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The Art of the Model

Models are now and always have been an integral part of the human experience. We create these models of the world with information provided from our five main sensory inputs: visual, auditory, tactile, olfactory, and taste. These models inform us of changes in our immediate perception and also permit understanding of these changes in comparison to past events. As infants we develop sophisticated models of motion, shape, distance, time, and cause/effect in an effort to relate to the new and confusing world around us. Starting from a nearly clean slate we must build an internal understanding for every new experience. Thus, the idea of creating an *abstraction* of the world in an effort to understand complex ideas is inherent to human behavior. Taking conscious control of this behavior to capture, understand and express complex information is the essence of the Art of Modeling.

As infants we also have a limited ability to express ourselves. We are limited to crying when startled or unhappy, and cooing when comforted. While these simple forms of communication are sufficient to indicate the desire for food or to have one's diaper changed, they do not provide the ability to associate specific objects with other similar objects. The development of language skills permits a greater level of self-expression; the ability to identify objects by name allows for the association of those objects to other similar but different objects. Eventually, this leads to the ability to create abstract models to reason about complex concepts. George Orwell in his famous novel "1984" was very aware of the connection between language and the ability to reason about complex abstract ideas. In his novel the development of "Newspeak" was an attempt by the government to limit creative thinking by altering and eliminating the words for undesirable concepts – such as civil rights and personal freedoms. As Orwell writes, "The purpose of Newspeak was not only to provide a medium of expression for the world-view and mental habits proper to the devotees of Ingsoc[1], but to make all other forms of thought impossible." ([2], p. 246). While the idea that language can be used to control

[1] The Socialist state of Orwell's world

thought has been discredited, it is cleat that language is critical to communication and represents the underpinning of all forms of modeling.

Since human cognition is a complex combination of innate instinct and learned behavior, a great deal of time is required to build up a robust world-view that can be used to relate new information to old [3]. Initially, these internal mental models[2] represent our ability to identify and associate concrete objects, but eventually they provide for more complex reasoning. For example, a person who attends a class on accounting principles may attempt to understand that subject in relation to previously learned behavior, such as balancing a checking account. In fact, abstract and impressionist painters often make use of this innate tendency by presenting a picture that can be interpreted differently by each viewer Figure 1-1.

Figure 1-1. Impressionist Painting (Claude Monet, Une Alle du Jardin de Monet, Giverny)

Our internal abstract models of the world are also critical to the communication of complex concepts with other people [4, 5]. For example, it would be impossible for a person from a hunter-gather culture, who has never had contact with the modern world, to understand the principles of refrigeration simply by describing the mechanics; it is completely foreign to their experience. To succeed, first you would need to have a shared

[2] A mental model is defined as each persons internal perception of an idea or event – it is how we relate new information to our existing store of experience.

communication medium (language, pictures, gestures, etc.). Once you can share ideas, you would then need to translate your understanding into ones that can be related to their internal models of the world: examples of food storage, the effect of cold temperatures on spoilage, etc. In other words, you would need to align your model explaining a phenomenon to a shared experience with intended audience [6].

A close alignment of one person's world views with another leads to a higher likelihood of understanding. This is one of the reasons that people form tight in-groups based on shared experiences [7], because of the comfort afforded by the reduced need to "understand" one another when communicating. The idea of "clicking" with another person is based on a shared understanding of a number of experiences, leading to a reduced effort to share information and a sense of familiarity.

For people involved in the creation of models for system analysis, these concepts are important when the model is intended for use by people other than just the modeler. By definition, when I create a model it will reflect my understanding of a subject. In order for my model to be useful to others I need to ensure that I am capturing the right abstraction level and using a model form that meets the expectations and needs of the audience. For example, if I am modeling an automotive engine for mechanics vs. engineers I should focus on engine elements for repair and replacement as opposed to power generation.

To express these ideas, the psychologists use the term *cognitive resonance* to represent the situation of matched internal world views between the modeler and the audience, and *cognitive dissonance* to describe a situation where the presentation is disconnected from the audience's experience or expectation.

