Constructive Interpretation in Design Thinking

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Abstract. This paper presents a framework for modeling the way that designers interpret their world during design activity. Designers interpret the world through their expectations. Expectations are derived from situation. Agents form concepts in situations and use concepts in situations. A model of concept formation based upon a geometric representation of conceptual space is described. In the model, expectations are constructed from memory within a situation. In interpretation, the world is made to look like expectations. Some preliminary explorations with an implementation are described.

Keywords. Interpretation; situatedness; constructive memory; conceptual spaces.

Introduction

A designer constructs the world that they experience through the process of interpretation. Interpretation in design is concerned with: (i) the production of expectations that are useful to a design task; and (ii) the construction of an interpretation from these expectations. Through interpretation, the designer experiences a world that is constructed to look like the world that they are expecting. We are concerned with the nature of expectations and how they are structured by situations (Gero, 2007).

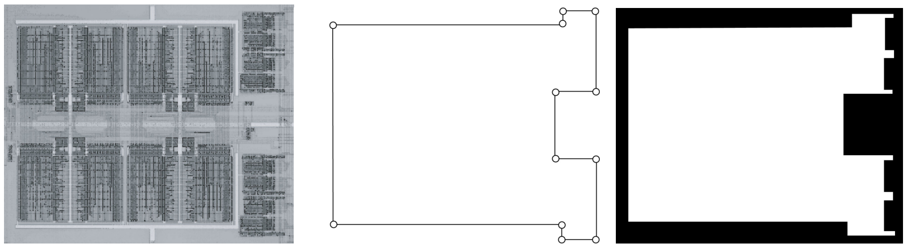
A designer engaged in a design task has the ability to see the world in a way that is useful for their design activity. Consider that a designer is engaged in developing a concept for a large government building. Upon seeing the image in Figure 1(a), which came from a picture of a circuit board, they see something useful for the design task. The same phenomenon can be observed when designers see unexpected things in their own work (Suwa et al 2000).

This is possible because there is no limit to the number of ways that the world could be interpreted. It is the designer that imposes the interpretation. An interpretation is made up of a representation and a meaning for that representation. A representation is the way that the designer sees the structure or syntax of the world. Meaning refers to the semantic properties given to things in the world. Semantic properties are distinguished in that they are not completely localizable to the part of the world at hand; they require reference to other knowledge inside the agent (Hofstadter 1980).

There is no single representation waiting to be registered by a designer, in the same way that a sketch of a design can be represented in a CAAD program in multiple ways. For example, the image in Figure 1(a) could be represented using nodes and orientations, Figure 1(b), or figure-ground, Figure 1(c).

There is no single meaning for a representation. The image in Figure 1(a) could be given meaning by a designer as a building plan or as a circuit board. In all of these possible meanings, designers seem to be able to produce one that is useful to their current design task.

This work presents a framework for representing the cognitive processes of interpretation during design activity. Its focus is upon the way that situations give meaning to concepts when they are formed and when they are used.



(a) *(b)* *(c)*

Figure 1
An image (a) with two possible representations using (b) nodes and orientations and (c) figure/ground

Situations and expectations

The framework is built around the effect of situations in constructing an interpretation. Expectations are constructed within a situation (Gero and Smith, 2007). A designer brings together knowledge about a design task when commencing it (Gero, 1990), such as expectations about the way the design will progress and expectations about the results of actions. For example, a designer might have a great deal of experience and technical expertise in sketching but in a specific design task the designer expects specific things from the sketch activity that relate to this point in this design task.

We refer to where a designer is at cognitively as a 'situation', the designer's current world-view. Knowledge about the world that arises from perceptual information and its use are referred to as concepts. A situation is knowledge about the world that arises from concepts and their use.

The effect of a situation is that concepts are coordinated and manipulated to be useful to where the designer is currently at (Clancey, 1999). For example, an attention mechanism is one way in which a situation can affect the use of concepts. A concept can contain knowledge across many modalities (e.g. aural, visual) and many prototypical instances of that concept (Murphy, 2002). One way that a situation coordinates concepts is by paying attention to which modalities and prototypes are relevant to where the designer currently is at.

