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THE C-OODA: A COGNITIVE VERSION OF THE OODA LOOP TO REPRESENT C^2 ACTIVITIES.

Topic: C^2 process modelling

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Abstract

The OODA loop has been proposed to represent the decision cycle of pilots in air force environments. One of the advantages with the loop is that it captures the continuous nature of C^2. It provides also a useful framework to identify and compare critical phases of both own and enemy decision cycles. However, the OODA is limited by two major problems. First, its unidirectional and sequential representation is not adequate to illustrate dynamic and complex situations. Second, its simple representation provides a low level of cognitive granularity. The loop includes abstract concepts that do not provide the kind of details required to identify adequate support systems design and training programs development. Many alternatives have been suggested to overcome the first problem. The objective of this paper is to address the second problem by proposing a cognitive version of the OODA loop, the C-OODA. The C-OODA loop is based on a modular conception of the OODA loop, the M-OODA loop. The M-OODA loop, proposed by Breton & Rousseau (2004), offers good possibilities to represent dynamic and complex situations. In the C-OODA loop, the improvement of the level of granularity is done from the inclusion of well-know theories and models such as Situation Awareness (Endsley, 1995) and Recognition-Primed Decision model (Klein, 1988; 1993).

Introduction

In the mid-1950s, John Boyd proposed the OODA (Observe-Orient-Decide-Act), to represent the decision cycle of pilots in air force environments. The OODA loop in itself can be labelled a simple control system as described by Jagacinski and Flach (2003). It is a very simple action cycle originating in observing the environment and terminating by acting on it.

Based on the premise that everyone acting in a given situation must first observe the environment and understand it in order to choose the right course of action, the high level of abstraction of the OODA loop provides a valid representation of own and enemy decision cycle. As a consequence, the OODA loop representations of own and enemy decision cycles enable the evaluation of own and enemy decision-making processes as well as the identification of their critical phases.

The simple representation of the OODA loop stresses also the importance of two critical factors in the environment, time constraints and information uncertainty, on the decision cycle execution. In order to deal with the time constraints, the phases of the loop must be executed as quickly as possible. To reduce the information uncertainty, they must be performed accurately. The mutual influence between these two factors brings up the concept of accuracy-speed trade-off. The cycle must be done as quickly as possible without compromising much its accuracy. It can also be said that it must be done as accurately as possible without slowing significantly the speed of the process. It is often said that the superiority of the C^2 on the battlefield is attained by performing own decision cycle faster and better than the opponent.

Despite many critics and proposed alternatives, the original version of the OODA is still extensively used to represent C^2 decision cycle. For instance, in the U.S. Navy (NDP 6) on C^2, the OODA loop is given a central position as the basis for describing the Decision-Execution cycle in C^2. Similarly, US Army FM 6.0 considers the OODA loop to be a valuable tool for illustrating a commander's decision-making processes, albeit admittedly simplistic.

There are some factors that explain the positive acceptance of the OODA loop as a valid representation of decision-making in C^2 military doctrine. The central aspect is that the OODA loop captures the continuous nature of C^2. The implementation of a given decision (Act), at a given moment has an influence on the environment and that effect is observed by the ongoing Observe process of the next decision cycle.

Plehn (2000) argues that the OODA loop has been accepted in doctrine without extensive examination. The major benefit with the OODA lays in its simple representation of the decision cycle in C^2 environments. However, there are two mains types of limitations associated with this simple representation.

The first type concerns its limited ability to represent dynamic and complex situations typical of C^2. The representation suggests a bottom-up linear sequential process system. The loop has no representation of the feedback or feed-forward loops needed to effectively model dynamic decision-making. It also suggests a process model with a single entry point triggered by events in the environment. This results in a single possible sequence of processes. Consequently, it cannot adapt to different levels of expertise in decision-making and to the diverse task contexts existing in real situations. A second type of limitations is a consequence of its simple and high-level representation of processes. The loop includes abstract concepts that do not provide the kind of details required for it to be used as an efficient analytical tool for adequate support systems design and training programs development. In fact, the loop provides a low granularity level of representation.

The objective of this paper is to increase the level of granularity of the OODA loop by formulating a detailed cognitively valid representation of the C^2 decision cycle, the C-OODA (Cognitive-OODA). This version should present a high level of granularity and still include components required to represent dynamic and complex situations typical of C^2. The challenge related to this effort is to keep the level of representation of the resulting model relatively simple.

The C-OODA stands as the latest in a series of attempts at modifying the OODA loop to take into account its documented limitations. Thus, before presenting the C-OODA, it worth reviewing a number of revisions of the OODA that can be seen as milestones in trying to achieve a valid and efficient C^2 model of the OODA family.

The Extended OODA loop

Fadok, Boyd & Warden (1995) address problems associated with the classical OODA loop by proposing a more complex and detailed version. As it is shown in Figure 1, this extended OODA loop includes feedback and feed-forward loops. The improvement of the level of granularity is mainly focused on the Orient process. One can readily see implicit guidance and control loops and feed forward loops extending from this process. These loops make the Orient process a central contributor for guidance of the early and late processes. The Decide and Act processes also send feedback to the Observe process. The content of the Observe process is made more explicit.

As is often the case in modeling, while the extended model is more representative of decision-making, it becomes more complicated and, consequently, less useful for communication purposes. For instance, the factors included in the Orient process are very diverse and in some cases difficult to estimate, as is the case, for the “Genetic Heritage” factor. However, it remains that it is a valuable effort to modify the classical version of the OODA loop.

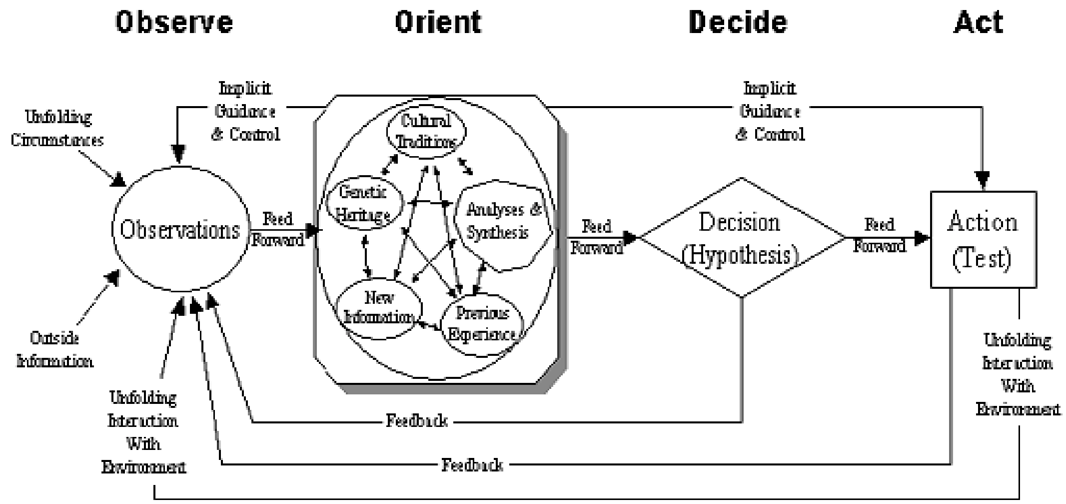

Figure 1. The extended OODA loop (Fadok, Boyd & Warden, 1995).

The Iterative OODA loop

Breton & Bossé (2002) also acknowledge the need to adjust the OODA loop to the dynamic aspect of decision-making. They propose a version of the OODA loop that includes an iteration process between the Observe and the Orient phases (see Figure 2). Again, it is the Orient process that is the target of the changes in the loop. Breton & Bossé are more explicit concerning the nature of the feedback they include in the loop. It is a control loop enabling an iteration of the Observe process. The iteration process is based on the two factors critical in C^2 environments, time constraints and information uncertainty. The iteration process is interrupted when the time available for analysis is over or when an acceptable level of uncertainty is reached. It results in the activation of the Decide process and the selection of a course of actions that is implemented in the Act process.

