Cognitive Process Modeling

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Definition(s)…

- From the Oxford English Dictionary:
  - Cognition:

    "The mental action or process of acquiring **knowledge** and **understanding** through **thought**, **experience**, and the senses."

    - Knowledge …. = prior models and data?
    - Understanding … = ability to learn?
    - Thought… = signal processing?
    - Experience…= the process through with more data is acquired?

Cognitive Radar Definition(s)

- Sensors as Robots paradigm:

"As more knowledgeable and proven techniques are obtained, radar systems will begin to function as robots... the final step will be autonomous operation of these sensors under the intelligent robot paradigm."

- Dr. Simon Haykin:
  - Cognitive radar is embodied by 4 key characteristics, inspired by Dr. Fuster's work in cognitive neuroscience
    - The Perception Action Cycle
    - Memor
    - Attention
    - Intelligence

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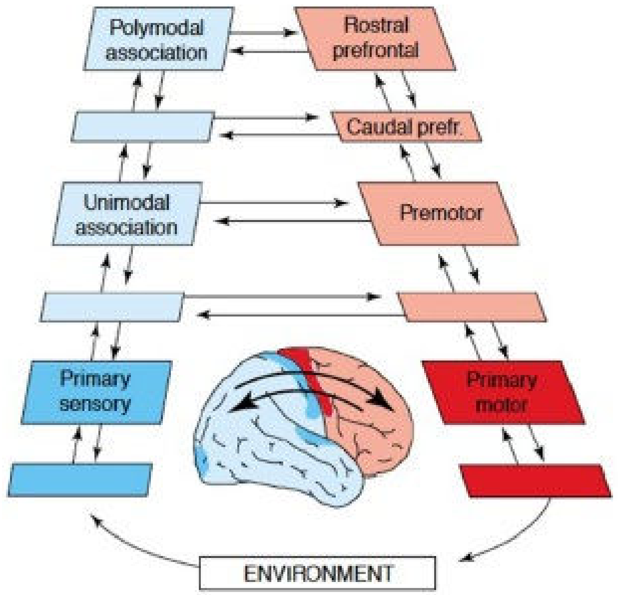
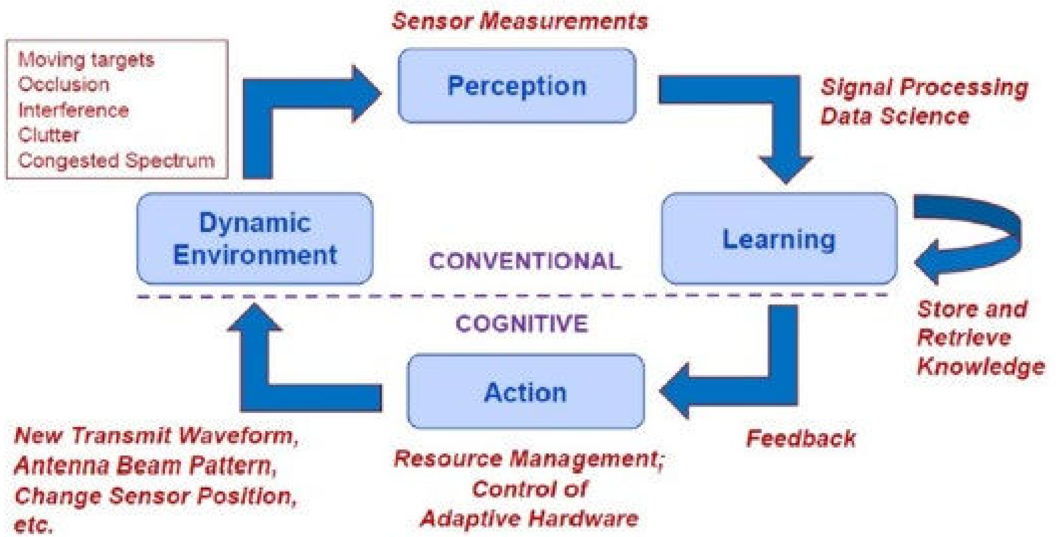
Comparisons with Fuster's Model



Fuster's Perception – Action Cycle for cognitive neuroscience



Perception – Action Cycle for radar remote sensing

Dr. Joaquin Fuster: claimed there were five essential processes: the PAC, attention, memory, intelligence, and **language**

Haykin's Definition

"Cognitive radar (CR), which differs from traditional active radar as well as fore-active radar by virtue of the following capability: The development of rules of behavior in a **self-organized** manner through a process called **learning** from **experience** that results from continued **interactions** with the environment."

