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# Dynamic Design: Cognitive Processes in Design Sketching

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## 1. Introduction

In the 1956 film *Le Mystère Picasso* (*The Mystery of Picasso*), Pablo Picasso completes twelve paintings. Due to specific camera angles and special transparent paper, the viewer only sees the appearance of marks; she only hears the hush of brush strokes, the mutters of the artist, and the brief interludes of instrumental music. After the film's taping, the twelve paintings are destroyed.

Picasso's process, or the processes of any great master, is so rarely exposed that the viewer becomes acutely aware of the thoughts that must occur during the creation of his piece. The final product therefore acquires much more meaning. Not only does the work exist as a completed piece, but also it exists as a series of additions and subtractions, decisions and changes-of-mind, continuations and reversals. The artist's choices are mysterious. The viewer cannot help but wonder why the master knew to put that stroke in that particular place, with that specific color, at that chosen time.

The cognitive processes in design thinking are complex. It is exciting and important to learn about these cognitive actions; great works of creativity have not only caused great awe and amazement in human civilization, but more simply hold the secret to how we see, move through, create, and relate to our visual, spatial, and temporal world.

Because of the complexity of processes in design cognition, it is necessary first to delineate the categories of cognitive action, and second to create a general taxonomy by which they can be classified. These tasks become even more challenging considering that a large part of design cognition is visual, not verbal. Though a designer can explicitly learn basic skills through either verbal instruction or physical practice, novel design creations may come from an implicit reorganization or "riffing" off of prior verbal or spatial learning. It can be difficult for even the most advanced designers to explain their thought process behind each decision (Suwa, Purcell, and Gero 1998). It is the quiet mystery of the creative process that presents both the challenge and also the interest in decoding design thinking.

Sketching, either with traditional materials or with computer aided design programs, offers a window into the cognitive process of design. Sketches serve not only as a record of an idea, but also as a hotbed of visual cues from which new ideas can be generated (Schon 1983). Designers are thus thought to have a dynamic relationship with their sketches, where each physical/perceived aspect suggests a move or alteration for the next sketch. Further, a mark's function and meaning can both initiate a design move, and also adapt in response to an already established design move (Goldschmidt 1994).

Two overlying principles define the dynamic process of design. *Emergence*, or *unexpected discovery* refers to the creation of unanticipated, new ideas in response to visual cues from an existing sketch. *Reinterpretation* refers to the transformation and adaptation of previous ideas, already expressed in the original sketch (Menezes and Lawson 2006). These two principals are based on cognitive actions of different categories, that is, they are responses to different *kinds*[1] of visual cues in the sketch. The relationship among these different types of cognitive actions, and their persistence through the duration of the sketch, can be mapped to form a holistic description of the design process.

In the first section of the paper, I will outline the schema of design cognition presented by Suwa, Purcell, and Gero 1998. In response, I will present possible limitations to their model, which I find makes it ultimately insufficient for explaining both top-down and also bottom-up influences on design decisions. In conducting my analysis, I will appeal to research comparing traditional versus digital design methods. Finally, I will evaluate the effectiveness of some current digital design programs to complement the cognitive design processes outlined in my research.

## 2. A Schema for Cognitive Action in Design

I have already made one important distinction between *emergence* and *reinterpretation* in dynamic manipulation of ideas in sketching. Though important, this distinction is rather superficial considering the numerous and varied cognitive actions that contribute to the generation or refinement of an idea.

Several attempts have been made to devise a more informative, general taxonomy for design analysis. One approach divides design into *process* and *content*. Process includes problem solving, planning, determining goals, and strategizing. Content refers to what designers see, think about, and depict (Dorst and Dijkhuis 1995).

Another approach attempts to address the difference between *visual* and *non-visual* information in designs. The visual elements are the "what" and "where" qualities of each mark, and the relationships of these qualities to one another. Non-visual elements are the knowledge about and the functionality of the design (Suwa and Tversky 1996). The advantage of a visual/non-visual distinction is that it not only explores different types of elements in a sketch, but also examines possible dependencies among them. For example, an architect recognizes that the shape and size of one of the depicted features (a visual element) in a sketch would create a functional response in the movement of crowds through the space (a non-visual element). Though this form/function connection may seem simple, the addition of even more types or *kinds* of classifications, and a webbing of these classifications, permits an intricate map of cognitive actions in design (Suwa, Purcell, and Gero 1998).

[1] *Kinds* of visual cues will be detailed and explained later in the paper.

