Interfacing Situations

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1 Introduction

This paper[1] is the first in a series of two, in which we (i) explore some aspects of *heterogeneous systems of representation and communication*[2] (ii) show how American Sign Language (ASL) exhibits some of those features; (iii) draw some morals for the design of interfaces. This paper explores (i) at some length and ends with a brief look at (ii).

Heterogeneous systems of representation and communication are systems that combine representations whose meanings work on different principles, such as pictures and words. (We will try to reserve the word "language" for natural languages, like English and American Sign Language (ASL), and not use it for just any system of structured representations.)

This talk reflects work that we have been doing in collaboration with Cathy Haas of the Archimedes Project at CSLI and Bill Stokoe of Gallaudet University, having to do with *richly grounded meaning* in ASL.

Richly grounded meaning or RGM is a generalization of what Peirce called "iconicity"; the symbol and what it symbolizes are naturally rather than arbitrarily connected.[3] The key word here is "arbitrary"; probably most RGM symbols are conventional in the sense developed by David Lewis in *Convention* ([22]), but there is a natural connection between the symbol and what it symbolizes. The traditional word instead of "natural" might be "resemblance". We emphasize that what is in question is something psychological; a robust cognitive correspondence between properties of a symbol (which must have enough interesting properties to ground such a relation, hence "richly grounded") and properties of that which is symbolized. Resemblance is too restrictive. There are,

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[1] To appear in the *Proceedings of the Conference on Information-Oriented Approaches to Logic, Language and Computation*; the conference was held June 12-15, 1994, at St. Mary's College, Moraga, California.

[2] Our choice of "heterogeneous" follows Barwise and Etchemendy's "heterogeneous reasoning".

[3] The concept of RGM is described more fully in ([23]).

we think, various logical properties that correlate with, contribute to, and may even be necessary conditions of such natural correspondences, but whether a system that meets the logical requirements actually works to give an intuitive system is always a matter of psychological fact. A correspondence that is cognitively robust for one person may not be for another, due to different experiences stemming from difference in training, culture, and the like.

Heterogeneous communication systems combine arbitrary-conventional symbols with richly grounded ones. Maps, charts, Hyperproof[4], graphical user interfaces and American Sign Language are all, we think, heterogeneous communication systems.[5]

As the examples of Hyperproof and stylized documents suggest, there has been a lot of thinking about heterogeneous communication systems going on by people attending STASS conferences, and we will draw particularly on work from STASS II by Barwise and Etchemendy ([1, 2]) and Stenning and Oberlander ([4]).

In all of the cases, symbols with arbitrary-conventional meaning (ACM) are combined with symbols with RGM. For example, the upper part of a Hyperproof screen has a pictorial diagram of a blocks world, while the bottom part gives information about the same situation in the predicate calculus. The top part may contain labels, ACM symbols that allow the integration of information. In a map, symbols with ACM (like "Lincoln" and "Omaha" are placed in a 2-dimensional representational system (or are used to label dots in such a system) in which distance and direction are used to represent distance and direction.

We do the following:

- Discuss criteria that have been offered for what makes representations diagram-like or picture-like. We will look at Barwise and Etchemendy, Larkin and Simon, and Stenning and Oberlander.
- On the basis of ideas and examples gathered from these authors, we will provide a list of criteria which allow us to distinguish among text-like, chart-like, diagram-like map-like and picture-like representations.
- We will then show how ASL incorporates text-like, chart-like and diagram-like systems of representation.

Before plunging into this, however, we want to put it in a larger perspective, by briefly describing how we see the Archimedes Project at CSLI and the present state of the computer and communications industry as motivating the study of heterogeneous systems of representation and communication.

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[4] Hyperproof is system for teaching basic elements of reasoning, developed by Jon Barwise and John Etchemendy ([**?**]).

[5] We also think that stylized documents of the sort discussed by Devlin and Rosenberg fit into this category, although we won't discuss them tonight.

2 The Archimedes Project and Heterogeneous Communication Systems

The Archimedes Project at CSLI has to do with the accessibility of information to people with disabilities. It turns out that many themes from the situation-theoretical perspective are quite relevant to and we think helpful in thinking about this, in particular the distinction between information and particular ways of presenting information.

We use the term "disabled" for individuals with some condition or injury that prevents them from picking up information or initiating action in one or more of the standard ways. "Handicapped" means that one cannot pick up information that most people around one can, or cannot do the things most people around one can. Disability is often a contributing factor to being handicapped, but it is neither a necessary nor a sufficient condition. We are handicapped when we travel in Japan, because there is loads of information of which we cannot take advantage, not knowing Japanese. An individual with a disability that requires her to use a wheelchair may have no difficulty getting information from a computer screen and inaugurating actions with a keyboard and mouse; she is not handicapped by her disability in this activity.