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Guerci's Definition

A system that is capable of sensing, learning, and adapting to complex situations with performance approaching or exceeding that achievable by a subject matter expert.

Bell's Definition

While a fully adaptive radar may employ feedback and use prior knowledge stored in memory, a cognitive radar **predicts** the consequences of actions, performs explicit **decision-making**, **learns** from the environment, and uses **memory** to store the learned knowledge.

Charlish's Definition

Cognitive radar is a radar system that acquires knowledge and understanding of its operating environment through online **estimation**, **reasoning**, and **learning** or from databases comprising context information. Cognitive radar then exploits this acquired knowledge and understanding to enhance **information extraction**, **data processing**, and **radar management**.

Farina's Definition

A cognitive radar system follows the four principles of cognition:

The perception-action cycle, memory, attention, and

intelligence.

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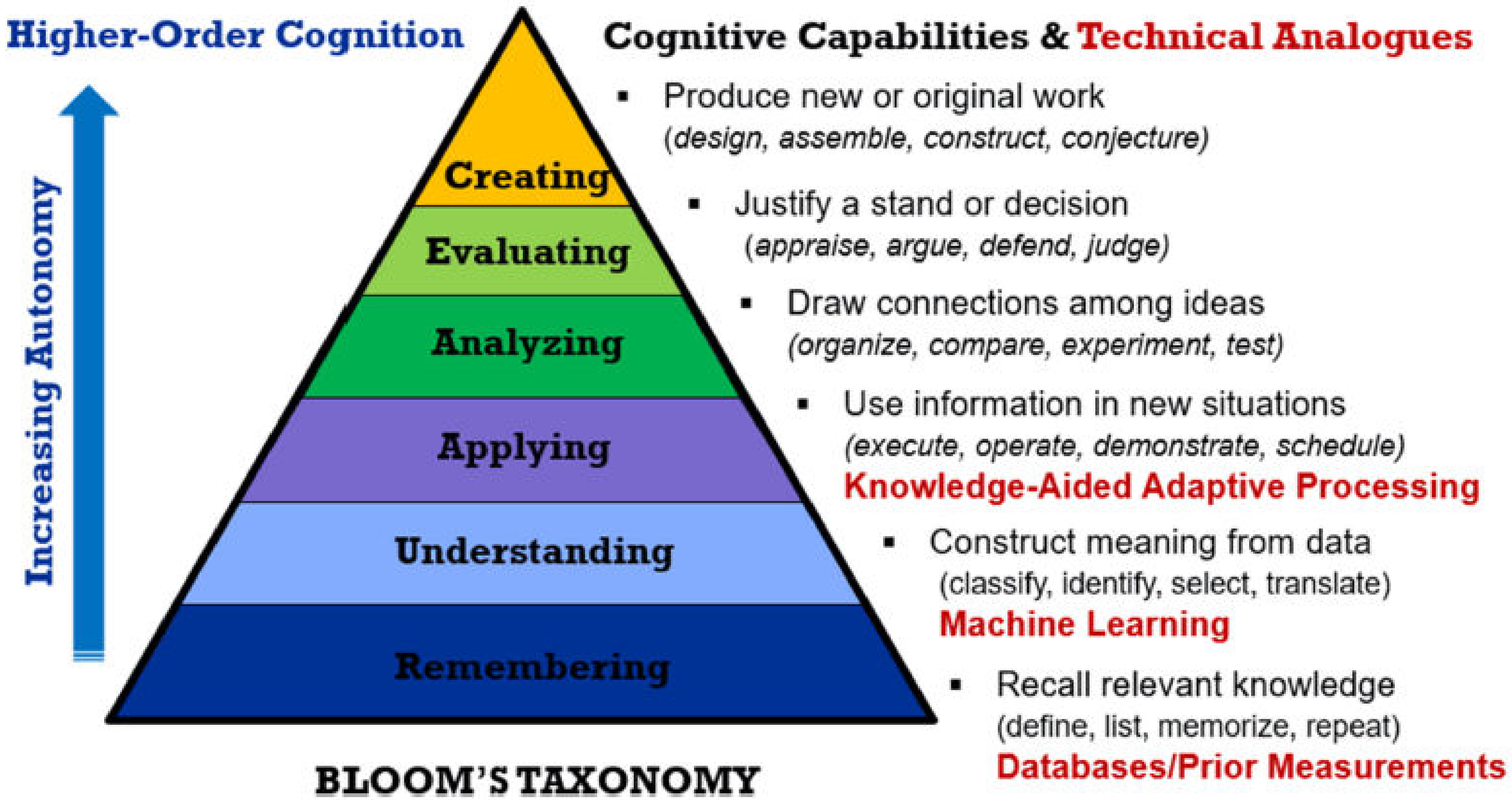
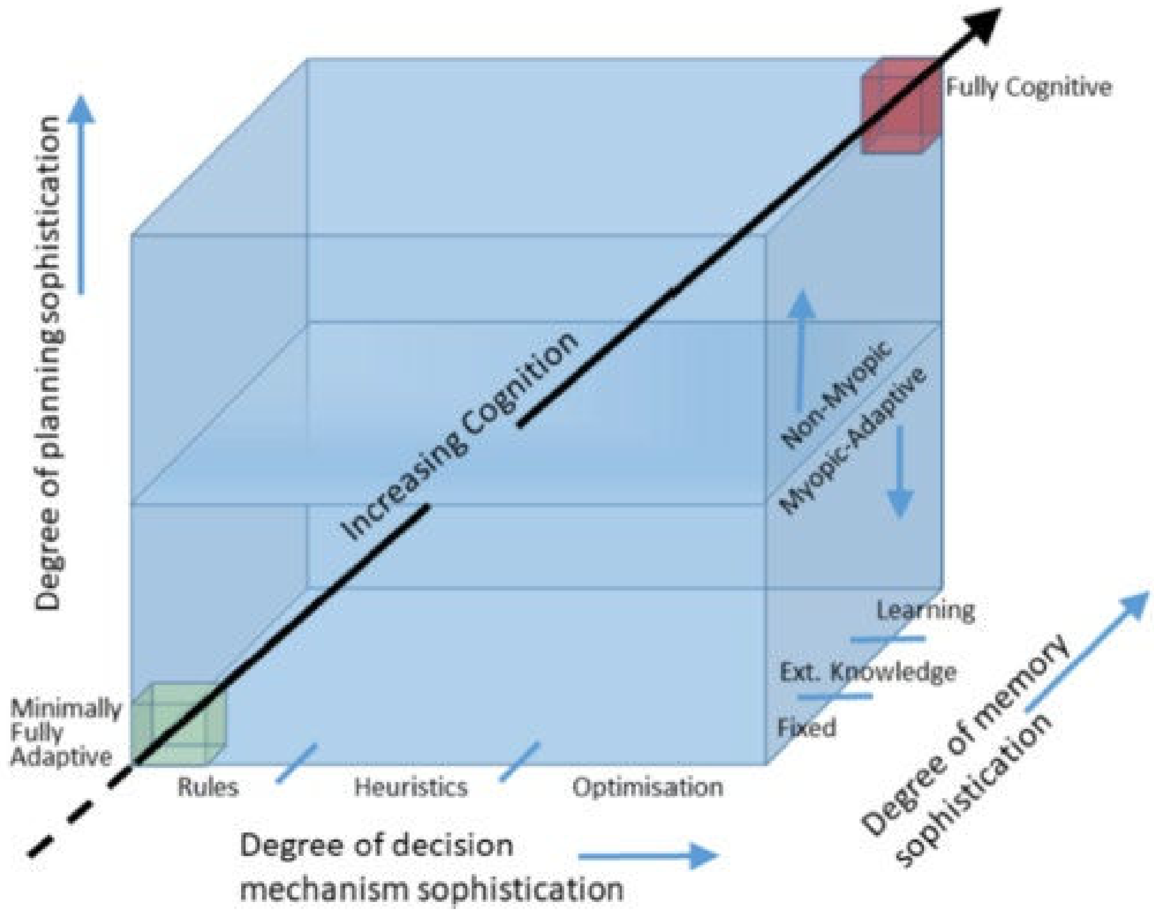
IEEE Standard Radar Definitions 686

