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Reading Strategies for Graphic Models from an Experiment in Data Model Perception

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Abstract
Many different types and styles of graphic models are used to facilitate human communication between an information system user and a system analyst/designer, as well as for presentation of operating data systems. In each case, it is assumed that the user can correctly interpret the information provided in the graphic model and that the model correctly depicts important system aspects, such as information types, structure, behavior, integrity rules, etc. Unfortunately, the user may not always view the graphic model in the way anticipated by the system designer. In fact, very little is known about how graphic models are read or how the graphic style of the model might influence its perception and comprehension.

In the following, we present an analysis of the effect of graphic style on the reading strategies used for interpretation of graphic data models. Our observations indicate that a subject's reading strategy frequently contains different patterns, one for viewing the model and another type for verbal articulation. Both viewing and articulation patterns appear to be related to model comprehension and influenced by the graphic style of the model.

Keywords user profiles, reading patterns, graphic perception, graphic data models

1. Background

Graphic models of system specifications are used extensively as communication tools between users and designers of information systems to illustrate information structure, behavior, and constraint requirements. When used as a design tool, the assumption is that the user will be able to read and understand the model and confirm that it correctly depicts important requirements for the system. However, little is known about how users read and interpret graphic models.

Research on programmer interpretation of system specifications has concentrated on flow chart, tree, or decision table presentations of processes, under the hypothesis that presentation formats effect comprehension [Wrig73, Broo80]. An experiment which presented programmers with design specifications in three spatial formats: sequential, hierarchical, and branching flow charts, indicates that the combined use of a succinct program design language and a branching spatial arrangement significantly facilitated design interpretation [Shep82]. Currently researchers are classifying the visual similarity of graphs, tables, maps, diagrams, networks and icons. [Lohse94]. Although this research provides an insight into interpretation of graphic presentation of processes, it does not investigate the effect of graphic style on reading strategies or interpretation of the more static structural and constraint information in data models.

One method of gathering data to study whether graphic style effects reading patterns and model interpretation is to track eye movements while subjects give an oral interpretation of models presented in different graphic styles. Eye movement registrations consist of fixations or the length of time the eye remains focused on one area before moving to another area. Processing information occurs only during fixations [Wolv83]. A minimum of 100 to 125 milliseconds of fixation duration is needed to view an item and transmit that information to the brain [McCo83]. According to a reading model based on immediacy, text is interpreted immediately during an eye fixation, the fixated word is available for cognitive processing within a few tens of milliseconds. The eye stays fixated on a word as long as necessary to process it [Just80]. Although the immediacy theory is sometimes challenged, researchers agree there is a relation between fixation time and the subjects attention to a specific area. Eye movements can help us determine how much attention is given to critical portions of a data model. The oral protocol allows evaluation of model comprehension.

In the following, we present an analysis of the reading strategies used for interpretation of three different styles of graphic data models: highly graphic, embedded structures, and list based. The questions studied here relate to how variations in graphic style effect data model reading strategies and model comprehension. We are particularly interested in:

- What reading strategies are used for graph interpretation.
- How graphic style effects reading strategy.
- Which graph components are seen / not seen.
- If graphic style effects user comprehension.
- If reading strategy is correlated to model comprehension.

1.1 Reading Graphic Models

When reading a graphic model, the user must first view the model to see which components it consists of, interpret the model components, and finally articulate (present) the interpretation. The first and last phases are directly observable.

Viewing patterns, can be observed using eye-tracking equipment. Eye movement data describes the sequence in which a scene is read, which areas are seen, and the distribution of attention given to different graph areas. The number of eye fixations used for interpretation varies with scene complexity and can be used as a measure of interpretation effort. Our data indicate that the distribution of fixation duration within each graph area is equivalent to the fixation count.

Articulation patterns are discernable from the verbal protocol recorded while the subject interprets the data model. Graph comprehension is also measured from the verbal protocol. The eye fixation data enhances comprehension analysis by allowing distinction between components which were seen but not articulated and those which were not seen.

