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“Integration of the Dynamic Model of Situated Cognition in the Design of Edge Organizations”

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Integration of the Dynamic Model of Situated Cognition in the Design of Edge Organizations

Abstract

Much of the R&D in Network Centric Warfare has been on technology. Improvements in connectivity and processing speed challenge the integration of technological and human elements into a single C2 framework. The Dynamic Model of Situated Cognition (DMSC) was developed as an analysis method explicitly representing the human-technology relationships. It takes into account that sensors are susceptible to errors and to attack; inaccurate data from technological systems may propagate as misinformation to decision-makers. Any organization, including edge organizations, then makes decisions under uncertainty. This paper analyzes the use of signal validation to address shortcomings of technological systems. The sensor system should present validated information to operators; and, when it cannot, it should identify uncertain information. Signal validation filters the blue forces' sensor errors and red forces' information warfare misinformation. As a result, the blue forces are presented with synthesized validated data or are informed it is uncertain. The impact of signal validation on knowledge flows and quality of decision-making in Command and Control processes using the DMSC is simulated with the computational modeling environment POW-ER (Project, Organization, and Work for Edge Research).

Introduction

Network Centric Warfare (NCW) has been in existence for over ten years [Cebrowski & Garstka, 1998]. Much of the effort put forth by NCW proponents has been focused on technology. Improvements in bandwidth, connectivity, and processing speed have moved us closer to the time where military practitioners of all services, in every part of the battlespace, will have access to the same data. Focusing on technological solutions with little consideration for the capabilities and limitations of the warfighters is imprudent. The result is that these novel technologies provide capabilities not needed by warfighters or they function in ways that are not compatible with warfighters. These solutions will quickly fall into disuse or will distract warfighters from the tasks that are truly important for mission accomplishment. Equally unacceptable is a narrow focus on cognitive processes of the humans without considering the military context or the technologies with which the warfighters must interact. Findings in this area by themselves may have limited applicability to warfighting. These findings must be shared with technologists who can then incorporate them into the design of new systems. Thus, cooperation and collaboration between technologists and human performance experts are critical to the success of NCW.

In 2003, the Dynamic Model for Situated Cognition (DMSC) was introduced in response to weaknesses in previous models to represent the entirety of a network centric organization. By explicitly including the human elements of a Command and Control (C2) system, it provided analysts with a means to address their capabilities and limitations as required by a complete doctrine, organization, training, materiel, logistics, personnel and facilities (DOTMLPF) perspective.

Quantifying human decision-making in the presence of incomplete and sometimes erroneous sensor data is a challenge. Poor decisions can result in loss of life and mission failure. Where mistakes are caught, even in a timely manner, they may result in large volumes of coordination and rework effort that can overwhelm an organization. This coordination and rework is hidden effort: it is not planned, tracked, managed or even acknowledged except by the overworked staff. We have found no single model that can adequately represent the impact of poor decisions nor represent how organizational structures along with data fusion can minimize the risk of such a decision. Specifically, how can human-focused knowledge networks & trust relationships influence decision-making? How can technology-focused techniques such as signal validation improve those decisions? This paper examines the application of Virtual Design Teams (VDT) [Jin & Levitt, 1996] with its extensions for edge organizations [Ramsey, MacKinnon & Levitt, 2007; Orr & Nissen, 2006] to this problem.

Review of the Dynamic Model of Situated Cognition

As first conceived, DMSC consisted of six ovals and three lenses. This is illustrated in Figure 1: Original DMSC, where there is a distinction between the roles of hardware and software system elements and the roles of people-ware elements. The three ovals on the left side (Ovals 1, 2 and 3) represent the technological side of the system. The three ovals on the right side represent the human cognitive processes [Miller & Shattuck, 2004]. Oval 1 represents ground truth of the total battlespace. This includes location and status of friendly, enemy and neutral forces; as well as terrain, weather and other environmental conditions. Oval 2 and Oval 3 are always subsets of the true picture, representing sensed objects and which of those are presented to users. The quantity and quality of the information is a function of sensor parameters and C2 system parameters. Not only is there a selective filtering of which parts of Oval 1 are propagated, but there is also the potential to include errors due to mistakes in sensor fusion algorithms.

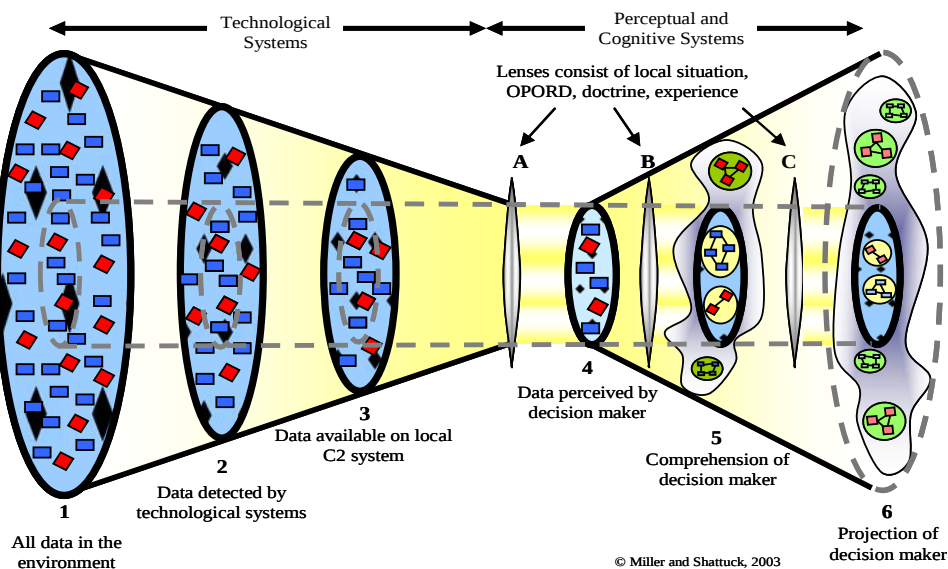


Figure 1: Original DMSC

Ovals 4, 5 and 6 on the right side of the model represent the perception of data elements, the comprehension of the current situation (sometimes called a mental model) and the individual's projection of current events into the future. Three lenses (A, B, and C) that transform the information between these last ovals consist of the local situation, the military OPERational ORDER (OPORD), military doctrine, the experience of the operator, and an individual's temporary state (stress, fatigue, etc).

Combat, especially under conditions of asymmetric threats and NCW, is a challenging environment for decision-making. As with any human-based enterprise, mistakes of perception and comprehension occur. Lense distortions result in inaccuracies in perceptions (Oval 4), comprehensions, (Oval 5) or projections (Oval 6).

Information from different sources may be in conflict. Sensors are susceptible to false positives and false negatives. The "red forces" are likely to use electronic combat tactics that provide misleading information to the "blue forces" and vice versa. To address this issue, Miller and Shattuck [2006] have modified their initial DMSC model to account for the fact that the data provided by the "Technological Systems" may be flawed and that it may propagate as misinformation to the "Perceptual and Cognitive Systems", i.e. decision-maker, with the potential for disastrous consequences. Figure 2 [Miller & Shattuck, 2004] depicts the DMSC model with sensor errors and lens distortions.

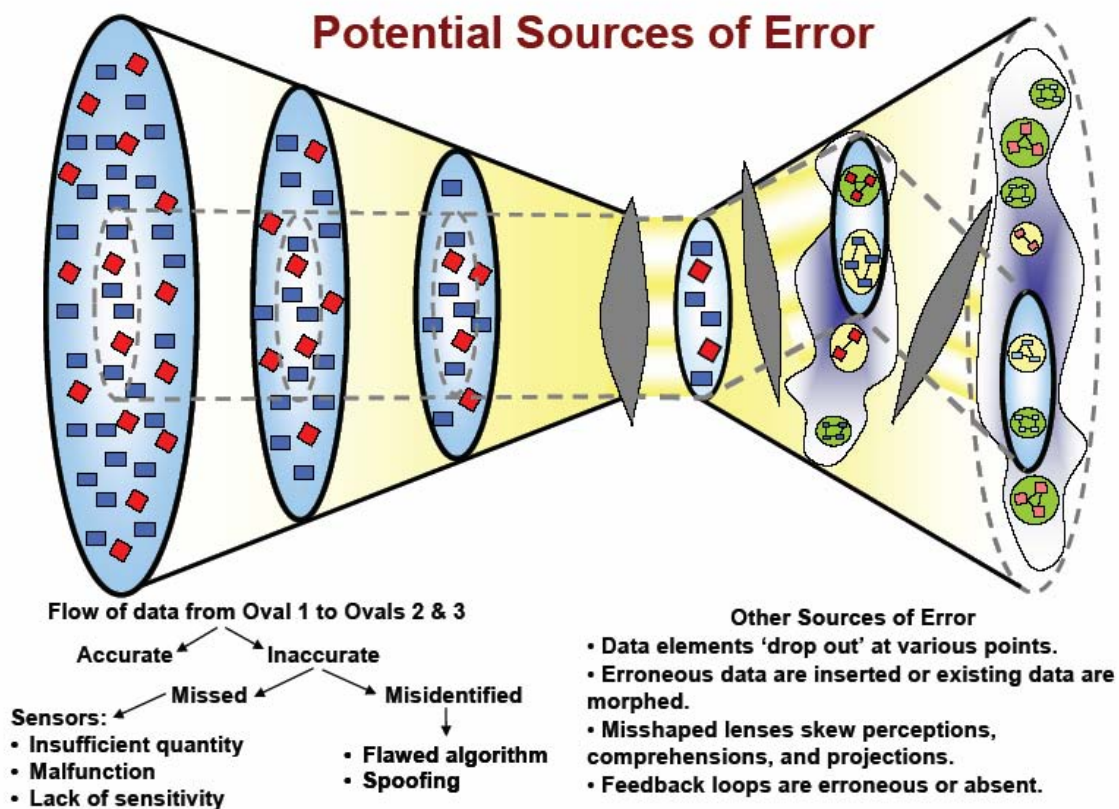


Figure 2: Sources of errors in situation awareness

Once inaccurate data are accepted into any stage of the hardware identification and human cognition processes, this inaccuracy propagates through the remaining ovals, leading to inaccurate conclusions and potentially poor decisions on the part of a force commander. Any organizational structure, including the edge organization, then faces making decisions under uncertainty, which is challenging even in a conducive environment. To aggravate the situation, the warfighters often have to make life-bearing decisions that require short response times under a high-level of fatigue or stress. In these situations, the decision process is “perceptual rather than conceptual” [Hutton and Klein, 1999]. The model can include feedback loops to represent the result of decision-making processes. These decisions include direction to physical forces and management of sensor and network resources as shown in Figure 3 [Miller & Shattuck, 2004]. Other feedback includes adjustments to OPOD and local doctrine, which is an attempt by the decision maker to reduce the distortions introduced by misaligned lenses.

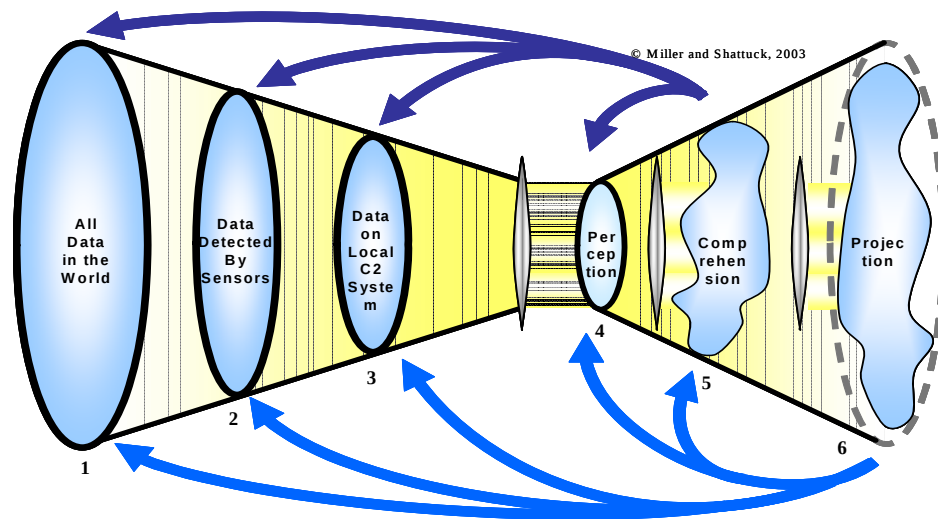


Figure 3: DMSC with oval feedback

A more thorough treatment of the original model, recent extensions, and current applications can be found in Miller and Shattuck, 2006. Figures 1 and 2 are from that paper. Further extensions can be found in Miller, Miller and Shattuck, 2007.

