This thesis touches upon many areas of work, many intellectual and artistic fields of endeavor. This chapter reviews some of the previous work in these areas, and sets the stage for the arguments that follow. It concludes with an overview of the remainder of this document.

Chapter 1 — Context

The works presented in this thesis border on three broad subjects — contemporary choreography, both with and without the involvement of computers, artificial intelligence and computer graphics. Parts of its presentation will also touch upon computer music and user-interface design. These are fields with long traditions and many practitioners, so the work that I present and the arguments I develop in this thesis must be contextualized with respect to each of these areas. During this contextualization the central themes behind my artworks will emerge. We will see a new model, a new metaphor, for interactive art-making brought out of artificial intelligence and demonstrated in the context of dance theater; we will see how this model differs from the prevalent synthetic and analytic techniques of interactive art and dance technology; and we will begin to see what fruits this maneuver might have for both artificial intelligence, computer music and computer graphics.

1. On computation and dance

Many of the works presented in my thesis are collaborations involving choreographers. Three are live projections for dance theater — *Lifelike*, *22* and *how long...* — two of which — *22* and the central work *how long...* — are projections 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. All three pieces are difficult and expensive, and both this difficulty and expense come directly from the presence of these computers and the equipment required for them to sense the stage so that they can be a live part of the performance.

There is an existing field, positioned between the academy and the arts, of *dance technology*, a field of artists digitally and electronically augmenting dance. This work would seem to fit inside its domain. But, I choose not to draw much grounding context from this field, and I will postpone the contextualization of it until later in this chapter — if my work fits into this tradition, it does so uneasily. Rather I shall look at the recent history of modern dance in the absence of digital "augmentation". The recent line of "interactive" works for dance and computer have thoroughly failed to make much lasting impact on the dance world or the broader digital arts community. But there remains an uneasy but strong alloy of visual art, dance performance and computation that can be made. I believe the works presented in this thesis do just this, and point toward original ways of continuing this fusion in the future.

I will 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 is there for the taking — the "dance-technology" work that lays claim to the space where the union would occur has typically ignored what both computation and choreography could offer to each other.

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

One could write a long 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. But in order to trace the thread of algorithmic concern through 20th-century dance, 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.

Works referenced for Merce Cunningham are documented in the comprehensive book:

D. Vaughan, *Merce Cunningham, Fifty Years*. Aperture, New York, 1999.

they are arguably better contextualized for our purposes here in:

R. Copeland, *Merce Cunningham: the Modernizing of Modern Dance*, Routledge, 2004.

For Trisha Brown, the encyclopedic

H. Teicher (ed.) *Trisha Brown: Dance and Art in Dialogue*. MIT Press, Cambridge, MA, 2002.

is indispensable. For Bill T. Jones:

E. Zimmer and **S. Quasha**, *Body against Body: The Dance and other collaborations with Bill T. Jones and Arnie Zane*. Station Hill Press, New York, 1990.

A key tendency in computer science is the urge towards generalization — the replacements of constants with variables— and abstraction — the re-expression of prototypes as templates. 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 make 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 engineering programmer. The flux of generalizations and abstractions of computer science should, however, not be mistaken for the totalizations of natural science. Rather than seeking a coherent, global predictive and explanatory system, the systems of computer science are forever local, transformative, interconnected.

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 a new framework; and a resulting framework that is itself ripe for generalization.

This computational sensibility is present at two levels in the work of these choreographers. Firstly, in their choreographic processes — the systems, methods, and notations through which the choreographers create the dance. Secondly, in the finished work itself, as it appears on stage and as it is interpreted by the viewer. Of course, it is a defining feature of modern and contemporary dance that the boundary between "process" and "product" is often blurred.

As **Umberto Eco** points out in *The Open Work* (1962), from the second half of the 20th century, artists increasingly became fascinated by indeterminacy, process and open form, establishing a productive dialectic between this openness and the need to produce a "finished" work.

U. Eco, *The Open Work,* **A. Cancogni** (trans.) Harvard, 1999.

In the choreographic process, 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; any point of a stage can be a "front", and any connected set of joints can be thought of as a limb. What were once specified constants in a rigid description become variables in in a generative framework.

See, for example, Cunningham's comments on both "relativity" (as in physics) and animal motion in his work *Beach Birds for Camera* in: **J. Lesschaeve** (ed), *The Dancer and the Dance,Merce Cunningham in conversation with Jacqueline Lesschaeve*. Marion Boyars, New York, 1985.

See also: **M. Cunningham** and **D. Vaughan**, *Other animals: Drawings and Journals*. Aperture, New York, 2002.

A particularly revealing interview with Forsythe by **Paul Kaiser** in Performance Research, 4 (2), Summer 1999. Available online at:

http://www.kaiserworks.com/ideas/forsythe1.htm

figure 1. A body centered, fixed, "kinesphere".

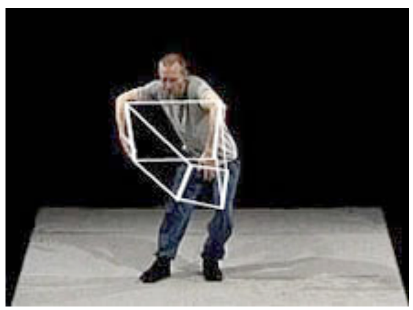


figure 2. A Forsynthian, "generalized", mobile, kine-polyhedron. From *Improvisation Technologies*, below.

But to find the most concentrated and self-contained examples of the generalization–specification cycle 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 are meta-methodological diagnoses attempted. For example, the most commonly mentioned strategy of Forsythe is his decentered kinesphere. Forsythe takes the established kinesphere of movement theorists (most notably Rudolph Laban) — a geometrical framework for the description of limb positions that forms the grounding of Laban's extensive analytical and notational techniques — and frees it from its anchor at the center of the dancer's body. This new, roaming, kinesphere, now centered on an elbow, an ear, or the midpoint between two hands, stands to inherit every analytical use to which Laban put his kinesphere; it is a *generalization* of Laban's analytical framework. Movements, within this framework, now 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 frameworks to deal again with the resulting material — systems of "alphabetization" or hidden geometry. These new representations of dance are in turn ripe for later generalization, an agglomerative cycle that is nothing less than the choreographic process. This is generalization and respecification as a computer scientist would recognize them.

This role of representation within the choreographic *process* indicates more points of connection with computer science. (The problematic issue of representation *on stage* will be addressed later.) The creation of computer programs often turns on representation — the virtual laying out of bits that represent, that stand for, an object. Just as with computer science's *generalization*, the world *representation* should be used with caution. In its basic sense representation occurs when something stands for something else. The relationship between representation and represented may be based on some kind of similarity — in this case this mimetic representation would have an iconic or "natural" relationship with the represented. However, the representative relationship may also be arbitrary — as in the relationship between signifier and signified in language. Computational representations are often arbitrary in this sense (although they are not necessarily experienced as such by the programmer or external viewer). Without the burden of strict imitation, these representations have the freedom to support computation and reconnection — in short, *transformation*. The mimetic/transformable distinction is of course not a binary opposition, but rather two poles of a continuum. Having set up this axis for the purposes of this section we shall see it questioned in later sections.

Walter Benjamin questioned the idea of the arbitrariness of language in his short essay *On the Mimetic Faculty*, offering an idea of *nonsensuous mimesis* that exploits the mimetic faculty of humans, indeed takes it to a higher level. We might extend this notion to computational representation.

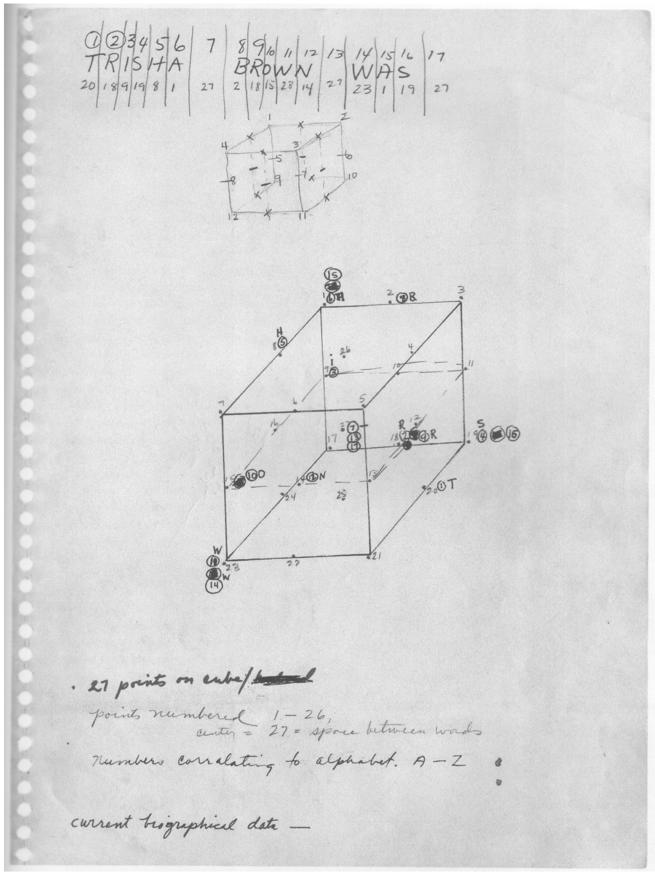
W. Benjamin, *On the Mimetic Faculty*, In: **P. Demetz (ed.)** *Reflections*, Harvest / HBJ, 1978.

Cunningham's earliest investigations of chance procedures had the flavor of computation and transformative representation about them. Motions were broken up, atoms identified, tokenized. These arbitrary tokens rearranged by the toss of a coin, the fall of the I-Ching yarrow sticks, 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 representations that support useful compositional actions.

These tendencies are articulated in: **J. Lesschaeve**, (ed.) *The Dancer and the Dance, Merce Cunningham in conversation with Jacqueline Lesschaeve*. Marion Boyars, New York, 1985.

They are "demonstrated" in: **F. Starr** (ed.) *Changes: Notes on Choreography*, Something Else Press, New York, 1968.

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



Drawings for *Locus* by Trisha Brown.

kinesphere into boxes, the arbitrary 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.

For the idea of theater as the "imitation of actions" goes back at least to **Aristotle**'s *Poetics* (1449b-1450a). Classical dance, with its emphasis on narrative, clearly belongs to this tradition.

This brings us to the presence of computational aesthetics on the *stage*, and the dance's relationship to the audience's expectations and reactions. And it is here that we should note how radical choreographers such as Cunningham, Brown, and Forsythe's relationship with dance history has been. While the choreographies of Sergei Diaghelev, Vaslav Nijinsky and George Balanchine all expand the expressive and representational powers of classical ballet from within, many contemporary choreographers, in particular Forsythe, threaten nothing less than the three-thousand-year-old mimetic basis of theater as an imitation of an action, in their displacement of overt mimetic representation by the fruits of covert computational representations.

> I think we are trying to create something life-like. a kind of autonomous form. Artificial life, so to speak, but cultural life. Fundamentally traditional arts animate people's expertise. Classical ballet, for instance, lacks its own vital force. Dance is a far more hybrid form of animation. It is like a drawing that is drawn into itself. As in the third act of *Eidos*, it is cellular autonomy; based on the same rules as every other one but each one reacting differently. It is hybrid aesthetic organization, better yet, hybrid aesthetic animation.
>
> William Forsythe, quoted in **T. Ozaki, (P. Vigilio trans.)**, *An Interview with William Forsythe*. (availability as above).

Process spills onto the stage throughout contemporary choreography, and with it the choreographer's computational sensibility. 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 re-acted out, numbered and named, by the performer. After declaring (quite pedagogically, unlike Brown's *Locus*) almost all of its motion 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 physical, rather than formal, 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 the fecundity of the "computational sensibility" outlined here, none of these techniques or inventions exist independent of a body and a theatre space. Cunningham's proposal that there are no fixed points in space meets the plain fact that the audience sits in one place, and the edge of the stage is all too fixed; his democratic use of the movement 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 (the harness and rope) exposed for all to see . In *Accumulation plus talking with water motor* (1978/1986) she shows, while 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 she carries on her back in a dance of light, but it is a heavy, obvious and almost domestic burden.

Dance technology theorist Scott deLahunta fears that choreographers have been backing away for decades from live performance technologies that are otherwise being integrated into theater. I hope that the work presented in this thesis offers an counterexample.

S. deLahunta, *Virtual Reality and Performance*, PAJ: A Journal of Performance and Art 24.1 (2002) 105-114

I believe that the creative potentialities of the dialogue between computers and choreographers lie in this shared computational sensibility. Digital artists can connect to, and radically expand, the vocabulary of the choreography that I have outlined. For are they not 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, transformed, and mechanical, between the theatrical, human, and perceived. They can offer this crucial expertise in return for the digital artist's computational virtuosity.

