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ABSTRACT

In this paper we offer an approach of website design based on Scientific Visualization. Websites may be conceptualized as information architectures that have been designed for a specific set of task(s). We aim to develop effective information representation through the technique of visualization in order to reduce cognitive load in performing such tasks. We approach this formalism by considering the specific task of online product purchase. We model tasks as a sequence of logical operators and discuss a way in which perceptual operators may substitute these logical operators. A replacement of logical operators with perceptual operators results in minimization of cognitive effort in information processing. Embedding these perceptual operators within the website enhances the website task performance. The important implication of this research is an alternative task oriented perspective of website design based on minimizing the cognitive effort in website tasks.

Keywords

Scientific Visualization, Logical operators, Perceptual operators

INTRODUCTION

An important pre-occupation of e-retailers is customer retention. Existing literature has looked at this issue in different ways: consumer's behavior in terms of technology acceptance and consumer trust in Internet stores (Gefen, Karahanna and Straub 2003), consumer satisfaction (Devaraj, Fan and Kohli 2003) and perceptions about website quality (Aladwani and Palvia 2002). We approach customer retention in this paper by understanding how websites could be designed to facilitate user tasks. Ganapathy, Ranganathan and Sankarnarayanan (2004) mention that websites that make it too cumbersome for product purchase (a typical user task) will never enjoy a competitive advantage. In this paper, our interest is to see how scientific visualization can be used to enhance user tasks on the website by reducing the cognitive load on the user. This reduced cognitive load would lead to increased efficiency of information processing, allowing the user to accomplish the task faster. Formally stated, our research question is–

- *How can Scientific Visualization be utilized for modeling of the consumer (user) task that results in the minimization of the user's information processing time, thus leading to more effectively designed websites*

The rest of the paper is organized as follows: First we explain Scientific Visualization and demonstrate its relation to website designing. Next we address how visualizations can be made effective. Next we propose an approach for website design based on Casner's (1991) task-analytic approach to visualization. We illustrate this approach by modeling the task of online purchase using an online product catalog.

SCIENTIFIC VISUALIZATION AND WEBSITES

Scientific Visualization (SV) means using computer generated graphics "to help people understand and clarify visually the relationships inherent in the data" (Zhang 2000). Visualization views representations as information architectures and the individual as an information processor. Information architecture is the organization of information, in terms of navigation, layout and search functionality (Campagnoni and Ehrlich 1989). A website is an example of an information architecture that allows the user to perform a predefined portfolio of tasks (e.g. product evaluation). In this paper we propose an approach for

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website design that is based on Casner's (1991) task-analytic approach to visualization. This approach models tasks as a sequence of operators. These operators may be logical or perceptual in nature. Logical operators represent the problem solving steps that are independent of any particular representation or display (textual or graphical) (Casner and Larkin 1989). Perceptual operators are defined as the "problem-solving steps performed specifically within the context of a visual display" (Casner 1991a).

Replacing the logical operators (LOPs) with perceptual operators (POPs) results in minimization of cognitive effort in information processing (Casner and Larkin 1989). We propose that the performance of a user's task can be made time efficient by designing websites that trigger perceptual operations during task processing instead of logical operations. Doing this shifts the cognitive load of inference from the user to the website. In other words, we are designing the website as an interface that presupposes the cognitive operations of the user and embeds them within the website.

WHAT MAKES VISUALIZATIONS EFFECTIVE

Visualizations are made effective through appropriate graphical representations of information. Scaife and Rogers (1996) describe three aspects of graphical representation that explain why these are more time efficient for cognitive task processing– computational offloading, re-representation and graphical constraining. Computational offloading is the ability to provide direct perceptual recognition of task solutions and exemplifies the cognitive benefits of graphical representation. Explicit pictorial representations allow for "solutions to be more readily read-off"(Scaife and Rogers 1996), while textual representation make information more implicit. This makes solving of tasks more computationally effortful (in terms of time) for the latter. Re-representation deals with choice of alternate formulations of depicting same information and is concerned with optimal use of inherent structural properties. For example multiplication using roman numerals are substantially more difficult than using Arabic numerals (Zhang and Norman 1994). Graphical constraining refers to how graphical representations streamline the inference process by constraining the interpretive choices (Stenning and Oberlander 1995), thereby making it more efficient.

In the context of our task-analytic approach, computational offloading is achieved by the systematic replacement of logical operations by perceptual operations. The rendering of these POPs in terms of actual graphical representation addresses re-representation. The selection of appropriate rendering automatically enables graphical constraining. In following sections we discuss our task analytic approach to web-design.

