Choreographing the Extended Agent:

performance graphics for dance theater

Marc Downie

Thesis Proposal for the degree of
Doctor of Philosophy at the
Massachusetts Institute of Technology.
November 2004.
The marriage of dance and interactive image has been a persistent dream over the past decades, but reality has fallen far short of potential for both technical and conceptual reasons. This thesis proposes a new approach to the problem and lays out the theoretical, technical and aesthetic framework for the innovative art form of digitally augmented human movement. I will use as example works a series of installations, digital projections and compositions each of which contains a choreographic component — either through collaboration with a choreographer directly or by the creation of artworks that automatically organize and understand purely virtual movement. These works lead up to two unprecedented collaborations with two of the greatest choreographers working today; new pieces that combine dance and interactive projected light using real-time motion capture live on stage.

As such the art context of this thesis might be that of “dance technology”. This is a field with many practitioners, few techniques and almost no theory; a field that is generating “experimental” productions with every passing week, has literally hundreds of citable pieces and no canonical works; a field that is oddly disconnected from modern dance’s history, pulled between the practical realities of the body and those of computer art and has no influence on the prevailing digital art paradigms that it consumes.

This thesis will seek to address each of these problems: by providing techniques and a basis for “practical theory”; by building artworks with resources and people that have never been assembled to date, in theaters and in front of audiences previously inaccessible to the field; and by proving by demonstration that a profitable and important dialog between digital art and the pioneers of modern dance can in fact occur.

This thesis will do this because of its methodological perspective — that of biologically inspired, agent-based artificial intelligence — and the technical depth to which this idea is taken. The representations, algorithms and techniques behind such agents are extended and pushed into territory new for both interactive art and artificial intelligence. In particular this thesis will focus on the control structures and the rendering of the these extended agents’ bodies, the tools for creating complex agent-based artworks in intense collaborative situations, and the creation of agent structures that can span live image and interactive sound production — each part an element of what it means to “choreograph” an extended agent for live performance.
Contents

4 On Computation and Dance — Background
14 Outline of themes and arguments
23 Principle technical contributions
29 Principle artistic works
34 Goals and Evaluations
37 Time-line and resources
38 Biography
39 Works Cited
On Computation and Dance — Background and Motivation

This section seeks to motivate the principle artworks; each of which involves a choreographic component — either through collaboration with a choreographer directly or through the creation of artworks that automatically choreograph purely virtual movement. The goal here is to indicate both the significance and the originality of the contributions that these artworks can make to the cultures of modern dance and digital performance art.

Many of the works presented in my thesis will be collaborations involving choreographers. Three will be live projections for dance theater, the central work will be a projection for interactive dance theater. These projections are generated in real time, the computers “seeing” the positions and motions of the dancers using state-of-the-art motion capture technology. The pieces are difficult and expensive, and both this difficulty and expense comes directly from the presence of these computers and the equipment required for them to sense the stage even in a their rather impoverished way.

Why then accompany, indeed, project over, dancers in a theater?

This answer is difficult to generate in the abstract — dance clearly does not require digital projections for its artistic viability, and there would be much work left in both the visual arts and in computer graphics to be done without contact with dance or performance. Further, the many recent “interactive” works for dance and computer have thoroughly failed to make much lasting impact on either the digital arts community or the dance world. But I believe that there remains an uneasy but strong alloy of visual art, dance performance and computation waiting to be made. This divides the question into two — is there work to be done between dance and digital art that will bear artistic and technical fruit? And what is the worth of that fruit?
The answer to the second half of this question is perhaps open to issues of personal taste and fashion, but the answer to the first half is important. In answering it I argue as follows: firstly, that there is surprising common ground between recent choreographic practice and computer graphics (as well as computer science), so much, in fact, that one can identify a “computational sensibility” in the work of many prominent choreographers in the last half century; secondly, that choreographic practice is one where such algorithmic concerns meet the realities, constraints, and meanings of the human body and the eyes of the audience, and as such offers a foil for the worst tendencies of technologically mediated art and a concrete platform for the best tendencies of computer science; and lastly that such a union between digital art and dance has not yet occurred — that to date the contemporary works laying claim to the space where the union would occur ignore what both computation and choreography could offer to each other, through a series of now almost conventionalized technical and artistic compromises.

A Computational Sensibility — the mechanics of generalization and abstraction, choreography as representation, dance as computation.

Although one could write a history of recent dance to separate this computational sensibility out from the more general intellectualization of the art form that has occurred over the last 50 years, to trace the thread of algorithmic concern through all of 20th century dance in all its forms is beyond the scope of this text. Instead, I’ll focus on a set of four central choreographers whose contributions to and impact on dance is unquestionable — Merce Cunningham, Trisha Brown, Bill T. Jones, and William Forsythe. It is my great fortune that three of them — Cunningham, Brown and Jones — are collaborators on works discussed in this thesis.
On abstraction: “Any problem in computer science can be solved with another layer of indirection.”

David Wheeler (chief programmer for the EDSAC project in the early 1950s)

A key tendency in computer science is the urge towards generalization and abstraction. This inheritance from mathematics is powerfully exploited to unmask problems as restatements of previously solved problems, to build generic machines that become the site of confluences of data previously considered disparate, suggesting new computations that can be carried out which in turn makes for new frontiers and problems. It lies at both the heart of computer science — in the form of the general Turing machine — and at the periphery — of the everyday activities of the software architecting programmer.

The signature of this tendency is: a recasting of an established formal system in new, more flexible terms, that immediately produces a range of new systems; an often rapid exploration of the outcomes of these systems; a selection and categorization of some of these “instantiations” into new framework; and a resulting framework that is itself ripe for generalization.

In the abstract we can see this tendency throughout dance in obvious places: the rapidly expanded palettes of Modern dance, generalizing the acceptable motion vocabulary to include the everyday, the pedestrian, even the animal. Cunningham’s earliest inventions and proclamations — the democracy of the stage space, and the rediscovery of the dancer’s back as a point of origin of motion can be interpreted as generalizations of a kind — that any point of a stage can be a “front”, that any connected set of joints can be thought of as a limb.

