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Integrating Transparency Models to Ecological Interface Design

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Ecological interfaces are used in many fields to facilitate the supervision of a dynamic and complex environment. These ecological interfaces can be designed based on analyses from the Cognitive Work Analysis (CWA) approach. These analyses can be completed by the exploitation of different conceptual frameworks to facilitate the design of the interface. To create an interface dedicated to human-machine cooperation, we propose to use the conceptual framework of transparency in addition to the CWA analyses. The objective is to present how transparency can help in the designing of ecological interfaces for autonomous agents. This communication shows what are the constraints that transparency models will highlight and how transparency models can be used. This integration of models in ecological interface design implies a better understanding of the intrinsic differences of the predominant models. This understanding involves an analysis of the strengths and weaknesses of each transparency model in interface design. In conclusion, the adaptive use of transparency in ecological interfaces seems to be a research perspective with great potential.

Keywords: Adaptive interface, Autonomous Agent, Cognitive Work Analysis, Ecological Interface Design, Human-Machine interaction, Transparency.

1. Introduction

Ecological interfaces have been used for many years to improve human-machine interactions, especially as they allow the operator to improve awareness of their environment and control of unexpected events (Naikar, 2017) by knowing its space of possibilities (what the operator can achieve in his current environment). The purpose and principle of an ecological interface is to represent the constraints and processes of an environment to facilitate the operator's work (Burns & Hajdukiewicz, 2003). The design of an ecological interface is intrinsically linked to the use of results from Cognitive Work Analysis (CWA) (Rasmussen & Vicente, 1989). The purpose of this paper is to clarify how transparency models can complement CWA results for the ecological interface design (EID).

2. Ecological Interface Design and Cognitive Work Analysis

The CWA is a "framework" with five different analyses (Stanton & al, 2017). Those analyses focus on the socio-technical system (STS) (i.e., “systems are made up of numerous interacting parts, both human and non-human, operating in dynamic, ambiguous and often safety critical-domains”, Stanton & Bessel, 2014, p.110). These modelling tools help to highlight the information required by users for carrying out the different functionalities in a constrained work environment (Tab. 1) (Bennet & Flach, 2019). These identified relationships with work functionalities and work constraints must then guide the design of ecological interface. The work domain analysis (WDA) helps to obtain the information to be displayed in the interface to show the constraints of the system and help in problem solving. The control task analysis (ConTA) allows to model the decisional and environmental constraint. The analysis of strategies (StrA) makes it possible to understand the procedural constraint. The analysis of the organisation and the cooperation (SOCA) allows to model the socio-organisational constraint and the task allocation. The Work Competencies Analysis (WCA) allows to model the constraints of the operator competencies according to the Skill, Rule and Knowledge levels proposed by Rasmussen (1983). To assist the interface design, these analyses can be complemented by using methodologies such as user-centred design or the application of ergonomic guidelines (Burns and Hajdukiewicz, 2004; Simon et al., 2021). Those methods facilitate the use CWA results, but can also be another way of analysing the constraint of the socio-technical system

Table 1: CWA methodology summary (Adapted from Rauffet & al., 2015)

Constraints identification	**Phase of CWA**
System Functional Constraints	Work Domain Analysis (WDA)
Decisional and Situational Constraints	Control task Analysis (ConTA)
Strategy Constraint to Achieve System Goal	Strategy Analysis (StrA)
Functional Allocation Constraints	Socio-Organisational and Cooperation Analysis (SOCA)
Functional Competencies Analysis	Work Competencies Analysis (WCA)

With the increased integration of autonomous agents in work teams, the interface is the main medium for human-machine dialogue. In the context of Human-Machine cooperation the use of the concept of transparency has been proposed to improve this dialogue (Chen, 2021). If the connection between the concepts of transparency and ecological interface is not new (Selkowitz, 2016; Pokam-Meguia et al., 2019), it seems necessary to shed light on how this concept of transparency can help interface designers.

