Pattern Views

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> "A picture is worth a thousand words, but that is the trouble: a thousand words describe the varying aspects of any one picture."[1]

Prelude: Basic Types of Reference

Representation or reference is about the relationship between visual tokens that appear in the computer medium and the structures and dynamics of the referent domain. After Goodman (1968), reference is a generic term "covering all sorts of symbolization, all cases of standing for" (Goodman, 1984, p. 55). The token(s) itself is a perceptible mark or form within the medium for representation. The token functions as a symbol of or signifies some aspect or state or change in the referent domain. It is the mapping between the visual form and its referents, given the interests and expectations of observers, that defines correspondence.

To discuss pattern views and in particular how analogical frameworks contribute to pattern views, we must first note the three basic modes of reference. There are extensive philosophical discussions available on these types of reference and other frameworks for thinking about reference (cf., Peirce, 1931; Goodman, 1968 and others in the field of semiotics).

1. Propositional reference.
In this type of reference, there is an arbitrary relationship between token and referent (e.g., words). This technique relies on description. The token functions referentially to "tell" the observer something about the state of the domain referent -- it is a descriptor. But this relationship is mediated by an association between the visual token and stored knowledge about what the token signifies in the referent domain. Again, the relationship between the token and the domain referent is arbitrary except for this mediation by stored knowledge. Note that, in addition to alphanumeric strings, "graphic" visual forms can refer propositionally.

In propositional reference data about plant state is represented in linguistic or numerical strings that describe or tell the observer something about the state of the domain referent. The observer extracts information by reading the state descriptor. By reading I mean extracting information requires the observer to focus conscious attention on the tokens and to make contact with stored knowledge (since the relationship between symbol and referent is arbitrary).

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[1] Gleitman and Gleitman, 1992.

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Note that only the current state of the domain referent is explicitly available in the representation. Propositional reference tends to be literal; the token or token complex tells you that one thing precisely and explicitly but little more. Other states that the referent could take are implicit, and, if needed, must be recalled or searched for by the observer.

2. Resemblance or iconic reference.
In this type of relationship between token and domain referent, the token looks like or resembles the referent in some way and, critically, it evokes or calls to mind the referent object in the observer. Another label that describes this type of referential process is pictographs. Most importantly for computer-based displays, iconic reference is a kind of naming -- what am I looking at.

Building an effective icon or pictograph depends in part on the observer population's preconceptions and experience with the referent and with the visual forms used in the pictograph. A token may successful evoke the referent by resemblance for one population but not for another.

Iconic and propositional reference are similar in that each evokes stored knowledge. In propositional reference this process is mediated by “reading” the abstract symbol (the tokens), while iconic reference provides a retrieval cue based on a recognition process. Icons like propositions categorize. The graphics matter only to the degree that they help evoke the referent; in other words, iconic reference helps the observer call to mind the referent of the icon.

Icons are normally considered to refer through physical resemblance. However, even a brief examination of many icon-like graphics in use today suggests that convention plays a role as well. As Nelson Goodman puts it, “Resemblance is heavily dependent on custom and culture” (Goodman, 1984, p. 57). Thus, resemblances can be built up by convention and frequency of encounter with these conventions. This process, while an abstraction of the referent object, can be built on to create new icons. A process of shortcutting occurs over time which can lead to a loss of immediate resemblance between token complex and referent.

The observer may have to have experience with the referent object/action for a resemblance-aided recognition process to occur. One may need experience with the usual ways of picturing this object in this culture. Often icons are reasonable depictions of the referent only once one knows the item being referred to.

3. Analogical reference.
In analogical representation the structure and behavior of tokens in the representational medium are related to the structure and behavior of what is represented -- the domain referent, through some “*natural*” constraint. One common example is maps. In this type of representation perceptions about the form of representation correspond to

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judgments about the underlying semantics, for example, a relationship between two elements of the representation corresponds to a semantic property of the world. Note that if the representation is to be more than a pictograph; the visual structure must be related to domain semantics and not simply resemble the physical appearance of the referent.

A classic case contrasting representations based on propositional reference and analogical reference occurs in the computerized cockpit where the crew uses a control-display interface proposition-based representation of future flight path to instruct the flight computers (the right of Figure 1) and the horizontal navigation or 'moving map' display situation awareness relative to future flight path (the map on the left). Working through the representation on the left is a classic of the cognitive consequences of indirect correspondence—slow, effortful, deliberative, with built in failure traps, while the analog framework representation is a classic of the cognitive consequences of direct correspondence—pick up integrated status at a glance or 'check reading', captures change, future oriented, and supports failure detection.

