EE3-27: Principles of Classical and Modern Radar

Passive, UWB, Cognitive and SAR Radar

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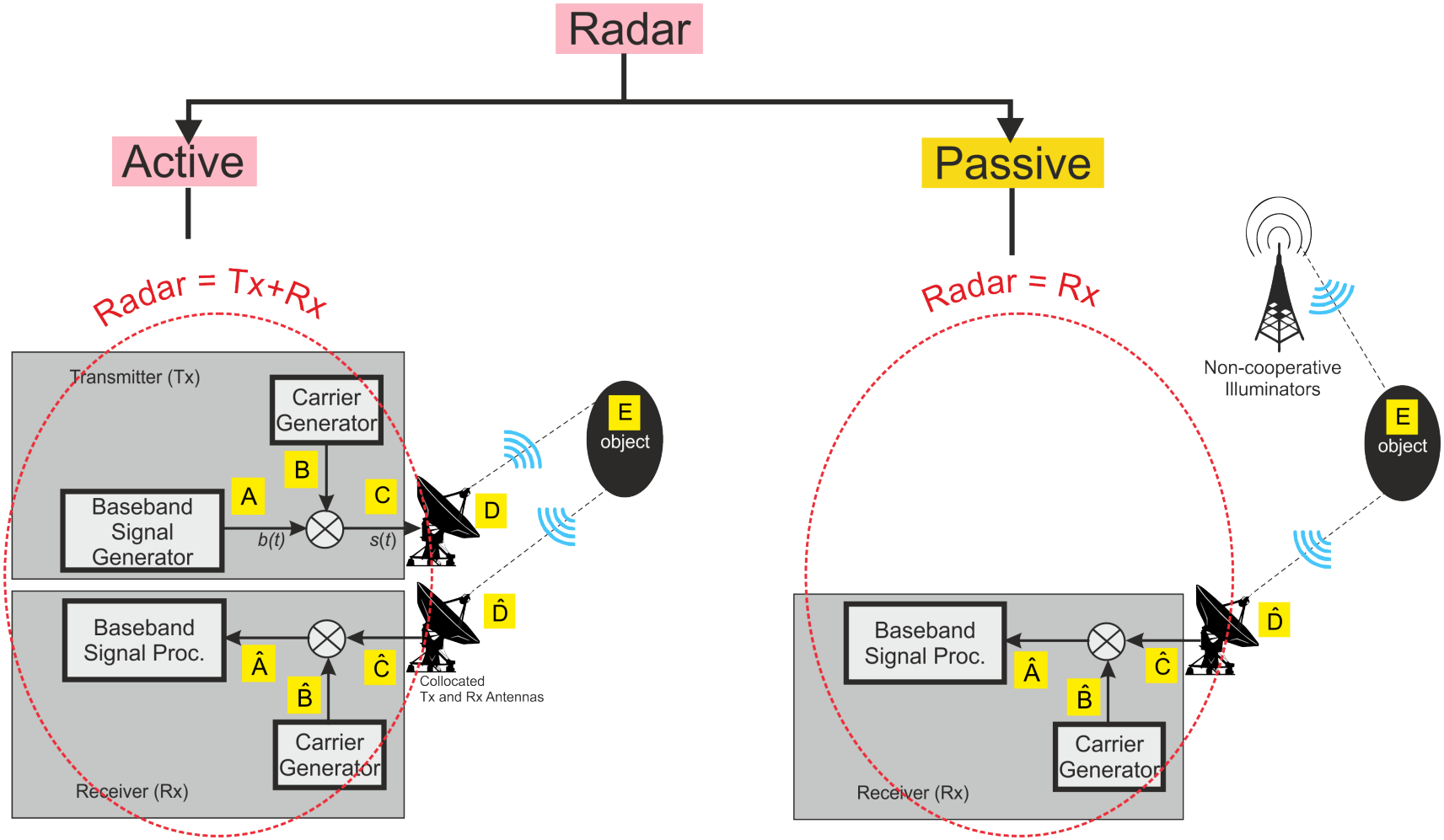
Passive Radar - Introduction

- we have seen in Topic 1 that radar can be classified as follows



- here we will focus to Passive Radar

Passive Radar - "To see without being seen"

- Unlike active systems, passive radar does not emit any waves of its own
- It offers a decisive operational advantage:
  - it cannot be located.
  - it cannot be jammed.
- Passive radar requires a whole lot of sophisticated signal processing software.
- "See without being seen" scenarios
- Passive Radar sensor fusion with active radars
- Detect emitting and non-emitting targets

Estimate?

  - In the case of non-emitting targets, it is possible to use other transmissions that just happen to be there. These are known as illuminators of opportunity.
  - Such transmissions may be
    - ★ other radars, or
    - ★ they may be communications, broadcast or navigation signals.