A central idea of the Archimedes Project is that people with disabilities are quite unnecessarily handicapped by systems that make information accessible only in one form, suited for a particular mix of perceptual abilities, or requiring a specific motor function to inaugurate action.

A recent example of this is "The GUI Problem" for blind computer users. Blind people work well with computers with DOS interfaces. Screen readers automatically convert the ASCII code to voice. But Graphical User Interfaces or GUIs have by and large been a disaster for them. Screen readers fail when they hit windows, pull-down menus, icons, and the like. "Road-kill on the information highway," as the blind scientist Larry Scadden said recently about the his adventures on the world-wide web.

The concept of *heterogeneous systems of communication* developed as we studied this problem. Our idea is that if we knew more about why such systems in general, and GUIs in particular, were popular, and seemed to help people work with and communicate information more efficiently, we would be better able to understand what sort accessible alternatives might be envisaged that would provide the same functionality.

Now it turns out that there is another example of a heterogeneous language that is in fact a great boon for people with disabilities, namely American Sign Language (ASL) which is used by many deaf people to communicate. ASL makes a particularly interesting object of study because it is a natural language, with all of the expressive power and subtlety of English or any other language. But because it is a language of gesture rather than sound, it provides many more opportunities for richly grounded meaning. Skilled ASL users employ the diagram-like possibilities of signing in clever ways, and have various techniques for integrating information.

We hypothesize that heterogeneous systems of communication arise whenever the possibility of richly grounded meaning is available. Neither spoken language by itself nor written language confined to text provides many opportunities, as the signal is rather thin. But when people are face-to-face and can use gestures, bits of paper, napkin, blackboards or whatever, they do so.

Now we want to say a little more about RGM generally.

It is important to distinguish RGM in elements and *higher-order* RGM. By an element, we mean representations of particular objects, such as dots for cities on a map and the parts of a picture that represent specific things. An element has RGM if it resembles (i.e., cognitively corresponds to) the object that it stands for. Many of the signs of ASL, and of other signing systems, strike people as having this property. However, there is an extensive literature arguing that this property does not play a primary role in the lexical items of ASL ([17], [19]). Although many signs may begin as iconic, they tend to become stylized. They lose the psychological features we associate with RGM signs, readily inferable meaning (RIM) and easily remembered meaning (ERM).[6]

We will call a system of representations "iconic" if it has lexical RGM. We distinguish three levels of iconicity. Pictures are fully iconic. The link between representations and what they represent is based on resemblance or some other cognitively robust connection. Maps are partly iconic. Many of the symbols on a map have no resemblance to what they represent, but many do, for example depictions of rivers and highways. Ordinary text is non-iconic. With a few exceptions, it is only arbitrary conventions which connect the basic symbols with what they represent.

By higher-order RGM, we have two things in mind. The first is what we call Internally Modifiable Meaning (IMM); even if a sign has little or no RGM, there may be a system of modifications to it that do. IMM is pervasive in ASL.

The ASL sign for *improve* is an example of this. The basic sign involves moving the right hand, palm facing back, first to the wrist and then near the crook of the extended left arm. This sign is basically ACM—although there is a certain naturalness in having an upwards movement as part of the sign for improvement. The important point is how modifications, where English uses adverbs, are handled. The amount of improvement may be signed by the relative distance moved on the forearm. This modification is readily inferable—anyone who knows the sign for improve will easily grasp what the modified signs mean.

The second thing we have in mind by higher-order RGM is illustrated in ASL by the presence of a mode of signing that is closer to drawing pictures or diagrams or maps than to constructing phrases or sentences, and this is what we will explore tonight.

3 What makes representations picture-like?

We turn now to the question of what makes a visually inspectable representation picture-like, map-like, diagram-like, chart-like or text-like.

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[6] Without in any way doubting the validity of this literature, we can also observe that the fight to rid ASL of its image as a system of icons coincided with the fight to have it recognized as a full-fledged language. From the time of Stokoe's pioneering work in the 60's through to the present, the emphasis in ASL studies has been on the similarities between ASL and spoken languages.

Our example is more or less taken from Example 5 in Barwise and Etchemendy's "Visual Information and Valid Reasoning" ([1]).

Here are two representations of the same situation, one a diagram, the other a textual description.

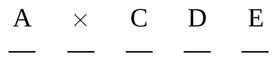

Figure 1: A diagram of five chairs and their occupants

a $\neq$ b, a $\neq$ c, etc.
a is a chair, b is a chair, c is a chair, etc.
a is to the left of b, b is to the left of c, etc.
A is a person, B is a person, etc.
A sits in a, C sits in c, etc.
b is not to be occupied.

