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# Engineering Awareness in Interfaces: Focus on Automation and Visualization

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## KEYWORDS

Engineering Interactive Systems, Situation Awareness, Automation, Visualisation.

## 1 INTRODUCTION

For the first time in the conference series, EICS 2022 is proposing two spotlights on Automation and Information Visualization. The intention is to foster the production of research results and to foster submission in these two areas with a specific focus on their engineering aspects. Indeed, when presented at conferences contributions in these areas usually focus on design aspects and user studies leaving the engineering aspects (how to make the solution work with required performance and without failures) outside of the contributions. This panel aims at using a Situation Awareness framework to demonstrate that automation and visualisation are in fact two complementary design options which can contribute to improving situation awareness of users. This panel consists of people with experience in automation, visualisation or both. After short presentations from each panelist, the panel will structure and trigger discussions with the audience on these two areas and their intersection, keeping the engineering aspect prominent.

## 2 SITUATION AWARENESS: PRINCIPLES AND APPLICATION

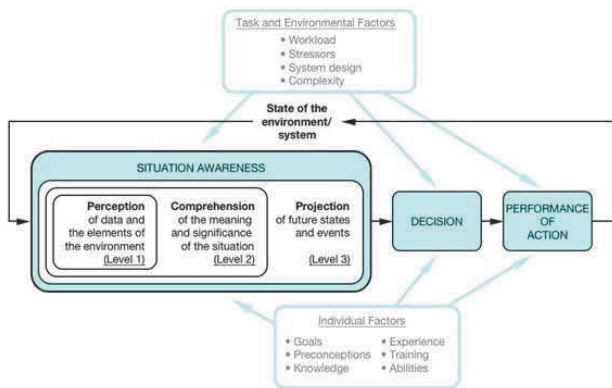
Situation awareness (SA) was defined by M. Endsley as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” [3]. It reinforces the general definition “knowing what is going on” [4] taking into account that SA is more than being aware of specific information. There is a need to understand the situation and also, to project systems’ states reaching the user’s goals. In addition, there are factors which influence the interpretation and usefulness of the concept:

- Individual (person or system) factors: ability to acquire SA (based on abilities, experience, and training), goals, and expectations.
- Tasks and environmental factors: capabilities of the system, interface, complexity, automation, etc. These factors represent how the system provides SA.

Both factors are also two points differentiated in SA (see Fig.1). The elements directly related with the users are essential to be aware about their current tasks. However, the environment is determinant for knowing what is going on and what will go on. For example, the state of the current user’ task in terms of steps to be done can be influenced by the steps to be done by a collaborator. If both tasks need to be finished as a requirement to start another issue, the need of solving a delay can be an important information to be aware of. The conjunction of information from the user and the environment generates that important awareness.

Several models of SA have been proposed as it represents an essential element when designing systems dealing with performance in tasks [7]. Amongst all of them, there is a remarkable model focused on the initial definition of SA described at the beginning of this section. This model defines SA through three phases (Fig.1) which are hierarchically related [4]. These phases can be considered as levels representing the steps to achieve SA in a progressive way from receiving information to project the analyzed context to the future. In this sense, the SA evolves over three states as a result of the user’s analysis:

- *Level 1* - Perception of the elements in the environment: The first state of SA is the perception of essential information about the environment (e.g. status and attributes). Example



**Figure 1: The situation awareness process as defined in [4] and . Figure adapted by Dr. Peter Lankton in May 2007 (Wikipedia)**

- A user perceives data: a car driver perceives traffic jam, indications of a policeman, ambulances and firefighters. All this information appears when the driver is advancing to a specific point of the motorway.
- *Level 2* - Comprehension of the meaning and significance of the situation: The second state is understanding the meaning of the elements from Level 1 knowing the information that is really important for the goals. In this second level, SA evolves towards being aware of the meaning of those elements in relation to the user's objectives and context. This step represents the importance of the Level 1 elements working together. It is not only needed to be aware of their existence as individual elements. Example - A user understands received data: a driver (example of Level 1) analyzes the received information as a whole and understands that there is an accident to the point to which he/she is moving the car.
- *Level 3* - Projection of future states and events: The last state of SA represents the ability to project future events based on the information obtained from the environment (Level 1) and its comprehension according to the current situation (Level 2). Example - A user predicts based on received data: a driver (example Level 1 and 2) detects in a dynamic context that there is a need to reduce the speed of the car to not crash. The driver is detecting a need to avoid problems in the near future based on the received information.