Information about *Lifeforms's* intentions can be found in: **T. W. Calvert, A. Bruderlin, S. Mah, T. Schiphorst, C. Welman**, *The Evolution of an interface for choreographers*. Interchi'93 — ACM Press, April 1993.

See, for example, Hotwired's ecstatic reporting of Cunningham's use of the computer:

http://hotwired.wired.com/kino/95/29/feature/index.html

as well as countless post-performance interviews and discussions by Cunningham.

Earlier attempts at this dialogue were often unsatisfying. For example, 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 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 hyper-mimetic representations of photorealistic "Hollywood computer graphics". This use of the computer seems oddly disconnected from the underlying computational practice that I have identified in his work. 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.

Of course, it would be just as unsatisfying to simply make a computer program that helps Cunningham roll dice — this duplication of the choreographer's role is unnecessary. We have to find some other way to create a programmer-choreographer dialogue. To inform the technologies and practices that we develop for the sake of this dialogue we clearly need to cast a net wider than contemporary choreography or even dance technology. In this regard the tools and techniques of computer music are fundamental to my approach.

Over the centuries, composers have developed notational representations that allow the distribution and reproduction, but more importantly the transformation and interpretation of music, without the instantiation of sound. A focus on the experimental transformation of music into a representation, on manipulations within and with this new form, and on subsequent reinterpretation and retransformation back into other 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 science's representations and music's notations are not just ways of seeing the world or music but locations for new ways of thinking about how to change it. Since this ground has been so fertile in the past, one of the central techniques in my work is to import the techniques and approaches of computer music into a new "computer dance" domain.

Dance notation continues to generate conferences and discussions but little permanent consensus. For a glimpse at the rather more interesting, less academic, personal notations of choreographers:

L. Louppe, B. Holmes, *Traces of Dance*, Dis Voir / DAP Publishers, New York, 1994.

But even outside of computer music *per se*, these exchanges are present throughout the history of music. The ascendancy of the twelve-tone row in Western music was propelled initially, I suspect, by the explosion of formal possibilities that this transformative unit caused. Its mid-century crystallization into an attempted totalization of musical form is opposed by a simultaneous notational explosion amongst experimental composers.

A compendium of mid century musical notations: **J. Cage,** *Notations*, Something Else Press, 1969.

The experimental / avant-garde distinction made by composer and musicologist Michael Nyman in describing this moment of music history, and the computational representations of computer music in general, will also help us calibrate our relationship to the "formalisms" of contemporary choreography. Nyman offers a distinction between "avant-garde" composers (the Boulez of the 1950s) who search for coherent systems, self-contained and self-constraining; and the "experimental" tendency (typified by Cage) concerned not with "prescribing a defined time-object", but rather "outlining a *situation* in which sounds may occur, a *process* of generating action (sounding or otherwise), a *field* delineated by certain compositional 'rules'."

M. Nyman, *Experimental Music: Cage and Beyond. 2nd ed.* Cambridge, UK: Cambridge Univ. Press, 1999 (p. 4).

In this analysis we see Forsythe, Brown, Jones and Cunningham allied most definitely with the experimental — sharing practices that "work through" a field delineated by temporary "rules", mining the potential latent in algorithmic systems as performed by their dancers, while temporarily protecting the integrity of the system from reproach. Only after the consequences of these computations have been discovered are these tactical formalisms aggressively questioned, toppled, robbed of any governing authority over practice as a whole. We will see a very similar practice developed in this thesis as I explicitly locate techniques that permit the development of algorithmic potential, and computational representations open to the unexpected, that simultaneously permit the navigation and culling of the resulting computational space. In the creation of autonomous "live" digital artworks, this method of working, which is at once ludic and serious, is at the core of my aesthetics.

In this regard we might also look to the "formalisms" of the French literary "workshop" *Oulipo*. In describing the relationship between novelist/mathematician Raymond Queneau and mathematics, author Jacques Roubaud describes the Oulipian imitation of the "axiomatic method" in the writing of literature. Reacting against the surrealist obsession with literary "freedom", Roubaud rejects the "mystical belief according to which freedom may be born from the random elimination of constraints." However, the Oulipian method of using constraints to generate texts claims no ultimate authority, since literary rules no longer have any foundation in value.

J. Roubaud, *Mathematics in the Method of Raymond Queneau*, reprinted in: **W. F. Motte Jr** (trans., ed.), *Oulipo: a primer of potential literature*, University of Nebraska Press, 1986 (p. 88, 89, 93).

2. On "mapping"

The field of dance technology — the use of computer and electronics in a dance theater context — is undeniably growing today. However, it is hard, from an academic standpoint, to consider this a well-functioning area of intellectual endeavor. 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 that has no influence on the prevailing digital art paradigms — largely taken from computer music — that it consumes.

If there is a term that tries to pass as a central concept in the theory of interactive digital artworks in a dance context it is *mapping*. I shall argue that this word has become vague almost past the point of usefulness, but at its core is a reference to the ability of digital computers to take data from one domain and transform it into another. This transformative core of interactive digital artworks is also the location of its "visualization" and "sonification" tendencies. This thesis proposes and, insofar as the terms mapping, visualization and sonification mean anything at all, contrasts an alternative point of origin for digital artwork: the interactive agent. But to attempt this contrast, and to contextualize the interactive dance work that is presented later, we will have to spend some time discussing the meanings that "mapping" has for the community.

Despite the term's imprecision, one can hardly cite a technical paper on dance technology without encountering the word. A representative example:

> Each part of the body has its unique limitation in terms of direction, weight, range of motion, speed and force. In addition, actions can be characterized by ease of execution, accuracy, repeatability, fatigue, and response. The underlying physics of movement lends insight into the selection of musical material. Thus, a delicate curling of the fingers should produce a very different sonic result than a violent and dramatic leg kick, since the size, weight and momentum alone would have different physical ramifications. To do this, physical parameters can be appropriately **mapped** to musical parameters, such as weight to density or register, tension to dissonance, or physical space to simulated acoustical space, although such simple one-to-one correspondences are not always musically successful. The composer's job then, is not only to map movement data to musical parameters, but to interpret these numbers to produce musically satisfying results. [emphasis added]

From **T. Winkler**, *Making motion musical: Gesture Mapping Strategies for Interactive Computer Music.* Proceedings of the 1995 International Computer Music Conference. San Francisco, International Computer Music Association, pp. 261-4.

However, more recently: **T. Winkler**, *Live Video and Sound for Dance.* From Video, Technology and Performance Festival, Brown University April 4-5, 2003. Available online at: http://www.brown.edu/Departments/Music/faculty/winkler/papers/

In what is in many ways the parent field of dance-technology, interactive music controller design, researchers talk of *mapping* sensor data to musical parameters, of the *mapping* problem, of classes of *mappings*, of good *mappings* and bad *mappings*, of intuitive *mappings* and unsuccessful *mappings*, of tools for *mappings*. Some 40% of the papers in the 2004 New Interfaces for Musical Expression conference use the term in all sincerity, as part of titles, abstracts, conclusions, problem statements and results. Here and elsewhere, mapping has become a analytical perspective and a methodology, an point of departure and a destination, a field of study, a description of a problem and a place where solutions are to be found.

$$\text{output} = f(\text{input})$$

This then is the core image for a whole branch of interactive music and much of the smaller field of interactive dance technology and, almost is if through infection by the vector of their shared tools, interactive art as a whole.

‣The step after hardware:

Raw values are received by Max via the VNS object, an object written by Rokeby to handle system configurations. From there, changing values representing the grid are displayed graphically, then scaled, mapped, or otherwise prepared to enter the system's response modules.
T. Winkler, *Motion Sensing Music*, Proceedings of the International Conference on Computer Music 1998, San Francisco, International Computer Music Association.

The mapping had to be both transparent to the user and complex enough to sustain interest if the system were to be used day after day. In our process, we took a top-down approach to mapping [...]
L. Gaye, R. Mazé, L. E. Holmquist, *Sonic City: The Urban Environment as a Musical Interface*, Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

‣Or the entire performance problem:

Our work on instrument design and instrumental performance interfaces has led us to consider in detail the mappings from the performer's gesture space to the listener's perceptual space.
G. Garnett, C. Goudeseune. *Performance Factors in Control of High-Dimensional Spaces*. **Proceedings of the International Conference on Computer Music. 1999.** San Francisco, International Computer Music Association.

Movements are identified and mapped in software to play and process sounds (Max/MSP), or to alter a live video feed using real-time video processing software (NATO). The computer generates most of the material based on the performer's movements, with each performance being a unique realization of the program's many potential responses.
T. Winkler, *Live Video and Sound Processing for Dance*, Video, Technology and Performance Festival, Brown University April 4-5, 2003. Paper available online at: http://www.brown.edu/Departments/Music/faculty/winkler/papers/

‣A prescription:

... there should be a correspondence between the size of a control gesture and the acoustic result. Although any gesture can be mapped to any sound, instruments are most satisfying both to the performer and the audience when subtle control gestures result in subtle changes to the computers sound and larger, more forceful gestures result in more dramatic changes to the computer's sound.
D. Hewitt, I. Stevenson, E-mic: Extended Mic-stand interface controller, Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

The underlying physics of movement lends insight into the selection of musical material. Thus, a delicate curling of the fingers should produce a very different sonic result than a violent and dramatic leg kick, since the size, weight and momentum alone would have different physical ramifications. To do this, physical parameters can be appropriately mapped to musical parameters, such as weight to density or register, tension to dissonance, or physical space to simulated acoustical space, although such simple one-to-one correspondences are not always musically successful.
From **T. Winkler**, *Making motion musical: Gesture Mapping Strategies for Interactive Computer Music.* Proceedings of the 1995 International Computer Music Conference. San Francisco, International Computer Music Association.

‣Or a vista of possibility:

More furious and strenuous activity, for example, could result in quieter sounds and silence. At the same time, a small yet deliberate nod of the head could set off an explosion of sound. Such "unnatural" correlations makes motion all the more meaningful.
ibid.

Objects such as a coffee mug can be instrumented and interactions with them mapped to sounds.
R. Hoskinson, K. van den Doel, S. Fels, *Real-time Adaptive Control of Modal Synthesis*, Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

Several mapping metaphors were explored; e.g. tongue position was used to play a physical model of the singing voice.
M. J. Lyons, M. Haehnel, N. Tetsutani, *Designing, Playing, and Performing with a Vision-based Mouth Interface*, Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

The system must be flexible in respect of providing unlimited mapping arrangements.
D. Hewitt, I. Stevenson, E-mic: Extended Mic-stand interface controller, Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

What these principles are meant to address is that the programmability of computer-based musical systems often make them too easy to configure, redefine, remap, etc. For programmers and composers, this provides an infinite landscape for experimentation, creativity, writing papers, wasting time, and never actually completing any art projects or compositions.
P. Cook, *Principles for Designing Computer Music Controllers*, ACM CHI Workshop in New Interfaces for Musical Expression (NIME), Seattle, April, 2001.

The tablet we use allows for simultaneous sensing of two devices, usually one in each hand. This rich, multidimensional control information can be mapped to musical parameters in a variety of interesting ways.
D. Wessel, M. Wright, *Problems and Prospects for Intimate Musical Control of Computers*, Computer Music Journal, 26 (3), MIT Press, 2002.

- The difference between success and failure, for the performer:

One or two reported on their check for causality between mouth action and aural effect: they found it sometimes easily visible but quite obscure at other times. This appeared to be mainly a function of the mapping.
M. J. Lyons, M. Haehnel, N. Tetsutani, *Designing, Playing, and Performing with a Vision-based Mouth Interface*, Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

- and for the audience:

The two primary goals of the mapping process are firstly to have a satisfying communicative relationship from an audience perspective and secondly to create a workable relationship from a performers' perspective which meets the requirements for satisfactory control of the sound source and allows high level performance skills to be developed.
D. Hewitt, I. Stevenson, E-mic: Extended Mic-stand interface controller, Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

While in traditional acoustic instruments the effects of the performer's physical activity on an instrument are already established by the physical properties of the instrument, in electronic instruments this relation must be previously designed. Mapping this relation can be critical for the effectiveness of an electronic instrument. [...]

The absence of a unique gestural mapping prevents the performer from deeply exploring the system's controlling mechanisms at the same time that it prevents the listener from connecting visual input and music.
F. Iazzetta, *Meaning in Musical Gesture*, in: *Trends in Gestural Control of Music*, **M. M. Wanderly** and **M. Battier** (eds.) IRCAM, 2000.

- The central problem that the artist faces:

We emphasise the importance of the mapping between input parameters and system parameters, and claim that this can define the very essence of an instrument [...] Moreover, the psychological and emotional response elicited from the performer is determined to a great degree by the mapping.
A. Hunt, M. M. Wanderley, M. Paradis, *The importance of parameter mapping in electronic instrument design*. Journal of New Music Research 23(4) 2003.

