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The Foundations of Experimental Semiotics: a Theory of Sensory and Conventional Representation

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Experimental semiotics is defined as the elucidation of symbols that gain their meaning by being structured to take advantage of the human sensory apparatus. In making this definition a distinction is made between languages which are fundamentally *sensory* and those which are fundamentally *conventional.* Experimental semiotics is concerned with the former. Sensory representations are good (or bad) because they are well matched to the early stages of neural processing of sensory information. They tend to be stable across individuals and cultures. Conversely, conventional languages gain their power from culture and are dependent on the particular cultural milieu of an individual. This theoretical distinction provides a basis for testable predictions about the ease of learning for languages in the two classes. The examples given are mostly based on the visual modality, but the distinction also applies to other sensory modalities. Methods for testing claims about sensory versus conventional languages are discussed.

Introduction

THE STUDY OF symbols (signifiers) and how they convey meaning (signified) is the basis of semiotics, the field of study originated by the French philosopher and linguist Saussure. This discipline has been mostly in the purview of philosophers, and those who study the validity of symbols based on their intuitive judgment with little or no empirical support. Thus the entire masterwork of Bertin [1] on the way graphical marks convey meaning is, for the most part, based on his subjective judgment, albeit highly skilled and sensitive judgment. Many claims are made for visual languages being easy to learn and use, although in certain cases these languages appear to be only visual to the extent that a written document is visual. It can be just as hard to learn to read some diagrams as it is to learn to read a written language. The purpose of this paper is to stake out a theoretical framework wherein claims about visual languages may be pinned down and forced to make testable predictions.

The basis of the argument made here is that some aspects of symbols derive their expressive power from being well designed to stimulate the sensory mechanisms, while others derive their expressive power from the social interactions which determine by convention the denotational significance of symbols. It is argued that sensory aspects of symbols are appropriate subjects of a science of experimental semiotics which can employ the full rigor of the empirical techniques developed by psychophysics and sensory neuroscience, while the latter conventional aspects of symbols are appropriate subjects for a very different interpretive methodology derived from structuralist social sciences. The claim is also made that some of the properties of

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sensory symbols are amenable to the usual criteria governing scientific theory and that knowledge gained in this way will be valid across cultural boundaries.

This distinction between sensory and social symbols of symbols has practical consequences. It is not worth exerting a huge amount of effort carrying out intricate and highly focused experiments to study something which changes as computer interfaces evolve in society. Yet much wasted effort is expended on studies of things which are properly grounded in corporate culture, inappropriately applying the methodologies of cognitive psychology and psychophysics. For example, much of the work on teleconferencing has ignored the subtle dynamics of business meetings in particular and human dialogue in general and has been a huge waste of money and effort.

There can be no stable all-encompassing theory of human–computer interaction, as there are few parts of human cognition which are not relevant to a complex program such as a computer-aided design package, and societies continue to evolve, with machines as one of their central ingredients; this year's optimal interface will not be optimal next year. On the other hand, there are aspects of perception which appear to be constant for all individuals, and even across species, and these are worth the effort of careful experimentation because the results obtained are valid across cultures. Moreover, these results can be directly applied to the design of symbols. The kinds of results I have in mind are such mundane things as the luminance contrast threshold for discriminable text, the audible tone range as well as more subtle things such as the different ways in which luminance and chrominance information is processed by the human visual system. Results such as these are precious because of their generality and because studies of these aspects of information can properly form the basis of a discipline of experimental semiotics. In this paper I present the justification that there can be such a discipline, outline the scope and methodology of such a discipline, and counter objections that the entire enterprise is ill founded—principally the objection that *all* aspects of symbols are culturally determined.

The most profound threat to the notion that there can be such a discipline as experimental semiotics comes from those who would insist that all symbols are conventional; that is, they are established by social interactions. Although the structuralist philosophers and critics disagree with one another on many fundamental issues, they are unified by a general insistence that symbols must be interpreted in their social context. Truth is relative to this social context, and meaning in one context may be nonsense in another. Thinkers such as Claude Levi-Strauss, Barthes and Lacan condemn the cultural imperialism and intellectual arrogance implicit in applying our intellectual standards to characterizing other cultures as 'primitive'. According to the most extreme version of this view the work of the student of cultures is so fatally prejudiced as to render most interpretation meaningless, or at least extremely evanescent (see, for example, Foucault [2]). The force of these arguments, and their relevance to the study of user interfaces, is undeniable. It is clear that many aspects of user interfaces can only be understood as artifacts within a culture. A trash can as an icon for deletion is meaningful only to those who know how trash cans behave.