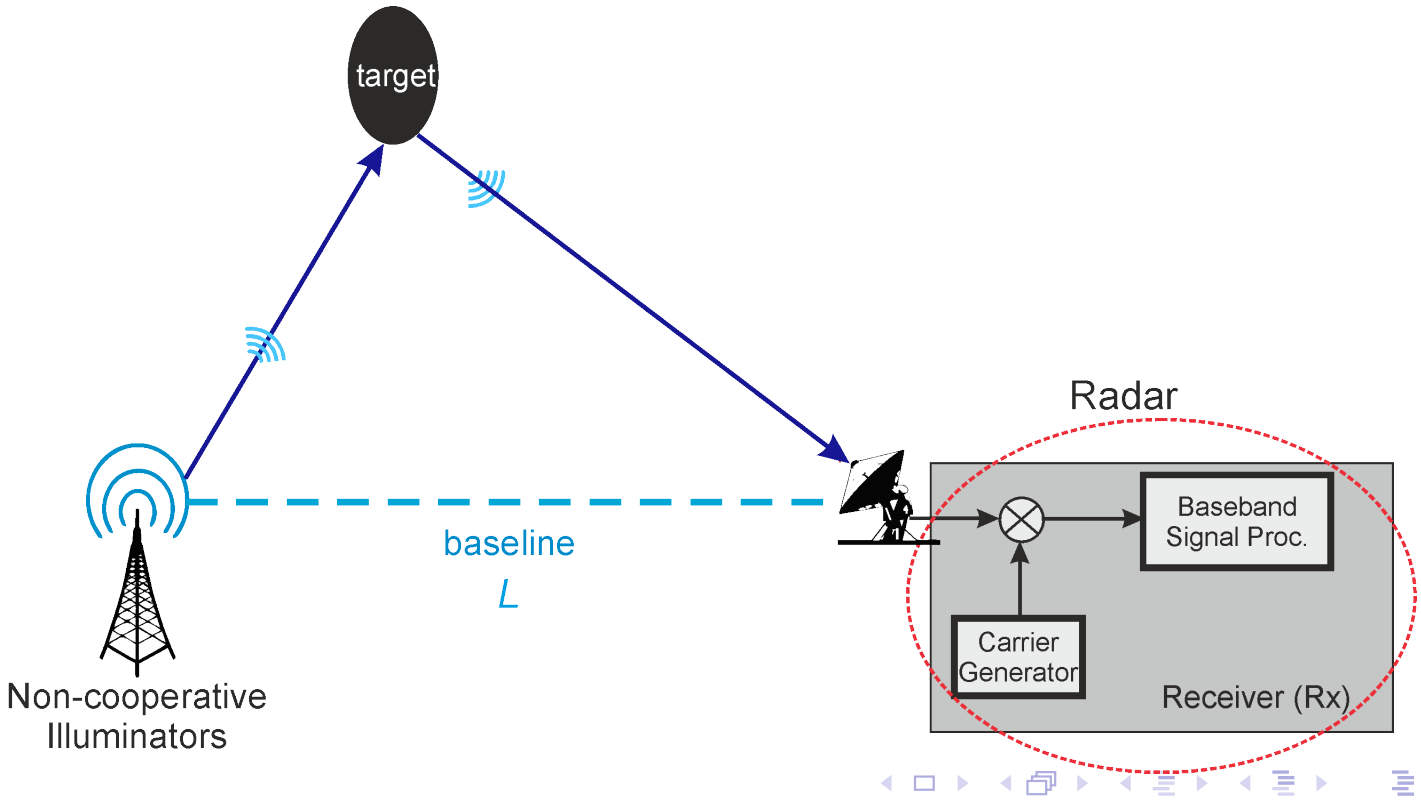
- In these days of spectral congestion there are more and more such transmissions (illuminators of opportunity), e.g. TV signals, mobile comms, DAB/DVB/T. The main advantages are:
  - they are often high-power and favourably sited.
  - allow use of parts of the spectrum (VHF, UHF, ...) that are not normally available for radar purposes - where there may be a counter-stealth advantage (in addition to the potential counter-stealth advantage that comes from the bistatic geometry)
  - no transmitting licence is needed, and
  - the radar is potentially completely covert, so countermeasures against it may be very difficult.

Examples (Illuminators)

- FM radio – To detect large aircraft at a distance of up to 200 km.
- DAB/DVB-T – Up to a distance of approximately 40 km, small aircraft can be detected with an error margin of just 20 m.

Passive Bistatic Radar

- Passive Radar based on illuminators of opportunity, is sometimes known as
  - passive bistatic radar (PBR),
  - hitchhiking,
  - parasitic radar or
  - passive coherent location (PCL)



