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Aesthetic Computing

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Overview

The phrase "Aesthetic Computing" while taken literally applies the philosophical area of aesthetics to the field of computing and work in the area is broadly defined as such; however, in my operational definition for the work we do at the University of Florida, aesthetic computing is treated as *embodied formal language*. The purpose of aesthetic computing is to deliver knowledge and practice of formal languages using aesthetic products as a vehicle. Aesthetic Computing is founded on an increasing collection of literature on the role of the body in learning, specifically in mathematics. This foundation is then applied to the field of computing whose formal language elements are extensions of mathematics. There are two questions that this new area raises:

Q1: *How can embodied cognition be situated within formal languages?*

Q2: *How can embodied cognition result in novel computer interfaces for formal languages?*

Q1 surfaces a host of sub-questions revolving around theory, philosophy, and analysis. Asking this question raises issues of motivation: 1) Why am I interested in this topic? 2) How is the area of aesthetic computing built on top of embodied cognition and philosophy? 3) Who has worked in this area (e.g., the literature)? Q1 is not enough, however. It is one matter to analyze and develop theory, but another to ask oneself "How can this theory be transformed into practice?" That is the essence of Q2. What should we be *doing, practicing, and creating* to take embodied cognition of mathematics and computing to the next level? We need to build a new generation of human-computer interfaces that are informed by embodied principles and use these principles as design elements for interacting with formal languages. A potential, and vital, third question would revolve around the effects on such computer interfaces on learning via assessment and scientifically-based research methods. This represents an area that aesthetic computing needs to investigate; however, most work to date is based on theory construction and engineering the novel interfaces.

The Aesthetic Computing Hypothesis is that given the embodied nature of cognition, we should realize this embodiment through novel human-computer interfaces for learning formal languages.

Context

I pose two questions as a means to provide context for the area of aesthetic computing:

1) Why is the term "Aesthetic Computing" being treated as "Embodied Formal Languages?" and 2) What are "Embodied Formal Languages"? For the first question, we must revisit the roots of the word "aesthetics." The original Greek definition of aesthetics, *αἰσθητικός* (*aisthetikos*), stems from another Greek word *aisthanomai*, meaning "I perceive, feel, sense." At the core of aesthetics, then, lies the body, and its interactions in forming concepts and knowledge. Aesthetics as embodiment. Aesthetics is, in breadth and depth, a much richer enterprise above this level (Kelly 1998), yet we maintain a view of aesthetics that is body-based even though Diffey (1995) notes that the term 'aesthetic' has largely lost its perceptual sense except in the word 'anaesthetic,' but retains its senses of "beautiful" and "artistic." As far as to why "Formal Languages" are used to characterize "Computing," we note that the bulk of theory of automata and computing is situated within linguistics -- although a subset of general linguistics that requires a formally well-defined specification and treatment.

Let us now consider the definitions of embodiment and formal language. Embodiment suggests the perception/action feedback loop present when the body interacts with its environment. So, it seems clear that an embodied approach to anything would involve sensorimotor functions - using the mouse, keyboard, multi-touch displays as well as donning a head-mounted display or using a tactile feedback device. Human-Computer Interaction is chock-full of approaches that leverage such technologies. But, embodiment is a much deeper concept than sensory stimuli and physical manipulation. We have a sense of presence with certain advanced technologies such as multi-user virtual environments (i.e., achieving different types of presence, including social). We also have a sense of presence when reading a book, since the book situates our "mind's body" within the narrative (ref. "narrative psychology" in Beck et al. 2011). Thus, embodiment can be measured objectively by hardware used to enable the senses, or subjectively through a presence instrument on the human subject. Embodiment should not be viewed as a rejection of abstraction, but rather as a complement to it (Devlin 2006).

Formal languages define a category of language that is artificial, such as a programming language. These languages stem from formal grammars which be based on text, shapes, or diagrams. FORTRAN, Java, and Perl are examples of formal languages, but so is the

eXtensible Markup Language (XML), Unified Modeling Language (UML), data structures, Morse code, and dynamic model structures used for simulation (Fishwick 1995, 2007a). Formal languages are frequently specified using grammars such as the Backus-Naur Form (BNF) and need not be text-based. For example, one can have formal audiovisual languages and also graph grammars. All formal language structures can be defined hierarchically using levels of abstraction (e.g., 3 finite state machine levels governing an underlying set of ordinary differential equations, which in turn are translated into the programming language Java, and then further into bytecode). Languages, therefore, are frequently defined in long chains of specification and translation. Each language has its own target functionality, culture, and adherents. Ghezzi and Jazayeri (1997) provide general concepts of specification for programming languages.

Personal Experiences and Influences

Art

It is easy to take the idea of embodied cognition for granted since it seems like something so natural—that the body plays a central role in cognition. However, an adherence to embodiment tends to change worldview when looking at objects. As an amateur artist, I collected many posters and prints of historically well-known artists. In middle school, I was strongly influenced by Thomas Gainsborough's work, in particular Figure 1.



Figure 1: Mr. and Mrs. Andrews, oil on canvas, Thomas Gainsborough, 1750. The National Gallery, London, UK.

I imagined with myself as an avatar that I could enter the painting, walk the wheat field, examine the trees, and engage in social discourse with Mr. and Mrs. Andrews. This led to a series of imaginary conversations and observations “in world.” The key point here is the “reading” of this work *as a form of embodied experience*. The Gainsborough painting was not a remote object of study for me, but rather an example of virtual reality, a time machine—an illusion that allowed me to immerse myself within the world of 18th century England. This approach is an example of Dewey’s *art as experience* (Dewey 1934) and relates to Grau’s (2004) argument about artists as the first virtual reality creators. The approach stresses that when we approach an object, we can interpret it dynamically via a bodily simulation with all of the perceptual and motor-based actions that the body affords. This way of thinking and acting can be applied to all objects and media, including mathematics and computing.

Mathematics

In elementary school, like hoards of other students throughout the world, I was taught the elements of arithmetic--its methods and laws, with many examples that were exercised using rote memorization and intense practice. Doing mathematics was highly action-based but the action was limited to solving multiple problems over extended periods of time. After the basic elements of arithmetic came algebra. Let's consider the following mathematical expression containing arithmetic with a sliver of algebra:

$$X = 2 * (3 + 4)$$

We have all been subject to such mathematical objects, as they are critical to an educated public. Learning all components of this equation was not easy--one had to understand the concept of a variable, operations of multiplication and addition, followed by the concept of a parenthetically-delimited group. Order of operations is also critical, as suggested by the group. So, for example, I can add 3 to 4 and then multiply by 2 to obtain 14, which was then set to X as an equivalence. Certain laws of arithmetic were useful in transforming expressions such as this one. The Law of Distribution states that $x(y + z) = xy + xz$ where x , y , and z are numbers, and the multiplication is implicit rather than being defined explicitly using $*$ as in the above equation. The teacher would define the law of distribution but give us many useful examples as a means to reinforce our understanding of the law and how it can be employed in symbolic manipulation. Such patterns of equivalence drove a static pattern-matching type of approach to mathematics.

