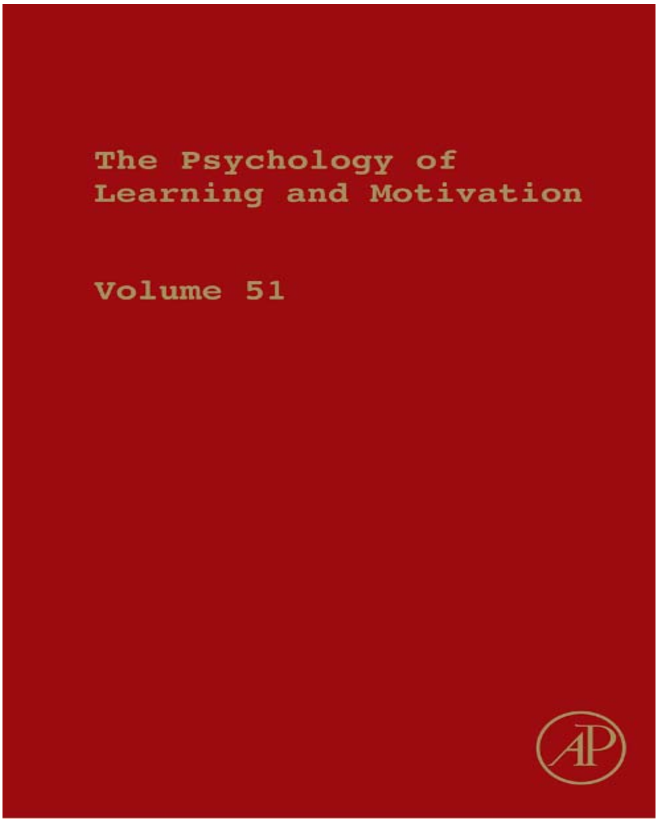

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CHAPTER NINE

Toward a Comprehensive Model of Comprehension

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Contents

Abstract

The goal of this chapter is to provide the foundation toward developing a more comprehensive model of reading comprehension. To this end, seven prominent comprehension models (Construction–Integration, Structure-Building, Resonance,

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Event-Indexing, Causal Network, Constructionist, and Landscape) are described, evaluated, and compared. We describe what comprehension models have offered thus far, differences and similarities between them, and what comprehension processes are not included within any of the models, and thus, what should be included in a *comprehensive* model. Our primary conclusion from the review of this literature is that current models of comprehension are not necessarily contradictory, but rather cover different spectrums of comprehension processes. Further, no one model adequately accounts for a wide variety of reading situations that have been observed and the range of comprehension considered thus far in comprehension models is too limited.

1. Introduction

1.1. Some Background, Our Purpose, and Our Approach

Comprehension, arguably the backbone of cognition, is the processing of information to extract meaning. It is a complex cognitive process that is necessary for virtually all higher-level cognitive activities, including learning, reasoning, problem solving, and decision making. Comprehension is necessary for the formation of durable memories for events (e.g., Bransford & Johnson, 1972) and has substantial implications regarding our subsequent decisions and actions involving information depicted in events, text, or films (Trabasso & Bartolone, 2003). Further, effective and creative problem solvers have been shown to spend considerably more time comprehending a problem before enacting solutions than less effective problem solvers (e.g., Csikszentmihalyi & Getzels, 1971; Gick & Holyoak, 1983). Comprehension has even been linked to affective response in the context of art appreciation (Millis & Larson, 2008).

Despite the importance of comprehension across a variety of areas of study in cognitive psychology, it has primarily been investigated in the context of text and discourse comprehension (see Graesser, Millis, & Zwaan, 1997 for an extensive review). And, text and discourse researchers have particularly focused on comprehension of text, as opposed to other mediums. This focus is at least partially influenced by the fact that texts provide a convenient modality for presenting stimuli. However, interest in the study of text comprehension is not merely a matter of convenience. Text comprehension is heavily studied because reading is a ubiquitous activity and central to functioning in an industrialized society. In addition, text comprehension is informative of cognition in general. First, text comprehension is complex and supported by a variety of lower and higher-level processes (Balota, Flores d'Arcais, & Rayner, 1990). Although many of these processes (and in particular lower-level processes such as orthographic processes, decoding) may be unique to reading, other processes are relevant to comprehension beyond the medium of text (Magliano, Radvansky, & Copeland, 2007). Moreover, many of the theoretical debates address central issues in cognition, such as the extent to which cognitive processes are modular versus interactive (e.g., Fodor, 1983; Marslen-Wilson & Tyler, 1987) and the extent that comprehension is supported by bottom-up versus effortful processing (e.g., Albrecht & Myers, 1995; Graesser, Singer, & Trabasso, 1994; Magliano & Radvansky, 2001; McKoon & Ratcliff, 1998; Myers & O'Brien, 1998). As such, we contend that the text comprehension literature and theories should be of interest to many researchers, including those outside the study of text comprehension per se.

It has been approximately 30 years since the first major processing model[1] of comprehension was proposed by Kintsch and van Dijk (1978), providing a foundation for most subsequent models. Despite the fact that many theories of text comprehension can be traced back to the seminal theory proposed by Kintsch and van Dijk (1978), expert and casual readers of this literature will agree that the theoretical landscape is quite complex. For example, in this chapter we discuss seven prominent models of comprehension, and we can assure the reader that we have left out numerous others from our discussion out of necessity. As one might expect, many of the models have been pitched against each other and as mutually exclusive (e.g., Albrecht & Myers, 1995). As is necessary for a science to grow, there has been a great deal of debate and a host of controversies in the field of discourse comprehension over the past several decades. And, like all fields of science, these debates have been both constructive and destructive. Indeed, it may be difficult for a budding researcher in this area to discriminate amongst the models and determine which is most relevant to address critical research questions of interest.

Upon reflection, we have come to the conclusion that the theoretical landscape is complex because researchers have focused on different aspects of discourse comprehension, different kinds of discourse (expository vs narrative), different kinds of reading situations (e.g., reading to learn for a course vs casual reading), and different sources of individual differences in comprehension. We believe that the time is ripe to reconsider the major and influential models of discourse comprehension with the goal of formulating a comprehensive theory of discourse comprehension. We consider the research in this field sufficiently mature to work toward a more comprehensive model of comprehension: a model that explains the full scope of comprehension processes. A first step toward such a model is to understand

[1] We use the term *model* rather than systematically distinguishing between models and theories. A model is usually used to refer to a theory that is implemented computationally, whereas a theory is usually used to refer to a verbal explanation of a set of phenomena. Here, however, we use the term model to refer to all seven theories that we consider, even though only a few of them are implemented computationally.

what comprehension models have offered thus far, what are the differences and similarities between them, and what comprehension processes are not included within any of the models, and thus, what should be included in a comprehensive model.

Our approach to this task relies on two devices. The first is a depiction in Figure 1 of potential comprehension situations. Figure 1 crosses the reader with the text in terms of the level of strategic or active reading expected by the reader and the ease of processing afforded by the text. Reading comprehension will tend to be best in quadrant A, where the ease of processing is high and the reader is strategic, and worse in quadrant D, where the ease of processing is low and the reader is not strategic. Comprehension will tend to be more superficial and thematic in quadrant B, and will tend to be limited more to a textbase-level understanding (i.e., a representation that primarily reflects the explicit content presented in the text) in quadrant C. Of course, these comprehension states are a function of a multitude of factors. For example, the ease of processing a text can depend on the familiarity of the words, the complexity of the domain, text readability, text cohesion, text domain or genre, and a multitude of other factors, some of which interact with one another. Similarly, the likelihood that a reader will engage in strategic comprehension processes can depend on reading skill, comprehension skill, motivation, metacognitive awareness, domain knowledge, reading strategy knowledge, goals, and tasks, which in turn can interact, not only with one another but also with characteristics of the text.

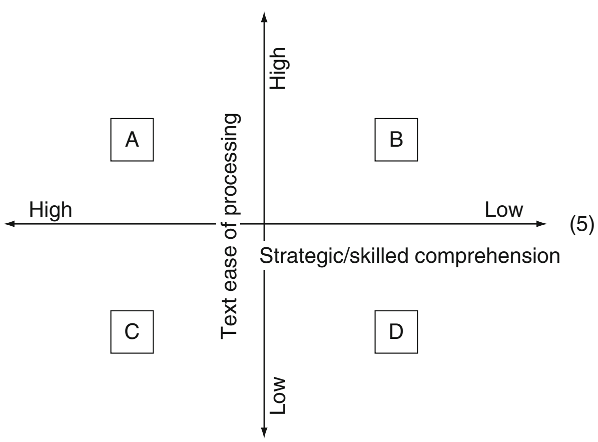

Figure 1 Four quadrants crossing the difficulty of the text and the degree to which the reader engages in strategic or skilled comprehension processes. The four quadrants describe the scope of comprehension situations to be accounted for by comprehensive comprehension models. Comprehension will tend to be best in quadrant A and worse in quadrant D. It is likely to be more superficial and thematic in quadrant B and dominated by a textbase level of understanding in quadrant C.

Despite the complexity of the factors that contribute to the four states depicted in Figure 1, it provides a platform for analyzing the foci of the comprehension models under consideration by considering each one across the four quadrants. By doing so, our contention is that we can develop a better understanding of the differences between current comprehension models and where we need to go in terms of developing more comprehensive models of comprehension.

The second device we use to evaluate comprehension models is a list of dimensions that vary in importance or inclusion between the models. We discuss those dimensions in Section 3 after we have described the seven comprehension models under consideration in Section 2. We then summarize our major conclusions from Sections 2 and 3 in Section 4. Then, in Section 5, we discuss issues that need be considered by a more comprehensive model of comprehension.

Our overarching purpose here is to better understand the theoretical assumptions that have been made by comprehension models and to identify necessary, unnecessary, and missing dimensions. There have been many comprehension models proposed over the last several decades, far too many to review here. Hence, to narrow the task, we focus here on seven models that have received the most attention, at least by text and discourse researchers. The seven theories that we discuss include three that have attempted to describe basic and overall comprehension processes: the *Construction–Integration* (CI) model (Kintsch, 1988, 1998); the *Structure-Building* model (Gernsbacher, 1997; Gernsbacher, Varner, & Faust, 1990); and the *Landscape* model (Linderholm, Virtue, Tzeng, & van den Broek, 2004; Tzeng, van den Broek, Kendeou, & Lee, 2005; van den Broek, Rapp, & Kendeou, 2005; van den Broek, Young, Tzeng, & Linderholm, 1999). We also describe four accounts that have centered primarily on the processes of going beyond the information in a target sentence, such as the retrieval of prior knowledge and inferential processes. These include the *Resonance* model (Albrecht & Myers, 1995; Myers & O'Brien, 1998; Myers, O'Brien, Albrecht, & Mason, 1994), the *Event-Indexing* model (Zwaan, Langston, & Graesser, 1995), the *Causal Network* model (Langston & Trabasso, 1999; Suh & Trabasso, 1993; Trabasso & Suh, 1993; Trabasso & van den Broek, 1985; Trabasso, van den Broek, & Liu, 1988; Trabasso, van den Broek, & Suh, 1989), and *the Constructionist* model (Graesser et al., 1994).

1.2. Comprehension: Some Basics

Comprehension is necessary for processing essentially all information that we encounter. Information is conveyed via a wide sort of media: in our surroundings, through conversations, in pictures, in video, and of course text. Though we comprehend through a wide variety of media, models of comprehension have focused on processes involved in understanding written text. This focus can be attributed to written text being a media that is more easily controlled, manipulated, and analyzed. Nonetheless, most models assume that their theories generalize to the understanding of information conveyed in discourse, and some hope that their assumptions generalize to the understanding of any media, including visual information. Here, though we refer to understanding of text, it is assumed that the term *text* can refer to written or oral discourse.

Theories of comprehension are universally concerned with the nature of a mental representation that emerges when readers and listeners process larger discourse structures such as stories, informational passages, books, textbooks, and conversations. The process of understanding the words, the sentences, and the relations between the sentences comprises comprehension. Its prerequisite, though not necessarily its precursor, is the decoding and parsing of the information. All comprehension models assume that lower-level processes such as word decoding and syntactic parsing contribute to comprehension, but that these processes are more or less in place at the start of the higher-level comprehension processes described by these models.

Language understanding, including lexical decoding and syntactical parsing, is a relatively separate field of study (e.g., Bock, 1982; Elman, 2004, 2009; Frazier, 1987; MacDonald, Pearlmutter, & Seidenberg, 1994; Tabor & Tanenhaus, 1999). The field of text and discourse picks up after basic language understanding, to explain processes germane to the comprehension of multiple ideas and the relations between those ideas. These processes include understanding the gist or underlying meaning of ideas; the priming (or *unconscious* activation) of related concepts, and the linking of ideas that are explicitly related. When those ideas are not explicitly related or when the comprehender seeks a deeper understanding, then inferences comprise a critical component of comprehension.

Most text and discourse researchers use the term *mental representation* to refer to the outcome of text comprehension processes. The reader's mental representation consists of information from the text, information that is related to the text, and the inferences that are generated. Inferencing is the process of connecting information in the environment (e.g., current sentence of a text) to information that is not in the current environment (e.g., information in the ensuing representation of the text, world knowledge, or episodic knowledge for past events, such as other texts or prior experiences). One type of inference connects current information to information that was previously encountered in the text, such as connecting the current sentence to a previous sentence. These are often called bridging inferences. Another type of inference connects current information to knowledge that is not in the text. For such knowledge-based inferences, the comprehender brings knowledge that is related to the text to the focus of attention, and by doing so, makes connections between the text and prior knowledge. These are often called associative inferences or elaborations. Where text and discourse researchers are divided is on the extent to which inferences are generated and the nature of those inferences. For example, there has been some debate over whether readers generate elaborative inferences that are not necessary for establishing coherence in understanding (e.g., Graesser et al., 1994; McKoon & Ratcliff, 1992).

As shown in Figure 2, these two types of inferences can be thought of as going *up*, or *back*, to prior text (i.e., bridging inferences) in contrast to going *outside* of the text to prior knowledge (i.e., elaborations). Of course, prior knowledge is continuously activated during comprehension: each time a word is encountered, prior knowledge is activated and related concepts are primed. When comprehenders have more knowledge about the domain, or about the world, then their understanding will be more rich and coherent because more concepts are automatically primed. Importantly, many researchers argue that this relatively automatic or effortless process of knowledge activation should not be confused with knowledge-based inferences (or elaborations) (e.g., Kintsch, 1993, 1998). Though, where the line should be drawn between the two is not clear.

1.3. Common Assumptions Across Comprehension Models

In our analysis of the seven models under consideration, we identified eight dimensions of comprehension that appear to be central to all of the models. These dimensions are listed and defined in Table 1. We describe them here because they not only serve to specify a set of cognitive systems and processes that support comprehension, but also this list clearly illustrates that comprehension has important links to other areas of cognition. That is, many of these dimensions are basic components of processing models for other dimensions of cognition.

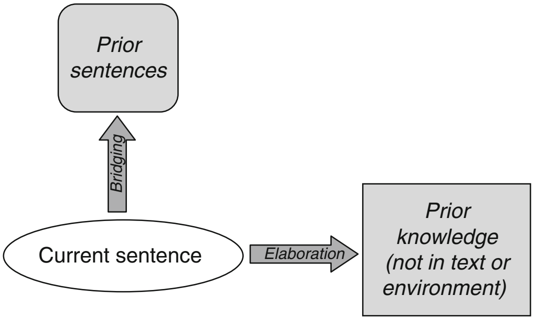

Figure 2 Inferences can be *up* to prior text, called bridging inferences, or *out* to prior knowledge, called elaborations.

Table 1 Eight Dimensions of Comprehension Models that are Either Important or Central to the Seven Comprehension Models Discussed Here.

1. **Connectionist architecture.** Following connectionist assumptions, most models assume that comprehension involves the parallel activation of information in the environment (e.g., words in the text), the underlying meaning of that information, and prior knowledge. Activation sources are often represented as layers in a network of nodes and links, with nodes representing words, propositions, or concepts, and links representing the relationships between them (e.g., predicates, verbs, causal connections).
2. **Spreading activation.** This is the notion that the activation of concepts spreads activation to related concepts, resulting in a change in their activation. Current models generally assume some sort of retrieval mechanism that determines what information is initially activated or available. Spreading activation is applied to the available concepts in memory, and this process changes the activation of concepts depending on their connectivity and initial strengths in the representation.
3. **Automatic unconscious processing.** Virtually all models assume that some information is available automatically during reading, and that there is some level of processing that is not consciously available to the reader. However, the nature of automaticity, which comprehension processes are automatic or unconscious, and the effects of unconscious processing is debated between models.
4. **Discourse focus.** Comprehension models commonly assume that there is an attentional focus by the reader and this focus changes across time and as the input changes. The memorial strength of concepts and ideas is in part related to the amount of attentional focus they receive during encoding.
5. **Convergence and constraint satisfaction.** Comprehension models generally assume that the activation of any given concept or idea is based on the degree to which it receives activation from related concepts and ideas. The mental representation is constrained by activated concepts and the relations between concepts in the input, as well as by information available from long-term memory.
6. **Mapping.** This is a general term to refer to processes to establish how the current linguistic input is related to the prior context. Mapping is influenced by referential and situational cohesion. It is likely an unconscious activity, but the product can be consciously available to the reader. A sense of continuity emerges from the mapping process. When mapping fails, the reader may be induced to generate inferences.
7. **Text-based inferencing.** This refers to making inferences that establish connections between discourse constituents (or bridging inferences). These inferences can result when mapping processes encounter referential or situational cohesion gaps. Relationships between ideas in the text must be inferred when explicit cues such as argument overlap and connectives are absent. These inferences may be considered part of the situation model to the extent that they reflect causal, motivational, temporal, and spatial relationships.
8. **Memory constraints.** Comprehension models generally assume that working memory capacity is limited. Some models of comprehension have adopted an information processing perspective wherein working memory and long-term memory are separate and working memory capacity is limited. Other models have adopted the long-term working memory perspective wherein recently activated or highly familiar information is quickly available from long-term (working) memory.

An overarching aspect of these comprehension models is that they all implicitly or explicitly assume that an underlying (1) *connectionist architecture* describes the nature of the memory representation for texts, wherein there are nodes and links, and these vary in strength. This aspect of theories of comprehension is important because it moves away from the early information-processing approach (e.g., Atkinson & Shiffrin, 1968; Baddeley, 2001) that assumes that short-term memory (or working memory) and long-term memory are separate, and toward models that assume that the focus of attention during reading comprises an activated state of long-term memory (see Healy & McNamara, 1996 for a review of memory models). Connectionist architectures assume parallel activation of concepts such that multiple concepts can be activated at the same time. They further assume that concepts are conscious to the extent that they are activated in memory. As such, some concepts may be activated below threshold, and thus primed, but not consciously available without additional stimuli.

Dimensions 2–7 in Table 1 essentially fall out of connectionist architectures. The second common assumption is that there is (2) *spreading activation* between concepts that are related or linked within the representation. Thus, when a concept is activated, its activation spreads and potentially primes (i.e., lowers the threshold) or activates related concepts.

A third assumption is that many processes that support comprehension are (3) *automatic or unconscious* to the reader. Readers are for the most part consciously aware of the products of comprehension, many of which are a result of the spread of activation (as will be more apparent when we discuss specific models of comprehension). This is not to say that readers are aware of all knowledge that is activated through a spread of activation. Although many concepts may be activated (or near threshold) in memory, only a subset may be consciously available in the reader's attention or focus at any one point in time. As such, these models assume that there is a focus of attention, or (4) *discourse focus*. Reading is an inherently goal-directed activity and like many such activities, readers have control over their attentional resources. Those aspects of the discourse that are most relevant to a reader's goals will be in the discourse focus. For example, if a reader is attempting to locate specific information in a text necessary to write a paper, content that semantically overlaps with the topic of the paper will be in the discourse focus more than information that is deemed less relevant.

The fifth common dimension of comprehension models is that what comes into focus is at least partially a function of (5) *convergence* and *constraint satisfaction*, such that the activation of a concept is determined by its relation to other concepts. Concepts that are related to other concepts in the discourse will receive more activation, and thus will be more memorable. This convergence of activation is the result of spreading activation. That is, related concepts spread activation to each other, and therefore, concepts with more connections to other concepts receive more activation.

The concepts with the greatest amount of activation become *conscious* and more memorable. Those with few connections recede from consciousness, or the discourse focus, and tend to be less memorable.

