Transforming Temporal Knowledge: Conceptual Change between Event Concepts

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This paper offers a preliminary analysis of conceptual change between event concepts. It begins with a brief review of the major findings of cognitive studies on event knowledge. The script model proposed by Schank and Abelson was the first attempt to represent event knowledge. Subsequent cognitive studies indicated that event knowledge is organized in the form of dimensional organizations in which temporally successive actions are related causally. This paper proposes a frame representation to capture and outline the internal structure of event concepts, in particular, their causal connections. The frame representation offers an effective method to analyze the relations between event concepts, and to expose the unique cognitive mechanisms behind conceptual change involved event concepts. Finally this paper shows that the frame representation of event concepts is instrumental to understanding an important historical episode of conceptual change in the context of nineteenth-century optics.

1. Introduction

The world that we live in consists not only in a variety of objects, such as atoms, birds and cars, but also in a variety of events, such as engine cycles, eating and waves. Ontologically, there are substantial differences between these two kinds of existence.[1] Objects typically have volume and mass and usually are containable and storable. Unlike objects, events have neither mass nor volume, and they are not containable or storable. A typical event is a sequence of actions or a series of changes of state, which always varies

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1. Except for the consensus that they are different from objects, there has not been much agreement among philosophers as to the precise nature of events. For example, whether events should be included in ontology as *bona fide* entities is still an open question; see Casati and Varzi (1996).

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with time. As reported by many cognitive studies, events are recognized, memorized, and understood by humans in ways significantly different from how objects are learned, and event concepts have unique structural characteristics distinguishable from those of object concepts (Chi 1992; Zacks and Tversky 2001; Chen 2003b).

But when philosophers of science studied conceptual changes or scientific revolutions in the recent past, they concentrated on changes between object concepts. In the existing literature, typical examples of conceptual change are transformations of taxonomic systems that offer classifications of objects (Kuhn 1991).[2] Consequently, many important historical episodes are interpreted as some kind of taxonomic change. For example, the Copernican revolution changed the taxonomy of celestial bodies, the chemical revolution rewrote the classification of substances, and the Darwin revolution restructured the kind hierarchy of biological organisms (Kuhn 1987; Thagard 1992; Hull 1989). But recent historical studies indicate that not every important episode of scientific revolution was associated with taxonomic change. For example, the transformation from the pre-Copernican notion "orb" to Kepler's notion "orbit," a critical development during the Copernican revolution (Barker 2001), was a conceptual change from an object concept ("orb") to an event concept ("orbit").[3] Similarly, the shift from the particle notion "side" to the wave notion "phase difference," one of the most difficult transformations during the optical revolution (Chen 2003a), was also a conceptual change from an object concept ("side") to an event concept ("phase difference"). These are not the only exceptions. Episodes of scientific revolution also involved transitions between event concepts, such as the development from "longitudinal wave" to "transverse wave" in physical optics in the beginning of the nineteenth century. The existing theory limited to taxonomic change and object concepts fails to account for the diversity of scientific change.

In this paper I will offer a preliminary analysis of conceptual change between event concepts.[4] In the following sections, I will first introduce the major findings of cognitive studies on event knowledge. The script model proposed by Schank and Abelson was the first attempt to represent event knowledge. Subsequent cognitive studies indicated that event knowledge

2. There are different understandings of the nature of taxonomic change. For example, Hacking (1993) proposes a nominalist interpretation, according to which no taxonomic kinds exist in nature, but Kuhn (1993) adopts a Kantian interpretation and claims that changes in taxonomy would also alter objects themselves.

3. See Goldstein and Hon, this issue, for more on the transition from orb to orbit in Kepler's astronomy.

4. For discussions of conceptual change from object to event concepts, see Chi (1992) and Chen (2003a, 2003b).

is organized in the form of causal sequences. Next, I will propose a frame representation to capture and outline the internal structure of event concepts, in particular, their causal connections. The frame representation offers an effective method to analyze the relations between event concepts, and to expose the unique cognitive mechanisms behind the conceptual change between event concepts. Finally I will show that this frame representation of event concepts is instrumental to understand an important historical episode of conceptual change in the context of nineteenth-century optics.

2. Knowledge of Events

We undoubtedly have knowledge of events. We usually have no difficulty participating in various complicated events (Abelson 1976). We are able to anticipate the likely consequences of actions in many daily events. For example, those who regularly eat in a restaurant would be quite confident that once they have been seated at a table and have read the menu, someone will appear to take orders. Also, we are able to make sense of a sequence of actions without knowing every detail because we can fill the gaps according to our knowledge of the event—most people could understand that a bank robbery has happened when they see that a person entered a bank wearing a ski mask and emerged shortly thereafter carrying a gun and a bag.

Schank and Abelson (1977) proposed a script model to represent our knowledge of events. According Schank and Abelson, people's knowledge of events consists in a variety of stereotyped sequences of routine actions. Examples of these stereotyped sequences of actions include riding a bus, visiting a doctor, eating in a restaurant, and so on. Through experiences, people acquire these cultural stereotypes along with their idiosyncratic variations. Schank and Abelson call these cultural stereotypes of action sequences "scripts."

Figure 1 is an outline of the script for "going to a restaurant" (Schank and Abelson 1977, p. 43). To be more specific, it describes the sequence of actions happening in a particular kind of restaurant—coffee shops. Schank and Abelson called this specific version "the coffee shop track," a distinct subclass of "going to a restaurant."[5] Similar to other abstract structures in knowledge representation such as schemas, scripts are made up of slots and the connections between these slots. For each of these slots, there is a default value that reflects a well-known, stereotyped situation. However,

5. The restaurant script has many distinct tracks, such as "the formal restaurant track," "the fast-food restaurant track," and "the take-away restaurant track," each of which has its own unique structure.

scripts are different from other schematic structures in two aspects. First, slots in scripts specify actions; second, connections between actions in scripts are temporal and causal. To perform the next action in the sequence, the previous action must be completed satisfactorily. Otherwise, a new action that is not prescribed in the original version of the script will be needed in order to get things going again. These temporal and causal connections make a script "an interconnected whole," in the sense that "what is in one slot affects what can be in another" (Schank and Abelson 1977, p. 41). In the restaurant script, the sequence of actions begins with "customer goes into restaurant" and ends with "customer leaves restaurant." These actions are linked temporally and causally—a preceding action not only occurs earlier, but also functions as one of the preconditions that enables the successive action. The preconditions for the beginning action are indicated by the entry conditions "customer is hungry" and "customer has money," and consequences of the ending actions are marked by the results "customer has less money," "customer is not hungry" and "owner has more money."

