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ABSTRACT

Methods are described for visualizing and characterizing user interactions with hypermedia systems; they have been found to be effective in several developmental and evaluation studies. Analyzing the patterns of user interaction makes it possible to evaluate the design and usefulness of such systems. Path algebras can be used to describe and compare routes users take through hypermedia systems. Directed graphs are another method of constructing a network representation of user paths using the Pathfinder algorithm. Another approach is to construct an image based on interaction data with the Toolbook program. Fifty-seven data files from a previous study were entered into the Toolbook program to generate a map of each user's interaction. Six gifted middle-school students, six teachers, and six doctoral students in instructional technology were asked to categorize the images and to associate them with course grades of the users. Although subjects could not generally associate images with grades, they were able to place them in identifiable categories, which suggests the potential of the method for depicting user paths. Nine figures illustrate the approaches. (Contains 16 references.) (SLD)

Title:

Visualization Techniques for Examining Learner Interactions with HyperMedia Environments

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The unprecedented freedom for users to control the scope and sequence of their interactions with hypermedia systems presents many challenges to those who design and study these systems in educational settings. Early efforts to develop hypermedia systems revealed that the inherent node-link structure is both advantageous and problematic (see Conklin, 1987). But when users have the freedom to follow any of a multitude of link permutations, disorientation often results. Further, without appropriate training, novice users do not possess the strategies necessary for effective "browsing" of large hypermedia documents (Duffy & Knuth, 1991). Many designers, therefore, advocate that features such as visual maps, search facilities, and guided tours be included in hypermedia systems to alleviate some of these problems (e.g. Hammond, 1989; Laurel, 1990, 1991).

With the emergence of hypermedia systems as a major architecture for educational and other information-oriented software comes the related problem of how to document and analyze user interactions with these systems for the purposes of research and evaluation. Many hypermedia systems to date have employed a "browsing" interface, but alternative approaches are also emerging (See Nelson & Palumbo, 1992). Regardless of the type of interface, many questions can be generated when studying the interactions of users with hypermedia systems. For example, how many users chose to follow a particular link, and why was one link chosen over another? How does the choice of one link affect choices of subsequent links? When are graphic images, animations, and video segments accessed? What user tasks are appropriate for guiding interaction with the system? Are there patterns of navigation that lead to more complete learning? These and many other questions need answers when designing, developing, and evaluating hypermedia applications for education and other settings.

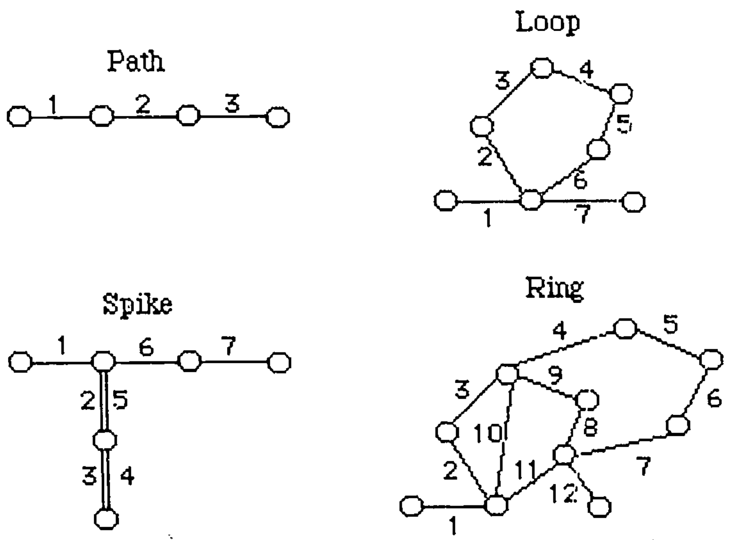
A wealth of user interaction data can be easily collected within many hypermedia development environments in order to study aspects of the interface, including the nature of user navigation patterns, the time spent at each node, and the use of help and other orienting facilities. The data can represent the paths a user follows through the system, and the choices made at each node in the system. The problem is that because of the nature of this data, traditional methods of analysis such as surveys or pretest-posttest designs, are not particularly effective for determining usability or comparing alternative interface designs. Researchers have had to develop new techniques for analyzing patterns of user interaction in order to evaluate the design and effectiveness of hypermedia systems (e. g. Misanchuk & Schwier, 1992). There is a need to categorize and compare groups of users in order to compare the effectiveness of alternative system features, as well as describing characteristics of interaction by individual users within the same system. This paper will discuss several methods for visualizing and characterizing user interactions with hypermedia systems that have been found effective in several development and evaluation studies.

