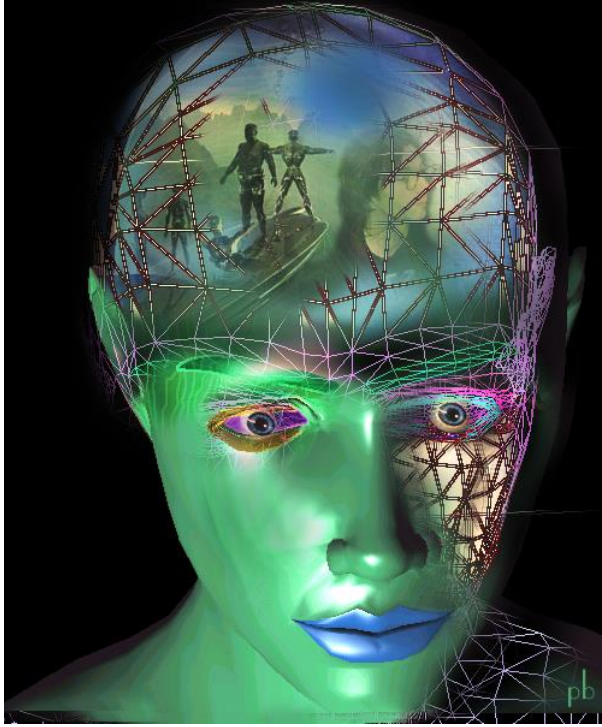
Embodied Intelligence

Machine motivation and cognition



Janusz Starzyk
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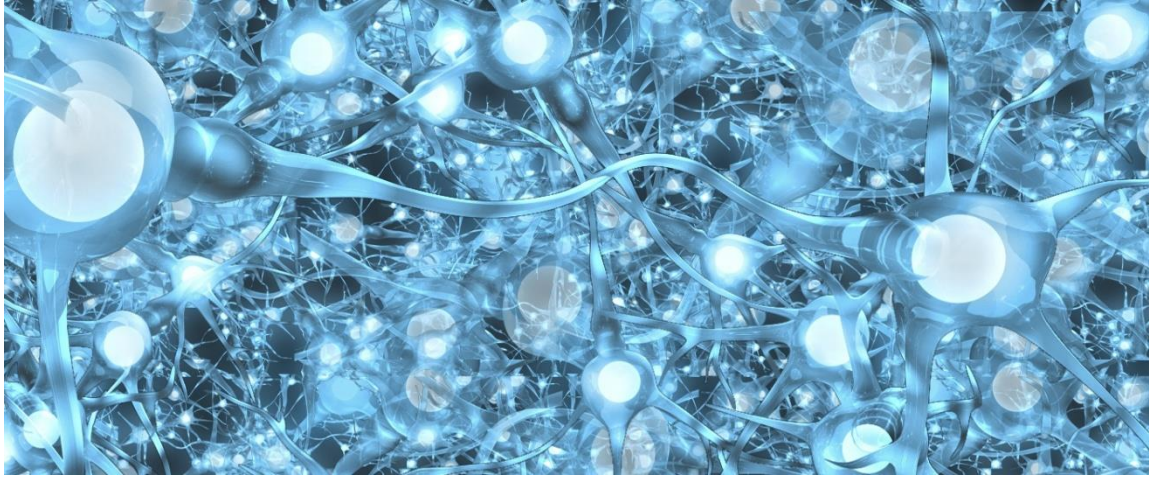
www.ent.ohiou.edu/~starzyk

Organization

- Traditional Artificial Intelligence.
- Embodied Intelligence (EI).
- Motivated Learning (ML).
- ML Cognitive Architecture.
- Attention Switching.
- Mental Saccades.
- Neoaxis Implementation.
- Conclusion.

http://dvice.com/archives/2009/03/expert-roundtab-1.php

Intelligence



- "…Perhaps the last frontier of science – its ultimate challenge- is to understand the biological basis of consciousness and the mental process by which we perceive, act, learn and remember.." from *Principles of Neural Science by* E. R. Kandel et al.
  - E. R. Kandel won Nobel Price in 2000 for his work on physiological basis of memory storage in neurons.
- "…The question of intelligence is the last great terrestrial frontier of science..." from Jeff Hawkins *On Intelligence.*
  - Jeff Hawkins founded the Redwood Neuroscience Institute devoted to brain research