However, during the ensuing lessons, I found it convenient to create an artificial method of solution that involved treating the numbers and symbols as physical objects. In

mathematics education, this kind of process is termed reification (Sfard 1994) and is related to constructivism (Piaget 1950) and constructionism (Papert 1980) where students create their own knowledge through a combination of ideas and life experiences. I used a virtual manipulation of the above expression by representing the distributive law through analogy and metaphor:

Grab the "2" object, which when juxtaposed with the "" operator, provides a biomechanical state where the "2" is pushed inward toward the group object defined within the parentheses "...". The "2" is pushed gradually and then when it reaches the edge of the spatial boundary denoted by "(", it moves through it to the other side and splits--in a biological fashion--into two clones that are attached to the "3" and to the "4," respectively. This cloning activity results in the expression $(2 * 3 + 2 * 4)$. The sub-expressions $2 * 3$ and $2 * 4$ are evaluated through further bodily activity. Pushing the 2 and 3 into the *, for example, results in multiplications. Similar reactions occur to perform the + operation last, as dictated by the learned order of operations. The result is then placed manually in a box with an X printed on it.*

Mathematics then, for me, had become akin to a full-body sport rather than simple operations requiring a collection of static text-based rules and patterns. The virtual manipulations might involve other embodied activities, where I might have "launched the 2" over a wall that bounds the parenthetical expression. While this is a personal experience, it is by no means unique as Sfard observes in her dialogue with Thompson (Thompson and Sfard 1994) where she notes the propensity for similar mental imagery: "My work with mathematicians brought lots of further evidence that, indeed, the inner world of a mathematizing person may look very much like a material, populated with objects which wait to be combined together, decomposed, moved and tossed around." Arzarello (2004) explains the difference between natural versus formal mathematical presentations, and surfaces the importance of gesture in using naturalistic explanations and interpretations in addition, or on the path, to the formal. The previous embodied description would be termed natural. Goldin and Kaput (1996) overview the effects of media on mathematical representation by noting "...changes in physical media that permit external representations to be action rather than display representations give these representations one characteristic of powerful internal representations." Hadamard (1996) studied mathematical thought, which echoed similar cognitive processing. This action-based narrative on mathematical symbols was not limited to the distributive law for me. For example in an expression such as $x + 2 = 4$, something interesting happens when moving numbers through the equals sign. There is a virtual line or plane that intersects at a right angle to the $=$. When a number such as 2 is

dragged through this vertical plane, the number flips its sign on the other side with a mirror-like effect, resulting in $x = 4 - 2$. The laws of commutativity and associativity have similar pseudo-physical, material, behaviors that can be used to understand and process arithmetic expressions.

The problem with my early experiences with embodied sense of symbol manipulation is that none of the books (or teachers) explained mathematics in this way, and I and likely many others, were forced to keep these somewhat peculiar cinematic episodes to ourselves. Whether this type of thinking is common requires more scientific studies and reflection upon the nature of mathematics. At the University of Florida, we have developed a web-based interactive tool that allows anyone to manipulate expressions in this fashion. We have also previously explored similar embodied representations involving a sense of presence in a virtual environment (Fishwick and Park 2008a).

My purpose in relaying this experience is to emphasize the importance of the body in understanding formal languages such as mathematics. Lakoff and Nunez (2000) presented a landmark compilation of mathematical metaphors that build on top of the philosophy of embodied cognition (Johnson 1987, Varela et al. 1992, Barsalou 2010). In particular, Johnson's image schemata such as containment, attraction, and equilibrium were integral aspects of my arithmetic experience. The literature in embodied thinking centers thought and knowledge on the body and is informed not only by areas such as conceptual metaphor (Lakoff and Johnson 1999, 2003), but also by subsequent empirical studies of the brain (Feldman and Narayanan 2004, Feldman 2008). Even more generally, language-based narrative appears to contain an embodied basis (Speer et al. 2007, Mar and Oatley 2008) defining natural language in terms of simulation. Reading a story about grasping or running can result in a cognitive simulation of these events and activities, as if the reader had been physically active. Going back in time to when the Method of Loci flourished (Yates 1966), we note that the act of memorizing a set of facts was turned into a rich, embodied process rather than viewed as mere associative retrieval. The area of situated learning and cognition (Brown et al. 1989, Lave and Wenger 1991) meshes well with the embodied approach in terms of its goals and methods: learning by doing.

In closing the discussion of an embodied mathematics, we should note that the concepts of "action", "interaction", and "process" can be framed within standard mathematical notation containing explicit aspects of functional composition, dynamics, and procedure (i.e., embodied-types of thought). For example, the aesthetics of geometry and shape can be constructed generatively (Leyton 2001, 2006) and dynamically via Blum's wave propagation-based medial axis (Leymarie 2006). We can

also use mathematics to create a formal representation of mathematical metaphors (Guhe et al. 2009), thus making a loop: grounding metaphors on mathematical expressions, where the metaphors themselves are formally defined.

The embodied approach has profound implications for mathematics, and by extension for applied mathematics, and computing since computing is a direct outgrowth of mathematics, and formulas such as the one described earlier are common objects found in software "expressions." If our thought is embodied then:

1. We should investigate the variety of metaphors used within mathematics and computing, and also their origins and cultural associations.
2. We should leverage the metaphorical, and embodied, substrate of language by creating new human-computer interfaces that reinforce and amplify this experience.
3. We should bring to bear other disciplines for whom "the body" is a natural component, such as the arts and humanities (Slingerland 2008), thus forming new interdisciplinary collaborations that span the academy.

Programming

The embodied approach was extended from mathematics into learning programming and data structures. Programming, in particular, is known to be rich in metaphor. Loops are just that: patterns of cyclic behavior -- small objects moving around a closed path as these objects perform other tasks. Sequential behavior is sometimes a movement along a spatial path, and functions are machines that take product inputs and produce outputs. Papert (1980) in his explanation of the LOGO language reinforces the importance of embodiment in a term he calls "syntonicity" where he notes "We have stressed the fact that using the Turtle as metaphorical carrier for the idea of angle connects it firmly to body geometry." Petre and Blackwell (1999) performed studies on programmers and results indicate metaphorical reasoning involving objects, motion and general embodied interaction. Metaphors such as these are not only present in all programming languages, but also in the theory of computation on which the theory of computing is based. For example, the Turing machine is an excellent example: a machine envisioned by Alan Turing in the 1930s consisting of a tape read/write head and an infinite tape. This metaphor may have been because of the extensive use of magnetic tape at the time. In the previous century, Charles Babbage used a "mill" in his computing engine. Interestingly, in the vast history of computing where these historical concepts are discussed (Ifrah 2001), most programming and computing was analog and embodied by definition and implementation. It is only relatively recently, that the

evolution from analog to digital has simultaneously sped up our computations, facilitated a computer revolution, but also disembodied our relations to computing.

Media

Media theorists have provided a host of approaches in understanding the evolution of media. McLuhan (1964) places importance, not only on the message created through a modulated medium, but the medium itself which affects the message. McLuhan employs the example of a light bulb which he claims is a "medium without a message." However, the light bulb can host a binary digit, and perhaps more in the case of multi-way switch bulbs in a means not unlike Morse code manipulated through signal lamps. Bolter and Grusin (2000) present a theory of media forms undergoing gradual alteration, generally technology-driven, causing us to examine issues of immediacy (seeing beyond the medium to the target signified) and hypermediacy (being aware and reflecting on the medium). New media studies place specific importance on materiality, the medium, and embodiment. Manovich (2002, p. 317), when he considers the "loop as a narrative engine," with a loop being defined as a common programming structure enabling index-based iteration, asks "Can the loop be a new narrative form appropriate for the computer age?"