But to find a concentrated and self-contained example of the generalization cycle whole we turn to Forsythe’s choreographic practice. Many examples drawn from his work have been described in the literature on the ideas behind choreography, but seldom has any meta-methodological diagnosis been attempted. For example, the most commonly mentioned strategy of Forsythe is his decentered kinesphere. Forsythe took the established kinesphere of movement theorists (most notably Rudolph Laban) — an geometrical framework for the description of limb positions that forms the grounding of Laban’s extensive analytical and
notational techniques — and freed it from its anchor to the center of the dancers body. This new, roaming, kinesphere, now centered on an elbow, an ear, or the midpoint between two hands, stands to inherit every analytical use that Laban placed his kinesphere to, it is a generalization of Laban’s analytical framework. Movements now, within this framework, acquire multiple explanations (disparate problems are unmasked and seen as related), new impetuses for moving are rapidly created as the ready-made machinery of Laban can be brought to bear on new joints, limbs and points (the data of dance), the palette radically expanded. Selection, categorization and reformulation then occurs as Forsythe builds new formalisms to deal with the material — systems of “alphabetization” or hidden geometry. These new representations of dance are in turn ripe for later generalization, a cycle that he himself makes much of. This is generalization and specification as a computer scientist would recognize.

The creation of computer programs often turns on issues of representation — the virtual laying out of bits that represent, that stand for, an object. This representation — be it of a number, an address-book, a musical note or a dancer’s body — is not the object it stands for, but the object transformed and transformable. Computers cannot do anything useful without representation, so obviously much discussion occurs amongst practitioners about how best to represent things to enable their manipulation and their reinterpretation, and reconnection with new things. Issues of Notation and representation are often related and in this computer science seems to share a notational concern with music in the ongoing play of computer programming languages. Over the centuries composers have developed notational representations that allow the distribution, but more importantly the transformation and interpretation of music, without the instantiation of sound. Its no surprise then that a focus on the transformation of music into a representation, manipulations within and with this new form and subsequent reinterpretation and retransformation back into sound or other representations can be found all along the border between computers and music — sound synthesis techniques, compression algorithms,
set-theoretic compositional strategies or new instrument design. Computer sciences representations and musics' notations are not just ways of seeing the world or music but locations for new ways of thinking about how to change it. A central technique in this thesis then will be to import the techniques and approaches of computer music into a new “computer dance” domain.

We have to borrow from other domains because border between computers and dance offers a different geography. Not only is this far less charted ground, dance itself has a different relationship within its own realm with notation. Classical ballet is a set, a vocabulary for sure, but the signature of computational representation — transformation, manipulation and retransformation — is harder to locate until the middle of the century. Modern dance produced a notational explosion similar to (but a little later than) that of music but never had an equivalent of a stave, never had a notational tradition to respond to, or a (pedagogically) stable point to return to. One result is the conferences dedicated to the concern about the lack of permanence, transferability and pedagogy of dance. But another is the relative obscurity of the representational / computational face of many choreographer’s work.

Cunningham’s earliest investigations of chance procedures had the flavor of representation about them. Motions were broken up, atoms identified, tokenized. These tokens rearranged by the toss of a coin, the fall of the I-Ching, and the new lines and tables recast the new motion material for his dancers. Cunningham shares this style with composer and collaborator John Cage at this time, and much of their quest for new compositional strategies could be re-read as a quest for useful representations that support useful compositional actions.

But a particularly simple and effective example can be found in a number of pieces by Trisha Brown in the 1970s. A transformation of the dancer’s kinesphere into boxes, the representation of these boxes by letters of the alphabet, the manipulation of the temporal sequencing of boxes by the creation of words


and messages and the retransformation of these messages into movement yields a dance — a complex semaphore often intersecting with the representation’s mirror — the spoken word. Since the space has been represented as a cube, new transformations (rotations and translations) of the cube suggest themselves, further interrupting this communication. This is the fundamental compositional technique behind Locus (1975).

Of course, what is missing inside this alphabetic representation is replaced either by the choreographer while fixing the piece (in the case of many works by Cunningham) or by the intelligence of the performer in the moment (in the case of Locus), faced with the almost impossible task of computing the results of the choreographic program. We as audience are presented with the act of computation itself and its negotiation with the constraints and limits of the human body.

This image of computation continues to appear throughout the history of dance. Forsythe is infamous for issuing instructions to ensembles that recast entire choreographies extremely late in the creative process (sometimes moments before first curtain). The results of these manipulations of the systems that produced the choreographies are literally “worked through”, computed, on stage in front of the audience, the intelligence of the individual dancers on display as much as their muscular memories. This image of performance as computation leads us to improvisational techniques where the relationships between parallel, often disparate, autonomous machines are negotiated live, where the performer improvises simultaneously inside and with a machine of their own making.

No clearer example of this tendency can be found than in choreographer / performer Bill T. Jones’s piece 21 (1983) in which a fixed, circular cycle of 21 poses is acted and reacted out, numbered and named, by the performer. After declaring (quite pedagogically, unlike Brown’s Locus) almost all of its motion


This work is available as a video: T. Bowes, 21 w/Bill T. Jones, 1987.
vocabulary, Jones begins to narrate while the numbered poses continue to appear and disappear, his narration, the movement of his body and the declared name of the poses all intersecting under the pressure and the limits of the structure of the piece and the abilities of the performer to negotiate their connections.

Here we reach the limits of this "computational sensibility" in modern dance, the limits of what the human body is capable of performing, the limits of what choreography can be. For all of the fecundity of the "computational sensibility" outlined here, none of these techniques or inventions exist outside of a dialectic with the body and the theatre space. Cunningham's proposal that there are no fixed points in space meets the plain fact that the audience sits in one place, his democratic use of the movements resources of the body pushes but goes no further than the limits of bipedal balance. Brown, in the piece Man walking down the side of a building (1970), produces a choreography that disrupts the audience's sense of orientation yet leaves the mechanics needed by humans to defy gravity exposed for all to see. In Accumulation plus talking with water motor (1978/1986) she shows simultaneously talking and dancing a choreography at the limit of memorization of narrative and of movement, in Homemade (1966) the performer has her movements amplified by the film projector they carry on their back in a dance of light, but it is a heavy and obvious burden.

