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TITLE

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System Number:

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97-P-36

Proceedings of the 29th Annual Conference of the Human Factors Association of Canada - 1997
Comptes rendus du 29e congrès de l'Association canadienne d'ergonomie - 1997

A Human-Machine Interaction Analysis using Layered Protocol Theory

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Human-Machine interface design continues to be an area of concern for theorists and practitioners alike. The interface must make the machine's states more transparent to the user, and vice-versa, as the systems become more complex. Layered Protocol Theory provides a framework for analysing the interaction between the human and the machine. This framework was applied to the interaction between a pilot and a helicopter avionics management system. Interaction deficiencies were identified and solutions were proposed to address the deficiencies.

1. Introduction

Communication and navigation are critical for flight. The Control Display Unit (CDU) provides the interface between the pilot and the aircraft avionics system in monitoring the aircraft systems and mission data. The process of interacting with the CDU is often not intuitive for the crew; improvements to the CDU interface are desirable to reduce the chance of error and to enhance the crew performance.

In 1995, the Canadian Forces recognised that proposed equipment and procedures run the risk of imposing more workload on the CH-146 Griffon flight crew if not properly implemented. Soon after, the CDU was identified to contribute significantly to the workload of the crew. Work is now underway to update the CDU software in order to minimise the "mis-communication" between the crew and the CDU.

Layered Protocol Theory (LPT) provides a framework where the belief states of two communicating partners are monitored throughout the passage of a message. The crew member and CDU may be seen as communicating partners, each attempting to move their current *beliefs* towards goal beliefs about themselves and each other by using feedback messages. Interaction deficiencies are determined by mapping out probable belief states and identifying feedback messages that inhibit the efficient completion of a given communiqué. Solutions can be proposed and designed within the interface that address the interaction deficiencies.

2. Perceptual Control and Layered Protocol Theories

Layered Protocol Theory is an extension of Perceptual Control Theory (PCT) (Powers, 1973) which describes the human information processing system in terms of Control System Theory (CST) (Van de Vegte, 1990). In the CST framework shown in Figure 1, psychological constructs such as stimuli, perception, decision, behaviour and response can be analysed using CST techniques.

Behavioural psychology argues that behaviours are being controlled in response to a stimulus. In PCT terms, however, a person acts on the world (or behaves) so that the perception is driven towards its goal state and the perceptual error is minimised. The perception itself is a transformation of stimuli generated by disturbances and behaviours that affect the world, thus closing the control loop. The core tenet of PCT is that all behaviour results from the control of perception, since it is the perceptual signal that is being controlled in the CST sense.

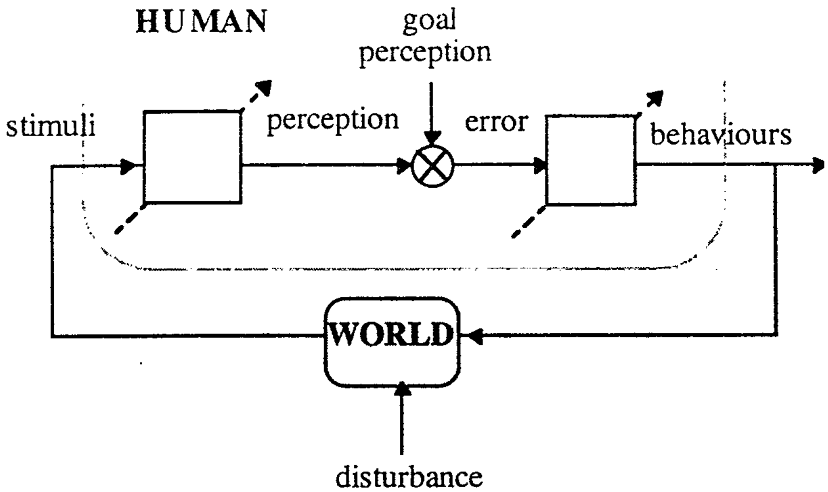

Figure 1: Perceptual Control Theory depicted as a classical control feedback system

The transformations between the stimuli and the perception, and the error and behaviours are part of an information processing model (Hendy, 1994) that involves the amount of information, the decision time, time available, levels of processing, experience, strategies, etc. PCT does not provide the details about the nature of these transformations, but simply says that they exist and are adaptive as indicated by the dotted arrow.

