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The 2009 A320 ditching on the Hudson River revealed to the public that critical decision-making ability was a key asset for pilots. Situation awareness and workload management are two key elements as well as the ability to anticipate how the situation will evolve. Thales Avionics is funding research through its HF research Lab (HEAL) on HMI facilitating pilot anticipation. This presentation covers a literature review on anticipation so as to develop a model of anticipation in a realistic flying task. Analyzing the concept of anticipation leads us to consider it as a metacognitive process relying on cognitive resource management, situation awareness and time management, using abstract representations. After reviewing these concepts, we focus on time management and anticipation. It reveals a closed loop mechanism inspired from the reafference principle. This will be the basis for a HMI based on a model of anticipation in flight.

The feat of ditching on the Hudson in January 2009 has revealed the criticality of certain decisions under high pressure. Metaknowledge and anticipation are the cornerstones of human ability to manage these types of situations: helping pilots to better anticipate situations is therefore a major challenge that the ASAP project (Anticipation Support for Aeronautical Planning) intends to address. This presentation is an anticipation-oriented literature review, with the intention to develop a model of anticipation in the context of a simulated flight task. This work will enable the design of a user-centered HMI prototype dedicated to assisting in-flight anticipation.

First, we will compare different definitions of the "*anticipation*" concept in diverse disciplinary fields. This will lead us to consider anticipation as a metacognitive process based on cognitive resource management, situation awareness and time management, using abstract representation. These themes are discussed with regard to their contribution to the process of anticipation. Second, we concentrate on time management within the scope of cognitive psychology. Emphasis is placed on the relationship with time and the environment: workload as a function of the perceived distance to the goal is specifically addressed. Finally, work on anticipation is presented, highlighting a closed-loop mechanism similar to the reafference principle.

Anticipation as a metacognitive process

Definition

Even though the term anticipate is commonly used, it is nevertheless still difficult to define precisely. We confuse it and often use *predict, foresee* and *plan ahead* instead. There is one idea common to these concepts; it is a process that is both in the present and the future, as suggested in its Latin etymology: "*anticipare*" means "*take in advance, take the initiative, take the lead*".

In psychology, Sutter (1983) defines anticipation as a "*movement by which man carries his entire being beyond the present into a future, near or far, that is essentially his future*". Even though this definition does not exclusively consider taking action, it elicits the idea of thinking ahead: to anticipate is to represent ourselves and our environment in a process of evolution and adaptation, it is a "*transplant of the future in the present*" (Minkowski (1968)). A new idea emerges from the definition of an anticipatory system in computer science provided by Rosen (1985): an anticipatory system is *"a system containing a predictive model of itself and/or of its environment, which allows it to state at an instant in accord with the model's predictions pertaining to a later instant".* In computer science, to anticipate entails two phases: a prediction phase and a phase of using the prediction. It is therefore a system that has a kind of "future memory", a database enabling it to infer the evolution of the situation as a function of similar situations already encountered.

In cognitive psychology, Cellier (1996) gives the following definition: an "*activity consisting of evaluating the future state of a dynamic process, determining the type and timing of actions to undertake on the basis of a representation of the process in the future, and, finally, mentally evaluating the possibilities of these actions. It is dependent on the overall goal assigned to an operator in a dynamic situation, which is to keep the process, physical or otherwise, within acceptable limits, and therefore avoid the propagation of disturbances. It is also governed by a logic aimed at reducing the complexity of a situation. Finally, it is a way of managing individual resources".* All of the preceding ideas are included in this definition: assessment of the evolution of the situation, mental simulation and encoding in both temporality and the action. However, a few additional points are presented: the teleonomic aspect, anticipation only makes sense in light of an overall goal; from a cognitive point of view, the process also meets the requirement to reduce the load and the complexity of the environment.

For this bibliographic work, we will therefore focus on anticipation as a metacognitive process enshrined in a dynamic temporality: a process aimed at conserving cognitive resources, requiring awareness of oneself and of the situation, as well as time management ability.

Anticipation as a means of cognitive economy: impact of cognitive resource management

In the management of the high-pressure situation presented earlier, it is essential for the pilot to avoid any cognitive overload. Anticipation is presented as a process that makes it possible to overcome the limits placed on his resources.

One strategy consists of spreading cognitive processing out through time: Amalberti (1995) gives the example of preparing a response in advance to a probable combination of events. This example is itself a continuation of the SRK model (Rasmussen (1983)): in the face of a complex situation requiring the use of knowledge to develop a response, anticipation enables the construction of a routine that is ready to be used when needed. Amalberti (1996) further clarifies this idea: the operator avoids complex situations as much as possible in line with his expertise, and prepares for those situations that he cannot avoid by preparing his responses in advance.