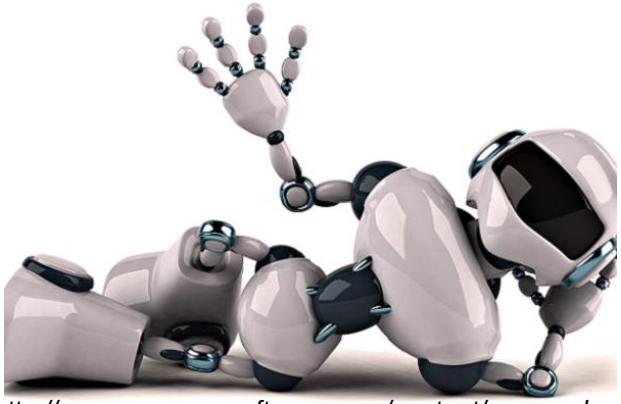
So what is Intelligence?

http://www.redorbit.com/news/science/

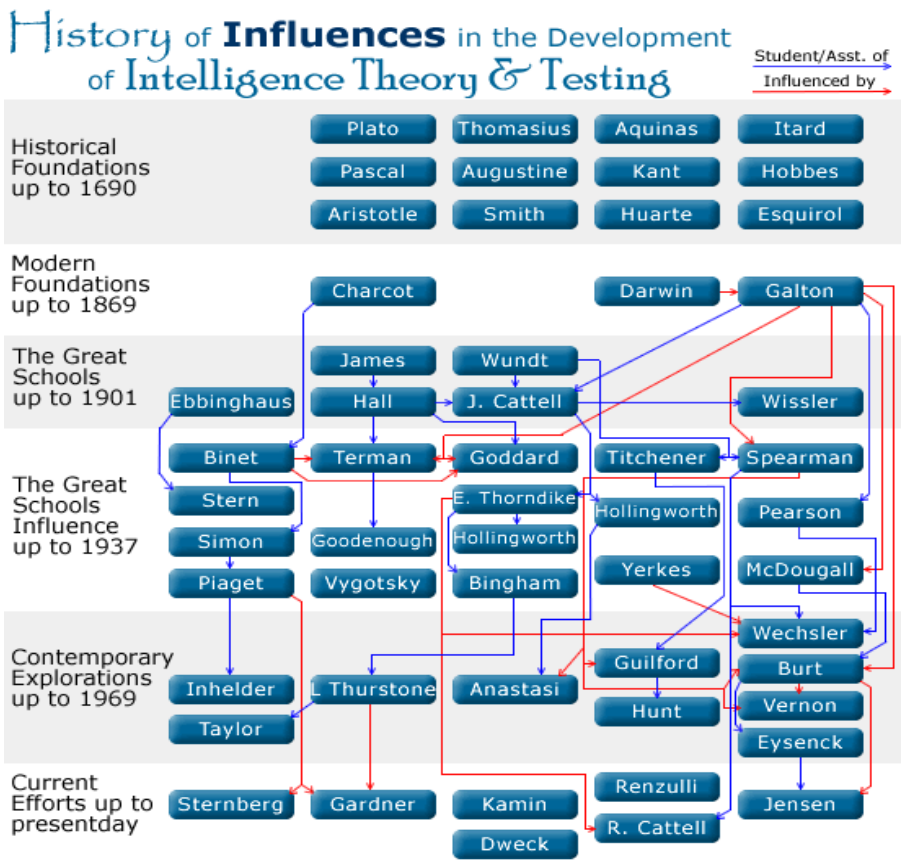
Various Definitions of Intelligence

- The American Heritage Dictionary:
  - **The capacity to acquire and apply knowledge.**
  - **The faculty of thought and reason.**
- Webster Dictionary:
  - **The act or state of knowing; the exercise of the understanding.**
  - **The capacity to know or understand; readiness of comprehension;**
- Wikipedia – The Free Encyclopedia:
  - **The capacity to reason, plan, solve problems, think abstractly, comprehend ideas and language, and learn.**
- Kaplan & Sadock:
  - **The ability to learn new things, recall information, think rationally, apply knowledge and solve problems.**
- On line dictionary dict.die.net
  - **The ability to comprehend; to understand and profit from experience**
- The classical behavioral/biologists:
  - **The ability to adapt to new conditions and to successfully cope with life situations.**
- Dr. C. George Boeree, professor in the Psychology Department at Shippensburg University:
  - **A person's capacity to (1) acquire knowledge (i.e. learn and understand), (2) apply knowledge (solve problems), and (3) engage in abstract reasoning.**
- Stanford University Professor of Computer Science Dr. John McCarthy, a pioneer in AI:
  - **The computational part of the ability to achieve goals in the world.**
- Scientists in Psychology:
  - **Ability to remember and use what one has learned, in order to solve problems, adapt to new situations, and understand and manipulate one's reality.**

Intelligence



http://www.acumen-software.com/content/personal-robot-assistants



Mainstream Science on Intelligence December 13, 1994:

An Editorial With 52 Signatories, by Linda S. Gottfredson, University of Delaware

Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience.

From http://www.indiana.edu/~intell/map.shtml

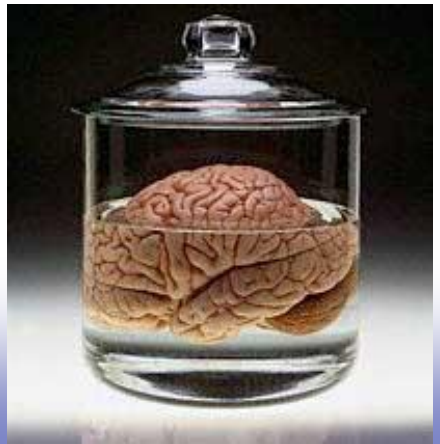
Animals' Intelligence