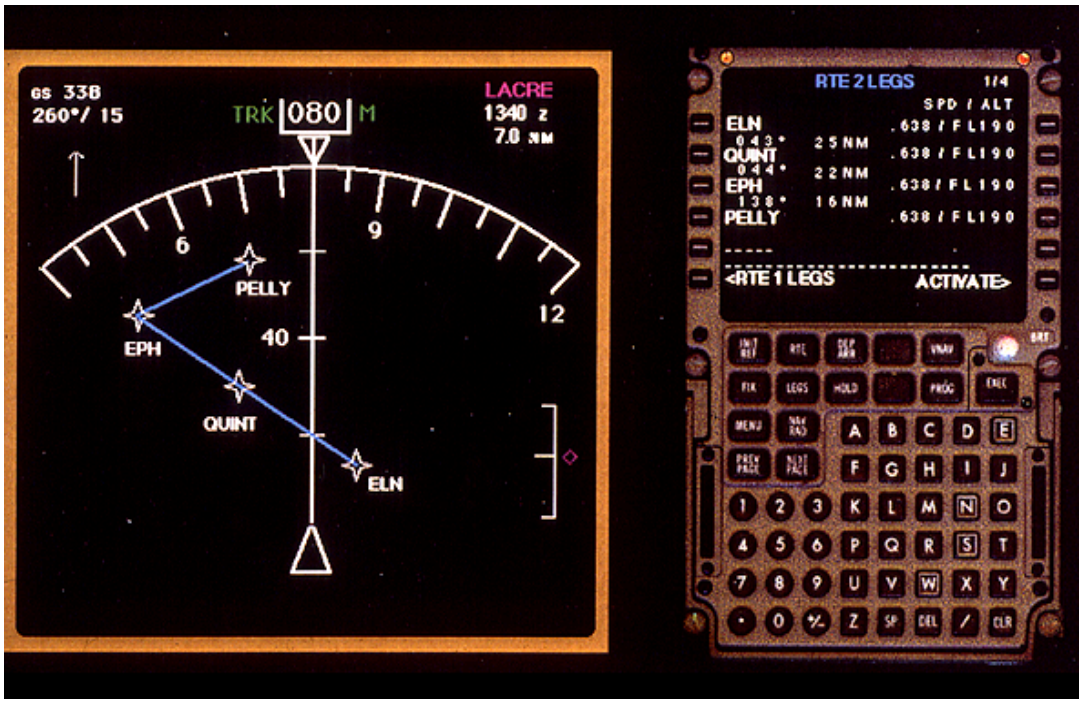

Figure x. Contrasting representations based on propositional reference and analogical reference in the computerized cockpit. The horizontal navigation or 'moving map' display provides situation awareness relative to future flight path (on the left) as compared to control-display interface based in propositions.

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Analogical representation has a variety of potential advantages for user information processing (cf., Goodman, 1968; Sloman, 1978). In part, these advantages derive from the power of organizing relationships in space as an aid to comprehension and conceptualization. The priority of space as an organizing principle is so compelling that non-spatial data are often given a spatial representation to improve human comprehension (e.g. Haber, 1981). And it is the power of analogical representation that undoubtedly contributes to the appeal and effectiveness of direct manipulation interfaces (Hutchins, Hollan and Norman, 1985).

Because the symbol and referent are not related on all dimensions, the difficult and critical design problem with analogical reference is to determine what is a useful **partial** isomorphism between the representation and the domain referent. In other words, representations are **selective**; they emphasize some aspects and de-emphasize others. This selectivity means that designers must determine what constraints between the symbol and what is symbolized should be established via techniques for analyzing the domain semantics (e.g., methods for cognitive work and task analysis) and via techniques for observing and modeling how new technology re-shapes activity in a field of practice.

Data or data relations about the monitored process are represented by **relationships** between visual tokens that appear on the display screen in analogical reference. Instead of directly noting some aspect of the state of the underlying domain, it is represented in the interface as a relationship or emergent feature of the structure and behavior of the visual elements. Thus, in analogical representation the structure and behavior of the representation (tokens and token complexes) is related to the structure and behavior of what is represented (referent process, device or system).