Suwa, Purcell, and Gero 1998 provide multifarious and specific categories for the cognitive processes of design thinking. With these classifications, they are able to both elucidate the relationships among them, and also delineate the origin of emergent and reinterpretive ideas in sketching. The coding scheme is based on four central practices: first, the distinction between visual and non-visual elements (an extension of what was presented above), second, the level of information processing required for each cognitive action, third, a theory of cognitive actions employed in environmental assessment[2], and fourth, their intense video and audio observation of working designers, specifically, architects (Suwa, Purcell, and Gero 1998).

*Segmentation* is the process by which each design move is identified as an individual action. Demarcating individual actions permits a further dimension of analysis, time, which can expand on the dependencies and relationships among different kinds of cognitive actions.

Suwa, Purcell, and Gero 1998 have defined four categories, or *kinds* of cognitive actions: *physical*, *perceptual*, *functional*, and *conceptual*. These categories reflect not only what is visual versus what is non-visual, but also what they hypothesize to be a hierarchy in information processing. They assume that information entering the human cognitive apparatus is first appreciated by the material senses (*physically*), then *perceptually* (visually), then semantically (*functionally* and *conceptually*, i.e. non-visually). The hope is not only that these different categories of design processes occur in a hierarchical order, but also that the higher-level actions are dependent on the lower level actions.[3] That way, the schema is designed to code both the actions themselves, and also the relationships among them (Suwa, Purcell, and Gero 1998).

The lowest-level cognitive actions are *physical*. These actions include marking, writing, or depicting, motioning with a hand or pencil, and looking at existing depictions. The *perceptual* category refers to the visuo-spatial cues outlined in the sketches: shape, size, and texture, spacial elements among parts: proximity, intersection, and arrangement, and composition of elements: grouping and uniformity. *Functional* considerations refer to a non-visual conception of information stemming from the depicted visuo-spatial information. Functional elements include first the behavioral effect of the depicted elements on people and the natural surrounding, and second the psychological and psychophysical effect of the depicted elements on the people who move through the outlined space (Suwa, Purcell, and Gero 1998). The idea of functional kinds originated from previous research in environmental assessment, and its affect on human psychology (Gero and Sudweeks 1994; Altman and Wohlwill 1983; Garling and Evans 199; Suwa and Tversky 1997). In designing a successful space, functional elements cannot be ignored or underappreciated.

Finally, *conceptual* elements refer not to visual or spatial elements, but rather to the designers' aesthetic preference, or subjective evaluation of success or failure of a certain design move. Often conceptual elements occur in response to a collection of different elements of the previous categories. However, conceptual action also refers to the initial goals of the design. Finally, conceptual elements reflect the designer's ability to discover

[2] A more detailed description of "environmental assessment" will follow.

[3] Though these assumptions are necessary for the Suwa et. al. schema, I will later describe how they limit the scope and applicability of this model.

new information from existing information, and to break down existing information or goals into sub goals (Suwa, Purcell, and Gero 1998). **Table 1** outlines the four different categories of cognitive actions, and describes their defining qualities.

**Table 1 Action categories**

| *Category* | *Names* | *Description* | *Examples* |
|---|---|---|---|
| Physical | D-action | Make depictions | Lines, circles, arrows, words |
| | L-action | Look at previous depictions | – |
| | M-action | Other physical actions | Move a pen, move elements, gesture |
| Perceptual | P-action | Attend to visual features of elements | Shapes, sizes, textures |
| | | Attend to spatial relations among elements | Proximity, alignment, intersection |
| | | Organise or compare elements | Grouping, similarity, contrast |
| Functional | F-action | Explore the issues of interactions between artefacts and people/nature | Functions, circulation of people, views, lighting conditions |
| | | Consider psychological reactions of people | Fascination, motivation, cheerfulness |
| Conceptual | E-action | Make preferential and aesthetic evaluations | Like-dislike, good-bad, beautiful-ugly |
| | G-action | Set up goals | – |
| | K-action | Retrieve knowledge | – |

(Suwa, Purcell, and Gero 1998)

The second aspect of this schema that requires a detailed description is the relationship between these four descriptive categories and their persistence through the duration of the sketch. *Longevity* refers to the creation and sustainment of an idea within the framework of emergence and reinterpretation principles. The step in the design process during which the idea is first discovered, or during which it is revisited, determines its temporal status. The longevity category, or *index,* is classified as *new, continual*, or *revisited*. If a designer performs an action in one of the four cognitive categories for the first time, then this action is classified as *new*. If a cognitive action is continued from the segment immediately preceding the current segment, this action is classified as *continual*. Finally, if the designer returns to an idea generated in a previous, but not contiguous segment, then this action is considered *revisited* (Suwa, Purcell, and Gero 1998). **Table 2**, **Table 3**, and **Table 4** outline the previously described categories with the added index variable.