A radar system that in some sense displays intelligence, adapting its operation and its processing in response to a changing environment and target scene. In comparison to adaptive radar, cognitive radar learns to adapt operating parameters as well as processing parameters and may do so over extended time periods.

Bloom’s Taxonomy



Griffiths' Levels of Cognition



EDDIE

Proposed Ontology for Cognitive Radar Systems

Colin Horne*, Matthew Ritchie, Hugh Griffiths

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Abstract: Cognitive radar is a rapidly developing area of research with many opportunities for innovation. A significant obstacle to development in this discipline is the absence of a common understanding of what constitutes a cognitive radar. The proposition in this article is that radar systems should not classed as cognitive, or not cognitive, but should be graded by the degree of cognition exhibited. We introduce a new taxonomy framework for cognitive radar against which research, experimental and production systems can be benchmarked, enabling clear communication regarding the level of cognition being discussed.

(PDF available through Semantic Scholar)

Cognitive Processes

Cognitive Processes

Perceptual	Memory	Language	Thinking
Perception generation	Long term	Concepts and Categorisation	Judgement and Decision Making
Attention	Working memory	Processing	Reasoning
Recognition	Learning	Comprehension	Problem Solving
		Production	Anticipation

Objective: Transition cognitive processes performed by the operator into automated processes in the radar system

(Courtesy of Alex Charlish)

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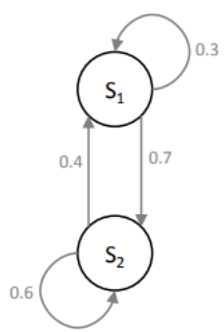
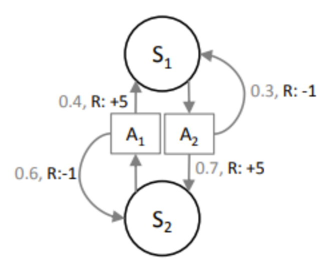
Decision Making

- Markov Decision Processes

Markov Models		Do we have control over the state transitions?	
		No	Yes
Are the states completely observable?	Yes	**Markov Chain**	**Markov Decision Process (MDP)**
	No	**Hidden Markov Model (HMM)**	**Partially Observable Markov Decision Process (POMDP)**
Example of fully observable markov models *(HMM / POMDP analogous)*		 Markov Chain with two states	 MDP with two states and two actions

Observability:

Does agent directly observe state?

OR

Does agent observe state through a sensor which has a measurement model (probability distribution of different observations given underlying state)