Thus, analogical reference is about building lawful relations in the representational medium that correspond to relations in the referent situation -- building linkages between parts of the representation or defining constraints between tokens that govern how they change relative to one another and the laws/constraints/relations that govern the behavior of the underlying referent world. For this reason some researchers have emphasized that representations built in this way are ecological in the sense pioneered by Gibson (e.g., Woods and Roth, 1988; Vicente and Rasmussen, 1992; Flach et al., 1996).

This is more than designing an individual sign but about inventing symbol systems. One finds the different levels and kinds of natural constraints operating in the referent world and then harnesses the representation to them. The representation exhibits the same constraints and relationships that the designer thinks are important in the referent world. Thus, the design at one level is an hypothesis about the referent world that is expressed as a representation of that world, i.e., a selection, a view, a perspective, one of many possible descriptions of that world.

Analogical reference is often seen as having the property of continuity in contrast to propositions which are about categorization. What are continuous functions? “An

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analog signal is continuous which means that if it goes from level A to level B, it must assume every value in between." When there are relationships between values or states A, B, and C such that, if state B is between state C and state A relative to some frame of reference, then to go from state A to state C one must go through state B. The property of continuity means that analogical reference expresses relationships relative to other values on a dimension.

In propositional reference all variability is compressed into a categorization -- it is either x or y, 1 or 0. The categorization process in propositional reference suppresses detail leaving only the categorical distinction. This is advantageous sometimes -- if the categorization process filters out irrelevant details -- and disadvantageous at other times. When the detail matters, as in continuous realms, the analogical has advantages. The categorization and loss of detail in a quantal process has a cost -- "we lose the potential for interpretation in a background" (Winograd, 1987). Hence the paradox in the epigraph that opened this section. The discussion on pattern-based views describe techniques to combine and to integrate these forms of reference in ways to take advantage of the strengths of each.

The property of continuity brings along the concept of neighborhood. Analog methods have the merit that adjacent states in the representation correspond to adjacent situations in the referent world. The effects of small changes and of gradual trends can therefore be explored. Transitions in the representation are "automatically" under the constraints that operate in the referent world, if the mapping is set up properly. Although as a corollary to this, neighboring states in the representation may be interpreted (decoded by the observer) as if they indicated conceptually neighboring states regardless of the designer's intent.

The properties of continuity and categorization are related to error tolerance and exploratory behavior. With analogical reference small changes can be explored and not produce large shifts in system state though it can introduce imprecision and noise. For propositional reference there is near-zero probability that physically neighboring states in the representation will represent conceptually neighboring possibilities. In fact, there is no concept of neighborhood in proposition reference or in representations based primarily on this type of reference. But the categorization process in this type symbolizing means that propositions are resistant to some kinds of disturbances (see Lenat and Brown, 1982 for one interesting case in the history of AI where incidental analogical and propositional relationships between representation and referent made the difference between successful and poor performance in discovery systems).

In analogical reference some relationships and changes in the representation are automatically under the constraints operating in the referent domain. Thus, the appeal of analogical representation for computer displays is in part a response to the burdens imposed by the virtuality of the computer medium. In design in a virtual medium a means to constrain the structure and behavior of the representation to the interesting aspects of the structure and behavior of the referent process for some goal and task context is necessary. Thus, using the virtuality of the computer medium for positive effect will require a role for analogical reference. This is why the design conceptual

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spaces, that is, to depict relations in a frame of reference is so basic in design for correspondence.

Correspondence or Appearance?

Usually displays are parsed into categories based on their visual appearance. We refer to tables versus graphs, guideline documents have lists of forms like pie charts, bar charts and so on, people tout their use of 'icons' to create a more 'intuitive' interface. Researchers have tried to devise studies to determine the relative value of "graphics versus tables," and review articles have tried to extract the conditions under which "graphs led to better performance than tables or no difference between graphs and tables." Finding coherence in the results has proved futile to date.

Why? -- Because these efforts confuse visual form—properties of the representation itself or appearance, with correspondence—properties of how the representation refers to the referent process in ways that help observers extract meaning.

