novel treatment form-factor with the goal of device deployment in large-scale clinical trials. Research reveals that gamma instrument interaction can strengthen cognitive function and sensory perception while increasing focus even in neurocognitively healthy individuals. Contact arrangement allows both patients and performers to create high-level musical abstractions as well as follow traditional notational melodies. Gamma MOON's heightened sensorial engagement recruits increased cognitive entrainment, multimodal expression and creative freedom.

275. **Hyperinstruments**

Tod Machover, Tristan Jehan, Rebecca Kleinberger

The Hyperinstruments project creates expanded musical instruments and uses technology to give extra power and finesse to virtuosic performers. They were designed to augment a wide range of traditional musical instruments and have been used by some of the world's foremost performers (Yo-Yo Ma, the Los Angeles Philharmonic, Peter Gabriel, and Penn & Teller). Research focuses on designing computer systems that measure and interpret human expression and feeling, exploring appropriate modalities and content of interactive art and entertainment environments, and building sophisticated interactive musical instruments for non-professional musicians, students, music lovers, and the general public. Recent projects involve the production a new version of the "classic" Hyperstring Trilogy for the Lucerne Festival, and the design of a new generation of Hyperinstruments, for Fensadense and other projects, that emphasizes measurement and interpretation of inter-player expression and communication, rather than simply the enhancement of solo performance.

276. **Hyperproduction: Advanced
Production Systems**

Tod Machover, Benjamin Bloomberg

Hyperproduction is a conceptual framework and a software toolkit that allows producers to specify a descriptive computational model and consequently an abstract state for a live experience through traditional operating paradigms, such as mixing audio or operation of lighting, sound, and video systems. The hyperproduction system is able to interpret this universal state and automatically utilize additional production systems, allowing for a small number of producers to cohesively guide the attention and perspective of an audience using many or very complex production systems simultaneously. The toolkit is under active development and has been used for new pieces such as Fensadense, and to recreate older systems such as those for the original Hyperstring Trilogy as part of the Lucerne Festival in 2015. Work continues to enable new structures and abstraction within the framework.

277. **Hyperscore**

Tod Machover, Tristan Jehan

Music software that lets anyone compose music. The first music software program designed to teach students and adults how to compose music simply by drawing lines on the screen.

278. **ImmerSound VR**

Rebecca Kleinberger

ImmerSound is a virtual reality experience wherein one can compose music by drawing in 3D. The resulting composition is a sculpted soundscape to be experienced both visually and in 3D audio.

The user starts by choosing an instrument in the system and testing the sound that this instrument would produce at different locations. Then the user can "paint" a melody in space, where the elevation of the "sound brush" defines the pitch of the instrument, and the speed of the hand corresponds to the tempo of the melody created. A wide range of instruments enables the creation of rich compositions with percussion, bass, classical instruments, and ambient sounds.

This project associates sounds and space in a new way by offering an intuitive and natural way to interact with music. One can also imagine the same type of visual compositional space used as a neutral zone for collaboration between two or more people in different geographical locations and from different cultural backgrounds, using the universal language of music to connect in less-biased ways. This system is a first example of the potential of virtual reality for music and experiences of connection.

279. **Interneternity**

Charles Holbrow

Interneternity is a dynamic musical composition built into the World Wide Web. The Internet changed the way that we listen to music, but music itself remains essentially unchanged. Can we create music that uses the Internet for more than a distribution medium? Can we make music that could not exist without the Internet?

Interneternity is an experimental integration of music composition and the World Wide Web. Instead of releasing this music as a static file, it was released in the form of a website. When the site launched, users could play the composition continuously from beginning to end. But each new connection to the web server changes the musical structure in some small way...and eventually the original composition is unrecognizable.

Certain interactions with the site may extend its lifetime, while certain interactions nudge the music towards inevitable disintegration. Will you get to hear the piece before it is broken forever?

280. **Man of My Words**

Hane Lee

Man of My Words is a wearable self-feedback voice changer for women to challenge internalized sexism. The experience is designed in two parts:

Auditory The electronic part of the device consists of a Bluetooth microphone and earbuds. When the female user speaks into the microphone, her voice is altered into a male voice and returned through the earbuds. By giving the perception of speaking in a male voice, this device is intended to break the association that the users have between themselves, their female, "weak" voice, and lack of authority.

Visual The top hat and a fake mustache, apart from their functional purpose of holding the microphone, were designed to create a more immersive, satirical experience. This device aims to more easily approach a serious social issue through comfortable humor.

281. **Media Scores**

Tod Machover, Peter A. Torpey

Media scores provide a means to orchestrate multiple modalities in the creation of expressive works of art and performance. New technologies afford numerous opportunities to tell stories and create expressive artworks through a variety of media. Media scores extend the concept of a musical score to other modalities in order to facilitate the process of authoring and performing multimedia compositions, providing a medium through which to realize a modern-day Gesamtkunstwerk. Through research into the representation and the encoding of expressive intent, systems for composing with media scores are being developed. Using such a tool, the composer will be able to shape an artistic work that may be performed through human and technological means in a variety of media and utilizing various modalities of expression. Media scores offer the potential for authoring content considering live performance data and the potential for audience participation and interaction. This paradigm bridges the extremes of the continuum from composition to performance, allowing for improvisatory compositional acts at performance-time. The media score also provides a common point of reference in collaborative productions as well as the infrastructure for the real-time control of any technologies used during a live performance.

282. **Memory Music Box**

Rebecca Kleinberger

We are transforming a classic music jewelry box into a digital memory box and Skype portal that enable those not familiar with technology to stay in touch with their family and friends. The box has three different modes. To switch mode the user only has to turn the small crank in the back, like they would do with a regular music box. The crank is linked to a rotary encoder. The back of the box is covered with a two-way mirror covering a small LCD screen; when the screen is turned off, it looks like a regular mirror but when the screen is on, it looks like a display. In the first mode, the box plays the favorite music of the user with the screen off. In the second mode, the display shows photographs of family and friends. By turning the crank or by clicking on the characters in the photographs, the box goes into mode 3, which is a Skype portal enabling the user to instantly call a family member face-to-face. This device is mainly imagined for elderly parents with dementia or memory loss.

283. **MM-RT**

Akito Oshiro van Troyer

MM-RT is a tabletop tangible musical interface that employs electromagnetic actuators and small permanent magnets to physically induce sounds on objects. When, for example, a box with permanent magnets inside is placed on top of a pad, an electromagnet installed below the pad actuates the permanent magnets, causing them to bounce and hit the walls of a box. Timbre generation on each box is physically and digitally constrained: Each object comprises different materials and size, and a granular synthesis technique (a digital form of time domain additive synthesis) is used to create the sound producing mechanism.

284. **Music Visualization via Musical Information Retrieval**

Tod Machover, Thomas Sanchez Lengeling

In a study of human perception of music in relation to different representations of video graphics, this project explores the automatic synchronization in real time between audio and image. This aims to make the relationship seem smaller and more consistent. The connection is made using techniques that rely on audio signal processing to automatically extract data from the music, which subsequently are mapped to the visual objects. The visual elements are influenced by data obtained from various Musical Information Retrieval (MIR) techniques. By visualizing music, one can stimulate the nervous system to recognize different musical patterns and extract new features.

285. **Nebula**

Rebecca Kleinberger

Nebula is a voice-controlled interactive software app that allow users to conduct a choir of diverse vocal sounds by using only their voice as input. The system is based on the Constellation project by Akito van Troyer that takes sonic material and organizes it visually to let anyone compose creative soundscapes. Nebula uses hundreds of vocal samples that are represented as individual stars and organized by perceptual and spectral audio features. The samples get triggered and activated when the user sings or produces any sound with the voice. The voice is analyzed in real time, and this analysis is then used to trigger and mix a cascade of sounds with similar features. The voice becomes a kind of conductor's baton that creates a dialogue without words between the individual and the community. And once a participant uses Nebula, their own voice, first used as a controller, is then transformed into a new sample adding an additional star to the experience for all subsequent participants. The result - a final cosmos of voices—provides material that might be used by composer Tod Machover for the final Philadelphia Voices City Symphony.

286. **Panoptic Journey**

Thomas Sanchez Lengeling

Imagine if you want to travel to a destination and once you are there hear only car horns, or see only blue, or feel a single spectral color of the city. The project is about experiencing a city in a different way and to discover distinct paths to travel. This is by including artificial soundscapes and visuals from other contexts. Part of this is knowing what sounds are around us and what are we looking at when we are walking in the city. The new experiences is an extra layer of sensory stimuli in the city. The study includes experiencing a city with colors and sounds from another location that we haven't been to. This "transfer" process transfers colors and sounds to another location - while still being in the same city. One potentially could transfer emotional content from one city to another one. Overall, the immersive and multi-sensory representation of a map is crucial for allowing participants to fully feel that place. In addition, the goal is to offer a helpful, immersive, subjective - rather than a detached, observational-experience.

287. **Philadelphia Voices**

Tod Machover, Philadelphia Orchestra and the citizens of Philadelphia

Philadelphia Voices is the latest in the series of City Symphonies projects that Tod Machover and the Opera of the Future group have created since 2012. Previous City Symphonies have centered on Toronto, Edinburgh, Perth, Lucerne, and Detroit.

Each project paints a musical portrait of a city—using "traditional" musical elements as well as real sounds recorded by residents—to portray the essence of their city's history and future. Everyone living in that city is invited to collaborate to create the symphony, resulting in an unprecedented creative collaboration around music, sound, and storytelling.

Philadelphia Voices has been in progress since spring 2017 and will culminate in performances in Philadelphia (Kimmel Center) and New York (Carnegie Hall) in April 2018. A special mobile app has been developed to allow anyone with a smartphone to collect sounds and video and to upload those files to a communal database for listening and morphing.

Opera of the Future researchers have created new software that enables anyone to contribute their voice to a specially-designed sonic landscape from Philadelphia. Workshops and special activities have been organized with local singers from every age and background, and Tod Machover has chosen several hundred of them to sing in the final performances with The Philadelphia Orchestra under the baton of its music director, Yannick Nézet-Séguin.

Since Philadelphia is considered the birthplace of American democracy, Philadelphia Voices will investigate the current state of democracy from a Philly perspective. The project will also consider the society in which we want to live, and what we are willing to do to achieve that ideal.

288. **Powers Live**

Tod Machover, Benjamin Bloomberg, Charles Holbrow, Elena Jessop, Simone Ovsey, Peter A. Torpey, Garrett Parrish, Justin Martinez, Kevin Nattinger

Death and the Powers: Global Interactive Simulcast

289. **Ritual I: The Thing Itself**

Nicole L'Huillier

Ritual I: The Thing Itself consists of a choreographed robotic body that is in constant flux. It performs a dance of repetitive patterns that become a trance ritual of vibrations and movement. The thing or dancing body stands on a metal sheet that vibrates with every move it makes; this way the body affects its territory with every movement. In return, the vibrations of the metal add to the vibration of the thing itself while it moves, and in this way the body is affected by its territory.

This is a feedback system, a cyclic loop, a transduction network, a ritual dance between a body and its territory. This ritual explores how agency becomes increasingly distributed among bodies and territories, which opens interactions of hybrid selves, blurring the limits of bodies and its environment, understanding them all as an assemblage of vibrant matter. The architecture comprises complex assemblages—nothing is something by itself, but things are themselves by being in a relationship with others. This is an entangled architecture of bodies. This is a way to explore and diversify the imaginative projections and potentials of a kinetic non-human body and how sound and vibration are key to trigger agency and vibrant presence.

It is the thing itself that has been allowed to be deployed as multiple, and thus allowed to be grasped through different viewpoints, before being possibly unified in some later stage depending on the abilities of the collective to unify them.

—Bruno Latour, *Assembling the Social: An Introduction to Actor-Network-Theory* (Oxford: Oxford University Press, 2005), 116.

290. **Schoenberg in Hollywood**

Tod Machover

A new opera inspired by the life of Austrian composer Arnold Schoenberg, exploring his life in Los Angeles after fleeing Hitler's Europe.

**Schoenberg in Hollywood
November 14-18, 2018
Emerson Paramount Center
Tickets | Opening Night**

291. **Seasons Change Together**

David Su, Dominique Star

Seasons Change Together is a collaborative song construction experience for multiple simultaneous participants. It represents a first step towards the creation of a framework, designed for interactive multiplayer musical experiences, that explores the potential for technology-enabled systems to facilitate collaborative creativity through expression, the emotional affordances of musical storytelling, and the spatiotemporal boundaries of co-presence.

Participants are presented with multiple interfaces that determine the musical texture, rhythmic patterns, and lyrical content of an interactive song. Individual participants can freely move between and share interfaces as they wish, allowing the experience to accommodate play sessions with variable user counts as well as encouraging participants to actively engage with all aspects of the song's construction through collaborative composition.

Drawing inspiration from improvisational practice in addition to game design and interactive storytelling, Seasons Change Together strives to open up new possibilities for experiencing music, narrative, and creativity in a social environment.

292. **SIDR: Deep Learning-Based Real-Time Speaker Identification**

Tod Machover, Rebecca Kleinberger, Clement Duhart

Consider each of our individual voices as a flashlight to illuminate how we project ourselves in society and how much sonic space we give ourselves or others. Thus, turn-taking computation through speaker recognition systems has been used as a tool to understand social situations or work meetings. We present SIDR, a deep learning-based, real-time speaker recognition system designed to be used in real-world settings. The system is resilient to noise, and adapts to room acoustics, different languages, and overlapping dialogues. While existing systems require the use of several microphones for each speaker or the need to couple video and sound recordings for accurate recognition of a speaker, SIDR only requires a medium-quality microphone or computer-embedded microphone.

293. **Sonic Enrichment at the Zoo**

Janet Baker, Rebecca Kleinberger, Gabriel Miller, Janelle Sands

This project is a collaboration between the MIT Media Lab and the San Diego Zoo to design and build interactive sonic enrichment systems for animals in managed care. Our approach is based on the potential of animal-animal and human-animal relationship as an environmental enrichment for the welfare of zoo-housed animals specifically in terms of animal vocal communication. Enrichment is a way for caregivers to provide animals with the opportunity to express natural behaviors and reduce stereotypic behaviors.

294. **Sonic Murals**

Alexandra Rieger

Giving voice and information to objects and spaces around us

Objects in our lives are usually either digital or not; mostly a wall is just a wall. The Sonic Murals project explores what happens when we blur those lines. Implementing touch capacitance and conductive pigments in an innovative way, any surface can become a sensor, a tool for data collection, or a musical instrument, as exhibited in this project. When interacting with touch or proximity sensors on a sonic mural, one can experience spacial exploration and sound creation on a multi-sensory level.

295. **Sound Cycles**

Tod Machover, Charles Holbrow, Rebecca Kleinberger

Sound Cycles is a new interface for exploring, re-mixing, and composing with large volumes of audio content. The project presents a simple and intuitive interface for scanning through long audio files or pre-recorded music. Sound Cycles integrates with the existing Digital Audio Workstation for on-the-fly editing, audio analysis, and feature extraction.

296. **Speech Companion**

Rebecca Kleinberger, Sebastian Franjou

Speech Companion is an exploration in the domain of real-time extraction of musicality from speech. Speech is one of the richest and most ubiquitous modalities of communication used by human beings. Its richness lies in the combination of linguistic and nonlinguistic information. Musicality is one of the most crucial nonlinguistic components of speech and covers tempo and rhythms of the speaker as well as the pitch variation and unique texture of the vocal sounds. Abstracting musicality from a speech in real time presents several challenges from latency to subjective pitch identification or recognizing voiced/unvoiced sounds. In this paper, we describe a new system for real-time extraction of the music present in everyday speech based on time and pitch quantization. Our system offers several modes from a simple synchronized melody line to a more complex accompaniment much like a singer accompanying herself at the guitar.

With such a system, we offer a proof of concept and a working prototype to explore the real-life situations where the music of speech impacts speakers or listeners such as in the contexts of infant-directed speech, language acquisition, human-animal communication, speech pathology, aphasia reeducation, or even music learning and musical composition.

297. **Taking a Line on a Walk**

Charles Holbrow

Bauhaus artist Paul Klee described the line as one of the atomic elements of art and architecture. He famously described drawing as "taking a line on a walk." What would a line on a walk look like in three dimensions?

This project uses our custom high-resolution AR rig to find out. See the very first test footage:

298. **Talking Drums**

Nicole L'Huillier, Yasushi Sakai, Thomas Sanchez Lengeling

"The Talking Drums" is a sound installation where we created a modular system for sending images through rhythmic patterns. It is an encrypted language to empower a musical community by sending secret messages, avoiding surveillance and listening to each other. It's inspired by the communication method and instrument used by African communities to send messages across the continent. They did this by drumming, and by a rhythmic language that only could be understood by the community.

For the installation we collected different objects from MIT's dump, especially obsolete technologies, such as hard drives and old screens.

299. **The SciFi Audio Workstation**

Charles Holbrow

The internet changed how we create, distribute, and consume music and media. Modern digital tools for creating music and media provide "cloud enabled" features like automatic backups, an asset marketplace, and real-time collaboration. Despite these features, current tools for creating music are still based on the personal computing paradigms of the 20th century. How will media production change in the 21st century?

Internet engineering introduced the concept of cloud-native applications. What would it mean for end-user experience to be truly cloud-native? This project shows a very early prototype that illustrates some of the possibilities. In this approach, the assets that make up a music project are securely exposed to the Internet, where they can be accessed and manipulated by digital services and human collaborators.

The long-term goal is to give individual content creators control of their data, and a share of the benefits provided by machine learning analytics. A longer description and technical blueprint can be found in *Turning the Digital Audio Workstation Inside Out*.

300. **The Telemetron**

Sands Fish, Nicole L'Huillier, Thomas Sanchez Lengeling, Sarah Hua

Today, the environments that humans occupy in space are designed for survival. Humans are carefully shuttled to and from space, and during their relatively short stays, they are provided with minimum supplies to remain alive and able to perform experiments. As we begin to plan less for short visits and more for life in space (such as a six to eight month trip to Mars and beyond) the question becomes: What does human culture look like in space?

Nicole L'Huillier and Sands Fish decided to explore how design and creativity might evolve as we begin to do more than merely survive in space. The Telemetron is a unique mode of musical performance that takes advantage of the poetics of zero gravity, and opens a new field of musical creativity. The project attempts to expand expression beyond the limits of earth-based instruments and performers. Leveraging sensors, data transmission and capture (for performance after flight), as well as their experience as composers and performers, Sands and Nicole explore a new body language for music.

The Telemetron was played for the first time during the inaugural Media Lab Space Exploration Initiative's Zero G flight. This instrument is a clear dodecahedron chamber that contains customized "chimes" containing gyroscopes. The chimes emit their telemetry as they spin and collide. Sensors record the position, direction, and spin of each chime. These elements create the composition. The performers play the instrument by moving it in space, shaking it, colliding it. The performance can be recorded to be experienced on earth or used as a live instrument during future space flights. The instrument can be played inside space craft or in the vacuum of space without the benefit of sound waves.

Recorded as a beautiful audio-visual experience, this experiment opens the doors for new forms of creative expression, and brings the magic of space to musicians. We hope to reach beyond the utilitarian, and toward the inspiring.

301. **The Telemetron Adventures**

Sands Fish, Nicole L'Huillier

The Telemetron is a musical instrument specially designed to be performed in microgravity environments. It is created to explore the poetics of movement in outer space and the relational aspects of an antigravitational performance between human and non-human bodies. Through this line of work, we explore how the creation of culture might evolve as we leave Earth. The Telemetron project proposes a space in space for everybody - a space to share, to create, to listen.

During the summer of 2018, the Telemetron was presented on different occasions:

The Telemetron was exhibited at Ars Electronica as part of the exhibition "A Glitch in the Stars" curated by the MIT Media Lab Space Exploration Initiative. Nicole L'Huillier designed the exhibition along with Sands Fish and Xin Liu.

The Telemetron was featured at Sónar+D, a festival that explores how creativity is changing our present and imagining new futures. Nicole was invited to speak in the "Making Music in Space" panel. She also gave a workshop called "Antigravitational Luthiers". Also, the Telemetron was part of The Zero Gravity Band Exhibition.

We published the paper "Telemetron: a musical instrument for performance in zero gravity" at NIME, and Sands Fish presented it at the international conference on New Interfaces for Musical Expression, describing the technical design of our first Telemetron.

Nicole also gave a talk about the Telemetron at the En Orbita Festival in NYC.

The Telemetron was created by Nicole L'Huillier and Sands Fish. With the assistance of Thomas Sanchez Lengeling, Sarah Hua, and Matt Carney. It was created on the context of the Space Exploration Initiative first zero gravity research flight. We are currently working on more space instruments, stay tuned.

302. **Tod Machover: Operas
1987-2014**

Tod Machover

This brief excerpt video shows a glimpse of some of Tod Machover's innovative, unusual opera realized at — and with the collaboration of — the MIT Media Lab over the past 30 years.

303. **Unpublished Spaces That Perform Themselves**

Nicole L'Huillier

As we generally experience on earth, there is no space without sound and there is no sound without space. Building on the understanding of music and architecture as creators of spatial experience, this project presents a novel way of unfolding music's spatial qualities in the physical world. Spaces That Perform Themselves exposes an innovative response to the current relationship between sound and space: where we build static spaces to contain dynamic sounds. What if we change the static parameter of the spaces and start building dynamic spaces to contain dynamic sounds?

A multi-sensory kinetic architectural system is built in order to augment our sonic perception through a cross-modal spatial choreography that combines sound, movement, light, color, and vibration. By breaking down boundaries between music and architecture, possibilities of a new typology that morphs responsively with a musical piece can be explored. As a result, spatial and musical composition can exist as one synchronous entity. These spatial choreographies build up the scenario to study the possible relationships between a human body and a robotic architectural body, throughout a dance of perception and matter.

This project seeks to contribute a novel perspective on leveraging technology, art, science, and design to provide a setting to enrich and augment the way we relate to the built environment. The objective is to enhance our perception and challenge models of thinking by presenting a post-humanistic phenomenological encounter of the world.

304. **Using the Voice as a Tool for Self-Reflection**

Tod Machover, Rebecca Kleinberger

Our voice is an important part of our individuality. From the voices of others, we understand a wealth of non-linguistic information, such as identity, social-cultural clues, and emotional state. But the relationship we have with our own voice is less obvious. We don't hear it the way others do, and our brain treats it differently from any other sound. Yet its sonority is deeply connected with how we are perceived by society and how we see ourselves, body and mind. This project is composed of software, devices, installations, and thoughts used to challenge us to gain new insights on our voices. To increase self-awareness, we propose different ways to extend, project, and visualize the voice. We show how our voices sometimes escape our control, and we explore the consequences in terms of self-reflection, cognitive processes, therapy, affective features visualization, and communication improvement.

305. **Vocal Vibrations**

**Tod Machover, Charles Holbrow, Elena Jessop, Rebecca Kleinberger, Le Laboratoire, The Dalai Lama Center at MIT
Expressive Performance for Body-Mind Wellbeing**

The Vocal Vibrations music is now available for exclusive download from Bowers & Wilkins. Vocal Vibrations was exhibited at Le Laboratoire Cambridge in March 2015. The original installation at Le Laboratoire Paris ran from March to September 2014.

Pattie Maes: Fluid Interfaces

Designing wearable systems for cognitive enhancement

306. A Flying Pantograph

Pattie Maes, Harshit Agrawal, Sang-won Leigh

We explore an art form where machines take on an essential role in the aesthetics and processes of the creation. Our main theme can be summarized as "body, hybrid, and evolve," as we study an artistic medium that incorporates mechanical machines that institutes a hybrid creation process as well as an expressive capacity beyond body limits.

Flying Pantograph transposes human-scale drawing acts to a physically remote output canvas in different scales and aesthetics. A drone becomes an "expression agent," modified to carry a pen and be controlled by human motions, then carries out the actual process of drawing on a vertical wall. Not only mechanically extending a human artist, the drone plays a crucial part of the expression as its own motion dynamics and software intelligence add new visual language to the art. This agency forms a strong link between a human artist and the canvas; however, at the same time, it is a deliberate programmatic disconnect that offers space for exploiting machine aesthetics as a core expression medium.

This seemingly straightforward technical realization is in fact a combination of non-trivial mechanical and algorithmic solutions. The drone, a floating machine, is relying on a slim chance of stabilization acquired by battling the vortex of air, the pressure and friction on the canvas surface, and the capricious mind of the human artist. This suspense, the vulnerability to instability, and the aftermath of crashing, poses a contrast with the optimistic idea of technologically evolved capability of a human artist.

At this critical point of balance, we embody an instance of evolution in form of an artistic medium. The interaction between people and our installation itself is one message, where the outcome drawing of the interaction offers another. This pushes forth the idea of collective and technological evolution across scale.

307. AlterEgo

Pattie Maes, Arnav Kapur

AlterEgo is a non-invasive, wearable, peripheral neural interface that allows humans to converse in natural language with machines, artificial intelligence assistants, services, and other people without any voice—without opening their mouth, and without externally observable movements—simply by articulating words internally. The feedback to the user is given through audio, via bone conduction, without disrupting the user's usual auditory perception, and making the interface closed-loop. This enables an human-computer interaction that is subjectively experienced as completely internal to the human user—like speaking to one's self. AlterEgo seeks to combine humans and computers—such that computing, the Internet, and AI would weave into human personality as an internal "second self" and augment human cognition and abilities.

The wearable system captures peripheral neural signals when internal speech articulators are volitionally and neurologically activated, during a user's internal articulation of words. This enables a user to transmit and receive streams of information to and from a computing device or any other person without any observable action, in discretion, without unplugging the user from her environment, without invading the user's privacy.

308. AttentivU

Pattie Maes, Nataliya Kos'myna

AttentivU helps you to stay attentive and engaged with your current task. It provides haptic feedback when it detects that you have a low attention span based on your brain signals. Our hope is that use of the system can train the wearer to increase his/her attention span.

309. Augmentative Communication Interfaces

Jaya Narain

We are creating new communication interfaces for people with speech and language disorders, incorporating technologies like physiological sensing and personalized machine learning. The goal of our work is to identify gaps in the technologies that exist and what people need, and create and test devices that meet those needs.

Do you have a speech or language impairment, or have a close friend or family member who does? We would really appreciate your feedback on our AAC device survey, which will help us identify promising architectures for further development. See the link below to the survey:

https://mit.co1.qualtrics.com/jfe/form/SV_6gmpNchtSf8vCLz

310. **Augmented Airbrush**

Pattie Maes, Joseph A. Paradiso

We present an augmented handheld airbrush that allows unskilled painters to experience the art of spray painting. Inspired by similar smart tools for fabrication, our handheld device uses 6DOF tracking, mechanical augmentation of the airbrush trigger, and a specialized algorithm to let the painter apply color only where indicated by a reference image. It acts both as a physical spraying device and as an intelligent digital guiding tool that provides manual and computerized control. Using an inverse rendering approach allows for a new augmented painting experience with unique results. We present our novel hardware design, control software, and a discussion of the implications of human-computer collaborative painting.

311. **BioEssence**

Pattie Maes, Judith Amores Fernandez, Artem Dementyev, Javier Hernandez, Xiqing Wang
A wearable olfactory display that monitors cardio-respiratory information to support mental wellbeing.

BioEssence is a novel wearable olfactory display that provides just-in-time release of scents based on the physiological state of the wearer. The device can release up to three scents and passively captures subtle chest vibrations associated with the beating of the heart and respiration through clothes.

312. **Chill.out**

Pattie Maes, Tomas Vega Galvez

Temperature influences our perception and cognition both consciously and subconsciously. These effects are rooted in our bodily experiences and interactions with the environment, and are even embedded as metaphors in our language. By learning how temperature affects us in different contexts, we can make use of that knowledge to create interventions that help us with personal growth.

This project seeks to apply thermal interfaces to assist with emotion and attention regulation. Stress and attention levels can be inferred using implicit user inputs such as electrodermal activity, heart rate variability, and relative facial temperature. This information can then be used to determine appropriate thermal feedback to implicitly modify the user's perception and aid with emotional and attention regulation in a minimally disruptive fashion.

313. **CocoVerse: A Playground for Cocreation and Communication in Virtual Reality**

Pattie Maes, Hisham Bedri, Wiley Corning, Scott W. Greenwald, Erin Hong
Real-time collaborative self-expression in virtual reality

314. **Cognitive Illusions and VR**

Misha Sra

This work explores the design of techniques based on the cognitive illusion of "inattention blindness" which is a failure to notice something happening in front of you when you are focused on something else. The aim is to direct a user's attention and manage their perception to create VR experiences with high levels of presence. The techniques were tested through a VR implementation of a disruption-free natural walking experience. Video and paper available here: <http://web.media.mit.edu/~sra/vmotion.html>

315. **Dormio: Interfacing with dreams for creativity**

Ishaan Grover, Adam Haar Horowitz, Pedro Reynolds-Cuellar, Oscar Rosello, Tomas Vega Galvez, Abhinandan Jain

Sleep is a forgotten country of the mind. A vast majority of our technologies are built for our waking state, even though a third of our lives are spent asleep. Current technological interfaces miss an opportunity to access the unique, imaginative, elastic cognition ongoing during dreams and semi-lucid states. In turn, each of us misses an opportunity to use interfaces to influence our own processes of memory consolidation, creative insight generation, gist extraction, and emotion regulation that are so deeply sleep-dependent. In this project, we explore ways to augment human creativity by extending, influencing and capturing dreams in stage-1 sleep. It is currently impossible to force ourselves to be creative because so much creative idea association and creative incubation happens in the absence of executive control and directed attention. Sleep offers an opportunity for prompting creative thought in the absence of directed attention, if only dreams can be controlled.

During sleep onset, a window of opportunity arises in the form of hypnagogia, a semi-lucid sleep state where we all begin dreaming before we fall fully unconscious. Hypnagogia is characterized by phenomenological unpredictability, distorted perception of space and time and spontaneous, fluid idea association. Edison, Tesla, Poe, and Dalí each accessed this state by napping with a steel ball in hand to capture creative ideas generated in hypnagogic microdreams when it dropped to the floor below.

In this project we modernize this technique, using an interactive social robot accompanied with an EEG system, muscular sleep stage tracking system, and auditory biofeedback. We are able to influence, extract information from, and extend hypnagogic microdreams for the first time: We found that active use of hypnagogia with the system can augment human creativity. This system enables future research into sleep, an underutilized and understudied state of mind vital for memory, learning and creativity.

316. **Electrostatic Playground: A Multi-User Virtual Reality Physics Learning Experience**

Hisham Bedri, Wiley Corning, Scott W. Greenwald, Erin Hong, Gabriel Fields, Sydney Gibson, Misha Jamy, John Belcher

Room-scale virtual reality opens up exciting new possibilities for exploratory learning. Phenomena that otherwise cannot be experienced directly (e.g. subjects that are microscopic, remote, or dangerous) can be transformed into environments that are immersive, interactive and social. Electrostatic Playground is a VR physics lab where multiple users can explore and discover principles of electrostatics through experimentation. It also concretizes abstract notions of electrostatics in the form of tangible, interactive objects. Users can learn by directly manipulating physics objects while receiving real-time feedback from the environment. We've incorporated the ability to record these interactions in order to provide a means of authoring content, reviewing one's notes, and teaching others. Electrostatic Playground is a multi-user lab where users can explore and discover principles in electrostatics.

317. **Elowan: A plant-robot hybrid**

Pattie Maes, Harpreet Sareen

Elowan is a cybernetic lifeform, a plant in direct dialogue with a machine. Using its own internal electrical signals, the plant is interfaced with a robotic extension that drives it toward light.

318. **EmotionalBeasts**

Guillermo Bernal

With advances in virtual reality (VR) and physiological sensing technology, even more immersive computer-mediated communication through life-like characteristics is possible. As a solution for the current lack of culture, expression, and emotions in VR avatars, we propose a two-fold solution. First, integrate bio-signal sensors into the head-mounted display (HMD) and implement techniques to detect aspects of the emotional state of the user. Second, connect the data collected to an expressive avatar: Emotional Beasts. The creation of Emotional Beasts allowed us to experiment with the manipulation of a user's self-expression in VR space and as well as the perception of others in it, with the goal of pulling the avatar design away from the uncanny valley and making it more expressive, more relatable to our own mannerisms. Based on this we have implemented a prototype system in which VR, human motion, and physiological signals are integrated to allow avatars to become more expressive in virtual environments in real time.

319. **Enlight**

Pattie Maes, Rony Kubat, Natan Linder, Natan Linder, Tal Achituv, Rony Kubat

In physics education, virtual simulations have given us the ability to show and explain phenomena that are otherwise invisible to the naked eye. However, experiments with analog devices still play an important role. They allow us to verify theories and discover ideas through experiments that are not constrained by software. What if we could combine the best of both worlds? We achieve that by building our applications on a projected augmented reality system. By projecting onto physical objects, we can paint the phenomena that are invisible. With our system, we have built "physical playgrounds": simulations that are projected onto the physical world and that respond to detected objects in the space. Thus, we can draw virtual field lines on real magnets, track and provide history on the location of a pendulum, or even build circuits with both physical and virtual components.

320. **Essence**

Pattie Maes, Judith Amores Fernandez

The sense of smell is perhaps the most pervasive of all senses, but it is also one of the least understood and least exploited in HCI. We present Essence, the first olfactory computational necklace that can be remotely controlled through a smartphone and can vary the intensity and frequency of the released scent based on biometric or contextual data.

321. **Express**

Pattie Maes, Tal Achituv, Daniel Kish (expert in perception and accessibility for the blind), Cristina Powell (artist)

We are developing a new and exciting tool for expression in paint, combining technology and art to bring together the physical and the virtual through the use of robotics, artificial intelligence, signal processing, and wearable technology. Our technology promotes expression in paint not only by making it a lot more accessible, but also by making it flexible, adaptive, and fun, for everyone across the entire spectrum of abilities. With the development of the technology, new forms of art also emerge, such as hyper, hybrid, and collaborative painting. All of these can be extended to remote operation (or co-operation) thanks to the modular system design. For example, a parent and a child can be painting together even when far apart; a disabled person can experience an embodied painting experience; and medical professionals can reach larger populations with physical therapy, occupational therapy, and art therapy, including motor/neuromuscular impaired persons.

322. **Food Attack**

Pattie Maes, Niaja Farve

The rise in wearable devices and the desire to quantify various aspects of everyday activities has provided the opportunity to offer just-in-time triggers to aid in achieving pre-determined goals. While a lot is known about the effectiveness of messaging in marketing efforts, less is known about the effectiveness of these marketing techniques on in-the-moment decision-making. We designed an experiment to determine if a simple solution of using just-in-time persuasive messaging could influence participants' eating habits and what types of messaging could be most effective in this effort. Our solution utilizes a head-mounted display to present health-based messages to users as they make real-time snack choices. We are able to show that this method is effective and more feasible than current efforts to influence eating habits.

323. **Guitar Machine**

Sang-won Leigh

Symbiotic guitar playing between human and machine fingers. The system can be used as a learning tool or a real-time augmentation to the human guitar player, offering previously impossible combinations of notes.

324. **Guitar Machine II**

Sang-won Leigh, Aby Jain (Electronic design)

Exploring robotic sound generation mixed with human movements on the guitar. Guitar Machine II is a robotic guitar that responds to human gestures, as well as other input means such as midi controllers or algorithmic composition.