Sixth, researchers agree that there are connections made between incoming and previously activated concepts, which is often referred to as (6) *mapping*. Seventh, when mapping fails, there is a process of generating *inferences*. Common to all models is the assumption that readers make connections between text constituents, inferring causal, spatial, and temporal relationships. These relationships are generally assumed to be established via a process of generating (7) text-based inferences. Virtually all theories of discourse comprehension describe the process of establishing coherence in understanding and as such, it makes sense that these processes are central to most theories.

The eighth assumption regarding (8) *memory constraints* does not necessary fall out of connectionist architectures. In fact, an information-processing perspective, postulating a separate working memory and long-term memory, is somewhat contradictory to a connectionist perspective, which generally assumes that working memory is the activated state of long-term memory. The memory constraints assumed by most comprehension models likely follows from their focus on higher-level (serial) processing of text, rather than the lower-level processes involved in reading, and as a result, comprehension models generally assume that the reader can process only 2–4 idea units or *propositions* at any one time.

2. A Review of Seven Comprehension Theories

In this section, we review seven comprehension models that have dominated text and discourse research over the past decades. We discuss the CI model first because it is the earliest computational model and provided a foundation for the field of text and discourse. The Structure-Building model is described next because, like the CI model, it was intended to be a general model of discourse processing. We then describe the Resonance, Event-Indexing, Causal Network, and Constructionist models, which address specific aspects of discourse processing (e.g., bottom-up processes, top-down processing, the construction of a situation model). Finally, the Landscape model is considered last because it attempts to combine contrasting assumptions from several models.

2.1. Construction–Integration

2.1.1. Overview and Some Historical Context

Kintsch first proposed the basics of the CI model in 1988, and then, in his 1998 book, expanded on the model and proposed a general processing framework for cognition. The CI model is considered to be the most complete and well-formulated model of text comprehension. Also, there is a computational implementation of the model (Kintsch & Welsch, 1991; Mross & Roberts, 1992) that can be used to test its theoretical assumptions as well as contrasting assumptions from other theories.

The CI model built upon the first psychological process theory of discourse comprehension proposed in 1978 by Kintsch and van Dijk (see also van Dijk & Kintsch, 1983). The Kintsch and van Dijk model shifted focus away from descriptions of the memorial representations for text toward the processes that give rise to comprehension (see van den Broek & Gustafson, 1999 for an extensive discussion of the history of discourse-processing research). The Kintsch and van Dijk model was far different from its contemporary, schema-based models of comprehension (e.g., Rumelhart, 1977; Schank & Abelson, 1977), in that it focused on processes and strategies during comprehension. It attempted to describe the iterative processes in mapping current discourse input to the prior discourse context, which is now considered to be central to comprehension. Moreover, Kintsch and van Dijk's model was ground breaking in that it relied on discourse analysis to identify the presence of cohesion cues in the discourse (relationships between sentences) that afford mapping between local and distal discourse constituents.

Although Kintsch and van Dijk's (1978) model was a critical first step, much was left out of this initial model. In 1983, the constructs of *situation* and *mental models* were introduced to the vernacular (Johnson-Laird, 1983; van Dijk & Kintsch, 1983), which led to a profound shift in the focus of discourse-processing theory and research. Similar to early schema theories, these constructs conveyed the critical notion that comprehension is more than deriving relationships between explicitly mentioned discourse constituents. Specifically, it involves generating inferences that lead to the incorporation of relevant background knowledge into the mental representation. Moreover, these constructs conveyed that deep comprehension reflects an understanding of the referenced and implied situations, rather than merely representing explicit content.

The notion of the situation model has become a dominant focus in research on discourse comprehension. Some theories have focused on delineating the inferences that guide the construction of a situation model (Graesser et al., 1994; McKoon & Ratcliff, 1992). Other research has focused on understanding the representational nature of situation models and how they reflect spatial, temporal, causal, and motivational relationships (e.g., Zwaan & Radvansky, 1998). Still others have focused on the extent to which situation models are supported by dumb, bottom-up processes compared to effortful, strategic processes (Graesser et al., 1994; Magliano & Radvansky, 2001; McKoon & Ratcliff, 1998; Myers & O'Brien, 1998; Singer, Graesser, & Trabasso, 1994).

2.1.2. Fundamental Assumptions

Kintsch (1988, 1998) reformulated and instantiated the CI model within a connectionist architecture and thus the assumptions described in Table 1 apply to the CI model. Here, we describe additional assumptions specific to the CI model, noting that it is challenging to describe all of the assumptions germane to a model that has been specified across three books and an uncountable number of experimental tests and demonstrations.

2.1.2.1. Construction–Integration The first aspect of the model is conveyed in its name, Construction–Integration. *Construction* refers to the activation of the information in the text and related knowledge. The construction process includes the initial activation of related knowledge (following principles of priming), including both relevant and irrelevant knowledge with respect to the immediate or intended context. This knowledge activation process is often referred to as *dumb activation* because it assumes that top-down processing does not constrain initial activation of knowledge. It has also been described as *retrieval based*, emphasizing the role of automatic memory retrieval processes in comprehension (Kintsch, 1998, p. 97). For each cycle of input during construction, there are four potential sources of activation. These sources include the current input (sentence or proposition), the previous sentence or proposition, related knowledge, and potentially (though not by default), reinstatements from prior text.

Integration refers to the spreading of activation across the network until it settles (i.e., the activation values for propositions stop changing as a result of spreading activation). This process results in greater activation for concepts that are linked to other concepts, and a loss in activation for peripheral concepts that have fewer connections to other concepts in the mental representation. Interestingly, spreading activation mechanisms are assumed during the integration process, but are not in the construction process (which is assumed to be retrieval based). During integration, activation sources from the construction process are iteratively integrated using a constraint satisfaction process (see Table 1, No. 5). In the CI model, the constraint satisfaction is implemented using vector multiplication followed by normalization (i.e., dividing by the most highly activated concept) until the network settles (i.e., when there is little change in node activation values). The normalization process follows from the assumption that activation resources are constrained by a limited working memory (see Table 1, No. 8); thus, activation is spread through the network, in the end leaving only those few concepts and ideas that are connected to many other concepts, whereas less connected concepts (e.g., those that are less semantically related) lose activation. The resulting *activation patterns* (i.e., the strengths of the nodes and links) from the Construction–Integration process can be viewed *dynamically* across iterations (i.e., as changes within a cycle) or across cycles (i.e., across sentences or propositions), or at the end of processing (i.e., for the entire passage).

2.1.2.2. Levels of Representation The CI model assumes that a sentence that is read comprises three *levels of representation* (Kintsch, 1988, 1998; van Dijk & Kintsch, 1983). The notion of levels within the reader's mental representation has been arguably one of the more influential assumptions of the model. Though other levels of representation have been included in various instantiations of the CI model (e.g., Doane, Sohn, McNamara, & Adams, 2000; Nathan, Kintsch, & Young, 1992), the principal levels are *the surface structure, the propositional textbase*, and *the situation model.*

The surface structure represents the words in the text and their syntactic relations. Each word in the text is represented by a node, and the links between nodes can be used to represent syntactic relations. Notably, the surface structure is often left out of the computational model because it is generally assumed to have little effect on comprehension. Indeed, there is no mention of the surface structure in Kintsch (1998).

2.1.2.3. The Textbase and Propositions The *textbase level* is represented in terms of *propositions*. One important assumption of the model is that the fundamental unit of processing is the proposition, which consists of a predicate and argument(s). The proposition generally represents one complete idea. It represents the underlying meaning of the explicit information in the text, discourse, or scene. For purposes of convention, regardless of the perceptual format of the information (verbal, written, visual), it is represented in the model propositionally. An atomic proposition consists of PREDICATE(ARGUMENT, ARGUMENT), where the arguments fill slots determined by the predicate (e.g., agent, object, instrument, goal). Example 1 comprises a predicate (hand) and three arguments including an agent (he), object (book), and goal (student).

Sentence: He handed the book to the student.
Propositional representation: hand(he, book, student) (1)

Tense and aspect are generally not included in the propositional representation. However, explicit information regarding time and place is represented within complex propositions, which consist of several subpropositions subordinate to a core proposition. The subpropositions can include modifiers as well as information about circumstance, as shown in Example 2 (presented in Figure 3). There are many ways to represent complex sentences propositionally, but this example is representative of a typical approach (see Kintsch, 1998).

Links in the mental representation are conveyed by the predicates and by overlap between arguments. Notably, *overlap between arguments* provides the principal means of connecting ideas. In contrast, overlap between predicates

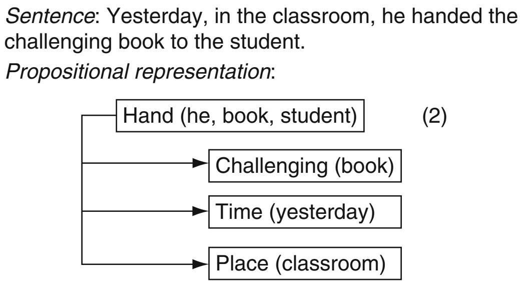

Figure 3 **Propositionalization of a sentence with a main proposition and subpropositions (Example 2).**

(verbs, modifiers) in the CI model does not result in connections between them. For example, the two sentences in Example 3 would be linked via argument overlap (via *classroom*) by default and thus would be more cohesive, whereas the two sentences in Example 4 would not necessarily be connected via the textbase.

Sentence 1: Yesterday, in the classroom, he handed the challenging book to the student. (3)
Sentence 2: All of the other children in the classroom cringed.
Sentence 1: Yesterday, in the classroom, he handed the challenging book to the student. (4)
Sentence 2: She handed it immediately to her neighbor.

Notice that in Example 4, there are no explicit arguments that provide overlap between the sentences. This results in a potential cohesion gap because, even though *handed* occurs in both sentences, overlap resulting from predicates is not included the model. This has theoretical implications concerning the nature of text cohesion; notably that it is driven solely by argument overlap and not by events and actions (Kintsch, 1995; cf. Giora, 1985; Magliano, Trabasso, & Graesser, 1999; Zwaan, Magliano, & Graesser, 1995). Nonetheless, the model would assume that the reader would be likely to make the inference that *she* was the *student* and this inference would connect the two sentences. These types of textual bridging inferences and knowledge-based inferences contribute to the situation model level of representation.

2.1.2.4. The Situation Model and Inferences The situation model includes all inferences that go beyond the concepts that are explicitly mentioned in the text. This construct has arguably garnered the most attention of the three levels of representation proposed by the model in discourse comprehension research since it was postulated in the early 1980s (Johnson-Laird, 1983; van Dijk & Kintsch, 1983). In the past decades, the situation model and textbase representations have often been treated as if they are compartmentalized rather than aspects of the same representation. If this characterization of the literature is correct, it reflects a fundamental misconception. Specifically, the situation model and the textbase should be viewed as different dimensions of the episodic memory for a text, rather than entirely different and separate mental representations of the text content (Graesser & Clark, 1985; Kintsch, 1988; van Dijk & Kintsch, 1983). In fact, as we will describe in greater detail in Section 2.4, the situation model provides one basis for establishing relationships between propositions in the textbase (e.g., Zwaan, Magliano et al., 1995), and thus could not possibly be extricated from it.

Kintsch (1998) classifies the *inferences* that contribute to the situation model level of representation according to whether they are *automatic* versus *controlled* and whether they are *retrieved* versus *generated*. The first dichotomy distinguishes information that is primed by the context (i.e., automatic) and information that is consciously or purposefully activated. This distinction is orthogonal to the differentiation drawn in Figure 2, because both bridging and elaborative inferences can be either (or more or less) automatic versus controlled.

The second dichotomy that Kintsch makes regarding inferences distinguishes information that is retrieved from the current context and information that is generated, going beyond the given information. This distinction more or less aligns with Figure 2, in that bridging inferences rely more on the current context whereas elaborations go beyond the given information.

Kintsch (1993, 1998) argues that only controlled, generated inferences (e.g., controlled, purposeful, or reasoned elaborations) are true inferences that go beyond the information in the text. In contrast, most comprehension researchers consider all four types to be inferences (e.g., Magliano & Graesser, 1991; Singer, 1988). Regardless of what is or is not considered to be an inference, it is generally assumed that connections among ideas in the text and connections to prior knowledge comprise the situation model. If a reader is less active, and activates little knowledge beyond the information in the text, then the situation model is assumed to be less coherent, leaving the reader with a predominately textbase level of understanding.

2.1.2.5. Microstructure and Macrostructure Orthogonal to the notion of levels of representation (e.g., the textbase and situation model) is the microstructure and macrostructure of the reader's representation. The microstructure is driven by local structure of the text whereas the macrostructure is driven by the text's global or hierarchical structure. The microstructure is akin to the propositional representation of the text but it represents the reader's mental representation and thus includes the reader's local inferences. The macrostructure is much the same as the microstructure if the text ideas are ordered serially. However, generally this is not the case and the reader constructs a hierarchical representation of the text. This structure may be relatively explicit in the text, for example as conveyed by headers and topic sentences. But, usually it is up to the reader to infer the global organization of text. This global understanding is often conveyed in terms of the text's *gist* (Kintsch, 1998; van Dijk & Kintsch, 1983).

2.1.2.6. Cohesion, Coherence, and the Situation Model A *coherent* understanding of a text or discourse emerges to the extent that the reader activates knowledge, incorporates that knowledge into the mental representations, and establishes connections between propositions in the discourse representation. Although these processes and outcomes are usually achieved without effort on the part of the reader, it is also assumed that breaks in the discourse (i.e., *cohesion* gaps) induce the reader to activate more knowledge and potentially engage in effortful inferential processes. If the reader can make relatively automatic connections to the prior discourse, then less prior knowledge will be activated. If gaps are encountered, then the reader will activate prior knowledge *to the extent that it is available.*

It is this assumption of the model that led to research by Britton and Gülgöz (1991), which demonstrated that the CI model can be successfully used to guide text revisions by identifying gaps in the discourse. Repairing those gaps by improving argument overlap (i.e., *cohesion*) in the text led to better comprehension in comparison to intuitively guided text revisions. However, the *coherence* of the reader's overall mental representation is most heavily influenced by the situation model. When the reader generates more prior knowledge and when there are numerous connections within the representation, the representation settles more quickly, is more stable, and results in a stronger long-term memory representation.

This aspect of the model led to predictions confirmed first by McNamara, Kintsch, Songer, and Kintsch (1996) that *the effects of text cohesion and prior knowledge interact* (see also McNamara, 2001; McNamara & Kintsch, 1996a; O'Reilly & McNamara, 2007a; Ozuru, Dempsey, & McNamara, 2009). These studies show that low-knowledge readers benefit from greater cohesion in the text because they lack the necessary prior knowledge to generate bridging inferences. When the text lacks cohesion, inferences may improve the reader's textbase-level understanding and those inferences may improve the situation model for individual sentences, but the reader is generally unable to generate the knowledge-based inferences necessary to make connections between separate ideas in the text (McNamara, 2004). By contrast, high-knowledge readers (who do not generate strategic inferences; O'Reilly & McNamara, 2007a) gain from the cohesion gaps in the text because they are induced by the gaps to access knowledge to understand the text. Thus, low-knowledge readers gain from high cohesion text, whereas high-knowledge readers gain from low cohesion text.

The theoretical explanation for these *cohesion* effects (for both high- and low-knowledge readers) rests on the assumption that comprehension is largely determined by the *coherence* of the reader's situation model, and this is a function of both the cohesion of the text and the inferences generated by the reader. This assumption is generally accepted by models of comprehension.

What is more in the line of debate is what comprises the situation model. The CI model relies on *argument overlap* as a proxy for other types of *situational relationships* (e.g., causal cohesion) and Kintsch (1995) has argued that argument overlap is sufficiently correlated with other sources of connections. However, others have argued with this contention (Giora, 1985; Magliano, Trabasso et al., 1999; Zwaan, Magliano et al., 1995). They argue that other sources of connectivity in the mental representation are crucial to comprehension, and cannot be sufficiently accounted for via indices of argument overlap.

Nonetheless, what is included in the situation model in the computational implementation of the CI model is generally up to the researcher. That is, more or less knowledge may be assumed and different types of connections can be included. Thus, it is possible to implement other kinds of relationships, particularly if their inclusion is guided by a theoretically based discourse analysis that identifies the presence and absence of situational cohesion (e.g., Magliano, Zwaan, & Graesser, 1999; Zwaan, Magliano et al., 1995).

2.1.2.7. The Proposition Controversy In addition to issues regarding the nature of the situation model and what types of inferences are drawn while reading, there is some controversy regarding the proposition as the sole means of representing ideas within the CI model. Some researchers have questioned the psychological validity of the proposition (Perfetti, Britt, & Georgi, 1995) and, because the proposition is generally considered to be most representative of verbal or symbolic thought, there is particular controversy regarding the importance of nonverbal and nonsymbolic thought such as images and sensory/motor representations (Zwaan, 2004). To accommodate such concerns, Kintsch (1998) acknowledges that ideas may be in the form of verbal, symbolic, iconic, or even embodied thoughts. For example, a reader's situation model corresponding to Example 1 could include associations such as those depicted in Example 5 depicted in Figure 4, which include the shape and color of the book as well as body movements. Kintsch argues that the ideas and relationships captured by propositional representations may reflect virtually any form of mental representations, including symbolic, perceptual, and motoric thought. It is important to keep in mind that no strong claim is made that these notations are analog to the actual mental representations, but rather they serve to represent these constructs within the constraints of the computational simulation. While some theorists may consider this accommodation to be

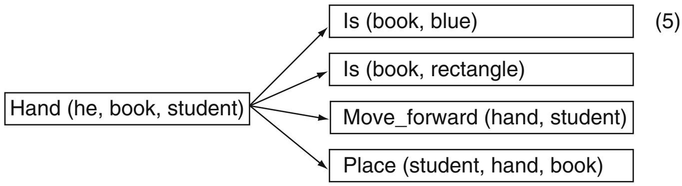

Figure 4 Propositionalization of *He handed the book to the student* including iconic and embodied aspects of the meaning, such as how the book looks and the direction of movement in giving the book (Example 5).

superficial, failing to capture the underlying differences between the various forms of thought and experience, no other solutions have yet been proposed to represent these differences within the constraints of computational simulations.

2.1.3. Conclusions and Where the Model Falls in the Quadrants

A primary purpose of the CI model is to explain learning from text (e.g., rather than story comprehension). Thus, much of the research spurred by the model has centered on further understanding comprehension and memory for information expressed in expository texts (e.g., encyclopedia passages, textbooks) or in problem-solving tasks (e.g., algebra word problems, computer programming tasks). As such, much of the research has centered on the importance of prior knowledge and the effect of knowledge. This places the CI model primarily in quadrants C and D (i.e., more challenging, expository texts), though it has also successfully simulated a variety of experimental findings involving narrative text (Kintsch, 1998).

The CI model and its implementation is powerful and parsimonious, but it does not explain all of the processes described in the context of some models discussed later in this review (e.g., the role and implementation of reader goals), as well as additional processes that have been shown to support comprehension (e.g., metacognitive processes); nor does it address individual differences in reading comprehension ability (cf. Goldman, Varma, & Cote, 1996; McNamara & McDaniel, 2004). Moreover, we will see in the remaining models that the focus changes as the research centers more on understanding passages that depict relatively familiar scenarios, such as those found in narrative text. As such, the remaining six models tend to focus more on quadrants A and B (i.e., narrative and descriptive texts).

2.2. Structure-Building Model

2.2.1. Overview and Some Historical Context

Gernsbacher (1990, 1997) proposed the Structure-Building Model with the goal of providing a theory of comprehension regardless of medium. The processes and mechanisms included in the model are assumed to be general cognitive operations that function regardless of how the information is conveyed (e.g., text, discourse, picture, or video). Gernsbacher has contended that comprehension ability is not necessarily tied to modality specific, lower-level processes, but rather that there are general cognitive abilities involved in comprehension that are common across modalities (e.g., Gernsbacher et al., 1990). Thus, the focus of the modal was on identifying and describing the processes that operated during comprehension of various media such as texts and pictures.

2.2.2. Fundamental Assumptions

The Structure-Building model describes comprehension in terms of three primary processes: (a) *laying a foundation* for the mental representation of the text or discourse structure, (b) *mapping* information onto that foundation, and (c) *shifting* to new structures when new information cannot map onto the existing structure because it is incongruent or it is the beginning of a new idea. There are the two mechanisms that operate to determine the strength of memory nodes: *enhancement* increases activation and *suppression* decreases activation. The following describes the model's assumptions.

