10.12.91/NOB

DRAFT FOR COMMENTS

MATCHING INFORMATION AND INTERFACE MODALITIES
An Example Study

Niels Ole Bernsen, Centre for Cognitive Informatics, Denmark

Summary: The paper presents an example study of information/interface modality matching in the domain of static 2-D graphical information display. The aim is to demonstrate the possibility and usefulness of an analytic and taxonomic approach to the study of interface modalities as vehicles for information presentation. The paper starts from an intuitive classification of static 2-D graphical information presentations or modalities; analyses these modalities into sets of information channels; revises the initial intuitive classifications based on the channels analysis; and provides matches between the analysed graphical modalities and the types of information for the presentation of which they are most well suited. This matching illustrates how to perform a theoretically justified selection of graphical modalities for the display of information having the described properties.

1. Introduction

Modern interface display technology, and not least graphical and multimedia interface technology, today has put at our disposal a range of presentation modalities which are superior to classical command languages and telegraph-style words and text for many human-computer interaction purposes. For instance, it is in many cases possible to develop, for a given type of information to be displayed, interface modalities having the same, e.g., spatial, semantics as that of the information to be exchanged at the interface. More generally, visual display technology will soon be capable of providing us with all or most known kinds of visual experiences. The advances in interface technology are bringing about a situation in which there are more and more possible combinations of interface presentations, modalities, and channels available for displaying a given body of information. In order to optimally handle this one-to-many matching situation, there is a need for a deeper understanding of the semantic contents of the information to be displayed as well as the semantic information-displaying capabilities of interface modalities. The development of a theory for information-interface matching and subsequent transformation (or mapping) of the information to be displayed into a suitable combination of interface modalities is an interesting possibility for supporting the choice of human-computer interfaces in particular cases.

This paper presents an example study of information/interface modality matching in the domain of static 2-D graphical information display. The aim is to demonstrate the possibility and usefulness of an analytic and taxonomic approach to the study of interface modalities as vehicles for information presentation. The paper departs from an intuitive classification of static 2-D graphical information presentations or modalities; analyses these presentations into parameter sets in terms of information channels; revises the initial intuitive classifications based on the channels analysis; and provides matches between the analysed graphical modalities and the types of information for the presentation of which they are most well suited. This matching allows a theoretically justified selection of graphical modalities for the display of information having the described properties. When generalised beyond the example study presented here, the approach offers the promise of providing a powerful tool for the selection of appropriate interface modalities for the display of given types of information in interface design and hence for solving the one-to-many matching problem mentioned above. The theoretical foundations for the approach are being described elsewhere (Bernsen, in preparation).

2. An example study

A recent paper (Lohse et al. 1991) describes two experiments using subjects with different backgrounds which converged on identifying hierarchically structured categories of visually conveyed, static 2-D graphical information types. A broad sample (40 different items) of graphical representations was used and subjects were judging these according to perceived (rather than functional) similarities and differences. The result was five main clusters indicating the existence of five distinct graphical information categories: *network charts, diagrams, maps, icons, and graphs/tables.* Each category (except icons, of which only two were used) had a more or less complex subcategory structure which was not analysed in the paper. Subjects took an intuitive approach to the classification. The paper offers few suggestions about the parameters which might (or should) have been operative in subjects' intuitive classifications. The following is an attempt to provide the relevant parameters. For each presumed graphical modality (a) a description is provided followed by (b) a list of the examples used, (c) an analysis of the information channels characterising the modality, and (d) a summary describing the crucial aspects of the modality (the letters and numerals in the examples sections below indicate the bottom-level clusterings of examples made by subjects in the experiments of Lohse et al. 1991).

1. *Network charts:*

- have a number of discrete components spatially distributed in (normally) 2-D and each consisting of symbols in boxes of one or more shapes; box shapes provide an extra channel of information and may be given conventionally created semantic significance (described symbolically somewhere on the chart);

- a network chart shows the interrelationships among its components by lines, arrows, or containment; connections between components may be labelled;

- the planar dimensions (e.g., top-to-bottom or left-to-right) of the network chart may or may not carry meaning;

- a good network chart has an efficient spatial arrangement of the components that is parsimonious and avoids intersecting lines;

- symbols indicate the presence or absence of data elements;

- meaning results (1) from an efficient spatial arrangement of the components, from (2) the meaning of the symbols, (3) sometimes from the conventionalised box shape meanings, and (4) sometimes from the use of planar dimensions to carry meaning;

- the components have no analogue correspondence with real world objects or geographic locations;

- network charts often impose a considerable cognitive task load for their decoding: users must read and view the relationships among the components to extract knowledge from the visual representation.