Signal Validation

As discussed above, the design of sensor systems is critical to NCW. Key requirements are [Miller and Shattuck, 2006]:

Requirement 1. The sensor system shall provide coverage and protection to the high-value assets against all credible threats.

Requirement 2. The sensor system shall be capable to detect spoofing activities.

Requirement 3. The sensor system shall display the accuracy and reliability of the sensor data.

Requirement 4. The data display shall not overload operators.

Requirement 1 is a complex and challenging problem for design and deployment of sensor systems for combat. Because no sensor system can be fielded with perfect performance or unlimited resources, it raises issues of decision-making under uncertainty. Design choices on sensor modes, locations, and platform integration require a quantitative assessment of the risk-reduction capabilities of different sensor systems when considered part of a whole combat capability. Suitable approaches exist for addressing Requirement 1 [Kujawski and Miller, 2007].

In this paper, we investigate the use of signal validation to meet Requirements 2-4. Using signal validation, the sensor system should present validated information to the operators or identify the information as uncertain and/or malicious. The resulting DMSC model is depicted in Figure 4. Signal validation filters the blue forces' sensor errors and failures and red forces' electronic combat misinformation. As a result, the blue forces are presented with synthesized validated data or else are informed that the data is uncertain or inconclusive. Signal validation helps to avoid data overload and reduces the probability of inappropriate actions.

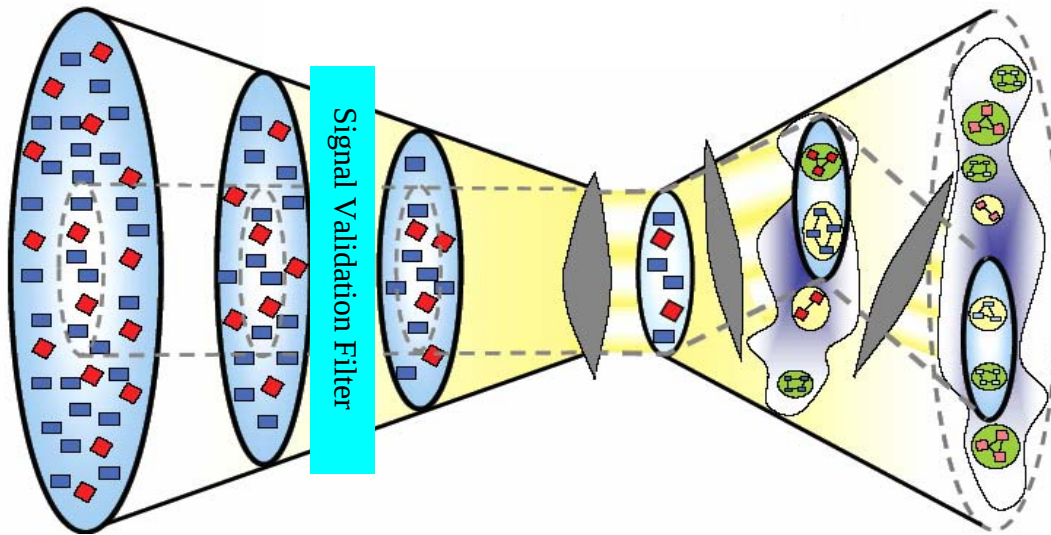


Figure 4: The use of signal validation to enhance situation awareness.

The difference between Figures 4 and 2 is that signal validation filters blue forces' sensor errors and failures and red forces' electronic combat misinformation. The blue forces can then readily discern the accuracy and reliability of the displayed data.

The key to successful signal validation is the ability to synthesize functionally diverse information in situations where the available direct data is not convincing. One of the authors [Kujawski, *et al*, 1987] has developed an inference process or decision estimator based on a Bayesian formulation. Related techniques are being successfully applied in critical applications including nuclear power plants, aviation, and space systems. We

propose to evaluate applicability of these techniques for protection against enemy attacks including terrorism.

The POW-ER Simulation Software

POW-ER (Project, Organization, and Work for Edge Research) is an extensible organization simulation platform developed as part of the Virtual Design Team (VDT) computational modeling research at Stanford University to optimize the workflow of an organization. POW-ER inherits most of its basic functionality from earlier VDT models. They are based on a workflow in which a network of tasks is defined like a PERT chart of a project in which some product is created. People within an organization are assigned to accomplish those tasks. Mistakes in executing those tasks are allowed to occur via a stochastic simulation engine controlled by probabilistic estimates. Rework occurs as a result of those mistakes. POW-ER also addresses the organizational elements that impact the ability of people to work effectively, including policies and structures (culture, communication, decisions, and meetings), staffing, knowledge networks and worker skill specialization. In a command and control system, the product being processed is information. It is possible to create agents representing a watch organization team executing assigned tasks [Ramsey, MacKinnon & Levitt]. Functional specialization can be included, along with skill learning and un-learning. It is relatively easy to run the simulation several times while changing knowledge networks, learning behavior, and even moving actors within an organization. One can then observe the impact on project duration and risk, worker backlog and rework impact.

Our goals are to (1) investigate the use of signal validation to improve the accuracy of information flows, (2) validate the DMSC against real data, and (3) demonstrate the applicability of the POW-ER simulation environment as a design tool for systems of systems including the warfighter. We introduce inaccuracies at different “Ovals” to quantify their impact on different organizational structures with different knowledge networks and analyze the impact of signal validation for different scenarios. We use the Tactical Network Topology field experiments as a sample organization engaged in decision-making in uncertainty to provide a baseline model to examine both signal validation and the situation simulation.

Tactical Network Topology (TNT) Field Studies

Each academic quarter, the Naval Postgraduate School (NPS) conducts a week-long field exercise at Camp Roberts. The exercises are sponsored by Special Operations Command (SOCOM) and are referred to as Tactical Network Topology (TNT) experiments. The TNT exercises provide excellent opportunities for NPS faculty and students (and selected organizations external to NPS) to test novel hardware and software applications in a field setting. The field setting, coupled with realistic scenarios, provides an attractive alternative to strictly controlled laboratory or computer-based simulation activities.

TNT 07-1 was conducted October 27 – November 3, 2006. Three days were dedicated to comparing methods for conducting searches with small Unmanned Aerial Vehicles (UAV). A total of 12 runs were completed. The scenarios for all 12 runs were similar. Four vehicles enter Camp Roberts through a checkpoint; but shortly after being processed, a routine database check reveals that the vehicles contain suspected enemy personnel wanted for questioning. UAVs are launched in an attempt to locate the four enemy vehicles. These searches are conducted at the discretion of experienced UAV operators.

Key players in these runs include the Tactical Operations Center (TOC) Commander, the Air Operations Commander (Air Boss), the Ground Operations Commander, the two UAV video feed observers in the TOC, the UAV operators in the field, and the red team commander. The TNT mesh network carries the live video feed from the UAVs to the TOC. The role of the TOC commander is supervisory in nature. The air boss communicates directly with the three UAV ground control units (GCUs) and directs the administrative and operational activities of the UAVs, including search patterns. The UAV video feed observers in the TOC were responsible for detecting and identifying the suspected enemy vehicles. Once the video observers detect and locate an enemy vehicle in the UAV video feed, they relay that information to the TOC commander who directs the Ground Operations Commander to send his vehicles to intercept the enemy. When that intercept occurs, the exercise is completed. The advantage of using this particular set of field exercises is that the reports of the UAV video observers were recorded and compared to “ground truth” [Shattuck, Miller and Miller, 2006]. This section describing TNT 07-1 is from that work. Mistakes in identifying and locating red team vehicles were identified as hits, misses, false alarms or correct rejections.

Creating a POW-ER Model

The TNT event is quite complicated. It demonstrates the use of many different types of sensors, networks and personnel working together. However, the missions executed were simple and limited in scope and time. The command structure was equally simple. The TOC Commander, based on input he received from the Air Boss and Ground Operations Commander, made all the decisions. Figure 5 depicts the basic task-based representation of TOC operations. It should be noted the organization most closely resembles a simple structure [Orr & Nissen, 2006] and is not an Edge organization. Indeed, one could argue that many of the principles exercised in this particular TNT were counter to some of the basic tenets of NCW. Further explanation of the task definitions requires some discussion of how actors are assigned to tasks and the level of work required. There are three “effort types” to describe how working man-hours and calendar time is calculated. The first and most common is “work-volume” which is the number of full-time equivalents (FTEs) taken by an individual to complete a task successfully (not counting rework yet). This is equivalent to the number of man-hour resources required for a task used when creating earned value project management tools. The second effort type is “work-duration” which is the amount of time required for a task regardless of the FTEs assigned. That is, it allows the modeler to accurately describe tasks that take, for instance, 10 days whether there are 2 or 5 or 10 people assigned. The third effort type is

max-duration which is the amount of work that can not be exceeded. This is equivalent to some service or consulting contracts that provide a given number of FTEs for a fixed amount of calendar time, regardless of task completion. At the end of the contract, work on the task stops. These are all common to creating Program Evaluation & Review Technique (PERT) charts or critical path method (CPM) and other task network project management tools. The “Operate UAV” tasks are of effort type “work-duration” of 40 minutes, which most closely simulates the fact that those are tied to the duration of the exercise, lasting until completion regardless of assigned position workload or other influences. The tasks “Manage Operations” and “Manage Air Operations” are configured in a like manner. The “Observe UAV video” tasks are of effort type “work-volume,” because in the model development we want to see the impact of rework and worker overload.

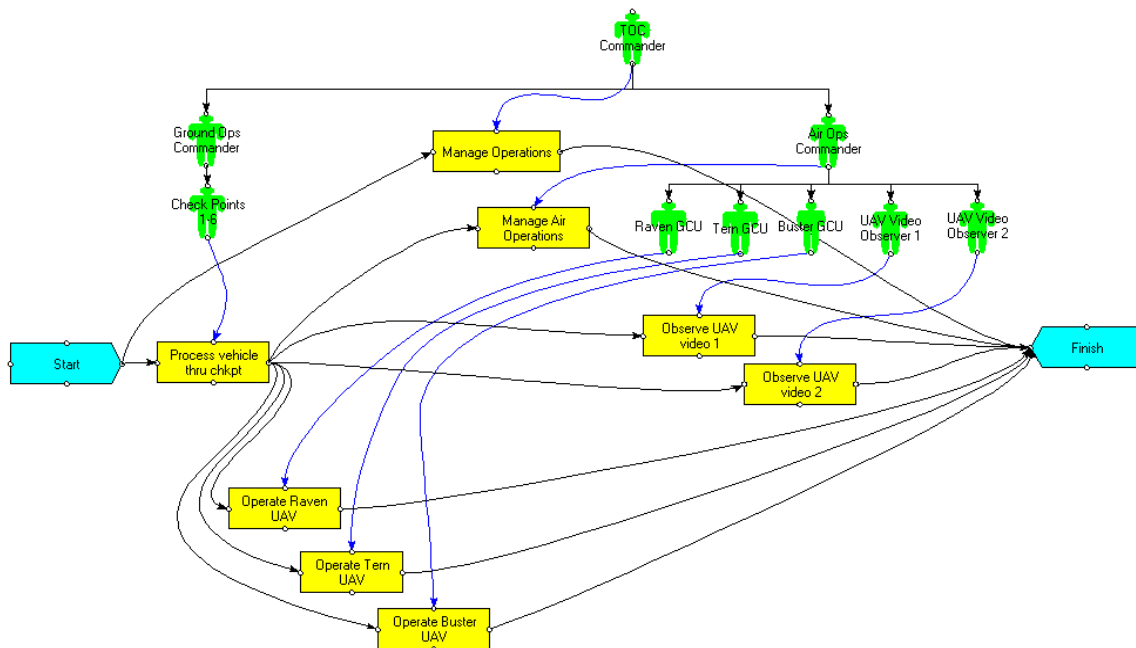


Figure 5: TNT 07-1 Baseline model in POW-ER

While the tasks and assignments in Figure 5 reflect the basic processes within the TOC, this first simple model does not help answer any of the questions we have posed. Tasks representing the video observers’ reports to the Air Boss and TOC Commander, the TOC Commander’s decision-making and the decision results need to be added. Figure 6 includes these additions. (In Figure 6, those elements common to Figure 5 have been cropped to improve readability and focus on the changes from the baseline.)