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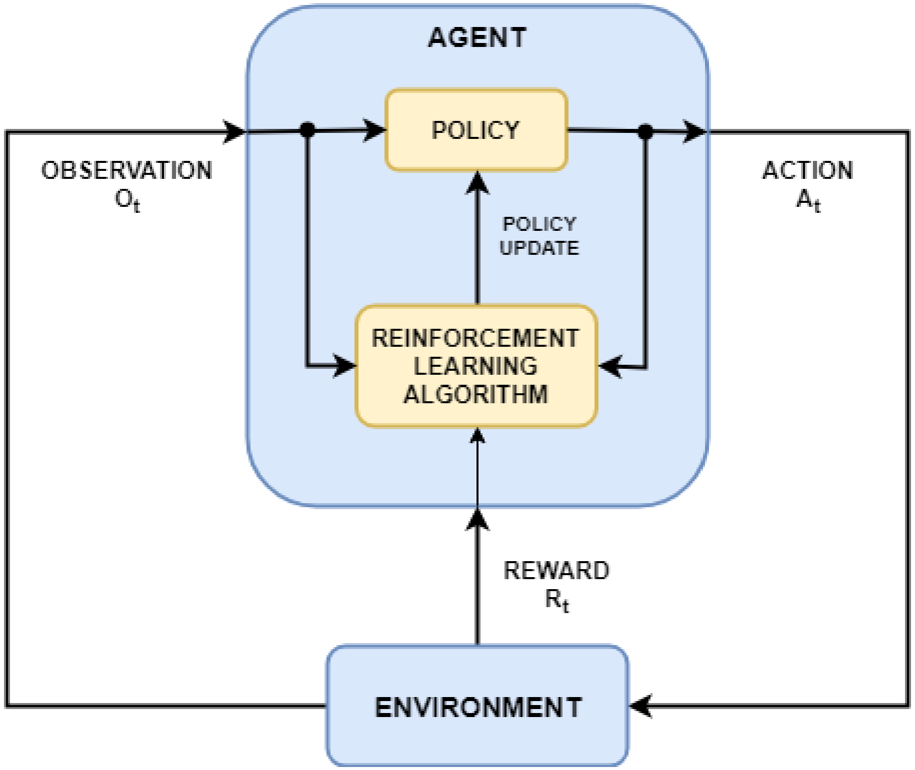
Decision Making

- Reinforcement Learning



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SEAN

Anticipation in Cognitive Radar using Stochastic Control

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***Abstract*—Previous works have identified key characteristics of a cognitive radar, such as knowledge exploitation, perception, action, memory, intelligence and attention. In this work, it is argued that the cognitive characteristic of anticipation can also enhance radar performance. In this paper it is shown that radar management using a partially observable Markov decision process (POMDP) enables the radar to act with anticipation. A method using policy rollout is applied to approximate a POMDP for a target tracking control problem. Through a simulated example it is demonstrated how the anticipative method departs from a purely adaptive approach, and the subsequent improvement in performance is quantified.**

2020 IEEE Radar Conference (RadarConf20)

Implementing Perception-Action Cycles using Stochastic Optimization

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***Abstract*—Cognitive radar problems involve the selection of actions based on the uncertain knowledge of a system state that is partially observed through noisy measurements. This process of sequential decision making under uncertainty can be considered as a stochastic optimization problem. This paper explicitly makes the connection between cognitive radar and stochastic optimization by presenting a framework for describing cognitive radar problems in terms of stochastic optimization, thereby pointing to ways to employ stochastic optimization for designing perception-action cycles in a cognitive radar.**

nities cover techniques and applications such as decision trees, stochastic search, optimal stopping, optimal control, (partially observable) Markov decision processes (MDPs/POMDPs), approximate dynamic programming, reinforcement learning, model predictive control, stochastic programming, ranking and selection, and multiarmed bandit problems. It has been shown [3] that these problems can be described in a single stochastic optimization framework, and the respective solution methodologies can be grouped into just four classes

Cognitive Bias

Challenge: Develop mechanisms that rapidly reach quality decisions in uncertain situations

Consider my decision to **fly** or **drive** to this event:

	Drive		**Fly**	
	Arrive safely	Car Accident	Arrive safely	Plane accident
	(p = 1-1/8000)	*(p = 1/8000)*	(p=1-1/11000000)	(p = 1/11000000)
Utility:	50	0	50	0

Correct decision can be found by expected utility theory:

Drive: 49.99375
Fly: **49.999991**

However, some people are terrified of flying and choose not to fly!

Neglecting Probability Bias:

- Tendency to disregard probability when making decisions
- Value high probability events lower, and low probability events higher (e.g. lottery)

(Courtesy of Alex Charlish)

Cognitive Bias

Cognitive Biases:

- Availability Heuristic - Overestimation of importance of available information
- Bandwagon Effect - Number of other believers influences own decision
- Clustering Illusion - Tendency to see patterns in random events
- Conservatism Bias - Slow acceptance of new information

What does this mean for a cognitive radar system?