325. **HandsOn: A Gestural System for Remote Collaboration Using Augmented Reality**

Pattie Maes, Kevin Wong

2D screens, even stereoscopic ones, limit our ability to interact with and collaborate on 3D data. We believe that an augmented reality solution, where 3D data is seamlessly integrated in the real world, is promising. We are exploring a collaborative augmented reality system for visualizing and manipulating 3D data using a head-mounted, see-through display, that allows for communication and data manipulation using simple hand gestures.

326. **HeartBit**

Oscar Rosello

HeartBit is an interface designed for haptic heart rate biofeedback. A handheld heart beats alongside your own, mirroring the size, weight, and movement of a hidden internal organ, now external and tangible in real-time. HeartBit offers a medium for users to self-regulate in moments of stress, anxiety or exertion: Control your heart to control your breath and body—for relaxation, performance enhancement, or augmented self-awareness.

327. **LeakyPhones**

Hiroshi Ishii, Tal Achituv, Amos Golan

LeakyPhones is a public/private headset that was designed to encourage face-to-face interactions, curiosity, and healthier social skills by letting users "peek" into each other's music just by looking at one another.

Gaze is an important social signal in human interaction. Though its interpretation may vary across cultures, it is generally agreed that eye contact indicates interest and the point of attention in a conversation. Despite this, many common personal computing technologies, such as our smartphones and headphones, require significant visual and auditory attention thereby inhibiting our ability to interact with others. LeakyPhones offers a new approach for addressing this challenge.

328. **Learning to dance in VR**

Misha Sra, Aske Mottelson

Virtual reality can help realize mediated social experiences where we interact as richly with those around the world as we do with those in the same room. The design of social virtual experiences presents a challenge for remotely located users with differently sized, room-scale setups like those afforded by recent commodity virtual reality devices like the HTC Vive. This work explores how we can allow remote users to learn to dance together in VR by mapping their individual physical spaces to a shared virtual space. Video and paper available here: <http://web.media.mit.edu/~sra/dancing.html>

329. **Masca**

Adam Haar Horowitz, Oscar Rosello, Tomas Vega Galvez, Irmandy Wicaksono, Ethan Weber

Masca is a flexible mask for sleep stage detection. Our device adapts to the human body using conformable piezoresistive fabric and silicone, enabling eyelid motion detection in a comfortable, affordable form factor. Eyes and eyelids change movement frequency predictably as sleep stage transitions occur, allowing for a simpler, more portable system than the typical high-density EEG required for sleep tracking. Tracking and influencing of sleep cognition opens up doors to targeted reactivation of daytime experience during sleep: a future in which the consolidation of emotion, memory and learning in sleep is rendered controllable by wearable electronics.

This device is modeled after Prof. Robert Stickgold's Nightcap, and we are grateful for his ongoing assistance with this project, aiming at further extending the benefits of sleep neuroscience.

330. **Mathland: Play with Math in Mixed Reality**

Ashris Choudhury, Mina Khan, Judith Sirera i Pulido, Fernando Trujano

Mathematical experiences are intrinsic to our everyday lives, yet mathematics education is mostly confined to textbooks. Seymour Papert used the term "Mathland" to propose a world where one would learn mathematics as naturally as one learns French while growing up in France. We built a mixed reality application that augments the physical world with interactive mathematical concepts and annotations to create a real-life Mathland. Using Mathland, people can collaboratively explore, experience, and experiment with mathematical phenomena in their real, physical environments using tangible objects. Mathland opens up new opportunities for mathematical learning using Papert's constructionist principles in an immersive environment that affords situated learning, embodied interaction and playful constructionism.

331. **Mnemo**

Neo (Mostafa) Mohsenvand

Mnemo is an integrated system to support human biographical memory. Mnemo is directed to serve people with impaired memory (e.g. Alzheimer's patients) by providing intuitive ways to benefit from large amounts of personal data.

332. **Move Your Glass**

Pattie Maes, Niaja Farve

Move Your Glass is an app built using the JavaScript-based Wearsript library to communicate with the native sensors and camera on the device. The app is an activity and behavior tracker that also tries to increase wellness by nudging the wearer to engage in positive behaviors. In particular, data from the tri-axial accelerometer and camera are collected and analyzed offline using a designated server. These results are then fed into a k-nearest neighbors machine learning routine and compared to training data to provide continuous differentiation between sitting/standing, walking, and running while the user is on the go. The ultimate goal is to log this information (and additional activity parameters) and convey activity summaries and, if necessary, prompts for increasing activity, back to users.

333. **NeverMind: Using AR for Memorization**

Pattie Maes, Marc Exposito Gomez, Oscar Rosello

NeverMind is an interface and application designed to support human memory. We combine the memory palace memorization method with augmented reality technology to create a tool to help anyone memorize more effectively. Early experiments conducted with a prototype of NeverMind suggest that the long-term memory recall accuracy of sequences of items is nearly tripled compared to paper-based memorization tasks. With this project, we hope to make the memory palace method accessible to novices and demonstrate one way augmented reality can support learning.

334. **PAL**

Mina Khan, Utkarsh Sarawgi

PAL (Personalized Active Learner) is a wearable system with on-device machine learning to help users with real-time, personalized, and context-aware memory augmentation, language learning, and self-awareness.

335. **Paper Dreams**

Guillermo Bernal, Haripriya Mehta, Lily Zhou

Paper Dreams explores the various modes of creativity that can be enabled by artificial intelligence.

A fair amount of current research has been focused on using machine intelligence to learn "creativity," from transfer learning of artistic styles to translation of languages. However, the application of current machine learning algorithms and multi-modal inputs to the augmentation of existing human creativity is a relatively unexplored area. By focusing on the dynamics of this human-machine interaction and working with the representations inside machine learning models, we can give people new tools for reasoning.

Our system at its current form provides a user with a canvas that it is more like a mirror, where we draw strokes and re-evaluate what our drawing looks like at each step in order to continue. We do this by building a neural network which takes a small number of input variables, called latent variables, and produces the entire sketch as output.

The machine can use analog modes of thinking to recognize what we are drawing and help us move forward. At the moment, Paper Dreams augments the drawing experience in three ways: by adding textures/colors, suggesting other elements/drawings for the scene, and introducing serendipity. To adjust the level of serendipity, the user has control of a dial that determines how "predictable" vs "unpredictable/nutty" you want these machine additions to be.

Some of the driving questions for this project are:

To what extent are these new tools enabling creativity?

Can they be used to generate ideas which are truly surprising and new, or are the ideas clichés, based on trivial recombinations of existing ideas?

Can such systems be used to develop fundamental new interface primitives?

How will those new primitives change and expand the way humans think?

336. **PhysioHMD**

Pattie Maes, Guillermo Bernal, Tao Yang

Virtual and augmented reality headsets are unique as they have access to our facial area, an area that presents an excellent opportunity for always-available input and insight into the user's state. Their position on the face makes it possible to capture bio-signals as well as facial expressions. The PhysioHMD platform introduces a software and hardware modular interface built for collecting affect and physiological data from users wearing a head-mounted display. The platform enables researchers and developers to aggregate and interpret signals in real-time and use them to develop novel, personalized interactions, as well as evaluate virtual experiences. Our design offers seamless integration with standard HMDs, requiring minimal setup effort for developers and those with less experience using game engines. The PhysioHMD platform is a flexible architecture that offers an interface that is not only easy to extend but also complemented by a suite of tools for testing and analysis. We hope that PhysioHMD can become a universal, publicly available testbed for VR and AR researchers.

To create a seamless experience, we have integrated several bio-signal sensors into the faceplate of an HTC VIVE VR headset and utilized the Shimmer3 sensor for emotion-sensing. For the collection of Galvanic Skin Response, dry electrodes were positioned on the forehead area due to the fact that it is one of the areas most dense with sweat glands. GSR data reflects emotional arousal, but in order to identify how arousal, valence, motivation, and cognition interact in response to physical or psychological stimuli, it becomes necessary to complement GSR with other biosensors. For the heart rate, a PPG (photoplethysmogram) sensor, which senses the rate of blood flow by utilizing light to monitor the heart's pumping action, was placed in the temple region of the user. This is done to get insights into the respondent's physical state, anxiety and stress levels (arousal), and to determine how changes in their physiological state relate to their actions and decisions.

337. **PsychicVR**

Pattie Maes, Judith Amores Fernandez, Xavier Benavides Palos, Daniel Novy

We present PsychicVR, a proof-of-concept system that integrates a brain-computer interface device and virtual reality headset to improve mindfulness while enjoying a playful immersive experience. The fantasy that any of us could have superhero powers has always inspired us, and by using virtual reality and real-time brain activity sensing we are moving one step closer to making this dream real. We non-invasively monitor and record electrical activity of the brain and incorporate this data into the VR experience using an Oculus Rift and the MUSE headband. By sensing brain waves using a series of EEG sensors, the level of activity is fed back to the user via 3D content in the virtual environment. When users are focused, they are able to make changes in the 3D environment and control their powers. Our system increases mindfulness and helps achieve higher levels of concentration while entertaining the user.

338. **Scanner Grabber**

Pattie Maes, Ethan Zuckerman, Tal Achituv, Luke Berndt (OpenMhz)

Scanner Grabber is a digital police scanner that enables reporters to record, playback, and export audio, as well as archive public safety radio (scanner) conversations. Like a TiVo for scanners, it's an update on technology that has been stuck in the last century. It's a great tool for newsrooms. For instance, a problem for reporters is missing the beginning of an important police incident because they have stepped away from their desk at the wrong time. Scanner Grabber solves this because conversations can be played back. Also, snippets of exciting audio, for instance a police chase, can be exported and embedded online. Reporters can listen to files while writing stories, or listen to older conversations to get a more nuanced grasp of police practices or long-term trouble spots. Editors and reporters can use the tool for collaborating, or crowdsourcing/public collaboration.

339. **SmileCatcher**

Pattie Maes, Niaja Farve

Our hectic and increasingly digital lives can have a negative effect on our health and wellbeing. Some authors have argued that we socialize less frequently with other people in person and that people feel increasingly lonely. Loneliness has been shown to significantly affect health and wellbeing in a negative way. To combat this, we designed a game, SmileCatcher, which encourages players to engage in in-person, social interactions and get others to smile. Participants wear a device that takes regular pictures of what is in front of them and the system analyzes the pictures captured to detect the number of smiles.

340. **STEM Accessibility Tool**

Pattie Maes, Rahul Kumar Namdev

We are developing a very intuitive and interactive platform to make complex information--especially science, technology, engineering, and mathematics (STEM) material--truly accessible to blind and visually impaired students by using a tactile device with no loss of information compared with printed materials. A key goal of this project is to develop tactile information-mapping protocols through which the tactile interface can best convey educational and other graphical materials.

341. **The Blank Canvas**

Adam Haar Horowitz, Boo Aguilar, Fernando Magalhaes, João Rosa, Matheus de Paula

The Blank Canvas directs immersion inwards using virtual reality, augmenting awareness of the microscopic worlds inside each of us and the science that is changing them today. It has been shown at Cannes Film Festival, Vision Summit, VR Sci Fest and the World Economic Forum.

This is the first episode of The Blank Canvas, a VR platform that showcases the future of science and scientific communication. So many of the brilliant contemporary innovations in science are lost to the general public because they happen at scales so small we can barely comprehend them. The Blank Canvas leverages the power of immersive technologies to make these ideas come to life in macro planetary scale, explaining themes like DNA editing, hacked viruses and CRISPR. We build collaborations between scientists and engineers for accurate, inspirational science storytelling that turns textbooks into experience.

342. **The Challenge**

Pattie Maes, Rosalind W. Picard, Niaja Farve, Natasha Jaques

Mental wellbeing is intimately tied to both social support and physical activity. The Challenge is a tool aimed at promoting social connections and decreasing sedentary activity in a workplace environment. Our system asks participants to sign up for short physical challenges and pairs them with a partner to perform the activity. Social obligation and social consensus are leveraged to promote participation. Two experiments were conducted in which participants' overall activity levels were monitored with a fitness tracker. In the first study, we show that the system can improve users' physical activity, decrease sedentary time, and promote social connection. As part of the second study, we provide a detailed social network analysis of the participants, demonstrating that users' physical activity and participation depends strongly on their social community.

343. **Theme | Engineering Dreams**

Pattie Maes

344. **VR Maze in Zero Gravity**

Neo (Mostafa) Mohsenvand

The brain uses space to index, organize, and retrieve memories. However, our sense of space depends on our perception of gravity. We plan to test and understand the effect of altering gravity on human memory. Our experiment consists of a virtual reality experience that exposes the user to a sequence of small random mazes. We will compare the results of the experiment under different gravitational conditions.

345. **WATCH**

Pattie Maes, Niaja Farve

WATCH is a system that attempts to measure the possible influence that a new time-management interface will have on improving the habits of a user. Users set goals for each of the activities detected by the app. Detected activities include physical activity and time spent in pre-defined locations. An Android app (WATCH) on their personal phones is able to track their activities (running, walking, and sitting) as well as their GPS location. Their progress in comparison to their goals is displayed on their home screens as a pie chart.

Neri Oxman: Mediated Matter

Designing for, with, and by nature

346. **3D Printing of Functionally Graded Materials**

Neri Oxman, Steven Keating

Functionally graded materials--materials with spatially varying composition or microstructure--are omnipresent in nature. From palm trees with radial density gradients, to the spongy trabeculae structure of bone, to the hardness gradient found in many types of beaks, graded materials offer material and structural efficiency. But in man-made structures such as concrete pillars, materials are typically volumetrically homogenous. While using homogenous materials allows for ease of production, improvements in strength, weight, and material usage can be obtained by designing with functionally graded materials. To achieve graded material objects, we are working to construct a 3D printer capable of dynamic mixing of composition material. Starting with concrete and UV-curable polymers, we aim to create structures, such as a bone-inspired beam, which have functionally graded materials. This research was sponsored by the NSF EAGER award: Bio-Beams: FGM Digital Design & Fabrication.

347. **Additive Manufacturing in Glass: Electrosintering and Spark Gap Glass**

Steven Keating, John Klein

Our initial experiments in spark electrosintering fabrication have demonstrated a capacity to solidify granular materials (35-88 micron soda ash glass powder) rapidly using high voltages and power in excess of 1 kW. The testbed high-voltage setup comprises a 220V 60A variable autotransformer and a 14,400V line transformer. There are two methods to form members using electrosintering: the one-electrode drag (1ED) and two-electrode drag (2ED) techniques. The 1ED leaves the first electrode static while dragging the second through the granular mixture. This maintains a live current through the drag path and increases the thickness of the member due to the dissipation of heat. Large member elements have been produced with a tube diameter of around 0.75". The 2ED method pulls both electrodes through the granular mixture together, sintering the material between the electrodes in a more controlled manner.

348. **Anthozoa**

Neri Oxman, Steven Keating, Prof. W. Craig Carter, Iris Van Herpen, Stratasys, Keren Oxman

A 3D-printed dress was debuted during Paris Fashion Week Spring 2013 as part of collaboration with fashion designer Iris Van Herpen for her show "Voltage." The 3D-printed skirt and cape were produced using Stratasys' unique Objet Connex multi-material 3D printing technology, which allows a variety of material properties to be printed in a single build. This allowed both hard and soft materials to be incorporated within the design, crucial to the movement and texture of the piece. Core contributors include: Iris Van Herpen, fashion designer (Amsterdam); Keren Oxman, artist and designer (NY); and W. Craig Carter (Department of Materials Science and Engineering, MIT). Fabricated by Stratasys.

349. **Beast**

Neri Oxman

Beast is an organic-like entity created synthetically by the incorporation of physical parameters into digital form-generation protocols. A single continuous surface, acting both as structure and as skin, is locally modulated for both structural support and corporeal aid. Beast combines structural, environmental, and corporeal performance by adapting its thickness, pattern density, stiffness, flexibility, and translucency to load, curvature, and skin-pressured areas respectively.

350. **Bots of Babel**

Neri Oxman, Jorge Duro-Royo, Markus Kayser, Jared Laucks, Laia Mogas-Soldevila

The Biblical story of the Tower of Babel involved a deliberate plan hatched by mankind to construct a platform from which man could fight God. The tower represented the first documented attempt at constructing a vertical city. The divine response to the master plan was to sever communication by instilling a different language in each builder. Tragically, the building's ultimate destruction came about through the breakdown of communications between its fabricators. In this installation we redeem the Tower of Babel by creating its antithesis. We will construct a virtuous, decentralized, yet highly communicative building environment of cable-suspended fabrication bots that together build structures bigger than themselves. We explore themes of asynchronous motion, multi-nodal fabrication, lightweight additive manufacturing, and the emergence of form through fabrication. (With contributions from Carlos Gonzalez Uribe and Dr. James Weaver (WYSS Institute and Harvard University))

351. **Building-Scale 3D Printing**

Neri Oxman, Steven Keating, John Klein

How can additive fabrication technologies be scaled to building-sized construction? We introduce a novel method of mobile swarm printing that allows small robotic agents to construct large structures. The robotic agents extrude a fast-curing material which doubles as both a concrete mold for structural walls and as a thermal insulation layer. This technique offers many benefits over traditional construction methods, such as speed, custom geometry, and cost. As well, direct integration of building utilities such as wiring and plumbing can be incorporated into the printing process. This research was sponsored by the NSF EAGER award: Bio-Beams: FGM Digital Design & Fabrication.

352. **Carpal Skin**

Neri Oxman

Carpal Skin is a prototype for a protective glove to protect against Carpal Tunnel Syndrome, a medical condition in which the median nerve is compressed at the wrist, leading to numbness, muscle atrophy, and weakness in the hand. Night-time wrist splinting is the recommended treatment for most patients before going into carpal tunnel release surgery. Carpal Skin is a process by which to map the pain-profile of a particular patient – its intensity and duration – and to distribute hard and soft materials to fit the patient's anatomical and physiological requirements, limiting movement in a customized fashion. The form-generation process is inspired by animal coating patterns in the control of stiffness variation.

353. **CNSILK: Computer Numerically Controlled Silk Cocoon Construction**

Neri Oxman

CNSILK explores the design and fabrication potential of silk fibers—inspired by silkworm cocoons—for the construction of woven habitats. It explores a novel approach to the design and fabrication of silk-based building skins by controlling the mechanical and physical properties of spatial structures inherent in their microstructures using multi-axis fabrication. The method offers construction without assembly, such that material properties vary locally to accommodate for structural and environmental requirements. This approach stands in contrast to functional assemblies and kinetically actuated facades which require a great deal of energy to operate, and are typically maintained by global control. Such material architectures could simultaneously bear structural load, change their transparency so as to control light levels within a spatial compartment (building or vehicle), and open and close embedded pores so as to ventilate a space.

354. **DCP: Digital Construction Environment**

Neri Oxman, Levi Cai, Barrak Darweesh, Steven Keating, Julian Leland

The Digital Construction Environment is the first architectural-scale structure fabricated with the Digital Construction Platform (DCP). Using the Mediated Matter group's Print-In-Place construction technique, an open-domed structure with a diameter of 14.6 m and a height of 3.7 m was manufactured over a print time of 13.5 hours.

355. **Digital Construction Platform**

Neri Oxman, Levi Cai, Steven Keating, Julian Leland

The Digital Construction Platform (DCP) is an experimental enabling technology for large-scale digital manufacturing. In contrast to the typical gantry-based approach to digital construction, robotic arm systems offer the promise of greater task flexibility, dynamically expandable workspaces, rapid setup times, and easier implementation with existing construction techniques. Potential applications for this system include fabrication of non-standard architectural forms; incorporation of data gathered on-site in real time into fabrication processes; improvements in construction efficiency, quality, and safety; and exploration of autonomous construction systems for use in disaster relief, hazardous environments, and extraterrestrial exploration.

356. **Digital Construction Platform v.1**

Neri Oxman, Levi Cai, Steven Keating, John Klein, Julian Leland, Dow Chemical, Altec

The Digital Construction Platform (DCP) is an in-progress research project consisting of a compound robotic arm system. The system comprises a 6-axis KUKA robotic arm attached to the endpoint of a 3-axis Altec hydraulic boom arm, which is mounted on a mobile platform. Akin to the biological model of the human shoulder and hand, this compound system utilizes the large boom arm for gross positioning and the small robotic arm for fine positioning and oscillation correction, respectively. Potential applications include fabrication of non-standard architectural forms, integration of real-time on-site sensing data, improvements in construction efficiency, enhanced resolution, lower error rates, and increased safety.

357. **Digitally Reconfigurable Surface**

Neri Oxman

The digitally reconfigurable surface is a pin matrix apparatus for directly creating rigid 3D surfaces from a computer-aided design (CAD) input. A digital design is uploaded into the device, and a grid of thousands of tiny pins, much like the popular pin-art toy, are actuated to form the desired surface. A rubber sheet is held by vacuum pressure onto the tops of the pins to smooth out the surface they form; this strong surface can then be used for industrial forming operations, simple resin casting, and many other applications. The novel phase-changing electronic clutch array allows the device to have independent position control over thousands of discrete pins with only a single motorized "push plate," lowering the complexity and manufacturing cost of this type of device. Research is ongoing into new actuation techniques to further lower the cost and increase the surface resolution of this technology.

358. **FABRICOLOGY: Variable-Property 3D Printing as a Case for Sustainable Fabrication**

Neri Oxman

Rapid prototyping technologies speed product design by facilitating visualization and testing of prototypes. However, such machines are limited to using one material at a time; even high-end 3D printers, which accommodate the deposition of multiple materials, must do so discretely and not in mixtures. This project aims to build a proof-of-concept of a 3D printer able to dynamically mix and vary the ratios of different materials in order to produce a continuous gradient of material properties with real-time correspondence to structural and environmental constraints.

359. **FIBERBOTS: Design of a multi-agent, fiber composite digital fabrication system**

Christoph Bader, Levi Cai, Barrak Darweesh, Sara Falcone, Joao Pedro Goncalves Marins Costa, Nassia Inglessis, Markus Kayser

FIBERBOTS is a digital fabrication platform fusing cooperative robotic manufacturing with abilities to generate highly sophisticated material architectures. The platform can enable design and digital fabrication of large-scale structures with high spatial resolution leveraging mobile fabrication nodes, or robotic "agents" designed to tune the material make-up of the structure being constructed on the fly as informed by their environment.

Some of nature's most successful organisms collaborate in a swarm fashion. Nature's builders leverage hierarchical structures in order to control and optimize multiple material properties. Spiders, for instance, spin protein fibers to weave silk webs with tunable local and global material properties, adjusting their material composition and fiber placement to create strong yet flexible structures optimized to capture prey. Other organisms, such as bees, ants and termites cooperate to rapidly build structures much larger than themselves.

360. **FitSocket: Measurement for Attaching Objects to People**

Hugh Herr, Neri Oxman, Jean-Francois Duval, Arthur J Petron

A better understanding of the biomechanics of human tissue allows for better attachment of load-bearing objects to people. Think of shoes, ski boots, car seats, orthotics, and more. We are focusing on prosthetic sockets, the cup-shaped devices that attach an amputated limb to a lower-limb prosthesis, which currently are made through unscientific, artisanal methods that do not have repeatable quality and comfort from one individual to the next. The FitSocket project aims to identify the correlation between leg tissue properties and the design of a comfortable socket. The FitSocket is a robotic socket measurement device that directly measures tissue properties. With these data, we can rapid-prototype test sockets and socket molds in order to make rigid, spatially variable stiffness, and spatially/temporally variable stiffness sockets.

361. **Functionally Graded Filament-Wound Carbon-Fiber Prosthetic Sockets**

Neri Oxman, Carlos Gonzalez Uribe, Hugh Herr and the Biomechatronics group

Prosthetic Sockets belong to a family of orthotic devices designed for amputee rehabilitation and performance augmentation. Although such products are fabricated out of lightweight composite materials and designed for optimal shape and size, they are limited in their capacity to offer local control of material properties for optimizing load distribution and ergonomic fit over surface and volume areas. Our research offers a novel workflow to enable the digital design and fabrication of customized prosthetic sockets with variable impedance informed by MRI data. We implement parametric environments to enable the controlled distribution of functional gradients of a filament-wound carbon fiber socket.

362. **Gemini**

Neri Oxman

Gemini—an acoustical "twin chaise"—spans multiple scales of the human existence extending from the warmth of the womb to the stretches of the Gemini zodiac in deep space. It recapitulates a human cosmos: our body—like the Gemini constellation—drifting in space.

363. **Glass I**

Neri Oxman, Chikara Inamura, Markus Kayser, John Klein, Daniel Lizardo, Michael Stern, Department of Materials Science and Engineering, MIT Glass Lab

Ancient yet modern, enclosing yet invisible, glass was first created in Mesopotamia and Ancient Egypt 4,500 years ago. Precise recipes for its production - the chemistry and techniques - often remain closely guarded secrets. Glass can be molded, formed, blown, plated or sintered; its formal qualities are closely tied to techniques used for its formation. From the discovery of core-forming process for bead-making in ancient Egypt, through the invention of the metal blow pipe during Roman times, to the modern industrial Pilkington process for making large-scale flat glass; each new breakthrough in glass technology occurred as a result of prolonged experimentation and ingenuity, and has given rise to a new universe of possibilities for uses of the material.

364. **Glass II**

Neri Oxman, Tal Achituv, Kelly Donovan, Giorgia Franchin, Chikara Inamura, Nassia Inglessis, Daniel Lizardo, Michael Stern, Tomer Weller, Michael Stern, Owen Trueblood, Peter Houk (project adviser), Andrea Magdanz, Susan Shapiro, David J. Benyosef, Mary Ann Babula, Forrest Whitcher, Robert Philips, Neils La White, Paula Aguilera, Jonathan Williams, Andy Ryan, Jeremy Flower, Lexus, Pentagram, Simson Gumpertz & Heger, Front Inc., MIT Central Machine Shop, Almost Perfect Glass (AKA APG)

Optically transparent and structurally sound, glass has played a significant role in the evolution of product and architectural design across scales and disciplines, and throughout the ages. Glass processing methods—such as blowing, pressing, and forming—have aimed at achieving increased glass performance and functionality. Nonetheless, techniques and technologies enabling controlled tunability of its optical and mechanical properties at high spatial manufacturing resolution have remained an end without a means.

365. **Lichtenberg 3D Printing**

Neri Oxman, Steven Keating

Generating 3D Lichtenberg structures in sintered media (i.e. glass) using electricity offers a new approach to digital fabrication. By robotically controlling the electrodes, a digital form can be rapidly fabricated with the benefits of a fine fractal structure. There are numerous applications, ranging from chemical catalysts, to fractal antennas, to product design.

366. **Living Materials Library**

V. Michael Bove, Neri Oxman, Bianca Datta, Sunanda Sharma

The control of living systems as part of design interfaces is of interest to both the scientific and design communities due to the ability of living organisms to sense and respond to their environments. They may, for example, detect and break down harmful environmental agents, or create beneficial products when environmental levels dropped below a certain threshold. However, it is also important for these systems to be reversible, so that the biological components are only active when their functionality is necessary, and the system can remain dormant otherwise.

The Living Material Library is an exploration of tunable hybrid systems. Our work in this area demonstrates the means through which intrinsic material properties may be functionally changed through environmental factors and, in turn, serve as dynamic substrates for living systems. Nearly all organisms have highly developed sensing capabilities, and have been shown to behaviorally respond to changes in substrate properties. By creating a tunable and reversible material system, we explore how cell behavior such as adhesion, patterning, and differentiation may be influenced via an active interface.

In this iteration, we propose a reversible material system that allows for control of living interactions (much like a light switch). We are particularly interested in fluid material systems (such as electrorheological fluids) that transition from a liquid-like to a solid-like state when exposed to electric fields and currents.

This endeavor brings to light the complex relationship between dynamic materials and living systems. While other methods of cell intervention often rely on light, chemicals, or temperature, here we explore substrate material properties as inputs for organisms. Our library may allow for more directed inquiry into processes such as collective cell durotaxis, general mechanotaxis, and active sensing. This marks an initial foray into establishing candidate design methods for responsive applications.

367. **Living Mushtari**

Neri Oxman, Christoph Bader, Steven Keating, Dominik Kolb, Will Patrick, Sunanda Sharma

How can we design relationships between the most primitive and the most sophisticated life forms? Can we design wearables embedded with synthetic microorganisms that can enhance and augment biological functionality? Can we design wearables that generate consumable energy when exposed to the sun?

368. **Making Data Matter: Voxel-Printing for the Digital Fabrication of Data across Scales and Domains**

Neri Oxman, Christoph Bader, Joao Pedro Goncalves Marins Costa, Dominik Kolb, Sunanda Sharma, James Weaver

We present a multimaterial voxel-printing method enabling the physical visualization of data sets commonly associated with scientific imaging. Leveraging voxel-based control of multimaterial 3D printing, our method enables additive manufacturing of discontinuous data types such as point cloud data, curve and graph data, image-based data, and volumetric data. By converting data sets into dithered material deposition descriptions, through modifications to rasterization processes, we demonstrate that data sets frequently visualized on screen can be converted into physical, materially heterogeneous objects.

Our approach alleviates the need to post-process data sets to boundary representations, preventing alteration of data and loss of information in the produced physicalizations. Therefore, it bridges the gap between digital information representation and physical material composition. We evaluate the visual characteristics and features of our method, assess its relevance and applicability in the production of physical visualizations, and detail the conversion of data sets for multimaterial 3D printing. We conclude with exemplary 3D printed datasets produced by our method pointing towards potential applications across scales, disciplines, and problem domains.

369. **Meta-Mesh: Computational Model for Design and Fabrication of Biomimetic Scaled Body Armors**

Neri Oxman, Jorge Duro-Royo, Laia Mogas-Soldevila

A collaboration between Professor Christine Ortiz (project lead), Professor Mary C. Boyce, Katia Zolotovskiy, and Swati Varshney (MIT). Operating at the intersection of biomimetic design and additive manufacturing, this research proposes a computational approach for designing multifunctional scaled-armors that offer structural protection and flexibility in movement. Inspired by the segmented exoskeleton of *Polypterus senegalus*, an ancient fish, we have developed a hierarchical computational model that emulates structure-function relationships found in the biological exoskeleton. Our research provides a methodology for the generation of biomimetic protective surfaces using segmented, articulated components that maintain user mobility alongside full-body coverage of doubly curved surfaces typical of the human body. The research is supported by the MIT Institute for Soldier Nanotechnologies, the Institute for Collaborative Biotechnologies, and the National Security Science and Engineering Faculty Fellowship Program.

370. **Monocoque**

Neri Oxman

French for "single shell," Monocoque stands for a construction technique that supports structural load using an object's external skin. Contrary to the traditional design of building skins that distinguish between internal structural frameworks and non-bearing skin elements, this approach promotes heterogeneity and differentiation of material properties. The project demonstrates the notion of a structural skin using a Voronoi pattern, the density of which corresponds to multi-scalar loading conditions. The distribution of shear-stress lines and surface pressure is embodied in the allocation and relative thickness of the vein-like elements built into the skin. Its innovative 3D printing technology provides for the ability to print parts and assemblies made of multiple materials within a single build, as well as to create composite materials that present preset combinations of mechanical properties.

371. **Organic Primitives**

Yasuaki Kakehi, Viirj Kan, Emma Vargo, Noa Machover, Serena Pan

A large portion of the chemical and biological processes underlying our everyday experience remains imperceptible to us. Be it the contents of rain, the ocean, or human tears, chemical codes mediate interactions between organic systems from the environment to our bodies and food.

As humans, we understand information mediated by our senses—through textures, symbols, odors, and tastes. In order to design for a wider array of sensory modalities in representing fluid-based information and enable user interaction with these systems, we have developed Organic Primitives. It is a new medium for transforming objects into information displays. Chemical input is converted into human senses through a set of color-, odor-, and form-changing materials.

372. **PCB Origami**

Neri Oxman

The PCB Origami project is an innovative concept for printing digital materials and creating 3D objects with Rigid-flex PCBs and pick-and-place machines. These machines allow printing of digital electronic materials, while controlling the location and property of each of the components printed. By combining this technology with Rigid-flex PCB and computational origami, it is possible to create from a single sheet of PCB almost any 3D shape that is already embedded with electronics, to produce a finished product with that will be both structural and functional.

373. **Printing Living Materials**

Neri Oxman, Steven Keating, Will Patrick, Sunanda Sharma, Eleonore Tham, Steph Hays, Professor Tim Lu, Professor Pam Silver

How can biological organisms be incorporated into product, fashion, and architectural design to enable the generation of multi-functional, responsive, and highly adaptable objects? This research pursues the intersection of synthetic biology, digital fabrication, and design. Our goal is to incorporate engineered biological organisms into inorganic and organic materials to vary material properties in space and time. We aim to use synthetic biology to engineer organisms with varied output functionalities and digital fabrication tools to pattern these organisms and induce their specific capabilities with spatiotemporal precision.

374. **Printing Multi-Material 3D Microfluidics**

Neri Oxman, Steven Keating, Will Patrick, David Sun Kong (MIT Lincoln Laboratory)

Computation and fabrication in biology occur in aqueous environments. Through on-chip mixing, analysis, and fabrication, microfluidic chips have introduced new possibilities in biology for over two decades. Existing construction processes for microfluidics use complex, cumbersome, and expensive lithography methods that produce single-material, multi-layered 2D chips. Multi-material 3D printing presents a promising alternative to existing methods that would allow microfluidics to be fabricated in a single step with functionally graded material properties. We aim to create multi-material microfluidic devices using additive manufacturing to replicate current devices, such as valves and ring mixers, and to explore new possibilities enabled by 3D geometries and functionally graded materials. Applications range from medicine to genetic engineering to product design.

375. **Rapid Craft**

Neri Oxman

The values endorsed by vernacular architecture have traditionally promoted designs constructed and informed by and for the environment, while using local knowledge and indigenous materials. Under the imperatives and growing recognition of sustainable design, Rapid Craft seeks integration between local construction techniques and globally available digital design technologies to preserve, revive, and reshape these cultural traditions.

376. **Raycounting**

Neri Oxman

Raycounting is a method for generating customized light-shading constructions by registering the intensity and orientation of light rays within a given environment. 3D surfaces of double curvature are the result of assigning light parameters to flat planes. The algorithm calculates the intensity, position, and direction of one or multiple light sources placed in a given environment, and assigns local curvature values to each point in space corresponding to the reference plane and the light dimension. Light performance analysis tools are reconstructed programmatically to allow for morphological synthesis based on intensity, frequency, and polarization of light parameters as defined by the user.

377. **Rottlace**

Neri Oxman, Christoph Bader, Dominik Kolb, Stratsys

Rottlace is a family of masks designed for Icelandic singer-songwriter Björk. Inspired by Björk's most recent album — Vulnicura — the Mediated Matter Group explored themes associated with self-healing and expressing "the face without a skin." The series originates with a mask that emulates Björk's facial structure and concludes with a mask that reveals a new identity, independent of its origin. What originates as a form of portraiture culminates in reincarnation.

378. **Silk Pavilion**

Neri Oxman, Jorge Duro-Royo, Carlos Gonzalez Uribe, Markus Kayser, Jared Laucks, James Weaver (Wyss Institute at Harvard University), Fiorenzoomenetto (Tufts University)

The Silk Pavilion explores the relationship between digital and biological fabrication on product and architectural scales. The primary structure was created of 26 polygonal panels made of silk threads laid down by a CNC (Computer-Numerically Controlled) machine.