Cognitive Resonance

When a guitar string is struck, the string vibrates at a particular frequency and wavelength based on the string length, tension, and composition. If one looks closely, it is possible to see the string vibrating between the two end points of the fret pin and the bridge on the sound board. This vibration is transmitted through the air to our ears as a series of compression waves which we perceive as sound. When these waves impact on another object that shares similar characteristics, a harmonic resonance will be imparted to the object. For example, if a second string is placed near the first and tuned the same way, the first string's vibrations will evoke vibration in the second.

In a similar manner, a model created for the purpose of communicating a particular subject should "strike a chord" with the audience. If this resonance is absent, the audience will have difficulty in understanding the content of the model (*mis*-sense), or worse yet, drawing incorrect conclusions presented by the model (*non*-sense). So, to create an effective model a modeler's primary responsibility is not only to accurately capture the subject information, but also to present that information in a form that will be readily and correctly understood by the intended audience.

This is no simple task. We have all experienced teachers that have a good grasp of the subject, but are unsuited to the task of communicating that information to students. By contrast, great teachers know how to package information in a way that captures the interest and excitement of the students. They bring the subject to life so it connects with the students. In other words, the content of the lesson *resonates* with the students who have better lesson retention.

There are a variety of ways to construct models of information. Many of these models use a symbology or icons to represent complex and repeating concepts. This is done to group or "chunk" concepts so that they may be easily remembered and manipulated [8]. Some obvious examples are mathematical symbology or chemical notation (Figure 1-2). The topics of mathematics and chemistry are sufficiently complex that complex constructs are necessary to explain and predict. Due to this complexity, these constructs would defeat most human understanding if they were presented in their entirety. Another example would be a map that was so detailed that in order to read it you would need to overlay it on the territory it describes. Such a map would not be very practical for the purpose of navigation, where portability is critical. In both of these cases, a model that abstracts the key information and relationships is necessary. These kinds of models typically use some form of symbology "short-hand" to abbreviate basic concepts; this is very like the use of professional jargon to succinctly describe a complex idea.

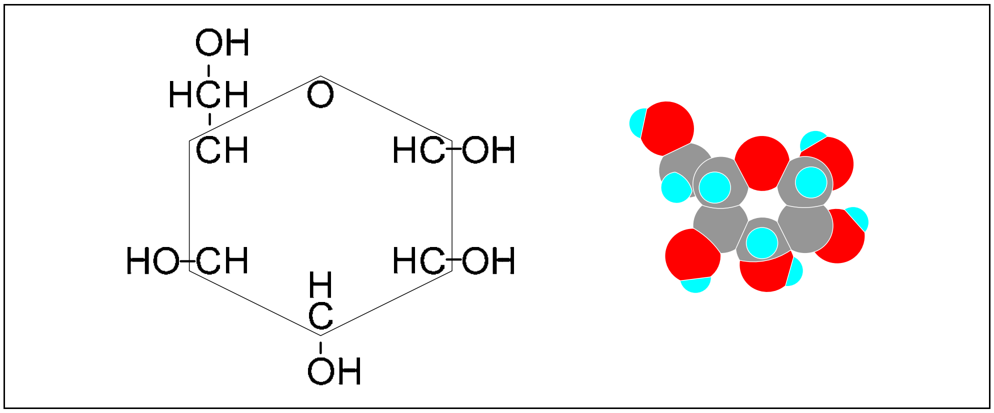

Figure 1-2. Two Chemical Representations for the Sugar Glucose

If a model uses symbology or icons it is critical that the intended audience understands the meaning of these symbols. In Figure 2, the symbology is not clearly defined; thus a viewer would have to be familiar with the representation of carbon atoms with a "C" (gray circle), oxygen with an "O" (red circle), hydrogen with an "H" (blue circle), and chemical bonds as lines or close proximity between letters (or adjacent circles). Similarly, a software UML class diagram will not serve to further the understanding of someone who does not understand the notation and semantics of such a diagram (Figure 1-3).