Within a complex system, such as a cockpit, the operator may be faced with a situation where several distinct temporal dynamics coexist (inertia of the airplane, transmitting information via the radio, etc.), Leplat & Rocher (1985) emphasize that, in these cases, anticipation exploits the temporal tolerance induced by these dynamics. We will discuss this later in more detail.

With regards to an activated plan, anticipation also consists of mentally simulating the evolution of a situation: this is the last level of Endsley's situation awareness model (Endsley (1995)), which we will also discuss later. When the task requirements increase, anticipation allows assumptions to be made on the evolution of the situation as well as to test them (Amalberti (1996)). The operator imagines the consequences of these situations and consequently changes his conduct by adapting his plan of action if necessary. This attitude allows him to keep the situation within controllable limits while managing any deviations to the plan. To illustrate this, in aviation education, it is said that "*the pilot must learn to be in front of his plane*" and should be encouraged to "*make permanent assumptions about the future situation in order to actively adapt to this situation and not wait for it to occur*". Thus, according to Amalberti (2001), anticipation enables the subject to integrate his own ability in order to impact one's environment and protect oneself from feared events by adjusting the plan.

Anticipation and projection of the evolution of the situation: impact of situation awareness

Even though we emphasized the importance of the representation of the situation during a crisis, it is still correlated to having a good awareness of the situation. The idea of anticipation is included in the definition given by Endsley (1987), "*situation awareness is 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."* The last part of the definition corresponds to level 3 of this model: awareness of the status and dynamic of the elements is made possible by the first two levels of the situation analysis and allow the evolution to be assessed.

Baumann & Krems (2009) add the following to this analysis: the information collected activates the associated knowledge stored in long-term memory. From this knowledge network, a coherent representation is constructed by following a constraint-satisfaction process: the compatible elements are activated, the incompatible elements deleted. The subject's expertise allows him to add expectations regarding the evolution of the situation to this representation. These expectations are related to schemas that are activated when certain environmental patterns are encountered; more details will be provided for this later.

Comprehension of the situation consists not only of giving coherence to the facts but also explaining them and predicting their evolution. This is therefore a continuous mechanism that is based on a dual relationship with temporality: backwards to explain the cause and forwards to predict the future. All comprehension is teleonomic: it therefore involves permanently constructing an adapted representation, at a given moment, depending on the specific purpose.

Time management

The concepts addressed earlier have shown that the idea of anticipation is inconceivable outside of a temporal framework. The issue of cognitive processes allowing the appropriation of this framework cannot be ignored.

The psychology of time

Michon (1985) defines time as "*the conscious experiential product of the processes that allow the (human) organism to adaptively organize itself so that its behavior remains tuned to the sequential (i.e., order) relations in its environment*." From this perspective, time is no longer a concept for which attributes need to be defined, nor can we still consider it as an intrinsic property of our world, but as a co-occurrence of processes that allows synchronization with the evolution of the environment. This implies that the cognition of temporality belongs in the field of declarative knowledge; the temporal representations would then be a form of high-level cognition.

Of all the theoretical concepts dealing with representations of time, we adopt one principal idea based on recurring events. Among farmers-ranchers, Valax (1986) establishes that a plan is determined around repeated daily pivotal tasks and time-based goals, which are irrelevant both before and after the appointed time. However, two systems provide margins of tolerance: tasks are always planned with some built-in flexibility to make up for a predecessor's possible delay, and open tasks, which are not constrained by a "*when to act*" and may be inserted in moments of calm. As briefly mentioned earlier, the process of anticipation plays a significant role in the situation described here: by simulating the evolution of his future cognitive load, the operator plays with the margins that time gives him to smooth out and avoid peaks in the cognitive load, i.e. cognitive overload. This means that the operator must be able to assess his cognitive investment based on the distance to the action.

Time and cognitive control

In managing the time available for the action, there is a fundamental difficulty related to the anticipation span. There is a proportional relationship between the distance to an expected event and the uncertainty around it. Hollnagel (1998) distinguished four types of control, functions of the perception of time available for the action and the familiarity of the situation: strategic, tactical, reactive and disorganized, which define different degrees of mastery of the situation and behavior types. This is closer to the SRK model (Rasmussen (1983)), mentioned above.