Examples:

a1 - organisational chart (hierarchy);
a2 - data model;
b - decision tree;
c1 - pert chart;
c2 - flow chart;
d - conceptual data model.

Channels:

- distribution of components laid out on the display;
- symbolically described components;
- boxes indicating components;
- box shapes;
- connections between components;
- connection types;
- symbolic labels on connections;
- basic metaphors, e.g., time runs from left to right; more is up, less is down (cf. Lakoff 1987);
- further information channels can be opened using, e.g., colouring or texture. Their conventional semantics is explained symbolically.

Figure 1. Network chart showing a work analysis of patient hospitalisation (from Rasmussen et al. 1991).

Summary: Network charts (using boxes, lines, arrows, containment, etc.) visually display interdependencies (and the lack of them) between symbolically described components. Insofar as network charts have an analogue character at all, this is due to the use of basic

metaphors (such as, e.g., that time is an imaginary dimension running from left to right in the chart). Network charts are close to natural language descriptions but are superior in their ability to display complex structure, interdependence, decomposition, sequence, and flow in abstract (including temporal) domains. Network charts can be considered as diagrams for abstract domains (see below).

2. *Diagrams:*

- diagrams express spatial information;

- like network charts, diagrams include the use of symbols to express information; however, in diagrams, symbols are being used to annotate displayed visual objects or situations which, although more or less simplified (or idealised or "prototypified"), have direct analogue correspondence with real objects so that they can be recognised on the display;

- this analogue relationship means that diagrams are limited to describing the structure of physical objects and situations or interrelationships and processes (including the temporal domain) associated with physical objects and situations;

- diagrams can present objects and situations at many different levels of abstraction; presentation at different levels of abstraction can be combined in one presentation;

- distinction can be made between *structure diagrams* and *process diagrams;*

- process diagrams require more effort to extract information than structure diagrams (presumably in part because temporal relationships have to be interpreted).

Examples:

a1 - Gibberellins;
a2 - circular tree diagram;
b - wheelbarrow ("exploded");
c1 - heart (parts described);
c2 - microscope (parts described - less abstract drawing than c1);
d - floorplan;
e1 - nitrogen cycle (air-soil);
e2 - microbiology;
f - cockpit air conditioning (layout).

Channels:

- recognisable spatial object or situation;
- recognisable properties and components;
- symbolically described properties and components;
- connections between components;
- connection types;
- symbolic labels on connections;
- further information channels can be opened using, e.g., colouring or texture. Their conventional semantics is explained symbolically.

Figure 2. Two diagrams jointly showing a structural decomposition of a screen environment (from May et al. 1990).

Summary: Diagrams symbolically describe components and properties of spatial objects and situations and of processes involving these while depicting them at the same time. The latter, and crucial, analogue aspect of diagrams makes them superior to natural language descriptions in their ability to display complex structure, interdependence, decomposition, sequence, and flow in spatial and spatio- temporal domains.

3. *Maps:*

- maps express spatial data;

- maps depict geographic location with various levels of abstraction of the true positions and spatial interrelationships of objects;

- maps have an analogue relationship to what they represent and are most often continuous rather than discrete;

- as in the case of the network chart boxes which might be given extra semantic significance by the symbolic and conventional association of different meanings with different box forms, maps may be given extra semantic significance through the symbolic and conventional association of different meanings with different colourings and texturings of map parts.

Examples:

a1 - UM campus (showing buildings);
a2 - Pittsburg map;
b - Crater Lake (perspectival map);
c - bus routes (highly abstract);

d1 - USA murder rates (textured map);
d2 - USA tornadoes (dotted map).

Channels:

- recognisable geographical setting;
- recognisable properties and/or components;
- symbolically described properties and components;
- connections between components;
- connection types;
- symbolic labels on connections;
- further information channels can be opened using, e.g., colouring or texture. Their conventional semantics is explained symbolically.

Figure 3. Two maps on the computer screen with different resolutions (from Barnard et al. 1991).

Summary: Maps are a special case of structure diagrams presenting spatial relationships between geographically significant positions.