The recognition of symbols is often tightly coupled to the level of abstraction represented by the symbol. An icon that is of a familiar shape, such as the icons in computer user interfaces to represent folders, files, controls, etc., will be more readily understood than one that is an abstract collection of shapes and colors. Further, society and culture will have a significant effect on the choice of symbology since some symbols will not be interpreted in a similar manner, and may in fact be interpreted as offensive by some members of the audience. This last point takes on increased significance when a development team is not collocated, as is the case with many outsourced projects. Later chapters will address these issues, and show how they affect the creation and presentation of system models.

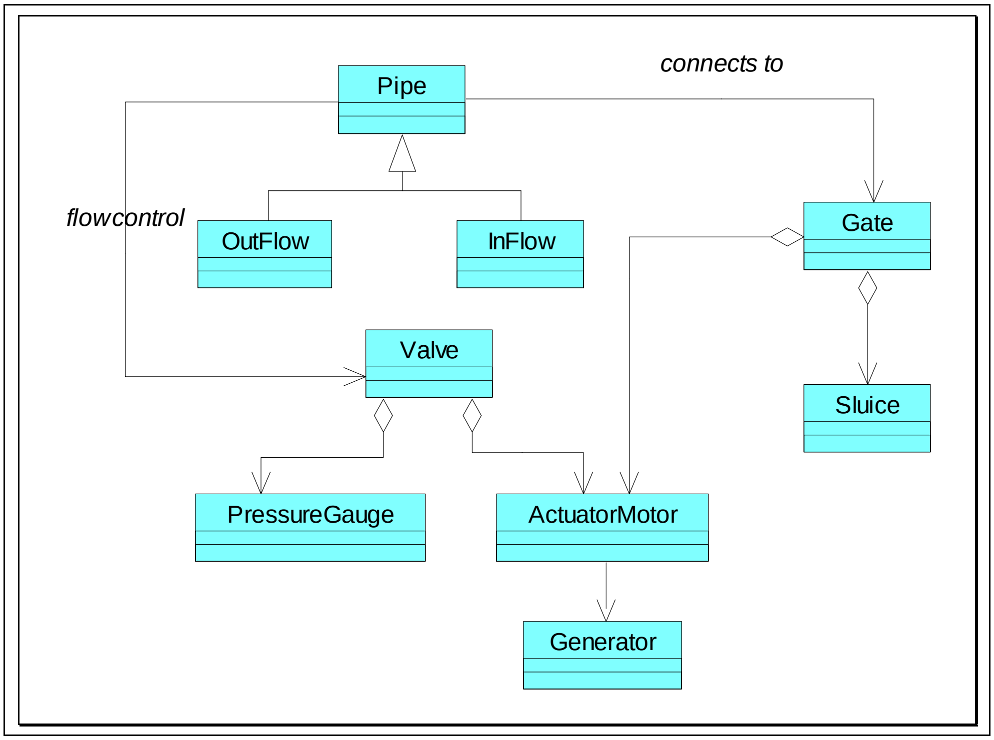

Figure 1-3. Example UML Class Diagram

Certainly the search for symbology that is universally understood is not a new one. Plato's "ideal Forms" represent an early attempt to identify the *eidos* (είδος) or essential qualities for different objects and concepts [9, 10]. The details of this philosophical discourse are not relevant here, but some of the mechanisms for determining the *eidos*, or "likeness", of a particular object or concept will be useful as we develop techniques for the creation of models in general, and software models in specific. The idea of an object's essential qualities and the kinds of relations that may be shared between different model elements will be further explored in Part II.

Perception and Representation of Models

A model can be defined as the abstraction of a complex system for the purpose of reasoning, simulating, analyzing, or communicating specific details of a subject. In this way, a model operates much like a magnifying glass lens; it focuses attention on items of direct concern while obscuring or omitting everything else (Figure 1-4).

