Anticipation in aeronautics: exploring pathways toward a contextualized aggregative model based on existing concepts

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Abstract

Within a civil and defence aeronautical context, the topic of anticipation as a cognitive resources saving process for safety considerations is brought up. A better cognitive resources management is one of the keys to increase the safety level of operation. To support pilots in their activity, it is mandatory to help them anticipate better. Such a support would greatly benefit from a user centred design. We present in this paper the cornerstone of our on-going bottom-up approach: an aggregative model of anticipation. This model is the result of collaboration between researchers in cognitive psychology, knowledge management, computer sciences, industrial automation and pilots. It leads to the necessity of building a model that embraces relevant concepts from different theoretical trends and fields and contextualizes them: within the framework of dynamic situations, such a model inevitably deals with time management. Thus one major challenge was to address both short and long term. As a first step, we will present here the relevant concepts and will demonstrate how they could be articulated altogether. This will introduce our aggregative model of anticipation. Secondly, some examples taken from the military and civil aeronautical field shall illustrate some applicative field situations.

Introduction

For more than two years now, the HEAL (Human Engineering for Aerospace Lab.) has been working on the ASAP (Anticipation Support for Aeronautical Planning) project. Pursuing the goal of helping pilots better manage their resources in a cockpit environment, a cognitive engineering approach was undertaken to design a support for pilots' anticipation.

As a first step and in the context of a collaboration of the aeronautical field and the human factors community, experts from both worlds worked together to define from a cognitive viewpoint what anticipating means for a pilot.

On the one hand, depending on the scientific fields, anticipation is defined in various ways. In cognitive psychology, Cellier (1996) gives the following definition: an "*activity consisting of evaluating the future state of a dynamic process, determining*

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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". This definition is close to the acceptation of an anticipatory system in computer sciences, which Rosen (1985) defines as following: "*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".*

On the other hand, pilots are taught to be "*in front of their plane*" and are encouraged to "*make permanent assumptions about the future situation in order to actively adapt to this situation and not wait for it to occur*" (Amalberti, 1996). Anticipation is a major skill that pilots are taught to develop all along their career. Thus we fed our anticipation model with interviews with an expert about mission commanding in an air combat context. Following a one-to-one process, we constantly confronted our theoretical construct to the actual constraints of these experts exercising anticipation.

Account taken of the situation dynamics, the collaboration of these two worlds led to the necessity to embrace relevant concepts coming from various theoretical trends and fields. As a first step, we will present the relevant concepts and will demonstrate how they could be articulated altogether. This will introduce the second part in which we present our aggregative model of anticipation. Finally some examples taken from the military and civil aeronautical field shall illustrate some applicative field situations.

State of the art

Anticipation is often considered as level 3 of Endsley's situation awareness model (Endsley, 1995): the one in which environment information is projected in time in order to assess future states. The postulate for this idea is that available time is mandatory, as well as an abstraction ability in order to well anticipate.

Hoc (1987) highlights the close link between abstraction ability and expertise: what distinguishes experts and naïve operators is the capacity to abstract data from a problem and fit them into a generic frame that it will specify. This result gives credit to the hypothesis according to which anticipation is an ability that defines experts. In our context, it justifies the approach aiming at providing pilots, particularly less experienced ones, a means to compensate a potential lack of anticipation ability.

Denecker (1999) distinguishes short term anticipation (sub-symbolic) relying on reflex loops, low level action control, and long term anticipation (symbolic) relying on the building of solutions that are based on rules and/or knowledge.

The cognitive architecture of dynamic control (Hoc & Amalberti, 1994) makes a bridge between these two ideas: on the basis of Rasmussen's control levels, projecting temporal depth is weighted with hierarchical levels. Implementing knowledge allows a long term projection while on the opposite side of the spectrum, implementing skills allows a short term projection.

In a previous experiment (Lini et al., 2012) we added the idea, implicit in the literature, of the relationship between control levels and cognitive workload. We established that given a control level (skills), an increase of anticipation temporal depth is actually correlated to an increase of cognitive workload.

In the aeronautics field, Reynolds (2006) adds the idea of uncertainty and defines 3 regions which are functions of time depth and situation dynamics: on the short term, situation is persistent. On the middle term (deterministic region), models allow having an accurate representation of the evolution of the situation. On the long term, (probabilistic region), because of combinatory explosions it is only possible to bet on the likelihood of an event to happen. We propose a model dealing with uncertainty.