Figure 2: A textual description of five chairs and their occupants

Figure 1 diagrams and Figure 2 describes a situation in which five chairs are arranged in a row and a person A occupies the leftmost chair, no one is allowed to occupy the second from the left, and C, D and E occupy the next three. The people are indicated by large letters in both figures; the chairs are indicated by lines in the first and small letters in the second.

What makes the first figure more picture-like, the second more text-like? We will begin our investigation by examining a list of criteria offered by Barwise and Etchemendy.

3.1 Barwise and Etchemendy's Criteria

In ([1]), Barwise and Etchemendy list six ways in which diagrammatic representation differs from linguistic representation: the former exhibit closure under constraints, conjunctive rather than disjunctive information, and homomorphic representation. They support symmetry arguments and perceptual inference.

The point with respect to symmetry arguments is that such arguments are often involved in reasoning with diagrams (for example the reasoning problem connected with Example 5). This point about reasoning with diagrams is not presented as either a necessary or a sufficient condition for something being a diagrammatic representation, so we are going to set it aside. The point about perceptual inference we will defer until later.

(We should emphasize that we are not indulging in the old-fashioned philosophical exercise of searching for the essence of pictures or diagrams or RGM. We are engaged in the new-fangled cognitive science exercise of looking for contributing factors to differences that we intuitively feel and exploit, that will lead to better and more useful classifications of the phenomena in which those differences are found, and may support increasingly detailed empirical and mathematical studies of the phenomena.)

So, as we were saying, what is the essence of pictures?

Homomorphism is at best a necessary condition. If we consider Figure 1 and Figure 2 we have homomorphism in both cases. We will make the point by showing the correspondence between the representing facts and the represented facts. We will call the lines in Figure 1, “1”,”2”,”3”,”4” and “5”; we will designate the people and chairs with large and small letters, respectively.

For the pictorial representation:

Not same line, 1,2	Not same chair, a, b
etc.	etc.
Is line, 1	Is chair, a
etc.	etc.
Is big letter, “A”	Is person, A
etc.	etc.
Is-left-of, “a”,”b”	Is-left-of, a,b
etc.	etc.
Is-above, “A”, 1	Sits on, A,a
etc.	etc.
Has × above, 2	Is not to be occupied, b

Figure 3: Homomorphism from diagram to chair situation

For the linguistic representation:

Have tokens flanking “$\neq$”, “a”,”b”	Not same chair, a,b
etc.	etc.
Has token before token of “is a chair”, “a”	Is chair, a
etc.	etc.
Has token followed by token of “is a person”, “A”	Is person, A
etc.	etc.
Have tokens flanking token of “is to the left of”“a”,”b”	Is-left-of, a,b
etc.	etc.
Have tokens flanking “sits in”, “A”, “a”	Sits on, A,a
etc.	etc.
Has token followed by token of “is not to be occupied, “b”	Is not to be occupied, b

Figure 4: Homomorphism from description to chair situation

Now Wittgenstein, noticing something like the sort of homomorphism we just presented, advanced the idea that sentences were pictures ([34]; see also [8]). He might be right at a suitably deep level, but at the level at which we are operating, we draw the conclusion that a homomorphism between the representing and the represented is not enough to make the representation diagram-like.

In the case of real pictures, it is not so clear that there is a perfect homomorphism. In a picture that uses perspective, one element being above another can signify that one thing is behind another or that one thing is above another. This may simply show that we have not chosen the representing relations carefully enough to find the homomorphism. We will assume that homomorphism is a good approximation of a necessary condition for being picture-like or diagram-like.

Now let's look at "closure under constraints". As Barwise and Etchemendy note, diagrams are physical situations and so they obey their own set of constraints. They say,

> By using a representational scheme appropriately, so that the constraints on the diagrams have a good match with the constraints on the described situation, the diagram can generate a lot of information that the user never need infer. Rather, the user can simply read off facts from the diagram as needed. This situation is in stark contrast to sentential inference, where even the most trivial consequence needs to be inferred explicitly ([1]).

As we understand it, the property in question is more fully describable as,

> Constraints on the facts in a representation R that represent facts about a relation Q are such that IF Q-facts $f_1 \ldots f_n$ are explicitly represented in R, and $f_1 \ldots f_n$ guarantee f-fact f_{n+1}, THEN R will explicitly represent f_{n+1}.

Here is an example. Let these three blocks be our situation:

Figure 5: The three-blocks situation

Let our picture-like representation be based on the idea that the representation will be a row of letters on a line from left to right, so that a letter being to the left of another represents the fact that the represented blocks are in the left of relation. We'll use "B" to name the block, "D" to name the diamond, and "T" to name the triangle.

B D T

Figure 6: Diagram-like representation of the three-blocks situation

Let our language-like representation be a sequence of sentences of the form "X is to the left of Y". If a sequence of letters X,Y flanks the "is to the left of" predicate, that represents that the block X stands for is to the left of the block Y stands for.