Figure 1-4. The effect of modeling on focus of attention

For example, consider a scale drawing of a city. In this model, the street level details are obscured to permit a larger view of the overall city structure. This is an example of the concept of *abstraction* and how it is used to create a model. Which brings me to the topic of model complexity, which can be summarized by the Golden Rule of Modeling:

> Golden Rule of Modeling – A model shall be as complex as necessary; no more or less

Models may be considered "good" if they are suitable for their purpose. For example, a model of a jet plane that has a scale of 1:1 may be exactly right for simulating the result of a crash, but is not very well suited to hang from the ceiling of my son's bedroom. So, for any system of sufficient size, with the rule of thumb of anything too complex to entirely encompass in one's mind, it is necessary to sacrifice some accuracy in favor of understanding. Further, since the human mind has a finite capacity to capture and retain information [8], in order to reason about a complex topic it is often necessary to break it down into smaller sections that can solved and re-synthesized back into the whole.

There are many ways to create models (which will be further explored in Part II), but the selection of the best technique is a function of experience, research, education, and intuition. Experience is best thought of as encountering a situation similar to one in the past where, perhaps by accident, a workable solution was found. Education is where someone else has solved the problem and is willing to teach this mechanism directly or via some other communication mechanism. Research involves experimentation with a variety of approaches to determine the most appropriate one. Intuition is involved when trying to create a new model form for a previously unknown problem, and making guesses on what might work best for a given audience.

When building a model it is often best to understand the intended audience before attempting to envision and create the model. Since there are many ways to represent a system, and a model is often intended for the purpose of communication, then the model should take into account an understanding of the intended audience, or there is a high likelihood of miscommunication. Because of this likelihood of confusion, when communicating ideas via a model it is often useful to consider how information flows between people (Figure 1-5). Several theories have been developed to explain the process by which information is transferred from one person to another; each of these models has in common the need for a "communication channel" through which the information flows. Often times this is verbal, as seen in a lecture hall or a meeting room. Frequently, visual communication is also used to convey information, as is the case with paintings and advertisements. However, no matter the medium of exchange there are two key aspects to communication: the generation of a message, and the interpretation of that message.

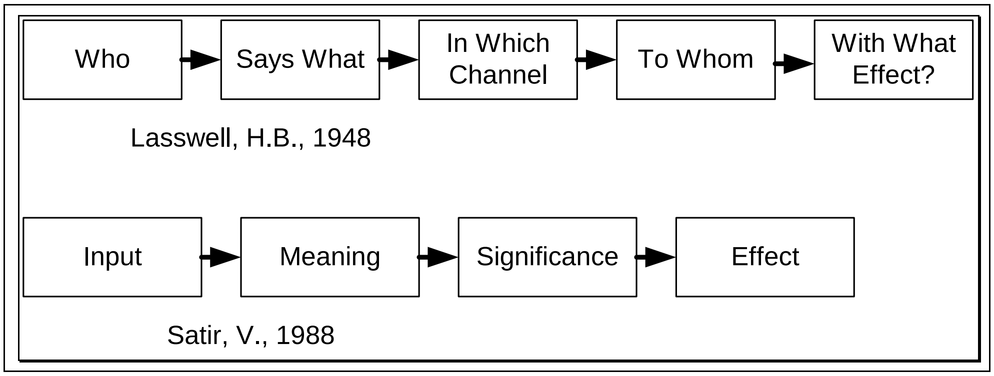

Figure 1-5. Two models for communication flows between people [11, 12]

As was mentioned above, individuals perceive and organize information through the use of mental models. However, no two people share the exact same experiences so no two mental models are exactly alike. This can lead to errors of interpretation based on differences in perceptions. For example, consider Figure 1-6, what is in the center box?