TASK-ANALYTIC APPROACH TO WEBSITE DESIGN

Our approach has multiple stages that are described in detail below.

Task definition Stage

In this stage, the designer first needs to understand the different task types that the website could service. Each of these tasks needs to be defined in terms of a broad problem statement. In the context of website designing, a task is defined as the set of activities, bounded by a set of assumptions and performed by the combination of the user and the system towards a specific goal. The natural language task definition has the following aspects:

1. Task objective/s
2. Representational assumptions
3. Assumptions about the user

Our description of the approach considers a single task.

Task decomposition Stage

As a next step, the designer has to decompose the task into a sequence of component steps and describe it in terms of its natural temporal flow. This decomposition should include the atomic sub-processes as well as all the decision points needed to achieve the task. This task decomposition may be done using a natural language description or could be done using tools like flowcharts.

Identification of LOPs

Identifying LOPs and their logical sequence is the next step. LOPs represent the cognitive aspect of the task. Identifying the cognition intensive portions of the task is the crux of the proposed approach. So in this step the designer needs to identify the cognitive intensive portion of the task (maximal information processing part) from the task definition above and model this part as a sequence of LOPs.

Substitution of LOPs by equivalent POPs

Research on utility of graphics from a cognitive processing perspective (Larkin and Simon 1987) has shown that graphic-based representations are more efficient than equivalent logical representations. This is done through substitution of quick perceptual inference for more demanding logical inferences. POPs are a formal representation of such perceptual inferences that can be performed by human beings. Casner (1991) understands POPs as analogous to LOPs, but characterizing information processing activities within the graphical context.

POPs are organized around a set of *primitive graphical languages* (Mackinlay 1986). These primitive languages represent the atomic entities of basic graphical representations. All graphical representations are built upon some fundamental notations in a Euclidean space. Therefore, these have to be built upon concepts that explain position in that space. Notations used to represent such fundamental concepts are termed as graphical primitives. In our two-dimensional space example Horizontal Position and Vertical Position are examples of graphical primitives. Our set of POPs that deal with spatial inferences would be based on these two primitives. For example, "left-of?" is a POP that is based on the primitive Horizontal Position and uses the concept of whether one object is to the left of another object. Again "determine-horizontal-dist" (based on the graphical primitive Horizontal Position) determines the degree of horizontal separation between two objects. An exemplar set of primitive graphical languages and the corresponding POPs is shown in table 1. For an exhaustive list see Casner (1991).

Graphical primitives → / POPs ↓	Horizontal position	Vertical position	Color
	Determine-horizontal-position	Determine-vertical-position	Determine-color
	Search-object-at-horizontal-position	Search-object-at-vertical-position	Search-object-with-color
	LeftOf?	Above?	Search-object-and-color
	RightOf?	Below?	Same-color?
	Horizontal-coincidence?	Vertical-coincidence?	
	Determine-horizontal-distance	Determine-vertical-distance	

Table 1. POPs

Substitution of the cognition-intensive LOPs identified in the previous step by the low cognition POPs is the next important step. However, operators (both LOPs and POPs) have two distinct functions – *search* and *computation.* So essentially the designer needs to identify POPs that perform same functions to be able to effect the substitution. In table 1 Determine-Horizontal-distance is a computational operator while Determine-horizontal-position is a search operator. So the former can only substitute a computational LOP and the latter only a search LOP. Consider a price comparison task. The visual representation (figure 1) allows us to replace the logical search function of finding a higher priced product by an equivalent perceptual search function - RightOf. Similarly a computation function – "find the cost difference of two objects", could be replaced by an equivalent perceptual operation Determine-Horizontal-Distance, between the price positions in the horizontal line.

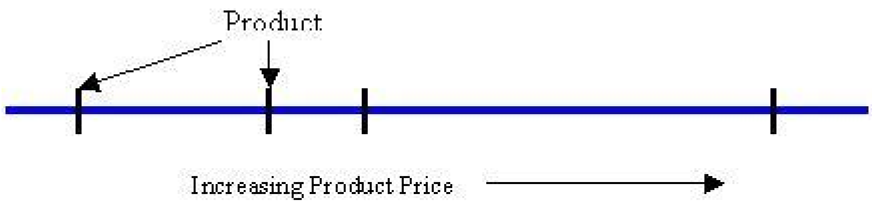

Figure 1. Visualization of a product price line

Rendering POPs within the website design

This final step involves choosing a suitable graphical representation congruent to the POPs. Rendering maps the logical facts to the graphical facts based on the POPs. A heuristic for deciding upon the graphical representation may be made by going back to the primitive graphic language of each of the POPs. For example points may be used to represent Horizontal position and Vertical Position. The designer needs to decide upon the representation based on the context of the task, as illustrated later in our example.