Therefore the proposed dialogue between computers and choreographers takes place around this computational sensibility — the digital artist could connect to and radically expand the vocabulary of choreography that I have outlined, for they are experts of generalization, representation and, if not computation as performance, surely the performance of computation. In exchange, choreographers and performers are experts of the negotiation between the abstracted, the transformed, the mechanic and the theatrical, the human, and spectator. This crucial expertise they offer in return for the digital artist's computational virtuosity in this dialogue.
Interactive dance performance and video — a plateau

There is little tradition of this dialogue; rather, most contemporary “digital dance” work falls short of such an exchange, failing to produce more than the sum of its parts. In my view this is for a number of reasons. It is my belief that the works made for and described in this thesis stand out as an attempt to indicate an exchange.

In the early 1990s, Forsythe published many of his choreographic techniques in a seminal pedagogical work — the CDROM *Improvisation Technologies* (1993). Crude, but effective, rotoscoped annotations of his inventions — generalized kinespheres, hidden representations, and obscuring constraints — overlaid Forsythe’s own dancing and were accompanied by examples from complete choreographies made for the Ballet Frankfurt. Effective, this tool was still in use for training new members of the company up until its dissolution. This work could have acted as a “call to arms” for both choreographers (showing that a powerful articulation of their ideas was possible and useful using new media) and would-be digital dance specialists (showing that a relationship could be made with dance on a level deeper than the visual appearance of the dancer), but instead *Improvisation Technologies* indicates a path not taken.

There are a number of reasons why the field did not develop and unfold in this way. I shall focus on diagnosing part of problem using only one symptom, which will also be useful in highlighting some of the differences between the work conducted for this thesis and the prevalent field. Part of the impasse is caused, I believe, to the interactive dance communities use of video as the computers’ way of seeing the stage. Video has a number of apparent conveniences — it is cheaper than other sensing technologies, the interfaces with computers have benefited considerably from recent consumer demand, a video frame or sequences of frames seem to offer a large amount of data, and finally it is, of course, easy to visualize how computation acts upon video; there is even a sub-field of dance that is concerned with dance on camera.
As such the number of dance performances using live and processed video is has been growing for a decade, the tools to support these works are being standardized, distributed and even sometimes supported. None of these things are true of the technology used for many of the works described in this thesis — motion capture. Not only can’t one buy in the store the tools used to build the pieces described in this thesis, but my principle pieces (How long...? and 22) are the first use of real-time motion capture in a major dance work. The underlying hardware technologies are expensive, specialized, obscure, and rare and precious.

Video, however, is a poor digital representation of human movement. Poor because it is not clear what transformations of pixel level representations have to do with transformations of human motion, much less a choreographic dialogue; poor because capturing it constrains the existing stage picture, the lighting and the set elements that have a longer tradition of relating to dance than video; poor because it is a fragile representation — slow it down, zoom in, or recast it and quickly video’s own materiality comes to the fore, leaking onto the surface of the works created with it and pinning the level of dialogue between the collaborators to a negotiation of appearances.

The computational sensibility outlined in this argument suggests starting a little closer to what it is that choreographers care about — human motion. Yet human motion is hard for a computer to see in the sea of pixels that is video. Modern dance is perhaps the worst-case scenario for the already challenging pursuits of the field of computer vision, the sophisticated and experimental techniques that would be required to begin to bring human dance motion out of the video frame are not yet stable enough for a sophisticated and experimental piece to be constructed upon them.

Similar situations exist in a related area — the digital tools for choreographers. As has often been repeated in the press Cunningham has been using the Lifeforms software for more than a decade now as part of his choreographic process. Ironically, however, such software is entirely concerned with the appearance of the virtual human figure, its technical concerns imported wholesale from linear key-frame animation rather
Lifeforms is a now fairly standard mix of keyframe animation and inverse kinematics that has been put together “specifically with the choreographer in mind”.

http://lifeforms.com

than offering any computational support to the choreographer. The tools all lead down the path of least technical resistance — the commodity hardware of computer video, the tried and tested representations of photorealistic “Hollywood computer graphics”. Despite his now expert use of computers to find shapes that he can no longer find on his own body, Cunningham still throws his own dice.

Choreographers and digital artists have more to offer each other.

Of course, motion capture is only a little closer to the concerns of choreographers — it is still unreconstructed movement, the human form still has to be identified, isolated, seen and be understood to some extent by the computers. Some of the work of this thesis has been to develop some core algorithms for understanding enough of human motion from motion capture data for the dialogue to begin.

Motion capture offers such a representation while also having the “benefit” that, having never captured the appearance of a dancer through a camera there is no easy way to regenerate it. Thus motion capture is in some sense immaterial, it has less tell-tale trace of its own, no surface flavor. Further, a direct presentation of the data, despite being orders of magnitude smaller than video, is shockingly readable. This, then, is representation that supports transformation and recasting: it is a place to begin generalizations from which abstractions can be made and on which algorithms can act and their actions, made visible, might yet be related more, in the eye of the audience, to human movement than they are to the representation that captured it.

Given the technical opportunity of working with such rich and ambiguous data, and the artistic opportunity of working with Brown, Jones and Cunningham, the challenge then is to build a dialogue that bridges the two opportunities. To face this challenge there are considerable technical problems that need to be addressed that range from the handling and “understanding” of the material, through how to synthesize a visual presentation of it, to how to find, build and maintain digital forms that can support an evening length performance. It is to my solutions to these problems that this proposal now turns.

This has been shown in a series of studies in the 70s and 80s, starting with G. Johansson, Visual perception of biological motion and a model for its analysis. Perception and Psychophysics 1973, 14: pp. 201-211. This work and the work of people who followed, showed that, when presented with a few points of motion (effectively the “dots” of motion capture) humans are capable of correctly labeling body parts in the absence of all of the points, recognizing gesture, differentiating gender, recognizing familiar people, and even recognizing their own motion.