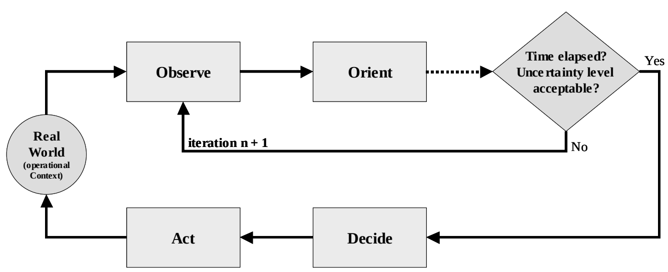

Figure 2. The iterative version of the OODA loop (Breton & Bossé, 2002).

The interest of that proposition lies in the more formal definition of control within the OODA loop processes. Breton & Bossé offers no modification to the classical version of the OODA loop to improve the level of cognitive granularity.

The CECA model

Bryant (2003) has developed the CECA model (Critique-Explore-Compare-Adapt), presented in Figure 3. This model offers a different alternative to the OODA loop to represent C^2 decision-making task. The CECA model is based on two premises. First, a military operation, at all levels, must begin with a plan. Second, the plan must be goal-directed and it should describe the states of the battlespace one wants to achieve across a specified period of time. According to Bryant, the plan becomes the basis of the conceptual model used in the decision-making loop.

While the classical version of the OODA loop suggests a bottom-up perspective (process initiated with the observation of an event), Bryant's model offers a top-down approach. The CECA loop begins with planning that sets the initial conceptual model of the situation. This model of the plan will dictate the operation throughout the decision-making process. The "Critique" phase concerns the identification of information needs by first questioning the conceptual model to identify critical aspects. This phase determines how the plan needs to be adapted to changing conditions and which information is needed to do so. It supposes that no plan is ever complete and that monitoring is a constant process. The "Explore" phase comprises the active and passive collection of data from the battlespace. According to Bryant, active data collection is directed to answering questions of the conceptual model's validity as quickly and accurately as possible. Passive collection is a filtering process in which events are monitored to identify aspects of the battlespace that should receive attention and be included in the situation model. In the "Compare" phase, the situation model is compared with the conceptual model to determine which aspects of the latter model are invalid or inconsistent with the current situation. The "Adapt" concerns the modification of the conceptual model.

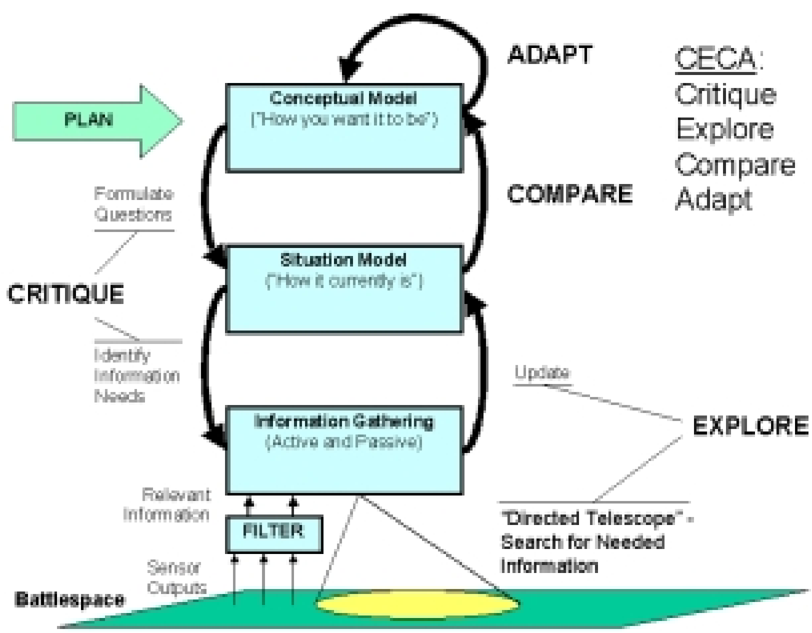

***Figure 3.** The CECA model (Bryant, 2003).*

The CECA model has the merit of proposing an interesting level of cognitive granularity. However, comparatively to models proposed by Fadok et al. and Breton & Bossé, it does not take its root in the classical version of the OODA loop. It proposes a completely new perspective to the C^2 decision cycle. As a result, it has the paradoxical effect of providing a more solid cognitive model, while discarding the benefits associated with the classical representation of the OODA loop. For instance, one benefit with the classical OODA loop is its capacity to represent own and enemy decision cycle. Within the CECA model, it should be a challenge to define enemy's conceptual model. Then, while the CECA model strengthens the cognitive background of C^2 decision cycle, the OODA may still be required to provide a comparative framework to own and enemy decision cycle. Consequently, mappings between the CECA model and the OODA may be required. Since, it involves different concepts at different level of abstraction, it should be a challenging task

The OODA loop adapted to NCW and EBO

In the dual context of Network Centric Warfare (NCW) and of Effect Based Operations (EBO), Smith (2002) discussed the value of the OODA loop. While acknowledging the usefulness of the OODA to represent a decision cycle applied to operational level interactions, he argues that it is limited by the particular operations that it was developed to represent, that is a pilot-to-pilot air combat. He claims that the OODA lacks the complexity one is faced with in larger operations involving multiple units and longer time scales, for instance. Smith presents an expanded version of the OODA loop (see Figure 4) that covers a general set of military operations from data understanding to action implementation. That coverage corresponds to the domain of the OODA loop.

Smith's version of the OODA adopts a partitioning of the OODA cycle in three domains: physical, information and, cognitive, that is more and more accepted. It also includes in detail the cognitive components that are required for handling complex military operations in the context of NCW. A two-part decision making process is described with control loops enabling Understanding/Knowledge/Information on one hand, and Sensemaking/Decision on the other. Its description of those two control loops is very much compatible with Bryant (2003) CECA model.

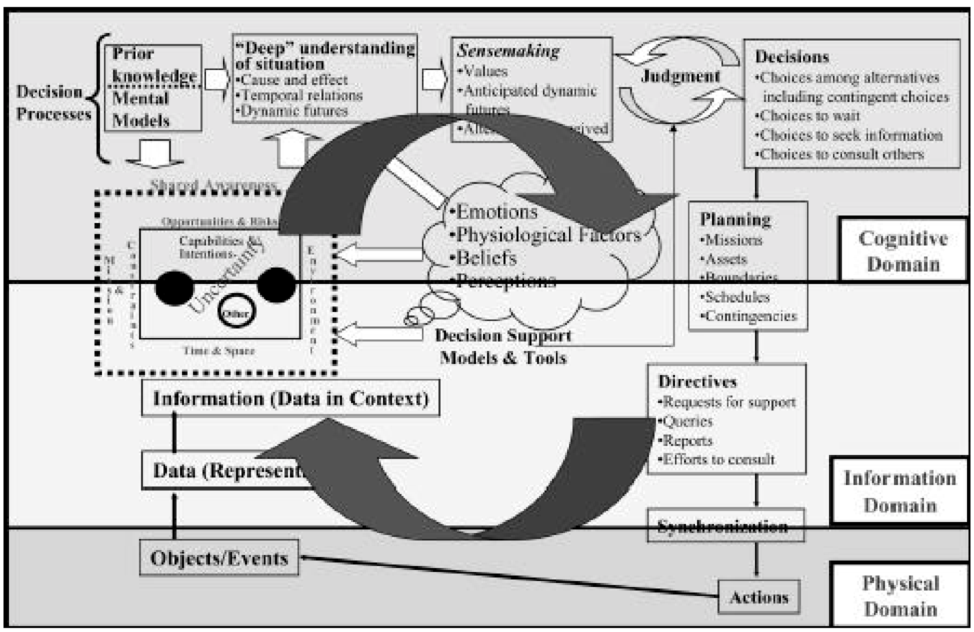

Figure 4. ***The OODA loop adapted to NCW and EBO (Smith, 2002)***

Smith's version of the OODA is probably the best example of present efforts to accommodate the OODA loop with the requirements of NCW. However, while it covers most topics of interest for making the OODA more up to date, it also generates a high level of complexity that makes it difficult to keep intact the critical perception-action flow typical of the classical OODA loop.