The other component of the script is a list of objects that function as general preconditions for the sequence of actions. These objects are further divided into two groups: role and prop. Roles are slots available to the actors who take the actions; "customer," "cook," "waiter," "owner," and "cashier" are the standard roles in the restaurant script. Props are the means that the actors use to accomplish the actions; "table," "menu," "food," "check," and "money" are the typical props in the restaurant script.

The sequence of actions in this script can be analyzed at two levels of abstraction. At a more abstract level, it is divided into what are referred to as scenes, such as "entering," "ordering," "eating," and "exiting." At a more concrete level, the sequence is divided into actions under different scenes. In this way, there is an hierarchical structure within a script. At the top of this hierarchy is a notion that summarizes the whole event of going to a restaurant. The overall event is then broken into four scenes, which in turn decompose into actions.

Schank and Abelson's script model represents an earlier attempt to capture the internal structure of event knowledge. Subsequent cognitive studies generally support the script model. A series of psychological studies indicates that scripts correspond to psychological reality, in the sense that people indeed use predetermined, stereotyped structures to understand routine events and that people have significant agreement on the actions that comprise these events.

Direct evidence for the existence of scripts comes from studies of recall and recognition. Bower, Black, and Turner have conducted a number of experiments to examine directly if people actually organize temporal in-

Script: Restaurant
Track: Coffee Shop
Props: Tables, menus, food, check, money
Roles: Customer, cook, owner, waiter, cashier

Entry Conditions: Customer is hungry.
Customer has money.

Results: Customer has less money.
Customer is not hungry.
Owner has more money.

Scenes:

1. Entering
Customer goes into restaurant.
Customer looks around.
Customer decides where to sit.
Customer goes to the table and sits down.

2. Ordering
Customer picks up menus.
Customer decides on food.
Customer orders food from waiter.
Waiter tells cook the order.
Cook prepares food.

3. Eating
Cook gives food to waiter.
Waiter gives food to customer.
Customer eat food.

4. Exiting
Waiter writes out check.
Waiter brings check to customer.
Customer gives tip to waiter.
Customer goes to cash register.
Customer gives money to cashier.
Customer leaves restaurant.

Figure 1. The Restaurant Script. Adapted from Shank and Abelson (1977).

formation in the form of script-like structures. In one of these experiments, they asked 30 or so subjects to list the typical actions that make up such events as "eating at a fancy restaurant," "attending a lecture," and "visiting a doctor." They found that the subjects had no trouble generating a series of ordered actions for each label and, more important, there was good agreement about what the actions were and what the main scenes were. For example, of 730 actions mentioned under "eating at a fancy restaurant," only four were completely unique—mentioned by a single person—and 25 actions were mentioned by at least 25% of the subjects (Bower, *et al.* 1979).

Furthermore, people also agree on the sequence of scripted actions. Galambos and Rips have conducted experiments to compare the role of sequences implied by scripts and the role of centrality offered by prototypes in event knowledge. They asked subjects to rank temporal episodes such as "going to a movie" and "starting a car" either in the order in which they would normally be performed or in the order of their relative importance in performing the activity. In their experiments, the subjects showed strong consensuses when they organized the episodes along the dimension of temporal sequence, while they showed fewer consensuses when they organized the episodes along the ranking of importance or centrality (Galambos and Rips 1982). This suggests that the subjects indeed used scripts instead of prototypes to represent event knowledge.

3. The Structure of Event Concepts

According to Schank and Abelson, the meaning of an action in a script is defined by its relations to other actions in the causal chain. Causal relations that typically occur in well-known situations are learned and represented in the forms of various associations in the memory. These associations function as pathways for eliciting priming or activation. A cue or a stimulus would spread along these pathways following the sequences defined by the causal associations. In this way, order of activation determines processing times. For information to be used in such tasks as recognition judgments, it must first be activated and then inspected. Information near the cue is activated and inspected faster than information far away from the cue. By emphasizing the causal connections between actions within scripts, Schank and Abelson implied that temporal orders in event concepts are represented in the form of dimensional organizations, in which their components are causally chained together according to increasing or decreasing values on the temporal dimension.

If temporal orders are represented in the form of dimensional organizations, a distance effect should exist; that is, in such a task as recognition judgment, the reaction time should be in proportion to the distance (the number of actions) between the prime and the target. When we judge which of two actions comes earlier in a sequence, we would react quickly if the distance is small, because we must search the causal link from either end until the positions of these actions are located.

Direct observations of the distance effect were reported by Foss and Bower (1986). In a series of experiments, they measured the time that subjects needed to understand a pair of statements that describe two actions in a sequence. The subjects were given two kinds of statement pairs—near-event sequences and far-event sequences. Near-event sequences contain two actions that are relatively close, such as "John made a sign" and "John participated in an anti-nuclear rally." Far-event sequences, however, contain two actions that are relatively far apart, such as "John made a sign" and "John wanted to stop construction of a nuclear power plant." The results of their experiments showed that the time it took to understand these pairs of actions depended on the distance of the events in the sequence: events that were further apart took longer to understand.[6]

The script model also implies a direction effect; that is, people should perform differently during forward and backward recall. Specifically, forward recall should be faster than backward recall. This follows from a generally accepted assumption that activation in memory can be asymmetrical in strength: the direction of activation that is processed more frequently will develop stronger connections. Because events are usually recalled and processed by following the direction defined by causal connections, that is, from beginning causes to end results, forward recall should be better established than backward recall.

Haberlandt and Bingham (1984) first reported observations of the direction effect. They asked subjects to decide whether or not pairs of statements are related, and they measured the number of errors that the subjects made in their decisions and the response time that the subjects needed to make their decisions. The subjects were given two types of statement pairs. In forward pairs, the two statements were arranged according to the temporal sequence defined by the script, such as "he got some logs" and "he lit the wood," while in backward pairs, statements were put in a reverse order, such as "he blew on the flame" and "he lit the wood." The results showed that the subjects made their decisions faster and more accurately for forward than backward pairs. The average response time for backward pairs was about 10% longer than that for forward pairs, and the number of errors in the decisions for backward pairs was almost double the number for forward pairs.[7]

6. Initial empirical studies did not verify the distance effect (Bower, *et al.* 1979; Nottenburg and Shoben 1980; Franklin and Bower 1988). But these reports of a non-distance effect can be attributed to faults in experimental designs. For example, Bower *et al.,* as well as Nottenburg and Shoben, paid little attention to the hierarchical structure of scripts and sometimes asked the subjects to make judgments between actions that belong to two different levels of abstraction, the abstract scene level and the concrete action level (Abbott, *et al.* 1985). Similarly, the reverse distance effect reported by Franklin and Bower was probably caused by the experimental design that tested the subjects repeatedly on the same materials (Zacks and Tversky 2001).