The levels represent an evolution process of awareness improving the knowledge about the environment. The final level contains the most advanced state of awareness and lets users be in better conditions to decide what action to perform in specific contexts. Therefore, the result of this awareness evolution is an essential element for dynamic decision making. It is what the framework of M. Endsley describes. In this context, we think it is possible to apply the evolution of situation awareness to additional awareness generating essential information for decision making such as the way the information should be visualized or automating critical

decisions. To that end, the two following sections describe awareness in visualization and automation following the guidelines of the described framework. Following the context of that framework, awareness is considered as an entity separate from decision making and the actions to perform which do not share factors affecting them what makes the separation essential as it is reflected in Fig.1. In this sense, the final stage of awareness is the input to make a decision according to individual, task and environmental factors. That decision will be the input of the actions to be performed that affects the state of the environment or system creating new conditions and then, a re-definition of situation awareness.

### 3 AWARENESS IN VISUALIZATION

The use of information technology in every aspect of life means that companies and governments are generating, gathering, and storing data at a rate which is growing every year. The provision of massive storage technology is rapidly outstripping the provision of tools for the effective analysis, exploration and comprehension of such voluminous data. Clearly this data is of little value unless useful information and hence knowledge can be derived from it. One approach to this problem is to convert the data into pictures and models that can be graphically displayed. The intuition behind the use of such graphics is that human beings are inherently skilled at comprehending data in visual forms.

Data and information visualization is a research area that focuses on the use of graphical techniques to present data in an explicit form i.e. the graphical presentation of abstract data. Such static or dynamic presentations (pictures) help people formulate an understanding of data and an internal model of it for reasoning about. Such pictures of data are an external artifact in the form of a physical presentation supporting decision making. While sharing many of the same goals of Scientific Visualization, Human Computer Interaction, User Interface Design and Computer Graphics, Information Visualization focuses on the visual presentation of data without a physical or geometric form (i.e. abstract). As such it relies on research in mathematics, data mining, data structures, algorithms, graph drawing, human-computer interaction, cognitive psychology, semiotics, cartography, interactive graphics, imaging and visual design.

A central challenge for data preparation is that "Real word data is dirty" and automatically collected large scale data can be inaccurate and incomplete and require various degrees of sanitisation and cleaning. Raw input data itself often needs to be standardized into a single well defined common format prior to other stages in the information visualization process. Data cleansing is a well understood problem in the database and data warehousing communities. Database providers have commercialized research and are now providing tools specifically designed to assist in data cleansing as part of the ETL (extraction, transformation and loading) process to populate data warehouses. A common starting concern is formatted data, different encodings of the same data, or data residing in incorrect fields. The data transformation and cleansing stage can have a direct effect on both the accuracy and speed of the overall process.

Next, and depending on the domain, filtering is often used before any visualization takes place. Elements of the model can be assigned

an a priori importance or classification type, then only elements above a certain threshold or in a particular category are considered. For example, an architectural sketch of a new building may be based on a large underlying building information model (BIM) that contains information about ducting, lighting, and landscaping. One filtered view may just include the basic structure of the building so the unnecessary details can be filtered out before this data is considered.

This technique is often applied in relational information visualization; for example the extraction of a minimum spanning tree of the data is a form of filtering. This tree can then be used to show the main “stem” of the relational information. Filtering is typically a pre-processing step that results in certain parts of the model being effectively ignored. Unlike hiding which incorporates the data but doesn’t present it until called for.