On shorter temporal spans, literature (Mundutéguy & Darses, 2007, Crognier & Fery, 2007) brings forward the idea of a perceptual and motor expertise, close to the reafference (Von Holst & Mittelstaedt, 1950) principle. An action-driven mental structure is pre-activated from the perception of a distinctive pattern of cues. It then tends to be validated by looking for matching cues in the environment.

Hollnagel (2003) and Tanida & Pöppel (2006) deal with the articulation between anticipation and control levels adding the idea of an interaction between these levels and a parallel functionning. The highest level (targeting loop) is working in parallel of the lowest level (tracking loop) in a process of mutual nourishment.

This state of the art highlights elements on which our model should put the stress. Selection of adequate mental structures is a fundamental point. The enaction (Maturana & Varela, 1980) community advocates the idea of an embodied cognition within the action itself. This hypothesis would support the idea of a competition between mental structures according to perceptual information which can be found in the multi-agents system literature (Maes, 1991). A high level monitoring structure guides the perception and prioritization as well as refinement, evaluation, and even construction of solutions and finally implementation. Our model focuses on the existence of such a high level control structure and the guidance criteria along the process as well as its parallel form.

Pathways to an anticipation model

The state of the art highlighted the main principles of our anticipation model. At first various layers of control are defined. Implementing as well as building schemes is cognitively costly: regardless of the control layer, each action requires cognitive resources in order to be validated and then performed. Therefore, a resources management process is mandatory.

Following computer science trends, a resource tokens system is implemented. Every time a scheme partially validates itself it is rewarded by a resource token. Schemes aim at gathering enough tokens to reach an inner activation level which will allow their implementation in due time. Higher levels manage both the awarding and the amount of available tokens.

This principle requires a recursive viewpoint of our framework. Defining objectives at a strategic level requires resource tokens as well as performing a sensory-motor action. This means that each layer can be considered through the prism of both the definition of what is to be done, the policy to achieve it and the actual means in order to do so.

In order to gather tokens, schemes are competing for their own activation: following a mutual activation/inhibition process, partial validation of a scheme spreads tokens in its network while its competitors lose tokens.

Presented in Figure 1 is the basis for an anticipation model. Three layers define three control levels. In a top-down approach, higher level layers define objectives that lower levels aims at finding a way to fulfil. In a bottom-up approach, higher levels undergo the action initiated by lower levels: if ends are defined on high levels, means are defined at low ones. A system of mutual activation/inhibition and a reward process are the key elements of our approach to cognitive resources management.

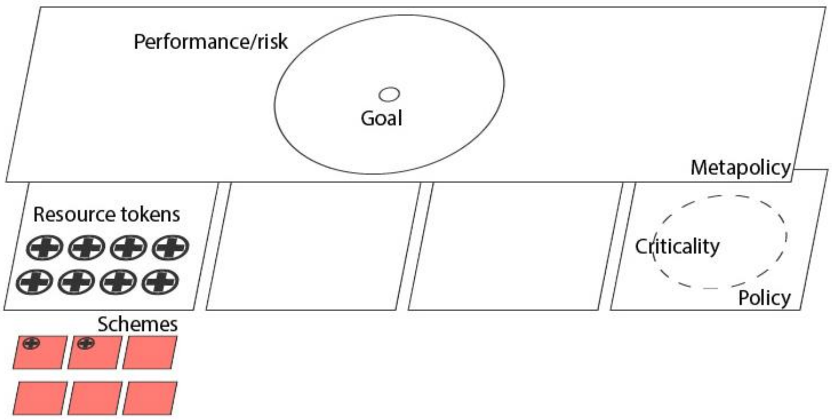

Figure 1. Three layers framework: higher is the meta policy (defining the goal and the performance to risk ratio), middle is the policy (criticality of the sub-objectives, resources tokens management), lower is the implementation (schemes validation process). Layers feed each other with information.

Layer 1

Meta-policy is the highest level. It defines both the objective and the performance to risk ratio to achieve this objective. Anticipation can only be conceived with regards to a determined objective. Meta-policy guides attention toward patterns of perceptual cues oriented to reaching the goal and pre-activates a set of schemes in order to do so (see Figure 2). The performance to risk ratio is also defined: what level of risk should be taken in order to reach what level of performance. For example, during an emergency landing, due to lethal consequences of a bad performance, performance to risk ratio is at its highest.