7. Barsalou and Sewell (1985) offered further evidence for the direction effect through a series of timed production experiments. Subsequent studies indicate that forward and backward recall involve different cognitive mechanisms. Forward recall is largely based on

The distance and direction effects confirm Schank and Abelson's insight that temporal knowledge is structured in the form of dimensional organizations in which temporally successive actions are related causally. By describing an event chronologically, from the beginning to the end, the script model is effective in capturing the temporal order. But it reveals very little about how these actions are causally chained together. A script says almost nothing explicitly about the causal connections between actions, except listing the beginning and ending points of the sequence. From the restaurant script, for example, we do not know how the scene "entering" actually causes "ordering," nor do we have any idea of the specific kind of causal connections in effect. Furthermore, the script model does not define the roles of objects in temporal sequences. Our experience tells us that a different state of a related object could change the action sequence; for example, if certain foods are not available in a restaurant, or a waiter does not interact with a customer in a proper manner, the action sequence would proceed in a way significantly different from the one outlined in the script. To overcome these problems, I propose to use frames to capture the dimensional organizations within event concepts.

A frame is a set of multi-valued attributes integrated by structural connections. Figure 2 is a partial frame representation of an object concept "car." The frame divides features into two groups, attributes and values. All exemplars of "car" share the properties in the attribute list such as "engine" and "size." Features in the value list, however, are activated selectively to represent the prototype of a specific subordinate concept. For example, a typical compact car is a vehicle whose value for "engine" is restricted to "4-cylinder" and whose value for "size" is "small." This frame representation outlines two kinds of intraconceptual relations. The first are hierarchical relations between attributes and values. A value is always attached to a particular attribute and usually describes either a part or a state of the attributes. The second are constraint relations between features. There are connections between attributes and between values: the power of "engine" is always correlated to the value of "size." These connections between attributes, also called structural invariants, impose constraints to the activations of values and produce systematic variability in values: if the value of "size" is "large," then the value of "engine" is likely "8-cylinder."

Using frames to represent event concepts requires a more complicated structure. Barsalou has offered several examples of crossed frame represen-

associations between actions defined by the script, while backward recall relies on visual-spatial similarities between the actions (Geiselman and Callot 1990; Li and Lewandowsky 1995).

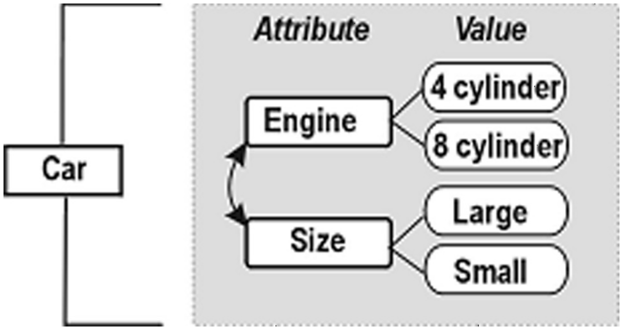

Figure 2. A Partial Frame for "Car".

tations for such event concepts as "engine cycle" and "buying things" (Barsalou 1992). These crossed frame models for event concepts contain two interconnected frames, representing both the sequence of actions and the related objects. Figure 3 is a partial frame representation for "going to a formal restaurant." It contains two frames. On the left-hand side of Figure 3 is a component frame that contains the major objects listed in the script ("food," "money," "table," "customer," "waiter," and "cashier").[8] These objects are treated as attributes, each of which has its own values. Values in the component frame do not describe parts of the attributes, but either states of the props or actions of the actors. For example, "owned by customer" and "owned by restaurant" are the two states of "money," and "walking," "selecting," and "eating" are the three actions of "customer." The frame also indicates that there are constraint relations between different sets of values. For example, if the value of "customer" is "selecting," the value of "waiter" is typically "interacting with the customer," or if the value of "customer" is "eating," then the value of "waiter" is "interacting with others."

On top of the right-hand side of figure 3 is a sequence frame that captures the succession of actions. The four attributes of this frame represent four specific moments in the sequence, or the four scenes in the script. Each of these attributes takes a set of specific values from the lists defined by the component frame. In Figure 3, for example, "ordering" in the action sequence takes six specific values from the six attributes in the component frame: "food owned by restaurant," "money owned by customer," "occupied table," "customer selecting," "waiter interacting with the customer," and "cashier interacting with others."

8. For the sake of simplicity, only three props and three actors are listed in the frame.

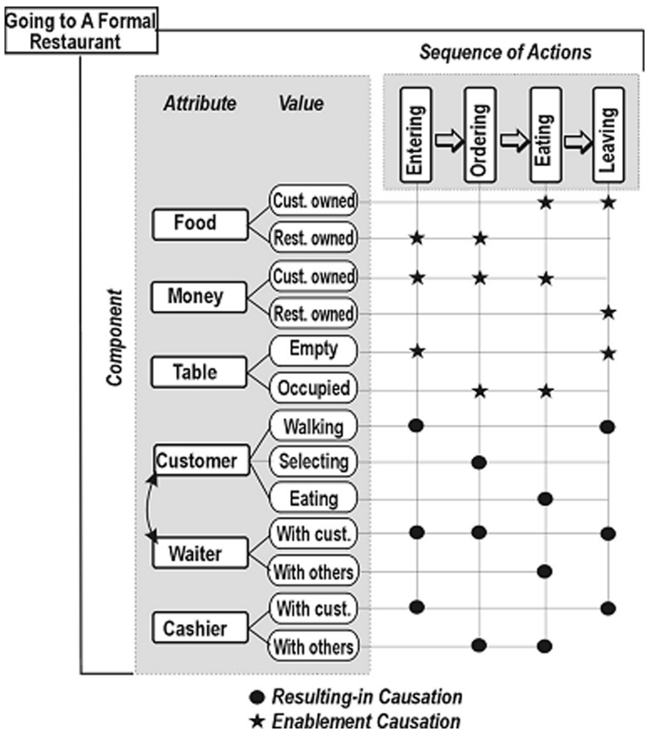

Figure 3. A Partial Frame for "Going to A Formal Restaurant".

By crossing a component and a sequence frame, the frame representation illustrates the causal connections underneath the event of "going to a formal restaurant." The selected values under each attribute of the sequence frame represent the causal conditions for that particular stage and the causal effects that are generated by the preceding scene. For example, the six selected values under "ordering" are the causal conditions that result in "ordering." At the same time, these six selected values are the results produced by a change of state during "entering." Each attribute of the sequence frame activates a distinctive set of values, and together they represent the causal network underneath the event.