When reading text, a Latin-language subject will tend to start at the upper-left, read to the right and down the page. The data on scene viewing suggest the location of fixations is not arbitrary, the subject commonly starts at the center and 'moves' to some dominant or informative object. A problem with these studies is that it is not clear what makes an object informative [Rayner92]. Data models have no defined start or end points, neither do they have a normal or correct reading sequence or even a dominant feature which can attract initial attention. None the less, they do contain features, for example; nodes, relationship lines, embedded structures, which appear to influence the viewing pattern chosen for interpretation.

In our experiment, most models (73%) were viewed using an identifiable pattern, either

- *serial* following a top-down text-reading pattern, in which each model component was studied in some detail before proceeding 'down' the model to the next model component, or
- *structural* following a top-center, fanout pattern, similar to scene viewing, where the focus of attention was on the model structure, represented by the relationship node and lines.

Articulation patterns were defined according to the sequence in which basic model concepts were articulated. The patterns so identified were either:

- *structural* presenting the model structure prior to the entity-attribute details, or
- *detail* giving the entity-attribute-domain-method details prior to the system structure (relationships).

Viewing and articulation patterns are not interdependent. We observed that several of our subjects used neither the serial nor structural viewing pattern, but chose a structured articulation pattern. Others preferred a structured viewing pattern but used a detailed pattern for articulation. Few of our subjects used a consistent viewing or articulation pattern, indicating that the choice of pattern may be influenced by the graphic style of the model.

1.2 Styles of Graphic Data Models

The graphic style of a data model, DM, is expressed by the choice of node symbols, the use of embedded structures, the use and placement of lists, and the types and placement of annotation used for specification of model concepts. Basic data model concepts include entities, inter-entity relationships, and attributes/methods. Graphic data models typically represent entity types as nodes, relationships as lines, and attributes as either lists or separate nodes. Attribute lists may be external to or embedded within the entity node symbol. Attribute domains may be represented as a separate node type or as an extension of the attribute name specification. The resulting graphic style of a data model can be classified as:

fully graphic, where each model concept is represented by a specific graphic symbol, example: the NIAM model [Nijs89],

embedded structure, where entity and relationship concepts have specific graphic symbols within which attributes, with domain specification, and methods are listed, example: the object-oriented data model, OODM, [Catt91].

list based, where entity and relationship concepts have specific graphic symbols, to which lists of attributes, with their domain specification, are attached, example: the structural semantic model, SSM, [Nord93].

System constraints, such as primary and foreign keys, relationship cardinalities, classification participation, and valid value sets, are typically represented as annotations in/on/or adjacent to the connection lines or the entity, relationship, or attribute node symbols. Types of annotation include underlining names, embedding names or numeric specifications within the node symbol, affixing the constraint to a node symbol or line. Domain value set restrictions may be annotated or appended to the domain specification. Cardinality constraints have the most varied representations: mandatory dots, arrow heads, and min : max notation are all used in various model types. An example of these graphic styles, with annotation variations, are given in the 3 equivalent graphic models of a project management database given in the appendix.

2. Graphic Model Perception- An Experiment

We designed an experiment to gather data on the effect of graphic style on the reading patterns used for data model interpretation. Data models of equivalent complexity were designed for six generally familiar information systems: student-course, project-management, library-borrowing, concerts, sales, and supplier-parts. Each of these systems was modeled using comparable versions of the NIAM, OODM, and SSM methodologies. Each of the model types was modified slightly to emphasize its basic graphic style: fully graphic, embedded, and list based respectively. Each model contained 2 independent interrelated entities, a classification structure with 2 subentities, 24 attributes, domain specifications with valid data value sets, primary key specifications, relationship cardinalities, and participation constraints.

Six experiment sequences were defined to balance model placement in the experiments. Immediately proceeding each experiment, the subject was given an example data model and verbal explanations of the terminology used. The subject was informed that the experiment consisted of 8 models, 2 each of 4 different data model types and instructed to give a complete, oral interpretation of each model and to indicate when each interpretation was finished. The fourth model type, IDEF1X [Loom86] was included as a benchmark for establishing the data model interpretation ability of the subjects. Maximum interpretation time allowed per model was 4 minutes. Average interpretation time was 2 minutes and 15 seconds per model.