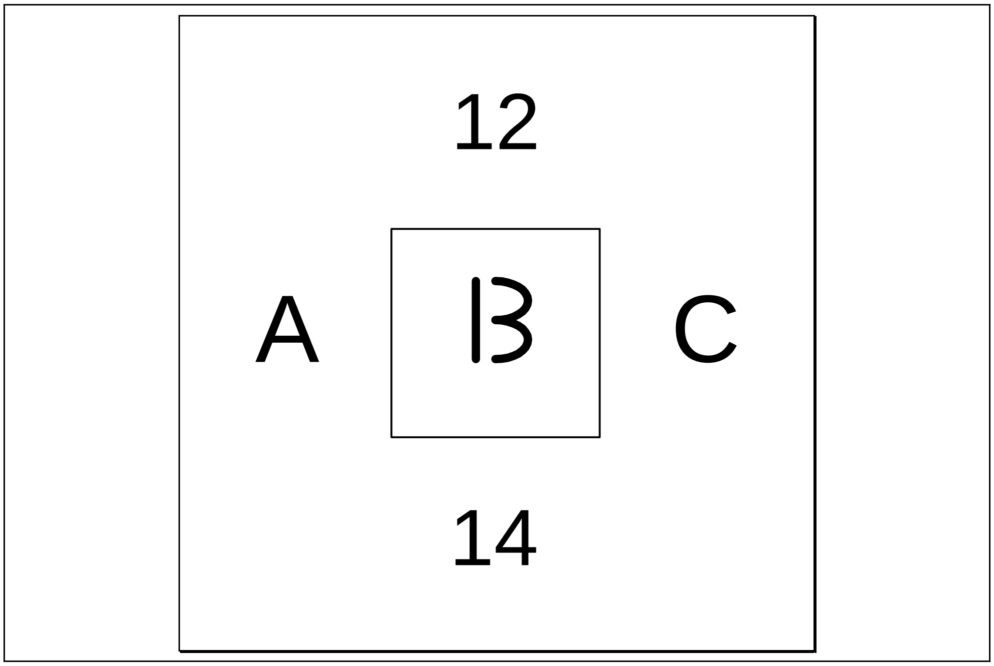

Figure 1-6. How perception is affected by context [13][3]

Depending on which context is chosen (vertical or horizontal), the answer may be the letter B or the number 13. In point of fact, the contents of the box are simply a straight line next to a line with two adjacent curves. It the mental models we have constructed that influence our interpretation of the symbology. To someone who cannot read or write (or uses different symbology for those operations) these figures are meaningless and this example would represent a very poor model indeed. The take-home point of this figure is that model icons and symbology may be interpreted differently by different audiences, and should be considered when creating a model display.

Learning and Reasoning

Models serve as more than just a communication device; models are also central to perception, memory, learning, and reasoning. For example, the construction of mental representations in short term memory is critical for our ability to process sensory information [3]. Reasoning is facilitated by the creation of possible solutions in the "working memory" to allow us to investigate different relationships between objects and events [14]. The use of mental "prototypes" to compare against perceived objects permits us to categorize the surrounding environment [15].

Cognitive Psychology is the branch of science that is devoted to the study of these aspects of human psychology. Cognition is the collected term that refers to our ability to

[3] As an interesting aside, Michael Chonoles, one of my reviewers, noted that his son saw the McDonalds™ golden arches as the center symbol.

focus attention[4] on a specific event, perceive that event via our senses, process the significance, and relate that information to previously collected information. Models, of all forms, are our way to deal with massive amounts of information with limited processing capability. We reduce the complexity of the perception problem by focusing attention to certain select inputs over others, and by "activating" on key features that are part of the subject of interest. For example, in the classic children's problem of finding specific shapes in a picture (e.g. Highlights for Children, published by Highlights for Children, Inc.) the desired simple object is hidden in a large, complex image. The child is shown the outline of the form and asked to identify its location in the image. The task is aided greatly by providing a template that the child holds in short term memory while scanning around the image. The mental image is compared to perceived features in the picture until a match is found. Interestingly enough, the desired object is always in the *perception field* (or in other words, available to the child's processing systems), but not recognized until matched to the template object. Once the object is located it becomes quite apparent as attention is "locked" on; after initial discovery the object is then easily relocated in future searches. In the creation of models this is critical in the creation of large, complex diagrams. The ability for a viewer to locate some key element of the diagram will be greatly aided by some form of distinguishing feature, such as color or shading, to call it out against the background of other diagram elements. This point will be further explored in Part III.

