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.

**Center for Mobile Learning**
The Center for Mobile Learning invents and studies new mobile technologies to promote learning anywhere anytime for anyone. The Center focuses on mobile tools that empower learners to think creatively, collaborate broadly, and develop applications that are useful to themselves and others around them. The Center's work covers location-aware learning applications, mobile sensing and data collection, augmented reality gaming, and other educational uses of mobile technologies. The Center's first major activity will focus on App Inventor, a programming system that makes it easy for learners to create mobile apps by fitting together puzzle piece-shaped 'blocks' in a web browser.

**Code Next**
Code Next, a Media Lab collaboration with Google, aims to create a new generation of computer scientists, innovators, and inventors and have them emerge from the underserved 8-12th grade Black and Latino populations. The pilot launched in January 2016 with two laboratories, one in NYC and one in Oakland. Currricula is being developed by the Media Lab. Code Next's first year of tutorials and maker activities are focusing on several domains: fabrication and design, digital music and interactive media, and game design. Our toolbox includes laser cutters, 3D printers, Scratch, Makey Makey, and Arduino. In the second year, we will introduce Python, Raspberry Pi, BeagleBone, and emphasize making code to make things that make things. Learning domains will emphasize computational design, mechatronics, robotics, web design, web technology, and 2D and 3D design. In addition, we teach parents technology and provide academic enrichment to our students. We will have four successive cohorts of freshmen (2016, 2017, 2018, 2019).

**Communications Futures Program**
The Communications Futures Program conducts research on industry dynamics, technology opportunities, and regulatory issues that form the basis for communications endeavors of all kinds, from telephony to RFID tags. The program operates through a series of working groups led jointly by MIT researchers and industry collaborators. It is highly participatory, and its agenda reflects the interests of member companies that include both traditional stakeholders and innovators. It is jointly directed by Dave Clark (CSAIL), Charles Fine (Sloan School of Management), and Andrew Lippman (Media Lab).

**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.

**Connection Science**
As more of our personal and public lives become infused and shaped by data from sensors and computing devices, the lines between the digital and the physical have become increasingly blurred. New possibilities arise, some promising, others alarming, but both with an inexorable momentum that is supplanting time honored practices and institutions. MIT Connection Science is a cross-disciplinary effort drawing on the strengths of faculty, departments and researchers across the Institute, to decode the meaning of this dynamic, at times chaotic, new environment. The initiative will help business executives, investors,
entrepreneurs and policymakers capitalize on the multitude of opportunities unlocked by the new hyperconnected world we live in.

**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.

**Emerging Worlds**
The Emerging Worlds SIG is focused on emerging opportunities to address pressing challenges, and leapfrog existing solutions. Emerging Worlds are vibrant ecosystems where we are rolling out new and innovative citizen-based technologies using a framework that supports the wide-ranging needs of urban populations. It is a co-innovation initiative to solve problems in areas such as health, education, financial inclusion, food and agriculture, housing, transportation, and local business.

**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.

**Future Storytelling**
The Future Storytelling working group at the Media Lab is rethinking storytelling for the 21st century. The group takes a new and dynamic approach to how we tell our stories, creating new methods, technologies, and learning programs that recognize and respond to the changing communications landscape. The group builds on the Media Lab’s more than 25 years of experience in developing society-changing technologies for human expression and interactivity. By applying leading-edge technologies to make stories more interactive, improvisational, and social, researchers are working to transform audiences into active participants in the storytelling process, bridging the real and virtual worlds, and allowing everyone to make and share their own unique stories. Research also explores ways to revolutionize imaging and display technologies, including developing next-generation cameras and programmable studios, making movie production more versatile and economic.

**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.

Pixel Factory
Data is ubiquitous in a world where our understanding of it is not. The Pixel Factory is a special interest group working to help people understand their data by making tools to transform data into stories. The Pixel Factory is led by the Macro Connections group, a group experienced in the creation of data visualization engines including: The Observatory of Economic Complexity (atlas.media.mit.edu), Immersion (immersion.media.mit.edu), and Pantheon (pantheon.media.mit.edu).

Space Exploration
The public grand opening of Space draws near. Much as biology has witnessed an explosion of DIY bio-hacking 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.

Ultimate Media
Visual media has irretrievably lost its lock on the audience but has gained unprecedented opportunity to evolve the platform by which it is communicated and to become integrated with the social and data worlds in which we live. Ultimate Media is creating a platform for the invention, creation, and realization of new ways to explore and participate in the media universe. We apply extremes of access, processing, and interaction to build new media experiences and explorations that permit instant video blogging, exploration of the universe of news and narrative entertainment, and physical interfaces that allow people to collaborate around media.

The most current information about our research is available on the MIT Media Lab website, at http://www.media.mit.edu/research.
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Design Fiction
Sparkling discussion about the social, cultural, and ethical implications of emerging technologies through design and storytelling

1. **Egstrom Farms**

   **Mary Tsang**

   A transgenic chicken commercial for ovulating women

   Egstrom Farms is a fictional company that raises genetically modified chickens that produce ovulation hormones in their egg whites. The eggs are marketed towards women who are either trying to get pregnant, or work as egg donors for the fertility industry. The slogan reads, "One egg a day is the fertility way." The project highlights a connection between women and chickens as raw commodities for the biotech industry, performing ways in which women are targeted for bio-consumerism. What is the rhetoric and imagery used in birth management products? Moreover, as avian transgenic technologies become further developed, is it possible to imagine a confluence of the poultry industry with the pharmaceutical health industry?

2. **Estrofem! Lab**

   **Mary Tsang**

   Geeking, workshoplogy, and freak science on the microcolonization of estrogen biomolecules Estrofem! Lab is dedicated to the development of a mobile estrogen lab: a set of tools, protocols, and wetware for low-cost, participatory biohacking necessitated by its genesis project, Open Source Estrogen. Regarded sometimes as hobo science, freak science, and public amateurism, the Estrofem Lab and its workshopologies aim to detect and extract estrogen from bodies and environmental sources, providing the contextual framework for why we hack estrogen, and why we perform science as citizens and hacktivists. This ongoing artistic investigation has led to creation of yeast estrogen sensors (YES-HER yeast) containing human estrogen receptor for detection, vacuum pump solid phase extraction (SPE) using cigarette filters, and DIY column chromatography using broken glass bottles, smashed silica gel, and methanol.
Miriam Simun
A transhumanist project towards co-evolution, rooted in desire

I Want to Become a Cephalopod

I Want to Become a Cephalopod is a trans-humanist proposal for using mostly the octopus, but also cuttlefish and squid, as a model species for the future of the human. This research began as a response to the ideology dominating the promises of genetic modification: the scouring of earthly genotypes in order to augment and “improve” human capabilities, or solve human “problems.” This positions other species and their DNA as yet another resource to be mined, extracted and manipulated, a sort of “shopping” or “collage” project for biology. In the Design Fiction group, we ask “what if?” What if the future of biology was rather an encounter with a species, as-is, and perhaps on its own terms? What if the term “model species” meant not that the species was for humans of high utilitarian use, easy to produce, maintain, practice science upon—what if “model” meant something more like the “mode” or “role model”?

What if I wanted to abandon the oncoming future of becoming a computer-aided AI robot, and become a cephalopod instead? What if the role of desire and fantasy in the discourse and practice of innovation was made explicit, even foregrounded? And what if the epic project of transhumanism focused first on training as a technology, rather than immediately moving to material, product-based intervention? What if we were to start Training Transhumanism (informed by the practices of the communities studied in ¡ONWARDS + UNDER!)?

To limit our thinking of the future of the human to its current form is limiting, and rooted in traditionalism. The first stages of becoming a cephalopod focuses on three main attributes:

(1) Camouflage.

To practice camouflage is to be a shape-shifter, constantly aware of one’s hyper-local environment, and ready in response. It is a practice of fluidity, flexibility, impermanent identity. I will create a training program for myself in order to develop these sensitivities and capabilities for the human, pulling from somatic practices, attention training, flexibility training (for both body and mind), ego relinquishment (the consistent internal representation of who we are). This will involve as few props as possible. A demonstration, and research interviews towards developing the practice, will be filmed.

(2) The Decentralized Brain.

The octopus has 3/5 of its neurons in her arms, and her arms can make decisions independent of the main brain (sometimes she has to watch her different arms to know what they are up to), while sharing a single intention “set” by the main brain. But how can a human decentralize her brain? She is a very centralized organism—head, on top of spinal cord, two appendages on either side, and so on… Perhaps it takes more than one person to become a cephalopod. Perhaps the question is not how does one human decentralize her brain, but how do two humans become a single organism (at least for some period of time)? How do we push beyond negotiation, beyond collaboration, to a place where two humans can share a single intention, and work as two arms in achieving it? And how might one train humans to be more sensitive and better adept in such relations? A training regimen is under development.

(3) Embodied knowledge, and relation to the world.

Cephalopods are basically giant tongues. They relate to the world through touch, chemically sensing what they encounter. Although octopuses in particular have excellent eyesight, what if the future of the human relied more on physical contact and chemical sensing (through our nose and mouth) in order to interact, understand, and act upon the world? How do we develop and extend our abilities to physically, tactically, and chemically sense the world?
Miriam Simun

¡ONWARDS + UNDER! proposes that as sea levels rise, particularly in highly populated coastal cities, the current plan to keep nature at bay and build a wall against the sea is untenable (and that walls against perceived threats not only do not work, but are dangerous metaphors to deploy). ¡ONWARDS + UNDER! proposes that we embrace a changing climate and a rising sea level, and respond by adapting our bodies, abilities and lifestyles to live more intimately in, on and under the sea. To understand what this might look like, I dove into cultures and histories of humans living intimately with oceans, including the physical and ecological practices diving women of Japan (Ama) and Korea (Haenyo); the pearl divers of the Arabian/Iranian Gulf (and in particular the music they use to organize their oceanic labors); the Moken people (sometimes called “sea-gypsies” or “water-people”) a buddhist Austronesian people that are trying to maintain a semi-nomadic hunter-gatherer lifestyle based almost exclusively on the sea amidst changing maritime and immigration regulations; the “Aquatic Ape” hypothesis which first became popularized as a feminist critique of dominant evolutionary theory and proposes that a crucial step in the evolution of homo sapiens involved a period of semi-aquatic lifestyle in what is now South Africa (the ape first stood up in water); and the recently invented sport/meditation culture of free-diving (which borrows techniques developed by the US military). This research is a mix of first and secondary sources: historical, interviews, site visits, and a personal embodied physical practice (“your urge to breathe is a lie” is a direct quotation from my free-diving instructor) - all research has been filmed and/or audio recorded.

What can we learn from the knowledge and practices developed by indigenous groups, extreme sports sub-cultures, and alt-evolutionary theorists in order to imagine a human future amidst ecological crisis?

Sputniko! Fukutake Foundation

Red String of Fate is an East Asian mythology in which gods tie an invisible red string between those that are destined to be together. Sputniko! has collaborated with scientists from NIAS to genetically engineer silkworms to spin this mythical “Red String of Fate” by inserting genes that produce oxytocin, a social-bonding “love” hormone, and the genes of a red-glowing coral into silkworm eggs. Science has long challenged and demystified the world of mythologies: from Galileo’s belief that the Earth revolved around the sun, to Darwin’s theory of evolution and beyond—but in the near future, could science be recreating our mythologies? The film unravels a story around the protagonist Tamaki, an aspiring genetic engineer, who engineers her own “Red Silk of Fate” in the hopes of winning the heart of her crush, Sachihiko. However, strange, mythical powers start to inhabit her creation....

Sputniko! Naruse Inokuma Architects

Teshima 8 Million Lab is the first Shinto shrine worshipping a genetically engineered life—a silkworm created in Sputniko’s new work Red Silk of Fate—Tamaki’s Crush. In the Shinto religion, “Yaoyorozu” (which literally means “8 Million”) is a word used to describe the myriad of gods believed to reside in almost anything, such as the wind, the ocean, trees, and animals. Conceived by artist Sputniko!, Teshima 8 Million Lab sets out to create new members of Yaoyorozu, forming a mythology from emerging science and art. Far from the big city and located on a site blessed with an abundance of nature, the facility invites the exploration of alternative perspectives on our future of nature and beliefs, as science continues to move forward.

Tranceflora—Amy’s Glowing Silk

Sputniko! National Institute of Agrobiological Sciences, Gucci

We collaborated with NIAS (National Institute of Agricultural Science) to genetically engineer silkworms to develop new kinds of silk for future fashion. For an exhibition at Tokyo’s Gucci Gallery, we designed a Nishijin-Kimono dress, working with NIAS’s glowing silk (created by injecting the genes of a glowing coral and jellyfish into silkworm eggs).

YOUR URGE TO BREATHE IS A LIE

Miriam Simun

YOUR URGE TO BREATHE IS A LIE (a direct quote from my free-diving instructor) is a progressive approach towards innovation, human response to ecological change, and the transhumanist project.