2. Pictures as Sensory Languages

The assertion that there can be such things as sensory languages faces some stiff opposition. There has been a debate over the last century between those who claim that pictures are every bit as conventional as words and those who allow that there may be a measure of similarity between pictures and the things they represent. This debate is crucial to the theory presented here since if even 'realistic' pictures do not embody a sensory language then it seems impossible that claims about diagrams can be supported. The nominalist philospher Nelson Goodman [3] has delivered some of the more forceful attacks on the notion of similarity in pictures.

> 'Realistic representation, in brief, depends not upon imitation or illusion or information but upon inculcation. Almost any picture may represent almost anything; that is, given picture and object there is usually a system of representation, a plan of correlation, under which the picture represents the object' (p. 38).

For Goodman realistic representation is a matter of convention, it 'depends upon how stereotyped the model of representation is, how commonplace the labels and their uses have become'.

These statements, taken at face value, invalidate any meaningful distinction between sensory languages and conventional languages, since they imply that all belong to the latter category. The evidence against this philosophical view comes from a number of scientific sources. In an heroic experiment, researchers Hochberg and Brooks [4] raised their daughter nearly to the age of two years in an environment without pictures and found that she was able to recognize depicted objects without instruction. Other cross species and cross cultural studies strongly support the idea that pictures are not simple arbitrary conventional codes (see Kennedy [5] for a review). How line drawings are able unambiguously to represent without training is still not fully understood, although the most likely explanation is that at some stage in visual processing the depicted outline of an object and the object itself excite similar neural processes [6, 7]. This view is made plausible by the ample evidence that one of the most important products of early visual processing is the extraction of linear features in the visual array.

It would be naive to deny the role of convention in representation; even with the most realistic picture or sculpture it is very rare for the artifact to be mistaken for the thing which is represented. Nevertheless, given a sensory representation, it may take the most minimal diectic gesture for the denotation to become clear, or it may be amply clear from the context of the representation. Very few languages may be entirely conventional (although some of the languages of mathematics may be close approximations) and none may be entirely sensory. However, the sensory vs. conventional distinction is valid and important, and of great practical significance. The importance of sensory components of visual languages is that these are exactly those components which need not be learned by anyone. This at least is the claim.

The theory of sensory languages is based on the idea that the human visual system has evolved as an instrument to allow us to perceive the physical and biological environment of the world. This is a philosophical Realist position expounded at length by J. J. Gibson [8]. This view holds that the physical world exists independently of the conceptual framework as we have developed to describe it, and it also holds that perception is veridical for the most part, with the exception of illusions.

Because of evolution, sensory processing structures exist which are tuned to detect aspects of the environment, and because of this the basic elements of a sensory 'grammar' are often based on structures which are physically present in the world.

Thus, for example, since objects in our world tend to have solid, well-defined boundaries, we are well adapted to perceiving the shapes and positions of surfaces in space. The human visual system uses a luminance 'channel' to perceive the shape of a surface from shading information. Whereas if this same information is presented through a purely chromatic (e.g. red–green) signal then the information is perceptually meaningless [19]. It is rules such as these (that shape from shading information can only be understood through a luminance modulated signal) which constitute the sensory grammar of perception, and any serious set of guidelines for information display should be grounded in such rules. Another good example of hard wired, low-level coding by the brain, is the existence of the unique hues red, green, yellow and blue, which are specific across a huge array of languages [10], are important psychophysically [11, 12] and whose physiological basis in the form of neural wiring is quite well understood [13].

We may also presume that the rules of gestalt perception derive from early visual processing, and so the pattern in Figure 1(a) is always seen as the wavy line overlying a rectangle [Figure 1(b)] and not as the objects in Figure 1(c). The object in Figure 1(d) must also be seen as unitary unlike the object in Figure 1(e) because of similar rules. The rules underlying a gestalt perception presumably derive from the mechanisms which have evolved for object perception (see Shepp and Ballesteros [14]).

The problem of representing the shape of a terrain (or other univariate map) has been solved in a large number of different ways using both sensory and conventional coding schemes which nicely exemplify the difference between conventional and sensory symbolic representation. The following series of examples start with the most unambiguously sensory and end with the most unambiguously conventional, leaving out many representations in between such as the use of contour lines.

