

Design method of interaction techniques for large information spaces

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ABSTRACT

Our work focuses on the design of interaction techniques for large information spaces. Our goal is not to define yet another visualization technique but to provide insights for the design of such techniques. Our design approach is based on ergonomic criteria that arose from a study of how the user perceives and manipulates a large information space. We then provide design rules that should help the designer in devising an interaction technique that verifies the ergonomic criteria. After the design of the interaction technique, the next step is software design. We establish links between our design rules/ergonomic criteria and the software architecture model. By applying our PAC-Amodeus model, we show how the software architecture model helps to either verify or assess the ergonomic criteria. We therefore adopt a predictive evaluation approach to the design of interaction techniques for large information spaces. We illustrate our design approach and results through our VITESSE system.

KEYWORDS: Design Method, Navigational Task, Ergonomic Criteria, Fisheye View, Software Architecture.

INTRODUCTION

One of the new design challenges for the domain of Human Computer Interaction (HCI) and Information Systems (IS) is the need to manage large quantities of information which is available to a variety of users having different information needs. For example in Information Retrieval Systems (IRS), we study the accessibility of the retrieved information. While most IRS rely on the power of indexing and search mechanisms, we focus on the user interface of such systems and on navigational interaction techniques because they can play a central role in accessing the retrieved information. Indeed the aim of navigational techniques is to maximize the amount of information perceivable and manageable by the user.

This paper focuses on the design of visualization and interaction techniques for large information spaces. We provide design rules identified from ergonomic criteria. We then illustrate the criteria and rules with our own system, VITESSE [22, 23, 29] that runs on the WWW. In the design method, the last step before coding, is software architecture modeling. In the context of VITESSE, we

demonstrate the suitability of our architectural model PAC-AMODEUS for our criteria and rules. In order to validate our approach we performed an experimental evaluation of VITESSE and we report its results at the end of the paper.

DESIGN METHOD

Our design method is based on a conceptual study of the user, her/his information needs and tasks while handling a huge quantity of information. The results of this conceptual study are used to identify ergonomic criteria that should be verified by the user interface. We then develop design rules that the designer can use for constructing a user interface that verifies the ergonomic criteria. Having designed the user interface, the software design is performed before the coding phase. We also show how the ergonomic criteria can be verified or at least assessed within the software design. This is the first step towards a predictive evaluation of the user interface. Finally the developed user interface can be evaluated using the ergonomic criteria.

The cornerstone of our design method is the ergonomic criteria. As shown in Figure 1, the ergonomic criteria define a bridge between the user's needs and tasks on the one hand and the design on the other. Ergonomic criteria are at the turning point between two worlds: the user study field and the user interface design field.

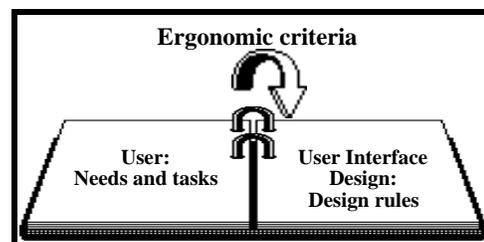


Figure 1: Ergonomic criteria at the turning point between two worlds.

Because of its interlinking location, ergonomic criteria must take into account the properties of both worlds: The criteria must abstract the characteristics of the user and her/his tasks and also define implications onto the user interface design. Figure 2 includes the main steps of our design approach and highlights the central role of the ergonomic criteria. The first step consists of studying the users tasks: In the

following section we provide insights into the task study of this step.

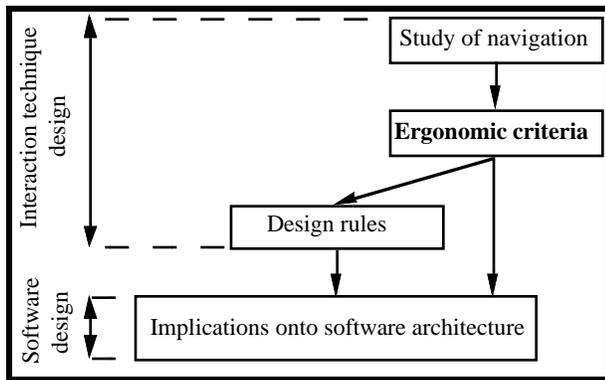


Figure 2: Design approach.

Information Needs and Tasks

Our overall goal is to incorporate the user, her/his characteristics and activities within the design process. For this reason, our design method is based on a conceptual study of the users, their information needs and tasks. When handling a huge quantity of information, the needs and tasks of the user are numerous. Without considering a particular system dedicated to a given domain, identifying all the tasks of the user is difficult. Clearly, tasks are domain-dependent. For example in the TTT taxonomy [26], at a higher level of abstraction, task-domain information actions are required. In addition Cleveland, Kosslyn and Wickens point out that the benefits of a visualization technique are domain-task dependent [14] [25]. The "Structuring the display" [18] method shows that one visualization technique is more appropriate for one particular task than for others by defining structure and transition path diagrams. From these considerations, we can find tools such as BOZ [6] that automatically generate 2-D graphics based on a description of the tasks to be performed. The BOZ system maps the description of the tasks onto perceptual operators in order to generate an optimal graph. In addition to the fact that tasks are domain-dependent, it is quite difficult to evaluate how a visualization technique best maps a task [28].

A more recent approach for tackling the problem is to identify the sub-tasks that define the domain-dependent tasks. These sub-tasks are domain independent. This approach corresponds to a classical hierarchical task analysis. This study started at a FADIVA workshop [15] where the difficulties of the enterprise were identified. Examples of sub-tasks that have been identified are: searching for a particular piece of information, grouping, comparing, analyzing, creating new information.

The literature is abundant with tasks a user is faced with in dealing with a huge quantity of information: For example the CHI'97 tutorial notes on Information visualization include such a list [12]. Likewise, in the TTT taxonomy [26], seven tasks are defined: overview, zoom, filter, details-on-demand, relate, history and extract.