A more recent review of this matter may be found in J. K. Hodgins, J. F. O’Brien, J. Tumblin, Judgments of Human Motion with Different Geometric Models, Transactions on Visualization and Computer Graphics, December 1998, Vol. 4, No. 4
Artificial Intelligence, Digital Art, Modern Dance and Music are fields that do not often mix and have not all come together in a single body of work or a single thesis previously.

The purpose of this section is to give an overview of the flow of the arguments as they weave through each of these area.

Outline of Themes and Arguments

1. The radically extended agent

For example, horizontal decompositions can be found in:
M. Minsky, The Emotion Machine, available pre-publication online at http://www.media.mit.edu/~minsky

as well as (of most relevance to our discussion here)

"vertical" diagrams of the agent problem are found in the works of
Rodney Brooks and Pattie Maes as well as many others:

Aaron Sloman articulates the integration of these two views succinctly. For example:

We begin with a description of the “classical” graphical agent, decomposed into perception, action and motor systems. While different architectures and practitioners emphasize different aspects of horizontal or vertical integration across these categories, such a decomposition is typical throughout the academic discipline, with agents sensing their environment (perception), deciding on the behavioral impact of this sense data (action), and working out how to perform that decision (motor). This will provide the basic ordering and vocabulary for the discussion of many of the systems implemented in this thesis.
The AI practiced here will be inspired by the competencies of animals rather than those of humans (c.f. Blumberg, above). Our thread between such AI and art will be similar to that articulated in: M. Whitelaw, *The Abstract Organism: Towards a Prehistory for A-Life Art*, Leonardo Vol. 34, No. 4, 2001.

and indeed will not be too distant from this article’s primary text: P. Klee, *The Thinking Eye*, George Wittenborn, NY, 1961.


The central argument here is to suggest that routes taken by digital artists converge with technical problems that are within the domain of agent-based AI. Space prevents the complete argument from entering here, for we should show this by tracing historical passages through contemporary computer music, technologically informed dance practice, and through an parallel analysis of the tools made and made available to digital artists in these fields. As the ideas and demands of these fields increase in complexity we as artists are faced with the problem of making computer programs that meet us, as humans, on our own territory — programs that “do the right thing” where the right thing is defined in our terms. This is nothing less than the domain of the artificial intelligence.

The introduction to this argument is also an opportunity to sketch some of the historical, aesthetic and methodological consequences of an AI-based approach to art-making. This sketch will be further refined during the main arguments of the thesis.

### 2. The agent body

Before focusing on revising the contents of these perception, action and motor systems, we should first look at the graphical and sonic materials from which we will construct the bodies of the agents and their virtual worlds. To motivate this discussion one should take a detailed look at the structure and composition of the graphic vocabulary of one piece — with Trisha Brown, entitled *How long does the subject linger on the edge of the body?* — where both the form and the movement of graphical characters are constructed from real-time analyses of the movement of dancers on a stage. This work is then an opportunity to present the “blendable body framework” — an animation framework that unifies disparate techniques for manipulating characters’ bodies in real time. This framework is the site of an integration of traditional computer graphical techniques such as inverse kinematics, mesh skinning, and multi-target blending, but also suggests...
novel extensions and reinterpretations of these techniques. This super-set of conventional algorithmic approaches is the site of a “generalization and abstraction” based dialog with Brown around the graphical formalisms used in her piece. For this suite is used to create the abstracted movement of the agents of the piece and can be described in contrast with the dominant body representations in computer graphics, computer games and digital art.

The standard techniques for rendering, understanding and manipulating human motion are insufficient for the domain of interactive dance projections.

Consider the task of approaching Trisha Brown’s choreography computationally (that is, here, digitally). This seems to demand a number of abilities not present in traditional computer graphics: a fluid, changeable hierarchy of point connections within and between bodies and their environment and between the memory of movement and the present, whereas the mainstream computer graphics body is a single fixed hierarchy in a single fixed moment in time; the fusion and interaction of multiple, simultaneous views of the stage into a single presentation — in particular the stage-diagram plan view, the body-oriented volume — whereas mainstream computer graphics has a trivial single camera model; the simultaneous exchange between point, line and plane forms on stage, whereas mainstream real-time computer graphics focuses almost exclusively on the planar triangle. Each of these goals requires an innovation: the blendable body representation is designed to approach the first, the re-projection renderers attack the second, and the glue system enables an ad hoc distributed exchange between systems for the third.

This piece’s aesthetics of “notation” will be discussed in relation to the technologies that underpin it founded on examples taken from the piece, and from the process of developing the piece. A systematic overview of the 12 notational techniques used in this work will be used to articulate both the artistic goals of the digital work and its relationship to the choreography. A technical description of the
ways in which these notational techniques are implemented will be useful in motivating later discussions concerning the computer scientific architecture and artistic tools. How each of these live notations can be efficiently implemented and connected together will be demonstrated in subsequent sections.

Finally we will turn to consider the construction and illustration of the space between the bodies on stage, at first noting the fundamental technical challenges that such considerations present to contemporary computer graphics pipelines. An example solution to some of these considerations is presented in the form of the Re-projection Renderer — a class of rendering techniques developed throughout the example work discussed to enable a fluid blending of view systems and an efficient and effective reuse of geometric complexity. One introductory example — an extension of an otherwise conventional cel-shader — and two more fully developed examples: from *How long...* where both abstract linear forms and planar "stage architectures" are rendered using these techniques will be given; and, for contrast, from "22", a collaboration with Bill T. Jones, where pre-made representational computer animation and video are combined.
3. Compositional approaches with AI agents.

Having discussed a broad range of materials with which to create graphical characters, and a class of representations that we have used to animate them, we have not yet given them any reason to move, nor have we described any control structure for that movement or anything a choreographer would identify as an organising formalism.

The generic posegraph motor system

Progressing upwards through our motor, action, and perception decomposition of the AI agent, we begin with a discussion of the responsibilities of the motor system and its interface with the agent’s body.