Characterizing user interactions using path algebras

Characterizing the interactions of individual users, or comparing groups of users, can be accomplished using several methods derived from mathematical set and graph theories (Backhouse & Carré, 1975; Carré, 1971). In the first method, path algebras are employed to describe and compare the routes users take through hypermedia systems (Alty, 1984). Users may follow a variety of types of paths through the two-dimensional space of a hypermedia database (Canter, Rivers & Storrs, 1985). Using simple programming techniques, it is possible to "trap" and save in data files the sequence of nodes visited by the user, along with the more specific user actions taken at individual nodes, such as clicks on buttons, menu selections, or viewing graphic images, animations, or audio and video segments.

The data files can be analyzed using algorithms that extract the nature of the "subpaths" of the total path followed by the user. The types of subpaths users follow through hypermedia systems can include rings, loops, paths, and spikes (See Figure 1). As described by Canter, Rivers, and Storrs (1985), paths are movements between nodes in a linear sequence from one node to another. Spikes occur when a user moves through a number of nodes, and then returns along the path to the initial node. Loops and rings are similar in that the user moves through a set of nodes that eventually returns to the original node in a circular pattern. Rings are created when a user loops through several patterns that visit nodes that were previously accessed. The path that an individual user follows while interacting with a hypermedia system gives an indication of the nature of that interaction at different points in time. Of course, the types of paths a user might follow will be determined in part by the organizational structure of the system. Hypermedia systems organized hierarchically will tend to generate paths with many spikes, as the user moves down a "branch" of the tree and then back to the "root". A linear organization for the hypermedia system will tend to produce many paths. Rings or loops tend to indicate that a user is revisiting nodes, perhaps to search for information, or perhaps because of disorientation.

Figure 1. Types of user paths through hypermedia systems.



The frequencies of each type of path followed during an individual user's interaction provides a basis for comparison between individuals and groups. These frequencies can be recorded for each user, and common parametric statistical procedures can be employed to compare the mean number of each path type for groups of users in order to determine whether the frequencies were significantly different. This approach provides a means for analyzing individual users' interactions that can be more precise than merely determining the frequency that one node is accessed from another node (Misanchuk & Schwier, 1992). There is also the possibility of comparing groups of users that is not afforded by other methods that focus on individual user access patterns. In this way, alternative interface design strategies can be compared using quantitative methods that may reveal several advantages of one design over another.

This method was employed with data collected in a prior study (Nelson, 1991) to further characterize the interaction patterns of various users who possessed different levels of prior knowledge for the domain presented in a hypermedia system. Two groups of users with high and low prior knowledge of the content completed one of three tasks with a hypermedia document (browse, search, or study). The results indicated that prior knowledge influenced interaction patterns (e.g., there were more "spikes" for individuals with lower prior knowledge). In addition, the results of this analysis also confirmed a design assumption that was made, namely, that definitions and examples of unfamiliar terms needed to be provided to users with low prior knowledge, but that these definitions and examples would not be accessed by users with high prior knowledge. The large number of "spikes" followed by some users was the result of their access of definition and example nodes for some concepts in the document. It appears that this method of analysis of user interactions with hypermedia systems can be useful in testing design alternatives. Extensions of this technique might utilize similar algorithms embedded within the hypermedia system to detect in real time some of the various interaction patterns, and to provide system interventions or guidance based on such analyses.

Characterizing user interactions using directed graphs

The second method employs graph theory to construct a network representation of the paths taken by individual users through a hypermedia document, and to compare the networks as generated by the Pathfinder algorithm (Schvaneveldt et al., 1985). Pathfinder was originally developed to study the associative characteristics of human memory, and has been applied in a variety of research studies (Schvaneveldt, 1990). The algorithm is applied to proximity data that represents participants' ratings of the degree of relatedness between a set of concepts. The resulting proximity matrices are analyzed by Pathfinder to construct a network representation. Correlations can then be computed between individuals' networks to determine the degree to which the networks are similar.