The M-OODA loop

Rousseau & Breton (2004) present a modular version of the OODA loop, the M-OODA loop (see Figure 5). The M-OODA describes basic architectural principles that implements dynamic properties in the OODA. It is based on a modular structure in which a module operates as a simple control system. A module is a task-goal directed activity formed of three components

(Process-State-Control). In each module, an input is fed into a Process that generates a State as its output.

The M-OODA incorporates explicit control and flow components more in line with the current understanding of military C^2. A Control component holds the criteria for iterating, adjusting, or interrupting the Process. Any process within the OODA is represented as such a module. Communication and coordination between modules are enabled by feed-forward and feedback loops. The Control component also directs communication between modules. Finally, any module can serve as an entry point in the decision cycle.

The M-OODA model modifies the OODA loop based on the following principles:

- It adopts a modular, or building blocks, approach in which each process of the OODA loop is represented as a generic module structured around three components: Process, State and, Control;
- It incorporates explicit control elements within and across modules enabling a bi-directional data/information flow between modules. It also includes a feedback loop within each module;
- It provides a basic architecture for modeling a variety of team decision-making in with the OODA loop.

As the name is suggesting, the M-OODA loop that its roots in the classical version of the OODA loop. It is, in fact, a modular representation of the OODA loop. The modular architecture provides a way to adequately represent the dynamic and complex nature of C^2 without requiring drastic changes as it is proposed in the CECA model. It also provides more details on the feedback and feed-forward loop than the extended OODA loop proposed by Fadok, Warden & Boyd (1995) and the iterative loop of Breton & Bossé (2002).

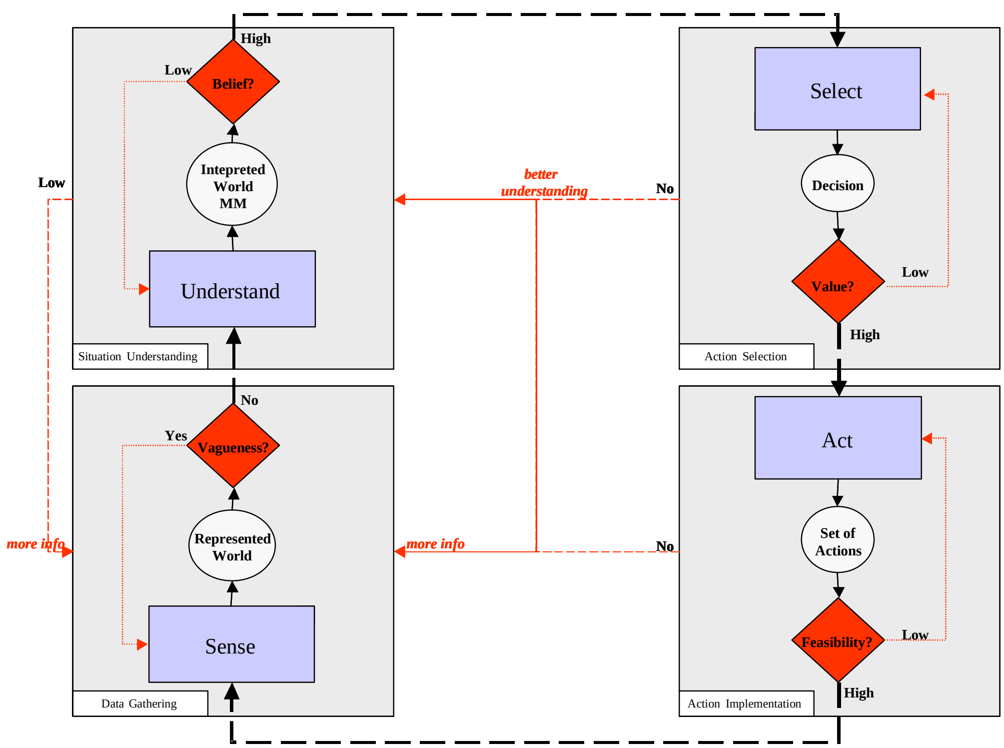

Figure 5: The M-OODA loop (Rousseau & Breton, 2004).

Rousseau & Breton's point of view was that for the OODA loop to remain a useful and accepted tool in the context of documents defining the armed forces doctrine on C^2, any modification has to keep explicit the high-level representation typical of the OODA loop, while accommodating dynamic and control concepts. In order to make explicit the goal of a module, each process of the OODA loop is represented with a specific goal-oriented module name:

- Observe = Data Gathering
- Orient = Situation Understanding
- Decide = Action Selection
- Act = Action Implementation

The M-OODA loop is developed by representing each OODA process with a basic module as described above. The M-OODA shares with the classical OODA the sequential operation of the modules. In such a model, the output of a module is strictly linked to the input of the next. It is that Output/Input connection that enables the sequential operation of the M-OODA cycle. However, since it allows retroaction between modules, it does not suggest a sequential and unidirectional processing.

The M-OODA loop provides a powerful means to represent dynamic control in the OODA, but it still operates at the low level of cognitive granularity that is a known limitation of the classical OODA.

Table 1 presents an evaluation of the OODA loop, the extended OODA loop, the iterative OODA loop, Smith's version of the loop and the M-OODA loop in regard of their capacity to represent dynamic and complex situations and their respective level of granularity.

Table 1. The evaluation of different C^2 decision cycle models in function of their capacity to represent dynamic and complex situations and their level of granularity.

	Capacity to represent dynamic and complex situations	Level of granularity
Classical version of the OODA loop	**Very Low** (bottom-up and sequential representation)	**Very low** (only a representation of major DM processes)
Extended OODA loop (Fadok , Warden & Boyd, 1995)	**High** (presence of request, FB and feed-forward loops)	**Medium** (focus only on the Orient process)
Iterative OODA loop (Breton & Bossé, 2002)	**Medium** (iterations possible only between the Observe & Orient processes)	**Very low** (only a representation of major DM processes)
Smith (2002)	**Very High** (inclusion of cognitive components and loops to handle complex situations)	**High** (provides details at the physical, information and cognitive domains)
CECA model (Bryant, 2003)	**Very High** (inclusion of an adaptation process)	**Medium** (focus mostly on the Orient process)
M-OODA loop (Rousseau & Breton, 2003)	**Very High** (presence of request, FB and feed-forward loops)	**Medium** (representation of the cognitive functions sustaining the Observe-Orient-Decide processes)

As can be seen in Table 1, the extended OODA loop, Smith's version of the OODA loop, the CECA model and the M-OODA offer good possibilities for representing the dynamic and complex nature of C^2 decision cycle process. However, except for Smith's version, they are all limited in terms of cognitive granularity. While offering a high level of cognitive granularity, the loop proposed by Smith is very complex from a representation and communication perspective. It is our contention that to remain useful and accepted from the military community, any alternatives to the OODA loop must keep explicit the high level of representation of the classical model.