A verbal protocol and eye movement data were collected for each subject. The latter using an Applied Sciences Laboratory Eye Movement Monitor connected to a Macintosh II computer. Eye location coordinates were computed 60 times a second as the subject viewed each graphic model on a 19" video monitor. A fixation was defined as at least 10 consecutive points within a 10 by 18 pixel area, giving a minimum fixation duration of 167 msecs. Fixations were counted for each concept and constraint area in each of the 8 model interpretations. 15 experiments had complete eye-tracking and audio data, giving 120 model interpretations, 30 for each model type.

2.1 The Subjects

System users, who are expected to read and confirm the correctness of data models, can be expected to have good knowledge of their application area (the topic area for the data model), some knowledge of computer applications, and some familiarity with the types of models used with computer applications. However, it is not reasonable to expect them to have training in the graphic syntax of a particular data model type. Ideally, the subjects for an experiment to test data model perception should represent this user group.

Our subjects were volunteer students from the Dept. of Information and Computer Science at the University of Hawaii at Manoa (ICS/UH). Of the 15 with complete audio and visual data, 10 were senior-level undergraduates from a course in systems analysis and design, and 5 were graduate students. Though they did have training in the development of system design models, and in particular in the use of the IDEF1X model which is taught and used at ICS/UH, none were familiar with the other model types used in the experiment.

It was assumed that the application areas used were from a common domain of knowledge and thus familiar to the subjects. While students do not represent system users, it was assumed that their strategies for reading data models of familiar applications would be similar to those utilized by system users when reading a model of their application domain.

2.2 Data Model Comprehension

A comprehension score was calculated for each model interpretation as the percent of correctly identified (and articulated) model components. The scores for the individual model interpretations varied considerably, from 27-91%. Average scores were calculated for each user's interpretation of the 2 models of each type, for each reader, and for each model-type. The readers were grouped by their comprehension score for the IDEF1X models into two skill levels for graphic model interpretation. All but one of the skilled IDEF1X model interpreters also had above average scores for the NOS (NIAM, OODM, and SSM) model interpretations, while most of the non-skilled readers had below average NOS scores.

Table 1 shows the average comprehension scores for each model type for all readers, and for the skilled and non-skilled reader groups. As expected, the readers performed significantly (p=0,003 using an ANOVA single factor test) better when interpreting models in a familiar model type (IDEF1X). Skilled readers recognized a fair portion of the unfamiliar model types, but had significantly poorer scores for the highly graphic model type (NIAM) then either the embedded or list structured models. (p=0,0492 and p=0,0395 for the NIAM : OODM and NIAM : SSM models, respectively. Calculated using a paired two sample ANOVA test.) The less-skilled readers articulated only the basic model components, omitting graph detail even though they were familiar with the data modeling concepts and constraints included in the models [Nord95].

	IDEF1X	NIAM	OODM	SSM
Total	71	52	59	58
Skilled	80	58	68	67
Non-skilled	61	46	49	48

Table 1: Average Comprehension scores for each Model Type for All Readers and Skilled and Non-skilled Groups

3. Graphic Model Interpretation

As noted earlier, model interpretation involves three steps: visual identification, comprehension and articulation. Incomplete model interpretation can result from graph components that were seen, but either were not understood or were considered unnecessary to the interpretation. Alternatively, the graph components were literally not seen and thus could not be articulated.

The problem of unseen components could lie in the viewing strategy chosen and/or in the graphic complexity of the model. In the following we will look more closely at these explanations.

3.1 Viewing Patterns

There was a significant (p=0,01 using an ANOVA test) difference between the viewing patterns of skilled and non-skilled readers. Skilled readers articulated 34% more graph components than the non-skilled readers, who consistently omitted graphic details. One explanation could be that the skilled readers use a more efficient viewing pattern which encourages a more complete model interpretation. Identification of the viewing patterns defined in section 1.1 can be made by studying the fixation concentration and movement (saccade) patterns during model interpretation.

serial (text oriented) patterns can be characterized by a higher than average concentration of saccades within the graph areas, while

structural (scene oriented) patterns can be characterized by a higher than average number of fixations focused on the relationship structure.

The average occurrence of 'same area fixations'for all interpretations was 37%, while the average focus on the relationship structures for all interpretations was 17%.

