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Proceedings of the Annual Meeting of the Cognitive Science Society, 10(0)

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1988

THE COMPREHENSION OF ARCHITECTURAL PLANS BY EXPERT AND SUB-EXPERT ARCHITECTS

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While much research on text comprehension has focused on narrative text, recent research has examined the underlying conceptual network representations and processes involved in the understanding of particular types of text structures such as narratives, procedures, conversations, problems, and descriptions (Frederiksen, 1985). One particular type, namely descriptive text, is used to present information about objects, states, events, or processes to a learner. The information given in a descriptive text allows the reader to develop networks of descriptive semantic information about a given topic. The focus of interest in studies such as these is to evaluate both the amount and type of descriptive semantic information which the learner has acquired from the text and the rules that are used to generate and integrate conceptual structures.

However, one may also acquire descriptive semantic information about an object from information sources other than text. That is, descriptive semantic structures are not language bound. There exist information sources which are non-linguistic and from which one also can generate a semantic description of an object. The ability to assign meaning to an object, regardless of the medium of presentation, is an important comprehension ability which takes place in everyday life.

Important domains in which information is presented in non-linguistic form are those that deal with graphics. Like texts, graphics present information about an object, but they do so in a different way. Thorndyke and Stasz (1980) have defined one type of graphic, namely, a map as a "symbolic 2-dimensional representation of an area which is large enough to navigate, i.e., a building, a city, or a country." Furthermore, maps are differentiated from other learning materials in two ways. First, they are more complex than typical textual materials because they contain both spatial and conceptual information, and they represent characteristics such as shape, and absolute and relative positions. Secondly, they present all their information simultaneously. Thus, in tasks in which graphics are used as sources of information, the ability to comprehend or interpret these sources is essential.

The purpose of the present research was to examine the underlying processes and representations involved in the comprehension of graphic information sources in architecture. The working hypothesis is that semantic processes and representations which are used in the understanding of descriptive texts should also operate in the understanding of graphic information sources. Architecture is an interesting domain in which to study this for two reasons. First, graphics are the information sources which are most commonly dealt with, and secondly, architects are trained to give verbal descriptions of buildings from their various drawings. This is a crucial and highly developed skill in architecture, and plays an important role in the evaluation of architecture students. During this evaluation session, called a Critique, students must give a full description of the building which they have designed, to a committee of examiners. Since this skill is part of the professional training of architects, the task of generating a verbal description based on the drawings of a building is not one which interferes with the processing or comprehension of the graphic stimuli themselves (cf. Ericsson and Simon, 1980). Furthermore, since the output is verbal, it allows for the application of methods of semantic analysis developed for natural language to the verbal protocols produced by subjects. These techniques of propositional and conceptual frame analysis

(Frederiksen, 1975, 1985) may be used to abstract the semantic information from subjects' natural language protocols and are both well-defined (in terms of semantic BNF grammars) and rigorous (analysis is guided by a computer program). Thus, they provide an excellent means to ascertain both the amount and type of information an individual has learned about a building from its graphic sources.

It is important to note that the problem that we are interested in is not one of how graphic information is perceived or encoded; rather, how its meaning (i.e., a description of the object it represents) is represented in "think aloud" protocols given by the subjects. Therefore, the nature of memory representation for visual objects is not an important issue here since the task was a "think aloud" interpretation of the object represented by the graphics, rather than of the graphic information itself. Of course representations for visual objects having characteristics which are symbolic and spatial in nature, are generated. Furthermore, these are required when modelling the processes by which semantic interpretations are assigned to graphic objects. However, since our current interest is in the semantic representations of the objects being represented by graphic information, the debate over the nature of representation for visual objects (cf. Anderson, 1977) will not be discussed.

The present research has several objectives. Perhaps the most important of these is to examine the processes involved in comprehending a chosen building from its graphic sources; that is, how do architects construct a "mental model" (Johnson-Laird, 1980) of a building as a three-dimensional entity from its graphics which present the information schematically in two-dimensions. Comprehension of graphics in architecture involves the interpretation of the graphics with regard to the following types of conceptual models: (a) the descriptive properties of the building, (b) its supporting structure, (c) its geometry, (d) possible movement and circulation in the building, (e) functions of building components and spaces, as well as other characteristics including its goals and its interpretation by a potential user of the building. In addition, any of these conceptual models can involve different categories of semantic information which are used to represent the meaning of graphic displays by architects. Semantic categories include the following which are identified in propositional models: categorization, attribution, function, composition (part structure), locative information, identity, similarity relations, events involving building components (e.g., movement), and algebraic, and dependency relations.