We look towards a model of concept formation and use in design where knowledge changes based upon where it is being used. Without situations, when a concept does not fit current circumstances it is either changed or a new concept created. With situations, concepts can be constructed so that they fit the current circumstances – concepts become tied to their use.

The Digital Cocktail Napkin (Gross and Do, 1996) is an example of a system that uses concepts based upon where the designer is at. It can interpret a line in one drawing as being different to the same line in another drawing because the expectations when looking at the drawings are different.

A framework for constructive interpretation

Using the conceptual spaces framework (Gärdenfors, 2000) we can represent a designer's cognitive system and model what is happening during interpretation. Conceptual spaces are used to represent, as geometric structures, information held by a designer about their world. In the framework we extend the idea of conceptual spaces to include situations as a coordinator and manipulator of concepts during their use and construction. We refer to the simulated designer in the model as an 'agent'.

An agent has sensors which produce data during interaction with the external world (e.g. an eye can sense changes in light, an ear changes in air pressure (Gärdenfors, 2000)). The different things about the world that can be sensed make up dimensions. Dimensions that are inseparable create a perceptual domain. Inseparable means that the agent cannot get information for one of the dimensions without getting information for all of them. For example, three dimensions that are related to visual perception are hue, brightness and chromaticity. The way the eye is structured, we do not get information for hue without also getting information about brightness and chromaticity. A perceptual domain (e.g. texture, color) is a space with dimensions of those things that the agent can sense.

A concept is a convergence zone that brings together spaces within perceptual domains that experience has shown to be related. For example, the concept for BANANA might bring together areas in the color domain that we might call yellow, green and brown with areas in a shape domain that we associate with the Lady Finger and Cavendish banana varieties. It implicitly adopts a prototype theory of concepts where the most typical perceptual regions (e.g. the colors and shapes above for a BANANA) are associated and less typical instances of a concept have some distance (measured in conceptual space) from a prototype (Murphy, 2002). Figure 2 shows the way that dimensions create the space of a perceptual domain, and the way that a concept associates regions in domains with each other. A part of the meaning of a concept comes from its relationship with other concepts.

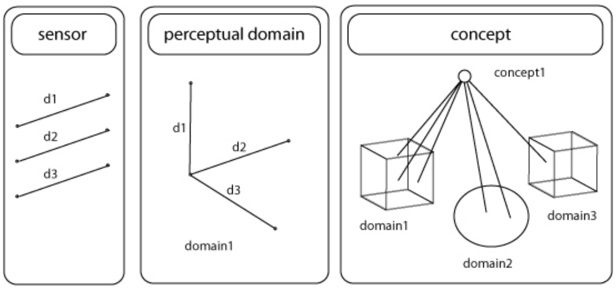


Figure 2
A sensor produces data that creates dimensions d1*,* d2 *and* d3*. The three dimensions together create a perceptual domain, domain1. A concept,* concept1*, brings together regions in different conceptual spaces.*

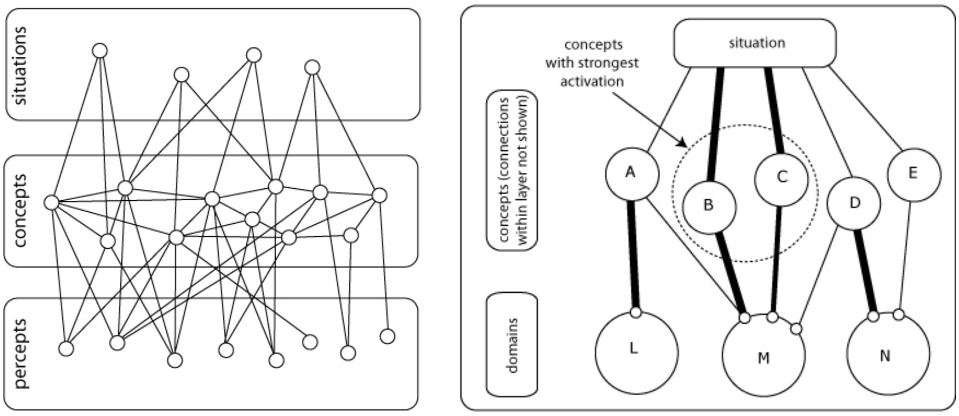
We extend conceptual spaces by including situations. In this framework, a situation coordinates concepts such that the agent learns how concepts fit together to be useful in the world. The situation sees things in the assembly of concepts and uses this to change the individual concept – the situation puts the whole into each part.