The objective of the present paper is to address the issue of cognitive granularity with the constraint of keeping explicit the high level representation of the classical version. We propose a model of the C^2 decision cycle, the C-OODA, which takes its roots in the classical version of the OODA loop and uses the modular architecture defined in the M-OODA loop proposed by Rousseau & Breton (2004). The M-OODA can be seen as a layered system in which different parts can be exploded for more details. The C-OODA model is an attempt at reducing the distortion that often results from modifications of the OODA loop aiming at a high granularity representation. Most alternatives to the OODA loop focus their modifications on a given process, often on the Orient one. It results in models that provide details on a given process while keeping the others at a low level of granularity. By using known cognitive theories and models to provide details on each component of the loop, it avoids the biases that come from focusing on a subset of OODA components. The use of the M-OODA architecture protects the high-level representation C^2 decision-making, valued in military documents.

The C-OODA loop: a cognitive version of the OODA loop

The improvement of the cognitive granularity of the OODA loop is based on the integration of two well-accepted cognitive models: Endsley's Situation Awareness (SA) model (Endsley, 1995) and Klein's Recognition-Primed Decision (RPD) model (Klein, 1988; 1993) within the framework of the M-OODA loop. The first two processes of the OODA loop (Observe-Orient) can be associated with Situation Assessment and Situation Awareness and well supported by Endsley's model. On the other hand, Breton & Rousseau (2001) have identified the RPD model has the best candidate to provide cognitive details in the decision-making side (Decide-Act) of the loop. This model has been developed from a Naturalistic approach typical of C^2 environment.

The cognitive background of the C-OODA

SA has been defined as a three-step process involving; 1) detecting or perceiving elements in the environment, 2) processing or comprehending the current situation, and 3) acting on the information or projecting the future status of the situation. There are other definitions that deviate more or less from Endsley's widely cited definition. The definition proposed by Endsley (1995) is:

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.

From this definition, as it can be seen, SA is concerned with the understanding of a situation without necessarily leading to a decision-making process. According to Endsley (2000), SA is depicted as the operator's internal model of the state of the environment. Obviously, while many other factors come into play to affect the quality of the decision-making process, SA must be considered as a main precursor to decision-making. For Endsley, it is possible to have perfect SA and yet make an incorrect decision and to have bad SA and take to best decision. Nevertheless, good SA should influence positively, in most circumstances, the decision-making process. Although there are strong links between SA and decision-making, Endsley states that it is important that both processes being recognized as independent ones. Unfortunately, that model of SA is rather linear and consequently suffers the same limitations as the classical OODA loop concerning the representation of dynamic C^2. Rousseau, Tremblay & Breton (2004) discussed that view of SA and proposed that SA could be improved by setting the processes described in Endsley's model in a more parallel and networked structure.

Elaborated by Klein (1988; 1993, see also Klein, Calderwood, & MacGregor, 1989), the RPD model stipulates that rather than weighting advantages and disadvantages of several alternatives, experienced decision makers use their experience to evaluate a situation and determine a solution or a possible course of action from the first attempt. In that sense, it can be applied to represent situations characterized by uncertain and incomplete information and marked by time pressure.

The RPD model has four basic components. The first component is the *recognition* of the current situation that is based on the degree of familiarity of the situation by comparison with one's mental index and experience. In RPD, recognition is applied differently than in multi-attribute decisions. Recognition of a valid situation directly activates a process of evaluation. There is no computation of a recognition index leading to a choice amongst a set of alternatives. Thus, on the one hand, if the situation appears unfamiliar, the decision maker will seek further information. On the other hand, if the situation is classified as familiar, the second component is applied. This second component consists in understanding the situation in the light of expectations, cues and goals. The third component consists of recalling relevant prototypic actions from prior experience. The fourth component is the evaluation, through mental simulation, of the potential and plausible consequences of each considered course of action. Each action is then evaluated independently; that is, not in comparison with other alternatives, as is the case with traditional decision models. Thus, the decision maker mentally visualizes how the situation could potentially evolve if a particular action were implemented.

From the RPD model, decision-making can be achieved at three different levels: Simple Match, Diagnosis of the situation, and Evaluation of the Course of Action. The result of the decision-making process for each of these levels is the implementation of the action. However, each includes various steps allowing for adaptation to the complexity and familiarity of the situation.

Even if they do not focus on the same part of the whole decision-making process, interesting observations and parallels can be made from the comparison of the SA and RPD models: Although they do not address it in details, both models include an observation phase labelled "Perception" for SA and "Recognition" in the RPD model. Klein defines the recognition activity as a feature matching process. In the context of developing the C-OODA, the Perception and Recognition processes are considered as being equivalent.

In the RPD model, the orienting phase of the decision-making process is represented with a general box labelled "Understanding". The understanding process is more detailed in Endsley's model with the inclusion of both "Comprehension" and "Projection" processes. This is not surprising since the SA model focuses on the understanding a situation. The Projection process raises the importance of the temporal aspect in understanding a situation. The decision part is kept outside of the SA model. The RPD is obviously more explicit for this part of the OODA loop. For Klein, the Decide activity is based on recalling and evaluating processes. Then, each phase of the loop can be decomposed into processes based on the SA and RPD models as shown in Table 2.

Note that the "Act" phase is not included in the decomposition. One reason is that the objective of this paper is to improve the level of cognitive granularity of the decision cycle represented by the OODA loop. The "Act" process represents the implementation of a given decision that is the result of the first three processes. One may suggest that the implementation of the decision, "the action", is sustained by a set of different functions (i.e. motor skills, physical functions). Then, for a matter of simplicity, we choose not to increase the level of cognitive granularity for the "Act" phase.

Table 2. Decomposition of the OODA loop phases based on the SA and RPD models.

OODA phases	SA	RPD
Observe	Perception	Feature Matching
Orient	**Comprehension + Projection**	Understanding
Decide	Decide	**Recall + Evaluation**

The description of the C-OODA loop

This section offers a description of the C-OODA presented in Figure 6. The modelling of the C-OODA is based on a set of principles:

- The high-level OODA processes must be represented explicitly;
- The architecture of the C-OODA is based on the M-OODA loop in order to keep explicit the notion of control and to allow an adequate representation of dynamic and complex situations;
- The Observe process is defined from both the SA perceiving process and the RPD features matching process;
- The Orient process is defined from the comprehension and projection activities of the SA model;
- The Decide process is defined from the recall and evaluate activities of the RPD model.

As it is shown in Figure 6, the increasing in granularity is kept aligned with the OODA phases and coherent with the M-OODA modelling principles. Then, each of the first three OODA phases is modelled as a structured set of two basic M-OODA modules. Only the "Act" process is not modelled.