(1) Embrace change: don’t build walls to hold the future back; adapt and dive right in
(2) Re-model the model species: to truly evolve, model the future of the human body-mind after the cephalopod
(3) Embrace the knowledge and abilities embedded in ancient rituals and global traditions of living in, on, under the water
(4) Train the human to biological limits of capacity and capability, and then add on technology
(5) Embrace desire

YOUR URGE TO BREATHE IS A LIE is a manifesto, a call to action, an invitation to become the future of the human, streaming in new ways towards each other and the sea.
<table>
<thead>
<tr>
<th>Topic</th>
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<tr>
<td><strong>Fadel Adib: Signal Kinetics</strong></td>
<td>Extending human and computer abilities in sensing, communication, and actuation through signals and networks</td>
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<tr>
<td>9. <strong>Cyber-Physical Security and Privacy (System &amp; Network Security)</strong></td>
<td>Fadel Adib In the age of ubiquitous connectivity and the Internet of Things, our security and privacy have taken on new dimensions. For example, how can we ensure that our locations are not being tracked from our cellphones? And, how can we prevent an unauthorized user from hacking into our smart home systems? Our research aims at developing primitives that can address these challenges. To do so, we explore intrinsically new security mechanisms that operate across all computing stacks to secure not only the bits but also the integrity of the sensed signals, and to protect the privacy of the sensed environments.</td>
</tr>
<tr>
<td>10. <strong>Health Sensing using Wireless Signals</strong></td>
<td>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.</td>
</tr>
<tr>
<td>11. <strong>Programming Wireless Networks (Computer Networks)</strong></td>
<td>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.</td>
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<tr>
<td>12. <strong>RFind: Extreme Localization for Billions of Items</strong></td>
<td>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.</td>
</tr>
<tr>
<td>13. <strong>RFly: Drones that find missing objects using battery-free RFIDs</strong></td>
<td>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.</td>
</tr>
<tr>
<td>14. <strong>Seeing Through Walls</strong></td>
<td>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.</td>
</tr>
</tbody>
</table>
### 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.

### 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.

### 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.

### 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.

### 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.

### 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.
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.

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.

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 designhumanandesign.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.

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.
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.

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.

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.

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.

What if you could not only see but also feel virtual objects as you interacted with them? This would enable richer and more realistic user experiences. We have designed a low-cost air-vortex generator to provide midair haptic feedback when a user touches virtual objects displayed on holographic, aerial, and other 3D displays. The system consists of a 3D-printed chamber and nozzle, five low-frequency transducers, and a custom-designed driver board. The air-vortex generator can provide localized haptic feedback to a range of over 100cm. With increased driving power and a more optimized nozzle design, this range could be extended to several meters.

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.

Pedro Colon-Hernandez

We propose a wearable object identification system which will allow users to “hover” their hands over objects and perform contextual interactions with them. The system will use a fusion of sensors to be able to perform the identification in a variety of situations. Users can interact with an object through conversations with an intelligent assistant to permit a hands-free, personalized experience. The system will explore augmented reality without the hassle of phones or head mounted devices, using verbal interactions. I will develop an architecture for the proposed system and present use cases of the system, such as a dieting system, among others.
32. **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.

33. **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.

34. **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.

35. **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.

36. **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.
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.

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 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.

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."

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.

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.

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.

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.

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.
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. The thermal fishing bob seeks to visceralize rather than simply visualize data by creating a data experience that makes water pollution data present. The bob measures water temperature and displays that data 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.
**Edward Boyden: Synthetic Neurobiology**

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

46. 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.

47. 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?

48. 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. 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.

49. Prototype Strategies for Treating Brain Disorders

Edward Boyden

New technologies for recording neural activity, controlling neural activity, or building brain circuits, may be capable some day 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 neural circuit computation, through prosthetic means. High throughput molecular and physiological analysis methods may also open up new diagnostic possibilities. 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.

50. Tools for Mapping the Molecular Structure of the Brain

Edward Boyden

Brain circuits are large, 3D structures. However, the building blocks—proteins, signaling complexes, synapses—are organized with nanoscale precision. This presents a fundamental tension in neuroscience—to understand a neural 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 the brain, so that comprehensive taxonomies of cells, circuits, and computations might someday become possible, even in entire brains. One of the technologies we are developing enables large 3D objects to be imaged with nanoscale precision, by physically expanding the sample (in contrast to all previous microscopies, that magnify light from the sample via lenses), a tool we call expansion microscopy (ExM). 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.
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 activity of many neurons 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. And, ideally, it would be possible to understand how those neural codes and dynamics emerge from subcellular computational events within individual cells. Our lab and our collaborators are developing a number of innovations 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 tools as well as new kinds of advanced brain-repair prostheses.

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

Cynthia Breazeal, Jin Joo Lee Dr. David DeSteno Dr. Fei Sha
A social robot modifies its behavior to change what you think about it!

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. We measured children’s empathy prior to their interactions with the social robot and collected behavioral and physiological measurements during these interactions. Our preliminary results suggest that 1) children perceived these social robots as having or lacking empathy; 2) they followed the empathic behavioral model of the robot in both the empathic and non-empathic interactions and 3) the interaction allowed for children to reflect on their own empathic behavior. These results suggest that interacting with social robots capable of behaving empathically or non-empathically, can elicit the same behavior in children while serving as an educational tool.

Conversational agents and connected toys are becoming common in homes. The 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 my group of designing social robots for nurturing children curiosity and learning, I decided to build a platform where children and parents can learn to program with embodied intelligent agents which 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 in various learning applications and what are the generalizable design considerations? In this research project I am addressing all these questions by allowing children and parents to use a visual programming interface to control and customize an embodied intelligent agents.

Demo video

Curious Learning: Understanding Learning Behaviors for Early Literacy
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.
Cynthia Breazeal, Stefania Druga, Anastasia Ostrowski, Hae Won Park, Nikhita Singh

The increasing geographical separation and the technological divide has made it more difficult for elders to interact with their families. Most countries are projected to see their population of 65 and older surpass the share that is younger than 15 by 2050. The limitations of current aging assisting solutions, the increased social and emotional toll on caregivers and inability of institutions to create structural solutions in a timely manner calls for a paradigm shift in the way we approach aging.

As researchers, designers, family members we view aging as a natural progression of life, and think about how we could solve this problem for our future selves while preparing the fullest possible experience of life.

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 the aging adults’ daily living assistance, social and emotional needs and intergenerational connection while exploring the optimized modalities for a social robot to successfully deliver these interactions and build a long-term companionship.

Ishaan Grover, Adam Haar Horowitz, Pedro Reynolds-Cuellar

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 out on an opportunity to access information from the unique cognition ongoing during dreams and drowsiness. 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 social robots’ unique interactive and embodied capabilities, accompanied by 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.

Cynthia Breazeal, Sigurður Örn Adalgeirsson, Nick DePalma, Jin Joo Lee Dr. Malte Jung Dr. Pamela Hinds

Emotionally supportive robots improve overall team functioning!

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.

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.
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.

See below for instructions on how to access the dataset.

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.

Thus, our project explores how to design child-robot interactions that encourage child-driven second 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 will work on some educational games together. Machine learning will be used to model the child’s learning states and emotional states, and then inform the robot’s decision making during the game play with the child. Thus, the robot’s behaviors will be tailored to individual child based on his/her learning styles, personality and learning/emotional states during the game play.

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 over multiple encounters, because every child learns and engages differently.

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.

How can we add the missing 'T' and 'E' in preschool STEAM education?
Nikhita Singh

With families living further apart, it has become increasingly difficult for people to stay connected—particularly in the case of grandparents and children. The challenge lies in deciding when, how and what to engage on. Can technology act as a proactive facilitator of human-human connection?

Social robots are uniquely positioned to act as active facilitators of human-human connection. However, in order to do so, they require the ability to be proactive. Proactivity demands that an agent not only respond to its environment, but also exhibit goal-directed behavior by taking the initiative. In this work, an ecosystem for connected social robots to utilize the surfaces of the home as a canvas for expression in order to engage grandparents and grandkids in human-human interaction is proposed.

This work models proactivity in an agent as a function of understanding the context, proposing a goal, and taking initiative through an interaction. Human studies will be conducted in order to understand and draw inspiration from human behavior to drive how a robot gets an individual’s attention. Further interaction studies will serve to design and evaluate the form of expression (robot, environment, or both) most relevant for given contexts.

Cynthia Breazeal, Mirko Gelsomini, Jin Joo Lee, Hae Won Park Tonghui Zhu

Realtime detection of social cues in children’s voices!

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!

Cynthia Breazeal, Sooyeon Jeong, Jacqueline M Kory Westlund, Hae Won Park Paul Harris (Graduate School of Education, Harvard University), Samuel Ronfard (Graduate School of Education, Harvard University), David DeSteno (Dept. of Psychology, Northeastern University)

Prior research with preschool children has established that book reading, especially when children are encouraged to actively process the story materials through dialogic reading, is an effective method for expanding young children’s vocabulary. A growing body of research also suggests that social robots have potential as learning companions and tutors for young children’s early language education. Social robots are new technologies that combine the adaptability, customizability, and scalability of technology with the embodied, situated world in which we operate.

In this project, we asked whether a social robot can effectively engage preschoolers in dialogic reading. Given that past work has shown that children can and do learn new words from social robots, we investigate what factors modulate their learning. In particular, we looked at whether the verbal expressiveness of the robot impacted children’s learning and engagement during a dialogic reading activity. This project was funded by an NSF Cyberlearning grant.

Cynthia Breazeal, Sooyeon Jeong, Jacqueline M Kory Westlund, Hae Won Park Paul Harris (Graduate School of Education, Harvard University), Samuel Ronfard (Graduate School of Education, Harvard University), David DeSteno (Dept. of Psychology, Northeastern University)

Robot Expressiveness Affects Children's Learning

Realtime Detection of Social Cues

Relational AI

Proactive, Connected Spaces

Robot Expressiveness Affects Children’s Learning
Cynthia Breazeal, Hae Won Park Goren Gordon (Tel Aviv)

Young Learner’s Companion
Developing Robot’s 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.

Ishaan Grover, Hae Won Park, Pedro Reynolds-Cuellar, Nikhita Singh

Can we enable social connectivity between astronauts and people on Earth through an embodied agent?

Astronauts actively communicate with their families on Earth through several forms of digital and voice communication, including phone calls, video conferencing, and email. However, as astronaut Scott Kelly describes in the Time documentary A Year in Space, the experience can be incredibly isolating despite these affordances. Shortcomings of these modes of communication lie in their inability to translate emotion effectively, failure to facilitate shared experiences, lack of physical feedback, and the resulting perceived lack of control. The psychological effects of these limitations can become heightened over time, and peak during moments when the family on Earth is in need of support. As space becomes more accessible, it is important to consider how we design for social connectivity between people on Earth and in space.

What if embodied social agents, besides being the astronaut’s personal sidekick, could help to facilitate a more connected experience between space and Earth? From C3PO in Star Wars to Rosie the Maid in The Jetsons, the idea of robots in space has been well explored in fiction universe. On Earth, embodied social agents have been shown to be effective in providing companionship, relieving stress and anxiety, and fostering connection among people. In this project to send an embodied social agent into zero gravity, we explore several key themes relating to the potential for this technology to offer better connection and shared experience between astronauts and people on Earth.

While in zero gravity, the embodied social agent interacts with people on cognitive, creative, and social tasks with varying degrees of proactive behavior. We collect physiological, audio, and video data of the experience as individuals complete a series of tasks with the agent with the goal of designing agents that can enable us to be more socially connected.

Cynthia Breazeal, Hae Won Park

Text-to-Motion: Automatic Sequencing of Animative Robot Motions

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 our corpus of animated robot speech from DeepMoji network, a long short-term memory (LSTM) network with an attention model trained on billion tweets.
**Canan Dagdeviren: Conformable Decoders**

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

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**Conformal, Implantable Viscosity, and Electrochemical Sensors**

Canan Dagdeviren, Mohamed Tarek, Atieh Sadraei, Zijun Wei

Continuous localized tissue monitoring and disease treatment

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**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.

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**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.

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**Miniaturized Neural System for Chronic, Local Intracerebral Drug Delivery**

Canan Dagdeviren, Carlos Nunez Lopez

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.
Kevin Esvelt: Sculpting Evolution
Exploring evolutionary and ecological engineering

79. 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.

The City as Classroom, City as Laboratory series presents the generation of a novel, multimodal educational series for youth in the Greater Boston and West Philadelphia areas, aged 8 to 13. In both instances, 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 cultivating 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.

The first session of this series will be offered this summer on the following dates:
City as Classroom Summer 2018—June 17th, 24th; July 1st, July 8th, 15th, 22nd.
Please visit this link to register.

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

80. 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.

81. 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.
Ecology, Evolution, and Engineering for Empowered Brains

Devora Najjar, Avery Normandin, Pedro Reynolds-Cuellar, Joshua Van Zak
EEEb Spring 2018: April 15, 29; May 13, 27; June 3.

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 neurodivergent 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).

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.

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.

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.

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.
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<td>87.</td>
<td>Studying the Evolution of Gene Drive Systems</td>
<td>Kevin Esvelt, Cody Gilianland, Jianghong Min</td>
<td>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.</td>
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<td>88.</td>
<td>Understanding Molecular Evolution</td>
<td>Kevin Esvelt, Erika Alden DeBenedictis</td>
<td>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.</td>
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### 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.

### 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.

### 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.
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.

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).

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.

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.
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<td>96.</td>
<td>Effect of a Powered Ankle on Shock Absorption and Interfacial Pressure</td>
<td>Hugh Herr, David Hill</td>
<td>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 &quot;dumb&quot; elastic prostheses has been reached; in order to make further strides we must integrate &quot;smart&quot; 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.</td>
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<td>97.</td>
<td>Electrical Interfaces</td>
<td>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)</td>
<td>Specific aims of our team are to stimulate and sense communications between the human nervous system, limbs, and bionic prostheses.</td>
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<td>98.</td>
<td>FitSocket: Measurement for Attaching Objects to People</td>
<td>Hugh Herr, Neri Oxman, Jean-Francois Duval, Arthur J Petron</td>
<td>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.</td>
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<td>99.</td>
<td>FlexSEA: Flexible, Scalable Electronics Architecture for Wearable Robotics Applications</td>
<td>Hugh Herr, Jean-Francois Duval</td>
<td>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.</td>
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<td>100.</td>
<td>Human Walking Model Predicts Joint Mechanics, Electromyography, and Mechanical Economy</td>
<td>Hugh Herr, Matt Furtney Stanford Research Institute</td>
<td>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 &quot;SuperFlex&quot; exosuit project.</td>
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<td>101.</td>
<td>Load-Bearing Exoskeleton for Augmentation of Human Running</td>
<td>Hugh Herr</td>
<td>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.</td>
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102. Neural Interface Technology for Advanced Prosthetic Limbs
Edward Boyd, 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.

