An Approach towards Considering Users' Understanding in Product Design

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Abstract. Although different techniques for supporting the process of designing exist, there is, at present, no easy-to-use and pragmatic way of helping designers to infer and analyse product representations that users form in their heads and to compare them with designers' own understanding of products. This paper is part of ongoing research that attempts to develop an approach for supporting designers in identifying, during the early stages of the design process, whether specific product features evoke similar understanding and responses among the users as among the designers of those features.

Keywords: Inclusive Design, Product-User Interaction, Mental Models, Cognitive Representations, Prior Experience.

1 Introduction

Features of many modern products are largely unusable for the majority of users as they frequently embody the intentions of designers and unverified assumptions about users' needs and wants. To design more inclusively, designers require guidance and tools that would help them to better understand users' understanding of product features, the goals they want to achieve in relation to products and the actions they exert on product features to achieve those goals. This paper describes the goal and structure of a new easy-to-use and pragmatic technique for designers, called the Goal-Action-Belief-Object (GABO) approach, developed to help designers model users' understanding and use of products and compare it with their own conceptual models.

2 Users' Internalised Models of Products

When users interact with a given product, they need knowledge of the functionality of that product, the relation of it to their task and the dialogue between their actions and product responses [15]. Intrinsically, human understanding is often perceived as a model and the theoretical construct of a mental model has, for over sixty years, been studied at length by researchers from different disciplines including cognitive psychology, artificial intelligence and human-computer interaction (HCI), etc. In 1943 Kenneth Craik [7] laid the foundation for the concept of a mental model by

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postulating that it is a small-scale model of external reality that people carry in their heads and use it to take various actions, conclude which is best and utilise this knowledge for future problem-solving. Nearly forty years later, Johnson-Laird [8], suggested that individuals construct internal models of the external world that enable them to make inferences and predictions, understand and explain phenomena, decide what actions to perform and control their execution. Norman [10] argues that the system image observable by the user should be consistent with the designer's conceptual model, and the mental model that a user brings to bear on a given task should be consistent with both these models. Payne [15] claims that users' models of products are fragmentary and as a result people have difficulties interacting correctly with products. While, diSessa [12] notes that mental models are heavily influenced by knowledge and experience with previously encountered products.

3 Prior Experience

Experience is a critical factor of how easy a product is to learn and use [1]. Rasmussen [3] claims that people process information on three levels: (1) skill-based level, which is automatic and non-conscious; (2) rule-based level, which is guided by the 'if (precondition) then (action)' rule; and (3) knowledge-based level, which accounts for unfamiliar situations for which no rules from previous experience are available. Reason [11] suggests that rule-based attempts in tasks are always tried first as people in general are "furious pattern matchers". If the problem can be pattern matched and only minor corrective rules need to be applied, then the processing will take place at the skill-based level. If, however, a 'pre-packaged solution' cannot be found at the rule-based level, then the information processing is carried out at the slower and more laborious knowledge-based level.

4 Modelling Design Activity

It has been suggested that extracting, measuring and comparing mental models can be best achieved through modelling [18]. Payne [14] believes that models of user interaction with products should be developed with a view of furthering psychological theory and providing conceptual and practical models in HCI. However, a plethora of tools for designers have been developed way before the theoretical foundations of the concept of mental models have been developed sufficiently and as a direct consequence those models are "very confusing and lack the predictive power to be of any practical or explanatory value" [16]. Yet a further consequence is that product designers are provided with very little guidance in adequately representing and comparing functional, conceptual and user information during product design.

Following a number of years spent researching the design activity at a large UK engineering company, Aurisicchio and Bracewell [17] propose the use of diagrams for documenting the structure of design information. They argue that diagrams can be supported by a wide range of computer-based diagramming tools (i.e. Visio, SmartDraw, Mindjet, Compendium, Cambridge Advanced Modeller, etc.), and since they are more visual than linear text documents, they are better for spotting patterns and gaining insights. Also, using diagrams is beneficial as they group together information that needs to be used together and minimally label that information, place similar information at adjacent locations, minimise shifts of attention and automatically support a number of perceptual inferences.