**Table 2 The list of the definitions of design actions which belong to 'physical' level**

| *Action ID* | *Definition* | | | *Name/description* |
|---|---|---|---|---|
| | *Category* | *Index* | *Dependent on* | |
| $D_{rf}$ | D-action | n | c or r L-action | Revise the shape, size or texture of a depiction |
| $D_{c}$ | D-action | n | Nil | Create a new depiction |
| $D_{ts}$ | D-action | r or c | Nil | Trace over a depiction on the same sheet of paper |
| $D_{td}$ | D-action | r or c | c or r L-action | Trace over a depiction on a new sheet of paper |
| $D_{sy}$ | D-action | n | n, c or r P-action | Depict a symbol that represents a relation |
| $D_{wo}$ | D-action | n | n, c or r (F- or P-) action | Write sentences or words that express ideas |
| L | L-action | r or c | Nil | Look at a previous depiction |
| $M_{rf}$ | M-action | n | n, c or r P-action | Move a pencil, attending to relations or features |
| $M_{od}$ | M-action | n | c or r L-action | Move a pencil over a previous depiction |
| $M_{a}$ | M-action | n, c or r | c or r L-action | Move a depiction against the sheet beneath |
| $M_{ut}$ | Impossible to define by our coding scheme | | | Use tools |
| $M_{ge}$ | Impossible to define by our coding scheme | | | Hand gestures |

(Suwa, Purcell, and Gero 1998)

**Table 3 The list of the definitions of design actions which belong to 'perceptual' level**

| *Action ID* | *Definition* | | | *Name/description* |
|---|---|---|---|---|
| | *Category* | *Index* | *Dependent on* | |
| $P_{sg}$ | P-action | n | Nil | Discover a space as ground |
| $P_{fn}$ | P-action | n | n D-action | Attend to the feature of a new depiction |
| $P_{fnp}$ | P-action | n | n P-action | Attend to the feature of a new relation or $P_{sg}$ |
| $P_{fp}$ | P-action | n | c or r (L-,D- or P-) action | Discover a new feature of an existing depiction, of $P_{csg}$ or of $P_{rsg}$ |
| $P_{rp}$ | P-action | n | Two c or r (L-, D- or P-) action | Discover a spatial or organizational relation |
| $P_{rnp}$ | P-action | n | n (D- or P-) action and c or r (L-, D- or P-) actions | Create or attend to a new relation between a new depiction and an existing one |
| $P_{rn}$ | P-action | n | Two n (D- or P-) actions | Create or attend to a new relation between two new depictions or $P_{sg}$ |
| $P_{cf}$ | P-action | c | c (L-, D- or P-) action | Continually attend to a feature |
| $P_{cr}$ | P-action | c | Two c (L-, D- or P-) actions | Continually attend to a relation |
| $P_{csg}$ | P-action | c | Nil | Continually attend to a space as ground |
| $P_{rf}$ | P-action | r | c or r (L-, D- or P-) action | Remember a feature of a depiction |
| $P_{rr}$ | P-action | r | Two c or r (L-, D- or P-) actions | Remember a spatial or organizational relation |
| $P_{rsg}$ | P-action | r | Nil | Remember a space as ground |
| $P_{ipsr}$ | P-action | r | n (D- or P-) action and c or r (L-, D- or P-) action | Implement a previously mentioned relation by giving new depictions or features |

n, c and r denote 'new', 'continual' and 'revisited' respectively.

(Suwa, Purcell, and Gero 1998)

**Table 4 The list of the definitions of design actions which belong to 'functional' level**

| *Action ID* | *Definition* | | | *Name/description* |
|---|---|---|---|---|
| | *Category* | *Index* | *Dependent on* | |
| $F_{np}$ | F-action | n | Nil | Think of a function independently of depictions |
| $F_{n}$ | F-action | n | n (P-, D- or L-) action | Associate a new depiction, feature or relation with a new function |
| $F_{re\text{-}i}$ | F-action | n | c or r (L-, D- or P-) action | Re-interpretation |
| $F_{cp}$ | F-action | c | Nil | Continually think of a function independently of depictions |
| $F_{c}$ | F-action | c | c (L-, D- or P-) action | Continually think of a function |
| $F_{r}$ | F-action | r | c or r (L-, D- or P-) action | Remember a function |
| $F_{rp}$ | F-action | r | Nil | Remember a function independently of depictions |
| $F_{i}$ | F-action | c or r | n (P-, D- or L-) action | Implement a previously explored function by creating a new depiction, feature or relation |

n, c and r denote 'new', 'continual' and 'revisited' respectively

(Suwa, Purcell, and Gero 1998)

