# Semantics of Simple Arrow Diagrams

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**Abstract**

Arrows illustrate a large variety of semantics in diagrams. An automated interpretation of arrows would be highly desirable in pen-based interfaces. This paper formalizes the structural patterns of arrows, and identifies three structural properties that contribute to the interpretation of arrows: (1) the assignment of components to three slots, (2) the semantic types of the components, and (3) the orientation of the components.

## Introduction

Arrows are a major component of diagrams. Despite their simple shapes, arrows capture a large variety of semantics, such as directions, movements, changes, temporal orders, interactions, and binary relations. Accordingly, arrows frequently appear in various graphic representations, such as traffic signs, illustrations, route maps, and flowcharts (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 in a diagram (Forbus and Usher, 2002). In this way, an automatic interpretation of arrows in diagrams remains a challenging problem.

Arrows have a remarkable ability to facilitate the communication of dynamic processes and complex mechanisms. The existence of arrows encourages people to interpret causal and functional aspects in a diagram (Tversky *et al*. 2000). For example, Figure 1 shows a diagram with a sequence of arrows, which captures a dynamic process 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* accompanied by an upward arrow symbol may illustrate an event where the tofu price rises. Similarly, it is deduced that the *soybeans consumption* accompanied by an upward arrow symbol indicates another event where the soybeans consumption increases. These two events are connected by another arrow symbol. Such an arrow symbol connecting two events is typically interpreted as a *causal relation*. Thus, people interpret that the decrease of the soybeans consumption may cause the rise of the tofu price.

This example indicates that the structural properties of arrows, such as accompaniments and connections, contribute to the interpretations of the arrows. The goal of this paper is to identify such structural properties inherent in an arrow that contribute to its interpretation.

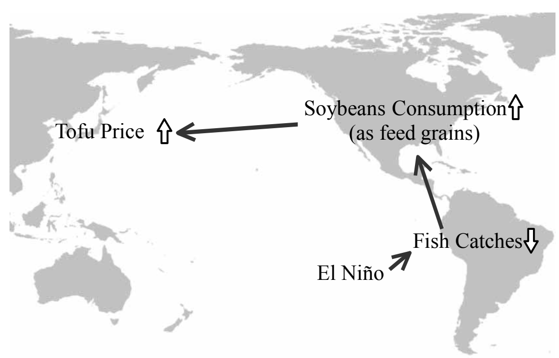


Figure 1: An arrow diagram depicting the influence of the El Niño Effect on the rise of the tofu price.

The appearance of an arrow symbol is subject to a variety of visual variables, such as length, width, shape, color, direction, orientation, and pattern (Bertin 1983). The arrow symbol alone, however, does not determine any specific meanings (Figure 2). The meaning of an arrow is composed when the arrow symbol refers to other surrounding elements. Thus, this paper focuses on the semantics associated with the surrounding elements, while the visual variables are kept invariant.

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

The combination of an arrow symbol and the surrounding elements to which the arrow symbol refers is considered a unit of meaning, and called an *arrow diagram*. Then, these surrounding elements 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 possible role and behavior of each component in the combination of the components, which are aligned in a certain meaningful way.

The remainder of this paper is structured as follows: First, we introduce the *slots* of arrow diagrams that capture the alignments of components, and observe how those alignments influence the interpretations of the arrow diagram. Then, we classify the components into five types, and demonstrate their influence on the interpretations. Based on these two settings, we distinguish arrow diagrams structurally. In addition, we demonstrate that the orientation of the components may provide a critical clue for determining a unique interpretation. Finally, conclusions and future works are shown.

## 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).

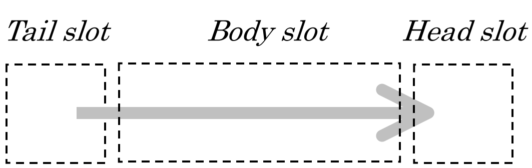


Figure 3: Three conceptual slots associated with an arrow symbol.

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 three slots are conceptual rather than physical areas, although we regard that the respective components are spatially contained in these slots.

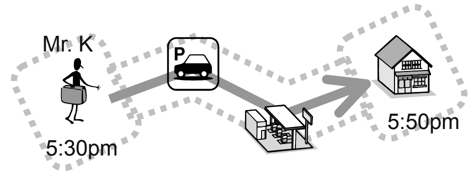


Figure 4: Three slots of an arrow diagram populated with components.

It is necessary to distinguish among these component slots, because the meaning of an arrow diagram changes if its components are placed in different slots. 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 *mounting a wheel to a car* to *removing a wheel from a car*. Figures 5c and 5d show another pair of arrow diagrams where an icon of Maine State has been moved from the head slot to the body slot, such that the meaning changes from *a traveler heads for Maine* to *a traveler passes through Maine*.