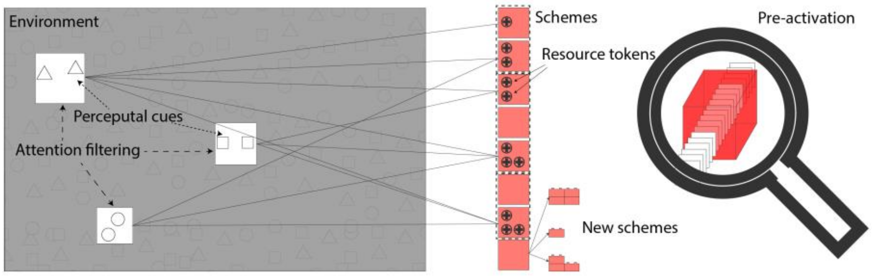

Figure 2. Attention guidance and pre-activation of a set of schemes: attention filtering from meta-policy highlights environment perceptual cues. These cues are related in long term memory with mental structures (schemes) oriented to achieving the goal (meta policy). Schemes networks are pre-activated (resource tokens credit) at the same time as new ones are created (exploitation vs exploration).

Layer 2

Policy is the mid-level. It manages the way to achieve the overall goal:

- Ratio between exploration of new solutions and exploitation of existing ones: depending on the context and the expertise, choice will be made to build new constructions more than adapt existing ones to the current context. Experts tend to explore less and exploit more in nominal situations. In critical situations, experts are able to change that ratio and innovate to find new ways to achieve one's goal.
- Criticality of sub-objectives: regarding the overall objective, it sets at a local level the criticality of each sub-objective. Consequences of a failure are weighted and resulting requirements are defined.
- Distribution of resources over the sublevel: accordingly to sublevel solutions' validity status, policy distributes "tokens" of resources.

Layer 3

Bottom is the implementation level. Schemes are recalled at the same time as new solutions are built. Each of these structures has a model of the evolution of the situation. This inner model is a representation of the scheme's action on the environment and its consequences. Schemes are weighted with situation dynamics: how sensitive their action is to uncertainty (likelihood of something unexpected to happen) and how their duration matches temporal constraints. Time to action is an inner representation of duration to due time.

The scheme aims at validating its own representation of the situation by looking for matching information. If expected patterns of cues are encountered in the environment, the scheme is activated and will therefore receive a resource token. All related schemes will then be activated as well. Conversely, conflicting schemes will be inhibited and lose tokens. The process is shown on Figure 3**.**

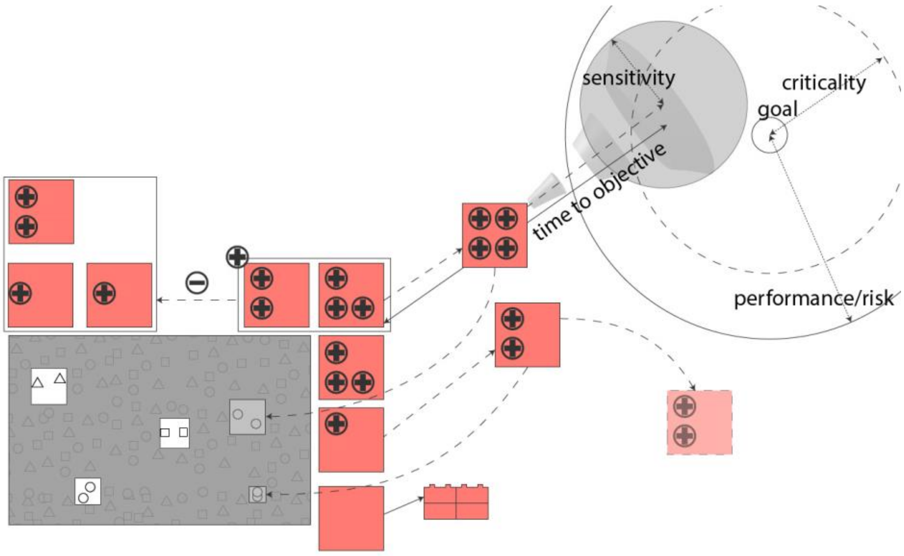

Figure 3. activation/inhibition process: schemes tend to validate themselves by looking for concurrent information in the environment (activation). If so, the scheme and its network are credited with tokens while competitors lose theirs (inhibition). The scheme has a representation of its print (grey circle) on the objective target: time to action with regards to its sensitivity to environment evolution. Its aim is to intercept the centre of the target (goal) within both the performance to risk circle (outer circle) and the criticality (inner circle).