SCIENTIFIC VISUALIZATION OF AN ONLINE PURCHASE TASK

In this section of the paper, we illustrate the above approach for a product catalog webpage of an e-retailing website by modeling an online purchase task.

Task Definition Stage

1. Task Objective – Make a product purchase decision from a product catalogue of competing products.
2. Representational Assumptions –
   a. Products have multiple attributes
   b. Attributes are quantifiable, at least in the form of attribute ratings.
   c. Attribute set is universal amongst competing products in a category.
   d. The representation facilitates choice but does not dictate it.
3. Assumptions about the user-
   a. The user has a definite purchase intention
   b. The user is not premeditated about the purchase, but not about the product
   c. The user can rank the attributes in terms of personal importance

Task decomposition stage

The task decomposition describes the presumed processes that occur once the user enters the webpage catalog. In this stage we describe the steps that a user would typically go through to choose a product from the web catalog. These are represented below

1. Provide input about product of interest
2. Get available list of attributes for comparing products
3. Select subset of attribute pertinent to personal purchase choice
4. Prioritize the chosen set of product attributes and get product ratings on each attribute

5. Form comparative evaluation of each product from the display
    a. Identify each product on the catalog representation
    b. Identify pertinent attribute
    c. Evaluate rating of each product on a particular attribute
    d. Find the highest rated product on an attribute
    e. Find the lowest rated product on an attribute
    f. Compute rating difference on products on an attribute
    g. Find products with identical rating on an attribute
6. Purchase product

Of the entire purchase process above, our focus is on step 5 (note: The breakdown of step 5 is illustrative, not exhaustive) as this represents the most intensive cognitive information processing aspect of the purchase. This particular step would be the focus of the next stage of our approach.

Identification of LOPs

We have already identified step 5 above as the cognitive intensive portion. We model this step through the formalism of LOPs. Each LOP corresponds to the nature language description of the corresponding sub-step.

a. IdentifyEachProduct
b. IdentifyPertinentAttribute
c. FindRatingOnAttribute
d. DetermineMaxValueOnAttribute
e. DetermineMinValueOnAttribute
f. ComputeRatingDifferenceOnAttribute
g. IdentifyProductsWithSameAttributeRating

The names of the LOPs have been chosen so as to be self-explanatory. Each LOP represents an inference procedure on the part of the user to undertake the task.

Identification of POPs and substitution of LOPs

The next important step is to identify the POPs that would be mapped to our LOPs of interest. The effectiveness of visualization would be realized if these LOPs are replaced by functionally equivalent POPs. Below in table 2 we show the set of POPs that fit our scenario.

Horizontal position	Vertical position	Color
Determine-horizontal-position	Above?	Determine-color
Search-object-at-horizontal-position	Below?	
LeftOf?		
RightOf?		
Horizontal-coincidence?	Determine-vertical-position	
Determine-horizontal-distance		

Table 2. POPs

	LOP	POP
1	IdentifyEachProduct (search operator)	Determine-color (search operator)
2	IdentifyPertinentAttribute (search operator)	Determine-vertical-position (search operator)
3	FindRatingOnAttribute (search operator)	Determine-horizontal-position (search operator)
4	DetermineMaxValueOnAttribute (search operator)	Search-object-at-horizontal-position (search operator)
5	DetermineMinValueonAttribute (search operator)	Search-object-at-horizontal-position (search operator)
6	ComputeRatingDifferenceOnAttribute (computational operator)	Determine-horizontal-distance (computational operator)
7	IdentifyProductsWithSameAttributeRating (computational operator)	Horizontal-coincidence? (computational operator)

Table 3. Mapping of LOPs to POPs.

The mapping of POPs to LOPs for our scenario is demonstrated in table 3. Note that each substitution is contingent on functional equivalence (i.e. search for search and computational for computational).

Rendering the POPs within the website design

In rendering, we need to represent the logical facts as graphical facts so that we can use the POPs. Our graphical rendering of product catalog is demonstrated in figure 2. This is adopted from the visualization of product catalog presented in Lee, Wang and Lee (2001).