When used to study navigation patterns in hypermedia, this method assumes that the more frequently a link is traversed by a user, the more direct is the association in the resulting Pathfinder network that represents the interaction pattern. To analyze the data, proximity matrices are constructed to represent the relative "proximity" of a node to every other node in the hypermedia document. In this case, proximity is defined as the number of times a node was visited through a link from another node. As shown in Figure 2, the raw data is used to construct the proximity matrix by analyzing the user's sequential moves between nodes. Each move from one node to another results in an increase in the frequency value of the corresponding cell in the matrix. So a move from node 1 to node 7 would increase the matrix cell at row 1-column 7 by one, and a move from node 7 to node 3 would increase the matrix cell at row 7-column 3 by one, and so on through the sequence of the raw data. After individual matrices have been developed for each user, group data can be derived by calculating the average value for each cell in the matrix (See Figure 2).

Figure 2. Deriving a proximity matrix from raw data, and averaging across a group of users.

1. A sequence of nodes ...

1,7,3,4,2,3,1,6,5,3,4,1,5,1,6,7,1

2. ...produces a proximity matrix for each user

	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7
Node 1	0						
Node 2	0	0					
Node 3	1	1	0				
Node 4	1	1	2	0			
Node 5	2	0	1	0	0		
Node 6	2	0	0	0	1	0	
Node 7	2	0	1	0	0	1	0

3. A number of proximity matrices...

4. ...are averaged to produce a group proximity matrix.

	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7
Node 1	0						
Node 2	1.3	0					
Node 3	2.1	.7	0				
Node 4	2.3	1.1	2.1	0			
Node 5	3.5	0	1.6	0	0		
Node 6	3.4	0	0	0	1.2	0	
Node 7	3.1	0	1.2	0	0	1.5	0

Once the proximity matrices are established, the Pathfinder algorithm can extract the representative network from the average matrix, as shown in Figure 3. A computer-based tool for analyzing data using the Pathfinder algorithm is available (Interlink, 1990). The relatedness coefficients used to plot various Pathfinder solutions from different data sets can be correlated to determine the degree of similarity of the paths taken by individuals or groups. The correlation values indicate the degree to which different groups of users followed similar paths through the hypermedia document. This method was also applied to the data from the study cited above. Correlations between the groups suggested that characteristics of the task may have influenced the interaction patterns of users. At least for this data set, searching and browsing tasks produced patterns that were more similar than for the study task, as indicated in the comparatively high correlations. This method may also be extended by hypermedia authors to specify the initial organization of the nodes and links in a hypermedia document (McDonald, Paap & McDonald, 1990).

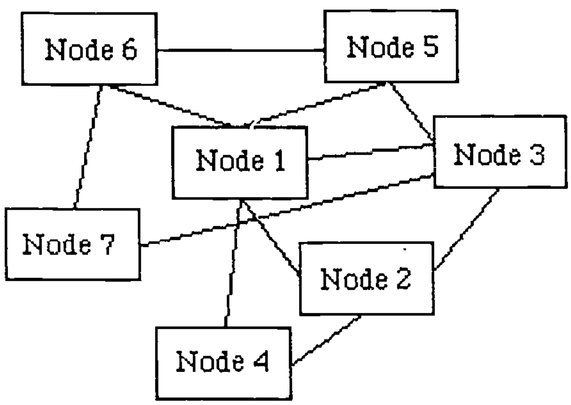
A Picture of the Users' Interaction

Another approach to visualizing the interaction path of an individual user is to construct an image based on the interaction data. The interaction that we wanted to represent was the amount of time spent on each screen, the direction of links, and the number of times that a screen was visited. In order to do this, each screen of information that was visited by the user is represented as a rectangle. The more time that is spent on a node, the larger the rectangle becomes. When a learner links from one piece of information to another, a line segment is drawn with an endpoint on the originating node and an arrowhead on the destination node.

Further, the more times a learner visits a node, the darker it becomes with a range of 4 (white, light gray, dark gray, black). The resulting image would then represent the interaction of that user.