4. *Icons:*

- are more or less abstract pictures with a single intended, unitary interpretation or meaning;

- icons can be pictures of typical exemplars of objects (*representational icons*); they can be abstract pictures containing some semantic "hint" as to what they represent (*abstract icons*); they can be fully abstract so as to contain no semantic "hint" as to what they represent (*arbitrary icons*, cf. Lodding 1983). Finally, icons can be symbolic abbreviations or acronyms (*symbolic icons*);

- icons can have recognisable properties or components the variations on which may be used to create a set of more or less similar icons with different interpretations (symbolically) assigned to them. In such cases, the properties or components act as channels of information;

- in many cases, icons are easy to decode since their meaning is well-known to users. In other cases, however, when icons are introduced on computer screens and are given a functional role in user task performance, their intended meaning and functionality is not self-evident to users and has to be explained and learned. In some cases, such as the Macintosh waste paper basket, the *function* of a screen icon is partly contrary to its immediate *meaning* (moving a diskette icon into the waste paper basket icon does not destroy the contents of the diskette but merely allows it to be ejected from the disc drive);

- icons, when well-designed, can be as self-explanatory and easy to learn and recognise as are words or symbolic expressions when users who are new to them have to perform a well-known task using them (Blankenberger and Hahn 1991);

- with experienced users, however, and assuming that icons have stationary positions on the screen, the specific character of an icon serving some particular function does not matter much: users establish a direct *screen location/functionality* association which is no longer dependent on the characteristics of the icon (Blankenberger and Hahn 1991);

- choice between icon design options is primarily of importance to (1) the phase of learning to perform a task with an interface, (2) tasks where users are normally novices, and (3) switching between different interface-task combinations where the mismatch between different icons and icon locations vs. unchanged functionality may cause problems;

- the utility of introducing arbitrary icons can be doubted, unless their introduction is likely to form a new standard in some domain. Even then, representational or abstract icons would seem preferable.

Examples:

a1 - Highway signs;
a2 - IBM logo.

Channels:

- iconic picture;
- recognisable properties or components;
- symbolic labels attached to icons;
- further information channels can be opened using, e.g., colouring, texture, or deformation to differentiate otherwise identical icons. Their conventional semantics is explained symbolically.

Figure 4. Abstract and representational icons with structural descriptions attached (from May et al. 1990).

Summary: Icons act as short-hand notations for labels (Lohse et al. 1991). As such, icons can be used for as many purposes as can symbolic labels. In current interface design, the use of icons focuses on representational or abstract icons having a semantics which is related to their task-relevant functionality. Such icons are used to guide mouse input to the system, to provide system state information, reminders, warnings, etc.

5. *Tables and Graphs:*

- *lists* are spatially ordered alphanumeric (or other) information; the order is simple: there is just one column;

- *tables* are lists or matrices (with several rows and/or columns) of primarily alphanumeric information;

- tables are discrete, symbolical, and propositional;

- *graphs* have 1-, 2-, or 3-D axes (in a somewhat extended sense of this term, see examples section below); the axes incorporate alphanumeric information and define a *graph space* which is being used to display data in a corresponding number of dimensions using points, lines (curves), areas, volumes, or clusters;

- graphs are easier to scan for trend information and other global information than are tables;

- point-reading from a table is easier than point-reading from a graph since graphs require recourse from the graph space to the axes.

Examples:

a1 - Dot chart: two alphanumerically described axes plus a 2-D space with systematically distributed dots;
a2 - Dow Jones averages: two alphanumerically described axes plus a 2-D space with a jagged (trend) line in it;
b - Gantt chart (a schedule): two alphanumerically described axes plus a 2-D space with bars of different sizes;
c1 - dollar bar chart (two dollar bills cut into bars): two alphanumerically described axes plus a 2-D space with dollar bill chunks of different sizes;

c2 - pie chart: circular, partitioned graph space for which the circumference acts as axis; corresponds to one alphanumerically described standard axis plus a 2-D space with chunks of different volumes or bars of different sizes;
d1 - response surface (three dimensions shown): three alphanumerically described axes plus a 3-D space occupied by a curved surface;
d2 - soil triangle; in this equilateral triangle, the three sides act as axes;
e1 - oil barrels (a row of them in different sizes);
e2 - yen vs. dollar (with big arrows pointing downwards);
f - Tale of two cities;
g - auto repair records;
h1 - t-table (rows and columns of figures): table: spatially ordered alphanumeric information;
h2 - spreadsheet budget (rows and columns): table: spatially ordered alphanumeric information;
i1 - periodic table (standard presentation with rows and columns): table: spatially ordered alphanumeric information overlaid by groupings of items in boxes;
i2 - list of integrals: list: spatially ordered alphanumeric information.