The frame representation also distinguishes different kinds of causal connections. Some of the causal relations depicted by the frame are typical, in which human agents somehow come in contact with objects and the actions of human agents result directly in changes of the objects, but others are atypical, in which the causes are not human agents nor are there direct links between causes and effects.[9] Among the causal conditions that are responsible for "entering," for example, "customer walking in," "waiter interacting with the customer," and "cashier interacting with the customer" are human actions and the objects changed by these actions bring about the stage of "entering." This kind of typical causal connection is sometimes called resulting-in causation. On the other hand, among the causal conditions responsible to "entering," "food owned by the restaurant," "money owned by the customer" and "empty table" are not human actions and do not change any object directly. They are states of the props. To function as causal conditions, they need some intermediate factors, such as motivations and actions of human agents. Only through these intermediate factors could these states of props enable the action of "entering." This kind of atypical causal connection is sometimes called enablement causation.

4. Event Concepts and Conceptual Change

Although we know quite a lot about events, misunderstandings about events happen frequently. Consider the following description of an event: "John went to a restaurant, ordered a Big Mac, paid for it and found a nice park to sit down." If we know the meaning of "Big Mac," we would activate the fast-food track of the restaurant script and understand the event. But if a reader does not know the meaning of "Big Mac," s/he might activate a different one such as the formal restaurant track. If so, the above sequence of actions seems rather odd—the formal restaurant track requires that the customer should eat before paying and should eat inside rather than outside the restaurant. Without an appropriate script, the reader might not be able to elaborate the unstated connections, nor could s/he answer such a question as "Did John eat?" This is an example of misconceptions about events—an inappropriate schema has been activated to represent an event that occurs in a fast-food restaurant.

Misconceptions about events make understanding difficult—"the lack of applicability of available scripts would make it harder (and take more time) for a hearer to understand" (Schank and Abelson 1977, p. 41). To amend this kind of misconception, a conceptual change between event concepts, that is, a shift from a previous and inappropriate representation to a proper one, is required. Misconceptions about events could also cause communication problems between individuals. When two persons activate different schemas to represent the same event, they could experience communication difficulties. A conceptual change between event concepts is also required for both sides to understand each other. How hard it

9. For a discussion of the prototypical properties of causation, see Lakoff (1987).

would be or how much more time it would take for an individual or a community to complete such a conceptual change depends, in part, on the extent to which the two relevant conceptual representations differ from each other.

The frame model offers an effective method to analyze the relations between different event concepts. First, we can inspect their structural relations by comparing their component frames. Two event frames could involve different objects—"waiter" appears only in the formal restaurant track but not in the fast-food track. More importantly, they could have different constraint relations. For example, the constraint relations between "customer" and "waiter" in the formal restaurant track no longer exist in the fast-food track. On the other hand, the fast-food track has a new constraint relation that "food" and "money" are never in the same hand (customers must pay before they can get the food).

Second, we can inspect their structural relations by comparing their sequence frames. Two event frames could have different temporal orders; for example, "ordering" could precede "entering" and "eating" could follow "leaving" in the fast-food track. More importantly, they could have different causal connections. In the formal restaurant track, "money owned by customer" is one of the causal conditions that enable "eating," but this is not the case in the fast-food track—money has been paid before "eating."

Each of these structural differences constitutes a possible source for cognitive error, and each of these structural differences indicates a specific direction for conceptual change to amend misconceptions for events. By analyzing intraconceptual relations, the frame representation reveals the characteristics of conceptual change between event concepts. A shift from one event concept to another is in many aspects different from a shift from one object concept to another. Specifically, conceptual change between event concepts involves unique cognitive mechanisms dissimilar to those underlying conceptual change between object concepts.

To achieve a conceptual change between object concepts, one must somehow adjust the corresponding attribute lists. How an object is classified or how a taxonomy is constructed may be directly determined by the numbers of attributes and values, as well as the relations between attributes and the relations between attributes and values. For example, since the frame for "car" (Figure 2) has two attributes and each of them has two values, there are four possible property combinations (2x2) and thereby four possible concepts at the subordinate level. Due to the constraints between the value sets, some of these property combinations are conceptually impossible, such as "4-cylinder engine" with "large size." The results are only two property combinations, which form two subordinate concepts—"compact car" and "full-size car." Any piecemeal adjustment in the lists of attributes, such as adding or deleting an attribute or a value, altering the hierarchical relations between attributes and values, and changing the horizontal relations between attributes, could cause holistic change in the object concept. For example, adding a value "medium" to the attribute "size" and "6-cylinder" to "engine" would cause a differentiation of the subordinate concepts—some instances of "compact car" are now put under a new subordinate concept "mid-size car." Similarly, replacing the attribute "size" with "door number" would cause a reorganization of the taxonomy—"coupe," "sedan," and "wagon" would become the new subordinates, and some instances of different concepts in the old taxonomy are now classified together. Thus, holistic taxonomic changes may be achieved by adjusting attribute lists in a piecemeal manner.

Conceptual change between event concepts, however, has a different cognitive mechanism. Like object concepts, one can change event concepts by altering their attribute lists. However, unlike object concepts, one cannot do so in a piecemeal manner. Changes of the attribute list in an event concept always require corresponding alternations of other structural relations, including those in the sequence frames, such as the temporal order and the causal connections between actions. Furthermore, changes of the attribute list in an event concept inevitably alter the meaning of the concept in a holistic way. For example, different attribute lists in the restaurant frame are usually associated with different temporal orders as well as different causal connections between actions, which in turn generate conflicting expectations. Adopting the fast-food track, for example, customers would expect that foods are ready when they enter, or at least they would expect little waiting time. The implications generated by changes of attribute lists could go beyond the observable level and alter the nature of the event as a whole. For example, the new constraint relations in the fast-food track imply a new assumption regarding the nature of business transactions—no loan in fast-food restaurants (customers must pay before they can get the food). The new attribute list itself also entails a different assumption regarding the division of labor in the business—no waiters are needed in fast-food restaurants.