Popular media have significantly shaped my thought process underlying aesthetic computing. For example, *Tron* (Kallay 2011), which debuted in 1982, is noteworthy because it was created based on a highly innovative screenplay which included a large piece of software, namely an "operating system," that could be experienced directly. Programs were bodies and the operating system was composed of a city-like space with lighted, moving vehicles and interacting programs. *Tron* is fairly unique in this way within the science fiction/fantasy genre. Other more recent cinematic offerings, while impressive and engaging, tend to ignore the "program." For example, on *Star Trek: The Next Generation*, we were introduced to the Holodeck where one could experience an ultimate virtual reality with full sensory simulation. A user would stop at the outside of the Holodeck and say "Computer. Load Holodeck Program A-3" or some such phrase, and then the Holodeck would load this program and the user would enter. However, we never actually experienced the program itself--only its inputs and outputs. Similarly, in *The Matrix*, we have a rich embodied experience of human characters who, in reality, are stored inside of a network of fluid-filled pods.

Despite our familiarity and utility with text-based process descriptions, it is remarkable and ironic that a hyper-real environment such as the Matrix affording real-time synthetic interactions and simulacra would have to be programmed by strange-looking rivulets of green rain, which are not obvious to anyone, presumably except for the operator well trained in this postmodern descendant of cuneiform script. This semiotic condition presents a stark contrast: practically unlimited full-sensory simulation on one hand produced by the program, and what amounts to glorified typewriter symbols on the other defining the program itself. It is as if one provides you with a highly maneuverable hypersonic jet plane to fly with the caveat that you need to pilot the plane by tapping on a straight key to produce Morse code dots and dashes. One would expect that, just perhaps, the capabilities that form programs and data might avail themselves of the practically unlimited human-computer interface that the Matrix provides. Rotman (2000, p. 67) poses the question that forms this concern, "What if language is no longer confined to inscriptions on paper and chalkboards but becomes instead the creation of pixel arrangements on a computer screen?"

Aesthetic Computing: Turning Computers Inside-Out

Computers have shrunk in size, and increased in number, considerably over the past half-century. We are familiar with news stories about how ever smaller and thinner computers and software are now ubiquitous in our culture to the point where we carry or wear them in our daily routines. The decrease in size and increase in number creates a situation where computing effects most consumer products. For example, the digital video recorder enables time and place shifting for movies and television shows. What is just as interesting is exploring how computing affects us and our thinking. Turkle (2005) explains this psychological phenomenon and closes with the phrase "we are all computer people now."

Turkle's argument has significant ramifications for computing, and I would go one step further to suggest that the way in which our thinking is changing culturally surfaces deep abstract concepts in computing to us as we use these devices: from number, to information structure, to process. Digital watches and video recorders (DVRs) are good examples. Most digital watches are multi-function. These watches contain the ability to act as a way to tell time, set a stop watch, or wake up to an alarm. To use the watch, you have to learn how to navigate a menu by repeatedly pressing a mode button. In each mode, there are sub-functions refining that mode's interaction. This experience of mode-button pressing directly maps to a fundamental theoretical structure in computing called a *finite state machine* (Hopcroft et al. 2000). It is not just that the finite state machine is embedded within the watch's silicon, but also that the human wearing

the watch becomes aware of this virtual machine's structure and its components through the experience of using the watch. The state machine *changes how the wearer thinks* even though the wearer is probably unaware of the formal mathematical notation of a state machine. The watch's software internals become embedded within our psychology and culture. A similar process occurs within most other household appliances such as the DVR, however, the state machines in DVRs are more complex than in watches---yet to understand how to navigate the hierarchical menus, one has to become fully aware of a new type of thinking (Negroponte 1996). Effects of computing on thought (e.g., neo-millennial/digital native learning styles) have also been covered in the context of learning (Dieterle et al. 2007).

Experience with computing artifacts is a form of information representation, where the definition of "representation" is expanded as a form of interaction rather than as a static object in the form of a sign. If the raw elements of computing--information, data, and software--are changing the way that we think and entering into our popular culture, it is natural to suggest that aesthetics of these raw elements can and should play a central role in computing. Aesthetics has evolved from the embodied, sensory, definition to a more comprehensive one offered by (Kelly 1998), a "critical reflection on art, culture, and nature." Aesthetics within computing results in new interaction modalities for computing artifacts such as formal languages. Given the preponderance of new ways to connect human with computer, there are many opportunities for creative representation. We categorize and study these new ways using the phrase *aesthetic computing*.

Why Aesthetic Computing?

Representation targets of aesthetic computing include terms such as data, information, software, and code. I use these terms somewhat interchangeably because of semantic overlaps. Data can be atomic or in the form of a structure. Code usually refers to software, which encompasses both data as well as process. Information theory tells us that all of this is a form of information since information can be decoded as atomic, structural, or procedural. I prefer terms such as code, software, or information when referring to the "computing" part of aesthetic computing since these terms encompass broader categories of items that can be represented, whereas the term "data" in common parlance tends to denote non-procedural forms of information.

The argument for aesthetic computing is as follows involves emerging areas of computing which have changed:

- Our relationship to each other and to nature. These aspects include ubiquitous (Greenfield 2006, Gershenfeld et al. 2004) and pervasive computing, customization and personalization of interfaces, and the new modalities for human-nature interaction as mediated through computing (e.g., the virtual reality continuum spanning physical, virtual, and augmented reality). Shared and customized interfaces for information visualization (Viegas et al. 2007), code sharing (Reas and Fry 2007), assisted with "remix culture" (Lessig 2008) create a networked, customized (Pine 2002) representational space.
- Our thought patterns, allowing computing artifacts such as information and software to permeate our experience. Salomon (1990) makes an argument for computing changing thought, resulting in *cognitive residues* from human-computer interaction. These studies are consistent with Turkle (2005).
- The importance of experience in computing in human-computer interaction (HCI). Cockton (2011) and Hassenzahl (2011) describe the shift in HCI from efficiency, alone, to experience, and Löwgren (2011) emphasizes the importance of interaction--a core aspect of experience. The emphasis on experience is related conceptually to embodiment (Lakoff and Nunez 2000, Johnson 2007) as a basis for cognition. The relevance of aesthetics in HCI is discussed by Tractinsky et al. (2000) and Norman (2004). Dourish (2004) lays out a philosophical foundation for embodiment in HCI through its beginnings in phenomenology.
- Our need as computer scientists to interact more frequently with artists and designers, since they represent the creative component of aesthetic inquiry, and so experience-based representations for the diffusing computing artifacts need to be studied with the help of artist-scientist collaborations (Buxton 1988, Malina 2011).

History of the Aesthetic Computing Field

I have been teaching a course in aesthetic computing for a decade (since 2000) and information on the most recent course can be found in (AC 2012). A preliminary paper was published on the concept (Fishwick 2002). A Dagstuhl seminar on Aesthetic Computing (Fishwick and Bertelsen 2002) was co-organized in Germany (Dagstuhl 2011) by myself, Roger Malina, and Christa Sommerer during the summer of 2002. This interaction resulted in several publications (Fishwick et al. 2005, Fishwick 2006, Fishwick, 2007b, Fishwick 2008b). Kelly et al. (2009) represents the most recent published workshop in the area. The use of the word "aesthetics" and "programs" can be found in several contexts, including Mohr (2011) and Nake (2009) who were early investigators in the aesthetics of interaction through the use of computer programs as a means of artistic expression. Knuth (2002) developed literate programming and made

note of the importance of aesthetics in programming. Knuth's interest in aesthetics went beyond the purely cognitive, and included artistic forms of typography and layout design for programs. For Knuth, it would seem that computing was an embodied experience.

