

Cognitive Energy Systems

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1. Preliminary Remarks

- **In dealing with the Smart Grid, the current paradigm is summarized in four words:**

Sense, Communicate, Compute, and Control

This paradigm is limited in scope.

- **In my view, given the ever-expanding power of the computer, a more compelling vision, motivated by the visual brain, is summarized in four new words:**

Perception, Memory, Attention, and Intelligence

Predictive Article¹

“I see the emergence of a new discipline, called Cognitive Dynamic Systems, which builds on ideas in statistical signal processing, stochastic control, and information theory, and weaves those well-developed ideas into new ones drawn from neuroscience, statistical learning theory, and game theory. The discipline will provide principled tools for the design and development of a new generation of wireless dynamic systems exemplified by cognitive radio and cognitive radar with efficiency, effectiveness, and robustness as the hallmarks of performance”.

1. Simon Haykin, “Cognitive Dynamic Systems”, Proc. IEEE, Point of View article, November 2006.

Beyond Cognitive Dynamic Wireless Systems

- **The 2006 article emphasized Cognitive Radio and cognitive Radar as examples of cognitive Dynamic Systems.**
- **Both Cognitive Radio and Cognitive Radar are now practical realities, providing the inspiration for other applications.**
- **Equally, modern energy systems may benefit from cognition.**