B is to the left of D
D is to the left of T

Figure 7: Linguistic representation of three-blocks situation

Now if we put in our diagram-like representation a representation to the effect that the box is to the left of the diamond, and one to the effect that the diamond is to the left of the triangle, we will have *eo ipso* put one in to the effect that the box is to the left of the triangle.

But, if we write the sentence "B is the left of D" and the sentence "D is to the left of T" we will not have thereby written the sentence "B is to the left of T".

So our diagram-like representation is closed under constraints, and our language-like one is not.

Why is this so? In Figure 6 the transitivity of the "is to the left of in a row" relation among tokens of letters matches the transitivity of being to the left of in a sequence of blocks. But as Figure 7 shows, the relation of having letters that flank the words "is to the left of" is not transitive. The relation holds between "B" and "D" and between "D" and "T" but not between "B" and "T".

Closure under constraints is a real difference between a diagram and a typical representation that is not diagram-like. But it is not a logically sufficient condition for being diagram-like. One can imagine a magic slate that always automatically produced the closing representation—i.e., would just write "A is to the left of C" when someone had written on it, "A is to the left of B" and "B is to the left of C". That would not be a diagram-like representation.

(Approximate) homomorphism and closure under constraints arise when (but perhaps not only when) we have *systematic, constrained and localized representation.* This requires that three conditions are met. First, a whole system of relations is systematically interpreted as representing another system of relations, rather than the interpretations being assigned piecemeal. Second, the representing relationships obey the constraints that correspond to those obeyed by the represented relationships. Third, there is only one token for each individual object.

Consider a diagram one might draw to show someone how to lay out a croquet court. A great many croquet courts of different sizes and oriented in different directions might satisfy the diagram. It is the relative distances and relative directions that count. For each court that satisfies the diagram there will be a homomorphism between distances between wicket symbols on the map and distances on the court, and between orientation on the diagram and directions. The homomorphism is not fixed piecemeal; once it is fixed that one distance on the diagram represents a certain distance in the world, all the other interpretations are fixed, and similarly with directions.

One could have systematic interpretation in a text-like representation; the distance relations might all by expressed by inter-related linguistic formulae, such as "being n meters", "being n+1 meters" etc. But such a linguistic relation would not be closed under constraints.

Note that the oddity or unnaturalness of our text-like homomorphisms comes, at least in part, from the fact that we allow more that one token for a given object in a given representation.[7] Our diagram of a croquet court, however, meets what we call "the unique token requirement". There is one and only one representation for each wicket. All the representing facts about that wicket—the facts that represent its distance from other wickets, its direction, and any other facts about it that are represented—will involve that one representation.

Multiple-token representation is ubiquitous in language, of course. It has the effect of destroying the constraints that guarantee closure. Returning to the example involving Figure 5, if we had allowed ourselves to use two tokens of "D" in our representation of the row of shapes in Figure 6, then we could have had a representation that explicitly represented B being to the left of D, and D being to the left of T, without having an explicit representation of B being to the left of T.

Finally, Barwise and Etchemendy say that diagrammatic representations are conjunctive rather than disjunctive. This should not be taken to mean that a particular representing fact cannot represent a range of alternatives. There are many actual croquet courts, facing different directions and with different distances between the wickets, that satisfy the diagram we are imagining. The point is rather that the effect of adding a new representing fact to a picture or diagram-like representation is to conjoin a fact to what is already represented, not provide an alternative. This is a consequence of systematic, constrained and localized representation. One creates new representations by placing new representations for individual objects onto the diagram. The new representation cannot represent an alternative for one of the wickets already represented, by the unique token requirement.

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[7] In lectures John Etchemendy makes essentially this point by calling the diagrammatic part of the Hyperproof display "token based".

3.2 Larkin and Simon

This property of unique token representation is related to the use of locations for grouping information, that Larkin and Simon emphasize ([6]). They provide three reasons why diagrams can be superior to verbal descriptions for solving problems.

- Diagrams can group together all information that is used together, thus avoiding much searching for the elements needed to make a problem-solving inference.
- Diagrams typically use location to group information about a single element, avoiding the need to match symbolic labels.
- Diagrams automatically support a large number of perceptual inferences, which are extremely easy for humans.

The first two reasons emphasize the way diagrams use location to group information about a single object. This is lost when one uses the system of types and token. Many different tokens of the same type designating the same individual object may be scattered around a document, so that the information the document contains about that individual is not localized. It is a feature of perception that the perceptually accessible information about an individual is centered on that part of the perception that we think of as being *of* the individual. Monadic or intrinsic facts about the individual will be picked up by inspection of the individual, and relational facts will involve of part of the scene that involves the individual. This sort of localization makes looking at a diagram or picture *like* looking at the things themselves, and permits the inferential abilities of the perceptual system to be exercised on the diagram or picture.