As a solution to these often conflicting responsibilities, the generic, hierarchical posegraph motor system is a representation that has been used throughout the work of the Synthetic Characters Group. Beginning with a purely representational character we can move through the example work to the abstraction of Loops and Fluid Canvas where the methodological and technical needs for a motor system framework that is body representation agnostic can be most clearly demonstrated.

Finally this motor system offers us the first chance to attack the decomposition of the agent into clear layers, and, as greater decision-making complexity begins to be required by the motor system, we can see that the boundaries between systems become blurred — functionally and architecturally. With the modifiable
“animations” of “22” (themselves complex assemblages of video, geometry, skeletons and animations) we shall see a specific example: where the motor, action and perception hierarchy becomes inverted, with aspects of perception and action selection being embedded in a motor-system-like framework.

This will be an argument that starts with the example from “22” and builds throughout the section, finally motivating a set of solutions described in the final section — “tools” — and in particular the "Glue systems".

New action selection techniques

An overview of the problems of action selection will be undertaken using four incrementally complex action selection algorithms, which start with examples from the Synthetic Characters Group’s "c4 character system". A systematic analysis of these approaches will yield a more general set of design patterns. The scope and utility of re-engineering a generalized version of these techniques shall be demonstrated in the installation work of Loops and its accompanying music Loops Score where the manipulation, and indeed "scoring", of a static set of actions provides the fundamental long term compositional technique in the piece.

The introduction of the Loops installation, which consists of a colony of interacting creatures responding to motion capture data of Merce Cunningham, will then serve as a point where the technical and artistic limitations of the idea of "emergence" begin to show themselves. By highlighting these points of frustration in the design of a subsequent installation, which demanded a more nuanced and multi-level control over the temporal patterning of creatures, my installation Music Creatures points towards a radically new action selection framework — the Diagram system. An overview of the goals of this synthesis of classical AI planning concerns and real-time, behavior based implementation will be discussed here, and the Diagram system’s fundamental blending of perceptual and action-selection considerations will add further weight to the ongoing structural argument. While the Music Creatures exploit some of the
Diagram system's capabilities to generate their behavior moment to moment, we shall see that in How long... the system is used to structure everything from the large scale flow of the piece to how the virtual agents on stage reconfigure their points and lines.

Motor systems and the mapping problem

Finally, having blended motor systems with action selection, and action systems with techniques typically found in machine learning and thus perception systems, we complete the triangle and discuss an example of perception and motor system integration in the form of the Distance Mapping algorithm. This algorithm, which enables cross-domain manipulations with very little arbitrary specification on the part of the artist, was developed originally as a fast motion-analysis technique for the dancers in How long... The same approach has also been used as a core musical manipulation in Loops Score, as a graphical manipulation in How long... and as a source of temporal modulation in “22”.

Through each of these examples, we can locate this particular approach to the problem — dominant in contemporary interactive art practice — of cross-media relationships inside a discussion of the conceptual reach and practical limitations of digital art’s ideas concerning “mapping”.

Any review of the proceedings of an interactive arts conference will show that Mapping remains a central concept to the field (for example NIME 2002). Of particular concentration is the review: Organised Sound, vol 7 no 2. Aug 2002.


4. Tools and Craft

A suite of tools, techniques and core representations have been developed during the creation of the work described in this thesis. Three factors demand that these supporting technologies be approached as core problems. Firstly, of central importance to the nature of the works has been the collaborative way in which they have been realized — each artwork involved either other engineers and researchers or other artists, choreographers and composers. This has often required an improvisatory style which, in turn, necessitated environments for improvisation over a non-static set of technical assets. Secondly, the sheer range, aesthetically and technically, of the work has demanded the extraction of reusable and generic components, principles and patterns. Finally, the very nature of the work itself — that of complex assemblages of interacting elements — forces us to look at the “glue” that holds the elements together and the way they are manipulated by the artist during their process, not as an unfortunate interstitial space but as a location for primary research.

The results of such research are presented in a variety of forms. The first is the “Fluid” environment, the primary environment for the prototyping and development of the artworks since Loops, which uses the existence — the visualization and the malleability — of this code-glue to make a graphical improvisation platform. The currently prevalent tools and conceptual structures used in interactive digital art are insufficient and need radical revision.

The “Fluid” environment comes out of a systematic revisitation of the assumptions and critiques of the data-flow paradigm dominant in contemporary digital art practice. It will take the form of an unprecedented synthesis of design principles drawn from and embodied in many disparate design environments.
Four examples of constructing assemblages of the representations previously discussed will complete the description of this environment: the modifiable animations of “22”, the complex motor programs of *Music Creatures*, the progression from improvisations to the finished work for *How long...*, and the “debugging” of a pre-existing creature not made in *Fluid*.

The remaining forms are reusable design patterns that are common throughout the works, but have not been articulated within either the AI literature nor the digital art literature to date. While the AI community is increasingly focused on the problems of large-scale systems, and digital artists are constantly pushing the complexity limit of their tools, there is a paucity of general principles for managing complex assemblages of interacting elements. At the same time, digital artists have little need for yet another tool if it is unaccompanied by significant theory and criticism of digital tools in general. The “Glue system” is a set of practical and lightweight extensions to programming languages and 5 reusable design patterns that leverage both the *Fluid* system and existing development environments and languages to re-enable modularity in the presence of both finite technical resources, and an exploratory art practice. They form the hidden technological underpinnings that make other contributions such as the Diagram system, the generic motor system and the Blendable body representation maintainable, extendable, controllable and deployable.
This section summarizes the eight key technical contributions of this thesis work. These tools, algorithms and representations are behind the artworks that will be presented but have much broader applicability that those artworks — rather than visual art, musical composition, and projections for dance theater, they concern themselves with artificial intelligence, computer graphics and the languages and tools digital artists use. As such they possess evaluation criteria that stand independent of the artworks.

Principle technical contributions

1. the Extended Posegraph motor system.