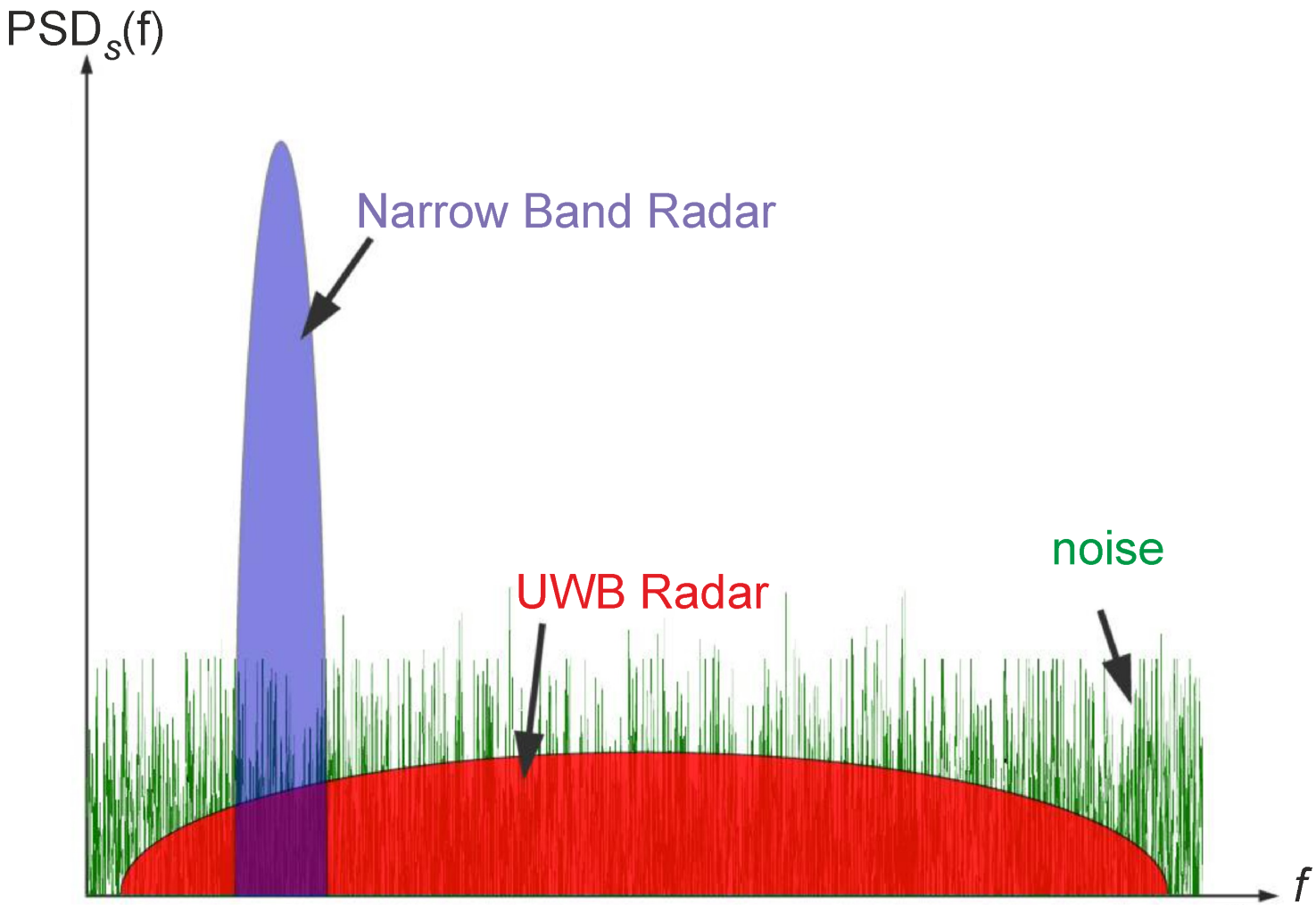
UWB Radar

- Ultra Wide-band (UWB) radar systems transmit signals across a much wider frequency spectrum than conventional radar systems

- UWB Radar signals are usually very difficult to detect.
  - The transmitted UWB signals have a power spectrum which is lower than the allowed unintentional radiated emissions for electronics and the noise.

- UWB pulse radar transmit pulses with very short durations - less than 1 nanosecond).
  - The spectrum of a very narrow-width pulse has a very large frequency spectrum approaching that of white noise as the pulse becomes narrower and narrower. These very short pulses need a wider receiver bandwidth than conventional radar systems.

UWB Radar (cont.)



Summary

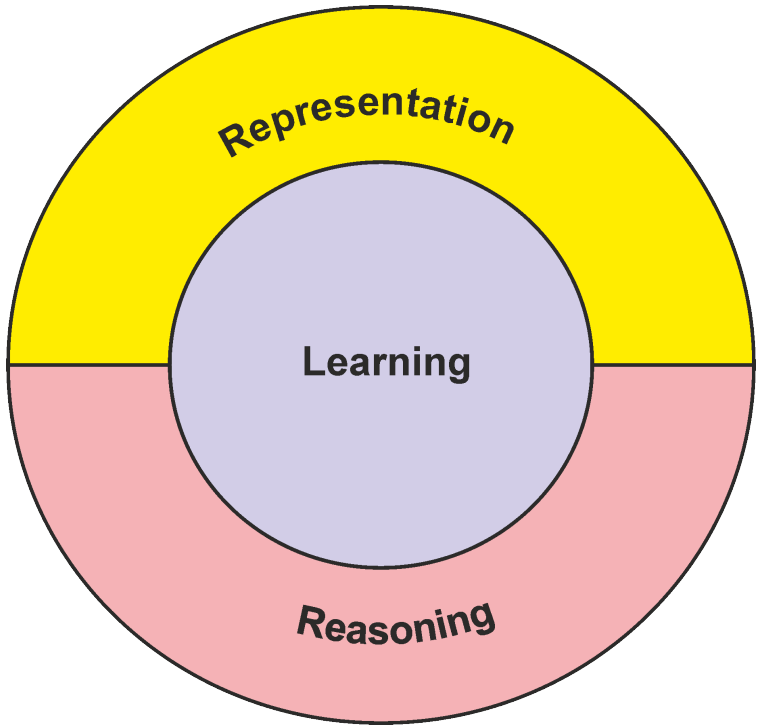
- The amount of spectrum occupied by a signal transmitted by a UWB-radar (i.e., the bandwidth of the UWB signal) is at least 25 percent of the center frequency.
  - Thus, a UWB signal centered at 2 GHz would have a minimum bandwidth of 500 MHz and the minimum bandwidth of a UWB signal centered at 4 GHz would be 1 GHz.
  - Often the absolute bandwidth is larger than 1 GHz.
- Whether this radar is transmitting or not cannot be determined by measurement from the outside of the radar as its transmit pulses do not differ from environmental noise.
- The theory described in this course is also applied to UWB radar. However, the hardware required is more expensive than non-UWB radar systems.

Cognitive Radar

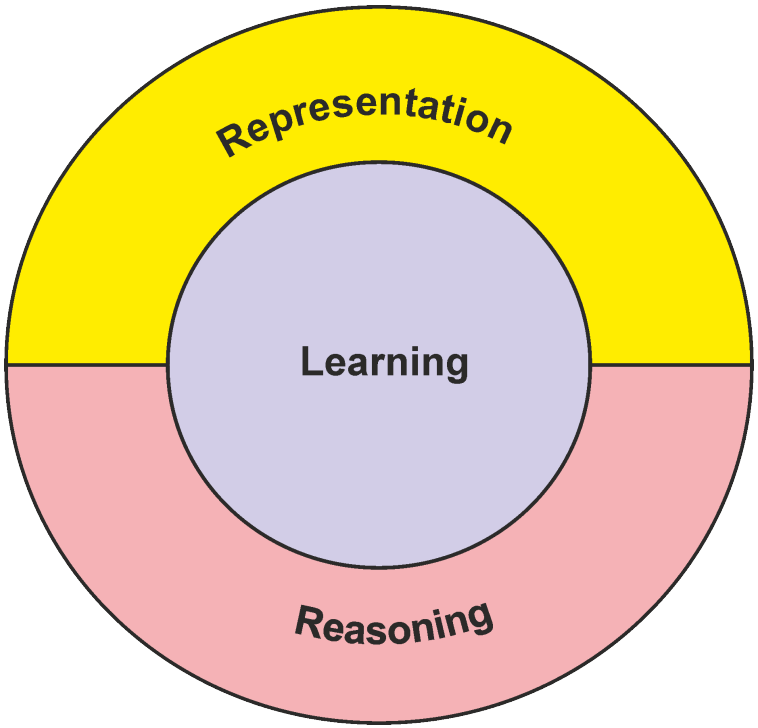
Definition (AI)