3.3 Stenning and Oberlander

There are two ways that one could end up with two representations of the same object. One could have two tokens of a type, both of which designate the object. This is ruled out by the unique-token property. But one could also have two types assigned to the same object, like “Tully” and “Cicero”. Then a representation could satisfy the unique token requirement, but still have multiple representations, and multiple loci of information, about a single object. In “Words, Pictures and Calculi,” Stenning and Oberlander point out that it is a feature of graphical representations to not allow this.

Stenning and Oberlander find the difference between graphical representations and textual representations in a property they call specificity. We suggest that there are several aspects to specificity that are worth distinguishing. The major division is between *determinateness* and *regimentation*. Determinateness we further divide into two kinds, *issue determinateness* and *Berkeley determinateness*.

Determinateness. The basic idea of issue determinateness is that if a representation raises an issue, it settles it. Let our representation be the following two sentences:

- Madeline is charming. David works at SRI.

The representational resources of this representation allow us to raise two further issues: Is David charming? Does Madeline work at SRI? But the representation does not settle them.

We will say that an issue, in the situation-theoretical sense of a relation and a suitable sequence of arguments, is available from a representation if the representation contains items that stand for the relation and each of the arguments. Issue determinateness means that all available issues are settled by the representation—that is, that it explicitly represents that the answer for the issue is yes or no (polarity 1 or 0).

This property requires more of a picture or diagram than the property of closure under constraints that Barwise and Etchemendy mentioned. Suppose we have a representation of the fact that A is larger than B and a representation of the fact that C is below D. The closure condition does not require that we have representations that tell us whether or not A is below B, or C is larger than D, but this property does. However, it does seem that systematic, constrained and localized systems of representation meet this condition. In such a system, an element represents things about the object it designates in virtue of having various properties and standing in various relations. Each of the other elements will have properties of the same kind and stand in relationships of the same kind. So issues that are settled for one object, will be settled for all. For example, when one puts a dot representing Omaha on a map, making issues about Omaha available in our sense, that dot will be a certain distance from all the other dots. Putting the dot on the map, which makes the issues available, also settles them.

The second notion of determinateness is suggested by Stenning and Oberlander's citation of Berkeley, so we call it "Berkeley determinateness". What impressed Berkeley was the fact that you couldn't draw a picture of a triangle or have a mental image of a triangle that wasn't a picture or mental image of some definite type of triangle, scalene, isosceles, right angle, etc.

To state what Berkeley determinateness entails, we need the determinable-determinate distinction. This is exemplified by color and red, or height and 5'3", or shape and 3/4/5 right triangle or weight and 180 pounds. Any object that has a determinable property (shape, color, size) has some determinate value of it. But it is not the case in general that a representation that represents an object as having a determinable property represents the object as having some determinate value of it. If we say, "David has an interesting shape," I imply that he has a shape, but I don't say exactly what his shape is.

It is a property a representational system might have, relative to some category of properties, that if it represents an object as having a determinable property then it represents that object as having some determinate value of it. This is what we call Berkeley determinateness with respect to that category of properties.

However, it is not generally the case with pictures that they are Berkeley determinate with respect to the visually detectable properties they depict. An artist need not decide whether she is painting a picture of tall people standing in front of a tall tree or short people standing in front of a short tree. She represents the people and the tree as having height (and arguably, weight) but not specific heights and weights. But if she included a scale, and thus provided a systematically homomorphic representation, the picture would have this property.

The fact is that there are some correspondences that are so natural, that it is difficult to imagine alternatives. If you are going to use closed figures to represent shapes, what shape should a triangle represent? It seems that the natural answer is, triangles. What should an isosceles triangle represent? An isosceles triangle. The representation will have a determinate value of each of its determinable properties, and so if it represents exactly the same properties it has, the representation will be Berkeley determinate.

But this doesn't generalize. If we are going to use objects with size to represent sizes, what size should a one inch figure represent? The answer is not so obvious. We are familiar with representing one size with another, and one distance with another, but not with representing one color with another, or one shape with another.

Given a systematic, constrained and localized system of representation, we need to fix rather than merely constrain the homomorphisms between representing and represented relations to get Berkeley specificity. With our croquet court diagram we could do this by adding a scale and a north arrow.

Our conclusion then is that systems that are systematic, constrained and localized need not be Berkeley determinate. That is an additional property. Some systems may have it because there is a very natural built in "interpretation-fixer" that we assume at least as a default: red represents red, yellow represents yellow, etc. Other systems may have it because devices like a scale or a north arrow fix the homomorphism.