Not all "graphics" are the same from the point of view of correspondence. Since symbolization is a three part relation -- a linkage where marks in a medium represent something for someone in some goal/task context, how a graphic refers depends upon the linkage between all three. As a result, marks in a medium that appear different—linguistic or graphic—can be used to refer or symbolize in the same way. This is common in computer interfaces where graphic elements, attributes, and forms are used to refer propositionally.

As a result, we find many interfaces that appear to use a diverse set of visual elements and attributes (hues, shapes, shading, lines, curves, numbers and words) but in fact all refer or symbolize propositionally. As a result, it is common to find interfaces and displays that exacerbate data overload because they over-rely on propositional reference and only to represent elemental data units about the referent process. This over-reliance forces the observer to engage in a serial and effortful process to collect and integrate inter-related data. Over-reliance on propositional reference and digital forms tends to

- make it difficult to put data into context,
- makes it difficult to highlight events,
- creates the problem of fleeting data,
- increase the need for the user to navigate through the virtual data space to collect and integrate related data.

This means that if propositional reference is the dominant technique in a representational system, then there is a strong tendency for the dissociation of related data to hobble observers search for meaning.

The antidote is to use analogical frameworks as the basic means for establishing correspondence and then to annotate on top of that framework propositions and icons.

Advantages of Analogs

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Analogical reference produces economies of processing in problem solving by reducing memory, referencing and computational demands.

If A represents S analogically, then relationships within S are represented in A without being explicitly named in A. Thus, modifying a diagram also and automatically changes the relationship between the modified object and all other objects in the picture. The effects or consequences of the change do not have to be calculated; they can be directly observed.

Using a map one can get to all of the relationships involving a certain place through a single access point; by contrast, each part of the region would have to be referred to many times, in a large number of statements, if the same data set was expressed as a description (where the structure of the representation is independent of the structure of what is represented). As a result, it is easier with a map to access any part of a mutually relevant data set given any one element of the set.

In representations that make effective use of analogical reference, non-useful possibilities are inherently difficult to follow and useful possibilities are easy to follow because constraints in the semantics of the domain (including causal and consequential relations) are expressed as constraints in the syntax and allowable transformations of the representation. For example, it is harder to invent a drawing of an impossible object than it is to describe an impossible object.

All of the above help reduce the dependence of performance on user working memory capacity because the analogical representation acts as an external memory or provides the contextual retrieval cues (e.g., Norman and Bobrow, 1979; Norman, 1988; Zhang, 2000).

In contrast propositions, as literal and categorizations, tell you precisely and explicitly one thing but little more. A proposition can indicate one state but leaves all other states that the referent could take implicit (and a memory burden for the observer to meet to achieve correspondence). Relationships between states are absent or downplayed (though language does contain relationship/pattern words such deteriorating). Propositions do allow for direct movement from any one place to any other without needing to go through intermediate regions, if one knows the indexing code.

Poly-Reference and Orchestrating Forms of Reference

The basic types of reference, analogical, propositional, and resemblance, are articulated in various ways and in various combinations to achieve correspondence when creating a pattern view as a coherent view into a process. It is not that one type of reference is the correct choice; it is not that there is some matrix of forms of reference by tasks that can be used as a compilation of knowledge on graphic design. The designer uses these types of reference as resources to achieve correspondence.

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This is the case because computer-based displays and systems are **poly-referential**. A single display is very likely to use several different kinds of reference intermingled together to achieve the desired effect.

For example, a designer uses a filled versus hollow graphic form to represent a valve and whether it is open or closed. This simple form uses at least two forms of reference. The graphic is intended to function as an icon to indicate that the object being referred to is a valve or a class of valves (say flow control valves). The hollow or filled character of the form refers to the state of the valve propositionally. Add an alphanumeric string to the graphic to represent the specific valve in question and we have added another use of propositional reference to the form as well.

Another example of the poly-referential nature of graphic forms occurs with a block of displayed text. As a linguistic marks this is clearly propositional reference. But as many studies of reading have shown and good typography designers understand, there are analogical cues in linguistic material. Remove the word shape cues by presenting the linguistic material printed all in capitals or in certain type styles and reading fluency and comprehension can be affected very significantly.

We can see the multiple layers of reference also in the flickering of the needle on a pressure gauge in the context of measuring blood pressure in critical care medicine. Multiple cues are present. The position of the needle relative to the reference scale is a type of analogical reference (indicating average pressure). The movement of the needle also refers analogically to direction and rate of change. The flickering of the needle also can be a type of analogical reference indicating whether the gauge is working or not.