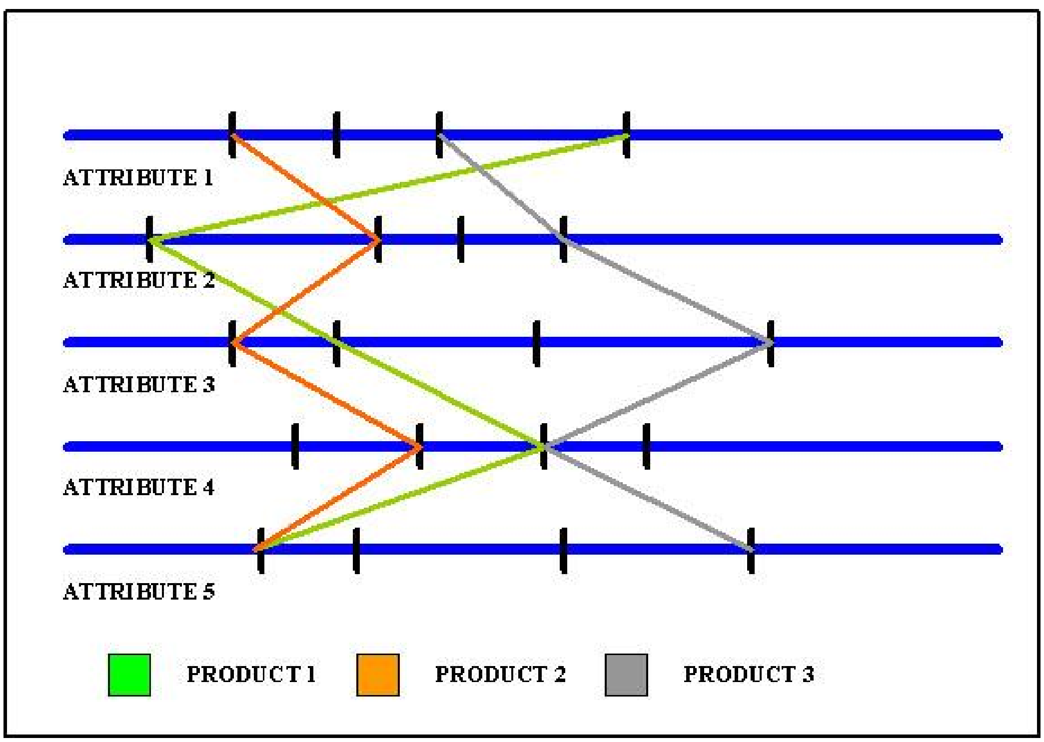

Figure 2. A Visual Catalog

In this figure

- Horizontal Axes represent attributes with product ratings marked off by vertical lines. Ratings increase from left to right. Vertical position of axes represents descending attribute priority (topmost: highest)
- Color encodes products
- Ratings for same product are connected across attributes

We will now demonstrate how this rendering represents the POPs

- Color identifies products (Determine-color)
- Vertical position identifies particular attribute axes (Determine-vertical-position)
- Rating of a particular product is determined through its horizontal position on the axis (Determine-horizontal-position)
- Maximum and Minimum rating is identified by leftmost or rightmost position on axis (Search-object-at-horizontal-position)
- Horizontal distance of rating positions on axis determines rating difference between products for an attribute. (Determine-horizontal-distance)
- Products with identical ratings occupy same position on an axis (Horizontal-coincidence?)

The visual representation simultaneously embeds the concepts of computational offloading, re-representation and graphical constraining.. Essentially the visualization achieves computational offloading by allowing users to quickly form holistic inferences (e.g. overall attractiveness of Product 3 is inferred not through evaluating individual rating values but by observing that the line-representing Product 3 has most spatial shift to the right). Re-representation is appropriately done by assigning the horizontal position for price discrimination, vertical position for attribute discrimination and color for product. Graphical constraining is achieved by providing a minimalist rendering, thus eliminating distraction. In summary this visualization faithfully conforms to the theoretical percepts that make graphical representations time-efficient, by making users' task execution less effortful.

CONCLUSION

The primary contribution of this study is the formulation of an innovative task-centered website design approach using visualization. The paper also provides a new formalized heuristic of website design that addresses reduction of user's cognitive effort in generic terms. Of course the amount of reduction could be further improved by more sophisticated heuristics incorporating individual differences (e.g. skill, experience), an issue which can be taken up by future research.

In this paper we use the example of a relatively simple task. The motivation behind this was to facilitate explanation of our approach. This approach has already been tested in relatively more complicated task domains like Airline Reservation and class scheduling, although not in the context website representations.

Our next objective would be to empirically test whether triggering perceptual inferences within websites increases user efficiency.

Future research should extend it to different and more involved website task domains. It should also address dynamic website representations based on user inputs of profile and experience can be looked at.

With regards to practical implications, this task-centered approach of website design could be used by web developers in developing efficient commercial websites, leading to potentially more consumer satisfaction and retention. This would help businesses leverage their online presence to a great extent.

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