- Defining intelligence through humans is not appropriate to design intelligent machines:
  - Animals are intelligent too

- Dog IQ test:
  - Dogs can learn 165 words (similar to 2 year olds)
  - Average dog has the mental abilities of a 2-year-old child (or better)
  - They would beat a 3- or 4-year-old in basic arithmetic,
  - Dogs show some basic emotions, such as happiness, anger and disgust
  - "The social life of dogs is very complex - more like human teenagers - interested in who is moving up in the pack, who is sleeping with who etc," says professor Stanleay Coren from University of British Columbia
  - Border collies, poodles, and german shepards are the smartest dogs

Traditional AI

- Abstract intelligence
  - attempt to simulate "highest" human faculties:
    - language, discursive reason, mathematics, abstract problem solving
- Environment model
  - Condition for problem solving in abstract way
  - "brain in a vat"



Embodied Intelligence

- Embodiment
  - knowledge is implicit in the fact that we have a body
    - embodiment supports brain development
- Intelligence develops through interaction with environment
  - Situated in environment
  - Environment is its best model

Design Principles of Intelligent Systems

from Rolf Pfeifer “Understanding of Intelligence”

- synthetic methodology
- time perspectives
- emergence
- diversity
- frame-of-reference
- cheap design
- complete agent principle

http://www.lirmm.fr/~krut/wordpress/?attachment_id=226

Design Principles of Intelligent Systems

from Rolf Pfeifer “Understanding of Intelligence”

- Interaction with complex environment
- ecological balance
- redundancy principle
- parallel, loosely coupled processes
- asynchronous
- sensory-motor coordination
- value principle

Drawing by Ciarán O’Leary- Dublin Institute of Technology

The Principle of Parallel, Loosely Coupled Processes

- Intelligent behavior emergent from agent-environment interaction
- Large number of parallel, loosely coupled processes
- Asynchronous
- Coordinated through agent's