Part of the representation design process is to understand something about how to orchestrate different techniques to achieve more direct correspondence.

Contrasting Analogs and Propositions

Typically, we oppose analogs and propositions as if they were exclusive ways of representing, e.g., choose either an analog or digital watch. However, as in the epigraph to the next section indicates, a designer "does not really have a choice between two ways of representing information; often both are necessary. The question is where to put them." What is interesting is that the same property is both an advantage and in other circumstances a disadvantage.

Consider these commonplace characterizations of analog vs. digital:

Digital is precise; analog approximate: No, propositional is literal, indicating one thing, and only one thing, at a time; while analog encodes multiple relations (consider the EKG example).

Analogs are complex; propositions simple. Graphics that represent through analogical reference appear complex in part because they have non-atomic components. In propositional reference the token-symbol and referent stand in a one-to-one

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relationship. In iconic reference the token-icon and the thing identified also stand in a one-to-one relationship. When there are many pieces of data to be conveyed, the danger in the case of 1 to 1 relationship of representation and datum is a piecemeal representation that imposes all of the burdens to integrate related data on the observer (indirect correspondence).

Propositional requires directed attention. The positive part of this is that the reference says what this is this and demands for one to look at this. But it is also negative – when many things are competing for attention there will be overload. Analog reference supports peripheral pick up. The positive part of this is that there are multiple things which can be indicated (a rich form of reference). However, the negative side of this is that when many relations are present, it is not obvious which relations will be noticed, attended to, and processed.

Digital requires no decoding; analog has to be learned: No, both have interpretative burdens but where they fall depends. Learning to see is the cost of analog reference. With propositional reference there is a reading cost each time the tokens are decoded, plus one must learn the language.

Successful design orchestrates multiple forms of reference. The basic types of reference are tools for analysis of differences in correspondence. The value is not that there is a simple and single "right" answer. Rather understanding aspects of these three basic types of reference help one break apart how the marks may function for observers leading to new ideas to be explored and new questions to be posed.

A Technique for Analyzing Reference

One useful technique is captured in the epigraph to this chapter. To analyze how a graphic represents try to substitute words for the graphic. Can you replace the graphic with a single word or two? What is lost in this substitution? Are there many relations captured in the graphic which require lengthy exposition in words?

If there is no more information about the referent in the graphic than in the words, then the graphic is likely to refer propositionally (but check to see if the categorization is iconic). If to re-represent the graphic in words requires a lengthy linguistic string, then it is fair to suspect that the graphic refers analogically.

Representing Data or Representing Relations?

Data become informative or meaningful based on their relationship to larger frames of reference and the interests and expectations of the observer. The key is -- relationships are informative.

Typically, the basic unit of display is each individual piece of data—what is known as a one datum/one display structure (Goodstein, 1981; Woods, 1991; Vicente and Rasmussen, 1992). The cognitive processes necessary to collect and integrate these data to form higher order assessments go on in the head of practitioners—indirect

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correspondence. Piecemeal display is common in the computer medium as each piece of data is indicated by its own mark(s). The representation is 1 to 1 -- for each thing to be represented there is a single token or token complex in the medium. Observers directly see the markers and infer the relations in their head. The question is what are the kinds of cognitive activities that are needed to go from markers to relations and where do bottlenecks occur.

It is easy, when design is based only on data availability and when computational constraints dominate,[2] to create computer based systems with this one datum/one display structure. But think about an alternative way to organize representations. One could make kinds of relations the basic unit of display. This is the power of the computer medium from a representational point of view. The observer directly see relations, where specific tokens in the medium serve as markers for defining relations.

For example, consider the algebraic expression, x=2y+3, or the Cartesian plot of this relationship between x and y. Both complexes of tokens express a relation; the specific marks in either of these representations function to define the relation. In one case, the equation, the relationship is abstract; to interpret the relation encoded by these marks the observer has to know the larger symbol system and to activate knowledge about that symbol system. In the other case, the Cartesian plot, the relationship is directly visible. The observer still has to know about how to interpret these marks based on a larger symbol system (e.g., watch children being instructed in creating and interpreting Cartesian plots in math class). But the relationship is directly and externally available which can effect the kinds of reasoning that are easy or more difficult to do about the relation.

In both cases the observer has to use knowledge albeit different knowledge, to move from one expression of the relationship to the other.