2.2.2.1. Laying the Foundation Laying the foundation refers to the processes that occur when a comprehender is first confronted with information (e.g., the beginning of a novel) or when the topic changes (e.g., the beginning of a chapter). According to the model, encoding the initial content in a discourse has an important status in the process of building the representation in that these structures essentially become a metaphorical foundation (functionally akin to the foundation of a building) for mapping subsequent information. Laying the foundation is assumed to be more resource demanding than other processes such as mapping. It is an iterative process that operates at the beginning of sections, story episodes, paragraphs, and even at the level of sentences.

The assumption that laying a foundation occurs during comprehension is supported by three sources of evidence. First, comprehenders show *slower reading times* during the initial stages of processing, such as when they read the first sentence of a paragraph (e.g., Glanzer, Fischer, & Dorfman, 1984; Graesser & Mandler, 1975) or the first sentence of an episode (e.g., Haberlandt, Berian, & Sandson, 1980). They also process more slowly the first picture of a picture story (Gernsbacher, 1983). Second, the first sentences in a story provide *better cues* for recalling the remainder of the story (Mandler & Goodman, 1982). And, finally, comprehenders show an advantage for *first mention*, where the first mentioned protagonist is more easily accessed than the second mentioned. For example, in the sentence, *Tina gathered the kindling, and Lisa set up the tent*, the first protagonist, Tina, is more quickly accessed in memory than is Lisa after reading both clauses (e.g., Gernsbacher, Hargreaves, & Beeman, 1989). Thus, even though Lisa is more recent, Tina is more accessible in memory.

2.2.2.2. Mapping and Shifting Once the foundation is laid, then the comprehender maps information onto the structure. The likelihood of information successfully *mapping* to the structure is driven by syntactic, referential, temporal, locational, and causal overlap (Gernsbacher & Givon, 1995). Overlap can be signaled in various ways including *syntactic* cues (Gernsbacher, 1991; Gernsbacher & Robertson, 2002), *concept repetition* (e.g., Haviland & Clark, 1974), *pronominal reference* (e.g., Lesgold, 1972), temporal and locational *contiguity* (Anderson, Garrod, & Sanford, 1983; Black, Turner, & Bower, 1979; Haenggi, Gernsbacher, & Bolliger, 1993), *causal coherence* (Deaton & Gernsbacher, 1997; Keenan, Baillet, & Brown, 1984; Myers et al., 1987; Zwaan, Magliano et al., 1995), and *emotional contiguity* (Gernsbacher, Goldsmith, & Robertson, 1992). When comprehenders cannot map to a structure, then a substructure is built, which in turn requires laying another foundation. This is called *shifting*. When a comprehender shifts, a new foundation or substructure is created, and the process is begun anew.

2.2.2.3. Enhancement and Suppression Comprehension depends on the efficient construction and maintenance of mental structures. If new information is related to the current structure, then it is *enhanced* and incorporated into the mental structure. It is added to the foundation. However, if new information is not related to the current structure, the comprehender may shift to a new mental substructure (building a new foundation), or alternatively, *suppress* the new irrelevant information.

Unlike most of the models discussed in this review, the Structure-Building model provides an explanation for *individual differences in comprehension skill*. According to the model, skilled and less-skilled comprehenders can be distinguished in terms of the efficiency of suppression processes which determine how quickly the irrelevant meanings of ambiguous words lose activation (Gernsbacher & Faust, 1991; Gernsbacher et al., 1990). Suppression is considered in the Structure-Building model to be the result of a *directed* reduction in activation by way of a mechanism that allows skilled comprehenders to inhibit irrelevant information, but is lacking for less-skilled comprehenders (e.g., Gernsbacher & St. John, 2000; cf. McNamara & McDaniel, 2004). For example, homographs such as bug, match, mold, and spade have multiple meanings that are initially activated regardless of the meanings' relevance to the sentence context (e.g., Kintsch & Mross, 1985; Swinney, 1979; cf. Simpson & Krueger, 1991). Gernsbacher et al. (1990) presented participants with experimental sentences ending with homographs such as *He dug with a spade* or control sentences such as *He dug with a shovel*, followed by an inappropriate target word, ACE. The participant decided if it was related to the previous sentence. They found an ambiguity effect such that response times to reject the inappropriate word were slower for the homograph sentences than for the control sentences when the target word was presented after only 50 ms. The slower response times indicated that the activation of the irrelevant meaning of the sentence-final ambiguous word competed with the correct response. However, after a 1000 ms delay, interference from the irrelevant meaning disappeared for skilled comprehenders, but remained for less-skilled comprehenders.

The efficiency of suppression also has implications for mapping and shifting. The model proposes that readers with more effective suppression mechanisms create fewer substructures because they are able to inhibit irrelevant information, rather than creating a new substructure. Less-skilled comprehenders, by contrast, are assumed to have inefficient suppression mechanisms, which leads to multiple substructures being created and maintained (Gernsbacher, 1990, 1997).

2.2.3. Conclusions and Where the Model Falls in the Quadrants

Like the Construction–Integration model, the Structure-Building model was intended to be a general model of comprehension. However, the Structure-Building model has focused primarily on narrative texts, and is supported primarily by experimental evidence using single sentences or pictures, and short, manipulated passages. Another unique aspect of the model is that there is greater focus on explaining individual differences in comprehension skill. Although reading ability differences are not conceptualized in terms of strategic comprehension in the Structure-Building model, the model might be considered to cover both quadrants A and B.

In principle, the metaphor of Structure Building should apply to reading situations that fall into quadrants C and D involving more challenging texts such as expository. However, the dimensions that support mapping specified by the model may not be adequate to explain the mapping processes for these texts. For example, building a coherent structure for a compare and contrast distinction may not be sufficiently supported by mapping between text constituents based on referential, causal, temporal, and spatial relationships.

Although Gernsbacher (1990, 1997) interprets the empirical findings used to support the notions of laying a foundation, shifting, and suppression as revealing separate and unique processes required in order to begin building a structure, or construct a mental representation, we take issue with this claim. In Section 5.1, we argue that these three mechanisms may be conceived of as properties that emerge from other dimensions of comprehension models. We contend that there are more parsimonious accounts and that a comprehensive model need not specify assumptions or parameters that are unique and distinct from those postulated for more basic comprehension and cognitive processes in order to account for processes associated with these three mechanisms.

2.3. The Resonance Model

2.3.1. Overview and Some Historical Context

The Resonance model was proposed by O'Brien, Myers, and colleagues (Albrecht & Myers, 1995; Albrecht & O'Brien, 1993; Myers & O'Brien, 1998; Myers, O'Brien, Albrecht, & Mason, 1994) to explain how information that is relatively distant from the focal sentence is reactivated. The primary focus was on activation of information from a text that is no longer available in working memory, though in principle the model also applies to the activation of relevant world knowledge as well (Rizzella & O'Brien, 2002). The reactivation and activation of knowledge is important to comprehension because this reactivated information is often critical for constructing coherence via the mapping process, the generation of inferences, and the construction of the textbase and situation models.

At the time that the model was initially proposed there was some debate regarding whether readers reactivate distal text information when there are local cohesive relationships such as those that arise from argument overlap (Graesser et al., 1994; McKoon & Ratcliff, 1992; Singer et al., 1994; Suh & Trabasso, 1993). The minimalist hypothesis proposed by McKoon and Ratcliff (1992) stated that in the absence of strategic, motivated, or goal-oriented processing of text, readers will not make inferences linking local and distant information. Rather, they will make inferences (e.g., to access distant text) only when there is a break in local coherence (i.e., the absence of explicit relationships between adjacent sentences) or when information from long-term memory is easily available. McKoon and Ratcliff contended that automatic inferences are made by readers only when neither explicit information nor general knowledge leads to a coherent representation of a text. Otherwise, if the text is locally coherent, inferences are assumed to be necessarily strategic.

Contrary to the minimalist hypothesis, the Resonance model proposed that knowledge activation and inference processes could be induced by breaks in either local or global coherence. They based their argument on evidence showing that distant information is reactivated by the reader, for example either to resolve anaphoric reference (e.g., Dell, McKoon, & Ratcliff, 1983; O'Brien, Duffy, & Myers, 1986) or to explain an action that deviates from expectations (e.g., Klin, 1994; Klin & Myers, 1993; Trabasso & Suh, 1993). It is important to note that although the Albrecht and O'Brien (1993) demonstrated that distal knowledge is reactivated even under conditions where there is local cohesion, the Resonance and Minimalist positions are no longer viewed as incompatible in that they both emphasize the role of bottom-up, memory-based processes in comprehension.

2.3.2. Fundamental Assumptions

Proponents of the Resonance model have argued that automatic, memory-based retrieval mechanisms (e.g., Hintzman, 1986; Ratcliff, 1978) were sufficient to explain inference processes. According to the *memory-based view*, the memory representation serves as a retrieval structure composed of images, perceptual features, conceptual features, and interitem information (e.g., Raaijmakers & Shiffrin, 1981). Elements in working memory serve as *cues*, or signals, to inactive portions of long-term memory. The Resonance model assumes that the activation is in continuous flux. Signals are constantly being sent, such that what *resonates* in long-term memory changes with each change to working memory contents. In addition, information from long-term memory resonates regardless of its relevance, akin to the *dumb activation* process proposed within the construction phase of Kintsch's (1988, 1998) CI model.

A prevalent paradigm used to support the model has been commonly called the *contradiction paradigm*. Participants read texts that describe characteristics of protagonists (e.g., vegetarian) or their goals (e.g., book a flight). In one version of the narratives, subsequent sentences contradict the earlier text information related to these characteristics or goals, and in the other version it does not. For example, Mary, the protagonist is described as a vegetarian. Later in the story, Mary orders a hamburger. In the consistent version of the story, information is provided that would explain why Mary would order a hamburger and in the inconsistent version that information is not provided. Increased reading times for the contradiction sentences in the inconsistent versions relative to the consistent versions are viewed as evidence that the contradiction is detected. Notably, most of reported effects in support of these claims show differences of less than 100 ms. Given that humans cannot engage in problem solving or strategic processes within 100 ms, this aspect of the data lends toward an interpretation of the effects of such coherence breaks as leading to automatic (resonance) rather than strategic processes to resolve the contradiction.

The fundamental assumption of the model is that concepts in working memory (e.g., from prior text) and in a focal sentence serve as signals to *both active and inactive elements* in the memory representation as well as the reader's knowledge base. Across several studies, it has been shown that at least three factors influence whether readers detect a contradiction in text: (a) *conceptual overlap* between trait or goal information and the target sentences, (b) *distance* between these two text regions, and (c) the extent to which the trait or goal information is *elaborated* in the text (e.g., Albrecht & Myers, 1995; Albrecht & O'Brien, 1993; Myers et al., 1994). These findings are interpreted as evidence that signals resonate as a function of these three factors.

One notable feature of the model is that there are no assumptions regarding the strength of elements: all inactive elements are assumed to have equal strength. More recent elements are more likely to resonate because they are assumed to have more features in common with the contents of working memory. However, the effect of feature overlap is also influenced by the degree to which the antecedents are elaborated in the distant discourse, wherein greater elaboration of a distant antecedent will make it more available than a recent, unelaborated antecedent (O'Brien, Plewes, & Albrecht, 1990). This occurs, again not because of the strength of the element, but because elaborated concepts have a greater *number of features* that can *resonate* to the contents of working memory. The presence of other potential antecedents also affects the Resonance process, such that more than one potential antecedent causes interference and slows processing (Corbett, 1984).

2.3.3. Conclusions and Where the Model Falls in the Quadrants

In sum, the Resonance model describes factors that influence the activation phase of comprehension (Long & Lea, 2005). It is compatible with the CI model, but centers more specifically on the factors that influence memory-based retrieval processes. In contrast to the CI model, the Resonance model has been tested solely with narrative texts, and thus the application of the model's assumptions to more challenging, expository texts has not been explored. Further, the model assumes that the Resonance process is automatic and therefore is not under the control of the reader, forgoing the need to assume active inference processes by the reader. Thus, little is said about the role of strategic comprehension processes, and researchers have yet to explore the role of comprehension skill in the context of this model (cf. Lassonde, O'Brien, & McNamara, 2008). As such, it seems to fall somewhere in the middle of quadrants A and B in that it does not describe a highly motivated or strategic reader (at the far edge of quadrant A), but also does not describe the minimalist reader (at the far edge of quadrant B).

2.4. The Event-Indexing Model

2.4.1. Overview and Some Historical Context

Since the introduction of the construct of *situation model* (van Dijk & Kintsch, 1983), it has dominated the focus of research in text comprehension (see Zwaan & Radvansky, 1998 for an extensive review). This focus has been driven, at least partially, by a lack of consensus among researchers regarding the representational nature of the construct and the processes that support its construction. A good deal of early research on situation models focused on assessing whether readers keep track of spatial relationships and the movements of characters within a narrative world (e.g., Glenberg, Meyer, & Lindem, 1987; Morrow, Bower, & Greenspan, 1989). However, later research indicated that spatiality is not a critical aspect of situation model construction. This research suggested that readers do not closely monitor and represent detailed spatial information during reading unless that information is important for establishing causal coherence (Sundermeier, van den Broek, & Zwaan, 2005), the reader has a goal to monitor spatial information (Zwaan & van Oostendorp, 1993), or the reader has considerable preexisting knowledge about the spatial layout of the fictive world (Morrow et al., 1989). Given the limited role of spatiality, combined with a lack of specificity offered by the CI model, the Event-Indexing model was developed with the purpose of more fully understanding the components and the processes involved in situation model construction (Magliano, Zwaan et al., 1999; Zwaan & Radvansky, 1998; Zwaan, Langston et al., 1995). It differs from the CI model in that it emphasizes the role of situation model construction in establishing relationships between discourse constituents, rather than knowledge-based inference generation. It also differs from the CI model in its focus on narrative, event-based texts. As such, much of the recent research on the situation model focuses on its role in establishing coherence in the reader's mental representation for narrative texts that include events.

2.4.2. Fundamental Assumptions

A central assumption of the Event-Indexing model is that the cognitive system is more attuned to perceive *dynamic events* (changes in states) rather than static information that is part of the larger event sequence. As such, it is most applicable to texts that describe events that unfold in space and time (e.g., narrative). Additionally, unlike the CI model, the Event-Indexing model emphasizes the role of verb semantics in conveying information about dynamic events (Zwaan, Langston et al., 1995). That is, verb predicates, rather than arguments (e.g., noun phrases; see Section 2.1.2.3), contain the majority of the semantic information regarding an event conveyed in a discourse. Similar to early proposals on situation models (Gernsbacher, 1990; Sanford & Garrod, 1981; van Dijk & Kintsch, 1983), the Event-Indexing model assumes that situational coherence can be established along multiple *dimensions of continuity*. However, the model goes beyond early theories of situation model construction and specifies that readers specifically monitor and establish coherence along five dimensions: *time, space, causality, motivation*, and *agents* (cf. Gernsbacher, 1990).

2.4.2.1. Stages of Mental Model Construction According to the Event-Indexing model, there are at least three stages of mental model construction. The first is the *current model*, which reflects the focal event reflected in the sentence that is being read. This representation contains the propositional representation and inferences that are generated during reading. Although these inferences can be knowledge-based in nature (e.g., Graesser, 1981; Graesser & Clark, 1985), the Event-Indexing model primarily focuses on the contribution of situational bridging inferences that are related to the five dimensions specified by the model. This distinguishes the Event-Indexing model from the CI model (Kintsch, 1988, 1998), which primarily focuses on how general and domain knowledge can be incorporated into the situation model.

Second, the *integrated model* refers to the situation model that is currently under construction and that is updated as the current model is computed and encoded into it. And, finally, the *complete model* reflects the model for a text as it is represented after reading has been completed. It is important to note that both the integrated and complete models are not static. The complete and integrated models are similar, but the complete model reflects the status of the representation when reading has been completed. When reading a novel over several sittings, the complete model would reflect the status of the representation at the end of each reading session. The activation levels and degrees of connectivity between story constituents change as each complete model is mapped onto the integrated model. The complete model can also change over time, and in particular as a function of ruminations and strategic processing that occur after reading a text.

2.4.2.2. Components of the Mental Representation Integrated and complete models can contain both static and dynamic elements (Copeland, Magliano, & Radvansky, 2006; Magliano et al., 2007; Zwaan & Radvansky, 1998). In terms of static components, a situation (or episode) is defined and bound by a *spatial–temporal framework*, which is the space and time where the event unfolds (e.g., doctor's office, between 2:00 and 3:00 in the afternoon). Time is static in this sense because there is only one time period used to provide the framework to define an event. Spatial–temporal frameworks contain *tokens* that represent entities, such as people, animals, objects, abstract concepts, and so forth. Associated with these entities can be various *properties*. These properties can include external physical characteristics, such as size, color, or weight, and internal properties, such as emotional states and goals. Finally, there are *structural relations* among entities within a framework, such as spatial, social, and ownership relations. Situation models contain dynamic elements in that events can be related to one another via *linking relations*, which correspond to the five dimensions specified by the model. These linking relationships can be conceptualized as situational bridging inferences and provide one basis for constructing coherence in understanding (Magliano, Zwaan et al., 1999; Zwaan, Magliano et al., 1995; Zwaan & Radvansky, 1998).

2.4.2.3. Continuity Monitoring The Event-Indexing model assumes that readers concurrently monitor and represent the extent to which text events are related along the dimensions of time, space, causality, intentionality, and agency (Magliano, Zwaan et al., 1999; Zwaan, Langston et al., 1995; Zwaan, Magliano et al., 1995; Zwaan & Radvansky, 1998). The current model can be mapped onto the integrated model to the extent that readers perceive and infer how the two models are related in terms of time, space, causality, motivation, and protagonist. As mentioned earlier, a fundamental difference between the Event-Indexing and CI models is that the Event-Indexing model assumes that mapping between discourse constituents is driven by event and causal relations between predicates (as conveyed by verb and verb phrases in particular) rather than argument overlap (Magliano, Zwaan et al., 1999; Zwaan, Langston et al., 1995; Zwaan, Magliano et al., 1995). This is based on the assumption and evidence that verbs are more informative of the event structure in a narrative than are nouns (Kurby, Britt, & Magliano, 2005; Radvansky, Zwaan, Federico, & Franklin, 1998; Zwaan, Langston et al., 1995).

When relationships between discourse constituents are readily perceived and inferred, establishing coherence can be achieved with little processing effort. However, as readers perceive breaks in continuity, their resolution may require effort and time (e.g., Magliano, Zwaan et al., 1999; Zwaan, Magliano et al., 1995). Moreover, breaks along several dimensions may indicate that a story episode has ended and a new one has begun (Magliano, Zwaan et al., 1999; Magliano et al., 2001; Zwaan & Radvansky, 1998). Studies in support of the Event-Indexing model have shown that readers monitor shifts in the dimensions specified by the model while processing a narrative (Magliano, Zwaan et al., 1999; Magliano et al., 2001; Rinck & Weber, 2003; Therriault & Rinck, 2007; Zwaan, Magliano et al., 1995). Many of these studies have relied on a correlational approach because it is difficult to construct experimental texts that contain manipulations of more than two dimensions. This approach involves conducting a discourse analysis of a text to determine how text constituents are related along all or a set of the five dimensions specified by the models. This discourse analysis is then correlated with behavioral measures, such as reading time or the likelihood of grouping story events together.

In general, the assumption that readers monitor continuity of events along the dimensions specified by the model has been substantiated, but not all dimensions carry equal weight. For example, Magliano, Miller, and Zwaan (2001) found that when processing narrative film, breaks in temporal cohesion had a bigger impact on the perception of the event structure than breaks in spatial cohesion, despite the fact that film is an inherently spatial medium. Similarly, during the first reading of a text, reading times increase when there are breaks in causal and temporal cohesion, but not spatial cohesion (Magliano, Zwaan et al., 1999; Zwaan, Magliano et al., 1995). Nonetheless, readers do appear to monitor breaks in spatial cohesion when rereading a text (Zwaan, Magliano et al., 1995).