Table 2a shows the usage distribution of the viewing patterns for all readers and for the skilled and non-skilled reader groups. Table 2b shows viewing pattern usage for each model-type. 67% of the models were viewed in a systematic manner, using the serial and/or structural patterns. Not surprisingly, skilled readers were the most systematic. It appears that model type strongly influences the choice of viewing pattern and that neither of the model types using embedded graphics (OODM nor IDEF1X) invited a systematic reading pattern. The serial and structural patterns are not disjoint. 11% of all interpretations used both, with the list-structured model-type (SSM) inviting this strategy most frequently.

	Serial	Structural	Both	Neither
All readers	38	41	11	33
Skilled	48	41	11	22
Non skilled	27	41	11	43

Table 2a: Viewing Pattern Usage by Reader Group, percent

	IDEF1X	NIAM	OODM	SSM
Serial	30	60	23	7
Structural	33	37	20	73
Both	10	10	3	20
Neither	47	13	60	10

Table 2b: Viewing Patterns Used by Data Model Type, percent

3.2 Articulation Patterns

Articulation strategies may enhance model interpretation by encouraging attention to detail and thus a more complete presentation. The subjects used over 70 articulation sequences for the 9 data model concepts, of which 80% included the basic entity-attribute-relationship structure. This was used to distinguish 2 articulation patterns:

structural starting with the entity-relationship structure, followed by the attribute sets and constraints and

detail starting with an entity-attribute description followed by the connecting relationships.

Table 3a shows articulation pattern usage for all readers and for the 2 skill level groups. Table 3b shows the pattern usage by model type and for all models of the experiment. Note that the structural pattern was preferred by the skilled users, while the non-skilled readers used the detail pattern most often but also had a relatively high percentage of incomplete interpretations. An incomplete interpretation is one that does not include the relationship structure.

The structural pattern was dominant for articulation of the embedded structure models (IDEF1X and OODM), while the detail pattern was dominant for the highly graphic (NIAM) models.

However, with so many incomplete presentations, it is not possible to determine a clear relationship between articulation pattern and the graphic style of the model.

Usage of the structural pattern is associated with the best interpretations and was clearly preferred for the familiar IDEF1X models. This could be an indication that it can be taught.

	Structural	Detailed	Incomplete
All readers	43	37	20
Skilled	52	32	16
Non skilled	34	40	25

Table 3a: Articulation Pattern Usage by Reader Group, percent

	IDEF1X	NIAM	OODM	SSM
Structural	63	20	43	43
Detail	30	50	20	47
Incomplete	7	30	37	10

Table 3b: Articulation Pattern Used by Data Model Type, percent

4. Summary of Observations

Graphic data models are intended to support user-designer communication during planning and specification of an information system. They are also used by database management systems to provide support for query formulation. Usually, an IT trained system analyst/designer develops the data model and then asks the user to read and confirm that the model correctly specifies system requirements, alternatively specify correct queries to an implemented database.

Data model interpretation strategies utilize both a viewing pattern and an articulation pattern. Two-thirds of the models were viewed in a systematic, structural and/or serial manner, with skilled readers using a systematic pattern for 78% of their interpretations. The graphic style of the data model influences the choice of viewing pattern, with the dominant (360%) pattern for highly graphic and list based styles encouraging serial (text oriented) and structural (scene oriented) viewing respectively.

80% of the model interpretations were 'complete' in that the basic entity-attribute-relationship structure of the model was articulated. Skilled readers used a structural articulation pattern for most (52%) of their interpretations. None of the unfamiliar model types encouraged use of this pattern, though it was dominant for presentation of the familiar (IDEF1X) models, indicating that it can be taught and will effect positively the quality of model comprehension.

Both the highly graphic and list based models encourage systematic viewing though with differing strategies, structured and serial respectively. Since the interpretation of the highly graphic models, which encourage serial viewing strategies, was significantly poorer than the list based models, a tentative 'conclusion' could be that a list based graphic style, which encourages a structured (scene oriented) viewing strategy gives the best support for model interpretation.

Our analysis is based on verbal and visual data collected while 15 subjects interpreted 120 data models presented in 4 data model types representing 3 graphic styles. Though this is a small and not necessarily representative study, we believe that if the correlation between list based graphic styles, structured reading patterns, and high model comprehension can be confirmed, then this knowledge could be used for training of both the system user and system designer. Structured articulations could also be built into data model editors and system presentations to enhance model understanding.