## 3. Pros and Cons of the Suwa, Purcell, and Gero 1998 Schema

The first advantage of the Suwa et. al. system is that it successfully creates a generalized vocabulary by which to define primary, singular design actions. The generalized vocabulary allows for a structured, hierarchical diagram of design thinking, which informs three important questions: which primitive design actions play an integral role in design thinking, how do they play this role, and what is the origin of generated ideas (Suwa, Purcell, and Gero 1998)? Examining the relationships among the elements in the diagrams, their dependencies, their hierarchies, and their feedback is not only important for understanding the complex cognitive functions of design, but also is important for the possibility of extending their influence to other cognitive processes.

Though the coding system proposed by Suwa, Purcell, and Gero 1998 has definite analytical applicability, it also has some problems. Their method bases the four-category breakdown on supposed information processing demands (Suwa, Purcell, and Gero 1998). Not only can these information processing demands be uncertain, but also their connection to higher and lower cognitive "levels" is unreliable and undefined. A one-to-one correspondence between information processing levels may be too simple, especially considering the possibility that feedback between categories can happen implicitly, before the cognitive action is expressed (Hawkins 2004). Though this method strives to create an informative webbing of the connections among four levels of cognitive action, it fails to address the possibility that implicit feedback, especially from higher-order, goal-directed areas of the brain, might alter the explicitly expressed chain downwards.

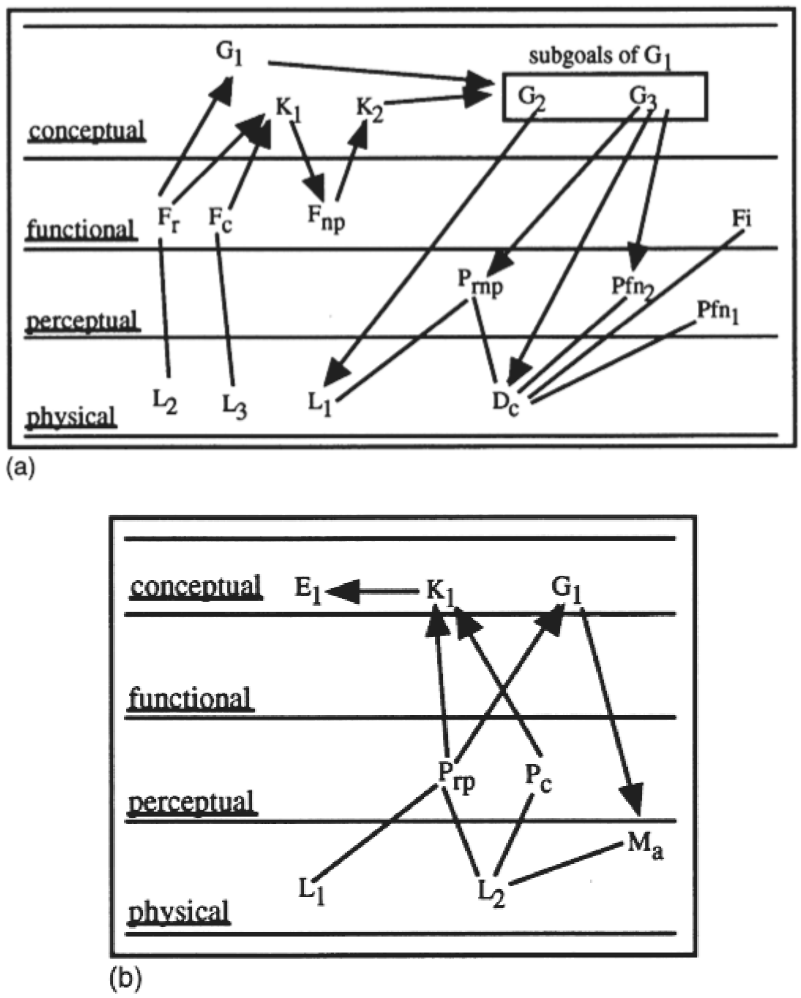
Despite their under-emphasis on feedback from higher-level design cognition, the Suwa, Purcell, and Gero 1998 method does purport to show some validity directly within their classification system. That is, though their theory cannot be globally applicable to design thinking because of their failure to outline both directions of influence, the Suwa, Purcell, and Gero model offers some important information about the cognitive actions that *are* outlined in the schema. Their schema is robust enough to ask: do particular kinds of cognitive acts dominate in the design process, and do actions in a certain cognitive level tend to correlate with actions belonging to another level (Suwa, Purcell, and Gero 1998)? This second question especially, could expose where some of these implicit feedback connections would occur if they somehow became measurable.