Task and Environmental factors have been shown to significantly impact the process of visualization. Current workloads can result in observers missing important changes in the visual display while lighting conditions in the same space can alter color perception. Individual factors, such as existing mental models, knowledge of visual variables or cultural factors on use of color can complicate matter further. The five aspects from perception to performance require an understanding of how they relate to the process of visualization.

Perception of visualization: at the basic level a user can visually perceive the visual displays elements e.g. visual variables. This can include shapes, color, movement of visual elements, labels etc. In the traditional view of information visualization processing, the key stages here are data transformation, visual mapping, presentation mapping and rendering. Decisions made in each of these four stages direct what is to be perceived and what physical presentation (e.g. 2D vs 3D) will be employed. Comprehension of visualization: a key stage is to understand the visual elements with respect to the underlying domain from which the data is drawn. This could include mapping a particular color to the understanding of the status of a system or the respective size of visual elements to understand the various amounts. By inspecting the visual elements presented, one starts to grasp a picture of the system the data is trying to represent. At this stage, percept transformation into a visual mental model occurs, the process of understanding the visual encoding and developing insight gives rise to the comprehension of the data. Projection of visualization: once insights have been drawn from the visualization then projection into the future states and events can begin. The mental model allows the user to anticipate future changes in the system and to start make decisions about how to act accordingly. Decision with visualization: here decisions can be made which can either impact all the earlier stages in the visualization pipeline, changing filters, altering the mapping of visual variables, changing colors etc. Or the decisions can pertain to the domain or system from which the data is drawn. Classic examples here include the decision to buy or sell a stock based on viewing data about changing prices, betting on a sports game having viewed data about past player performance or deciding to alter the heat configuration in a powerplant having viewed a visualization of the sensor readings from across the plant. Performance of action with visualization: the action of purchasing the stock, of placing the bet

or altering the heat level are each real actions which can come once situational awareness has been developed.

## 4 AWARENESS IN AUTOMATION

Nowadays, operators of safety critical systems are facing more and more sources of information competing for attention which might affect their abilities to complete their tasks. Automation (in particular design-time allocation of operator’s tasks to the system) can reduce tasks’ complexity and time consumption allowing operators to focus on other tasks [5]. However, too much (or inadequate) automation can lead to complacency, loss of situational awareness about the current status and future evolutions of the system, skill degradation or boredom [9]. On the contrary, not enough automation can lead to an overload, too complex to manage tasks, continuous input, ... which may lead to human errors and degraded performance of the overall system [6]. However, allocating or delegating operators’ tasks to the system brings a lot of complicated issues (both on the system and operators sides). Using the Situation Awareness (SA) framework from Endsley supports the identification of these issues introduced by increased automation. We thus propose to instantiate the five activities of the SA framework. Clearly, the two related factors (tasks and environment factor on one side and individual factor on the other) are deeply influenced by the automation itself. One important aspect is that This understanding might be about the automation itself or the work to be performed with automation. Perception of automation: Automation embeds information (usually called resources) that might or might not be perceivable by the user. Similarly, part of the behavior of automation might be made visible e.g. what will be the next action. Comprehension of automation: The perceived information from automation might allow users to understand what the automation has done, what it is doing. This can be done by perceiving information presented by the automation to the user (covering both work-related information or automation-related behavior). Projection of automation: The perceived and understood information might allow users to understand what the automation will do next and why it will do it. This project is key in situation awareness as it allows users to include the future functioning of automation before making decisions. Decision with automation: based on previous activities users will be able to decide which actions to perform. Here again, the decision might concern automation itself or automation with respect to the work they are performing. Decisions could be thus to stop automation (as the actions envisioned from the projection phase do not conform with the work to be performed). Performance of action with automation: Once the decision on what to do and how to it is made, users will perform the actions which might result in evolutions of the automation or of the outcome of the work.