Partially Observable Markov Decision Process

Given current knowledge b_t:

$$\arg\max_a R(b_t, a) + E[\boldsymbol{V}^*_{H-t-1}(\boldsymbol{b}_{t+1})|b_t, a]$$

Value Approximation

Given current knowledge b_t:

$$\arg\max_a R(b_t, a) + \boldsymbol{f}(\boldsymbol{b}_{t+1}|\boldsymbol{b}_t, \boldsymbol{a})$$

Key Questions: - Do we copy humans and utilise rough learnt heuristics?
- Or do we prefer computationally intensive yet correct decisions?

Compromise - Performance guarantees for greedy decisions, e.g. submodularity [1]

[1] Krause, Andreas, Ajit Singh, and Carlos Guestrin. "Near-optimal sensor placements in Gaussian processes: Theory, efficient algorithms and empirical studies." *The Journal of Machine Learning Research* 9 (2008): 235-284.

(Courtesy of Alex Charlish)

Concepts and Categories

Challenge: Develop radar behavioural responses based on categories

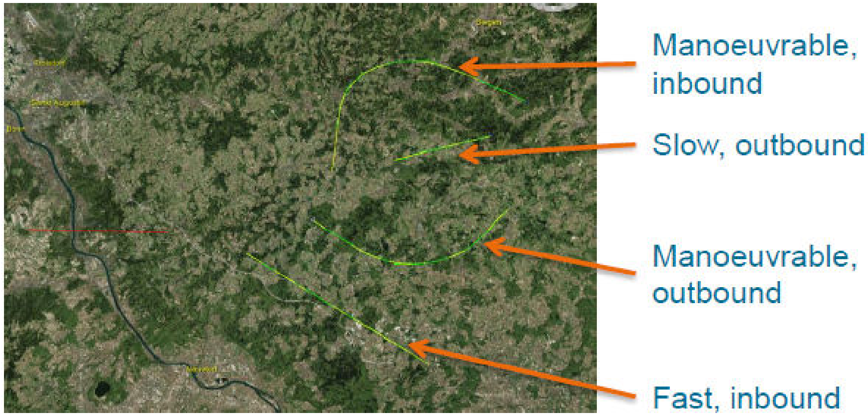
A category is: Set of objects to which the same concept is applicable

Enables set of instances to be treated identically

Example Categories:

- *Friendly, foe, neutral*
- *Threatening, non-threatening*
- *Vehicle type, manoeuvrability*

Idea behind target prioritisation methods *(e.g. fuzzy logic [1])*



Opportunity:
- Concepts and categorisation is applied in higher level information fusion!
- Exploit research conducted in other disciplines

[1] Miranda, S. L. C., Baker, C. J., Woodbridge, K., & Griffiths, H. D. (2007). Fuzzy logic approach for prioritisation of radar tasks and sectors of surveillance in multifunction radar. IET Radar, Sonar & Navigation, 1(2), 131–141.

(Courtesy of Alex Charlish)

Reasoning

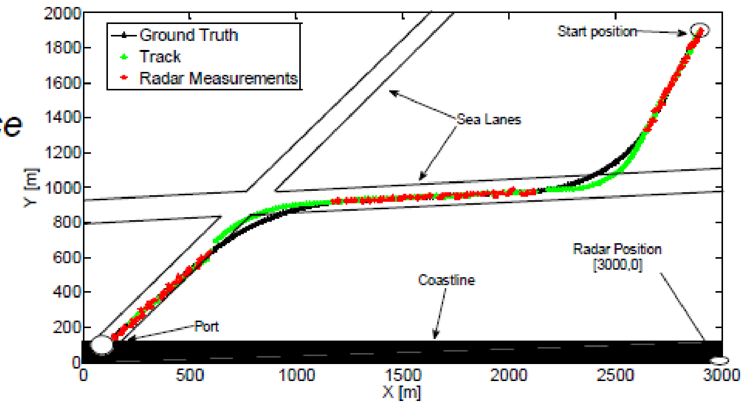
Challenge: Develop new understanding of the situation based on observed data