Some concepts are more important to a situation than other concepts. Some domains are more important to a situation than other concepts. The situation changes the way that domains work by changing the conceptual space.

Constructing expectations from memories

Memory is a reflection of how the agent has adapted to its environment (Gero and Smith 2007). Memory comes about through experience. Memory is always utilized within an experience such that the same memory queried in different experiences can produce a different construction. We draw a distinction between 'memory', where something about an experience is stored, and an 'expectation', which is a construction that uses the knowledge in memory. A memory is always constructed in a situation, which is to say that the same knowledge used in at a different time within a different world-view may take a on a different meaning.

Figure 3(a) shows the data that is stored in memory in this framework, where lines between nodes represent a weighted connection. The agent stores in its memory: situations (information about the coordination of concepts), concepts (information about the coordination of percepts) and percepts (information about the coordination of senscepts: the output of sensors via a sensation process that a perceptor uses). It also stores information about the way that concepts are related to each other. This specific suggestion of the structure of memory is not so important as that the agent does store something during experience and many architectures for memory are possible (e.g. Liew and Gero 2004). The framework implements some of the ideas described in constructive memory literature in the way that expectations are constructed (Gero 1999, Riegler 2005).



(a) *(b)*

Figure 3
(a) Percepts, concepts and situations are stored in the memory and draw their meaning from the weighted connections between them; and (b) situations bring the whole into the parts of the agent's cognitive state changing perceptual domains and expectations prior to interpretation. Bolder lines indicate stronger activation

Situations are constructed through either: (i) changes to a current situation during experience; or (ii) construction of a situation from memory. The construction of a situation from memory in this framework has four main steps: (i) concepts associated with the situation in memory are activated (ii) spreading activation across connections between concepts brings other concepts into the situation; (iii) percepts associated with activated concepts become active; (iv) the situation changes the conceptual spaces within which percepts are located.

A concept C has an activation A_C that is given by Equation 1 as the weight of the connection between the situation S and the concept in memory w_{SC}:

$$A_C = w_{SC} \tag{1}$$

The result of this is that concepts that experience has shown to be associated with a situation are activated in the construction of the situation. For example, an agent that has experience designing bridges might have concepts for SUPPORT and SPAN that are expected when commencing the design task.

Spreading activation of concepts (Anderson 1983) facilitates construction of a set of concepts that is indicative of where the agent is currently at in its knowledge of the world. The way that an expectation is constructed from a memory is affected by its experiences since that memory was created. In a similar way, the connections between concepts and percepts can be changed by experiences following the creation of a memory, so the use of that memory is affected by the experiences since its creation. Spreading activation occurs with a concept that has been activated C_1 and a concept that experience has shown to be expected to be associated with it, C_2. The activation of this second concept, Equation 2, is determined by the activation of the first, the weight between the two concepts and a 'decay rate' parameter in the model, d :

$$A_{C2} = A_{C1} \, . \, w_{C1C2} \, . \, d \tag{2}$$

The focus of this paper is upon the way that the situation affects the creation of expectations. Some expectations are perceptual and some are conceptual. In conceptual spaces, a percept exists within a perceptual domain. What this means is that many concepts can have expectations in the same perceptual domain. For example, many concepts have expectations in the perceptual domain of color. In this way, the concepts within a situation affect the way that each one is used in constructing expectations. In Figure 4 we see that both concepts expect to find perceptual color information that is close to the yellow prototype. The expectations strengthen each other, so that in both concepts the agent is primed to expect yellow. This is one way in which the situation manipulates the conceptual space, articulating the effects of concepts being activated together. A percept P has activation A_P as a sum from all activated concepts that are connected to it, Equation 3.