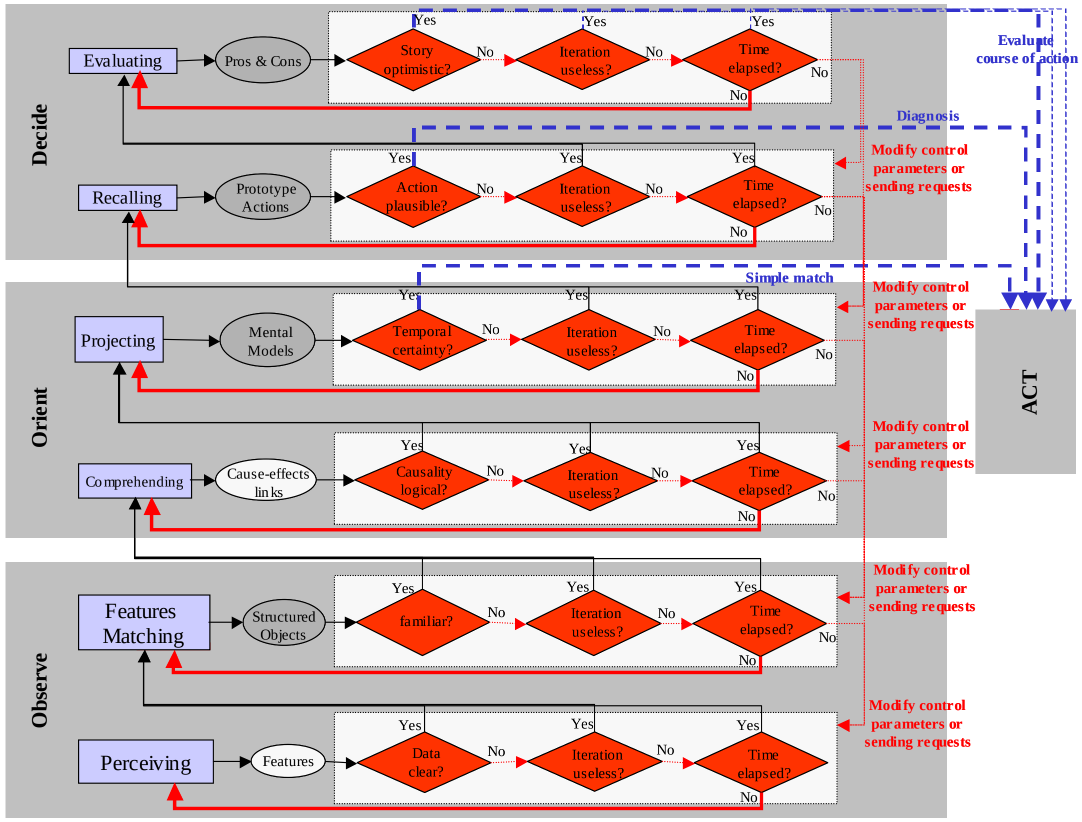

Figure 6. The C-OODA loop.

The improvement of the cognitive granularity

There are two stages in the Observe phase. The first stage registers features from the environments. The second stage matches these features with knowledge stored in operator's long-term memory in order to extract structured objects from these features. These structured objects form a scene defining a given situation. A high level of familiarity would rise, from the long-term memory information and knowledge required to act automatically and accordingly to the goals and expectancies related to the situation. The Observe phase corresponds to functions of perceiving, suggested by Endsley's model of SA and features matching, included in the RPD model. Interestingly, this conception of the Observe phase is compatible with the classical Feature Integration theory proposed by Treisman (1988). According to Treisman, in a first stage, salient features of stimuli are detected automatically by independent feature modules (i.e. colour, size, distance, etc.). In the second stage, these features are integrated together to form a unitary object. These objects become the basic elements of information considered in the decision cycle. Treisman's theory of Features Integration suggests that the detection of features is cognitively automatic while the their integration is controlled.

The Orient phase is also composed of two general stages. In the first one, causal relationships between the structured objects identified in the Observe phase are analysed. One benefit with Endsley's model of SA is that it includes a projection process that raises the importance of the temporal aspect in understanding a given situation. One may have an understanding of a static picture, but it is critical to understand how the situation may evolve within a volume of time and space in order to act correctly. Then, in the C-OODA loop, both the comprehending and projecting processes define the Orient phase. While, the first process alone may produce a set of causal links, the end result of these two phases in the development of mental models defining the situation and how it may evolve. In the classical version of the OODA loop, the Orient phase has been defined as the process responsible of the understanding and analyzing of the situation. Then, it becomes natural to identify this phase with the SA theory proposed by Endsley (1995).

In the classical version of the OODA loop, the Decide phase is seen as the process in charge of the selection of the most appropriate course of actions among a set of alternatives. It is not explicit, in the OODA loop conception, where and how the set of alternatives is elaborated. It may be the result of the Orient phase that is fed into the Decide phase or a specific activity included in the Decide one. This ambiguity shows the strong link between the Orient and Decide phases. One may suggest that in some simple and familiar circumstances, the identification of the most appropriate course of action is already made in the Orient phase. In other more complex and unfamiliar situations, specific recalling activities that take place in the Decide phase may be required. The link between the understanding and deciding on actions has been clearly represented in the RPD model proposed by Klein (1988; 1993). Then, the two stages included in the Decide phase of the C-OODA are imported from the RPD. These two stages are "recalling" and "evaluating". From the recalling stage results a list of prototype actions. The evaluating stage consists of evaluating the pros and cons of each proposed action.

The representation of the control components

The M-OODA illustrates the importance of the notion of control in the task performance with the inclusion of control, feedback and feed-forward loops. The notion of control is essential in dynamic and complex situations. In the M-OODA loop version proposed by Rousseau & Breton (2004), the control components are not detailed. In the C-OODA loop, these components are exploded in three distinct classes of control criteria, one being specific to the nature of the process and the state in a given C-OODA phase and the two others being general across all the three C-OODA phases.

Specific and General criteria

In the C-OODA loop, each process is controlled by a set of three control criteria components. One is specific to the nature of that process and its resulting state. For instance, the Observe phase includes two processes, perceiving and features matching that produces respectively a set of features and a set of structured objects. Their specific criteria are the clearness of the features produced from the perceiving process and the familiarity of the structured objects built from the features matching process. Then, the specific criteria control the quality of each Process-State couple included in the different phases of the C-OODA loop. Table 2 shows these different criteria according to the phases of the OODA.

In addition to the specific criteria, two other general classes of criteria are included in the C-OODA phases. These criteria are generally applied to each Process-State couple included in the C-OODA phases. A first general criterion concerns the usefulness of executing further iterations to improve the certainty level of a given state produced from a given process. In some circumstances, even if the thresholds associated with the specific criterion for a Process-State couple is not met, the iteration process may be stopped if further iteration does not seem to increase significantly the certainty level. This criterion is generally applied through each C-OODA phase. However, for each Process-State couple, its value is strongly influenced by the specific criterion value. The evaluation of the usefulness of additional iteration is necessarily function of the gain in information that these additional iterations generate. This raises the importance of evaluating the costs and benefits associated with executing further iterations. For instance, one may accept an important cost in terms of resources and time if an additional iteration is expected to provide a considered valuable piece of information.

As stated above, the advantage of the battlefield will be given the one that performs the decision cycle better and faster. This premise raises the importance of speed of execution as being as important as the accuracy of execution. In fact, the challenge in the battlefield is to reach the optimal performance within the shorter period of time as possible. Every decision support systems pursues the objective of reducing human errors and time execution. The first two criteria are mainly related to the execution accuracy. The third criterion, which is generally applied through all the C-OODA phases, concerns the time available to execute each sub-process. In some situations, even if the certainty thresholds are not met and further iterations would be expected to provide valuable information, the iteration process may have to be ended when the time to proceed to another iteration is longer than the time available in the situation.

Note that this control component refers to the time allowed to execute a given C-OODA stage. However, there is still a general time constraint that affects the total C-OODA cycle. In some circumstances, when the time available to execute the complete decision-making process has elapsed, the final decision will be based on incomplete processing. If an action is absolutely required, the decision-maker will act at the best of his knowledge. The notion of general time constraint raises the importance of scheduling the time allowed to execute the different C-OODA phases.

Table 3. Specific control criteria for the OODA phases.

OODA phase	Process ⇔ State	Control criteria
Observe	Perceiving ⇔ Features	Clearness
	Features Matching ⇔ Structured Objects	Familiarity
Orient	Comprehending ⇔ Cause-Effect links	Causality Logic
	Projecting ⇔ Mental Models	Temporal certainty
Decide	Recalling ⇔ Prototype Actions	Action plausibility
	Evaluating ⇔ Pros & Cons	Story prognostic

Setting the control parameters

All these criteria, specific or general, can be explicitly defined and externally set based on the goals, expectancies related to the mission and the commander's intent. For instance, in a given mission, an officer could set as a function of his goals, objectives, expectancies and needs, specific certainty levels to be reached within a specific period of time, based on the environmental constraints.