2.4.3. Conclusions and Where the Model Falls in the Quadrants

In sum, the Event-Indexing model specifies processes that are primarily involved in establishing relationships between discourse constituents, rather than the generation of knowledge-based inferences (i.e., incorporating general or episodic knowledge into the discourse representation). Because the inferences are necessarily based on general world knowledge, such as knowing a likely sequence of events, we view the process of establishing these relationships as inferential in nature and conceptualize the mapping processes specified by the Event-Indexing within the general class of bridging inferences (i.e., inferences that establish coherence between propositions in the textbase).

The Event-Indexing model is applicable exclusively to texts that describe event sequences. As such, it is most relevant to research on narrative comprehension, including both simple narratives (Magliano, Zwaan et al., 1999) and more challenging literary narratives (Zwaan, Magliano et al., 1995). However, it has not been tested in the context of expository or argumentative texts, and likely would not apply as well or consistently to those genres. The model also makes no assumptions regarding reading ability or reading goals, though one would assume that the reader must be sufficiently motivated and skilled to generate the inferences necessary to construct a coherent situation model. As such, the event-based model seems to apply more to reading contexts that fall within quadrant A where processing should be relatively easy and the reader sufficiently skilled.

2.5. The Causal Network Model

2.5.1. Overview and Historical Context

As noted in the previous section, there was a general drive among text and discourse researchers to better understand the nature of the situation model. One notable line of research in that regard was pursued by Trabasso and colleagues, who focused on the role of causality in comprehension (Suh & Trabasso, 1993; Trabasso & Sperry, 1985; Trabasso & van den Broek, 1985; Trabasso et al., 1989; van den Broek & Trabasso, 1986). The Causal Network model (Trabasso et al., 1989) made two critical contributions. First, it provided a psychological account of how readers generate causal inferences and build representations for the causal episodes described in a narrative text. Second, it provided a principled system of discourse analysis for theoretically identifying the potential causal relationships between story clauses. This system offers discourse researchers a tool to identify structural features of a text, which can then form the basis to generate principled predictions regarding causal processing (Magliano & Graesser, 1991). Conducting such a discourse analysis certainly requires training. However, participants who are naïve to formal definitions of necessity make causal relatedness judgments that are sensitive to whether there are necessary relationships between two events (Trabasso et al., 1989), which lends credence to the psychological validity of the criteria for determining causal relationships between events.

2.5.2. Fundamental Assumptions

The Causal Network model provides a theoretical account of some aspects of inference generation and situation model construction during reading. An important assumption of this model is that understanding is primarily achieved through *causal reasoning*. That is, causal inferences provide the primary basis for constructing a coherent representation for a text, at least for texts that describe events that unfold over time and place. Accordingly, there exists within the text an ''ideal'' causal structure that reflects the implicit causal relationships between discourse clauses, and this structure can be uncovered through principled decision rules that drive the discourse analysis.

2.5.2.1. Components of the Mental Representation The analytic model is based on a *general transition network* that specifies conceptual categories of the narrative constituents that occur in an event-based text and the types of causal relationships that bind these constituents. Story clauses can be classified according to how they fit into an episodic structure, which consists of categories of story units (Stein & Glenn, 1979). These categories include *settings, events, goals, attempts, outcomes*, and *reactions*. Settings of story episodes introduce characters, time, and place. Events are unintentional changes in state, and can be distinguished from outcomes, which are changes in state that are the direct result of intentional actions. Goals reflect the desired states of agents depicted in stories. Attempts are the actions of agents, presumably to achieve some stated or unstated goal. Finally, reactions are changes of psychological states of agents (e.g., affective responses, changes in knowledge states).

Although the model bears some resemblance to story grammar theories (Mandler & Johnson, 1977; Stein & Glenn, 1979; Thorndyke, 1977), the primary difference between these theories and the general transition network is the specification of the types of causal relationships that are constrained by the conceptual categories. The model assumes that there are four types of causal relationships: *enabling, psychological, motivational*, and *physical*. The causal relationships between story clauses are relationships constrained by the story categories. Settings enable all other categories. Events can physically cause other events and psychologically cause characters to have goals and reactions. Goals can motivate other goals, attempts, and outcomes. Attempts can enable other attempts and physically cause or enable outcomes. Outcomes can enable or physically cause other outcomes. Outcomes, as well as events, can psychologically cause characters to have reactions and goals.

2.5.2.2. Discourse Analysis The model specifies a discourse analysis for identifying the potential causal relationships afforded by the text. The causal relationships specified by the model for a particular story are based on the logical criteria of *necessity* and *weak sufficiency* in the circumstances (Mackie, 1980). An event A is necessary for an event B if event B will not occur in the story without event A. Furthermore, if event A occurs in the story, then event B is likely to follow. Conducting a Causal Network analysis yields a network of causal relationships, such that some story constituents are more central than others (Trabasso & van den Broek, 1985; Trabasso et al., 1989). This network can take on a hierarchical structure, especially when there is an implicit hierarchy of goals (Suh & Trabasso, 1993; Trabasso & Suh, 1993). A Causal Network analysis can then be used to predict a variety of comprehension outcomes, such as inference generation (Magliano, Trabasso et al., 1999; Trabasso & Suh, 1993; van den Broek, 1990), the availability of goals (Lutz & Radvansky, 1997; Magliano & Radvansky, 2001; Suh & Trabasso, 1993), perceived strength of causal relationships between story constituents (Trabasso et al., 1989), sentence importance judgments (Trabasso & Sperry, 1985), and the likelihood of recalling story events (Trabasso & van den Broek, 1985; van den Broek & Trabasso, 1986).

2.5.2.3. Implementation of the Model A version of the Causal Network model was implemented in the context of a hybrid-connectionist model derived from the CI model (Langston & Trabasso, 1999; Langston, Trabasso, & Magliano, 1999). The Causal Network model has one main storage buffer called the text representation, which contains nodes, connections between nodes, and quantitative values that change over time as each new node is entered. The quantitative values correspond to the activation values and connection strengths of each node. The model executes computations based on a spread of activation among nodes in the model, which leads to an adjustment of connection strengths.

The formulas that govern the spread of activation and settling of the network are nearly identical to the CI model. However, there are several important differences between the CI model and the implementation of the Causal Network model. First, the CI model derives the network representation from hand-coded propositions. In contrast, the Causal Network model network is derived from a Causal Network analysis and includes a series of causal relationships between nodes representing story clauses. This input does not take into account the episodic category of the clauses, type of causal relationships, or the direction of the causes (A causes B or B causes A). Another difference is that the implementation of the Causal Network model is designed to model only the effects of establishing causal relationships on processing and the ensuing memorial representation. On the other hand, the CI model generally includes knowledge that is not explicit in the text.

A final difference is that the implementation of the Causal Network model does not incorporate a working memory constraint. That is, all nodes currently represented in the network can be activated, not simply those that are within parameters of the WM constraints determined by the researcher. The model assumes that the activation of all nodes can dynamically change as a function of introducing new causal relationships. This assumption has some psychological plausibility if one assumes that there is a long-term working memory that renders some concepts quickly accessible (Ericsson & Kintsch, 1995). The removal of working memory constraints is also more plausible if it is assumed that some concepts receive activation, but are not consciously available to the reader.

The model yields three measures (i.e., node activation values, cycles to settle, and node connection strengths) that have been used to simulate behavioral data from experiments conducted by Trabasso and his colleagues and other researchers (Langston & Trabasso, 1999; Langston et al., 1999). These measures can be used to simulate a variety of online and offline measures of processing and comprehension. For example, Trabasso and Suh (1993; Suh & Trabasso, 1993) assessed the availability of character goal information as a function of whether there was an implicit hierarchical causal structure or linear causal structure to the text. Both think-aloud and probe recognition latencies demonstrated that the character goals have a higher state of activation at critical target sentences (that have implicit causal relations to the explicit goal statements) in the hierarchical text than the linear text. Activation levels produced by the model have strong correlations with these behavioral measures (Langston et al., 1999). As another example, the model was used to simulate a well-established finding that reading times decrease for target sentences as a function of the distance between the causal relationship and the prior context (Myers, Shinjo, & Duffy, 1987). Langston and Trabasso (1999) constructed a causal network for the materials used by Myers et al. (1987) and used connection strengths to simulate causal distance. They found significant negative correlations between connection strengths and reading time.

2.5.3. Conclusions and Where the Model Falls in the Quadrants

The research conducted in support of the Causal Network model demonstrates the importance of causality for comprehension and memory of text. In fact, one could argue that is a central dimension of situation models for event-based text. Importantly, the Causal Network model can be implemented in a connectionist framework, which illustrates that the Causal Network model is fundamentally compatible with the CI model. In contrast, however, research to support the Causal Network model, like the Event-Indexing model, has lent greater credence to the importance of the other situational relationships (e.g., causal, temporal, spatial) besides the referential connections that dominate the CI model.

Like the Event-Indexing model, the Causal Network model is exclusively applicable to texts that describe events. In principle, event-based texts and texts with apparent causal relationships can occur in any of the reading situations depicted in the four quadrants. However, the model is limited to specifying causal inferences that are based on explicit content in the discourse context and cannot specify causal inferences that are based on general knowledge.

Although the Causal Network model has been aligned with perspectives of comprehension that assume that comprehension arises from effortful processing (Graesser et al., 1994; Magliano & Radvansky, 2001), the model is agnostic as to whether the connections are established via bottom-up or effortful processing. That is, it does not make specific assumptions regarding the roles of strategic processing in establishing causal relationships (cf. Magliano & Radvansky, 2001). Nonetheless, as with the Event-Indexing model, we can assume that the reader must be sufficiently motivated and skilled to encode causal relationships in text and generate causal inferences, placing the Causal Network model more within quadrant A.

2.6. The Constructionist Theory

2.6.1. Overview and Historical Context

The Constructionist theory of comprehension (Graesser et al., 1994) was specifically proposed to explain those factors that constrain the inference processes that support comprehension during reading. At the time that Graesser et al.'s paper was published, a central research question in discourse psychology regarded what inferences were routinely generated during reading (e.g., Long & Golding, 1993; Magliano, Baggett, Johnson, & Graesser, 1993; McKoon & Ratcliff, 1992; Potts, Keenan, & Golding, 1988). For example, as discussed earlier, the minimalist hypothesis assumed that inferences that serve to establish global coherence are generated when they are supported by automatic memory retrieval or when local coherence cannot be achieved. Additionally, McKoon and Ratcliff (1992) characterized Constructionist theories of comprehension as assuming that readers routinely generate all possible inferences. The Constructionist theory was in part proposed in response to this claim. Specifically, it conveys a constructivist notion of inference generation that is constrained and makes specific predictions regarding the types of inferences that are routinely generated during reading and the conditions that give rise to their generation.

Since the publication of this seminal paper, a more central issue in discourse comprehension research has been the assessment of the extent to which comprehension is supported by bottom-up, data-driven processes as compared to top-down, explanatory processes (Albrecht & Myers, 1995; Magliano & Radvansky, 2001; Myers & O'Brien, 1998). Although the Constructionist theory acknowledges that comprehension is supported by memory-based retrieval and automatic processes (Graesser et al., 1994), the theory clearly emphasizes the role of top-down and controlled processes in comprehension. Likewise, those researchers who emphasize the role of bottom-up processes clearly acknowledge that comprehension can be supported by top-down processing (McKoon & Ratcliff, 1992, 1998; Myers & O'Brien, 1998). Despite this mutual acknowledgment of the role of top-down and bottom-up processes in comprehension, many researchers who have advocated bottom-up perspectives took umbrage with the Constructionist theory (e.g., Albrecht & Myers, 1995).

2.6.2. Fundamental Assumptions

According to the Constructionist theory, deep understanding is achieved through active, constructive processes that have been characterized as *search for meaning* (Bartlett, 1932; Graesser et al., 1994; Stein & Trabasso, 1985). There are three assumptions of the theory that define a search for meaning. A *coherence assumption* specifies that deep meaning is achieved when readers construct situation models that reflect both local and global coherence. An *explanation assumption* specifies that individuals have a drive to seek explanations for events that they experience (Hart & Honore, 1959; Hilton & Slugowski, 1986; Mackie, 1980; Ranney & Thagard, 1988; Schank, 1986). Explanations provide one basis for achieving coherence in understanding (Graesser et al., 1994; Magliano, Trabasso et al., 1999). The model assumes that readers routinely assess the extent to which they can generate explanations for events based on knowledge available to them, particularly regarding causal antecedents, agent goals, and causal relationships. To this end, readers engage in an evaluative process that consists of a naïve assessment of whether inferred and implicit antecedents provide the necessary and sufficient conditions for the focal event (Mackie, 1980; Trabasso et al., 1989).

Finally, a *reader goal assumption* specifies that readers construct representations that are consistent with their comprehension goals. If the goal entails a standard of comprehension consistent with meaning making, then readers will generate inferences that support the construction of a coherent situation model (i.e., local and globally coherent). Contrastingly, if a goal involves shallow processing (e.g., skimming through a text for key words), then the resulting text representation will be disjointed and incoherent.

The theory is formally described as a set of production rules that specify the discourse features that must be present in a focal sentence for the cognitive processes that give rise to these inferences to occur. For example, one production rule states that if the current discourse constituent states the action or goal of a character, the readers will explain why these actions or goals occurred. Readers will "search" information sources in working memory or long-term memory for plausible superordinate goals. However, to our knowledge these production rules have never been formally implemented.

The theory makes specific predictions regarding the types of knowledge-based inferences that should be routinely generated during reading, at least when the readers' goal is to deeply comprehend what they are reading.

The theory in general predicts that readers generate inferences that provide a basis for achieving explanatory coherence. Consistent with the model, there is a vast amount of evidence that causal antecedent inferences (Magliano et al., 1993; Singer & Halldorson, 1996; Zwaan, Magliano et al., 1995) and character goal inferences (Long & Golding, 1993; Singer & Richards, 2005; Suh & Trabasso, 1993) are routinely generated during reading, which are the primary inferences that provide a basis for achieving explanatory coherence. In contrast, elaborative and predictive inferences, which are not central for achieving explanatory coherences, are not routinely generated during reading (e.g., Magliano et al., 1993) or are only generated when they are highly constrained by the discourse context (e.g., Fincher-Kiefer, 1993; Murray, Klin, & Myers, 1993; van den Broek, 1990; Whitney, Ritchie, & Crane, 1992).

As mentioned earlier, researchers who advocated bottom-up perspective of comprehension took issue with the Construction theory. Long and Lea (2005) clarified at least one reason why these researchers had issues with the Constructionist theory. Specifically, Graesser et al.'s (1994, Table 2) articulation of the production rules that guide inference processing suggests that prior knowledge is actively searched to meet the drive for explanatory coherence. Long and Lea (2005) provide a detailed discussion of why an active search is not psychologically plausible. They conceptualized the search for meaning as an evaluative process that operates on information that has become available to working memory via memory-based retrieval, which is consistent with the Resonance model (Myers & O'Brien, 1998).

2.6.3. Conclusions and Where the Model Falls in the Quadrants

The Constructionist theory specifies inference and evaluative processes that support comprehension. The model can be aptly thought of as describing a highly motivated, strategic reader who routinely engages in goal-directed, effortful processing during comprehension, placing the model in quadrants A and C. However, one could venture that by specifying the processes expected in ideal reading situations, the model consequently describes what the less strategic or less-skilled reader does *not* do (Bereiter & Bird, 1985; McNamara, 2007; McNamara et al., 2006; O'Reilly & McNamara, 2007a; Paris & Myers, 1978; Pressley & Afflerbach, 1995). If the model is conceived as also describing what happens (i.e., comprehension deficits) when the three reader assumptions (i.e., coherence, explanation, goals) fail, then the model might be said to describe comprehension across all four quadrants. However, there is little specification in the model as to how comprehension will vary as a function of the reader's adherence to these assumptions. Nor does the model specify whether or how comprehension will vary as a function of the difficulty or characteristics of the text. Nonetheless, of the models discussed thus far, along with the CI model, we see the Constructionist model as most applicable to the study of comprehension in authentic educational settings. It is these contexts where researchers strive to understand the factors that influence readers' drive for the search for meaning and to identify ways to help struggling readers learn how to read strategically (Graesser, 2007; McNamara, 2007).

2.7. The Landscape Model

2.7.1. Overview

The Landscape model, developed by van den Broek and colleagues, is designed to simulate the fluctuation of concept activation while reading (Linderholm et al., 2004; Tzeng et al., 2005; van den Broek et al., 1999, 2005). The model is similar to the CI model (Kintsch, 1998) in a number of ways. First, it is an implemented model and consequently subsumes the assumptions listed in Table 1. In addition, similar to the CI model, it assumes that there are four sources of activation, including the current input, carryover from the prior cycle, reinstatements from prior information sources, and related knowledge. Also like the CI model, the reading process can be viewed in a cyclical manner across the course of reading and parameters can be modified to test a variety of theories.

Because of its computational similarity to the CI model, it is useful to compare the two. The primary difference between the Landscape model and the Construction–Integration model regards assumptions on activation and learning. Specifically, according to the Landscape model, the activation of concepts can be automatic or strategic through assumptions regarding the source of activation and the amount of activation.

2.7.2. Fundamental Assumptions

The Landscape model proposes that there are two types of mechanisms are involved in reinstatements and prior knowledge activations: *cohort activation* and *coherence-based retrieval*.

2.7.2.1. Cohort Activation Cohort activation varies from 0 to 1 and essentially serves the function of passively mapping related concepts to the reader's mental representation of the text. When a concept is activated during reading, all other concepts concurrently activated become associated with it via a delta learning rule (Gluck & Bower, 1988a,b; McClelland & Rumelhart, 1985). This rule results in an asymptotic learning curve as a function of the number of times concepts co-occur in working memory. Via this process, each concept connects with other concepts to form a *cohort*, which are associative memory traces or textual interconnections. When a concept in a cohort is activated, the other concepts in that cohort are also activated, assuming limited working memory resources. This mechanism can be used to simulate memory-based inferences as described by the Resonance model (Myers & O'Brien, 1998; O'Brien & Myers, 1999;

O'Brien, Rizzella, Albrecht, & Halleran, 1998; van den Broek et al., 2005). However, the Resonance model does not assume learning per se, and the Landscape model also includes a learning rate parameter, which determines the amount of learning as a function of another parameter called *expectancy*.

2.7.2.2. Coherence-Based Retrieval Coherence-based retrieval is a strategic mechanism that takes into account the reader's standards of coherence, for example as influenced by reading goals (Linderholm et al., 2004; van den Broek et al., 2005). It does so through a parameter that varies the degree of activation of text elements. Depending on the standard of coherence assumed to be adopted by the reader, the experimenter sets this parameter to a value between 1 and 5 as a function of the element's importance to certain relations in the text (e.g., referential, causal, temporal, and spatial connections). As such, coherence-based retrieval is intended to simulate the *search/effort after meaning* mechanism described by the Constructionist view of reading (Graesser et al., 1994; Singer et al., 1994). For example, simulating a more superficial reading goal involves lowering the activation values for elements assumed to be involved in causal relations. Contrary to the Constructionist view, the Landscape model seems to assume search after meaning processes are reflective of either retrieval mechanisms or late reading processes. Specifically, when van den Broek et al. (2005) conducted a simulation to account for both Resonance and Constructionist processes, they assumed that these two types of processes varied along a time line of early (bottom-up) and late (top-down) processes, respectively. Notably, the assumption that Constructionist processes are late (after 500 ms) and top-down runs somewhat counter to the original claims by Graesser et al. (1994), but is in line with a good deal of experimental evidence (Long & Golding, 1993; Magliano et al., 1993; Till, Mross, & Kintsch, 1988).

2.7.2.3. Other Differences Compared to CI Model The Landscape model differs from the CI model in two other ways. First, there are no assumptions in the Landscape model concerning levels of comprehension. That is, whereas the CI model assumes that there are surface, textbase, and situation model levels of understanding, the Landscape model does not implement these differences.

Second, units of analysis in the Landscape model can be the proposition, idea unit, sentence, or essentially whatever is of interest to the experimenter. In contrast, the notion of the proposition as the unit of analysis in the CI model is inherent to its theoretical basis. This aspect of the Landscape model moves it away from notion of the proposition as the fundamental unit of processing. Notably, one consequence of this is that the model tends to put a more weight on each word in the text. Further, although the move away from the proposition facilitates implementation for some aspects of the model (i.e., one need not propositionalize the text), it also renders more difficult comparisons between various uses of the model.