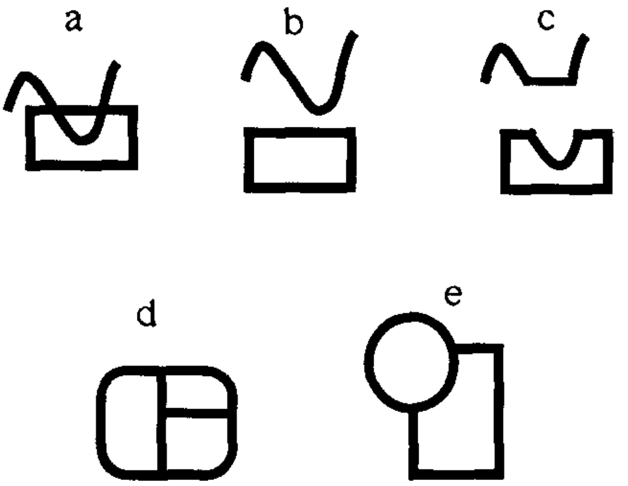

Figure 1. The pattern in 'a' is perceptually decomposed as 'b' and not as 'c'. The object in 'd' is perceived as unitary (although subdivided into regions) unlike that in 'e'

1. A physical model: a physical plaster model is sometimes the ultimate resource for terrain representation. In this case, the same sensory mechanisms are used to visualize the shape of the landscape as would be used observing the shape of any relatively small-scale part of the environment. The only convention involved here is the change of scale, and the fact of representation itself. No explanation is needed to convey the fact that peaks represent peaks, and valleys represent valleys, the shape of the model is the shape of the terrain and no learning is required to understand that shape.
2. Shaded computer graphics rendering in an artificial virtual environment: an alternative to a physical model is a computer graphics representation in an artificial virtual environment. The key element to this representation is that the image dynamics are arranged so that the subject has the illusion of moving with respect to the landscape [15]. Tactile feedback is a current development. As in (1), the sensory mechanisms are those used to perceive the everyday environment.
3. A map which is pseudo-colored by height: this case is a complex blend of the conventional and the perceptual. It has been shown that if the colour sequence is chosen so as to increase in luminance monotonically (or lightness) with height then the perception of the form of the surface is enhanced [16]. This can be related to the evidence cited earlier that form perception is carried preferentially by the luminance channels of the visual system, and not the chromatic channels. However, discovering shape from such maps is also conventional and requires considerable skill in interpretation.
4. Random spot height values displayed as numbers: displaying height values as printed numbers on a map seems completely conventional, and is obviously a poor method for displaying shape information. However, a considerable sensory element remains, namely the topographic correspondence between the 2-D spatial arrangement of the image to the 2-D spatial arrangement of the represented terrain.
5. List of spot height values: a table of latitude, longitude and height positions is a conventional representation of a surface which has no obviously sensory components.

A different kind of map, the kind that represents a bus or subway system, is a better example for demonstrating the role of gestalt factors in visual language design. Clearly, such classical gestalt principles as good continuity, closure and connectedness are extremely important in creating a map in which a given route is perceived as continuous and distinct from other routes. In so far as the map uses such principles it can be said to be sensory. However, in the use of color coding to label different bus lines the map may be conventional.

Because the examples given so far relate to color and shape perception, it should not be thought that the domain of sensory languages is restricted in this way. There are other sensory languages covering all aspects of perception: in the domain of animation Michotte [17] did extensive work on what induces the percept of causality, Lethbridge and Ware [18] showed that movements based on very elementary behavior functions are capable of exciting percepts of social interaction and Rimé *et al.* [19] showed that similarly simple percepts can be valid cross-culturally. In the domain of sound perception what Gaver [20] calls iconic perception accords most closely with what has been called sensory here (Gaver has a much broader concept of the sensory).

3. Properties of Sensory Languages

An entirely different kind of theory is required to account for interfaces which are primarily sensory and those that are primarily conventional. The former can be derived from theories of perception which apply to 'the human visual system' or even 'mammalian visual systems' in some cases, whereas the latter must necessarily be social in nature, since conventional languages are rooted in society. Some of the important properties of sensory representations are listed below.

