A Transactional Theory of Hypertext Structure
A Transactional Theory of Hypertext Structure

Text structure has long been an important element in theoretical and empirical investigations of reading. It has been used to specify the content and character of text passages, as a basis for scoring comprehension and recall of readers, and to generalize empirical research results (Meyer, 1985). Structure has also assumed a central role in studies of hypertext, traditionally defined as “non-linear” written or pictorial material (Nelson, 1965, p. 93). Moreover, given the explicit representation of large-scale structure in hypertext, researchers have been able to define a variety of qualitative (Canter, Rivers, & Storrs, 1985; Bernstein, 1998) and quantitative measures to assess document structure (Botafogo, Rivlin, & Shneiderman, 1992) and navigation (McEneaney, 1999, 2001). While text structure theory has advanced our understanding of reading in print, however, structural methods have found only limited application in empirical studies of hypertext, despite studies suggesting that complexity can impede comprehension (e.g., Edwards & Hardman, 1989; Cockburn & Jones, 1996). If we hope to better understand the nature of structure in hypertext and readers’ efforts to comprehend it, one natural place to begin this effort is with concepts developed in our print tradition to assess how these constructs might contribute to our understanding of hypertext.

Hypertext, however, poses special problems for existing models of text structure (e.g. Graesser, 1985; Meyer, 1985; Kintsch & van Dyke, 1978.) One problem is that branching in hypertext undermines the concept of a single common text structure that all readers encounter, resulting in a multidimensional structure that introduces different possible readings. This multidimensional structure, commonly represented as a network of nodes and links, represents a virtual structure (Rosenberg, 1996; Park, 1998) defining possible readings of a text, while each individual reading of a hypertext is based on a specific episodic structure resulting from one reader’s navigational choices within the larger virtual structure. But, as noted, admitting multiple
potential structures within a larger virtual text conflicts with the notion of a unitary text structure, leading to serious problems in our efforts to transfer what we know about print structure to hypertext. What is the structure of a text, if we must abandon the concept of a single unifying structure? And if we cannot establish a “standard” structure how should we speak of semantic or rhetorical structures, the comprehension of readers, or the generalization of research findings?

The purpose of this paper is to outline a more general theory of hypertext structure, to describe how elements of the model have been applied in some recent empirical studies, and to consider some implications and applications of the proposed model for reading theory and practice in both hypertext and traditional print. Finally, and perhaps most important of all, I hope to demonstrate that the proposed model can be considered an extension of Rosenblatt’s (1978; 1994) transactional model of reading, a model that currently serves as a foundation for a great deal of productive work in literacy studies.

Overview

At the core of transactional theory (Rosenblatt, 1978, 1994) is the notion that meaning is produced in a transaction of a reader with a text. In contrast with more traditional models, which typically “locate” meaning within the text and conceive of reading as the extraction of that meaning, transactional theory defines meanings as rooted in a reader’s personal experience in reading (i.e., the evocation), subject to personal reflection and self-awareness (i.e., the response) and shaped by our efforts to articulate and explain our understanding so that we can share our experiences with others (i.e., the interpretation.) Moreover, while acknowledging what is unique and personal in the reading event, transactional theory also defines larger social meanings as emergent properties of the experiences of many readers through the application of methods guided by the principle of “warranted assertability” (Dewey, 1938). Although the problem of
structure differs in important ways from problems related to meaning in hypertext, there are
some striking correspondences across these two problems. A transactional view of text structure,
for example, requires us to reject the notion of structure as a property of text in the same way this
theory rejects the notion that meaning is a property of text. More specifically, it requires “a
dynamic reader- as well as text-oriented understanding of rhetorical or critical terms such as
form or structure (Rosenblatt, 1994, p. 91).” In a transactional view, therefore, text structure (like
meaning) is generated in a specific reading transaction and the problem of validating claims
concerning broader shared structures also requires warrants that are grounded in social
processes.

Briefly, the transactional analysis of hypertext structure developed in this paper identifies
three distinct types of structure: virtual structures that specify what is possible, episodic
structures, that specify outcomes of individual reading transactions, and emergent structures that
specify broader shared structures that emerge from the accumulated transactions of multiple
readers. In the present context, virtual structure is defined by the nodes and links that make up a
hypertext and can be viewed as a property of the text itself. Episodic structure, on the other hand
results from a specific transaction involving a reader and text, and corresponds to the structure a
reader creates during reading. Finally, emergent structures are abstracted structure patterns,
based on both episodic structures and agreed upon (i.e., warranted) methods for collecting,
organizing, and representing those collective structures.