It is the development of paradigms or algorithms that require machines to perform cognitive tasks, at which humans are currently better

- AI's three key components

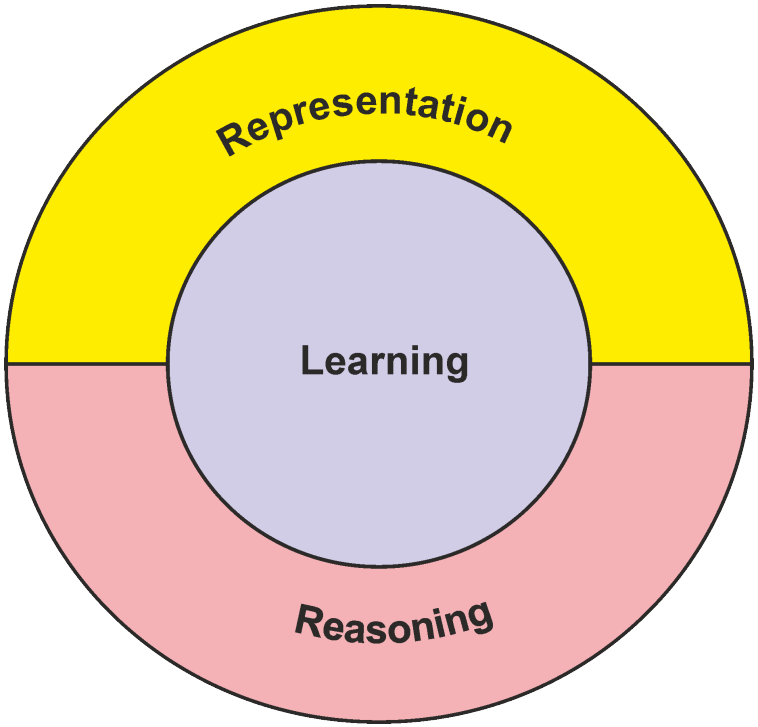


Description of AI's Three Key Components

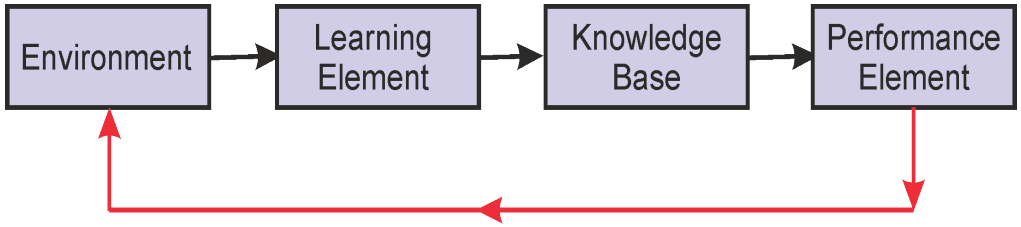


- Representation: use of a language of symbol structures to represent both general knowledge about a problem domain of interest and specific knowledge about the solution to the problem;
- Reasoning: is the ability to solve problems.
  - Problem solving may be viewed as a searching problem. A common way to deal with search is to use
    - ★ rules,
    - ★ data, and
    - ★ control (Nilsson, 1980).
  - The rules operate on the data, and the control operates on the rules.

Description of AI's Three Key Components (cont.)



- Learning: In the simple model of machine learning is shown below



  - the environment supplied some information to a learning element.
  - The learning element uses this information to make improvements in a knowledge base, and finally
  - the performance element use the knowledge base to perform its task.

Cognition and Cognitive Radar Definitions

Definition (National Institute of Mental Health)

- Cognition: conscious mental activity that informs a person about his or her environment. Cognitive actions include
  - perceiving,
  - thinking,
  - reasoning,
  - judging,
  - problem solving
  - remembering.

Definition (Cognitive Radar)

is an intelligent system that is aware of its surrounding environment (i.e., outside world), uses prior knowledge as well as learning through continuing interactions with the environment, and thereby adapts both its Rx and Tx in response to statistical variations in the environment in real-time so as to meet specific remote sensing objectives in an efficient, reliable, and robust manner

