ATC in ACT-R: a Computational Model of Conflict Detection between Planes in Air Traffic Control

Éric Raufaste
CNRS and University of Toulouse-II
5 Allées A. Machado
31058 Toulouse cedex, France
raufaste@univ-tlse2.fr

ABSTRACT

We present a computational model of the mental processes involved by conflict detection between two planes. It implements Rantanen and Nunes (2005) hypothesis, along with more specific strategies for cases where altitude is not enough for deciding. The model describes how perceptual (e.g., angles of plane headings) and symbolic cues (e.g., flight levels) are processed, from eye-movements on the radar screen to response on the keyboard.

Keywords

Modeling, risk perception, air traffic control.

MODELING THE AIR TRAFFIC CONTROL TASK

Much of the Air Traffic Controller (ATC) task consists in maintaining a sufficient separation between planes. In this study, conventional thresholds for minimal separation are 5 NM (Nautical Miles) on the horizontal plane, and 1FL (Flight Level = 1000 feet) on the vertical plane. Thus, controllers have to anticipate plane positions and to detect conflicts, that is, situations where some planes are at risk of an “air proximity” incident. Controllers use a variety of information sources, including paper strips and radar screens. The latter combine analogical (drawings of planes and routes, speed vectors, etc.) and symbolic cues. For example, altitude is typically provided as a number. Thus, in order to improve radar screen design, one needs to understand how those cues are encoded, combined, and how the judgment about potential air proximities is formed.

THE RANTANEN AND NUNES EXPERIMENT

Rantanen and Nunes [1] recently published an experimental investigation of conflict detection where participants had to decide whether pairs of planes were in conflict or not. They varied several factors, such as angles between headings (0°, 45°, 90°, 135°, 180°, 225°, 315°), relative speeds (0 vs. 10 to 50 knots), “miss distance” (i.e., the minimal horizontal distance, 2.5 vs. 7.5nm), altitudes (same or different by at least 1 FL). Because their investigation was related to the en route sector, where planes often cruise at a constant flight level, experimental scenarios exhibited planes navigating at constant altitudes.

THE ACT-R ARCHITECTURE

ACT-R [2] stands for “Adaptive Control of Thought-Rational”. It is the first unified theory of cognition. Its psychological plausibility is grounded on experimental results of cognitive psychology. Recent works also make the link with neurophysiological data [3].

ACT-R is a modular architecture. Each module takes in charge an isolated function and exchanges information with other modules by means of buffers. Some modules handle peripheral cognition, that is, the link between the environment and deep mental processes. Examples are the visual and audio modules for the input, the motor and speech modules for the output. Other modules handle central cognition. Examples are the goal module, the declarative and procedural memory modules. All modules work in parallel but a basic tenet of ACT-R is that a serial process controls the flow of thoughts. This process, implemented as a production system, consists in a permanent loop that repeatedly selects and executes one single production at a time. A production is a rule with a condition part and an action part. In each cycle, the condition part is compared to the buffer states. Rules that match are selected into a “conflict set”. The conflict resolution mechanism selects at most one production based on an expected utility calculus. The selected production is then fired. One cycle typically lasts 50 ms.

Writing an ACT-R model consists in specifying the initial declarative and procedural knowledge of the simulated agent. Then it is placed in simulated experimental conditions and it is given the goal to do the task. Various computational models have been proposed around the ATC task taken as a whole (e.g., [4,5]). The present one focuses on a particular subtask of the controller: deciding whether a particular pair of planes is in conflict.

STRATEGIES INCLUDED IN THE MODEL

As proposed in [1], our model assumes a lexicographic processing where the decision criteria that enable the fastest decision are investigated first. Such strategy would maintain the level of mental workload as low as possible.

Perceptual processing in the first place

[1] proposed that altitude is examined first, even before angles. However, processing altitude entails comparing two values available only in numerical form on the interface. This treatment cannot be perceptual. In line with our previous work on expertise [6], a strategy where perceptual processing took place first was preferred. Thus, heading

differences are analyzed first and sorted into 4 categories: divergent, same, opposing, and converging. Deliberate strategies that take perceptual analyzes as input come later. Due to the speed of perceptual processing, RTs observed in [1] are compatible with our approach.