Just as the subject of a fugue must be thought out for its potential for future exploration and expansion, here too, the composer is challenged to find musical gestures that serve the dual purpose of creating melodic interest while generating a function applicable to signal processing.
T. Winkler, *Interactive Signal Processing for Acoustic Instruments*, Proceedings of the 1991 International Computer Music Conference. San Fancisco, International Computer Music Association.

- The solution endlessly deferred as future work:

The next stage in the process is to develop workable mapping strategies and to implement the compositional process.
D. Hewitt, I. Stevenson, E-mic: Extended Mic-stand interface controller, Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

The opportunity and challenge of this system is to devise strategies for mapping so very many degrees of freedom into a meaningfully expressive whole.
C. Dobrian, F. Bevilacqua, *Gestural Control of Music Using the Vicon 8 Motion Capture System*. Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

Since my sound processing software is in continual development, no definite mapping scheme is in use yet.
C. Palacio-Quintin, ***The Hyper-Flute***, Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

However, even with more meaningful feature extraction,finding compelling mappings for the output of such a system will continue to be a challenge.
D. Merrill, *Head-Tracking for Gestural and Continuous Control of Parameterized Audio Effects*, Proceedings of the 2003 Conference on New Interfaces for Musical Expression.

Current work with the Metasaxophone involves continued exploration of extended mapping possibilities for physical models.
M. Burtner, *The Metasaxophone: concept, implementation, and mapping strategies for a new computer music instrument*. Organised Sound 7(2): 2002.

A lot of the ongoing work on the visual feedback is going to be included into the working prototype in the near future and we have been working intensively on the object design and mapping issues, which will also be reflected in the final instrument design.
M. Kaltenbrunner, G. Geiger, S. Jordà, *Dynamic Patches for Live Musical Performance*, Proceedings of the 2004 Conference on New Interfaces for Musical Expression.

Mappings allow for any sound to be mapped to any input arbitrarily, and the extreme freedom and range of possibility makes it hard to construct mappings that look and sound "real" to an audience. It is still not well understood how to construct mappings such that they intuitively map well to an action; this is because interactive music is still an extremely new art form.
T. Marrin Nakra: *Synthesizing expressive music through the language of conducting*. Journal of New Music Research. 2002, 31 (1). 2001.

Of course, mathematicians have stretched the potential field of meaning of the above equation beyond all the horizons that we can see from here; almost anything could be written as the above definition. But if this definition has no limits it has no use. In practice one can sense in this "function-like" aspect of mapping is a kind of college-level, piecewise linear or otherwise smooth, locally stationary, state-less, typically decomposable relationship between input and output. Such a vision acts as a normative idea of how, in this field, numbers get transformed into numbers. The best work in the field, of course, pushes against this central tendency, but the rules and arena remain fixed.

For a survey of synesthesia from both an artistic and biological perspective:

R. E. Cytowic, *Synesthesia: A Unity of the Senses,* New York: Springer-Verlag, 1989.

This term, and the ideas it accretes, spans decades. The source of the lasting power of this description of interactive art is hard to locate exactly. It would be tempting to suggest that it is residue from the early century tropes of synesthesia and eurythmics interacting with the purely technical possibilities of the "multimedia". Perhaps it is a weak theoretical echo of the color organ or the Theramin. More likely, however, is that it was brought into the field from analogue music synthesizers and never left, reinforced, as we will suggest later in this work, by the tools and environments used and promoted by artists themselves. These tools continue to suggest that the interchangeability and equivalence of the digital signal has in some way a predictive or explanatory power over the relationships between disparate media.

In dance technology it is not hard to find statements concerning mapping that border on the banal and meaningless:

> By being aware of these laws, it is possible to alter them for provocative and intriguing artistic effects, creating models of response unique to the computer. More furious and strenuous activity, for example, could result in quieter sounds and silence. At the same time, a small yet deliberate nod of the head could set off an explosion of sound. Such "unnatural" correlations makes motion all the more meaningful.

Continued from above: **T. Winkler**, *Making motion musical: Gesture Mapping Strategies for Interactive Computer Music.* Proceedings of the 1995 International Computer Music Conference. San Francisco, International Computer Music Association, pp. 261-4.

These articulations are often no more complex than: if the dancers move quickly the music gets louder, or that the bass notes are blue and the treble red. Unless one has unshakeable faith in a broad, universal synesthesia or a natural order of relationships, these function-like statements are equally *meaningful* when inverted: the dancers move quickly and the music gets softer.

The community itself is turning against the term: for example, the New Interfaces for Musical Expression Keynote in 2002:

J. Chadabe, *The Limitations of Mapping as a Structural Descriptive in Electronic Instruments*. Proceedings of New Instruments For Musical Expression, Dublin.

Rather, meaning is not located in this word.The term is clearly long outliving its usefulness and its predictive and explanatory power has long left us. If this "map-ism" is deployed as a metaphor, what does it metaphorically connect with? Are there interesting physical systems that are satisfactorily read in this way? Do any of the natural analogues that researchers are also interested in map anything? what part of a flute transforms concrete, quantized measured data? what part of the audience manipulates a stream of readings? If we are interested in *inter*action, why start with a formula that goes only one way? If it is only a metaphor, why then is it embodied directly in *data-flow* interfaces and underling architectures of common digital art tools? The agent metaphor, developed in this thesis in a manner of particular use to art-making, stands directly opposed to mapping in this most banal sense; and I believe it to be of more use than the term in its more diffuse applications.

At the very least it will allow access to interactions that this function-like stance does not. Indeed, the agent's very autonomy acts to thwart a deeply penetrating analysis input to output from having any long term success — in describing the behavior of an agent — or synthetic utility — in thinking about how to build an agent to do something. The complication, and this opposing agent "metaphor", helps illuminate the roots of mapping's troubles. One weakness stems directly from the flattening of detail, inherent in words that populate the descriptions of maps —"move quickly", "louder", "bass", "blue" — that comes just prior to tying these surface properties together. This is a *category error* perpetrated by the artist on their own thinking and practice — confusing a way of measuring or a way of controlling something with the thing itself; confusing part of the effect (appearance) for the totality of the cause (process); confusing a particular control surface (the volume knob) or a particular derived quantity (say, the sum of distances divided by times) with a more internal structure of the process and the context which to my eye is never flat, never just a number waiting be plucked from nature by hardware.

On the one hand this is a particularly surprising mistake for the digital artist to make, for unlike the scientist or engineer who takes nature as they find it, they have at least partial responsibility for both the surfaces — the controls and the viewpoints — and much of the thing being controlled or viewed. Be it the view from psycho-physics, computer science, or digital art itself, these simple numbers and parameters are only byproducts of selected solutions, not the givens of any particular problem domain. On the other hand it is an understandable strategy. In quickly binding "sensor" to "output" inside a digital setting, mapping deflates the awesome *potential* of the algorithmic before it can appear. The space of algorithmic relationships is slowly and safely explored on a scaffolding of one sensor-to-output thread at a time. The vertiginously parametric opportunities of digital tools are both the object of fascination of the digital art world and its greatest fear. They are, in much of the community's work, collapsed and hidden from view by its very conception of the problem.

Where the connective statements of maps do have an importance is *either* in the micro-scale of the hardware and software that executes a work *or* in the broad strokes of a preliminary sketch. Pieces of hardware and software must and do pass numbers between themselves — but the days have long passed when there were efficiency or protocol problems that put this level of discussion at the fore of this field's theorizing. Developers, collaborators must and will pass general ideas around concerning what might happen and when and will make such broad connective statements — but the days have long passed when these connections could justifiably mark the end rather than the beginning of a discussion. The field of potential is too large to be explored armed only with these statements, and the work is too difficult for them to be of much lasting use. Mapping should be receding in digital art's rearview mirror, not as a solved or exhausted problem, but as an idea either too small or too broad to really fit.

Toward the agent

However, underneath this falsely unifying term, there is an interesting and relevant story underway in the literature, which again our competing agent metaphor helps diagnose. I possess the following suspicion about the development of mappings: that as we seek to build better mappings, we are led from the simplicities of "complete specification" — connecting the wire between input and output — down two divergent routes with inevitable termini. The first of these is better interfaces for complete specification, ones that yield *faster* ways of exploring that space of wires. The second is, sometimes disguised, unsupervised machine learning — to give us *easier* ways of describing the mappings of space. The former path leads to the environments that dominate today — advanced tools for trying out a relationship, discarding it, tuning it, trying another. These are the tools that are commodified, taught in schools, and have had to date more permanence than most of the art made with them. They allow the working artist to confront the space of possible mappings, to confront the potential devel-

I believe that many tools today fall into the category of allowing artists to try more things faster. For example, the *Max* series of graphical environments: http://www.cycling74.com.

As for the emerging trend towards using unsupervised techniques for "advanced mapping", a few recent examples: **A. Cont**, **T. Coduys**, **C. Henry**, *Real-time Gesture Mapping in Pd Environment using Neural Networks*.

and, **J. Mandelis** and **P. Husbands**, *Don't Just Play it, Grow it! : Breeding Sound Synthesis and Performance Mappings*

Both are from the Proceedings of the 2004 conference on New Interfaces for Musical Expression, Hammamatsu, Japan.

R. Bencina, *The Metasurface – Applying Natural Neighbour Interpolation to Two-to-Many Mapping*. In Both are from the Proceedings of the 2005 conference on New Interfaces for Musical Expression, Vancouver, Canada.

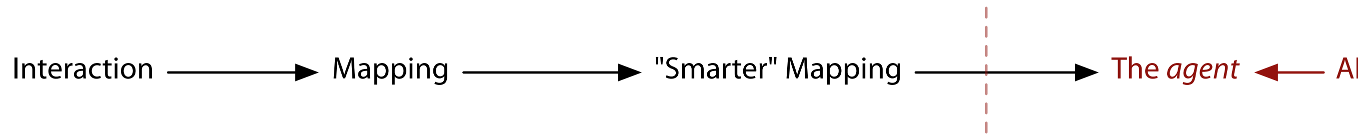


figure 4. A depiction of the trend towards "smarter mapping" found in the academic literature of interactive art. What comes after this work's piecemeal approach to "smartness" ?

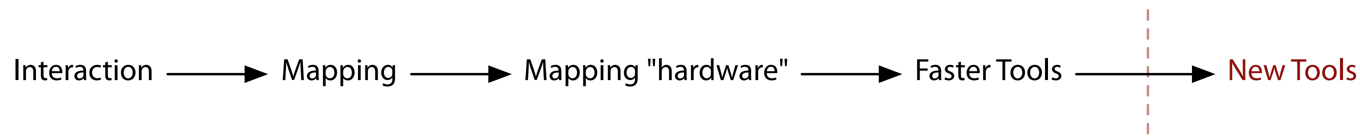


figure 3. A depiction of the trend towards "faster mapping". The dominant tools available today are constructed by analogy with the early "hardware" of interactive art and concentrate on alowing the artist to try a large number of alternative mappings. What comes after the simple speed and flexibility of software over hardware?

There is a story here that goes in an altogether direction from art back towards the biological:

M. Whitelaw, *The Abstract Organism: Towards a Prehistory for A-Life Art*, Leonardo Vol. 34, No. 4, 2001.

and indeed there is a broad sensibility shared in this thesis with this article's primary text:

P. Klee, *The Thinking Eye*, George Wittenborn, NY, 1961.

A more sustained reflection on this artist's relationship to contemporary art practice can be found in:

P. Boulez, *Le Pays Fertile: Paul Klee*, Editions Gallimards, Paris, 1989.

oped by digital manipulation by trying out *more things* more quickly. The latter path leads toward nothing less than supervised machine learning — environments for *training* mappings, and *inducing* them out of interactions. These, rather more niche and rather more academic ideas, seek to allow the working artist to confront that unknown space of potential by trying out *smarter things* and by navigating around the space in smarter ways. Ironically, we might say that these tools seek to actually provide a useful map for the space of mappings.

As this latter thread becomes more developed, and its systems meet the realities of rehearsal and distribution as well as the opportunities afforded by complex assemblages of code, and more sophisticated artistic intentions, I believe that it will all end up squarely in the domain of artificial intelligence.

Artificial intelligence, as articulated by its pioneers, is nothing less than the task of getting computers to do the "right thing" — despite our inability to describe in the kinds of ways that computers prefer what the "right thing" is, or at the kinds of detail that computers demand what the operating environment will be. AI is thus the study and construction of new ways of articulating how systems should behave given a higher level, a more human level, a more convenient description of the desired behavior and the environment in which they will operate.

This thesis starts at the opposite end of this reading of modern interactive digital art. Rather than start with mapping in micro or macro and move toward either art environments or academic artificial intelligence, it starts with both AI and the tools for art-making, and heads towards interactivity, "multimedia" transformation and connection.