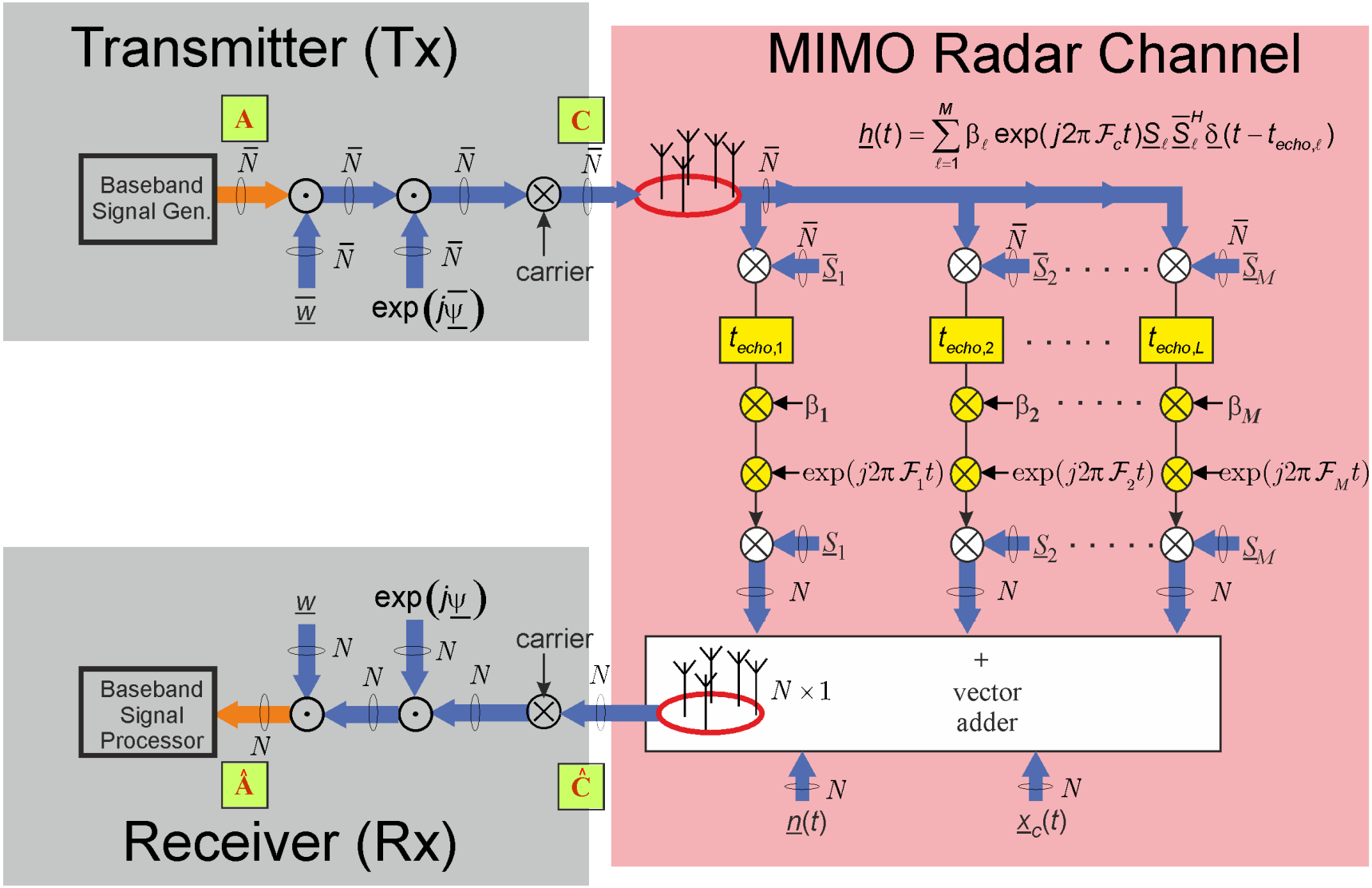
Biological Cognitive Properties vs Cognitive Radars

Biological Cognitive Properties vs Cognitive Radars	
Cognitive Actions	**Cognitive Radar Equivalent**
Perceiving	Sensing
thinking, reasoning, judging, problem solving	Expert systems Adaptive Algorithms and Computation
remembering	Memory, Environmental Databases

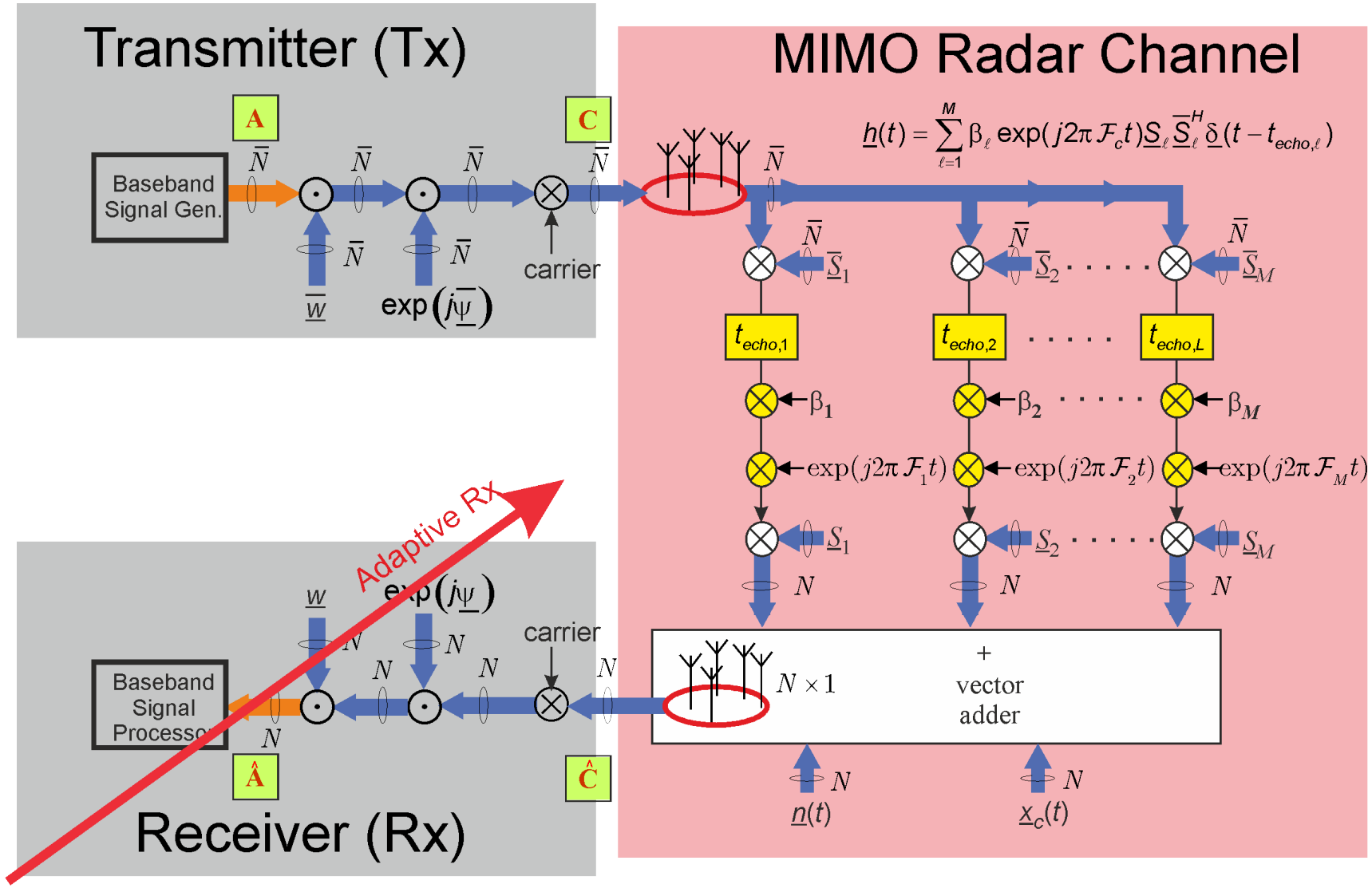
- e.g.: in cognitive MIMO radar, Tx signal auto-correlation matrix is adaptively optimized.