379. **SpiderBot**

Neri Oxman

The SpiderBot is a suspended robotic gantry system that provides an easily deployable platform from which to print large structures. The body is composed of a deposition nozzle, a reservoir of material, and parallel linear actuators. The robot is connected to stable points high in the environment, such as large trees or buildings. This arrangement is capable of moving large distances without the need for more conventional linear guides, much like a spider does. The system is easy to set up for mobile projects, and will afford sufficient printing resolution and build volume. Expanding foam can be deposited to create a building-scale printed object rapidly. Another material type of interest is the extrusion or spinning of tension elements, like rope or cable. With tension elements, unique structures such as bridges or webs can be wrapped, woven, or strung around environmental features or previously printed materials.

380. **Synthetic Apiary**

Neri Oxman, Jorge Duro-Royo, Markus Kayser, Sunanda Sharma,

The Synthetic Apiary proposes a new kind of environment, bridging urban and organismic scales by exploring one of the most important organisms for both the human species and our planet: bees. We explore the cohabitation of humans and other species through the creation of a controlled atmosphere and associated behavioral paradigms. The project facilitates Mediated Matter's ongoing research into biologically augmented digital fabrication with eusocial insect communities in architectural, and possibly urban, scales. Many animal communities in nature present collective behaviors known as "swarming," prioritizing group survival over individuals, and constantly working to achieve a common goal. Often, swarms of organisms are skilled builders; for example, ants can create extremely complex networks by tunneling, and wasps can generate intricate paper nests with materials sourced from local areas.

381. **Vespers II**

Neri Oxman, Christoph Bader, Dominik Kolb, Sunanda Sharma, Rachel Smith, James Weaver

Novel technologies for additive manufacturing are enabling design and production at nature's scale. We can seamlessly vary the physical properties of materials at the resolution of a sperm cell, a muscle cell, or a nerve cell. Stiffness, color, hygroscopy, transparency, conductivity, even scent, can be individually tuned for each three-dimensional pixel within a physical object. The generation of products is therefore no longer limited to assemblages of discrete parts with homogeneous properties. Rather like organs, objects can be computationally "grown" and 3D printed to form materially heterogeneous and multi-functional products.

382. **Vespers III**

Neri Oxman, Christoph Bader, Joao Pedro Goncalves Marins Costa, Sunanda Sharma, Rachel Smith, James Weaver

Vespers is a collection of masks exploring what it means to design (with) life. From the relic of the death mask to a contemporary living device, the collection embarks on a journey that begins with an ancient typology and culminates with a novel technology for the design and digital fabrication of adaptive and responsive interfaces. We begin with a conceptual piece and end with a tangible set of tools, techniques and technologies combining programmable matter and programmable life.

The project points towards an imminent future where wearable interfaces and building skins are customized not only to fit a particular shape, but also a specific material, chemical and even genetic make-up, tailoring the wearable to both the body and the environment which it inhabits.

Imagine, for example, a wearable interface designed to guide ad-hoc antibiotic formation customized to fit the genetic makeup of its user; or, consider smart packaging or surface coatings devices that can detect contamination; finally, consider environmentally responsive architectural skins that can respond to, and adapt—in real time—to environmental cues. Research at the core of this project offers a new design space for biological augmentation across a wide breadth of application domains, leveraging resolution and scale.

The collection includes three series. The first series features the death mask as a cultural artefact. The final series features a living mask as an enabling technology. The second series mediates between the two, marking the process of 'metamorphosis' between the ancient relic and its contemporaneous interpretation. The living masks in the final series embody habitats that guide, inform and 'template' gene expression of living microorganisms. Such microorganisms have been synthetically engineered to produce pigments and/or otherwise useful chemical substances for human augmentation such as vitamins, antibodies or antimicrobial drugs. Combined, the three series of the Vespers collection represent the transition from death to life, or from life to death, depending on one's reading of the collection.

383. **Wanderers**

Neri Oxman, Christoph Bader, Dominik Kolb

The Wanderers were unveiled as part of the exhibition: 'The Sixth Element: Exploring the Natural Beauty of 3D Printing' on display at EuroMold, 25-28 November, Frankfurt, Germany. This work was done in collaboration with Christoph Bader and Dominik Kolb. The wearables were 3D-printed with Stratasys multi-material 3D printing technology. Members of the Mediated Matter group led by Will Patrick and Sunanda Sharma are currently working on embedding living matter in the form of engineered bacteria within the 3D structures in order to augment the environment.

384. **Water-Based Additive
Manufacturing**

Neri Oxman, Christoph Bader, Jorge Duro-Royo, Nicolas Hogan, Andrea Ling, Laia Mogas-Soldevila, Yen-Ju (Tim) Tai, Joshua Van Zak, Dr. Javier G. Fernandez (Wyss Institute, Harvard University)

This research presents water-based robotic fabrication as a design approach and enabling technology for additive manufacturing (AM) of biodegradable hydrogel composites. We focus on expanding the dimensions of the fabrication envelope, developing structural materials for additive deposition, incorporating material-property gradients, and manufacturing architectural-scale biodegradable systems. The technology includes a robotically controlled AM system to produce biodegradable composite objects, combining natural hydrogels with other organic aggregates. It demonstrates the approach by designing, building, and evaluating the mechanics and controls of a multi-chamber extrusion system. Finally, it provides evidence of large-scale composite objects fabricated by our technology that display graded properties and feature sizes ranging from micro- to macro-scale. Fabricated objects may be chemically stabilized or dissolved in water and recycled within minutes. Applications include the fabrication of fully recyclable products or temporary architectural components, such as tent structures with graded mechanical and optical properties.

Joseph A. Paradiso: Responsive Environments

Augmenting and mediating human experience, interaction, and perception with sensor networks

385. **BioEssence**

Pattie Maes, Judith Amores Fernandez, Artem Dementyev, Javier Hernandez, Xiqing Wang
A wearable olfactory display that monitors cardio-respiratory information to support mental wellbeing.

BioEssence is a novel wearable olfactory display that provides just-in-time release of scents based on the physiological state of the wearer. The device can release up to three scents and passively captures subtle chest vibrations associated with the beating of the heart and respiration through clothes.

386. **Chain API**

Joseph A. Paradiso, Gershon Dublon, Brian Mayton, Spencer Russell

RESTful services and the Web provide a framework and structure for content delivery that is scalable, not only in size but, more importantly, in use cases. As we in Responsive Environments build systems to collect, process, and deliver sensor data, this project serves as a research platform that can be shared between a variety of projects both inside and outside the group. By leveraging hyperlinks between sensor data clients can browse, explore, and discover their relationships and interactions in ways that can grow over time.

387. **ChainFORM**

Hiroshi Ishii, Joseph A. Paradiso, Artem Dementyev, Ken Nakagaki

ChainFORM is a modular hardware system for designing linear shape-changing interfaces. Each module is developed based on a servo motor with added flexible circuit board, and is capable of touch detection, visual output, angular sensing, and motor actuation. Moreover, because each module can communicate with other modules linearly, it allows users and designers to adjust and customize the length of the interface. Using the functionality of the hardware system, we propose a wide range of applications, including line-based shape changing display, reconfigurable stylus, rapid prototyping tool for actuated crafts, and customizable haptic glove. We conducted a technical evaluation and a user study to explore capabilities and potential requirements for future improvement.

388. **ChromoSkin**

Joseph A. Paradiso, Chris Schmandt, Cindy Hsin-Liu Kao, Manisha Mohan, Katia Vega,

Makeup has long been used as a body decoration process for self-expression and for the transformation of one's appearance. While the material composition and processes for creating makeup products have evolved, they still remain static and non-interactive. But our social contexts demand different representations of ourselves; thus, we propose ChromoSkin, a dynamic color-changing makeup system that gives the wearer ability to alter seamlessly their appearance. We prototyped an interactive eye shadow tattoo composed of thermochromic pigments activated by electronics or ambient temperature conditions. We present the design and fabrication of these interactive cosmetics, and the challenges in creating skin interfaces that are seamless, dynamic, and fashionable.

389. **Circuit Robots: Mass Manufacturing of Self-Actuating Robots**

Joseph A. Paradiso, Artem Dementyev, Jifei Ou, Jie Qi
Integrating sensors and actuators using flexible electronics

Currently, the manufacturing of self-actuating and self-sensing robots requires non-standard manufacturing techniques and assembly steps to integrate electrical and mechanical systems. In this work, we developed a novel manufacturing technique, where such robots can be produced at a flexible electronics factory. We developed the technique using standard industrial machines, processes, and materials. Using a lamination process, we were able to integrate air pouches or shape memory alloy (SMA) inside a polyamide-based flexible circuit to produce bending actuators. The bend angle of the actuators is sensed with a chain of inertial measurement units integrated on the actuator. Air-pouch actuators can produce a force of a 2.24N, and a maximum bend angle of 74 degrees. To demonstrate, we manufactured a five-legged robot with the developed actuators and bend sensors, with all the supporting electronics (e.g., microcontrollers, radio) directly integrated into the flexible printed circuit. Such robots are flat and lightweight (15 grams) and thus conveniently compact for transportation and storage. We believe that our technique can allow inexpensive and fast prototyping and deployment of self-actuating and self-sensing robots.

390. **Circuit Stickers**

Joseph A. Paradiso, Leah Buechley, Nan-wei Gong, Jie Qi

Circuit Stickers is a toolkit for crafting electronics using flexible and sticky electronic pieces. These stickers are created by printing traces on flexible substrates and adding conductive adhesive. These lightweight, flexible, and sticky circuit boards allow us to begin sticking interactivity onto new spaces and interfaces such as clothing, instruments, buildings, and even our bodies.

391. **Circuit Stickers Activity Book**

Joseph A. Paradiso, Leah Buechley, Jie Qi

The Circuit Sticker Activity Book is a primer for using circuit stickers to create expressive electronics. Inside are explanations of the stickers, and circuits and templates for building functional electronics directly on the pages of the book. The book covers five topics, from simple LED circuits to crafting switches and sensors. As users complete the circuits, they are also prompted with craft and drawing activities to ensure an expressive and artistic approach to learning and building circuits. Once completed, the book serves as an encyclopedia of techniques to apply to future projects.

392. **Circuit Storybook**

Joseph A. Paradiso, Kevin Slavin, Jie Qi, Sonja de Boer

An interactive picture book that explores storytelling techniques through paper-based circuitry. Sensors, lights, and microcontrollers embedded into the covers, spine, and pages of the book add electronic interactivity to the traditional physical picture book, allowing us to tell new stories in new ways. The current book, "Ellie," tells the adventures of an LED light named Ellie who dreams of becoming a star, and of her journey up to the sky.

393. **Cognitive Audio**

Ishwarya Ananthabhotla, David Ramsay

When we form memories, not everything that we perceive is noticed; not everything that we notice is remembered. Humans are excellent at filtering and retaining only the most important parts of their experience—what if our audio compression had the same ability?

Our goal is to understand what makes sound memorable. With this work, we hope to gain insight into the cognitive processes that drive auditory perception and predict the memorability of sounds in the world around us more accurately than ever before. Ultimately, these models will give us the ability to generate and manipulate the sounds that surround us to be more or less memorable.

We envision this research introducing new paradigms into the space of audio compression, attention-driven user interactions, and auditory AR, amongst others.

394. **DoppelLab: Experiencing Multimodal Sensor Data**

Joseph A. Paradiso, Gershon Dublon, Brian Mayton

Homes and offices are being filled with sensor networks to answer specific queries and solve pre-determined problems, but no comprehensive visualization tools exist for fusing these disparate data to examine relationships across spaces and sensing modalities. DoppelLab is a cross-reality virtual environment that represents the multimodal sensor data produced by a building and its inhabitants. Our system encompasses a set of tools for parsing, databasing, visualizing, and sonifying these data; by organizing data by the space from which they originate, DoppelLab provides a platform to make both broad and specific queries about the activities, systems, and relationships in a complex, sensor-rich environment.

395. **Doppelmarsh: Cross-Reality Environmental Sensor Data Browser**

Joseph A. Paradiso, Gershon Dublon, Don Derek Haddad, Evan Lynch, Brian Mayton, Spencer Russell

Doppelmarsh is a cross-reality sensor data browser built for experimenting with presence and multimodal sensory experiences. Built on evolving terrain data from a physical wetland landscape, the software integrates real-time data from an environmental sensor network with real-time audio streams and other media from the site. Sensor data is rendered in the scene in both visual representations and as 3D sonification. Users can explore this data by walking on the virtual terrain in a first person view, or flying high above it. This flexibility allows Doppelmarsh to serve as an interface to other research platforms on the site, such as Quadrasense, an augmented reality UAV system that blends a flying live camera view with a virtual camera from Doppelmarsh. We are currently investigating methods for representing subsurface data, such as soil and water temperatures at depth, as well as automation in scene and terrain painting.

396. **Experiential Lighting: New User Interfaces for Lighting Control**

Joseph A. Paradiso, Matthew Aldrich, Nan Zhao

The vision of pervasive computing is now mainstream. These connected devices permeate every aspect of our lives. Yet, we remain tethered to arcane user interfaces. Unlike consumer devices, building appliances and utilities perpetuate this outdated vision. Lighting control is a prime example. Here, we show how a data-driven methodology—using people and sensors—enables an entirely new method of lighting control.

We are evaluating new methods of interacting and controlling solid-state lighting based on our findings of how participants experience and perceive architectural lighting in our new lighting laboratory (E14-548S). This work, aptly named "Experiential Lighting," reduces the complexity of modern lighting controls (intensity/color/space) into a simple mapping, aided by both human input and sensor measurement. We believe our approach extends beyond general lighting control and is applicable in situations where human-based rankings and preference are critical requirements for control and actuation. We expect our foundational studies to guide future camera-based systems that will inevitably incorporate context in their operation (e.g., Google Glass).

397. **FabricKeyboard**

Joseph A. Paradiso, Irmandy Wicaksono

Multimodal textile sensate media as an expressive and deformable musical interface

In the area of intelligent textiles, we are exploring a multi-modal, fabric-based, stretchable sensate surface for physical interaction media, specifically as deformable musical interface.

The fabric keyboard consists of multi-layer textile sensors machine-sewn in a keyboard pattern, and it detects different stimuli such as touch, pressure, stretch, proximity, and electric field. This allows users to explore physical and non-contact gestures for expressive on-body and on-surface musical performance. We've also developed additional textile-based inputs such as ribbon controller, trackpad, and fur for more expressive control. This soft sensate surface contributes toward developing seamless, self-aware, and washable media.

398. **FingerSynth: Wearable Transducers for Exploring the Environment through Sound**

Joseph A. Paradiso, Gershon Dublon

The FingerSynth is a wearable musical instrument made up of a bracelet and set of rings that enables its players to produce sound by touching nearly any surface in their environments. Each ring contains a small, independently controlled audio exciter transducer. The rings sound loudly when they touch a hard object, and are silent otherwise. When a wearer touches their own (or someone else's) head, the contacted person hears sound through bone conduction, inaudible to others. A microcontroller generates a separate audio signal for each ring, and can take user input through an accelerometer in the form of taps, flicks, and other gestures. The player controls the envelope and timbre of the sound by varying the physical pressure and the angle of their finger on the surface, or by touching differently resonant surfaces. The FingerSynth encourages players to experiment with the materials around them and with one another.

399. **Grappler: Arrays of bistable elements for landing distributed sensor networks on low gravity bodies**

Juliana Cherston, Paul Strohmeier, Paul Strohmeier, University of Copenhagen

Can a modified snap bracelet be used to land infrastructure on an asteroid?

It is notoriously difficult to stick a landing on a low gravity body, particularly if locomotion across the body is desired. We have been studying the use of arrays of bistable pinching elements for grapppling onto the unpredictable contours of asteroids and other distant low gravity bodies. Each pinching element is mechanically actuated via an impact force, much like a snap bracelet. By coupling together arrays of such elements, we seek to demonstrate that the chain can conform with added precision to the topological structure of the body, as well as grapple more effectively.

This mechanism can ultimately be used to land large-scale structures like nets and tethers across the body, which then serve as infrastructure for crawling distributed sensors or sensory membranes, among other possibilities.

A concept paper on the broader work was published by the 31st Annual AIAA/USU Conference on Small Satellites.

There may also be compelling uses for the technology on Earth for adhering sensors to terrain that is erratic and difficult to access, like the roof of a cave, or structures at the bottom of the sea floor.

Two prototypes - one equipped with sensors - were tested on a microgravity flight by throwing them at a rocky target object. Data from the flight will be used to characterize the behavior of chains of 1 vs. 3 bistable elements in order to inform future design decisions.

400. **Hacking the Sketchbook**

Joseph A. Paradiso, Jie Qi

In this project we investigate how the process of building a circuit can be made more organic, like sketching in a sketchbook. We integrate a rechargeable power supply into the spine of a traditional sketchbook, so that each page of the sketchbook has power connections. This enables users to begin creating functioning circuits directly onto the pages of the book and to annotate as they would in a regular notebook. The sequential nature of the sketchbook allows creators to document their process for circuit design. The book also serves as a single physical archive of various hardware designs. Finally, the portable and rechargeable nature of the book allows users to take their electronic prototypes off of the lab bench and share their creations with people outside of the lab environment.

401. **Halo: Wearable Lighting**

Joseph A. Paradiso, Nan Zhao

Imagine a future where lights are not fixed to the ceiling, but follow us wherever we are. In this colorful world we enjoy lighting that is designed to go along with the moment, the activity, our feelings, and our outfits. Halo is a wearable lighting device created to explore this scenario. Different from architectural lighting, this personal lighting device aims to illuminate and present its user. Halo changes the wearer's appearance with the ease of a button click, similar to adding a filter to a photograph. It can also change the user's view of the world, brightening up a rainy day or coloring a gray landscape. Halo can react to activities and adapt based on context. It is a responsive window between the wearer and his or her surroundings.

402. **Haptic Footprint**

Paul Strohmeier

We only perceive a tiny sliver of the world around us. We are constrained by what our senses can process. These senses evolved to react to what is immediately important for our survival. Our technological development has outstripped the pace at which our physical senses evolve. We do not have access to things such as the electromagnetic spectrum at 2.5 GHz, even though it is relevant to the day to day life of most of us. We are poor at perceiving things such as changes in the chemical composition of the air we breathe, even though it is critical for our long term survival as a species.

Can we augment a stroll through nature with sensory experiences usually outside the range of our perception? Haptic Footprints explore using vibrotactile rendering for this purpose.

403. **Hear There: Ubiquitous Sonic Overlay**

Joseph A. Paradiso, Gershon Dublon, Spencer Russell

With our Ubiquitous Sonic Overlay, we are working to place virtual sounds in the user's environment, fixing them in space even as the user moves. We are working toward creating a seamless auditory display, indistinguishable from the user's actual surroundings. Between bone-conduction headphones, small and cheap orientation sensors, and ubiquitous GPS, a confluence of fundamental technologies is in place. However, existing head-tracking systems either limit the motion space to a small area (e.g., Oculus Rift), or sacrifice precision for scale using technologies like GPS. We are seeking to bridge the gap to create large outdoor spaces of sonic objects.

404. **ListenTree: Audio-Haptic Display in the Natural Environment**

V. Michael Bove, Joseph A. Paradiso, Gershon Dublon, Edwina Portocarrero

ListenTree is an audio-haptic display embedded in the natural environment. Visitors to our installation notice a faint sound emerging from a tree. By resting their heads against the tree, they are able to hear sound through bone conduction. To create this effect, an audio exciter transducer is weatherproofed and attached to the tree's roots, transforming it into a living speaker, channeling audio through its branches, and providing vibrotactile feedback. In one deployment, we used ListenTree to display live sound from an outdoor ecological monitoring sensor network, bringing a faraway wetland into the urban landscape. Our intervention is motivated by a need for forms of display that fade into the background, inviting attention rather than requiring it. We consume most digital information through devices that alienate us from our surroundings; ListenTree points to a future where digital information might become enmeshed in material.

405. **Living Observatory: Sensor Networks for Documenting and Experiencing Ecology**

Glorianna Davenport, Joseph A. Paradiso, Gershon Dublon, Don Derek Haddad, Brian Mayton, Spencer Russell

Living Observatory is an initiative for documenting and interpreting ecological change that will allow people, individually and collectively, to better understand relationships between ecological processes, human lifestyle choices, and climate change adaptation. As part of this initiative, we are developing sensor networks that document ecological processes and allow people to experience the data at different spatial and temporal scales. Low-power sensor nodes capture climate and other data at a high spatiotemporal resolution, while others stream audio. Sensors on trees measure transpiration and other cycles, while fiber-optic cables in streams capture high-resolution temperature data. At the same time, we are developing tools that allow people to explore this data, both remotely and onsite. The remote interface allows for immersive 3D exploration of the terrain, while visitors to the site will be able to access data from the network around them directly from wearable devices.

406. **Low-Power Gesture Input with Wrist-Worn Pressure Sensors**

Joseph A. Paradiso, Artem Dementyev

We demonstrate an always-available, on-body gestural interface. Using an array of pressure sensors worn around the wrist, it can distinguish subtle finger pinch gestures with high accuracy (>80%). We demonstrate that it is a complete system that works wirelessly in real time. The device is simple and light-weight in terms of power consumption and computational overhead. Prototype's sensor power consumption is 89uW, allowing the prototype to last more than a week on a small lithium polymer battery. Also, device is small and non-obtrusive, and can be integrated into a wristwatch or a bracelet. Custom pressure sensors can be printed with off-the-shelf conductive ink-jet technology. We demonstrate that number of gestures can be greatly extended by adding orientation data from an accelerometer. Also, we explore various usage scenarios with the device.

407. **Low-Power Wireless Environmental Sensor Network**

Joseph A. Paradiso, Brian Mayton

Tidmarsh is a 600-acre former cranberry farm near Plymouth, MA that has undergone a restoration to wetland. We have instrumented the site with an extensive network of custom low-power environmental sensor nodes, microphones, and cameras. The data from the network is made available in real time and has enabled a number of explorations into the ways that people can experience and learn from large-scale, long-term sensor installations.

See sensor data, listen to live audio, and watch live camera feeds on the Tidmarsh website.

408. **Mediated Atmosphere**

Joseph A. Paradiso, Asaph Azaria, Robert Richer, Nan Zhao

The Mediated Atmosphere project envisions a smart office that is capable of dynamically transforming itself to enhance occupants' work experience.

In the knowledge economy, worker satisfaction is paramount to retention and productivity. Recent studies have identified a decline in workplace satisfaction. Our research demonstrates how Mediated Atmosphere address this growing need. We created a workspace prototype equipped with a modular real-time control infrastructure, integrating biosignal sensors, controllable lighting, projection, and sound.

409. **Mindful Photons: Context-Aware Lighting**

Joseph A. Paradiso, Matthew Aldrich, Nan Zhao

Light enables our visual perception. It is the most common medium for displaying digital information. Light regulates our circadian rhythms, affects productivity and social interaction, and makes people feel safe. Yet despite the significance of light in structuring human relationships with their environments on all these levels, we communicate very little with our artificial lighting systems. Occupancy, ambient illuminance, intensity, and color preferences are the only input signals currently provided to these systems. With advanced sensing technology, we can establish better communication with our devices. This effort is often described as context-awareness. Context has typically been divided into properties such as location, identity, affective state, and activity. Using wearable and infrastructure sensors, we are interested in detecting these properties and using them to control lighting. The Mindful Photons Project aims to close the loop and allow our light sources to "see" us.

410. **NailO**

Joseph A. Paradiso, Chris Schmandt, Artem Dementyev, Cindy Hsin-Liu Kao

NailO is a wearable input device in the form of a commercialized nail art sticker. It works as a miniaturized trackpad the size and thickness of a fingernail that can connect to your mobile devices; it also enables wearers to customize the device to fit the wearer's personal style. NailO allows wearers to perform different functions on a phone or PC with different gestures, and the wearer can easily alter its appearance with a nail art design layer, creating a combination of functionality and aesthetics. From the fashion-conscious, to techies, and anyone in between, NailO can make a style, art, or a design statement; but in its more neutral, natural-looking example it can be worn and used only for its functionality. As a nail art sticker, NailO is small, discreet, and removable. Interactions through NailO can be private and subtle, for example attracting minimal attention when you are in a meeting but need to reply to an urgent text message. Mimicking the form of a cosmetic extension, NailO blends into and decorates one's body when attached, yet remains removable at the wearer's discretion, giving the wearer power and control over the level of intimacy of the device to one's body.

411. **Programmable Paintings**

Joseph A. Paradiso, Leah Buechley, Jie Qi

Programmable Paintings are a series of artworks that use electronic elements such as LED lights and microphone sensors as "pigments" in paintings. The goal is to blend traditional elements of painting—color, texture, composition—with these electronic components to create a new genre of time-based and interactive art.

412. **Prosthetic Sensor Networks:
Factoring Attention,
Proprioception, and Sensory
Coding**

Joseph A. Paradiso, Gershon Dublon

Sensor networks permeate our built and natural environments, but our means for interfacing to the resultant data streams have not evolved much beyond HCI and information visualization. Researchers have long experimented with wearable sensors and actuators on the body as assistive devices. A user's neuroplasticity can, under certain conditions, transcend sensory substitution to enable perceptual-level cognition of "extrasensory" stimuli delivered through existing sensory channels. But there remains a huge gap between data and human sensory experience. We are exploring the space between sensor networks and human augmentation, in which distributed sensors become sensory prostheses. In contrast, user interfaces are substantially unincorporated by the body, our relationship to them never fully pre-attentive. Attention and proprioception are key, not only to moderate and direct stimuli, but also to enable users to move through the world naturally, attending to the sensory modalities relevant to their specific contexts.

413. **Rovables**

Joseph A. Paradiso, Chris Schmandt, Deborah Ajilo, Artem Dementyev, Cindy Hsin-Liu Kao, Stanford University (Inrak Choi, Maggie Xu, Sean Follmer)

We introduce Rovables, a miniature robot that can move freely on unmodified clothing. The robots are held in place by magnetic wheels, and can climb vertically. The robots are untethered and have an onboard battery, microcontroller, and wireless communications. They also contain a low-power localization system that uses wheel encoders and IMU, allowing Rovables to perform limited autonomous navigation on the body. In the technical evaluations, we found that Rovables can operate continuously for 45 minutes and can carry up to 1.5N. We propose an interaction space for mobile on-body devices spanning sensing, actuation, and interfaces, and develop application scenarios in that space. Our applications include on-body sensing, modular displays, tactile feedback and interactive clothing and jewelry.

414. **SensorChimes: Musical
Mapping for Sensor Networks**

Joseph A. Paradiso, Evan Lynch

SensorChimes aims to create a new canvas for artists leveraging ubiquitous sensing and data collection. Real-time data from environmental sensor networks are realized as musical composition. Physical processes are manifested as musical ideas, with the dual goal of making meaningful music and rendering an ambient display. The Tidmarsh Living Observatory initiative, which aims to document the transformation of a reclaimed cranberry bog, provides an opportunity to explore data-driven musical composition based on a large-scale environmental sensor network. The data collected from Tidmarsh are piped into a mapping framework, which a composer configures to produce music driven by the data.

415. **SensorKnits: Architecting
textile sensors with machine
knitting**

Hiroshi Ishii, Joseph A. Paradiso, Don Derek Haddad, Daniel Oran, Jifei Ou

Digital machine knitting is a highly programmable manufacturing process that has been utilized to produce apparel, accessories, and footwear. Our research presents three classes of textile sensors exploiting the resistive, piezoresistive, and capacitive properties of various textile structures enabled by machine knitting with conductive yarn.

416. **SensorTape: Modular and
Programmable 3D-Aware
Dense Sensor Network on a
Tape**

Joseph A. Paradiso, Artem Dementyev, Cindy Hsin-Liu Kao

SensorTape is a modular and dense sensor network in a form factor of a tape. SensorTape is composed of interconnected and programmable sensor nodes on a flexible electronics sub-strate. Each node can sense its orientation with an inertial measurement unit, allowing deformation self-sensing of the whole tape. Also, nodes sense proximity using time-of-flight infrared. We developed network architecture to automatically determine the location of each sensor node, as SensorTape is cut and rejoined. We also made an intuitive graphical interface to program the tape. Our user study suggested that SensorTape enables users with different skill sets to intuitively create and program large sensor network arrays. We developed diverse applications ranging from wearables to home sensing, to show low-deployment effort required by the user. We showed how SensorTape could be produced at scale and made a 2.3-meter long prototype.

417. **SkinBot: A Wearable, Skin-
Climbing Robot**

Joseph A. Paradiso, Artem Dementyev, Sean Follmer, Javier Hernandez, Inrak Choi

We introduce SkinBot: a lightweight robot that moves over the skin's surface with a two-legged suction-based locomotion mechanism and captures a wide range of body parameters with an exchangeable multipurpose sensing module. We believe that robots that live on our skin, such as SkinBot, will enable a more systematic study of the human body and offer great opportunities to advance our knowledge in many areas such as telemedicine, human-computer interfaces, body care, and fashion.

418. **SoundSignaling**

Ishwarya Ananthabhotla

Drawing inspiration from the notion of cognitive incongruence associated with Stroop's famous experiment, from musical principles, and from the observation that music consumption on an individual basis is becoming increasingly ubiquitous, we present the SoundSignaling system—a software platform designed to make real-time, stylistically relevant modifications to a personal corpus of music as a means of conveying information or notifications. From the substantial body of HCI research demonstrating the negative attentional implications of a daily inundation of notifications, we highlight two challenges associated with standard audio notifications—a “switch cost” that impedes productivity, and a lack of awareness of a user's cognitive load—that have the potential to be addressed by such a system without active activity estimation. Through this work, we suggest a re-evaluation of the age-old paradigm of binary notifications in favor of a system designed to operate upon the relatively unexplored medium of a user's musical preferences.

419. **SpaceSkin: Aerospace-grade electronic textiles for distributed sensing on persistent orbital structures**

Juliana Cherston

The outermost skin of a space-based structure is designed using materials known to protect against the harsh elements of space. Simultaneously, the skin provides a unique opportunity to characterize the environment proximate to a spacecraft and to perform real-time damage detection. Thus, we propose developing an aerospace-grade fabric that simultaneously senses and protects, emulating the dual protective and sensory capabilities of biological skin. Aerospace-grade sensory skins will serve a key role in next generation haptic feedback systems for spacesuits, as well as next generation thermal blankets for distributed detection of high velocity debris impact.

For example, Beta Cloth—the outermost layer of the International Space Station—is particularly resilient to atomic oxygen erosion and extended UV radiation exposure. It is also regularly exposed to high velocity debris impact. We draw from recent advances in functional fibers and electronic textiles in order to weave sensors directly into the teflon-coated fiberglass that comprises Beta Cloth, enabling the skin to detect and characterize impact events. We seek to demonstrate that the well-characterized, protective properties of aerospace-grade woven materials can be preserved even when modified to include sensory functionality.

Our work begins by examining integrated piezoelectric yarns for vibration sensing. We will also consider state-of-the-art manufacturing methods (e.g., device-in-fiber technology [1]) and intriguing high velocity impact sensing modalities; e.g., detection of impact plasma RF emission [2]). Other possibilities include the use of free-flying external optical sensors that collaborate with the skin to assess damage (“Skin and Eyes”), as well as work towards making the sensory skin robust to cutting, sewing, and wrapping.

[1] Tao, Guangming, et al. “Multimaterial fibers.” *Lab-on-Fiber Technology*. Springer, Cham, 2015. 1-26.

[2] Lee, N., et al. “Measurements of freely-expanding plasma from hypervelocity impacts.” *International Journal of Impact Engineering* 44 (2012): 40-49.

420. **TESSERAE: Self-Assembling Space Architecture**

Ariel Ekblaw

The future of human habitation in space, from Low Earth Orbit (LEO) to planetary systems far beyond, lies in self-assembling, adaptive, and reconfigurable structures. Rather than transporting the weight of gantries and risking astronaut Extravehicular Activities (EVAs), we can lower payload weight, reduce assembly complexity, and revolutionize space-structure modularity by relying on these new paradigms of construction and structure deployment.

This project proposes a multi-year research effort to study, characterize, and prototype TESSERAE: Tessellated Electromagnetic Space Structures for the Exploration of Reconfigurable, Adaptive Environments. TESSERAE will function as multi-use, low-cost orbiting modules, that supply a critical space infrastructure for the next generation of zero gravity habitats, science labs, staging areas for on-surface exploration, and more. Unlike large-scale habitats proposed for entire space colonies, the TESSERAE should be thought of as flexible and reconfigurable modules to aid in agile mission operations. Our mission concept focuses on supporting Lunar and Mars surface operations, with multiple, interlocking TESSERAE acting as an orbiting base, in addition to supporting the coming waves of space tourists in Low Earth Orbit.

An early TESSERAE prototype was successfully deployed on the Space Exploration Initiative's November 2017 zero gravity flight. This research mission validated the v1 mechanical structure, magnet polarity, and self-assembly protocol. An upcoming deployment on Blue Origin's suborbital launch platform will test the embedded sensor network, communication architecture between tiles, and additional parameters for self-assembly.

421. **Tid'Zam**

Joseph A. Paradiso, Gershon Dublon, Clement Duhart, Don Derek Haddad, Spencer Russell

Tid'Zam is an ambient sound analysis system for outdoor environments. It is a component of the Tidmarsh Farms project which monitors the environmental evolution of an industrial cranberry farm during its ecological restoration of wetland. Tid'Zam analyzes the audio streams generated by the deployed microphones in the wild in order to detect the sonic events happening on the site, such as bird calls, insects, frogs, rain, storms, car noise, human voices, and more.

This system is used to cross-validate other sensors for weather monitoring to identify, geolocalize, and track present wildlife and bird specimens over time. It also controls the audio mixers in order to mute or change the gain on noisy microphones.

422. **VisualSoundtrack**

Joseph A. Paradiso, Ishwarya Ananthabhotla

We present VisualSoundtrack, a system designed as a tool for soundtrack composers to experiment with original musical content in differing musical "styles." The system allows a user to rapidly prototype musical ideas with respect to the target media (such as a film or podcast) by having him/ her input original musical motifs, capitalizing on a corpus of existing soundtrack samples to source various styles, and allowing the user to identify the most appropriate style sources for the target media by visually architecting a path through a highly abstracted feature space.

Alex 'Sandy' Pentland: Human Dynamics

Exploring how social networks can influence our lives in business, health, governance, and technology adoption and diffusion

423. **Active Fairness in Algorithmic Decision Making**

Alex 'Sandy' Pentland, Michiel Bakker, Alejandro Noriega Campero, Bernardo Garcia-Bulle, visiting student, Human Dynamics group
Algorithmic Fairness

Society increasingly relies on machine learning models for automated decision making. Yet, efficiency gains from automation have come paired with concern for algorithmic discrimination that can systematize inequality. Substantial work in algorithmic fairness has surged, focusing on either post-processing trained models, constraining learning processes, or pre-processing training data. Recent work has proposed optimal post-processing methods that randomize classification decisions on a fraction of individuals in order to achieve fairness measures related to parity in errors and calibration. These methods, however, have raised concerns due to the information inefficiency, intra-group unfairness, and Pareto sub-optimality they entail.

Active Fairness

The present work proposes an alternative active framework for fair classification, where, in deployment, a decision maker adaptively acquires information according to the needs of different groups or individuals towards balancing disparities in classification performance. We propose two such methods where information collection is adapted to group- and individual-level needs, respectively. We show on real-world datasets that these can achieve: 1) calibration and single error parity (e.g., equal opportunity) and 2) parity in both false positive and false negative rates (e.g., equal odds). Moreover, we show that, by leveraging their additional degree of freedom, active approaches can outperform randomization-based classifiers previously considered optimal, while also avoiding limitations such as intra-group unfairness.