To sum up, at a higher level of task analysis, tasks are domain-dependent. At a finer grained level of analysis, we

identify general sub-tasks such as the ones of the FADIVA study or the seven tasks of the TTT taxonomy. At this level of analysis, it becomes difficult to identify an exhaustive list of sub-tasks. Based on these considerations, in our design method we consequently adopt an interaction-based approach and we study the elementary tasks the user will perform, namely querying and browsing as defined in the model of information exploration [30]. Based on this model, we consider two relevant dimensions (out of three dimensions in the original space), presented in Figure 3: "Target orientation" and "Structural responsibility".

- The "Target orientation" dimension identifies two tasks, querying and browsing. "Browsing is distinguished from querying by the absence of a definite target in the mind of the user." [30]. Querying corresponds to the task "searching for one piece of information" in the FADIVA Benchmark. In [16], querying and browsing are respectively designated as "searching and browsing" (Figure 3), whereas in [4] they are respectively named "exploration and identifying objects", showing that the terminology is not well established. Nevertheless the distinction between the two tasks is clearly defined and depends on the cognitive state of the user and his/her information needs.
- Structural responsibility refers to the responsibility for performing the task either by the user or the system. Along this dimension, two values are defined: mediated (task performed by the system) and navigational (task performed by the user). In [16], mediated and navigational responsibility are referred to as "querying and navigating". This dimension corresponds to the criterion "Task migrability" in our design space [1] [13]. It refers to the transfer of control for execution of tasks between user and system.

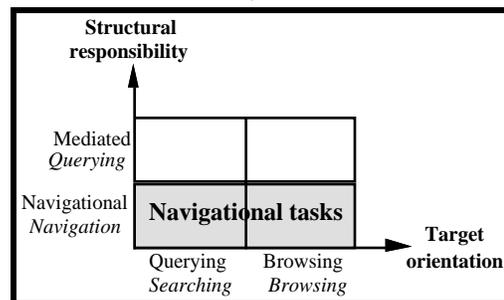


Figure 3: Two dimensions of the information exploration model [30]. (The two dimensions presented during the CHI'97 workshop on Navigation [16] are presented in italics.)

In this paper and as shown in Figure 3, we focus on navigational tasks (querying or browsing). As explained in [8], "attending to navigational issues in design is where we can have a large amount of impact in terms of improving ease of use and appeal in electronic world". In [4] navigational tasks are also described as crucial for the usability of the system. In the following paragraph we characterize navigation in order to identify ergonomic criteria that will then guide the design of navigational interaction techniques.

Navigational Tasks

Our starting point is the model of information exploration: Navigational tasks can involve looking for a definite target or discovering what is available in the space. Navigation consequently addresses the following two questions [10] [4]:

- Where am I now?
- Where is ...? or How do I get to ...? or Is there a ... somewhere in the environment?

The first two questions underline the spatial activities involved in navigational tasks. Additionally the time dimension has also been shown to be crucial [17]. Space and time strategies define intertwined characteristics involved in navigational tasks. Figure 4 presents our framework for characterizing navigation. This framework covers the basic aspects of navigation identified during the CHI'97 workshop on Navigation [16]. For example Darken defines navigation as "Wayfinding + Locomotion".

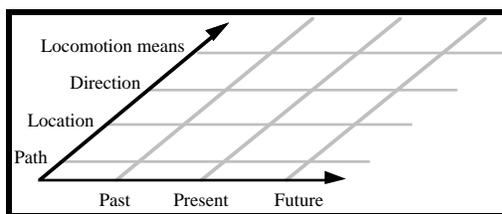


Figure 4: Characterization of navigation.

For the case of navigational retrieval, the user's information needs characterize the navigational task. It is consequently important to study the information needs in order to better understand the task and identify the relevant information to be made perceivable. In [19] [7] we present a taxonomy of users' information needs: We define axes that group various intrinsic properties of an information need. For example the "users' need characteristics" axis identifies two properties: the definition of the need (values from well-defined to fuzzily-defined) and the stability of the need. Navigation is a powerful interaction technique for addressing these issues. Another axis deals with the way information can be designated (connote/denote): These two means of designation require different navigation techniques.

Based on the characteristics of navigation presented in Figure 4, we select the ergonomic criteria that should be verified by the designed navigational techniques. This represents the second step in our design method.

Ergonomic Criteria

We select the ergonomic criteria that are most relevant to navigational techniques. These criteria belong to our criteria space [1] [13]. Three selected criteria contribute to interaction flexibility and three additional criteria are concerned with interaction robustness:

- Interaction flexibility refers to the multiplicity of ways with which the user and the system exchange information. The three selected criteria that contribute to interaction flexibility are: representation multiplicity, adaptability and I/O reuse.
- Interaction robustness covers features which support the successful achievement and assessment of navigable tasks performed by the user. The three selected criteria

which support interaction robustness are: observability, honesty and predictability.

In the following sections, we describe these criteria and their impact on navigation.

Flexibility Criteria

Representation multiplicity involves flexibility of information space rendering in order to face the diversity of user's characteristics and tasks. Multiple representations better support different tasks. Representation multiplicity relies on output multimodality: In [21] we define a modality as the coupling of a physical device d with a representational system r : $\langle d, r \rangle$. As suggested in [4] output multimodality can be fruitfully used in navigation, for example by changing a graphical map into a verbal set of instructions: In this example two devices are used, the screen and the loudspeaker, as well as two representational systems, a graphical and linguistic representation. Multiple representations of the information space using the same device such as the screen is also a case of output multimodality. Representation multiplicity must be distinguished from "interactive" externalizations [28] in which features of the data are made salient as and when required ("filtering" approach). Representation multiplicity and "interactive" externalizations are two complementary approaches for facing the diversity of user's tasks.