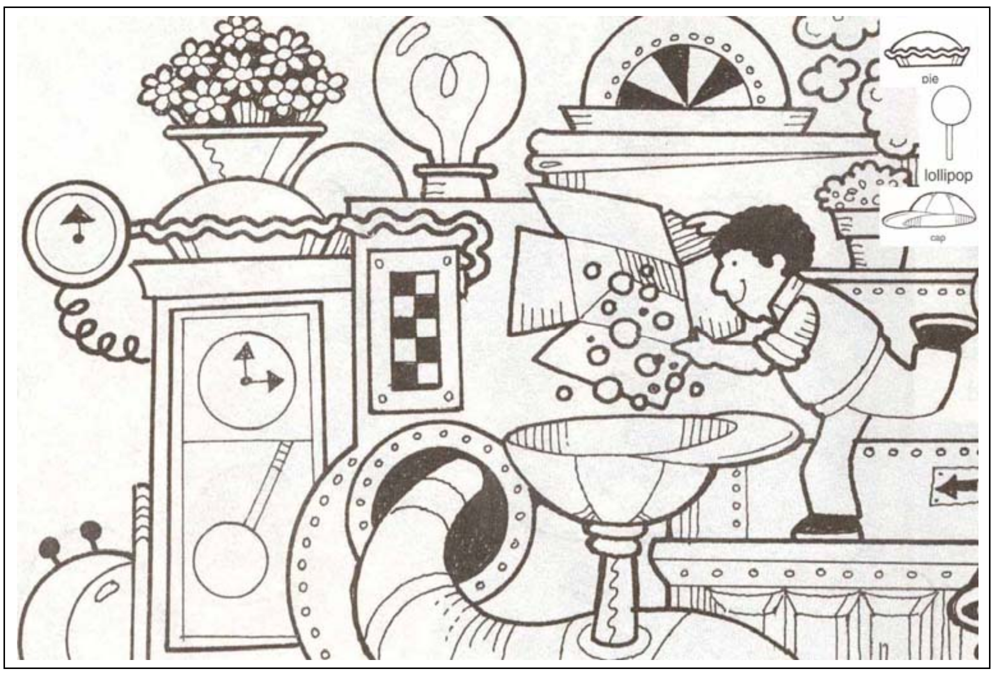

Figure 1-7.Hidden Pictures: locate the figures (upper right) in the main picture (permission required – Highlights for Children, Inc.)

[4] Here attention is used in the psychological sense to represent the focus of the mental reasoning machinery on processing some form of sensory input (such as visual).

Beauty and the Beholder

The subject of beauty has intrigued people for millennia. The classic philosophers argued frequently and at length on the qualities of beauty without forming any solid conclusions as to the source of our sense of beauty and "rightness" [10]. In more recent times, researchers in psychology, while not having any greater success in *defining* beauty, have formed theories that describe this aspect of human perception. Gestalt theory, from early research efforts in Cognitive Psychology, presents a set of principles for the organization of visual perception that have been shown to hold for most people [3, 16-18]. These principles are organized into general rules:

- Factor of Proximity
- Factor of Similarity
- Factor of Uniform Destiny (Common Fate)
- Factor of Objective Set
- Factor of Direction
- Factor of Closure
- Factor of Past Experience

We will explore some of these rules in latter chapters, most particularly in Part III during our discussions on presentation of visual models. The Gestalt factors are based on studies that have shown that people search for the simplest possible organization of visual elements, which the early Gestaltists M. Wertheimer called the "Law of Prägnanz". Gestaltists held that the closer a particular organization scheme came to the "simplest" possible combination, the more likely this organization would be recognized by most people. Consider Figure 1-8, what groupings are perceived? The majority of people would answer "four groups of two" instead of one group of eight. This is an example of the Gestalt principle of Proximity where objects that are in close proximity are associated into a single group. This Factor plays a part in diagram creation where elements may be grouped closely together to suggest some form of association.