The fact that some representing properties such as colors and shapes seem to have a built in interpretation-fixer can create problems for designers of representational systems. Lingraphica is a system designed by Dick Steele for the use of global aphasics, who have lost the ability through brain injury to remember the meanings of words. Steele designed an iconic, MacIntosh-based system for communicating with aphasics. He concentrated for a while on recipes, which he found that his patients could follow unassisted, by figuring out the meaning of the icons.

He had trouble coming up with an icon for "stir". The natural way to do it is with a dynamic icon showing a bowl of stuff being stirred by a spoon, say. But how to make this an icon for "stir" and not "stir with a spoon"?

Regimentation Stenning and Oberlander give this list of representation systems, to indicate some points along a dimension they call "regimentation":

> ...a quantified abstraction; a disorderly text; an orderly text;...an alphabetized table of intercity distances; the same table with cities ordered by longitude in the column labels and latitude in the row labels; and finally a map.

Stenning and Oberlander connect this dimension with the number of ways there are for making a representation true, and this connects regimentation with determinateness. We'll bypass the issues here, and note that at least one aspect of regimentation connects with localization and the unique token requirement.

In an ordinary piece of text, there are no limitations on the number of different tokens that might stand for a given individual object, nor any restriction on where they might occur. Still, a good orderly presentation will exhibit some localization of information. Consider for example the CSLI brochure that is given to prospective Industrial Affiliates. There is a paragraph headed by the name of each researcher, which contains certain vital facts about them. A reader might turn to this page to know who, for example, John Etchemendy is. But tokens of the name "John Etchemendy" might also occur elsewhere in the brochure; not all the information about Etchemendy is localized.

Stenning and Oberlander compare such more or less orderly texts with a mileage chart and a map. In a mileage chart, there are two tokens of each name, one labeling a column, one labeling a row. Finally, with a map, we have one token per object represented.

This suggests a dimension defined by the constraints on the number and location of tokens of names, with the unique token constraint at one end and the total lack of constraints found in disorderly text at the other. We will use just a rough and ready classification: no constraints, some constraints, and the unique token requirement.

4 From Texts to Pictures

Now we will focus on four of the factors we have discussed, which will help us to distinguish five patterns of representation found in texts, charts, diagrams, maps, and pictures. We regard this typology as a first step, neither comprehensive nor final.

- Iconicity. Recall, we use this term to mean that the representational *elements* have richly grounded meaning. We distinguished fully iconic, partly iconic and non-iconic systems of representation.
- Systematic, constrained interpretation. In both the picture and the map, spatial relations among representations correspond to spatial relations among the represented items. Spatial relations are not represented by individual symbols, as in text, but through a system of relationships among representations. The relations among representations obey constraints that correspond to those obeyed by the relations they represent.
- Localization. In the picture and the map all the representing facts that carry information about a given individual object will involve a single (token) representation of that object. It is fully localized. With charts there are some constraints, although more than one token is allowed; they are partially localized. There are no constraints with text; the information is not localized.
- Berkeley determinateness. This is systematic homomorphism when a determinate interpretation is provided, e.g. a scale and a north arrow for maps.

	Iconic	Systematic, Constrained Interpretation	Localized	Berkeley Determinate
Texts	No	No	No	No
Charts	No	No	Partly	No
Diagrams	Partly	Yes	Fully	No
Maps	Partly	Yes	Fully	Yes
Pictures	Fully	Yes	Fully	No

Table 1: Five types of representation

We can depict these factors in a way that gives us some rough but useful categories, going from text-like to picture-like.

Note that the “yes” entry for maps under Berkeley Determinate appears to be an anomaly in that every other feature is added or is increased as the representational type moves from text to pictures. In this one respect, maps are more “picture-like” than pictures. Alternatively, one might justify a partial “yes” on the grounds that the scale for many pictures is implicitly fixed by our real-world knowledge.

5 ASL as a Heterogeneous System of Communication

On our analysis of ASL, it has three modes or “states”, that reflect the way that space is being used to carry information. We call these states the *text* state, the *chart-like* state, and the *animated-diagram* state. We claim that the text state is text-like, the chart-like state is chart-like and the animated-diagram state is diagram-like, in the senses indicated by the chart in Table 1.

The text state. This is ordinary signing space. Gestures that correspond to vocabulary items are strung together to make longer phrases and sentences. Relationships, tenses, etc., are indicated by word-order and other arbitrary conventions. Representation is not systematic and constrained, but piecemeal and unconstrained in the way that speech or written text is.

ASL in text state is as expressive as any natural language. Abstract ideas, disjunctions, and the like can all be expressed; its limitations at any given time are just the limits of the vocabulary.

One problem with ASL in text state, however, is that it can be very slow. Bellugi has shown that on average it takes twice as long to make a sign as to utter the corresponding English word. However, she has also shown that signers stay even with speakers in the rate at which they express thoughts ([19]). We believe that an important reason for this is the use of the other two states.