A second objective is to identify from the verbal protocols characteristics which differentiate expert and sub-expert performance for this task based on their semantic interpretations of the chosen building.

A third objective is to investigate the nature of expertise in architecture which is a domain that is both highly symbolic and semantically rich.

The most important previous work within the domain of architecture pertinent to the present study is that of Akin (1979) who has adopted a problem-solving approach to design in architecture. Akin has studied the heuristics used in the design process. However, the semantic representation and interpretation of the graphic information is not addressed centrally in his work. Thus, the present research will contribute to the body of expert-novice literature with architecture as the domain of study. It also has the potential to contribute information and methods pertinent to other domains in which the sources used are primarily graphic or pictorial in nature, such as cartography and radiology.

Method

Subjects

A total of eighteen subjects participated in this study. Seven of these, the "sub-expert" group, were students who had recently completed their fourth year in the school of Architecture at McGill University. A total of nine professional architects comprised the expert group, all of whom had a minimum of two years experience as professional architects.

Two professors in the School of Architecture at McGill University also participated in the study for the purposes of developing an expert descriptive frame, i.e., a Reference Model for the building. These experts were chosen for their particular expertise pertinent to the task of providing a verbal description of buildings based on graphic information. One has particular expertise in the analysis of building plans and the verbal description of such plans; the other has developed a classification system for the characterization of architectural information systems which is used to teach students how to interpret buildings. These two experts will be referred to as "participant experts".

Materials

Four plans (ground , second level, third level, and roof) , three sections, an axonometric drawing and two aerial photographs of this building comprised the materials for this study. The building which was chosen for this study is The Atheneum, which was designed by Richard Meier. This building, which is located in New Harmony, Indiana, serves as an information and tourist centre for the towns' visitors. It was selected for its interest and the availability of these particular graphic information sources for it.

Procedure

The graphic sources were presented in the following order: plans, sections, axonometric drawing, and aerial photographs. Each set (plans, sections, axonometric, and aerials) presented additional information about the building. The procedure for testing was identical for all participants. All subjects were asked to give a "think aloud" interpretation of the sources. More specifically, they were asked "to describe, in as much detail as possible, all the information that they knew about the building from the sources given, specifying which source they were referring to, and the location within it (top, bottom, left, right, etc.)". All protocols were tape recorded and transcribed. All plans were available simultaneously for examination by the subjects, and subsequently all sections were simultaneously available. Thus a subject could shift from one graphic source to another of the same type during the performance of the task.

The present study will analyze only the results from the first type of graphic source given, namely, plans. Since the other sources were introduced after these, the subsequent information sources cannot have had an influence on the interpretation of the building plans.

Development of Reference Model from Participant Experts' Protocols

The coding of subjects' protocols was based on matching them to a Reference Model of the building. To develop such a model, protocols produced by the participant expert architects were analyzed. This involved several steps. First, all statements in their protocols which were descriptions of the building were identified (in contrast to statements such as architectural critiques, historical influences, descriptions of one's thought processes, etc.). The purpose to this was to have protocols for propositional analysis which would include only descriptive information about the chosen building.

The second step was to identify all graphic objects which were referred to by the two participant experts and assign them alphanumeric codes. Thus, each graphic object was assigned a numerical label for identification purposes.

Third, a propositional analysis (Frederiksen, 1986) was carried out on each of the expert protocols in order to ascertain the semantic information described by each expert.

Fourth, a descriptive semantic network (i.e., descriptive frame) was constructed based on these propositions. Finally all links (i.e., correspondences) between semantic objects in the network and graphic objects were identified.

Coding of Subjects' Protocols

Subjects' protocols were transcribed,

descriptive statements were identified (as in the participant experts' protocols), and these statements were matched to information in the Reference Model and to graphic objects when reference was made to graphic elements. The basic data resulting from this coding of subjects' protocols is the presence of specific nodes or links of the Reference Model, of graphic objects for which semantic descriptions were made, and of links between semantic information and graphic objects. From these basic data, frequency counts were made of the various categories of semantic or graphic information.