5 Requirements for Easy-to-Use Modelling Approach

Previously, modelling techniques such as ACT-R [5], GOMS [6], SOAR [2] and TAFEI [4] had been developed to help designers to focus on users' goals and actions. Most of them incorporated task analysis of what a person is required to do to achieve their goal and what operational difficulties they faced [9]. However, for different reasons, including the complexity of architecture and specific skills necessary to use these techniques, so far none of them has effectively been transferred to product design in order to benefit the end users. Consequently, in order to offset the lack of an easy-to-use and pragmatic technique for modelling users' understanding and use of products and comparing it with designer conceptual models, we developed the Goal-Action-Belief-Object (GABO) modelling approach for designers. The GABO approach was developed in conjunction with information elicited from interviews with twenty product designers and observations with fifty users of everyday products. Our goal for development of the GABO approach was that it should be visual, easy and quick to understand, implement and use, it should lead toward improvement in design practice to increase the chances of producing an accessible and usable product, and designers should find significant productivity and differentiation gains in using it.

6 Rules of the GABO Modelling Approach

The GABO approach works on the premise that the contents of people's minds (i.e. their knowledge, theories and beliefs) should be explored by designers in order to better understand users' behaviour in relation to products [15]. Consequently, it is aimed at representing minimum information about users' preferences to identify areas of design where people's mental models are compatible with the designer model and where they differ. Though, it needs noting that the GABO approach does not focus on the structure of the human mind and is not in any way aimed at representing information about the actively changing parts of mental models. Instead, it intends to capture and represent the current and static contents of users' mental models during interaction with a given product.

6.1 Structure of the GABO Modelling Approach

The GABO approach is aimed at encouraging designers to focus on users' understanding and use of products through representing the following elements:

1. **goals** that users want to achieve during interaction with products,
2. correct and incorrect **actions** that they exert on product interfaces
3. **beliefs** about actions that they bring from previous interactions with other products to interactions with new products, and
4. understanding of the impact of their actions on functional **objects**.

When using the GABO approach, designers are required to create three types of models:

1. engineering model
2. designer model, and
3. a number of individual user models.

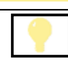
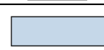
The engineering model is essentially a functional analysis diagram encompassing the objects of a given product, the engineer's beliefs about the function of each object, external interface-based and internal object-based actions that need to be taken to change objects' states and transform available inputs into the desired outputs, and goals that pertain to actions driven by human input and applied on the objects. The structure of the engineering model is different to the structure of the designer model and the individual user models as its purpose is to act as a reference for designers when they construct the designer model.

The designer model includes the overall goal(s) that the designer thinks that the potential users should set for their product usage, the actions that need to be taken to get the users to achieving their goals with that product, the beliefs that correspond to users' actions and contain the designers' description of the appearance, functionality and behaviour of that product, and the objects that are envisaged by designers to sit on the top of the interface of the product and be exploited by users.

The structure of an individual user model is very similar to the designer model as it captures the overall goal(s) that a given user wants to accomplish with a particular product, the actions that a user wants and thinks they need to perform to achieve their goal(s) with that product, the beliefs that correspond to the user's actions and provide the user's internal understanding of the appearance, functionality and behaviour of that product, and the objects that the user is using to carry out their actions.

The DRed platform [17] has been used during development of the GABO approach as a testing ground for representation and comparison purposes. However, it needs noting that the GABO approach is aimed to be platform independent. During the use of the DRed software, the GABO approach's goal, action, belief and object elements were assigned their corresponding DRed elements. Accordingly, the DRed's Task (Pending) element was used as a goal's symbol, the Answer (Open) element was chosen to represent an action, the Issue (Open) element was given a belief's symbol and the Block (Internal) element was selected as a counterpart for an object. The GABO approach's corresponding DRed elements are shown in Table 1.

