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Potential advantages of cognitive sensor-to-effector loops (CStELs)

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ADM(S&T): Assistant Deputy Minister of Science and Technology
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Overview

- Objective of this presentation
- Observe-orient-predict-decide-act (OOPDA).
- CStEL cybernetic model
- Adaptive versus cognitive systems
- Information versus cognition
- Background, kill chain and CStSL
- Effectors
- Example of a cognitive socio-sensing system
- Assessing CStELs advantage (changes in cognitive tasks)
- Conclusion

Potential advantages of cognitive sensor-to-effector loops (CStELs)

Objectives of this paper

This paper proposes the adoption of cognitive sensor-to-effector loops (CStELs) to gain advantages over challenging opposing forces. It is based on the Observe-Orient-Predict-Decide-Act (OOPDA) loop of FORCEnet and a cybernetic model used by the author for analysis. It argues that the adoption of CStELs is advantageous and the benefits are potentially higher than the risk. Evidence of this hypothesis is supported by results from data analysis of preparedness exercises over several years.

Adding cognition contributes to prediction

Adding prediction to the observe-orient-decide-act (OODA) cybernetic loop, as reported in a 2007 FORCEnet Naval Postgraduate School (NPS) report by Camacho et al., we have an observe-orient-predict-decide-act (OOPDA) loop.

This is similar to the cybernetic models used by the author in analysing coalition live and simulated exercises where the decision-making processes at command centers can be interpreted as a cognitive adaptive-control system. Changes in parameters in this kill chain allow one to compare legacy systems as sampled to a cognitive one (one with AI), i.e., the 'cognitive sensor-to-shooter loop' (CStSL), or 'cognitive sensor-to-effector loops' (CStELs).

Loop used for assessing success rate

1- monitor the situation;

2- assess the situation and estimate adversarial intent;

3- develop alternative course-of-action (COA);

4- predict their consequences for both sides (own and opposing forces);

5- decide a COA; and

6- direct its execution while monitoring the evolving situation in the environment (cycle 1 to 6).

Differences between adaptive and cognitive systems

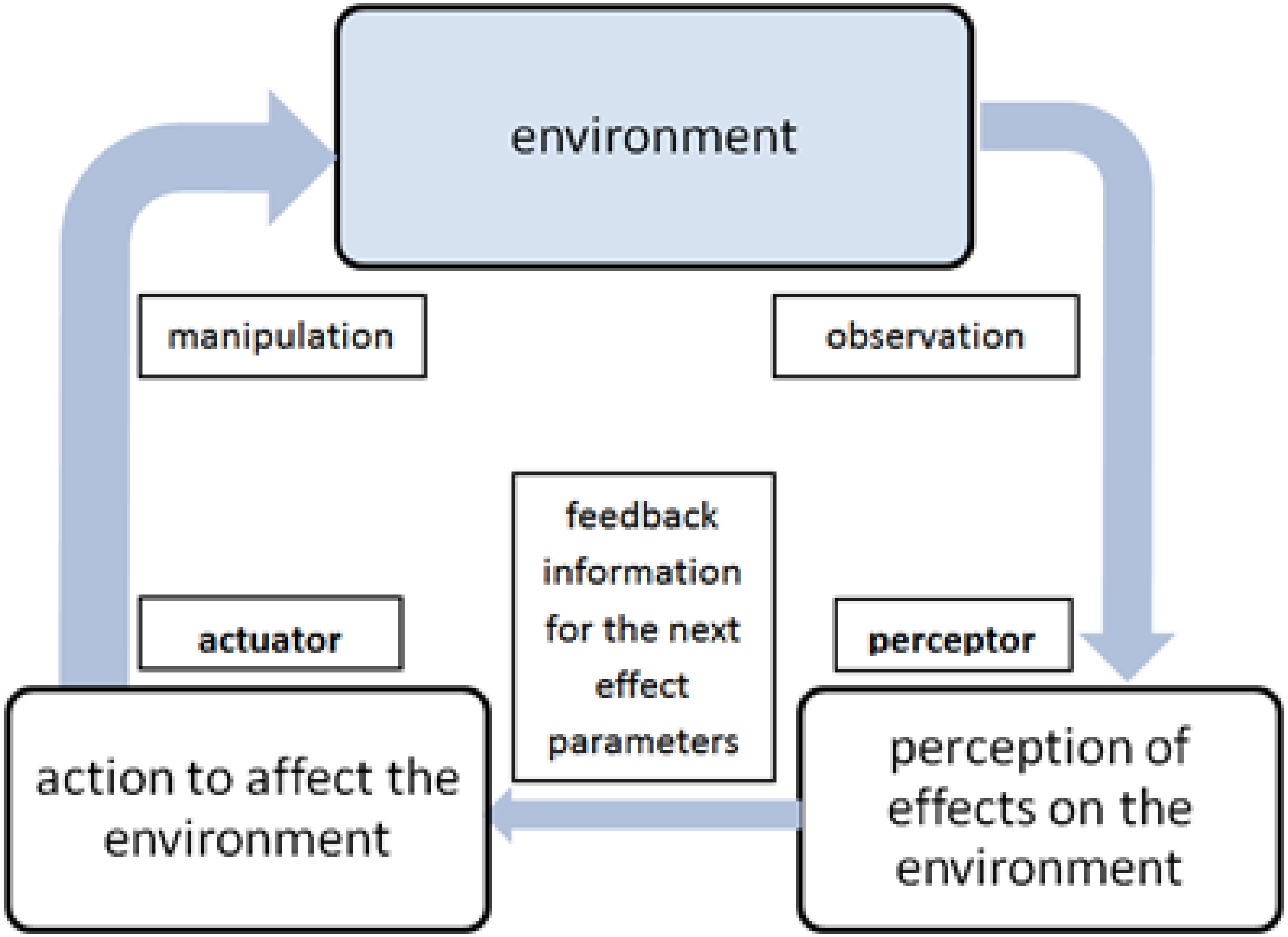
- **Adaptive systems are capable of modifying their parameters using predefined rules or algorithms in response to a sensed environment or signal changes.**
- **Cognitive systems actively stimulate (using an actuator to send signals) the environment to dynamically and autonomously adjust their operational parameters according to the feedback obtained (observation seen by a perceptor). They learn from continuous stimulation and observation to adapt both their algorithms and waveforms in order to achieve predefined task objectives.**