Aesthetic computing is unusual in that aesthetics are intended to be applied to computing rather than in the inverse direction: using computing to create artistic products. Examples of aesthetic computing, therefore, capture a kind of "boomerang effect" where elements of computer graphics, ubiquitous computing, and mixed reality interfaces can be used to interactively represent that which formed these technologies--namely the information and software.

In terms of academic curricula, Aesthetic Computing has been taught for a decade at the University of Florida in the form of two classes, which are usually combined: CAP 4403 (undergraduate) and CAP 6402 (graduate). The combined classes began as part of the Digital Arts & Sciences (DAS) programs (Fishwick 2010) designed and developed to connect computing with the arts. The class has undergone several stages since 2000:

1. (2000-2005) Representational alternatives to software artifacts -from numbers and expressions, to data structures and programs. There was one physical project, with the other two projects resulting in digital representations. The physical product was exhibited in several gallery areas on and off campus allowing passers-by to comment and explore.
2. (2006-2009) Alternative representations for mass media and communications. This emphasis required students to employ representational creativity but with the idea of starting with a contemporary news story and then mining this issue for the software artifacts in the story that were to be represented. The physical project was eventually dropped since many of the computers science students in the mid to later years had little in the way of design or art backgrounds.
3. (2010-2011) Representation using web mining and APIs. This was an effort to create more automation in the representational process with students finding sources of information and then, mostly using APIs, to translate this information into creative representations. Most students use data as their information but others used more complex web structures (e.g. XML) as sources.
4. (2012) A focus on representation of data structures, mathematical models, and dynamic models and programs. The end product is either an interactive game or video production whose goal is to facilitate education of computing concepts for early-age groups and non-computing specialists. This is the current incarnation of the class (AC Class 2012).

We use the term aesthetics in the spirit of Kelly's definition, but also extend the concept of "critical inquiry" to include the creative aspect of design and art. This is only natural, for engaging in critical inquiry presupposes and requires the creative act. Studies in aesthetics are numerous (Audi 1999, Kivy 2004) often with underlying attempts to find universal attributes of beauty (Scruton 2011). My view on aesthetics is one that focuses on that which is generated as a result of cultural inquiry, which is to say the vast diversity of design and art forms. This "aesthetics as diversity" approach is similar in spirit to Hogarth (Burke 1943) with the associated phrase, "unity in variety."

Toward Software as Embodied Experience

Introduction

Partial justification for the use of embodiment as a form of representation is based on educational learning styles (Dede 2005). Also, our ongoing research indicates a significant correlation between presence and memory in a virtual environment (Fishwick et al. 2010) with results currently in the journal submission phase. Recent mixed reality memory studies such as (Ikei and Ota 2008) indicate positive effects on memory in an augmented environment. Instruments and studies on memory performance within virtual environments are being continually refined and investigated. Parsons and Rizzo (2008) introduce a test of validity for a virtual environment cognitive instrument called VRCPAT. Johnson and Adamo-Villani (2010) note significant effects of immersion on short term spatial memory. Embodied interaction with technology provides us with an understanding of internal logic, software, and process usually through pure experience. For example, we learn the state machine of a DVR through repetitive DVR use. While a large population may require this learning, not everyone may be required to take representation to the next step: from interaction to reflection and reification. The latter steps, however, have potential utility in entertainment (the arts, games) as well as in education.

Audiovisual Explorations: Steampunk Obesity Machine

Let's consider one such artifact, which is defined by a system dynamics model found in systems science and simulation. Figures 2 and 3 are two different representations of a System Dynamics flow graph (Forrester 1991) capturing the temporal nature of human metabolism.

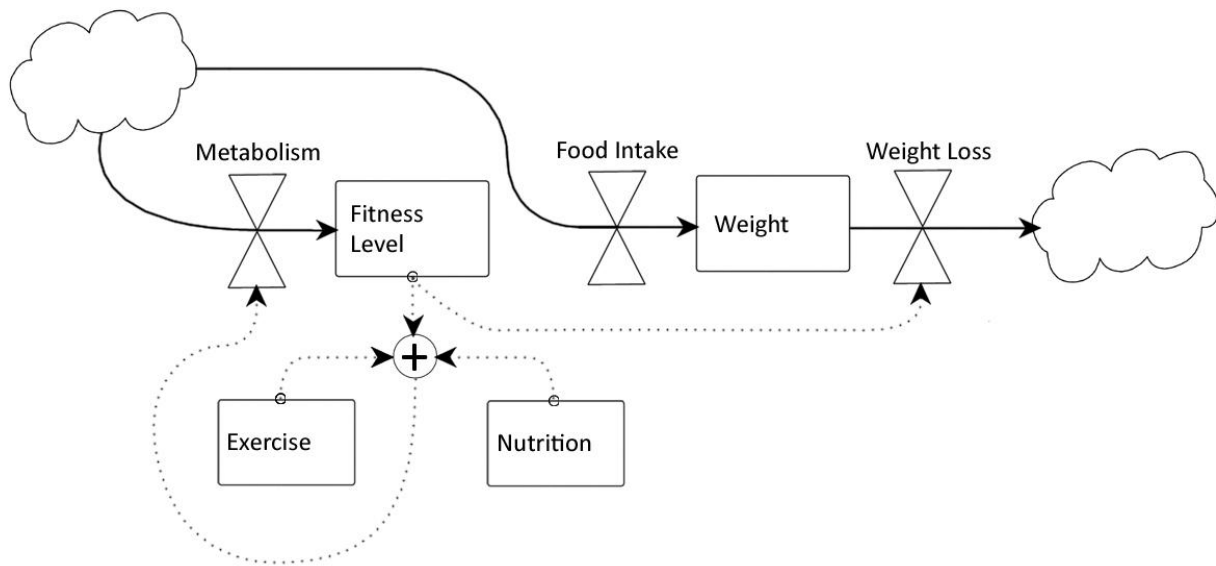


Figure 2: A System Dynamics flow graph with two levels (i.e., stocks) and three rates.
Copyright 2008 Inderscience Publishing, Fishwick (2008b).

The diagram in Figure 2 represents a virtual machine based on the analogy of fluid flow. Fluid starts from source node (left-most "cloud" icon) and proceeds to flow through a system of levels separated by rates to a sink node (right-most cloud icon). More generally, the fluid flow can be construed as a kinetic energy flow since fluid velocity is the dominant flow variable. At the start of the machine, at the left, fluids pours into metabolism and food intake to suggest that the more energy, the higher the *Fitness Level* but also the higher the *Weight*. The rate variable, *Metabolism*, is proportional to a functional combination of Fitness Level, Exercise, and Nutrition. The nature of this precise formula is not present in the model since the model is an abstract representation of the dynamics. The solid curve arrows reflect fluid flow through the system, and the dashed curve arrows reflect control settings to change the rates on the valves. Figure 2 is a hypothetical example, and is not put forth as an accurate or valid simulation model of nutrition but rather to demonstrate that similar diagrammatic models are widely used in science and engineering. These types of models were originally implemented as physical, analog computers although their more frequent existence today is as digital models with a diagrammatic front end authoring capability. The MONIAC, or "Phillips Machine," is one such example (Swade 2000, Ryder 2009) from the analog computing era.