Categories for Data Analysis

Graphic categories. These include the number of graphic objects from each plan that are linked to semantic descriptions, and the frequencies of particular types of graphic information such as: objects, structures, spaces, features, etc.

Types of descriptive models. These include the amount of semantic information included in subjects' interpretation protocols that reflects different types of models of the building, in particular: building description, supporting structure, geometry, and circulation and access.

Categories of semantic information in the network. Categories of semantic information with examples taken from the participant expert's protocol were as follows:

1) object classification or identification: this category consists of objects whose identity or category was given. Examples of this are:

"That's probably the space [over the auditorium]", "This must be the balcony [here, over the stage]".

2) attribute description: descriptive information given with regard to the physical attributes of the objects. Examples are:

"[It's] a pretty high semi-enclosed space", "It's a pretty odd building."

3) function: includes information with regard to the function of objects within the building, and the functions of the building itself. Examples are:

"[It doesn't seem like it's a theatre of sorts], more for music I imagine", "[It's a ramp] for the handicapped".

4) information about events, i.e., circulation and movement through the building: refers to statements given with regard to the paths travelled by people who are in the building. Examples are:

"This is the top level which gives access to this stair", "you can go from this level higher up to the 3rd floor".

5) physical processes underlying building structure: information pertaining to the physical structure and processes of the building or it's various parts. Examples are:

". . .which is supported by this column here". "Inside this space which is used to support this 3rd floor part of the building which sticks out."

6) composition (part structure): information referring to the various parts of the building. Examples are:

"it is a building that has a large auditorium *[which is for public access]*",
". . *it seems to have larger and smaller* elements. . ."

7) Point location: i.e., an object which goes from one point in a 1, 2, or 3 dimensional region to another point in a 1, 2, or 3 dimensional regional, or an object which goes from one point in a 1,2, or 3 dimensional region but has no specified secondary location. Examples are:

"This is a stair which you can go from the front.", " It goes from the ground floor to the 2nd floor, and ends up at the 3rd floor."

8) Containment location: the location of an object which is contained in a 1,2,or 3 dimensional region. Examples are:

"which has a stair which should show up at the second floor", "It's outside the building envelope essentially".

9) Adjacency location: location which is specified as being relative to the location of another object, i.e. below , above, etc. Examples are:

> "That's probably the space over the auditorium", "There's a space underneath here."

10) Direction location: location which is also specified as being relative to a centre point, or location which specifies the direction which an object goes toward. Examples are:

> "The space which is on the north side.", "These stairs are going up".

For further definition of types of location see Frederiksen (1975).

Links between graphic objects and semantic descriptions. Categories are based on combinations of types of graphic objects and types of semantic information associated with them in subjects' protocols. For example, graphic objects may be assigned to semantic categories, spaces may be assigned functions, and particular features may be associated with relative locations.

Design and Construction of Within Subject Variables

The design of the study involves one between-group factor: level of expertise. Within-group factors are constructed to correspond to the above mentioned categories. In each of a series of multivariate repeated measures analysis of variance, particular within-group factors will be investigated in terms of their main effects and their interactions with the between-group factor (i.e., to investigate expert and sub-expert differences in terms of the effect).

Results and Discussion

Results in this paper will be restricted to illustrative data for one of the participant expert architects and two of the sub-experts.

Frequencies were tabulated for all of the categories of semantic information (objects, descriptions, function, circulation, structure, composition, and the four location categories, namely, point location, containment location, adjacent location, and direction location) for the participant expert and each of the two sub-experts. These categories of semantic information were grouped into three sets since they reflect different aspects of the subjects' interpretations of the plans.

The first set of measures consisted of frequencies for two categories: the number of objects identified in the building, and the amount of descriptive information given about the objects in the building. Results are given in Figure 1. Here we see that the participant expert produced higher frequencies than did the sub-experts for both these categories. Thus, the participant expert identified a greater number of objects within the building than did the sub-experts, and he gave more descriptive information about the building as well.

