Semantics of Simple Arrow Diagrams*

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Abstract
Arrows illustrate a large variety of semantics in diagrams. An automated interpretation of arrow diagrams would be extremely useful in pen-based interface. Through the formalization of the structural patterns of arrow diagrams, this paper identifies three structural properties of arrow diagrams that contribute the interpretation of arrows: (1) the assignment of the components to the three slots, (2) the semantic types of these components, and (3) the orientation of the objects.

1. Introduction

Arrows are a major component of diagrams. With their simple shape, arrows capture a large variety of semantics, such as directions, movements, changes, interactions, sequences, and relations. Accordingly, they frequently appear in various illustrations, such as traffic signs, manuals, route maps, and flow diagrams (Horn 1998; Wildbur and Burke 1998). Pen-based interactions with computers are also expected to support the use of diagrams with arrows. In the current pen-based systems, however, people still cannot use arrows naturally, due to the restriction of the arrows to a small set of meanings (Kurtoglu and Stahovich 2002; Landay and Myers 2001; Alvardo and Davis, 2001) or the cumbersome requirement to specify the meaning of every arrow (Forbus and Usher, 2002). In this way, an automatic interpretation of diagrammatic arrows remains a challenge.

The existence of arrows encourages people to interpret causal and functional aspects in the diagram (Tversky *et al.* 2000). For example, Figure 1 shows a diagram with a sequence of arrows, which captures a mechanism that the El Niño Effect (i.e., the sea temperature rise in the Southeastern Pacific) indirectly influences the rise of tofu prices in Japan, due to fewer fish caught in South America and an implied growth in the consumption of soybeans in North America. Such an interpretation, however, requires an intricate reasoning process based on our commonsense. For example, an upward arrow symbol is known to conventionally express *rise* or *increase*, and a price is known to rise; therefore, people deduce that the *tofu price*, with an upward arrow symbol next to it, may illustrate an event where the tofu price rises. Similarly, it is deduced that *soybeans consumption*, with an upward arrow symbol next to it, indicates another event where the soybeans consumption increases. These two events are connected by another arrow symbol. Such an arrow connecting two events is typically interpreted as *causality*. Thus, people can interpret that the decrease of the soybeans consumption causes the rise of the tofu price.

In this way, the structural properties of arrows contribute the interpretation of arrows. The goal of this paper is to identify the structural properties inherent in an arrow diagram that contribute to its interpretation.

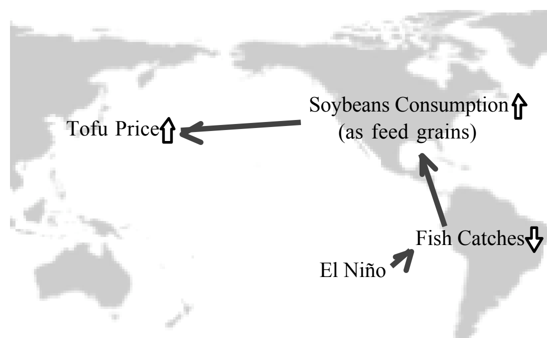

Figure 1: An arrow diagram depicting the influence of the El Niño Effect on the rise of the tofu price.

The appearance of arrow symbols are subject to a variety of visual variables, such as length, width, shape, color, direction, orientation, and pattern (Bertin 1983). The arrow symbols alone, however, do not determine any specific meanings (Figure 2).

Figure 2: Variations of the visual parameters of an arrow symbol (Horn 1998).

The meaning of an arrow is organized when the arrow symbol refers to other surrounding elements. Thus, within this paper, the focus is on the semantics associated with the

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elements to which an arrow symbol refers and, therefore, the visual variables will be kept invariant.

The combination of an arrow symbol and the elements to which the arrow symbol refers is considered a unit of meaning, and called an *arrow diagram*. Then, the elements to which the arrow symbol refers are called the *components* of the arrow diagram. The interpretation of an arrow diagram is not a simple symbol-recognition process of individual components, but requires the consideration of the arrangement of the components, possible behavior of each component, and the possible relations among the components.