Though Suwa, Purcell, and Gero do admit that their schema requires a mostly bottom-up interpretation of the cognitive actions in design, they offer no implications of this limitation to the applicability of their model. Consider for example that an architect draws an arc in her sketch. The cognitive arrow could go one of two ways: (i) the arc was drawn for no specific reason and with no explicit goal in mind. After drawing it, the architect decided that this shape would allow for a proper view and flow for its visitors through the depicted space. Or, (ii) the architect had in mind the goal of both creating a pleasant view and also allowing reasonable room for crowds. Some previous knowledge about arcs in space informed her drawing an arc into the design (Suwa, Purcell, and Gero 1998). Because a simple verbal or observational evaluation from a designer or sketch may not resolve the direction of thought processes in creating this arc, Suwa, Purcell, and Gero 1998 have decided to focus on the bottom-up method, or the (i) analysis, where physical and then perceptual phenomena inform higher cognitive function . Though this restriction makes sense within the structure of their code, and the code's focus on information processing as a measure of cognitive demand, it similarly ignores a top-down, or feedback hypothesis, which is undeniably present in educated design scenarios.

Again, if one adopts this bottom-up schema however, Suwa, Purcell, and Gero 1998 are able to determine some important connections and dependencies among their categories. First, if one recalls, the different categories become associated with a timeline over which the design is created and refined (*segmentation*). The first temporal phase of the design process involves problem analysis, the second consists of spatial arrangement, and the third requires functional exploration. Each of these phases is established by the frequency of certain categories of cognitive design action. Functional actions cluster in the functional exploration stage, and physical actions dominate the problem analysis phase (Suwa, Purcell, and Gero 1998).

Suwa, Purcell, and Gero 1998 also examine how the usage frequency of these four cognitive categories varies with reference to one another. One finding is that when drawing is frequent (*physical*), then looking at existing drawings (*perceptual*) becomes less frequent and vice versa. They also found that the visuo-spatial material perceptible in sketches act as cues for functional associations (Suwa, Purcell, and Gero 1998). See **Figure 1a** and **Figure 1b** for an example of these complete coding webs, which do include some top-down processes.

**Figure 1**




(Suwa, Purcell, and Gero 1998)

This last point, that visuo-spatial cues in sketching can elicit functional ideas and interpretations, is evidence for the idea of dynamic design. To recapitulate from above, the hypothesis behind a dynamic design processes states that information in sketches act both as a recording for ideas, and also as a treasure trove of visual cues that effect new goals, conceptions, and directions for future iterations of sketch. Therefore, both initial goals and knowledge drive a designer in a top-down fashion, and also perceptual features of the drawing itself, and the physical drawing process, contribute in a bottom-up fashion to the development of a design. Suwa, Purcell, and Gero 1998 summarize their conclusions about the role of sketches in design cognition: "sketches serve as a physical setting in which design thoughts are constructed on the fly in a situated way (Suwa, Purcell, and Gero 1998)."

## 4. Differences in Design Cognition for Traditional versus Computer Aided Design

Examination of the cognitive actions of design sketching has shown that sketches are an important setting for the creative process. Designers like architects for example, have many materials available with which to make or aid in sketching. The abundance of computer aided design (CAD) programs has lured some designers away from traditional materials; it is becoming increasingly necessary that all designers have some familiarity with digital design tools. Though both traditional materials and CAD are valid methods for creating visual sketches, many designers find themselves feeling more comfortable, preferring, and advancing their skill-set in only one. The questions surface: which tool encourages the kinds of cognitive actions during sketching that allow for the most creativity and development in the sketch/design process, and how might these tools be improved or combined to maximize the design process?

A paper by Bilda and Demirkan 2002 examines these two questions using a coding scheme very similar to the one outlined above. Their results show that traditional media have advantages over digital media regarding attention to, and reaction to visuo-spatial cues, specifically the relationship between elements in the design, and the quantity and variety in problem solving methods to address the design goals. CAD tools do offer the unique capability of modifying parts within a sketch without having to make an entirely new iteration. CAD also more seamlessly supports the development of the conceptual phase of the design process (Bilda and Demirkan 2002), as technical drawing skills are less of an obstacle when drawing aids are provided by the software.