*Virtual Structures in Hypertext*

The framework adopted in this analysis of hypertext structure is that of the traditional node-and-
link model of hypertext. Although not without drawbacks (e.g., Stotts & Furuta, 1989; Turine, de
Oliveira, & Masiero, 1997), this model of hypertext has proven to be a useful conceptual
framework from both theoretical and empirical perspectives. Central to this framework is the
formalization of a hypertext network with nodes representing content and links representing structure. At least part of the popularity of the node and link model can be attributed to two simple but powerful constructs in this model: adjacency matrices that are well suited to mathematical analysis and labeled directed graphs (digraphs) that present structural information in a readily interpreted visual form.

An adjacency matrix is a table that records each unique link in a hypertext document. Typically, an adjacency matrix consists of a table of zeroes and ones with labeled rows and columns. A “1” in cell (a,b) indicates there is a link from node “a” to node “b”. A “0” in a cell indicates that there is no direct link between the two nodes. In Figure 1A, for instance, the two entries of “1” in the first row indicate that there is a direct link from node 0 to nodes 3 and 5. Zeroes appear in all other positions in this row because no other direct links are present. Figure 1B illustrates the digraph that corresponds to this adjacency matrix, demonstrating that the network consists of eight nodes (numbered 0 - 7) and 13 links (the double-headed arrow connecting node 0 and node 3 represents two links.)

Although the adjacency matrix and its corresponding digraph represent structure, they do so by defining structural boundaries, and this is the sense in which they represent a virtual structure. Virtual structures define a navigational space within which individual readers create episodic structures by selecting pages as they navigate a hypertext. Typically, a node in a hypertext will link to one or more other nodes in that hypertext. Inspection of Figure 1B, for example, indicates that node 2 provides a link to node 4, and node 7 provides three different outbound links, to nodes 1, 2, and 3. The freedom that hypertext provides readers at branching points (i.e., nodes with more than one link) means different readers can navigate a hypertext in different ways. Moreover, as the number of nodes (or the rate of linking) increases, the range of possible reader paths increases exponentially, creating a structural state space of considerable size within even
modestly sized hypertext documents.

By analogy with the concept of an adjacency matrix, a path matrix can be defined to represent frequencies of transitions from each node to every other node within a given path (similar to that proposed by Pirolli, Pitkow, & Rao, 1996). Moreover, just as the adjacency matrix yields a corresponding digraph, a path matrix (see Figure 2B) can be used to generate a path digraph (see Figure 2C) that displays the episodic structure defining an individual reading episode or path. Furthermore, if the hypertext under examination is closed, a path matrix can be normalized by representing every node in the hypertext, regardless of whether it appears in the path. As a result of this normalization, it is possible to sum individual path data to create aggregated path matrices that can be displayed to express emergent structures. The normalizing expansion of the path matrix is achieved by inserting rows and columns filled with zeroes in the appropriate places in the path matrix so that every node in the hypertext is represented in the expanded path matrix (see Figure 2D). The net result of this expansion is to embed the path within the larger structure of the hypertext. The structural features of the original path matrix are preserved while establishing a normal form for all paths. As a result of this normalization, individual path matrices can be summed to yield group (i.e., emergent) matrices. Mathematica (Wolfram Research, 1999) routines were developed to reformat path data so that individual and aggregated path digraphs could be produced using GraphViz 1.3 (Ellson, Koutsofios, & North, 1998), a widely used and freely available graphing tool developed by AT&T research labs.

*Episodic Structures in Hypertext*

While virtual structures are defined by what is possible in hypertext, episodic structures are defined by the choices readers actually make during reading events. In the formalism presented, a sequence of nodes selected while reading defines a path that, with appropriate transformations, yields numerical metrics and structural displays. Significantly, not only do these metrics and
displays correlate with hypertext reading measures (McEneaney, 2000, 2001), they also provide a basis for conceptualizing and interpreting individual reading events. In a transactional sense, these episodic structures represent the text as individual readers actually experience it. As indicated in Figure 3, while the variability of these structures is considerable, there is an underlying visual logic. Patterns of navigation range across a well-defined visual continuum with a shallow hierarchy at one end (A & B) and a strongly linear pattern at the other (I & J).