Figure 3 shows the same model which is a synthetic rendition of Figure 2, reified using a "steampunk machine" since its structure is reminiscent of the cyberpunk aesthetic that continues to be popular since its inception in Gibson's work (Cavallaro 2000). Steampunk culture has connotations of "reclaiming tech for the masses" (Grossman 2009). Water is pumped using steam-power underneath the wooden floor. This water shoots out of two brass orifices that represent the two valve-icons in Figure 2. Water filled glass containers represent the level quantities, and wood/brass control rods connect everything together as in Figure 2. The human avatar on the left is demonstrating the machine in action to us or we may become the avatar. The natural question is why anyone might want to construct such a machine when Figure 2 might do. For the answer to this, we have additional questions to ask, with possible use-cases.

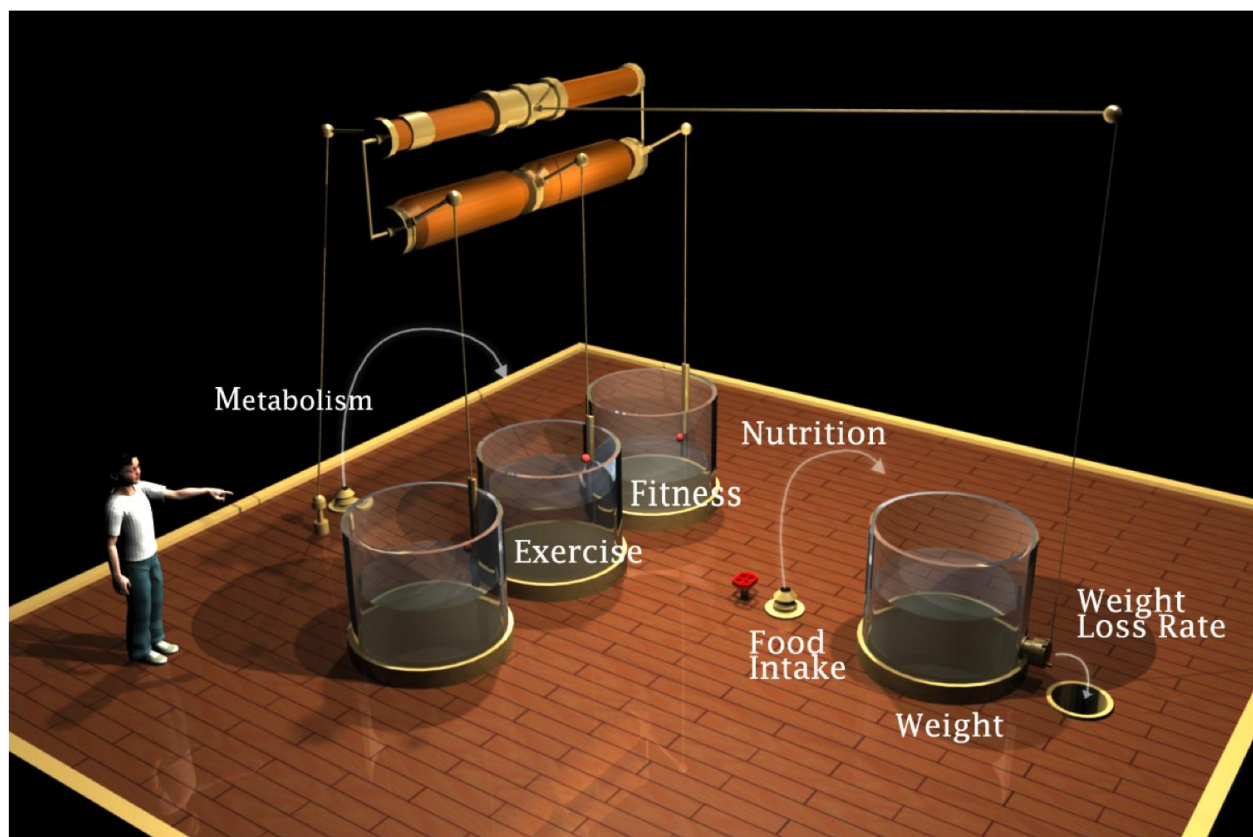


Figure 3: A steampunk obesity machine isomorphic to Figure 2. Copyright 2008 Inderscience Publishing, Fishwick (2008b).

Figure 2, and the equations that map to this diagram, are most often used by scientists familiar with the system dynamics method. It is unlikely that these scientists have any interest in structures such as Figure 3 mainly because they are comfortable and familiar with more formal representations. However, the vast majority of the population may require additional motivation if they are to understand, and be motivated or influenced

by, the more formal representations. Therefore the machine for Figure 3 is appropriate for education and entertainment. It is easy to imagine the machine in Figure 3 being engaging especially with game-like features that required certain goals such as stabilizing the water level in the Weight container.

Visual Representations of Data

There are numerous additional examples of artworks that, if used as guidance, can lead to aesthetic computing products useful for education. The vast majority of examples are the encoding and presentation of data rather than of program or model. This is logical given that data repositories and accessibility are expanding rapidly and that they represent the simplest and easiest to grasp forms of information. Consider the model of a single number shown in Figure 4.



Figure 4: The relative size of the U.S. debt if it reaches 15 trillion dollars. The large rectangular block represents stacks of one hundred dollar bills (Oto Godfrey, <http://usdebt.kleptocracy.us>)

This encoding of number as a stack of one hundred dollar bills is given context by familiar objects whose size is known through pictures or experience (e.g., the Statue of Liberty, a football field, a truck). One might take this same approach to representing other analog representations of monetary amounts through choosing different familiar objects. A participant's engagement can have both artistic and mathematical consequences. For example, we can imagine performing operations on numbers in this

type of representation much as we have done manually in the past with quipus and abaci.

Consider Huff's prime number series (Huff 2006) with two example encodings of prime factors shown in Figure 5.

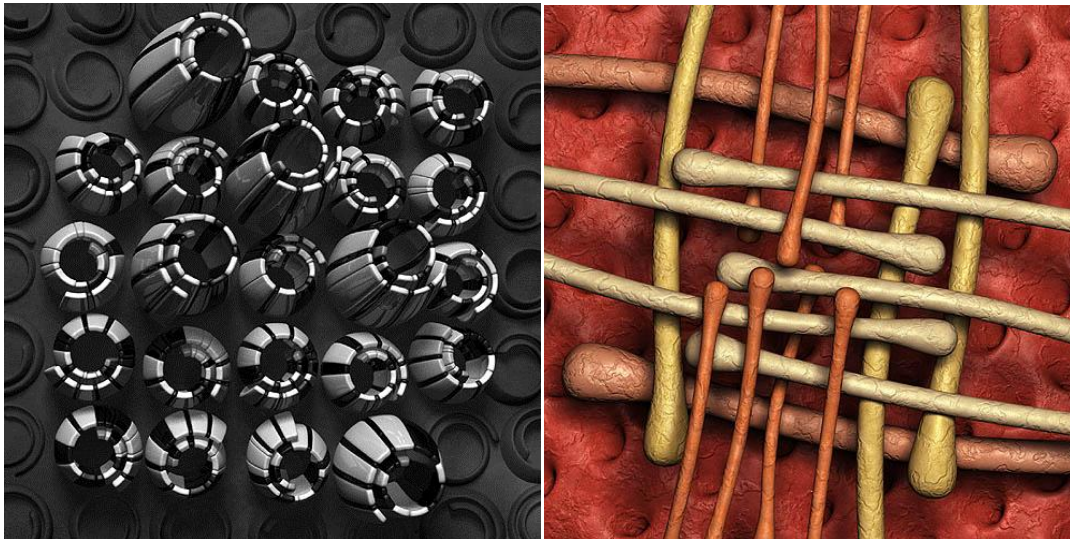


Figure 5: Prime number factorization encodings (EPF: 2003:V:A:997141 and 2000.24),
(Kenneth A. Huff, <http://www.kennethahuff.com>)