–sensory-motor system

–neural system

–interaction with environment

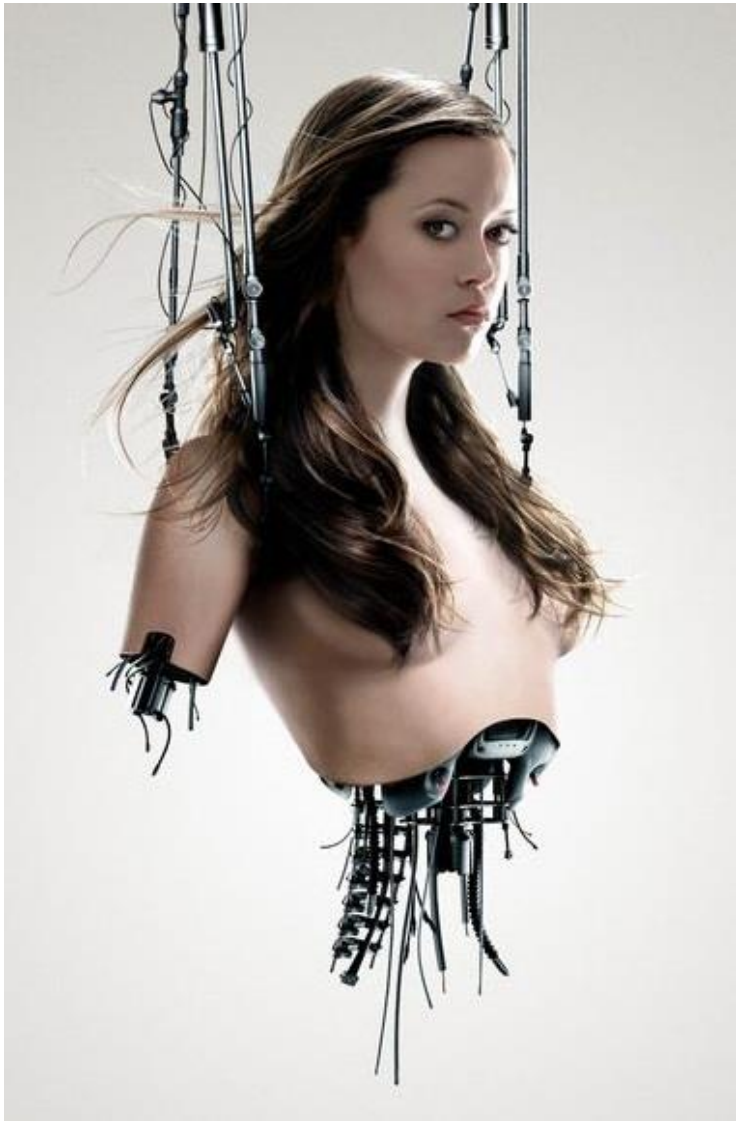
http://edwardrippen.com

Generation of Sensory Stimulation through Interaction with Environment

- multiple modalities
- constraints from morphology and materials
- generation of correlations through physical process
- basis for cross-modal associations

http://onesassydoctor.blogspot.com/

What is the Embodied Intelligence ?