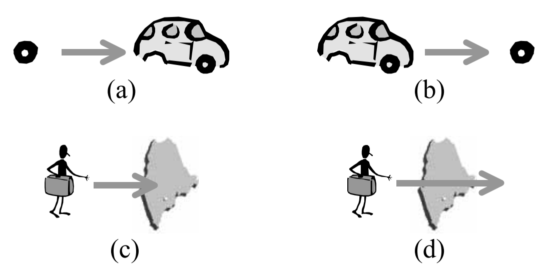


Figure 5: Two pairs of arrow diagrams, each with the same components in different slots.

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

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

## Five Types of Components

A component of an arrow diagram may be mentioned by an icon, 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* takes an action. A person, a car, and a house are examples of objects (A house seems inactive but people may regard that a house takes such an action as sheltering a person).
- An *event* occurs in time, and characterized by a set of changes. An event occurs at an instance (e.g., a traffic accident) or over an interval (e.g., a conference).

- A *location* is a point or a homogeneous region in space. Examples of locations are a mountain's peak (a point) and a mountain (a region).
- A *moment* is an instant or a homogeneous interval in time. Examples of moments are a departure time of a flight (an instant), or hours on an airplane (an interval).
- 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 the corresponding components by a line or an arrow.

The influence of these 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 of head components lead to different interpretations of the arrow diagrams: the traveler *leaves* his bag (Figure 6a), the traveler *participates in* the AAAI spring symposium (Figure 6b), and the traveler *heads for* Maine (Figure 6c). On the other hand, arrow diagrams with identical alignments of component types often lead to a same class of interpretation. For example, Figures 6c and 6d, both showing the configurations in which an object fills the tail slot and a location fills the head slot, illustrate the movement of the object *heading for* the location.

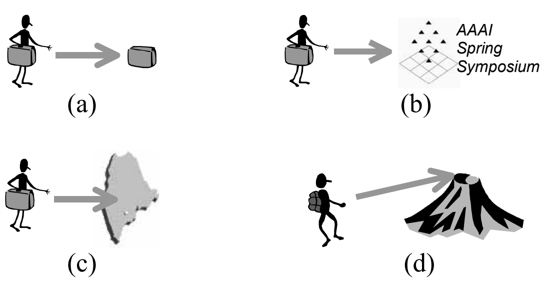


Figure 6: Arrow diagrams with various types of head components: (a) object, (b) event, (c) location, and (d) location.

With five types of components and three slots, $5^3$ types of arrow diagrams with exactly one component in each slot 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 $6^3 = 216$ types arrow diagrams are distinguished. They are called *simple arrow diagrams*, since 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, a simple arrow diagram will be denoted symbolically as ($c$, $c$, $c$).

Among 216 types of simple arrow diagrams, some lead automatically to a unique class of interpretation. For example, ($O$, –, $L$) is always interpreted 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 distinction that arises from the component types leads to the second postulate of parsing arrow diagrams:

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

## Intrinsic Orientation of Objects

If an arrow diagram has more than one object, its interpretation depends on which object is supposed to move. For example, Figure 7a has two possible 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 symbol's orientation. An object expressed by an icon often has 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. Such intrinsic orientations of objects are often critical to determine a unique 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 set of objects, only Figure 7b is uniquely interpreted as *a car approaches to a person*.

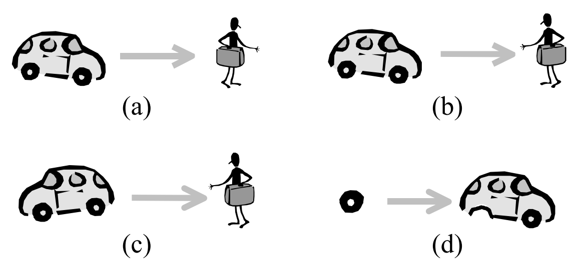


Figure 7: Arrow diagrams with different object orientations: (a) (+, ,+), (b) (+, ,–), (c) (–, ,–), and (d) (*, ,0).

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 either + or *. Therefore, if an arrow diagram refers to only one + or * object, the valid interpretation is uniquely determined (Figures 7b and 7d). If all objects are – or 0, then the arrow diagram may illustrate no movement or imply a movement of something that is not explicitly drawn in the diagram. For example, Figure 7c may illustrate a static relation between a car and a traveler or a scenario that *a person brings out something 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.*

## Conclusions

To understand the meaning of every arrow in a diagram is often a fundamental first step for the correct understanding of the whole process or mechanism illustrated in the diagram. This paper identified three structural properties of arrow diagrams, which are available as the postulates of parsing 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 interpretation are derived from the distinction of simple arrow diagrams, which was introduced in this paper. Then, the valid interpretation is determined from these candidates with the aid of various clues, which includes the object orientations. Since arrows are major components of diagrams, this method is expected to enhance the usability of pen-based systems such that their users can freely represent various semantics with arrows.

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