Basics of Cognitive Radar vs Classical MIMO Radar

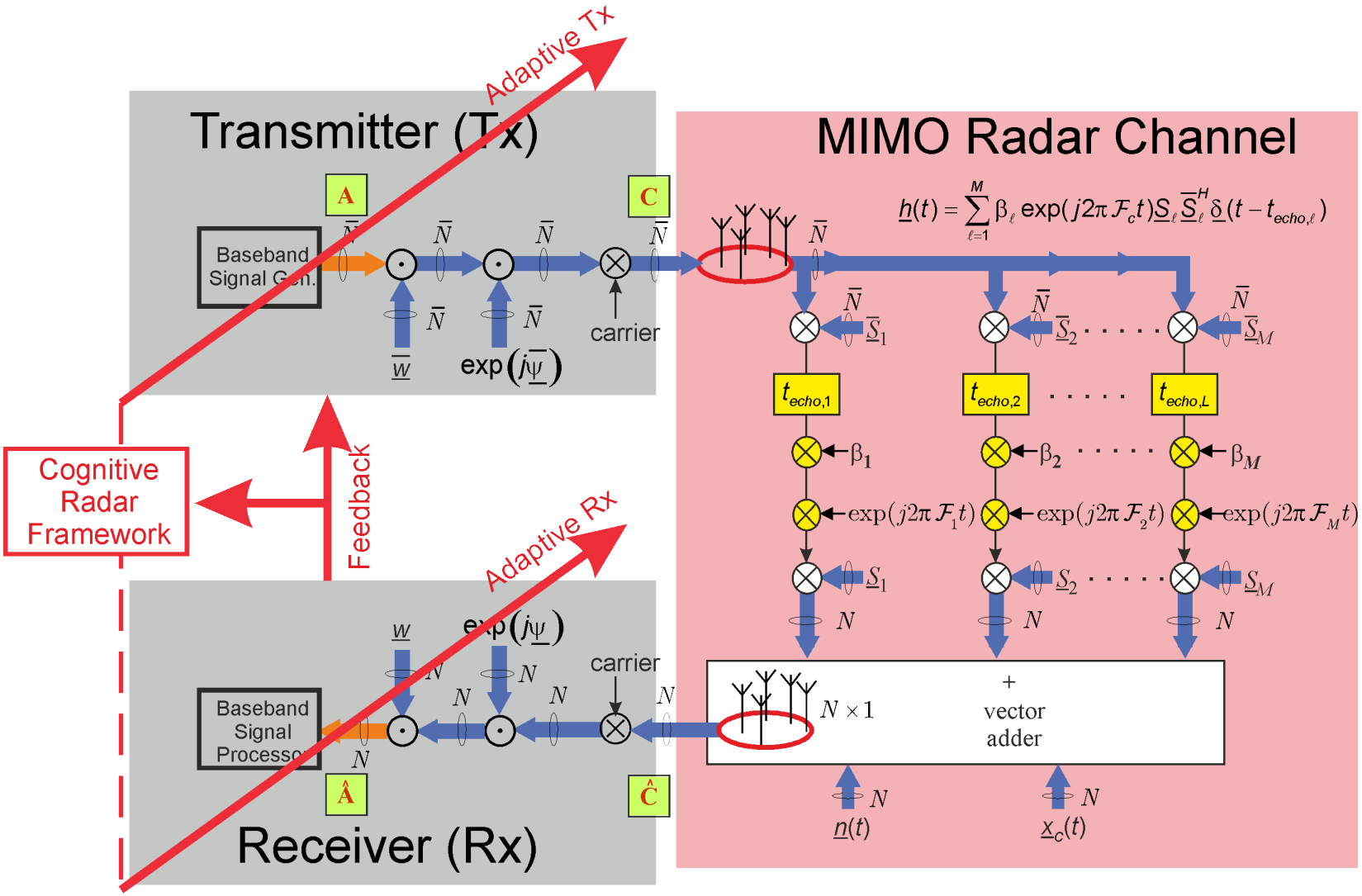
Classical MIMO Radar



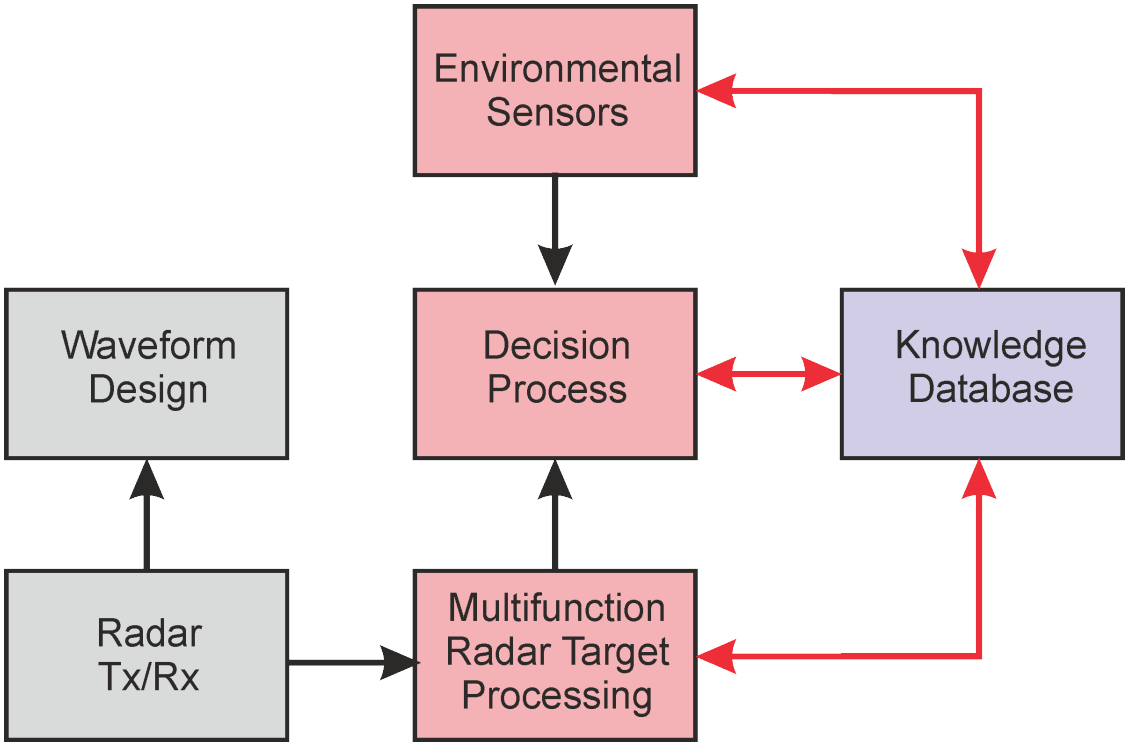
Adaptive MIMO Radar



Cognitive MIMO Radar



General Cognitive Radar Framework

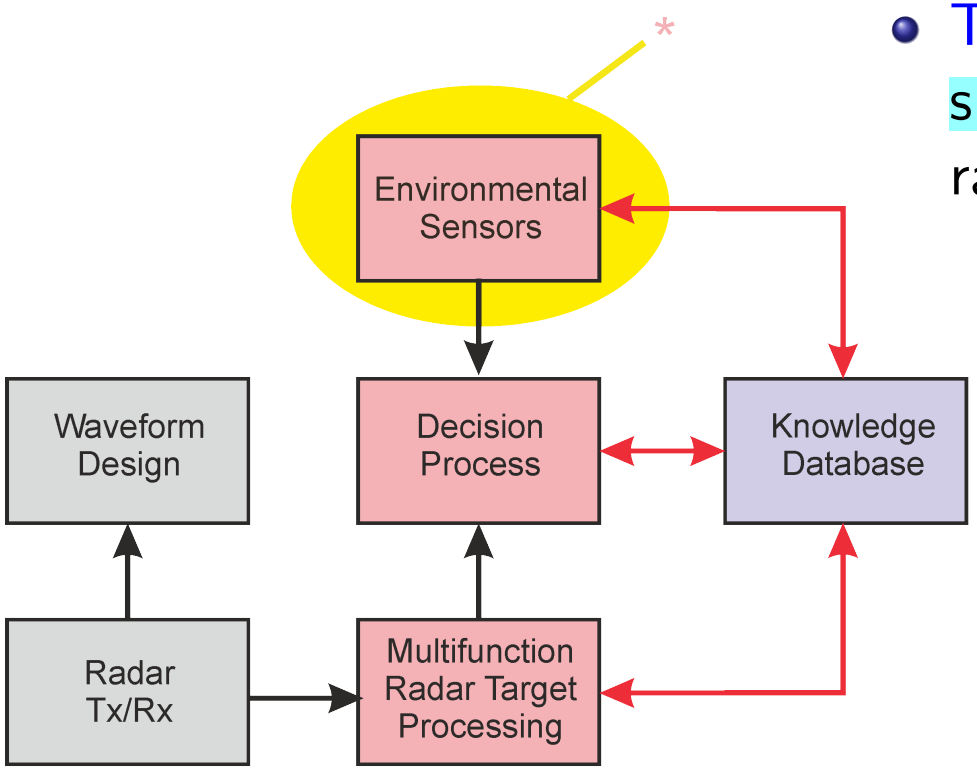


- The knowledge of the environment is achieved through the use of components, such as radar Tx, radar Tx, and environmental sensors.

Riat Abad, et al, "Basic Understanding of Cognitive Radar", *IEEE ANDESCON Conference*, 2016