The remainder of this paper is structured as follows: Section 2 introduces the slots of arrow diagrams that capture the alignments of components, and demonstrates how those alignments influence the interpretation. Section 3 classifies the components into five types, which also influence the interpretation, and distinguishes arrow diagrams by the types of components placed at each slot. Section 4 observes that the orientation of the components influences the judgment of the validity of interpretations. Conclusions and future work are discussed in Section 5.

2. Three Slots of an Arrow Diagram

An arrow symbol is a deictic reference frame, identifying three different areas that contain the components of the arrow diagram. These three areas are referred to as the *tail slot*, the *head slot*, and the *body slot* (Figure 3).

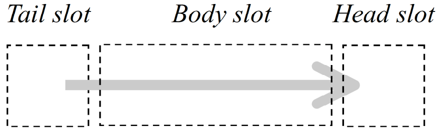

Figure 3: The three conceptual slots associated with an arrow symbol.

Each component of an arrow diagram is uniquely assigned to one of these three slots, thereby making the distinction of *tail components*, *body components*, and *head components*. Each slot may contain zero, one, or more components (Figure 4). These slots are conceptual rather than physical areas, although the respective components are spatially close to or even spatial contained in these slots.

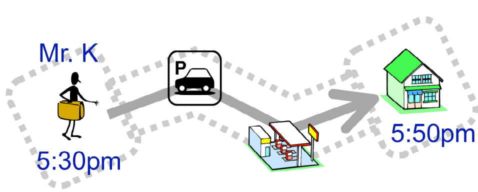

Figure 4: The slots of an arrow diagram populated with components.

It is necessary to distinguish among these component slots, because the same symbols, used in different slots, conveys significantly different meaning. For example, Figures 5a and 5b show two arrow diagrams in which the tail and the head components have been exchanged, essentially reversing the meaning of the diagram from *adding a wheel to a car* to *removing a wheel from a car*. Figures 5c and 5d show another pair of arrow diagrams where the head component has been moved to the body component, such that the meaning changes from *a traveler heads to Maine* to *a traveler passes through Maine*.

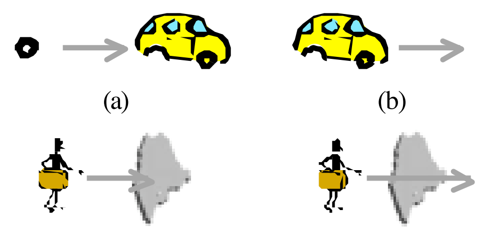

Figure 5: Two pairs of arrow diagrams, each with the same components in different slots.

The importance of the three component slots leads to the first postulate of parsing arrow diagrams:

- *The assignment of the components to their slots (tail, body, head) captures critical information about the meaning of an arrow diagram.*

3. Five Types of Components

A component may be mentioned by a symbol, a text, or a specific position in the background drawing. In semantic level, however, the following five different types of components are distinguished:

- An *object* is an entity, either physical or conceptual, that can play actions or participate in interactions. A person, a car, and a house are examples of physical objects, while a project and a land parcel are examples of conceptual objects.
- A *location* is a point or a homogeneous region in space, expressed either graphically or as text. Examples of locations are a mountain's peak (a point) and a mountain (a region).
- A *moment* is a point or a homogeneous period in time, expressed either graphically or as text. Examples of moments are a departure time of a flight (a point), or hours on an airplane (a period).
- An *event* is a dynamic phenomenon that occurs at a certain place (i.e., events do not move spatially). Events always exist temporally. An event occurs at an instance (e.g., a traffic accident) or sustains for a period (e.g., a conference).
- A *note* is a description that supplements another component, usually in the form of text. Some notes are located close to the corresponding components, while others are connected to their components by a line or an arrow.