Reynolds (2006) addresses this question in the aeronautical field. He states that, in the short term, we place ourselves in a persistent area, where the environment will not change very much. A little further in the future, models, such as physical laws, can be applied to get a relatively accurate idea of the evolution of the situation; we have now positioned ourselves in a deterministic area. Beyond a certain distance in time, the rules for assessing the evolution of a situation are subject to a combinatorial explosion linked to the set of variables to be considered. Here, we are in a probabilistic area, in which the slope of the uncertainty curve increases exponentially. This raises the question of the relationship between gain associated with anticipation and cost associated with the uncertainty generated by the distance to the event and thus, the importance of planning.

Planning

Hoc (1987) defined planning as "*the development or implementation of plans*". He attributes two fundamental properties to the plan: it is both schematic and orientated towards anticipation. Several cognitive psychology concepts related to the plan express this second characteristic. Thus, the notion of scheme introduced by Piaget (1952) continues in this direction: any action in reality would be made with a previously established scheme in mind and then adapted to the current situation. Therefore, this involves a mental representation that contains a component of expectations about the evolution of the situation that is action-orientated with an identified purpose.

The concept of schema (Bartlett (1932)) provides a second element in this analysis. Bobrow & Norman (1975) hypothesize that this structure, which is not fully specified, represents the relationships between the variables and the constraints on these variables. They will be distinguished during the implementation through environmental cues, which determine its application. Anticipation operates on this idea.

Anticipation

To illustrate how anticipation works, Tanida & Pöppel (2006) propose a wider application of the reafference principle proposed by von Holst & Mittelstaedt (1950) . Mundutéguy & Darses (2007) confirm this functioning in the context of driving a car: a schema of the situation is activated from a set of sensory cues detected in the environment. An efferent copy of the expectation component is made in order to be compared with the objective reality; this is called a corollary discharge. In order to validate the chosen representation, an oriented search for cues is carried out. The schema constitutes an active means of recognition in itself: once activated, it guides and orientates the search for information in order to validate itself (Amalberti (1996)). The schema is validated when all of its contents in the situation are determined, but the mechanisms provide an opportunity to address any existing gaps by values that are, by default, seemingly realistic.

The teleonomic component of the schema is submitted to two forms of monitoring (Amalberti (1996)): an external monitoring, involving the physical process and the situation, and an internal monitoring, involving the cognitive actor of the process. In case of a problem (negative self-evaluation of the performance), the internal supervision makes it possible to increase the cognitive load in order to adjust the selected mental model: enrichment, adjustment or even construction of a new solution. This metacognitive monitoring is also in charge of arbitrating the following processing: intensity, priority, stopping.

On a more global scale, the Cognitive Architecture of Dynamic Control model described by Hoc & Amalberti (1994) illustrates the possibility for the operator to open several cognitive loops at the same time, which project to different levels of temporal depth: a knowledge base is partially activated through the current representation, and partially mobilized at an unconscious level by an activation lattice controlled by this representation. The performance, models and anticipations are continually self-evaluated. The operator's cognitive limits results in compromises with regard to the possible corrections, function of the available resources and different requirements related to the task. Three loops take place within three different temporalities, three distinct ambitions to make corrections, from automatic control to the complete reconsideration of the current representation. As presented earlier, the attentional supervisor is responsible for both filtering and weighting the sensory inputs as well as a potential local change of the level of control of the action.

In line with the work presented earlier, two alternatives are available to design an efficient tool: help to choose the right plan, or help to validate it. A fundamental paradox appears at this stage: helping the operator to anticipate basically makes sense in the case where a representation of the situation is too terse. The paradox resides in the fact that to automatically provide help would result in giving him precisely this representation. In fact, this is another argument in favor of the direction followed until now: the operator is at the center of the decision loop. The potential additional information that we could give him would help him to construct or complete his representation but is not, in any case, intended to replace it.

Conclusion

In this bibliographical work, we have established that anticipation is a metacognitive process aimed at optimizing cognitive resources, based on situation awareness and time management. Its operation in a closed loop opens opportunities for constructing an HMI aide for anticipation. In the ASAP project, the design method is centered on the final user: the understanding of its cognitive functioning in terms of anticipation makes it possible to envisage the design of the tool while keeping the end-user in mind.

This bibliographical review opens up two development directions: first, contextualization in the aviation industry; this will involve breaking down the tasks constituting a defined flight phase based on their relationship with anticipation. This formalization will allow the creation of a knowledge base in order to fuel future HMI prototypes. Second, the definition of the optimal span of anticipation in a flying task: this will involve defining the window of time within which the help information given for anticipation will improve the performance at a locally minimal cognitive price.

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