General Cognitive Radar Framework (cont.)

The environmental sensors

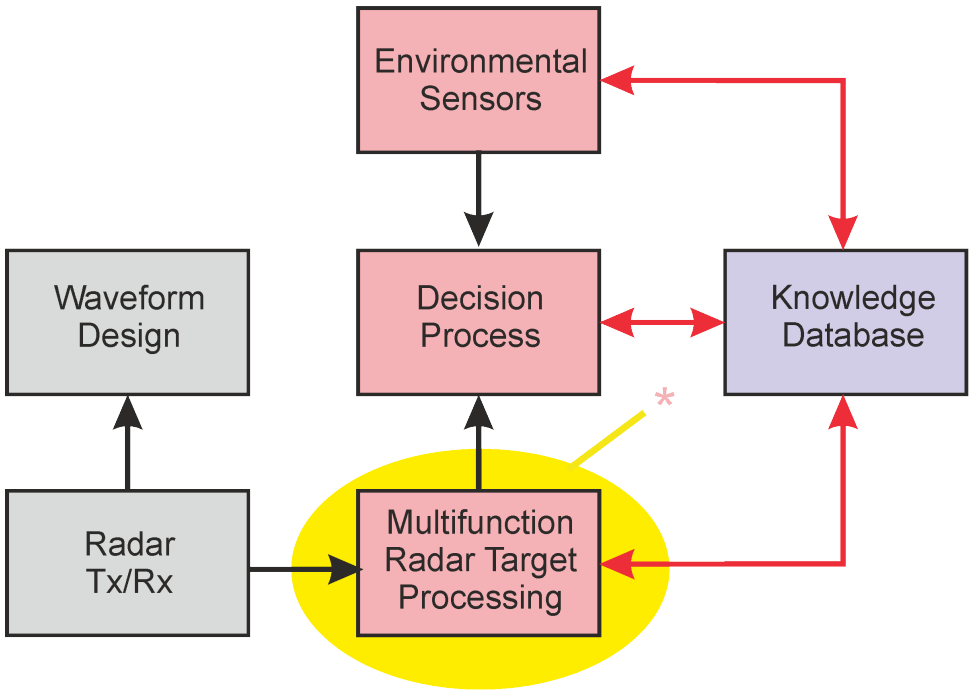


- The environmental sensors: provide supplemental information to enhance radar's performance;
  - the environmental sensors are not used for target detection. The radar Rx and Tx are used for target detection, and use reconfigurable hardware.
  - The reconfigurable hardware supports the Tx and Rx of adaptable waveforms $\underline{b}(t)$, and the architecture needed for a multifunction radar approach.