2.7.2.4. Empirical Evidence The Landscape model is motivated by a good deal of experimental evidence and has been validated in several studies. One way to validate the model is to examine the correlations between participants' recall of a text and the activation values for the concepts in that text. If activation values are high, then the participant should be highly likely to recall those concepts (e.g., van den Broek, Virtue, Everson, Tzeng, & Sung, 2002) and reading times should be more rapid (Linderholm et al., 2004), at least for narrative text. In one such study by van den Broek, Risden, and Husebye-Hartmann (1995), seven participants read narrative passages and after each sentence, they rated a list of concepts on their relatedness. Their ratings correlated 0.79 with the model's activation values, but only 0.46 when referential and causal reinstatements were removed from the model. These same participants also recalled the passages after a delay. Including both node and link strengths, the model accounted for 64% of the variance. Additionally, the most highly activated concept across the cycles was highly likely to be recalled first.

2.7.3. Conclusions and Where the Model Falls in the Quadrants

One strength of the Landscape model is its flexibility. However, this is also its greatest weakness. To use the implemented model, the text must be parsed (without set guidelines) and all of the elements' activation values and connections (i.e., the activation matrix) must be set by hand. This freedom can lead to both human error and an ability to change a multitude of parameters and settings to fit the data. Also, because the values must be set by hand, the model is effectively limited to texts with a relatively small number of sentences.

Nonetheless, the Landscape model provides the first move toward a model that unites assumptions from competing models, including the Construction–Integration model, the Resonance model, and the Constructionist model. Moreover, although it has been primarily tested in the context of narrative texts, it is the most comprehensive of the models in that comes closest to covering all four quadrants and places a good deal of focus on simulating individual differences.

3. Evaluation of Models

3.1. Dimensions That Vary Across Models

In the prior section, we described seven influential models of discourse comprehension. Our central assumption is that by and large, these models are not mutually exclusive, but rather focus on different aspects of comprehension. One way to conceptualize these differences is in terms of the specific dimensions assumed by each model. We have already described eight dimensions that are relatively common across the models (Table 1). We also identified 29 dimensions that varied sufficiently among the models to afford comparisons between them. Certainly there other dimensions that we could have considered; however, these 29 seemed to capture the most important aspects of these models.

We grouped these dimensions into four categories: *features* of the discourse, *processes* (i.e., both continuous and late), *products*, and *extratextual dimensions*. As shown in Table 2, we rated each of the seven models on the relative importance within the model of the 29 dimensions. The labels are somewhat arbitrary, but in our ranking a "3" indicates that the dimension was deemed to be central to the model, which means that the model postulates detailed assumptions regarding this dimension and it is a dimension that distinguishes that model or type of model from others. A "2" indicates that the dimension is deemed to be important to the model but does not specify detailed assumptions regarding the dimension. A "1" indicates that the authors have acknowledged the importance of the dimension in general, but it is beyond the scope of the model. A "0" indicates that the dimension is omitted by the model. Finally, a "−1" indicates that the dimension is contradictory to the model.

These ratings are not experimental data by any means but rather provide an overview of our own extensive analysis of these models. And, the ratings naturally reflect our own biases and personal understandings of the models. In sum, the ratings are debatable (and we debated quite a bit about them). Nonetheless, they provide a useful platform to compare the models' assumptions.

In the following sections, we describe these dimensions and discuss the relative centrality of each dimension across the seven models. We approach this task by examining the ratings within each of the four categories of dimensions.

3.1.1. Features of the Discourse

The four dimensions that we categorized as features are listed and defined in Table 3. Features of the discourse refer to aspects of the discourse content that occur either within text constituents or across text constituents. These features are important because they provide input or cues to the cognitive systems that support comprehension for processing (Gernsbacher & Givon, 1995; Graesser et al., 2004; Magliano & Schleich, 2000). There are innumerable features of discourse ranging across the characteristics of the word, the sentence, the discourse context, and so on. But, here, we have listed only four features that we believe distinguish between the seven models.

Each model assumes that at least one feature of the discourse is central because these features are the basis for mapping processes. Some theories

Table 2 Ratings of the Seven Models on Model Dimensions as to Whether the Dimension is Critical (3), Important (2), Acknowledged (1), Absent (0), or Contradictory (− 1).

		Model						
Category	Dimension	Construction–integration	Structure building	Resonance	Constructionist	Event indexing	Causal network	Landscape
Features	Grammatical morphology and syntax	1	2	0	0	1	0	0
	Referential cohesion	3	3	3	1	− 1	− 1	2
	Situational semantics	2	0	0	1	2	0	0
	Situational cohesion	1	2	0	3	3	3	3
Processes	Dynamic activation	2	2	3	1	0	3	3
	Integration/settling	3	0	1	1	0	2	1
	Memory-based retrieval	2	0	3	1	1	0	2
	Knowledge-based inferencing	3	1	2	3	1	0	2
	Dumb activation	3	2	3	0	0	0	2
	Continuity monitoring	1	0	1	3	3	3	1
	Laying a foundation	0	3	0	0	0	0	0
	Shifting	0	3	0	0	3	0	0
	Suppression	2	3	1	0	0	0	1
Products	Situation model	3	1	0	2	3	2	2
	Propositional textbase	3	1	0	1	1	0	1
	Levels of representation	3	0	0	1	1	0	0

(Continued)

Table 2 (*Continued*)

Category	Dimension	Model: Construction–integration	Structure building	Resonance	Constructionist	Event indexing	Causal network	Landscape
	Local coherence	3	0	2	3	0	1	1
	Global coherence	3	0	2	3	0	1	1
	Sources of information	2	0	1	1	0	0	3
	Levels of comprehension	3	1	0	2	0	0	1
	Hierarchically structured representation	3	1	0	2	0	3	1
Extratextual	Goals	1	0	0	3	0	0	2
	Task	0	0	0	1	0	0	0
	Affect	1	0	0	0	0	0	0
	Standards of coherence	0	0	0	3	0	0	3
	Evaluation of comprehension	1	0	0	3	0	0	2
	Drive for explanation	0	0	−1	3	0	3	1
	Embodiment	1	0	0	0	0	0	0
	Imagery	1	1	0	0	1	0	0

Table 3 Definitions for Features that Vary in Importance Across the Seven Comprehension Models.

Grammatical morphology and syntax. Surface form and grammatical morphemes provide cues regarding the construction of the mental representation for a discourse. For example verb aspect provides readers with cues regarding whether events continue in the narrative context (e.g., walked to the store is completed, walking to the store is ongoing), which has implications on the availability of verb information and other constituents in working memory.

Referential cohesion. Referential cohesion refers to the amount of explicit overlap between referents, concepts, and ideas in a text. There is greater referential cohesion to the extent that words, nouns, concepts, and ideas overlap between sentences and between paragraphs. Local referential cohesion refers to properties of the text between consecutive sentences and near sentences. Global cohesion refers to how each sentence and paragraph overlaps with the text as a whole.

Situational semantics. Situational semantics comprise information within a discourse constituent (e.g., clause, sentence) that describes circumstance such as place, time, or manner. In a propositional representation, this information may constitute subpropositions for a core proposition. For example, She had dinner at midnight, is comprised of the core proposition, had(she, dinner) and the subproposition, time(midnight).

Situational cohesion. Situational cohesion is reflected by the potential for deriving connections between propositions based on situational semantics and implicit relationships. Discourse constituents can be related to one another along several dimensions of situational continuity: time, space, causality, goals, and entities. The Causal Network model is an example of a tool to establish the presence of cues related to situational cohesion.

emphasize the importance of referential cohesion (e.g., the CI model), whereas others emphasize the role of situational cohesion (e.g., the Event-Indexing model). Referential cohesion refers to the extent to which arguments in the current discourse input explicitly connect to arguments or concepts that have been established in the prior discourse. The CI model, for example, determines links between concepts in adjacent propositions according to the overlap between referents or arguments. Referential cohesion thus provides one potential source of information to guide the process of mapping. Referential cohesion is either central or important to the CI, Structure-Building, Resonance, and Landscape models, whereas it can be considered contradictory to the Event-Indexing and Causal Network models. In lieu of referential cohesion, the latter two models determine links via connections related to actions and events as conveyed in predicates.

As we discussed in Section 2, the difference between these models centers around the emphasis on arguments versus predicates in the mapping process. The Event-Indexing model assumes that verbs guide the mapping process because they carry the bulk of the information about the events in a text (Zwaan, Langston et al., 1995). There is some controversy with respect to whether referential cohesion is sufficient to guide the mapping process (Giora, 1985; Kintsch, 1995; Magliano, Zwaan et al., 1999; Trabasso, Suh, & Payton, 1995; Zwaan, Langston et al., 1995). Although Kintsch (1995) acknowledges that situational cohesion may influence the mapping process, he has argued this dimension should be highly correlated with referential cohesion. However, there is some evidence that this is not the case with naturalistic narrative text and that, at least for narrative texts, situational cohesion is central to mapping (Zwaan, Magliano et al., 1995).

Indeed, much of the controversy over the differential focus on these two features is likely driven by the foci of the models on different genres of texts. Narrative texts likely require different processes from the reader than do expository texts. Indeed, there a many differences between narrative and expository texts. Narrative texts are more easily and successfully understood than expository texts (Best, Ozuru, Floyd, & McNamara, 2006). Narrative texts are read nearly twice as fast as expository text (Graesser, Hauft-Smith, Cohen, & Pyles, 1980; Haberlandt & Graesser, 1985), but recalled nearly twice as well (Graesser, Hoffman, & Clark, 1980). Narrative texts are more likely to convey life experiences, person-oriented dialogue, and familiar language in the oral tradition than are expository texts (Bruner, 1986; Rubin, 1995; Tonjes, Wolpow, & Zintz, 1999). In contrast, the purpose of expository texts is to inform the reader of new information, so by definition they generally use more unfamiliar words and demand more knowledge that fewer people possess. As such we assume that both referential and situational cohesion should be important for a comprehensive model of comprehension, but that the relative importance of these forms of cohesion in the mapping process may vary from discourse to discourse.

There were two dimensions of features that were not deemed to be important across models, situational semantics and grammatical morphology and syntax. Situational semantics refers to the semantic content that is derived from the construction of a propositional representation of a text. This may lead one to assume that researchers proposing these theories assume that these features are unimportant, but this is likely not the case. Many theories, such as the CI model operate on the assumption that the propositions have already been constructed. Therefore, they typically do not explicitly describe how situational semantics are derived, what kinds of information are represented, and how they guide processing. This also explains why morphology and syntax are left out as well. That is, this lower-level information is typically lost after propositions are constructed (Fletcher & Chrysler, 1990; Schmalhofer & Glavanov, 1986). However, there is some evidence that this could be a mistake because there is evidence that these features influence the availability of information in working memory and guide processes such as mapping and situation model construction (Gernsbacher & Jescheniak, 1995; Gernsbacher & Shroyer, 1989; Givon, 1989, 1992, 1995; Magliano & Schleich, 2000; Morrow, 1985, 1986). Although a few models acknowledge the importance of lower-level features, they do not make specific assumptions regarding how morphology and syntax guide processing.

3.1.2. Comprehension Processes

Obviously, the primary input during reading is the text and therefore, the processes assumed by the models operate on the features of the discourse. Virtually all of the models we discuss here are processing models and therefore, the critical assumptions posited in the theories focus on processing. Also, the primary differences between the models are reflected in the relative importance of comprehension processes. The processes we have listed in Tables 2 and 4 vary from continuous processes that operate throughout the processing of a text constituent (e.g., clause or sentence) and late processes, which may operate near the end of processing a text constituent and may involve spill over processing. Continuous processes begin immediately upon the activation of information that supports them (Just & Carpenter, 1980). We do not include early processes in this list because the vast majority of these refer to lower-level processes (e.g., decoding, syntactic) that are not within the scope of these theories.

With two exceptions (i.e., the Constructionist and Event-Indexing models), the notion that activation of information sources dynamically fluctuates across processing cycles is relatively central to most theories. Although dynamic activation would presumably be tied to the integration of concepts and the network settling toward a stable mental representation, this latter process is explicit within only four of the models, namely the CI, Resonance, Causal Network models, and Landscape Model. The dynamic fluctuation of activation in the mental representation can be mediated by passive, memory-based retrieval mechanisms (Myers & O'Brien, 1998) or as a result of establishing relationships between discourse constituents (Langston & Trabasso, 1999; Langston et al., 1999).

However, one general observation that distinguishes the seven models is the relative emphasis on the importance of automatic, bottom-up processes and goal directed, top-down processes in support of comprehension. For example, the CI and Resonance models place a heavy emphasis on the role of automatic, bottom-up processes in supporting mapping. Neither deny that top-down processes operate, but assume that much of the work that supports mapping is achieved through an automatic, integration/settling process. In contrast, the Constructionist model specifies the role of goal directed processing on comprehension. Although the Constructionist and

Table 4 Definitions for Processes that Vary in Importance Across the Seven Comprehension Models.

Dynamic activation. The availability of information sources in working memory and long-term working memory are in constant flux and change when new relationships are established. As such, activation dynamically changes across the time span of information processing.

Integration/settling. Information from various sources is integrated using an iterative process until the network shows little change in values between iterations. The network settles when there is little change in activation values and it has become stable.

Memory-based retrieval. Information from the text representation or prior knowledge is probabilistically retrieved based on principles related to memory and features of the text including referential cohesion, elaboration of the antecedent, availability of other antecedents, and distance in the mental representation. It involves dumb activation and is automatic and continuous in that the current contents of working memory are continuously resonating with information sources.

Knowledge-based inferencing. Generating knowledge-based inferences (or elaborations) is going beyond information explicit in the text and involves accessing related knowledge, which may be incorporated into the mental representation.

Dumb activation. Dumb activation is a bottom-up process, as opposed to top-down, where prior knowledge related to the information in the text is activated regardless of whether it is relevant or irrelevant to the context.

Continuity monitoring. Readers monitor the sense of how well the current linguistic input fits with the prior discourse context. This sense of continuity is influenced by and can influence inference generation. Continuity monitoring may be the emergent state resulting from mapping.

Laying a foundation. Processing at the beginning of a discourse, episode, or sentence can require additional processing time. This phenomenon is referred to in the Structure-Building model as laying a foundation for the discourse structure, onto which subsequent discourse constituents are mapped.

Shifting. The Structure-Building model assumes that when a comprehender fails to make connections between constituents in a discourse, there may be a shift to a separate mental structure.

Suppression. Successful comprehension requires ignoring irrelevant information in the discourse, such as irrelevant meanings of ambiguous words. The process of focusing on relevant meanings, and discarding irrelevant meaning is referred to as suppression. Some theories assume that this occurs as a function of inhibiting the irrelevant meanings. Other theories propose that it is an emergent effect of enhancing the relevant meaning.

Resonance models have been described as mutually exclusive accounts of comprehension (Albrecht & Myers, 1995), it is generally accepted that they need not be (Graesser et al., 1994; Kintsch, 1998; Long & Lea, 2005; Myers & O'Brien, 1998; van den Broek et al., 2005; Wolfe, Magliano, & Larsen, 2005). When readers have a substantial amount of relevant background knowledge and the text is not overly difficult, mapping processes are most likely largely supported by automatic processes. However, in instances where there is a specific task that provides an explicit goal for reading, the text is difficult, or the information is relatively unfamiliar to the reader, deep comprehension most likely does require conscious and deliberate problem solving (Collins, Brown, & Larkin, 1980). This does not mean that readers will necessarily engage in effortful processing to achieve an adequate degree of comprehension. Nonetheless, educational contexts should presumably aspire to engender the ideal reader, such as that described by the Constructionist model.

One may find it perplexing that we designate text-based inferences as a common feature (see Section 1.3), but not knowledge-based inferences. It is well understood that knowledge-based inferences are at least important, if not central to comprehension (e.g., Graesser, 1981; Graesser et al., 1994; Kintsch, 1998). Indeed, as mentioned above, a central distinguishing factor between theories of discourse comprehension during the 1980s and early 1990s regards differences in predictions on what inference categories are routinely generated online during reading (see, for reviews, Graesser et al., 1994; McKoon & Ratcliff, 1992). Whereas most models discussed here specify assumptions that are related to text-connecting inferences, not all specifically describe assumptions related to knowledge-based inferences. For example, the Causal Network model exclusively focuses on text-based inferences rather than knowledge-based inferences.

Continuity monitoring is also important to successful reading. At least three theories specify that continuity monitoring is central to the theory. Continuity monitoring is a late, evaluative process that operates on the output from the mapping processes. It essentially involves an evaluation of the extent to which the current linguistic input fits into the prior discourse context. The Causal Network analysis describes this as an implicit evaluation of the extent to which there are necessary and sufficient causal antecedents available in working memory (Trabasso et al., 1989). However, a key feature of continuity monitoring is that it does not involve a conscious awareness of the cohesive features of the discourse that affect perceived sense of fit. Hence, continuity monitoring may be primarily supported by bottom-up processes, rather than strategic, top down processes.

There are three dimensions that are for the most part, uniquely assumed by the Structure-Building model, and are not explicitly included in many of the other models, laying a foundation, shifting, and suppression. Laying a foundation is the process of beginning to build a structure; shifting is the process of moving away from one structure to another; and suppression is the mechanism that allows the reader to avoid shifting, by inhibiting irrelevant information. The authors of the other six models may implicitly assume that at some points in comprehension, such as in the initial phases or at breaks in comprehension, the reader engages in effortful processes such as knowledge activation. However, none of the other models identify laying a foundation as separate from other phases of comprehension. Likewise, because the notion of shifting is tied to laying a foundation, there are few other models that include it within their assumptions. One exception can be seen in our judgment that shifting is a process that is central to the Event-Indexing model. This assessment was made because the continuity monitoring assumption of the model assumes that readers perceive that new episodes begin when there are breaks in multiple dimensions. There is evidence that breaks in multiple dimensions of situational continuity does lead to increased processing time (Zwaan, Magliano et al., 1995) and perceptions that there is an episode shift (Magliano et al., 2001). Nonetheless, these data do not necessarily suggest that shifting is necessarily a unique cognitive process.

Suppression is similarly a concept that has been focused on primarily within the context of the Structure-Building model. Notably, although negative links are not necessary to drive out irrelevant information in the CI model (McNamara & McDaniel, 2004; Rowe & McNamara, 2008), Kintsch (1998) also adopted the notion of suppression in the form of inhibitory links. However, few of the other models have focused on this concept or process (cf. O'Brien, Albrecht, Hakala, & Rizzella, 1995).

3.1.3. Products of Comprehension

Processes and mental operations give rise to various mental representations, each representing different aspects of comprehension (Balota et al., 1990; Graesser et al., 1994; Kintsch, 1988; Kintsch & van Dijk, 1978; van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). Products of comprehension (see Tables 2 and 5) refer to mental representations resulting from comprehension processes, which can contain multiple levels of meaning (Fletcher, 1994; Graesser & Clark, 1985; Graesser et al., 1997; Kintsch, 1988; Kintsch & van Dijk, 1978; van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). It is noteworthy that there is often a misconception that these products represent discrete representations which would be more aptly conceptualized as different aspects of the mental representation that is constructed for a discourse (Graesser & Clark, 1985).

There are two models that focus more on the qualitative and structural aspects of the products of comprehension, the CI and the Constructionist models. The focus on these products, particularly by the CI model, stems from it being one of the first models, and the one that is described in most detail. As such, these products of comprehension may very well be more or

Table 5 Definitions for Products of Comprehension that Vary in Importance Across the Seven Comprehension Models.

Situation model. To the extent that the textbase level of understanding is incomplete or includes implicit information, the comprehender must make inferences that go beyond the text. Those inferences can include inferred connections between separate parts of the discourse and links to prior knowledge. The situation model can be both local and global. That is, there can be a situation model level of representation for a sentence, and there can be a situation model representation for larger chunks of discourse, or an entire passage.

Propositional textbase. It is assumed that the comprehender constructs the deeper meaning of a sentence from the surface information (e.g., word, syntax). This deeper meaning is represented symbolically as a proposition, which is assumed in some theories to be the fundamental unit of processing. The proposition includes a core proposition with a predicate (e.g., verb) and arguments, as well as subpropositions (e.g., modifiers, situational semantics).

Levels of representation. A discourse representation is comprised of multiple dimensions, including the surface, textbase, situation model, and pragmatic levels. These levels of representation are not independent of one another, but together comprise the mental representation for a discourse.

Local coherence. This is an aspect of the comprehender's mental representation comprising the established relationships between the current linguistic input and the immediately prior discourse context or local chunks of text. The mental representation tends to be locally coherent to the extent that the comprehender has made connections between consecutive constituents in the discourse (words, ideas, sentences).