424. **Augmented Eternity and Swappable Identities**

Hossein Rahnama

Have you ever wondered what a friend would do if she was in your decision-making situation? Or thought about where a family member might go if he was visiting a travel destination with you? In many cases, you can only guess what a person would do if they were in your shoes. But now you may be able to securely "borrow their identity" and ask a question with the confidence of receiving a relevant and valuable answer.

Can software agents become our digital heirs? Can a head of state, a scientist, or a business owner leverage machine intelligence to complement succession planning? What if you could select the digital identity of a deceased person from a social network and activate it as a pluggable ontology into your iPhone's Siri and ask a question?

Our digital identity has become so rich and intrinsic that without it, it may feel like a part of us is missing. The number of sensors we carry daily and the digital footprints we leave behind have given us enough granular patterns and data clusters that we can now use them for prediction and reasoning on behalf of an individual. We believe that by enabling our digital identity to perpetuate, we can significantly contribute to global expertise and enable a new form of an intergenerational collective intelligence.

425. **bandicoot: A Python Toolbox for Mobile Phone Metadata**

Alex 'Sandy' Pentland, Yves-Alexandre de Montjoye

bandicoot provides a complete, easy-to-use environment for researchers using mobile phone metadata. It allows them to easily load their data, perform analysis, and export their results with a few lines of code. It computes 100+ standardized metrics in three categories: individual (number of calls, text response rate), spatial (radius of gyration, entropy of places), and social network (clustering coefficient, assortativity). The toolbox is easy to extend and contains extensive documentation with guides and examples.

426. **Blockchain: A New Framework for Robotic Swarm Systems**

Alex 'Sandy' Pentland, Eduardo Castello Ferrer, Dr. Thomas HardjonoProf. Marco Dorigo

Swarms of robots will revolutionize many applications, from targeted material delivery to farming. However, the characteristics that make them ideal for certain future applications, such as robot autonomy or decentralized control, can also be an obstacle when transferring this technology from academia to real-world problems. Blockchain, an emerging technology, demonstrates that by combining peer-to-peer networks with cryptographic algorithms, a group of agents can reach agreements without the need for a controlling authority. The combination of blockchain with other distributed systems, such as robotic swarm systems, can provide the necessary capabilities to make robotic swarm operations more secure, autonomous, flexible, and even profitable.

427. **Collective Sensemaking in Cryptocurrency Community**

Alex 'Sandy' Pentland, Eaman Jahani, Peter Krafft, Esteban Moro Egido, Yoshihiko Suhara

Participants in cryptocurrency markets are in constant communication with each other about the latest coins and news releases. Do these conversations build hype through the contagiousness of excitement, help the community process information, or play some other role? Using a novel dataset from a major cryptocurrency forum, we conduct an exploratory study of the characteristics of online discussion around cryptocurrencies. We find that coins with more information available and higher levels of technical innovation are associated with higher quality discussion. People who talk about serious coins tend to participate in discussion displaying signatures of collective intelligence and information processing, while people who talk about less serious coins tend to display signatures of hype and naivety. Interviews with experienced forum members also confirm these quantitative findings. These results highlight the varied roles of discussion in the cryptocurrency ecosystem and suggest that discussion of serious coins may be oriented towards earnest, perhaps more accurate, attempts at discovering which coins are likely to succeed.

428. **Data for refugees**

Alex 'Sandy' Pentland, Michiel Bakker, Jose Balsa Barreiro, Yan Leng, Alfredo Morales-Guzman, Vivek K. Singh

Data for refugees is a big data challenge whereby Turk Telekom opens a large dataset of anonymized mobile phone records to research groups for the purpose of providing better living conditions to Syrian refugees in Turkey.

We introduce different measures extracted from mobile phone metadata to study the integration of refugees along three dimensions: (1) social integration, (2) spatial integration, and (3) economic integration through signatures of employment activity. We use these measures to compare integration across different regions in Turkey and find striking differences both in the distributions of these dimensions and the relations between them.

The paper is currently under review but will be shared soon.

429. **Data-Pop Alliance**

Alex 'Sandy' Pentland, Harvard Humanitarian Initiative, Overseas Development Institute

Data-Pop Alliance is a joint initiative on big data and development with a goal of helping to craft and leverage the new ecosystem of big data--new personal data, new tools, new actors--to improve decisions and empower people in a way that avoids the pitfalls of a new digital divide, de-humanization, and de-democratization. Data-Pop Alliance aims to serve as a designer, broker, and implementer of ideas and activities, bringing together institutions and individuals around common principles and objectives through collaborative research, training and capacity building, technical assistance, convening, knowledge curation, and advocacy. Our thematic areas of focus include official statistics, socio-economic and demographic methods, conflict and crime, climate change and environment, literacy, and ethics.

430. **DeepShop: Understanding Purchase Patterns via Deep Learning**

Alex 'Sandy' Pentland, Xiaowen Dong, Yoshihiko Suhara

The recent availability of quantitative behavioral data provides an opportunity to study human behavior at unprecedented scale. Using large-scale financial transaction data, we propose a novel deep learning framework for understanding human purchase patterns and testing the link between them and the existence of individual financial troubles. Our work opens new possibilities in studying human behavioral traits using state-of-the-art machine learning techniques, without the need for hand-engineered features.

431. **Enigma**

Alex 'Sandy' Pentland, Guy Zyskind, Oz Nathan

A peer-to-peer network, enabling different parties to jointly store and run computations on data while keeping the data completely private. Enigma's computational model is based on a highly optimized version of secure multi-party computation, guaranteed by a verifiable secret-sharing scheme. For storage, we use a modified distributed hashtable for holding secret-shared data. An external blockchain is utilized as the controller of the network, manages access control and identities, and serves as a tamper-proof log of events. Security deposits and fees incentivize operation, correctness, and fairness of the system. Similar to Bitcoin, Enigma removes the need for a trusted third party, enabling autonomous control of personal data. For the first time, users are able to share their data with cryptographic guarantees regarding their privacy.

432. **Healthy Blockchain**

Alex 'Sandy' Pentland, Shada Alsalamah, Eduardo Castello Ferrer, Dr. Hessah Alsalamah (King Saud University, Saudi Arabia), Dr. Shiroq Al-Megren (King Saud University, Saudi Arabia) Dr. Thamer Nough (King Saud Medical City, Saudi Arabia), Dr. Thomas Hardjono (MIT Connection Science), Dr. Heba Kurdi (King Saud University, Saudi Arabia)

Achieving a safe privacy-preserving information sharing environment for individualized care using blockchain-based technology in multiple use cases in the healthcare space.

433. **Improving official statistics in emerging markets using machine learning and mobile phone data**

Alex 'Sandy' Pentland, Yves-Alexandre de Montjoye, Eaman Jahani, Pål Sundsøy, Johannes Bjelland, Linus Bengtsson

Mobile phones are one of the fastest growing technologies in the developing world with global penetration rates reaching 90%. Mobile phone data, also called CDR, are generated every time phones are used and recorded by carriers at scale. CDR have generated groundbreaking insights in public health, official statistics, and logistics. However, the fact that most phones in developing countries are prepaid means that the data lacks key information about the user, including gender and other demographic variables. This precludes numerous uses of this data in social science and development economic research. It furthermore severely prevents the development of humanitarian applications such as the use of mobile phone data to target aid towards the most vulnerable groups during crisis.

We developed a framework to extract more than 1,400 features from standard mobile phone data and used them to predict useful individual characteristics and group estimates. We here present a systematic cross-country study of the applicability of machine learning for dataset augmentation at low cost. We validate our framework by showing how it can be used to reliably predict gender and other information for more than half a million people in two countries. We show how standard machine learning algorithms trained on only 10,000 users are sufficient to predict individual's gender with an accuracy ranging from 74.3 to 88.4% in a developed country and from 74.5 to 79.7% in a developing country using only metadata. This is significantly higher than previous approaches and, once calibrated, gives highly accurate estimates of gender balance in groups. Performance suffers only marginally if we reduce the training size to 5,000, but significantly decreases in a smaller training set. We finally show that our indicators capture a large range of behavioral traits using factor analysis and that the framework can be used to predict other indicators of vulnerability such as age or socio-economic status. Mobile phone data has a great potential for good and our framework allows this data to be augmented with vulnerability and other information at a fraction of the cost.

434. **Incentivizing Cooperation Using Social Pressure**

Alex 'Sandy' Pentland, Dhaval Adjodah, David Shrier

Cooperation in a large society of self-interested individuals is notoriously difficult to achieve when the externality of one individual's action is spread thin and wide. This leads to the "tragedy of the commons," with rational action ultimately leaving everyone worse off. Traditional policies to promote cooperation involve Pigouvian taxation or subsidies that make individuals internalize the externality they incur. We introduce a new approach to achieving global cooperation by localizing externalities to one's peers in a social network, thus leveraging the power of peer pressure to regulate behavior. The mechanism relies on a joint model of externalities and peer-pressure. Surprisingly, this mechanism can require a lower budget to operate than the Pigouvian mechanism, even when accounting for the social cost of peer pressure. Even when the available budget is very low, the social mechanisms achieve greater improvement in the outcome.

435. **Leveraging Leadership Expertise More Effectively in Organizations**

Alex 'Sandy' Pentland, Dhaval Adjodah, Alejandro Noriega Campero

We believe that the narrative of only listening to experts or trusting the wisdom of the crowd blindly is flawed. Instead we have developed a system that weighs experts and lay-people differently and dynamically and show that a good balance is required. We show that our methodology leads to a 15 percent improvement in mean performance, 15 percent decrease in variance, and almost 30 percent increase in Sharpe-type ratio in a real online market.

436. **Managing Travel Demand: Location recommendation for system efficiency**

Alex 'Sandy' Pentland, Yan Leng, Larry Rudolph, Jinhua Zhao

Growth in leisure travel has become increasingly significant economically, socially, and environmentally. However, flexible but uncoordinated travel behaviors exacerbate traffic congestion. Mobile phone records not only reveal human mobility patterns, but also enable us to manage travel demand for system efficiency. We propose a location recommendation system that infers personal preferences while accounting for constraints imposed by road capacity in order to manage travel demand. We first infer unobserved preferences using a machine learning technique from phone records. We then formulate an optimization method to improve system efficiency. Coupling mobile phone data with traffic counts and road network infrastructures collected in Andorra, this study shows that uncoordinated travel behaviors lead to longer average travel delay, implying opportunities in managing travel demand by collective decisions. The interplay between congestion relief and overall satisfied location preferences observed in extensive simulations indicate that moderate sacrifices of individual utility lead to significant travel time savings. Specifically, the results show that under full compliance rate, travel delay fell by 52 percent at a cost of 31 percent less satisfaction. Under 60 percent compliance rate, 41 percent travel delay is saved with a 17 percent reduction in satisfaction. This research highlights the effectiveness of the synergy among collective behaviors in increasing system efficiency.

437. **Measuring and Reducing Social Segregation in Cities**

Dan Calacci, Xiaowen Dong, Esteban Moro Egido

We use high-resolution geospatial data collected from mobile phones to measure social segregation at an unprecedented resolution in cities across the United States. Social segregation happens when people of varying socioeconomic groups in a city have little opportunity to be exposed to people different than them.

To construct this measure, we aggregate high-resolution data from over 4.5 million users in the principal metro areas in the US to characterize places in the city by how mixed their visitors are by income. Using this measure, rather than traditional residential metrics, reveals that social exposure in third places is crucial to understanding economic segregation patterns in cities. In fact, the social segregation of different economic groups is dependent on an extremely small proportion of overall venues in a city.

We also look at how much individual citizens would need to change their behavior in order to make their patterns of exposure more integrated. Surprisingly, small changes in the amount of time people spend in different categories of places—changes as low as 2-5%—can reduce their social segregation by half.

We're currently working on finalizing these results and exploring how we might translate these findings into policy.

438. **Mobile Territorial Lab**

Alex 'Sandy' Pentland, David Shrier

The Mobile Territorial Lab (MTL) aims at creating a "living" laboratory integrated in the real life of the Trento territory in Italy, open to manifold kinds of experimentations. In particular, the MTL is focused on exploiting the sensing capabilities of mobile phones to track and understand human behaviors (e.g., families' spending behaviors, lifestyles, mood, and stress patterns); on designing and testing social strategies aimed at empowering individual and collective lifestyles through attitude and behavior change; and on investigating new paradigms in personal data management and sharing. This project is a collaboration with Telecom Italia SKIL Lab, Foundation Bruno Kessler, and Telefonica I+D.

439. **On the Reidentifiability of Credit Card Metadata**

Alex 'Sandy' Pentland, Yves-Alexandre de Montjoye

Even when real names and other personal information are stripped from metadata datasets, it is often possible to use just a few pieces of information to identify a specific person. Here, we study three months of credit card records for 1.1 million people and show that four spatiotemporal points are enough to uniquely reidentify 90 percent of individuals. We show that knowing the price of a transaction increases the risk of reidentification by 22 percent, on average. Finally, we show that even data sets that provide coarse information at any or all of the dimensions provide little anonymity, and that women are more reidentifiable than men in credit card metadata.

440. **OPAL 4 Health**

Alex 'Sandy' Pentland, Abdulrahman Alotaibi, Shada Alsalamah, Jose Balsa Barreiro, Eduardo Castello Ferrer, Anne Kim (Computer Science and Molecular Biology, MIT); Dr. Thomas Hardjono (MIT Connection Science); Prof. Björn Eskofier (Machine Learning and Data Analytics (MaD) lab, Germany)
Open Algorithms (OPAL)

441. **Open Badges**

Alex 'Sandy' Pentland, Oren Lederman, Akshay Mohan

We present Open Badges, an open-source framework and toolkit for measuring and shaping face-to-face social interactions using either custom hardware devices or smart phones, and real-time web-based visualizations. Open Badges is a modular system that allows researchers to monitor and collect interaction data from people engaged in real-life social settings.

442. **openPDS/ SaferAnswers: Protecting the Privacy of Metadata**

Alex 'Sandy' Pentland, Yves-Alexandre de Montjoye, Erez Shmueli, Brian Sweatt

In a world where sensors, data storage, and processing power are too cheap to meter, how do you ensure that users can realize the full value of their data while protecting their privacy? openPDS is a field-tested, personal metadata management framework that allows individuals to collect, store, and give fine-grained access to their metadata to third parties. SaferAnswers is a new and practical way of protecting the privacy of metadata at an individual level. SaferAnswers turns a hard anonymization problem into a more tractable security one. It allows services to ask questions whose answers are calculated against the metadata, instead of trying to anonymize individuals' metadata. Together, openPDS and SaferAnswers provide a new way of dynamically protecting personal metadata.

443. **OPEN TrialChain**

Alex 'Sandy' Pentland, Shada Alsalamah, Anne Kim (Computer Science and Molecular Biology, MIT); Christopher Milan; Dr. Thomas Hardjono (MIT Connection Science); Prof. Björn Eskofier (Machine Learning and Data Analytics (MaD) lab, Germany)

In this project, we are motivated to address clinical trials issues using Blockchain technology. We propose, OPEN TrialChain, a privacy-preserving Blockchain-based data sharing infrastructure that uses open algorithms between stakeholder of the federation in the clinical trials ecosystem. OPEN TrialChain balances between the sharing of clinical data and the need for subject's privacy protection by allowing queries on decentralized raw datasets from which it returns aggregated safe answers that are blinded (i.e. anonymized). Using Type II Diabetes as a case study, we study the adoption of OPEN TrialChain and how it can address clinical trials issues. Results show that OPEN TrialChain, first, encourages pharmaceutical companies to report their trial results with higher fidelity, as well as, federated ones to provide more detailed results in return for their peers' detailed results. Furthermore, it allows for multiple studies to be queried for results from underrepresented demographics, producing greater insight from previously ignored minorities. Finally, analysis done using OPEN TrialChain should illustrate meaningful results without violating the privacy of individuals. Eventually, OPEN TrialChain is expected to optimize the clinical trial ecosystem by improving patient safety, saving lives, cutting drug development costs, encouraging transparent results, preserving patients privacy, and maintaining pharmaceuticals integrity.

444. **Prediction Markets: Leveraging Internal Knowledge to Beat Industry Prediction Experts**

Alex 'Sandy' Pentland, Dhaval Adjodah, Alejandro Noriega

Markets are notorious for bubbles and bursts. Other research has found that crowds of lay-people can replace even leading experts to predict everything from product sales to the next big diplomatic event. In this project, we leverage both threads of research to see how prediction markets can be used to predict business and technological innovations, and use them as a model to fix financial bubbles. For example, a prediction market was rolled out inside of Intel and the experiment was very successful, and led to better predictions than the official Intel forecast 75 percent of the time. Prediction markets also led to as much as a 25 percent reduction in mean squared error over the prediction of official experts at Google, Ford, and Koch industries.

445. **Recurrent Neural Network in Context-Free Next-Location Prediction**

Alex 'Sandy' Pentland, Yan Leng, Larry Rudolph, Jinhua Zhao

Location prediction is a critical building block in many location-based services and transportation management. This project explores the issue of next-location prediction based on the longitudinal movements of the locations individuals have visited, as observed from call detail records (CDR). In a nutshell, we apply recurrent neural network (RNN) to next-location prediction on CDR. RNN can take in sequential input with no restriction on the dimensions of the input. The method can infer the hidden similarities among locations and interpret the semantic meanings of the locations. We compare the proposed method with Markov and a Naive Model proving that RNN has better accuracy in location prediction.

446. **Rhythm: Open measurement and feedback tools for human interaction**

Dan Calacci, Oren Lederman, Akshay Mohan

Rhythm is a collection of open-source tools to make it easier for researchers to examine, analyze, and augment human interaction. Rhythm includes hardware to measure face to face interaction, software platforms to quantify social dynamics from online videoconferencing, and analysis and visualization tools to craft interventions that affect social behavior. For more information, visit rhythm.mit.edu, or our main github repository.

447. **RoboChain: A Secure Data-Sharing Framework for Human-Robot Interaction**

Alex 'Sandy' Pentland, Eduardo Castello Ferrer, Ognjen (Oggi) Rudovic, Dr. Thomas Hardjono

A learning framework for secure, decentralized, computationally efficient data and model sharing among multiple robot units installed at multiple sites.

448. **Secure Sharing of Wildlife Data**

**Alex 'Sandy' Pentland, Remo Frey
Leveraging the power of platforms, big data, and advanced analytics for species protection and the public good in a privacy-preserving, scalable, and sustainable manner**

Modern tracking technology enables new ways of mining data in the wild. It allows wildlife monitoring centers to permanently collect geospatial data in a non-intrusive manner and in real time. Unfortunately, such sensible data is exposed to fraud and misuse and there is already a first reported case of "cyber-poaching." Based on stolen geospatial data, poachers can easily track and kill animals. Meanwhile, cautious monitoring centers limited data access for research and public use. We propose a novel privacy-preserving system to allow these monitoring centers to securely answer questions from the research community and the public while the raw data is protected against unauthorized third parties. Based on the core system, several new applications are conceivable, such as a mobile app for preventing conflicts between human and wildlife or for engaging people in wildlife donation. Besides providing a solution and working on specific use cases, the intention of this project is to start a discussion about the need for data protection in the animal world.

449. **SMART^2 OPAL**
Alex 'Sandy' Pentland, Abdulrahman Alotaibi, Shada Alsalamah, Jose Balsa Barreiro, Haijing Hao, Dr. Areej Al-Wabil (King Abdulaziz City for Science and Technology, Saudi Arabia), Dr. Hessah Alsalamah (King Saud University, Saudi Arabia), Dr. Shiroq Al-Megren (King Saud University, Saudi Arabia), Dr. Heba Kurdi (King Saud University, Saudi Arabia), Prof. Björn Eskofier (Machine Learning and Data Analytics (MaD) lab, Germany), Leili Soltanisehat (Old Dominion University, USA), Dr. Michael Cavanagh (University of Sydney, Australia)
 Privacy-preserving mHealth application using Open Algorithm (OPAL) architecture to address urgent care challenges in Riyadh, Saudi Arabia.
450. **Social AI and Extended Intelligence**
Alex 'Sandy' Pentland, Dhaval Adjodah, Peter Krafft, Esteban Moro Egido
 There is a deep fear that human jobs will be replaced by AI. Rather than racing against the machines, our aim is to show that a human-AI combination will perform better than humans and AI working alone. Although no man is better than a machine for some tasks, "no machine is better than a man with a machine" (Paul Tudor Jones). Thus, by building "bots" that are compatible with human behavior, and specifically leverage the manner in which humans use social information, we have been able to build bots that extend human intelligence capabilities. In a large-scale financial trading experiment, we have shown that groups of humans and "socially compatible" AI bots can successfully incorporate human intuition into their decisions and consequently not only do better than humans alone, but also do better than similar AI bots that use only objective information.
451. **Social Bridges in Community Purchase Behavior**
Alex 'Sandy' Pentland, Xiaowen Dong, Vivek K. Singh, Yoshihiko Suhara
 The understanding and modeling of social influence on human economic behavior in city environments can have important implications. In this project, we study human purchase behavior at a community level and argue that people who live in different communities but work at similar locations could act as "social bridges" that link their respective communities and make the community purchase behavior similar through the possibility of social learning through face-to-face interactions.
452. **Social Capital Accounting**
Alex 'Sandy' Pentland, Takeo Nishikata, Thomas Hardjono, MIT Connection Science
 To better understand and improve the quality of our lives, there has been a need for measuring non-economic capital such as social capital and natural capital in addition to economic capital. Quantifying non-economic capital, however, is not easy and has not been widespread. In this project, we propose a system where individuals can start measuring their social capital, turning them into a real-world asset that enables the improvement their economic wellbeing, while preserving individual privacy and security.
453. **Social Learning Recommender Bots**
Alex 'Sandy' Pentland, Dhaval Adjodah, Peter Krafft, Esteban Moro Egido
 We build recommender bots that use machine learning and network analytics to create personalized recommendations for users on various social and financial platforms. We show that bots that work not just on the raw user data, but instead build on human intuition, do far better. We are in the process of live testing these bots on various platforms.

454. **Social Physics of Unemployment**

Alex 'Sandy' Pentland, Abdullah M. Almaatouq

Earlier studies proved that behavior is highly shaped and constrained by one's social networks, and demonstrated ways in which individuals can manipulate these networks to achieve specific goals. A great example is the much-studied "strength of weak ties" hypothesis, which states that the strength of a tie between A and B increases with the overlap of their friendship circles, resulting in an important role for weak ties in connecting communities. Mark Granovetter first proposed this idea in a study that emphasized the nature of the tie between job changers in a Boston suburb and the contacts who provided the necessary information for them to obtain new employment. Basically, although people with whom the job seekers had strong ties were more motivated to provide information, the structural position of weak ties played a more important role. The implication is that those to whom one is weakly tied are more likely to move in different circles, and will thus have access to different information than the people to whom you are tied more strongly.

Much of our knowledge about how mobility, social networks, communication, and education affect the economic status of individuals and cities has been obtained through complex and costly surveys, with an update rate ranging from fortnights to decades. However, recent studies have shown the value of mobile phone data as an enabling methodology for demographic modeling and measurement.

Many of our daily routines are driven by activities either afforded by our economic status or related to maintaining or improving it, from our movements around the city, to our daily schedules, to our communication with others. As such, we expect to be able to measure passive patterns and behavioral indicators, using mobile phone data, that could describe local unemployment rates. To investigate this question, we examined anonymized mobile phone metadata combined with beneficiaries' records from an unemployment benefit program. We found that aggregated activity, social, and mobility patterns strongly correlate with unemployment. Furthermore, we constructed a simple model to produce accurate reconstructions of district-level unemployment from mobile communication patterns alone.

Our results suggest that reliable and cost-effective indicators of economic activity could be built based on passively collected and anonymized mobile phone data. With similar data being collected every day by telecommunication services across the world, survey-based methods of measuring community socioeconomic status could potentially be augmented or replaced by such passive sensing methods.

455. **The Atlas of Inequality**

Alex 'Sandy' Pentland, Dan Calacci, Xiaowen Dong, Esteban Moro Egido

Segregation is hurting our societies and especially our cities. But economic inequality isn't just limited to neighborhoods. The restaurants, stores, and other places we visit in cities are all unequal in their own way.

The Atlas of Inequality shows the income inequality of people who visit different places in the Boston metro area. It uses aggregated anonymous location data from digital devices to estimate people's incomes and where they spend their time. Using that data, we've made our own place inequality metric to capture how unequal the incomes of visitors to each place are. Economic inequality isn't just limited to neighborhoods; it's part of the places you visit every day.

Try it yourself here:

The Atlas of Inequality

The Atlas of Inequality is a project from the Human Dynamics group at the MIT Media Lab and the Department of Mathematics at Universidad Carlos III de Madrid.

It is part of a broader initiative to understand human behavior in our cities and how large-scale problems like transportation, housing, segregation, or inequality depend in part on the emergent patterns of people's individual opportunities and choices.

456. **The Ripple Effect: You Are More Influential Than You Think**

Alex 'Sandy' Pentland, Xiaowen Dong, Yan Leng, Esteban Moro Egido

The well-known "small-world" phenomenon indicates that an individual can be connected with any other in the world through a limited number of personal acquaintances. Furthermore, Nicholas and Fowler show that not only are we connected to each other, but we could also shape the behavior of our friends' friends. In this project, we are interested in understanding how social influence propagates and triggers behavioral change in social networks. Specifically, we analyze a large-scale, one-month international event held in the European country of Andorra using country-wide mobile phone data, and investigate the change in the likelihood of attending the event for people that have been influenced by and are of different social distances from the attendees.

Our results suggest that social influence exhibits the ripple effect, decaying across social distances from the source but persisting up to six degrees of separation. We further show that influence decays as communication delay increases and intensity decreases. Such ripple effect in social communication can lead to important policy implications in applications where it is critical to trigger behavior change in the population.

Kent Larson, Alex 'Sandy' Pentland, Luis Alberto Alonso Pastor, Eduardo Castello Ferrer, Arnaud Grignard

Modern cities have to respond to the growing demands of more efficient and sustainable urban development, as well as an increased quality of life. In this context, the cities of the future will need the ability to gain insight about current urban conditions and react dynamically to them. According to this view, "smart cities" can be seen as cybernetic urban environments in which different agents (e.g., citizens) and actuators (e.g., robots) exploit the city-wide infrastructure as a medium to operate synergistically. Urban Swarms explores the feasibility of swarm robotics systems in urban environments. By using bio-inspired methods, a swarm of robots is able to handle important urban systems and infrastructures, improving their efficiency and autonomy. A diverse set of simulation experiments were designed and conducted using real-world GIS data. Results show that the proposed combination is able to outperform current approaches. Urban Swarms not only aims to show the efficiency of our proposed solution, but also to give insights about how to design and customize these systems. CityScope Volpe ABM model has been customized to integrate Swarm behavior using the Gama Platform as an open source project.

Rosalind W. Picard: Affective Computing

Advancing wellbeing by using new ways to communicate, understand, and respond to emotion

458. **Affective Response to Haptic Signals**

Rosalind W. Picard, Grace Leslie, Suranga Nanayakkara, Singapore University of Technology and Design

This study attempts to examine humans' affective responses to superimposed sinusoidal signals. These signals can be perceived either through sound, in the case of electronically synthesized musical notes, or through vibro-tactile stimulation, in the case of vibrations produced by vibrotactile actuators. This study is concerned with the perception of superimposed vibrations, whereby two or more sinusoidal signals are perceived simultaneously, producing a perceptual impression that is substantially different than of each signal alone, owing to the interactions between perceived sinusoidal vibrations that give rise to a unified percept of a sinusoidal chord. The theory of interval affect was derived from systematic analyses of Indian, Chinese, Greek, and Arabic music theory and tradition, and proposes a universal organization of affective response to intervals organized using a multidimensional system. We hypothesize that this interval affect system is multi-modal and will transfer to the vibrotactile domain.

459. **An EEG and Motion-Capture Based Expressive Music Interface for Affective Neurofeedback**

Rosalind W. Picard, Grace Leslie, Singapore University of Technology and Design, Simon Lui

This project examines how the expression granted by new musical interfaces can be harnessed to create positive changes in health and wellbeing. We are conducting experiments to measure EEG dynamics and physical movements performed by participants who are using software designed to invite physical and musical expression of the basic emotions. The present demonstration of this system incorporates an expressive gesture sonification system using a Leap Motion device, paired with an ambient music engine controlled by EEG-based affective indices. Our intention is to better understand affective engagement, by creating both a new musical interface to invite it, and a method to measure and monitor it. We are exploring the use of this device and protocol in therapeutic settings in which mood recognition and regulation are a primary goal.

460. **Automated Tongue Analysis**

Rosalind W. Picard, Weixuan 'Vincent' Chen, Craig Ferguson, Javier Hernandez, Akane Sano

A common practice in Traditional Chinese Medicine (TCM) is visual examination of the patient's tongue. This study will examine ways to make this process more objective and to test its efficacy for understanding stress- and health-related changes in people over time. We start by developing an app that makes it comfortable and easy for people to collect tongue data in daily life together with other stress- and health-related information. We will obtain assessment from expert practitioners of TCM, and also use pattern analysis and machine learning to attempt to create state-of-the-art algorithms able to help provide better insights for health and prevention of sickness.

461. **Autonomic Nervous System Activity in Epilepsy**

Rosalind W. Picard, Ming-Zher Poh

We are performing long-term measurements of autonomic nervous system (ANS) activity on patients with epilepsy. In certain cases, autonomic symptoms are known to precede seizures. Usually in our data, the autonomic changes start when the seizure shows in the EEG, and can be measured with a wristband (much easier to wear every day than wearing an EEG). We found that the larger the signal we measure on the wrist, the longer the duration of cortical brain-wave suppression following the seizure. The duration of the latter is a strong candidate for a biomarker for SUDEP (Sudden Unexpected Death in Epilepsy), and we are working with scientists and doctors to better understand this. In addition, bilateral changes in ANS activity may provide valuable information regarding seizure focus localization and semiology.

462. **Behavioral Indications of Depression Severity**

Rosalind W. Picard, Szymon Fedor, Asma Ghandeharioun

In collaboration with Massachusetts General Hospital, we are conducting a clinical trial exploring objective methods for assessing depression and its severity.

We are challenging the assessment methods that were created decades ago and which rely mostly on self-reported measures. We are including information from wearable sensors and regular sensors in mobile phones to collect information about sleep, social interaction, and location changes to find behavioral patterns that are associated with depressive symptoms.

463. **BioEssence**

Pattie Maes, Judith Amores Fernandez, Artem Dementyev, Javier Hernandez, Xiqing Wang
A wearable olfactory display that monitors cardio-respiratory information to support mental wellbeing.

BioEssence is a novel wearable olfactory display that provides just-in-time release of scents based on the physiological state of the wearer. The device can release up to three scents and passively captures subtle chest vibrations associated with the beating of the heart and respiration through clothes.

464. **BrainBeat: Breath-Based Music Therapy**

Rosalind W. Picard, Asma Ghandeharioun, Grace Leslie

Can we sonify calming breathing and passively influence a state of calm?

Deep breathing has been scientifically proven to affect the heart, brain, digestive system, and the immune system. We believe designing a technology to promote deep breathing can facilitate transition into a calm state.

Nowadays, many people are spending a significant amount of time listening to music while working or studying. This makes music a good means for providing auditory breathing cues. While it has been shown that liminal auditory cues can be effective in encouraging a healthy breathing pattern, we are examining the use of subliminal encouragement of breathing modulation using music. Auditory ambient feedback has long been studied and is proved to be effective. It has been explored in concert settings, interactive installations, and smartphone applications. However, our aim is to design an intervention that is unobtrusive and doesn't keep people from doing their primary work.

In order to find the best auditory feedback design, we have designed a controlled study comparing an interactive rhythmic ambient music track that responds to a user's current breathing patterns to a fixed rate music track whose speed of playback is pegged to a rate slightly below the user's natural resting breathing rate. A control condition with no music is also included. We will compare the resulting breathing patterns, heart rate, EEG signals, and self-reported measures to determine if the ambient music feedback has any effect on the user's state of mind and body. If successful, a musical system to subliminally encourage calming breathing patterns may be integrated into workplace environments, hospitals, and other places where it is necessary to promote less stressful and healthy environments.

465. **BrightBeat: Effortlessly Influencing Breathing for Cultivating Calmness and Focus**

Rosalind W. Picard, Asma Ghandeharioun

The relationship between breathing and self-reported stress is bidirectional. Respiration pattern is an indicator of stress, but it can also be manipulated to induce calmness.

In this project we explore this relationship via novel means of interaction. BrightBeat is a set of seamless visual, auditory, and tactile interventions that mimic a calming breathing oscillation, with the aim of influencing physiological syncing and consequently bringing a sense of focus and calmness.

The animation above shows an exaggerated version of BrightBeat. These interventions are designed to run easily on commonplace personal electronic devices, respect the user's privacy, and not to require constant focus or attention in order to be effective.

466. **Building the Just-Right-Challenge in Games and Toys**

Rosalind W. Picard, Elliott Hedman

With the LEGO Group and Hasbro, we looked at the emotional experience of playing with games and LEGO bricks. We measured participants' skin conductance as they learned to play with these new toys. By marking the stressful moments, we were able to see what moments in learning should be redesigned. Our findings suggest that framing is key: how can we help children recognize their achievements? We also saw how children are excited to take on new responsibilities but are then quickly discouraged when they aren't given the resources to succeed. Our hope for this work is that by using skin conductance sensors, we can help companies better understand the unique perspective of children and build experiences fit for them.

467. **EDA Explorer**

Rosalind W. Picard, Weixuan 'Vincent' Chen, Szymon Fedor, Natasha Jaques, Akane Sano, Sara Taylor, Victoria Xia

Electrodermal Activity (EDA) is a physiological indicator of stress and strong emotion. While an increasing number of wearable devices can collect EDA, analyzing the data to obtain reliable estimates of stress and emotion remains a difficult problem. We have built a graphical tool that allows anyone to upload their EDA data and analyze it. Using a highly accurate machine learning algorithm, we can automatically detect noise within the data. We can also detect skin conductance responses, which are spikes in the signal indicating a "fight or flight" response. Users can visualize these results and download files containing features calculated on the data to be used in their own analysis. Those interested in machine learning can also view and label their data to train a machine learning classifier. We are currently adding active learning, so the site can intelligently select the fewest possible samples for the user to label.

468. **Electrocardiogram collection in noisy ambulatory environments with Android smartphone devices**

Daniel Lopez Martinez

The explosion of mHealth in both abundant and resource-constrained countries is both a cause for celebration and for concern. While mHealth clearly has the potential to deliver information and diagnostic decision support to the poorly trained, it is not appropriate to simply translate the technologies which the trained clinician uses into the hands of non-experts. In particular, it is important that the explosion of access does not lead to a flooding of the medical system with low quality data and false negatives. Clearly for mHealth to expand, a paradigm shift in how data is analysed must occur. Data must be vetted at the front end, using automated algorithms, to provide robust filtering of low quality data.

This project addresses the specific problem of vetting the quality of electrocardiograms (ECGs) collected by an untrained user in ambulatory scenarios using smartphone devices.