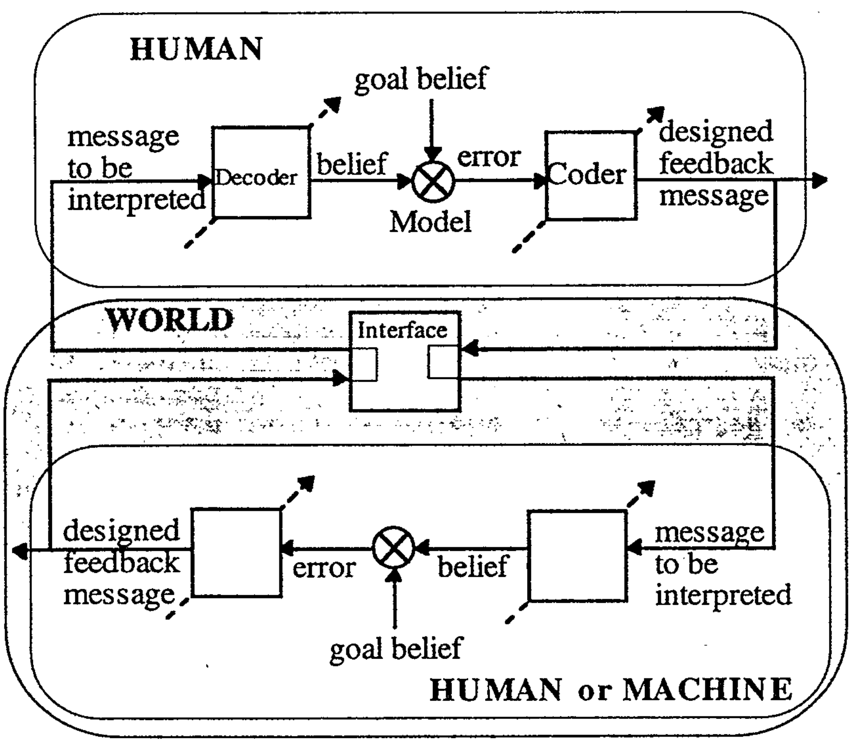

Figure 2: Layered Protocol Theory provides a framework to analyse interaction.

Layered Protocol Theory (LPT) originated from the study of language and communication. Taylor (1993) recognised that the LPT provided a framework where the interaction between two communicating partners may be analysed. In Figure 2, the world of Figure 1 is expanded to include models of a partner and the interface through which they communicate.

Beliefs and feedback messages are the LPT analogues of perceptions and behaviours in PCT (see Farrell et. al., 1997 for a complete discussion of LPT and PCT). A belief is defined as a vector of perceptions, implying that each belief component can be described by its own PCT loop. The LPT transformations convert a belief error into a designed feedback message, and a message to be interpreted into a current belief. The design-interpret paradigm (Thomas, 1973) represents the adaptive nature of the message. LPT has adopted this paradigm even though the transformations are named Coder and Decoder.

Not shown in Figures 1 or 2 is the hierarchical nature of both theoretical frameworks. That is, feedback messages from higher level control loops become goal beliefs for lower level loops, and lower level belief loops must be stabilised before their belief states can be transformed into messages to be interpreted at higher levels of abstraction. For example, in writing this paper I wanted to describe some thoughts on interface design techniques. In doing so, I first must have a belief that the concepts are described clearly, which in turn, drives the belief that the words are used properly, which drives the belief that the letters are correct, and so on. Once the beliefs at the letter, word, and concept level are stable then the highest goal belief of describing interface design techniques may be satisfied.

The multi-dimensional and hierarchical nature of LPT makes it difficult, though not impossible, to apply a rigorous mathematical analysis to the dual control loop system. Alternatively, a descriptive analysis is explored. That is, the belief states and the designed and interpreted feedback messages are described in context of CST principles with words.

3. The Layered Protocol Tool

The Layered Protocol Tool (LPTool) is a software program that allows the user to generate, define, and annotate views on the interaction model. LPTool facilitates the description of the beliefs and messages within an individual LPT loop, the belief hierarchical structure, and the passage of messages between partners. For a complete description of LPTool and its views see Farrell and Semprie (1997) and Taylor et. al. (1997).

A Transmit Protocol Node (PN) is an icon within the LPTool that represents the top LPT loop (or originator) in Figure 2. A Receive PN represents the bottom loop from the originator's perspective. That is, the originator has a model of the other partner's belief states, and interpreted and designed messages. This perspective permits the originator to code and decode their feedback messages appropriately. Thus, two mirrored hierarchical structures emerge representing models of both partners from the originator's point of view.

The PNs shown in Figure 3 are generated within a Network View. They have three letters and four quadrants so that the analyst may access different views of the interaction, and define and annotate the beliefs and messages. The PNs' three quadrants provide windows onto the Nine Element View, the General Protocol Grammar (GPG), and the Job Processing Chart. The Job Processing Chart and the fourth quadrant are not currently functional but have been identified for dynamic simulation purposes.

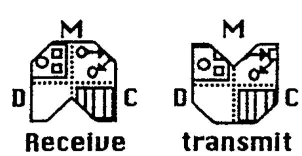

Figure 3: The goal belief, message to be interpreted, and the designed feedback message are defined and annotated in the Model (M), Decoder (D), and Coder (C), respectively.

The interaction deficiencies were found by examining the belief states and feedback messages that inhibited the achievement of goal beliefs. The model had missing, incorrect, or redundant feedback messages that led to slowly stabilising or unstable belief states, and ultimately a break down in communication. The deficiencies were found by listing the feedback messages within each protocol node, and determining if they were implemented within the current CDU interface. If not, proposals were made to revise the CDU interface so that it would address the interaction deficiencies.