Table 1. Four elements of the GABO approach and their corresponding DRed symbols

GABO Approach's Element Types	Corresponding DRed Element Types
Goal	Task Name
Action	
Belief	
Object	

The modelling of products using the GABO approach involves four stages. In the first stage, designers need to refer to a drawing of the actual engineering model of a given product to better understand what product elements and operations are functionally and structurally possible before they design interface features that will sit on the top of the engineering parts. Figure 1 shows an example of an engineering model of a complex-to-use toaster represented using the GABO approach in DRed software.

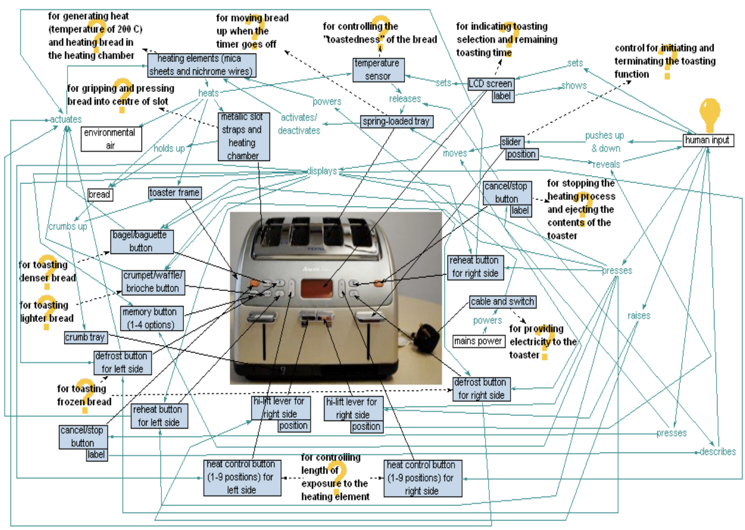


Fig. 1. Engineering model of a complex-to-use toaster drawn using the GABO approach

In this example, the engineering model has been represented using the object elements; the belief elements to explain the objective of each object; and the main relationships between different objects. Also, the action element was used to connote human input and DRed's External Block element to signify external entities such as human input, bread, mains power and environmental air.

In the second stage of using the GABO approach, designers are required to draw one collective product model using goal, action, belief and object elements and accompany each element with simple descriptive text based on a rigorous semantic coding language of their own choice for the purpose of pattern matching elements in designer and user models during model comparison. For instance, the semantic coding language that has been used to draw the designer and user models in this paper uses different verb and noun combinations depending on which type of element—goal (*verb* + *noun*), action (*verb+ing* + *noun*), belief (*noun* + *to+verb*), object (*noun*)—it is describing. An example of a designer model of a complex-to-use toaster represented using the GABO approach in DRed in shown in Figure 2. Due to the sheer size of this designer model, only a part of it is included in this paper.

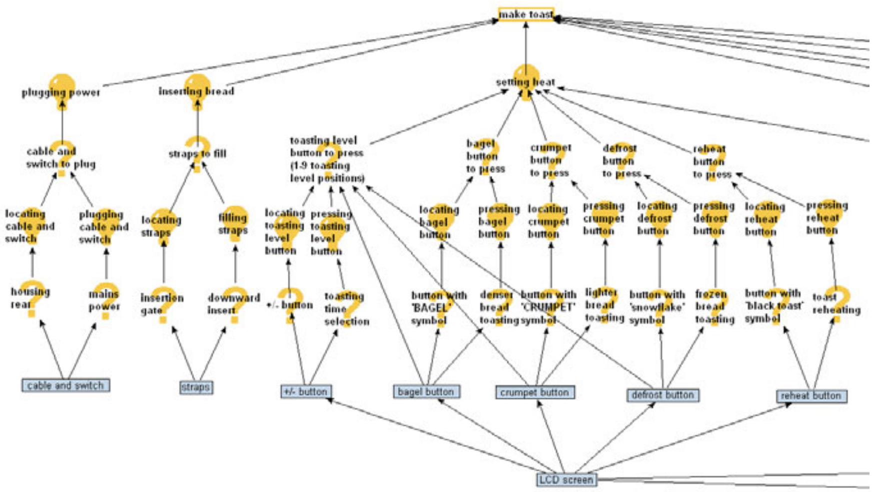


Fig. 2. Part of designer model of a complex-to-use toaster drawn using the GABO approach

In this example, the designer model of a complex-to-use toaster has been represented using the goal element to signify the master user goal pertaining to a toaster's usage; the action elements to indicate the sequence of actions that designers think that users have to perform to accomplish their goal with a toaster interface; the belief elements to provide designer description of the appearance, functionality and behaviour of toaster features which users are required to exert their actions on and to elucidate the position of different features and how user actions need to be taken to correctly operate them; and object elements to specify the functional features that are envisaged by designers to sit on the top of the toaster interface and be exploited by users.