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APPENDIX: NIAM, OODM, and SSM Data Models for a Project Management Application

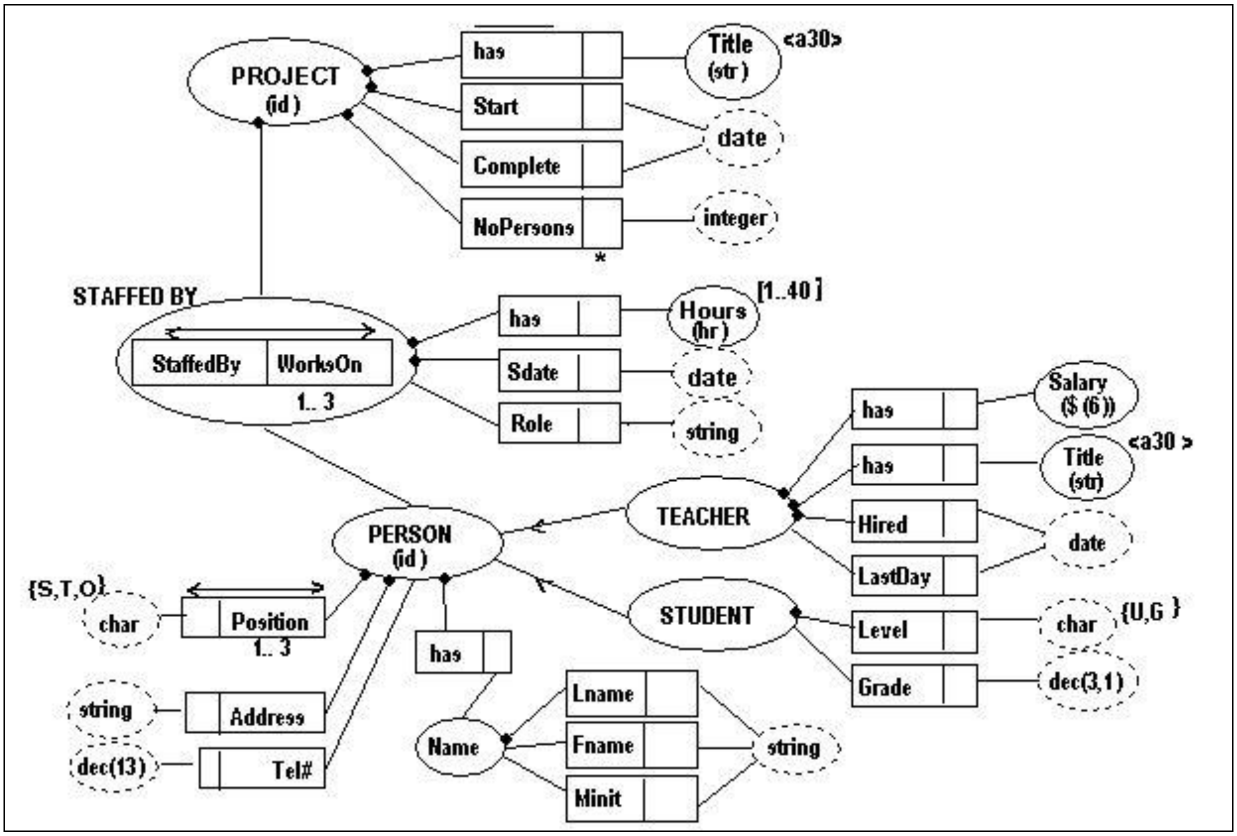

Figure A.1: NIAM Data Model for a Project Management Application