With five types of components and three slots, 5^3 different arrow diagrams with exactly one component in each could be distinguished. Since arrow diagrams may have empty slots as well, a sixth component type, the empty component, is introduced. Together with the five non-empty components, a total of 6^3=216 different arrow diagrams are distinguished. They are referred to as *simple arrow diagrams* as they are related to exactly one arrow symbol and each slot has at most one component. With $c \in \{M, E, L, O, N, -\}$, referring to moment, event, location, object, note, and empty component, respectively, an arrow diagram will be denoted symbolically as (c,c,c).

The influence of the component types on the interpretation of an arrow diagram is highlighted in the following examples. Figures 6a-c show three configurations in which an object (a traveler) fills the tail slot, whereas the head slot is filled with an object (a bag), an event (AAAI spring symposium), and a location (Maine), respectively. These different types in the head slots lead to different interpretations of the arrow diagram: the traveler *leaves* his bag (Figure 6a), the traveler *participates in* the conference (Figure 6b), and the traveler *heads to* Maine (Figure 6c). On the other hand, arrow diagrams with identical alignments of component types usually lead to a same class of interpretation. For example, Figures 6c and 6d, both showing configurations in which an object fills the tail slot and a location fills the head slot, illustrate the movement of an object *heading to* a location.

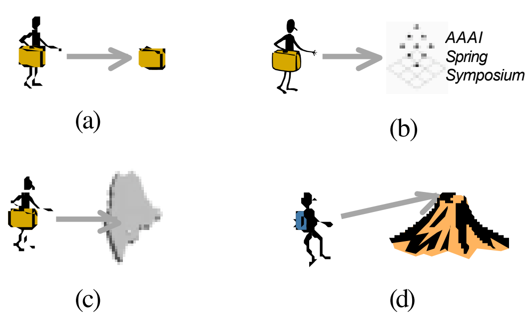

Figure 6: Arrow diagrams with various component types: (a) $(O,-,O)$, (b) $(O,-,E)$, (c) $(O,-,L)$, and (d) $(O,-,L)$.

Among 216 different simple arrow diagrams, some lead automatically to a unique class of interpretation. For example, $(O,-,L)$ is always interpreted uniquely as a movement of the object heading to the location (Figure 6c and 6d). On the other hand, some arrow diagrams follow more than one class of possible interpretations. An example is $(O,-,O)$, which is discussed in the next section.

The distinctions that arise from the different slot types leads to the second postulate of parsing arrow diagrams:

- *The distinction of the component types* $c \in \{M, E, L, O, N, -\}$ *is needed for parsing the meaning of an arrow diagram.*

4. Intrinsic Orientation of Objects

If an arrow diagram has more than one component type *object* (e.g., $(O,-,O)$), its interpretation depends on which object is supposed to move. For example, Figure 7a has two interpretations: *a car approaches a person* and *a person leaves from a car*. In such a case, an important aspect for a successful interpretation is the object's orientation with respect to the arrow symbol. Since the arrow symbol is the framework for the diagram's deictic reference system, the participating objects are evaluated with respect to the arrow's orientation. A sketched object may have an intrinsic orientation toward which the object usually moves. For example, in Figure 7b, the intrinsic orientation of a car is identical to the arrow symbol's orientation (i.e., both point to the right), whereas that of a traveler is opposite to the arrow symbol's orientation. Those intrinsic orientations of objects are often critical to determine a valid interpretation. For example, in Figure 7b, since only the intrinsic orientation of the car is identical to the arrow symbol's orientation, only the car is supposed to move. Thus, although Figures 7a and 7b refer to the same objects, Figure 7b is uniquely interpreted as *a car approaches to a person*, whereas the diagram in Figure 7a is ambiguous.