469. **EMMA: An Emotionally Intelligent Personal Assistant for Improving Wellbeing**

Asma Ghandeharioun, Daniel McDuff, Mary Czerwinski

The delivery of mental health interventions via ubiquitous devices has shown a lot of promise. A natural conversational interface that allows longitudinal symptom tracking and appropriate just-in-time interventions would be extremely valuable. However, the task of designing emotionally aware agents is still poorly understood. Furthermore, the feasibility of automating the delivery of just-in-time mHealth interventions via such an agent has not been fully studied. In this project, we explore the design and evaluation of EMMA (EMotion-Aware mHealth Agent).

EMMA conducts experience sampling in an empathetic manner and provides emotionally appropriate micro-activities. We show the system can be extended to detect a user's mood purely from smartphone sensor data.

We have conducted a three-week user study (N=58). Our results show that extroverts preferred EMMA significantly more, and that our personalized machine learning model was effective, as was relying on ground-truth emotion samples from users.

470. **Emotional Navigation**

Rosalind W. Picard, Craig Ferguson, Javier Hernandez

Before automobiles were invented and widely adopted, animals like horses were the most common mode of transportation. While this change brought significant improvements in terms of reliability and efficiency, it also removed a core component: the emotional relationship that existed between the person and the animal.

While largely ignored, the emotional states of drivers are quite important, as they influence not only driving behavior but also the safety of all road users. For instance, driving can be quite an emotionally stressful experience and, while certain amounts of stress help the driver to remain alert and attentive, too much or too little can negatively impact driving performance and safety. Furthermore, stress in large doses has been linked to a large array of adverse health conditions such as depression and various forms of cardiovascular disease.

The Emotional Navigation special interest group is led by Dr. Javier Hernandez with the goal of stimulating research efforts at the intersection of Automotive and Affective Computing.

471. **Emotion Recognition in Scene Context**

Rosalind W. Picard, Agata Lapedriza Garcia, Ronak Kosti (UOC), Jose Alvarez (NVIDIA), Adrià Recasens (CSAIL, MIT)

The goal of this project is providing machines with the ability of understanding what a person is experiencing from her frame of reference, taking into account the scene context: where is this person, what is this person doing, how does this person look, etc.

You can find more information about this project on this website.

472. **Emotion/wellbeing x skincare cosmetics**

Akane Sano

The project aims to investigate the relationships between emotion, wellbeing, skin, and skincare cosmetics. In our first study, we measured emotion/wellbeing, heart rate, and respiration using a mobile phone and a wearable sensor during consumer in-use test.

473. **Fathom: Probabilistic Graphical Models to Help Mental Health Counselors**

Henry A. Lieberman, Rosalind W. Picard, Karthik Dinakar, MIT EECS, Jackie Chen

We explore advanced machine learning and reflective user interfaces to scale the national Crisis Text Line. We are using state-of-the-art probabilistic graphical topic models and visualizations to help a mental health counselor extract patterns of mental health issues experienced by participants, and bring large-scale data science to understanding the distribution of mental health issues in the United States.

474. **FEEL: A Cloud System for Frequent Event and Biophysiological Signal Labeling**

Rosalind W. Picard, Yadid Ayzenberg

The wide availability of low-cost, wearable, biophysiological sensors enables us to measure how the environment and our experiences impact our physiology. This creates a new challenge: in order to interpret the collected longitudinal data, we require the matching contextual information as well. Collecting weeks, months, and years of continuous biophysiological data makes it unfeasible to rely solely on our memory for providing the contextual information. Many view maintaining journals as burdensome, which may result in low compliance levels and unusable data. We present an architecture and implementation of a system for the acquisition, processing, and visualization of biophysiological signals and contextual information.

475. **Image Sentiment Analysis**

Agata Lapedriza Garcia

In this project we explore how to recognize and localize affect in images.

476. **Improving RNN Sequence Generation with RL**

Natasha Jaques

This project investigates a general method for improving the structure and quality of sequences generated by a recurrent neural network (RNN) using deep reinforcement learning (RL). Our method, which we call Sequence Tutor, allows models to improve sequence quality with RL, while maintaining information originally learned from data, as well as sample diversity. An RNN is first pre-trained on data using maximum likelihood estimation (MLE), and the probability distribution over the next token in the sequence learned by this model is treated as a prior policy. Another RNN is then trained using reinforcement learning (RL) to generate higher-quality outputs that account for domain-specific incentives while retaining proximity to the prior policy of the MLE RNN. To formalize this objective, we derive novel off-policy RL methods for RNNs from KL-control. The effectiveness of the approach is demonstrated on two applications; 1) generating novel musical melodies, and 2) computational molecular generation for drug discovery. For both problems, we show that the proposed method improves the desired properties and structure of the generated sequences, while maintaining information learned from data.

477. **Improving Wellbeing for Office Workers**

Rosalind W. Picard, Akane Sano, Sara Taylor, Terumi Umematsu

Excessive stress can decrease office workers' productivity and negatively impact overall health. This project aims to predict office workers' stress levels using physiological and behavioral markers based on heart rate, skin conductance, skin temperature, and acceleration. Building on knowledge and models developed for student populations in the SNAPSHOT study and collecting new data from worker populations, we plan to improve stress-level prediction performance for office workers. Furthermore, we will also study how to improve productivity by decreasing stress. In order to accomplish this, we will look for causal factors that increase stress and possible interventions that can be deployed to office workers to decrease these factors.

478. **Improving Wellbeing Prediction Performance Using Temporal Machine Learning Models**

Rosalind W. Picard, Akane Sano, Sara Taylor, Terumi Umematsu

This project aims to improve the prediction accuracy of wellbeing (stress, mood, and health levels) using temporal machine learning models. We extend our previous approach using Long Short-Term Memory models and time series data from the SNAPSHOT study. In addition, we consider adaptive methods to fill in missing data with time series information. We also develop the model using modifiable behavioral features such as bedtime, and examine how these contribute to wellbeing, so that people can get better control over how to improve their personal well-being.

479. **Injection Study**

Rosalind W. Picard, Daniel Lopez Martinez

Many drugs, such as monoclonal antibodies, are administered using parenteral delivery devices via subcutaneous injections. Unfortunately, needle phobia, anxiety before and during needle insertion and pain during injections are key aspects that lead to poor therapeutic compliance and prevent wider applicability and acceptance of this technology across patient groups. Therefore, in order to improve patient experience, traditional pain scores using a visual analog scale (VAS) or other similar techniques have been used to compare and investigate different subcutaneous injection methodologies. However, they are subjective and it is difficult to power a clinical study to show significant differences in pain.

In this study, we propose to use electrodermal activity (EDA), heart rate variability (HRV), and facial expression analysis as potential endpoints to determine quantitative pain scores during the injection process, together with other secondary endpoints such as wellness aspects of patients (e.g. sleep quality). Therefore, the objective of this study is to evaluate these endpoints in subcutaneous injections for different injection methodologies (consisting of different dose volumes, flow rates, needle gauges and injectate viscosity) in a clinical setting in humans. The data will be used to understand pain upon injection and see if there is any correlation between traditional pain scores (e.g. visual analog scale) and our proposed endpoints.

480. **"Kind and Grateful": Promoting kindness and gratitude with pervasive technology**

Rosalind W. Picard, Asaph Azaria, Asma Ghandeharioun, Sara Taylor

We have designed a novel system to promote kindness and gratitude. We leverage pervasive technologies to naturally embed gratitude inspiration in everyday life. Mobile sensor data is utilized to infer optimal moments for stimulating contextually relevant thankfulness and appreciation. We analyze the interplay between mood, contextual cues, and gratitude expressions.

481. **Learning via Social Awareness: Improving Sketch Representations with Facial Feedback**

Rosalind W. Picard, Natasha Jaques, Jesse Engel, David Ha, Fred Bertsch, Douglas Eck (Google Brain)

In the quest towards general artificial intelligence (AI), researchers have explored developing loss functions that act as intrinsic motivators in the absence of external rewards. This paper argues that such research has overlooked an important and useful intrinsic motivator: social interaction. We posit that making an AI agent aware of implicit social feedback from humans can allow for faster learning of more generalizable and useful representations, and could potentially impact AI safety. We collect social feedback in the form of facial expression reactions to samples from Sketch RNN, an LSTM-based variational autoencoder (VAE) designed to produce sketch drawings. We use a Latent Constraints GAN (LC-GAN) to learn from the facial feedback of a small group of viewers, and then show in an independent evaluation with 76 users that this model produced sketches that lead to significantly more positive facial expressions. Thus, we establish that implicit social feedback can improve the output of a deep learning model.

482. **Lensing: Cardiolinguistics for Atypical Angina**

Rosalind W. Picard, Karthik Dinakar, Matthew Nock (Harvard), David Blei (Columbia), Catherine Kreatsoulas (Harvard)

Conversations between two individuals—whether between doctor and patient, mental health therapist and client, or between two people romantically involved with each other—are complex. Each participant contributes to the conversation using her or his own "lens." This project involves advanced probabilistic graphical models to statistically extract and model these dual lenses across large datasets of real-world conversations, with applications that can improve crisis and psychotherapy counseling and patient-cardiologist consultations. We're working with top psychologists, cardiologists, and crisis counseling centers in the United States.

483. **Leveraging artificial intelligence for the assessment of severity of depressive symptoms**

Depressive disorders are ranked as the single largest contributor to non-fatal health loss (7.5% of all Years Lived with Disability), affecting an estimated 300 million people[1]. Evidence-based treatments are available and measurement-based care has been described as the gold standard. Monitoring of depressive symptoms is currently performed with self-administered and interview-based assessment methods conducted by clinicians in their offices. However, the shortage of mental health specialists and the limited resources available to primary care physicians who often manage patients with depression prevent close monitoring of symptoms, delaying optimal treatment, and potentially prolonging suffering. Passive recording of behavioral data (gathering information without an individual's direct input) has been identified as a potentially feasible method for long-term monitoring of depression.

During the past decade, along with the development of wearable sensors, we have seen the progressive use of machine learning, which has allowed for the development of complex models. The combination of sensor technology and machine learning enables detailed measurement in real time of a wealth of behaviors predicting variation of depression. Our interdisciplinary team, including one of the leading labs on depression research at the Massachusetts General Hospital and the Affective Computing group at the MIT Media Lab, has conducted a study applying machine learning analytics to create a model combining wristband sensor data and phone-based passive measurements to assess depression. In our pilot study with chronically depressed patients monitored over eight weeks, we found that an algorithm based on biological and behavioral sensor data could estimate depression severity evaluated by a clinician with high accuracy, comparable to the inter-rater reliability.

In this project, we build from our pilot study and develop an objective, passive, sensor-based algorithm able to detect depression and early response as well as predict response. We will monitor for 12 weeks 100 adults with Major Depression Disorder who just started treatment. The identification of reliable, objective, passive assessment of depression with biosensors will have significant ramifications for the monitoring of depression, early detection of response, and ultimately contribute to the advancement of precision medicine.

[1] World Health Organization. "Depression and other common mental disorders: global health estimates." (2017).

484. **Machine Learning for Pain Measurement**

Rosalind W. Picard, Daniel Lopez Martinez, Ognjen (Oggi) Rudovic

Pain is a subjective experience commonly measured through patients' self reports. Unfortunately, self-report measures only work when the subject is sufficiently alert and cooperative, and hence they lack utility in multiple situations (such as during drowsiness) and patient populations (such as patients with dementia or paralysis). To circumvent the limitations of pain self-reports, in this project we are developing automatic methods for pain estimation based on physiological signals and/or facial expressions.

485. **Mapping the Stress of Medical Visits**

Rosalind W. Picard, Elliott Hedman

Receiving a shot or discussing health problems can be stressful, but does not always have to be. We measure participants' skin conductance as they use medical devices or visit hospitals and note times when stress occurs. We then prototype possible solutions and record how the emotional experience changes. We hope work like this will help bring the medical community closer to their customers.

486. **Measuring Arousal During Therapy for Children with Autism and ADHD**

Rosalind W. Picard, Elliott Hedman

Physiological arousal is an important part of occupational therapy for children with autism and ADHD, but therapists do not have a way to objectively measure how therapy affects arousal. We hypothesize that when children participate in guided activities within an occupational therapy setting, informative changes in electrodermal activity (EDA) can be detected using iCalm. iCalm is a small, wireless sensor that measures EDA and motion, worn on the wrist or above the ankle. Statistical analysis describing how equipment affects EDA was inconclusive, suggesting that many factors play a role in how a child's EDA changes. Case studies provided examples of how occupational therapy affected children's EDA. This is the first study of the effects of occupational therapy's in situ activities using continuous physiologic measures. The results suggest that careful case study analyses of the relation between therapeutic activities and physiological arousal may inform clinical practice.

487. **Mobile Health Interventions for Drug Addiction and PTSD**

Rosalind W. Picard, Richard R. Fletcher

We are developing a mobile phone-based platform to assist people with chronic diseases, panic-anxiety disorders, or addictions. Making use of wearable, wireless biosensors, the mobile phone uses pattern analysis and machine learning algorithms to detect specific physiological states and perform automatic interventions in the form of text/images plus sound files and social networking elements. We are currently working with the Veterans Administration drug rehabilitation program involving veterans with PTSD.

488. **Modulating Peripheral and Cortical Arousal Using a Musical Motor Response Task**

Rosalind W. Picard, Grace Leslie, Annabel Chen, Singapore University of Technology and Design, Nanyang Technological University, Simon Lui

We are conducting EEG studies to identify the musical features and musical interaction patterns that universally impact measures of arousal. We hypothesize that we can induce states of high and low arousal using electrodermal activity (EDA) biofeedback, and that these states will produce correlated differences in concurrently recorded skin conductance and EEG data, establishing a connection between peripherally recorded physiological arousal and cortical arousal as revealed in EEG. We also hypothesize that manipulation of musical features of a computer-generated musical stimulus track will produce changes in peripheral and cortical arousal. These musical stimuli and programmed interactions may be incorporated into music technology therapy, designed to reduce arousal or increase learning capability by increasing attention. We aim to provide a framework for the neural basis of emotion-cognition integration of learning that may shed light on education and possible applications to improve learning by emotion regulation.

489. **Onsite Stress Measurement**

Rosalind W. Picard, Judith Amores Fernandez, Marc Exposito Gomez, Szymon Fedor, Javier Hernandez, Daniel McDuff, Robert R. Morris

Occupational stress can be described as a harmful emotional and physical response that occurs when high demanding job conditions cannot be met by the resources of the worker. This type of stress is usually associated with feelings of frustration, anger, and fear and can lead to dissatisfaction and lack of motivation in the long-term. Furthermore, high levels of stress can impair decision making, decrease productivity, and lead to high amounts of accidents and job absenteeism. Despite the well-studied negative outcomes, workplace stress is still considered a necessary evil by many people as it helps us keep up with the pace of modern society. Leveraging state-of-the-art sensing technologies and AI, this project seeks to advance the measurement, understanding, and management of stress in real-life settings.

490. **Open-Source SPRING**

**Kristy Johnson
Open-Source Instructions for Building SPRING System**

491. **Panoply**

Rosalind W. Picard, Robert R. Morris

Panoply is a crowdsourcing application for mental health and emotional wellbeing. The platform offers a novel approach to computer-based psychotherapy, targeting accessibility without stigma, engagement, and therapeutic efficacy. A three-week randomized-controlled trial with 166 participants showed Panoply conferred greater or equal benefits for nearly every therapeutic outcome measure compared to an active control task (online expressive writing). Panoply significantly outperformed the control task also on all measures of engagement, and is now being commercialized at itskoko.com.

492. **Personalized Animated Movies**

Rosalind W. Picard, Fengjiao Peng

Storytelling is a fundamental way in which human beings understand the world. Imagine watching a movie telling the story of your life, how would you respond to it and how would it change your perception of your own memories? Personalized animated movies are generated from Unity, customized to each user's mood and behavior data collected through self-reports. Our study shows that personalized animations can elicit strong emotional responses from participants and lengthier writing of self-reflection compared to a non-personalized control. Moving forward, we're looking at using personalized animation to encourage cognitive reappraisal and positive thinking.

493. **Personalized Machine Learning for Autism Therapy**

Rosalind W. Picard, Ognjen (Oggi) Rudovic, Jaeryoung Lee, Miles Dai, Björn Schuller, Dalibor Veljkovic, Boris Milicevic
EngageME: Personalized machine learning and humanoid robots for measuring affect and engagement of children with autism

EngageME is a project aimed at building a new technology to enable automatic monitoring of affect and engagement of children with ASC (Autism Spectrum Conditions) in communication-centered activities.

This work has been published in Science Robotics, June 2018.

494. **Personalized Machine Learning for Future Health**

Rosalind W. Picard, Ognjen (Oggi) Rudovic

The view on Alzheimer's Disease (AD) diagnosis has shifted towards a more dynamic process in which clinical and pathological markers evolve gradually before diagnostic criteria are met. Given the wide variability in data available per subject, inherent per-person differences, and the slowly changing nature of the disease, accurate prediction of AD progression is a significant, difficult challenge. The goal of this project is to devise novel Personalized Machine Learning Models that can accurately capture future changes in the key biomarkers and cognitive scores related to AD and other neurological conditions. As the basis for our framework, we use the Alzheimer's Disease Neuroimaging Initiative (ADNI) dataset—the largest publicly available dataset for AD research. These data are highly heterogeneous and multi-modal, and include imaging (MRI, PET), cognitive scores, CSF biomarkers, genetics, and demographics (e.g. age, gender, race). The developed models are the break-through in machine learning for health-care as they allow personalized forecasting of the diseases' progression - in contrast to the traditional "one-size-fits-all" approaches. This capability is of great importance to both clinicians and those at risk of AD since it is critical to early identification of at-risk subjects, construction of informative clinical trials, and timely detection of AD.

495. **Physio FreeFall**

Rosalind W. Picard, Szymon Fedor, Natasha Jaques, Kristy Johnson, Sara Taylor

This project seeks to examine the effects of altered gravity on an individual's physiology during parabolic flight. Specifically, we will collect flight participants' heart rate, heart rate variability, breathing rate, skin temperature, and skin conductance measurements using wearable, wireless sensors in order to determine the response of these biosignals to zero/hyper/microgravity and feelings of nausea.

The results of this research will have both significant scientific and civilian value. To our knowledge, this experiment will be the first to investigate the new Multiple Arousal Theory in the context of motion sickness, as well as altered gravity. This theory was developed in the Affective Computing group at the MIT Media Lab and examines asymmetry in skin conductance signals from right and left wrists as differing metrics of emotional arousal and intensity. The parabolic flight configuration provides an inimitable circumstance to systematically analyze the evolution of these signals over the course of the repeated parabolic flight path. For example, we expect to see globally heightened stress and emotional arousal on the first pass, with maximal skin conductance peaks from both wrists just before the first moment of weightlessness. We expect these peaks to monotonically decrease over time with each pass, but to remain more elevated (relative to an individual's baseline) for participants experiencing more self-reported nausea during flight. For individuals not experiencing extreme nausea, we expect to see a much higher skin conductance signal from their right wrists compared to their left (for right-handed participants) during the first few passes, with this difference decreasing steadily as the participant habituates to the flight pattern and sensations.

Note that NASA and other researchers—including the Boston-local scientists at the Ashton Graybiel Spatial Orientation Lab at Brandeis University—have investigated spatial orientation and motion sickness, but they are just beginning to add the use of physiological sensors to their work. Not only does this demonstrate that the proposed experiment is at the forefront of scientific inquiry, but it also facilitates potential collaboration with world-renowned experts in the Boston area!

In addition to sensor data, we intend to collect pre- and post-flight surveys recording participant reactions to different levels of gravity, including points at which they experienced nausea or discomfort. Pre-flight surveys will include nausea sensitivity metrics, designed to determine how likely a person is to feel nausea (i.e., separating those who feel carsick on a drive through town versus those who approach rollercoasters without hesitation). It will also ask about each participant's feelings of anxiety, nausea, and excitement in anticipation of flying. Note that while these feelings may be experienced simultaneously, each one has a different effect on one's physiology.

After the flight, we will ask participants to rank which sections of the flight (e.g., beginning, middle, end) prompted the greatest sensations of anxiety, nausea, and excitement and to what degree. We will also annotate the flight video recordings to denote periods of high anxiety, nausea, or excitement.

Then, we will use the survey, annotation, and sensor information to build a model that predicts when an individual might experience distress in altered gravity environments. This aspect of the study will leverage our research group's unique expertise building machine learning algorithms for physiological data, but the results could have widespread impact. For example, such a system could be deployed to space travelers to help them monitor their physiology and anticipate or prevent feelings of discomfort during flight. As access to space travel becomes more pervasive, it is critical to understand the physiological effects of altered gravity on a population that does not solely include astronauts or specially trained individuals. Our models, along with the use of low-cost, commercially available sensors, would enable "space hacking" by tourists and other non-technical personnel, allowing them to measure and track their biosignals to achieve optimal wellness during space travel.

496. **Place Recognition and Categorization**

Agata Lapedriza Garcia, Bolei Zhou, Aditya Khosla, Aude Oliva, Antonio Torralba (CSAIL, MIT)

The Places dataset (website) is designed following principles of human visual cognition. Our goal is to build a core of visual knowledge that can be used to train artificial systems for high-level visual understanding tasks, such as scene context, object recognition, action and event prediction, emotion recognition, or theory-of-mind inference.

You can try our online demo.

497. **Predicting Bonding in Conversations**

Rosalind W. Picard, Natasha Jaques

We show that using thin slices (< 1 minute) of facial expression and body language data, we can train a deep neural network to predict whether two people in a conversation will bond with each other. Bonding is measured using the Bonding subscale of the Working Alliance Inventory. We show that participants who experience bonding perceive their conversational partner as interesting, charming, and friendly, and do not perceive them as distant or annoying.

The data are collected from a user study of naturalistic conversations, in which participants were asked to interact for 20 minutes, and were recorded using cameras, microphones, and Microsoft Kinects. To ensure participants did not become self-conscious of their non-verbal cues, they were told the purpose of the study was to train machine learning algorithms to read lips.

We show that not only can we accurately predict bonding from participants' personality, disposition, and traits, but that we can predict whether the participant will experience bonding up to 20 minutes later, using only one-minute thin slices of facial expression and body language data. This ability could be extremely useful to an intelligent virtual agent, because if it could detect at one-minute intervals whether it was bonding with its user, it could make course corrections to promote enjoyment and foster bonding. We provide an analysis of the facial expression and body language cues associated with higher bonding, and show how this information could be used by an agent to synthesize the appropriate non-verbal cues during conversation.

498. **Predicting Perceived Emotions in Animated GIFs with 3D Convolutional Neural Networks**

Rosalind W. Picard, Weixuan 'Vincent' Chen

Animated GIFs are widely used on the Internet to express emotions, but automatic analysis of their content is largely unexplored. To help with the search and recommendation of GIFs, we aim to predict how their emotions will be perceived by humans based on their content. Since previous solutions to this problem only utilize image-based features and lose all the motion information, we propose to use 3D convolutional neural networks (CNNs) to extract spatiotemporal features from GIFs. We evaluate our methodology on a crowdsourcing platform called GIFGIF with more than 6,000 animated GIFs, and achieve better accuracy than any previous approach in predicting crowdsourced intensity scores of 17 emotions. We have also found that our trained model can be used to distinguish and cluster emotions in terms of valence and risk perception.

499. **Predicting Students' Wellbeing from Physiology, Phone, Mobility, and Behavioral Data**

Rosalind W. Picard, Asaph Azaria, Asma Ghandeharioun, Natasha Jaques, Ehi Nosakhare, Akane Sano, Sara Taylor

The goal of this project is to apply machine learning methods to model the wellbeing of MIT undergraduate students. Extensive data is obtained from the SNAPSHOT study, which monitors participating students on a 24/7 basis, collecting data on their location, sleep schedule, phone and SMS communications, academics, social networks, and even physiological markers like skin conductance, skin temperature, and acceleration.

We extract features from this data and apply a variety of machine learning algorithms, including Gaussian mixture models and Multi-task Multi-Kernel Learning; we are currently working to apply Bayesian hierarchical multi-task learning and Deep Learning as well.

Interesting findings include: when participants visit novel locations they tend to be happier; when they use their phones or stay indoors for long periods they tend to be unhappy; and when several dimensions of wellbeing (including stress, happiness, health, and energy) are learned together, classification accuracy improves. The biggest classification accuracy improvements come when we use multi-tasking algorithms to leverage group data while customizing a model for each participant.

500. **QuantifyMe**

Rosalind W. Picard, Craig Ferguson, Akshay Mohan, Akane Sano, Sara Taylor

Unlike traditional randomized controlled trials that generalize relationships in large groups of people, single-case experiments seek to quantify an individual's reaction to an intervention by measuring an independent variable's effect on a dependent variable (i.e., an intervention's effect on an outcome behavior). These single-case experiments are then combined back together using Bayesian Statistics methods in order to learn more general patterns about a population. We are interested in single-case experiments that test the causal relationships between behaviors that have been observed to be correlated with higher wellbeing.

Thus, instead of using an RCT to find what works for the imaginary "average" person, we can learn what works for each individual and then carefully combine data to generalize the results to other real individuals.

To our knowledge, single-case experiments have not been implemented in a smartphone app format. We believe that a successful app will allow researchers to dramatically scale the number of participants in these studies.

Code available on GitHub!

501. **Real-Time Assessment of Suicidal Thoughts and Behaviors**

Rosalind W. Picard, Szymon Fedor, Massachusetts General Hospital, Harvard

Depression correlated with anxiety is one of the key factors leading to suicidal behavior, and is among the leading causes of death worldwide. Despite the scope and seriousness of suicidal thoughts and behaviors, we know surprisingly little about what suicidal thoughts look like in nature (e.g., How frequent, intense, and persistent are they among those who have them? What cognitive, affective/physiological, behavioral, and social factors trigger their occurrence?). The reason for this lack of information is that historically researchers have used retrospective self-report to measure suicidal thoughts, and have lacked the tools to measure them as they naturally occur. In this work we explore use of wearable devices and smartphones to identify behavioral, affective, and physiological predictors of suicidal thoughts and behaviors.

502. **SkinBot: A Wearable, Skin-Climbing Robot**

Joseph A. Paradiso, Artem Dementyev, Sean Follmer, Javier Hernandez, Inrak Choi

We introduce SkinBot: a lightweight robot that moves over the skin's surface with a two-legged suction-based locomotion mechanism and captures a wide range of body parameters with an exchangeable multipurpose sensing module. We believe that robots that live on our skin, such as SkinBot, will enable a more systematic study of the human body and offer great opportunities to advance our knowledge in many areas such as telemedicine, human-computer interfaces, body care, and fashion.

503. **SNAPSHOT Study**

Rosalind W. Picard, Weixuan 'Vincent' Chen, Asma Ghandeharioun, Natasha Jaques, Daniel Lopez Martinez, Ehi Nosakhare, Fengjiao Peng, Ognjen (Oggi) Rudovic, Akane Sano, Sara Taylor, Terumi Umematsu, Harvard Medical School, Brigham and Women's Hospital

The SNAPSHOT study seeks to measure Sleep, Networks, Affect, Performance, Stress, and Health using Objective Techniques. It is an NIH-funded collaborative research project between the Affective Computing and Collective Learning groups, and Harvard Medical School's Brigham & Women's hospital. Since fall 2013, we've run this study to collect one month of data every semester from 50 MIT undergraduate students who are socially connected. We have collected data from about 250 participants, totaling over 7,500 days of data. We measure physiological, behavioral, environmental, and social data using mobile phones, wearable sensors, surveys, and lab studies. We investigate how daily behaviors and social connectivity influence sleep behaviors and health, and outcomes such as mood, stress, and academic performance. Using this multimodal data, we are developing models to predict onsets of sadness and stress. This study will provide insights into behavioral choices for wellbeing and performance.

504. **SPRING: A Smart Platform for Research, Intervention, & Neurodevelopmental Growth**

Rosalind W. Picard, Kristy Johnson

SPRING is a custom-built hardware and software platform for children with neuro-differences. The system automates data acquisition, optimizes learning progressions, and encourages social, cognitive, and motor development in a positive, personalized, child-led play environment. The quantitative data and developmental trajectories captured by this platform enable systematic, multi-modal, long-term studies of different therapeutic and educational approaches to autism and other developmental disorders, as well as a better understanding of motivation, engagement, and learning for the general population.

505. **StoryScape**

Rosalind W. Picard, Micah Eckhardt, Craig Ferguson

Stories, language, and art are at the heart StoryScape. While StoryScape began as a tool to meet the challenging language learning needs of children diagnosed with autism, it has become much more. StoryScape was created to be the first truly open and customizable platform for creating animated, interactive storybooks that can interact with the physical world. Download the android app and make your own amazing stories at <https://storyscape.io>.

506. **The Challenge**

Pattie Maes, Rosalind W. Picard, Niaja Farve, Natasha Jaques

Mental wellbeing is intimately tied to both social support and physical activity. The Challenge is a tool aimed at promoting social connections and decreasing sedentary activity in a workplace environment. Our system asks participants to sign up for short physical challenges and pairs them with a partner to perform the activity. Social obligation and social consensus are leveraged to promote participation. Two experiments were conducted in which participants' overall activity levels were monitored with a fitness tracker. In the first study, we show that the system can improve users' physical activity, decrease sedentary time, and promote social connection. As part of the second study, we provide a detailed social network analysis of the participants, demonstrating that users' physical activity and participation depends strongly on their social community.

507. **The enTRAIN Study:
Physiological Synchrony in
Children with Autism**

Rosalind W. Picard, Kristy Johnson, Northeastern University

Individuals with autism are known to have difficulties connecting with other people, reciprocating social interactions, and being emotionally regulated by others. Yet, until recently, very little attention has been given to the way people interact together, in a system, rather than by themselves. We propose a new way to collect data on how caregivers and their children, with and without autism, affect and are affected by each other (i.e., how they "sync up" with one another), both in their behavior and in their physiology. We also introduce a customizable digital-physical smart toy platform that will allow us to test hypotheses and collect data about patterns of caregiver-child synchrony in a naturalistic and engaging environment. MIT and Northeastern are forging a new collaboration between smart toy technology and autism research that will help uncover how the social brain develops.

508. **The Guardians**

Rosalind W. Picard, Craig Ferguson, Fengjiao Peng, Sara Taylor

The Guardians Project aims to use the same game design principles used in mobile game platforms to create greater engagement with individuals. The Affective Computing group is developing a custom video game with an independent patient reporting outcome tool to increase adherence to completion of patient reported outcomes.

Forming positive health habits can be difficult. Whether it's taking medication, sticking to a diet, or going to the gym, it's tough to commit to a new schedule long enough to form a habit. It is even more difficult when a person is asked to do something regularly that does not directly and immediately benefit them. This is an issue when clinical researchers need study participants to report outcomes regularly over a long period of time. Adherence is lost, resulting in suboptimal clinical outcomes and the loss of important data.

Mobile video games, on the other hand, generate an increased amount of adherence (as seen by an estimated market revenue of over \$40.6 billion in 2016**). Mobile video games have captured the attention of a wide variety of demographics and are often targeted to specific subgroups in order to increase engagement with a number of in-game features. These games use common design techniques and mechanics to produce a loop that draws players to return on a regular schedule and encourages them to watch ads, share on social media, or pay a fee for special rewards within the game.

By using the same game design principles, we aim to replace typical video game behaviors, like watching ads or sharing on social, with new behaviors that help improve the player's wellbeing.

This project is a collaboration between the Affective Computing research group and Media Lab member company Takeda Pharmaceuticals.

**according to research by SuperData Research and Unity Technologies

509. **Traditional Chinese Medicine-
Inspired Pulse Analysis**

Rosalind W. Picard, Weixuan 'Vincent' Chen, Javier Hernandez, Akane Sano

This study aims to bring objective measurement to the multiple "pulse" and "pulse-like" measures made by practitioners of traditional Chinese medicine (TCM). The measurements are traditionally made by manually palpating the patient's inner wrist in multiple places, and relating the sensed responses to various medical conditions. Our project brings several new kinds of objective measurement to this practice, compares their efficacy, and examines the connection of the measured data to various other measures of health and stress. Our approach includes the possibility of building a smartwatch application that can analyze stress and health information from the point of view of TCM.

510. **Tributary**

Rosalind W. Picard, Yadid Ayzenberg

The proliferation of smartphones and wearable sensors is creating very large data sets that may contain useful information. However, the magnitude of generated data creates new challenges as well. Processing and analyzing these large data sets in an efficient manner requires computational tools. Many of the traditional analytics tools are not optimized for dealing with large datasets. Tributary is a parallel engine for searching and analyzing sensor data. The system utilizes large clusters of commodity machines to enable in-memory processing of sensor time-series signals, making it possible to search through billions of samples in seconds. Users can access a rich library of statistics and digital signal processing functions or write their own in a variety of languages.

511. **Understanding emotions in
multiple sclerosis patients**

Rosalind W. Picard, Daniel Lopez Martinez

More information coming soon.

512. **Valinor: Mathematical Models to
Understand and Predict Self-
Harm**

Rosalind W. Picard, Karthik Dinakar, Matthew Nock (Harvard), Eric Horvitz (Microsoft Research)

We are developing statistical tools for understanding, modeling, and predicting self-harm by using advanced probabilistic graphical models and fail-soft machine learning in collaboration with Harvard University and Microsoft Research.

513. **Wavelet-Based Motion Artifact Removal for Electrodermal Activity**

Rosalind W. Picard, Weixuan 'Vincent' Chen, Szymon Fedor, Natasha Jaques, Akane Sano, Sara Taylor

Electrodermal activity (EDA) recording is a powerful, widely used tool for monitoring psychological or physiological arousal. However, analysis of EDA is hampered by its sensitivity to motion artifacts. We propose a method for removing motion artifacts from EDA, measured as skin conductance (SC), using a stationary wavelet transform (SWT). We modeled the wavelet coefficients as a Gaussian mixture distribution corresponding to the underlying skin conductance level (SCL) and skin conductance responses (SCRs). The goodness-of-fit of the model was validated on ambulatory SC data. We evaluated the proposed method in comparison with three previous approaches. Our method achieved a greater reduction of artifacts while retaining motion-artifact-free data.

514. **WorldBeat: Hearing the World Differently**

Rosalind W. Picard, Asma Ghandeharioun, Alexander J Lynch, Media Lab UROP

Can we modulate the way we hear the world around us to make it more calming or to induce focus?

While technology is usually associated with causing stress, technology also has the potential to bring about calm. In particular, breathing usually speeds up with higher stress, but it can be slowed through a manipulation, and in so doing, it can help the person calm down. We are exploring a range of interventions to influence breathing without requiring any focused attention in order to be effective. In multiple projects, we have looked at dynamic composition of music, modulation of screen brightness, and headphone volume to create a seamless pulsating behavior, similar to breathing biofeedback, to indirectly influence breathing. Our preliminary analyses show promising results that such seamless modulation indeed have an influence on breathing rate and pattern.

In this project, we explore modulating insertion gain on a headphone in harmony with affective signals, particularly breathing rate. We study the influence of this dynamic change between "inside" and "outside" sources of sound to induce a sense of calmness. We experiment in simulated environments that resemble different situations such as a library, a busy street, and a fireplace.

We would like to thank Dan Gauger for giving us equipment and his thoughtful suggestions, including the project name. We would also like to thank Bose for making this project happen.