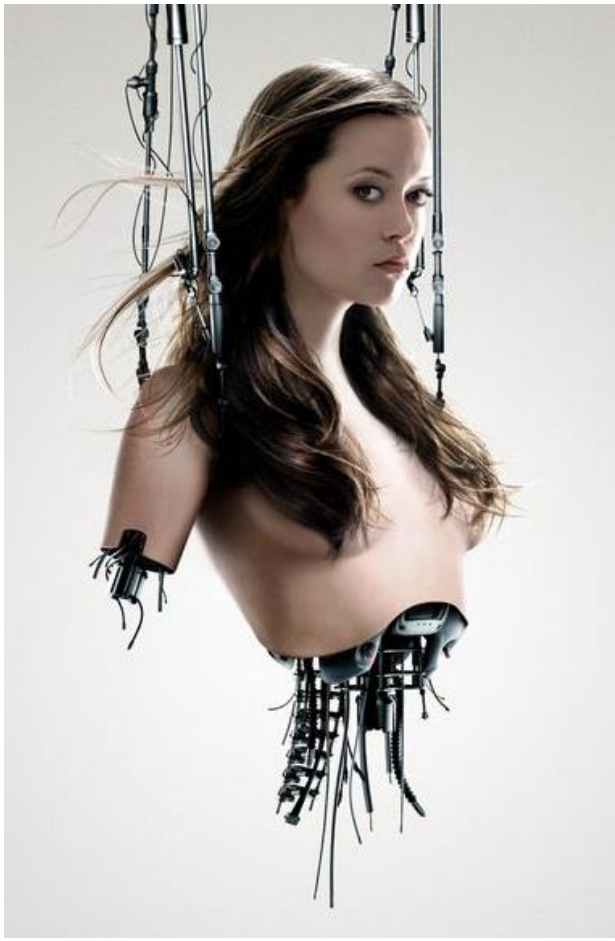


Embodied Intelligence

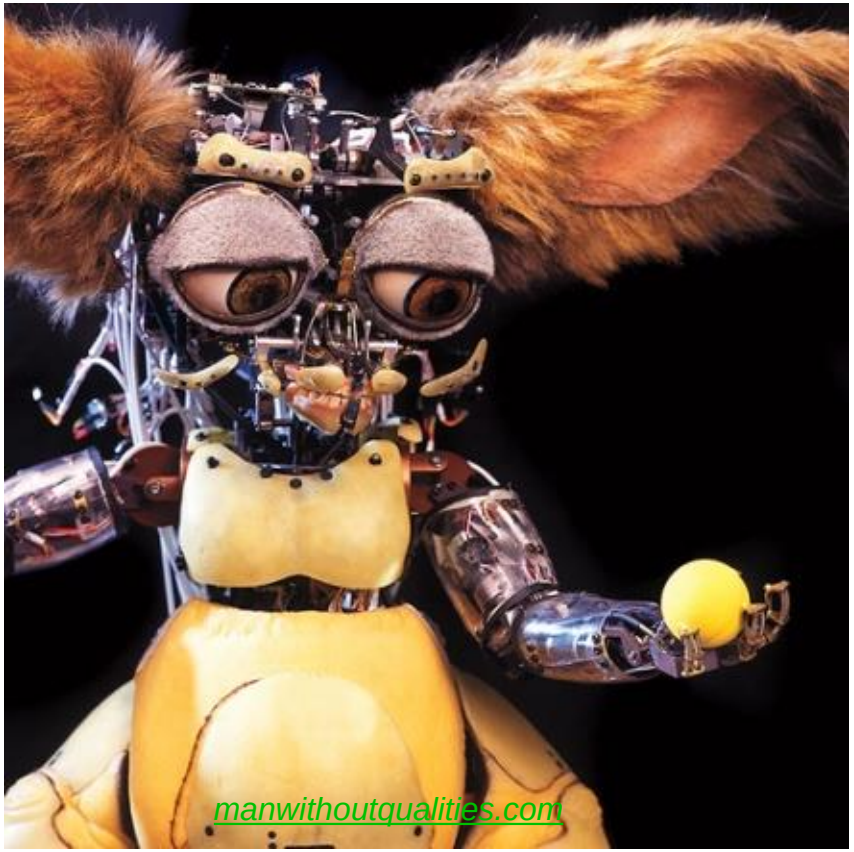
- Definition
- Embodied Intelligence (EI) is a mechanism that learns how to survive in a hostile environment
  - Mechanism: biological, mechanical or virtual agent with embodied sensors and actuators
  - EI acts on environment and perceives its actions
  - Environment hostility is persistent and stimulates EI to act
  - Hostility: direct aggression, pain, scarce resources, etc
  - EI learns so it must have associative self-organizing memory
  - Knowledge is acquired by EI

Embodied Intelligence

- Knowledge is not entered into EI systems, but it results from learning successful interactions with the environment.
- Embodied intelligent systems deal with unpredictable and dynamic situations in the environment by learning, which gives them a high degree of autonomy.
- Learning in such systems is incremental, with continuous prediction of the input associations based on the emerging models in its memory.