For CStELs, components are spatially distributed across the asset at play (radars, command centers, etc.).

Cognitive systems

- **While adaptive systems react to their environment using predefined rules, cognitive ones can develop in real time new rules with or without supervision.**
- **Cognitive systems, to reach users' goals use different machine learning techniques and memory retentions to address:**
  1. **immediate reaction types (parasensory and premotor),**
  2. **plan tactics (complex and abstract information of perceptual or executive character) or**
  3. **change strategy (dynamics of the perception–action cycle in sequential behavior, speech, and reasoning) toward goals.**

Generic cognitive cycle AKA sense-learn-act cycle



(adapted from Haykin)

Background, kill chain and CStSL terminology - 1

FORCEnet is the operational construct and architectural framework for Naval Warfare in the Information Age:

1. **It reports on the subject of accelerating the sensor-to-shooter kill chain**
2. **Goal: effective Cruise Missile Defense system design achieving the smallest possible reaction time from threat detection to weapons firing**
3. **Measures of performance (MOPs) included statistics on numbers of:**
   a. **information assurance attacks;**
   b. **electronic countermeasures softkills;**
   c. **threat missiles killed by interceptor missiles;**
   d. **re-engagements; and**
   e. **leakers.**

Background, kill chain and CStSL terminology - 2

FORCEnet and Open Architecture expedite data flow to support common services and reduce human interaction in the kill chain.

The sensor-to-shooter kill chain can be hastened by introducing automated processes and computational intelligence, using fuzzy logic and neural networks, which in turn curtails time lost due to organic intervention.

Unfortunately, neural network technology in 2007 was not sufficiently mature, but recent research and development with neural networks shows promise for the design as well as for other adaptive technologies, which can increase system automation and reduce reaction time.

Background, kill chain and CStSL terminology - 3

Now a decade later, it appears that we are at the cusp of practical specialized artificial intelligence (AI) in small devices which is critical to the CStEL concept.

The CStEL concept offers a vision of future real-time information systems tailored to command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) system requirements.

Future C4ISR will rely heavily on a large number of generic and specialized Internet of intelligent things (IoIT) providing some cognitive ability and enhanced agility in complex scenarios.

Situation prediction

The purpose of situation prediction is to estimate the enemy course of action (COA) and potential impact of the battleforce's planned actions, to predict real-time, near real-time, and non-real-time operational situations.

For model-based-measure (MBM), the notion of predicted position was associated with physics-aware dead reckoning models implemented in Newtonian mechanics.