To assess how direct or indirect is the correspondence of referent, representation and observer, test if the following criterion is met: the observer directly 'sees' or extracts the higher order relation and the marks function only as the carriers of that relation. In other words, does attention go to the carrier marks from which one builds the relation with cognitive effort or does attention go directly to the relationship which happens to be specified by these particular marks. For the latter to occur learning has to take place but this is perceptual learning -- learning how to see the marks as symbols for a referent process.

Different Types Of Reference Implicate Different Types Of Learning

The content of a proposition is given as the categorization itself. The proposition tells you the state of the referent, if you know how to read it. However, the meaning of the

[2] For example, it is often much easier computationally, particularly in the development environments available to those who would realize a design in the computer medium, to build a virtual data space by assigning each piece of data a single form and placing it in a single 'home.'

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propositional is indirect -- it depends on other knowledge and on knowledge of the larger symbol system for one to determine what the categorization means.

For analogical reference, one must learn how to see the relationships in the representation as relationships in the referent—perceptual learning. Once this skill has been acquired the observer "directly" sees the relationships so encoded (Mandler, 1992). This appears to be a mentally economical process when many cognitive demands can occur packed in time.

Do you have to learn how to read analog frameworks ? Yes—through perceptual learning experiences which are unique to experiencing how the representation captures relationships and events in the referent (by playing domain events and scenarios through the representation as the observer practices finding the meaning in the scenario).

Do you have to learn how to read digital forms? Yes—one has to learn the language or code (if you know the language, you just read out the results). This leads people to try to design a universal language using graphic elements. This has turned out to extremely difficult (e.g., see Goodman's 1984 analysis); after all the evolution of a language is a long, distributed and ongoing process.

Do you directly see information in analogs? If prior perceptual learning has occurred so that the observer recognizes the domain signature or pattern in the analog.

Do you interpret propositions? Yes, reading requires activating knowledge about the coding system and applying that system to interpret the otherwise arbitrary tokens. However, this process can get to be automatic and fast through over-learning the coding system and practicing reading (applying the coding system to interpret token strings).

Attribute Binding and Object Perception

Perceptual systems produce the result where people focus on objects and relations and are only secondarily aware of the attributes (the carriers) that specify those relationships.

> "I am standing at the window and see a house, trees, sky. And now, for theoretical purposes, I could try to count and say: there are . . . 327 nuances of brightness (and hue). Do I see "327"? No; I see sky, house, trees."
>
> Wertheimer, 1923; translated by N. Sarter

Normally we see or are aware of the end result of perceptual processes -- an organized field of objects and relations. Although, we can direct our attention to these attributes or external factors may force attention to those attributes. We see a figure against a ground. We see one object and its relationship to others (spatial position, causal or intentional relations). I will refer to this property of human perceptual systems

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functioning in natural perceptual fields as attribute binding. An object serves to integrate a variety of attributes into a coherent concept. Attributes are processed, relatively, to help parse the perceptual field into a set of coherent objects at different scales. We 'see' the objects; processing of attributes occurs in the context of building that larger structure.

Another aspect of attribute binding as indicated in the quote from Wertheimer is that observers use all of the attributes and relations, not just the ones that you think about as designer, to organize the perceptual field into a coherent scene of inter-related objects.

What will count as relations and attributes is intrinsically connected with choices concerning the representation system for establishing correspondence. Whether a physical property is an attribute or a relationship can only be assessed once a particular representational system has been proposed. The designer of a representational system defines what will be attributes and what will be captured through relationships between these carrier marks.

Then, how does all of this relate to propositional and analogical reference. Propositional and analogical are different in this: propositional reference provides a specific attribute that correspond to the referent state. Analogical reference builds a relational property that changes in correspondence to the referent. In the former, the attribute can be directly apprehended but at the cost of minimizing any relational properties in which it participates. The latter (analogical reference) represents the base property as a relational property in the representation, and it supports portrayal of the relations in which that property participates. But the relation may not be directly specified by specific marks; only by relations between such marks. Note this is complicated to express because the properties of the referent world can be attributes or relational and the representation can be attributes or relational and then there are the mappings between the two.