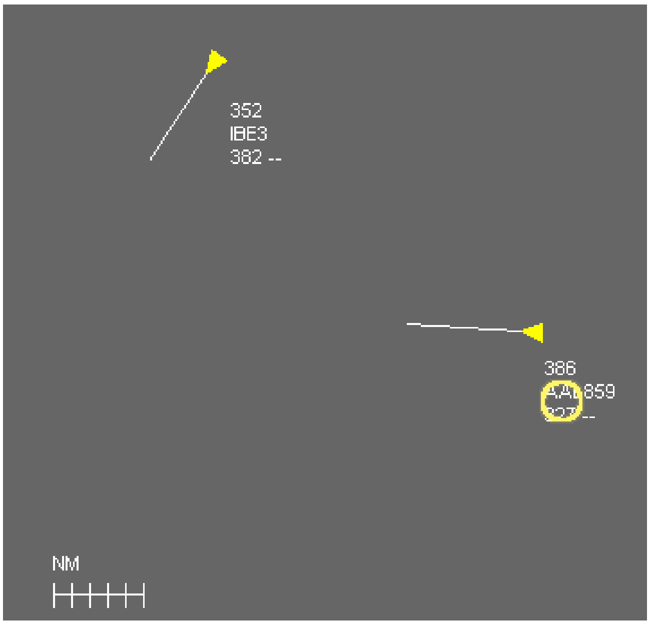

Figure 1. Part of a screenshot of the radar interface. It represents two planes with headings and speed vectors. Symbolic data comprise altitude, flight identification, and horizontal speed. In the lower left corner is the scale. The circle displays the part of the interface currently under the focus of attention.

Differences in altitudes

The model computes perceptual processing first but assumes that the first deliberate processing is about altitude differences [1]. Thus, immediately after processing angles, it checks whether altitudes differ by more than 1 FL—even in the case of diverging headings. It concludes “no conflict” in such case or in the case of diverging headings. Next criteria are examined only in the case of different altitudes.

Differences in speed

Differences in speed are crucial in the case of pursuit, i.e., for two planes having the same heading. If the follower plane does not fly faster than the leader there can be no conflict (no scenario starts by a separation violation). Speed difference is first assessed by visually comparing the lengths of speed vectors. If the difference falls below a threshold the model also checks the symbolic value of horizontal speed before deciding. Speed difference is not checked for planes in opposition.

Differences in lateral separation

In the cases of (i) opposing planes or (ii) pursuit with the follower plane flying faster, lateral separation is checked. The model mentally slides one plane according to its heading until it reaches the other. The duration of this mental move depends on the initial distance of the planes. When the mental move reaches the target plane, lateral distance is mentally evaluated and compared to the perceptual criterion provided by the scale on the interface (Figure 1). The decision is “conflict” when the separation appears to be shorter than the scale, non conflict otherwise.

CURRENT LIMITS AND PERSPECTIVES

Modeling all conditions in [1] requires more experimental investigation of the mental processes used to handle them. For example, there is a wide variability in the human processing of converging angles with same altitude. The rate of errors committed by human participants was also exceedingly high in one condition of [1] (about 55% of errors in the non conflict / same altitude / opposing angle). Specific experiments are currently being realized to provide us with new data on the mental processes involved by such biases. In the future we plan to go beyond modeling the kind of situations addressed by [1]. For example, a crucial function for modeling approach rather than en route control only is anticipation of flight level changes. Adding the vertical dimension is clearly a challenge since it will require a deeper understanding of the processes required by spatial mental simulation. In particular, little is known in the psychology literature about the visuospatial working memory and how it is articulated with other reasoning and decision processes.

ACKNOWLEDGMENTS

I thank Esa Rantanen for providing a detailed description of stimuli used in [1]. This work also benefited from innumerable technical advices provided by Daniel Bothell.

REFERENCES

1. Rantanen, E. M., & Nunes, A. (2005). Hierarchical conflict detection in air traffic control. International Journal of Aviation Psychology, 15, 339-362.
2. Anderson, J. R., & Lebiere, C. (1998). The atomic components of thought. Mahwah, NJ: Lawrence Erlbaum Associates.
3. Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., & Qin, Y. (2004). An integrated theory of the mind. Psychological Review, 111, 1036-1060.
4. Niessen, C., Leuchter, S., & Eyferth, K. (1998). A psychological model of air traffic control and its implementation. In F. E. Ritter & R. M. Young (Eds.), Proceedings of the Second European Conference on Cognitive Modelling (ECCM-98) (pp. 104-111). Nottingham: Nottingham University Press.
5. Lee, F. J., & Taatgen, N. A. (2002). Multitasking as Skill Acquisition. In W. D. Gray, & C. Schunn (Eds.), Proceedings of the 24th Annual Conference of the Cognitive Science Society (pp. 572-577). Hillsdale, NJ: Erlbaum
6. Raufaste, E., Eyrolle, H., & Mariné, C. (1998). Pertinence generation in radiological diagnosis: Spreading activation and the nature of expertise. Cognitive Science, 22, 517-546.