One interaction deficiency example was found in the FUNCTION protocol. As an option appears on the screen, it is activated. The pilot can not simply view the options without activating them. In LPT terms, the pilot has no way of aborting a message at this level. The proposed solution would be to have separate actions (messages) to select and activate an option. The CDU display would then need to show whether an option has been selected or activated.

5. Conclusions

A Layered Protocol analysis of a Control Display Unit was performed using a new software program called LPTool. The LPTool program assisted in identifying the required feedback messages during the interaction. The analysis was applied to the interaction between the pilot and the CDU as partners in establishing a radio communication link. The interaction deficiencies were listed, and proposed design solutions were presented that addressed the deficiencies. The LPT model did not provide a method for designing an interface. It did, however, yield the critical feedback messages for moving both partner's belief states towards their desired goal states.

The interaction deficiencies identified by the Canadian Forces have been confirmed using a Layered Protocol Theory analysis. Recommendations and specifications for an improved CH-146 CDU interface may be derived from the research results. However, further work is required to determine the impact of the new design on workload and performance.

6. References

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Listed below are some lessons learned for constructing an interaction model using LPTool:

- Start and end at levels where a designer may affect changes.
- Define the partner for which the model is to be developed (i.e., the originator).
- Make hierarchical connections between Model, Decoder, and Coder of PNs.
- Completely annotate all views before generating and annotating supporting PNs.

4. CDU-Pilot Interaction Model

The LPT framework was applied to a pilot-CDU interaction. At the highest level of abstraction the pilot wanted to establish a communication link between the aircraft and a ground station. The CDU was considered to be the pilot's partner who wanted to believe that a radio link has been established. These were statements of the partners' goal beliefs. If the pilot did not believe that a communication link was established, then feedback was designed and transmitted wanting to see a radio and security channel chosen, and a mode and frequency set. These messages became lower level goal beliefs. If the belief about the frequency setting, for example, did not match its goal belief, then the belief about the correctness of the key press became the last level of abstraction. In turn the pilot received feedback messages from the CDU display and interpreted it for the each level. That is, the display would show if the right key was pressed, the desired frequency was set, and a communication link was established.

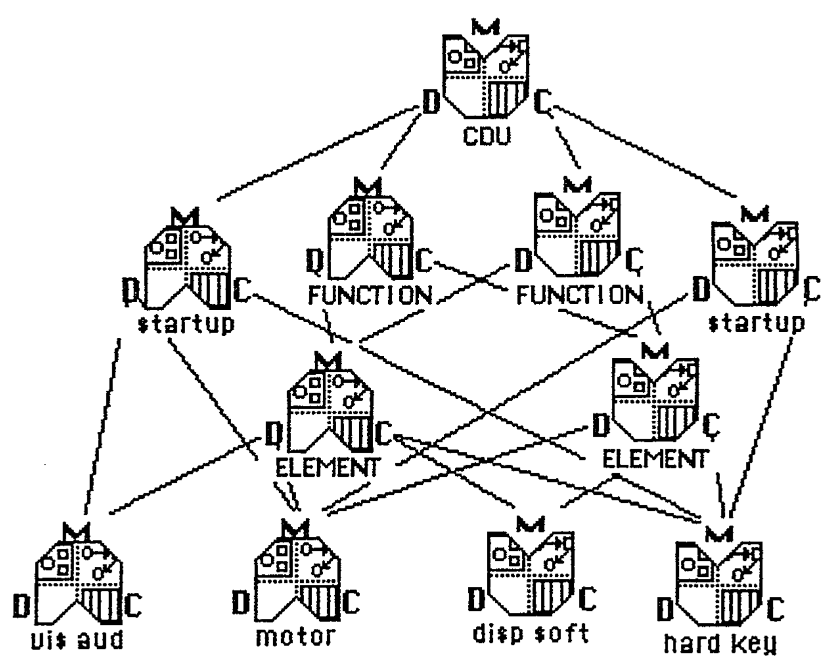

Figure 4: Network View of the pilot-CDU Interaction Model

Figure 4 shows the Network View of the CDU-pilot interaction protocols in hierarchical form. Each protocol node represented different probable belief states and feedback messages. For example, the FUNCTION protocol represented the interaction in establishing a communication or navigation link; both link types have different content but the same structure (i.e., protocol). The same is true for the ELEMENT protocol that represented radio, frequency, mode, or security settings. The model was stopped at the interface level where the pilot could receive visual and audio messages from the CDU displays, and could transmit tactile messages via the CDU soft and hardkeys.

RÉSUMÉ
La conception d'interfaces personne-machine est toujours un domaine d'intérêt tant pour les théoristes que les praticiens. L'interface doit faire en sorte de rendre les états de la machine davantage invisible pour l'usager, et vice-versa, au fur et à mesure que les systèmes deviennent plus complexes. La théorie du protocole en couches (*Layered Protocol*) offre un cadre de référence en vue d'analyser l'interaction entre l'humain et la machine. Ce cadre a été appliqué à l'interaction entre un pilote et un système de gestion d'hélicoptère. Les faiblesses quant à l'interaction ont été identifiées et des solutions ont été proposées afin de pouvoir les résoudre.

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