Channels:

Tables:
- symbolic information;
- rows;
- columns;
- additional channels can be opened using, e.g., boxes, highlighting, bold, italics, etc., as symbolically explained somewhere on the table.

Graphs:
- axes (one, two, or three orthogonal, a circle circumference, a triangle's sides, etc.);
- symbolic information along the axes;
- a graph space defined by the axes;
- dots;
- lines (curves);
- areas;
- volumes;
- clusters;
- symbolic annotations in graph space;
- objects from the semantic domain of the graph having the role of dots, curves, areas, or volumes;
- further information channels can be opened using, e.g., colouring or texture. Their conventional semantics is explained symbolically.

Figure 5. Table with (1a) payments, (1b) amount paid, and (1c) debt. A bar chart providing the same information as in (1b).

Summary:

Tables order discrete, symbolic information in one or two dimensions. Extra information channels may be opened in order to display different roles of the data or additional order among the data. The use of two dimensions facilitates viewing correspondencies between different rows and columns. Tables are otherwise close to natural language data enumerations.

Graphs consist of a number of symbolically specified axes defining a non-symbolic space within which information is spatially represented using abstract dots, curves, areas, volumes, and clusters or identifiable objects having the same basic functionality as the dots, curves, areas, volumes, and clusters. The space allows the representation of global relationships among data in a way which is (more or less) clear and easy to access for quantitative comparison, spotting of trends, global profile, etc.

3. Concluding discussion

As can be seen from the channels analysis above, we end up with a somewhat different taxonomy of static, 2-D graphical modalities from the intuitive results experimentally obtained by Lohse et al. (1991).

We have seen that *network charts* can be considered as diagrams for abstract domains. The domains being abstract, network charts are only able to utilise a limited amount of non-symbolic information. Metaphors may of course be introduced *ad libitum,* but they are not essential to the informational contents being communicated. *Diagrams*, although no better off than are network charts as far as the temporal dimension is concerned, are able to exploit analogue representations of spatial information about objects and situations, their properties and components and the processes involving them. In this way, diagrams merely or primarily have to "annotate" the depicted objects or situations. *Maps*, as it turns out, are merely a special case of (structure) diagrams. Since there is a basic (non-spatial analogue vs. spatial analogue) difference between network charts and diagrams, it is *not* the case that they form a continuum of possible representations. The closest they can get to each other would seem to be when, in a diagram, the 2-D space is merely used to indicate spatial distinctness between spatial or spatio-temporal components, so that the visible spatial relations between components have no significance otherwise. Such cases can be found in, e.g., the domain of computer network diagrams.

Icons, being short-hand notations for symbolic labels, would seem potentially preferable to these primarily in their representational or abstract forms. It is their short-hand character, rather than their analogue character, which seems to imply that their functionality nearly always has to be explained to users or learned by trial and error.

Whereas maps are a special case of diagrams, *tables* and *graphs* turn out to be generically different. The difference is that graphs, but not tables, involve a symbolically defined space within which data and information can be globally represented using discrete or continuous geometrical quantities. These quantities only accidentally (even though they may have been so designed through the use of metaphor or metonymy) bear analogue relationships to real-world objects. The temptation to classify together tables and graphs derives, it seems, from the fact that *any collection of data or information which can be represented in tables can also be represented in graphs, and vice versa* (more on the temptation below). Both in practice and in theory, however, as indicated above, the standard route of information presentation refinement goes from tables to graphs.

The taxonomy is presented in Figure 6. Figure 6 is a network chart presenting a structural analysis of the abstract domain of static 2-D graphical modalities.