For object concepts, adjustments of attribute lists could be done not only in a piecemeal, but also in a consensual manner. Many cognitive studies have shown that when we construct a frame to represent an object concept, our selections of the attributes are not arbitrary. People often agree with each other on selected attributes in the process of frame construction, although they shared very little in their background beliefs and eventually adopt totally different frames. They frequently prefer features that contain rich spatial information as attributes. For biological objects, body parts are such preferable features—they are spatially salient because they are identifiable by their shapes and because they collectively outline the overall shape of the referents. Thus, body parts are frequently selected as attributes in constructing frames for biological concepts (Rosch, *et al.* 1976; Tversky and Hemenway 1984). The preference for spatially salient features in attribute selection can provide a common platform to form a chain of reasoning for conceptual change and to conduct rational comparison between rival taxonomies. By focusing on the justifications for the attribute adjustments, scientists can offer reasoned arguments for conceptual transformation between object concepts, and the scientific community can eventually reach consensuses through a series of rational debates (Nersessian 1984; Shapere 1989; Chen 2002).

It is more difficult to reach consensus on attribute adjustments in event concepts than in object concepts. Because of its holistic nature, any change of the attribute list in an event concept requires transformations in the sequence frame. To construct a sequence frame, one must bring order to a temporal flux of continuous change. Forming a sequence frame involves a process of conceptual partitioning, in which the mind extends a boundary around a portion of what would otherwise be a continuum of time. Cognitive studies have found that people are able to cut the continuity of temporal experience into discrete, bounded units in a non-arbitrary manner. In a series of experiments, Newtson and Engquist asked subjects to break a continuous stream of action, such as a man searching for a lost item in a desk, into meaningful units. The subjects were instructed to identify those "breakpoints" at which one meaningful action ends and another begins. Repeated tests showed that the subjects never selected these breakpoints randomly or arbitrarily. Instead, most breakpoints that they picked corresponded to moments at which a maximum number of physical features are changing, and there is reasonably good agreement across the subjects as to what the breakpoints are (Newtson and Engquist 1976). But our consensus on temporal partitioning is not as strong as the one based on the preference for spatially salient features in object concepts, and our consensus easily and quickly disappears. Studies found that subjects readily varied the number of breakpoints identified in a given sequence in response to all kinds of variations trivial or even unrelated to the sequence, such as what kind of intent-related information about the actor in the sequence is supplied, whether the sequence was presented to the subjects contiguously, and even who gave instructions to the subjects, a co-worker or a supervisor (Zadny and Gerard 1974; Newtson 1973; Frey and Newtson 1973). These indicate that the consensus in temporal partitioning is highly contextual, reflecting not only our interpretations of the meaning of the action sequence but also our reactions to the conditions of the partitioning process. The complexity in temporal partitioning makes it difficult to reach consensuses on attribute selections, and subsequently difficult to form a chain of reasoning for conceptual change between event concepts.

Because of the holistic nature of event concepts and the contextual nature of temporal partitioning, conceptual change between event concepts exhibits many unique characteristics that are not found in taxonomic change. In many ways, this is a distinct kind of conceptual change that deserves our further investigation.

5. A New Perspective on A Conceptual Change in Nineteenth-Century Optics

Our cognitive analysis of event concepts can offer a new perspective on the history of early nineteenth-century optics. Most existing accounts characterize this historical episode mainly in terms of the conceptual change from the particle to the wave theory, both of which are treated as systems of taxonomy (Cantor 1983; Chen 1995). Little has been said to another important conceptual change that happened in the same historical period, the transformation from the longitudinal to the transverse model in the wave tradition. At the beginning of the nineteenth century, almost all wave theorists believed, at least publicly, that waves are longitudinal vibrations. It was Fresnel who introduced the notion of transverse waves to explain the newly discovered phenomenon of polarization in 1822. Subsequently, transverse waves replaced longitudinal waves to become the dominant wave model. Historically speaking, the transformation from the longitudinal to the transverse model was the precondition for the later replacement of the particle theory by the wave theory. Without the notion of transverse vibrations, the wave theory would have not been able to demonstrate its explanatory advantages over its rival. Cognitively speaking, the conceptual change from the longitudinal to the transverse model was as profound as the one from the particle to the wave model. Many prominent wave theorists, including Arago and Thomas Young, could not complete this conceptual change in their whole lives.

Among those who failed to complete this conceptual change, Young is particularly interesting. On the one hand, Young was a well-trained wave theorist who had no trouble understanding the major notions and principles of the tradition. On the other hand, he experienced great difficulties in comprehending the notion of transverse wave and reacted negatively toward Fresnel's proposal. Why did Young fail to comprehend the transverse model correctly? If "longitudinal wave" and "transverse wave" were two object concepts, the transition between them could be achieved by adjusting the attribute lists in a piece meal manner. As a prominent wave theorist, Young should have been able to complete these adjustments. To understand Young's failure, we must notice that both "longitudinal wave" and "transverse wave" are not object but event concepts, representing two conflicting pictures of wave transmission.

Strictly speaking, waves are processes, different from events in many ways. For example, events are heterogeneous in the sense that components of an event are not events anymore, but processes are homogeneous, that is, any part of a process is of the same nature as the whole. Furthermore, events are countable because each event has a starting and an ending point, but processes are indefinite because they do not have terminal points (Mourelatos 1978). But there are still significant similarities between processes and events. Like an event, a process is a temporal series of changes of states, linked one to another by causal connections. We can continue to use the frame model developed in the previous sections to represent both "longitudinal wave" and "transverse wave."

According to the longitudinal model, waves of light oscillate along the direction of propagation, the same way as the vibrations of sound. Figure 4 is a partial frame representation for "longitudinal wave." On the left-hand side of the figure is a frame representing the components for the process. Unlike social events in which actors are usually involved, natural processes typically have only objects as components. The sole attribute in the component frame represents the longitudinal oscillations in the wavefront, and its values describe specific phases of the oscillations (only four are listed for the sake of simplicity). On the right-hand side of figure 4 is a frame that captures the temporal sequence. The attributes in this frame represent different moments in the sequence, each of which takes a specific value corresponding to the attribute in the component frame. For example, T1 is the moment when the phase of the longitudinal oscillations is "π," T2 is the moment when the phase is "½π," and so on. This model implies that light is spatially symmetric, and it provides a reasonable explanation for unpolarized light.