— a flexible, hierarchical and fast interface between action selection and animation, used to power a range of works that are extremely wide-ranging both in terms of their technical requirements and their aesthetics. The posegraph motor system uses a directed, weighted graph structure to represent the space of motions possible for an agent to perform. New animation material is then built by performing various searches across the graph structure. Care is taken to ensure that the nodes of the graph, at each layer of the hierarchy, can contain a heterogeneous mix of animation data, or even control logic that drives the searching of lower levels. As the agent body is extended we shall see a broad variety of graph “contents” developed — for each example work discussed in this thesis will contain an implementation and at least one instantiation of this system. However, throughout the gamut of agent bodies presented the posegraph control structures and the interfaces remain the same. This representation will be evaluated based on its ability to simultaneously power believable, representational characters (such as dogs and wolves) that learn about their bodies as well as the diverse range of less representational, less conventional, creatures introduced in this thesis.
2. the Blendable Body system.

— a new representation of an arbitrary graphical body for an animated “character” that allows a multiple, *ad hoc* set of competing processes to manipulate its movement. The central representation is an hierarchical radial basis function approximator that makes it easy to write constraints and body controllers that appear and disappear over the time of the characters body even in situations where the topology of the “body” is changing. Contained within the system, as deployed in three of the example works, are algorithms that are superset of the conventional ways of manipulating and rendering graphical characters — skinning algorithms, inverse kinematic approaches and motion interpolation techniques. This system is presented as a design study in the challenges and benefits of building motion architectures that are representation agnostic. It will be evaluated based on its ability to support a sustained dialogue with modern choreographers that result in artworks that recognise and that are integrated with their practice.
3. the Re-projection renderers.

—a core part of the rendering styles in many of the example pieces, a re-projection renderer is an approach to achieving a variety of visual effects on contemporary graphics hardware. The basis for these renderers is the re-texturing, through projection, of distorted versions of previous frames of animation onto current scene geometry. This technique thus plays to such commodity hardware’s core strength — textural, or “fill-rate” complexity — while using very little dynamic geometry. The result is a wide range of visual styles that are highly controllable through a small number of control points and parameters; extensions to the technique include a renderer that incorporates pre-rendered video, allowing a range of graphical presentation that extends from the abstract to the photoreal. These algorithms will be successful if they extend the current understanding of the possibilities of relatively inexpensive graphics hardware.
4. the Diagram system.

— a new perception and action selection layer for agents that offers new ways of composing simple perceptual recognizers into more powerful assemblages, a design goal prevalent in both AI research and computer music. At its core is an extension to a previously published probabilistic action selection framework — the Synthetic Characters Group’s c43 system — to enable speculation, backtracking and multiple hypotheses across both the action selection and the perception system. The result is a system that draws on the strengths of reactive systems — their responsiveness and interactivity — while making them much more suitable for producing complex patterns in time — the central problem in both “performance graphics” and computer music. This system was used for the creation of autonomous creatures for two interactive installations and the piece *How long...* and will be evaluated in two ways: firstly through a series of code studies, drawn from the principle and secondary artworks, that demonstrate significant decreases in the complexity of code required to solve problems that repeatedly appear; secondly, by showing the Diagram systems applicability to similar problems very prevalent in the digital art world.

5. the Distance Mapping algorithm.

— a new class of algorithms that are a super-set of multi-dimensional scaling (Mds) approaches allowing disparate representations to be coupled together by programmers. A fast, iterative, online Mds-like algorithm is used to build a bridge between two domains, given only a description of two distance metrics which can themselves, in turn, be learnt online or during rehearsal. Manipulations in one domain are converted intuitively and reversibly to manipulations in another. This will be presented as a powerful technique to help solve mapping problems in digital art, while specific examples from the domains of motion analysis and musical time are developed for two different dance theater pieces.
6. the Generalized B-tracker algorithm.


This algorithm is presented as a lightweight, reusable tool in the creation of the perceptual layers of a diverse range of "radically extended agents". It is a fusion of an iterative graph-matching algorithm used to provide synthetic characters with object persistence and a distributed "conditional density propagation" approach for maintaining and fusing multiple simple hypotheses. Examples of its use are drawn from two of the discussed works. This algorithm will be evaluated by presenting new results in understanding data provided real-time motion capture streams, specifically the relationship of Bill T. Jones improvisations to the established formal constraints of the piece 22.

7. Fluid — graphical dataflow programming reconsidered.

— a new system for the rapid, collaborative construction of code assemblages has been created and used during a number of residencies as a platform for the prototyping of digital artworks and as a tool for live graphical improvisation. This system was designed by systematically revisiting the assumptions and conventionalities of the data-flow programming tools now dominant in the digital art world. The completed system augments data-flow programming with an extended version of the python scripting language, adds a language-use aware version history database and a graphical constraint system. This system will be evaluated through case studies drawn from the intensive, and time-critical, collaborative residencies that have been used to create many of the artworks here. These case studies shall exploit the database “back-end” of the Fluid environment that provides detailed histories of the work done in each of these residencies.
8. the Glue systems — techniques and representations for architectural simplicity.

— a set of representations presented as the key design patterns behind all of the example works and as the solutions to a number of more general problems in the creation of complex assemblages of code. Specific implementations include the addition of dynamic scoping, complex multi-method dispatch and coroutines to the Java programming language through byte-code injection, preprocessing and creative use of existing syntax. The goal is to bring to a mature object oriented language some of the features of smaller, agile languages while maintaining the features that make the language suitable for large, complex projects — type safety and compatibility with conventional compilers and programming environments. These extensions help maintain separations-of-concerns and modularity while allowing the densely connected code forms demanded by large-scale AI agents and complex digital artworks. They will be described by case-history — showing code-examples from previous work that become simpler to understand and easier to maintain when these ideas are applied.
This section introduces the principle works that will form the examples, the source for the case-studies and the demonstrative proofs for this thesis.

Principle artistic works

1. *How long does the subject linger on the edge of the volume... — 2005*

Interactive projections for a real-time motion-captured stage with choreography by Trisha Brown. To premiere April 14, 2005, Lincoln Center.