Of course there is a reason why this direction is against the flow of the community. Making live interactive programs that are artificially intelligent is a difficult and obscure pursuit, and only recently has it made sense to move away from solely focusing on increasing the scope of what computers can do (the size of the potential field) to devote a little time to considering the practice of making them do it (how that field is navigated). Digital artists need new ways of conceiving their digital methods in order to take advantage of these opportunities. It is my belief that by starting where I believe the field is heading, almost inevitably, in a piecemeal fashion and by doing so in a way that is open to influences and problems across both computer music and computer animation, I will be able to create new classes of artworks, new classes of experiences, in new ways. To make the above stratagem realizable, both AI and digital tools need significant and careful navigation and revision. That is what this thesis sets out to start.

This engineering, or authorship perspective, is given a broad manifesto in: **R. Brooks**, *Intelligence without Representation*, Artificial Intelligence, 47 (1991) 139-159.

For an emphasis on this human-level *description*, for example:

"Artificial intelligence is the science of making machines do things that would require intelligence if done by men"

from **M. Minsky**, *Semantic Information Processing*, MIT Press, 1968.

This is accompanied by, but not indistinguishable from, an emphasis on *human-level* problems in that work. My thesis work breaks with any remaining AI tradition of human *replacement* and instead focuses on an AI thread of human *augmentation* in the broadest sense — augmentation by both the artifact (the finished artwork) and the techniques for creating the artifact (the ways in which that "finished" is defined and found).

Work presented in this thesis will therefore take the AI community's concept of *the agent* as its central organizing principle and offers this as a replacement for dance technology and interactive arts *mapping*.

Before sketching its relationship with the history of AI, we should begin with the pioneers of the agent-based. Brooks cites four hallmarks of this *nouvelle AI*, or what we are calling here agent-based style of work: **situated** — the boundary between the agent and the world is porous, with the world directly influencing the system; **embodied** — the agent acts upon the world and senses immediately itself acting; **intelligent** — as acting in the world as far as judged by outside observer; **emergent** — this intelligence is not confined to particular computational engine, nor is responsibility for the external action located in one particular place but arises out of the agent's interaction with the world.

The decomposition is from **R. Brooks**, *Intelligence without Reason*, MIT AI Lab Memo 1293.

The decomposition of action selection details is from **R. Brooks**, *Challenges for Complete Creature Architectures*, In Proceedings of the first international conference on simulation of adaptive behavior, Paris, France, 1991.

This is similar to the set of concerns given by: **P. Maes**, *Modeling Adaptive Autonomous Agents*, Artificial Life, 1 (1), 1994. pp. 135-62.

Elsewhere in the literature we see the terms *behavior-based* and *interactionist* to refer to this style of artificial intelligence practice. For our purposes here these terms are indistinguishable and merely serve to re-indicate the emphasis on finding an AI practice that is focused on the how the agent acts in, on *and* with the world.

In *software* agents, which are the only ones discussed in this work, we expand upon the definition of the "world" to include software worlds (although for interactive systems these worlds are in turn connected to ours), and we expand upon the definition of "body" to include software bodies — control structures that operate on material that can be rendered graphically. Indeed, part of the contribution of my work is to push the agent-based approach into new worlds (dance theater, and to a lesser extent computer music) and new bodies — musical bodies and non-constant, non-figurative bodies.

Note that in: **M. Minksy**, *Society of Mind*, Simon & Schuster, New York, 1988, we see a broader, more inclusive and more abstract use of the term agent — his *Society of Mind* is a radically heterogeneous society of mindless agents, none of which have the scale of, or the same structure as, the normative agent model described here. We shall start with this large, monolithic agent description and move towards the heterogeneity of Minsky's society, but we will keep the term agent for the "creature-as-a-whole"

We will need some more terms and a more concrete model of an agent to proceed through this. One segmentation that I propose, which is both generic and useful, decomposes the software agent into three coupled systems, which we shall label as the **perception system**, the **action system** and the **motor system**. I believe this picture can be read into if not read from much agent-based work

— it is a generically descriptive decomposition of many practitioners' agent architectures.

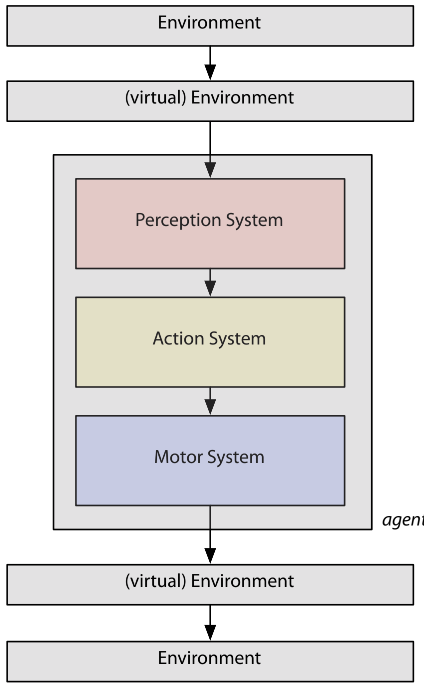


figure 5.
The agent, for our definition here, is decomposed into three parts — perception, action and motor systems.

Describing the "contents" or the fields of competences for each of these systems will be a task undertaken throughout this document. However, some starting points are of use.

The **perception system** of an agent is the area that takes the world as it finds it and begins to transform it into a form more convenient for the creature. Often this is where measurements become symbols, where raw sensations given in what form hardware and the world can offer become categorized, or at the very least scaled, filtered and perhaps fused. In *Dobie*, a synthetic dog that can be trained in many of same the ways that a real dog can, the perception system holds onto and adapts models of spoken commands ready to classify the incoming speech from the trainer; in *how long...* many agents' perception systems try to follow dancers from the stage despite the presence of noise and missing information. The flow of control, update and activation of a perception system is only partially under the "control" or the autonomy of the agent, and it is necessarily shared with the moment-to-moment changes in the world.

The **motor system** of an agent is the area that coordinates the body's relationship to the world. Often, this is where the commands of the action system meet the constraints of animation and the constraints of the world. It is most often the site of expectations about how the body should move in and interact with the world, and ongoing monitoring of how progress is being made. In the case of graphical (and musical) agents it is where pre-made material enters, often on its own terms, the agent. This material is spliced, blended and layered to synthesize the manipulation of the agent's body. In *Dobie*, the motor system splices, blends and layers from a library of pre-made, hand-made dog animations; in *how long...* agents with no natural analogue often find and integrate their motion material by sampling movement from the stage. The flow of control, update and activation inside a motor system is only partially under the command of the action system of an agent, and only partially under the command of imperatively written code made ahead of time. This control is necessarily shared with constraints of the agent's material and the uncertainties of the body which it controls and world in which it acts.

The **action system** selects the actions to perform based on the perceptual state and the state of the motor system and articulates these selections to the motor system. Using the language of Brooks an action system is usually judged by three criteria: **salience** — are the actions appropriate and relevant to the context?; **coherence** — do the actions make sense to an observer over time?; and **adequacy** — are the actions *in toto* sufficient to get the creature to achieve its goals? We can fine-tune these criteria from the point of view of an author of an agent: salience — has the creature, in integrating its perceptual world, taken advantage of the correct aspects of world, or responded to the unexpected in the correct way?; coherence — does the temporal patterning of the actions chosen amount to something?; and adequacy — has the creature enough actions, and enough competence to explore and modify its actions to yield the desired long-term behavior?

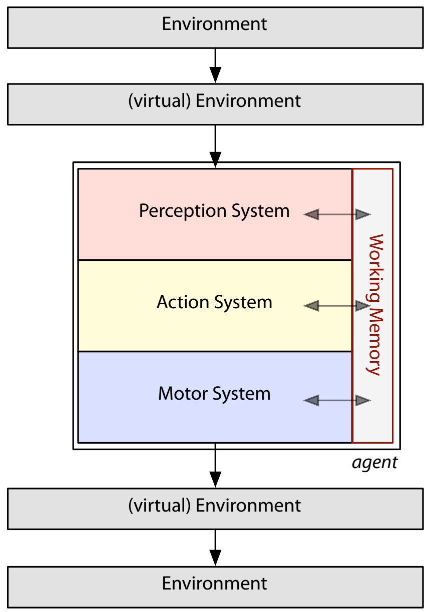


figure 6.
Additionally, in the systems developed for this thesis, we add an additional infrastructural "system" for the purposes of internal communication

This diagram also hints at the "execution cycle" of each of these systems. Often it is translated directly into a sequential update of perceptual, action and motor systems in order to complete one "evaluation" of the agent. It is further, but rather confusingly in this presentation, the place where the terms "bottom-up" and "top-up" act. In our case here the sense of gravity is reversed, and bottom-up, or the data-driven enters through the perception system form the top, and the top-down, or agent-driven is exerted from the core outwards.

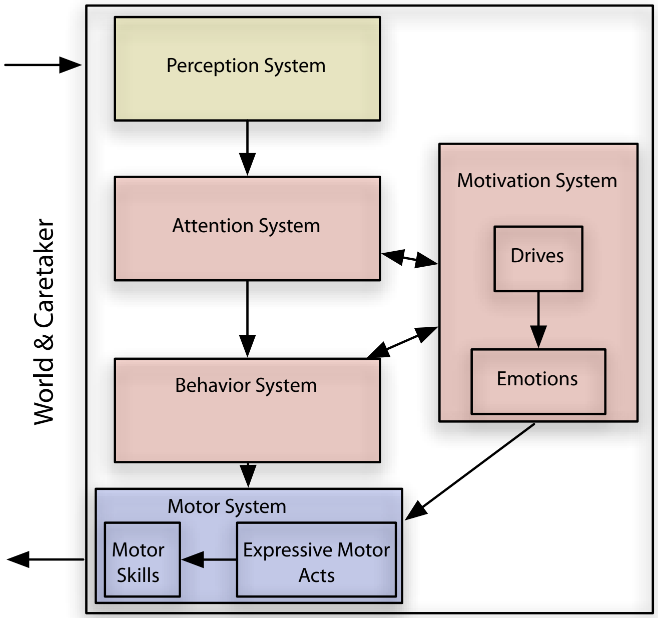


figure 7.
In the interactive robot, Kismet, Breazeal et al. divide the internal mechanisms as above. Coloring as per *figures 1* and 2. From **C. Breazeal,** *A Motivational System for Regulating Human-Robot Interaction*, Proceedings of AAAI-98.

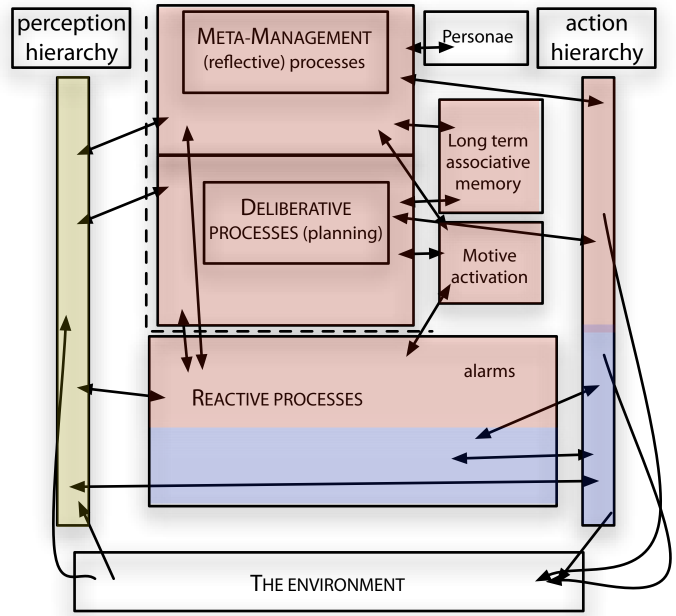


figure 8.
Further afield, Aaron Sloman's more "human level" artificial intelligence framework still permits a similar decomposition. Note that in this work, as is typical with such architectures, the space devoted to motor system issues is vastly reduced. Coloring as per *figures 1* and 2. From **M. Minsky, P. Singh, A. Sloman,** *The St. Thomas common sense symposium: designing architectures for human-level intelligence.* The AI Magazine, Summer 2004.

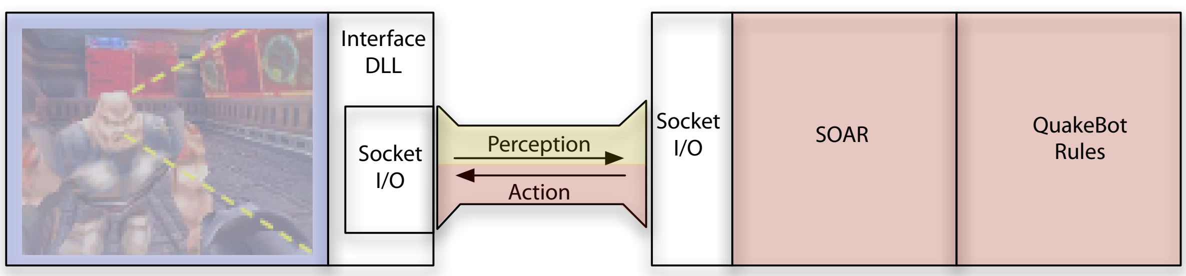


figure 9.
In this work the Soar general purpose AI architecture has been coupled to the computer game Quake. In this diagram, the "motor system" of the agents is almost entirely located inside the computer game itself. From **J. E. Laird,** *It knows what you're going to do: adding anticipation to a Quakebot,* International Conference on Autonomous Agents, Proceedings of the fifth international conference on Autonomous agents, 2001.