103. 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.

104. 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.

105. 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.

106. 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 project 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.

107. Tethered Robotic System for Understanding Human Movements
Hugh Herr, Jian-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.
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.

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.

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.
ClintonCircle is a tool to help people easily explore the Hillary Clinton Email Archive, the Podesta Emails, and the DNC Email Archive. ClintonCircle is built based on Immersion, a project from the Collective Learning group.

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.

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

DIVE is a new data exploration platform that enables users to build rich stories from any dataset using just a few clicks. By combining intelligent ontology detection, recommendation-based visualization and analysis, and dynamic story sharing, DIVE aims to lower the barrier-to-entry to work with data.

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.

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.

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.
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.

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 systems 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 reunification 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-differences 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 context of scholarly communities that were separated by institutions.

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.

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.

Ali Almossawi

Participie was a design experiment on direct participation for constrained choices (like budgets).

Phil Salesses, Deepak Jagdish, Daniel Smilkov

Place Pulse is a crowdsourcing effort to map urban perception. By asking users to select images from a pair, Place Pulse collects the data needed to evaluate people’s perceptions of urban environments. This data is also the data used to train Streetscore. Place Pulse was developed by Phil Salesses as part of his requirement to complete his master’s thesis. The present version of Place Pulse was re-engineered by Daniel Smilkov and Deepak Jagdish.
Cesar A. Hidalgo, Andrew Lippman, Kevin Zeng Hu, Travis Rich, Thariq Shihipar

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.

Ambika Krishnamachar

Can I borrow your network? Shout! is a marketplace for retweets that allows people to exchange micro-contracts for future retweets. Shout! facilitates the coordination of social media diffusion efforts by groups.

Cesar A. Hidalgo, Rosalind W. Picard, Weixuan 'Vincent' Chen, Asma Ghandeharioun, Natasha Jaques, Daniel Lopez Martinez, Ehi Nosakhare, Fengjiao Peng, Ognjen (Oggi) Rudovic, Akane Sano, Sara Taylor 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.

Cesar A. Hidalgo, Ramesh Raskar, Nikhil Naik

Computer vision uncovers predictors of physical urban change

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.

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

Collective memory is the common representation of the past created by a group of people. This type of memory is a result of a complex social process where cultural pieces, such as musical pieces or films, are created, broadcasted, and then forgotten. Here, we use data on the present and past popularity of music, movies, and biographies to study how the fame of different types of cultural pieces decay from our collective memory. We show that the attention received by a cultural piece or icon decays with age as a two-step process. To explain the two stages of forgetting, we propose a mathematical model that formalizes two important concepts in the literature on collective memory: communicative and cultural memory—respectively, the memory sustained by human communication, and the memory sustained by the physical recording of content (books, images, etc.). Our model captures the two-step process observed in the data, with an initial fast decay followed by a relatively slower decay. Our findings show that the dynamics of human forgetting are quite universal and can be characterized by a narrow set of mathematical functions, and that the theories about collective memory advanced in previous literature can be formalized in a mathematical model that can capture the empirically observed forgetting dynamics.

Cesar A. Hidalgo, Cristian Esteban Candia Vallejos, Cristian Ignacio Jara Figueroa Albert-Laszlo Barabasi

Temporal Scales of Human Forgetting
Events are able to trigger our remembers and make us go deeper in our memories. When the event affects a group of people, we can say that it makes us go deeper in our collective memory. Collective memory is defined as the common representation of the past created by a group of people, this means that collective memory modulates our identity as a society. So, if something or someone is able to modify collective memory, there is a probability to change our conception of the past. Therefore, quantify the impact of events in collective memory help us to understand how beliefs, customs, and identities change over time. Certainly, one of the most important events, which affects individuals and groups of people, is death. Death is the beginning of the forgetting, but also is a memory trigger at the individual and group level, and certainly affects the behavior of people, but we don’t know how much, for how long, nor in what sense.

For decades, the scholars who have studied collective memory, historical memory, popular memory, or cultural memory, have explored how populations remember historical events. The empirical side of this literature has focused on identifying the functional forms describing how ideas, events, and people are forgotten at both the individual and group—collective—scales. However, the mechanisms that trigger remembering have got little attention. Two remarkable works are related with how airplanes crash trigger remembers of other events and how technological shocks shape what society remembers.

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 us, Death, Nobel Prize, Academy Awards (Oscars), Ballon d’Or, Golden Globes, and Grammy’s. All of these events show an exogenous-critical non-trivial heard behavior, as described by Crane and Sornette 2008.

Figure A shows the daily pageviews received by five celebrities. To make the scales comparable, Figure B presents the number of page views minus their initial popularity, normalized by the peak popularity experienced at the moment of death, this is the normalized popularity. After this normalization, all curves collapse into a similar behavior with a characteristic exponent (Fig. B), $PV = t^{-b+c}$, where $b$ is the characteristic exponent and $c$ is a plateau level of popularity after death.

For all date, we find that at the moment of death, people experience a peak in the number of page views received, which is linearly proportional to their pre-death attention, followed by a power-law decay with an exponent of around -1.35 (Fig. E and F).

Moreover, we study whether the attention received by these biographies, at the long-term (parameter $c$) is larger than the attention they received prior to their death. For ~70% of these biographies, we find a positive and significant “attention premium,” which grows sub-linearly with biography’s pre-death popularity (as $y=ax^b$ with $b=0.87$), meaning that the premium is relatively larger for less popular biographies prior to their death. Besides, the other ~30% of these biographies show a negative attention premium, this is telling us that there are changes in the collective memory in both directions. Finally, we compare attention dynamics of death and other different events, such as Nobel Price, Ballon d’Or, Golden Globe, Oscar’s, and Grammy’s (Fig G), and we find several differences, the most important is (with exception of Nobel Price) they don’t have a significant impact on the long-term popularity.

These findings add to the growing body of literature studying the dynamics of forgetting and collective memory, and they show that collective forgetting can be described using simple mathematical functions. Furthermore, understanding the dynamics of forgetting of cultural productions and cultural icons, can help us understand success in those domains where it can be equated to reach.

Future work will be focused on how a burst of events affect memorability and the creation of cultural icons, it means people who are able to overcome the time barrier and prevalence in our collective memory.
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 right strategy for countries wanting to diversify their economies?

Economic diversification has become an important development goal among medium-income countries, especially among those relying on the export of commodities such as Chile, Peru, Saudi Arabia, and Kazakhstan. Given past research, the obvious intuition is to follow a pragmatic strategy focused only on related activities. But our research with the Masdar Institute in Abu Dhabi shows that this intuition may be flawed.

We used mathematical models and simulations to compare multiple economic diversification strategies. What they found is that always targeting the “low-hanging fruit”—related activities—is not the optimal choice. Instead, the researchers found that countries can do better by using dynamic strategies, targeting related products at the beginning and the end of the development process, but switching to targeting more unrelated activities when they reach an intermediate level of development. At this critical point, the future diversification opportunities—opened by an unrelated activity—compensate for a country’s reduced probability of success in it. Although counterintuitive, sometimes, targeting an activity that is not the easiest to develop accelerates the process of economic diversification.

At low levels of economic development, targeting unrelated activities may be too hopeful. But when economies enter an intermediate level of development, it is optimal to take larger risks and target activities that are relatively unrelated. So the important question for countries is when to switch strategies.

But the idea of dynamic strategies is not only interesting for economic development, it is also a contribution to network science. We have formalized the problem of identifying optimal economic diversification strategies as a problem of strategic diffusion in networks.

For the most part, researchers working on network diffusion have been using strategies focused on nodes with specific characteristics, like highly connected or central nodes. Our results show that in this case, those strategies are far from optimal, since the optimal strategies need to change which nodes to target at each step.

But the research was not limited to only finding the theoretical optimum. It also compared the theoretical strategies with the empirical behavior of countries, as they diversify their products and research activities in the networks of related products and research areas.

**Examples**

Germany, the United States, and South Korea are examples of three economies with high levels of complexity and large and diversified product portfolios. Conversely, Angola, Paraguay, and Bangladesh are low-complexity economies with few developed products. According to our findings, countries at these two extremes should continue to develop products or activities that work for them.

For instance, Germany would benefit from continued development in fields where they have shown success: chemicals, health products, and aircraft parts while Bangladesh should continue to target products in the garment, textile, and agriculture sectors. The reasons why countries at these two opposite extremes would benefit from the same development strategy are arguably different: highly developed economies would be looking to specialize their industrial capabilities; underdeveloped ones to consolidate local knowledge before taking risks.

In contrast, countries such as Malaysia and Turkey are between these two extremes. In an intermediate stage of diversification, these countries would benefit from developing activities unrelated to their current product portfolios. This means moving away from garment manufacturing and perhaps investing in machinery and chemicals or health-related products.
Social learning has shown that people are more likely to learn from those who are seen as prestigious, talented, or that 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 be 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

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<tr>
<th>Project</th>
<th>Description</th>
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| 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.  
Honorable Mention Paper Award, UIST 2016 |
| 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 |
| Auto-Inflatables | Amos Golan, Ken Nakagaki, Jifei Ou, Penelope Eugenia Webb |
Cells’ biomechanical responses to external stimuli have been intensively studied but rarely implemented into devices that interact with the human body. We demonstrate that the hygroscopic and biofluorescent behaviors of living cells can be engineered to design biohybrid wearables, which give multifunctional responsiveness to human sweat. By depositing genetically tractable microbes on a humidity-inert material to form a heterogeneous multilayered structure, we obtained biohybrid films that can reversibly change shape and biofluorescence intensity within a few seconds in response to environmental humidity gradients. Experimental characterization and mechanical modeling of the film were performed to guide the design of a wearable running suit and a fluorescent shoe prototype with bio-flaps that dynamically modulates ventilation in synergy with the body’s need for cooling. |
| 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. |
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<th>141.</th>
<th><strong>Cillia: 3D-Printed Micro Pillar Structures for Surface Texture, Actuation and Sensing</strong></th>
<th>Hiroshi Ishii, Gershon Dublon, Jifei Ou Felix Heibeck, Chin-Yi Chen, Liang Zhou</th>
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<td>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.</td>
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<th>142.</th>
<th><strong>HydroMorph</strong></th>
<th>Hiroshi Ishii, Ken Nakagaki, Thariq Shihipar Anthony Stuart, Chantine Akiyama, Yin Shuang, Jim Peraino, Pasquale Totaro</th>
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<td>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.</td>
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<th>143.</th>
<th><strong>Inflated Appetite</strong></th>
<th>Hiroshi Ishii, Jifei Ou, Wen Wang, Lining Yao Chin-Yi Cheng</th>
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<td>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 &quot;communicate&quot; 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.</td>
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<th>144.</th>
<th><strong>inFORM</strong></th>
<th>Hiroshi Ishii, Daniel Leithinger, Alex Olwal</th>
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<td>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.</td>
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<td>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.</td>
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<th>146.</th>
<th><strong>Kinetix</strong></th>
<th>Hiroshi Ishii, Jifei Ou, Jannik Peters</th>
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<td>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. What the resulting KinetiX structures look like and what characteristics they possess are determined with the help of computer-supported simulations. This makes it possible to derive mathematical models that contain the physical properties and design attributes of the material. Various configurations of the KinetiX structure are then tested by architectural software and stored to a library of various design options.</td>
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<th>147.</th>
<th><strong>LineFORM</strong></th>
<th>Hiroshi Ishii, Ken Nakagaki</th>
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<td>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.</td>
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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.

**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.

**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.

**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 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.

**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.
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

Programmable Droplets

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.

Radical Atoms

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.

TRANSFORM

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.

TRANSFORM: Adaptive and Dynamic Furniture

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.
Hiroshi Ishii, Daniel Visan Levine, Wen Wang, Lining Yao Chin-Yi Cheng, Teng Zhang

We developed a concept of transformative appetite, where edible 2D films made of common food materials (protein, cellulose or starch) can transform into 3D food during cooking. This transformation process is triggered by water adsorption, and it is strongly compatible with the ‘flat packaging’ concept for substantially reducing shipping costs and storage space. To develop these transformable foods, we performed material-based design, established a hybrid fabrication strategy, and conducted performance simulation. Users can customize food shape transformations through a pre-defined simulation platform, and then fabricate these designed patterns using additive manufacturing. Three application techniques are provided: 2D-to-3D folding, hydration-induced wrapping, and temperature-induced self-fragmentation, to present the shape, texture, and interaction with food materials. Based on this concept, several dishes were created in the kitchen, to demonstrate the futuristic dining experience through materials-based interaction design.
Joseph M. Jacobson: Molecular Machines

Engineering at the limits of complexity with molecular-scale parts

Affinity: Deep learning API for molecular geometry

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

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 Alane Scans and other experimental methods, contributing to the study of diseases and development of new therapeutics.

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.

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

Kent Larson, Luis Alberto Alonso Pastor, Nai Chun Chen, Juanita Devis, Ronan Doorley, Arnaud Grignard, Yan Leng, Carson Smuts, J. Ira Winder, Yan Zhang Nina Lutz

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.

Kent Larson, Luis Alberto Alonso Pastor, Juanita Devis, Arnaud Grignard, Jason P. Nawyn, 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 (OBSE), Marc Vilella (OBSE), Oriol Travesset (OBSE), Jordi Martin (University of Girona), Xavier Forne (FEDA), Josep Ribes (ActuaTech), Oriol Lordan (University of Barcelona), Cristina Yañez (UdA), Francesco Pilia, Anna Penzo, Tossaporn Saengja, Ronald Dooley, Yan Leng, Anna Sinelnikova, Brian Wheatman, Alejandro Noriega

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
Kent Larson, Luis Alberto Alonso Pastor, Juanita Devis, Ronan Doorley, Arnaud Grignard, Ariel Noyman, J. Ira Winder Naichun Chen, Yan Leng, Alejandro Noriega, Joseph Cunningham, Reijul Sachdev, Claire Tsao, David Sukhin, Tanya Ivonchyk, 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, and 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.