Review of the episodic structures suggested that subjects whose patterns were most linear had tended to assume a “passive” approach to using the hypertext, relying on built-in structures similar to navigational strategies noted in other recent studies (Titus & Everett, 1996; Thiel & Müller, 1996; Agosti, 1996), depending on whether subjects rely on a built-in general strategy (i.e., “passive”, “matching”, and “browsing” approaches) or seek out a less obvious, but potentially more relevant, structural framework to support their use of hypertext (i.e., “active”, “exploration”, and “search” approaches). Specifically, it appeared that these passive readers relied much more heavily on a page turning strategy that followed a predetermined reading sequence embedded in “next” and previous” buttons, while subjects generating more hierarchically organized structures adopted a strategic approach leading to hierarchical patterns of movement with the table of contents and section-specific index pages serving as the root and branch points in their paths (indicating repeated visits to these pages during the reading episode.) Moreover, these results have more “local” analogs in the literature on reading in print, with more effective readers typically adopting a more strategic, metacognitive approach to text, while less able readers tend to read with a poorly defined sense of purpose or little critical engagement (e.g., Barton, 1997; Gourgey, 1999; Lifford, Byron, & Jean Ziemian, 2000; Taraban, Rynearson, & Kerr, 2000).

While there continues to be a pressing need for detailed empirically-grounded theories of
navigation that focus on navigational particulars (McKnight, Dillon, & Richardson, 1993), there
is clearly also a need for a broader theory that can account for the ways people orient themselves
when faced with complex tasks. Studies cited above (McEneaney, 2001; Titus & Everett, 1996;
Thiel & Müllner, 1996; Agosti, 1996) suggest a fundamental dispositional characteristic that may
lead some to more active engagement, while others are content to rely on more generic strategies
related to the way the text is presented (in this case, in the design of the interface.) There is also
evidence that this fundamental orientation can interact with a subject’s capacity to self-regulate
or manage learning, with the somewhat surprising result that less effective self-regulators may
actually benefit more from a passive orientation than they do from an active one (Beishuizen,
Stoutjesdijk, & Van Putten, 1994). Ultimately, understanding particulars of reading in electronic
environments is likely to require that we step back from navigational details far enough to see
the broader dispositions and foundational metacognitive skills that people bring to reading and
learning in hypertext.

*Emergent Structures in Hypertext*

As noted earlier, the methods used to generate individual episodic structures also support the
summation of these structures into larger emergent structures that represent a generalized
navigational pattern for groups of readers. In its most basic form, an emergent structure simply
sums all episodic structures generated by individuals within a group. The problem with a simple
summation of episodic structures, however, is that a single link is not “representative” in any
significant sense of larger patterns and may, in fact, simply reflect idiosyncratic navigation or
error (e.g., unintended link selection.) Moreover, display of all link traversals typically
undermines the visual utility of the emergent structure display by swamping it with unique or
rarely used paths (as is evident in Figure 4A.) Emergent structures can, however, be screened to
remove random sources of noise and idiosyncratic pathways by setting a threshold value that
must be met in order for a link traversal to be displayed. In addition, by gradually increasing a
threshold value, it becomes possible to define a series of progressively more abstract structures,
as illustrated in the sequence of displays in Figure 4.

Emergent structures in Figure 4 are drawn from a study that simulated consumer decision
making. Subjects “purchased” modular housing using a moderately complex hypermedia system
comparable in size to the one used in generating the episodic structures displayed in Figure 3.
Figure 4A illustrates the emergent structure that results when the link traversal threshold is set to
zero. By setting the threshold to this value, every link traversal used by every subject is depicted,
resulting in a very complex network of paths, some of which depend on only a single transition.
Setting a link traversal threshold to progressively larger values, however, winnows unique or
rarely used paths, while retaining paths that are repeatedly used. In effect, the link traversal
threshold reveals an emergent structure in the same way that trails in a wood or across a grassy
field are revealed – through the accumulated action of many individuals. Moreover, as is
apparent in these illustrations, these progressively abstracted emergent structures more clearly
illustrate roles that nodes and other larger-scale structures play in the navigation of readers as a
group. Node 2 clearly serves as a gateway to the larger structure, while node 3 serves as a
primary index node for a shallow hierarchy of structurally related nodes. Nodes 6 and 26 also
serve as index nodes for smaller navigational hierarchies, while other nodes (e.g., node 83) serve
as bridges connecting otherwise distinct areas of the larger structure.