Statistics from MBM represented as figures will be used later in this presentation to show the evidence that acceleration of the FORCEnet loop with appropriate supervised AI for the cognitive functions provides a net advantage.

Effectors

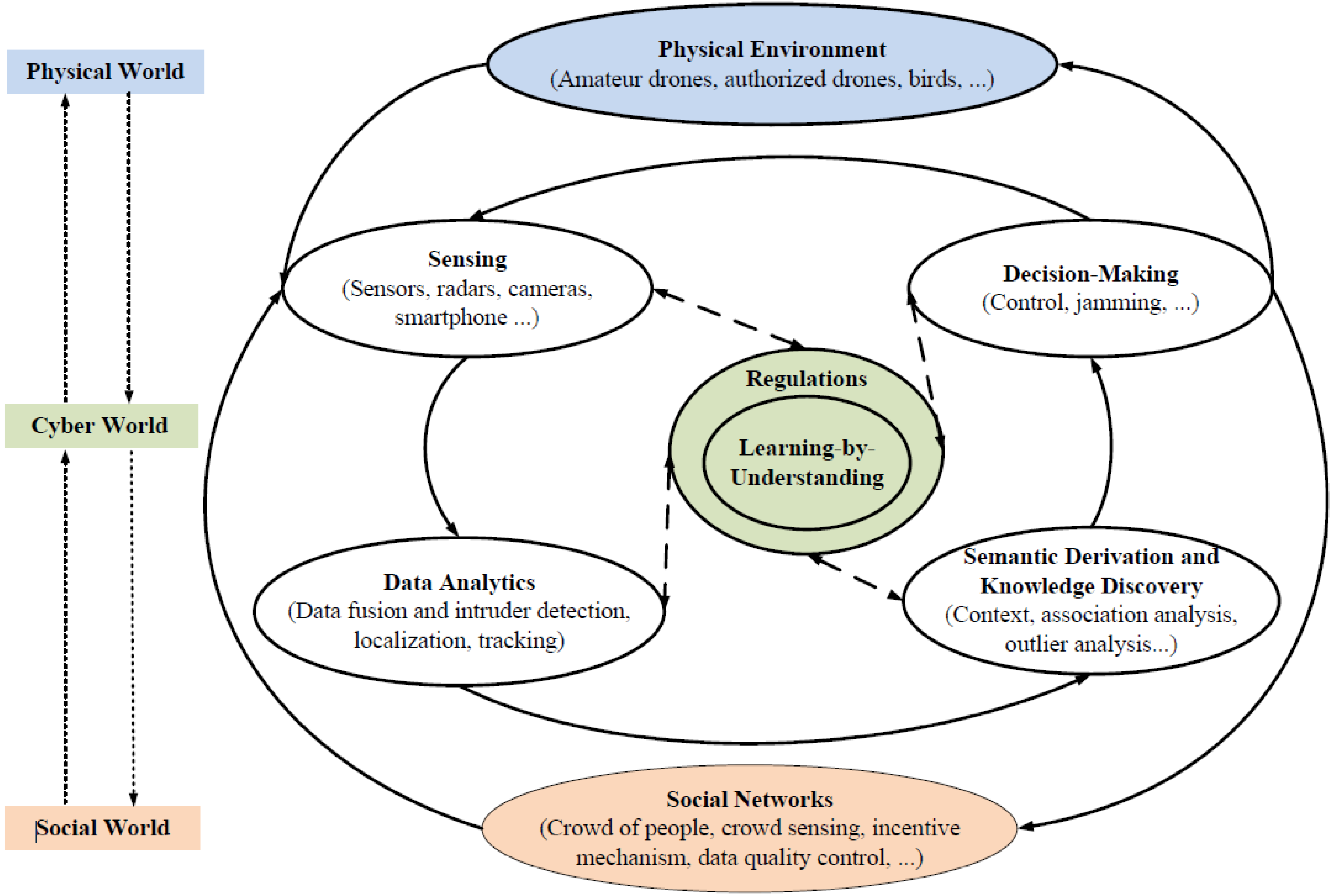
Effectors include a variety of technologies applied to environment or targets. They could be hardkill and softkill interventions such as electronic countermeasures (ECM), jamming, electronic warfare (EW) and its cognitive version, CEW.

For hardkill and softkill, predicting outcomes against threat targets requires comparing COAs and their time lines.