Between 1819 and 1821, Fresnel introduced the transverse model to account for interference of polarized light (Buchwald 1989). According to Fresnel, waves of light oscillate perpendicularly to the direction of propagation. Even natural light—that is, unpolarized light—contains only transverse oscillations, and is always completely asymmetric. Mathematically, a transverse oscillation can be decomposed into two orthogonal vibrations with a certain phase difference. The distinctions between polarized and unpolarized light consist in the phase difference and amplitude ratio of the two orthogonal components of a light beam. The orthogonal components of polarized light always have a fixed phase difference and a fixed amplitude ratio, while the phase difference and amplitude ratio of unpolarized light vary over time. Figure 5 is a partial frame for "transverse

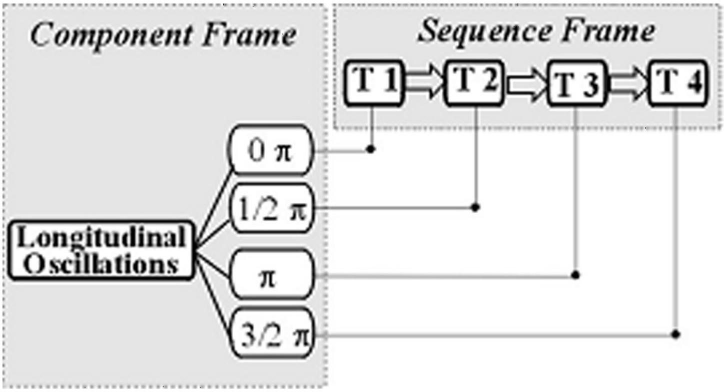

Figure 4. A Partial Frame for "Longitudinal Wave".

wave." The attributes in the component frame represent the orthogonal components of transverse oscillations in the wavefront, and their values describe their specific phases. On the right-hand side is a frame that captures the temporal sequence. The attributes in this frame represent different moments in the sequence, each of which takes a specific value corresponding to each attribute in the component frame. With different value assignments, the frame can represent different states of polarization. For example, Figure 5 describes a process in which the two orthogonal components have a stable phase difference (½π,), and thereby represents polarized light. If the two orthogonal components in the figure are given an unstable phase difference, then it represents unpolarized light.

The frame representations display several differences between the longitudinal and the transverse model. The most obvious one is between their component frames. In the longitudinal model, the component attribute is "longitudinal vibrations," while in the transverse model, the attributes are two transverse vectors. This reflects two distinct explanatory mechanisms, one parallel and the other perpendicular to the direction of propagation. This difference drew the attention of most contemporaries, and the two models consequently got their names in terms of these explanatory mechanisms.

But the two models had a couple deeper, frequently misunderstood, differences in their sequence frames. First, the two models assume different sequences of actions. In the longitudinal model, the sequence of actions is a density-alternation process. Longitudinal oscillations alter the density of the medium (the ether particles), and generate alternations of density in the front. A high-density moment at the front causes a low-

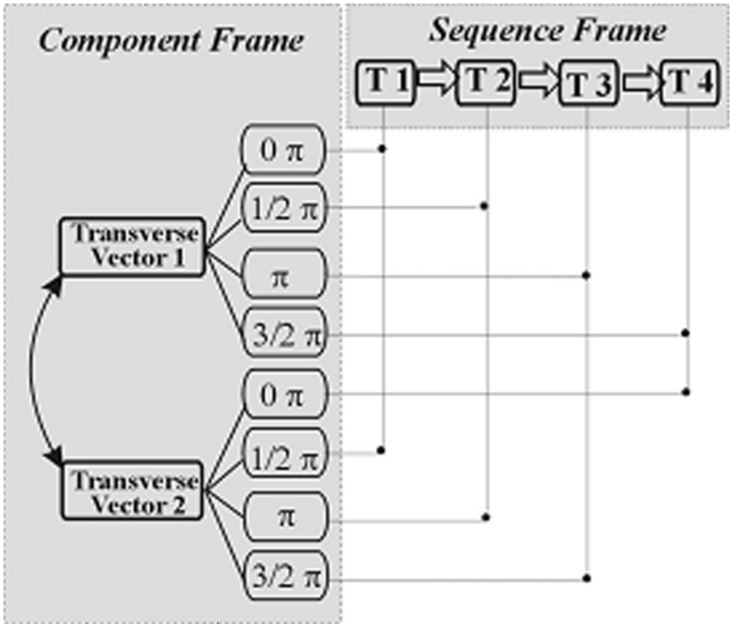

Figure 5. A Partial Frame for "Transverse Wave".

density moment by rarefaction, which in turn produces a moment of high-density by compression. Thus, the sequence of actions in the longitudinal model is mechanical, in which successive moments are related by force. In the transverse model, however, the sequence of actions is not mechanical. Decomposing oscillations into two perpendicular vectors is a mathematical operation originated from the necessity of explaining interference of polarized light. Since two coherent waves with perpendicular planes of polarization always have a resultant in the wavefront, a wave can always be decomposed, conceptually but not experimentally, into two orthogonal components. Since a specific phase relation at a particular moment does not mechanically cause the phase relation in the subsequent moment, the sequence frame of the transverse model illustrates a kinematic process; that is, describing the oscillations without regard to their causes.

Furthermore, the two models presuppose different understandings of the nature of light. The longitudinal model implies that the mechanisms that distinguish polarized from unpolarized light are spatial. To explain polarization, almost all believers of the longitudinal model, including Fresnel before he hypothesized the alternative, added a new element to the component frame—a transverse attribute representing oscillations perpendicular to the direction of propagation. Various states of polarization were accounted for in terms of the existence of the spatially distinct longitudinal and transverse oscillations. If only longitudinal oscillations exist, the ray of light is unpolarized; if only transverse oscillations exist, polarized; and if both exist, partially polarized. According to the transverse model, however, states of polarization cannot be determined in terms of any spatial standards, because even unpolarized light is spatially asymmetric. The key to defining polarization is a temporal standard—whether there is a synchronized variation of phases between the two transverse components during the process of oscillations.

Thus, to complete the conceptual change from the longitudinal to the transverse model, one must abandon not only the component frame of the former, but also, perhaps more importantly, its sequence frame. Apparently, Young failed to do so. He was able to accept the component frame of the transverse model, but he continued to adopt the sequence frame of the longitudinal model.

Evidently, Young did not have trouble in adopting the component frame of the transverse model. In fact, he was the first person who entertained the idea of transverse oscillations of the ether, several years before Fresnel. In a letter to Arago dated January 12, 1817, Young agreed that it was possible to use transverse vibrations to explain the phenomenon of polarization (Young [1817] 1855, p. 383). Although Young did not know how such transverse oscillations could be derived from the longitudinal ones, he was willing to accept them hypothetically. Young did not have conceptual obstacles to accept the new component frame of the transverse model. But Young was less successful when he dealt with the sequence frame. When he contemplated the possibility of transverse waves, he did not understand the two assumptions associated with the transverse sequence. In a letter to Arago dated April 29, 1818, Young elaborated his speculations about transverse waves by offering an analogy—transverse waves are similar to vibrations of a stretched cord agitated by an oscillating motion at one of its ends.[10] In terms of the sequential and causal mechanisms embedded in the process of oscillations, vibrations of a stretched cord are more similar to longitudinal than to transverse waves. First, a stretched cord illustrates a mechanical process: the oscillating source generates a series of displaced and equilibrated states, which are related by force. Second, with mechanical vibrations as the analogy, it becomes difficult to appreciate the conceptual decomposition proposed by Fresnel, because such a mathematical operation is valid only in kinematic

10. This letter is now missing. Arago communicated Young's idea to Fresnel, who recalled Young's analogy in an article published in 1831 (Wood 1954).

analyses. Without the conceptual decomposition, the synchronized variation of phases that defines the states of polarization is obscured and transverse oscillations become a spatial notion. Thus, Young's understanding of transverse waves was inconsistent. On the one hand, he accepted the component frame of the transverse model and considered transverse oscillations as a possible explanatory mechanism. On the other hand, he continued to adopt the sequence frame of the longitudinal model and conceptualized the process of transverse oscillations as mechanical and spatial.