$$A_P = \sum A_{Cx} \, . \, w_{CxP} \tag{3}$$

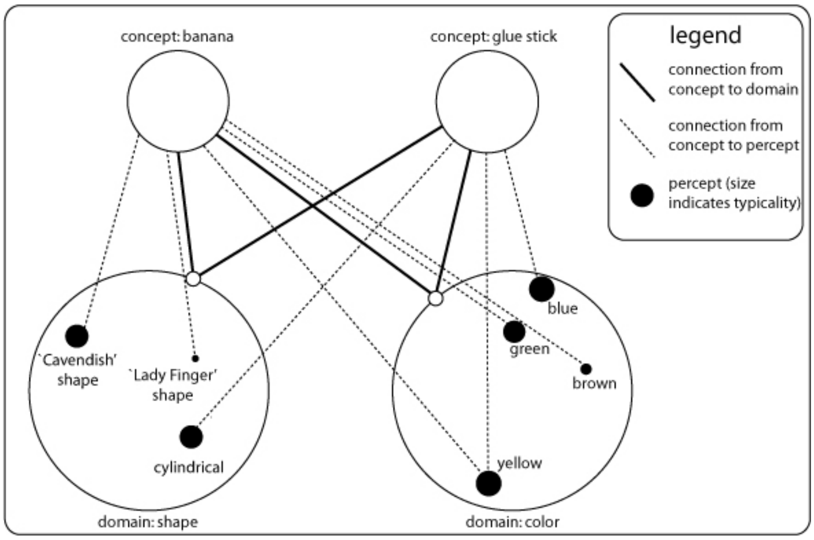


Figure 4
Concepts affect each other in creating expectations of perception

The situation brings the whole into the parts of the agent's cognitive state. One way that this can occur is through changing the nature of the conceptual space within perceptual domains. Within a situation, some concepts are more strongly activated than other concepts. For example, when designing a house the concept ROOF might be more strongly activated than the concept CHIMNEY. Further, within each concept, each domain has a level of significance. For example, shape might tend to be more important than color in the concept of a banana. From this information, within the situation, each domain is said to be important to the situation to a certain degree. In Figure 3(b) we see that concepts B and C are more strongly expected than A, D and E. We also see that domain M is important to B and C so we would expect that in this situation the domain

M would be more important than L and N. The importance of each domain D_I is given by a sum of the activation of each concept and the weight of the connection between that concept and the domain, Equation 4:

$$D_I = \sum A_{Cx} \, . \, w_{CxD} \tag{4}$$

This domain importance changes the way that the conceptual space in that perceptual domain behaves within this situation.

Push and pull in perception

Interpretation can be viewed as the interplay of two different forces: a pull from expectations to make data fit with what is expected and a push from what is being discovered in the outside world (Gero and Kannengeisser, 2004). Push and pull operate between all of the 'layers' in the cognitive system of the agent: situation, conception, perception and sensation. Between any two layers, pull involves expectations being used to construct data from what is available (e.g. concepts constructing from available percepts). Push involves data that has not been used for pull causing a revision of expectations (e.g. unexpected percepts suggesting that different concepts ought to be expected).

The perceptual layer holds expectations about the senscepts that are going to come into it. This is represented as regions in the conceptual space of the domain that are activated by expectations. When senscepts are produced by sensors, these regions pull senscepts towards them. In other words, the agent is perceiving what it expects to perceive rather than simply a direct representation of what it is sensing. The implication of this is that there are many ways that one set of sense data can be perceived, many ways that a single set of percepts can be conceived and many ways that a single set of concepts can be brought together into a situation. Pull of senscepts to percepts in conceptual space can be understood by analogy to the way that gravity distorts space such that a large mass appears to pull a smaller mass towards it. Figure 5 shows a snapshot of one perceptual domain. More typical percepts and more strongly expected percepts have a stronger pull.