Resistance to instructional bias. Many sensory phenomena, such as illusions and effects such as cognitive contours, persist despite the knowledge that they are in fact illusory [21]. Figure 2 shows the effect of an illusory transparent overlaying square which is perceived as present and as illusory at the same time.

Understanding without training. A sensory language is one for which the significance is immediately perceived without additional training. Once the primary diectic gesture is understood, indicating that the sound or image is *intended to represent something*, then what is represents should be clear without further instruction. Moreover, it will be understood across cultures and across age groups.

Sensory immediacy. Since the processing of conventional languages is usually assumed to be a higher level of processing, built on top of the sensory preprocessing, it will usually be the case that the sensory can be understood faster than the conventional. However, this will not necessarily be true for highly learned languages, such as the language of everyday speech.

Cross cultural validity. A sensory language can be understood across cultural boundaries. These can be national boundaries or the boundaries between different user groups.

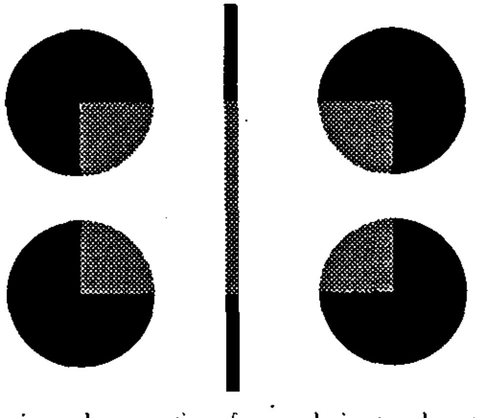

Figure 2. This pattern gives rise to the perception of an overlaying translucent rectangle which appears to overlay and fill in between the discs and the vertical bar. The fact that the illusion appears illusory—the observer is quite aware that, in fact there is no overlying rectangle—does not make it go away

4. Testing Claims of a Language Being Sensory

An entirely different set of methodologies is appropriate to the study of representations of the sensory and conventional types. In particular, the methods of classical psychophysics will be useful. A list of research techniques is given below.

1. *Psychophysics: discovering sensory dimensions.* The methods of psychophysics have successfully elucidated many of the fundamental sensory processing mechanisms. In the color domain these include trichromacy theory and opponent processing theory [11, 12]. These theories existed long before neurophysiological studies revealed the receptors and neural wiring which underlies the early stages of color processing. Psychophysical techniques are normally used for studies intended to reveal the fundamental early sensory processes. It is often assumed (sometimes wrongly) that instructional biases are not significant in these studies and extensive studies are often carried out on only one or two observers. For the most part this is not a problem and results obtained more than a cenury ago by such eminent researchers as Helmholz have stood the test of time. Psychophysical methods are ideal for discovering the important sensory dimensions of color, visual texture, sound, touch, etc., and more than a century of work already exists: the classical work on color has long ago discovered the basic dimensions of color perception. One of the contributions which future work may make is the elaboration of visual texture perception as applied to the problem of representing information on maps. We have made a beginning [22] but much remains to be done. The fundamental goal of such studies is to discover and to model the characteristics of the early visual processing channels, and to apply the results to the problems of information display.
2. *Psychophysics: resistance to instructional bias.* By deliberately attempting to influence psychophysical judgments by training it is possible to determine the resistance of the phenomena to instructional biases and thereby gain information about the interrelationships of sensory and conventional processing. Highly resistant phenomena are likely to be sensory—that is, be based on early visual processes.
3. *Psychophysics: testing sensory immediacy.* Since sensory languages are based on early visual processing it should be possible to show that these are processed first. The techniques which are used to study 'preattentive processing' are relevant here [23, 24]. In these studies certain properties of stimuli have been shown to be processed in parallel and regions distinguished by these properties exhibit the 'popout' phenomena. An example is the visual search for instances of the number 3 in a page of other digits. A serial search is necessary. However, if the target 3 is colored red and all of the others are not then it will be immediately visible. Thus the kind of shape recognition required for the task is serial whereas the color processing is parallel. The determination of which properties of visual patterns are preattentive has obvious applications in creating guidelines for the design of symbols to denote regions of maps.
4. *Psychophysics: testing existing theories using stimuli from an applied problem domain.* This is the mundane task of applying a result obtained in the laboratory under highly controlled and restricted stimulus conditions and determining whether it applies in the context of a practical task. For example, theories of

simultaneous color and luminance contrast have been shown to apply to the reading of pseudo-colored maps [16]. A large amount of the work in human–computer interaction necessarily falls into the category of bridging the gap between applications and theory.