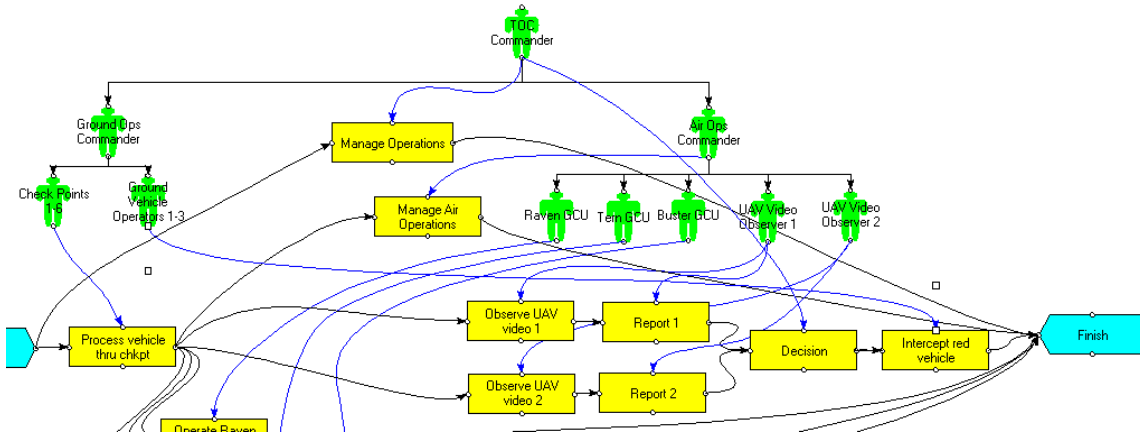


Figure 6: Decision result

The model in Figure 6 still is not quite right, because the observers make reports constantly and the TOC commander makes decisions on where to deploy his ground forces based on those reports. It is a cycle or series of “observe-report-decide” sequences. This simulates just one sequence, but is representative of the entire evolution. Also, we have not yet included the possibility of making a mistake and the resulting rework. We assume that it will be identified with most confidence during the “intercept red vehicle” task. That is, when a friendly vehicle is dispatched to a location, but no enemy vehicle is present, something went wrong. This is modeled as rework within the “decision” task, which in turn implies rework in the reporting tasks. To account for this, we add communication links and rework links between those tasks (Figure 7, which has also been cropped to minimize redundant information from the baseline).

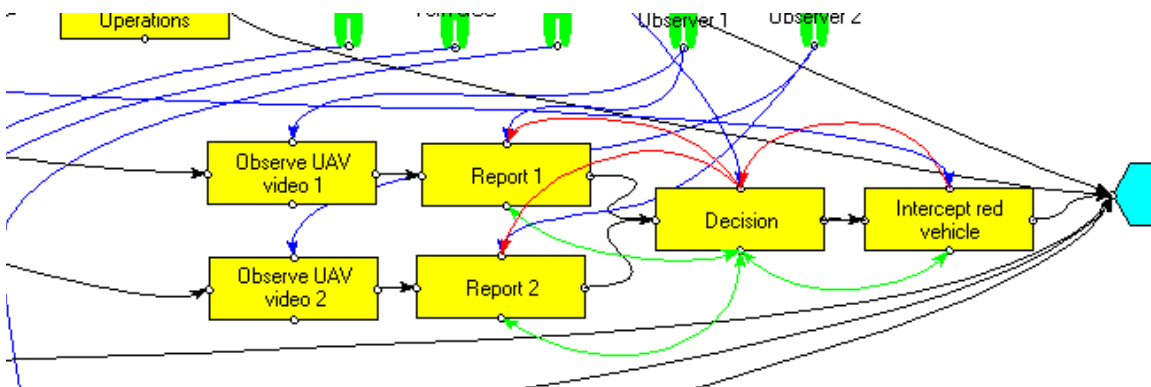


Figure 7: Rework resulting from poor decisions

A rework link identifies the flow of exceptions from a task to a previous one. The “strength” of the link indicates how much rework in the target task is caused by one time increment of rework in the exception task. Because intercepting a vehicle can take up to 10 minutes in this scenario, but decision-making only takes a small fraction of this time, a strength value of 0.3 was assigned to that link. That is, for time unit of rework involved in “intercept,” only 0.3 times that is reworked in “decision.” Similarly, the strength of rework links from the decision task to the observe tasks was set to 1.0. A communication

link between two tasks indicates that people assigned to them need to interact with each other. This is important because it adds to the communication overhead required during rework. The addition of rework requires us to set some variables at the project level in POW-ER. The first of these is “Project Exception Probability” which represents the modeler’s estimate of how often an exception will occur on any task within the project. From this value, individual tasks can be assigned a solution complexity of high, medium or low which makes their probability of exception 20% less than, equal to, or 20% higher than the project exception probability. We set the project probability at only 0.20 to start, which is consistent with a simple structure organization operating in a 21st century environment [Orr & Nissen, 2007]. As we are only interested in rework in the decision task and intercept task, we set the solution complexity of those tasks to “medium” and all other tasks to “low.” While this model provides insight into the overhead and rework associated with incorrect decisions, it is challenging to quantify that in terms of the number of incorrect decisions made.

Previous application of the DMSC to help quantify C2 performance in this TNT exercise identified each opportunity in which a target vehicle was within the sensor footprint of one of the UAVs and identified TOC personnel response as follows [Shattuck, Miller & Miller, 2007]:

- Miss – Target in range of UAV but not detected by TOC personnel
- Hit – Target in range of UAV and correctly detected by TOC personnel
- False alarm – Target not in range of UAV, but TOC personnel report target present
- Correct rejection – Target not in range of UAV and no detection reported.

POW-ER provides for alternative and conditional processes via its “branch” element. One path is chosen over another based on the modeler’s input. In this way, one can more accurately identify the impact of the four above conditions. The additional probabilistic nodes and branches are depicted in Figure 8. In the interest of keeping the diagram simple, duplicate actors and duplicate tasks have been combined. The resulting actors have been edited to reflect more than one full time equivalent and the work volumes of their assigned tasks have been similarly adjusted. This seems more appropriate because we can now quantify rework resulting from misses and false alarms. Indeed, rework and communications links have been included for those incorrectly processed cases.

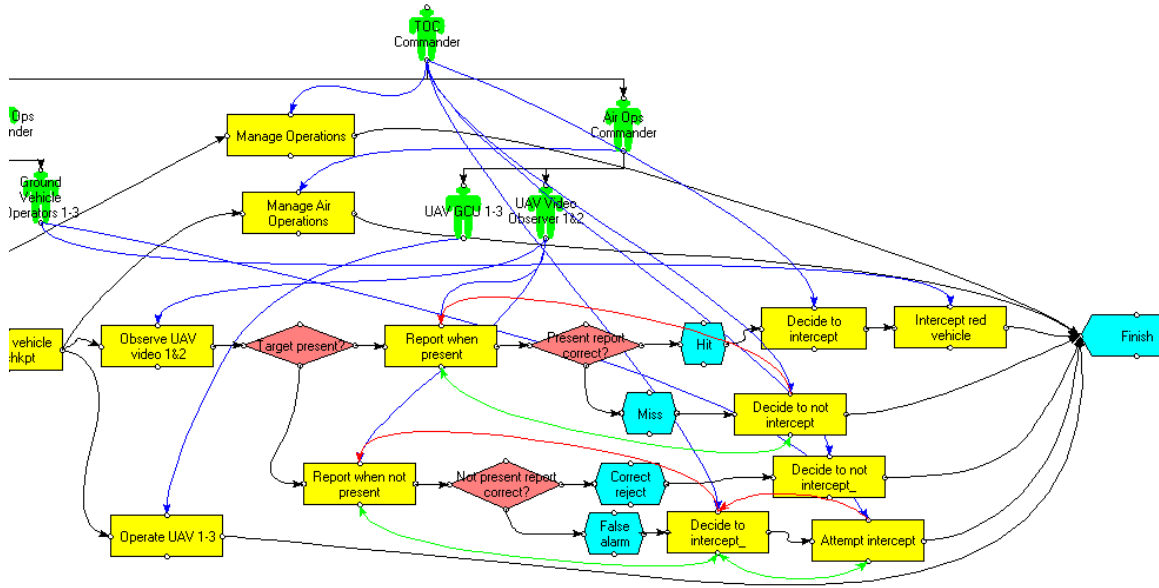


Figure 8: Branches in model with rework

Conclusions and Future Direction

We have just scratched the surface in this area. It is like wading into the confluence of the theories of human cognition as modeled in DMSC, computational modeling of organizations for C2, and sensor validation. POW-ER can be used to model this kind of organizational structure engaged in this kind of decision-making. Even though there are limitations in terms of faithfully representing the looping nature of searching for and then prosecuting target, we believe our simplifying assumptions are valid and will result in reliable results. The next steps in the process are to map the results of POW-ER (rework, overhead and worker backlog) onto the appropriate ovals in the DMSC and to examine the differences a signal validation function would provide.

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Integration of the Dynamic Model of Situated Cognition in the Design of Edge Organizations

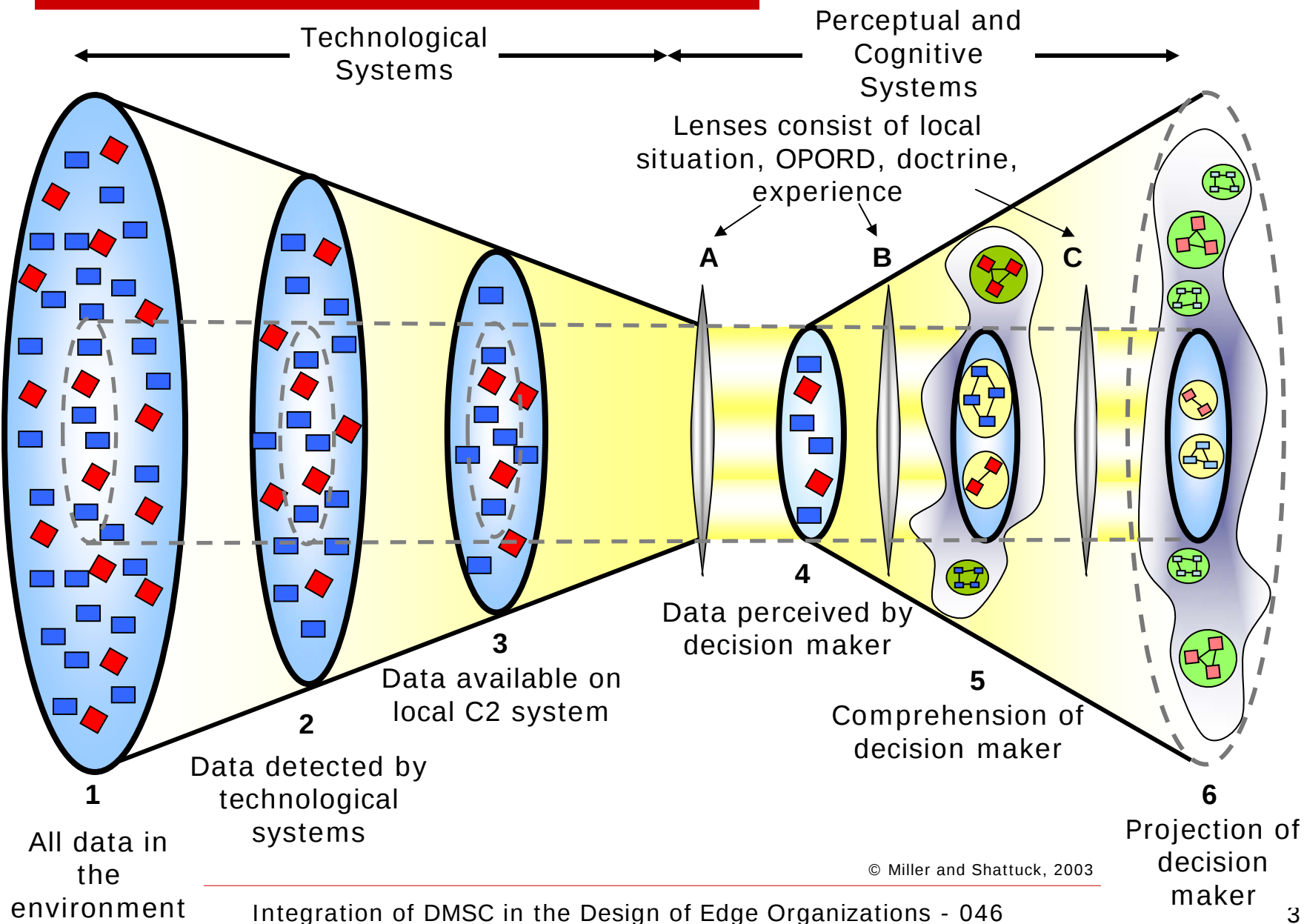
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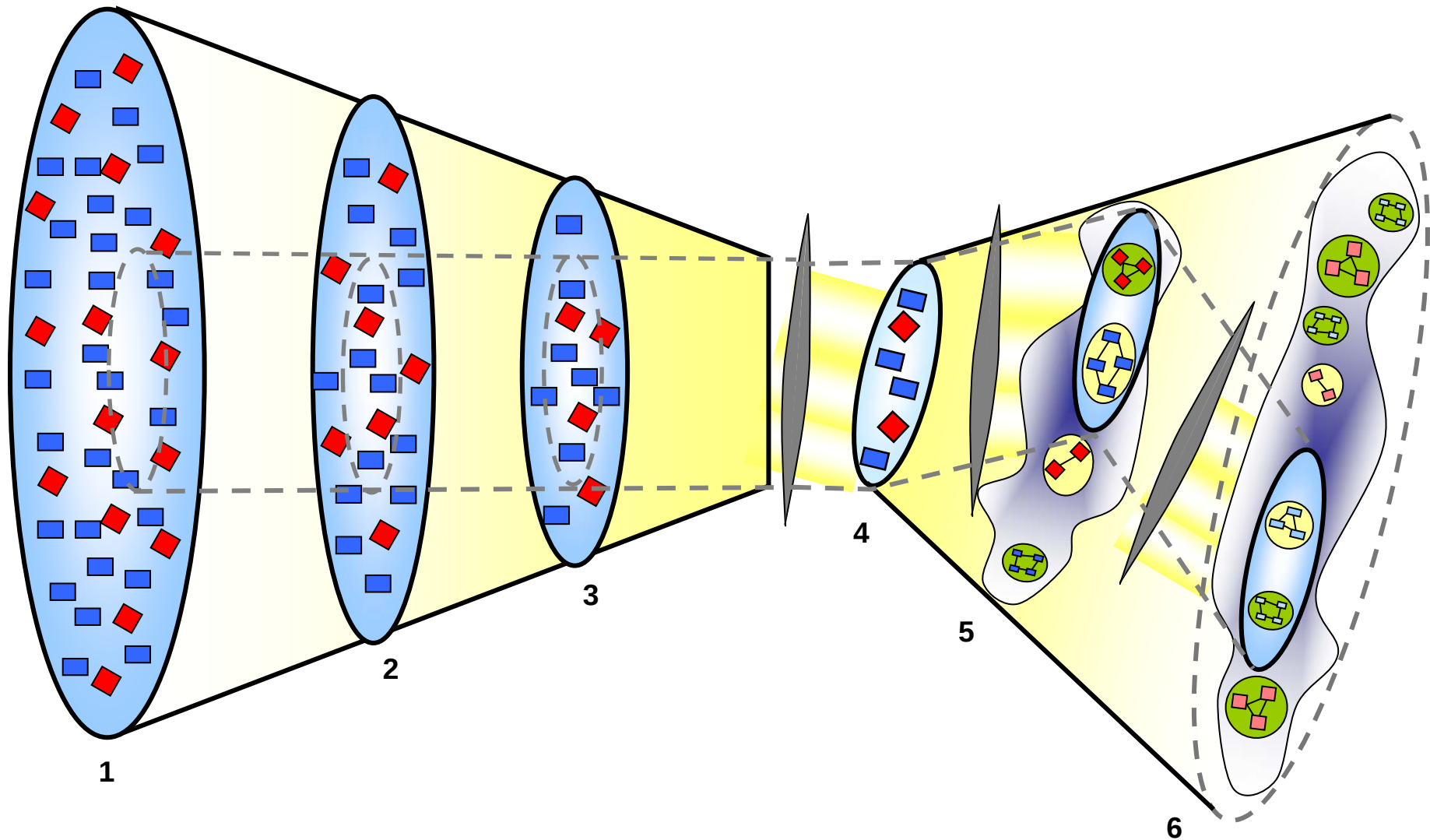
Introduction & Motivation