Iyad Rahwan: Scalable Cooperation

Reimagining human cooperation in the age of social media and artificial intelligence

515. **AI Ethics and Governance**

Iyad Rahwan, Tenzin Priyadarshi

This project will support social scientists, philosophers, and policy and legal scholars who undertake research that aims to impact how artificial intelligence technologies are designed, implemented, understood, and held accountable. It will also provide a platform to create, convene, and support a diverse and powerful network of people and institutions who are working to steer AI in ethically conscious directions, both in fields of specialized AI as well as general AI. The project will investigate the social implications of the maturation and proliferation of AI. It will help catalyze and support research that advances AI in the public interest and fund engineers who want to help define public interest in AI through the code they write and machines they build.

The initiative also organized a high-level symposium at the Media Lab on the topic that took place in April 2016 between the academic community and industry leaders working on AI.

516. **AI Spirits**

Matthew Groh

Media manipulation technologies have the power to vanish people from photographs. Yet their souls live on in the deep memory of these algorithms of omission.

517. **A Voting-Based System for Ethical Decision Making**

Iyad Rahwan, Edmond Awad, Sohan Dsouza, Neil Gaikwad, Joint work with Carnegie Mellon: Ritesh Noothigattu, Pradeep Ravikumar, Ariel D. Procaccia

The problem of ethical decision making presents a grand challenge for modern AI research. Arguably the main obstacle to automating ethical decisions is the lack of a formal specification of ground-truth ethical principles, which have been the subject of debate for centuries among philosophers (e.g., trolley problem). We present an algorithm to automate ethical decisions; using machine learning and computational social choice (new theory of swap-dominance efficient voting rules), we propose to learn a model of societal preferences, and, when faced with a specific ethical dilemma at runtime, efficiently aggregate those preferences to identify a desirable choice. Finally, we implement and evaluate a system for ethical decision making in the autonomous vehicle domain, using preference data collected from 1.3 million voters through the Moral Machine website. Our proof of concept shows that the decision the system takes is likely to be the same as if we could go to each of the 1.3 million voters, ask for their opinions, and then aggregate their opinions into a choice that satisfies mathematical notions of social justice.

518. **Cognitive Limits of Social Networks**

Iyad Rahwan, Lorenzo Coviello

There is a wide cultural belief in the power of the Internet and social media as enablers of collective intelligence. They help us spread information rapidly, and learn useful information from each other. But there are fundamental limits to the capabilities of those networks. Understanding these limits is essential to improving social media and allowing society to make the most of it.

519. **DARPA Shredder Challenge: Crowdsourcing Under Attack**

Iyad Rahwan, Manuel Cebrian

The Internet has unleashed the capacity for planetary-scale collective problem solving (also known as crowdsourcing). However, the very openness of crowdsourcing makes it vulnerable to sabotage by rogue or competitive actors. To explore the effect of errors and sabotage on the performance of crowdsourcing, we analyze data from the DARPA Shredder Challenge, a prize competition for exploring methods to reconstruct documents shredded by a variety of paper shredding techniques.

520. **DeepMoji**

Iyad Rahwan, Bjarke Felbo, Nick Obradovich, Alan Mislove, Anders Søgaard, Sune Lehmann, Holly Shablack, Kristen Lindquist, Max Lever

Emotional content is an important part of language. There are many use cases now showing that natural language processing is becoming an increasingly important part of consumer products. We are attempting to learn more about human emotions.

In his 2006 book *The Emotion Machine*, legendary computer scientist Marvin Minsky (co-founder of the field of Artificial Intelligence and one of the founding faculty members of the MIT Media Lab) wrote about the central role of emotions in reasoning—reminding us that AI will only be capable of true commonsense reasoning once it has understood emotions. To Minsky, emotions are not the opposite of rational reason, something to be weeded out before we can think clearly; rather, emotions are just a different way of thinking.

TRY DEEPMOJI HELP TEACH OUR AI ABOUT EMOTIONS

But this is hardly helpful to a computer scientist trying to construct an emotional machine by programming a concrete set of rules. If you ask two people to explain what makes a particular sentence happy, sad, serious, or sarcastic, you will likely get at least two different opinions. Much of what determines emotional content is context-specific, culturally constructed, and difficult to describe in an explicit set of rules.

521. **Ethics of Autonomous Vehicles**

Iyad Rahwan, Edmond Awad, Sohan Dsouza, Azim Shariff, Jean-François Bonnefon

Adoption of self-driving, Autonomous Vehicles (AVs) promises to dramatically reduce the number of traffic accidents, but some inevitable accidents will require AVs to choose the lesser of two evils, such as running over a pedestrian on the road or the sidewalk. Defining the algorithms to guide AVs confronted with such moral dilemmas is a challenge, and manufacturers and regulators will need psychologists to apply methods of experimental ethics to these situations.

522. **Evolution of the Social Contract**

Iyad Rahwan, Manuel Cebrian, Alex Rutherford, Yonatan Lupu, Brad LeVeck, Manuel Garcia-Herranz

Political constitutions describe the fundamental principles by which nation-states are governed, the political and legal state institutions, the powers, procedures, and duties of those institutions, and the rights and responsibilities of individuals. How do these constitutions develop over long periods of time? What is the interplay between colonial history and global, time varying trends in determining the characteristics of a country's constitution? We explore these questions using new techniques of computational social science.

523. **Future of Work: Automation, Labor & Cities**

Iyad Rahwan, Manuel Cebrian, Morgan Ryan Frank, Esteban Moro Egido, Alex Rutherford

As advances in robotics and artificial intelligence revive concerns about the impact of automation on jobs, a question looms: How will automation affect employment in different cities and economies? We use tools from complex systems and urban science to explore this question.

524. **Global Cooperation**

Iyad Rahwan, Morgan Ryan Frank, Nick Obradovich, Lijun Sun
Measuring Cooperation at Scale

525. **Honest Crowds**

Iyad Rahwan, Lorenzo Coviello, Morgan Ryan Frank, Lijun Sun, NICTA, Manuel Cebrian

The Honest Crowds project addresses shortcomings of traditional survey techniques in the modern information and big data age. Web survey platforms, such as Amazon's Mechanical Turk and CrowdFlower, bring together millions of surveys and millions of survey participants, which means paying a flat rate for each completed survey may lead to survey responses that lack desirable care and forethought. Rather than allowing survey takers to maximize their reward by completing as many surveys as possible, we demonstrate how strategic incentives can be used to actually reward information and honesty rather than just participation. The incentive structures that we propose provide scalable solutions for the new paradigm of survey and active data collection.

526. **Human-Machine Cooperation**

Iyad Rahwan

Since Alan Turing envisioned Artificial Intelligence (AI), a major driving force behind technical progress has been competition with human cognition (e.g. beating humans in Chess or Jeopardy!). Less attention has been given to developing autonomous machines that learn to cooperate with humans. Cooperation does not require sheer computational power, but relies on intuition, and pre-evolved dispositions toward cooperation, common-sense mechanisms that are difficult to encode in machines. We develop state-of-the-art machine-learning algorithms that cooperate with people and other machines at levels that rival human cooperation in two-player repeated games.

Scientific writings:

Jacob Crandall, Mayada Oudah, Tennom, Fatimah Ishowo-Oloko, Sherief Abdallah, Jean-François Bonnefon, Manuel Cebrian, Azim Shariff, Michael A. Goodrich, Iyad Rahwan. Cooperating with Machines. arXiv:1703.06207

527. **Identifying the Human Impacts of Climate Change**

Iyad Rahwan, Manuel Cebrian, Bjarke Felbo, Esteban Moro Egido, Nick Obradovich, Pinar Yanardag

Climate change is going to alter the environments that we depend on in myriad ways. We're using data to identify and quantify these potential human impacts.

528. **Moral Machine**

Edmond Awad, Sohan Dsouza, Iyad Rahwan, Azim Shariff, Jean-Francois Bonnefon

The Moral Machine is a platform for gathering a human perspective on moral decisions made by machine intelligence, such as self-driving cars. We generate moral dilemmas, where a driverless car must choose the lesser of two evils, such as killing two passengers or five pedestrians. As an outside observer, people judge which outcome they think is more acceptable. They can then see how their responses compare with other people. If they are feeling creative, people can also design their own scenarios, for others to view, share, and discuss.

Visit the Moral Machine.

529. **MyGoodness**

Iyad Rahwan, Edmond Awad, Zoe RahwanErez Yoeli

There are over one million registered charities in the United States alone, and many more worldwide. How do you choose among them?

MyGoodness is a simple game that helps you understand how you give. In the game, you will make 10 giving decisions. Each decision is between two choices, and you tell us which you prefer.

At the end of the game, we give you a summary of your 'goodness' and how it compares to others. You can share that feedback with whomever you would like.

530. **Nightmare Machine**

Iyad Rahwan, Manuel Cebrian, Nick Obradovich, Pinar Yanardag

For centuries, across geographies, religions, and cultures, people try to innovate ways of scaring each other. Creating a visceral emotion such as fear remains one of the cornerstones of human creativity. This challenge is especially important in a time when we wonder what the limits of Artificial Intelligence are: Can machines learn to scare us? Towards this goal, we present you Haunted Faces and Haunted Places: computer generated scary imagery powered by deep learning algorithms!

531. **Norman**

Iyad Rahwan, Manuel Cebrian, Pinar Yanardag

We present Norman, world's first psychopath AI. Norman was inspired by the fact that the data used to teach a machine learning algorithm can significantly influence its behavior. So when people say that AI algorithms can be biased and unfair, the culprit is often not the algorithm itself, but the biased data that was fed to it. The same method can see very different things in an image, even "sick" things, if trained on the wrong (or, the right!) data set. Norman suffered from extended exposure to the darkest corners of Reddit, and represents a case study on the dangers of artificial intelligence gone wrong when biased data is used in machine learning algorithms.

Norman is an AI that is trained to perform image captioning; a popular deep learning method of generating a textual description of an image. We trained Norman on image captions from an infamous subreddit (its name is redacted due to its graphic content) that is dedicated to documenting and observing the disturbing reality of death. Then, we compared Norman's responses with a standard image-captioning neural network (trained on MSCOCO dataset) on Rorschach inkblots—a test that is used to detect underlying thought disorders.

Visit norman-ai.mit.edu to explore what Norman sees!

532. **Opinion Aggregation**

Iyad Rahwan, Edmond Awad

Opinion aggregation on social media uses various mechanisms, such as "Likes" or thumbs-up/-down, which handle a single item at a time. In many domains (e.g., political discussion), we need to consider the relationships between different claims, and how they rebut one another through complex webs of arguments and counter-arguments. We study methods for aggregating opinions about such complex argument networks, the quality of the outcomes of different methods of opinion aggregation, and whether strategic agents can manipulate those outcomes.

533. **PlusMinus**

V. Michael Bove, Kevin Esvelt, Iyad Rahwan, Danielle Wood, Ethan Zuckerman, Hildreth England

Ride-sharing, social media, artificial intelligence. These are examples of socially-beneficial, net-positive technologies that have shown us the dark side of a move-fast, break-things ethos. In visible or invisible ways, these technologies have also had unexpectedly—and disproportionately—negative impacts on some of society's most vulnerable citizens.

PlusMinus provides both a structure for Media Lab researchers to work with members and other outside collaborators on impact and equity issues, and a force for changing our internal culture to bring these considerations more consciously into our design and evaluation processes. As part of the Media Lab's continuing investigation into complex, adaptive systems, PlusMinus is...

Equipping future technologists with the space, community, and skills to reflect on, critique, and inclusively design technologies for equitable, positive social impact before, during and after they're deployed.

Examining—in collaboration with member companies and sponsors—how to radically re-cast design processes both inside the Lab and outside it, to improve our collective understanding of the pluses and minuses of the technologies shaping our lives.

We envision a community of Pls, research staff, and students who concentrate their research on PlusMinus issues—exploring how the benefits of their research might be distributed equitably across society if projects were to be scaled up, how to evaluate ongoing research for early hints of possible trouble, and how to mitigate negative impacts should they appear.

534. **Promoting Cooperation through Peer Pressure**

Iyad Rahwan

Cooperation in a large society of self-interested individuals is notoriously difficult to achieve when the externality of one individual's action is spread thin and wide on the whole society (e.g., in the case of pollution). We introduce a new approach to achieving global cooperation by localizing externalities to one's peers in a social network, thus leveraging the power of peer-pressure to regulate behavior. Global cooperation becomes more like local cooperation.

535. **Shelley: Human-AI Collaborated Horror Stories**

Iyad Rahwan, Manuel Cebrian, Pinar Yanardag

Project website: shelley.ai

Human-AI collaborated stories: stories.shelley.ai

Follow @shelley_ai to collaborate with Shelley!

For centuries, across geographies, religions, and cultures, people have innovated ways of scaring each other. Creating a visceral emotion such as fear remains one of the cornerstones of human creativity. This challenge is especially important at a time when we are exploring the limits of artificial intelligence: Can machines learn to scare us?

In Halloween 2016 we presented the Nightmare Machine—computer-generated scary imagery powered by deep learning algorithms.

This Halloween, we present Shelley: Human-AI Collaborated Horror Stories!

Shelley is a deep-learning powered AI who was raised reading eerie stories coming from r/nosleep. Now, as an adult—and not unlike Mary Shelley, her Victorian idol—she takes a bit of inspiration in the form of a random seed, or a short snippet of text, and starts creating stories emanating from her creepy creative mind. But what Shelley truly enjoys is working collaboratively with humans, learning from their nightmarish ideas, creating the best scary tales ever. If you want to work with her, respond to the stories she'll start every hour on her Twitter account, and she will write with you the first AI-human horror anthology ever put together!

536. **Society-in-the-Loop**

Iyad Rahwan

Recent rapid advances in Artificial Intelligence (AI) and Machine Learning have raised many questions about the regulatory and governance mechanisms for autonomous machines. This is not about individual gadgets, but about complex, networked systems of humans and algorithms making decisions in business, government, and the media. We need conceptual frameworks for designing new governance architectures for these human-machine social systems. In doing so, it is helpful to learn lessons about human cooperation and governance from political philosophy and cultural anthropology. Read more [here](#).

537. **The Science of AI Research**

Iyad Rahwan, Manuel Cebrian, Morgan Ryan Frank, Dashun Wang (Kellogg School of Management, Northwestern University)

We must proactively tackle the economic, social, and societal implications that accompany the widespread deployment of AI technology. In service to this goal, examining the evolution of AI research itself could provide a valuable input into models of AI's impact (e.g., models of the future of work).

538. **TuringBox: Democratizing the study of AI**

Iyad Rahwan, Manuel Cebrian, Abhimanyu Dubey, Ziv Epstein, Bjarke Felbo, Matthew Groh, Nick Obradovich, Blakeley H. Payne, Judy Hanwen Shen

TuringBox is a platform that makes it easier for social and behavioral scientists to study Artificial Intelligence algorithms. It is a two-sided marketplace. On one side, AI contributors upload existing and novel algorithms to be studied scientifically by others, gaining reputation in their community as a result. They can also upload software that interacts with deployed AI systems that are already on the Internet. On the other side, AI examiners develop and post machine intelligence tasks to evaluate and characterize the behavior of AI algorithms, including novel questions of societal importance.

Ramesh Raskar: Camera Culture

Making the invisible visible—inside our bodies, around us, and beyond—for health, work, and connection

539. **6D Display**

Ramesh Raskar, Nikhil Naik

Is it possible to create passive displays that respond to changes in viewpoint and incident light conditions? Holograms and 4D displays respond to changes in viewpoint. 6D displays respond to changes in viewpoint as well as surrounding light. We encode the 6D reflectance field into an ordinary 2D film. These displays are completely passive and do not require any power. Applications include novel instruction manuals and mood lights.

540. **AnEye: Extending the Reach of Anterior Segment Ophthalmic Imaging**

Ramesh Raskar, Shantanu Sinha

Eye exams via a slit lamp are critical in early diagnosis of diseases such as cataracts, corneal injury, and pterygia, in order to avert vision loss. The slit lamp is one of the most versatile tools in an ophthalmologist's clinic, but is big, expensive, and is designed with specialized ophthalmic clinics in mind. AnEye is a suite of portable, computationally driven solutions that leverage modern optics and commercially available consumer electronics to extend the reach of examinations of the anterior segment of the eye well beyond large hospitals and clinics, into resource-constrained settings such as rural mass-screening camps, mobile ophthalmology clinics, and even primary care.

541. **Architecture Selection for Deep Neural Networks**

Otkrist Gupta

We introduce MetaQNN, a meta-modeling algorithm based on reinforcement learning to automatically generate high-performing CNN architectures for a given learning task. The learning agent is trained to sequentially choose CNN layers using Q-learning with an ϵ -greedy exploration strategy and experience replay. The agent explores a large but finite space of possible architectures and iteratively discovers designs with improved performance on the learning task. On image classification benchmarks, the agent-designed networks (consisting of only standard convolution, pooling, and fully-connected layers) beat existing networks designed with the same layer types and are competitive against the state-of-the-art methods that use more complex layer types. We also outperform existing meta-modeling approaches for network design on image classification tasks.

542. **Beyond the Self-Driving Car**

Ramesh Raskar, Barmak Heshmat Dehkordi, Gurmukh Bhasin

This concept gallery shows the chain of startups and ideas that will follow after the emergence of self-driving cars.

543. **Blind and Reference-Free Fluorescence Lifetime Estimation via Consumer Time-of-Flight Sensors**

Ramesh Raskar, Ayush Bhandari, Commonwealth School, Christopher Barsi

Fluorescence lifetime imaging is a significant bio-imaging tool that finds important applications in life-sciences. Widely known applications include cancer detection and DNA sequencing. To that end, fluorescence microscopy which is at the heart of bio-imaging is an electronically and optically sophisticated device which is prohibitively expensive. Our work demonstrates the fluorescence microscopy like functionality can be achieved by a simple, consumer sensor such as the Microsoft Kinect which costs about \$100. This is done by trading-off the precision in optics and electronics for sophistication in computational methods. Not only this allows for massive cost reduction but leads to several advances in the area. For example, our method is calibration-free in that we do not assume sample's relative placement with respect to the sensor. Furthermore, our work opens new pathways of interaction between bio-imaging, optics and computer vision communities.

544. **Calibration Invariant Imaging**

Ramesh Raskar, Otkrist Gupta, Barmak Heshmat Dehkordi, Guy Satat, Matthew Tancik

Object Classification through Scattering Media with Deep Learning

A method for classifying objects hidden behind a scattering layer with a neural network. Training on synthetic data with variations in calibration parameters allows the network to learn a model that doesn't require calibration during lab experiments.

Traditional techniques to see through scattering media rely on a physical model that needs to be precisely calibrated. Computationally overcoming the scattering relies heavily on accurately calibrated physical models. Thus, such systems are extremely sensitive to a precise and lengthy calibration process.

In this work we overcome this bottleneck by utilizing neural networks and their ability to learn models that are invariant to data transformation. In our case, the transformations are variations in the imaging system calibration parameters. To that end, we create a synthetic dataset that contains variations in all calibration parameters (we use a Monte Carlo forward model to render the measurements). The system is then tested on actual lab experiments without specific calibration or tuning.

545. **Coded Computational Photography**

Ramesh Raskar, Nikhil Naik

Computational photography is an emerging multi-disciplinary field at the intersection of optics, signal processing, computer graphics and vision, electronics, art, and online sharing in social networks. The first phase of computational photography was about building a super-camera that has enhanced performance in terms of the traditional parameters, such as dynamic range, field of view, or depth of field. We call this Epsilon Photography. The next phase of computational photography is building tools that go beyond the capabilities of this super-camera. We call this Coded Photography. We can code exposure, aperture, motion, wavelength, and illumination. By blocking light over time or space, we can preserve more details about the scene in the recorded single photograph.

546. **Computation Ear Imaging**

Anshuman Das

Computation photography applied to imaging the middle ear for infections.

547. **Distributed and collaborative learning**

Ramesh Raskar, Praneeth Vepakomma
Split Learning: Distributed deep learning without sharing raw data

Abstract: Can a server utilize deep learning models for training or inference without accessing raw data from clients? Split learning naturally allows for various configurations of cooperating entities to train (and infer from) machine learning models without sharing any raw data or detailed information about the model.

Key idea: In the simplest of configurations of split learning, each client (for example, radiology center) trains a partial deep network up to a specific layer known as the cut layer. The outputs at the cut layer are sent to another entity (server/another client) which completes the rest of the training without looking at raw data from any client that holds the raw data. This completes a round of forward propagation without sharing raw data. The gradients are now back propagated again from its last layer until the cut layer in a similar fashion. The gradients at the cut layer (and only these gradients) are sent back to radiology client centers. The rest of back propagation is now completed at the radiology client centers. This process is continued until the distributed split learning network is trained without looking at each others raw data.

Split Learning Papers:

- 1.) Split learning for health: Distributed deep learning without sharing raw patient data, Praneeth Vepakomma, Otkrist Gupta, Tristan Swedish, Ramesh Raskar, (PDF) (2018)
- 2.) "Distributed learning of deep neural network over multiple agents", Otkrist Gupta and Ramesh Raskar, In: Journal of Network and Computer Applications 116, (PDF) (2018)
- 3.) Survey paper: No Peek: A Survey of private distributed deep learning, Praneeth Vepakomma, Tristan Swedish, Ramesh Raskar, Otkrist Gupta, Abhimanyu Dubey, (PDF) (2018)

Split learning's computational and communication efficiency on clients:

Client-side communication costs are significantly reduced as the data to be transmitted is restricted to initial layers of the split learning network (splitNN) prior to the split. The client-side computation costs of learning the weights of the network are also significantly reduced for the same reason. In terms of model performance, the accuracies of Split NN remained competitive to other distributed deep learning methods like federated learning and large batch synchronous SGD with a drastically smaller client side computational burden when training on a larger number of clients as shown below in terms of teraflops of computation and gigabytes of communication when split learning is used to train Resnet and VGG architectures over 100 and 500 clients with CIFAR 10 and CIFAR 100 datasets.

Versatile plug-and-play configurations of split learning

Versatile configurations of split learning configurations cater to various practical settings of i) multiple entities holding different modalities of patient data, ii) centralized and local health entities collaborating on multiple tasks, iii) learning without sharing labels, iv) multi-task split learning, v) multi-hop split learning and other hybrid possibilities to name a few as shown below and further detailed in our paper here (PDF)

News stories about this work

MIT Technology Review

548. **Efficient Lensless Imaging with a Femto-Pixel**

Ramesh Raskar, Guy Satat, Matthew Tancik
Lensless Imaging with Compressive Ultrafast Sensing

Traditional cameras require a lens and a mega-pixel sensor to capture images. The lens focuses light from the scene onto the sensor. We demonstrate a new imaging method that is lensless and requires only a single pixel for imaging. Compared to previous single pixel cameras our system allows significantly faster and more efficient acquisition. This is achieved by using ultrafast time-resolved measurement with compressive sensing. The time-resolved sensing adds information to the measurement, thus fewer measurements are needed and the acquisition is faster. Lensless and single pixel imaging computationally resolves major constraints in imaging systems design. Notable applications include imaging in challenging parts of the spectrum (like infrared and THz), and in challenging environments where using a lens is problematic.

549. **Food sensing on smartphones**

Anshuman Das

We demonstrate a smartphone based spectrometer design that is standalone and supported on a wireless platform. The device is inherently low-cost and the power consumption is minimal making it portable to carry out a range of studies in the field. All essential components of the device like the light source, spectrometer, filters, microcontroller and wireless circuits have been assembled in a housing of dimensions 88 mm × 37 mm × 22 mm and the entire device weighs 48 g. The resolution of the spectrometer is 15 nm, delivering accurate and repeatable measurements. The device has a dedicated app interface on the smartphone to communicate, receive, plot and analyze spectral data. The performance of the smartphone spectrometer is comparable to existing bench-top spectrometers in terms of stability and wavelength resolution. Validations of the device were carried out by demonstrating non-destructive ripeness testing in fruit samples. Ultra-Violet (UV) fluorescence from Chlorophyll present in the skin was measured across various apple varieties during the ripening process and correlated with destructive firmness tests. A satisfactory agreement was observed between ripeness and fluorescence signals. This demonstration is a step towards possible consumer, bio-sensing and diagnostic applications that can be carried out in a rapid manner.

550. **Health-Tech Innovations with Tata Trusts, Mumbai**

Ramesh Raskar, Anshuman Das

We believe that tough global health problems require an innovation pipeline. We must bring together the people and providers facing health challenges to form what we call an innovation continuum: inventors building new low-cost technologies; developers capable of rapidly iterating on these inventions for use in the real world; clinicians and end users to validate our creations; and entrepreneurs, philanthropists, and development agencies to scale our solutions. We are asking big questions such as: What billion-dollar ideas could impact a billion lives in health, education, transportation through digital interfaces, digital opportunities, and applications for physical systems? Using machine learning, computer vision, Big Data, sensors, mobile technology, diagnostics, and crowdsourcing, we are conducting research at the Media Lab, and also collaborating with innovators in three centers in India and in other centers worldwide. Innovations like this launched the effort to create the Emerging Worlds initiative.

551. **High-Frequency LIDAR Using Beat Notes**

Ramesh Raskar, Achuta Kadambi

Time of Flight 3D cameras like the Microsoft Kinect are prevalent in computer vision and computer graphics. In such devices, the power of an integrated laser is amplitude modulated at megahertz (MHz) frequencies and demodulated using a specialized imaging sensor to obtain sub-cm range precision. To use a similar architecture and obtain micron range precision, this paper incorporates beat notes. To bring telecommunications ideas to correlation ToF imaging, we study a form of "cascaded Time of Flight" that uses a Hertz-scale intermediate frequency to encode high-frequency pathlength information. We show synthetically and experimentally that a bulk implementation of opto-electronic mixers offers: (a) robustness to environmental vibrations; (b) programmability; and (c) stability in frequency tones. A fiberoptic prototype is constructed, which demonstrates 3 micron range precision over a range of 2 meters. A key contribution of this paper is to study and evaluate the proposed architecture for use in machine vision.

552. **Hyderabad Eye Health Collaboration with LVP**

Ramesh Raskar, Anshuman Das

We believe that tough global health problems require an innovation pipeline. We must bring together the people and providers facing health challenges to form what we call an innovation continuum: inventors building new low-cost technologies; developers capable of rapidly iterating on these inventions for use in the real world; clinicians and end users to validate our creations; and entrepreneurs, philanthropists, and development agencies to scale our solutions. We are asking big questions such as: What billion-dollar ideas could impact a billion lives in health, education, transportation through digital interfaces, digital opportunities, and applications for physical systems? Using machine learning, computer vision, Big Data, sensors, mobile technology, diagnostics, and crowdsourcing, we are conducting research at the Media Lab, and also collaborating with innovators in three centers in India and in other centers worldwide. Innovations like this launched the effort to create the Emerging Worlds initiative.

553. **Identi-Wheez: A Device for In-home Diagnosis of Asthma**

Ramesh Raskar, Nikhil Naik, Guy Satat

Asthma is the most common chronic illness among children. The skills required to diagnose it make it an even greater concern. Our solution is a child-friendly wearable device that allows in-home diagnosis of asthma. The device acquires simultaneous measurements from multiple stethoscopes. The recordings are then sent to a specialist who uses assistive diagnosis algorithms that enable auscultation (listening to lung sounds with a stethoscope). Sound refocusing algorithms enable the specialist to listen to any location in the lungs. The specialist also has access to a sound "heat map" that shows the location of sound sources in the lungs.

554. **Imaging Behind Diffusive Layers**

Ramesh Raskar, Barmak Heshmat Dehkordi

Locating and classifying fluorescent tags behind turbid layers using time-resolved inversion

Using time resolved and sparse optimization framework to locate and classify fluorescent markers hidden behind turbid layer: The use of fluorescent probes and the recovery of their lifetimes allow for significant advances in many imaging systems, in particular medical imaging systems. Here, we propose and experimentally demonstrate reconstructing the locations and lifetimes of fluorescent markers hidden behind a turbid layer. This opens the door to various applications for non-invasive diagnosis, analysis, flowmetry, and inspection. The method is based on a time-resolved measurement which captures information about both fluorescence lifetime and spatial position of the probes. To reconstruct the scene, the method relies on a sparse optimization framework to invert time-resolved measurements. This wide-angle technique does not rely on coherence, and does not require the probes to be directly in line of sight of the camera, making it potentially suitable for long-range imaging.

More details:

http://web.media.mit.edu/~guysatat/project_scattering.html

<http://web.media.mit.edu/~guysatat/fl/>

555. **Imaging through Scattering Media Using Femtophotography**

Ramesh Raskar, Nikhil Naik

We use time-resolved information in an iterative optimization algorithm to recover reflectance of a three-dimensional scene hidden behind a diffuser. We demonstrate reconstruction of large images without relying on knowledge of diffuser properties.

556. **Imaging with All Photons**

Ramesh Raskar, Barmak Heshmat Dehkordi, Guy Satat

How to see through tissue

We demonstrate a new method to image through scattering materials like tissue and fog. The demonstration includes imaging an object hidden behind 1.5cm of tissue; it's like imaging through the palm of a hand. Our optical method is based on measuring and using all photons in the signal (as opposed to traditional methods, which use only part of the signal). Specifically, we use a time-resolved method that allows us to distinguish between photons that travel different paths in the tissue. Combining this unique measurement process with novel algorithms allows us to recover the hidden objects. This technique can be used in biomedical imaging, as well as imaging through fog and clouds.

557. **Inverse Problems in Time-of-Flight Imaging**

Ramesh Raskar, Ayush Bhandari, Achuta Kadambi

We are exploring mathematical modeling of time-of-flight imaging problems and solutions.

558. **LensChat: Sharing Photos with Strangers**

Ramesh Raskar, Nikhil Naik, Wei-Chao Chen

With networked cameras in everyone's pockets, we are exploring the practical and creative possibilities of public imaging. LensChat allows cameras to communicate with each other using trusted optical communications, allowing users to share photos with a friend by taking pictures of each other, or borrow the perspective and abilities of many cameras.

559. **Looking Around Corners**

Ramesh Raskar, Ayush Bhandari, Micha Feigin-Almon, Otkrist Gupta, Achuta Kadambi, Nikhil Naik, Andreas Velten (Morgridge Institute for Research), Thomas Willwacher (Harvard University), Mouni Bawendi (MIT Department of Chemistry)

Using a femtosecond laser and a camera with a time resolution of about one trillion frames per second, we recover objects hidden out of sight. We measure speed-of-light timing information of light scattered by the hidden objects via diffuse surfaces in the scene. The object data are mixed up and are difficult to decode using traditional cameras. We combine this "time-resolved" information with novel reconstruction algorithms to untangle image information and demonstrate the ability to look around corners.

560. **Nashik Smart Citizen Collaboration with TCS**

Ramesh Raskar, Anshuman Das

We believe that tough global health problems require an innovation pipeline. We must bring together the people and providers facing health challenges to form what we call an innovation continuum: inventors building new low-cost technologies; developers capable of rapidly iterating on these inventions for use in the real world; clinicians and end users to validate our creations; and entrepreneurs, philanthropists, and development agencies to scale our solutions. We are asking big questions such as: What billion-dollar ideas could impact a billion lives in health, education, transportation through digital interfaces, digital opportunities, and applications for physical systems? Using machine learning, computer vision, Big Data, sensors, mobile technology, diagnostics, and crowdsourcing, we are conducting research at the Media Lab, and also collaborating with innovators in three centers in India and in other centers worldwide. Innovations like this launched the effort to create the Emerging Worlds initiative.

561. **NETRA: Smartphone Add-On for Eye Tests**
Ramesh Raskar, Nikhil Naik
Can a person look at a portable display, click on a few buttons, and recover his or her refractive condition? Our optometry solution combines inexpensive optical elements and interactive software components to create a new optometry device suitable for developing countries. The technology allows for early, extremely low-cost, mobile, fast, and automated diagnosis of the most common refractive eye disorders: myopia (nearsightedness), hypermetropia (farsightedness), astigmatism, and presbyopia (age-related visual impairment). The patient overlaps lines in up to eight meridians, and the Android app computes the prescription. The average accuracy is comparable to the traditional method -- and in some cases, even better. We propose the use of our technology as a self-evaluation tool for use in homes, schools, and at health centers in developing countries, and in places where an optometrist is not available or is too expensive.
562. **New Methods in Time-of-Flight Imaging**
Ramesh Raskar, Ayush Bhandari, Anshuman Das, Micha Feigin-Almon, Achuta Kadambi
Time-of-flight (ToF) cameras are commercialized consumer cameras that provide a depth map of a scene, with many applications in computer vision and quality assurance. Currently, we are exploring novel ways of integrating the camera illumination and detection circuits with computational methods to handle challenging environments, including multiple scattering and fluorescence emission.
563. **Optical Brush: Enabling Deformable Imaging Interfaces**
Ramesh Raskar, Barmak Heshmat Dehkordi
Our deformable camera exploits new, flexible form factors for imaging in turbid media. In this study we enable a brush-like form factor with a time-of-flight camera. This has enabled us to reconstruct images through a set of 1100 optical fibers that are randomly distributed and permuted in a medium.
564. **PhotoCloud: Personal to Shared Moments with Angled Graphs of Pictures**
Ramesh Raskar, Otkrist Gupta, Nikhil Naik
We present a near-real-time system for interactively exploring a collectively captured moment without explicit 3D reconstruction. Our system favors immediacy and local coherency to global consistency. It is common to represent photos as vertices of a weighted graph. The weighted angled graphs of photos used in this work can be regarded as the result of discretizing the Riemannian geometry of the high dimensional manifold of all possible photos. Ultimately, our system enables everyday people to take advantage of each others' perspectives in order to create on-the-spot spatiotemporal visual experiences similar to the popular bullet-time sequence. We believe that this type of application will greatly enhance shared human experiences, spanning from events as personal as parents watching their children's football game to highly publicized red-carpet galas.
565. **Portable Retinal Imaging**
Ramesh Raskar, Everett Lawson, Nikhil Naik, Alex Olwal, Gordon Wetzstein
The major challenge in preventing blindness is identifying patients and bringing them to specialty care. Diseases that affect the retina, the image sensor in the human eye, are particularly challenging to address, because they require highly trained eye specialists (ophthalmologists) who use expensive equipment to visualize the inner parts of the eye. Diabetic retinopathy, HIV/AIDS-related retinitis, and age-related macular degeneration are three conditions that can be screened and diagnosed to prevent blindness caused by damage to retina. We exploit a combination of two novel ideas to simplify the constraints of traditional devices, with simplified optics and clever illumination in order to capture and visualize images of the retina in a standalone device easily operated by the user. Prototypes are conveniently embedded in either a mobile hand-held retinal camera, or wearable eyeglasses.
566. **Reading Through a Closed Book**
Barmak Heshmat Dehkordi
Terahertz time-gated spectral imaging for content extraction through layered structures.
567. **Reflectance Acquisition Using Ultrafast Imaging**
Ramesh Raskar, Nikhil Naik
We demonstrate a new technique that allows a camera to rapidly acquire reflectance properties of objects "in the wild" from a single viewpoint, over relatively long distances and without encircling equipment. This project has a wide variety of applications in computer graphics, including image relighting, material identification, and image editing.
568. **Second Skin: Motion Capture with Actuated Feedback for Motor Learning**
Ramesh Raskar, Nikhil Naik
We have created a 3D motion-tracking system with automatic, real-time vibrotactile feedback and an assembly of photo-sensors, infrared projector pairs, vibration motors, and a wearable suit. This system allows us to enhance and quicken the motor learning process in a variety of fields such as healthcare (physiotherapy), entertainment (dance), and sports (martial arts).