The visual world has a natural hierarchical structure where objects at one scale are parts at another scale, etc. Again the virtuality of the computer means that these relationships are not captured in a representation automatically -- the designer must constrain the relationships among the tokens in the computer medium to capture the hierarchy of part-whole relationships resident in the referent world. How to do this is both the opportunity and the penalty of the virtuality of the computer.

Form And Content Are Not Independent

However, it is also fundamental to appreciate that relations and carriers, form and content mutually interact -- they are not independent.[3]

[3] Design for data availability or the context free approach to HCI assumes that form and content are independent. For the context bound approach which is taken here, it is axiomatic that form and content interact. Furthermore there is a good empirical and psychological basis for this stance.

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The conventional wisdom on the form and content of information displays is that the three questions -- what to display? how to display it? when to display it (or when to examine it)? -- are independent of each other. In the representation aiding design approach these three are inter-tangled.

In other words, one cannot make a sharp distinction between the medium of representation and the message represented (e.g., Kolers and Ostry, 1974). Media do not act as passive carriers for independent messages. Psychological studies are replete with examples that show, for human cognition, there is a tight coupling between form and content (e.g., Kolers and Ostry, 1974; Gonzalez and Kolers, 1982). Remove typographical shape cues in text (e.g., by making the text all capitals) and reading comprehension is impaired. Change the perceptual characteristics of a visual stimulus and, through changes in perceptual organization, visual search performance is radically affected (the pop out effect). The medium or carrier of meaningful messages is not independent of the meaning that is carried for the human cognitive system. This property (which I believe applies to all cognitive systems, distributed, human and machine) constrains the development of computer-based representations. Factors about the marks made in the medium for representation are the resources and carriers of meaning . The details at the interface level can make all the difference about how an aiding concept actually affects human performance.

Parts exist not as simply components of a larger whole (e.g., as linearly added components), rather the parts exist as carriers of their function within the whole (Goldmeier, 1982). Meaning attaches to the whole, to the end product of the grouping. Since elements at whatever level function as carriers of larger wholes, "the process of organization reduces the stimulus data ... it groups large number of picture elements into a small number of seen objects and their parts." "What is perceived ... are the units and subunits, figures on a background, which result from perceptual grouping" (Goldmeier, 1982, p. 5, emphasis added).

Unlike attributes, relations can only be ascribed to an object by reference to other attributes or relations. Our job in designing Pattern Views is make apparent the relationships which are carried by various marks –relationships as the basic unit of representation, and avoid designs where the elements and marks themselves become the focus for the observer.

Analogical Frameworks

> "Our most familiar and least questioned cliche prevents us from thinking more deeply about the often awkward relationship between pictures and words. A writer does not really have a choice between two ways of representing information; often both are necessary. The question is where to put them." [4]

[4] Myron Krueger, 1983, p. 212.

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In analogical or analog frameworks data about the referent process is represented by *relationships* between visual tokens that appear in the display medium. Instead of directly noting some aspect of the state of the underlying domain, it is represented as a relationship or emergent feature of the structure and behavior of the visual or perceptible elements.

The unit of representation used in analog frameworks is the **relationship** between an indicator and some reference scale or, more broadly, some **frame of reference**. An analog framework represents through the **movement** of an indicator relative to landmarks within a frame of reference (an analog always carries a frame of reference with it implicitly or explicitly).

An analog framework represents through the *movement of an indicator relative to landmarks within a frame of reference.* The indicator/framework relationship is used to show the state of a focal or primary datum against a background of the set of possible states and references values.

The relationship between indicator and frame of reference include several factors:

(a) how the indicator moves relative to this frame and specific referent values/states within the frame of reference—dynamics (for example, the analog horizontal navigation display in the left panel of Figure x is called a moving map as it updates position, e.g., heading scale at the top, relative to the future flight plan);

(b) the type of frame of reference, the grain of analysis within the frame of reference, what points or regions define landmarks, and the level of abstraction;

(c) the fact that there are usually multiple relevant frames of reference -- juxtaposition of multiple frames of reference (for example, in the moving map display (for example, the analog horizontal navigation display in the left panel of Figure x juxtaposes 3 domain relevant frames of reference in the representation—the plan, time, heading).

Thus, in analog frameworks information about the referent is encoded as dynamic *relationships* between visual tokens. This allows for a rich set of encodings in an analog framework. There can be, if designed properly, a multiplicity of cues, i.e., a kind of parallel presentation of data. Analog frameworks include dynamic relationships -- the movement of the indicator relative to landmarks in the frame of reference.