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

**AUGMENTED REALITY URBAN SIMULATION**

cityI/O is intended to reduce complexity in design and planning tools and to support data-driven environment for planners, designers and decision makers. cityI/O uses modern simulation tools and employs cutting edge AR applications in order to offer an immersive user experience for planning professionals and the general public alike. 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, cityI/O offers cities, municipalities and planning authorities the ability to better communicate complex planning processes and to aggregate the public’s opinion in real time. cityI/O’s scalable server side allows multiple users to collaborate, participate and voice their opinion on design and planning initiatives.

**CITYI/O HAMBURG**

cityI/O Hamburg augmenting cityMatrix table. This deployment allows design in the urban context of Rothenburgsort neighborhood.

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

**CityMatrix - An Urban Decision Support System Augmented by Artificial Intelligence**

**Thesis Citation**

**Abstract**

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.
Kent Larson, Luis Alberto Alonso Pastor, Juanita Devis, Ronan Doorley, Arnaud Grignard, Michael Lin, Jason P. Nawyn, Ariel Noyman, Carson Smuts, Phil Tinn, Yan Zhang Núria Macià,Marc Villeda (OBSA), Marc Pons (OBSA), Guillemin Francisco Giné (OBSA), Cristòlia 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 & Environment, Mobility, Dynamic urban planning) for the future urban challenges of the country. We are collaborating on a unique initiative providing Andorrans research, knowledge, methods and tools to carry out such transformation.

Learn more below about City Science Andorra research below.

Kent Larson, Luis Alberto Alonso Pastor, Arnaud Grignard, Ariel Noyman

Aalto University, Finland, and the MIT Media Lab’s City Science Initiative 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).

Kent Larson, Ariel Noyman, J. Ira Winder

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.

Tongji University, Shanghai, and the MIT Media Lab’s City Science team 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.

Join international mayors, technical experts, high level CEOs and academics as we discuss and model our cities latest visualization tools. Join us as we discuss service platforms, co-creative city structures, and our future beyond the smart city. We strive to create more livable, innovative and entrepreneurial cities using dynamic urban programming for innovative futures.

Learn more and register here

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.

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 distilment 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.
Kent Larson, Mohammad Hadhrawi, J. Ira Winder
We recently led a workshop in Saudi Arabia, with staff from the Riyadh Development Authority, to test a new version of our CityScope platform. With only an hour to work, four teams of five professionals competed to develop a redevelopment proposal for a neighborhood near the city center. The platform evaluated their designs according to energy, daylighting, and walkability.

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.

Kent Larson, Chrisoula Kapelonis, Carson Smuts
The esc-Pod (or Escape Pod): 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.

Kent Larson, J. Ira Winder &nbsp;Nina Lutz (MIT)
This is an open source geo spatial exploration tool. Using various public APIs including Open Street Map and the United States Census, we can make dynamic, flexible models of how people are moving through the city. These models include accessibility in cities, multimodal transportation networks, and diversity. Overall this allows anyone with or without an urban planning background to build strong models with geospatial and urban data. This system works dynamically with a Tactile Matrix, which is an interactive decision support system that allows users to instantly and collaboratively explore the models in a tangible way.

Photos by Nina Lutz.

Kent Larson, J. Ira Winder &nbsp;Giovanni Giorgio (GSK)&nbsp;Joana Gomes (GSK)&nbsp;Mason Briner (GSK)&nbsp;Joyce Chen (MIT)&nbsp;Andrew Rutter (GSK)&nbsp;John Dyson (GSK)&nbsp;Marti Head (GSK)&nbsp;Magalie Rocheville (GSK)&nbsp;
This project is the first of two projects in collaboration with GSK. We are developing a computational simulation that allows a human user (or AI) to test drug manufacturing investment scenarios for an entire portfolio over multiple years. We aspire to help decision-makers understand the possible impact of new techniques such as CBM on selected key performance metrics. This game like simulation allows various stakeholders to come together and make collaborative decisions regarding the entire supply chain. The software works dynamically with a Tactile Matrix, which is an interactive decision support system that allows users to instantly and collaboratively explore the models in an approachable, tangible way.

Screenshots courtesy of Ira Winder. Photos by Nina Lutz.

Kent Larson, J. Ira Winder &nbsp;Nina Lutz (MIT)&nbsp;Yusuf Roohani (GSK) &nbsp;Joyce Chen (MIT)&nbsp;Amy Taylor (GSK) &nbsp;Rusty Fries (GSK) &nbsp;Lynn Tucker (GSK) &nbsp;Marti Head (GSK) &nbsp;Magalie Rocheville (GSK)
This is the second project from the GSK collaboration. This project considers how space and collaboration are intertwined. We are developing a computational simulation and tool that allows stakeholders from across the GSK organization to modify their existing pharmaceutical site to encourage collaboration between scientists and optimize for space and time efficiency. Our model is a case study in how one’s workplace influences their tasks and interactions. The software works dynamically with a Tactile Matrix, which is an interactive decision support system that allows users to instantly and collaboratively explore the models in an approachable, tangible way. Users can change the population by adding more scientists and can change the site by suggesting architectural changes and moving places and equipment.

Screenshots courtesy of Nina Lutz.
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 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.

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.

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.

Kent Larson, Luis Alberto Alonso Pastor, Ronan Doorley, Arnaud Grignard, Esteban Moro Egido, Ariel Noyman Zhekun Xiong [MIT SA+P], Nuria Macia [Acuta Andorra]&nbsp;
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

Work by Ariel Noyman, Ronan Doorley, Zhekun Xiong, Luis Alonso, Arnaud Grignard Advised by 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.
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.

Kent Larson, J. Ira Winder Nina Lutz (MIT)
This project focused on pedestrian accessibility in collaboration with Singapore Centre for Liveable Cities. Researchers and planners came together to design an interface that would allow both citizens and planners to interact with a model regarding pedestrian accessibility. The tangible interface allows users to come together to have conversations and make interventions to make the case study area more accessible for pedestrians.

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.

Spatial Flux: A seamless pneumatic surface that morphs to embrace the human body in zero gravity.

Carson Smuts J P Nawyn is also an author, creator, and collaborator on this project.
View the TerMITes website for more information
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 WiFi 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.

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.

Kent Larson, Luis Alberto Alonso Pastor, Ryan C. C. Chin, Arnaud Grignard, Mohammad Hadhrawi, Michael Lin, Ariel Noyman, Carson Smuts, Phil Tinn, J. Ira Winder, 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.
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.

To address these issues, the City Science group proposes a holistic research framework encompassing five themes:

- **Persuasive Electric Vehicle** — What is a truly suitable system design for the emerging urban context and societal aspirations?
- **Human-Machine Cooperation** — How can we facilitate coexistence, trust-building, and collaboration between people and machines, especially in pedestrian areas?
- **Smart Infrastructure** — What sort of new infrastructure can help sustain public sector participation/operation and maximize public interest and safety?
- **Service Deployment and Optimization** — How do we forecast the supply of fleets to meet emerging travel demands and service needs in cities?
- **Open-Source Platform** — How can new technology respond to the diverse industrial, socio-economic, and educational needs of society?

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.

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

195. **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 on the range. 8K Time into Space aims to provide responsive and intuitive experiences for video consumption.

196. **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.

197. **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 timeline. 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.

198. **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 PubPub, the main project.

199. **FiftyNifty**  
Andrew Lippman, 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.
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.

IoT Recorder
Andrew Lippman, Thariq Shihipar
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.

MedRec
Agnes Cameron, Nchinda Nchinda, Kallirroi Retzepi
Electronic Health Records (EHRs) were never designed to manage the complexities of multi-institutional, lifetime medical records. As patients move between providers, their data becomes scattered across different organisations, losing easy access to past records. As providers — not patients — are the primary stewards of EHRs, patients face significant hurdles in viewing their reports and correcting erroneous data. This also forms an interoperability challenge between different provider and hospital systems, where IT providers can charge exorbitant prices for data exchange interfaces, as "information blocking" is economically incentivised.

Medrec proposes a system that prioritises patient agency, giving a transparent and accessible view of medical history. Most importantly, patients must be assured that their records (and the metadata associated with them) remain fully confidential, to retain trust and continued participation in the medical system. The blockchain provides the means for this — as a 'trustless' model for storing transactions.

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

NewsClouds
Andrew Lippman, Thariq Shihipar
NewsClouds presents a visual exploration of how the news reporting of an event evolves over time. Each "cloud" represents a publication and each competing news organization usually emphasizes different aspects of that same story. Using the time sliders, that evolution becomes evident. In addition, each word or phrase can be expanded to show its links and context. We are building an archive of events associated with ongoing US election developments.

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.
Panorama

An interface for smashing filter bubbles, Panorama is built to allow open, transparent, and collaborative exploration of news from all across the political map. It presents different perspectives and encourages serendipity in news exploration, versus getting all of our news from one single source. Panorama is a human-in-the-loop interface. The computer processes more than 10,000 news stories each day, both broadcast and written, and it uses machine learning algorithms to decide what topics each story is talking about and if the stories are positive, subjective, or trending. The machine learning process pours over massive datasets and learns to generalize in smart ways, but not in the same smart ways that humans generalize. As a result, it can be brilliant and also get very confused. With Panorama, some of the training data was a large open set of movie reviews, and while this is a great dataset to start with, it is not mapped so well to news stories. As humans interact with Panorama, they are encouraged to give better labels to stories; those labels are fed back into the algorithm to make it better.

Having a lot of information about each news story and all stories together allows us to create an open-box news aggregator. With most aggregators we use today (like the Facebook News feed), the user has no idea what are the algorithms and filters that decide what s/he will see. Panorama is open; the user can decide to view everything, or filter only to specific things that he s/he is interested in, by playing with the sliders and seeing in real time how the news feed changes accordingly. For example, you could easily get all stories about animals, from the right side of the political map, that are also positive and objective. Panorama also exposes interesting patterns, such as the topics that different news sources focus on every day, and what sources had many objective versus subjective stories.

Perspectives

The news is probably one of the first things people check in the morning, but how much does what you know and understand about the world depend on your news source? Will you view the world differently if you head over to CNN instead of BBC?

“Perspectives” is presenting top news stories from many points of view. The viewer can easily see the different perspectives and get the whole story.

PubPub

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.

Solar Micro-Mining

Bitcoin generates net-new value from "mining" in a distributed network. In this work, we explore solar micro-mining rigs that transform excess energy capacity from renewable energy (hard to trade) into money (fungible). Each rig runs a small Bitcoin miner and produces Bitcoin dust for micropayments. We envision these micro-miners populating a highly distributed network, across rooftops, billboards, and other outdoor spaces. Where systematic or environmental restrictions limit the ability to freely trade the underlying commodity, micro-mining produces new economic viability. Renewable energy-based, micropayment mining systems can broaden financial inclusion in the Bitcoin network, particularly among populations that need a currency for temporary store of value and must rely on flexible electricity off the grid (e.g., unbanked populations in the developing world). This exploration seeds a longer-term goal to enable open access to digital currency via account-free infrastructure for the public good.

Super Cut Notes

A large portion of popular media is remixed: existing media content is spliced and re-ordered in a manner that serves a specific narrative. Super Cut Notes is a semi-comical content remix tool that allows a user to splice and combine the smallest bits of media: words. By tapping into the dataset of our group’s SuperGlue platform, it has access to a huge dictionary of words created by SuperGlue’s transcription module. Users are able to input a text of any length, choose video-bits of individual words that match their text, and create a video of their combination—in the style of cut-and-pasted ransom notes.

SuperGlue

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.
<table>
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<tr>
<th></th>
<th><strong>The Glass Infrastructure (GI)</strong></th>
<th>Andrew Lippman, Michail Bletsas, Richard D. Borovoy, Jon Ferguson, Catherine Havasi, Henry Holtzman, Polychronis Ypodimitopoulos</th>
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<td>This project builds a social, place-based information window into the Media Lab using 30 touch-sensitive screens strategically placed throughout the physical complex and at sponsor sites. The idea is get people to talk among themselves about the work that they jointly explore in a public place. We present Lab projects as dynamically connected sets of “charms” that visitors can save, trade, and explore. The GI demonstrates a framework for an open, integrated IT system and shows new uses for it.</td>
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<th><strong>This Is How</strong></th>
<th>Andrew Lippman, Tomer Weller</th>
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<td>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.</td>
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<th><strong>VR Codes</strong></th>
<th>Andrew Lippman</th>
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<td>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.</td>
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<th><strong>Wall of Now</strong></th>
<th>Andrew Lippman, Tomer Weller</th>
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<td>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.</td>
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<th><strong>Watch People Watch</strong></th>
<th>Andrew Lippman, Suzanne Wang, Tomer Weller</th>
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<td>Recording your reaction to a short video is becoming the new gossip; famous watchers get as many as 750,000 views. We attempt to transform this utterly useless and talentless event into a socially constructive alternative to simultaneous, synchronized, group viewing. Any user can opt in to be recorded and added to the shared, collective viewing experience. No talent or skills required.</td>
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# Tod Machover: Opera of the Future

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

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<th>216.</th>
<th>Aether Muse</th>
<th>Charles Holbrow</th>
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<td>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.</td>
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<th>217.</th>
<th>Ambisonic Surround-Sound Audio Compression</th>
<th>Tod Machover, Charles Holbrow</th>
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<td>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.</td>
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<th>218.</th>
<th>Breathing Window</th>
<th>Tod Machover, Rebecca Kleinberger</th>
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<td>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.</td>
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<tr>
<th>219.</th>
<th>...but not simpler...</th>
<th>Tod Machover</th>
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<td></td>
<td>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!</td>
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<th>220.</th>
<th>Chronosonogy: Sonic Sensory Time Shifting</th>
<th>Alexandra Rieger</th>
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<td>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.</td>
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221. **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.