## 5 THE GAME OF FIFTEEN: AUTOMATION VIA VISUALIZATION

This section presents a simple example in which automation takes place by means of a visualization technique called magic squares [1]. We show that only by using that visualization several human-made tasks are migrated to the visualization which thus automates these tasks. We use this example to highlight the impact of this evolution on situation awareness.

### 5.1 Game of Fifteen: Main Principles and Rules

The Game of Fifteen is a two player game in which each player chooses and selects, in turn, a number (graphically represented as a token) ranging from 1 to 9. The first player who gets a combination of three numbers (amongst the set of tokens that s/he has selected) for which the sum is exactly 15 wins the game. No explicit rule defines who plays first, thus requiring players to reach an agreement. At any time one of the players may declare to be the winner as soon as the player believes that the set of tokens he or she owns matches the winning condition. An example of a user interface for a computerized version of this game is shown in Fig.2. Each player play in turn, the computer offers no assistance. We can see that in Fig.2, situation awareness is supported by the display of multiple information:

- the name of the player currently playing;
- the name of the player that must wait;
- the tokens selected by player 1 (currently 5 and 9);
- the tokens selected by player 2 (currently 8);
- the tokens that can still be selected (currently 1, 2, 3, 4, 6, and 7).



Figure 2: An example of User Interface for the Game of Fifteen

In order for player 2 to know what to select, the activity is rather complex. Player 2 must first perceive the current situation Player 2 might want to try to win (i.e. selecting a token that will still allow player 2 to win) based on the current token selected i.e. token 8. A good choice would be token 3 (projection in the situation awareness framework). Indeed, as number 4 is still available if, after taking 3, player 2 picks number 4, player 2 will win). Another strategy would be to prevent player 1 from winning. In that case player 2 should select token 1. Indeed, as player 1 already has tokens 5 and 9, if (after player 2 has played) player 1 selects token 1, the conditions are met (3 tokens for which the sum equals 15). This complex activity for selecting tokens is complex and would thus be a good candidate for automation. One might think of an algorithm computing all the possible combinations for each player and then proposing the most adequate selection. Automation for the games of fifteen has been studied in [2] highlighting benefits and drawbacks for doing so. Current enthusiasm for artificial intelligence would, for sure, argue that machine learning technologies could provide an adequate solution to the token selection task.

### 5.2 Game of Fifteen: Automation Using Visualization

Fig. 3 presents a new user interface that exploits visualization to support the token selection task (among others). In that user interface the tokens have disappeared and are replaced by a Tic-Tac-Toe grid. For each cell in this grid a value is associated (and is presented in Figure 4). Player 1 (resp. player 2) plays by clicking on an empty cell of the grid. This selection is then rendered with a cross (resp. a circle) in the cell.. Situation awareness information of this user interface is :

- the name of the player currently playing,
- the name of the player that must wait,
- the cells selected by player 1 (currently 2 cells with crosses),
- the cell selected by player 2 (currently 1 cell with circle),
- the cells that can still be selected (currently 6 cells).

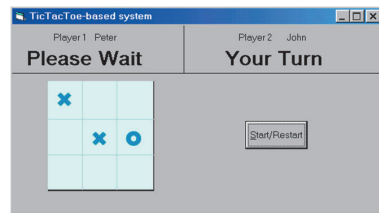


Figure 3: Another example of User Interface for the Game of Fifteen (Tic-Tac-Toe visualization) exploiting Magic Square organization as presented in Fig.4

However, the connection between the cells and the tokens requires using the additional information presented in Figure 4. This figure represents a 3x3 magic square [8]. A magic square of order n is an arrangement of all the number from 1 to n<sup>2</sup> in a n x n square so that each row, column and diagonal adds up to the same value S. Generally speaking  $S=(n^2+1)/2$  which means that for every 3x3 magic square this value is 15. In order to select a token, it is only needed to look at the tic-tac-toe grid in Figure 3. For instance player 2 needs to understand that Player 1 will win at the next turn by selecting the cell at the bottom-right corner (comprehension in situation awareness). In order to prevent player 1 from winning (projection part of the situation awareness) then Player 2 must select that very cell.