Analog frameworks can show *in parallel* the current value or state against the complete set of values or states that the referent could take within a frame of reference. The frame of reference serves as an organizing principle that establishes a conceptual space or map-like structure. This is one way to follow the basic principle of putting data in context, and it represents a different strategy for coping with data overload -- organization (Tufte, 1990). Showing state against a frame of possible states also

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illustrates how properly designed analog frameworks can maximize the potential of the external representation to serve as an external memory for the observer.

Usually, there are several frames of reference relevant to the property in question. The designer must determine how to connect the multiple frames of reference. Then an indicator can represent via its position or movement relative to any of these multiple frames in parallel.

It is important to maintain the distinction and mapping between the frames of reference that concern the referent process (e.g., the flight plan, time, and heading are three domain frames of reference in the aviation case in Figure x) and the constructed frame of reference in the representation. The designer constructs a frame of reference using space extent in the medium of display and spatial relationships between token sets (in the aviation example of the horizontal navigation analog map, the constructed frame of reference is defined by the space created between the fixed 'own plane' marker (the triangle at the bottom center), the heading scale curving across the top, and the current heading line (the vertical line connecting the own plane marker. Also note that the relative movement between the heading line and the heading scale reveals the inherent dynamics of the process (changing heading).

In contrast representational systems built up from propositions consist of a assemblage of elements. Finding and integrating elements to extract relationships, higher order assessments, and assess change becomes a deliberative and effortful cognitive process—building low or indirect correspondence into the fundamental character of the representational system. Attempts to find ways to organize the assemblage of elements easily become arbitrary, narrow or metaphorical. Instead, models of the referent process should be used to define the organization, make relationships and higher order concepts the unit of organization, and define the frames of reference essential to analog representations.

To be effective in designing analog frameworks, one should check

- Have all of the states/behaviors of the referent property or process represented in the indicator/frame relationship (for example, computer based analog displays of sensor values often forgot to include states such as offscale or failed sensor).

- Is the frame annotated with all of the relevant reference values or landmarks within a frame of reference (defining the context for interpreting the state or behavior).

- Check how the dynamics of the representational components of an analog framework (how indicators move relative to frames and landmarks) capture and reveal all of the meaningful changes and events in the referent process.

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- Is the framework annotated with icons or propositions as identifiers, propositions to provide precise reference, and highlighters to draw attention to specific events, changes, or states?

Dynamic relationships in analog frames
Remember there are three basic representational components to an analog form: the indicator of actual state or value (current, past, future), one or more frames of reference (often the range of possible numerical values), and specific reference values/states within a frame of reference (for example, a target value or range).

A wide variety of dynamic relationships are possible among the three basic components of an analog frame—the indicator of actual state or value (current, past, future), one or more frames of reference (dimensions of possible relationship), and specific reference values/landmark states within a frame of reference (for example, a target value or range).

For example, the state indicator can move against a fixed frame of reference (classic analog meters). One could add fixed reference states/landmarks or moving reference values (a classic pursuit display in cockpits; Roscoe et al., 1981).

If the reference state is a dynamic state in itself (from an algorithm or inference, showing a moving state indicator against a fixed reference scale creates the classic compensatory display (see Roscoe et al., 1981 for aviation examples).

The analog horizontal navigation display in the left panel of Figure x illustrates the case where the current state is fixed—the current location of your plane does not change but is always at the bottom center, to make the future flight path the focus—where you are going.

Summary
Notice how the effective use analog framework brings the 4 basic principles for correspondence into practical design: discover meaningful frames of reference, put data into context of related data, reveal events, and highlight contrasts. This allows us to specify one basic means to design of pattern views:

- Create an analogical field or conceptual space as a base—the frame of reference in the representation corresponds to meaningful dimensions of models of the referent process.

- Capture reference and contextual states as landmarks in the framework.

- Make dynamics of the referent observable in the relative movements and changes in the indicator/frame/landmark space.

- Overlay propositions to specify the state of the various pieces of the larger picture.

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These principles are well illustrated in the analog horizontal navigation display in computerized 'glass' cockpits (left panel of Figure x).

These principles help meet one of the basic goals of establishing direct correspondence via analog frameworks—that is, to shift the basic structure of a representational system from a one datum/one display structure (or element organization) to a structure based on relationships.