- ❑ Original DMSC introduced in 2003
 - Explicitly included human elements
 - More complete DOMLPF analysis of C2 systems
 - Consistent with capabilities-based assessment
- ❑ Applied in numerous situations
- ❑ What to do about errors?
 - Quantify rework, loss, other impacts?
 - Quantify impact of efforts to minimize error propagation via models?

Original DMSC

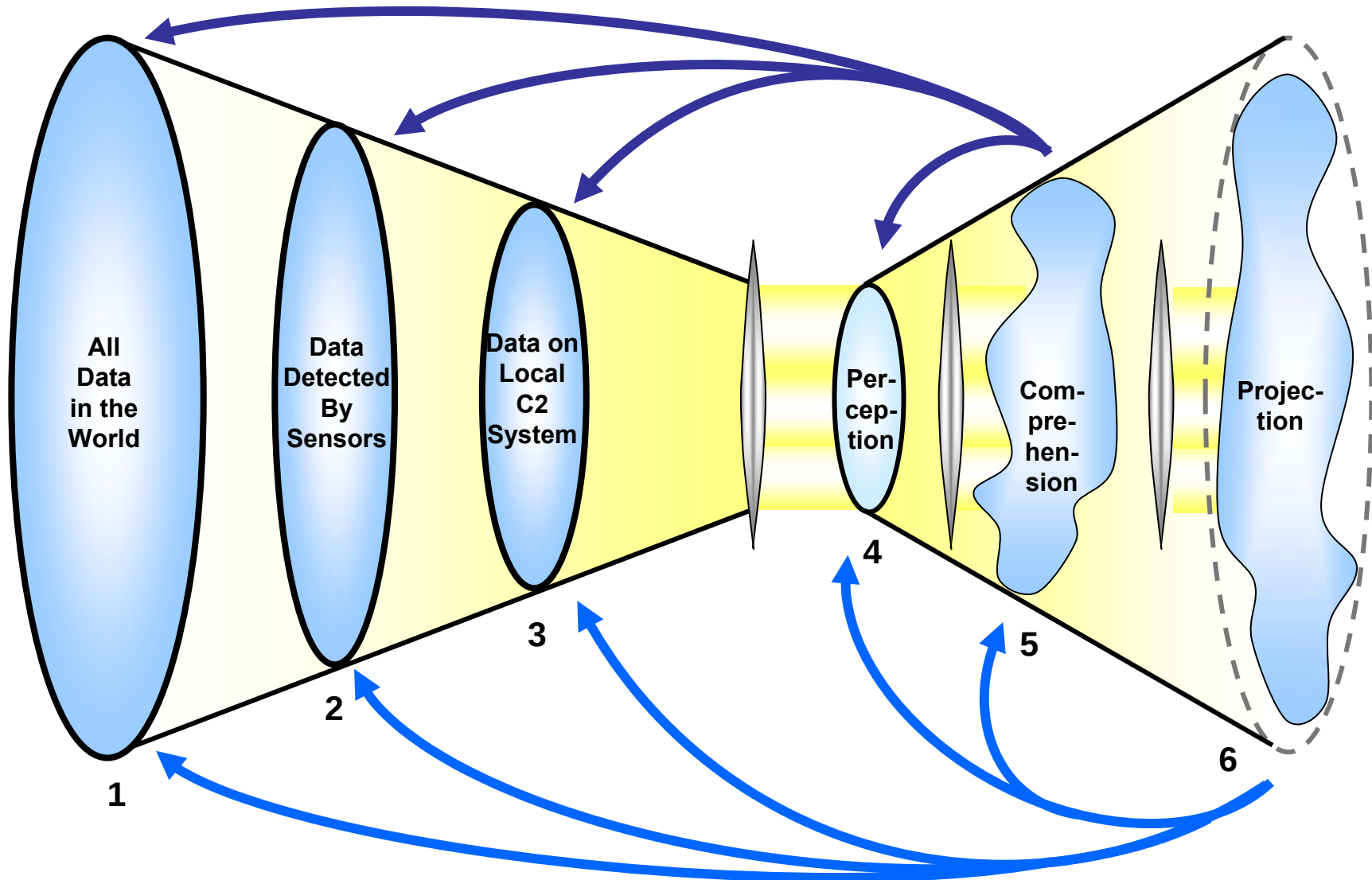


Lens Distortions



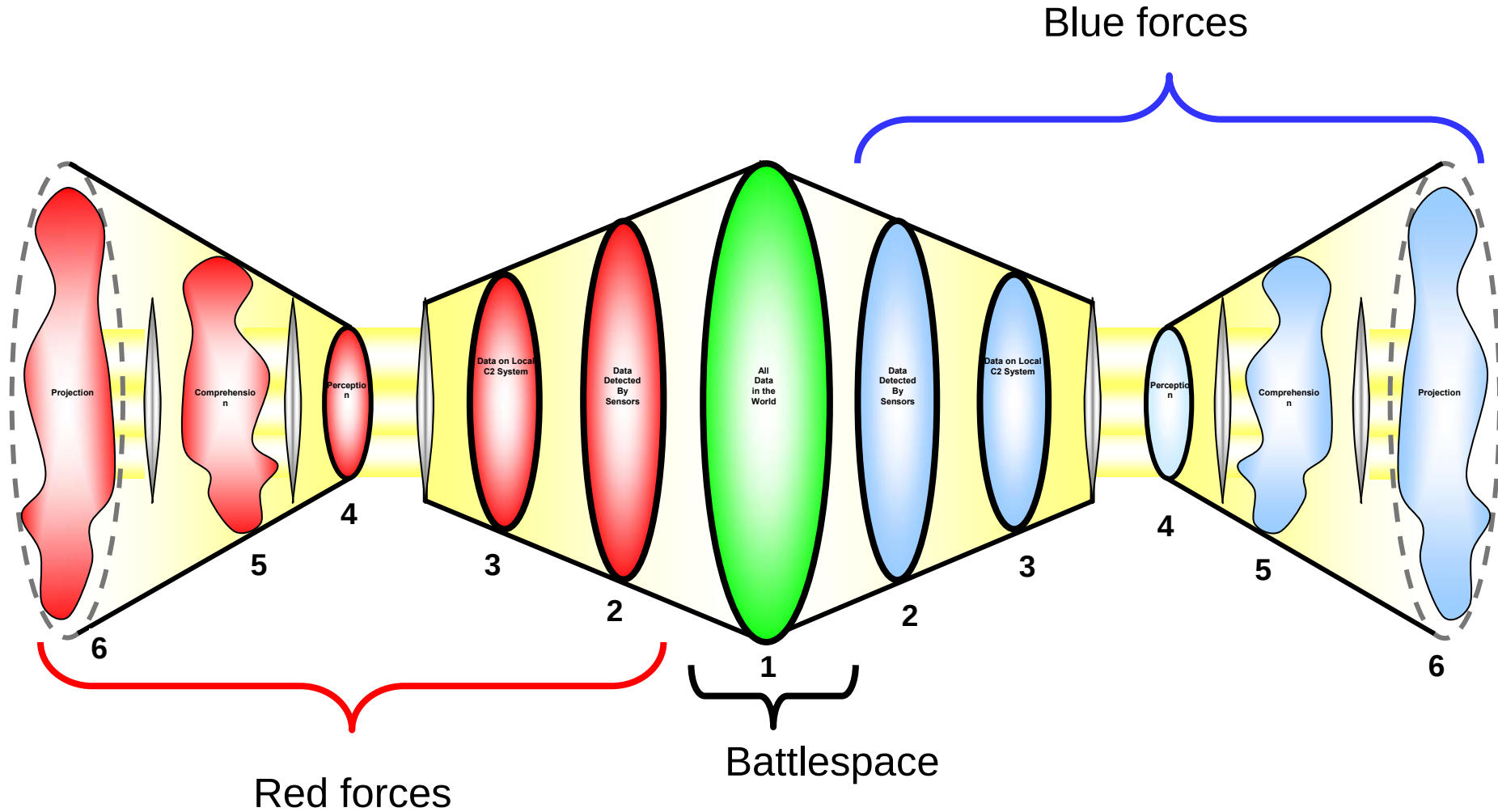
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Oval Feedback