3. Transparency Concept

Transparency can be defined as the ability of an autonomous agent to communicate about different information (states, processes, etc.) to facilitate cooperation with a human agent (Chen et al., 2014; Lyons, 2013).

There are three predominant models for transparency (Rajabiyazdi & Jamieson, 2020). Johnson et al. (2014) propose a way to operationalize transparency using a task analysis. They propose three central elements. Observability is the fact of making visible the information of the stakeholders (knowledge about the team, the task, or the environment). Predictability is the fact that behaviours are predictable so that one can rely on the other (to rely on). And Directability is the ability to influence and give order to the other. Those elements can be linked to the two models that we will present and use in this communication. Those two models focus on the autonomous agent, and the information it must and can disclose to the human. As Rajabiyazdy and Jamieson mention, these models have a prescriptive side. The first of these two models is Lyons' (2013): Human-Robot Transparency Model. This model proposes that the transparency of an autonomous agent is established along two dimensions (Fig. 1). The first dimension is "robot-to-human" (rTOh) and includes four sub-dimensions (presented as model by Lyons) (intention model, task model, analytic model, and environment model).

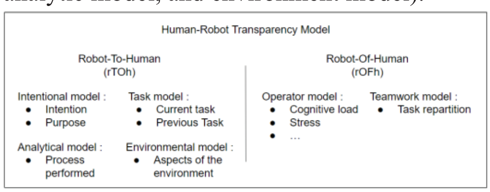

Figure 1. Human-Robot Transparency Model, based on Lyons (2013)

The second dimension is "robot-of-human" (rOFh) and includes two sub-dimensions (also called model) (operator model and cooperation model).

The second model is proposed by Chen et al. (2018): Situation Awareness-based Agent Transparency. This model follows the precedent one proposed by Chen et al. (2014) and is based on the concept of Situation Awareness as proposed by Endsley (1995), as well as on the BDI (Belief, Desire, and Intention) model by Rao and Georgeff (1995) and the PPP (Process, Purpose, and Performance) by Lee and See (2004). This model proposes three levels of transparency of the autonomous agent (referred as SAT 1, 2 or 3) that will improve the situational awareness (referred as SA) of the operator (Fig. 2). The operator's level 1 SA is improved by the presentation of basic information about what is going on (propositions, states, intentions, goals, i.e., SAT 1). The level 2 SA is enhanced by why the autonomous agent performs this action (access to reasoning processes and constraints exerted by the environment, i.e., SAT 2). Finally, the level 3 SA integer what the operator should expect (projections and probabilities, i.e., SAT 3).

Situation Awareness-based Agent Transparency

Level 1 : Goals & Actions
Agent's current status/actions/plans
- Purpose
- Process
- Performance
- Perception

Level 2 : Reasoning
Agent's reasoning process
- Reasoning Process
- Motivations : constraints

Level 3: Projections
Agent's projections/predictions; uncertainty
- Projection of future outcomes
- Uncertainty and potential limitations; Likelihood of success/failure
- History of performance

Figure 2. Situation Awareness-based Agent Transparency, based on Chen et al. (2018)

In this paper, we propose to show how these two models complement the results of the CWA by providing additional information on the five CWA analyses. This additional information can then be used to structure and/or complete the specifications of an ecological interface for the Human-Machine dialogue. In the same way as Burns and Hajdukiewicz (2004) when they presented other methods for the CWA, transparency models presented here are at the same time complementary to the insights from the CWA and an alternative way to obtain those insights. There may be some overlap between the information obtained from the different models and a full CWA approach. Those models can also be used as a control step to see if the interface addresses all the elements needed for a human-machine interaction.