Thus, in a parallel process and depending on perceived information in the environment, schemes are activated and inhibited at the same time. They progressively fulfil their representation of their action on the environment toward goal-reaching, while still taking into account every layer constraints. Figure 4 shows the representation of a scheme action with regards to situation uncertainty: acting long before due time makes it unlikely to reach the objective with the expected performance to risk ratio and criticality. On the opposite of the spectrum, reducing uncertainty, projection of the action consequences on the environment matches criticality requirement.

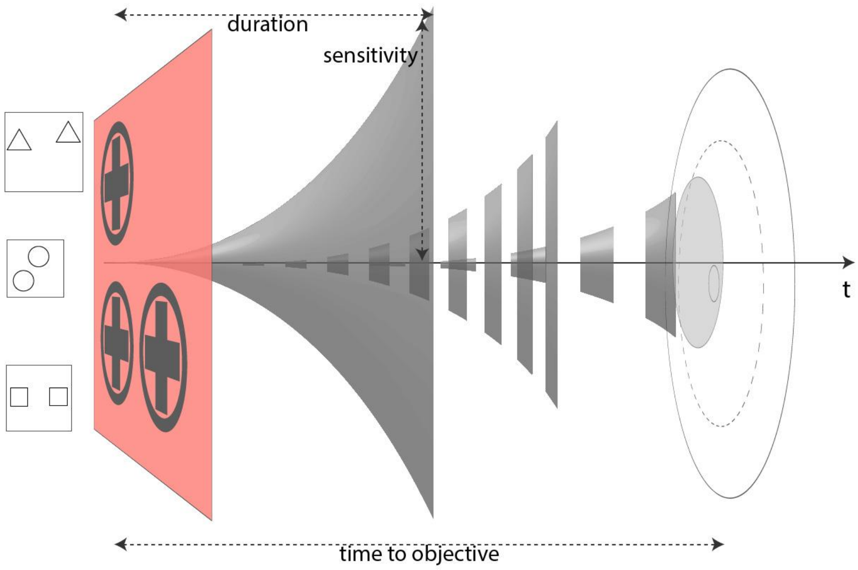

Figure 4. projection regarding time to action and sensitivity. Scheme projects its effect on the environment toward the target (grey circle on the left, see Fig. 3). A sensitive scheme will have a greater chance to miss the target projecting far in the future than waiting for this uncertainty to decrease.

The inhibition process (loss of tokens) encourages the validation of highly activated schemes, which have better chance to gather information. In the schemes network, some are more likely to be inhibited than others. These weak solutions are not better or worse than others, they simply have not been experienced enough to strengthen. Due to expertise some schemes are preferred to others: they primarily get resource tokens over competing unusual schemes.

Implementation of a scheme over another is a function of both time to action representation of the scheme and its inner activation level. The more tokens a scheme gets the more activated it is. Above a certain proper level of activation the scheme can be implemented. This proper level of activation is considered as the inner cost of the scheme.

Depending on the exploration/exploitation ratio defined in the policy layer, new schemes are designed at the same time. This process is a costly one which needs resource tokens as well as other schemes.

These three layers are an interpretation framework that can be used at several levels of temporal depth: meta-policy can itself be considered as the implementation of a scheme chosen via a higher policy in order to achieve an overall goal deeper in time.

Examples in flight combat

In order to contextualize our approach, we had the possibility to conduct interviews with a fighter pilot regarding the expertise of mission commander within the Air Force Fighter Command. In the course of our study, we showed a strong correlation between the intellectual construction of the situation by these experts and the model which we had in mind. Thus we led a one-to-one theoretical construction of our model by challenging it with the actual constraints experienced by these professionals exercising anticipation.

It seems that cognitive mechanisms merge with the methodology applied by these experts. We made an effort to discriminate the result of their appropriate current mode of thought from what surfaces from their education about the design and the construction of solutions.

The studied case was the creation of a raid far behind enemy lines requiring a target laser shooting. A raid also known as COMAO (COMposite Air Operations) is composed of several tens of aircrafts of diverse capacity and grouped in packages. The management of these various packages is a real challenge in terms of organization, maximal efficiency and safety. The purpose is to manage complex systems under strong temporal constraints in a dynamic environment, within a space subjected to a fast evolution. De facto, the risks for unforeseen events on such a plan are numerous and it is not possible to plan all of them in an exhaustive way during mission planning.

The experts' current practice consists of:

- planning from the initial mission building to a significant number of alternative plans but also beyond these plans,
- considering fast reconfigurations of these objectives in order to be able to face various relative what-ifs.