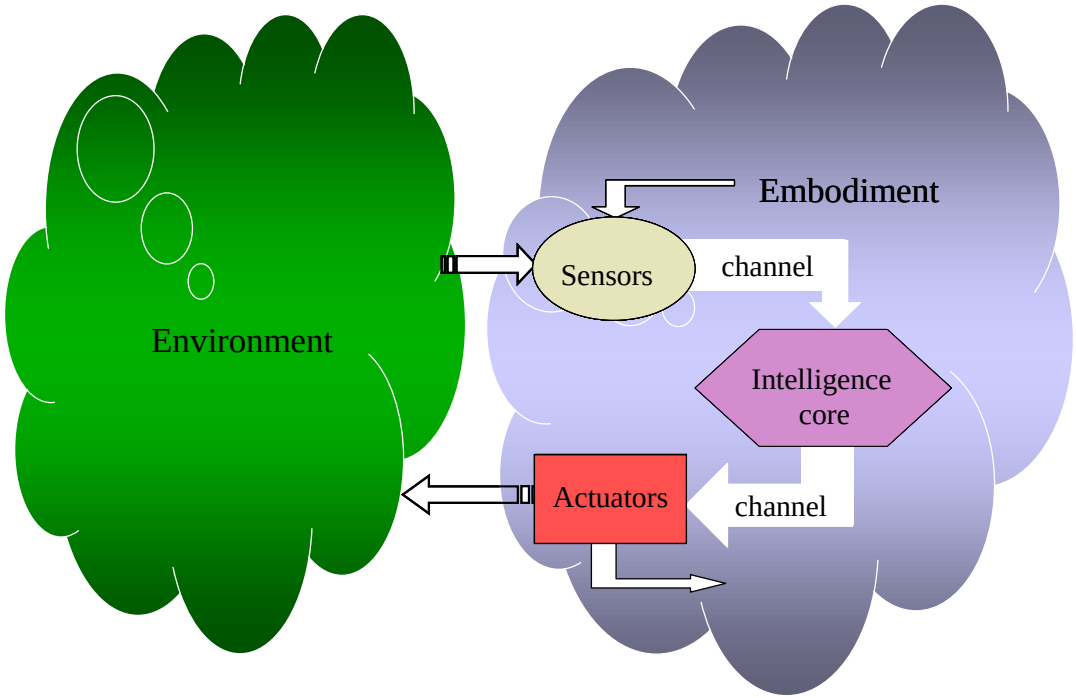
What is Embodiment of a Mind?



http://elainewintman.com

Embodiment of a Mind

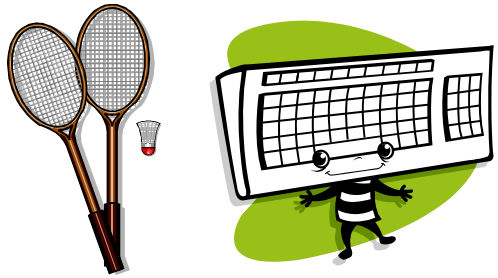
- Embodiment of a mind is a part of environment under control of the mind
- It contains intelligence core and sensory motor interfaces to interact with environment
- It can be virtual and it can change



Embodiment of a Mind

- Brain learns own body's dynamic
- Self-awareness is a result of identification with own embodiment
- Embodiment can be extended by using tools and machines
- Successful operation is a function of correct perception of environment and own embodiment

http://www.plasticpals.com/?attachment_id=33904



Challenges of Embodied Intelligence

(a)

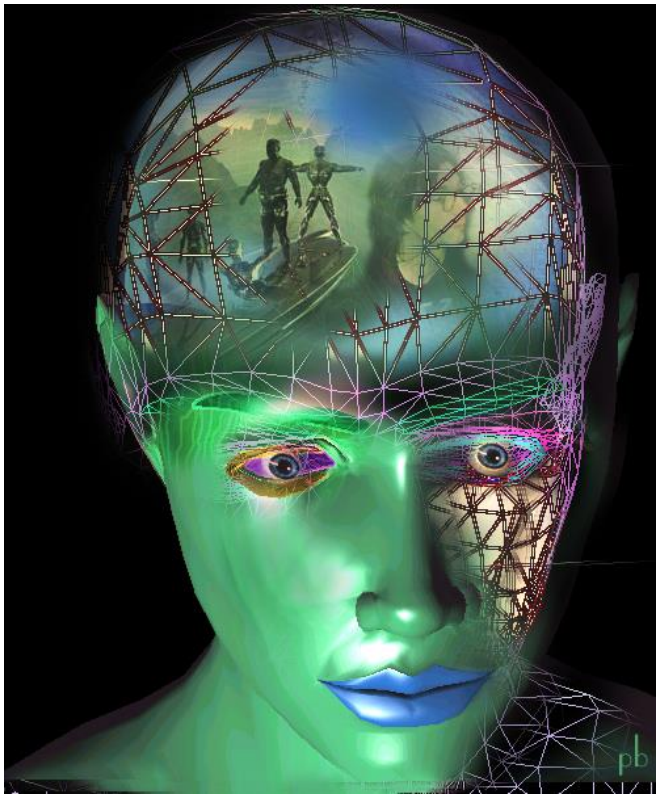
(b)

http://cdn.grin.com

How to Motivate a Machine ?