Fleetingness, the fact that actions happen over a very short time, requires anticipating that one countermeasure or missile interception may fail.

Using some prediction techniques helps to build the sequence of actions required to attain a high degree of confidence of successfully intercepting the threatening target(s).

Example of a cognitive socio-sensing system



This system can detect, jam, capture or destroy targets.

With the permission from the authors; Labbé-Ding, 31 July 2018

Finally are CStELs advantageous over systems relying mainly on humans for cognitive tasks?

This is a complicated domain and a difficult question to answer.

With the MBMs developed for analysing and studying a large set of RIMPAC exercise data using substantial simulation runs, the author evaluates what happens when human interventions are mainly executed by AI using hypothesised architecture changes.

Model-based measures (MBMs)

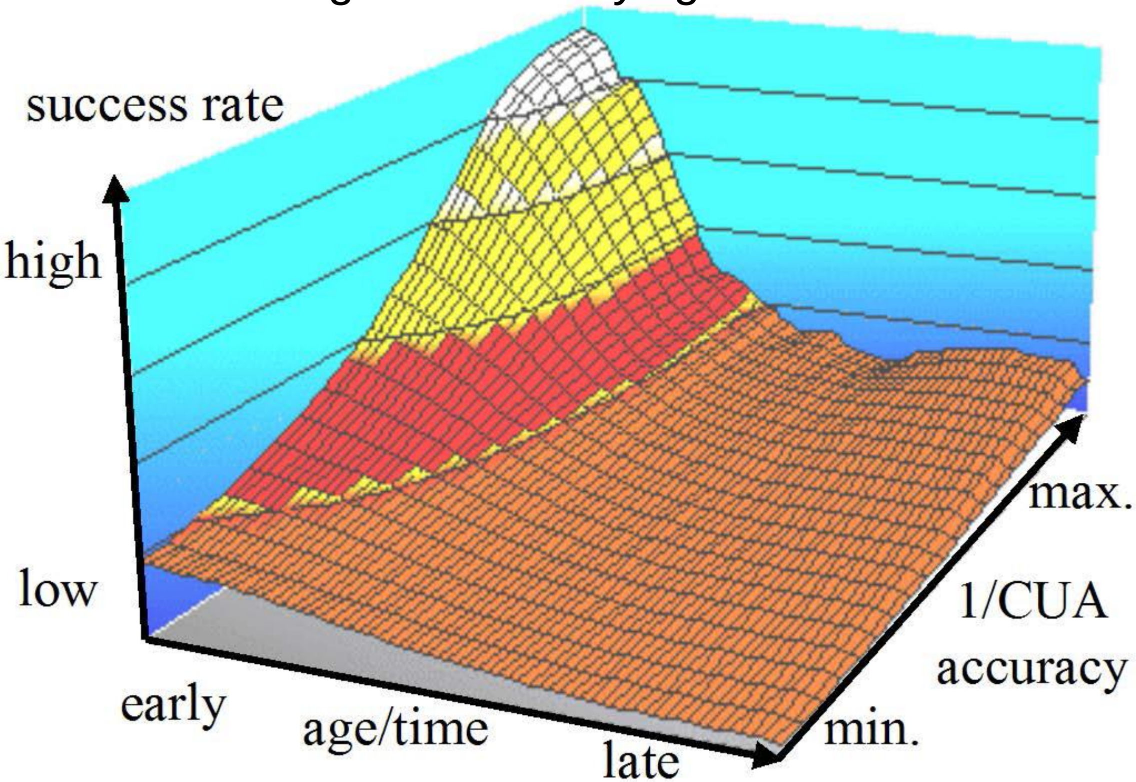
Studies of various architectures of information processing and exchange in support of large coalition preparedness exercises focussing on the outcomes of engagements based on the quality of information provided to decision makers allowed one to develop a general model linking engagement success rate to timeliness and intrinsic positional accuracy of sensors (accuracy is inversely proportional to each circular-uncertainty area (CUA) of a sensor report). These studies showed that the engagement success rates significantly improved as the **high rate of sensor reports is processed more closely to the sensors** because such architectural changes allowed improving the timeliness of tactical actionable information to decision makers and weapon systems.

CStELs being faster move toward the top of the figure

Potential mission success rate as function of input information age and accuracy for a fixed effector's strategy.

Replacing or accelerating the cognitive tasks or functions of the loop as architectural changes, allowed improving the timeliness of tactical actionable information to decision makers and weapon systems, while improving the engagement success rate.