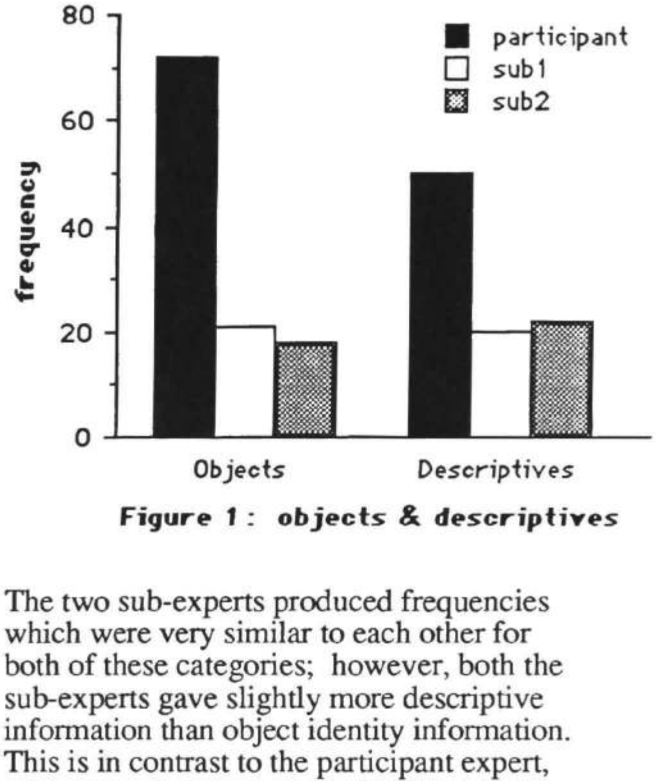

Figure 1 : objects & descriptives

The two sub-experts produced frequencies which were very similar to each other for both of these categories; however, both the sub-experts gave slightly more descriptive information than object identity information. This is in contrast to the participant expert, who gave a larger amount of object identity information than descriptive information. Thus the expert's model of the building included more objects and a greater amount of descriptive information for these objects. The sub-experts' identified fewer objects, but identified a greater amount of descriptive information for these objects.

The second set of frequencies consisted of the following categories: function, geometry, circulation, structure, and composition/part. Figure 2 presents these results. The participant expert produced higher frequencies than did the sub-experts for three of the five categories, namely, function, circulation, and part/ composition. Sub-expert 1 produced the highest frequency for geometry, whereas the participant expert produced the lowest frequency for this category. With respect to structure, the participant expert and sub-expert 2 produced the same frequencies.The two sub-experts produced very different patterns of frequencies.

Since these measures reflect the extent of particular types of conceptual information in the "Building Models" constructed by the subjects, differences in frequencies of a category may reflect either differences in ability to generate particular kinds of semantic information, differences in strategies reflecting the strategic importance assigned by a subject to particular kinds of semantic information, or both. For example, if we assume that differences in frequencies across categories for the Expert reflect strategic differences (and not ability differences), we may conclude that the expert gave strategic priority to: (a) functions of building spaces and components, (b) circulation or movement through the building (what we may call the "Walk Through Strategy"), (c) the composition of the building, that is its part structure, and (d) the supporting structure of the building. The expert did not give priority to the geometry of the building as it was reflected in the plans.

Sub-expert 1 gave priority to the geometry of the plan, adopting a "geometric strategy", and to the part structure, i.e., the composition of the building. This subject also appears to have used the "Walk-Through Strategy". The second sub-expert also emphasized geometry, but also generated information in all of the other categories, with the exception of circulation. Thus, this subject appears to have adopted strategic priorities more like those of the expert, but was less successful in applying them. It is interesting to note that the "Geometric Strategy", unlike the other strategies, involved principally a description of the plans rather than the building which is represented by the plans. Sub-experts apparently carried out "shallower" processing of the plans, emphasizing information which was more directly depicted in the plans.