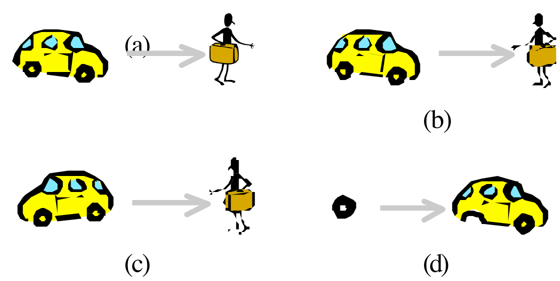

Figure 7: Arrow diagrams with different object orientations: (a) (+, ,+), (b) (+, ,-), (c) (-, , -), and (d) (0, ,*).

If the orientation of an object is same as the arrow symbol's orientation, the object is called *positively oriented* (+). Conversely, if the orientation of an object is different from that of the arrow symbol, the object is called *negatively oriented* (-). An object that does not move, like a car without a wheel in Figure 7d, is called *static* (0). Conversely, an object that may move in any direction, like a wheel in Figure 7d, is called *neutral* (*). If an illustrated scenario premises an object to move, this object must be + or *. Therefore, if an arrow diagram refers to only one + or * object, the valid interpretation is uniquely determined (Figure 7b and 7d). If all objects are – or 0, however, the arrow diagram may illustrate no movement, or it may imply a movement of something that is not explicitly drawn in the diagram. For example, Figure 7c may be interpreted as *a relation between a car and a traveler* or that *a person brings out something* (such as his bag) *from a car*.

The above discussion leads to the third postulate of parsing arrow diagrams:

- *The intrinsic orientation of an object is critical information to determine a unique interpretation of a scenario that accompanies a movement.*

5. Conclusions

To understand the semantics of each arrow in a diagram is often a fundamental first step for the correct understanding of the whole mechanism or phenomenon illustrated in the diagram. This paper identified three structural properties of arrow diagrams, which are available as the postulates of parsing simple arrow diagrams. Based on these postulates, we are now developing a formal method for interpreting simple arrow diagrams. In this method, the candidates of the interpretations are derived from the distinction of simple arrow diagrams introduced in Section 3, and then the valid interpretation is selected from these candidates with the aid of various clues, which includes the object orientations discussed in Section 4. Since arrows are major components of diagrams, this method is expected to enhance the usability of pen-based systems such that their users will be able to freely express various semantics simply by drawing arrow diagrams.

6. References

Alvardo, C. J. and Davis, R. 2001. Resolving Ambiguities to Create a Natural Sketch Based Interface. In: *Proceedings of the 17th International Joint Conference on Artificial Intelligence* (IJCAI-01), pp. 1365-1374. Seattle, WA.

Bertin, J. 1983. *Semiology of Graphics: Diagrams, Networks, Maps*. University of Wisconsin Press: Madison, WI.

Forbus, K. D. and Usher, J. M. 2002. Sketching for Knowledge Capture: A Progress Report. In: *Proceedings of the 7th International Conference on Intelligent User Interfaces*, pp. 71-77. San Francisco, CA: ACM Press.

Horn, R. E. 1998. *Visual Language: Global Communication for the 21st Century*. Bainbridge Island, WA: MacroVu, Inc.

Kurtoglu, T., and Stahovich, T. F. 2002. Interpreting Schematic Sketches Using Physical Reasoning. In: *AAAI Spring Symposium*, *Sketch Understanding, 2002*. Melon Park, CA. AAAI Technical Report SS-02-08, 78-85.AAAI Press.

Landay, J. A. and Myers, B. A. 2001. Sketching Interfaces: Toward More Human Interface Design. *Computer* 34(3): 56-64.

Tversky, B.; Zacks, J.; Lee, P.; and Heiser, J. 2000. Lines, Blobs, Crosses and Arrows: Diagrammatic Communication with Schematic Figures. In: Anderson, M.; Cheng, P.; and Haarslev, V. (eds.) *Theory and Application of Diagrams*, pp. 221-230. Berlin: Springer.

Wildbur, P. and Burke, M. 1998. *Information Graphics: Innovative Solutions in Contemporary Design*, Thames & Hudson.