Global coherence. This is an aspect of the comprehender's mental representation comprising the established relationships between discourse constituents (sentence, paragraph) and the discourse as a whole. The mental representation tends to be globally coherent to the extent that the comprehender has established an organizational structure within a larger discourse context.

Sources of information. Information can be made available from several information sources, such as the current linguistic input, the prior discourse representation, relevant world knowledge, and other episodic memories. These are the building blocks for constructing the memorial representation.

Levels of comprehension. Comprehension can be conceptualized as existing on a continuum rather than as a discrete or holistic construct. Levels of comprehension can vary from reading situation to the next, over the course of reading a document, or over time (one may initially not fully understand a text, but engage in postreading processes that lead to a deeper sense of comprehension). Levels can be described in various ways such as surface versus deep, textbase versus situation model, and so on.

Hierarchically structured representation. The implicit and explicit relationships between discourse constituents lead to a hierarchically structured representation. Certain discourse elements will be central to the structure of the discourse in the memorial representation. For example, in some situations, readers may be sensitive to a hierarchical structure of the characters' goals. This concept is also captured within the macrostructure of the CI model.

less universally accepted by the authors of the other five models; however, they receive little to no focus in those five models.

Of the products, the one that most clearly stands out as central or important to most models is the situation model. Since this construct was first postulated (Johnson-Laird, 1983; van Dijk & Kintsch, 1983), it has arguably been a central focus of discourse comprehension research. This stems from the general assumption that deep meaning rests in the construction of a representation that reflects the implicit situation, rather than representing the explicit content.

Each of the theories may emphasize different processes that support the construction of a situation model. For example, the CI model emphasizes the role of knowledge-based inferences in the construction of a situation model, whereas the Event -Indexing and Causal Network models emphasize the role of text-based inferences that reflect situational continuities (e.g., causal, spatial, temporal). Clearly, both knowledge-based and text-based inferences are central to the construction of a situation model and a comprehensive theory must explain the processes that support both general classes of inferences.

It is somewhat surprising that only the CI model explicitly assumes that the representation of the text content is propositional in nature. Some models acknowledge this as an aspect of the representation, but allow other forms of representation, and some models leave it out entirely. This is aligned with the concepts of levels of representation, and the local and global coherence of that representation. While it seems that the field as a whole embraces these concepts, few models other than the CI model have focused on these aspects of comprehension.

Another dimension for which we found sparse mention within models is sources of information. At some level, we presume that all of the models assume that there are various sources of information during comprehension, specifically the discourse context (i.e., current sentence and textbase representation for the prior text) and relevant knowledge (world and episodic knowledge). These sources are the basis for the construction of inferences, the textbase, and situation model. Graesser et al. (1994) conducted a similar exercise in evaluating models, but on a much smaller scale. In doing so, they listed information sources as a common assumption. However, we found that only the Landscape model explicitly included this dimension and the CI model does so implicitly. Moreover, the Landscape model discusses information sources in lieu of the construction of the textbase and situation model (Tzeng et al., 2005). We believe that information sources should be treated differently than the constructs of the textbase and situation model because the latter imply a constructed mental representation, but the former do not. Rather, information sources are activated knowledge that contribute to the construction of these representations and fluctuate in activation as a function of features of the discourse (Todaro, Magliano, Millis, McNamara, & Kurby, 2008).

The other two dimensions that are not prominent across models are the notions of levels of comprehension and hierarchically structured representations. Levels of comprehension is a concept focused on primarily, again, by the CI model. Although it seems to be embraced by the field, there are few other models for which it is a focus. Nonetheless, it is a critical dimension to consider, particularly when devising measures to assess readers' comprehension. For example, researchers have often used the levels of comprehension construct to develop questions that assess understanding of explicitly conveyed information (i.e., the textbase) as contrasted with inferences that may have been generated to understand the text (i.e., the situation model; e.g., McNamara, 2007; McNamara & Kintsch, 1996a). As such, this construct has been useful in developing questions that enable researchers to assess different aspects of the mental representation for a text and thus afford more precise indices of how well a reader has comprehended a text.

The hierarchical structure of the readers' understanding is orthogonal to the notion of levels of representation. Within the context of the CI model, the hierarchical representation is captured most in the macrostructure. This structure emerges from the text as well as the reader's prior knowledge, and thus global inferences about the text. In the context of the Causal Network model, the hierarchical organization of mental representation can be conceptualized as an emergent property of text-based inferences, and in particular, causal inferences. For example, when characters have an explicit superordinate goal that guides their actions, causal inferences linking goals with subgoals and goals with actions create the hierarchical structure (Suh & Trabasso, 1993).

The notion of global coherence aligns somewhat to the hierarchical structure of the mental representation of the text. This is contrasted with local coherence which is more closely tied to the textbase representation. Local and global coherence have a rich history in discourse comprehension theory and research. These constructs took center stage when McKoon and Ratcliff (1992) proposed the minimalist hypothesis that readers only seek to establish global coherence when they fail to achieve local coherence. The Constructionist theory was, in part, posited in response to the minimalist hypothesis and Graesser et al. (1994) explicitly stated the assumption that readers have a drive to achieve both local and global coherence. Since this debate, it has been established that readers routinely establish both local and global coherence (e.g., Suh & Trabasso, 1993), which can be achieved in part via dumb, bottom-up processes (Myers et al., 1994).

Like the notion of hierarchical structure, we view local and global coherence as emergent properties of the inferential processes that support the construction of a situation model. That said, these constructs are important for research on individual differences in comprehension ability. Specifically, the comprehension processes of less-skilled comprehenders tend to operate on the local context (one or two sentences), whereas skilled comprehenders routinely engage in inferential processes that support the construction of a global coherent situation model (Cote & Goldman, 1999; Magliano & Millis, 2003; Millis, Magliano, & Todaro, 2006). Another way of viewing these processes is in terms of the reader's microstructure and macrostructure representation of the text. Local coherence is driven primarily by the microstructure and global coherence by the macrostructure (Kintsch, 1998).

3.1.4. Extratextual Dimensions

We use this category to refer to processes that are relatively high level, and that likely occur postintegration (though not necessarily). These are also more pragmatic processes, reflecting metalinguistic or social aspects of the reader or the reading context that can influence processing and the nature of the ensuing products (see Tables 2 and 6). It is clear that extratextual dimensions of comprehension comprise an underserved category. Only three models explicitly included any extratextual dimensions. Both the Constructionist and Causal Network models consider the reader's drive for explanation to be a critical component of comprehension and explanation-based processes are assumed to be central to mapping according to the Constructionist model (Graesser et al., 1994). These models assume that the process of explanation essentially underlies the comprehension process, such that the reader continuously strives to explain the information on the page. This claim contrasts with models such as the Resonance model, which assumes that most of comprehension occurs as a result of automatic memory retrieval processes, as well as evidence indicating that explanation-based processes occur after 500 ms (Long & Golding, 1993; Magliano et al., 1993; Till et al., 1988).

Only two models, the Constructionist and Landscape models, explicitly include more than one of the dimensions we have categorized as extratextual. This is linked to their focus on top-down processes, in contrast to bottom-up processes such as dumb activation. The Landscape model stands out as the only model that has attempted to simulate variations in readers' standards of coherence, which are assumed to emerge from factors such as the reader's purpose or goal for reading (Linderholm et al., 2004; van den Broek et al., 2005). There is a good deal of evidence that instructions given to readers, their goals, and their purpose for reading has substantial effects on reading processes and comprehension (Linderholm & van den Broek, 2002; Lorch, Lorch, & Klusewitz, 1993; Narvaez, van den Broek, & Ruiz, 1999; van den Broek et al., 2001). For example, van den Broek et al. (2001) found that readers generated more bridging inferences and paraphrases when reading to study, whereas they generated more elaborations and editorial remarks when reading for entertainment. As described in the review of the Landscape model, these variations in reading purposes, and consequent standards of coherence, are simulated by manipulating the activation values for elements involved in relations such as causal connections, such that those

Table 6 Definitions for Extratextual Dimensions that Vary in Importance Across the Seven Comprehension Models.

Goals. Some comprehension models such as the Constructionist model assume that reading is an inherently purposeful activity. As such, readers are assumed to always have a goal when reading a discourse. This goal varies in explicitness and discreteness. For example, a reader may have a vague and implicit goal to be entertained or a specific and explicit goal to identify explanations for some event provided by the authors.

Task. Reading may be contextualized within some larger task, such as learning for a class or to write a paper. The task can provide the goal or purpose for reading. Tasks are sometimes provided by some environmental context, such as school, work, and so on. The task involves some activity for which the information obtained from the reading will be used, such as a postreading activity (taking a test, writing a paper, answering questions, analyzing the text).

Affect. Affect refers to the reader's emotional response to the discourse. Readers can have emotional responses to reading including joy, amusement, frustration, and confusion.

Standards of coherence. Comprehenders are assumed, in some theories, to have a minimum threshold of comprehension that is being sought, called the standard of coherence. If a reader has a low standard of coherence, then understanding the discourse at a superficial or even incomplete level will be sufficient. Readers with a high standard of coherence will be more likely to generate inferences in order to understand the text at a deeper or more complete level. Readers' standard of coherence can vary as they read a text or it may be a source of individual differences in comprehension skill.

Evaluation of comprehension. This is the assumption that comprehenders routinely evaluate their sense of comprehension. This evaluative process will be guided by a standard of comprehension or coherence, which is also determined by comprehension goals.

Drive for explanation. Comprehenders are assumed to have a drive for a sense of explanatory coherence that comprises why events, actions, and states occur in a given context. Accordingly, comprehenders routinely infer causes of events and that the drive is controlled by an implicit evaluation of causal fit—are there necessary and sufficient antecedents available in memory? The drive for explanation becomes conscious and explicit when memory-based retrieval fails to activate necessary and sufficient causes.

Embodiment. A central assumption of theories of perceptual symbols is the notion that areas of the brain that are responsible for perceiving and acting in the world are also involved in knowledge representation. Processing language involves activating the perceptual and sensory/motor areas of the brain. Similarly, theories of embodiment assume that information processing is affected by the comprehender's understanding from the standpoint of the human body.

Imagery. Although comprehension models often represent discourse in terms of propositional, or via some other abstracted representational means, comprehension models assume that comprehension involve multiple modalities and modes of representation, including verbal, symbolic, and iconic modalities. The creation of images while understanding discourse is assumed to be fundamental process of comprehension.

readers who have lower standards of coherence are assumed to have lower activation values for those elements, and vice versa. Consequently, the reader with lower standards of coherence has a weaker memorial representation.

The final two processes that we have included as extratextual dimensions are embodiment and imagery. Embodiment is closely aligned with perceptual symbols theories (Barsalou, 1999a; Zwaan, 2004) that assume that the brain systems correlated with perceiving and acting in the world are also involved in knowledge representation, language processes, and event comprehension. It is certainly debatable if embodiment is a process in and of itself, or rather, a consequence of multiple processes. However, we consider perceptual symbols and embodiment as processes in the context of Barsalou's (1999b) Perceptual Symbols theory and Glenberg's (1997) theory of Embodiment. Both theories assume that perceptual symbols support comprehension through a process in which perceptual symbols are activated and mapped onto the discourse context through a process of simulation (see also Zwaan, 2004). Likewise, there is a growing interest in the influence of imagery on comprehension (Horton & Rapp, 2003). Certainly, all comprehension models assume that the reader is creating iconic images while reading (Kintsch, 1998). The alternative notion is simply ridiculous.

Nonetheless, there is growing recognition that these factors are not trivial for discourse comprehension (Dijkstra, Zwaan, Magliano, & Graesser, 1995; Graesser et al., 1997; Ohtsuka & Brewer, 1992; Tan, 1996), and in particular in educational contexts (Snow, 2002). Take for instance affect. Readers and viewers arguably experience narrative texts and films to gain an affective response (e.g., a sense of pleasure, suspense, fear). Moreover, a reader's level of engagement is very likely influenced by the degree and nature the affective response to a narrative.

Perhaps one could view the exclusion of extratextual dimensions from theory as a necessary sin of omission. The objective is to specify models such that they can be computationally implemented and it is challenging, to say the least, to quantify the impact of many of these factors on comprehension in a manner consistent with this objective. For example, the relationship between affective response and discourse processes is not yet completely understood: they may be related (Ohtsuka & Brewer, 1992) or they may be separate, but coexisting processes. However we contend that the state of the field is such that a comprehensive theory should postulate assumptions and parameters that are sensitive to these factors.

3.2. Correlations Between Models

Another way in which the ratings in Table 2 can be used is as a means to assess the correlations between the models (see Table 7). Again, these are not experimental data, but simply an interesting lens through which we can

Table 7 Correlations Between Models as Reflected by the Dimension Ratings in Table 3.

	Structure building	Resonance	Event indexing	Causal network	Constructionist	Landscape
Construction–Integration	− 0.02	0.51**	− 0.12	− 0.02	0.08	0.19
Structure Building		0.20	0.09	− 0.10	− 0.44*	− 0.02
Resonance			− 0.24	0.06	− 0.04	0.43*
Event Indexing				0.31	0.09	− 0.06
Causal Network					0.43*	0.25
Constructionist						0.49**

*$p < 0.05$ and **$p < 0.01$.

view the models. Notably, the correlations are negatively biased because they do not include the common dimensions across all of the models (see Table 1), and rather solely the ratings in Table 2. Given the number of observations and the fact that these correlations are based on the authors' ratings, one should consider the magnitude and direction of the coefficients in additional to their alpha levels. Nonetheless, these distinguishing features reveal commonalities among the models.

First, we see in Table 7 that the CI model is correlated with only one other model, the Resonance model. This corroborates views expressed by several researchers that these two models are exemplars for *memory* models. It is somewhat surprising, nonetheless, that the CI model does not show higher correlations with the other models, particular given that the CI model provides the foundation for most of them. Although this result may emerge because we did not include the common dimensions between the models (which are core assumptions of the CI model), it may also reflect the other six models' focus on dimensions that were not specified in the CI model. This notion converges with the analysis of the models discussed with respect to Figure 3, in that the CI model has focused primarily on quadrants C and D, whereas the other models have focused primarily on quadrants A and B.

The Landscape model correlates with both the Resonance model and the Constructionist model, corroborating claims by van den Broek et al. (2005) that the Landscape model is consistent with both of these seemingly contradictory models. The Causal Network model correlates with the Constructionist model and has a moderate (although relatively high in the context of this matrix), but nonsignificant coefficient with the Event-Indexing model, likely reflective of not only the common foci of the models (on situation model construction) but also the professional links between the authors of the models.

Notably the Event-Indexing model was not significantly correlated with any other model, and only weakly correlated with the Causal Network model. These latter correlations likely reflect a common focus on situation model construction and the lack of significant correlation likely reflects that the Event-Indexing model focuses on aspects of the situation model generally ignored by other models. Indeed, since the publication of Zwaan and Radvansky (1998), the Event-Indexing model has had a dominant influence on situation model research.

The Structure-Building model is not correlated to any other models, and is negatively correlated with the Constructionist model. We found this surprising because, like the CI model, it can be characterized as a general processing framework for discourse comprehension and there is a large body of data supporting the assumptions of the model (Gernsbacher, 1997). There are at least three explanations for these low correlations. First, the processes of laying a foundation and shifting are unique to this theory (and arguably emerging properties) and mapping is a unique property not included in the correlations. Second, although the construct of suppression is evident in other models, the Structure-Building model places a unique emphasis on it. This is related to the third explanation, that the Structure-Building model is unique in its focus on the role of individual differences in suppression to explain individual differences in comprehension skill.

4. Summary of Model Reviews and Evaluations

The purpose of Sections 2 and 3 was to provide a framework for making sense of the broad theoretical landscape covered by the text comprehension literature. In Section 2, we provided a description of seven leading comprehension models. In Section 3, we examined dimensions that varied between the models. As is the nature of this relatively subjective evaluation provided in Section 3, there is nothing we have claimed that could not be debated. Yet, we have proposed platforms that hopefully allow the reader to view the models from various angles and perspectives. Regardless of whether we are right or wrong in our analysis, these perspectives provide novel means of considering and evaluating comprehension models.

What do we conclude from these perspectives? Several differences between the models emerged in our discussions. One controversy that has emerged regards the degree to which readers engage in explanation-based versus memory-based processes. Although these two perspectives have often been described as incompatible (e.g., Albrecht & Myers, 1995), they can also be conceptualized as describing different processes operating over the course of comprehension (Long & Lea, 2005; Magliano & Radvansky, 2001). Along these lines, van den Broek et al. (2005) provided evidence via a Landscape model simulation that cohort activation was aligned with the Resonance model (i.e., memory-based processes) whereas coherence-based retrieval processes were aligned with the Constructionist model (i.e., explanation-based processes).

The issue concerning explanation-based versus memory-based processes is related to the primary objective of virtually all models of discourse comprehension being to describe the general mapping processes that support the construction of a coherent text representation. There are several common assumptions that support mapping processes, but there is also some divergence across models. The majority of the divergence centers on whether mapping processes can be characterized either as bottom-up or top-down. We believe that neither perspective is mutually exclusive and that a comprehensive model must be able to describe when comprehension will be supported by effortful processes in addition to bottom-up processes.

The issue that has emerged consistently across many of the models regards the nature of and processes to build a situation model while reading. The concept of the situation model is most strongly associated with the CI model, which describes it as driven by an interaction between information in the text and activated prior knowledge, and notably, by the presence or absence of referential overlap. In contrast, the Event-Indexing and Causal Network models assume that the situation model captures an underlying event and causal sequence that takes place within a fictive time and place. These models by consequence place greater emphasis on the role of conceptual overlap among verbs as providing the primary basis for achieving coherence rather than coreference between referents or arguments (Zwaan, Magliano et al., 1995). We propose that this difference between the two classes of models results from differences in research foci (e.g., expository vs narrative text comprehension) rather than fundamental differences between the models. This observation leads to an interesting, yet untested, prediction that whereas variation in referential cohesion should affect expository text comprehension (McNamara, Louwerse, McCarthy, & Graesser, 2009), verb and causal cohesion may have a greater impact on narrative (and perhaps history) text comprehension (McNamara, Graesser, & Louwerse, 2008).

Our driving claim is that the differences across the models discussed here stem primarily from differences in terms of the foci of the models and from describing different comprehension situations. For this purpose, in Section 2, we described the models in terms of their foci in reference to Figure 1. First, the CI model tends to be more concerned with quadrants C and D (i.e., more challenging, expository texts). In contrast, most of the other models focus on easy reading (e.g., narrative) and ideal readers (e.g., college students in top schools) represented by quadrants A and B (i.e., narrative and descriptive texts). The Structure-Building model focuses somewhat on explaining individual differences in comprehension skill, and thus might be considered to cover both quadrants A and B. We reasoned that the Resonance Theory falls somewhere in the middle of quadrants A and B in that it describes neither the highly motivated or strategic reader nor the minimalist reader. The Event-Indexing and Causal Network models, by contrast, focus on readers in quadrant A, namely relatively skilled readers confronted with relatively easy texts. Finally, the Constructionist and Landscape models come closest to covering all four quadrants, though for different reasons. Overall, the majority of the models place greater focus on conscious, goal-driven processes, and on events and actions. In contrast, the CI model, in the context of primarily informational text, has focused more on bottom-up activation processes, and less so on conscious processes. And, there is a greater focus on conceptual content, such as that provided by arguments (e.g., nouns), rather than the effects of events and actions (e.g., predicates, verbs).

With respect to Figure 1, the current models provide a good start in describing processes across the four quadrants. However, it seems that these leading theories do not address the same types of readers nor do they investigate comprehension using the same types of texts. Clearly, comprehension will vary along these dimensions, and experimental results will be influenced by these dimensions. Further, we observed in Section 3 that the models uniformly ignore both the lowest and highest levels of comprehension. That is, there has been little to no focus on the reading process (e.g., decoding and parsing), and even less focus on extratextual aspects of comprehension. We discuss these issues as well as what a comprehensive model of comprehension would need to more fully consider in more depth within the following section.