The Animated-Diagram State. In the talk on which this paper is based, we demonstrated the use of the animated diagram, but description will have to suffice here. Our favorite illustration is based on an actual event, a small automobile accident in which a member of our group was involved. Here is a textual description:

> I was stopped at light, thinking about nothing in particular. Suddenly, a car ran into my car from the right rear. It scraped along the right side of my car, knocking it to one side, and came to a stop ahead and to the right of my car.

A signer could do this just like it is done in English, with signs corresponding one-to-one with words. That's not how it would normally be done in ASL—and in fact if one tried to do it that way, it would be thought of as something quite different, "Signed Exact English". The normal way to convey this description would involve using the hands to demonstrate the crash. The hands would be held in a shape that conventionally means "vehicle", but the movements are homomorphic and readily inferable. The story can be told in about the same time it takes to tell it in spoken English, and in far less time than it would take to tell it in Signed Exact English.

The dynamic nature of the diagram means that our criteria need to be satisfied for the motion relations as well as the static relations. It compares to a motion picture but it is not picture-like because it is not fully iconic. It is localized. The hands (or particular fingers—depending) represent individual objects, and any individual object will be represented at any given time only by one hand or finger. It is systematic and constrained. Spatial relations between the representing hands or fingers represent spatial relations between the represented objects; movement means movement, and so forth. It need not be determinate. So on our criteria this state is diagram-like.

The diagram state has the disadvantages of diagram-like representation as well as the advantages. Abstract ideas and disjunctions are not easily representable.

The chart-like state. The third state uses localization to group information about a given individual or topic, but does not use space homomorphically.

Suppose you are comparing Neil and George. Neil is medium-height; George is tall. Neil is bubbly; George is reserved. And so forth. In the chart-like state, an ASL signer can subdivide the signing space into two regions, one for Neil and one for George. Then she can sign the various attributes in the appropriate region. If she wants to call attention to attributes to be compared or contrasted, she can sign one pair at a time (like filling in one row of a chart) thus indicating the attributes to be contrasted and the respective possessor of the attributes with one motion. If it is important to note that an attribute is the same in both cases, for example if Neil and George were both thirty-five, she could make the sign for that age in a neutral space, and then use the bi-directional sign "same" between the regions. This is a little like drawing an arrow between two cells of a chart to highlight a connection.

Situations can also be compared in this way; that is each region can contain an animated diagram. This is an operation somewhat analogous to "case-splitting" in Hyperproof.

This state of ASL meets our criteria for being chart-like. It is non-iconic, not systematic and constrained and not determinate. But it differs from unconstrained text in using location to group information, and obeying the unique-token requirement.[8]

State-transitions. Since space is used differently depending on whether the signer is in the text, animated diagram, or chart-like state, there is the possibility of ambiguity and confusion. For example, does the signing of "Neil" to the right and "George" to the left indicate that Neil and George were standing beside each other in some situation being described or that regions of space are being labeled? Such ambiguity is usually precluded because signers indicate their state transitions, for example by moving the signing space. We say more about state-transition conventions in the second paper of this series ([7]).

6 Conclusion

We have investigated factors that make representations more or less picture-like; several factors emerged, and consideration of those factors gave us five kinds of representational systems. We argued that ASL is a heterogeneous system of communication, using three of the five types.

In the paper that forms the second part of this essay, we will develop an account of the devices used in ASL to move from one state of representation to another, and to transfer information across the states. We then look at the different kinds of representational systems that are used by modern, graphically-based computer interfaces. We examine how some of the same problems arise that have been successfully solved by ASL, and explore the possibility of exporting such solutions from ASL to graphical interfaces. And we use our categories to speculate on the use of sound icons or earcons, three-dimensional sound, and other devices to create interfaces that provide the advantages of graphical interfaces to individuals who are blind.

References

[1] Barwise, Jon and John Etchemendy. Visual Information and Valid Reasoning. In *Visualization in Mathematics*, ed. W. Zimmerman. Washington, DC: Mathematical Association of America, 1990.

[2] Barwise, Jon and John Etchemendy. Information, Infons, and Inference. In [3]

[3] Cooper, R., K. Mukai, and J.Perry (eds), *Situation Theory and Its Applications*, vol. 1. CSLI Lecture Notes Number 22. Stanford: CSLI Publications, 1990.

[4] Stenning, Keith and Jon Oberlander. Words, Pictures and Calculi. In [5]

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[8] This is not exactly right, since Neil's name might not only be used to label his chart, but could conceivably also appear in the list of George's attributes—if, for example, Neil were George's brother.

[5] Barwise, Jon, Jean Mark Gawron, Gordon Plotkin and Syun Tutiya. *Situation Theory and Its Applications*, vol. 2. CSLI Lecture Notes Number 26. Stanford: CSLI Publications, 1991.