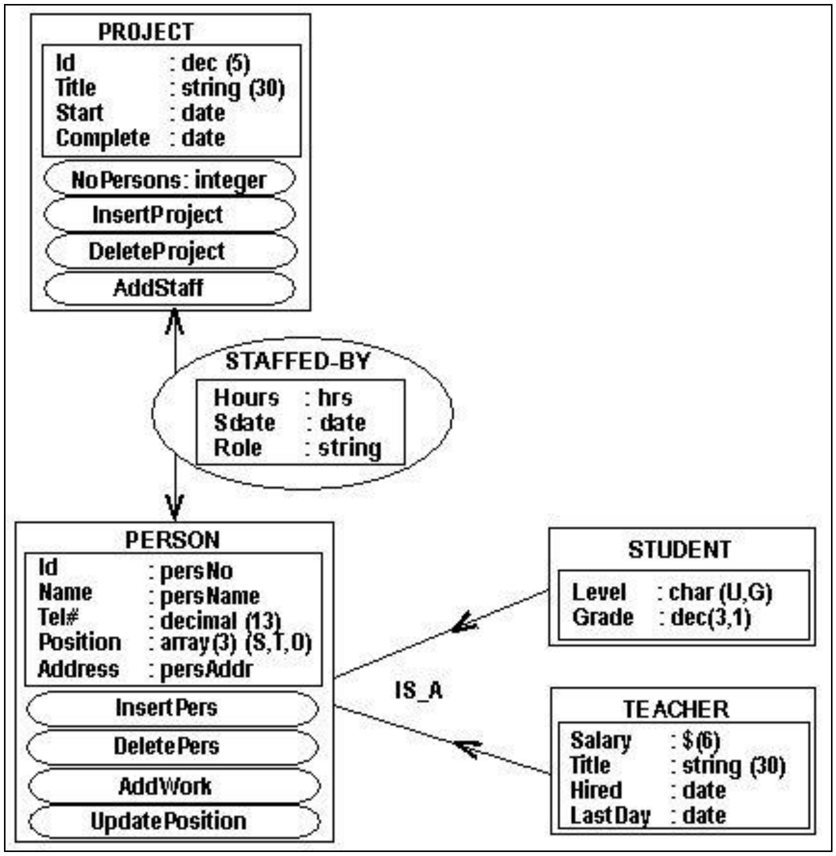

Figure A.2: OODM Data Model for a Project Management Application

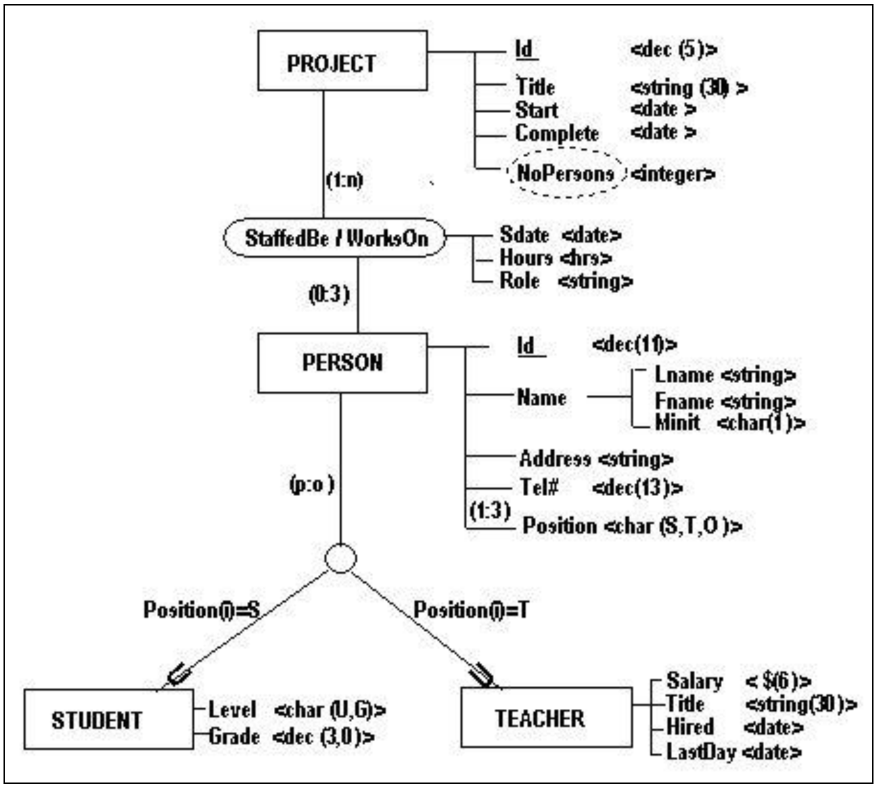

Figure A.3: SSM Data Model for a Project Management Application