The Bilda and Demirkan 2002 paper evaluates the number and kinds of cognitive action in each of three testing stages. One group undertakes a design challenge through traditional, then digital, then traditional methods (HAND-CAD-HAND), and the other group approaches the design problem CAD-HAND-CAD. Evaluating the segmentation and types of cognitive action in each of these phases yields the results summarized above. In addition, the research shows some evidence about sketching media in general that may in itself effect the differences in cognitive action. For example, whereas traditional media promotes the physical description of form in the sketch, digital media promotes its conception in the mind (Marx 2000). The detailed, intense, and rapid visualization of forms in digital media encourages more imagination of form rather than physical depiction of form; therefore, the next iteration/alteration more likely occurs in the designer's head rather than on paper (Won 2001). This internal cognitive manipulation offers an explanation for the greater number of cognitive actions *observed* in the traditional media verses the digital media[4].

There are several other notable aspects of digital design programs that may prove significant in their contribution to the overall design process. Because CAD encourages rich visual imagery, digital design tools are more time consuming; designers become bogged

[4] Once again, this schema tests *explicit* cognitive action. If the digital media encourages more implicit actions, then fewer recorded actions may not be due to fewer cognitive actions in digital sketching en masse, but rather fewer that are sensitive to this particular evaluative tool.

down by the details of the visual stimuli in the sketch. However, when designers actively sketch in CAD, they rarely use these details as visual cues from which to exercise their conversation with the sketch (Bilda and Demirkan 2002). CAD software is also non-responsive to many physical acts of design, including arm movements, gestures, doodling, and physically copying. Copying proves a particularly important act in sketching because it usually precedes a reinterpretive process (Bilda and Demirkan 2002).

One important design action that is highly prevalent in the use of digital media is the modification of existing forms (Bilda and Demirkan 2002). Instead of physical actions of copying and gesticulating, the digital environment offers the ease of slight modification and movement of forms.

One must consider the advantages and disadvantages of each method when attempting to combine them to maximize design processes. Suwa, Purcell, and Gero 1998 and also Bilda and Demirkan 2002 highlight the abundance and importance of physical action in the beginning stages of the design process. Here, the weight of the pencil, the physical act of copying, and the outline of a rough relationship among forms is most important. Appealing to the bottom-up design process outlined by Suwa, Purcell, and Gero 1998, perceptual features are only afterwards appreciated and evaluated for their functional value.

It seems that CAD software would maximally contribute to the latter parts of the design stages: adding to the concept and goal of the design, and permitting the small modification of highly detailed graphics. After the initial stages of design, the explicit, physical design process has already been completed, and the more implicit, knowledge-based, and visualization advantages of CAD can start to contribute to the development of the design concept. In terms of the explicit/physical versus implicit/visualization capabilities in traditional and digital media, designers may derive their comfort and preference for either tool from their comfort with either of these problem-solving methods.

## 5. Evaluating Current Digital Design Tools and Software

Bilda and Demirkan 2002 suggest one method to encourage the *physical* cognitive actions in digital design by structuring software so that it mimics some of the more important aspects of design in traditional materials. For example, the act of copying could be simulated by introducing a transparent layer (Bilda and Demirkan 2002) to a current sketch that would either mechanically copy an area of the sketch, or allow the designer to trace certain parts of the sketch.

Though some attention can be given to making functions within digital design packages more like traditional design materials, it may be more beneficial to improve the transition from beginning stages in traditional design, to finishing and refining stages in digital design. Digital design has definite advantages in later stages, but the time and effort to translate or recreate the analogue sketch in digital media is not only difficult, but also time consuming. Without a proper translational tool, the creative and design progress in the traditional media may be lost. Because of these translation issues, designing both outside and inside CAD may seem redundant, or disconnected.

Many digital design programs are working to improve this translation process so that the work outside of the computer does not go to waste, and is seamlessly transitioned into CAD software. This way, there is no overlap, loss of design creativity, cognition, or information, and there is no gain of computer artifact in the design. Rather, the digital software performs maximally: allowing for small manipulations, holistic visualizations, simulation, representation of finer detail, and more universal communication of design concept through a rendered, realistic model.

Research has been devoted to creating effective translation tools that use mathematical algorithms to turn two-dimensional sketches into three-dimensional models in CAD software. As mentioned above, drawn sketches offer an ambiguity that aids in the physical and perceptual actions of dynamic design. However, current design software demands a high level of precision, and a lack of ambiguity. Put differently, "The acronym CAD evokes a common imagery of grid snaps, tight tolerances, and exactitude, and these inflexible constraints can severely inhibit the freedom and abstraction necessary for exploratory design (Schweikardt and Gross 2000)." The benefits of a more pictorially ambiguous beginning, combined with the need for a better translation between analogue and digital sketching, has fostered a new kind of CAD software.