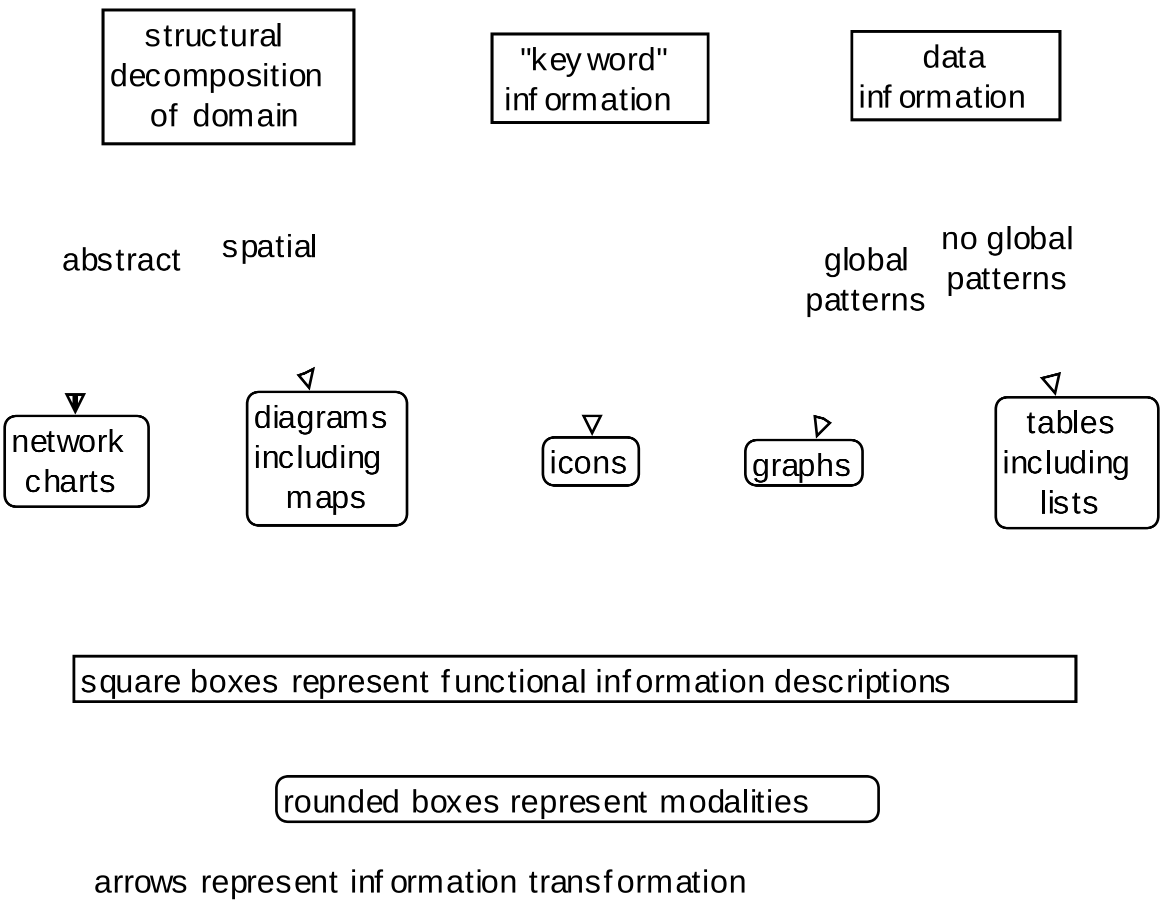

Figure 6. A taxonomy of static 2-D graphical modalities.

The main, important differences within the taxonomy are as follows:

Network charts vs. diagrams (including maps):

Common property: presentation of structural analysis of complex domains.

Main distinguishing property: presentation of abstract domains without any essential use of visually analogue characterisation vs. presentation of spatial domains partly characterised in a visually analogue manner.

Network charts vs. graphs and tables:

Common property: No essential use (as distinct from the use of metaphor or metonymy) of visually analogue presentation.

Comment: Graphs may use analogue representations, but seem to do so only accidentally in the sense that the quantities represented might just as well have been represented in a more abstract manner. Similarly, network charts may use analogue representations of nodes in some cases, but again that would only be an accidental use of analogue representations.

Main distinguishing property: presentation of structural analysis of domain vs. no presentation of structural analysis of domain (i.e., at best, in graphs, we have a structured presentation of data as being *correlated* with something described on the graph axes). Structural domain decomposition and data presentation are two very different functions, so we should not expect any representational continuum to exist between network charts, on one hand, and graphs and tables on the other.

Graphs and tables vs. diagrams (including maps):

Common property: there are hardly any common properties worth mentioning and hence no representational continuum to be expected.

Main distinguishing properties: no presentation of structural analysis of domain (i.e., at best we have a structured presentation of data as being correlated with something described on the graph axes) vs. presentation of structural analysis of domain; no essential use of visually analogue presentation vs. essential use of visually analogue presentation.