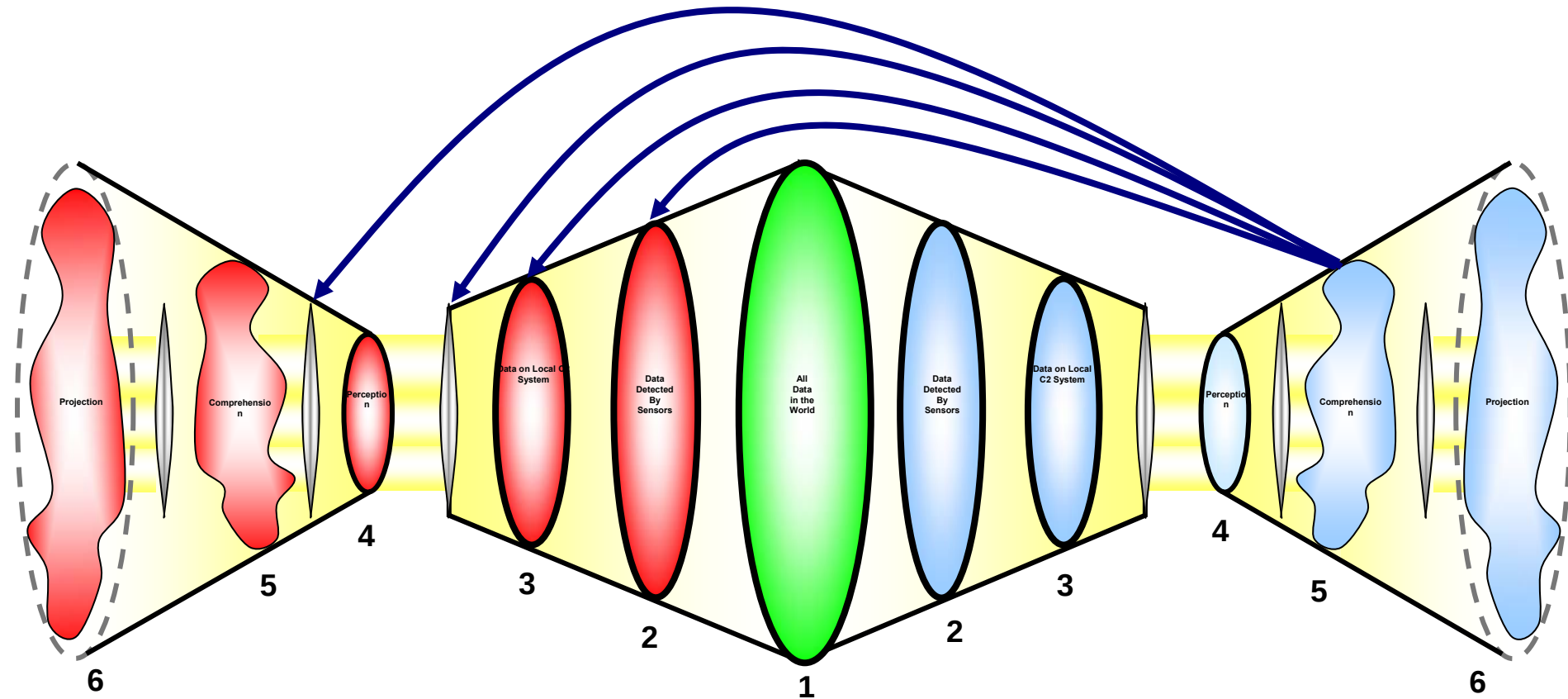


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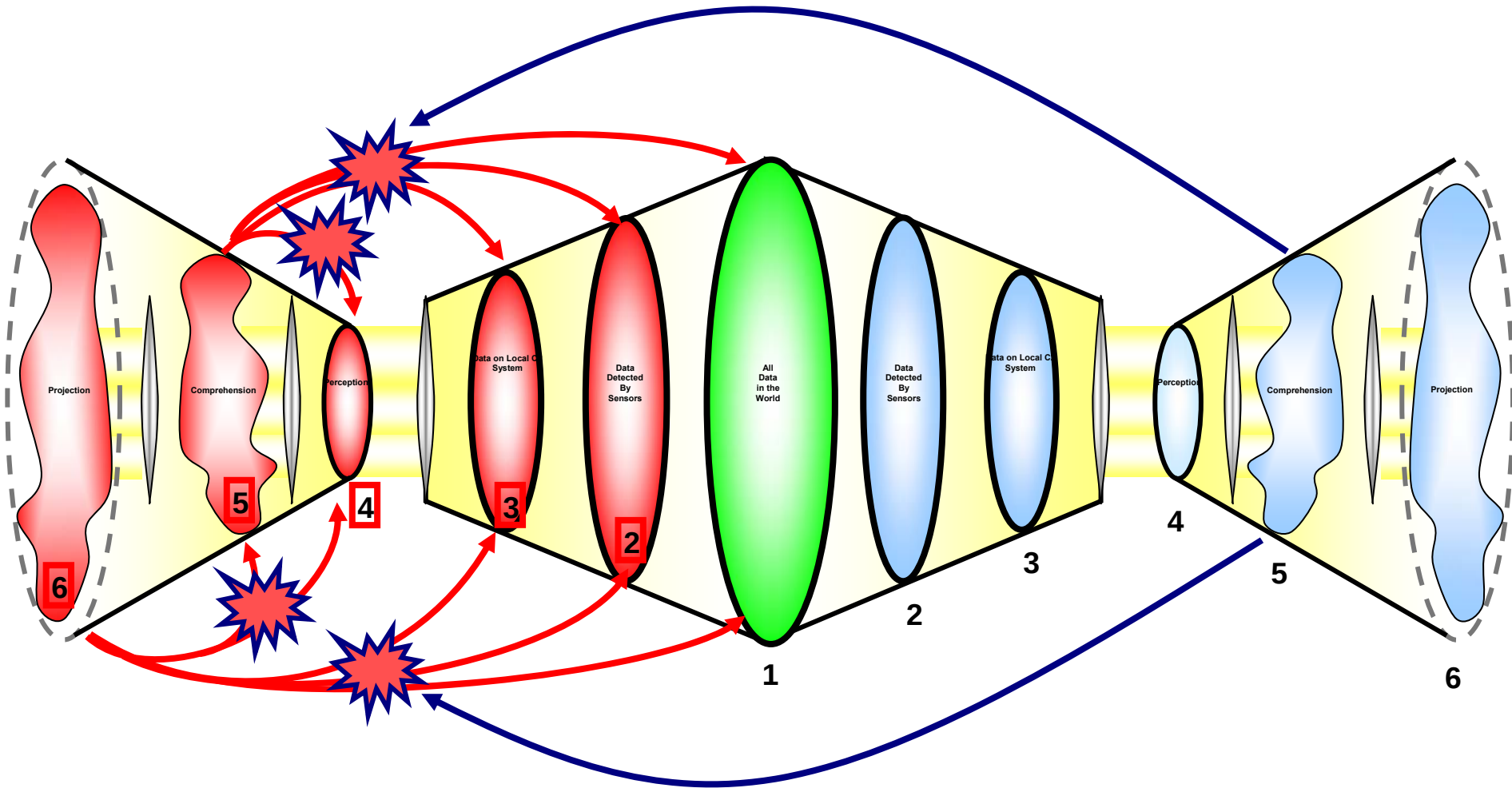
A Recent Extension