This is the work in which I present the most complete picture of the *radically expanded agent body*, with graphical agents sampling and manipulating motion captured from the stage, while constructing spaces around them that illustrate the relationships between the live dancers. Interaction with Trisha Brown's visual art-making led to the revisitation of the aesthetics of drawn gesture, the development of a formal, but dynamic, "stage architecture" for the piece and the diagrammatic representation of motion processes. Brown's computation as performance is met with algorithms that "learn live" in front of the audience.

Almost all of the technical contributions of this thesis are exploited in this work. The "Glue systems", the family of core design patterns that connect algorithms and representations, is fundamental to the creation of this piece. Further, the piece owes much of its creation to extensive prototyping with the "Fluid" toolset. The "Distance Mapping" algorithm provides a bi-directional connection with the evolving musical score, while the perception and action selection techniques developed in this thesis are the basis for both the analysis of the stage and the control over temporal structure of the work as a whole.
2. “22” — 2005

To premiere Walker Art Center, Summer 2005. Interactive projections for a real-time motion-captured stage with choreography and performance by Bill T. Jones.

While the visual elements of *How long* may be described as abstracted motion on abstract form, the vocabulary in this work is the opposite: a series of pre-composed graphical materials is twisted out of shape, both graphically and temporally, by the motion and narration of a central performer. Taking as its point of departure Bill T. Jones’s landmark 1980s piece “21”, his performance offers an unexpected demonstration of a non-linear, non-literal narrative form inside which visual elements can cooperate with performance, narration and music. Such formal structure enables a connection between the ideas in this thesis and the “scripting based” views prevalent in computer games and some interactive narrative techniques. In this piece I present my richest representational graphical forms using the “Re-projection renderer” — specifically to meet Jones’s “pedagogic” presentation of is motion material, that demands a visual presentation that can create danger while presenting the same cycle of material repeatedly.
3. **Loops — 2001-4**


A “digital portrait” of choreographer Merce Cunningham, based on his 1977 piece for hands entitled *Loops*, formed the impetus behind the creation of the “generic motor system” structure used and developed in each of the other works presented here. It also represents the first direct point of contact between the history of chance operations in art, in which collaborators John Cage and Merce Cunningham play a major role, and the probabilistic action selection techniques of artificial intelligence. Note that the dialogue between digital artist and choreographer aimed for in this thesis could not have been said to occur in this or the two other works with Cunningham, at a collaborative level for reasons that, given his collaborative technique (that of avowed “non-collaboration”), should be all too clear.

4. **Loops Score — 2004**

Music for *Loops*. Premiered at the Ars Electronica Festival 2004.

This new musical component to the *Loops* installation has a competing colony of musical creatures listening to the voice of Merce Cunningham and responding through a sonic vocabulary of John Cage’s prepared piano. The work provides the clearest example of the use of the Fluid graphical system, toy-examples of the distance mapping algorithm, as well as reusing much of the “Diagram system”. An inversion of the human charm of Cunningham / Cage’s *How to Pass, Kick, Fall and Run* where words, movement and time collide in performance.
5. *Music Creatures — 2000-2003*


A set of installations where graphical creatures make music through the movement of their bodies and illustrate their understanding of sound though the construction and growth of those bodies. The most recent music creatures installation formed the motivation behind the “Diagram system”. This work will also serve as a focus for the discussion of the aesthetics of mapping, approaches to the sound / image problem in digital art based in the understanding of movement and the ability to produce it, rooted in choreography’s vocabulary of relationships to music.
6. The periphery — 2001-

*AlphaWolf* (2001) — interactive simulation of wolf social behavior with the Synthetic Characters Group.


These works are either being developed on a time-line outside that of this thesis or were completed *en route*. In either case they will simply act as supporting examples to the central arguments and are included solely to the extent that these arguments benefit from the context of a broad range of domains and applications.
How long does the subject linger on the edge of the volume...
— Goals and Evaluations

The evaluation methodology described in B. Hubbard, A Theory for Practice. MIT Press, MA, 1995, has been influential in shaping the ideas for evaluating the non-technical contributions of this work.

From a purely artistic standpoint, this work can then be evaluated in terms of its cultural impact against two different cultures. One, the culture of modern dance specifically, and theatre arts in general and secondly, the culture of “dance-technology” specifically and digital performance art in general. On the one hand we aim to make our techniques and algorithms related to and be a genuine response to modern choreographic practice, its rich “tradition” and its future. On a technical level we seek a relationship with the core problems of digital performance art and a broad applicability to not only the author’s art practice but the practice of other artists as well.

A parallel, and no less important, way of evaluating the technical ideas described in this thesis is to trace the relationship between technical contributions and the artworks themselves. I am fortunate that there is a considerable body of work to present that I can use to demonstrate the a narrative by which the technologies built for one piece suggest, inspire or provoke the underpinnings of the next. Thus, by going through a series of installations, theater productions and compositions all created in collaboration with different people with different means and media we shall see, in miniature, concrete examples of the broad applicability that I claim.
Further, in this proposal I have argued that there is a genuine dialogue that could take place between a digital artist and a choreographer that is currently not present in the field, that there is work to be done between them — the techniques that I present underpin such a dialogue. In this last section I would like to suggest that there is an aesthetic point of connection as well, although I will confine my argument to showing how the visual elements for How long..? might tie in with the rest of the work in this thesis.

Since motion capture offers few pre-made ideas about how to present the data that it offers, we are faced when deciding upon the surface appearance of the new dance pieces with a blank page. Aesthetically, the projections for How long..? have take as a point of departure Brown’s visual art, her dance diagrams, her notational systems while simultaneously returning to my previous, hand-drawn, gestural graphical style. Brown’s dance diagrams are fascinating in that they are not visual depictions of a stage picture; rather they are illustrations of a processes that create dances; they are visual programs run on human computers. My programs are hidden programs run on visual, virtual agents. The metaphorical field between choreographer and visual artist, choreography and projections is one of description, illustration and communication of process.