5. Toward a Comprehensive Theory of Comprehension

Our ultimate goal is to outline a comprehensive model of comprehension that extends upon the CI model and contains features specified by the other six models. This model should be able to account for the varied comprehension situations depicted in Figure 1. A comprehensive model should be able to account for not only situations where demands are low, such as quadrants A and B, but also when processing demands high, such as quadrants C and D. One could argue that the CI and Landscape models can make these distinctions. However, none of the implemented models can account for strategic processing, although the implementation of the parameters associated with standards of coherence within the Landscape model is a step in the right direction. Moreover, none of the models can account for the individual difference factors or contextual factors that would lead to readers falling in quadrants A and C versus D.

Although our ultimate goal is to push the field toward a more comprehensive model that can account for these different reading situations, it is critical that a comprehensive model be implemented computationally. One attractive feature of the CI model is that it can account for many aspects of discourse comprehension with a relatively small set of assumptions and parameters in the implemented model. However, as is evident in our discussion thus far, a comprehensive model would have to go beyond the CI model to account for the reading situations depicted in Figure 1. The overarching purpose of the analysis presented above was to work toward an understanding of what each of the seven models offers in their explanations of the processes underlying comprehension, to identify commonalities and differences between models, and to identify missing components. In this section, we outline the directions we consider most important to include in what might provide a more comprehensive model of comprehension. However, tough decisions will have to be made so that a comprehensive model can be implemented.

Our starting assumption is that the common features listed in Table 1 need to be explicitly part of a comprehensive model and it is the dimensions that vary across models that must be carefully considered for inclusion in the comprehensive model. Many of these features support basic processes that fall into quadrant B and operate more or less in the other quadrants. In an effort to narrow down explicit features, we first discuss the dimensions discussed above that need to emerge from the explicit features and processing assumptions of a comprehensive model. Next we discuss the nonconsensual features, processes, products, and extratextual components of comprehension that were discussed above and that should be explicitly part of a comprehensive model. We then discuss dimensions of comprehension that have been ignored by most if not all of the comprehension models, but need be considered in more comprehensive models of comprehension. These include cognitive features and processes relevant to decoding and parsing, extratextual aspects of comprehension, individual differences in comprehension skill, and processes involved in the comprehension of alternative modes of communication.

5.1. Emergent Properties of Models

There are some dimensions of models that can be considered emergent properties, rather than processes, products, or rules that must be implemented in the model (Rumelhart & McClelland, 1986; Rumelhart, 1984). Connectionists have claimed that many behaviors that have the appearance of being rule based may be emergent from the operations of lower-level features. In the context of purely connectionist models, virtually all of the dimensions we have discussed might be emergent. Here, we operate at a higher level of scrutiny by considering those properties that could or should fall out of the model in that they or their effects are apparent as a result of other dimensions of the model.

We have argued here that some, but not all, of the models' dimensions may emerge from explicit features and processing assumptions that should be explicitly part of it. One approach toward a level of parsimony in a comprehensive model is to identify which dimensions can be considered emergent properties of other dimensions. Also, some properties should emerge from the system, as a test of the fundamental assumptions of the model.

Thus, in this section, we identify emergent dimensions among those we have considered. We have included five processes (dynamic activation, continuity monitoring, laying a foundation, shifting, suppression) and four products (levels of comprehension, local coherence, global coherence, hierarchical structured representation). We assume that features, at least those we considered here, cannot be emergent properties because features by necessity must be implemented.

The first process we consider emergent is the notion of the dynamic fluctuation of activation. This is relevant to changes in activation values in the course of comprehension such as described by the Landscape model (e.g., van den Broek et al., 1999), as well as to the notion of different mental models as proposed by the Event-Indexing model (i.e., the current, integrated, and complete models; e.g., Magliano, Zwaan et al., 1999). We believe that dynamic fluctuation of activation is a feature that emerges from at least two processes. The first is memory-based retrieval (Myers and O'Brien, 1998). That is, given that the content of working memory naturally changes across sentences in a discourse, the retrieval cues will change. As such, the activation of knowledge sources fluctuates across sentences. Additionally, dynamic activation occurs via the mapping processes and text-based inferences (Magliano, Trabasso et al., 1999; Langston & Trabasso, 1999; Langston et al., 1999). When relationships are established between the current sentence and the nodes in the discourse representation, there are implications regarding the availability of nodes in the entire network (Langston & Trabasso, 1999; Langston et al., 1999). Thus, dynamic activation is an aspect of comprehension that emerges from changes in the retrieval cues (e.g., the text itself) and changes in concepts' activation levels resulting from mapping and inference processes.

The second dimension that we consider emergent is continuity monitoring. Within our definition in Table 4, we state that continuity monitoring may emerge from the mapping processes. Readers are consciously aware of the output from the mapping processes. When relationships between the current sentence and the prior discourse context are established, there is a sense of fit, whereas readers will be aware of a lack of fit when relationships cannot be established (Magliano, Zwaan et al., 1999). Moreover, this construct has substantial overlap with the metacognitive process of evaluating one's sense of comprehension. As such, there may not be a need to specify a feature or parameter in a comprehensive model that corresponds to continuity monitoring, though it need emerge from the assumptions of the model.

The three processes proposed by the Structure-Building model, laying a foundation, shifting, and suppression, may also be viewed as emergent. Gernsbacher (1990, 1997) interprets the effects of comprehension processes involved in laying a foundation as revealing processes unique to comprehending information after the initial sentence, clause, or picture. Alternatively, these effects can be interpreted as emergent properties of constraint-based connectionist systems such as the CI model (Kintsch, 1998). One problem with the Structure-Building interpretation is that it implicitly requires that the comprehender be aware of beginnings of and changes in episodes, or that somehow, this separate process of laying a foundation kicks in automatically. Alternatively, the evidence observed in support of comprehenders laying a foundation can be viewed in terms of three phenomena. First, the lack of background information at the start of a discourse means that there is no information primed, and there is no information to link back to and as such, processing will necessarily take longer (McNamara & Kintsch, 1996b). Second, the network will be more sparse because there are fewer textual cues and there is no information previously activated. A sparse network is less coherent, and thus takes longer to settle and is less stable. Thus, this aspect too will lead to longer times to process the information. Third, because there is no related information previously activated, there will be less interference. This lack of interference will result in primacy effects. Due to release from proactive interference, these effects would also be observed at the change of an episode.

Notably, these three phenomena could be viewed as compatible with the Structure-Building framework. Nonetheless, rather than viewing the effects associated with shifting as a need to create a new substructure, they can also be viewed in terms of two processes within the CI framework. First, gaps in discourse cause a break in the model, as described earlier. Second, when this occurs, the reader must make inferences to make connections to prior discourse or knowledge, or the reader continues without making connections. In the first case, those inferences take time to the extent that the knowledge is not readily available, but do not take extra time when the context and content is highly familiar (Ericsson & Kintsch, 1995). In the second case, the network will be sparse and lack connections, which takes more time to settle (i.e., corresponding to longer reading times). These explanations may be consistent with the Structure-Building model, but they run counter to the assumption that laying the foundation and shifting entail unique processing.

Whether suppression may or may not be an emergent property is a question of parsimony, but it is also a theoretical choice. The notion of suppression in the Structure Building is captured in an inhibition mechanism that allows skilled readers to ignore irrelevant information. Because negative links are needed, inhibition would not be an emergent property of connectionist systems. However, McNamara and colleagues (McNamara, 1997; McNamara & McDaniel, 2004; Rowe & McNamara, 2008) have shown that suppression can emerge without negative links (or inhibition) within the CI model by assuming that suppression results from greater activation of relevant information which results in a more coherent situation model representation. Based on research showing that skilled comprehenders make more inferences to prior discourse and to prior knowledge (e.g., Long, Oppy, & Seely, 1994; Oakhill & Yuill, 1996; Whitney, Ritchie, & Clark, 1991), McNamara (1997) assumed that less-skilled comprehenders activate a minimal number of extrasentential concepts to understand the target sentence, whereas skilled comprehenders activate more concepts that are not explicit in the textbase. In sum, skilled comprehenders construct a more coherent, richer situation model when reading because more inferences are generated and more knowledge is activated. Replicating Gernsbacher's results, the network representing the less-skilled reader took more time to suppress the irrelevant meaning of the ambiguous words, and the network representing the skilled readers took less time, without including negative links between the relevant and irrelevant meanings (see also Rowe & McNamara, 2008; cf. Kintsch, 1998). McNamara and McDaniel (2004) further showed that differences in the ability to suppress irrelevant information also emerge as a function of prior knowledge. When the reader has more prior knowledge, irrelevant meanings of ambiguous words are suppressed more quickly, regardless of reading skill. Thus, greater activation of knowledge results in faster suppression of irrelevant concepts.

It is important to note that McNamara's (1997) explanation does not rest on more or less activation of the relevant meaning of any particular word, nor does it predict greater activation of the relevant interpretation of the sentence. Gernsbacher and Faust (1991) demonstrated that the meaning of the ambiguous word is not more or less activated as a function of comprehension skill. For example, they demonstrated that skilled and less-skilled comprehenders showed equivalent facilitation for the appropriate meaning (*GARDEN*) in a biased context, *He dug with a spade*, compared to an unbiased context, *He picked up the spade*. However, McNamara's (1997) simulation of Gernsbacher and Faust's data showed that these differences emerged from interference from the irrelevant interpretation of the sentence (for less-skilled comprehenders) and not because of differences in facilitation at either the lexical level or the propositional level. Rather, McNamara's interpretation rests on the notion that without a coherent situation model representation of the sentence, the irrelevant interpretation of the sentence remains activated. By contrast, the increased associations in the skilled comprehender simulation essentially take over the network such that the irrelevant meanings more quickly die out. The lack of competition for resources between relevant and irrelevant interpretations results in residual activation for the irrelevant meaning of the ambiguous word. Accordingly, less-skilled comprehenders do not use resources effectively, whereas skilled comprehenders' maximal use of resources drives out irrelevant information.

In sum, we have included four products to be considered as emergent properties. One might argue that all products should emerge from explicit features in the model; however, we have included only those products that are dimensions of the quality of the reader's mental representation. The first is that of levels of comprehension. This is a concept closely tied to the CI model, which postulates that different aspects of the readers' mental representation are more or less dominant, and this dominance is reflected in various measures that tap into the various levels of the mental representation. For example, if the reader has focused primarily on the explicit concepts on the text, and has not generated abundant inferences, then the textbase-level representation would be expected to be more fully developed, whereas the situation model representation (depending on the text) would be weaker. These aspects are expected to be apparent via different types of comprehension measures (e.g., van den Broek, 1994). Recall and text-based questions tap the reader's textbase-level representation and measures such as bridging inference questions, sorting tasks, and problem-solving questions are assumed to tap the situation model representation. Because levels of comprehension emerge from the reader's comprehension processes and from the representation built by the reader, we consider it to be emergent.

Likewise, the notions of local and global coherence are descriptions of relationships or the nature of the mental representation. As stated above, the distinction between these two has a long history and has been important for distinguishing between theories (e.g., Graesser et al., 1994; McKoon & Ratcliff, 1992; Singer et al., 1994). However, this is arguably no longer the case. To elaborate, some have treated local and global coherence as referring to establishing relationships between adjacent and distal constituents (e.g., McKoon & Ratcliff, 1992). As such, the constructs of local and global coherence can be considered a classification of different distances that can occur with respect to established relationships between discourse constituents (established through coreference or text-based inferences). It is important to note that others have conceptualized global coherence as a property of a representation that enables readers to derive an overarching, organizational structure (e.g., Graesser et al., 1994). Nonetheless, we still view it unnecessary to implement formal assumptions regarding global coherence in a comprehensive model because it is just that, a property of the representation that should emerge from features and processes assumed within the model.

We also consider the construct of hierarchical representations as a description of the nature of discourse representations. This aspect emerges when a discourse constituent(s) (e.g., explicit character goal) becomes central to the representation because it is related to many other discourse constituents. For example, in a James Bond movie or novel, the character is given a goal at the beginning of the story and that goal becomes an organizing feature of the plot structure. The node reflecting that goal is the highest node in the hierarchy. However, it takes on that status as a result of mapping and text-based (i.e., causal) inferences. It is important to note that not all texts afford a hierarchically structured representation and as such, this is driven by features of the discourse.

In this section, we have considered which dimensions need not be implemented explicitly in a comprehensive model, but may be expected to emerge from other dimensions. We consider it important to discriminate in a model between those dimensions that must be implemented and those that are emergent dimensions of a model; first, because emergent properties should essentially fall out of the model, or emerge from the fundamental features and processes assumed within the model, and, second, because such an approach leads to a more parsimonious model. In the following sections, we consider dimensions of comprehension that are lacking from current models but should be considered in a more comprehensive model of comprehension.

5.2. Features of the Discourse

It is important for a comprehensive model to explain how features of the discourse guide processing. As discussed in the evaluation section, two features of text have been considered in depth thus far in the comprehension literature: referential cohesion and situational cohesion. We consider these two features both to be fundamental dimensions of comprehension.

However, morphology-, syntax-, and sentence-level semantics (i.e., situational semantics) have largely been ignored in formal models of comprehension. As we have already discussed, this is largely due to the fact that most theories focus on mapping processes that presumably operate after the meaning of a sentence is computed (i.e., after the computation of a propositional representation). However, given the growing body of evidence that morphology and syntax guide processes such as mapping and situation model construction (Carreiras, Carriedo, Alonso, & Fernandez, 1997; Givon, 1995; Magliano & Schleich, 2000; Morrow, 1985, 1986), we believe that a comprehensive theory must take into account the impact of these features on discourse comprehension.

One challenge stems from the fact that discourse analyses are sometimes necessary to identify the presence of these features. These analyses can be labor intensive and require specialized training. An alternative would be to have the comprehensive model rely on computational linguistics to analyze the presence of features that guide processing, rather than human judges. A means of doing so is provided by tools such as Coh-Metrix (Graesser et al., 2004; McNamara et al., 2009). Coh-Metrix is a tool that provides numerous indices of language automatically. Coh-Metrix uses lexicons, part-of-speech classifiers, syntactic parsers, latent semantic analysis, and several other components that are widely used in computational linguistics. For example, the MRC database is used for psycholinguistic information about words (Coltheart, 1981). WordNet has linguistic and semantic features of words, as well as semantic relations between words (Miller, Beckwith, Fellbaum, Gross, & Miller, 1990). Syntax is analyzed by syntactic parsers, such as Apple Pie (Sekine & Grishman, 1995) and Charniak's parser (Charniak, 2000), whereas the Brill's (1995) part-of-speech tagger identifies the syntactic classes of words, including unknown words on the basis of syntactic context. Coh-Metrix currently analyzes texts on three major categories of cohesion: coreference, conceptual (LSA), and connectives. It also provides features of words, such as frequency, concreteness, and polysemy, as well as the density of various classes of words. Of course Coh-Metrix *itself* should not be included within a comprehension model. Coh-Metrix simply provides information about the text using artificial intelligence techniques. However, analyses using such tools can inform which features are important in target texts and how they may differ from a larger class of texts. Also, the types of tools used in Coh-Metrix may lead to greater sophistication in comprehension models, affording the inclusion of a wider range of features using more objective and efficient methods.

Another approach that may afford accounting for lower-level features is the use of algorithms such as latent semantic analysis (LSA), which can be used to simulate word and world knowledge (e.g., Landauer, McNamara, Dennis, & Kintsch, 2007). LSA computes the semantic similarities between words, sentences, and paragraphs using statistical representation of world knowledge based on corpus analyses (Landauer & Dumais, 1997; Landauer et al., 2007). There are many algorithms similar to LSA that have been developed to extract meanings of words by using first or second-order co-occurrence from large bodies of text (e.g., Griffiths, Steyvers, & Tenenbaum, 2007; Jones & Mewhort, 2007; Landauer et al., 2007). More recent endeavors have centered on extracting not only semantics but also syntactic constraints of words, and thus the spectrum of lexical knowledge. One implication from this research is that knowledge about a word is extracted from experiencing the word in a variety of contexts, and thus the meaning of the word is captured in those experiences, and from the word's relation to other words. Words' meanings are generally thought of as "located" in a high-dimensional space relative to other words (or concepts and ideas). This assumption is quite similar, and at least compatible, with assumptions that a lexicon cannot contain all of the necessary information about a word (Elman, 2004, 2009).

In sum, one reason lower-level features have been ignored is due to challenges of implementation. Another reason for which lower-level features germane to word and sentence processing have been ignored in comprehension research regards a separation of fields of study and a consequent difference in computational approaches. Researchers in the area of language learning focus largely on how semantic and syntactical knowledge is acquired; thus, the majority of the computational models are connectionist learning models (e.g., Chang, Dell, & Bock, 2006; Elman, 1993; McRae, Spivey-Knowlton, & Tanenhaus, 1998). These models tend to focus on how humans can learn semantic and syntactic knowledge about words, and how this knowledge manifests in the understanding of syntactically ambiguous sentences. As such, the computational models are of a very different nature and focus than are models of text and discourse comprehension. In comprehension models, by contrast, all of the knowledge about the lexicon (semantic and syntactic) is assumed to have been already learned, and the model focuses on how knowledge is used to understand larger bodies of text and discourse (i.e., beyond the word and the sentence). Thus, these hybrid-connectionist models assume that an underlying layer could be attached to any comprehension model, such that the reader begins with relatively successful word and sentence understanding.

Thus far, this approach has been largely successful. Yet, it may no longer be viable if the goal is to develop a comprehensive theory of comprehension. One reason to consider lower-level features regards the issue of the dynamic nature of language and discourse understanding. Namely, comprehension processes occur over time, change and fluctuate over time, and show rapid, sometimes instantaneous access to multiple sources of information. This rapid, online access to knowledge cannot be easily explained within hybrid-connectionist architectures. Future accounts of comprehension may need to turn to theories of word and sentence understanding, and purely connectionist architectures (e.g., recurrent networks) in order to fully account for comprehension.

Another reason to more explicitly consider lower-level features regards the notion of emergent properties (Rumelhart & McClelland, 1986; Rumelhart, 1984). Some aspects of comprehension may emerge from features and processes that occur at the word and sentence levels. Rule-based computational models do not seem viable in the long run because of the vast number of rules and situations that would need to be accounted for within the model. Essentially, both lower-level and higher-level models need contend with the same problem: how does the reader access such a vast body of knowledge so quickly. One possibility is that consideration of the knowledge that seems to reside at lower levels of cognition may inform higher-level models; and vice versa.

5.3. Comprehension Processes

As is evident from the discussion of the models, there has been a debate regarding the extent to which mapping processes can be guided by dumb, bottom-up processes or effortful processing. Our conclusion from this literature is that when texts are relatively easy (quadrants A and B), the mapping can be considered primarily a bottom-up process. As such, the nonemergent processes of dumb activation, integration/settling, and memory retrieval would be necessary components of a comprehension model. However, it may be the case that mapping processes must be supported by effortful strategic processes in addition to bottom-up processes when the text are difficult and when the reader has the disposition to read strategically (e.g., quadrant C). However, parameters in a comprehensive model that correspond to effortful processing are more appropriately categorized as *extratextual* because these processes are likely to be driven by the goals or disposition of the reader, which are discussed in Section 5.5.

There is little controversy regarding the need for comprehension models to account for both text-based and knowledge-based inferences, and in particular for the former which contributes to mapping. The CI and Landscape model and the computational version of the Causal Network model provide excellent examples regarding how text-based or knowledge-based inferences can be generated via bottom-up inference processes. With respect to text-based inferences, there is still a need for the use of discourse analyses to identify where these inferences are likely to occur (Langston & Trabasso, 1999; Langston et al., 1999). Developing a computational model that can automatically detect causal or other relationships is still a long way off. Nonetheless, a comprehensive theory can rely on these connectionist-based approaches for specifying the bottom-up processes that support inference generation. However, as suggested in Figure 1, effortful processes can impact inference generation, depending on the nature of the text and the motivation of the reader. A comprehensive model must be able to account for these situations. As such, approaches for modeling the influence of effortful processing on inference generation is discussed in Section 5.5.

5.4. Products of Comprehension

As is evident in our discussion of emergent properties in Section 5.1, we contend that many of the dimensions associated with the product of comprehension represent descriptions of mental representations and should not be explicitly part of a comprehensive model, but rather should emerge from fundamental assumptions of the model. However, it is debatable whether the notion of levels of representation and the related constructs, textbase and situation models are emergent properties or instead necessitate explicit assumptions. It is possible that these could emerge from lower-level features (such as the words and syntax) in combination with assumed processes that act on those features. But this remains to be tested, because there are as yet no such models. An argument that they are not emergent stems from the necessity to assume that there are different forms of representation, and that they have different qualities and features. Also, levels of representation, including the textbase and situation model representations play integral roles in both theoretical and empirical aspects of discourse comprehension. Moreover, these constructs are central to understanding differences in the memory representations in the four quadrants in Figure 1. For example, the relative strength of the situation model should be high for reading situations in quadrant A, but relatively low in quadrant C.