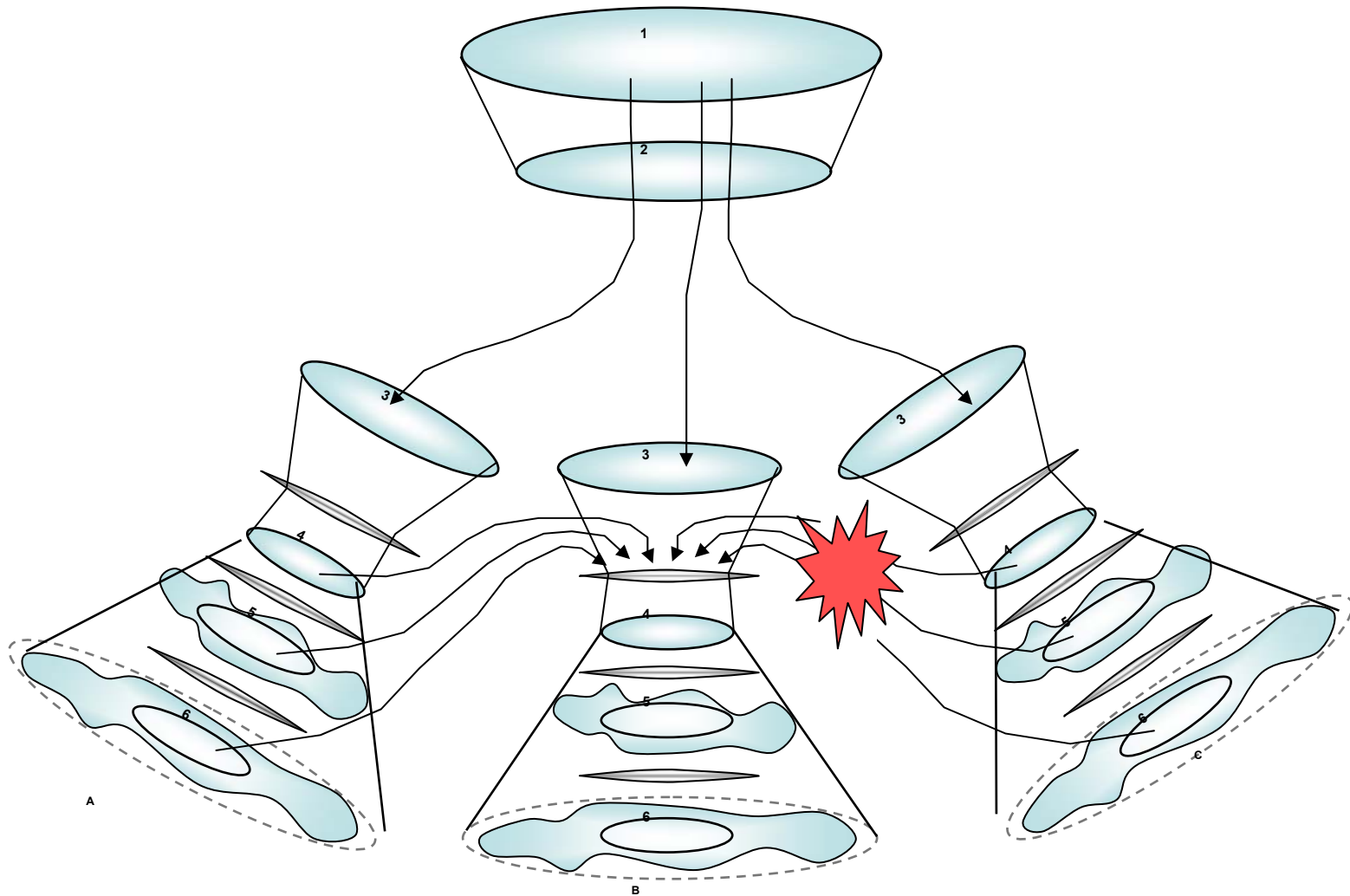
C2 Warfare



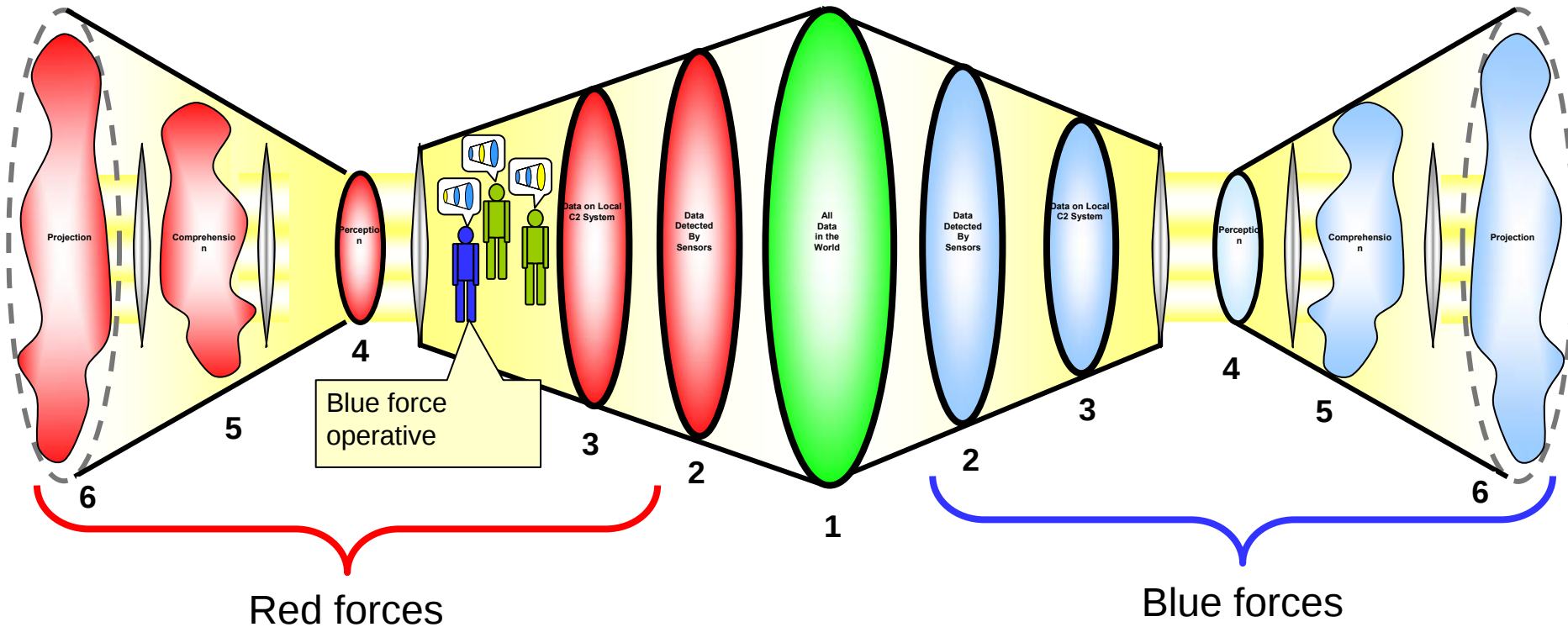
Disruption of Feedback



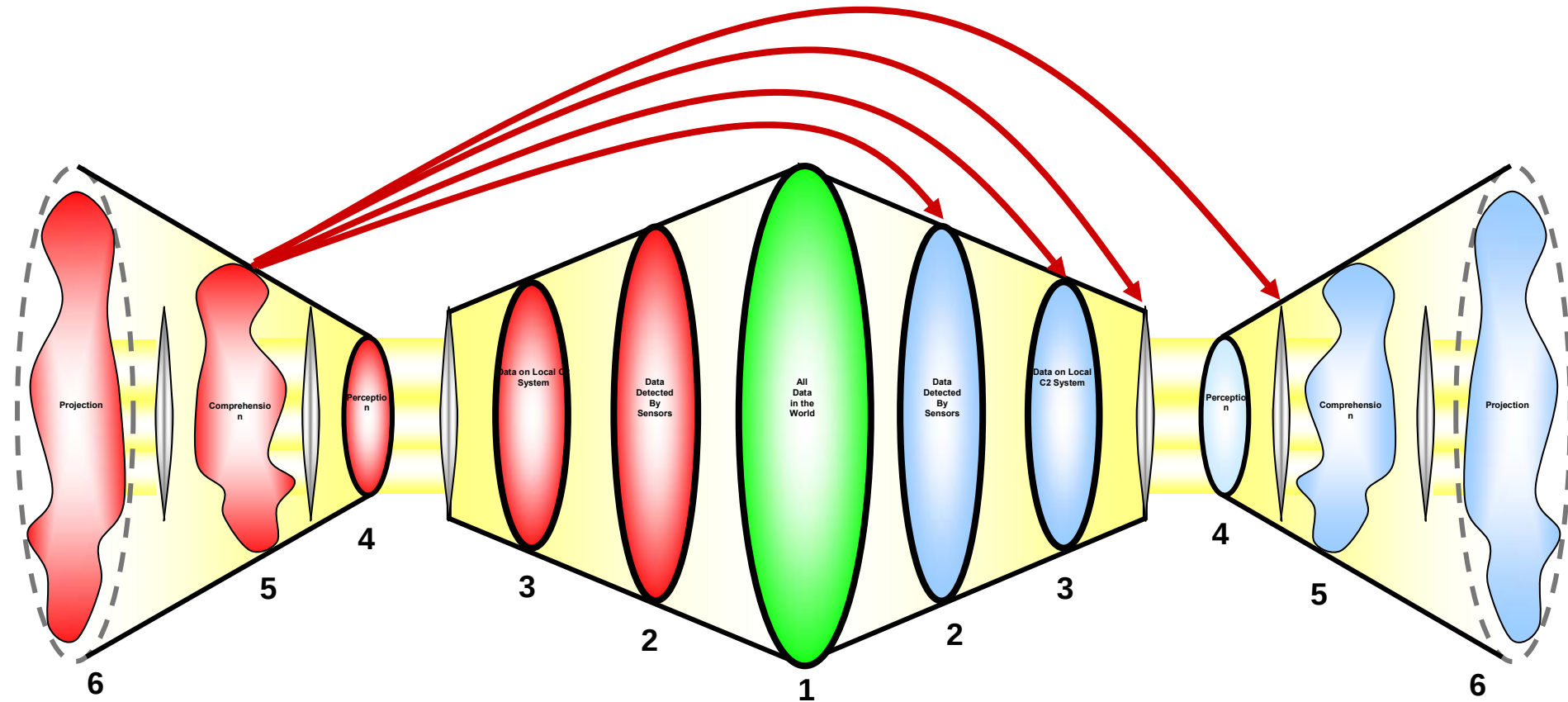
Counter-Communications Action



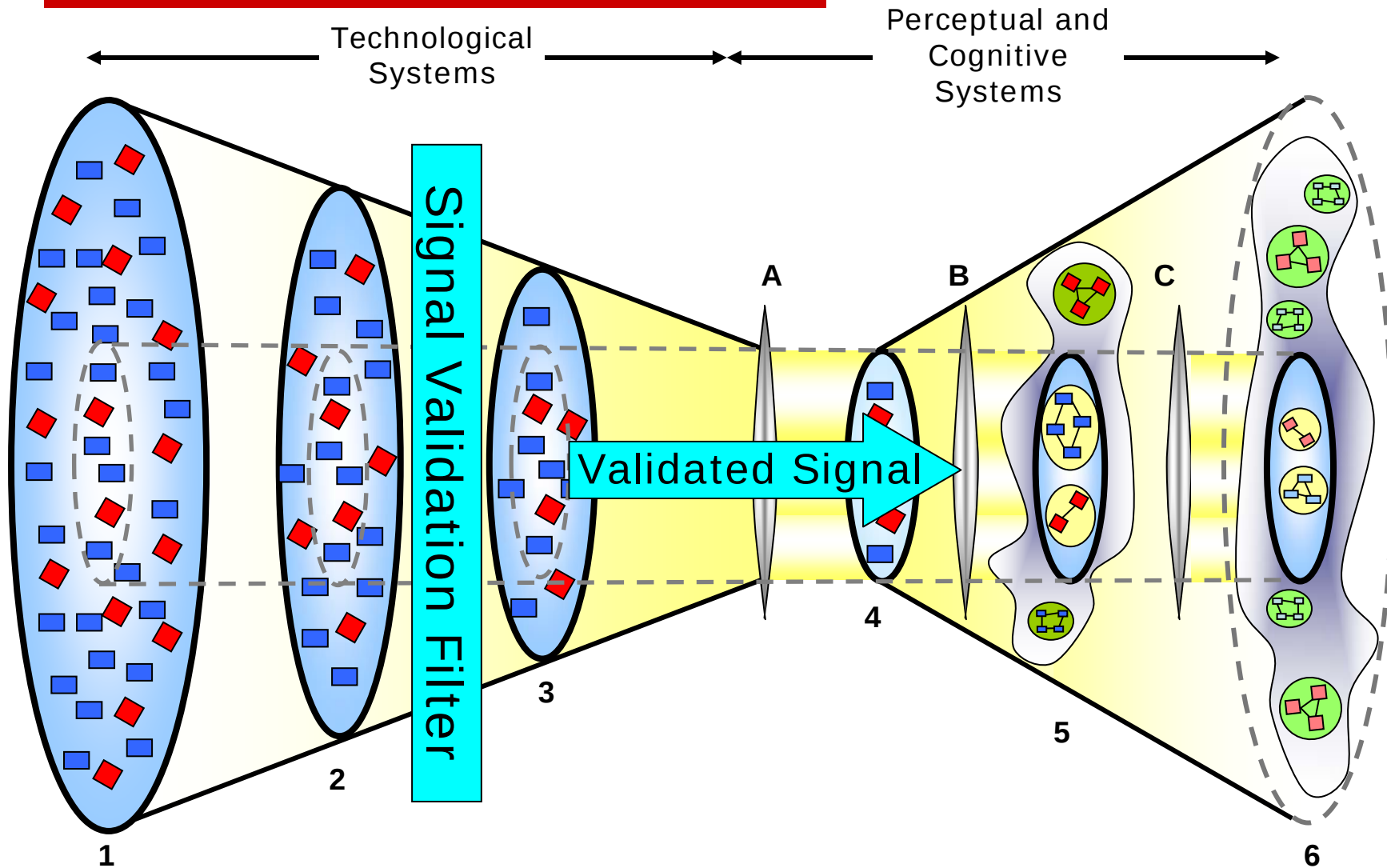
Direct Human Interaction



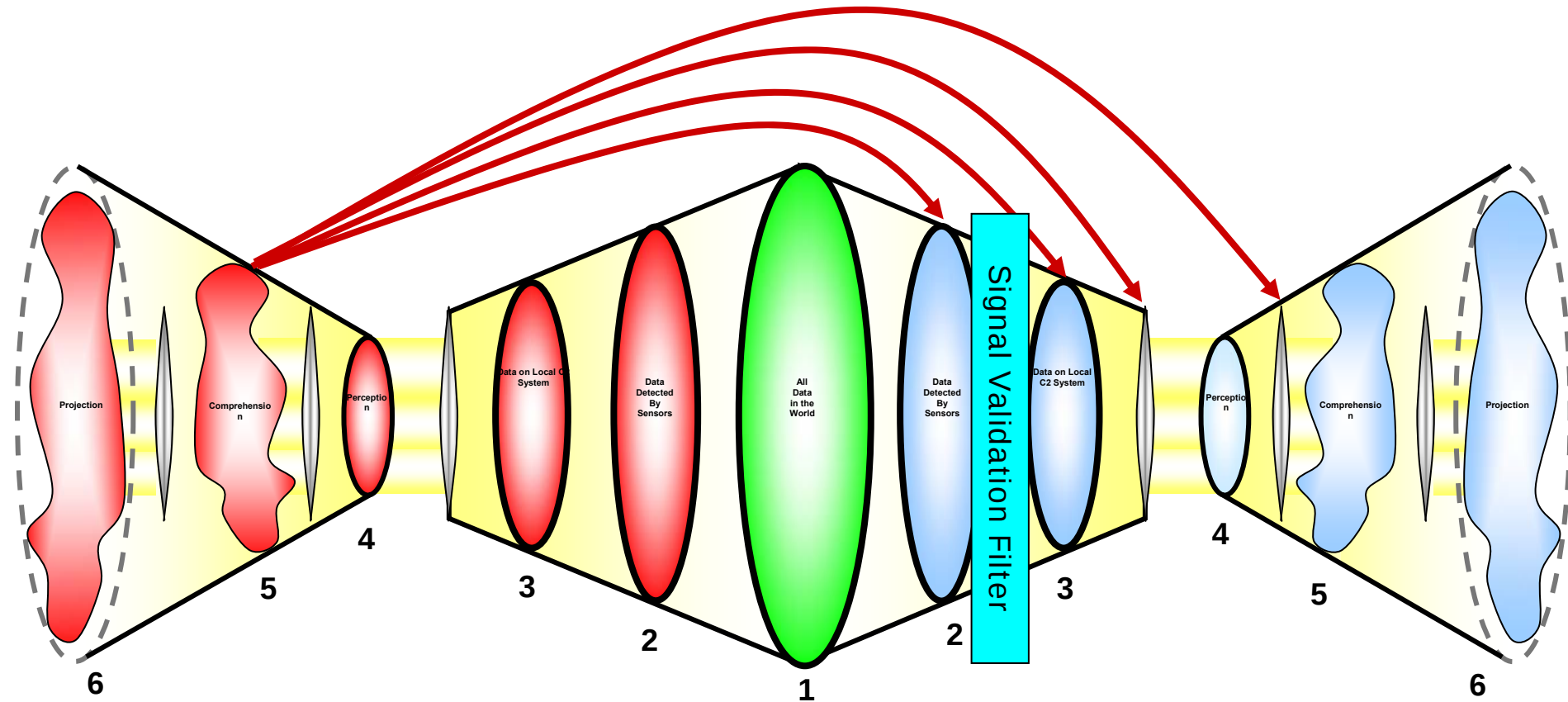
Red Force on Offense