4. Integration of transparency concept in Ecological Interface Design

As seen previously, the CWA permits to identify the constraints of a socio-technical system with its methodological tools. The identification of these constraints makes it possible to define the space of possibilities of an operator in a defined situation. The transparency models allow us to understand the information that can improve the human-machine dialogue. This information can be used to define the prerequisites for the creation of an interface. Conversely, data from the CWA will feed into transparency models by specifying the information needed in a given socio-technical system (Pokam-Meguia et al., 2019). The complementarity of these approaches must be used to develop an environment favourable to the implementation of the autonomous agent in a work situation, while preserving the performance of the human-machine team (Fig. 3).

4.1. Integration of Human-Robot Transparency model

Thus, Lyons' model allows the designer, by putting the focus on the autonomous agent, to obtain its constraints. This change of focus allows to highlight different elements and constraints complementary to the constraints resulting from the CWA analysis (Tab 2). Each of the illustrative examples will be based on a pizza preparation robot. If the work domain analysis allows to model the functional constraints of a given environment, the models of the intention (rTOh) and of the task (rTOh) are the counterpart from the point of view of the autonomous agent.

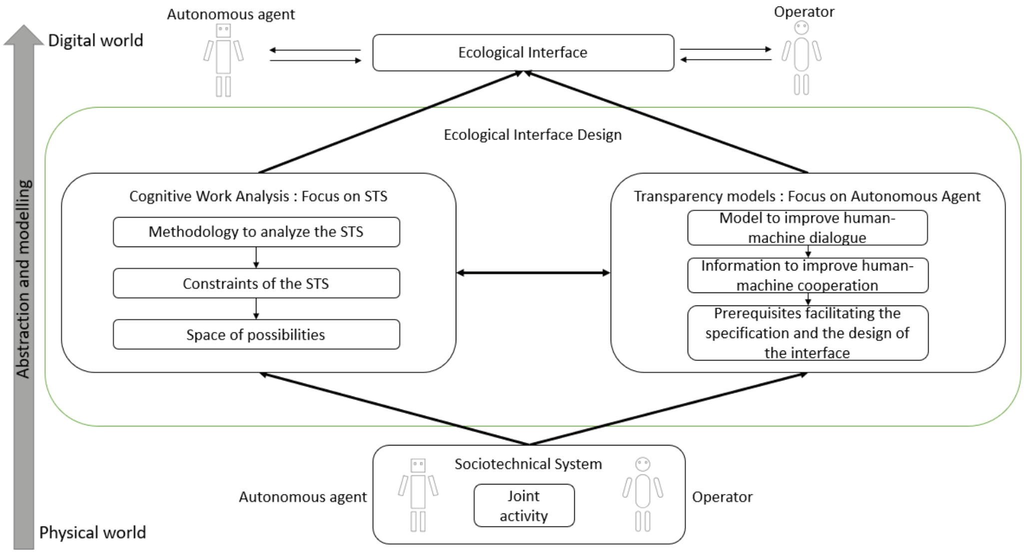

Figure 3. Synthesis of CWA and Transparency model complementarity for EID

These two models will formalise the objectives and functions of the autonomous agent. In terms of design, the interface will have to reflect what the autonomous agent wants to accomplish and what it does to reach this goal. For example, the ecological interface of a pizza-making robot will need to communicate that it wants to make a pizza (intention model) and that to do so it needs to knead the dough and heat it (task model).

The control task analysis provides access to the constraints related to the contexts in which a task is performed (situational constraints) and to the cognitive processes associated with it (decisional constraints). The task model (rTOh), the environment model (rTOh) and the analytical model (rTOh) illustrate these same constraints from the point of view of the autonomous agent. The robot will have to communicate through the interface that it is trying to cook the pizza (task model), that this task will be done when the previous pizza has been cooked (environment model), and that it needs to wait a certain time before taking the pizza out of the oven in order to have a crispy dough (analytical model).

The strategy analysis will make it possible to highlight the constraints of the different procedures allowing to obtain the same result. The analytical model (rTOh) will highlight these same constraints by displaying the different procedures that the autonomous agent can use. The robot will have to communicate about the possible procedures to use to monitor the pizza such as monitoring the time or watching the colour of the dough (analytical model).