It is also interesting to note that two features of the sequence of displays in Figure 4 seem to
suggest both that it is important that the exploration of emergent structures not be prematurely
curtailed, and that there seems to be a natural technique for recognizing when further increases in
threshold values may no longer be useful. Specifically, at least one quite distinct navigational
pattern (the linear sequence defined by nodes 19 to 24 in Figure 4E) only becomes obvious after
the threshold reaches a fairly high level, indicating that lower frequency patterns may mask those of a higher frequency until a threshold is applied that effectively removes those of lower frequency. Moreover, as the threshold is gradually increased, there appears to come a point where nodes or small networks of nodes begin to become isolated from the main structure (see nodes 22 and 23 in Figure 4F), suggesting that the integrity of the larger structure has been compromised and that further increases in the threshold value are not likely to be productive.

**Interpretations and Implications**

The techniques and analyses that have been presented offer a framework that distinguishes among three different types of hypertext structure, all of which may play important roles in thinking about how readers understand and use hypertext. A virtual structure represents structural potential in the sense that it defines boundaries within which readers are constrained to operate without specifying how any given reader actually chooses to read. Episodic structures, on the other hand, are created by individual readers within the boundaries of the larger virtual structure during a specific reading episode and thus represent the structure a reader actually experiences. Finally, emergent structures represent larger social patterns of hypertext use that can serve either to reveal structurally distinct general patterns of a given hypertext, or distinctive patterns of use by different groups of hypertext readers (McEneaney, 2001).

Although these techniques and the analyses they support are rooted in a formal framework developed independently of transactional theory, there are compelling reasons, both theoretical and applied, for concluding that the correspondences of transactional theory and hypertext structure described above are not simply random points of contact but represent genuine theoretical overlap. Other work that adopts a specifically literary focus (like transactional theory) has, for instance, noted similar correspondences between literary theory and recently developed technologies of reading and writing including, but not limited to, hypertext. Critical theorists, in
particular, have argued that features we associate with text are not intrinsic to text itself and represent unfortunate and "thoroughly unnatural (McArthur, 1986, p. 69)" artifacts of the technologies of traditional print (i.e., the book). Others have advocated we "abandon conceptual systems founded upon ideas of center, margin, hierarchy, and linearity and replace them with ones of multilinearity, nodes, links, and textual networks (Landow, 1992, p. 2)." "What is unnatural in print will become natural in the electronic medium" because hypertext literally embodies poststructuralist conceptions of the open text (Bolter, 1991, p. 143). "Critical theory promises to theorize hypertext, and hypertext promises to embody and thereby test aspects of theory, particularly those concerning textuality, narrative, and the roles or functions of reader and writer (Landow, 1992, p. 3)." Perhaps, however, conceptual and theoretical productivity represents the best test of the marriage of formalism and literary theory advocated. That is, what kind of utility can transactional theory and the theory of structure outlined above contribute to one another?

From a technical perspective, transactional theory provides an interpretive framework for thinking about hypertext that is rooted in a broader theory of human action that addresses what is a significant and conspicuous absence in a great deal of theoretical work in hypertext: the human context that makes hypertext meaningful. Although there are some notable exceptions (see e.g., Bernstein, 1998; Andersen, 1997; Marshall, 1998), most theoretical work in hypertext tends to focus on defining systems that adhere to formal properties that are deemed mathematically or technically desirable or are simply presumed to connect with reader experiences on broad generally unstated principles (e.g., a simpler interface is easier to use). Studies of readers in traditional print, however, suggest that a reliance on common sense can be dangerous, with experimental outcomes that sometimes point to counterintuitive results. Although common sense might suggest simpler texts are easier to read, simplifying modifications may not help and can
even reduce readability (e.g., Klare, 1984; Pearson & Camperell, 1981; Davison & Kantor, 1982), and providing readers adjunct “aids” has the potential to interfere with rather than promote comprehension. Although effective application of technology requires technically sound foundations, unless we can relate these technologies to the ways human readers and writers think about their objectives, our theories of hypertext are almost certain to miss their mark. Conversely, as the quote from Landow (1992, p. 3) cited above points out, systematically defined and concretely implemented technologies of reading and writing have the potential to both reveal and test otherwise inaccessible elements of transactional theory.