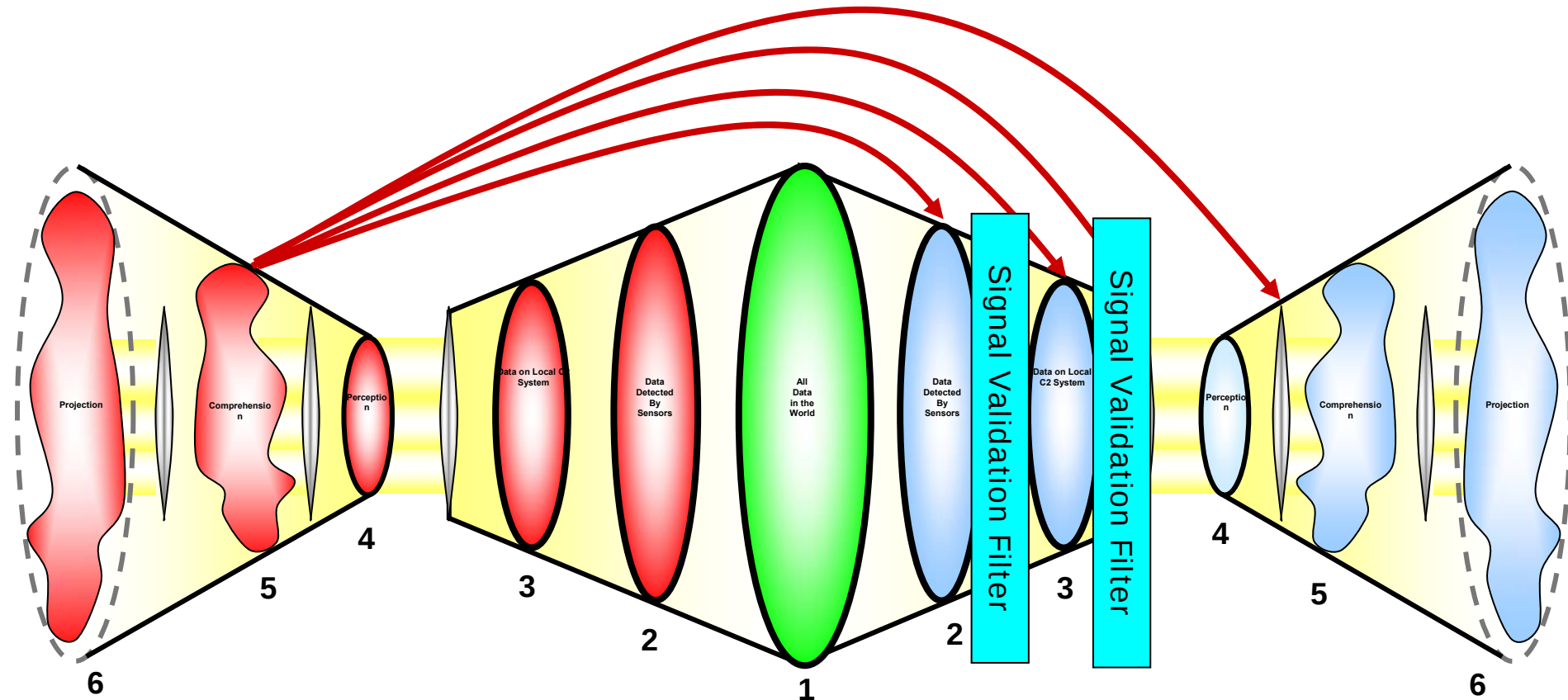
Signal Validation & C2 Warfare



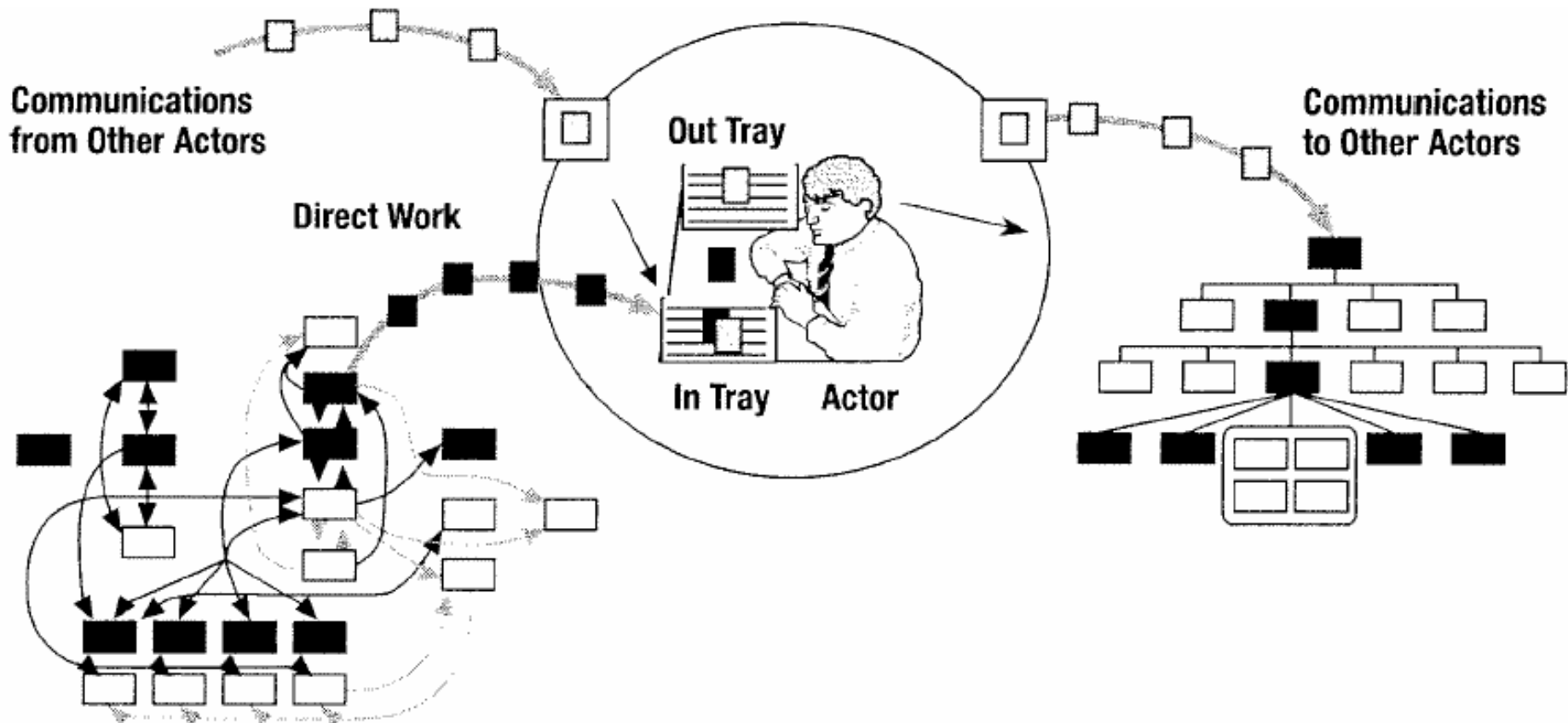
Red Force on Offense & Signal Val.



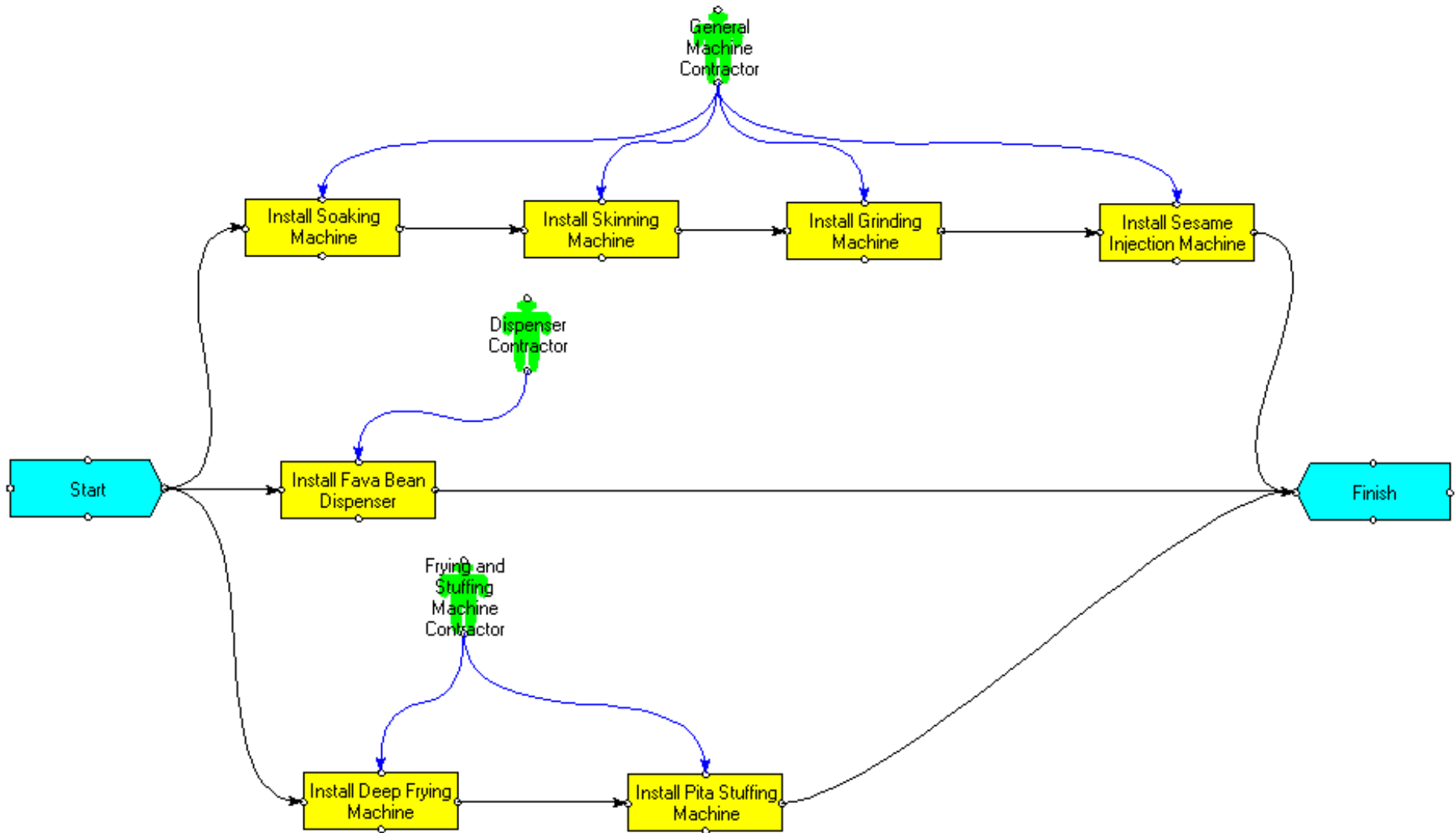
Red Force on Offense & Signal Val.



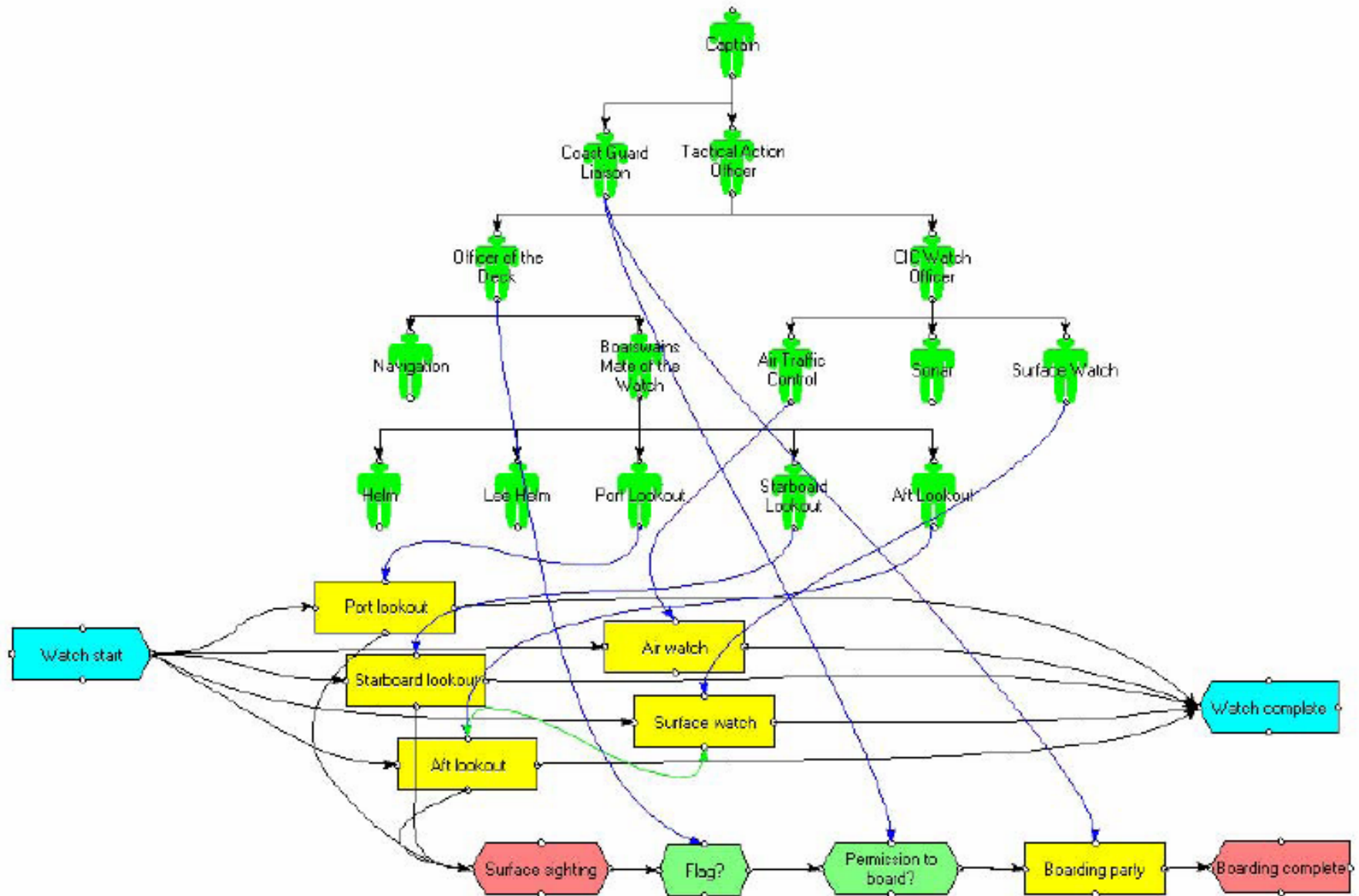
VDT Modeling Environment



Project, Organization and Work for Edge Research (POW-ER)