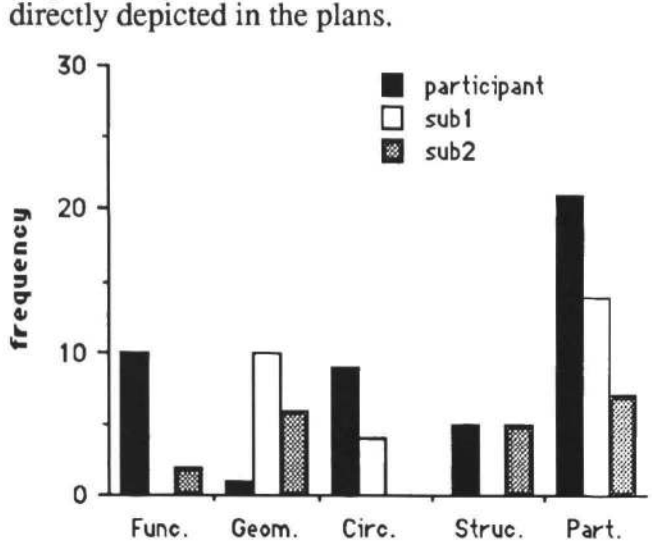

Figure 2: categories 3-8

The third set of frequencies comprises the four locative categories identified previously. Differences in the frequencies of these categories reflect the types and complexity of locative descriptions of the building. Figure 3 presents these results. The participant expert produced high frequencies for three of the four locative categories: point location, containment and direction. Containment location involves specifying inexact location of an object with reference to a region of the building (e.g., a floor or area). Point location involves more precise location of objects (or parts of objects such as their extremities) with respect to other objects. For containment location, the frequencies of the two sub-experts were identical and much lower than those of the expert, while for point location, the sub-experts' frequencies were lower than that of the expert and were different from each other: sub-expert 2 was very low and sub-expert 1 was intermediate in frequency.

With respect to the other two locative categories, adjacent location and direction, differences between the expert and sub-expert 1 were less apparent. Sub-expert 1 showed higher frequencies than did either the expert or the other sub-expert for adjacency location For direction location, the frequency for the expert was very similar to that produced by sub-expert 1. Sub-expert 2 produced frequencies that were very low for both of these categories. Except for containment location, the expert and sub-expert 1 were similar in the types of locative structures they generated to represent the spatial characteristics of the building, while sub-expert 2 had difficulty generating a spatial-locative representation for the building.

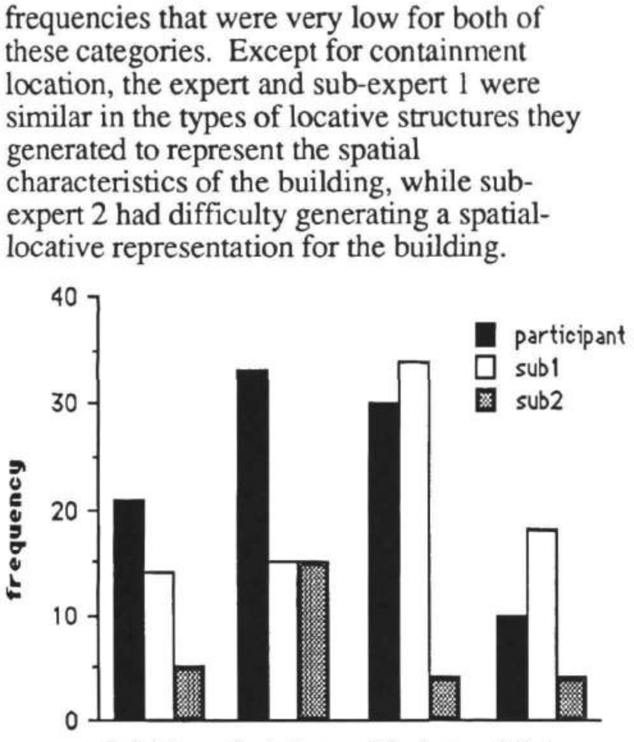

Figure 3: location

Although these results are only preliminary, they illustrate the kinds of differences that an analysis of the complete data on these measures is likely to reveal. The effects of prior knowledge of the building will also be analyzed in order to see whether there are any significant effects on these categories. It is interesting to note that many of the sub-experts in the full sample had some prior knowledge of the building due to the fact that it is a modern one and modern architecture comprises part of their curriculum; however, preliminary analyses suggests that the performance for these subjects on several of the categories was still lower than that of one participant expert architect who had no prior knowledge of the building whatsoever.

Preliminary analysis of these data suggest that the processes involved in comprehending architectural drawings are different, both quantitatively and qualitatively, for experts than they are for sub-experts. These differences, if substantiated by analyses of variance, may be attributed to differences in strategies employed in generating a semantic description of the building, and in the effectiveness of the processes associated with different categories or types of descriptive. In addition, prior knowledge of engineering, building functions, principles for structuring space, geometric principles used in design, and principles governing movement in architectural spaces are certainly involved. What is clear, however, is that very complex and differentiated semantic information structures are involved in the comprehension of architectural plans, and that these structures can be uncovered through a semantic analysis of natural language interpretations.

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