5. *Phenomenology*: *testing sensory immediacy*. Subjective reports of perception can be very useful in gaining quick information about how vivid an impression is. However, this information must always be treated with caution since instructional biases can easily have a large effect.
6. *Cross cultural studies*: *testing universality across cultures*. Studies such as the famous Berlin and Kay [10] study of color naming are a valuable test of the universality of a coding. However, the homogenization of world culture is making this resource less and less accessible.
7. *Child studies*: *testing the importance of learning*. By using the techniques of behaviorism it is possible to discover things about a child's sensory processing even before that child is capable of speech. It is also possible to gain useful data from five year-old children, who presumably have all of the basics of sensory processing in place, but still have a long way to go in learning the conventions of our culture.

5. Conventional Representation

The purpose of this paper is to elucidate the sensory more than the conventional. However, a few words on the conventional are needed to describe the area of knowledge that experimental semiotics cannot hope to encompass. Culturally embedded aspects of user interfaces change across cultures and over time. What was once strange and in need of explication becomes the basis for elucidating metaphors as computers become one of the most powerful sources of symbols in our society. Thus, the mouse, menus, pointing method of interaction, can in many cases be the starting point for learning interaction techniques, functioning as aids, rather than drains on cognitive resources.

The highly focused narrow questions asked by psychophysics are wholly inappropriate to answering questions about computer interactions which are tightly embedded in culture. Instead a more appropriate methodology may derive from anthropologists such as Clifford Geertz [25] who advocated 'thick description'. This approach is based on careful observation, immersion in the culture and an effort to keep 'the analysis of social forms closely tied... to concrete social events and occasions,... and to organize it in such a way that the connections between theoretical formulations and descriptive interpretations [are] unobscured by appeals to dark sciences'. In other words, the observer tries to be intelligent, objective and not too fanciful. The point is that the elaborate paraphernalia of formal experiment is not appropriate in situations of human–computer interaction which are culturally dominated.

In the domain of human–computer interaction research a similar kind of semiotic analysis has been effectively championed by Carroll and coworkers in what they call 'artifact analysis' [26]. According to this view user interfaces are best viewed as artifacts, and studied much as the anthropologist studies other cultural artifacts. The 'artifact centered' approach borrows from the social sciences; its methodology is derived from careful observation and the analysis is intellectual rather than a rigorous empirical hypothesis testing.

6. Conclusion

Experimental semiotics should not deal with those aspects of symbols and symbol use that are deeply embedded in culture. Many would argue that this includes all symbols; however, the claim made here is that the use of color (as in pseudo coloring and shading), texture, 3-D space and motion, and many other aspects of symbols, all depend primarily on the basic sensory mechanisms, the first few levels of neural processing in the retina, lateral geniculate nucleus and visual cortex. Also, while the counter argument is made that neural structures are demonstrably plastic in the early years of development (and hence may be culturally determined), the minimal requirements for normal development of the visual system appear to be such things as the presence of edges, continuous images, movement patterns and so on. Interaction of the nervous system with everyday reality is the basis of normal perception, where everyday reality consists of objects with surfaces, the law of gravity, the fact that light travels in straight lines, etc. Given these ubiquitous properties of the everyday world the evidence suggests that we all develop the same basic neural structures, irrespective of the cultural milieu. If we accept these arguments, there can be aspects of symbols which are constant across cultures. I have argued that this domain certainly encompasses such mundane issues as the desirable luminance contrast level of text on a background, and the use of texture; it may also encompass, to a lesser extent, the deep structures of thought and language.

It cannot be claimed that it is easy to distinguish and elucidate ·tween sensory languages and conventional languages. In many cases the two are intracately interrelated. Willats [6], for example, describes the way in which conventional perspective views and optical perspective views are often combined by artists in representations. The conventional stereotyped view of an object may often be more effective as an iconic memory aid, but this does not prohibit it from being placed in a stylized conventional representation. However, to attempt this elucidation must be a worthwhile endeavor. In particular, where we can identify components of languages as sensory, we can begin to make statements about the naturalness and ease of learning of a representational scheme which are valid across a wide variety of social contexts. The practical payoff is that by analyzing a representation into its sensory and conventional components we can understand what training will and will not be necessary.

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