However, a distinction must be made between setting externally the parameter values (i.e. setting certainty level to be reached, setting the time available to execute the task, sending specific request, etc.) and the personal (internal) interpretation of these values. This simple distinction raises considerably the complexity of the task of setting the control parameters.

According to Pigeau & McCann (2000), one key aspect of C^2 is the propagation of commander's intent among his subordinates. According to his intention, a commander may set the control parameters. However, the challenge is to make sure that each of his subordinates has an accurate understanding of his intention. This aspect raises the importance of sharing information between team members and brings all relevant pitfalls associated with human communication. Obviously, the interpretation of the control parameters values set from the commander's intent should be strongly influenced by one's background, expertise, knowledge, culture and personality traits.

From that point of view, control components can be seen as "translators" of the commander's intent into parameters that are coherent with the specific processes operating within a given OODA phase.

Another aspect increasing the complexity of setting control parameters is linked to the evaluation of the gap between the certainty value to be reached and the actual certainty value. While the desired certainty value may be explicitly set (standards to be reached), the actual value is, most of the time, mainly defined from a subjective evaluation. Then, the resulting evaluation of the gap between both values, related to the iteration usefulness criterion, is necessarily subjective. Nelson & Narens (1980) state that there is only a weak positive correlation between metacognition states like feeling of knowing and the performance. This feeling of knowing that is not necessarily correlated with the real certainty value will determine the need for further iterations. Here again, factors such as cultural background, expertise, knowledge and personality traits are affecting this evaluation process.

Finally, the complexity of setting control parameters is also increased by the distinction between the real period of time available and the subjective evaluation of the time available. According to MacGregor (1993), time urgency refers to an internally imposed time pressure; that is, people impose on themselves the obligation to accomplish more and more tasks in an ever-shorter amount of time. Then, even with no explicit time constraints, someone may feel temporal urgency. The reverse is also true. Some people may not feel the time urgency even with the presence of important time constraints. Factors mentioned above such as decision-maker's expertise, skills and personality traits are likely to affect the feeling of time urgency. In the context of a decision-making task, time-stress, defined as the ratio of the time available to perform a task to the time required, constrains the decision maker to act quickly, which may lead to neglecting relevant information, processing the incorrect or irrelevant information, omitting or delaying action, and then reducing the quality of decision. Time-stress is one factor responsible for cognitive overload in military settings. Overall, time-stress may influence decision-making in terms of reducing information searching and processing (Orasanu & Backer, 1996). The effect of time-stress would influence the level of parameters settings for the specific criteria and the iteration usefulness criterion. Jobidon, Rousseau & Breton (2004) have shown that time pressure affected subjective time available, subjective time required and consequently, these subjective estimates determined the control strategy adopted in a dynamic task.

Because of the discrepancies between real control parameters values and their subjective evaluations that one may make based on his background, expertise, etc. setting those parameters can be a challenging and task. This situation asks for a continuous monitoring of those parameters in order to adjust the task performance to the situation. The dotted red arrows on the right side of Figure 6 suggest that these control parameters can be modified in order to improve the accuracy level of the state or the time taken to reach that level. The simple distinction between the real certainty value and its subjective evaluation may also stand for explaining individual differences in the task performance.

Walkthrough the C-OODA loop

In order to show the functioning of the C-OODA loop, we illustrate three different decision-making situations, Simple Match, Diagnosis and Evaluate Course of Action, typical of Klein's RPD model in the C-OODA loop (Figures 7-9). In these Figures, we have removed all unnecessary arrows in order to clearly show the pathway of each decision cycle.

The Simple Match decision cycle

The Simple Match level depends on the environmental features that are registered. It is activated when the current situation is simple and straightforward; that is when the crucial elements of the situation, the objectives, and the typical course of action to implement are easily recognized and identified (Klein, 1996; 1997).

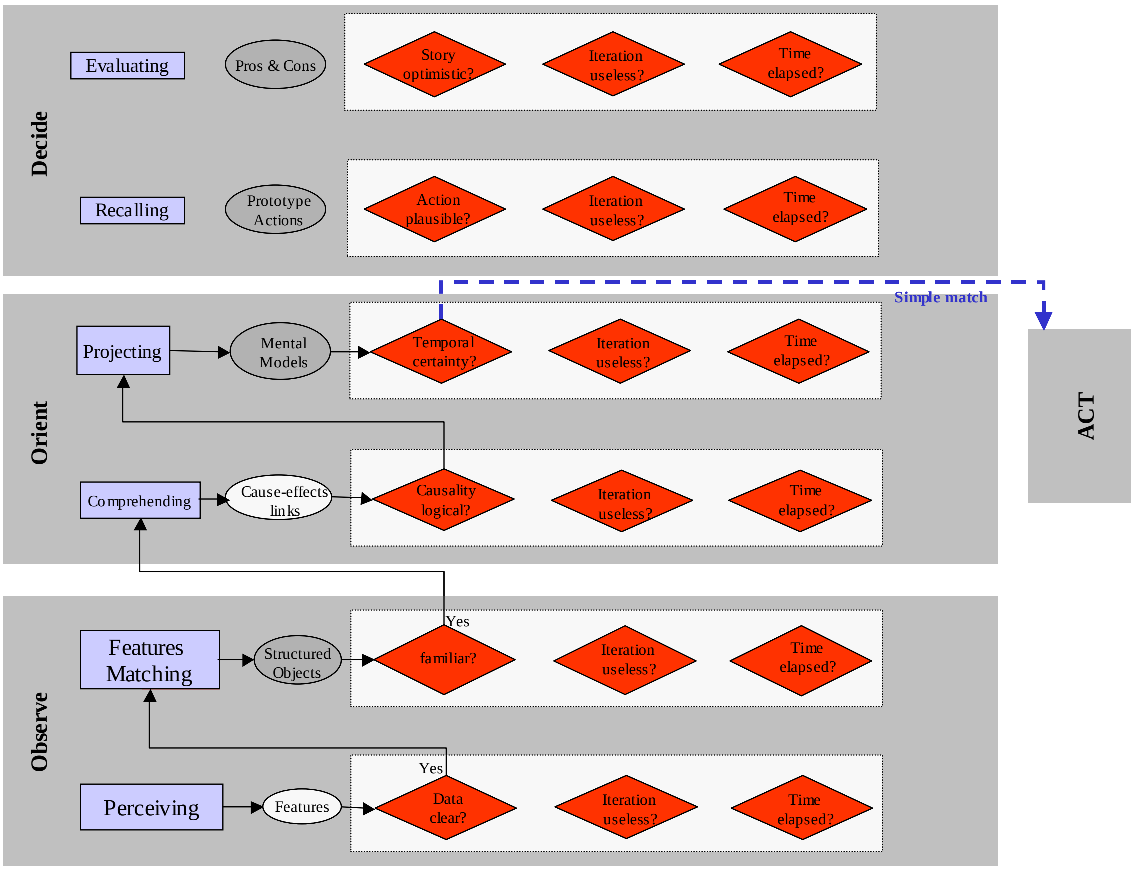

Figure 7. The Simple Match decision-making level.

The C-OODA loop is explicitly compatible with the Simple Match decision cycle. This level occurs in both the Observe and Orient phases of the model. As it is shown from the example illustrated in Figure 7, features are perceived from the environment. Since, their certainty level reaches the desired threshold, no further iteration is required. These features are instantly fed into the features matching process in order to automatically extract structured objects. According to Treisman's theory of Features Integration, the detection of features is automatic while its integration is controlled. However, in presence of highly familiar features, the controlled process of integration may become more and more automatic. For that to occur, automatic cognition has to be situated. The actions associated, through practice, with a particular object would be displayed in the context of a specific task and environments. In the Observe phase, the familiarity of the situation is assessed. A high level of familiarity would trigger, from long-term memory, well-known and practiced cause-effect links. These causal relationships are part of a valid and familiar mental model that contains tested and approved actions. Consequently, in the Orient phase, the adequate causal links, part of a mental model are simply triggered. Note that since this process is automatic and effortless, the evaluation, from their specific criteria, of the causal links and mental models is automatic and requires little mental workload.