569. **Seeing Through Realistic Fog**

Ramesh Raskar, Guy Satat, Matthew Tancik

Seeing through dense, dynamic, and heterogeneous fog conditions. The technique, based on visible light, uses hardware that is similar to LIDAR to recover the target depth and reflectance.

The system relies on ultrafast measurements, used to computationally remove inclement weather conditions such as fog, and produce a photo and depth map as if the fog weren't there (with contrast improved by 6.5x in dense fog conditions).

Applications

Autonomous and augmented driving in challenging weather.

Airplanes and helicopters take off, landing and low level flight in dense fog conditions.

Trains traveling at normal speeds during inclement weather conditions.

570. **Shield Field Imaging**

Ramesh Raskar, Nikhil Naik

We present a new method for scanning 3D objects through a single-shot, shadow-based method. We decouple 3D occluders from 4D illumination using shield fields: the 4D attenuation function which acts on any light field incident on an occluder. We then analyze occluder reconstruction from cast shadows, leading to a single-shot light-field camera for visual hull reconstruction.

571. **Single Lens Off-Chip Cellphone Microscopy**

Ramesh Raskar, Nikhil Naik

Within the last few years, cellphone subscriptions have spread widely and now cover even the remotest parts of the planet. Adequate access to healthcare, however, is not widely available, especially in developing countries. We propose a new approach to converting cellphones into low-cost scientific devices for microscopy. Cellphone microscopes have the potential to revolutionize health-related screening and analysis for a variety of applications, including blood and water tests. Our optical system is more flexible than previously proposed mobile microscopes, and allows for wide field-of-view panoramic imaging, the acquisition of parallax, and coded background illumination, which optically enhances the contrast of transparent and refractive specimens.

572. **Single-Photon Sensitive Ultrafast Imaging**

Ramesh Raskar, Barmak Heshmat Dehkordi

The ability to record images with extreme temporal resolution enables a diverse range of applications, such as time-of-flight depth imaging and characterization of ultrafast processes. Here we present a demonstration of the potential of single-photon detector arrays for visualization and rapid characterization of events evolving on picosecond time scales. The single-photon sensitivity, temporal resolution, and full-field imaging capability enables the observation of light-in-flight in air, as well as the measurement of laser-induced plasma formation and dynamics in its natural environment. The extreme sensitivity and short acquisition times pave the way for real-time imaging of ultrafast processes or visualization and tracking of objects hidden from view.

573. **Skin Perfusion Photography**

Ramesh Raskar, Guy Satat

Skin and tissue perfusion measurements are important parameters for diagnosis of wounds and burns, and for monitoring plastic and reconstructive surgeries. In this project, we use a standard camera and a laser source in order to image blood-flow speed in skin tissue. We show results of blood-flow maps of hands, arms, and fingers. We combine the complex scattering of laser light from blood with computational techniques found in computer science.

574. **Smartphone spectrometer for food sensing**

Ramesh Raskar, Anshuman Das

A smartphone based spectrometer design that is standalone and supported on a wireless platform. The device is low-cost and the power consumption is minimal making it portable to perform a range of studies in the field. Essential components of the device like the light source, spectrometer, filters, microcontroller and wireless circuits have been assembled in a housing that fits into a pocket and the entire device weighs 48 g. The device has a dedicated app on the smartphone to communicate, receive, plot and analyze spectral data. Validations of the device were carried out by demonstrating non-destructive ripeness testing in fruits. Ultra-Violet fluorescence from Chlorophyll present in the skin was measured across various apple varieties during the ripening process and correlated with destructive firmness tests. This demonstration is a step towards possible consumer, bio-sensing and diagnostic applications that can be carried out in a rapid manner.

575. **Streetchange**

Cesar A. Hidalgo, Ramesh Raskar, Nikhil Naik

Computer vision uncovers predictors of physical urban change

576. **StreetScore**
- Cesar A. Hidalgo, Ramesh Raskar, Nikhil Naik, Jade Philipoom**
- StreetScore is a machine learning algorithm that predicts the perceived safety of a streetscape. StreetScore was trained using 2,920 images of streetscapes from New York and Boston and their rankings for perceived safety obtained from a crowdsourced survey. To predict an image's score, StreetScore decomposes this image into features and assigns the image a score based on the associations between features and scores learned from the training dataset. We use StreetScore to create a collection of map visualizations of perceived safety of street views from cities in the United States. StreetScore allows us to scale up the evaluation of streetscapes by several orders of magnitude when compared to a crowdsourced survey. StreetScore can empower research groups working on connecting urban perception with social and economic outcomes by providing high-resolution data on urban perception.
577. **The Next 30 Years of VR**
- Ramesh Raskar, Barmak Heshmat Dehkordi**
- In this visual brainstorming, we present the next 30 years of VR in a set of concept designs.
578. **Theory Unifying Ray and Wavefront Lightfield Propagation**
- Ramesh Raskar, Nikhil Naik, Tom Cuypers, George Barbastathis, Se Baek Oh**
- This work focuses on bringing powerful concepts from wave optics to the creation of new algorithms and applications for computer vision and graphics. Specifically, ray-based, 4D lightfield representation, based on simple 3D geometric principles, has led to a range of new applications that include digital refocusing, depth estimation, synthetic aperture, and glare reduction within a camera or using an array of cameras. The lightfield representation, however, is inadequate to describe interactions with diffractive or phase-sensitive optical elements. Therefore we use Fourier optics principles to represent wavefronts with additional phase information. We introduce a key modification to the ray-based model to support modeling of wave phenomena. The two key ideas are "negative radiance" and a "virtual light projector." This involves exploiting higher dimensional representation of light transport.
579. **Time-folded optics**
- Ramesh Raskar, Barmak Heshmat Dehkordi, Guy Satat**
Rethinking photography optics in the time dimension
- What if we could design optics in time instead of space?
580. **Time-of-Flight Microwave Camera**
- Ramesh Raskar, Micha Feigin-Almon, Nikhil Naik, Andrew Temme, Gregory Charvat**
- Our architecture takes a hybrid approach to microwaves and treats them like waves of light. Most other work places antennas in a 2D arrangement to directly sample the RF reflections that return. Instead of placing antennas in a 2D arrangement, we use a single, passive, parabolic reflector (dish) as a lens. Think of every point on that dish as an antenna with a fixed phase-offset. This means that the lens acts as a fixed set of 2D antennas which are very dense and spaced across a large aperture. We then sample the focal-plane of that lens. This architecture makes it possible for us to capture higher resolution images at a lower cost.
581. **Towards In-Vivo Biopsy**
- Ramesh Raskar, Barmak Heshmat Dehkordi, Guy Satat**
- A new method to detect and distinguish between different types of fluorescent materials. The suggested technique has provided a dramatically larger depth range compared to previous methods; thus it enables medical diagnosis of body tissues without removing the tissue from the body, which is the current medical standard. It uses fluorescent probes, which are commonly used in medical diagnosis. One of these parameters is the fluorescence lifetime, that is the average time the fluorescence emission lasts. The new method can distinguish between different fluorescence lifetimes, which allows diagnosis of deep tissues. Locating fluorescence probes in the body using this method can, for example, indicate the location of a tumor in deep tissue, and classify it as malignant or benign according to the fluorescence lifetime, thus eliminating the need for X-ray or biopsy.
582. **Trillion Frames Per Second Camera**
- Ramesh Raskar, MIT Department of Chemistry, Mounqi Bawendi**
- We have developed a camera system that captures movies at an effective rate of approximately one trillion frames per second. In one frame of our movie, light moves only about 0.6 mm. We can observe pulses of light as they propagate through a scene. We use this information to understand how light propagation affects image formation and to learn things about a scene that are invisible to a regular camera.
583. **Ultrasound Tomography**
- Ramesh Raskar, Micha Feigin-Almon, Nikhil Naik, Brian Anthony**
- Traditional medical ultrasound assumes that we are imaging ideal liquids. We are interested in imaging muscle and bone as well as measuring elastic properties of tissues, all of which are places where this assumption fails quite miserably. Interested in cancer detections, Duchenne muscular dystrophy, and prosthetic fitting, we use tomographic techniques as well as ideas from seismic imaging to deal with these issues.

584. **Unbounded High Dynamic Range Photography Using a Modulo Camera**

Ramesh Raskar, Nikhil Naik, Boxin Shi, Hang Zhao, Sai-Kit Yeung, Christy Fernandez-Cull

We present a novel framework to extend the dynamic range of images called Unbounded High Dynamic Range (UHDR) photography with a modulo camera. A modulo camera could theoretically take unbounded radiance levels by keeping only the least significant bits. We show that with limited bit depth, very high radiance levels can be recovered from a single modulus image with our newly proposed unwrapping algorithm for natural images. We can also obtain an HDR image with details equally well preserved for all radiance levels by merging the least number of modulus images. Synthetic experiments and experiments with a real modulo camera show the effectiveness of the proposed approach.

585. **VisionBlocks**

Ramesh Raskar, Nikhil Naik

VisionBlocks is an on-demand, in-browser, customizable, computer-vision application-building platform for the masses. Even without any prior programming experience, users can create and share computer vision applications. End-users drag and drop computer vision processing blocks to create their apps. The input feed could be either from a user's webcam or a video from the Internet. VisionBlocks is a community effort where researchers obtain fast feedback, developers monetize their vision applications, and consumers can use state-of-the-art computer vision techniques. We envision a Vision-as-a-Service (VaaS) over-the-web model, with easy-to-use interfaces for application creation for everyone.

Mitchel Resnick: Lifelong Kindergarten

Engaging people in creative learning experiences

586. **Agent-based Programming Interfaces for Children**

Tina Quach, Andrew Sliwinski

A conversational, voice-based interface for creating and playing Scratch projects makes Scratch accessible to children regardless of visual ability. Just as Scratch's visual language lowers the barrier to entry for sighted children, the conversational interface lowers the barrier for children with visual impairments. The screenless interface is inspired by voice assistants and demonstrates the potential for programming through conversation.

587. **Bricoleur**

Sean Hickey

Bricoleur allows makers of all ages to explore the creative possibilities of video and audio as programmable media on mobile devices. Using hand-drawn gestures and a Scratch Blocks-based interface, makers can quickly create complex interactive stories, animations, and artworks by capturing and programming images and sounds from the world around them.

588. **Clubhouse Teen Summit**

Mitchel Resnick, Natalie Rusk, Jaleesa Trapp, The Clubhouse Network

Teen Summit is a biennial week-long Youth Leadership event that brings Clubhouse youth together from each of the 100 Clubhouses internationally. Youth leaders explore issues relevant to them and propose solutions through the creative use of innovative, high-end technologies. The 2018 Teen Summit will take place in late July at Boston University, featuring a college and career fair, collaborative cross-cultural activities, and many other opportunities for educational, career, and personal growth.

589. **Computational Tinkering**

Mitchel Resnick, Carmelo Presicce, Natalie Rusk

As children tinker with materials in the world, they are constantly putting things together and taking them apart. They are learning through play — trying out new ideas, exploring alternate paths, making adjustments, imagining new possibilities, expressing themselves creatively. In the process, they learn about the creative process and develop as creative thinkers.

As digital technologies enter the lives of children, there is risk that they will crowd out tinkering, with children spending more time watching screens than tinkering with materials. Yet, in our work, we have seen how digital technologies can also be used to open up new opportunities for tinkering.

Working in collaboration with the Tinkering Studio at the Exploratorium, Fondazione Reggio Children and the LEGO Foundation, we are developing a new generation of tools, activities, and spaces to support playful investigation and experimentation, integrating digital and physical materials.

The new activities will enable children to engage in new types of inquiry into light, sound, motion, and storytelling. In the initial set of activities, called "light play," children can program colored lights and moving objects to make dynamic patterns of shadows.

590. **Creative Learning Africa**

Yusuf Ahmad, Marian Muthui,

The Lifelong Kindergarten group develops technologies and activities that engage people in creative learning. We're exploring a few directions with our work in Africa:

1. Supporting creative learning across contexts

Instruction-focused learning and an emphasis on narrow outcomes continue to dominate formal and informal environments. As school systems seek to adapt to changes in technology, we're exploring ways to support school systems, educators, and informal learning organizations in reconstructing outcomes and pedagogy that better prepare young people for lifelong, creative learning.

2. Creative Learning Communities

We're exploring two kinds of communities in particular: (a) a maker-focused community that connects makers with employers while helping makers document and translate their skills to professional contexts and (b) supporting the development of creative learning communities—connecting individuals and organizations working to support creative learning in formal and informal learning environments.

Building on the work of Aprendizagem Criativa no Brasil (Creative Learning in Brazil—a decentralized network of educators, designers, systems leaders, foundations, and companies all involved in or hoping to support creative learning) and other initiatives, we hope to first gather stories of educators across a range of contexts, connect them with one another (including at the 2019 Africa Scratch conference), support co-development of resources, and hopefully engage in movement building.

3. Creative vocational learning

Vocational, 21st-century skills trainings are in high demand across the world—and especially in areas with high unemployment. Trainings tend to be dominated by traditional instruction and often limited to a particular set of skills. Moreover, while some of these trainings might help a student get a specific job or progress on a particular skill, they don't prepare students for lifelong, creative learning—and the world that students will be entering.

In this environment, we're exploring how to bring creative learning principles to the design and facilitation of "vocational trainings"—with the aspiration to create a model for more open-ended, playful, passionate, and peer-driven vocational learning that provides a springboard for lifelong learning.

We're piloting this work with the Mekatilili Initiative in Nairobi, Kenya.

591. **Creative Learning in Brazil /
Aprendizagem Criativa no Brasil**

Mitchel Resnick, Leo Burd

The Lemann Creative Learning Program is a collaboration between the MIT Media Lab and the Lemann Foundation to foster creative learning in Brazilian public education.

Established in February 2015, the program designs new technologies, support materials, and innovative initiatives to engage Brazilian public schools, afterschool centers, and families in learning practices that are more hands-on, creative, and centered on students' interests and ideas.

O Programa Lemann de Aprendizagem Criativa é uma colaboração entre o MIT Media Lab e a Fundação Lemann visando incentivar a aprendizagem criativa na educação pública do Brasil.

Criado em fevereiro de 2015, o programa cria novas tecnologias, materiais de apoio e iniciativas que ajudem escolas públicas, organizações de educação não formal, e famílias a implementar práticas de aprendizagem que sejam mais mão na massa, criativas e centradas nos interesses dos alunos.

592. **Desafio Aprendizagem Criativa Brasil 2019**

Mitchel Resnick, Leo Burd

ATENÇÃO: Saiu o resultado do Desafio Aprendizagem Criativa Brasil 2019! Clique aqui para conhecer os fellows e os projetos selecionados!

O Desafio Aprendizagem Criativa Brasil visa fomentar a implementação de soluções inovadoras que ajudem a tornar a educação brasileira mais criativa, prazerosa, relevante, colaborativa e inclusiva para crianças e jovens de todo o país.

Organizado pela Rede Brasileira de Aprendizagem Criativa, e contando com o apoio da Fundação Lemann e do MIT Media Lab, o Desafio também tem como objetivo identificar, conectar e apoiar indivíduos brasileiros – artistas, pesquisadores, educadores, desenvolvedores de tecnologia, empreendedores e tomadores de decisão – que possam ter um papel-chave no avanço de práticas de aprendizagem criativa em escolas públicas (do Ensino Fundamental ao Ensino Médio) e ambientes de aprendizagem não formais de todo o Brasil.

Os representantes dos projetos selecionados ganharão uma Creative Learning Fellowship para ajudar a implementar seu trabalho.

As inscrições vão até o dia 13 de janeiro de 2019 e devem ser feitas única e exclusivamente através do formulário abaixo.

Clique aqui para a chamada de projetos completa.

Clique aqui para o formulário de inscrição.

Clique aqui para respostas às perguntas mais frequentes.

Atenção: esta página será atualizada periodicamente com mais informações sobre o Desafio.

Discussões sobre o edital estão ocorrendo no fórum da Rede Brasileira de Aprendizagem Criativa.

593. **Duct Tape Network**

Leo Burd, Alisha Panjwani, Rachel Garber

The Duct Tape Network (DTN) is a series of fun, hands-on maker clubs that encourage young children (ages 7-10) to use cardboard, tape, wood, fabric, LED lights, motors, and more to bring their stories and inventions to life. We are designing an educational framework and toolkit to engage kids in the creation of things that they care about before they lose their curiosity or get pulled in by more consumer-oriented technology. Work on DTN started in 2014 as part of a collaboration with Autodesk and is now expanding to communities all around the world.

594. **Festival of Invention and Creativity**

Leo Burd

The Festival of Invention and Creativity (FIC) is a great celebration of the inventive, collaborative, and hands-on spirit of Brazilian education. In it, children, young people, their families and educators have opportunity to explore high and low tech tools and materials, participate in interactive workshops and learn in a stimulating and relaxed way.

The Festival aims to disseminate, inspire and facilitate the implementation of creative learning activities in schools and non-formal educational environments.

In 2018, the Brazilian Creative Learning Network, with support from the MIT Media Lab and the Lemann Foundation, facilitated the organization of more than 15 regional Festivals throughout the country.

O Festival de Invenção e Criatividade (FIC) é uma grande celebração do espírito inventivo, colaborativo e mão na massa da educação brasileira. Nele, crianças, jovens, seus familiares e educadores tem a oportunidade de explorar materiais e tecnologias high e low tech, participar de atividades interativas, e aprender de forma estimulante e descontraída.

O Festival tem como objetivos divulgar, inspirar e facilitar a implementação de atividades de aprendizagem mão na massa em escolas e ambientes de educação não formal.

Só em 2018, a Rede Brasileira de Aprendizagem Criativa, contando com o apoio do MIT Media Lab e da Fundação Lemann, facilitou a organização de mais de 15 Festivais regionais por todo o país.

595. **Getting Started with Scratch**

Shruti Dhariwal, Natalie Rusk

Every day, young people around the world use the Scratch programming language to create and share thousands of interactive projects on the Scratch website. Yet many students aren't sure how to get started coding their own projects.

To address this, we have launched a new set of free resources to help students learn to create with code. The Things to Try page offers a variety of project ideas, such as creating an animated story, making a pong game, or designing a virtual pet. For each theme, students can use step-by-step tutorials or printable activity cards. In addition, the site offers educator guides you can use to organize a class or workshop based on the theme.

The Scratch Activity Cards is a collection of more than 80 colorful cards with 11 project themes. The front of each card illustrates an activity students can do with Scratch, such as animating a character or keeping score in a game. The back of the card shows how to snap together blocks of code to make their projects come to life.

These resources are designed to let students learn at their own pace and personalize their projects. Students can work individually or pair up to make projects together.

596. **Learning Creative Learning**

Mitchel Resnick, Yusuf Ahmad, Shruti Dhariwal, Lily Gabaree, Sean Hickey, Katherine McConachie, Yumiko Murai, Marian Muthui, Carmelo Presicce, Natalie Rusk, Eric Schilling, J. Philipp Schmidt, Srishti Sethi, Andrew Sliwinski, Jaleesa Trapp, Moran Tsur, Grif Peterson

Learning Creative Learning is an online course and community of educators, designers, technologists, and tinkerers exploring creative learning. Participants create hands-on projects based on their interests, explore new technologies, and share ideas with peers from more than 100 countries. The course is organized by the Lifelong Kindergarten group at the MIT Media Lab.

A new round of the course will be offered from October 9 - November 20, 2018. The course is free, and open to everyone.

597. **Microworlds**

Mitchel Resnick, Sarah Otts, Natalie Rusk, Moran Tsur

The MIT Scratch Team is exploring ways to make it easier for newcomers to get started creating with coding. We are designing "microworlds"—customized versions of the Scratch editor that contain a small set of blocks for making projects based on a theme.

Microworlds offer a more creative entry point to coding. While many introductory coding experiences focus on engaging children in puzzles with one right answer, microworlds provide an open-ended experience, enabling children to explore, experiment, and create, while still providing a more simplified and scaffolded entry point into coding.

Each microworld includes subset of the Scratch programming blocks that are most relevant and useful for the particular interest area, along with specialized graphical assets related to the interest area. In addition to aligning with a particular interest area, each microworld highlights how coding can enable young people to create projects and express ideas with code. For example, by tinkering with the music microworld, young people can see how they can use code to make musical melodies and beats; by tinkering with the soccer microworld, young people can see how they can use coding to make objects move and start building their own game.

The project is part of the Coding for All project. The Coding for All project brings together an interdisciplinary research team from the MIT Media Lab, the Digital Media and Learning Hub at University of California Irvine, and Harvard University's Berkman Center for Internet and Society to develop new online tools and activities to engage more young people in developing computational fluency, particularly youth from groups currently underrepresented in computing.

598. **Paper Circuits**

Jie Qi

Paper circuitry blends conductive craft materials with electronics components to engage learners in circuit building and programming through making arts and crafts. Learners can take advantage of the expressive richness of paper to create artifacts that are technically functional, aesthetically unique and personally meaningful. Chibitronics circuit stickers are a toolkit designed for paper circuits that transforms flexible circuit boards into interactive stickers for crafting circuits.

599. **Rede Brasileira de Aprendizagem Criativa**

Leo Burd

Somos uma rede de educadores, artistas, pesquisadores, empreendedores, alunos e outros interessados na implementação de ambientes educacionais mais mão-na-massa, criativos e interessantes nas escolas, universidades, espaços não-formais de aprendizagem e residências de todo o Brasil.

A Rede Brasileira de Aprendizagem Criativa surgiu em 2015 a partir de uma parceria entre o Programaê (uma colaboração da Fundação Lemann com a Fundação Telefonica Vivo) e o Lifelong Kindergarten Group do MIT Media Lab. Atualmente, contamos com centenas de participantes de todo o Brasil.

600. **Scratch 3.0**

Carl Bowman, Kasia Chmielinski, Timothy Mickel, Eric Rosenbaum, Ray Schamp, Andrew Sliwinski, Christopher Willis-Ford

Since the release of Scratch in 2007, young people around the world have programmed and shared more than 15 million Scratch projects. The first generation of Scratch was an application that kids downloaded to local machines. With Scratch 2.0, the second and current generation of Scratch, kids create and share their interactive stories, games, and animations directly in web browsers.

Scratch 3.0 is the next generation of Scratch which takes this experience further by empowering children to create with technology on their mobile devices. In addition, Scratch 3.0 puts a special emphasis on creating with a wide variety of mediums including sound, data, and even the physical world by seamlessly integrating with IoT and digitally enhanced construction kits.

601. **ScratchBit**

Mitchel Resnick, Kreg Hanning, Jie Qi, Eric Rosenbaum, Natalie Rusk, Andrew Sliwinski

ScratchBit is an effort to enable children to create more seamlessly in both the physical and digital world by creating a dedicated physical interface for the Scratch programming language and environment. Designed to be rugged, low cost, and highly composable, the ScratchBit allows children to take the materials around them—such as cardboard, clothes, skateboards, and trees—and transform them into inputs to their digital creations on Scratch. Unlike the Makey Makey which was designed to make these connections electronically, the ScratchBit is designed to create these connections through motion and mechanism.

602. **Scratch BlockArt**

Shruti Dhariwal

Scratch BlockArt is an experimental visualization tool designed to let children discover their own computational patterns on Scratch. Existing methods often utilize data about the types of programming blocks used in children's projects to generate a quantitative assessment of a project's computational complexity based on limited criteria. BlockArt presents an alternative approach for revealing this data to young creators themselves. Rather than datafying children's creations, BlockArt is designed to transform the data about their code into creative objects that can spark children's curiosity and enable them to reflect on their own styles and choices.

For a given username, the tool dynamically generates colorful visualizations representing the number and diversity of programming blocks used in each of their shared projects over time. Children can also click to see the project behind the visualization. The idea is not to evaluate whether they use more or less 'complex' blocks, but to reveal how the types of blocks children use are based on their motivations and interests behind creating a specific project. It also shows how looking at the diversity of code in all their projects is a better representation of their learning trajectory than providing a quantitative assessment on individual projects without additional context.

603. **Scratch Community Blocks**

Mitchel Resnick, Sayamindu Dasgupta, Natalie Rusk, Andrew Sliwinski, Benjamin Mako Hill

Scratch Community Blocks is an NSF-funded project that extends the Scratch programming language to enable youth to analyze and visualize their own learning and participation in the Scratch online community. With Scratch Community Blocks, youth in the Scratch community can easily access, analyze, and represent data about the ways they program, share, and discuss Scratch projects.

604. **Scratch Day**

Mitchel Resnick, Kasia Chmielinski, Champika Fernando, Saskia Leggett, Abisola Okuk

Scratch Day (day.scratch.mit.edu) is a network of face-to-face local gatherings, on the same day in all parts of the world, where people can meet, share, and learn more about Scratch, a programming environment that enables people to create their own interactive stories, games, animations, and simulations. We believe that these types of face-to-face interactions remain essential for ensuring the accessibility and sustainability of initiatives such as Scratch. In-person interactions enable richer forms of communication among individuals, more rapid iteration of ideas, and a deeper sense of belonging and participation in a community. The first Scratch Day took place in 2009. In 2015, there were 350 events in 60 countries.

605. **Scratch Extensions**

Sayamindu Dasgupta, Stefania Druga, Kreg Hanning, Eric Rosenbaum, Andrew Sliwinski, Christopher Willis-Ford

The Scratch extension system enables anyone to extend the Scratch programming language through custom programming blocks written in JavaScript. The extension system is designed to enable innovating on the Scratch programming language itself, in addition to innovating with it through projects. With the extension system, anyone can write custom Scratch blocks that enable others to use Scratch to program hardware devices such as the LEGO WeDo, get data from online web-services such as weather.com, and use advanced web-browser capabilities such as speech recognition.

606. **Scratch in Space**

Christan Balch, Eric Schilling

The Scratch Team invited young people from around the world to create Scratch projects designed specifically to be played in zero gravity. Scratch members submitted over two hundred projects to this special initiative. Eric Schilling from the Scratch Team deployed a diverse collection of these projects on the Space Exploration initiative's inaugural research flight in zero gravity.

607. **ScratchJr**

Mitchel Resnick, Sayamindu Dasgupta, Chris Garrity, Timothy Mickel, Andrew Sliwinski

ScratchJr makes coding accessible to younger children (ages 5-7), enabling them to program their own interactive stories, games, and animations. To make ScratchJr developmentally appropriate for younger children, we revised the interface and provided new structures to help young children learn relevant math concepts and problem-solving strategies. ScratchJr is available as a free app for iPads, Android, and Chromebook. ScratchJr is a collaboration between the MIT Media Lab, Tufts University, and Playful Invention Company.

608. **Scratch Memories**

Shruti Dhariwal

Scratch Memories is a web-based visualization tool that empowers children to celebrate and reflect on their creative journey with Scratch. The system dynamically generates personalized visualizations in the form of a video, highlighting a user's key moments, diverse creations, and collaborative experiences in the online community.

Existing tools for visualizing children's progress in computational learning are primarily designed for educators, and often focus exclusively on evaluating predefined concepts in individual projects. The goal of Scratch Memories is to present a new approach towards designing positive reflective experiences that value the full range of children's contributions as members of a creative community.

The tool engages young people to reflect on their personal growth over time—starting from their first experiments with code to seeing the increasing diversity and complexity of their projects over time; and from their initial interactions in the community to seeing how their projects have inspired others around the world. Such reflective experiences can not only help young creators feel proud about how far they have come, but also to feel inspired by their own trajectories to continue exploring new possibilities.

609. **Scratch Online Community**

Mitchel Resnick, Christan Balch, Sarah Otts, Natalie Rusk, Eric Schilling

Launched in 2007, the Scratch Online Community enables children, primarily between the ages of 8 and 16, to share interactive media such as games, stories, and animations created with the Scratch programming environment. As of September 2016, Scratch members had shared more than 16.3 million projects, and had exchanged over 87.4 million project comments.

610. **The Clubhouse Network**

Mitchel Resnick, Leo Burd, Chris Garrity, Sean Hickey, Natalie Rusk, Elisabeth Sylvan, Jaleesa Trapp, Claudia Urrea

The Clubhouse provides a creative and safe out-of-school learning environment where young people from underserved communities around the world work with adult mentors to explore their own ideas, develop new skills, and build confidence in themselves through the use of technology.

The first Clubhouse was established in 1993, as a collaboration between the Lifelong Kindergarten group and The Computer Museum (now part of the Boston Museum of Science). Four guiding principles were created to empower youth from all backgrounds to become more capable, creative, and confident learners. The four principles are: learning by designing, following one's interests, building a community, and fostering respect and trust. Since then the network has expanded to more than 100 centers in 19 countries, serving more than 25,000 young people annually.

The Lifelong Kindergarten group continues to develop new technologies, introduce new educational approaches, and lead professional-development workshops for Clubhouses around the world.

Deb Roy: Social Machines

Promoting deeper learning and understanding in human networks

611. **ChatterBox**

Eric Chu

Speech synthesis in tutor mode. Using phones for literacy learning is an empowering application of mobile technology, but there are elements of the human tutor that have yet to be replicated in current apps. Namely, when reading a story, a tutor is likely to be more expressive and colorful in tone. When encountering a new word, a tutor might emphasize the vowel phoneme or stress a consonant pair the child has yet to master. By modeling speech with deep neural networks, our speech synthesizer will be able to interpolate between speaking styles, switching from 'normal' mode to 'tutor' mode as needed.

612. **Collective Debate**

Ann Yuan

On Collective Debate, users take a test of their morality, then debate an artificial agent regarding a controversial claim: that differences in professional outcomes between men and women arise from bias as opposed to biology. Users indicate how much they agree with the claim, then they exchange arguments with the agent (who assumes the opposite position). After the debate, users are asked to re-evaluate their position. The artificial agent is trained to select arguments that nudge the user to become more moderate.

613. **FlipFeed**

Deb Roy, Nabeel Gillani, Martin Saveski, Prashanth Vijayaraghavan, Ann Yuan

FlipFeed is a Google Chrome Extension that enables Twitter users to replace their own feed with that of another real Twitter user. Powered by deep learning and social network analysis, feeds are selected based on inferred political ideology ("left" or "right") and served to users of the extension. For example, a right-leaning user who uses FlipFeed may load and navigate a left-leaning user's feed to observe the news stories, commentary, and other content they consume. The user can then decide to flip back to their own feed or repeat the process with another feed. We hope tools like FlipFeed will enable us to explore how social media platforms can be used to mitigate, rather than exacerbate, ideological polarization by helping people explore and empathize with different perspectives.

614. **Human-organized Swarms**

Nazmus Saquib

Swarm robotics traditionally have relied on autonomous organization of swarm robots using localization algorithms and self-actuation. In this project, we introduce and explore a new human-machine paradigm where humans (specially children, in the context of this project) organize and "actuate" the swarm units to solve specific educational tasks, and the swarms infer their group's spatial configuration and sense individual interactions with the child to provide feedback on learning/educational outcomes. By giving the child autonomy to manipulate the spatial configuration, we explore a shared cognitive paradigm wherein children and swarms work together to learn.

615. **Instrumentation of Montessori Learning Materials**

Nazmus Saquib

The Montessori Method is an educational approach that emphasizes independence and respect for a child's natural development process. Montessori materials are a hallmark of the Montessori Method. These self-teaching tools encourage exploration of concepts in the areas of mathematics, language, sensorial development, and practical life, and allow children to direct their own learning with the light guidance of teachers and peers.

We envision a novel framework of unobtrusive sensor networks to understand and reflect on a child's learning progress, by instrumenting existing Montessori learning materials using distributed sensing techniques.

616. **Pathways**

Deb Roy, Peter Beshai, Nabeel Gillani, Prashanth Vijayaraghavan

Our social networks influence our sense of what's possible: we can't aspire to be cancer researchers, activists, or artificial intelligence engineers if we've never been exposed to these as possibilities. Unfortunately, many children grow up in environments replete with exposure gaps, impeding awareness and ultimately limiting their conceptions of which opportunities are available to them.

Pathways is a web application that seeks to scaffold career exploration and introspection among young people in order to help them explore a) what kinds of topics they might pursue in the future, b) in which capacities they might pursue these topics, and c) examples of education and career pathways others have traversed to get where they are today. The tool uses several data science and machine learning techniques to process self-reported education and career data from thousands of individuals in the Greater Boston area.

Ultimately, we hope tools like Pathways can help enhance exposure and spark new social network ties that help foster greater upward mobility and an improved quality of life.

617. **Play Analytics**

Eric Chu, Anneli Hershman, Juliana Nazare, Mina Soltangheis, Ivan Sysoev

Analyzing detailed data from SpeechBlocks to understand how kids engage with constructionist literacy learning technologies, with the goal of empowering caregivers (e.g. parents, older siblings, tutors) with these insights.

618. **Playful Words**

Preeta Bansal, Eric Chu, Anneli Hershman, Sneha Priscilla Makini, Juliana Nazare, Deb Roy, Nazmus Saquib, Mina Soltangheis, Ivan Sysoev

While there are a number of literacy technology solutions developed for individuals, the role of social—or networked—literacy learning is less explored. We believe that literacy is an inherently social activity that is best learned within a supportive community network including peers, teachers, and parents.

By designing an approach that is child-driven and machine-guided, we hope to empower human learning networks in order to establish an engaging and effective medium for literacy development while enhancing personal, creative, and expressive interactions within communities. We aim to create a network of learners to engage students from different communities in socially collaborative, self-expressive, and playful literacy learning opportunities via mobile devices.

To learn more about this project, please check out: <http://playfulwords.org/>

619. **ShapeBlocks**

Deb Roy, Nazmus Saquib

ShapeBlocks is a play analytics observatory that tracks, remembers, and aids players in building traditional LEGO-style structures. As players build a structure using these blocks, an underlying geometry engine analyzes the players' moves and suggests next steps (if a target structure is provided). The players can see real-time updates of what they are building in 3D. Instead of only suggesting, the AI learns from the players' moves and corrects itself through reinforcement learning. This essentially gives an opportunity for children and machines to learn shapes and geometry together.

Other use cases include urban design, and interactive strategy games and/or storytelling experiences that fuse the physical and virtual world together.

This is a work in progress. The hardware is complete, and the AI tool and games are currently being built.

620. **Social Mirror**

Deb Roy, Nabeel Gillani, Ann Yuan

Social Mirror is a web application that helps Twitter users interactively explore the politically active parts of their social network. Worsening political polarization over the past several years has exacerbated ideological echo chambers, which in turn have further fueled polarization by widening knowledge and empathy gaps between disparate groups. We hope digital tools like Social Mirror can help inspire self-reflection, and ultimately, intellectual humility by providing people with a new view of their social media ecosystems and helping them form new network connections.

621. **SpeechBlocks**

Anneli Hershman, Sneha Priscilla Makini, Juliana Nazare, Ivan Sysoev

SpeechBlocks is a smartphone app that allows children to explore spelling principles in an open-ended way. Children rearrange words on the screen by pulling them apart and putting them together with their fingers. Each word formed is pronounced aloud by a speech synthesizer. The interactions afforded by the app were informed by current research findings in early literacy learning. To alleviate the fear of making a mistake, and to support fun exploration, we excluded the notion of "right" and "wrong" from our design: Nonsense words are pronounced along with regular words, much to children's amusement. While the app is intended to help children acquire basic reading and writing skills, it has also turned out to be a medium for self-expression and creativity.