These assumptions inherited from the longitudinal model became obstacles that prevented Young from appreciating the possibility of transverse waves as a physical reality. Without understanding the implied synchronized variation of phases, Young treated transverse oscillations as a spatial attribute. But adding a transverse element to the longitudinal model in this way he could not improve its explanatory power. For example, as long as the longitudinal component exists, it is impossible to explain why two rays polarized at right angles do not interfere with each other. Relations to the theories of mechanics became Young's sole criterion for evaluating the transverse hypothesis. From this perspective, Young's reasoning was straightforward and logical. According to the principles of mechanics, all transverse waves require an elastic force that tends to bring the displaced particle back to its equilibrium position. The question is where such an elastic force originates. Citing Savart, Young believed that the cause of the elastic force in any material is "a symmetrical arrangement" of the constituent parts (Young [1823] 1855, p. 416). Thus, Young logically concluded that "this [elastic] force constitutes the rigidity or hardness of a solid body, and is wholly absent from liquids" (Young 1807, vol.1, p. 180). If a solid is the only form of material that supports transverse waves, the ether must be solid—an absolutely absurd conclusion. This became Young's main reason to reject the transverse model. He called Fresnel's transverse hypothesis "appalling in its consequences," because "it might be inferred that the luminiferous ether, pervading all space, and penetrating almost all substances, is not only highly elastic, but absolutely solid!!!" (Young [1823] 1855, p. 415).

In the meantime, Fresnel fully understood the conceptual problems of the transverse model, but he treated them with a different attitude. To Fresnel, the most important consideration was the explanatory successes of the transverse model. By conceptualizing polarization as a temporal process characterized by a synchronized variation of phases, Fresnel was able to explain those puzzling results from his experiments of chromatic polarization. The explanatory successes verified his kinematic approach. So, although Fresnel also worked hard to develop a mechanical account for the transverse model, he did not expect that he could completely reconcile the transverse model and the ether mechanics. Instead, he asserted that, if those conceptual problems continued, it was the ether mechanics, not the transverse model, that needed to be revised. Otherwise, "It would then be but little philosophical to reject an hypothesis to which the phenomena of optics so naturally lead, for no other reason than because it does not agree with these equations [of mechanics]" (Fresnel [1827] 1852, p. 262).

These different attitudes toward the conceptual problems of the transverse model originated from different understandings of the process of oscillations. Because Fresnel regarded it as a kinematic process characterized by temporal relations, he could appreciate the explanatory merits of the transverse model and understated its conceptual problems. Contrary, because Young viewed it as a mechanical process characterized by spatial relations, he could not see the merits of the transverse model and emphasized its conceptual problems. In this way, Young failed to complete the conceptual change from the longitudinal to the transverse model.

6. Conclusion

Transformation between event concepts is a different kind of conceptual change. Because event knowledge is organized in the form of temporal and causal sequences, conceptual change between event concepts has its own unique cognitive mechanisms. Unlike to transformations involving object concepts, conceptual changes between event concepts cannot occur in a piecemeal way and are more difficult to achieve in a consensus manner. Our cognitive analyses of transformations of event knowledge offer a new perspective to study conceptual change in the history of science. The key to understanding the shift from longitudinal to transverse wave in early nineteenth-century optics is to represent these notions as event concepts.

The discussion also raises a question about the method of analyzing conceptual change. Most previous philosophical analyses of taxonomic changes focused on the semantic aspect of conceptual change, that is, on the relationship between concepts and their referents. This approach is possible because an object concept can be represented by a set of properties. Each specific combination of these properties constitutes a subordinate concept with unique referents, and all of these subordinate concepts form a contrast set that collectively determines the referents of the superordinate concept. Thus, conceptual change of taxonomic concepts can be defined by the changes in the related concepts' referents, and a redistribution of referents can be used as a key indicator of revolutionary change (Kuhn 1991).

However, it is difficult, if not impossible, to analyze transformation of event knowledge through analyzing the relationship between event concepts and their referents. Event concepts cannot be represented by a set of properties. Our knowledge of events is organized in the form of dimensional organization, and its components are chained together temporally and causally as sequences of actions. Differences between sequences of actions usually do not manifest themselves as differences between referents. Two distinct sequences of actions can have the same list of properties—they are merely connected in different ways. Thus, conceptual change of event knowledge typically does not involve a redistribution of referents; instead, it is usually the result of a reorganization of the internal conceptual structure. To understand this kind of conceptual change, we need to focus on how event concepts are represented structurally during the cognitive process. In particular, we should analyze the intraconceptual relations within event concepts. By illustrating the internal connections that constitute temporal and causal sequences, the frame representation of event concepts is an effective means to analyze the cognitive mechanisms behind transformation of event knowledge.

References

Abbott, Valerie, John Black, and Edward Smith. 1985. "The Representation of Scripts in Memory." *Journal of Memory and Language,* 24:179–99.

Abelson, Robert. 1976. "Script Processing in Attitude Formation and Decision Making." P. 290 in *Cognition and Social Behavior.* Edited by J. S. Carroll and J. W. Payne. Hillsdale, NJ: Erlbaum.

Barker, Peter. 2001. "Incommensurability and Conceptual Change During the Copernican Revolution." Pp. 241–271 in *Incommensurability and Related Matters.* Edited by H. Sankey and P. Hoyningen-Huene. Boston: Kluwer.

Barsalou, Lawrence. 1992. "Frames, Concepts, and Conceptual Fields." Pp. 21–74 in *Frames, Fields and Contrasts: New Essays in Semantical and Lexical Organization.* Edited by A. Lehrer and E. Kittay. Hillsdale, NJ: Erlbaum.

Barsalou, Lawrence and Daniel Sewell. 1985. "Constrasting the Representation of Scripts and Categories." *Journal of Memory and Language,* 24:646–65.