Adaptability refers to the user's ability to adjust the form of input and output. For example, the user may have the choice of representation of the information space (in the case of representation multiplicity). As explained in [27]: "On one hand maintaining a consistent structure is vital for learning, but the influence of task and individual exploratory style seems to suggest configuration." The distinction between adaptability and adaptivity (automatic adaptability) is that the user plays an explicit role in adaptability, whereas his role in an adaptive interface is more implicit. Adaptivity in navigation must be carefully used [4]. On the one hand adaptivity is good when locally applied, for example to dynamically show the next paths to follow at a given location. On the other hand adaptivity of the representation of the whole information space is not suitable because of screen stability in order to maintain user context for navigation.

I/O reuse refers to the capacity of the system to allow usage of previous input or output as future input. This allows us to specify an input expression by referring to previous input or output expressions. In navigational techniques, the user must be able to reuse outputs (the information space) as inputs in order to directly manipulate the information space. It leads to faster and more direct interaction with the information space. In addition I/O reuse can reduce the navigational effort. For example using Opendoc, the user can edit foreign documents, directly where they appear without navigational effort: To do so an application can invoke other applications.

Robustness Criteria

Observability allows the user to evaluate the internal state of the system from the perceivable representation of that state. State evaluation allows the user to compare the

current perceived state with the state intended in the action: Such evaluation may eventually lead to a plan revision. Based on our framework of Figure 4, examples of variables that should be observable are: the set of elements (location), the set of links (path), the time to reach an element (locomotion means), the focus of interaction (current location), the local neighborhood (future location, path and direction).

Because of the limited size of the screen, observability of the set of elements is impossible in its entire scope and detail. One interesting solution to the problem is to make observable one sub-set of the elements in detail while maintaining the global set of elements observable without detail, using compression procedures: This approach is called "Focus + Context". The users can therefore rely on the global context to orient themselves and on the current focus to make sense of the local information. Tunnel vision (i.e., loss of peripheral vision) can cause severe disorientation [2].

In [11], we find requirements for a strongly navigable world that are related to the observability criterion. For example:

- Requirement VN1a (residue distribution). Every node must have good residue at every other node. [11]

In other words some residue or scent of the target must be observable by the user from any nodes. This requirement makes Observability of residue a challenging problem [11].

Honesty requires that the observable state is correctly interpreted by the user. Honesty is closely related to the observability criterion. It is an important criterion when distortion functions are used to make the whole information space observable by the user. In such cases there is a high risk of misinterpretation by the user. Generally, the distortion function defines the appearance of elements (size, location, color etc.) based on an estimated degree of interest (DOI) of the user. For example with a fisheye view technique the distortion is based on the distance of the elements from the current location or focus of the user.

Predictability means that user knowledge of interaction history is sufficient for determining the result of future interaction. In dealing with both space and time strategies, predictability is an important attribute of navigational techniques because it enables the user to fully determine the consequences of the next input action: where should I arrive, knowing where I am and where I have been. Consistency is a sub-criterion that contributes to predictability. For example metaphors for information spaces are frequently used in order to assist users in navigating throughout the information space. A metaphor defines correspondences between two worlds: It is crucial that these correspondences are consistent [4].

Design Rules

The above ergonomic criteria are a first step towards designing efficient navigational techniques. Nevertheless these criteria cannot easily be applied for designing interaction techniques. Some of the criteria need

refinements. The natural next step is then to define design rules based on these criteria.

Rules Based on the Flexibility Criteria (Representation Multiplicity, Adaptability and I/O Reuse)

To face the diversity of tasks and users characteristics, we advise use of multiple representational systems in order to make the information space perceivable by the user. The user can then select the representational systems (adaptability of the user interface). However the choice of representational systems must not increase the complexity of the user interface. We define two design rules:

- R1: The representational systems must be easy to change (direct access).
- R2: Temporal continuity must be guaranteed while changing the representational systems in order to provide visual continuity. The user should not be lost in the space because she/he switched from one representational system to another one.

One design solution for providing temporal continuity between two representational systems consists of applying a progressive morphing technique that provides a smooth change from one representational system to another one.

Rules Based on the Robustness Criteria (Observability, Honesty and Predictability)

We define rules for the observability and honesty criteria. As explained above, observability of the information space in its entire scope and detail is impossible. In order to nevertheless satisfy these criteria, we combine several representational systems for rendering the information space. We advocate complementary usage [20] of representational systems in order to satisfy the observability and honesty criteria. Complementarity is one of the principles that is identified in our CARE (Complementarity, Assignment, Redundancy and Equivalence) design space [9].

We first need to characterize a representational system in order to combine the representational systems. We identify three dimensions namely partial/global, precise/vague and distorting/non distorting:

- On the one hand, a representational system is global if it renders the whole set of information. On the other hand, it is partial if only a sub-set of elements is rendered at a given time.
- A representational system is precise if each element is presented with detail and vague if not.
- A representational system may or may not be based on a distortion function.

We can now state three rules related to the observability and honesty criteria:

- R3: The representational system used to present the focus of interaction must be precise and not rely on a distortion function.
- R4: If it is not possible to present the whole information space using one precise and global representational system, two representational systems can be combined, one being (partial, precise) and one (global, vague).

- R5: If two representational systems are combined to present the information space, spatial continuity must be guaranteed between the two representations [17] in order to provide visual continuity.

We define one rule related to predictability and consequently consistency by stating that :

- R6: The navigational tools (locomotion means) must be uniform along the user interface (reusability of the navigation tools).

In [8], we find a principle of design that is related to Rule R6: "A persistent navigational structure must be provided." In addition guidelines for hypermedia generally recommend that the navigational buttons are placed at the same location throughout the user interface.

Conclusion

We think that the ergonomic criteria and the design rules provide a useful framework for the design of navigational techniques in large information spaces, by helping the designer to identify the right questions. We now illustrate the ergonomic criteria and design rules using our VITESSE system. We also show how the applied criteria and rules can be assessed and verified within the software architecture of VITESSE before the coding phase.

THE VITESSE SYSTEM

The VITESSE system visualizes the results of a query submitted to a search engine on the WWW. Results of a web search engine can define a huge information space. The VITESSE user starts by specifying a query sent to a selected web engine and then navigates in the results space. VITESSE is independent of the search engine. It represents a new approach for accessing the WWW and one attempt to face the problems of navigating on the WWW. Such problems of navigation are well-known [3] and can result in getting "lost in hyperspace".