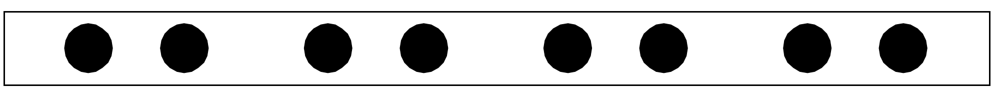

Figure 1-8. Gestalt Factor of Proximity

In addition to the Gestalt principles, our sense of beauty is heavily influenced by familiarity, symmetry, and contrast between figure and ground. Humans seek structure and order in our environment, such that we will see patterns even in random arrangements. Objects that are placed symmetrically tend to be more appealing, and are perceived as being well balanced and in harmony with one another.

Many of the theories of Cognitive Psychology will be useful as we explore modeling in general, and system modeling in specific. We will return frequently to the Gestalt principles as we explore the creation, organization, and presentation of models. Theories on memory, attention, learning, reasoning, and problem solving will also be explored in the context of modeling. As should be apparent from this introduction, people are highly experienced in creating models as a natural part of perceiving the world; however, the creation of models for the specific purpose of reasoning about a complex subject, and the presentation of that reasoning to others, is a far more challenging task requiring practice and effort. In the chapters to follow, I will attempt to combine studies in psychology, art, and systems analysis into a single theme that illustrates the fine art of modeling.

Summary

1. All humans create models, starting from infancy where we need to understand the complex and confusing world in which we have been born. Over time these "mental models" aid us in the understanding of language, and allow for the basis of human reasoning and understanding of complex concepts.
2. "Cognitive resonance" describes the ability to create a model that will closely align to the expectations of the audience. If a presentation does not resonate with the audience it is not as likely to result in understanding and learning. A likely result of "cognitive dissonance" is mis-sense, or difficulty in understanding the content, and non-sense where the content is incorrectly interpreted.
3. Models often use symbology, icons (visual), or sound patterns (auditory) to represent complex subjects in a more compact form. This is done as an aid to human understanding which has limited capacity to process information. However, if the symbology is not familiar to the audience, its use will defeat the purpose of the model. Recognition of symbols is directly related to the level of abstraction represented by the symbol or icon.
4. Models are similar to a magnifying glass in that a part of a subject is placed as the focus while the remainder of the topic is obscured or omitted. Thus, the key feature of a model is to reduce the complexity of a subject, via abstraction, down to a level that can be manipulated. Creation of models is a function of experience, research, education, and intuition, with the best modelers understanding how communication occurs between people.
5. Models also serve the purpose of facilitating learning and reasoning. Cognitive Psychology represents studies into the use of "internal models" for the purpose of perception, memory, reasoning, and learning.
6. The Gestalt school holds that there are a collection of rules about human visual organization. These rules include the idea that objects placed close to one another will be perceived as a group, as well as objects that are similar in form. The Law of Prägnanz is used to describe the level of "goodness" that a particular organization of elements will take.

Tips and Traps

Discovery of the expectations of an audience for a specific model is often a trial and error experience. When considering a model form it is often best to create a prototype model from a small subset of the overall problem for presentation to the expected audience. This technique ensures that the model form that has been selected will meet the audience's need, preventing a great deal of re-work if the model form is not appropriate.

Learning is often improved by limited duration exposure that is repeated several times. A one hour session repeated several times is much better for long term retention than a single 3 hour session (e.g. interrupted study vs. "cramming"). In my experience this principle seems to hold for model creation as well. Avoid attempting to create the entire model in one sitting; it is far better to include numerous spaces between information gathering and capture sessions.

Questions and Exercises

Question #1

What is the purpose of human attention? Why does attention "wander"?

Question #2:

"Beauty is in the eye of the beholder," what does this statement mean? Is a sense of beauty innate in humans?

Question #3

It was stated that models are for perception, reasoning, and communication. What other models uses can you imagine?

Exercise #1: Problems with Communication

In the far distant future you have been tasked with the job of the first contact with an alien species called the *Snoog*. This species uses scent as the primary mode of communication and has no understanding of verbal speech. Fortunately for you, a previous research team has determined that the range of scent for the Snoog is very similar to humans, and you have access to a machine that can replicate any desired sequence or type of odorant. Consider how you would go about introducing yourself and explaining the purpose of sound in human communications.

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