One program, called Digital Clay is intended to interpret hand-drawn sketches as three-dimensional digital models (Schweikardt and Gross 2000). Programs like Digital Clay involve digital design elements, and computer-based sketch recognition software. The translation is outlined simply: (i) designers sketch with traditional media, (ii) the drawing is latched and rectified[5], (iii) the boundaries and vertices are labeled, (iv) three-dimensional coordinates are assigned, (v) the model is displayed in Virtual Modeling Reality Language (VMLR), (vi) the translated model is ready for further digital manipulation (Schweikardt and Gross 2000). With these six steps, Digital Clay attempts to mimic free sketching in traditional media, and translate the sketch into a highly revisable digital environment.

Another type of digital design program does not translate analogue sketches into a digital environment, but aims to use certain techniques of analogue sketching in a digital setting. With this method, no translation is needed. Again, the more important aspects of early sketches are the ambiguity of forms, and the physical act of depicting them. FiberMesh incorporates several key components of analogue sketching in a digital setting including a highly sensitive control function, the ability to iteratively refine the design, and the reuse of existing parts in a design. FiberMesh also attempts to mimic analogue sketching through its reliance on drawn curves to define and characterize surfaces and objects. The advantage of the highly sensitive control function is that it, like a pencil, is interactive and smoothly responsive (Nealen, Igarashi, Sorkine, and Alexa 2007). The next iteration of such a program should consider the weight, and repetition of the line, and the direction in which the curves are drawn.

## 6. Design Cognition Contributes to the Larger Framework of Understanding Cognition

[5] "Latched" refers to the closing and connecting of lines in a drawing. "Rectified" refers to the straightening of lines in a drawing.

In design, sensory or physical information enters the human perceptual system and filters through levels of analysis defining individual characteristics, perceptual qualities, functional qualities, and conceptual qualities. Yet, there must also be a downward stream of associations flowing from a more holistic understanding of the principles of design. That is, there must be some benefit, or at least some effect, of learning about design to make "better," undoubtedly more top-down decisions in the creative process. For example, recognition of certain sequences and tendencies in a design with reference to learned theories about what makes a good design, draws attention to certain depictions in that design, and may influence design choices as a result. This knowledge is the learned knowledge, semantic knowledge, and the conceptual knowledge, at the top of the cognitive ladder.

Unlike a sensory-based system such as the visual system, a cognitive hierarchical system of design may not be specified to one particular region or cell type. Still, information enters this network and is passed on, cut apart, added to, reorganized, edited, and redirected because of recognition of learned or observed sequences and patterns. This top-down evaluative process in design is most active in highly trained designers, such as artists and architects, and should therefore be inseparable from many models of dynamic design. Because Suwa, Purcell, and Gero 1998 apply a mostly unidirectional schema to the design cognition of skilled architects, there is major fault in their applying that schema to that population.

Multidirectional design cognition is important; it seems nearly impossible that only one information processing direction could produce the type of rapid, complex cognitive action that is required in dynamic design. Though perhaps silent, implicit, and to this date immeasurable, the implicit cognitive action, and the feedback from higher-level cognitive control centers are integral to the understanding of dynamic design. The next question for studies in design cognition, then, is how these hidden connections can be exposed either through behavioral patters, or through patterns in brain activation.

## 7. The Power of Hierarchies and Pattern Recognition in Human Conception of the World

Pattern recognition, and the interaction among different kinds and levels of cognition are helpful in modeling and understanding both complex and simple functions of the mind. In *The World Well Lost*, contemporary philosopher Richard Rorty presents what one can interpret as a keen, unexpectedly neuroscientific analysis of human perception of the world. He states,

> Now to put my cards on the table, I think that the realistic true believer's notion of the world is an obsession rather than an intuition. I also think that Dewey was right in thinking that the only intuition we have of the world as determining truth is just the intuition that we must make new beliefs conform with a vast body of platitudes, unquestioned perceptual reports, and the like (Rorty 1972).

We can infer from this statement that human coordination of knowledge, and conception of the world, comes from an obsessive observation and absorption of frequently reoccurring patterns among us. These high frequency events turn into the stereotypes, platitudes, and habits that form our common semantic knowledge. From this semantic knowledge, we form our rationally driven mutual expectations about the outside world and about each other. Not only is Rorty proposing a human obsession for patterns, but he is also saying that this obsession, and organization process, comes naturally and implicitly to us by intuition.