MBM figure for a varying CUA

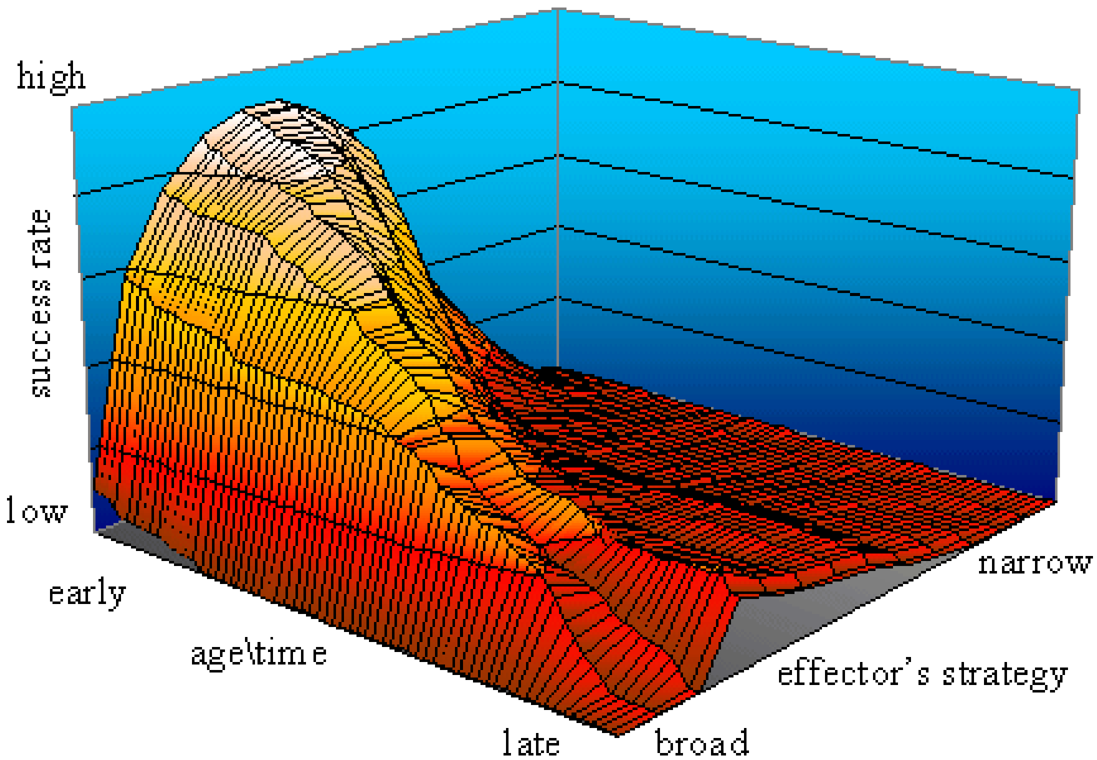


Source Paul Labbé 2002

MBM figure for a varying effector's strategy

Potential mission success rate as a function of input information age and effector's strategy.

This result is difficult to understand. For example, it shows that timeliness is very critical for moving targets. In addition, it shows that very narrow effector strategy requires more accurate targeting data and that an additional effector lock in on target step is required (as for high energy laser, HEL). If the strategy is too broad, the likely collateral damages are unacceptable.



Source Paul Labbé 2002

Cognitive effectors and sensors!

So far the focus was on the loop cognitive tasks, but cognition at both the effector and sensor levels would provide additional advantages over the interception success rates demonstrated.

An example of significant improvement from a sensor with cognition, a cognitive radar (CR) versus a traditional active radar (TAR) using the same signal processing, the Cubature Kalman filter (CKF), for a velocity root-mean-square error (RMSE) of about 7.5 m/s: CR took 0.17 s and TAR 2.4 s, so CR was more than one order of magnitude faster.

Conclusion

FORCEnet studied the effect of accelerating the kill chain. In this paper, 10 years later, the author demonstrated that complementing or replacing some of the human cognitive tasks in sensor-to-shooter loops by competent cognition able AI or expert systems, with or without human supervision, results in a substantial gain in the CStEL (kill chain). In addition, by using cognitive sensors, networks and effectors, one expects to see not only cumulative effects of these cognitive components but likely some multiplicative impacts on successful identification tasks, COAs and interceptions. This is confirmed by MBMs for large exercises (RIMPAC).

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