5.5. Extratextual Dimensions

Very few models have considered extratextual features, and only one feature, standards of coherence, has been implemented formally (i.e., within the Landscape model). Nonetheless, comprehension involves more than just the text. It includes the reader, the tasks or activities, and the social context of the comprehension process (Snow, 2002). The strategies that the reader uses (and does not use), the reader's metacognitive awareness, and the reader's goals are a few examples of the extratextual dimensions that have large effects on reading comprehension (e.g., McNamara, 2007). Yet, a good majority of text comprehension research has centered on explaining comprehension processes germane to text, without considering these extratextual dimensions. Essentially, the reader is often left out of the equation. Consequently, a critical aspect of reading that is painfully lacking from comprehension models is the notion of the reader's free will. Readers are not passive buffers that take in text, process it, and spit out a representation. Readers make conscious decisions to engage in a wide variety of actions. They decide to start reading, stop reading, skim text, read deeply, focus, not focus, outline, reread, go back to the beginning, skip to the end, and so on. They have goals and they often prepare to engage in specific tasks after reading. They read individually and in groups, and they sometimes share common goals with others in their social context. They ask each other questions and sometimes even seek answers.

These more pragmatic, effortful, and even less effortful aspects of the comprehension process are noticeably absent components of comprehension models (McNamara, 2007). One reason for this absence is that our understanding of reading is based primarily on reading in the laboratory, where we sit the participant down, give instructions to read, and the participant appears to cooperate (at least by moving the eye and turning pages). This approach leads to an understanding of comprehension relatively void of either pragmatics or effortful, strategic processing.

Another reason why extratextual dimensions have not been incorporated is because we have an incoherent understanding of the processes involved. Although there is an increase in attention on the interactive natures of the reader, the text and the task, little has yet been done with regard to social context. We have a somewhat better understanding of effortful processes. For example, comprehenders' drive for explanation is clearly an important component of a comprehensive model. First, there is considerable evidence that event comprehension can be both guided and improved by explanatory processes (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Hilton & Slugowski, 1986; Magliano & Radvansky, 2001; McNamara, 2004; Trabasso & Magliano, 1996; Trabasso & Suh, 1993), which was the motivation for incorporating it into the Constructionist model. Second, in some situations, explanation is important for causal reasoning (Trabasso & Magliano, 1996; Trabasso & Suh, 1993).

The primary challenge to explicitly incorporate pragmatic and explanatory processes into a comprehensive model is to establish how they can be implemented. One way to implement changes as a function of pragmatic or goal-driven processes is to assume the consequences of those processes, and then implement those consequences within the model. For example, effects of variations in standards of coherence (e.g., as a result of reader goals) have been successfully simulated in the Landscape model by changing the activation values of elements in the text (Linderholm et al., 2004; van den Broek et al., 2005). However, this approach does not offer a satisfactory explanation for how those activation values become higher. Because the activation values are decided by the experimenter, they do not emerge from more fundamental assumptions in the model. It is not clear what cognitive processes could be responsible for activation values of concepts to have higher activation values before the information is processed (unless this is assumed to emerge from word- and sentence-level processing that occur somehow prior to comprehension processes).

By contrast, the Resonance model (O'Brien & Myers, 1999) makes the assumption that activation values are driven by the number of features linked to the concept. A greater number of features linked to a concept results in greater resonance to the contents of working memory. Accordingly, the likelihood of recalling an item is driven by the number of links to that item (via features). This is somewhat unsatisfactory as a solution because it leaves out exactly what a feature is and how it became linked to the concept.

Along similar lines, McNamara (1997; McNamara & McDaniel, 2004) assumed in the context of the CI model that one source, if not the principal source, of an increase in concepts' activation levels results from greater associative processing. That is, when more related concepts are activated, that feeds activation to concepts in the text. As such, it would be assumed that a higher standard of coherence results in more inference generation and more elaborative processing, and these associations result in a more coherent network, and higher activation levels for key concepts in the text. This same assumption would be made for readers with greater prior knowledge or higher reading skill, who tend to activate more knowledge or make more inferences while reading. This approach aligns with the notion in the CI model that situation model construction is critical to deep comprehension. Thus, whereas the Landscape model focuses on the explicit concepts in the text, and how relations drive activation, the approach by McNamara would extend the cause of differences in comprehension to the degree to which the comprehender went beyond the text.

These examples illustrate cases where the researcher makes assumptions about the outcome of the reader's behaviors, but the behavior itself is not in the model. In the case of the Landscape model, the activation values are changed, and in the case of the Resonance model (O'Brien & Myers, 1999) and McNamara's (1997) knowledge-based simulation, the researcher needs to include those associations within the constructed network. These approaches are somewhat unsatisfactory because the models' predictions do not emerge from processing assumptions within the model outside the subjective control of the researcher (see, e.g., Frank, Koppen, Noordman, & Vonk, 2008, who elaborate on this potential weakness of models).

One alternative approach would be to combine the connectionist architecture with a symbolic rule-based system. For example, within the Constructionist model, these types of processes were articulated within production rules. Similarly, in a CI-based model developed to simulate a problem-solving task, Doane et al. (2000) combined the CI model with a production rule system. They included a separate layer in the system that essentially sat on top of the Construction–Integration process, which assessed the state of comprehension and task completion, which in turn resulted in the activation of consequent behaviors. Essentially, certain behaviors or actions would fire depending on the state of the system. Such a system could be implemented to simulate goal-driven behaviors in comprehension by assuming that such behaviors, thoughts, or actions occur postintegration of the current information (e.g., after each sentence or clause). These production rules could fire other rules, which might result in a variety of behaviors such as continuing reading, rereading, activating related knowledge, searching the text, and so on.

While this is a viable solution, formalizing a sufficient set of production rules to explain the wide variety of phenomena and interactive effects that may emerge in varied reading situations could be unyielding, or at best a very long task. Also, an important issue to consider is whether using production rules is an artificial solution, and whether these more conscious behaviors can emerge from some other, more basic dimensions of the model.

So far this discussion has centered on issues surrounding the simulation of goal-driven, effortful processes during comprehension. Another important issue regards the effects of processes related to imagery and the relationship between the information in the text and the reader's body. There is a growing body of evidence that language processes are supported by the activation of perceptual symbols and embodied cognition (Glenberg, 1997; Glenberg & Kaschak, 2002; Madden & Zwaan, 2003; Stanfield & Zwaan, 2001; Zwaan, 2004; Zwaan, Madden, Yaxley, & Aveyard, 2004; Zwaan, Stanfield, & Yaxley, 2002). An argument could be made that a comprehensive model should contain explicit assumptions regarding how perceptual symbols and embodiment guide comprehension. However, we think this may be premature. First, to date, the research in support of embodiment is restricted to word- and sentence-level processing. Thus, we do not have a clear understanding of the impact of these factors on processes germane to comprehension of larger bodies of text. Second, to our knowledge, there is no computational model that has been produced that incorporates these constructs. Third, we adopt the perspective that a connectionist framework is the best approach for a comprehensive model. The nodes in a connectionist model could correspond to perceptual symbols; however, exactly how they would operate differently from how nodes currently function in a connectionist model of comprehension, such as the CI model, is unclear. At this point, we are left with the unsatisfying conclusion that our understanding of the construct of perceptual symbols and how they operate to support comprehension is not sufficient to implement them into a formal model. We strongly suspect that this will change in the coming years.

5.6. Comprehension Skill Differences

A comprehension model should be able to explain individual differences in comprehension skill: what do good comprehenders do differently than less-skilled comprehenders? However, few of the models attempt to explicitly explain or account for the comprehension skill differences, and none have done so considering the broad spectrum of situations depicted in Figure 1. Rather, most of the comprehension models that we have considered here focus on general comprehension processes, assuming an average reader in an average situation reading some given type of text (within one or two quadrants in Figure 1). Thus, too little attention has focused on accounting for individual differences in comprehension ability in the context of comprehension models.

What are the signatures of comprehension skill? The ability and tendency to generate inferences is likely the most critical difference between skilled and less-skilled comprehenders. Skilled readers also more successfully resolve anaphoric reference, select the meaning of homographs, process garden-path sentences, make appropriate inferences online, and integrate text structures (e.g., Long & Golding, 1993; Oakhill, 1983; Singer, Andrusiak, Reisdorf, & Black, 1992; Singer & Ritchot, 1996). Skilled readers are also more likely to generate inferences that repair conceptual gaps between clauses, sentences, and paragraphs, whereas less-skilled readers tend to ignore gaps or fail to make the inferences necessary to fill in the gaps (e.g., Garnham, Oakhill, & Johnson-Laird, 1982; Long et al., 1994; Magliano & Millis, 2003; Magliano, Wiemer-Hastings, Millis, Muñoz, & McNamara, 2002; Oakhill, 1984; Oakhill & Yuill, 1996; Oakhill, Yuill, & Donaldson, 1990; Whitney et al., 1991; Yuill & Oakhill, 1988; Yuill, Oakhill, & Parkin, 1989). Less-skilled readers are also less likely to generate topic related inferences and less likely to integrate incoming information with preceding discourse (e.g., Long et al., 1994). Consequently, less-skilled readers perform poorly on questions that address text-based or implicit inferences, even when the text is made available while they answer the questions (Oakhill, 1984).

Skilled comprehenders read in a goal-directed fashion and are able to strategically adjust how they read based on those goals (Gaskins, Satlow, & Pressley, 2007; Pressley & Afflerbach, 1995; Pressley, Forrest-Pressley, Elliot-Faust, & Miller, 1985; Pressley & Woloshyn, 1995). Moreover, they demonstrate better awareness of reading strategies and are better able to indicate when reading strategically is appropriate (O'Reilly & McNamara, 2007b; Taraban, Kerr, & Rynearson, 2004; Taraban, Rynearson, & Kerr, 2000). This underscores the importance implementing into a comprehensive model the extratextual dimensions that correspond to the evaluative and metacomprehension processes associated with a drive for comprehension, standards of coherence, and comprehension evaluation.

There have been several mechanisms proposed to account for comprehension skill differences (see, for a review, McNamara et al., 2008). The first, and the only one in the context of a comprehension model, is suppression (Gernsbacher, 1990). However, as we discussed earlier, there is evidence that suppression may emerge from inference processes (McNamara & McDaniel, 2004) and the research in support of inhibition was limited to psycholinguistic paradigms which typically involve processing only one or two sentences. The second proposed explanation of skill differences is working memory capacity (e.g., Just & Carpenter, 1992), such that better readers have more capacity and thus are able to process more information. However, there is only correlational evidence in favor of this notion, and it has not played a large role in comprehension theories (McNamara, de Vega, & O'Reilly, 2007; McNamara & Scott, 2001). A third is word knowledge (e.g., Chiesi, Spilich, & Voss, 1979). However, word knowledge is highly related to domain and world knowledge, which is a construct that is separable from comprehension skill (Perfetti, 1988). A fourth explanation is that better comprehenders differ in their use of long-term working memory (Ericsson & Kintsch, 1995). Accordingly, long-term working memory allows faster access to familiar information, and more-skilled comprehenders more effectively use long-term working memory. Though viable, some problems with this account are that long-term working memory is conflated with both prior knowledge and the use of reading strategies.

Thus, while various explanations and mechanisms have been proposed to account for differences in skill, including suppression, working memory, knowledge, and long-term working memory, it seems evident that more work needs to be done to account for skill differences within the context of comprehension models. Likewise, individual differences in general have been relatively ignored within comprehension models. More attention needs to be paid to how the assumptions underlying models of comprehension vary by reader, text, and context. We suspect that if such an approach were adopted earlier in the literature, arguments on whether readers do or do not generate this or that inference would have ended long ago, because these issues quite clearly vary as a function of the focus of the researcher in terms of the quadrants displayed in Figure 1. Endeavors to further investigate these factors and how they interact should lead to better understandings of how and when different processes emphasized in comprehension models are more or less likely to be evident.

5.7. Alternative Modes of Communication

The focus of these comprehension models has largely been on the comprehension of text presented in the written form. Most theorists assume that their models' assumptions largely extend to the comprehension of verbal discourse, and at least one model (i.e., the Structure-Building model) assumes that the assumptions extend to comprehension of information regardless of modality (verbal and visual). However, none of the models have in a detailed manner described differences between modalities, nor have they explained the integration of modalities.

One area ignored thus far by comprehension models is the effects of gestures. This is not to say that there is not research on the effects of gestures on comprehension (Cutica & Bucciarelli, 2008; Lozano & Tversky, 2006). However, thus far, these issues have not been incorporated within comprehension models. Similarly, issues surrounding text–picture integration and multimedia comprehension have been largely ignored by comprehension model theorists. This is partly an issue of the complexity of specifying a model of *text* comprehension, let alone comprehension of all modalities. In the case of implemented models, it also stems from the constraints imposed from programming issues. That is, how to depict a picture, graphic, or gesture computationally has not yet been solved. Additionally, the lack of integration of multimedia into comprehension models stems from a need for more, and better, research in these areas. Unfortunately, researchers who have investigated text–picture integration issues have concentrated largely on issues regarding the picture (and not the text) and on working memory constraints related to human factors issues, rather than on the cognitive processes related to text–picture integration. Moreover, the theoretical perspectives that have driven text–picture integration research have been largely based on outdated information processing theories and have tended to be more descriptive than explanatory in focus (Chandler & Sweller, 1991; Mayer, 2006; cf. Schnotz, 2002). As a consequence, it is not obvious how current theories of text–picture integration will meld with theories of text comprehension, at least the ones described here. Developing a complete understanding of comprehension calls for more research that focuses on the nature of multimedia, multimedia processing, and cross-modality integration of information and that more fully takes into account the processes involved in reading as well as processing involved in picture comprehension. In sum, progress is needed from both text comprehension and text–picture integration theorists in developing more viable models to explain the cognitive processes involved in multimedia processing.

6. Concluding Remarks

Our purpose here has been to outline where the field of text and discourse needs to go in order to move toward a comprehensive model of comprehension. We have made three principal conclusions based on our analysis of the current models of comprehension. The first is the current models of comprehension are not necessarily contradictory, but rather cover different spectrums of comprehension processes. We depicted these spectrums using Figure 1, which conveys the range of comprehension as a function of the reader and the text. The second conclusion is that although the models have collectively done so, no one model adequately accounts for a wide variety of reading situations depicted in Figure 1. Our third conclusion is that the range of comprehension considered thus far in comprehension models is too limited. It is time to go beyond the four quadrants in Figure 1. A comprehensive model needs to include a wide variety of phenomena that have not been considered thus far. Here, we have discussed the need to account for reader differences and text differences. Also, we have argued that it would benefit comprehension models to include assumptions regarding lower-level features and processes. Finally, there is a wide spectrum of issues that have not yet been tackled by current models. These include higher-level pragmatic processes and comprehension beyond text and discourse, including multimedia processing.

A comprehensive model will only be viable if it can generate testable predictions and can be computationally implemented. Given these criteria, it would be prudent to propose a model that contains explicit assumptions and parameters associated with the entire set of dimensions discussed in the last section. A comprehensive model will potentially include all of the dimensions that we have listed in Tables 1 and 2. However, some dimensions should emerge from fundamental assumptions and mechanisms in the model. Additionally, one obvious conclusion from our review is that, although many of the dimensions may be important, our understanding of them is not at the point where they are ready to be implemented in a comprehensive model.

A theoretical model of comprehension that comprehensively accounts for the full range of comprehension processes should optimally cover the four quadrants in Figure 1 and it must cover the range of bottom-up (automatic) and top-down (effortful) comprehension processes. Clearly, there are situations where bottom-up processes will likely fail to lead to a deep level of comprehension that is consistent with the reader's goals. A comprehensive theory should be able to specify the conditions when bottom-up processes will and will not be sufficient for comprehension and when top-down processes are likely to operate.

We propose that the spectrum of comprehension processes that have been observed in research emerges from three basic cognitive processes: spreading activation (e.g., priming), unconscious retrieval (e.g., memory-based retrieval), and conscious processing (e.g., strategies, problem solving, reasoning). In turn, these three processes serve to activate information sources in the text (i.e., bridging inferences in Figure 2) and sources outside the text (e.g., elaborative inferences), though in different ways. Such a schematic accounts for a wide range of inferences including text-based and knowledge-based inferences and also accounts for the range of automaticity that has been observed in the literature. The extent to which readers engage in less automatic inferences and mapping processes is likely to be a function of both the success of those processes and readers' goals and motivation.

A comprehensive model needs to also account for differences that occur as a function of genre. Reading processes, and in particular those involved in coherence building, differ as a function of text genre. Whereas the construction of the mental model of the text will rely primarily on event and causal elements within a narrative text, it relies more on referential (and causal) elements in expository text (particularly science text). Accounting for effects of genre within a model cannot be achieved simply by having a ''genre'' parameter because that would assume a genre detection homunculus and such an approach ignores mixed genres (which predominate).

The bottom line is that a comprehension model cannot be divorced from the text itself. It must take into consideration the text features, and how those text features guide how the reader processes the information in the text. For example, there are features of text that are more narrative-like, features that are more history-like, and features that are more science-like, and so on (e.g., Dempsey, McCarthy, & McNamara, 2007; Duran, McCarthy, Graesser, & McNamara, 2007; McNamara et al., 2008). Readers can detect these features very quickly in text, within about 3–7 words of the first sentence of the text (McCarthy, Myers, Briner, Graesser, & McNamara, 2009). In addition, the words themselves contain a host of other cues to the reader, driving expectations (e.g., through priming) on what words are likely to follow within a sentence and which ones are not (e.g., Elman, 2009). It is clear to us that although lower-level features have been for the most part ignored by comprehension researchers, without great consequence to the success of the models, this is largely because most of the models have centered on one type of text or another. A model that modulates processing as a function of genre (e.g., making links between verbs and nouns) will have to be sensitive to the characteristics of the text—just as the reader is. This will likely require a more complex connectionist architecture than what has been implemented thus far by comprehension theorists.

At the same time, the model also needs to go beyond the word. There is substantial evidence that readers derive meaningful idea units (i.e., propositions) when reading. Comprehension involves deriving larger units of meaning from the explicit text and inference processes and establishing relationships between them. As such, the simple solution of using the word as the unit of processing is not optimal. One question is whether the process of deriving the propositional unit can emerge from lower-level processes in the model. In either case, the role of idea units in comprehension cannot be ignored.

Just as the model cannot be divorced from the text, it cannot ignore the reader. What the reader brings to the situation—the ability or tendency to generate inferences, knowledge of words, knowledge of strategies, reasoning ability, knowledge of the domain, motivation, goals, and so on. These factors are important to consider and need to be included in a comprehensive model. One approach to this objective that we suggest avoiding is including mechanisms and parameters that simulate the effects of reader characteristics descriptively, but do little to explain what cognitive processes the readers are using and why they affect processing in the way that they do. Likewise, the model should account for conscious thoughts and decisions made while reading: strategies, reasoning, explanation, and so on. However, effortful, deliberate behaviors are not easily simulated in connectionist architectures. As discussed in Section 5, it is not clear where the solution lies to this problem, but it will likely require a hybrid architecture that lays a symbolic (e.g., production rule) system on top of a connectionist architecture.

Finally, we believe that more work needs to be done to understand comprehension in different modes and multimedia processing before a model can be developed that captures those processes. One possibility, however, is that those processes that are inherent to reading text generalize to the processing of all media (e.g., Gernsbacher & Faust, 1991). As such, working to build a more comprehensive model may bring us closer to accounting for comprehension regardless of medium. However, we reserve some pessimism on this point, particularly if the model includes both lower-level and higher-level processes.

The task that awaits the field of text and discourse to develop a comprehensive model of comprehension is daunting. First, researchers need to seriously reconsider and expand beyond the modeling approaches that have been used thus far in the comprehension literature. Second, a significant challenge will be to develop a model that not only accounts for the host of simple effects, but also accounts for the dependencies and interactions, particularly between characteristics of the text and the reader (i.e., that lie in the third and fourth dimensions of Figure 1). Despite these challenges, the time is clearly ripe for researchers and theorists to begin to think about comprehension more globally, across a range of tasks, readers, and reading situations.

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