Nelson's (1991) data were used in the Toolbook program to generate an image of the interaction each student had with the system. There were a total of 57 images produced (one for each subject). In the Nelson study, each subject was a student in an undergraduate educational psychology class. The system that they examined was a hypermedia program on the field of educational psychology. There were three groups. The Study group was told that they will have a test on the content in the program. The Browse group was told to evaluate the program because it might be used in later classes. The Index group was asked to find definitions to a list of words.

Figure 3. Pathfinder solution for hypothetical data.



Method

The 57 data files for the subjects in the Nelson (1991) study were entered into the Toolbook program to generate a map of each individual learner's interaction with the program. These 57 images were printed and copies were made. The images were given to three different groups: Gifted middle school students (n=6), teachers in an introductory educational computing course (n=6), and instructional technology doctoral students (n=6). The first two groups were given the 57 images and some paper clips and were instructed to place the images on a table and try to categorize the images into 3 to 5 groups. They were then asked to write a description of the procedure they followed to create the categories and to describe the categories. The third group did the same thing, except they were told what the images represented and each image indicated which group from the Nelson study the image was from.

The only performance data available from the Nelson study was the course grade each subject received. While this is a very indirect measure of the impact of the instructional package, it was the only one available. Grades in the sample were either A, B or C. Unfortunately, for a variety of reasons, only 38 of the 57 images could be associated with a grade. The categories generated by the groups in the current study were then used in a chi-squared analysis. One dimension was the grade received by the learner and the other dimension was the category generated by the subjects in this study. A total of 18 chi-squared tests were conducted.

Results

Results indicated that there was only one subject whose categorization strategy resulted in a statistically significant result in regards to the grade received in the course(see, Figure 4). The categories were: (W) "Has more dark squares than any other kind" (see, Figure 5); (X) "Has more white squares than any other kind" (see, Figure 6); (Y) "Has more polka dot (light gray) squares than any other kind;" and, (Z) "Two highest patterns were tied." Unfortunately, expected values are very low in the lower categories and would result in questionable conclusions. However, given the exploratory nature of this research methodology, it is worth taking a closer look.

Figure 4. Summary table and observed frequencies for the only significant categorization scheme based on grade in the course and created by N2.

Summary Table for Grade, N2

Num. Missing	0
DF	6
Chi Square	19.886
Chi Square P-Value	.0029
G-Squared	•
G-Squared P-Value	•
Contingency Coef.	.586
Cramer's V	.512

Observed Frequencies for Grade, N2

	W	X	Y	Z	Totals
A	12	9	0	2	23
B	5	7	0	1	13
C	0	1	1	0	2
Totals	17	17	1	3	38

It appears that the first category (W) has many people who received an A in the class. This first category can be described as a pattern where the user returned to most screens at least 3 times. Also, of interest is that the majority of the people who got a B in the course fall into category X. This category can be described as a pattern where the majority of the screens in the program were visited only once. This result points toward an interesting question for future research. That is, does the pattern where the learner returns to the same screen many times result in better learning? And, if this statement is true, can a system be designed that adjusts the level of user control based on this interaction pattern. There were not enough people who received a C or fell into the last two categories to conclude anything about them.

Figure 5. An example of category W created by N2.