The two encodings in Figure 5 are pieces of fine art, but could also be potentially used to motivate students to appreciate prime factorization through puzzle-making. For example, consider where one might provide to someone a visual encoded integer and then ask that person to identify the number and factors. Figure 6 shows two additional examples of information presence: Levin's infoviz graffiti for data, and Living Light. The graffiti is a deliberate mechanism for surfacing numbers of societal relevance in public places. Living Light is a permanent outdoor pavilion in Seoul, South Korea. The pavilion's purpose is to allow spectators to visualize environment levels such as air quality. As pervasive computing extends into the future, most flat surfaces become display surfaces opening up numerous possibilities for bringing information into our daily lives. Figure 7 shows a model of a city which is turned into a computer program-like artifact, or automaton, whose output is a musical score.



Figure 6: Left (Infviz Graffiti/Adjustable Pie-Chart Stencil, Golan Levin), Right (Living Light, David Benjamin and Soo-In Yang)



Figure 7: Pianola City Music (Akko Goldenbeld, <http://akkogoldenbeld.com>).

Textual Representations

The examples so far have been mainly visual; however, it is often desirable to use thinking similar to that described earlier for mathematical expressions, but to extend this to software for example. Emerging areas in the humanities such as software studies (Fuller 2008) and critical code studies (Marino 2006) situate the need for studying formal languages using some dimension of hermeneutics. These areas also provide opportunity for creation of new human-computer interfaces. For example, we may treat software as a full hyper-mediated structure (Roth et al. 1994, Anderson et al. 2000). One can then, through an embodied approach facilitated by link interaction, treated formal language-based constructs as hypermedia.

Art and Design as Creative Influences for Embodied Formal Languages

The provided examples including Figures 3 through 7 are related to aesthetic computing in different ways. Since aesthetic computing is embodied formal languages with an educational goal as a final end product, I will overview how these examples might achieve that goal. Table 1 contains 5 columns: column 1 refers to a previously described image or product; column 2 is the original medium; column 3 is a hypothesized goal for the last 5 rows (i.e., since the original intention is not known but assumed); column 4 is an example repurposing of the original product for a formal language goal (column 5). Let's consider the 3rd row. The product has been designed to a highly compelling and attractive display of the national debt. This creative use can be recast as a new way to learn *number sense*. The formal language products are only examples and have not been constructed by anyone, however, the original art and designs are dually inspirational -- for their original goal or purpose, and for a form that leverages their embodied characteristics for the purpose of formal language instruction.

Table 1: An aesthetic transformation to formal language learning objectives

Example	Original Product	Aesthetic Goal (hypothesized)	Formal Language Product (example)	Formal Language Goal
Personal Experience (Arithmetic)	Typographic Image	To illustrate elegance of the mathematical form	Game with moving operators and operands	To teach laws of arithmetic
Steampunk Obesity Machine (Fig. 2)	Raster Image art work	To create steampunk genre-related imagery	Video illustrating functional mechanism and control	To teach System Dynamics Methodology
US National Debt (Fig. 3)	Raster Image art work	To illustrate the magnitude of the US debt using scale	A tactile set of blocks and objects	To teach number sense
Prime Number Factorization (Fig. 4)	Raster Image art work	To celebrate organic forms using prime number encoding	An adventure game using encodings as 3D puzzles	To teach about prime numbers and factorization
Infoviz Graffiti (Fig. 5a)	Graffiti and Template in	To present societal	An alternate reality game	To teach concept of percentage

	Outdoor location	information to the public	(hunting for graffiti)	
Living Light (Fig. 5b)	Outdoor sculpture	To present environmental information to the public	A kinetic sculpture	To teach data structures
Pianola City Music (Fig. 6)	Indoor kinetic art work	To explore an architecture-music interface	Indoor kinetic object	To teach concept of a data search via sound
Hyper-mediated software engineering	Web-based computational literature	To represent cultural knowledge	Hyper-mediated software/code	To encourage learning of how to code

Table 1 portrays aesthetic computing through repurposing existing art works, but this procedure is optional. Formal language-based products that capture the essence of embodied interaction can be designed directly from initial design, to detailed design, and onto an implementation. The Steampunk Obesity Machine (Table 1, Row 2) is a case in point. Even though a posterboard image (Figure 3) was part of a curated art exhibit (Harn 2011), the image was meant as a preliminary design for a virtual machine to teach System Dynamics concepts. The machine has not yet been constructed.

Embodied Computing using Serious Gaming

The discussion of aesthetic computing and the interpretation of it via embodied formal language would be incomplete without reference to video and console game cultures. Two examples are illustrative: logic circuits in the game Minecraft (2011) and the game called Code Hero (PrimerLabs 2011). Minecraft is a “block game” where players move around a space and build using blocks using a mining metaphor. Some of the procedural capabilities within the game have engaged members of the community to create basic circuits, leading up to full-fledged computers out of the logic circuitry. Since Minecraft is highly interactive, and invokes a sense of presence to boot, this type of hacking is consistent with the concepts in aesthetic computing: players are working together to form circuits through embodied interaction. Primer Labs recently created a game called Code Hero where the play learns a programming scripting language such as Javascript. It is the means for this pedagogy, however, which places it squarely in the embodied realm: a player has a gun that “shoots code” at a target object, thus causing that object to react to the code. This is, in actuality, a reified form of data flow in a manner similar to the capabilities within lambda calculus and languages based on that formalism such

as Lisp (e.g., consider the “map” functions where a function can accept another function as input and then apply that function to arguments, producing output). Figure 8 shows a Minecraft arithmetic logic unit (ALU) described by Ganapati (2010), and Figure 9 shows a snapshot from Code Hero.