Although the predominant flow is from, in this diagram, top to bottom, there is much, in a complex creature, that goes the other way. Perceptual states can be created from proprioception of the state of the action system, the state of the motor system or the state of the body itself. In action systems that support the learning of new relationships, it is the action system that guides the perceptual development. Such is the confusion, at this level of discussion, of the flow of communication between these systems that we draw an alternative diagram, with an additional box, labeled "working memory". This area in the systems that are built for this thesis is where much of the complex communication occurs, and forms a better description of the systems as implemented than the alternative tangle of arrow.

A famous example of subsumption architecture implemented robot that collects soda cans is given in : **J. H. Connell**, *A colony architecture for an artificial creature*, MIT Ph.D. Thesis in Electrical Engineering and Computer Science, MIT AI Lab Tech Report 1151 (June 1989).

by the time we arrive at:

R. Brooks, *Elephants don't play chess*, Robotics and Autonomous Systems 6 (1990) 3-15,

the problems of fusing sensor signals prior to entry into the subsumption architecture is becoming apparent.
The commencement of *expressive* robotics:

R. Brooks, C. Breazeal , R. Irie, C. C. Kemp, M. Marjanović, Brian Scassellati, Matthew M. Williamson, *Alternative Essences of Inteligence*, Proceedings of the American Association of Artificial Intelligence 1998, AAAI Press, CA.

states this decomposition directly, as does: **C. Breazeal**, *Sociable Machines: Expressive Social Exchange Between Robot and Human*. Artificial Intelligence Laboratory. Cambridge, MA, MIT. 2000.

This division between perception, action, and motor systems has been often hidden, suppressed or marginalized in the literature. For example, Brooks's early "subsumption architecture" work: where each subsumption layer might either inhibit or suppress elements of the layer below it, Brooks typically builds his own vertical architecture through sensor inputs, an augmented finite state machine "action selection" and motor outputs. The complexities of the sensing (which in the case of the early robotic vision work were significant) or ordering movement (which on wheel robots are insignificant) are left out of the diagram. However, as the bodies of robots (and later graphical characters) grow more complex and as the perceptual worlds of the robots grow more complex, "sensor input" as a description necessarily yields to something that is worth labeling perception system and "motor output" similarly yields to "motor system". By the time we arrive at humanoid robots this decomposition into perception, action and motor competencies is evident and fundamental.

This decomposition will serve as a useful starting point for our further complications and recastings of the agent metaphor throughout this thesis.

The agent concept itself offers a way of navigating AI literature. But there is another perspective on this body of work that is relevant to this thesis. This I shall call the authorship stance — the descriptive and critical stance toward an AI system that is based on what it like to make things inside it.

Descriptions of the creative process allowed or encouraged by practitioners' systems are surprising hard to find in the extant literature, and they are a hidden subtext to the papers, a secret currency between researchers. Classical, or non-agent-based, AI research often approaches this stance obliquely and narrowly; one can detect only hints of the engineering reality of the *practice of AI* underneath a kind of academic politeness. Some of this trace manifests itself in the questions commonly asked of published systems — does the system scale? is it robust? These questions might be taken to be "can a person reasonably add to the system without it collapsing?", "is it possible to debug?", "how does it fail?" These questions are typically the hardest for scientific method to reach, but of significant relevance to this thesis — this is, after all, an argument for and an articulation of an agent-based *practice*.

Of course what is reflected in the history of the field and the level of critique and discussion in the field's papers, what one might call the *science of* AI, is only partially related to the practice of AI. It remains to be argued elsewhere whether this disconnect, indeed, this failure of academic AI discourse to integrate the use of AI into the discussion, shares any blame for the growing unease with the progress made by the field and the ambiguity of the relationship between a core academic AI and the more clearly engineering pursuits of either computer games or statistical machine learning. However, this peculiarity of the field is unavoidable if one approaches it to press its developments and techniques towards the service and synthesis of one's own art. For both broad-reaching frameworks and individual algorithms stand or fall in this foreign domain based not on their performance in the chosen micro-world or standard dataset but on the story that emerges when they turned loose within another micro-world — my micro-world — or on another dataset — the one that I'm faced with in a theater or a gallery.

Some of the motivation for the agent-based — and other distinct but related trends in the 80s and 90s such as connectionism and artificial life — came from an often open and explicit authorship twist: that reactive, connective, adaptive or behavior-based systems avoid the burden of knowledge engineering (i.e. knowledge authorship) and exploit a far closer relationship with statistical machine-learning techniques to avoid the hand-tuning, assembly or even creation of systems altogether.

On "repairing" the subsumption architecture to remove general purpose computation: **R. Brooks**, *How To Build Complete Creatures Rather Than Isolated Cognitive Simulators*, in: *Architectures for Intelligence*, K. VanLehn (ed), Erlbaum, Hillsdale, NJ, Fall 1989, pp. 225–239.

For example, we can use this position to reread Brooks's general appeal for simple natural analogs first, his structuring of layered behavior systems and his desire to limit the complexity of each layer to something much less than a general Turing machine as authorship prescriptions — the creation of systems that survive in complex worlds without the unconstrained complexity that characterized previous approaches.

From **R. Brooks**, *Elephants don't play chess*, Robotics and Autonomous Systems 6 (1990) 3-15,

> In our experience debugging the subsumption programs used to control our physically grounded systems has not been a great source of frustration or difficulty. This is not due to any particularly helpful debugging tools or any natural superiority of the subsumption architecture. Rather, we believe it is true because the world is its own best model (as usual). When running a physically grounded system in the real world, one can see at a glance how it is interacting. It is right before your eyes. There are no layers of abstraction to obfuscate the dynamics of the interactions between the system and the world. This is an elegant aspect of physically grounded systems.

Elsewhere the explosion of energy surrounding the related fields of neural networks, genetic programming and artificial life in general in the 1980s and 90s was fueled by the promise that these techniques seemed to have to dodge the whole question of system authorship.

However, Pattie Maes follows Brooks's lead and articulates the basis for considering the software agent, away from the world of robotics, virtually embodied in our computers as user interface or online as acting on our behalf. In fact, she explicitly judges action-selection strategies based not on their mathematical qualities, experimental results or in our terms here, the field of potential developed, but based on how easy or hard it is to make agents out of them.

P. Maes, *Modeling Adaptive Autonomous Agents*, Artificial Life, 1 (1), 1994. pp. 135-62.

Maes plots a line through the "hand-assembled, flat structures" of early Brooks, the early work of Leslie Kaelbling and Stanley Rosenschein into agents with explicit goals, and Maes's own "compiled" flat behavior networks towards the hand-assembled hierarchical structures of Bruce Blumberg. Again, by the time we reach Blumberg the demands of authorship, and the complexities of the micro-worlds in which the agents are put to work, are necessitating new more authorable action-selection mechanisms as well a clearer statement of the perception / action / motor system decomposition of the, in this case, graphical embodied agent. This is less of a shift of emphasis than a clarification of what agent-based AI has really been trying to find since its conception — a way of making things.

Overview from: **P. Maes**, *Modeling Adaptive Autonomous Agents*, Artificial Life, 1 (1), 1994. pp. 135-62.

L.P. Kaelbling and **S. Rosenschein**, *Action and Planning in Embedded Agents*, In: *Designing Autonomous Agents: Theory and Practice from Biology to Engineering and Back*, edited by P. Maes, MIT Press/Bradford Books, 1990.

B. Blumberg, *Action-selection in hamsterdam: lessons from ethology*. Proceedings of the third international conference on Simulation of adaptive behavior, Brighton UK. 1994.

Concern for how AI agents are authored takes one directly toward another field very related to the work presented here — graphically embodied interactive agents. This field has always had a little more concern for the techniques and difficulties of actually authoring characters, being closer to interaction design, digital entertainment, and computer game production.

Here of course, there are a number of examples of successful computer games that incorporate artificially intelligent characters and mainstream academic AI. The computer game industry is in the middle of an ongoing courtship bounded on the one side, I believe, by the willingness to articulate a useful authorship position by academic AI and on the other by an willingness to create new game genres that truly require and exploit artificial intelligence.

Evidence of this courtship includes a spate of "practical" books, including the AI Game Programming Wisdom series:

S. Rabin, *AI Game Programming Wisdom 1-2*, Charles River Media, Cambridge MA, 2002-3.

Even more conservative, the AI sections of the game programming gems series: **M. Deloura,** *Game Progamming Gems 1-3*, Charles River Media, Cambridge, MA, 2000-2.

and, **M. Buckland,** *Programming Game AI by Example*, Wordware Publishing , 2004.

Of the most notable recent successes, *The Sims*, for example, succeeded in dominating if not forging a genre based on manipulatable synthetic people — dodging many of the more complex issues of making these characters smart by successfully basing their smartness on a vast array of objects and events with which the characters can interact. Earlier the successful *Creatures* got quite far with a very interesting agent framework — I believe it is telling that one of the most popular extensions to that series was the "creature science kit" that enabled players to directly manipulate (author?) aspects of the creatures. It is perhaps also telling that there are striking parallels between the online communities that went up surrounding *Creatures'* success and the craze for the altogether un-intelligent Tamagotchi that came much later. Perhaps the success of these AI based games has less to do with crafting a genuine AI based genre that it initially appears. The recently interesting game *Black & White* — based on a central, learning agent — was certainly criticized by some as failing to find a stable genre — opting to combine instead world-building, role-playing and straight out fighting elements. The promised AI revolution of computer gaming has yet to take hold.

Maxis. *The Sims*, published by Electronic Arts. 2000-.

Millennium Interactive Ltd. *Creatures*, 1996.
— however, see **S. Grand, D. Cliff, A. Malhotra,** *Creatures: artificial life autonomous software agents for home entertainment*. Proceedings of the first international conference on Autonomous agents, ACM, 1997.

Bandai, *Tamagotchi*, 1996-7.

Lionhead Studios, *Black & White*, published by Electronic Arts. 2002.

However it is possible, in the field of graphical characters, both to remain inside academia and yet stray too far from our AI roots. Ken Perlin and Athomas Goldberg's classic Improv architecture appears at first to solve *the whole problem* — that of authoring interactive graphical characters or actors with personality — through the creation of simple, hierarchical scripts. Indeed, in reading these papers one might be forgiven for thinking that the problem — creating live interactive creatures with shallow but broad artificial intelligence — never existed in the first place, but rather was a cruel hoax perpetrated by AI researchers (and programming language researchers) on the animation, game design and artistic community at large.

K. Perlin and **A. Goldberg**, *Improv: a system for scripting interactive actors in virtual worlds*. In: SIGGRAPH 1996 International Conference on Computer Graphics and Interactive Techniques, Proceedings of the 23rd annual conference on Computer graphics and interactive techniques. ACM, 1996.

More detail concerning the motor level issues confronted in this work is given in: **K. Perlin**, *Real Time Responsive Animation with Personality*, IEEE Transactions on Visualization and Computer Graphics, 1 (1), 1995.

A closer look at these papers hints at the underlying problem that is not solved. That Perlin and Goldberg's architecture diagram omits any role for perception is an important clue. It is true that the interaction between the "behavior system" (the nest of scripts) and the "motor system" is a strong, indeed a seminal, contribution. That their motor system for character, with all of its kinematic, physical and content-level constraints survives when connected to its rather unpredictable action-system scripts is an important success. However, the interaction between this script-driven "behavior system" and the dynamic, unpredictable world is absent. Not a single one of the example action scripts in Goldberg's Lecture Notes in Artificial Intelligence talks about an external perception, influence or input, let alone one that can change by itself at an inopportune moment in a script's ballistic unfolding. This architecture, as applied to the problem of action selection in even simple, unscripted worlds, offers an outsider, at least, little in the way of authorship strategies or tactics. As this line of work emphasizes the problems faced by the meeting of animation and action, these papers offer a lasting contribution. However, the "AI authorship problem" remains.

A. Goldberg, I*mprov: A System for Real-Time Animation of Behavior-Based Interactive Synthetic Actors*. In Lecture Notes in Artificial Intelligence, Vol 1195, R. TrapplP. Petta (Eds.), 1997.

Similar criticisms can be levied against other animation-based work that appears to take on the problem of creating complete characters — for example: **J. Cassell, T. Bickmore, M. Billinghurst, L. Campbell, K. Chang, H. Vilhjálmsson, H. Yan**, *Embodiment in Conversational Interfaces: Rea*. Proceedings of the CHI'99 Conference. 1999.