A fundamental question is what motivates an agent to do anything, and in particular, to enhance its own complexity?

What drives an agent to explore the environment and learn ways to effectively interact with it?



How to Motivate a Machine ?

Can a machine that only implements externally given goals be intelligent?

If not how these goals can be created?

Oudeyer proposed an intrinsic motivation system.

- Motivation comes from a desire to minimize the prediction error.
- Similar to “artificial curiosity” presented by Schmidhuber.

How to Motivate a Machine ?

- I suggest that the hostility of the environment, in the definition of EI is the most effective motivational factor.
  - It is the pain we receive that moves us.
  - It is our intelligence determined to reduce this pain that motivates us to act, learn, and develop.
- Both are needed - hostility of the environment and intelligence that learns how to reduce the pain.
  - Thus pain is good.
  - Without pain we would not be motivated to develop.
  - Without pain there would be no intelligence.

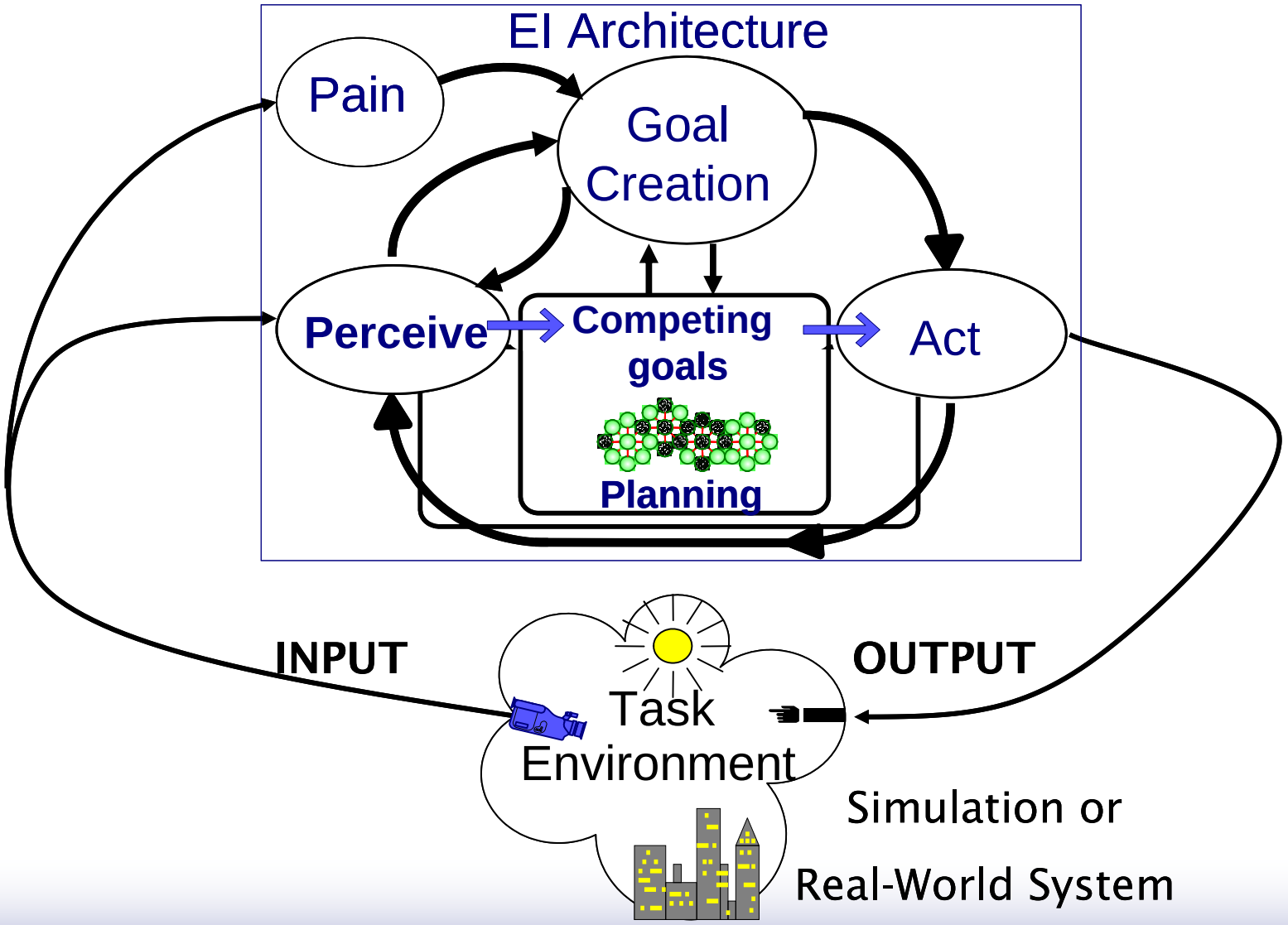
http://www.dougmather.co.uk/the-surprising-nature-of-motivation