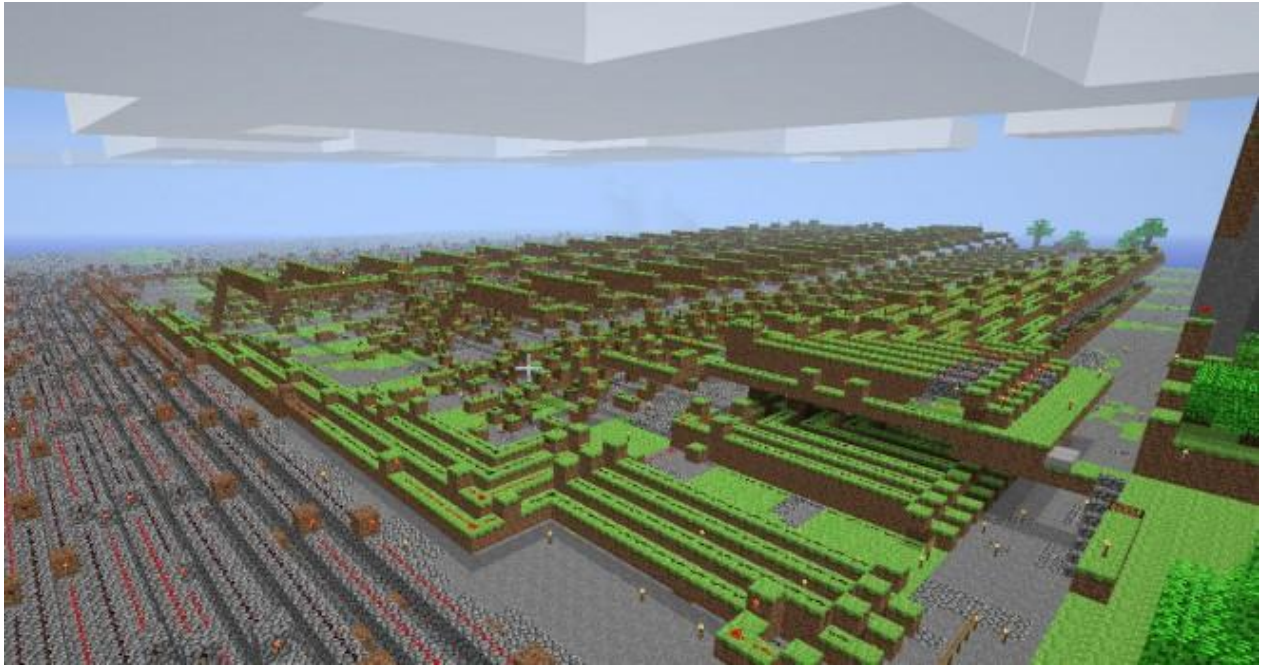


Figure 8: Arithmetic Logic Unit built with “redstone” in an immersive play space using the Minecraft game engine.



Figure 9: The Code Hero Game: talking to the Ada Lovelace avatar prior to entering a space to learn how to script code by shooting scripts at objects.

Collaborative Roles, Usability, and Experience

Aesthetic Computing begins with a formal language construct such as a number, data, model, or software. Then the challenge is to represent this construct through embodiment. We noted that "embodiment" can be as simple as pure reification without representation of existing objects when we demonstrated the ability to grab hold of numbers and move them toward operators. However, reification can also suggest object representation as in Figures 4 through 7. I need to address the "who" and "why" aspects of aesthetic computing.

First, who is going to be creating these representations? In the case of collaboration, I recommend teams of humanist scholars, artists, and computer scientists. Humanist scholars bring to bear different philosophies and theories which can help shape the resulting representation. The artist has the creative perspective and tools to create the representation, and the computer scientist can serve two roles: to help construct tools used by the humanist and artist in the extraction of information and in enabling the

interaction that ensues through externalizing embodiment in the human-computer interface.

Second, who is going to use the representations? Students in my aesthetic computing class are often initially confused why one would construct anything but diagrams. This confusion is expected but we must be careful when defining usability: usable for whom and for what purpose? We need to identify 1) the goal of the representation, and 2) the end target users. Goals for the embodied representations are education, arts and entertainment (e.g., cinema, visual and performing arts, fiction). Target users may be any grade level in school or some segment of the general public. From a psychological perspective, a broad view of "usability" can encompass user goals including: increased valence, motivation, and attitudinal change, as well as improved short or long term memory. Mathematicians and computer scientists are not the target, as these populations are adept at using existing notations. Aesthetic Computing is less stressed on information extraction, and more on the use of entertainment, arts, and humanities on formal languages with the largest practical effects being in education. Thus the target users are formal and informal learners of all elements of formal language-based instruction (e.g., mathematics, computer science).

The roles of participants in aesthetic computing will likely be different given the interests of each party. For the computer scientist, for example, Figure 5 serves as a design template for the creation of special effects and interactive games for the purpose of expressing elements of prime numbers and the factorization process into these numbers. The artist's work is a medium through which this aspect of formal language is creatively expressed. The goals of the artist and computer scientist are clearly different, but the means (i.e., representations of prime numbers) are common. This difference in ends, with similar means, plays out in the other examples. For instance, Perl poetry (i.e., poetry created using the programming language, Perl) may be an aesthetic product to the writer--a valid end in itself. To the computer scientist, this product represents a medium in which to express a different end--the formal language "message." Therefore, aesthetic computing by its arrangement of words comprising this phrase, is focused on computing--the learning of formal languages. However, aesthetic products play a key role in this learning activity and allow for the artist, scholar, and computer scientist to collaborate with different intentions and goals.

Other areas related to aesthetic computing are information visualization (Card et al. 1999, Ward et al. 2010), and software visualization (Eades and Zhang 1996, Stasko et al. 1998, Zhang 2007, Diehl 2010); however, the goals of these areas are generally quite different than for aesthetic computing. In information visualization, the goal is efficient

communication of data and information, whereas for aesthetic computing, the goal is education through highly embodied, and interactive, aesthetic products in the forms of art and entertainment. As such, Aesthetic Computing fosters a deeper experience than building representations meant for immediate consumption (e.g., newspaper diagrams and maps). Readers will observe that the use of metaphor is rich within the high level interactions with computers. We are an interface culture (Johnson 1997). However, the metaphors used on the "desktop" for instance, have not yet made their way into the core of mathematics and computing. Efforts such as computational thinking (Wing 2006) are a move in the right direction.

Laurel (1998) presciently captures a prerequisite for aesthetic computing in her "Computing as Theatre." However, Laurel was mainly constructing a case for human-computer interaction as a complex theatrical production, involving many of the same elements found in theatre. The *use* of computing, and its associated interaction phenomena, are like theatre. However, what we find is that as we break open the lid of the black box containing the atomic elements of normally hidden data, formulas, code, and models is that computing is theatre all the way down.

Toward a Method of Aesthetic Computing

While it is interesting to pose ideas and directions, a procedural method is something that can help to forge a discipline even if only as a general guide. Fishwick (2007b) was an initial attempt at this process with a small example of code that was represented as a collection of rooms in a building, complete with a partial narrative for context. Figure 10 serves as a basis for describing the approach used in (AC 2012):

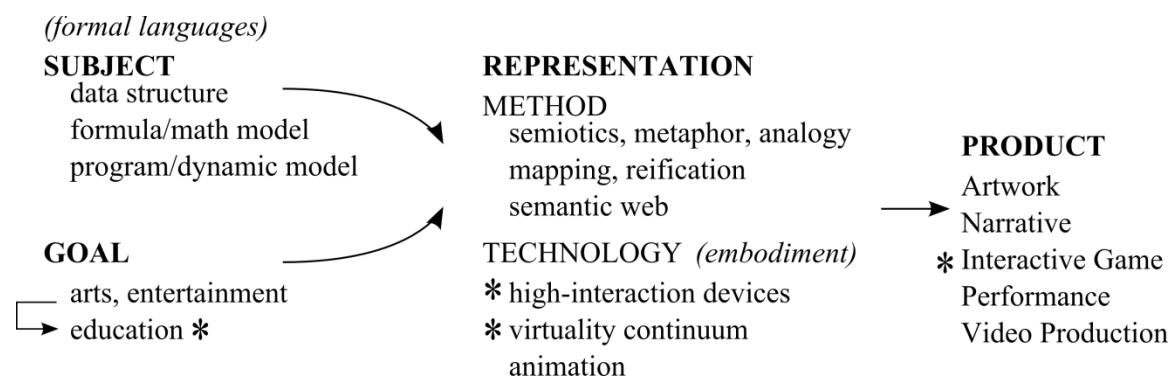


Figure 10: Aesthetic Computing Method

We begin (in the top left of Figure 10) with a formal language construct that is to be conveyed to non-specialists in mathematics and computing with the goal of broadening the exposure of computing concepts. The asterisks denote current emphases in (AC