[0]Note on Digital Hardware: A cognitive radar require usually a hardware architecture with reconfigurable components, e.g., replacing a single filter with a filter bank that is reconfigurable to match a known sensing scenario.

General Cognitive Radar Framework (cont.)

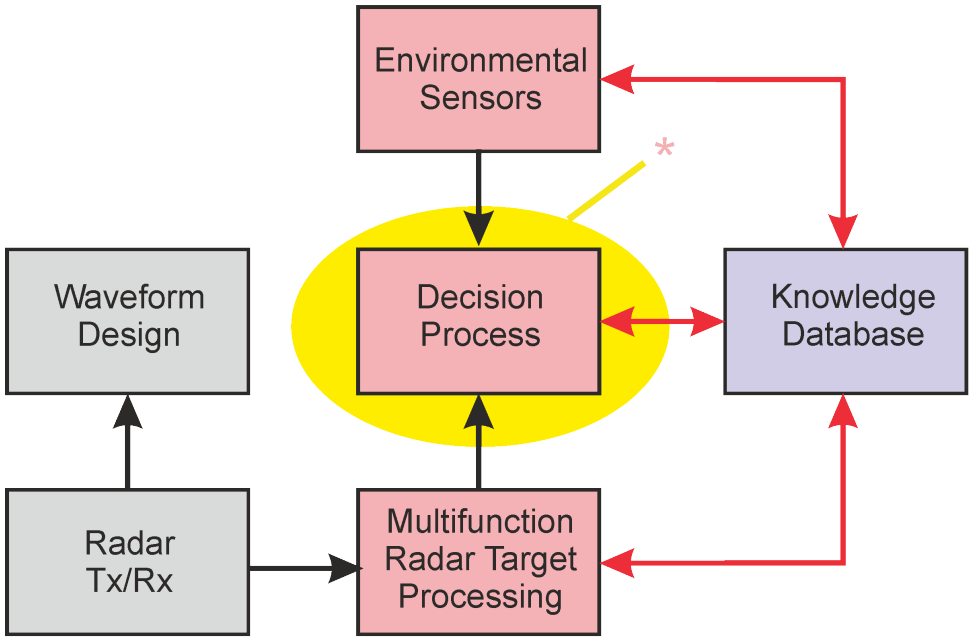
The multifunction radar



- The multifunction radar: it uses multiple radar functions to process the target information, (in order to achieve a better understanding of the targets and their environment)
- The target information is then sent to the decision process.

General Cognitive Radar Framework (cont.)

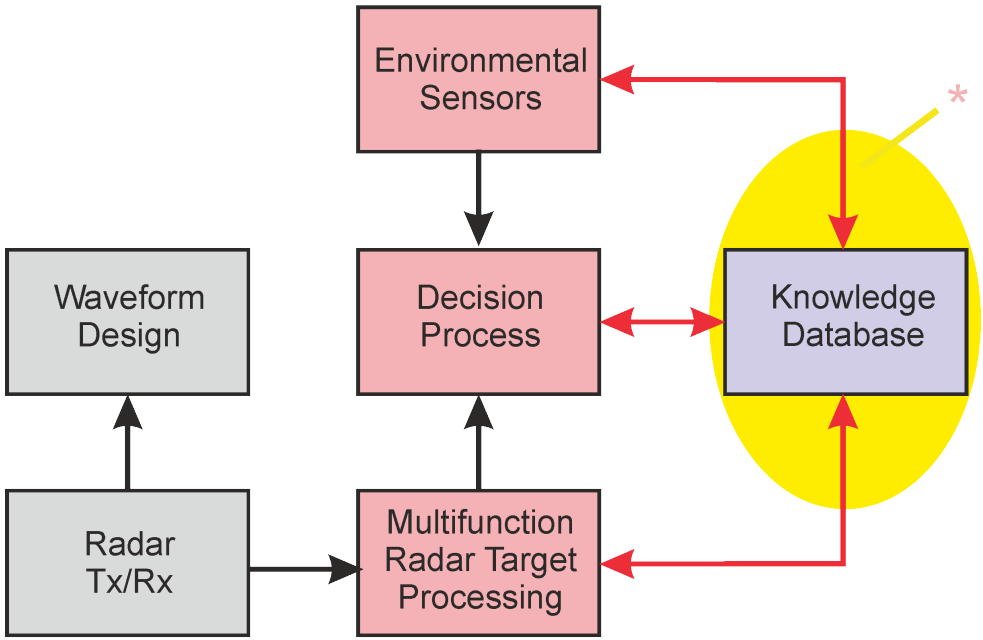
The decision process



- The decision process: consists of a variety of functions.
- It requires digital hardware and memory sufficient for real-time processing.
- It uses decision theoretic and learning algorithms, which process previous and present target information using multiple radar functions, such as the knowledge database and memory.

General Cognitive Radar Framework (cont.)

Knowledge database



- knowledge database and memory: store the features that are known a priori (or estimated using the processing algorithms).
  - For example, position and velocity features are used for the moving target indication radar function.
- The features are sent to the process for target assessment.

Synthetic Aperture Radar (SAR)

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Alberto Moreira, et al, "A Tutorial on Synthetic Aperture Radar", *IEEE Geoscience and Remote Sensing Magazine*, pp.6-43, March 2013.

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