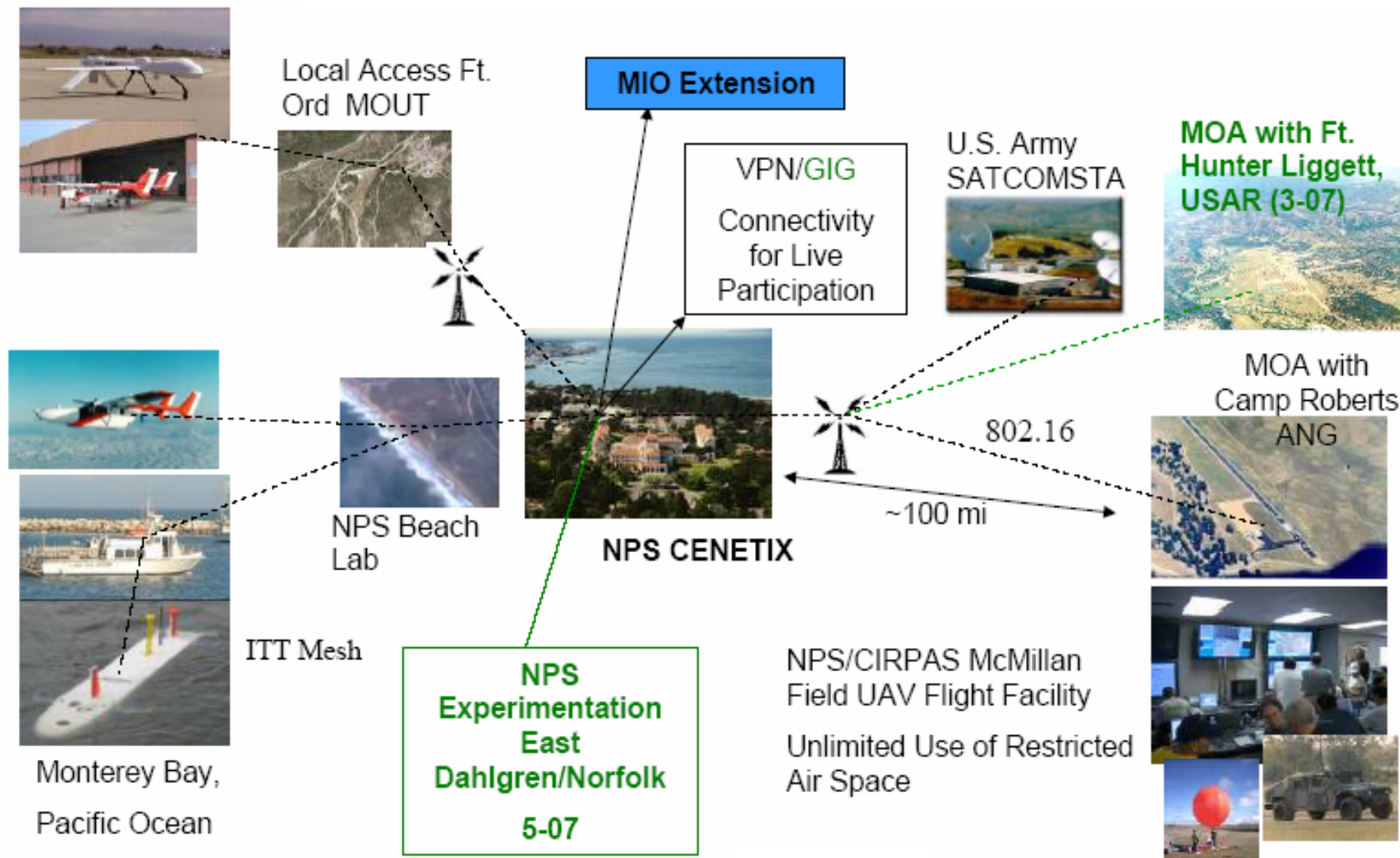
Project, Organization and Work for Edge Research (POW-ER)



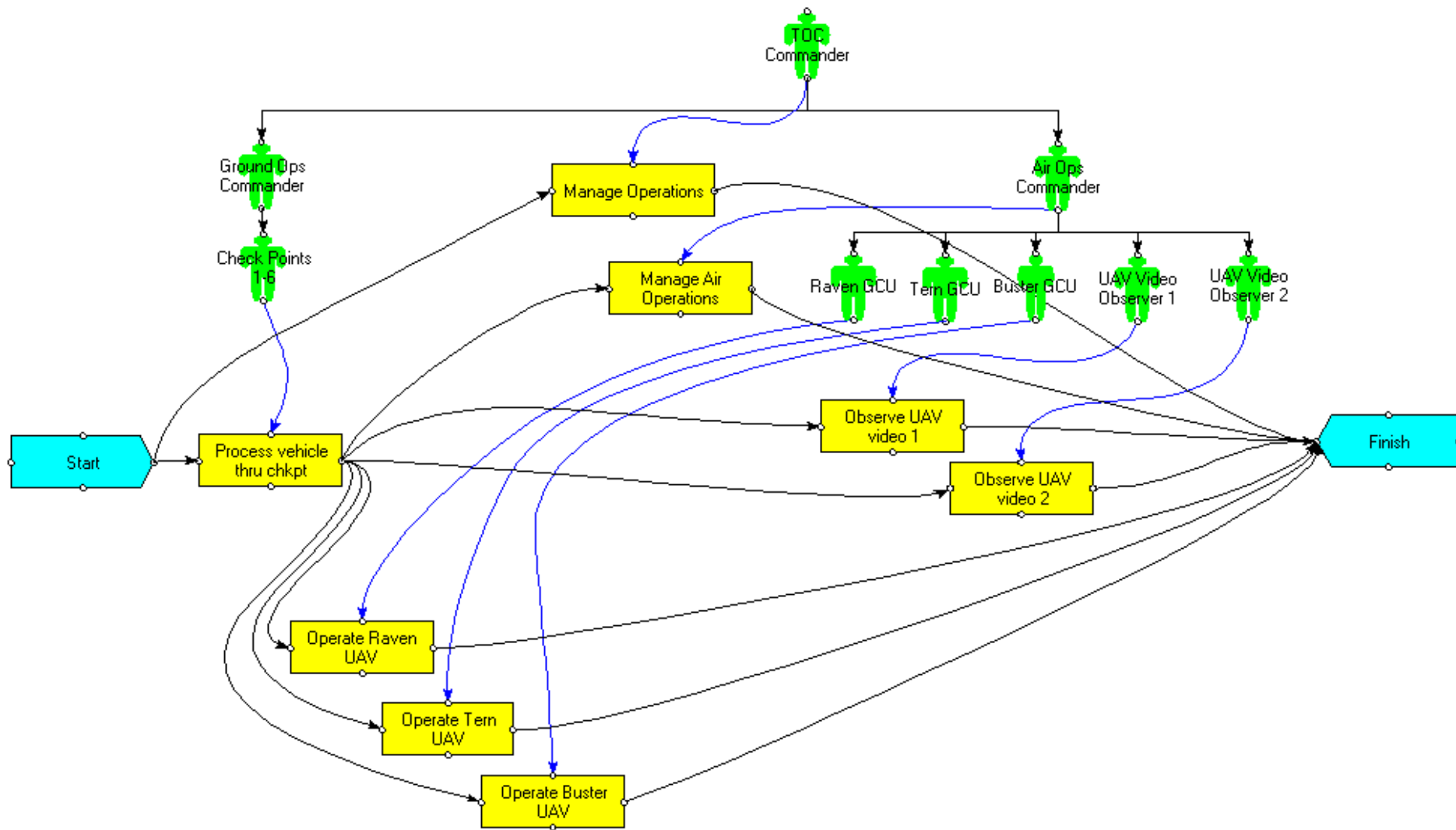
Tactical Network Topology Field Studies

NPS CIRPAS UAVs
and Manned Aircraft

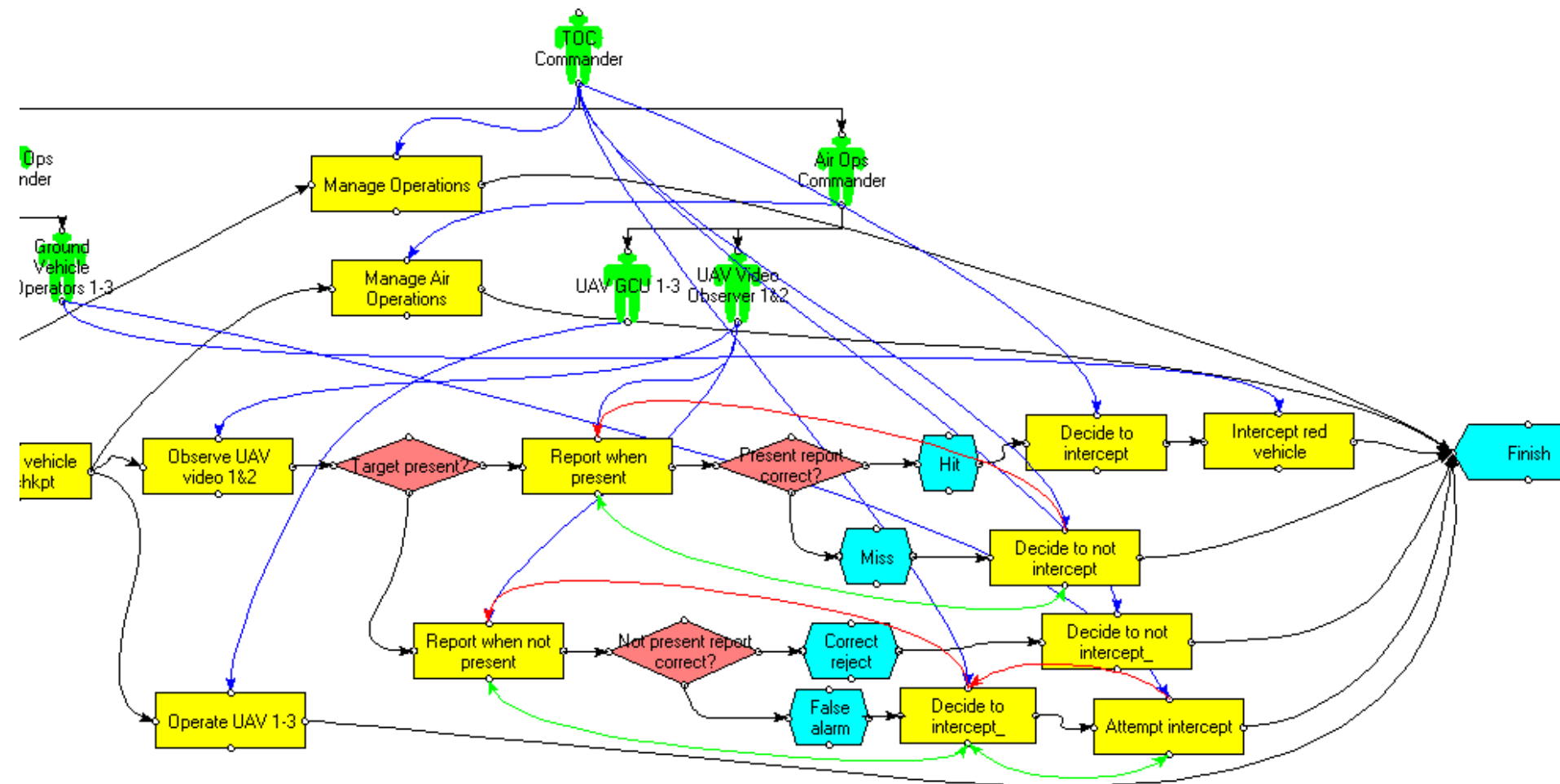
Sensor-UV-Decision Maker Networking Testbed



TNT 07-1 Baseline model in POW-ER



Branches Added



Only the beginning