[6] Larkin, J.H. and Simon H.A. Why a Diagram is (sometimes) worth ten thousand words. *Cognitive Science* 11: 65-100, 1987.

[7] Macken, Elizabeth, John Perry, Cathy Haas, William Stokoe. Forthcoming.

[8] Barwise, J. and J. Etchemendy. Visual Information and Valid Reasoning. In W. Zimmermann and S. Cunningham, (Eds.), Visualization In Teaching and Learning Mathematics. MAA Notes Number 19, 1991, 9-24.

[9] Barwise J. and J. Perry. Situations and Attitudes. Cambridge: MIT Press–Bradford Books, 1983.

[10] Battison, R. and I.K. Jordan. Cross-cultural communication with foreign signers: fact and fancy. In Sign Language Studies, 10; 1976, 53-80.

[11] Burks, A. “Icon, Index, and Symbol,” Philosophy and Phenomenological Research, Vol.IX, 1949.

[12] Clark, H. and R. J. Gerrig. Understanding Old Words With New Meanings. In H. Clark, Arenas of Language Use. Chicago: University of Chicago Press and CSLI, 1992.

[13] Cokely, D. and C. Baker. American Sign Language: A student text, Units 1-9. Silver Spring, MD: T.J. Publishers, Inc., 1980.

[14] CSLI. Annual Report of the Center for the Study of Language and Information, 1989-90. Stanford University: CSLI Reports, 1991.

[15] DeMatteo, A. Visual imagery and visual analogues in American Sign-Language. In L. Friedman (Ed.), On the other hand: New perspectives in American Sign Language. New York: Academic Press, 1977.

[16] Deuchar, M. Are signs of language arbitrary? In H. Barlow, C. Blakemore, and M. Weston-Smith (Eds.), Images and understanding: thoughts about images, ideas about understanding. Cambridge: Cambridge University Press, 1990.

[17] Frishburg, N. Arbitrariness and iconicity: Historical change in American Sign Language. Language, 51, 1975, 676-710.

[18] Grosjean, F. (1977). The perception of rate in spoken language and sign languages. Journal of Psycholinguistic Research, 22, 1977, 408-413.

[19] Klima, E. and Bellugi, U. The Signs of Language. Cambridge, MA: Harvard University Press, 1979.

[20] Kuschel, R. The silent inventor: The creation of a sign language by the only deaf-mute on a Polynesian island. In Sign Language Studies, 3, 1973, 1-27.

[21] Lillo-Martin, D., U. Bellugi, L. Struxness, M. O'Grady. The acquisition of spatially organized syntax. In Papers and Reports on Child Language Development, 24, Stanford University, 1985, 70-78.

[22] Lewis, D. Convention: A Philosophical Study. Cambridge: Harvard University Press, 1969.

[23] Macken, E., J. Perry, C. Haas. Richly Grounded Symbols in American Sign Language. *Sign Language Studies*, 81, Winter, 1993, pp. 375-394.

[24] McNeill, D. Hand and Mind: What gestures reveal about thought. Chicago: University of Chicago Press, 1992.

[25] Newport, E. and R. Meier. The Acquisition of American Sign Language. In D. Slobin (Ed.) The Crosslinguistic Study of Language Acquisition. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc., 1986.

[26] Perry, J. The Problem of the Essential Indexical and Other Essays. New York: Oxford University Press, 1993.

[27] Petitto, L. From gesture to symbol: The relationship between form and meaning in the acquisition of ASL. In Papers and Reports on Child Development, Stanford University, 22, 1983, 100-107.

[28] Reilly, J.S., McIntire, M.L., and Bellugi, U. The relationship between language and affect. In V. Volterra and C. Erting (Eds.) From Gesture to Language in Hearing and Deaf Children, Springer-Verlag, 1990, 128-41.

[29] Steele, R. Lingraphica. Talk at Stanford University, 1992.

[30] Stokoe, W.C., Sign language structure: An outline of the visual communication system of the American deaf. In Studies in linguistics: occasional papers 8. Buffalo, New York, 1960.

[31] Stokoe, W.C., D. Casterline, and D. Croneberg. A dictionary of American Sign Language. Washington, D.C.: Gallaudet College Press, 1965.

[32] Tversky, B. Speculations about Graphic Communications. In F.T. Marchese, (Ed.). Proceedings of the NYC-SIGGRAPH conference on understanding images. Springer-Verlag, in press.

[33] Valli, C. and C. Lucas. Linguistics of American Sign Language: A resource text for ASL Users. Washington, D.C.: Gallaudet University Press, 1992.

[34] Wittgenstein, Ludwig. *Tractatus-Logical Philosophicus*.

[35] Etchemendy, John. *The Theory of Propositions in Wittgenstein's Tractatus*.

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