Icons:

Icons are so obviously different from the other types of modality that there is no need for elaboration on this point.

Tables and graphs:

The distinction between tables and graphs has been defined above. The common property of tables and graphs is that of providing a structured presentation of data. That is why they are to a large extent interchangeable as far as represented information contents are concerned. The limit seems to be that of continuous quantities. Some kinds of graph can represent continuous quantities whereas it is difficult to represent continuous quantities in tables (except when incorporating mathematics). The interchangeability of graphs and tables with respect to information contents means that *it makes sense to compare, for the purpose of user accessibility and for a given set of information to be displayed, the use of different kinds of graphs and tables.* Such comparisons hardly make sense across the other modalities we have been looking at, whereas *intra-modality* comparisons are highly important for human-computer interaction purposes.

Clearly, what has been said above constitutes a first set of hypotheses based on a limited data set. A next step is to test the hypotheses against a much larger set of static 2-D graphical modalities. Reality may still turn out to behave in ways that are less clear-cut than we have been led to believe so far. However, the differences which have been found between the analysed modalities appear to be sufficiently deep to ensure the unlikelihood of a drastic change of the taxonomy. A further step will be to look for other modality types within the class of static 2-D graphical modalities in order to complete the taxonomy at this level. After that, if the system for modality characterisation turns out to work reasonably well, it will be appropriate to go beyond static 2-D graphical modalities and investigate other kinds of graphical representations (3-D, non-static, animated, etc.) as well as other multimedia modalities.

As indicated in the introduction, the ultimate purpose of analyses of the kind exemplified above is to provide a theoretical foundation for (1) *matching* a class of information to be graphically displayed on the computer interface (in this case, the screen) with possible interface modalities for displaying that information, and (2) computing an optimal, for the purpose of user performance, *transformation* of that information into graphical interface modalities. It is already possible to draw some tentative conclusions on guidelines for information transformation for interface design and other kinds of graphical information display from what has been said above. The conclusions are as follows:

- *if* what has to be displayed is a structural analysis of a complex abstract domain (possibly including time), *then* use network charts;

- *if* what has to be displayed is a structural analysis of a complex spatial domain (possibly including time), *then* use diagrams (including maps);

- *if* what has to be displayed is a set of data *and* it is not necessary (or possible) to display global patterns of organisation in the data set, *then* use tables;

- *if* what has to be displayed is a set of data *and* it is necessary (or possible) to display global patterns of correlational organisation in the data set, *then* use graphs;

- *if* what has to be displayed is a set of short-hand command and/or information items, *then* use either short-hand labels or representational, abstract, or symbolic icons having a semantics which is as close as possible to the semantics of the command and/or information item to be communicated.

Obviously, the types of static 2-D graphic modalities which have been considered in this paper are not optimal for all kinds of graphical information presentation. Other static 2-D graphic modalities which have not been considered may be even more useful for some purposes or the optimal solution may be one of using 3-D graphical modalities, non-static graphical modalities, or other solutions (multimedia, virtual reality, etc.).

References

Barnard, P.J., May, J., and Green, A.J.K.: Preliminaries for the application of approximate cognitive modelling to design scenarios. Esprit Basic Research Action AMODEUS, Project Document RP4/WP11, 1991.

Bernsen, N.O.: Toward a framework for multi-media interfaces (in preparation).

Blankenberger, S. and Hahn, K.: Effects of icon design on human-computer interaction. *Int. J. Man-Machine Studies* 35, 1991, 363-77.

Lakoff, G.: *Women, Fire, and Dangerous Things: What Categories Reveal about the Mind.* Chicago: University of Chicago Press 1987.

Lodding, K.N.: Iconic interfacing. *IEEE Computer Graphics and Applications* 3, 1983, 11-20.

Lohse, G., Walker, N.. Biolsi, K., and Rueter, H.: Classifying graphical information. *Behaviour and Information Technology* Vol. 10, No. 5, 1991, 419-36.

May, J., Barnard, P.J., Böcker, M., and Green, A.J.K.: Characterising structural and dynamic aspects of the interpretation of visual interface objects. Paper presented at the Esprit Conference 1990.

Rasmussen, J., Mark Pejtersen, A. and Goodstein, L.: Cognitive Engineering: Concepts and Applications. Draft April 1991.