We first describe the user interface design of VITESSE based on our criteria and rules. We then present the software architecture along the PAC-Amodeus model and show how to assess the criteria within it. We finally present the first results of our ergonomic evaluation.

User Interface Design

As shown in Figure 5, VITESSE displays the overall graph structure of the results: Each retrieved page (node) and their links are displayed. One retrieved page or node is displayed by a polygon. For each node we studied the relevant information to be displayed (observability criterion) inside a polygon: Many pieces of "meta"-information are relevant. VITESSE currently displays the creation date and the keywords frequency of a node as well as the connection time between two nodes. We are currently carrying out a survey about the information that should be observable for each node (<http://iihm.imag.fr/demos/UserStudy>). The selection of a node (double click) enables the user to access the web page (I/O reuse). We also studied the shape of the links; two shapes are available: a triangle and an arrow (representation multiplicity and adaptability criteria). On the one hand, triangle shapes visually underline the nodes from which several links initiate. On the other hand a classical arrow

shape emphasizes the nodes at which several links end. The two design solutions are relevant and their suitability depends on the users' information needs and tasks.

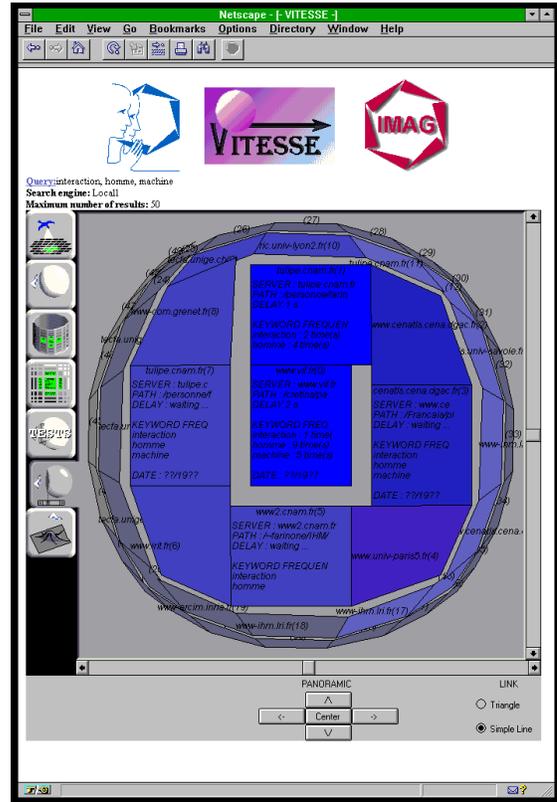
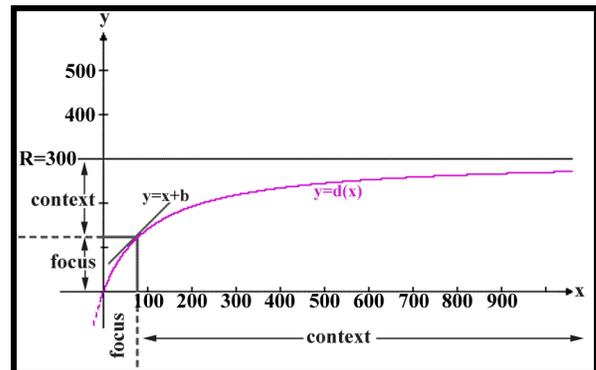


Figure 5: A snapshot from the VITESSE system. (The truncated spherical view is the current one.)

The 2D space is obtained by placing the most relevant retrieved page at the center and then placing the other pages so that they form a spiral around the center. In addition, the background colors of the polygons from blue to gray accentuate the spiral effect. VITESSE allows six representational systems of the space (representation multiplicity and adaptability criteria): birdeye view, polar and cartesian fisheyes. By using the birdeye view and by selecting the zoom option the user perceives the retrieved pages in a 2D space and can zoom in and out of the space. All the other representational systems distort the space and are based on the same following function d:



$$d(x) = \frac{R * Z}{-Z - x} + R$$

$$d^{-1}(x) = \frac{R * Z}{R - x} - Z$$

In the above equations, x denotes the pixel distance to be distorted while R and Z are the distortion parameters. R defines the maximal value of the function. In the above figure, the function d is compared to the identity function ($x=f(x)$), with R having the value 300 pixels. R consequently defines the size of the resulting visualization. For example in Figure 6 (b), R denotes the radius of the spherical view. Z defines the loop effect of the distortion. In the above figure, Z equals 112 pixels. The reciprocal function d^{-1} enables us to calculate the position of the mouse when the user directly manipulates the information space. In addition we used the function d^{-1} to define new representational systems.

Elementary Representational Systems

Based on the distorting function d , we defined four representational systems. All of them are global, distorting and precise for one part of the space and vague for the rest. We can first apply a planar or polar transformation on both the X and Y -axes. We thus obtain the two representational systems of Figure 6 (a) and (b). On the one hand the planar transformation has the advantage of preserving the lines and columns of the initial space (it could be useful if lines and columns have a meaning for the users tasks), and on the other hand the polar transformation is a spherical view of the space: Such a spherical view inclines the user naturally to rotate this space because the shape is known.