Here too we can recognize a repeated theme. I have attempted to show that this understanding of a feedback-dependent organization of the mind can be applied to higher cognitive functions such as design cognition. Rorty, now, has applied such a structure to the general method by which humans move through, and share the world.

One final example of this worldview is also taken from philosophy. In *Walking the Tightrope of Reason*, Robert Fogelin summarizes one of Kant's more important ideas in how humans conceive the world. He writes: "The first is that the world as we apprehend it is shaped or organized by mind-imposed concepts or categories. The world as it appears to us is not a pure deliverance of the sense but is instead the joint product of what the senses give us and what the mind imposes (Fogelin 71)" In this except, the conceptual understanding of the world shapes how we perceive it, just as the IT cells shape how we see a curve, and just as the goal of our design informs our depiction of forms in dynamic design.

## 8. Conclusion

I first ask my reader to consider the power behind the design process. Then, I focus on a specific explanation of dynamic design. Through my explanation, I set the groundwork for comparing design's high-level cognitive functioning with other functions of the mind. In unifying ideas from neuroscience, design, and philosophy, I present an explanation of the universality in the organization, appreciation, and practice of complex phenomena, especially those we experience as awesome expressions of the human mind.

## References

Altman, I and Wohlwill, J F (eds.). Behavior and the natural environment. New York: Plenum Press, (1983).

Bilda, Zafer and Demirkan, Halime. *An insight on designers' sketching activities in traditional versus digital media*. Design Studies. Vol. 24 (2003), pp. 27-50.

Dorst, K. and Dijkhuis, J. *Comparing paradigms for describing design activity*. Design Studies, Vol. 16, No. 2 (1995), pp. 261-274.

Fogelin, Robert. Walking the Tightrope of Reason. New York: Oxford University Press, 2003.

Garling, T and Evans, G W (eds.). Environment, cognition, and action. New York: Oxford University Press, (1991).

Gero, J S and Sudweeks, F (eds.). *Artificial intelligence in design*. '94 Kluwer, Dordrecht (1994), pp. 225-252.

Goldschmidt, G. *On visual design thinking: the wiz kids of architecture*. Design Studies, Vol. 15, No. 2 (1994), pp. 159-174.

Hawkins, Jeff w/ Blakeslee, Sandra. On Intelligence (First Edition). New York: Times Books, 2004.

Marx, J. *A proposal for alternative methods for teaching digital design*. Automation in Construction, Vol. 9 (2000), pp. 19-35.

McLaughlin, Brian and Bennett, Karen. *Supervenience*, The Stanford Encyclopedia of Philosophy (July 25, 2005), URL= < http://plato.stanford.edu/entries/supervenience/>.

Menezes, Alexandre and Lawson, Bryan. *How designers perceive sketches*. Design Studies, Vol. 27, No. 5 (September 2006), pp. 571-585.

Nealen, Andrew; Igarashi, Takeo; Sorkine, Olga; Alexa, Marc. *FiberMesh: Designing Freeform Surfaces with 3D Curves*. ACM Trans. Graph, Vol. 26, No. 3, Article 41 (July 2007), 9 pp.

Rorty, Richard. *The World Well Lost*. The Journal of Philosophy. Vol. 69, No. 19, Sixty-Ninth Annual Meeting of the American Philosophical Association Eastern Division. (October 26, 1972), pp. 649-665.

Schweikardt, Eric and Gross, Mark D. *Digital clay: deriving digital models from freehand sketches*. Automation in Construction, Vol. 9 (2000), pp. 107-115.

Schon, D. *The reflective practitioner; how professionals think in action*. Temple Smith, London (1983).

Simon, Herbert A. The Sciences of the Artificial (Second Edition). Cambridge: The MIT Press, 1981.

Suwa, Masaki; Purcell, Terry and Gero, John. *Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions*. Design Studies, Vol. 19 (1998), pp. 455-483.

Suwa, Masaki and Tversky, B. *How do architects interact with their design sketches in exploring design ideas?* Proceedings of 4th Australasian Cognitive Science. Conference '97 Newcastle, Australia (1997).

Suwa, Masaki and Tversky, B. *What architects see in their design sketches; implications for design tools*. Human factors in computing systems, In CHI'96 Conference Companion ACM, New York (1996), pp. 191-192.

Tufte, Edward R. The Visual Display of Quantitative Information. Cheshire: Graphics Press, 1983.

Won, P H. *The comparison between visual thinking using computer and conventional media in the concept generation stages of design*. Automation in Construction, Vol. 10 (2001), pp. 319-325.