222. **Cognitarium**

**Alexandra Rieger**

Cognitarium is a dynamic experiential preview of our early groundbreaking research in multimodal music and cognition. Distilled elements from innovative experiments, meld to create an in-room planetarium for the mind—underscored with selective frequencies, sounds defined by Tod Machover and performed live by cutting-edge double bassist Emilio Guarino.

As we collaborate within the neuroscience "space race," early findings reveal promising ways music-based applications could change the way we maneuver within the word. While learning to communicate with our brains through multisensory platforms, we hope to generate novel approaches to pathologies and illnesses in health and medicine, while broadening preventative, creative, and compositional possibilities.

223. **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.

224. **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.
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.

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.

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.

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.

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.
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.

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.

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.

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.

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.
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.

Nebula is a voice-controlled interactive software app that allows 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.

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 discovery 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 we are 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.

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.
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.

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.

Sound Cycles

Tod Machover, Charles Hollbrow, 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.

Spaces That Perform Themselves

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. The objective is to create a new type of architectural typology that morphs responsively with a musical piece. Presenting spatial and musical composition as one synchronous entity.

The goal is to create a multisensory environment where music’s perpetually changing characteristics reconfigure the spatial organization of a space. This space - a hanging cube - will perform a spatial choreography of sound, movement, light and color: presenting a dynamic room that is alive and in constant flux. This performance will construct an aesthetic experience that challenges models of thinking, presenting a post-humanistic phenomenological encounter of the world to stretching our cognition and malleable forms.

Spaces That Perform Themselves

Nicole L’Huillier

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.

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.
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.

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, screen.

Nicole L’Huillier, Sands Fish, 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.

Nicole L’Huillier and Sands Fish

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.
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.

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

Inventing the next-generation mobile device—highly personalized, wearable, and immersive—to support our unique needs and goals

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.

Pattie Maes, Arnav Kapur

AlterEgo

is a closed-loop, non-invasive, wearable system that allows humans to converse in high-bandwidth natural language with machines, artificial intelligence assistants, services, and other people without any voice—without opening their mouth, and without any discernible movements—simply by vocalizing internally. The wearable captures electrical signals, induced by subtle but deliberate movements of internal speech articulators when a user intentionally vocalizes internally, in likeness to speaking to one’s self. We use this to facilitate a bi-directional natural language computing system, where users receive aural output through bone-conduction earphones without obstructing a user’s physical senses. 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 and without invasion of the user’s privacy. AlterEgo aims to combine humans and computers—such that computing, the internet, and AI would weave into human personality as a “second self” and augment human cognition and abilities.

Pattie Maes, Joseph A. Paradiso

Augmented Airbrush

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.

Pattie Maes, Misha Sra, Prashanth Vijayaraghavan

Auris: Creating Affective Virtual Spaces from Music

Light, color, texture, geometry and other architectural design elements have been shown to produce predictable and measurable effects on our minds, brains, and bodies. This suggests spaces that can mirror or transform feelings or serve specific purposes like improving learning or enhancing wellbeing can be designed. With Auris, we take a first step towards the design of such spaces in virtual reality by attempting to automatically generate affective virtual environments that can affect our emotions. The input to Auris is a song (audio and lyrics) and the output is a VR world that encapsulates the mood and content of the song.
| 255. | **Body Quest: A Room-Scale VR Playground for Biology and Chemistry** | Scott W. Greenwald Wilhelm Weihofen, Theji Jayaratne, Wiley Corning, Max Rose  
Body Quest is a room-scale virtual reality playground for learning about biology and chemistry. Learning about how complex microscopic 3D structures interact is hard on paper, and only slightly easier with videos or passive 3D simulations. Interactive, room-scale VR environments open up new possibilities for building an intuitive and visual understanding of these subjects—and it can even be fun!  
Our video was submitted to the DOE EdSim Challenge. It is a fully functional prototype—the mixed reality video representing the physical and virtual experiences were composited in real-time by calibrating physical and virtual cameras, while filming in front of a green screen. The prototype is built around one particular biochemical interaction, whereby a viral protein cleaves sugar off the end of a mucus chain. We hope to develop future learning interactions around a general simulation backend, which will host both structured and unstructured learning experiences, including games. |
| 256. | **BrainVR: A Neuroscience Learning Experience in Virtual Reality** | Pattie Maes, Scott W. Greenwald Alex Norton and Amy Robinson (EyeWire), Daniel Citron (Harvard University)  
BrainVR is a learning experience for neuroscience that leverages motion-tracked virtual reality to convey cutting-edge knowledge in neuroscience. In particular, an interactive 3D model of the retina illustrates how the eye detects moving objects. The goal of the project is to explore the potential of motion tracked virtual reality for learning complex concepts, and build reusable tools to maximize this potential across knowledge domains. |
| 257. | **CocoVerse: A Playground for Cocreation and Communication in Virtual Reality** | Pattie Maes, Scott W. Greenwald  
Real-time collaborative self-expression in virtual reality. |
| 258. | **DermalAbyss: Possibilities of Biosensors as a Tattooed Interface** | Pattie Maes, Joseph A. Paradiso, Nicholas Barry, Virj Kan, Xin Liu, Katia Vega  
Can tattoos embrace technology in order to make the skin interactive?  
The DermalAbyss project is the result of a collaboration between MIT researchers Katia Vega, Xin Liu, Virj Kan and Nick Barry and Harvard Medical School researchers Ali Yetisen and Nan Jiang.  
DermalAbyss is a proof-of-concept that presents a novel approach to bio-interfaces in which the body surface is rendered an interactive display. Traditional tattoo inks are replaced with biosensors whose colors change in response to variations in the interstitial fluid. It blends advances in biotechnology with traditional methods in tattoo artistry.  
This is a research project, and there are currently no plans to develop Dermal Abyss as a product or to pursue clinical trials. |
| 259. | **Dormio: Interfacing with Dreams to Augment Human Creativity** | Ishaan Grover, Adam Haar Horowitz, Pedro Reynolds-Cuellar  
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 out on an opportunity to access information from the unique cognition ongoing during dreams and drowsiness. 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 social robots’ unique interactive and embodied capabilities, accompanied by 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. |
| 260. | **EmotionalBeasts** | Guillermo Bernal  
An experiment with the manipulation of a user’s self-expression in VR space and as well as the perception of others in it, providing some valuable tools to evoke a desired emotional reaction |
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.

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.

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.

EyeRing is a wearable, intuitive interface that allows a person to point at an object to see or hear more information about it. We came up with the idea of a micro-camera worn as a ring on the index finger with a button on the side, which can be pushed with the thumb to take a picture or a video that is then sent wirelessly to a mobile phone to be analyzed. The user tells the system what information they are interested in and receives the answer in either auditory or visual form. The device also provides some simple haptic feedback. This finger-worn configuration of sensors and actuators opens up a myriad of possible applications for the visually impaired as well as for sighted people.

FingerReader is a finger-worn device that helps the visually impaired to effectively and efficiently read paper-printed text. It works in a local-sequential manner for scanning text that enables reading of single lines or blocks of text, or skimming the text for important sections while providing auditory and haptic feedback.

Fluxa is a compact wearable device that exploits body movements, as well as the visual effects of persistence of vision (POV), to generate mid-air displays on and around the body. When the user moves his/her limb, Fluxa displays a pattern that, due to retinal afterimage, can be perceived by the surrounding people. We envision Fluxa as a transient wearable display to foster richer self-expression and communication in daily life. It can be used to enhance existing social gestures such as handwaving to get attention, as a communicative tool that displays the speed and distance covered by joggers, and as a decoration device that generates images around dancing bodies.

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 show that this method is effective and more feasible than current efforts to influence eating habits.
GVS or galvanic vestibular stimulation is a technology that directly affects a user’s vestibular system by altering their sense of balance and direction. It works through electrical stimulation via electrodes placed on the mastoid bones behind each ear. In standing users, GVS evokes a prolonged “galvanic body sway.” In walking users, it affects balance and causes users to stagger in the anodal direction. However, in walking users, with their head pitched forward, it causes them to turn smoothly from their planned trajectory in the anodal direction. Dark Room is a cooperative asymmetrical “escape the room” style game played by a VR and a PC user, inspired by the singleplayer mobile game Dark Echo. The PC user controls the walking direction of the VR user to guide them around virtual or physical obstacles. The VR player uses echolocation to detect obstacles.

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.

Pattie Maes, Pedro Colon-Hernandez, Anna Fuste, Mina Khan, Christian David Vazquez Machado

The onset of Mixed Reality as a platform offers the opportunity to create new playful paradigms for building and fostering creativity. The Holobits application leverages the tried and tested features of physical block building platforms like LEGO and introduces the benefits of building in mixed environments to support making and storytelling. The proposed system combines the hand tracking capabilities of the Leap Motion with the spatial mapping of Hololens to enable hands-on building experiences with virtual blocks, denoted as “bits.” These blocks have different attributes and characteristics that determine how they look and behave within the mixed reality building space. The platform also allows users to share their creative building process in a frame-by-frame fashion that enables remixing and reflection on every play session. Holobits allows users to record their interactions with their creations to create animated environments with ease and support storytelling. Another way to enable collaboration is to let kids share models (or download someone else’s creation in your space), allowing multiple users to build in a shared physical space or over distances, where a player can “hop” into the physical space of the Hololens user using virtual reality. Last but not least, we intend to integrate the Scratch visual programming toolkit into the Holobits platform to allow users to orchestrate their virtual creations and create the ultimate interactive stories.

Pattie Maes, Valentin Heun

HRQR is a visual Human and Machine Readable Quick Response Code that can replace usual 2D barcode and QR Code applications. The code can be read by humans in the same way it can be read by machines. Instead of relying on a computational error correction, the system allows a human to read the message and therefore is able to reinterpret errors in the visual image. The design is highly inspired by a 2,000 year-old Arabic calligraphy called Kufic.

Pattie Maes, Judith Amores Fernandez

Invisibilia seeks to explore the use of Augmented Reality (AR), head-mounted displays (HMD), and depth cameras to create a system that makes invisible data from our environment visible, combining widely accessible hardware to visualize layers of information on top of the physical world. Using our implemented prototype, the user can visualize, interact with, and modify properties of sound waves in real time by using intuitive hand gestures. Thus, the system supports experiential learning about certain physics phenomena through observation and hands-on experimentation.

Pattie Maes, Niaja Farve

Move Your Glass is an activity and behavior tracker that also tries to increase wellness by nudging the wearer to engage in positive behaviors.

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.
### Oasis

**Pattie Maes, Misha Sra**

Oasis won Silver at the Edison Awards 2017.

Oasis received the Best Paper Award at VRST 2016.

Oasis is a novel system for automatically generating immersive and interactive virtual reality environments using the real world as a template. The system captures indoor scenes in 3D, detects obstacles like furniture and walls, and maps walkable areas to enable real-walking in the generated virtual environment. Depth data is additionally used for recognizing and tracking objects during the VR experience. The detected objects are paired with virtual counterparts to leverage the physicality of the real world for a tactile experience. Our system allows a casual user to easily create and experience VR in any indoor space of arbitrary size and shape without requiring specialized equipment or training.

Oasis can be used, for example, to create storyspaces where friends and family can remotely participate in a session of storytelling around the campfire. The freedom to move around and interact with the virtual world allows for a new form of storytelling when combined with traditional narration techniques like vocalization, movement, and gestures. We call this human-in-the-loop storytelling, distinguishing it from current VR storytelling experiences where the software system is the storyteller.

### Open Hybrid

**Pattie Maes, Valentin Heun**

Open Hybrid is an open source augmented reality platform for physical computing and Internet of Things. It is based on the web and Arduino.

### PhysioHMD

**Guillermo Bernal**

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 and 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 used to determine how changes in their physiological state relate to their actions and decisions.

### PsychicVR

**Pattie Maes, Judith Amores Fernandez, Daniel Novy**

PsychicVR 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.

### Reality Editor

**Pattie Maes, Valentin Heun, James Hobin, Benjamin Reynolds**

The Reality Editor is a new kind of tool for empowering you to connect and manipulate the functionality of physical objects. Just point the camera of your smartphone at an object and its invisible capabilities will become visible for you to edit. Drag a virtual line from one object to another and create a new relationship between these objects. With this simplicity, you are able to master the entire scope of connected objects.
### Reality Editor 2.0

**Pattie Maes, Valentin Heun**

The Reality Editor is a web browser for the physical world: Point your phone or tablet at a physical object and an interface pops up with information about that object as well as services related to that object. The Reality Editor platform is open and entirely based on web standards making it easy for anyone to create Reality Editor enabled objects as well as Reality Editor applications that integrate the physical and digital world in one experience.

**Reality Editor version 2.0**

Reality Editor version 2.0 is now available for download and adds the following features:

- **World Wide Web conform content creation.**
- **Spatial Search** - Instantly browse through relevant information in the physical world around you. You to browse reality.
- **Bi-Directional AR** - A real-time interactions system.
- **Private and Decentralized infrastructure for connecting the IoT objects.**
- **Logic Crafting** - A visual programming language designed for Augmented Reality.

The Reality Editor works on iOS and you can get it here. Try it out with our Starter App and some Philips Hue Lights or the Lego WeDo 2.0. Learn more about Logic Crafting in our User Interface 101.

### Remot-IO: A System for Reaching into the Environment of a Remote Collaborator

**Pattie Maes, Judith Amores Fernandez**

Remot-IO is a system for mobile collaboration and remote assistance around Internet-connected devices. It uses two head-mounted displays, cameras, and depth sensors to enable a remote expert to be immersed in a local user's point of view, and to control devices in that user's environment. The remote expert can provide guidance through hand gestures that appear in real time in the local user's field of view as superimposed 3D hands. In addition, the remote expert can operate devices in the novice's environment and bring about physical changes by using the same hand gestures the novice would use. We describe a smart radio where the knobs of the radio can be controlled by local and remote users. Moreover, the user can visualize, interact, and modify properties of sound waves in real time by using intuitive hand gestures.