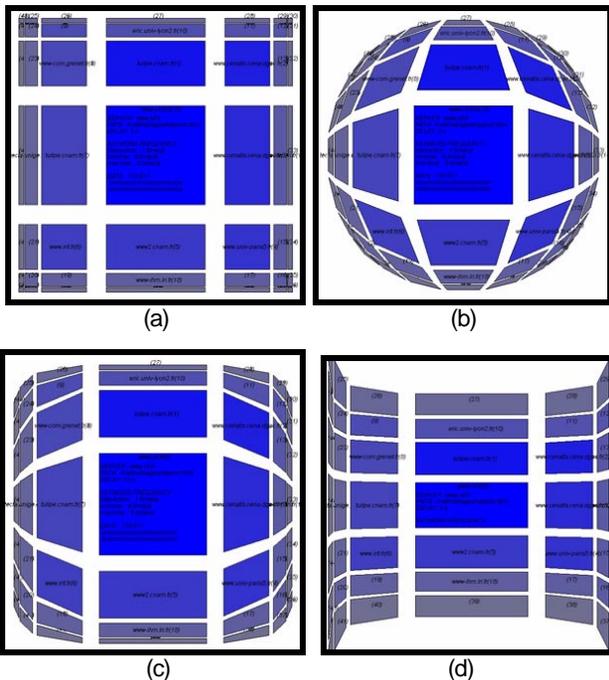


Figure 6: Four elementary representational systems. (a) Planar transformation (b) Polar transformation (c) Planar transformation on the X -axis and polar transformation on the Y -axis (d) Planar transformation on the X -axis and reciprocal polar transformation on the Y -axis.

Another approach consists of applying a planar transformation on the X -axis and a polar transformation on the Y -axis. We then obtain the representational system of Figure 6 (c). Such a system has the advantages of the two previous ones (Figure 6 (a) and (b)). In addition we can also apply a planar transformation on the X -axis and a reciprocal polar transformation on the Y -axis. The resulting representational system of Figure 6 (d) has the disadvantage of loosing in precision as concerns the focus of interaction but provides a better observability of the neighborhood of the focus. The representational system is nevertheless precise for only a part of the space around the focus.

Combined Representational Systems

The above elementary representational systems all define a distorted focus of interaction which is nevertheless precise. Rule R3 is therefore not verified. We consequently apply Rule R4 in order to combine two representational systems. Combined representational systems are based on two functions d and d' that we combine by using a characteristic function c defined on $[0,1]$: $dnew(x) = c(x)d(x) + (1-c(x))d'(x)$

In order to provide the spatial continuity advocated by Rule R5, two solutions are possible:

- The function c is continue.
- The function c is discontinue (value 0 or 1) and changes from 0 to 1 on the X -coordinate V of the intersection point between d and d' . $dnew$ is then defined as follows:

$$dnew(x) = \text{if } (x < V) \text{ then } d(x) \text{ else } d'(x)$$

For example we consider the function $dnew$ defined by combining the previously defined function d with the identity function:

$$dnew(x) = \text{if } (x < V) \text{ then Identity}(x) \text{ else } d(x)$$

Applying the function $dnew$, we obtain the truncated spherical representational system of Figure 7 (a). Such a representational system satisfies Rule R3 because the identity function is applied in order to render the focus of interaction. Rule R4 is also verified because we combine two representational systems, one being (partial, precise) and one (global, vague).

Interestingly, if we combine the function d with the identity function on the other way around:

$$dnew'(x) = \text{if } (x < V) \text{ then } d(x) \text{ else Identity}(x)$$

we obtain the "hill" representational system of Figure 7 (b) that opposes our rules but is quite easily understandable by the user.

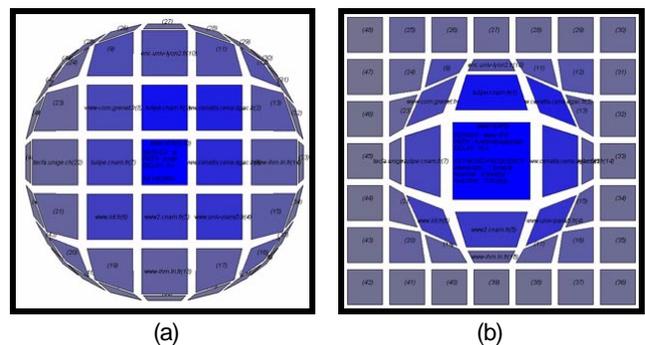


Figure 7: Two combined representational systems. (a) truncated spherical system (b) "hill" system.

Representation Multiplicity in VITESSE

In VITESSE the user has the choice of the six above representational systems. To design the user interface, we applied our rules. In order to make the change easy (Rule R1) we provide a permanent palette of icons on the left side of the space. Each icon symbolically presents the representational systems (Figure 5). At any time the user can freely switch from one representational system to another one. In addition the current selected system is highlighted. The temporal continuity advocated by Rule R2 is developed using a progressive morphing function while changing from one representational system to another one. In addition we used a redundant sonic modality to make the change more perceivable. Figure 8 schematizes the continuous change between two representational systems.

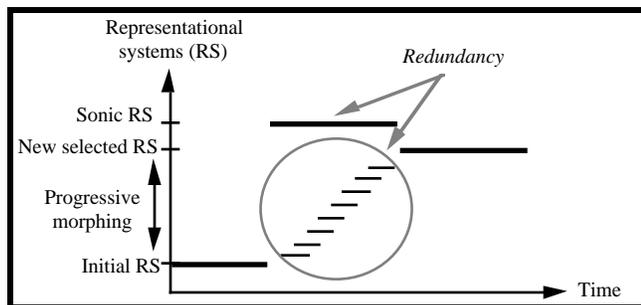


Figure 8: Progressive morphing between two representational systems and the use of a redundant sonic modality.

Finally we provide the same navigational tools for all the representational systems in accordance with Rule R6. The user :

- can directly move the space using the mouse,
- can use the scroll bars for a step-based motion,
- can use the navigational buttons at the bottom of the space (Figure 5),
- can use the center button to return to the most relevant retrieved page.

Software Design

Having explained how we design the user interface of VITESSE by applying our rules, we now focus on software architecture. We apply the PAC-Amodeus [20] model to the design of the VITESSE system. As shown in Figure 9, the PAC-Amodeus model advocates five components and refines the dialogue controller in terms of PAC agents. This refinement has many advantages including an explicit support for concurrency. PAC-Amodeus is geared towards satisfying the flexibility and adaptability software quality criteria, thus allowing efficient management of modifications. We do not describe the software architecture in detail but highlight the benefits of the model applied to VITESSE and the links with the ergonomic criteria and design rules.