2. The Four Basics of Cognition

The perception-action cycle

Memory

Attention

Intelligence

The Perception-Action Cycle

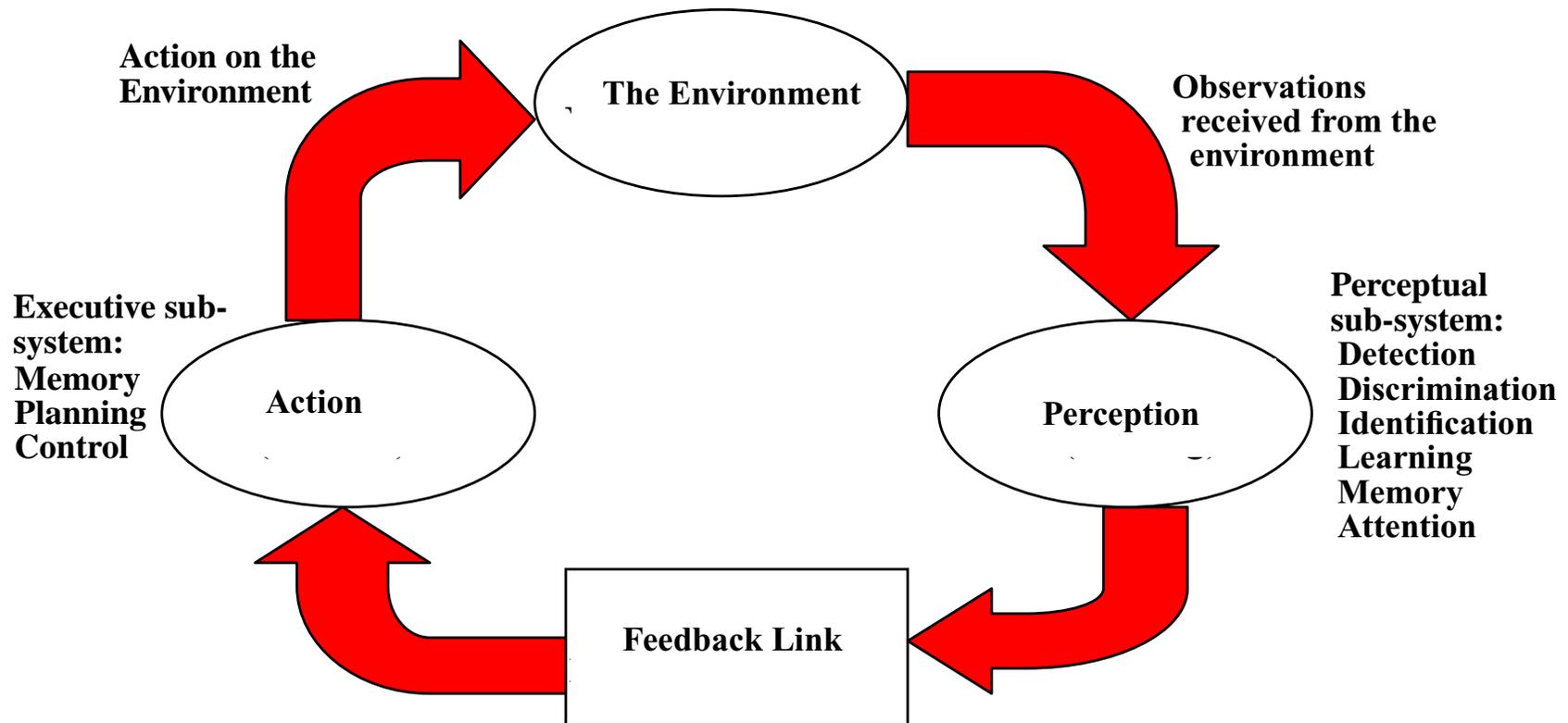


Figure 1: Graphical representation of what the visual brain performs in its most basic form

The function of perception-action cycle is to provide for information about the environment, gained through processing of incoming observations from one cycle to the next.

Memory

- ***Perceptual memory***, learning from incoming *observations* of the environment via reciprocal coupling with model of the environment.
- ***Executive memory***, learning from actions on the environment through reciprocal coupling with *library* of potentially useful actions.
- **Working memory** provides the means for reciprocal coupling between the perceptual memory and executive memory.
- **Both models are updated through learning from the environment**

The memory system as a whole provides the mechanism for predicting the consequences of actions taken by the system.

Attention

- **Unlike specific functional blocks for perception and memory, the attentional mechanism is distributed across the entire cognitive system, building on perception and memory**

The function of attention is to allocate the available resources.

Intelligence

- **This fourth property of cognition is facilitated through a combination of global and local feedback loops distributed across the cognitive system, building on perception, memory, and attention.**
- **It is therefore the most profound of all four properties of cognition, providing for:**
The decision mechanism to select intelligent choices in the face of uncertainties.

3. Networks of Sensors

Network of sensors for observing the environment

State estimation of the environment

Feedback information

Action on the environment through another network of sensors

Networks of Sensors for Observing the Environment

Key technologies include:

- **Sensing, metering, and measurement**
- **Communications, using the Internet and wireless links**

State Estimation of the Environment

- Formulation of *state-space model* for the environment, based on the underlying physics and practical realities of the energy system.

The state-space model consists of two sub-models:

- (i) *System sub-model*, describing evolution of the state across time.
- (ii) *Measurement sub-model*, describing the “nonlinear” dependence of the state on measurements (i.e., observables received from the network of sensors).

The perceptual sub-system has the task of estimating the hidden state of the environment by processing the observables.

Feedback Information

- **The perceptual sub-system is also responsible for computing a metric that summarizes, in the most effective manner possible, feedback information about the state of environment contained in the observables.**

This metric serves the basis of a cost-to-go-function to be minimized in the “executive sub-system” of the cognitive energy system.

Action on the Environment through Another Network of Sensors

- **The perceptual sub-system relates to the environment directly through the observables.**
- **On the other hand, the executive sub-system “sees” the environment indirectly through feedback information provided by the perceptual sub-system.**

By minimizing the cost-to-go function and building on its own memory, the executive sub-system is enabled to select intelligent controls that benefit the current set of observables.