The analysis of the organisational system will illustrate the constraints related to the organisation and allocation of tasks. These same constraints are found in the teamwork model (rOFh), through the communication of the allocation of functions within a team. The use of this model for the creation of the interface allows the autonomous agent to show the organisational constraints it perceives. The robot can thus communicate that it is in charge of cooking the pizza, but that once the pizza is out of the oven, it is up to the human operator to put it in the box (teamwork model)

Finally, the worker competence analysis allows us to have the constraints linked to these skills. The operator model (rOFh) allows to model the constraints that the autonomous agent perceives from the operator. The autonomous agent communicates here on what it perceives from the operator, both in terms of mental load, as well as its objectives. The ecological interface for the robot will then be to communicate to the operator that he does not have the skills to fold the box, and consequently support this lack of skill by displaying a method to help him

4.2. Integration of SAT model

As before, the model proposed by Chen et al. focuses on the autonomous agent. And in particular how this agent by its communicated information can improve the situational awareness of the operator. It is possible to see the contributions of the SAT model in two ways. The first is the explanation of the constraints OF THE autonomous agent and the second is how the robot can communicate to SUPPORT the operator via the situation awareness. For these two contributions, we will continue the illustrative parallel with the pizza robot.

The model proposed by Chen et al. is based on the principle of communicating what the autonomous agent does and why it does it. This model thus allows access to the functional constraints of the autonomous agent, but also to the decisional, situational and socio-organisational constraints.

Overall, level 1 of the SAT model highlights what the autonomous agent wants to do and how it wants to do it. The first level allows the autonomous agent to communicate on states (status of the environment and teammates), actions (process, progress and performance) and on the agent's intentions (purpose). This first level will thus allow access to different constraints (Tab. 2):

- Functional constraints thanks to the processes. The robot will say that it is preparing a pizza (purpose) and that it has associated tasks, for example kneading the dough (process)
- Decisional and situational constraints thanks to the status of the environment and the work situation. The status of the environment informs about what is going on. The robot communicates that the oven is at 200°.
- Procedural constraints thanks to the progression. This progression allows the operator to follow the progress of a known strategy. For example, the robot will say that it is at step 3 of the recipe.
- Socio-organisational constraints and operator skills with the teammate state. The robot will be able to describe the allocation of functions between itself and the operator.

Level 2 of the SAT model allows the autonomous agent to communicate on its reasoning. This reasoning will explain its intention and its processes (Tab. 2):

- On functional constraints, the reasoning will explain an end-means relationship, and vice versa. The goal will explain the process. The robot will communicate that to make the pizza it must cook it.
- On situational constraints, the status of the environment will explain the task or the goal. The robot will communicate that it is going to heat the pizza BECAUSE the oven is at 200°.
- On procedural constraints, the progression will be used to justify the move to the next step. "I'm going to step 4 BECAUSE I finished step 3". In a broader sense, the robot can also communicate about alternatives: "I prefer step 4.A after step 3".
- On the socio-organisational constraints, the teammate's state allows to understand the robot's actions. The robot will communicate that it cannot handle answering phone orders BECAUSE that is the operator's role.
- On the operator's skills, the teammate's state also allows to understand the robot's actions. It will communicate that it helps the operator to knead the dough because the operator does not have the skills to do so.