Overall Architecture

As shown in Figure 9, the Functional Core Adapter (FCA) serves as a mediator between the Dialogue Controller and the domain-specific concepts implemented in the Functional Core (FC). It is designed to absorb the effects of changes in its direct neighbors. The FCA operates as a translator between its two surrounding components and makes the Dialogue Controller independent of the selected web search engine located in the FC. This is a requirement of our VITESSE system: to be independent of the web search engines. At the other end of the spectrum, the Presentation Techniques Component (PTC) acts as a mediator between the Dialogue Controller and the Low Level Interaction Component (LLIC). Because of the PTC, the Dialogue Controller is independent of the underlying hardware and software platform. In particular each agent of the Dialogue Controller is independent of the JAVA/AWT toolbox that we used to develop the user interface. Finally the Dialogue Controller is refined in terms of a PAC agent. Each PAC agent is composed of three facets: a Presentation that defines its perceivable behavior, an Abstraction that defines the competence of the agent and a Control that maintains links between the Presentation and Abstraction facets. Interestingly each representational system is developed in the Dialogue Controller and is consequently independent of the search engine and the toolbox as well.

Dialogue Controller

We refine here the hierarchy of PAC agents of the Dialogue Controller. We provide a set of rules for deriving the hierarchy of agents in [24]. In the software design of VITESSE we apply two rules :

- R1-PAC: Use an agent to maintain visual consistency between multiple views.
- R2-PAC: Use an agent to synthesize actions distributed over multiple agents.

Each representational system provided by VITESSE is developed by one PAC agent, called the "RS agent". It is consequently easy to add or remove a representational system. The Abstraction part of the RS agent maintains the space. Information is not duplicated and only the positions of the polygons are maintained in the Abstraction facet. The Presentation facet manages the visualization on screen while the Control facet contains the distortion function. In addition we developed an agent, called "Morphing agent" which is a transient agent, dynamically created and destroyed by its parent agent called "Representation Multiplicity agent". The Morphing agent has the responsibility for providing temporal continuity while changing the representational system. Applying Rule R1-PAC, we obtain the hierarchy of Figure 10 (a). We then apply Rule R2-PAC in order to add an agent called "Navigational tools agent". The Presentation facet of the Navigational tools agent manages the buttons displayed at the bottom of the information space. Each action performed on the buttons must be sent to the RS agent. Applying Rule R2-PAC, we define one agent called "Cement agent" and we obtain the final hierarchy of Figure 10 (b).

Software Architecture and Ergonomic Criteria/Design Rules
 Based on this software architecture, we can conclude that the PAC-Amodeus model delivers the representation multiplicity criterion because of agent decomposition. Rule

R2 "temporal continuity" is delivered by the model because of the existence of the "Morphing agent". In addition Rule R6, "Reusability of the navigational tools" is again

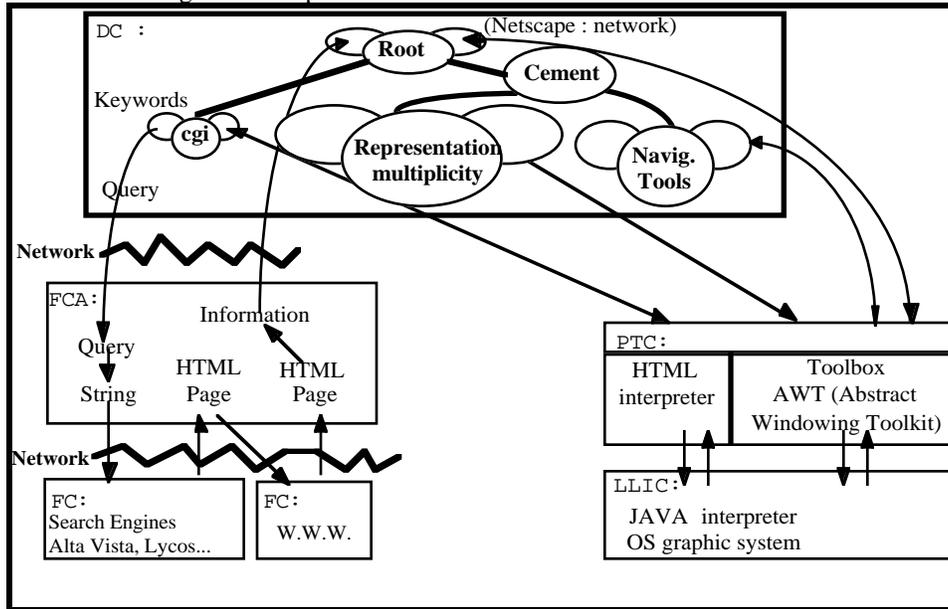


Figure 9: The overall architecture of VITESSE applying the PAC-Amodeus model.

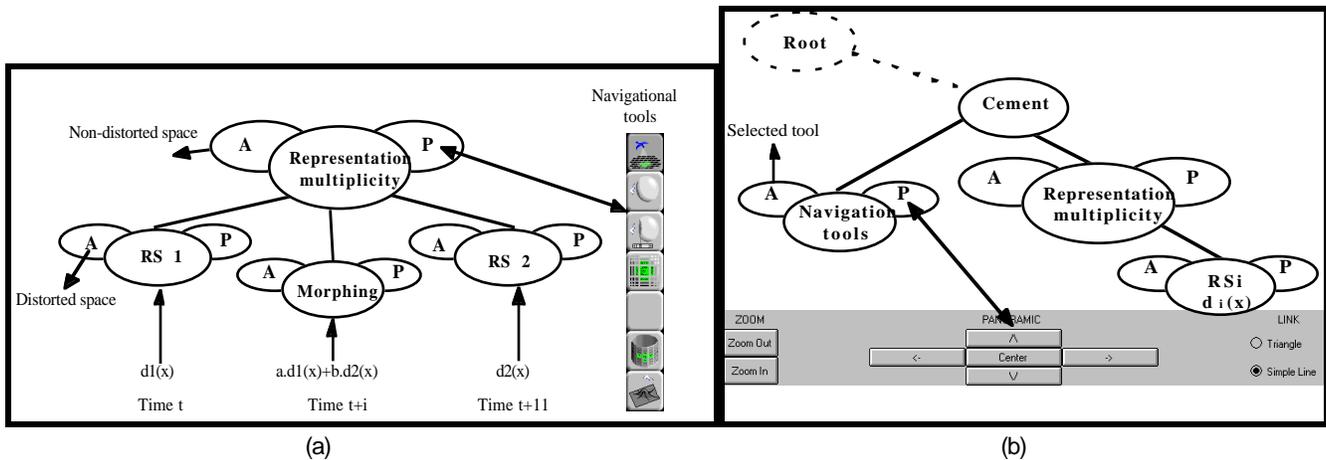


Figure 10: Dialogue Controller: (a) First refinement step (b) Final refinement step.