### 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.

### ShowMe: Immersive Remote Collaboration System with 3D Hand Gestures

**Pattie Maes, Judith Amores Fernandez**

ShowMe is an immersive mobile collaboration system that allows remote users to communicate with peers using video, audio, and gestures. With this research, we explore the use of head-mounted displays and depth sensor cameras to create a system that (1) enables remote users to be immersed in another person's view, and (2) offers a new way of sending and receiving the guidance of an expert through 3D hand gestures. With our system, both users are surrounded in the same physical environment and can perceive real-time inputs from each other.

### Skrin

**Pattie Maes, Joseph A. Paradiso, Xin Liu, Katia Vega**

Skrin is an exploration project on digitalized body skin surface using embedded electronics and prosthetics. Human skin is a means for protection, a mediator of our senses, and a presentation of our selves. Through several projects, we expand the expression capacity of the body's surface and emphasize the dynamic aesthetics of body texture by technological means.
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.

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.

Pattie Maes, Judith Amores Fernandez

TagMe is an end-user toolkit for easy creation of responsive objects and environments. It consists of a wearable device that recognizes the object or surface the user is touching. The user can make everyday objects come to life through the use of RFID tag stickers, which are read by an RFID bracelet whenever the user touches the object. We present a novel approach to create simple and customizable rules based on emotional attachment to objects and social interactions of people. Using this simple technology, the user can extend their application interfaces to include physical objects and surfaces into their personal environment, allowing people to communicate through everyday objects in very low-effort ways.

Adam Haar Horowitz Boo Aguilar, Fernando Magalhaes, João Rosa, Matheus de Paula

This is the first episode of ‘The Blank Canvas’, a Virtual Reality platform that showcases the future of science and scientific communication, today. 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 all in Magic School Bus style. We build collaborations between scientists and engineers for accurate, inspirational science storytelling that turns textbooks into experience.

The Blank Canvas directs immersion inwards, augmenting awareness of the microscopic worlds inside each of us and the science that is changing them today.

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.

Pattie Maes, Xin Liu, Yedan Qian

Tree is a virtual experience that transforms you into a rainforest tree. With your arms as branches and body as the trunk, you experience the tree’s growth from a seedling into its fullest form and witness its fate firsthand. Tree debuted at Sundance Film Festival 2017 New Frontier and also had its presentation in Tribeca Film Festival 2017.

The project is part of our research about body ownership illusion in Virtual Reality (early project: TreeSense). The tactile experience is crucial for establishing a body ownership illusion instead of restricting the experience to the visual world. We aim to have the audience not just see, but feel and believe “being” a tree.

The setup involves adding one controller/tracker per foot and one at the base of the back along with two hand-held controllers and the HMD. I’m using the FinalIK asset from the Unity Asset Store.
### 292. 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.

### 293. 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.

### 294. WordSense

**Pattie Maes, Christian David Vazquez Machado Takako Aikawa, Alexander Luh, Megan Fu, Afika Nyati**

As more powerful and spatially aware Augmented Reality devices become available, we can leverage the user’s context to embed reality with audio-visual content that enables learning in the wild. Second-language learners can explore their environment to acquire new vocabulary relevant to their current location. Items are identified, "labeled" and spoken out loud, allowing users to make meaningful connections between objects and words. As time goes on, word groups and sentences can be customized to the user’s current level of competence. When desired, a remote expert can join in real-time for a more interactive "tag-along" learning experience.

### 295. Words in Motion

**Pattie Maes, Christian David Vazquez Machado Takako Aikawa, Louisa Rosenheck**

Embodied theories of language propose that the way we communicate verbally is grounded in our body. Nevertheless, the way a second language is conventionally taught does not capitalize on kinesthetic modalities. The tracking capabilities of room-scale virtual reality systems afford a way to incorporate kinesthetic learning in language education. Words in Motion is a virtual reality language learning system that reinforces associations between word-action pairs by recognizing a student’s movements and presenting the corresponding name of the performed action in the target language. Experiments with Words in Motion suggest that the kinesthetic approach in virtual reality has less immediate learning gain in comparison to a text-only condition. However, virtual kinesthetic learners showed significantly higher retention rates after a week of exposure. Positive correlation between the times a word-action pair was executed and the times a word was remembered by the subjects, supports the premise that virtual reality can impact language learning by leveraging kinesthetic elements.
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.

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 1kW. 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.

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.

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.

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))
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.

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.

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.

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.

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.

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.
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.

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.

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.

Neri Oxman

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.

Neri Oxman

Gemini

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.

Neri Oxman

Chikara Inamura, Markus Kayser, John Klein, Daniel Lizardo, Michael Stern

Glass I

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.
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.

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.

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.

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?

A collaboration between Professor Christine Ortiz (project lead), Professor Mary C. Boyce, Katia Zolotovsky, and Swati Varshaney (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.
Monocoque

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.

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.

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.

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.

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.

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.
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.

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.

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.

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.

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.
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.

Neri Oxman, Christoph Bader, Jorge Duro-Royo, Nicolas Hogan, Andrea Ling, Laia Mogas-Soldevilla, Yen-Ju (Tim) Tai, Joshua Van Zak Dr. Javier G. Fernandez (Wyss Institute, Harvard University)
Joseph A. Paradiso: Responsive Environments

Augmenting and mediating human experience, interaction, and perception with sensor networks

332. **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.

333. **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.

334. **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.

335. **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.

336. **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.

337. **Circuit Storybook**  
Joseph A. Paradiso, Kevin Slavin, Jie Qi Sonja de Boer  
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<td>DermalAbyss: Possibilities of Biosensors as a Tattooed Interface</td>
<td>Pattie Maes, Joseph A. Paradiso, Nicholas Barry, Viirj Kan, Xin Liu, Katia Vega</td>
<td>The DermalAbyss project is the result of a collaboration between MIT researchers Katia Vega, Xin Liu, Viirj Kan and Nick Barry and Harvard Medical School researchers Ali Yetisen and Nan Jiang. DermalAbyss is a proof-of-concept that presents a novel approach to bio-interfaces in which the body surface is rendered an interactive display. Traditional tattoo inks are replaced with biosensors whose colors change in response to variations in the interstitial fluid. It blends advances in biotechnology with traditional methods in tattoo artistry. This is a research project, and there are currently no plans to develop Dermal Abyss as a product or to pursue clinical trials.</td>
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<td>339.</td>
<td>DoppelLab: Experiencing Multimodal Sensor Data</td>
<td>Joseph A. Paradiso, Gershon Dublon, Brian Mayton</td>
<td>Homes and offices are being filled with sensor networks to answer specific queries and solve predetermined 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.</td>
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<td>340.</td>
<td>Doppelmarsh: Cross-Reality Environmental Sensor Data Browser</td>
<td>Joseph A. Paradiso, Gershon Dublon, Don Derek Haddad, Evan Lynch, Brian Mayton, Spencer Russell</td>
<td>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.</td>
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<td>341.</td>
<td>Experiential Lighting: New User Interfaces for Lighting Control</td>
<td>Joseph A. Paradiso, Matthew Aldrich, Nan Zhao</td>
<td>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 &quot;Experiential Lighting,&quot; 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).</td>
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<td>342.</td>
<td>FabricKeyboard</td>
<td>Joseph A. Paradiso, Irmandy Wicaksono</td>
<td>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.</td>
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**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.

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**Fluxa**

**Pattie Maes, Joseph A. Paradiso, Xin Liu, Katia Vega**

Fluxa is a compact wearable device that exploits body movements, as well as the visual effects of persistence of vision (POV), to generate mid-air displays on and around the body. When the user moves his/her limb, Fluxa displays a pattern that, due to retinal afterimage, can be perceived by the surrounding people. We envision Fluxa as a transient wearable display to foster richer self-expression and communication in daily life. It can be used to enhance existing social gestures such as handwaving to get attention, as a communicative tool that displays the speed and distance covered by joggers, and as a decoration device that generates images around dancing bodies.

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**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 grappling 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.

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**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.

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**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.
As the restoration proceeds, we have deployed hundreds of wireless sensors to track the environment as it is transformed. Data from the sensors is made available in real time, feeding a multitude of projects within Responsive Environments. We are currently developing the next version of our sensing platform, hundreds of which will be installed in the coming months. The sensor node measures temperature, humidity, atmospheric pressure, sound, motion, and several wavelengths of light. External probes, such as soil moisture, temperature, and redox potential can be connected as well.

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.

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.

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.

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 experience 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.

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 access 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.

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Haptic Footprint

Paul Stroehmeier

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.

HearThere: 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.

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.

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 experience 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.

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 (>90%). We demonstrate that it is a complete system that works wirelessly in real time. The device is simple and lightweight 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.

Low-Power Wireless Environmental Sensor Node

Joseph A. Paradiso, Brian Mayton

Tidmarsh is a 600-acre former cranberry farm near Plymouth, MA that is being restored to natural wetland. As the restoration proceeds, we have deployed hundreds of wireless sensors to track the environment as it is transformed. Data from the sensors is made available in real time, feeding a multitude of projects within Responsive Environments. We are currently developing the next version of our sensing platform, hundreds of which will be installed in the coming months. The sensor node measures and wirelessly transmits temperature, humidity, atmospheric pressure, sound, motion, and several wavelengths of light. External probes, such as soil moisture, temperature, and redox potential can be connected as well.
### Mediated Atmospheres

**Joseph A. Paradiso, Asaph Azaria, Robert Richer, Nan Zhao**

The Mediated Atmospheres 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 Atmospheres 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.

### 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.

### 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 statement or be worn in a more neutral, natural-looking example. 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.

### 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.

### 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.

### Quantizer: Sonification Platform for High-Energy Physics Data

**Joseph A. Paradiso, Juliana Cherston**

Inspired by previous work in the field of sonification, we are building a data-driven composition platform that will enable users to map collision event information from experiments in high-energy physics to audio properties. In its initial stages, the tool will be used for outreach purposes, allowing physicists and composers to interact with collision data through novel interfaces. Our longer-term goal is to develop strategic mappings that facilitate the auditory perception of hidden regularities in high-dimensional datasets, and thus evolve into a useful analysis tool for physicists as well, possibly for the purpose of monitoring slow control data in experiment control rooms. The project includes a website with real-time audio streams and basic event data, which is not yet public.
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| **360. 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. |
| **361. 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. |
| **362. 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. |
| **363. Skrin** | **Pattie Maes, Joseph A. Paradiso, Xin Liu, Katia Vega** | Skrin is an exploration project on digitalized body skin surface using embedded electronics and prosthetics. Human skin is a means for protection, a mediator of our senses, and a presentation of our selves. Through several projects, we expand the expression capacity of the body’s surface and emphasize the dynamic aesthetics of body texture by technological means. |
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, thus supplying 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 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.

2018 Publication in AIAA SciTech proceedings:

Follow TESSERAE in the news:
Ars Technica piece on self-assembling space stations & biomimicry

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.

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

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<td>367.</td>
<td>Augmented Eternity and Swappable Identities</td>
<td>Hossein Rahnama</td>
<td>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 &quot;borrow their identity&quot; 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.</td>
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<td>368.</td>
<td>bandicoot: A Python Toolbox for Mobile Phone Metadata</td>
<td>Alex 'Sandy' Pentland, Yves-Alexandre de Montjoye</td>
<td>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.</td>
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<td>369.</td>
<td>Blockchain: A new framework for robotic swarm systems</td>
<td>Alex 'Sandy' Pentland, Eduardo Castello Ferrer Dr. Thomas HardjonoProf. Marco Dorigo</td>
<td>Swarms of robots will revolutionize many applications, from targeted material delivery to farming. However, the characteristics that make them ideal for certain future applications (robot autonomy, decentralized control, etc.) 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.</td>
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<td>370.</td>
<td>Data-Pop Alliance</td>
<td>Alex 'Sandy' Pentland Harvard Humanitarian Initiative, Overseas Development Institute</td>
<td>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.</td>
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<td>371.</td>
<td>DeepShop: Understanding Purchase Patterns via Deep Learning</td>
<td>Alex 'Sandy' Pentland, Xiaowen Dong, Yoshihiko Suhara</td>
<td>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.</td>
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372. 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 hash table 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.

373. Healthy Blockchain
Alex 'Sandy' Pentland, Shada Alsalamah, Eduardo Castello Ferrer Dr. Hassah Alsalamah- &nbsp;King Saud University, Saudi Arabia. Dr. Shiroq Al-Megren- &nbsp;King Saud University, Saudi Arabia. Dr. Thamer Nouh- King Saud Medical City, Saudi Arabia. &nbsp;Dr. Thomas Hardjono- MIT Connection Science. Dr. &nbsp;Heba Kurdi- &nbsp;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.

374. 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.

375. 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.

376. 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 fit a statistical model on unobserved preferences using a machine learning technique from phone records. We then formalize 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.

377. 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.
381. **OPEN TrialChain**  
**Alex 'Sandy' Pentland, Shada Alsalamah Anne Kim- Computer Science and Molecular Biology, MIT Christopher Milan- MIT Connection Science, Prof. Björn Eskofier- &nbsp;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.

382. **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 Kochi industries.