J. Cassell, H. H Vilhjálmsson, T. Bickmore, *BEAT: The Behavior Expression Animation Toolkit*. In: SIGGRAPH 2001, International Conference on Computer Graphics and Interactive Techniques. Proceedings of the 28th annual conference on Computer graphics and interactive techniques, ACM, 2001.

It might come as a surprise, then, that it is at the very point when artificial intelligence's anti-authorial positioning is at its greatest that the fusion of art and AI reach their apogee, as art approaches the excitement surrounding *artificial life* and *emergent systems*.

C. G. Langton (ed.), *Artificial Life*, Addison-Wesley, CA, 1989.

Artificial Life's point of origin is usually given as a workshop organized by Chris Langton around the study of living systems without biological structures — a field concerned with "life-as-it-could-be", the formal basis for life, rather than "life-as-it-is", the material basis of life. Unlike artificial intelligence the focus is very much on evolution, morphogenesis, and metabolism and in particular, on emergent structures.

Emergence is characterized by systems of prodigious yet ultimately rather uncontrollable and unengineerable production. The academic fields that momentarily looked set to fuse to create a stable artificial life alloy have apparently moved apart and onward, yet contemporary artificial intelligence, indeed, any interdisciplinary academic field that occurs after"A-Life", has failed to get comparable traction in the field of digital art — either in art theory or in art practice. We must revisit this power that emergent systems had over digital art if we are to construct a new analysis of AI's potential to provide tools for digital artists.

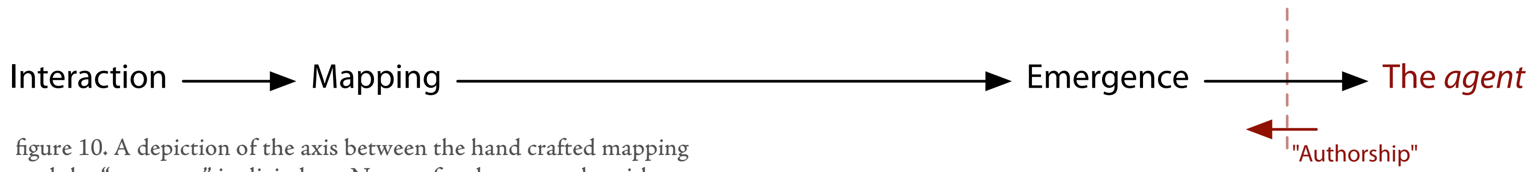


figure 10. A depiction of the axis between the hand crafted mapping and the "emergent" in digital art. Not confined to artworks with an explicit Artificial Life referent, we can detect a more general trend in interactive art: a belief that by the construction of complex systems, artists will gain access to new and interesting meaning-bearing forms. But how can one author an emergent system when the definition of emergence is the very surprise surrounding its unforeseen appearance?

Emergence itself is a difficult term to define, although a number of technical definitions exist. A most useful definition — seriously proposed at a time when Artificial Life was reconsidering its history — ties "genuine emergence" to a "lasting surprise" at a whole given an "apparently adequate description of its parts". This definition neatly captures the relationship between the captivating "coolness" of emergent phenomena, explaining some of the prevalence of "emergent art" over the last two decades, and their utter un-engineerability (or un-authorability). If an emergent phenomena stands or falls on the excitement of getting more out than one puts in, it conversely offers little advice on how one should go about getting anything in particular out of such a system. Artificial Life's emergence then stands more as an anti-methodology than a constructive practice and we should be as suspicious of "emergence" as we are of "mapping" as a point of origin for an art-making.

On defining emergence: **E. M. A. Ronald, M. Sipper, M. S. Capcarrère,** *Design, Observation, Surprise! A Test of Emergence. Artificial Life 5: 225–239 (1999).*

ALife reconsiders its progress and its lack of progress at the turn of the millennium:

M. Bedau, *Artificial Life VII: Looking Backward, Looking Forward. Artificial Life 6: 261–264 (2000)*

However, there is a long history of the biological entering digital art through an artificial life context and we should pause to contextualize this thesis with respect to this work. Indeed, Artificial-Life-based art seems an ideal context to locate work, such as this thesis, that seeks to handle the creation of complex, biologically inspired art.

There are a number of reviews of the still growing body of ALife/Art works. One review is **K. Rinaldo,** *Technology Recapitulates Phylogeny: Artificial Life Art*, Leonardo 31, No. 5,371–376 (1998). A more comprehensive compendium is **M. Whitelaw,** *Metacreation: Art and Artificial Life*, MIT Press, Cambridge, MA, 2004.

A retrospective review of the artists' work is: **C. Sommerer** and **L. Mignonneau**, *Art as a Living System: Interactive Computer Artworks*. Leonardo, Vol. 32, No. 3, pp. 165–173, 1999.

More recent work is included in:

L. Mignonneau and **C. Sommerer**, *Creating Artificial Life for Interactive Art and Entertainment*. Leonardo, Vol. 34, No. 4, pp. 303–307, 2001.

In particular, the forms evolved in: **K. Sims**, *Galapagos*. Installation.

There is much precedent: for example, the highly influential work of Christa Sommerer and Lauraunt Mignaux spans a number of installations that are structured by allowing gallery-goers to meddle in the evolution of simulated creatures — staying close to a natural analogue in both appearance and process — in *Interactive Plant Growing* 1993, *A-volve* 1994, *GEMMA* 1996. Yet at the same time these works contain profound, convenient and presumably deliberate misreadings of genetics, eliding phenotype and genotype, morphology and embryology. After all, in reality, manipulating individual base-pairs just wouldn't make much *sense*. It is not that a more faithful instantiated biological system would make for better art, but rather it's important to note that their line of biology avoids the trickier problems of agent-based artificiality — phylogeny, adaptation, behavior. From this perspective the equally influential work of Karl Sims is both less ambitious and more complete, in that it tries more simply to evolve creatures without genomic authorship on the part of the viewer and yet achieves graphics with astonishing apparent intentionality, strategy and even character.

Indeed, since Artificial Life is characterized by anonymity and group dynamics rather than personality and behavior, Artificial-Life-based art stands or falls on its ability to guide the interaction away from individual effort, intention and adaptation of the lives it purports to synthesize. This sleight of hand has resulted in a disconnect between theorizing and rhetoric surrounding interactive, Artificial-Life-based artwork. In fact, this literature reads like an argument for *artificial intelligence* based artworks. Strictly in terms of artificial life as a powerful meaning-bearing principle, gallery-goers are undeniably more familiar with a dog than with a fungus, a genome or a population distribution. No matter how artificial life bends or reprojects its biological inspirations and aspirations it will miss these relationships and readings.

M. Bedau, *Artificial Life VII: Looking Backward, Looking Forward. Artificial Life 6: 261–264 (2000)*

Stepping back, we might ask how artificial life itself is doing as a scientific field entering its middle age. According to recent reviews, one fundamental question that is posing considerable difficulty concerns creating example simulations that show multi-scale, and multi-level emergent properties. We know from nature that extremely deep chains of self-organizing and self-regulative structures are one of the hallmarks of biological systems.

This far on in the history of A-Life based art, the lack of plentiful systems that produce higher-order emergent structures at this point reads more as an obituary than a call-to-arms for the intersection of artificial life and digital art. As artists we are typically interested in structures that have more than one level. Indeed, we typically assumes that any rich starting place has more than one level. If I cannot "emergently" get to someplace where one long time-scale governs a shorter time-scale, where one space overlaps another, where a complex of small objects coalesce into a complex large object, then it is time to reconsider the excitement about the emergent.

As I have argued in my critique of mapping, the central problem of digital art is not *generating* potential, it is working with it and within it— it is navigating it; it is drawing an atlas with your collaborators and agreeing on the names of the continents; it is remembering where you have been in the space; it is turning this potential field into a work. And if the problem isn't generating potential, there is no need to be excited should it turn up or rather *emerge* without much effort on our part. Such easy possibility is not an omen of good art but a harbinger of effort to come.

Other intersections between art and artificial intelligence often slice AI too thinly — to glean potential without organization — building systems with specific deep but narrow competences. This is a classic criticism levied against main-stream artificial intelligence by both Brooks and Minsky at various points. Of the recent compendiums of articles on the use of artificial intelligence in music, the interdisciplinary corner of "art-making and AI" that has seen the most activity, two aspects stand out: firstly, almost all of the introductory descriptions of artificial intelligence fail to include the concept of an agent in their ubiquitous opening survey (opting instead to find a neat binary opposition between symbolic AI and, say, connectionism).

for **Brooks**, see references above, for **Minsky**, this is his central attack on mainstream AI in his upcoming *Emotion Machine*.

For example, many instances of this blindness to the agent are to be found: **E. R. Miranda (ed.)**, *Readings in Music and Artificial Intelligence*. Routledge, 1999.

Secondly, what practitioners mean when they write "music and artificial intelligence" is almost always "music and something that some AI has found useful'. Thus, we have admittedly fascinating work in music and the neural network, music and genetic programming, music and Markov models (hidden or not), music and self-organizing maps. Research that is called "music and AI" is generally missing a strong "music and complex AI systems" vein. On the one hand, this is unsurprising: artificial intelligence has always been encroached on by machine learning, artificial life, and exploratory statistics. On the other hand this is rather unexpected, given general interactive tendencies in this research (both as tool-for-composer and instrument/partner for performance) and the widespread acknowledgment of music as an art that if it has a definition at all is defined by the broad range of faculties that it draws upon and synthesizes.

music and connectionism — collected in: **P.M. Todd** and **D.G. Loy** (Eds.) *Music and Connectionism*. Cambridge, MA, MIT Press 1991. However, the field continues, music and (recurrent) neural networks: **D. Eck** and **J. Schmidhuber**, *Finding Temporal Structure in Music: Blues Improvisation with LSTM Recurrent Networks*. H. Boulard, editor, *Neural Networks for Signal Processing XII*, Proceedings of the 2002 IEEE Workshop. 747{756, New York, IEEE, 2002.

Music and generative grammars — **E. R. Miranda**, *Regarding Music, Machines, Intelligence and the Brain: An Introduction to Music and AI*. In **E.R. Miranda** (ed.) Readings in music and artificial intelligence, Hardwood Academic Publishers, 2000. And, of course, the much more sustained analytic work of **F. Lerdhal** and **R. Jackendoff**, *A Generative Theory of Tonal Music*, Cambridge, MA, MIT Press, 1983.

Music and genetic algorithms — one thread of research is concluded in: **P. M. Todd**, **G.M. Werner**, *Frankensteinian methods for evolutionary music composition*. In: **N. Griffith** and **P.M. Todd** (eds.), *Musical networks: Parallel distributed perception and performance* Cambridge, MA: MIT Press/Bradford Books 1999.

Music and Markov models: **L. Hiller** and **L. Isaacson**, *Musical Composition with a High-Speed Digital Computer*. Journal of the Audio Engineering Society. 1958. **M. Farbood** and **B. Schoner**. *Analysis and Synthesis of Palestrina-Style Counterpoint Using Markov Chains"* Proceedings of International Computer Music Conference. Havana, Cuba. 2001.

Finally, Minsky's classic manifesto for why the border between music and AI should be much longer and more intricate: **M. Minsky**, *Music, Mind, and Meaning*, Computer Music Journal, Vol. 5, Number 3. 1981.

However, the standout exceptions, I believe, are some of the best and lasting work in the field of computer music. Robert Rowe, George Lewis and David Cope have all built systems that have reached the openness, the mass and heterogeneity that are hallmarks of actual "artificial intelligence" systems. The former two have exploited in different ways the software agent metaphor and framework; all three have at least addressed if not looked closely at the languages , tool-sets, and representations needed for their work from an authorship perspective. We shall see shades of both Rowe and Lewis in the areas of this work that are most resolutely computer music directed, *Loops Score* and parts of *The Music Creatures*.

Robert Rowe's earlier work, *Cypher*, **R. Rowe**, *Interactive Music Systems: Machine Listening and Composing*, MIT Press, Cambridge MA, 1992.

David Cope's well known "Experiments in Musical Intelligence" project(s), surveyed in: **D. Cope,** *Virtual Music, Computer Synthesis of Musical Style*, MIT Press, Cambridge MA. 2001.

George Lewis's Voyager systems: **G. Lewis**, *Interacting with Latter-Day Musical Automata*. Contemporary Music Review 18/3 (1995): 99–112.