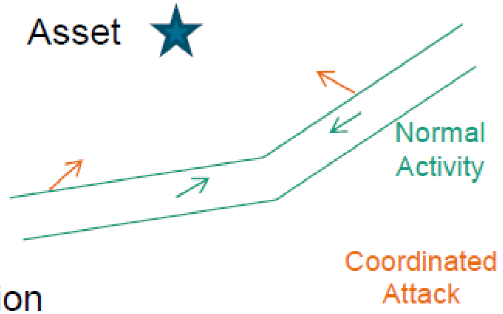
Examples:

- Road network information
  Example of reasoning in a Bayesian inference framework!

- Data drop outs
  *Can reason about target **intent***
  Can exploit 'pattern of life'

- Coordinated attack
  Can reason about anomalous behaviour
  Can reason about coordination of objects





Opportunity: - Reasoning is applied in information fusion
- Exploit research conducted in other disciplines

(Courtesy of Alex Charlish)

DEEPAK

- IntechOpen:
  https://www.intechopen.com/chapters/57862

Home > Books > Topics in Radar Signal Processing

OPEN ACCESS PEER-REVIEWED CHAPTER

Sense Smart, Not Hard: A Layered Cognitive Radar Architecture

WRITTEN BY

Stefan Brüggenwirth, Marcel Warnke, Christian Bräu, Simon Wagner, Tobias Müller, Pascal Marquardt and Fernando Rial

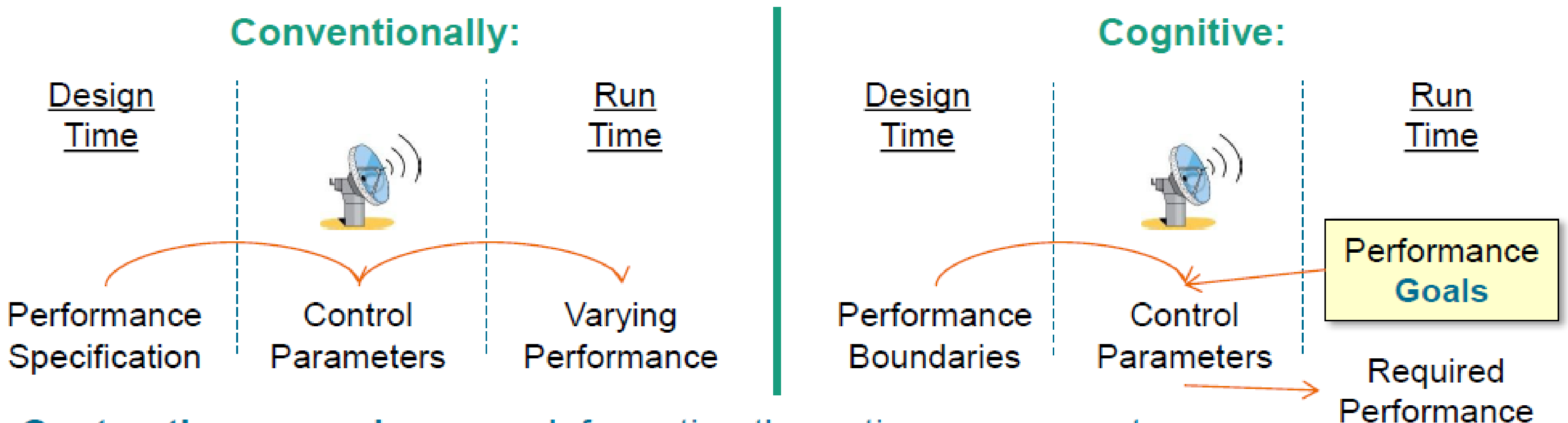
Submitted: June 12th, 2017, Reviewed: September 29th, 2017, Published: May 16th, 2018

DOI: 10.5772/intechopen.71365

Problem Solving

Challenge: Develop automated problem solving

*"a problem exists when a living organism has a **goal** but does not know how this **goal** is to be reached"* [1]



Contrasting example:

Information theoretic management

Maximises information production

Quality of service based management

*Optimises mission orientated quality **goals***

[1] K. Duncker, "On Problem Solving," *Psychological Monographs*, vol. 58, no. 270, pp. 1–113, 1945.