383. **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 decords (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.
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<th>Number</th>
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<tr>
<td>384</td>
<td>Rhythm: Open measurement and feedback tools for human interaction</td>
<td>Dan Calacci, Oren Lederman, Akshay Mohan</td>
<td>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. Visit rhythm.mit.edu.</td>
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<td>385</td>
<td>Secure Sharing of Wildlife Data</td>
<td>Alex ‘Sandy’ Pentland, Remo Frey</td>
<td>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.</td>
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<td>386</td>
<td>SMART^2 OPAL</td>
<td>Alex ‘Sandy’ Pentland, Abdulrahman Alotaibi, Shada Alsalamah, Jose Balsa Barreiro Dr. Areej Al-Wabil-Leila Soltanisehat-Old Dominion University, USA.Dr. Michael Cavanagh-University of Sydney, Australia.</td>
<td>Privacy-preserving mHealth application using Open Algorithm (OPAL) architecture to address urgent care challenges in Riyadh, Saudi Arabia.</td>
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<td>387</td>
<td>Social AI and Extended Intelligence</td>
<td>Alex ‘Sandy’ Pentland, Dhaval Adjodah, Peter Krafft, Esteban Moro Egido</td>
<td>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.</td>
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<td>388</td>
<td>Social Bridges in Community Purchase Behavior</td>
<td>Alex ‘Sandy’ Pentland, Xiaowen Dong, Vivek K. Singh, Yoshihiko Suhara</td>
<td>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.</td>
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<td>389</td>
<td>Social Learning Recommender Bots</td>
<td>Alex ‘Sandy’ Pentland, Dhaval Adjodah, Peter Krafft, Esteban Moro Egido</td>
<td>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.</td>
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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 telecommunications services across the world, survey-based methods of measuring community socioeconomic status could potentially be augmented or replaced by such passive sensing methods.

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.
Rosalind W. Picard: Affective Computing

Advancing wellbeing using new ways to communicate, understand, and respond to emotion

392. 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.

393. 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.

394. 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.

395. Automatic Stress Recognition in Real-Life Settings
Rosalind W. Picard, Szymon Fedor, Javier Hernandez, Robert R. Morris

Technologies to automatically recognize stress are extremely important to prevent chronic psychological stress and pathophysiological risks associated with it. The introduction of comfortable and wearable biosensors has created new opportunities to measure stress in real-life environments, but there is often great variability in how people experience stress and how they express it physiologically. In this project, we modify the loss function of Support Vector Machines to encode a person's tendency to feel more or less stressed, and give more importance to the training samples of the most similar subjects. These changes are validated in a case study where skin conductance was monitored in nine call center employees during one week of their regular work. Employees working in this type of setting usually handle high volumes of calls every day, and they frequently interact with angry and frustrated customers that lead to high stress levels.

396. 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.
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.

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.

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.

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.
Rosalind W. Picard, Ognjen (Oggi) Rudovic

**Machine Learning and Humanoid Robots for Measuring Engagement of Children with Autism**

EngageME is a project aimed at building a new technology that can better engage children with Autism Spectrum Conditions (ASC) in communication-centered activities.

In this context, EngageME investigates the use of humanoid robots such as NAO. To facilitate the children’s engagement during their interaction with NAO, EngageME explores multi-modal behavioral cues (facial expressions, head pose, audio, and physiology) to realize a fully automated context-sensitive estimation of engagement.

This technology builds upon state-of-the-art machine learning, bringing novel personalized and culture-tailored models for engagement measurement.

Henry A. Lieberman, Rosalind W. Picard, Karthik Dinakar MIT EECS, Jackie Chen

**Fathom: Probabilistic Graphical Models to Help Mental Health Counselors**

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.

Rosalind W. Picard, Yadid Ayzenberg

**FEEL: A Cloud System for Frequent Event and Biophysiological Signal Labeling**

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.

Natasha Jaques

**Improving RNN Sequence Generation with RL**

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.

Rosalind W. Picard, Daniel Lopez Martinez

**Injection Study**

Many drugs, such as monoclonal antibodies, are administrated 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.
408.  "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.

409.  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.

410.  Machine Learning for Pain Measurement
Rosalind W. Picard, Daniel Lopez Martinez, Ognjen (Oggi) Rudovic &nbsp;
Pain is a subjective experience commonly measured through patient’s self report. Unfortunately, self-report measures only work when the subject is sufficiently alert and cooperative, and hence they lack utility in multiple situations (e.g. during drowsiness) and patient populations (e.g. 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.

411.  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.

412.  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.

413.  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.

414.  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.
Rosalind W. Picard, Szymon Fedor Massachusetts General Hospital, Brigham and Women’s Hospital

Current methods to assess depression and then ultimately select appropriate treatment have many limitations. They are usually based on having a clinician rate scales, which were developed in the 1960s. Their main drawbacks are lack of objectivity, being symptom-based and not preventative, and requiring accurate communication. This work explores new technology to assess depression, including its increase or decrease, in an automatic, more objective, pre-symptomatic, and cost-effective way using wearable sensors and smart phones for 24/7 monitoring of different personal parameters such as physiological data, voice characteristics, sleep, and social interaction. We aim to enable early diagnosis of depression, prevention of depression, assessment of depression for people who cannot communicate, better assignment of a treatment, early detection of treatment remission and response, and anticipation of post-treatment relapse or recovery.

Kristy Johnson
Open-Source Instructions for Building SPRING System

Rosalind W. Picard, Robert R. Morris

Panoply

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.

Rosalind W. Picard, Fengjiao Peng

Personalized Animated Movies

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.
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.
420. **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.

421. **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.

422. **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.

423. **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!
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.

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.

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.

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.

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.

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.
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<td>This study aims to bring objective measurement to the multiple &quot;pulse&quot; and &quot;pulse-like&quot; measures made by practitioners of traditional Chinese medicine (TCM). The measurements are traditionally made by manually palpitating 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.</td>
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<th>431.</th>
<th>Tributary</th>
<th>Rosalind W. Picard, Yadid Ayzenberg</th>
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<td>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.</td>
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<th>432.</th>
<th>Understanding emotions in multiple sclerosis patients</th>
<th>Rosalind W. Picard, Daniel Lopez Martinez</th>
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<td>More information coming soon.</td>
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<td>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.</td>
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<th>434.</th>
<th>Wavelet-Based Motion Artifact Removal for Electrodermal Activity</th>
<th>Rosalind W. Picard, Weixuan 'Vincent' Chen, Szymon Fedor, Natasha Jaques, Akane Sano, Sara Taylor</th>
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<td>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.</td>
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Iyad Rahwan: Scalable Cooperation
Reimagining human cooperation in the age of social media and artificial intelligence

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.

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.

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.

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.

What would your city look like after a disaster?

Deep Empathy is a collaboration between the Scalable Cooperation group and the UNICEF Innovation Office to pursue a scalable way to increase empathy.

The brutal, six-year-old Syrian war has affected more than 13.5 million people in Syria, including 80% of the country’s children—8.4 million young lives shattered by violence and fear. Hundreds of thousands of people have been displaced and their homes destroyed.

But people generate a response that statistics can’t. And technologists—through tools like AI—have opportunities to help people see things differently. We wondered: “Can AI increase empathy for victims of far-away disasters?” This question led us to create a provocation for the research community to examine how AI can create narratives to tell the stories of some of the world’s most intractable problems.
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.

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

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.

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.

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.

Iyad Rahwan, Morgan Ryan Frank

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.

Iyad Rahwan, Lorenzo Coviello, Morgan Ryan Frank, Lijun Sun

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.
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:

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.

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.

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.

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!

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 (the 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!
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.

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.

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!

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.

TuringBox: Democratizing the study of AI

Iyad Rahwan, Manuel Cebrian, Abhimanyu Dubey, Ziv Epstein, Bjarke Felbo, Matthew Groh, Jordan Hoffman, Nick Obradovich, 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**

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<td>457</td>
<td>6D Display</td>
<td>Ramesh Raskar, Nikhil Naik</td>
<td>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.</td>
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<td>458</td>
<td>AnEye: Extending the Reach of Anterior Segment Ophthalmic Imaging</td>
<td>Ramesh Raskar, Shantanu Sinha</td>
<td>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.</td>
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<td>459</td>
<td>Architecture Selection for Deep Neural Networks</td>
<td>Ramesh Raskar, Barmak Hesmat Dehkordi Gurmukh Bhasin</td>
<td>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 $\epsilon$-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.</td>
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<td>460</td>
<td>Beyond the Self-Driving Car</td>
<td>Ramesh Raskar, Barmak Heshmat Dehkordi Gurmukh Bhasin</td>
<td>This concept gallery shows the chain of startups and ideas that will follow after the emergence of self-driving cars.</td>
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<td>461</td>
<td>Blind and Reference-Free Fluorescence Lifetime Estimation via Consumer Time-of-Flight Sensors</td>
<td>Ramesh Raskar, Ayush Bhandari Commonwealth School, Christopher Barsi</td>
<td>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.</td>
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<td>Calibration Invariant Imaging</td>
<td>Ramesh Raskar, Otkrist Gupta, Barmak Heshmat Dehkordi, Guy Satat Matthew Tancik</td>
<td>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.</td>
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<td>Coded Computational Photography</td>
<td>Ramesh Raskar, Nikhil Naik</td>
<td>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.</td>
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<td>Computation Ear Imaging</td>
<td>Anshuman Das</td>
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<tr>
<td>Efficient lensless imaging with a femto-pixel</td>
<td>Ramesh Raskar, Guy Satat Matthew Tancik</td>
<td>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.</td>
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<td>Food sensing on smartphones</td>
<td>Anshuman Das</td>
<td>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.</td>
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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.

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” which 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.

Ramesh Raskar, Anshuman Das

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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.

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/tf/
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.

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 1.5 cm 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.

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.

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.

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), Moungi 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.

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.

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.

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.
The gram-positive cocci Streptococcus pneumoniae causes pneumonia, otitis media, meningitis, and bacteremia in pediatric, elderly, and immunocompromised populations. Pneumococcal infection is the leading cause of pneumonia in children worldwide. Pneumococcal infections also occur frequently in at-risk populations including individuals with diabetes, asthma, chronic obstructive pulmonary disease, cardiovascular disease, human immunodeficiency virus (HIV), and sickle cell disease. In developed countries, pneumococcal infection is responsible for approximately 30% of all adult pneumonia cases and has a mortality rate of 11% to 40%. Due to this organism’s impact on both morbidity and mortality in adults and children, healthcare efforts have relied on vaccines to reduce the rate of pneumococcal disease over the past 30 years. Vaccine research has focused on using immunogenic proteins and carbohydrates found on the pneumococcal surface as antigens.

Previous efforts to use protein vaccines were not successful as they only stimulated the human immune system. New research from Dr. Pratik Shah reports discovery of new protein molecule to immunize children, currently utilized by government agencies in Brazil, China and the Gates foundation, to develop affordable vaccines for prevention of pneumococcal diseases. Dr. Shah’s approach cripples the bacterial nutrient acquisition and virulence pathways in addition to promoting effective recognition by the host immune system.

Project 1: Discovery of novel protein vaccine antigens protective against Streptococcus pneumoniae pneumonia and invasive infections
Discovered a bacterial ABC transporter that results in significant protective immunity in mice against carriage, pneumonia and bacteremia
Protein antigen-PotD used by government of Brazil and China in vaccine development and awarded Raymond Sarber National Award for Discovery in Microbiology by American Society of Microbiology.

Project 2: Elucidate the role of host and bacterial polyamine metabolism in bacterial infections
Discovered polyamine biosynthesis and transport mechanisms are required for pneumococcal infection and are targets for prophylactic and therapeutic interventions

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**Next-generation protein vaccines against infectious diseases**

Pratik Shah

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Project 2: Elucidate the role of host and bacterial polyamine metabolism in bacterial infections
Discovered polyamine biosynthesis and transport mechanisms are required for pneumococcal infection and are targets for prophylactic and therapeutic interventions
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.

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).

Ramesh Raskar, Nikhil Naik

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.

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.

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.

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.

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.
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.

Cesar A. Hidalgo, Ramesh Raskar, Nikhil Naik
StreetChange
Computer vision uncovers predictors of physical urban change

Cesar A. Hidalgo, Ramesh Raskar, Nikhil Naik Jade Philipoom
StreetScore
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.

Ramesh Raskar, Barmak Heshmat Dehkordi
The Next 30 Years of VR
In this visual brainstorming, we present the next 30 years of VR in a set of concept designs.

Ramesh Raskar, Nikhil Naik Tom Cuypers, George Barbastathis, Se Baek Oh
Theory Unifying Ray and Wavefront Lightfield Propagation
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.

Ramesh Raskar, Micha Feigin-Almon, Nikhil Naik Andrew Temme, Gregory Charvat
Time-of-Flight Microwave Camera
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.

Ramesh Raskar, Barmak Heshmat Dehkordi, Guy Satat
Towards In-Vivo Biopsy
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.
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.

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.

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.

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

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.

At Computer Clubhouse after-school centers, young people (ages 10-18) from low-income communities learn to express themselves creatively with new technologies. Clubhouse members work on projects based on their own interests, with support from adult mentors. By creating their own animations, interactive stories, music videos, and robotic constructions, Clubhouse members become more capable, confident, and creative learners. 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). Since then the network has expanded to more than 100 centers in 20 countries, serving more than 25,000 young people annually. In 2015 the Computer Clubhouse changed its name to The Clubhouse Network. The Lifelong Kindergarten group continues to develop new technologies, introduce new educational approaches, and lead professional-development workshops for Clubhouses around the world.

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.

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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.
Mitchel Resnick, Leo Burd

ATENÇÃO: Saiu o resultado do Desafio Aprendizagem Criativa Brasil 2018! Clique aqui para conhecer os fellows e os projetos selecionados!

O Desafio Aprendizagem Criativa Brasil é uma iniciativa da Fundação Lemann e do MIT Media Lab que visa fomentar a implementação de soluções inovadoras – novas tecnologias, produtos e serviços – que ajudem a tornar a educação brasileira mais mão na massa, significativa, colaborativa e lúdica.

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, especialmente no que se refere a projetos mão na massa envolvendo programação e construção no mundo físico, em escolas públicas (de Educação Infantil 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 9 de fevereiro 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.

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.

Leo Burd

O Festival de Invenção e Criatividade é uma grande celebração do espírito inventivo, colaborativo e mão na massa da educação brasileira. Nele, crianças, jovens, seus familiares e educadores terão a oportunidade de explorar materiais e tecnologias high e low tech, participar de atividades e aprender de forma estimulante e descontraída.