In the visual arts we see a similar pattern, and when an agent-based framework is claimed we should eye it as closely as we inspect artificial-life-based art's biological inspiration. This is not to critique the success of the art itself, but to inspect the strength and practical use of the metaphor. Flavia Sparacino constructs an "intentional agent"-based interactive graphical and music dance space but the metaphor seems thin — the agent is missing a body of any complexity to control and the work is much closer to the principles of mapping perceived movement than the description immediately reveals. Claudio Pinandez sustains a longer agent narrative within the field of interactive drama, using real actors and live graphics, and his agents represent an important early perceptual contribution to understanding the drama realm live. Some of the fruits of Carnegie-Mellon's "Oz" project are also of relevance, including the "Façade" project and more recent work, which has tried to broaden the possible cultural application of AI considerably.

Flavia Sparacino reviews her work with an agent-based bent in: **F. Sparacino, G. Davenport, A. Pentland,** *Media in performance: Interactive spaces for dance, theater, circus, and museum exhibits*. IBM Systems Journal, 39 (3&4), 2000.

Claudio Pinandez's work in "computer theater": C. S. Pinhanez, *Computer theater*. Technical Report 378, M.I.T. Media Laboratory Perceptual Computing Section, May 1996.

The "Oz Project" is reviewed at its beginning: **J. Bates,** *The Nature of Character in Interactive Worlds and The Oz Project*, Technical Report CMU-CS-92-200, School of Computer Science, Carnegie Mellon University, Pittsburgh, PA. October 1992.

And near its end: **M. Mateas,** *An Oz-Centric Review of Interactive Drama and Believable Agents*. Technical Report CMU-CS-97-156, School of Computer Science, Carnegie Mellon University, Pittsburgh, PA. June 1997.

Its "successor" the "Façade project": **M. Mateas** and **A. Stern**, *Architecture, Authorial Idioms and Early Observations of the Interactive Drama Facade*. Technical Report CMU-CS-02-198, School of Computer Science, Carnegie Mellon University, Pittsburgh, PA. December 2002.

However, as the interactionist or agent-based reaches drama and narrative the possibility of an interaction between cultural production and artificial intelligence, as constructed by actual AI / art practitioners is now being seriously written about. Most related to this work is Michael Mateas contributions to locating the classical AI versus interactionist AI debate with respect to the working artist's cultural production. Out of the ashes of this rhetorical bonfire he fuses a third way, an alternative "expressionist AI".

M. Mateas, *Interactive Drama, Art, and Artificial Intelligence. Ph.D. Thesis*. Carnegie-Mellon University, December, 2002.

In his writings Mateas explicitly warns artists against aligning themselves too strongly with "interactionist techniques" which might result in them "missing out on a rich field of alternative strategies for situating AI within culture". This rejection is deemed necessary to license the *Oz* project's use of "traditional AI" structures for its natural language- and narrative-based works.

The root of this criticism thus appears to be a misunderstanding about the role of the agent metaphor in contemporary AI practice and the relationship of the agent as used today with the agent as used in early Brooks. The rejection of the *prescriptive* power of the agent-as-metaphor arises from a disagreement with an imagined *proscriptive* thrust of the early rhetoric that surrounded its birth. It is as if the organization of the debate perpetuated in brief historical capsules (and thesis context sections such as this) froze in the early 90s. The agent functions today as an organizing principle, and as such organizes extremely hybrid structures that press into service representations and algorithms that in the 90s might have been perceived as heretically classical, and can do so without becoming "vacuous". The agent-as-metaphor is not a position that rejects materials, but it does structure them strongly. What one "misses out on" with a rejection of the agent as a poetic metaphor is a set of ideas about how one might go about structuring a complex system that interacts with a dynamic, unpredictable world of which it itself is a part. While stance neutrality on any particular AI debate might initially seem an appealing non-position for an artist (one who wishes to remain external to the field of AI), to my mind this position simply recapitulates the narrative of endless potential and new possibilities that Mateas justifiably finds suspect in early interactionist AI.

Rather, I argue it is more productive for the AI / artist to choose some broad and useful organizing principles over a practice of ensuring the perpetual blankness of their slate. I further disagree with Mateas's insistence on the novelty of the artist's focus on authorship issues within AI or even the transformative possibilities of artists engaging in an AI practice. AI, and in particular agent-based AI, has always has a profoundly important engineering tendency which has maintained an interest on the authorship problems of AI. To make an opposition — that art focuses on the negotiation of meaning as mediated by the object, while AI focuses on the internal structure and its interaction — that is, to make a clean separation between art's art and AI's science, one has to first strip AI of its engineering core. As much as I appreciate the difference of the value structures apparent in both literatures, this opposition is not clear cut in practice. That this core has been poorly expressed in AI's relationship within the workings of scientific culture, publication and discourse is, I feel, undeniable. But absence of evidence here is not evidence of absence. The artists who exploit the AI tradition and literature are certainly not the first to make things using AI techniques.

However, what is true is that this line of work takes the agent-based directly toward the parts of human activity that AI has found so hard to reach — the use of language and complex human narrative. In contrast, the work presented in this thesis, which deals exclusively with non-linguistic, non-narrative domains, is somewhat dislocated from the few examples of uses of AI in theater and drama. Behind this dislocation is a significant difference of approach.

A review of much of this work can be found in: **J. Gratch, J. Rickel, E. Andre, N. Badler, J. Cassell** and **E. Petajan.** *Creating interactive virtual humans: Some assembly required.* IEEE Intelligent Systems, 2002.

And a point of origin: **N. Badler, C.W. Phillips** and **B. L. Webber**, *Simulating humans: computer graphics animation and control*, Oxford University Press, 1993.

From the broad-and-shallow-agent researchers behind the Oz Project:

"It has been suggested to us that it may be impossible to build broad, shallow agents. Perhaps breadth can only arise when each component is itself modeled sufficiently deeply. In contrast to the case with broad, deep agents (such as people) we have no *a priori* proof of the existence of broad, shallow agents."

from: **J. Bates, A. B. Loyall, W. Scott Reilly**, *An Architecture for Action, Emotion and Social Behavior*. Technical Report CMU-CS-92-144, School of Computer Science, Carnegie Mellon University, Pittsburgh, PA. May 1992.

The story of Classical AI versus Nouvelle AI has often been presented as story of the narrow-and-deep (the classical chess-playing computer) versus the small-but-complete (Brooks's intelligent insect). The *Oz* project, *Façade* and the work, for example, of Justine Cassell and Norman Badler and the general tradition of language- and gesture-based intelligent agents all stretch the small-but-complete of the agent to a broad-and-shallow — an "aspect ratio" unenvisaged and unintended by Brooks; a breadth that goes all the way out to human language.

There is little *a priori* evidence to suggest that convincing broad and shallow agents are possible. And despite the constructive work that has occurred in this area, I find the work in general has failed to coalesce a generally useful set of core techniques and ideas for practicing different classes of "breadths". This is, of course, rather unsurprising — if there were a small set of reusable ideas that enabled a host of ultra-broad-yet-shallow agents over a comprehensive set of human-level domains, then there would be no need for any "depth" and AI would have simply imagined its core troubles.

The work presented here follows a more conservative and consolidating path. When an agent is described as broad we mean as broad the world that we put the agent to use in (and no broader, and no narrower). And when it is said to be shallow, it means supple, and not over-committed to a particular problem domain ahead of time. The frameworks that back the agents developed in this thesis have all found use and instantiation in multiple agents, often designed by multiple people. That these agents do not extend their apparent breadth all the way out to human-level competencies is part of the cost at this time of developing more fundamental and reusable frameworks: *Dobie* looks to the training of real dogs in order to work through, to an unprecedented level, the details and needs of trainable computer systems; *alphaWolf* looks to wolf behavior for its core interaction.

Toward an aesthetics and a practice of the agent-based

Signs of this tactical compromise are to be found directly in the artworks presented in this thesis. *The Music Creatures* offers up multiple fragments of human-musical competency rather than an attempt at a totalizing human whole, looking instead to the proto-musical competencies of animals; *how long…* similarly offers a sequence of overlapping agents that slice through the choreography in different ways and different times, while each attempt by the agents is left radically incomplete. *Loops Score* takes a narration as its score but plays with aspects that lie halfway between language and meaning, sound and music.

The perpetual inadequacy of these agents can be compared to the nonexistent "human-level" artificial intelligences that they refuse to fake — an "automatic music generating system" (in the case of *The Music Creatures*); a "live choreography notating system" (for *how long…*) or a "meaning-to-music converter" (for *Loops Score*).

This rejection results in a series of works that are continually trying to catch up with their material, constantly off-balance, perturbed by — rather than at equilibrium with — the gallery or stage that they share. The resulting artworks develop an agent-based aesthetics of intention, effort and transience. Every other aspect of these works — from the gestural, hand-drawn qualities of their imagery to their attitude to human motion as it evaporates in front of their gaze — gathers around this unstable core.

This privileging of disequilibrium in my gallery works may seem no more than a matter of personal style, a mere reaction against the well-trodden paths of computer graphics and interactive art. However, I believe it also to be nothing less than the condition of contemporary dance — and a symptom of the computational sensibility in modern choreography in particular. Is not this disequilibrium implied by the gap between the audience's inevitable search for mimetic representation and the transformative calculus hidden in this choreography? Is it not this transience that Forsythe points to when he calls dance the poetry or architecture "of disappearance"?

c.f. **R. Sulcas**, *William Forsythe: The poetry of disappearance and the great tradition*. previously available online:

http://frankfurt-ballett.de/articles2.html

however, since the dissolution of the Ballett Frankfurt, this paper is currently available through the internet archive:

http://web.archive.org

Further, the agent metaphor, and the technologies to which it will lead us, offer fertile ground for the growing of small algorithmic ideas, hypothetical enabling constraints, and game-like forms that are open to the possibilities of chance and interaction. But more importantly, unlike the cold computation that computers find so effortlessly, but like the "parallel computers" of Forsythe's dancers, artificial intelligence's technologies of learning and adaptation, and its structuring of the problems of perception and movement, allow artists to work through the consequences of these tactical formalisms.

It is like parallel computing. In the old days, to make a dance in which nothing changes, people used their perception to make a rigid structure, we use our perception now to make a very complex structure. If I have 8 people figure out a dance from the inside, I have 8 people looking at 8 different things, from which they make connections. So basically what you are seeing in the third act of *Eidos* is a huge connection machine, using the human being as the original machine. It is primitive and wonderful, like a game; always the same game, but each time played differently.

William Forsythe, quoted in **T. Ozaki, (P. Vigilio trans.)**, *An Interview with William Forsythe*. (availability as above).

4. "Non-photorealism" and computer graphics

The goals and metrics of photorealistic computer graphics are relatively well understood. This synthesis of the primary algorithms, of forward and inverse ray-tracing, radiosity and surface-modeling techniques came at a time when practice had not irretrievably outstripped theory. Drawing deeply on our understanding of the physics of the world it is possible to interpret the wide variety of photorealistic techniques in a single unifying framework which can in turn be used to derive, or at the very least locate, approximations that are inside the current real-time envelope accessible to contemporary graphics hardware.

One, inspirational, *post hoc* synthesis of photorealistic computer graphics is Andrew Glassner's formulation of the rendering equation in **A. Glassner**, *Principles of Digital Image Synthesis*. Morgan Kaufmann Publishers, Inc, San Francisco, 1995.

Any theory of non-photorealistic computer graphics is in immeasurably worse shape. Having benefited from, or at the very least been able to co-opt, the hardware created for these immersive, realistic graphics, the field of non-photorealistic works seems too large to unify, too diverse to theorize over and its boundaries too poorly defined for us to artificially construct a set of natural kinds to examine and reason with.

One might, however, start finding some orienting landmarks, if not in the aesthetics of the resulting works, in the techniques or technical styles deployed therein. It is a field, after all, wedged between the predominantly photorealistic theoretical legacy of military virtual reality and Hollywood special effects and the, again, predominantly photorealistic technical affordances offered by the commodity hardware necessitated by computer games.

An excellent online resource covering this area is to be found at: **C. Reynolds**, http://www.red3d.com/cwr/npr/

In print, a review: **T. Strothotte, S. Schlechtweg**, *Non-Photorealistic Computer Graphics: Modeling, Rendering and Animation*. Morgan Kauffman, 2002.

While we might feel that all kinds of non-photorealistic life has taken root in this space, I believe that we'll find a limited number of survival strategies at work. A comprehensive survey of all of non-photorealism in computer graphics is a demanding task — it is, after all, a field that is defined principally in terms of what it is *not* — and I shall limit the discussion here to trying to organize one corner of this space that works in real-time, that is concerned with live and interactive settings and is not devoted solely to duplicating early twentieth-century painting or nineteenth-century engraving. We will try to find these landmarks or axes throughout this document to locate technical styles, to examine the tensions navigated by certain technical approaches or to look at possible groupings of the aesthetic results of these practices.

Despite more than a decade of dominance, development and convergence **Adobe corporation's**, Photoshop and Illustrator (www.adobe.com) remain separate, distinct and normative on their application domains.

A review of "modern" versus "classical" OpenGL (www.opengl.org): **R. J. Rost**, *OpenGL Shading Language*, Addison-Wesley, 2002.