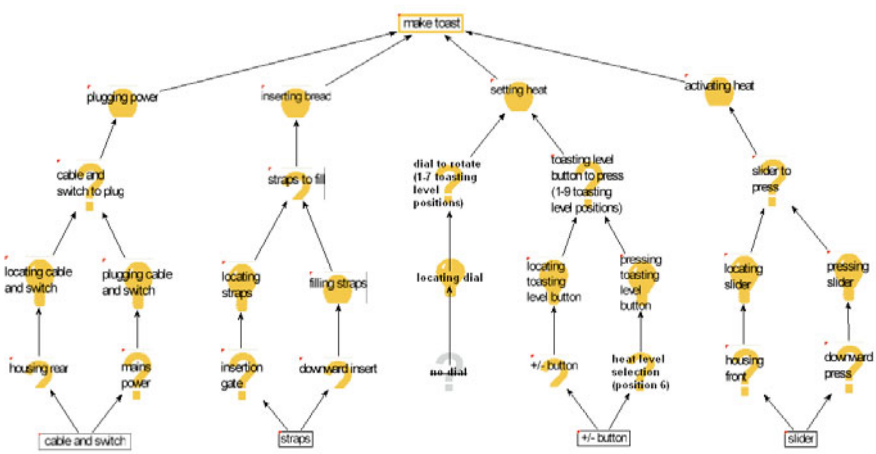


Fig. 3. User model of a complex-to-use toaster drawn using the GABO approach

In the third stage of using the GABO approach, designers need to run observations with users of products using a verbal protocol (think-aloud) and keep a log of users' goals, actions, beliefs and objects. Subsequently, designers should use the information collected from study participants to draw several individual user models using goal, action, belief and object elements and, as in the design model, accompany each element with simple descriptive text based on a rigorous semantic coding language of their own choice. Similarly to the elements used in the designer model example, the elements in individual user models have been annotated with four different verb and noun combinations. An example of an individual user model of a complex-to-use toaster represented using the GABO approach in DRed in shown in Figure 3.

In this example, the individual user model of a complex-to-use toaster has been represented using the goal element to signify the master user goal pertaining to a toaster's usage; the action elements to indicate the sequence of actions that a user wants and thinks they need to perform to accomplish their goal with a toaster interface; the belief elements to provide a user's internal understanding of the appearance, functionality and behaviour of toaster features which they are required to exert their actions on and to convey the position of different features and how a user thinks their actions need to be taken to correctly operate these features; and lastly object elements to stipulate the functional features that a user is familiar with, accustomed to operate and immediately associates with a toaster form. It needs noting that the block element has a blue background only in the designer model and the background colour of all the transcluded block elements in user models is white.

In the fourth stage of using the GABO approach, designers need to compare similarities and differences between each user model and the designer model using an appropriate algorithm (either manually or computationally), check the degree of compatibility between the designer model and the individual user models and make appropriate design decisions relating to the inclusivity of future product features.

6.2 The GABO Comparison Procedure

The GABO approach stipulates that any two models (a designer model and an individual user model) are compared based on: (1) presence of the same vertices in the two models and (2) connectivity between two given vertices in the two models. The comparison procedure is carried out (either manually or computationally) using a function from set theory that measures similarity between graphs with common vertex and edge sets [13]. This function is used for measuring both the presence of vertices and the connectivity between vertices in the designer model and the individual user models, with the designer model acting as the main model against which each user model is checked for compatibility. The assumption is that by using the GABO approach's function, designers will be able to make close estimates of the degree of compatibility of their intended goals, actions, beliefs and objects regarding product usage with the goals, actions, beliefs and objects of heterogeneous users. The function for checking presence of vertices in designer model and user models is as follows:

$$P(D,U) = |V_D \cap V_U| / |V_D|, \quad (1)$$

where

- $P =$ value between 0 and 1, where
  - 0 means that an individual user model is not compatible with the designer model, and
  - 1 means that an individual user model is 100% compatible with the designer model
  - Any value between 0 and 1 indicates the degree of compatibility of a user model with the designer model (e.g. if $P(D,U)$ = 28/88, then the compatibility level equals 0.31, which means 31% compatible)
- $D =$ designer model
- $U =$ user model
- $V_D =$ the set of vertices in designer model
- $V_U =$ the set of vertices in user model
- $V_D \cap V_U =$ the set of all vertices that are members of both V_D and V_U.

This function assumes that two vertices are the same (one from the designer model and one from the user model) if they belong to the same element type, for instance the belief element type, and contain the same semantic grammar.

The function for checking connectivity of vertices in designer model and each user model is as follows:

$$C(D,U) = | E_D \cap E_U | / | E_D |, \tag{2}$$

where

- $C =$ value between 0 and 1, where
  - 0 means that an individual user model is not compatible (dissimilar) with the designer model, and
  - 1 means that an individual user model is 100% compatible (identical)with the designer model
  - Any value between 0 and 1 indicates the degree of compatibility of a user model with the designer model (e.g. if $C(D,U)$ = 30/114, then the compatibility level equals 0.26, which means 26% compatible)
- $D =$ designer model
- $U =$ user model
- $E_D =$ the set of edges in designer model
- $E_U =$ the set of edges in user model
- $E_D \cap E_U =$ the set of all edges that are members of both E_D and E_U.

The connectivity function assumes that two edges are equal if they join two vertices that belong to the same element type and have identical semantics.

7 Evaluation of the GABO Modelling Approach

The usefulness and effectiveness of the GABO approach was evaluated with eight designers from a range of small and large organisations based in the UK during two five hour workshop sessions. Designers, aged between 29 and 52, were asked to work on two redesign tasks, one of which required them to redesign an interface of a household product with a complex-to-use interface (either a toaster or a coffee maker) using a method of choice and the other task required them to redesign an interface of one of the aforementioned two products using the GABO approach. When the tasks were completed, each designer was asked to individually fill out an evaluation questionnaire composed of a number of quantitative and qualitative questions.

Overall, the designers marked, on average, point 5 on a 7-point scale indicating how useful the GABO approach was in identifying and capturing users' understanding and the problems users encounter during product use. This procedure was mirrored when investigating designers' opinion regarding designers' understanding of product functionality with the understanding of users, the result being point 5.5 on the scale. Likewise, indicating ease-of-use, the designers on average gave the GABO approach a score of 4.3. In addition, five designers believed that the GABO approach helped them to produce a better design than an alternative approach, while three designers said that they would need more time to use it to determine as to whether it was better or worse than the alternative method.

8 Discussion and Conclusion

This paper discussed the role of mental models and prior experience in product-user interaction and existing modelling techniques for representing users' goals and actions. Since there is, at present, no easy-to-use and pragmatic technique for representing and comparing designers and users' understanding and usage of everyday products, this paper proposes the GABO approach for designers which bridges that gap. The GABO approach consists of four stages in which designers need to: (1) refer to the engineering model of a product to better understand how different product parts interact with one another; (2) create a designer model of that product using appropriately annotated goal, action, belief and object elements and compare it with the engineering model to see what features should be mounted on the top of the underlying functional parts; (3) investigate how different users understand and use product features, create several individual user models using goal, action, belief and object elements annotated in the same semantic style as their counterpart elements in the designer model; and (4) compare the designer model with individual user models using a function from set theory (either manually or computationally), check the degree of compatibility between the designer model and the user models and make appropriate design decisions relating to the inclusivity of future product features. Results from the evaluation study with eight designers indicate that designers find the GABO approach fairly useful and effective in identifying key similarities and differences in designers and users' understanding and usage of products.

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