A primeira edição do Festival de Invenção e Criatividade ocorrerá na POLI-USP, em conjunto com a FEBRACE 2017 - 15ª Feira Brasileira de Ciências e Engenharia - entre os dias 21 e 23 de março, com visitação aberta e gratuita.

Para maiores informações, consultar o site: http://www.ficmaker.org.br/

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.
Learning Creative Learning is an online course that introduces ideas and strategies for supporting creative learning. The course engages educators, designers, and technologists from around the world in applying creative learning tools and approaches from the MIT Media Lab. We view the course as an experimental alternative to traditional Massive Open Online Courses (MOOCs), putting greater emphasis on peer-to-peer learning, hands-on projects, and sustainable communities.

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 a 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.

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.

Leo Burd

Somos una 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 Programa (uma colaboração da Fundação Lemann com a Fundação Telefônica Vivo) e o Lifelong Kindergarten Group do MIT Media Lab. Atualmente, contamos com centenas de participantes de todo o Brasil.

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.
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<th>Page</th>
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<tr>
<td>515.</td>
<td>ScratchBit</td>
<td>Mitchel Resnick, Kreg Hanning, Jie Qi, Eric Rosenbaum, Natalie Rusk, Andrew Sliwinski</td>
<td>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 MakeyMakey which was designed to make these connections electronically, the ScratchBit is designed to create these connections through motion and mechanism.</td>
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<td>516.</td>
<td>Scratch Community Blocks</td>
<td>Mitchel Resnick, Sayamindu Dasgupta, Natalie Rusk, Andrew Sliwinski Benjamin Mako Hill</td>
<td>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.</td>
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<tr>
<td>517.</td>
<td>Scratch Day</td>
<td>Kasia Chmielinski, Saskia Leggett, Abisola Okuk</td>
<td>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.</td>
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<tr>
<td>518.</td>
<td>Scratch Extensions</td>
<td>Sayamindu Dasgupta, Stefania Druga, Kreg Hanning, Eric Rosenbaum, Andrew Sliwinski, Christopher Willis-Ford</td>
<td>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.</td>
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<td>519.</td>
<td>Scratch in Space</td>
<td>Christian Balch, Eric Schilling</td>
<td>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.</td>
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<td>520.</td>
<td>ScratchJr</td>
<td>Mitchel Resnick, Sayamindu Dasgupta, Chris Garrity, Timothy Mickel, Andrew Sliwinski</td>
<td>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.</td>
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<tr>
<td>521.</td>
<td>Scratch Memories</td>
<td>Shruti Dhariwal</td>
<td>Scratch Memories is a dynamically generated, personalized web-based visualization that celebrates a Scratchers’s journey by highlighting their key moments, creations, and connections in the online community. It is designed as a way for young people to reflect back on their creative experiences with Scratch — 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 encourage them to keep going further. The project processes public data from Scratch API and utilizes Javascript and other web frameworks to generate a personalized video for a given Scratch username.</td>
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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.
Deb Roy: Social Machines

Enabling human-machine collaborations for listening, learning and engaging across communities

523. 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.

524. 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.

525. 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.

526. 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.

527. Play Analytics

Eric Chu, Annelli 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.

528. Playful Words

Preeta Bansal, Eric Chu, Annelli Hershman, Sneha Priscilla Makini, Juliana Nazare, Deb Roy, Nazmus Saquib, Mina Soltangheis, Ivan Sysoev

To learn more about our lab’s learning project, please check out: http://playfulwords.org/
**529. Rumor Gauge: Automatic Detection and Verification of Rumors on Twitter**

Deb Roy, Soroush Vosoughi

The spread of malicious or accidental misinformation in social media, especially in time-sensitive situations, such as real-world emergencies, can have harmful effects on individuals and society. In this work, we developed models for automated verification of rumors (unverified information) that propagate through Twitter. To predict the veracity of rumors, we identified salient features of rumors by examining three aspects of information spread: linguistic style used to express rumors, characteristics of people involved in propagating information, and network propagation dynamics. The predicted veracity of a time series of these features extracted from a rumor (a collection of tweets) is generated using Hidden Markov Models. The verification algorithm was trained and tested on 209 rumors representing 938,806 tweets collected from real-world events, including the 2013 Boston Marathon bombings, the 2014 Ferguson unrest, and the 2014 Ebola epidemic, and many other rumors about various real-world events reported on popular websites that document public rumors. The algorithm was able to correctly predict the veracity of 75% of the rumors faster than any other public source, including journalists and law enforcement officials. The ability to track rumors and predict their outcomes may have practical applications for news consumers, financial markets, journalists, and emergency services, and more generally to help minimize the impact of false information on Twitter.

**530. 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.

**531. 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.

**532. SpeechBlocks**

Anneli Hershman, Sneha Priscilla Makini, Juliana Nazare, Ivan Sysoev

SpeechBlocks is a self-expressive literacy app that helps young children explore alphabetic principles through manipulating letter blocks. Phonemes and words are heard when letter blocks are tapped, put together (blended into words), or pulled apart (segmented into sounds). There is no correct combination of letters, so children can create real and nonsense words. SpeechBlocks encourages children’s intrinsic motivation by avoiding extrinsic rewards such as points or prizes. Words from a “word shelf” and letters from a “letter shelf” serve as scaffolds that children can use and remix.

**533. StoryBlocks**

Anneli Hershman, Juliana Nazare Marc Exposito (Research Assistant, Lab for Social Machines) Saul Woolf (Undergraduate Student, Worcester Polytechnic Institute) Molly Scott (Graduate Student in the Infant &amp; Child Laboratory, Temple University)

Supporting self-expression through story telling and story remixing.

StoryBlocks is a mobile application where children can create stories using a combination of oral narrative and written text as well as build off each other’s narratives to create collaborative stories. We tested a physical version of StoryBlocks with kids to see what sorts of stories they would create.
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 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.
Deb Roy, Soroush Vosoughi Sinan & Aral (MIT Sloan School of Management)

We investigated the spread of all of the verified news stories—verified as either true or false—distributed on Twitter from 2006 to 2017.

With a data set of roughly 126K stories tweeted by around 3M people over 4.5M times, we classified news as true or false using information from six independent fact-checking organizations that exhibited 95-98% agreement on the classifications. False information spread significantly farther, faster, deeper, and more broadly than the truth in all categories of information, and the effects were more pronounced for false political information than for false information about terrorism, natural disasters, science, urban legends, or financial information. We found that false information was more novel than true information, which suggests that people were more likely to share novel information. While false stories inspired fear, disgust, and surprise in replies, true stories inspired anticipation, sadness, joy, and trust.

Contrary to conventional wisdom, robots accelerated the spread of both true and false news at the same rate. This implies that false news spreads more than the truth because humans—not robots—are more likely to spread it.

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.
Chris Schmandt: Living Mobile
Enhancing mobile life through improved user interactions

537. **Amphibian: Terrestrial SCUBA Diving Simulator Using Virtual Reality**  
Chris Schmandt, Jingru Guo, Raymond Wu, Misha Sra, Rodrigo Marques  
SCUBA diving as a sport has enabled people to explore the magnificent ocean diversity of beautiful corals, striking fish, and mysterious wrecks. However, only a small number of people are able to experience these wonders, as diving is expensive, mentally and physically challenging, needs a large time investment, and requires access to large bodies of water. Most existing SCUBA diving simulations in VR are limited to visual and aural displays. We propose a virtual reality system, Amphibian, that provides an immersive SCUBA diving experience through a convenient terrestrial simulator. Users lie on their torso on a motion platform with their outstretched arms and legs placed in a suspended harness. Users receive visual and aural feedback through the Oculus Rift head-mounted display and a pair of headphones. Additionally, we simulate buoyancy, drag, and temperature changes through various sensors.

538. **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.

539. **DuoSkin**  
Chris Schmandt, Andres Calvo, Cindy Hsin-Liu Kao Asta Roseway, Christian Holz, Paul Johns  
DuoSkin is a fabrication process that enables anyone to create customized functional devices that can be attached directly to the skin. Using gold metal leaf, a material that is cheap, skin-friendly, and robust for everyday wear, we demonstrate three types of on-skin interfaces: sensing touch input, displaying output, and wireless communication. DuoSkin draws from the aesthetics found in metallic jewelry-like temporary tattoos to create on-skin devices which resemble jewelry. DuoSkin devices enable users to control their mobile devices, display information, and store information on their skin while serving as a statement of personal style. We believe that in the future, on-skin electronics will no longer be black-boxed and mystified; instead, they will converge towards the user friendliness, extensibility, and aesthetics of body decorations, forming a DuoSkin integrated to the extent that it has seemingly disappeared.

Credits:  
MIT Media Lab in collaboration with Microsoft Research*

540. **Intrepid**  
Chris Schmandt, Ethan Zuckerman, Manisha Mohan  
Every 98 seconds, a person in the United States is sexually abused. Every 16 hours, a woman in the United States is murdered by her romantic partner or ex-partner. Sexual abuse, assault, and harassment are regarded as some of the most common human rights violations in the world by the United Nations. Our work examines methods to prevent sexual assault, from prehistoric times to latest technologies, to inform contemporary designs. Intrepid investigates multiple methods to detect initial signs of assault and develop methods for communication and prevention of assault. We also explore olfactory stimuli as a potential means to prevent sexual assault in real-time.
Chris Schmandt, Deborah Ajilo, Artem Dementyev, Cindy Hsin-Liu Kao Oksana Anilionyte (RCA), Inrak Choi (Stanford), Sean Follmer (Stanford)

This work explores a dynamic future in which the accessories we wear are no longer static, but are instead mobile, living objects on the body. Engineered with the functionality of miniaturized robotics, this “living” jewelry roams on unmodified clothing, changing location and reconfiguring appearance according to social context and enabling multiple presentations of self. With the addition of sensor devices, they can actively respond to environmental conditions. They can also be paired with existing mobile devices to become personalized on-body assistants to help complete tasks. Attached to garments, they generate shape-changing clothing and kinetic pattern designs—creating a new, dynamic fashion.

It is our vision that in the future, these robots will be miniaturized to the extent that they can be seamlessly integrated into existing practices of body ornamentation. With the addition of kinetic capabilities, traditionally static jewelry and accessories will start displaying life-like qualities, learning, shifting, and reconfiguring to the needs and preferences of the wearer, also assisting in fluid presentation of self. With wearables that possess hybrid qualities of the living and the crafted, we explore a new on-body ecology for human-wearable symbiosis.

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.

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.

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.

Chris Schmandt

Variable Reality is an augmented reality system designed for reading digital and physical books more intuitively and efficiently. Through a head-worn display device such as Oculus Rift, the user is able to instantly access and display any desired book contents onto either a real book or a hand, depending on the need and affordability. Quick-hand gestures integrated with the system further facilitate natural user interactions.
### Ethan Zuckerman: Civic Media

**Creating technology for social change**

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<th>546.</th>
<th><strong>Action Path</strong></th>
<th>Ethan Zuckerman, Rahul Bhargava, Erhardt Graeff, Emilie Reiser</th>
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<td></td>
<td>Action Path is a mobile app to help people learn about and engage with issues in their community. The app uses push notifications tied to geography that invite people to provide meaningful feedback on nearby issues as they traverse the city. Most platforms for civic engagement, whether online or offline, are inconvenient and disconnected from the source of the issues they are meant to address. Action Path addresses barriers to effective civic engagement by inviting people's input, converting individual actions into collective action, and providing context and a sense of efficacy.</td>
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<th>547.</th>
<th><strong>Algorithmic Justice League</strong></th>
<th>Ethan Zuckerman, Joy Buolamwini</th>
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<tr>
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<td>Algorithmic Justice League aims to:</td>
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<td>- highlight algorithmic bias through provocative media and interactive exhibitions</td>
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<td>- provide space for people to voice concerns and experiences with coded discrimination</td>
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<td>- develop practices for accountability during the design, development, and deployment phases of coded systems.</td>
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<th>548.</th>
<th><strong>Civic Entertainment</strong></th>
<th>Ethan Zuckerman, Anushka Shah</th>
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<td>Civic Entertainment is a project based at the Center for Civic Media, MIT Media Lab that explores the intersection of civic engagement with film, television, radio, 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.</td>
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<td>The research focuses on studying the ways in which fiction media can affect thought and behavior-change, 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 the techniques to balance civic education with humor or drama within entertainment.</td>
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<td>The project has a key focus on Indian entertainment and works with Civic Studios, a Mumbai-based production firm, on creating civic entertainment content for young people across India.</td>
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<th>549.</th>
<th><strong>CivilServant: User-Led Randomized Trials Online</strong></th>
<th>Ethan Zuckerman, J Nathan Matias Merry Mou</th>
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<td></td>
<td>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 in an open repository of collective knowledge on practices that contribute to fair, flourishing social life online.</td>
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<td>The first experiment, in a 13.2 million subscriber community, showed that posting rules at the top of conversations prevents problems and increases engagement.</td>
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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.

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!

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

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.

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.

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.
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 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.

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 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

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.

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.
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.

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.

Ethan Zuckerman, Matthew Carroll, Catherine D’Ignazio

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.

Ethan Zuckerman, Poseidon Ho, Emilie Reiser, Nickolaos Savidis

OpenScope is an open source project that combines three components for anyone to explore the micro world anytime, anywhere. The 3D-printable open hardware turns your smartphone into a 200x microscope, the image processing application helps you recognize specific objects, and the online community allows you to share and contribute your findings from the microscope. OpenScope is expanding microscopy technologies beyond research laboratories and transforming the way we interact with the micro world.

Ethan Zuckerman, Catherine D’Ignazio

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.

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.
566. **Peer Appreciation in the Workplace**

Ethan Zuckerman, J Nathan Matias, Andrés Monroy Hernandez, Emma Spiro

Organizations are deploying gratitude-tracking systems to encourage appreciation, promote prosociality, 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.

567. **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

568. **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.

569. **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.