The "score / orchestra" fissure is discussed in **R. Boulanger** (ed.) *The Csound Book: Perspectives in Software Synthesis, Sound Design, Signal Processing and Programming*, MIT Press, 2000.

Max/MSP is available at: http://cycling74.com

One pole I shall refer to as "textural"; it has a corresponding anti-pole "geometric". These terms come from a purely technological distinction: these places embody the parallel paths of real-time computer-graphics architectures that always must incorporate manipulations at the level of the individual pixels and at the level of points, lines and planar elements. This is the perennial separation between bitmap image-manipulation software (e.g. Adobe Photoshop) and the vector-based (e.g. Adobe Illustrator); this is the difference between "fill-rate" and "vertex operations" that graphics-accelerating hardware performs; between the "fragment shader" and the "vertex program" of the modern, reinvented core OpenGL, or the "imaging" and "primitive" pipelines of OpenGL's previous core. Similar cleavages appear elsewhere: the sample level (textural) of the Music N / CSound family of musical programming languages is encoded in a different language to the score (geometry); the blocks of musical signal (textural) are distinct from the world of lists and bangs (geometric) of Max/MSP.

Image-based rendering, early work includes: **P. Debevec, C. J. Taylor, J. Malik**, *Modeling and Rendering Architecture from Photographs: A hybrid geometry- and image-based approach*. In: SIGGRAPH 1996 International Conference on Computer Graphics and Interactive Techniques, Proceedings of the 23rd annual conference on Computer graphics and interactive techniques. ACM, 1996

An overview: **C. Zhang** and **T. Chen** *A survey on image-based rendering-representation, sampling and compression*. In: *Signal Processing: Image Communication*, January 2004, 19, (1), pp. 1-28

For the technique of normal mapping, an introduction can be found in any "game graphics" textbook. For a more detailed practical discussion: **D. H. Eberly**, *3D Game Engine Architecture : Engineering Real-Time Applications with Wild Magic*, Morgan Kaufmann, 2004.

At present I believe we are a point where the textural is on the ascendancy in computer graphics in general and in interactive digital art in particular. The real-time realism of recent computer games owes more to the textural complexity afforded of normal-mapping than it does to the geometric complexity of the rather low-polygon models that carry those static textures. And of course, interactive graphics is dominated today by the processing of video (texture). The rise of "image-based" rendering techniques that work either mainly or solely with 2d images exploiting the convenience of video sampling compounds this trend.

This is not due to technical opportunity; in the case of interactive art the decompression and manipulation of multiple video streams still taxes modern hardware and the gap between the resolution of interactive, textural, video-based work and its audience's high definition televisions shows no signs of narrowing quickly. Rather, a full diagnosis of the fascination with video in particular and the textural in general requires a little more disentangling.

To cite just two influential examples of geometrically controllable texture: **S. Strassmann.** *Hairy Brushes*. In SIGGRAPH 1986 International Conference on Computer Graphics and Interactive Techniques, Proceedings of the 13rd annual conference on Computer graphics and interactive techniques. ACM, 1986.

and:

L. Markosian, M. A. Kowalski, S. J. Trychin, L. D. Bourdev, D. Goldstein, and **J. F. Hughes.** *Real-Time Nonphotorealistic Rendering*, In: SIGGRAPH 1997 International Conference on Computer Graphics and Interactive Techniques, Proceedings of the 24rd annual conference on Computer graphics and interactive techniques. ACM, 1997.

In any case, the best, and most interesting work in the field of non-photorealism has been some work to bridge this texture / geometry segmentation marrying the the controllability of geometry with the fluidity of texture. Often, however, this work has focused on developing one particular style, taking photo-realism's geometry and texturing it appropriately, rather than finding a broader, experimental framework. I know of no work to date that provides a generic framework or principles for synthesis of an animated form that lies between the purely abstract and abstractions from sampled material. The purpose of the *re-projection rendering* techniques developed in this thesis is to provide an instance of such a framework.

Live computer graphics and the stage

The textural / geometry pole is of use in analyzing the contemporary use of live graphics in a dance theater setting. Increasingly today the ascendancy of textural computer systems is echoed by those working in dance technology who are turning to video technology to "sense the stage". Where does this come from? and where is it going?

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

In the early 1990s, Forsythe published many of his choreographic techniques in a seminal pedagogical work — the CDROM *Improvisation Technologies* (1993). Crude, but effective, hand-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 Ballett 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 by the dance technology community at large. There are a number of reasons why the field did not develop and unfold in this way. I shall focus on diagnosing part of the 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 due, I believe, to the interactive dance community's use of video as the computer's 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 concerned with dance on camera, which offers a veil of precedent and theory.

Some recent examples of the ongoing trend towards video-based sensing and/or projection in dance include the work by the dance company **Troika Ranch** *Future of Memory*, 2003, by media artist **Klaus Obermaier**, *Apparition*, 2004 and *Vivisector*, 2002, **Wayne McGregor** / Random Dance's *AtaXia*, 2004.

In each of these works, the primary sensing technologies (for both the real-time works and the pre-prepared video materials) and the primary body representation used digitally is the video frame. The apparent (in)ability for video to allow computational "access" to human in these works often stands remarkably at odds with the stated intentions of the artists involved.

Unsurprisingly, then, the number of dance performances using live and processed video has been growing for a decade; the tools to support these works are being standardized, distributed and sometimes even 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, rare and precious.

here is a little history of motion capturing dance, much of it is reflected in the work of Paul Kaiser and Shelley Eshkar (collaborators on *Loops*, *Loops Score*, *how long...* and *22*). Information available online: http://www.openendedgroup.com

For a review of a broader range of work:

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

Video, despite its apparent mimetic transparency, is a poor *computational representation* of human *movement*. It is poor because it is not clear what transformations of pixel-level data 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.

While it may be technically accurate to say that "video is used to sense the stage" during a typical interactive dance work, little transformative representation of the stage actually takes place: the stage is sensed by video but not perceived by video, and little representation of the stage survives the transportation through video into the computer. Rather, this video input leads directly to a predominantly textural computational methodology, an aesthetic of image-based abstraction turning around limited mimetic representations inside the computer.

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 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.

In that variable lighting, camera placement, multiple overlapping bodies, a variety of motion with a large dynamic range, and even costume conventions seem to be exactly configured to thwart much of the seated, upper-torso focus of practical computer vision research.

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 duplicate it — there is no path of least resistance leading to duplication and repetition. Motion capture is the basis for a hybrid representation: one that lies between the purely computational and the dedicatedly mimetic.

This double aspect of motion capture is clear: it is computational because computers can clearly manipulate it with considerable ease; yet, a direct presentation of the data is shockingly readable. This, then, is representation that supports transformation and recasting — and it is the place that we will meet the computational sensibility of contemporary choreography.

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, 14: pp. 201-211. 1973.

his 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, 4 (4), December 1998

This, then, is surely the place to begin generalizations from which abstractions can be made and on which algorithms can act. These actions, made visible, might yet be related more, in the eye of the audience, to human movement than they are to the technology that captured it and the representation that stored it. In the language developed above motion capture necessitates a geometric force and a point of departure from the abstract to re-project motion back onto the stage. This is the technical point of contact around which a dialogue between programmer and choreographer can occur, an intermediate point that is neither automating say, the dice rolling of Cunningham, nor simply duplicating the appearances of the performer.

Towards ambiguous computational graphics

For example, the 2D image based work in **K. Sims**, *Artificial Evolution for Computer Graphics.* in Computer Graphics, 25(4), July 1991. or the *Genetic Images* installation, with **K.Sims** *Evolving 3D Morphology and Behavior by Competition*. In: *Artificial Life IV Proceedings*, R. Brooks & P. Maes (eds.) , MIT Press, 1994.

Armed with the textural / geometric opposition it is possible to project artworks onto it. Karl Sim's genetic programming / artificial-life-based work (for example, the Galapogous installation) is towards the"geometric", while his earlier, arguably less lasting work is textural.

Few works are nimble enough to play between these poles. Golan Levin and Zach Liberman's performance work for hands, projectors and cameras, "The Manual Input Sessions", draws its motivating humor from the dramatization of the crossing point between shapes made from hands (the abstract, made through a most resolutely geometric use of video) and hands made from shapes (the abstracted). In the Klaus Obermaier's influential work for projections over dance theater *Apparition* or the earlier *Vivisector*, it is not the play of figure / ground that is of lasting interest; rather it is the threat of video unusually born of transformation — human body parts re-projected onto other body parts — rather than as bearer of mimetic intent. Of course, in these works (the later of which uses video to capture the silhouette of the dancers) this is achieved, if it is achieved at all, through careful rehearsal rather than clever digital representation — but that they are succeeding, to my eye, exactly at the point where they are pushing against the affordances offered by the image making technologies that they use is critical to the argument here.

G. Levin and **Z. Liberman,** *The manual input sessions*. 2004. Performance.

K. Obermaier, *Apparition*, 2004. and *Vivisector*, 2001-2.

In each of these performance-based works it is the vertiginous places during the performance where the imagery loses its definite location between textural and geometric. I argue that non-photorealistic graphics, if it is to move beyond technical demonstrations of mimicry, or mere novelty, will only find its contact with a lasting use in lasting digital art in these technically difficult, ambiguous, middle grounds.

"I think we are in a very curious position today because, when there is no tradition at all, there are two extreme ends. There is direct reporting that is like something that is very near to a police report. And there is only the attempt to make great art. And what is called the in–between art really, in a time like ours, doesn't exist. [...] ... with these marvelous mechanical means of recording fact, what can you do than go to a very much more extreme thing where you are recording fact not as simple fact but on many levels, where you unlock the areas of feeling which lead to a deeper sense of the reality of the image, where you attempt to make the construction by which this thing will be caught ... " (p. 66).

Francis Bacon, in **D. Sylvester**, *Interviews with Francis Bacon*, Thames-Hudson, 1975.

The "real world" seems to be stacked in favor of the textural over the geometric. The "reality" of photo-realistic graphics remains heavily dependent on sampled or procedurally generated textures; the physicality of the drawn line is revealed as much in the surface qualities of the paper and the interaction between layers of graphite as in the geometric shape of the drawing; both the softness of the organic and the abrasiveness of its patina explode geometric complexity. Given these challenges, it is no wonder that the most recent increases in graphical processing power and machine learning have given birth to a sub-field of "image-based" off-line computer graphics.

There is a textural bias to the aesthetics of all this processing power. The apparent "softness" of the organic form was at one point the most sought after and precious commodity of computer graphics, photo-real or not. The "gaussian blur" was a popular benchmark of processing muscle; the smooth curve of the non-uniform rational b-spline a hallmark of sophisticated and expensive non-polygonal manipulation. But more often than not the texturality of computer graphics fumbles its physical, or even biological, referent in real time transformation. For its coveted smoothness are the result not of an unspeakable multitude of past processes acting on the geometric, they are rather anti-patina: an erasure of history, a hiding of the lack of process by which the rendering came about. The gaussian blur *deletes* high frequency information; the smooth interpolate surfaces are skins stretched through a *hidden* 3-dimensional lattice.

The aesthetics of the work I wish to develop reveals process. Thus in computer graphics, photo-real or not I begin at an unconventional and inconvenient place. The works presented in this thesis stem from a common search: can we find a non-photoreal, geometrically controllable textural aesthetic? Can their texture be the trace of a process rather than an additional decorative layer? Can geometry interact on a textural surface? Can these interactions be metaphorically physical or biological but geometrically rather than texturally faked? It is from these principles that the work, by the time we are ready to enter dance theater, readies itself to accept motion-capture material and play with the mimetic and transformative possibilities offered.

Concluding remarks

In surveying some of the context of this thesis this chapter has sketched its main arguments. From the narrowest to the broadest they are:

that with its recent focus on the "textural", live graphics in dance theater fails to allow either computer graphics or simply computer algorithms sufficient access to the very stuff of dance and choreography — human movement; that new rendering techniques and new sensing methodologies must be developed and incorporated into the field of dance technology for genuinely computational interactive artworks to be created; that, paradoxically, prominent choreographers today are outpacing the dance-technologist's deployment of computational ideas.

that it is time for an articulation of the agent-based in digital art; that in particular, this should be seen as a platform from which to critique the prevalent synthetic and analytic approaches of interactive art in general and dance technology in particular. The agent-based offers a radically different path for creating and navigating the *potential* developed by computation processes in comparison with either interactive art's "mapping" or artificial life's "emergence", and an alternative point of origin for the development of digital art-making tools. This metaphor provokes and accepts choreographies use of "tactical formalisms" as a working practice.

that the time is ripe for algorithmic art and contemporary choreographic practice to enter into a genuine, constructive dialogue; that for too long the interactive digital arts have largely ignored the precedent of and opportunity offered by dance.

These arguments will be fleshed out in the chapters that follow, and all of them will be found in the final works for dance theater that I present.