Bower, Gordon, John Black, and Terrence Turner. 1979. "Scripts in Memory for Text." *Cognitive Psychology,* 11:177–220.

Buchwald, Jed. 1989. *The Rise of the Wave Theory of Light: Optical Theory and Experiment in the Early Nineteenth Century.* Chicago: The University of Chicago Press.

Cantor, Geoffrey. 1983. *Optics After Newton: Theories of Light in Britain and Ireland, 1704–1840.* Manchester: Manchester University Press.

Casati, Roberto and Achille Varzi. 1996. *Events.* Brookfield: Dartmouth.

Chen, Xiang. 1995. "Taxonomic Changes and the Particle-Wave Debate in Early Nineteenth-Century Britain." *Studies in History and Philosophy of Science,* 26:251–71.

———. 2002. "The 'Platform' for Comparing Incommensurable Taxonomies: A Cognitive-Historical Analysis." *Journal for General Philosophy of Science,* 33:1–22.

———. 2003a. "Why Did Herschel Fail to Understand Polarization? The Differences Between Object and Event Concepts." *Studies in History and Philosophy of Science,* 34: 491–513.

———. 2003b. "Object and Event Concepts: A Cognitive Mechanism of Incommensurability." *Philosophy of Science,* 70: 962–974.

Chi, Michelene. 1992. "Conceptual Change Within and Across Ontological Categories: Examples from Learning and Discovery in Science." Pp. 129–86 in *Cognitive Models of Science.* Edited by R. Giere. Minneapolis: University of Minnesota Press.

Foss, Carolyn and Gordon Bower. 1986. "Understanding Actions in Relation to Goals." Pp. 94–124 in *Advances in Cognitive Science,* Vol. 1. Edited by N. E. Sharkey. Chichester, England: Ellis Horwood.

Franklin, Nancy and Gordon Bower. 1988. "Retrieving Actions from Goal Hierarchies." *Bulletin of the Psychonomic Society,* 26:15–18.

Fresnel, Augustin. (1827) 1852. "Memoir on Double Refraction." *Scientific Memoirs,* 5: 238–333.

Frey, Jerry and Darren Newtson. 1973. "Differential Attribution in an Unequal Power Situation: Biased Inference or Biased Input?" *Proceedings of the Annual Convention of the American Psychological Association,* 1973:125–26.

Galambos, James and Lance Rips. 1982. "Memory for Routines." *Journal of Verbal Learning and Verbal Behavior,* 21:260–81.

Geiselman, Edward and Robin Callot. 1990. "Reverse Versus Forward Recall of Script-Based Texts." *Applied Cognitive Psychology,* 4:141–44.

Haberlandt, Karl and Geoffrey Bingham. 1984. "The Effect of Input Direction on the Processing of Script Statements." *Journal of Verbal Learning and Verbal Behavior,* 23:162–77.

Hacking, Ian. 1993. "Working in a New World: The Taxonomic Solution." Pp. 275–310 in *World Changes.* Edited by P. Horwich. Cambridge, MA: The MIT Press.

Hull, David. 1989. *Science as a Progress.* Chicago: University of Chicago Press.

Kuhn, Thomas. 1987. "What Are Scientific Revolutions?" Pp. 7–22 in *The Probabilistic Revolution,* Vol. 1. Edited by L. Kruger, L. Diston and M. Heidelberger. Cambridge, MA: The MIT Press.

———. 1991. "The Road Since Structure." Pp. 3–13 in *PSA 1990,* Vol. 2. Edited by A. Fine, M. Forbes and L. Wessels. East Lansing: Philosophy of Science Association.

———. 1993. "Afterwords." Pp. 311–41 in *World Changes.* Edited by P. Horwich. Cambridge, MA: The MIT Press.

Lakoff, George. 1987. *Women, Fire, and Dangerous Things: What Categories Reveal About the Mind.* Chicago: The University of Chicago Press.

Li, Shu-Chen and Stephan Lewandowsky. 1995. "Forward and Backward Recall—Different Retrieval-Processes." *Journal of Experimental Psychology-Learning Memory and Cognition,* 21:837–47.

Mourelatos, Alexander. 1978. "Events, Processes, and States." *Linguistics and Philosophy,* 2:415–34.

Nersessian, Nancy. 1984. *Faraday to Einstein: Constructing Meaning in Scientific Theories.* Dordrecht: Reidel.

Newtson, Darren. 1973. "Attribution and the Unit of Perception of Ongoing Behavior." *Journal of Personality and Social Psychology,* 28:28–38.

Newtson, Darren and Gretchen Engquist. 1976. "The Perceptual Organization of Ongoing Behavior." *Journal of Experimental Social Psychology,* 2:436–50.

Nottenburg, Gail and Edward Shoben. 1980. "Scripts as Linear Orders." *Journal of Experimental Social Psychology,* 16:329–47.

Rosch, Eleanor, *et al.* 1976. "Basic Objects in Natural Categories." *Cognitive Psychology,* 8:382–439.

Schank, Roger and Robert Abelson. 1977. *Scripts, Plans, Goals, and Understanding.* Hillsdale, NJ: Lawrence Erlbaum.

Shapere, Dudley. 1989. "Evolution and Continuity in Scientific Change." *Philosophy of Science,* 56:419–37.

Thagard, Paul. 1992. *Conceptual Revolutions.* Princeton, NJ: Princeton University Press.

Tversky, Barbara and Kathleen Hemenway. 1984. "Objects, Parts, and Categories." *Journal of Experimental Psychology: General,* 113:169–93.

Wood, Alexander. 1954. *Thomas Young: Natural Philosopher, 1773–1829.* Cambridge: Cambridge University Press.

Young, Thomas. 1807. *A Course of Lectures on Natural Philosophy and the Mechanical Arts.* London: Johnson.

———. (1817) 1855. "Letter to M. Arago." Pp. 380–384 in *Miscellaneous Works of the Late Thomas Young,* Vol. 1. Edited by G. Peacock. London: John Murray.

———. (1823) 1855. "Theoretical Investigations Intended to Illustrate the Phenomena of Polarization." Pp. 412–417 in *Miscellaneous Works of the Late Thomas Young,* Vol. 1. Edited by G. Peacock. London: John Murray.

Zacks, Jeffrey and Barbara Tversky. 2001. “Event Structure in Perception and Conception.” *Psychological Bulletin,* 127:3–21.

Zadny, Jerry and Harold Gerard. 1974. “Attributed Intention and Informational Selectivity.” *Journal of Experimental Social Psychology,* 10:34–52.