delivered by the model because of agent decomposition: The fact that there is one "Navigational tools" agent common to all the representational systems guarantees this.

The characteristics of each representation system and the corresponding design rules (Rules R3, R4 and R5) can be assessed by checking the RS agents. Consequently the model does not carry these criteria and rules but supports its assessments by locating where the criteria should be implemented. Finally Rule R1, "easy to change the representational system" can be assessed within the Presentation facet of the Representation Multiplicity agent. Again the model does not deliver the rule but supports its assessment.

Usability Testing

We carried out an experimental evaluation of VITESSE based on various scenarios. The goal of the experiment was to evaluate the usability of the representational systems and the navigational tools provided by VITESSE. To do so our scenarios include the two navigational tasks of Figure 3: searching and browsing. We skipped the query specification phase in order to have a constant information space.

We asked 17 participants (8 males and 9 females) to perform the scenarios. All of them were non-computer scientists between 20 and 40 years old. They all know how to use a computer and 76% of them use a computer in their professional activities. None of them know how to use a search engine and surf on the web. Except for one,

participants were working in couples. Each couple of participants know each other (typically two colleagues at work) and we asked them to think aloud and to provide explanations.

During a test session, we filmed the users actions, the screen and recorded all the exchanged information and explanations between the two participants. At the end of each session, we asked the two participants to comment on the recorded session and explain the difficulties. Each session lasted two hours, one hour for performing the scenarios and one for commenting on the experiment.

Users' reactions were positive overall and they all succeeded in completing the scenarios. The use of multiple representational systems has been observed. At most, three different representational systems have been used during a session. Globally, for each representational system the percentage of usage is:

- zoom or birdeye view: 61% (non distorting view)
- spherical view: 20% (Figure 6b)
- cartesian view: 9% (Figure 6a)
- truncated spherical view: 6% (Figure 7a)
- cylinder view: 2% (Figure 6c)
- hill view: 2% (Figure 7b)

We identify four types of usage of the multiple representational systems:

- Exclusive usage of the birdeye representational system: 61% of the participants adopted this usage. However, quantitative analysis of the data highlights that this usage implies: more elementary actions (zoom in and out) and more time to complete the scenarios.
Most of the participants explained to us that this representational system is quite familiar and consequently more understandable.
- Combined use of the birdeye system with another one: The birdeye system was first used to get a global view and locate an area of interest. The users then changed the representational system in order to obtain a precise focus. We observed that after time the users did not come back to the birdeye view, showing that they developed a cognitive map while using a distorting representational system.
- Exclusive usage of a distorting representational system: The spherical system and the truncated spherical system were more often used because the resulting representation corresponds to a familiar shape.
- Test/Retry usage: Some of the participants visited web pages without previously obtaining information about the pages. The corresponding polygons were not in the focus.

In conclusion, some of the evaluation results confirm that our criteria and design rules are valid. Nevertheless more usability testing must be carried out, with more participants. The most encouraging points of this usability testing are:

- Many of the participants use different representational systems based on their tasks,

- although the users prefer the birdeye view at the beginning, they then work with the distorting views showing that they are able to develop a cognitive map of the space.

SUMMARY AND FUTURE DIRECTIONS

The goal of the work presented here has been to gain understanding of navigational techniques and their design. We think that the ergonomic criteria and the design rules provide a useful framework for the design of navigational techniques in large information spaces, by helping the designer to identify the right questions. In addition we identify hooks between the user interface design and the software design: We show how our ergonomic criteria and design rules can be verified or at least assessed within the software design by applying our PAC-Amodeus architectural model. We illustrate each step of our design method, from the tasks analysis step to the software design step using our VITESSE system and present results of an ergonomic evaluation of VITESSE.

In one research avenue we will further exploit output multimodality to enhance the navigational techniques. Multiple representation systems are one case of multimodality involving use of one output physical device (i.e., the screen). In VITESSE we also used a sonic modality in a redundant way with graphical animation to highlight the transition between two representational systems. We have recently developed dynamic sonic landmarks: Sonic landmarks vary according to the focus of the user. To mark an element, we developed a toolglass [5] that enables the user to select both the sonic landmark and the location by performing one click . We now need to test its usability.

In another research avenue we will focus on collaborative navigation in the same information space. We have developed another extension of VITESSE that enables the user to know what others think about a particular web page. To do so we developed a magic lens [5] that displays the opinions of others to be superimposed on the information space. This is one case of asynchronous collaborative navigation. We now plan to work on synchronous navigation. If we are operating, based on the design space of Figure 3, we need to add a new value called "another user" on the "Structural responsibility" axis: In other words for a given task (querying or browsing) we now have three cases: the user, the system or another user responsible for performing the task.