This starting point enables a recapitulation, in miniature, of the proposed dialogue between digital artist and choreographer. The aesthetics of the projections for this piece draw directly from generalizing, transforming, representing and computing what is happening on the stage and indicating the audience that this is already occurring in the theater and has already occurred in the creation of the work. A goal is to enable a visual and interpretive mobility for the audience in their reading of the dance, and in their writing of the dances mechanisms over-and-above what they normally are given by a staging of a dance piece.
One danger is that the projections become authoritative, flattening into a single reading the play of relationships before they even unfold. The other pole is that the obscurity of the projections erase the connection between the dancers and any dance. These dangers are faced by every piece labelled “interactive” but here the stakes could hardly be higher — one of the most evocative aspects of Brown’s recent work is the simultaneous choreography of appearance and occultation of movement — the unexpected and alarming clarity of what ought to be complex, and the disorienting disappearance of what should be visible. To prevent this alarming alchemy from occurring would be a considerable failure. Several techniques are deployed in the creation of the systems that, in turn, create the works described in this thesis, to prevent the relationships between their media (be they projections over dancers or animations with music) from either disintegrating or fusing solid. An articulation of these strategies will be a thread between the technical discussions and the artistic ambitions of this thesis.

However, while the goal of a single communicative result is jettisoned, the communicative flavor of the dance diagram is retained in my own aesthetic and will be central to the animated diagrams that will accompany the dance. This spirit is very much in keeping with the central technical concerns of the whole body of work — animation and music — that will be presented in this thesis.

To quote music psychologist Michel Imberty, one of many to grapple with the communicative in music:

All [music’s] temporal substance is nourished by our way of being in the world; that is, in our time, our culture, our perceptions, our bodies, our emotions, and our sentiments. It is not communication but a representation of our ability to communicate, it is a stylized game for our opening to the world, it is communication without an object to communicate. In this sense, music is indeed, the symbol of our fundamental relation to time, life, and death.

This statement could easily be extended to include the other “temporal arts”, including, of course dance. A deep engagement with this meta-communicative aspect of the temporal arts — music and animation as well as dance — is central to the artistic and technical work presented here.
Four week-long residencies with Jones mean that “22” requires only rehearsal time in order to be finished. Three weeks with Brown will be augmented by another ten days in theaters in January and February. Due to the nature of the pieces presented in this thesis there are a number of rigidly fixed dates in this thesis time-line. All other principle artworks have been completed, documented and exhibited.

Time-line & Resources

January 8  "Keynote introduction" of 22 and How long... at Association of Performing Arts Presenters meeting
January 19-22 Development residency: John Jay Theater, Lincoln Center New York (With Brown)
February 10-17 Development residency: Arizona State University (With Brown)
March 30 — April 9 Development residency: Arizona State University (With Brown and Jones)
April 10 Invitational Premiere of 22 and How long...: Arizona State University
April 14 Public Premiere of How long...: Rose Theater, Lincoln Center New York
June 2 Public Premiere of 22: Walker Performing Arts Center, Minnesota

— November All fundamental code development for 22 has been completed and tested, and will now simply track changes of form that arise in rehearsals and meetings with Jones. Much of the documentation of the processes and the ideas behind 22 has been completed and edited during the collaboration.

December Condensation of writings and notes to date on previous works.
Review of fundamental code and Fluid scripting database history; extraction of design cases.

— January A first draft of the fundamental code was used in July during a residency with Brown, this will continue to be developed until early January.
Collaboration and dialogue with Brown continues via the production of short documents on the structures of How long... Taken together these will form the textural and graphical description of the work for the thesis.

March Complete "Radically Extended Agent Body" chapters.
Late April Complete "Tools" chapters
May Complete "Compositional approaches with AI Agents" chapters.
June Defend

Resources 22 and How Long... are fully funded by the National Endowment for the Arts, the National Science Foundation and by the Lincoln Center for Performing Arts. Additional engineering and equipment support for these performances and future performances has been made available by Motion Analysis Corporation.
Currently all Media Lab equipment required for the completion of this thesis has been allocated.
Marc Downie — Biography

Marc Downie is an artist and artificial intelligence researcher who lives and works in Massachusetts, USA. Born in Aberdeen, UK he has an MA in natural science and a MSci in physics from the University of Cambridge. After graduating at the head of his class with the Mott Prize in the Natural Sciences, he packed his computer and left the UK to become an artist.

Downie has collaborated extensively with colleagues at the MIT Media Lab, leading projects such as AlphaWolf (A Prix Ars Electronica honorable mention in 2002), Dobie (Siggraph 2002), and (void *) (Siggraph 2000). These large interactive works presented advances in the fields of interactive music, machine learning and computer graphics. More recently, in 2003, his solo piece Music Creatures: Experiments in Intelligent Form was commissioned by the Ars Electronica festival.

In addition, Downie has created digital projections with artists Merce Cunningham, Paul Kaiser and Shelley Eshkar (Both Loops and Lifelike, for the recent Merce Cunningham Dance Company work Fluid Canvas 2002-3) and is currently constructing new works for interactive dance theater in collaboration with choreographers Bill T. Jones, Trisha Brown. The piece with Trisha Brown will premiere at the Lincoln Center, New York, in 2005. His work has been shown internationally at venues including Ars Electronica, ZKM, Siggraph, ICA London, the Brooklyn Academy of Music and the Barbican Centre.


Works Cited

AliasWavefront, Maya, software package, http://www.aw.com


CMU Alice, software package, http://www.alice.org/


G. Deleuze, F. Guattari, Mille Plateaux: Capitalisme et Schizophrenie, Minuit, 1980.

G. Deleuze, Logique de Sensation, Minuit, 1969.


M. Girard, S. Amkraut, Character Studio, software package, http://www.discreet.com


Infomus Lab, eyes-web, software package, [http://www.infomus.dist.unige.it/eywindex.html](http://www.infomus.dist.unige.it/eywindex.html)


S. deLahunta *Dialogues on Motion Capture* Proceedings of IDAT 1999.


*Lifeforms*, software package, [http://lifeforms.com](http://lifeforms.com)


M. Pukette, pd, software package, http://www.crea.ucsd.edu/~msp/software.html


Troika Ranch Future of Memory, dance performance, 2003


ZKM, Improvisation Technologies (CDROM), ZKM (Center for Art and Media Technology) / Ballett Frankfurt, 1993.