In the classical version of the OODA, there is no detail on where and how alternatives are identified. In very familiar situations, it is believed that a known adequate alternative is already identified following the Orient phase. It is typical of the Simple Match in which the Decide phase may be simply skipped or bypassed.

The Diagnosis decision cycle

Diagnosis is an illustration of a situation where the decision is the result of the stages included in the Orient phase and the first stage of the Decide one (see Figure 8). The Diagnosis level is required to cope with the presence of uncertainty concerning the situation. This given situation is not necessarily complex, but it does not refer to familiar mental models. Then, Diagnosis represents an attempt to establish a relationship between an event and causal factors in order to define the situation and find an acceptable explanation for it. Diagnosis processing implies a greater cognitive effort than Simple Match, because the decision maker must heed a variety of information.

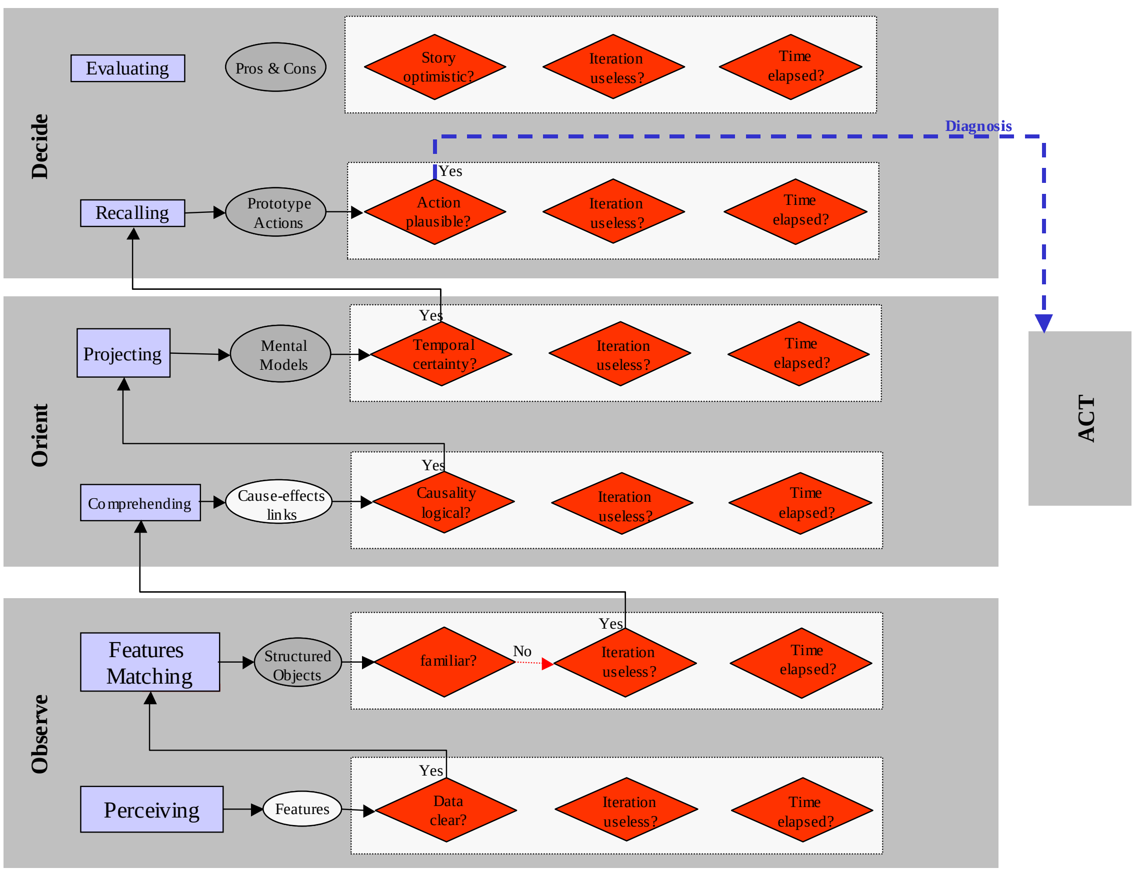

Figure 8. The Diagnosis decision-making level.

As mentioned above, the C-OODA model proposes that the Diagnosis level is performed by the two stages, comprehending and projecting, in the Orient phase and the first stage, recalling, of the Decide one. The Diagnosis level can be divided in two sub-processes. In the first one, executed from the comprehending stage, the diagnosis process involves the categorization of the situation based on a set of "if-then" rules. In the next one, under the responsibility of the projecting stage, the projection of the status of the situation within a volume of time and space is executed. This process evaluates what would be the consequence, in a near future, if changes occur for the status of the objects included in the mental model. The result of the projecting stage influences the recall of potential actions that can be applied in the given situation. The potential actions can be deducted from the combination of two or more known cause-effect rules.

Figure 8 does not include iterations for the recalling stage. However, the Diagnosis level can be seen as a "trial-error" process. For instance, if the actions are judged, from the specific criterion, as been implausible, other potential actions are recalled from the long-term memory and evaluated until a given one meets the plausibility threshold. Note that the iteration process may involve other OODA phases. For instance, requests can be sent to the Observe phase to provide more information or the Orient one to clarify the meaning of a given piece of information.

The Evaluate Course of Action decision cycle

In a case where the Diagnosis level does not allow the identification of an adequate solution to a complex and unfamiliar situation, decision-making may switch to the higher analytical level, the Evaluate Course of Action level. That level of decision-making is based on a more evaluative process that takes time and resources. Consequently, the use of such process can be significantly hampered by the presence of time constraints in the situation. This Evaluate Course of Action level requires the mental simulation of the envisaged course of action to evaluate potential difficulties, possible solutions and, consequently, to determine if this action must be implemented or if further evaluation is required to identify a new course of action (Klein, 1997).