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REFERENCES

1. Abowd, G., Coutaz, J. and Nigay, L. Structuring the Space of Interactive System Properties. Engineering for

- the Human-Computer Interaction, Elsevier Science Publishers B.V., 1992, 113-128.
2. Beaudoin, L., Parent, M.A., Vroomen, L. C. Cheops: A Compact Explorer For Complex Hierarchies In Proc. of Visualization 96, San Francisco, October 1996.
 3. Benford, S., Snowdon, D., Brown, C., Reynard, G. and Ingram, R. The populated web: Browsing, searching and inhabiting the WWW using collaborative virtual environments. In Proc. of INTERACT'97, Sydney, 14-18 July 1997, 539-546.
 4. Benyon, D., Höök, K. Navigation in Information Spaces: supporting the individual. In Proc. of INTERACT'97, Sydney, 14-18 July 1997, 39-46.
 5. Bier, E., Stone, M., Fishkin, K., Buxton, W., Baudel, T. A Taxonomy of See-Through Tools. In Proc. of CHI'94, Boston, April 24-28 1994, 358-364.
 6. Casner, S. A Task-Analytic Approach to the Automated Design of Graphic Presentations. ACM Transaction Graphics, Vol. 10, No. 2, April 1991, 111-151.
 7. Chevallet, J-P., Gauthier, G., Mulhem, P., Nigay, L. Conception des Systèmes de Recherche d'Informaztion Multimédia. In Proc. of IHM'96, Grenoble, 16-18 Sept. 1996, 85-90.
 8. Czerwinski, M. Navigation in Electronic Worlds-Do or Die. CHI'97 Workshop on Navigation in Electronic Worlds, Atlanta, March 23-24, 1997. <http://www.research.microsoft.com/research/ui/marycz/chinav97.html>.
 9. Coutaz, J., Nigay, L., Salber, D., Blandford, A., May, J. and Young, R. Four Easy Pieces for Assessing the Usability of Multimodal Interaction: The CARE properties. In Proc. of INTERACT'95, Lillehammer, June 1995, 115-120.
 10. Dieberger A. Navigation in Textual Virtual Environments using a City Metaphor. PhD thesis, 1994. <http://www.lcc.gatech.edu/faculty/dieberger/>.
 11. Furnas, G. Effective View Navigation. In Proc. of CHI'97, Atlanta, March 22-27 1997, 367-374.
 12. Gershon, N., Card, S., Eick, S. Information Visualization. CHI97 Tutorial notes, Atlanta, March 24 1997.
 13. Gram, C., Cockton G. Ed., Design Principles for Interactive Software. Chapman&Hall, 1996.
 14. Ignatius, E., Senay, H., Heller R. Perceptual Guidance for Visualization Design. Thomson Multimedia Resource, 1996 Edition, Thomson Technology Labs, ISBN 0-534-50719-0, Chapter 2. <http://www.thomtech.com/mmedia/tmr97/chap2.htm>.
 15. Ioannidis Y. The FADIVA Benchmark - Version 0*. <ftp://ftp.dis.uniroma1.it/pub/santucci/in/FADIVA/Ioannidis.ps>. FADIVA activities: http://www.cui.darmstadt.gmd.de:80/visit/Activities/Fadiva/workshop_programm.html.
 16. Jul, S., Furnas, G. Navigation in Electronic Worlds: A CHI 97 Workshop. SIGCHHI Bulletin, Vol. 24, No. 4, October 1997.
 17. Mackinlay, J., Robertson G., Card, S. The Perspective Wall: Detail and Context Smoothly Integrated. In Proc. of CHI'91, New Orleans, April 27-May 2 1991, 173-179.
 18. May, J., Scott, S. and Barnard, P. Structuring Displays: a psychological guide. Eurographics Tutorial Notes Series. EACG: Geneva, 1995. Fourth edition, 1997: <http://www.shef.ac.uk/~pc1jm/guide.html>.
 19. Mulhem, P., Nigay, L. Interactive Information Retrieval Systems: From User Centered Interface Design to Software Design. In Proc. of SIGIR'96, Zurich, August 18-22 1996, 326-334.
 20. Nigay, L., Coutaz, J. A design space for multimodal interfaces: concurrent processing and data fusion. In Proc. of INTERCHI'93, Amsterdam, April 24-29, 1993, 172-178.
 21. Nigay, L., Coutaz, J. A Generic Platform for Addressing the Multimodal Challenge. In Proc. of CHI'95, Denver, May 7-11 1995, 98-105.
 22. Nigay, L., Vernier, F. Navigable worlds. CHI'97 Workshop on Navigation in Electronic Worlds, Atlanta, Georgia, March 23-24, 1997. <http://iihm.imag.fr/nigay/WK-NAVIGATION>.
 23. Nigay, L., Vernier, F. Multiple representations of navigable worlds. CODATA Euro-American Workshop, Visualization of Information and Data: Where We Are and Where Do We Go From Here?, 24-25 June 1997.
 24. Nigay, L., Coutaz, J. Software Architecture Modelling: Bridging the Worlds Using Ergonomics and Software Properties. In Formal Methods in Human-Computer Interaction, Springer-Verlag, ISBN 3-540-76158-6, 1997, Chapter 3, 49-73.
 25. Senay, H. and Ignatius, E. A Knowledge-Based System for Visualization Design. IEEE Computer Graphics And Applications, 14(6), 1994, 36-47.
 26. Shneiderman, B., Designing the User Interface: Third Edition. Chapter 15. Information Exploration: Search and Visualization, 1997, Addison-Wesley Publishers, Reading, MA. Also: The eyes have it: A task by data type taxonomy of information visualizations, In Proc. of IEEE Symposium on Visual Languages '96, IEEE, Los Alamos, Sept. 1996, 336-343.

27. Sutcliffe, A. Structural and Behavioural Models for Supporting Navigation. CHI'97 Workshop on Navigation in Electronic Worlds, Atlanta, March 23-24, 1997. <http://www-personal.engin.umich.edu/~sjul/nav97/sutcliffe.html>.
28. Tweedie, L. Characterizing Interactive Externalizations. In Proc. of CHI'97, Atlanta, March 22-27 1997, 375-382.
29. Vernier, F., Nigay, L. Représentations Multiples d'une Grande Quantité d'Information. In Proc. of IHM'97, Poitiers, 10-12 Sept. 1997, 183-190.
30. Waterworth, J., Chignell, M. A Model of Information Exploration. Hypermedia, 3(1), 1991, 35-38.