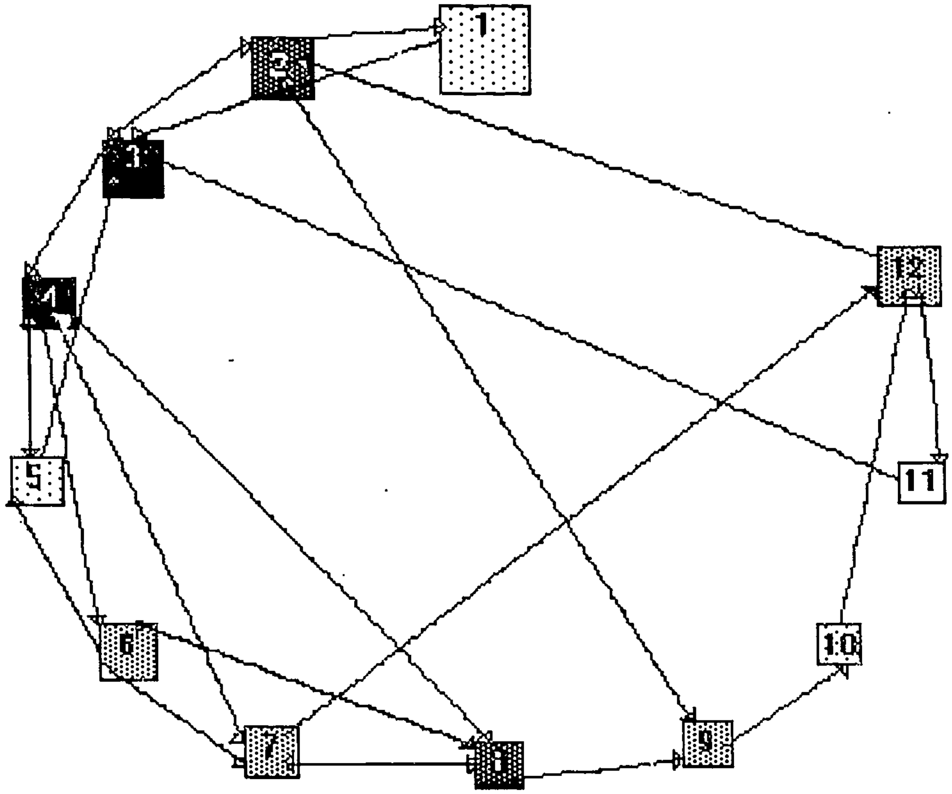


Figure 7. Summary table and observed frequencies for the only categorization scheme that was significant for grade as based on treatment group.

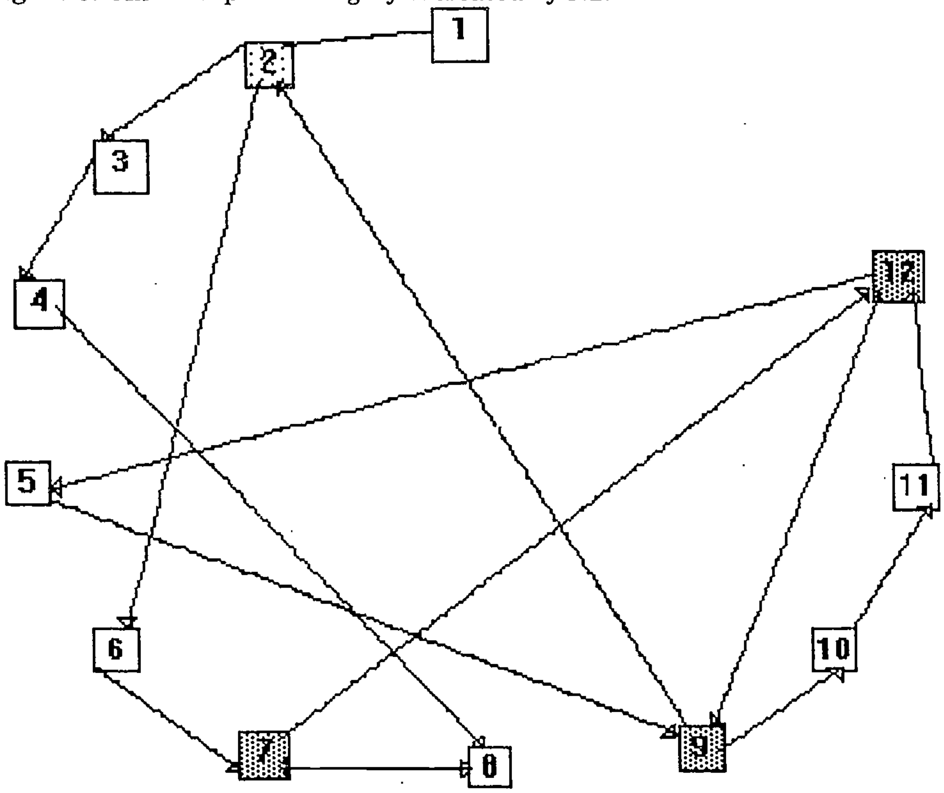
Summary Table for Group, N2

Num. Missing	0
DF	6
Chi Square	9.992
Chi Square P-Value	.1250
G-Squared	•
G-Squared P-Value	•
Contingency Coef.	.456
Cramer's V	.363

Observed Frequencies for Group, N2

	W	X	Y	Z	Totals
Browse	3	6	0	1	10
Index	3	8	1	1	13
Study	11	3	0	1	15
Totals	17	17	1	3	38

Figure 6. An example of category X created by N2.