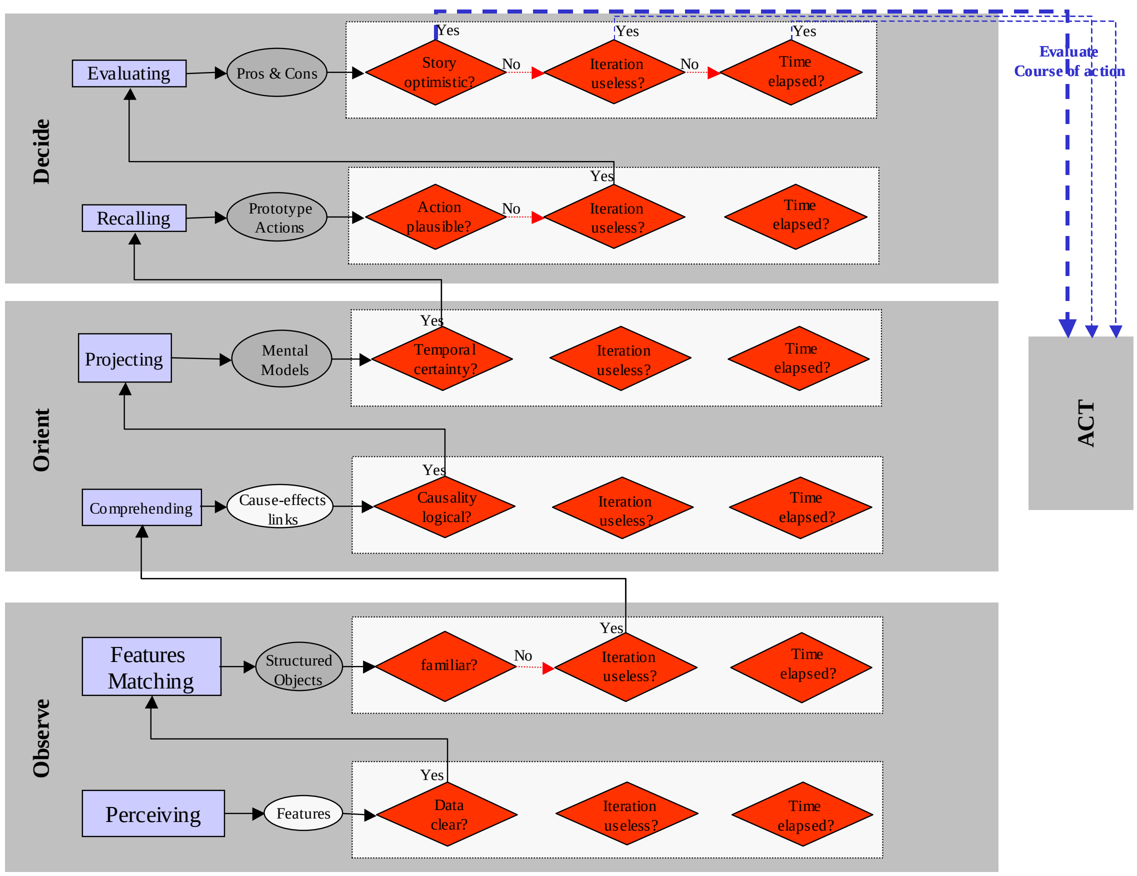

Figure 9. The Evaluate Course of Action decision-making level.

Similarly to the Diagnosis level, Evaluate Course of Action level relies on the complete execution of both the Observe and Orient phases of the C-OODA loop. The distinction between both levels lays in the involvement of the third phase, the Decide one, particularly in the results of the control components of the recalling stage (as illustrated in Figure 9). The Diagnosis level is performed to identify the best alternative as long as further iterations are seen to be useful and there is still time available to execute them.

Following the recall of potential actions, a mental simulation process evaluates the pros and cons of selecting those actions in the current situation. As it is shown in Figure 9, if the result of the evaluation stage through the mental simulation is optimistic, the prototypical action is selected to be implemented. In some situations, actions with lesser level of confidence can be selected (as shown by the thin dotted blue arrows). These situations happen when an action must absolutely be implemented, the story does not provide a high-level of optimism, further iterations seem useless or the time to execute them is not available.

Conclusion

In this paper, we propose the C-OODA loop model to meet the need for high-level cognitive granularity representation of C^2 decision cycle compatible with the OODA loop model. The C-OODA is modelled within the M-OODA framework in order to benefit from the capacity of representation of complex and dynamic situations and to keep explicit the notion of control inherent to the M-OODA loop model.

One advantage with the C-OODA is that it does not focus the modelling effort on a specific subset of OODA process, namely the Orient process, as was the case for other attempts at modifying the OODA loop (Fadok, Warden & Boyd, 1995; Breton & Bossé, 2002; Bryant, 2003). In the C-OODA, the cognitive granularity is improved for the first three phases of the OODA. A second advantage with the C-OODA model is that it keeps explicit the well-accepted low granularity representation of the classical OODA loop. Other models (e.g. Smith, 2002; Bryant, 2004) have the paradoxical effect of providing a solid cognitive model while discarding the benefits associated with the classical representation of the OODA loop. As it is the case for the M-OODA loop, the C-OODA is tightly mapped with the classical version of the OODA loop.

Despite many critics, reviews and alternatives, the OODA loop is still very popular in military documents and is still used to represent the C^2 decision cycle. It is our point of view that to remain a useful and accepted tool in the context of documents defining the armed forces doctrine on C^2, any C^2 model has to keep explicit the high-level representation typical of the OODA loop. The challenge is to keep that valued simple high level representation while accommodating dynamic and control concepts and providing more details on the cognitive processes involved. The C-OODA loop, based on the modular architecture of the M-OODA loop, offers are relatively simple representation that can stand for both own and enemy decision cycle.

Nevertheless, the improvement of the cognitive granularity necessarily brings, as a side effect, the increase in the modelling complexity. The OODA loop is much more simple than the C-OODA illustrated in Figure 6. Then, for communication purpose, the classical version of the OODA loop is probably more appropriate. That may be another reason explaining the popularity of the classical version of the loop.

There might be a way to address the issue by adjusting the complexity level of the model to the modelling need. That would require: 1) to identify the specific need for modelling and 2) adjust the level of cognitive granularity and modelling accordingly. For instance, if the objective of the model is to simply represent the major phases included in the C^2 decision cycle, then the more appropriate model may be the OODA loop. As it is shown in Table 4, if the objective of the modelling effort is to illustrate complex and dynamic situations, and to show the role of the control components, then the M-OODA loop may be required even if this model increases the representation complexity. If a high-level of cognitive granularity is favoured to the detriment of the representation simplicity, then the C-OODA may be used. If teamwork is to be modeled, the

T-OODA loop developed by Breton & Rousseau (2003) can be useful. The T-OODA, also based on the M-OODA model, offers a set of basic modules, guidelines and principles from which team C^2 model can be developed to represent various C^2 team configurations. It is then possible to describe a scalable zoom-in/zoom-out process between these different models based on the objective of the modelling effort.

Table 4. The different OODA models in function of the objective of the modelling effort and the level of cognitive granularity.

Model required	Objective of the modelling effort	Cognitive granularity	Disadvantages
OODA	-Simple representation of C^2 decision process	Low	-Do not represent complex and dynamic situations
M-OODA	-Representation of complex and dynamic situations -Introduction of control processes within the loop	Medium	-Increased level of complexity for the representation -Model still includes generic processes
T-OODA	-Representation of complex and dynamic situations -Introduction of control processes within the loop -Represent teamwork	Medium	-Increased level of complexity for the representation -Model still includes generic processes
C-OODA	-Cognitively valid representation of C^2 decision-making process -Provides inputs to design process	High	-Representation with high level of complexity

The C-OODA loop is part of a family of C^2 decision cycle models that take their roots in the classical OODA loop model (see Figure 10). Altogether, the M-OODA, C-OODA and T-OODA offer a framework to illustrate the different aspects of C^2.

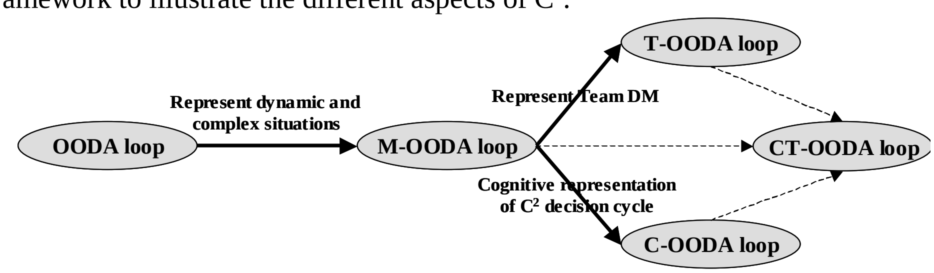

Figure 10. The Family tree of OODA models.

The fact that all these models that address different aspects of C^2 take their roots into the classical version of the OODA loop can be a positive factor in the acceptance of these models by the military community. The whole set of these different OODA loops provides a general framework to 1) represent dynamic and complex situations (M-OODA), 2) represent team decision-making (T-OODA) and 3) provide a cognitive representation of the C^2 decision cycle. By taking their roots in the OODA loop and being based on the same architecture, these models are compatible altogether. They benefit from the advantages related to the OODA loop while addressing specific OODA loop limitations. The next step is to develop a model, the CT-OODA that will improve the cognitive granularity level of the T-OODA loop.

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