Table 2: Integration of Transparency models into ecological interface design

Constraints modelling in Ecological Interface	Cognitive Work Analysis	Human-Robot Transparency Model (Lyons, 2013)	Situation Awareness-based Agent Transparency (Chen et al., 2018)	
			SAT 1	SAT 2
Functional	WDA	rTOh: Intention & Task	Process & Purpose	Process ~ Purpose
Decisional and Situational	ConTA	rTOh: Task, Analytical & Environment	Environment Status	Environment Status ~ Process/Purpose
Procedural	StrA	rTOh: Analytical	Progression	Progression ~ Process/Purpose
Socio-organisational, allocation	SOCA	rOFh: Teamwork	Teammate Status	Teammate Status ~ Process/Purpose
Operator' s competencies	WCA	rOFh: Operator	Teammate Status	Teammate Status ~ Process/Purpose

The second contribution is at a finer level and is intended to help the operator in specific situations. The idea here is to use transparency as an aid to the operator to respond to situations identified through the CWA in a dynamic way. Once the decisional, situational, procedural, socio-organisational or worker competences constraints of the human operator are identified, it is possible to use the three levels of transparency to adapt the communication of the autonomous agent. If an operation requires the operator to have a situational awareness that takes into account the uncertainties, then it is necessary to present in the interface the information up to level 3. To know if the operator should stop giving new commands to the robot, the robot can communicate to him what it is doing (SAT 1), that it cannot use more than 3 ovens at the same time (SAT 2) and that accepting new commands brings a risk of causing delay (SAT 3).

On the other hand, if the skill to be adopted requires the use of a rule, a transparency on level 1 can be proposed. The robot does not have any fresh cream for the pizza base, it communicates to the operator its situation (SAT 1), the operator having been trained in this sense, tells him to go and get some.

Similarly, if the operator's competence only requires a skill, the robot will be able to communicate on its situation (SAT 1). The robot communicates about its need to be restarted, and the operator presses the corresponding button.

Above those integration into ecological interface design, Human-robot transparency model and Situation awareness based-transparency model can help with the specification. The designer can use the transparency model as a structure to guide his research beforehand. This integration can also help the designer with a post check of the interface. The designer can use the dimensions and the levels to see if its interface contains enough information for the operator. For example, the designer can check if there is a way to have access to the processes of the autonomous agent (analytical model (see Fig. 1) or the level 2 (see Fig. 2)). If not, it might be necessary to add it to have a better ecological interface.

5. Conclusions

In the same way that the concept of transparency has been integrated into a new model of acceptability (Vorms & Combs, 2022), it seems appropriate to explore its integration into the design of ecological interfaces for autonomous agents. A new generation of research on ecological interfaces is emerging (Kant & Sudakaran, 2021), and transparency can be integrated in it. Indeed, transparency models allow an improvement of human-machine cooperation through the prism of information communication that calibrates trust and improves awareness. This integration will help to identify constraints of the autonomous agent. It will also help to structure the specification by providing guidelines and can be used as a double check to the results from a global analysis of the system. Therefore, we identify two emerging areas of research regarding the use of transparency in the design of an ecological interface. First, it is still necessary to understand the effects of transparency in the context of human-machine dialogue. Should all the information from the models be implemented in an interface or its use should be more parsimonious and context sensitive? This leads to the second point which concerns the interest of studying the possibility of an adaptive transparency according to the users or the context. Indeed, the models of Chen et al. (2018) and Johnson et al. (2014) used in the design of an ecological interface integrate an adaptive notion (depending on strategies, context, user, or behavior). This adaptability could be the response to several types of triggers (Sarter, 2007):

- physiological and/or psychological states
- the level of expertise of the users
- user behaviour

The goal would be to promote certain behaviours or strategies of users in interaction with the machine and to avoid its misuse or disuse (Akash et al., 2020). Also, it would be interesting to understand how the framework proposed by Johnson et al. (2014) could implement other elements into ecological design. In order to better understand the interest and use of transparency within an ecological interface, it seems important to differentiate the approaches proposed by these models to help in their future use. This differentiation must be done by understanding the strengths and weaknesses of these models in the conception of ecological interfaces.

In this communication we have shown how the CWA and the transparency models are complementary to define what information should be communicated. For a broader perspective on improving dialogue for a safer interaction, it might be interesting to also investigate how to communicate information. Commonly we use visual interface, but we can think of another modality like sound. Ecological interface could be helpful and adapt to more situation with a new spectrum of communication modality.

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