A related question to the one described above is how do the categories generated by subject N2 relate to the experimental treatments in the original Nelson (1991) study? Figure 7 depicts the results of this analysis. While the result is not significant, a pattern similar to grade can be seen. That is, there are a large number of subjects that are both in the study treatment and fall into the pattern where the user returned to most screens at least 3 times (category W). Likewise, the pattern where the majority of the screens in the program were visited only once (category X) is well represented by the Browse and Index treatments. While it is premature to make any kind of definitive statement about whether these patterns are at all related to learning, it does hold some promise for a more rigorous experimental examination.

Chi-squared analyses were performed on the categories generated by the subjects in this study with the treatment groups in the Nelson study. The results indicated that all of the Instructional Technology doctoral students' categories were significantly related to the treatment groups. This is not surprising given that the doctoral students were aware of the groups and from which group each image came. There were also two subjects that were not informed of what the images represented that resulted in significant categories. These categories were generated by the teacher group in the current study and the results are depicted in Figures 8 and 9.

Figure 8. Summary table and observed frequencies for significant categorization scheme based on treatment group.

Summary Table for Group, N4

Num. Missing	0
DF	6
Chi Square	13.218
Chi Square P-Value	.0397
G-Squared	•
G-Squared P-Value	•
Contingency Coef.	.508
Cramer's V	.417

Observed Frequencies for Group, N4

	S	T	U	V	Totals
Browse	2	4	0	4	10
Index	2	6	2	3	13
Study	1	0	4	10	15
Totals	5	10	6	17	38

Figure 9. Summary table and observed frequencies for significant categorization scheme based on treatment group.

Summary Table for Group, N6

Num. Missing	1
DF	4
Chi Square	10.972
Chi Square P-Value	.0269
G-Squared	•
G-Squared P-Value	•
Contingency Coef.	.478
Cramer's V	.385

Observed Frequencies for Group, N6

	O	Q	R	Totals
Browse	3	2	4	9
Index	4	4	5	13
Study	0	1	14	15
Totals	7	7	23	37

For subject N4, categories T and V seem to define people in the treatment groups best. That is, category T does not include anyone from the study treatment group. Similarly, category V accounts for the majority of the study group (10 out of 17). The categorization scheme used by subject N4 is based on the shading of nodes (just as subject N2). In order to be included in category T, the picture should contain "no more than 2 different shades." Category V for subject N4 was that there were "no more than 4 different shades of boxes." Upon examining the nature of the images for the category T, we noticed that most all of these images had the 2 shades of light gray and white (all but 2 of them). This is not an interaction pattern that would indicate that these learners were returning to screens to re-examine information. On the other hand, the V category shows a pattern of behavior that certain screens are visited once, others twice, etc. While it is pure conjecture on our part, this would indicate that the users in this category were judging the value of the information and returning to screens that were important and not returning to screens that were not.

Subject N6 used a categorization scheme that was based on both frequency of returning to a screen (shade) and the number of screens visited (the number of nodes on the image). Categories O and Q can be collapsed into a single category where there were "no dark gray or black boxes and 6 or fewer boxes." Category R would be the opposite (the image contained dark gray or black boxes and it had more than 6 boxes). It is interesting to note that frequency of visiting screens is such an important attribute (it is an aspect of each of the categories described). Future research ought to examine this navigation pattern more closely.

Conclusions

The three methods for analyzing user interactions with hypermedia systems described above have been successfully employed to compare the patterns of navigation exhibited by groups of users in several studies. The last analysis seems to also provide some potential for further research more directly related to navigation patterns as they relate to learning. The analysis of peoples interactions with hypermedia systems is quite complex. The capability to visualize this interaction allows a researcher the ability to examine many different attributes simultaneously within the image. The results indicate that there appears to be merit to this type of analysis.

At this time, the methods in this paper appear promising for further research into usability studies of hypermedia systems, as well as more basic research into various theories of human-computer interaction. The latter research will also require additional methodologies in order to obtain the rich descriptions of interaction with hypermedia that is necessary to further develop theories and principles for the design of such systems.

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