2012). Target users will depend on the type of formal language. If the goal is number sense, and the numbers are fairly simple, we may be looking at elementary school children. If the formal language are simple algebraic formulas, perhaps 8th grade mathematics. More complex mathematical and computing structures may require higher grades, including universities and in postgraduate, informal learning contexts. One of the desirable outcomes of this approach to representation, though, is to expose very young children to seemingly complex data structures and programs by using games and video as motivational media. I expect that the approaches may serve as 1) scaffolding for later, more traditional, instruction and notations, and 2) secondary devices (e.g., puzzles) to reemphasize concepts that some learners find difficult using standard notations. The goal is not to eliminate standard notations as this would be counterproductive. Representation is divided, in Figure 10, into two components: methods that achieve representation and technologies that support embodiment. End products that emphasize, or surface, embodiment can vary. A good piece of fiction can create a strong sense of presence and virtual embodiment whereas a weak interactive game may be left ignored if not well designed.

New Connections

A primary goal of mine in fostering aesthetic computing is to link disciplines -- especially those in computing to the humanities and arts. As evidenced by designers and humanist scholars, artifacts such as "code" and "data" are now being interpreted and recreated. There are many reasons for this. Perhaps, the ubiquitous computing trend is the most significant driver--software is everywhere and so, by natural extension, cultural. I welcome the artists, designers, and humanists into the "formal languages" space and hope that through collaborations and interdisciplinary discussions and critique that we might re-humanize core elements of computing, and perhaps even mathematics.

Disciplinary and Technical Challenges

The area of aesthetic computing is not without its challenges. The goal is to leverage embodiment theories toward building new computer-based interfaces for learning formal languages. Disciplines that I have covered have sub-areas that are all targeted toward this goal, but significant challenges remain for each area:

- *Mathematics*: the literature in mathematics education, and in the application of cognitive linguistics within mathematics learning, is well-founded and supports aesthetic computing. This body of knowledge, however, is more focused on analysis and theory construction rather than, through analogy, building new interfaces in mathematics education to take full advantage of the embodiment

theories through realization. Some efforts in *virtual manipulatives* are a good start but this work should expand to employ the next generation of interface capabilities that stress embodiment (e.g., multi-touch displays, body tracking, mixed/virtual reality technology).

- *Computing*: the literature in computing education provides fairly easy-to-use interfaces for seeing the results of executing programs; however, the programs are often limited to the canonical alphanumeric notation with all of the human interaction being in the program execution rather than inside the program. Efforts at software visualization move in the direction required by aesthetic computing, and yet, there is a much wider set of possibilities for representation if the goal is to teach non-specialists especially through immersion, situated learning, and interactive games. Diagrams are fine for communication but if the goal is to explore deeply embodied approaches for learning, additional media and newer interfaces--as recommended for mathematics education--should be more thoroughly investigated.
- *Humanities*: the work in cognitive linguistics, and resulting embodiment theories, ground the work in aesthetic computing but as with the work in the philosophy of mathematics learning, there is little corresponding effort in realizing these theories in a human-computer interface. Conversely, the work in cultural theory production is recently targeting "code" specifically as a new type of literacy (e.g., critical code studies). And yet, this production tends to avoid linguistic analysis and instead focuses on socio-historical analysis. New, embodied, interfaces for code can build off of the scholarly analysis but these interfaces should also be informed by key facts of semiotics (e.g., analogy and metaphor) which lay at the foundation of formal languages. There appears to be a bias toward textual notation rather than exploring broader forms of "embodied literacy," which would include textual notation as one dimension.
- *Art & Design*: works of art have traditionally treated formal languages as "black boxes," tools needed to create art or designs. Unlike in the humanities, where code has become subject material, in art, code tends to be treated purely as a tool, whether embedded in package or programmed via a text-based development environment. The only exception to this observation would be in typography within graphic design, where the subject material is the text. More explorations are required so that formal languages become the active subjects of artwork.

Each one of these four areas has some common challenges. Observing that analogy is the engine of metaphor in scientific practice, aesthetic computing products can be

created with an increased attention to analogy. Another observation is that with the exception of Art & Design, there is a classical focus on alphabetic notation. Such notation serves us well and has enriched our formal languages. However, there are other types of notations that exercise more of the body's sensorimotor functions. Diagrams are a good place to start in seeing this transition since with diagrams spatial metaphors for text-based notations abound, but we should not limit our embodied explorations to diagrams.

A primary aesthetic computing challenge is technological. It is still relatively expensive to build new interfaces based on the types of products described by the figures previously shown. "3D modeling" as a real-time technical interface capability is nowhere near the futuristic landscapes of Tron, the Matrix, and the Holodeck. Modeling and animating in three dimensions remains a major challenge compared with diagrammatic approaches, and even diagram-based software modeling (e.g., model-driven architecture) struggles for acceptance in the marketplace of software engineering solutions because of the relative ease of using textual symbols. Human-computer interaction solutions are expanding in scope and capability, but we still are a long way from being able to easily and inexpensively become embodied in our formal language constructs.

Summary: The Argument for Embodied Formal Language

This essay began with personal experiences in mathematics and then moved on to discussions of embodied cognition, along with some examples of where aesthetic computing could be applied. The area of aesthetic computing rests primarily on the foundation of embodiment--whether we believe that our bodily interactions form our thought. This assumption of embodiment runs deep in philosophy. We all recognize that we have body and mind, and most would agree that the latter is the effect of the former. It is only fairly recently, though, that literature has arisen to indicate a strong relationship to the extent that thought itself, even for abstract objects, is embodied. The theory that undergirds embodiment is compelling, but we have the nagging question about how this theory can change what we do and how we act. If I imagine that I am imagining grabbing and pushing a number through a pseudo-biological membrane during arithmetical operations, I want to build a human-computer interface that reinforces this mental sequence by infusing theory into practice. This perceived need matches the aesthetic computing hypothesis stated at the start of the manuscript: *Given the embodied nature of cognition, we should realize this embodiment through novel human-computer interfaces for learning formal languages.*

Achieving this realization involves a more thorough understanding of the interplay among disciplines and how embodiment theories in those disciplines interact and connect. The realization also requires a host of newer “virtuality continuum” technologies that allow us to achieve what Biocca refers to as degrees of progressive embodiment (Biocca 1997). The technologies and their characteristics are overviewed for virtual reality by Sherman and Craig (2002), and by Bowman et al. (2004), and for augmented reality by Bimber and Raskar (2005).

Where to Learn More about Aesthetic Computing

For a thorough understanding of computing as a discipline, and its artifacts which are represented in aesthetic computing, the 1998 ACM Computing Classification System (CCS 1998) serves as a good starting point. Even though my treatment of aesthetics is based on its original, perceptual, definition, Kelly (1998) collects that which erupted from this kernel in philosophy and the arts in four volumes. Even though information visualization is centered on efficient communication (e.g., reading the equivalent of a diagram in a newspaper), some archives such as *infoesthetics* curated by Vande Moere (2011) are broader and contain a wide variety of potential use cases—from efficient communication to experience, education, and play. For text-based representations, HASTAC (2011) serves as a high level repository of bloggers and projects, many of which are associated with *digital humanities*. The reader is encouraged to review articles cited in this chapter.

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