(Courtesy of Alex Charlish)

LADI

Feature Article:

DOI. No. 10.1109/MAES.2019.2957847

The Development From Adaptive to Cognitive Radar Resource Management

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INTRODUCTION

Cognitive radar can be defined as [1]:

A radar system that acquires information, knowledge, and understanding *about its operating environment through online estimation, reasoning and learning, or from datasets comprising context. A cognitive radar then exploits the acquired information, knowledge, and under-*

effective control of the transmitter degrees of freedom, thus unlocking the full potential of the system. Management becomes even more crucial for the current trend of multifunction RF systems, as the additional functions place additional demands on the shared resources. Since radar resource management techniques have implemented perception-action cycles for many decades, it is a topic that is very closely related to cognitive radar.

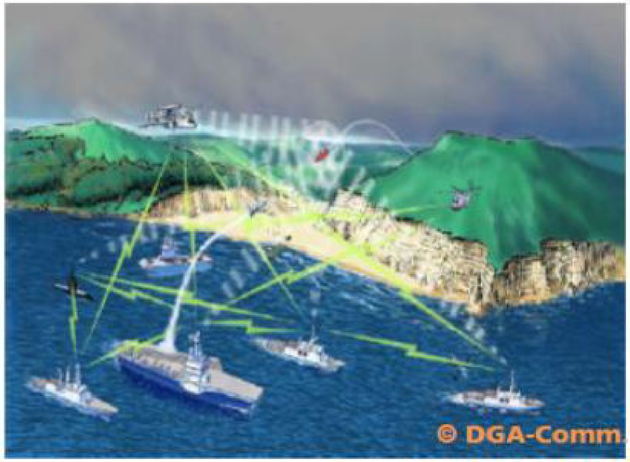
Language

Communication Capability

- Communication with other sensors and platforms
  Coordinate with other platforms
- Interface to the operator

Role in Human Cognition

- Strong: Language is conceptually necessary for thought
- Weak: Language is necessary for the acquisition of concepts



Example [1]

- Knowledge of radar emissions is represented by a stochastic context free grammar
- Radar pulses are mapped into symbols and processed with inference engine to estimate system state and system parameters

What is the role of language production, processing and comprehension for cognitive radar?

(Courtesy of Alex Charlish)

EMRE

1106 IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 56, NO. 3, MARCH 2008

Signal Interpretation of Multifunction Radars: Modeling and Statistical Signal Processing With Stochastic Context Free Grammar

Alex Wang and Vikram Krishnamurthy, *Fellow, IEEE*

***Abstract*—Multifunction radars (MFRs) are sophisticated sensors with complex dynamical modes that are widely used in surveillance and tracking. Because of their agility, a new solution to the interpretation of radar signal is critical to aircraft survivability and successful mission completion. The MFRs' three main characteristics that make their signal interpretation challenging are: i) MFRs' behavior is mission dependent, that is, selection of different radar tasks in similar tactic environment given different policies of operation; ii) MFRs' control mechanism is hierarchical and their top level commands often require symbolic representation; and iii) MFRs are event driven and difference and differential equations are often not adequate. Our approach to overcome these challenges is to employ knowledge-based statistical**

threats. The electronic support algorithm described in this paper considers the self protection of the target from radar threats, and a major component of which is the interpretation of the intercepted radar pulses in terms of the possible radar modes, such as "search" and "track maintenance." In the current problem setup, because we focus on the target perspective, the radar model is simplified by removing its multiple target tracking capability, and we limit the scenario to having only one multifunction radar in the proximity of the target.

In building electronic support systems to analyze radar signals, statistical pattern recognition has been used extensively.