8	3	4
1	5	9
6	7	2

Figure 4: A 3 by 3 Magic Square. Each line, column and diagonal sums up to 15

## 6 BIOGRAPHY OF PANEL MEMBERS

### 6.1 Juan Enrique Garrido Navarro

Juan Enrique Garrido Navarro is Lecturer at the Computer Science and Engineering Department of the University of Lleida and coordinator of the Interuniversity Masters in User Experience of the University of Lleida (Spain) and the Universidad Abierta y a Distancia - UNAD (Colombia). From January 2019 to August 2021, he was the coordinator of the master's degree in Informatics Engineering, which is the first master in Spain to offer dual training in an official master's degree whose learning language is English. He is member of the following entities: Research Group on Human-Computer Interaction and Data Integration (GRIHO, UdL), Human-Computer Interaction Association (AIPO) which is the most important Spanish, Latin HCI entity, Special Interest Group on HCI (SIGCHI) and ACM and, member of the HCI Latin-American and Spanish HCI network. Since September 2009, Juan Enrique has focused his research on Human-Computer Interaction, collaborative systems, ubiquity, awareness, context-awareness and natural interaction.

### 6.2 Philippe Palanque

Philippe Palanque is professor in Computer Science at the University Toulouse 3 in France. Since the early 90's his research focus is on interactive systems engineering proposing notations, methods and tools to integrate multiple properties such as usability, dependability, resilience and more recently user experience. These contributions have been developed together with industrial partners from various application domains such as civil aviation, air traffic management or satellite ground segments. Recently he has been involved in the specification of future interactive cockpits and their interactions and in the modelling of operational states of civil aircraft (with direct support from and close collaboration with Airbus). He has been working in the area of automation for more than ten years, was a member of the SESAR Higher Automation Levels in Aviation network of excellence. He was steering committee chair of the CHI conference series at ACM SIGCHI, is a member of the CHI academy and chair of IFIP Technical Committee 13 on Human-Computer Interaction (TC13). He edited and co-edited more than twenty books or conference proceedings including the "Handbook on Formal Methods in Human-Computer Interaction" published by Springer in 2017.

### 6.3 Aaron Quigley

Aaron Quigley is a Professor of Computer Science in the School of Computer Science and Engineering in the University of New South Wales in Sydney Australia and he serves as Head of School. His research interests include discrete computing, global HCI, pervasive and ubiquitous computing and information visualisation on which he has delivered over 50 invited talks. He has published over 190 internationally peer-reviewed publications including edited volumes, journal papers, book chapters, conference and workshop papers. Aaron is an ACM Distinguished Member, an IEEE Senior Member, and was a general co-chair for the ACM CHI Conference on Human Factors in Computing Systems in 2021. He is the chair elect for the ACM CHI Conference steering committee and he serves on the Yirigaa Advisory Board.

### 6.4 Marco Winckler

Marco Winckler is full professor at the Université Côte d'Azur where I am responsible for the track on HCI at the department of Informatics at Polytech Nice. He develops research at the laboratory I3S (UMR 6070) in Sophia Antipolis, France where he is a member of the SPARKS team of the CNRS and the joint research project WIMMICS team of the INRIA Sophia Antipolis Méditerranée. His research is concerned with the Engineering of Interactive Systems. Over the years, he has investigated the use of models for describing interactive systems in many application domains such as ground segment systems, e-government, and mobile applications. A substantial part of his work was dedicated to the development of Web applications and his current topics of interest cover Web Engineering domain and methods for specifying online/offline navigation and client-side adaptation of Web sites. In recent years, his research embraced themes of Information Visualization methods for describing visualization techniques, complex visualization pipelines (more specifically, for processing linked data/semantic Web data) and chained visualizations. Marco Winckler is general chair of ACM SIGCHI EICS 2020 and 2022, member of the steering committee of INTERACT and secretary of IFIP TC 13 committee.

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