In each perceptual domain there is a 'slippage' parameter (French, 1995) that is driven by the situation that determines the reach of pull from the expectations of perception. In Figure 5, we have a number of expected percepts within each domain. Each percept has a degree of activation based upon its connections to activated concepts within the situation, represented by the size of the bold circles in Figure 5. Each percept exerts a force of pull to try and make every senscept move towards it (within the conceptual space created by the perceptual domain). A senscept requires a certain amount of attraction to make it move towards a percept, where this amount is a function of the size of the domain and the slippage parameter. The slippage parameter is a function of the domain importance within the situation. The result of this is that some senscepts will be drawn to percepts whilst others will not move from their position in conceptual space.

Push and pull in conception

The outcome from push and pull in perception is that a number of expected percepts have been constructed. There are also senscepts that have been pulled to unexpected percepts, as well as senscepts that have not been pulled to any percepts. Push and pull in conception is similar to push and pull in perception. Conception tries to construct the concepts that it is expecting. The outcome of this is that some percepts have been used in constructing concepts. Other percepts push into conception, activating other concepts, bringing them into the set of expectations.

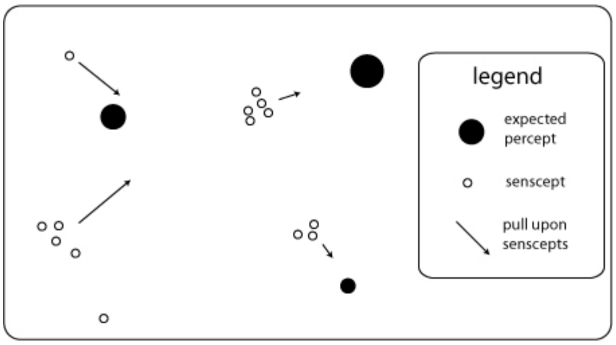


Figure 5
Pull as a force within conceptual space, exerted by percepts upon senscepts

Push and pull in situation

In a similar way, the situation tries to construct itself from the concepts available. The whole interpretation process begins with a situation activating concepts. However, through push, the concepts that are now active may be quite different to what was expected. The situation attempts to construct from the concepts available and if it cannot then the situation is changed, a different situation activated or a new situation created.

The effects of interpretation

The agent is changed by the process of interpretation. Memory was used initially to construct expectations for interpretation. Through the push and pull of interpretation, these expectations can be significantly changed if the expectations were not useful. The state of the agent before and after interpretation is different, and the agent learns from this. This is an example of grounding knowledge in its use.

An example of the framework

An implementation of this framework is being developed. In a non-design example of interpretation the agent's world is made up of bags and objects. The world is generated stochastically. Objects are generated and distributed into bags according to specified probabilities. The objects and their distribution is inspired by the bags of University students such that certain objects tend to be found together, e.g. laptops, computer cables and mice; notepads and pens; stethoscopes and PDAs.

In the initial experience development phase the agent experiences the world and a number of things occur: (i) it develops concepts as groupings of percepts that occur together; and (ii) it develops situations from concepts that occur together. The outcome of this phase is that the agent is able to generate expectations based upon its first person knowledge of the world. Once the implementation has been tested on this simple world it will be applied to a variety of scales of a design domain.

Discussion

Some preliminary results from the model support the belief that a constructive interpretation agent should have the following capabilities: (i) if a sensor is broken in the agent then the agent can still construct interpretations from its expectations; (ii) previously unencountered stimuli can be interpreted by the agent in a way that is useful to it; and (iii) two initially identical agents (i.e. having exactly the same knowledge about the world) in different situations can produce different interpretations of the same stimulus.

There is both anecdotal and research-based evidence that designers work within situations, which affect the trajectory of their designing (Suwa et al 2000). Interpretation is seen as involving a construction of expectations from memory and a construction of the interpretation from expectations. In this way an agent constructs the world within which it designs. A computational model of constructive interpretation in design thinking will serve two purposes: it will allow the testing of the cognitive explanation of observed designer behavior, and provide a basis for carrying out experiments to determine the effects of parametric variations on the resulting behavior.

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