This capacity is probably one of the major modalities of proactive construction of anticipation. It is permanently stimulated by the effective evolution of plans facing actual environments as well as the related and multiple interactions linked to the mission. Finally the key of the success for these experts is the ability to take distance from immediate action, which allows them to evolve very quickly in terms of level of abstraction, from the *meta policy* to the *implementation*.

The very first criterion in the representation building of the problem taken into consideration by the experts (*meta policy*) is commitment i.e. which efficiency is targeted and at what accepted risk (*performance to risk ratio*). Such a consideration is above the *objective* by itself. For instance, directives may be to curb offensive actions of the opponent while minimizing the risks of direct loss. So, to be in adequacy with this request, the pursued objective will be to neutralize during 24 hours the main oil warehouse. The choice of an *objective* over another one lies on its efficiency but the final call is more about the risks associated to it. This takes place at the *meta policy level*.

Once the objective is selected, it is necessary to take into account the various sub-objectives necessary for its realization as well as the mode of resolution, using existing solutions (*exploitation*) or constructing new ones (*exploration*) with regard to the mission commanders' experience. This takes place at the policy level. In our study case, we have to define the exact points of desired impact (DMPI) and all the conditions to be filled, such as the support of Electronic Warfare, or the tactics and the axis of attacks compared with the nature of the target and its defence. What remains is to take into account all other sub-objectives like domestic aspects (air-refuelling, tactical constraints).

From the initial solution (objectives/sub-objectives group), it is necessary to define and organize the various tasks to be performed and link them while having a notion of the task's criticality compared to the plan.

Efforts are deployed by experts to maintain consistency or detect discriminating tasks. Sequences of tasks in connection with a sub-objective are aggregated in one meta task (*schemes' network*) in order to facilitate handling within the plan. Such a cognitive tool allows experts to have an overall vision of current tasks and to be reactive in case of what-if. This appears to be an expert technique for cognitive resources saving, dedicated to anticipation. Naturally this mechanism is permanent and continually feeds higher levels of abstraction.

A mental simulation of what will happen during the flight is performed while on the ground (*projection with uncertainty*). We focus on the sub-objective target. It is then necessary to think about:

- constraints of the axis of arrival,
- weapons preparation (fuze, delay),
- choice of the mode of firing,
- laser selections (IT, Freq.),
- identification of the target with the associated firing criteria,
- roll out constraints.

From the initial plan and the associated tasks we make a dynamic assessment of the various potential solutions in terms of feasibility and risk robustness (*sensitivity to environment evolution*). The first criterion will be feasibility (reaching the objective in this context) which better answers *resources management* than robustness which depends more on its *sensitivity* to environment.

Thus we determine the relevance of each with regards to the associated risk. In order to do so it is necessary to establish the potential factors of incident and to assess the real resources to perform this task (*proper level of activation*). Expertise is a major determinant at this level.

Expertise is also very important through lessons learned, to compare resources involved to the solution efficiency. Experience allows to manage potential unforeseen and to make solutions selection for each task according to their robustness, thus limiting the cognitive cost. Change of solution through time and its confrontation to environment's evolution (*validation*) aims at consolidating or invalidating its relevance (*competition between schemes*).

This complex process is permanent and parallel. A real time top-down and bottom-up spreading is performed in all layers of action building and feed with information at every level of abstraction (*parallel process*).

Choice of solutions will be directly impacted by the constraints induced by the navigation, timing, weather changes and threats (*resource tokens credit*).

The most relevant solutions in front of these potential drifts of the plan will be credited (*highest tokens credit*).

Conclusion

In a multidisciplinary context and with a will to mix concepts coming from different communities, we designed the basis for an anticipation model that supports actual constraints met in the aeronautical field.

The goal pursued through this effort is to anchor theoretical basis in order to design an anticipation support for pilots. Our framework offers a canvas for a user-centred approach: the various layers provide refinement levels which already proved useful in HMI design and evaluation (Vicente & Burns, 1996).

Further work is needed on the resources management issue: for instance, about how schemes are weighted regarding expertise and cognitive cost.

Such an anticipation support needs to be considered in a more global perspective: providing a 'cognitive prosthesis' to pilots' anticipation skills raises the matter of the transfer of expertise. Underneath are ethical issues about degrading pilots' skills and challenges about training. Defining the limits of human cognition in a human factors approach should not legitimize a techno-centred implementation.

The result of our experts' collaboration should draw conclusions on these topics in a further paper.

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