The three types of hypertext structure that have been defined provide one instance where technology can serve to clarify transactional theory. Although the notions of openness and constraint play a central role in Rosenblatt’s thinking (see particularly chapter 5 in Rosenblatt, 1994), these concepts remain largely inaccessible within the uniquely personal experiences of individual readers where “context guides the reader in the process of selecting out - from the range of inner possibilities - the kinds of responses, referential and affective, that are appropriate [my emphasis] (1994, p. 75).” Hypertext, however, takes a small but significant part of those “inner” possibilities and externalizes them in the form of hypertext links. Virtual structure in a hypertext introduces a more specific and concrete use of the terms “openness” and “constraint” where it becomes both theoretically and empirically meaningful to ask about the relative openness and constraint of different texts. Episodic structures provide a window on the transaction itself, presenting an artifact that is directly derived from the reading transaction, supporting both quantitative and qualitative interpretations. Finally, emergent structures serve to reveal the openness and constraint of texts from a broader social perspective that is so important in transactional theory’s response to the problem of interpretive relativism. Emergent structures also provide a concrete basis for empirically defining “standard” readings and comparing the
readings of different readers in ways that address Rosenblatt’s requirement that comparisons be based on explicitly defined standards of adequacy (1994, p. 124.)

The interpretive scheme described earlier regarding readers’ general orientation to hypertext (i.e. active vs. passive) also has a suggestive overlap with the concept of stance and can provide a basis for a concrete interpretive framework for thinking about structural artifacts of stance in electronic reading environments. For example, one interpretation of the benefit provided by more hierarchical episodic structures in the studies displayed in Figure 3 is that the readers who produced these structures selected a more task-appropriate efferent stance and were not induced by features of the interface (e.g., next and back buttons) to adopt a more “narrative” (i.e., aesthetic) approach in their reading. Rosenblatt’s view of stance, with relatively minor modification, can be applied as a broader explanatory framework for what McEneaney (2001) has termed a general “orienting strategy subjects adopt when faced with a complex cognitive task (p. 780)” in attempting to account for observed patterns in the ways readers use hypertext.

Summary and Conclusions

This article defines a theoretical framework that integrates transactional theory (Rosenblatt, 1978, 1994) with recently developed formal methods that support the analysis of reader navigation in hypertext (McEneaney, 1999, 2001). Transactional theory provides the larger framework within which formal analysis of reader navigation in hypertext is situated. The concept of reader stance is proposed as one way to account for persistent general patterns of reader navigation in hypertext that have been widely reported but still elude principled explanation. Transactional theory suggests interpretations for three distinct types of hypertext structure. Virtual structures represent the openness and constraint of a hypertext by defining boundaries within which readers operate. An episodic structure represents a reading pattern generated by an individual in a specific reading episode. Emergent structures define larger social
patterns based on aggregations of episodic structures that can serve as generalized social structures based on a given population of readers. Although the framework proposed is preliminary, transactional theory appears to provide a productive framework for formal techniques that support conceptualizing and analyzing hypertext structure.

References


Davison, A. & Kantor, R. N. (1982). On the failure of readability formulas to define readable texts:


http://www.acm.org/sigchi/chi96/proceedings/papers/Pirolli_2/pp2.html

Conference of the Association for Computing Machinery, 22-30. New York: ACM.


Figure Captions

Figure 1. An adjacency matrix (A) and its corresponding graphical representation (B).

Figure 2. A path (A) and its corresponding path matrix (B), path diagram (C), and expanded path matrix for a subset of nodes (D).

Figure 3. Episodic structures created by 10 different readers in the same hypertext.

Figure 4. Emergent structures based on six different link traversal threshold values.
Figure 1

A. An adjacency matrix for the digraph depicted in B.

B. A node and link representation of the adjacency matrix presented in A.
A. Path = <6,30,6,37,6,15,16,6,21,23,24,6,35,6>.

<table>
<thead>
<tr>
<th></th>
<th>from</th>
<th>6</th>
<th>15</th>
<th>16</th>
<th>21</th>
<th>23</th>
<th>24</th>
<th>30</th>
<th>35</th>
<th>37</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>23</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>35</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>37</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

B. Path matrix.

C. Path diagram.

D. Expanded path matrix for a portion (nodes 21-30) of the path matrix (outlined within Figure 4B).