4. Risks and Uncertainties in the Environments

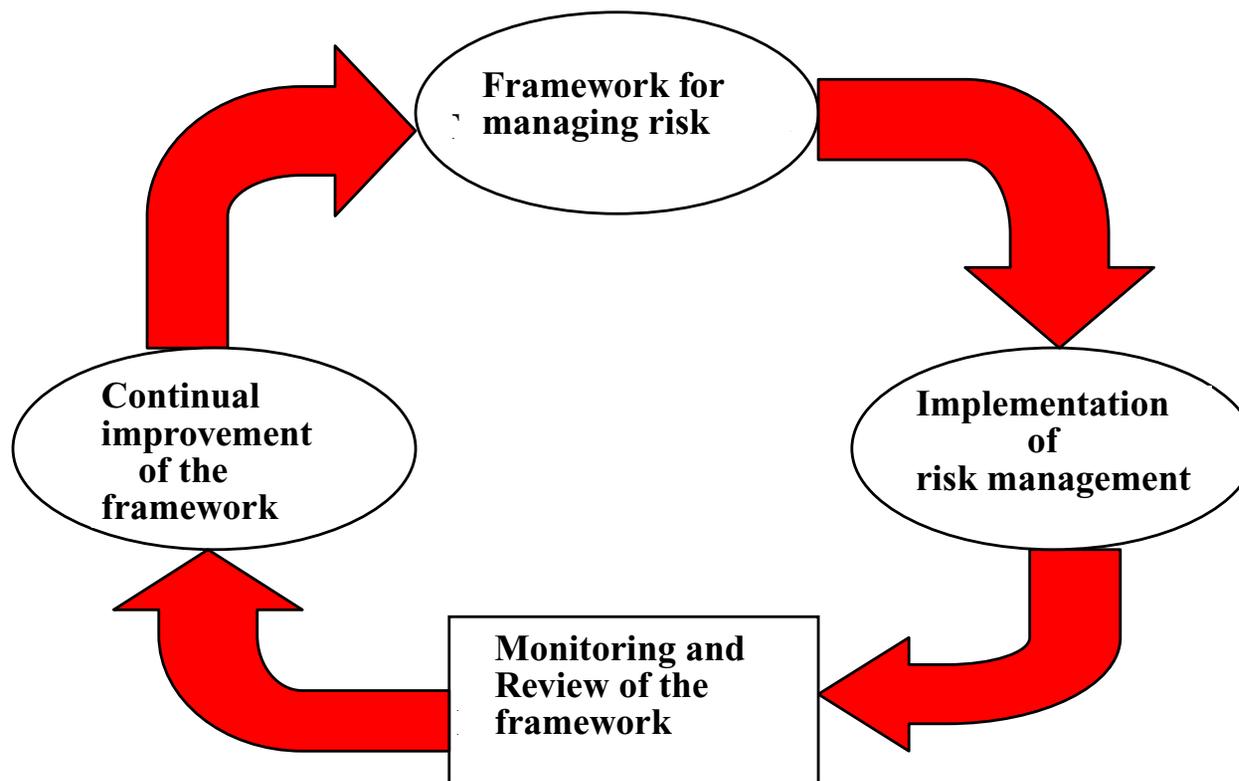
- **As it is in any electrical power network, the major risks deal with physical reliability issues:**
 - (i) system balance across the energy state, which requires the ability to react (respond) to weather conditions and the loss of different constituents of the microgrid, especially wind energy and solar energy.**
 - (ii) Stability and price uncertainty in the electrical power network.**
- **With the network of sensors being a constituent of the microgrid, the communication links may give rise to uncertainties of their own.**

Some notes on Risk Management:²

- (i) Risk management should be an integral part of the decision-making process.**
- (ii) It should explicitly address sources of uncertainty.**
- (iii) It should be structured and based on the best available information.**
- (iv) Last but by no means least, risk management should be dynamic, iterative and continually respond to changes in the microgrid.**

Motivated by the human brain, it may well be that self-organizing dynamic risk management is the way to proceed.

². Notes (i) to (iv) are taken from the ISO/TMB/WG Risk Management, 2007-06-15.



**Figure 2: Cyclic operation of risk management
(This figure is adapted from the ISO document)**

Concluding Remarks

- 1. Basically, what I have described here is applicable to a microgrid.**
- 2. For a large-scale energy system, I see a multiplicity of cognitive sub-systems interconnected, forming a Cognitive Network of cognitive sub-systems.**
- 3. In other words, cognitive information processing is distributed among nodes of a large-scale cognitive network.**

I thank you for your attention

and

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