622. **StoryBlocks**

Marc Exposito Gomez, Anneli Hershman, Juliana Nazare, Saul Woolf (Undergraduate Student, Worcester Polytechnic Institute), Molly Scott (Graduate Student in the Infant & Child Laboratory, Temple University)

Scaffolding storytelling to connect children through self-expression

StoryBlocks is a smart-expressive medium, designed in collaboration with Sesame Workshop, that aims to bring a new level of interactivity into children's educational media and stories while promoting empathy, social-emotional development, and literacy development through storytelling. In StoryBlocks, children transition between an animated narrative that sets up a social conflict, and an interactive comic-style composition that allows children to construct their own solutions and share their stories while engaging in critical thinking and reflection.

623. **The Electome: Measuring Responsiveness in the 2016 Election**

Deb Roy, Sophie Chou, Andrew Heyward, Perng-Hwa Kung, Neo (Mostafa) Mohsenvand, William Powers, Raphael Schaad, Russell Stevens, Prashanth Vijayaraghavan, Soroush Vosoughi, Project Alumni: Eric Chu, Neo (Mostafa) Mohsenvand, Raphael Schaad, Sophie Chou, Perng-Hwa Kung, Uzra Khan, Shawn Musgrave, Kevin Aiken

The Electome: Where AI Meets Political Journalism

The Electome project is a machine-driven mapping and analysis of public sphere content and conversation associated with the 2016 presidential election campaign. Through its unprecedented view of the national election conversation, LSM aims to shift some of our collective focus from who's winning/losing (traditional "horse race" polls and projections) to the issues the campaign is being fought over (the "Horse Race of Ideas"). The Electome is fueled by two primary data streams: the entire Twitter archive and daily output (the so-called 500m Tweet per day "fire hose") as well as a sample of daily content from 30 digital news sites (5k-6k stories per day). A series of machine learning algorithms identify those Tweets and stories specifically about the election, then classify them by topic, candidate, organization and a number of other filters. The classified data is then run through various semantic and network analytics that continuously measure and visualize:

the share of conversation or coverage that any given issue or candidate commands on Twitter and in the news media, respectively — and how the two platforms are aligned

which issues are most closely associated with each candidate on Twitter (via co-occurrent candidate/issue references in single Tweets)

how much of the public sphere conversation and coverage is about substantive issues as compared to politics (polls, projections, process) and the candidates' character and personality

specific sub-topics and representative Tweets within broader conversations about specific issues or candidates

the level of "incivility" (profanity, insults, violence, ethnic/sexual slurs) within the public Twitter conversation about any given issue or candidate

who is influencing the public sphere election conversation (via a composite Twitter/media influence metrics)

LSM's deployment of Electome analytics has been supported by the Knight Foundation, with the goal of fueling news coverage that is more responsive to what matters most to the public. To that end, LSM has:

provided customized analysis to several Electome media outlets—including the Washington Post, Bloomberg News, CNN Politics and Fusion—as well as publishing its own analysis in Medium

collaborated with the Commission on Presidential Debates to offer Electome analysis to the general election debates' moderators and credentialed journalists

also collaborated with the Roper Center for Public Opinion Research at Cornell University for integration of the Center's polling in Electome analytics/dashboard

and built a self-service dashboard featuring several Electome analytic tools for journalists and analysts to produce their own issue-driven analyses and visualizations.

Looking beyond the 2016 election, LSM sees Electome technology as enabling new forms — and, importantly, creators — of investigative and explanatory journalism by democratizing access to powerful data mapping, analysis and visualization tools.

624. **The Story Learning Machine**

Deb Roy, Eric Chu, Russell Stevens, Prashanth Vijayaraghavan, Soroush Vosoughi

The Storytelling project uses machine-based analytics to identify the qualities of engaging and marketable media. By developing models with the ability to "read" emotional arcs and semantic narrative video content, our researchers aim to map video story structure across many story types and formats.

To complement this content-based analysis, our researchers are also developing methods to analyze how emotional and semantic narratives affect viewer engagement with these stories. By tracking "referrals" of video URLs on social media networks, our researchers hope to identify how stories of different types and genres diffuse across networks, who influences this spread, and how video story distribution might be optimized. Given this project's two-pronged strategy, our hope is to develop a robust story learning machine that uniquely maps the relationship between story structure and engagement across networks.

Danielle Wood: Space Enabled

Advancing justice in Earth's complex systems using designs enabled by space

625. **Accessibility of the microgravity research ecosystem**

Danielle Wood, Christine Joseph

For decades, the International Space Station (ISS) has operated as a bastion of international cooperation and a unique testbed for microgravity research. Beyond enabling insights into human physiology in space, the ISS has served as a microgravity platform for numerous science experiments. In recent years, private industry has also been affiliating with NASA and international partners to offer transportation, logistics management, and payload demands. As the costs of flying projects to the ISS decrease, the barriers limiting non-traditional partners, like emerging space nations and startups, from accessing the ISS as a platform also decrease.

However, the ISS in its current form cannot be sustained forever. As NASA looks towards commercialization of the low Earth orbit (LEO) space and the development of a cislunar station, concrete plans for shifting the public-private relationship of the ISS are unclear. With the consistent need to continue microgravity research—from governments and private industry—understanding the socio-technical and policy issues that affect the marketplace for future microgravity platforms is essential to maintaining an accessible and sustainable space economy.

How will the US and other governments design public-private partnerships to pursue economic and social goals in the LEO microgravity ecosystem? What governance structures will influence who is eligible to operate platforms for activities including tourism, research, manufacturing, and outreach? How will international collaboration occur in the future LEO microgravity ecosystem?

This project contributes to progress on these questions by offering technology policy insight using methods from Systems Engineering. Through case study research and numerous expert interviews, this project examines the stakeholders, needs, objectives, system functions and forms for the ISS and microgravity research platforms now and in the future. Particular attention is paid towards explaining the market dynamics that affect the administrative and economic barriers to entry for emerging space nations and non-traditional spaceflight participants.

626. **Candlewax Rockets: A green alternative for in-space propulsion**

Javier Stober

Paraffin wax shows promise as a high-performing hybrid rocket propellant for chemical propulsion systems. Its inherent safety and simplicity advantages and low cost (less than \$4/kg) make it well-suited for widespread adoption for launch and in-space applications. Its benign nature compared to the toxicity and carcinogenicity which characterize currently used propellants, such as hydrazine and nitrogen tetroxide, make paraffin an especially strong candidate for new entrants to the propulsion community.

The Space Enabled research group is focused on the use of paraffin wax for small satellite missions. Specifically, we are investigating the centrifugal casting of paraffin into annular geometries on Earth as well as in microgravity. The research group envisions the repurposing of paraffin thermal insulation at end of life for deorbit maneuvers. However, such a mission would require centrifugal casting of paraffin in orbit—a task which has never been done before. The microgravity environment is expected to reduce rotation rate demands for uniform casting, and the overall experimental investigation aims to quantify the differences between 1-g and microgravity centrifugal casting.

627. **Design for a Citizen Science and Public Engagement Project Celebrating Antarctica and the Southern Ocean**

Lizbeth Barrios de la Torre

Antarctica is a unique and beautiful continent that is key to the global ecosystem and climate. Research based in Antarctica is helping scientists explore cutting-edge questions in oceanography, physics, climate science, ecology, and more. To most members of the public, however, Antarctica appears to be a cold and inhospitable place with little relevance to daily life. This project asks if combining a citizen science campaign and an immersive museum experience can increase a sense of stewardship to care for Antarctica within people around the world.

For this project, the Space Enabled research group designed a concept for an interactive, room-scale multi-sensory presentation providing education regarding the Antarctic. This presentation is designed to be placed in an informal education venue such as an aquarium or science museum. The immersive presentation helps participants understand this dynamic region through an experience that combines photos, video, sound, smell, and temperature changes. The information draws on multiple types of data from earth science satellites (i.e., ICESAT), airborne science platforms (i.e., IceBridge), and in-situ sensors (i.e., underwater video cameras and photographs). As participants go through the experience, they hear vignettes about specific research areas in Antarctica, including studies on penguin colonies, ice cores, meteorite searches, and ocean food chains.

In addition to the physical, interactive presentation, the second aspect of the project involves a companion Citizen Science campaign. Specifically, citizen scientists and students located in countries near the Southern Ocean (including Chile, South Africa, New Zealand, and Australia) are invited to participate in a data collection campaign about their part of the Southern Ocean. A proposed mobile application in both English and Spanish could invite participants to submit photographs of the shoreline on the Southern Ocean. Our team is prototyping a small, low-cost kit that allows citizen scientists to take measurements such as temperature, salinity and pH measurements from coastal areas facing the Southern Ocean. Information from these citizen scientists could be incorporated into the physical presentation in the museum. Meanwhile, the visual aspects of the presentation may be provided online as photo or video files that could be downloaded to host on their own platforms.

628. **Earthrise | A 50 Year Contemplation**

Danielle Wood, Lizbeth Barrios de la Torre, Rachael Petersen

In December of 1968, the first human voyage to the moon catapulted the population of Earth into a new era of space exploration and self-reflection. It was during this voyage that astronauts Bill Anders and Jim Lovell recognized a familiar pale blue dot in the distance and snapped a photo, providing us with the first view of Earth from this distant vantage point. Since its release, this image has been the subject of various works of art and literature. After having seen the Earth from space, some astronauts reported a cognitive shift in awareness about the planet. This shift helped them recognize the fragility of Earth and has inspired feelings of global citizenship. Thanks to the writings of author Frank White, we now call this shift, "The Overview Effect."

The Media Lab's Space Enabled research group asks if it is possible to create a similar cognitive shift in Earthlings through an experiential installation piece meant to inspire global citizenship as well as universal citizenship. "Earthrise: A 50 Year Contemplation" will celebrate the original Earthrise photo by creating a meditative space of reflection where participants are transported to the surface of Earth's moon to reflect on themselves, Earth, and the solar system. The viewer will be immersed in the sensory experience that surrounds them. Through artificially creating "The Overview Effect," and altering our perspective, might we also inspire a more sustainable approach in our exploration of the solar system?

Frank White, author of *The Overview Effect: Space Exploration and Human Evolution*, is launching "The Human Space Program" through his new book, *The Cosma Hypothesis: Implications of the Overview Effect* (Emergent Media; February 2019). The goal of the Human Space Program is to create a comprehensive, sustainable, and inclusive plan for exploring and developing the solar system. It is built around White's "Cosma Hypothesis," which addresses the question, "What is the purpose of human space exploration? Why has the evolutionary process brought humanity to the brink of becoming a spacefaring species?" White's surprising conclusion: Homo sapiens have a very significant role to play in the evolution of the universe (Cosma). Space Enabled appreciates the opportunity to dialogue with Frank about these fundamental questions shaping the moral compass of human exploration beyond earth.

By Lizbeth B. De La Torre, Rachael Petersen, Frank White and Danielle Wood

629. **Integrated Complex Systems Modeling**

Jack Reid

One of the six research methods used by the Space Enabled research group is creating models of complex systems by drawing on techniques from systems engineering, social science, and earth science. The environment, human vulnerability and societal impact, human decision-making, and technology design are four domains with complex interactions that can be simulated in computer models. Environmental models use physics-based simulations or empirical regressions to estimate the behavior of natural features in the atmosphere, water, or vegetation. Human vulnerability and societal impact models estimate how people are impacted by environmental hazards, such as hurricanes, or ecosystems services, such as the benefits of forests. Human decision-making models simulate the actions taken by humans in response to environmental features, while the technology design model allows humans to explore options for technical systems (such as earth observation satellites) to improve awareness of the state of the environment.

While significant benefit has come from addressing each domain individually in existing models, and yet more from considering certain groupings (such as the economic valuations that combine both decision-making and societal impact), capturing all four together in an integrated software model can enable us to overcome important challenges that lie at the intersections of these domains.

The Space Enabled research group aims to develop an open-source standard for software model interfaces and begin to build an open-source library of new and existing computational models for use in a variety of applications. Hopefully this library will be used to facilitate the use of remote sensing data, craft policy here on Earth, and design new remote sensing platforms. As we progress and work towards version 1.0, we hope others will join us in this endeavor.

630. **PlusMinus**

V. Michael Bove, Kevin Esvelt, Iyad Rahwan, Danielle Wood, Ethan Zuckerman, Hildreth England

Ride-sharing, social media, artificial intelligence. These are examples of socially-beneficial, net-positive technologies that have shown us the dark side of a move-fast, break-things ethos. In visible or invisible ways, these technologies have also had unexpectedly—and disproportionately—negative impacts on some of society's most vulnerable citizens.

PlusMinus provides both a structure for Media Lab researchers to work with members and other outside collaborators on impact and equity issues, and a force for changing our internal culture to bring these considerations more consciously into our design and evaluation processes. As part of the Media Lab's continuing investigation into complex, adaptive systems, PlusMinus is...

Equipping future technologists with the space, community, and skills to reflect on, critique, and inclusively design technologies for equitable, positive social impact before, during and after they're deployed.

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We envision a community of PIs, research staff, and students who concentrate their research on PlusMinus issues—exploring how the benefits of their research might be distributed equitably across society if projects were to be scaled up, how to evaluate ongoing research for early hints of possible trouble, and how to mitigate negative impacts should they appear.

Ethan Zuckerman: Civic Media

Creating technology for social change

631. **Actionable Auditing:
Coordinated bias disclosure
study**

Joy Buolamwini

Algorithmic auditing has emerged as a key strategy to expose systematic biases embedded in software platforms, yet scholarship on the impact of algorithmic audits on increasing algorithmic fairness and transparency in commercial systems is nascent. To analyze the impact of publicly naming and disclosing performance results of biased AI systems, we investigate the commercial impact of Gender Shades, the first algorithmic audit of gender and skin type performance disparities in commercial facial analysis models. This paper 1) outlines the audit design and structured disclosure procedure used in the Gender Shades study; 2) presents new performance metrics from targeted companies IBM, Microsoft, and Megvii(Face++) on the Pilot Parliaments Benchmark (PPB) as of August 2018; 3) provides performance results on PPB by non-target companies Amazon and Kairos; and 4) explores differences in company responses as shared through corporate communications that contextualize differences in performance on PPB. Within seven months of the original audit, we find that all three targets released new API versions.

All targets reduced accuracy disparities between males and females and darker and lighter-skinned subgroups, with the most significant update occurring for the darker-skinned female subgroup that underwent a 17.7% - 30.4% reduction in error between audit periods. Minimizing these disparities led to a 5.72% to 8.3% reduction in overall error on the Pilot Parliaments Benchmark (PPB) for target corporation APIs. The overall performance of non-targets Amazon and Kairos lags significantly behind that of the targets, with error rates of 8.66% and 6.60% overall, and error rates of 31.37% and 22.50% for the darker female subgroup, respectively.

While algorithmic fairness may be approximated through reductions in subgroup error rates or other performance metrics, algorithmic justice necessitates a transformation in the development, deployment, oversight, and regulation of facial analysis technology. Consequently, the potential for weaponization and abuse of facial analysis technologies cannot be ignored, nor the threats to privacy or breaches of civil liberties diminished even as accuracy disparities decrease. More extensive explorations of policy, corporate practice, and ethical guidelines are thus needed to ensure vulnerable and marginalized populations are protected and not harmed as this technology evolves.

632. **Algorithmic Justice League**

Ethan Zuckerman, Joy Buolamwini

www.ajlunited.org

An unseen force is rising—helping to determine who is hired, granted a loan, or even how long someone spends in prison. This force is called the coded gaze.

However, many people are unaware of the growing impact of the coded gaze and the rising need for fairness, accountability, and transparency in coded systems. Without knowing discriminatory practices are at play, citizens are unable to affirm their rights or identify violations.

The Algorithmic Justice League aims to:

highlight algorithmic bias through provocative media and interactive exhibitions

provide space for people to voice concerns and experiences with coded discrimination

develop practices for accountability during the design, development, and deployment phases of coded systems.

633. **Art Cube: the Ambulatory Art
Exhibit**

Cindy Bishop, Lorrie LeJeune

As we know from our 'maker' classes and workshops, different capabilities and approaches can yield remarkable projects. Let's facilitate a 'smart' building that is at least as much about the people as the tech.

Because the walls and halls of E14 and E15 are subject to building codes and approvals, we decided to create our own walls that can contain and display, conceal or reveal, and in the true MIT innovative spirit, move. As a result, our ArtCube was born. Once we gather the remaining materials to finish construction, we will open for submissions (beginning of 2019).

634. **Civic Entertainment**

Ethan Zuckerman, Anushka Shah

Civic Entertainment is a project based at the Center for Civic Media that explores the intersection of civic engagement with film, television, radio, theatre, literature, and digital entertainment. The project aims to study the modes in which entertainment can create greater knowledge of public institutions, motivate citizens towards democratic duties, and present effective strategies of social and political change.

The research focuses on studying the ways in which fiction media can affect change in thought and behavior, develops case studies of past and existing films and television shows that reflect or carry elements of civic engagement, explores the representation of protest and activism in popular culture, and experiments with techniques to balance civic education with humor or drama within entertainment.

The project has a key focus on Indian entertainment and works with Civic Studios (www.civictudios.com), a Mumbai-based production firm, on creating civic entertainment content for young people across India.

635. **CivilServant: User-Led
Randomized Trials Online**

Ethan Zuckerman, J Nathan Matias, Merry Mou

The CivilServant project supports online communities to run their own experiments on the effects of moderation practices on antisocial behavior, harassment, discrimination, and community well-being online. All results are published to an open repository of collective knowledge on practices that contribute to fair, flourishing social life online.

The first experiment, in a 13.2 million subscriber community, showed that posting rules at the top of conversations prevents problems and increases engagement.

636. **Code4Rights**

Ethan Zuckerman, Joy Buolamwini

Code4Rights promotes human rights through technology education. By facilitating the development of rights-focused mobile applications in workshops and an online course, Code4Rights enables participants to create meaningful technology for their communities in partnership with local organizations. For example, Code4Rights, in collaboration with It Happens Here, a grassroots organization focused on addressing sexual violence, created the First Response Oxford App to address sexual violence at Oxford University. Over 30 young women contributed to the creation of the app, which provides survivors of sexual violence and friends of survivors with information about optional ways to respond, essential knowledge about support resources, critical contact details, and answers to frequently asked questions.

637. **DataBasic**

Ethan Zuckerman, Rahul Bhargava, Catherine D'Ignazio

DataBasic is a suite of web-based tools that give people fun and relevant ways learn how to work with data. Existing tools focus on operating on data quickly to create some output, rather than focusing on helping learners understand how to work with data. This fails the huge population of data literacy learners, who are trying to build their capacity in various ways. Our tools focus on the user as learner. They provide introductory activities, connect to people with fun sample datasets, and connect to other tools and techniques for working with data. We strongly believe in building tools focused on learners, and are putting those ideas into practice on these tools and activities. Visit databasic.io today to try it out!

638. **Data Culture Project**

Rahul Bhargava

Struggling to build your organization's ability to work with data? Use our hands-on learning program to kickstart your data culture.

datacultureproject.org

Data is everywhere right now. But many organizations like yours are struggling to figure out how to build capacity to work with data. You don't need a data scientist; you need a data culture.

Use our self-service learning program to facilitate fun, creative introductions for the non-technical folks in your organization. These are not boring spreadsheet trainings. The free tools and activities on the linked website are hands-on and designed to meet people where they are across your organization, and build their capacity to work with data. Try to kickstart your data culture by running one activity per month as a brown bag lunch. Our videos and facilitation guides will lead you through running them yourself.

639. **Data Therapy**

Ethan Zuckerman, Rahul Bhargava

As part of our larger effort to build out a suite of tools for community organizers, we are helping to build their capacity to do their own creative data visualization and presentation. New computer-based tools are lowering the barriers of entry for making engaging and creative presentations of data. Rather than encouraging partnerships with epidemiologists, statisticians, or programmers, we see an opportunity to build capacity within small community organizations by using these new tools. This work involves workshops, webinars, and writing about how to pick more creative ways to present their data stories.

datatherapy.org

640. **DeepStream**

Ethan Zuckerman, Gordon Mangum, Vivian Diep, David Anderton

Citizens and journalists are increasingly choosing to live stream civic events. But live streams are currently hard to find and lack in-depth information about the events being documented. DeepStream seeks to increase participation in this emergent form of media by creating tools for live stream curation. Users can add relevant news stories, images, tweets, and other media to almost any live or on-demand video to create more informative and engaging viewing experiences. To help find relevant videos, Deepstream includes a search engine that lets you find live streams across multiple platforms with a single search query.

By lowering the technical barriers to creating enhanced live and on-demand videos, Deepstream makes it possible for newsrooms or individuals to curate the chaos of live streams from major global events, add media to video in real-time like fact-checking live political debates, or create enhanced version of documentaries with extra footage and related stories that appear at specific times. Our goal is to connect viewers to global events in a way that emphasizes local perspectives and deeper engagement, while maintaining the experience of immediacy and authenticity that is an essential part of live streaming.

641. **Empowerment-Based Design and Evaluation of Civic Technology**

Erhardt Graeff

Civic technology should empower us as citizens. But despite its breadth as a field, civic technology often takes its lead from Silicon Valley companies that espouse design goals potentially hazardous to participatory democracy. As an example, Facebook has been used to help organize democratic social movements around the world, but it has also allowed undemocratic actors to inflame partisanship and hate at the same time. I explore: How might we design civic technologies for citizen empowerment and evaluate their impact on this goal?

With their increasingly important role as mediators of democracy, it is insufficient for civic technology designers to evaluate their designs in terms of ease of use and increased engagement with their platform. Research from political and developmental psychology shows the importance to lifelong civic engagement of learning experiences that cultivate a citizen's perception they can make change (political efficacy) and their belief in having responsibilities to the public good (civic identity). To achieve these positive feedback loops, we need a richer framework for civic technology design.

This project proposes two solutions: 1) empowerment-based design principles for civic technology, and 2) a prototype toolkit for evaluating the impact of civic technology on political efficacy. Because empowerment is contextual, the proposals here focus on tools and platforms built to support "monitorial citizenship," an increasingly popular form of civic engagement aimed at holding institutions accountable.

642. **First Upload**

Ethan Zuckerman, Matthew Carroll, Joe Goldbeck, Cynthia Fang

First Upload is a tool for verifying the authenticity of news imagery. It helps find the first upload of imagery, particularly videos. Finding the person who uploaded a video is a key to determining authenticity, because often it is necessary to contact that person directly. It is being developed with input from YouTube and Bloomberg. Currently we have a working prototype, built for the YouTube site.

643. **FOLD**

Matthew Carroll, Cesar A. Hidalgo, Ethan Zuckerman, Alexis Hope, Kevin Zeng Hu, Joe Goldbeck, Nathalie Huynh

Some readers require greater context to understand complex stories. FOLD (fold.cm) is an open publishing platform with a unique structure that lets writers link media cards to the text of their stories. Media cards can contain videos, maps, tweets, music, interactive visualizations, and more.

FOLD is used by journalists, educators, and storytellers around the world.

644. **Gender Shades**

Ethan Zuckerman, Joy Buolamwini

The Gender Shades project pilots an intersectional approach to inclusive product testing for AI. **Algorithmic Bias Persists**

Gender Shades is a preliminary excavation of the inadvertent negligence that will cripple the age of automation and further exacerbate inequality if left to fester. The deeper we dig, the more remnants of bias we will find in our technology. We cannot afford to look away this time, because the stakes are simply too high. We risk losing the gains made with the civil rights movement and women's movement under the false assumption of machine neutrality. Automated systems are not inherently neutral. They reflect the priorities, preferences, and prejudices—the coded gaze—of those who have the power to mold artificial intelligence.

645. **Gobo**

Ethan Zuckerman, Rahul Bhargava, Alexis Hope, Yasmine (Jasmin) Rubinovitz

Take control of your social feed.

Gobo is a social media aggregator with filters you control. You can use Gobo to control what's edited out of your feed, or configure it to include news and points of view from outside your usual orbit. Gobo aims to be completely transparent, showing you why each post was included in your feed and inviting you to explore what was filtered out by your current filter settings. Learn more and try it out on <https://gobo.social>.

To use Gobo, you link your Twitter and Facebook accounts to Gobo and choose a set of news publications that most closely resembles the news you follow online. Gobo retrieves recent posts from these social networks and lets you decide which ones you want to see. Want more posts from women? Adjust a slider to set the gender balance of your feed... or just click on the "mute all men" button and listen to the folks who often get shouted down in online dialogs. Want to broaden the perspectives in your feed? Move the politics slider from "my perspective" to "lots of perspectives" and Gobo introduces news stories from sources you might not otherwise find.

Gobo retrieves posts from people you follow on Twitter and Facebook and analyzes them using simple machine learning-based filters. You can set those filters – seriousness, rudeness, virality, gender and brands – to eliminate some posts from your feed. The "politics" slider works differently, "filtering in", instead of "filtering out" – if you set the slider towards "lots of perspectives", our "news echo" algorithm will start adding in posts from media outlets that you likely don't read every day.

gobo.social

646. **Going Dark: Collective action in the reddit Blackout**

J Nathan Matias

How do people who lead communities on online platforms join together in mass collective action to influence platform operators? Going Dark analyzes a protest against the social news platform reddit by moderators of 2,278 communities in July of 2015. These moderators collectively disabled their communities, preventing millions of readers from accessing major parts of reddit and convincing the company to negotiate over their demands. This study reveals social factors—including the work of moderators, relations among moderators, relations with platform operators, factors within communities, and the isolation of a community—that can lead to participation in mass collective action against a platform.

647. **LinkedOut: Codesigning societal reentry with returning citizens**

Ethan Zuckerman, Rubez Chong Lu Ming

LinkedOut aims to define and build solutions to facilitate societal reentry for formerly incarcerated individuals.

In collaboration with the Office of Returning Citizens (ORC), an office under the City of Boston that facilitates reentry, LinkedOut is working to design a reentry infrastructure to shut the revolving door of incarceration and reincarceration.

Our work seeks to break down the structural and societal barriers to successful reentry. At the structural level, we are building technologies to develop richer data biographies of the lives of returning citizens, and in doing so provide policymakers with the robust data required for effective reentry programs. Importantly, our goal is to embed values in technology design to humanize the reentry process. On the societal level, we have begun to expose holes in the moral fabric of society as we draw attention to the dehumanization and stigmatization of returning citizens. These invisible societal norms disempower returning citizens from rebuilding their lives. Thus, our work demands a reimagination of our current justice system—one that rehabilitates rather than retributes, that embraces rather than excludes—to design for a successful reentry journey.

Here are some of our current deliverables:

Defining metrics for measuring resilience

Designing UX/UI for Case Management Model system

Developing an accountability tool for returning citizens to reclaim their reentry journey

Building a service design framework for the Office of Returning Citizens

648. **Make the Breast Pump Not Suck Hackathon**

Ethan Zuckerman, Tal Achituv, Catherine D'Ignazio, Alexis Hope, Taylor Levy, Che-Wei Wang, Alexandra Metral

In September 2014, 150 parents, engineers, designers, and healthcare practitioners gathered at the MIT Media Lab for the "Make the Breast Pump Not Suck!" Hackathon. As one of the midwives at our first hackathon said, "Maternal health lags behind other sectors for innovation." This project brought together people from diverse fields, sectors, and backgrounds to take a crack at making life better for moms, babies, and new families.

649. **Make the Breast Pump Not Suck Hackathon 2018**

**Catherine D'Ignazio, Alexis Hope
A Case for Breastfeeding Innovation
Breastfeeding saves lives.**

If women globally were able to meet the WHO's public health goal to exclusively breastfeed for the first six months, we would prevent 823,000 infant deaths. For every 597 women who optimally breastfeed, one maternal or child death is prevented.

Breastfeeding promotes long-term wellness for mother and baby.

Breastfeeding protects against child infections and malocclusion, increases intelligence, and reduces the risk of obesity and diabetes for children¹. Breastfeeding decreases mothers' risk of breast cancer and optimal breastfeeding would lead to 20,000 fewer cases every year¹. It may also protect against ovarian cancer and diabetes¹. Women who are supported to successfully establish breastfeeding in early months have a lower risk for postpartum depression.

Breastfeeding saves healthcare costs.

If women in the US were able to meet the WHO's public health goal to exclusively breastfeed for the first six months, we would save \$17.2 billion dollars in annual costs treating preventable events, including infant and maternal deaths, SIDS, ear infections and necrotizing enterocolitis in babies, and heart attacks, diabetes and breast cancer in mothers.

Work environments and policies in the US are hostile to breastfeeding.

The US is one of only three nations worldwide without paid parental leave. The other countries in this club are Papua New Guinea and Lesotho⁴. Women's return to work outside the home is the leading factor for early weaning⁵. Most US work environments do not provide material or policy-based support for breastfeeding women, including parental leave, flexible schedules, on-site daycare, breaks and spaces for nursing and pumping.

The Hackathon

Our team is thrilled to produce a weekend with the leading innovators in breastfeeding and postpartum health, along with many mamas, papas, babies, students, and newcomers. This time around we have a focus on equity and inclusive innovation in breastfeeding. We want to catalyze the development of tech, products, spaces, clothing, programs and services that have an eye on affordability and access as well as cultural diversity.

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650. **Media Cloud**

Ethan Zuckerman, Rahul Bhargava, Sands Fish, Natalie Gyenes, Alexis Hope, Anushka Shah, David LaRochelle, Hal Roberts

Media Cloud is a platform for studying media ecosystems. By tracking millions of stories published online, the system allows researchers to track the spread of memes, media framings, and the tone of coverage of different stories.

We aggregate data from over 50,000 news sources from around the world and in over 20 languages including Spanish, French, Hindi, Chinese, and Japanese. Our tools help analyze, deliver, and visualize information about media conversations on three primary levels: attention and coverage peaks of issues, network analysis, and clustered language use.

The platform is open source and open data, designed to be a substrate for a wide range of communications research efforts. Media Cloud is a collaboration between Civic Media and the Berkman Klein Center for Internet and Society at Harvard Law School.

To learn more or register for a free account, check out www.mediacloud.org.

651. **NetStories**

Ethan Zuckerman, Adrienne Debigare, Dalia Othman

Recent years have witnessed a surge in online digital storytelling tools, enabling users to more easily create engaging multimedia narratives. Increasing Internet access and powerful in-browser functionality have laid the foundation for the proliferation of new online storytelling technologies, ranging from tools for creating interactive online videos to tools for data visualization. While these tools may contribute to diversification of online storytelling capacity, sifting through tools and understanding their respective limitations and affordances poses a challenge to storytellers. The NetStories research initiative explores emergent online storytelling tools and strategies through a combination of analyzing tools, facilitating story-hack days, and creating an online database of storytelling tools.

652. **NewsPix**

Ethan Zuckerman, Matthew Carroll, Catherine D'Ignazio, Catherine D'Ignazio, Emerson College Engagement Lab, Jay Vachon

NewsPix is a simple news-engagement application that helps users encounter breaking news in the form of high-impact photos. It is currently a Chrome browser extension (mobile app to come) that is customizable for small and large news organizations. Currently, when users open a new, blank page in Chrome, they get a new tab with tiles that show recently visited pages. NewsPix replaces that view with a high-quality picture from a news site. Users interested in more information about the photo can click through to the news site. News organizations can upload photos ranging from breaking news to historic sporting events, with photos changing every time a new tab is clicked.

653. **Open Water Project**

Ethan Zuckerman, Catherine D'Ignazio, Don Blair, Adrienne Debigare, Public Lab Community

The Open Water Project aims to develop and curate a set of low-cost, open source tools enabling communities everywhere to collect, interpret, and share their water quality data. Traditional water monitoring uses expensive, proprietary technology, severely limiting the scope and accessibility of water quality data. Homeowners interested in testing well water, watershed managers concerned about fish migration and health, and other groups could benefit from an open source, inexpensive, accessible approach to water quality monitoring. We're developing low-cost, open source hardware devices that will measure some of the most common water quality parameters, using designs that makes it possible for anyone to build, modify, and deploy water quality sensors in their own neighborhood.

654. **PageOneX**

Ethan Zuckerman, Rahul Bhargava, Edward Platt

Newspaper front pages are a key source of data about our media ecology. Newsrooms spend massive time and effort deciding what stories make it to the front page. PageOneX makes coding and visualizing newspaper front page content much easier, democratizing access to newspaper attention data. Communication researchers have analyzed newspaper front pages for decades, using slow, laborious methods. PageOneX simplifies, digitizes, and distributes the process across the net and makes it available for researchers, citizens, and activists.

655. **Peer Appreciation in the Workplace**

Ethan Zuckerman, J Nathan Matias, Andres Monroy Hernandez, Emma Spiro

Organizations are deploying gratitude-tracking systems to encourage appreciation, promote pro-sociality, and monitor employee wellbeing. We present the case study of one such system, called Gratia, adopted by a Fortune 500 company for over four years. We analyzed 422,209 messages of thanks and examined temporal patterns of appreciation, reciprocity, and repeated interactions. We also compared the formal organizational chart to the informal network expressed through the system. We found that gratitude is strongly reciprocated, that time between thanks is relatively long, and that it is predominantly given to peers outside one's immediate team.

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657. **Promise Tracker**

Ethan Zuckerman, Rahul Bhargava, Joy Buolamwini, Alexis Hope, Jude Mwenda Ntabathia, Emilie Reiser

Promise Tracker is a citizen-monitoring platform designed to help communities track issues they care about and use that information to advocate for change with local government, institutions or the press. Using a simple web application, community groups can design a mobile phone-based survey, distribute the survey to community members' phones, collect data using a mobile app, visualize it on a map, and use the resulting data to advocate for change. We are currently partnering with civil society groups, universities, and government oversight agencies in Brazil who are implementing Promise Tracker as part of multi-sector alliances to monitor public spending and services. Key collaborators include:

University of São Paulo's CoLaboratory for Development and Participation

Ministry of Transparency, Oversight and the Comptroller-General

Federal University of Pará's Laboratory for Innovation and Oversight in the Public Sector

Social Observatory of Belém

Project SOL

Humanitas360

658. **Scanner Grabber**

Pattie Maes, Ethan Zuckerman, Tal Achituv, Luke Berndt (OpenMhz)

Scanner Grabber is a digital police scanner that enables reporters to record, playback, and export audio, as well as archive public safety radio (scanner) conversations. Like a TiVo for scanners, it's an update on technology that has been stuck in the last century. It's a great tool for newsrooms. For instance, a problem for reporters is missing the beginning of an important police incident because they have stepped away from their desk at the wrong time. Scanner Grabber solves this because conversations can be played back. Also, snippets of exciting audio, for instance a police chase, can be exported and embedded online. Reporters can listen to files while writing stories, or listen to older conversations to get a more nuanced grasp of police practices or long-term trouble spots. Editors and reporters can use the tool for collaborating, or crowdsourcing/public collaboration.

659. **The Babbling Brook**

Ethan Zuckerman, Catherine D'Ignazio

The Babbling Brook is an unnamed neighborhood creek in Waltham, MA, that winds its way to the Charles River. With the help of networked sensors and real-time processing, the brook constantly tweets about the status of its water quality, including thoughts and bad jokes about its own environmental and ontological condition. Currently, the Babbling Brook senses temperature and depth and cross-references that information with real-time weather data to come up with extremely bad comedy. Thanks to Brian Mayton, the Responsive Environments group, and Tidmarsh Farms Living Observatory for their support.

660. **The Constant Atlas**

Jia Zhang

An interactive atlas of census data for direct consumption by individual citizens.