Motivated Learning

- I designed a pain-driven mechanism to motivate a machine to act, learn, and develop.
  - It uses externally defined pain signals that are associated with primitive pains.
  - Machine is rewarded for minimizing its pain signals.
  - It creates higher level needs and motivations.

- Motivated learning (ML) is learning based on the self-organizing system of goals/needs in the embodied agent.
  - Machine creates higher level (abstract) goals based on the lower level pain signals.
  - It receives internal rewards for satisfying its goals (both primitive and abstract).
  - ML applies to EI working in a hostile environment.

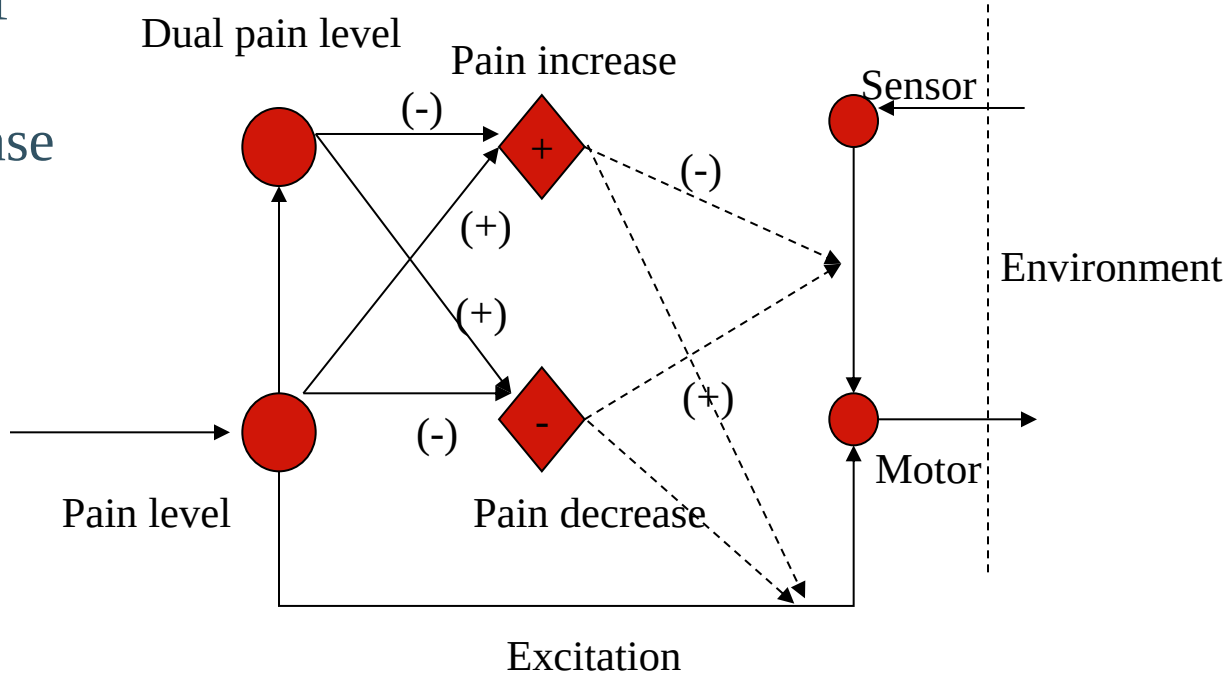
EI Interaction with the Environment



EI machine interacts with environment using its three pathways

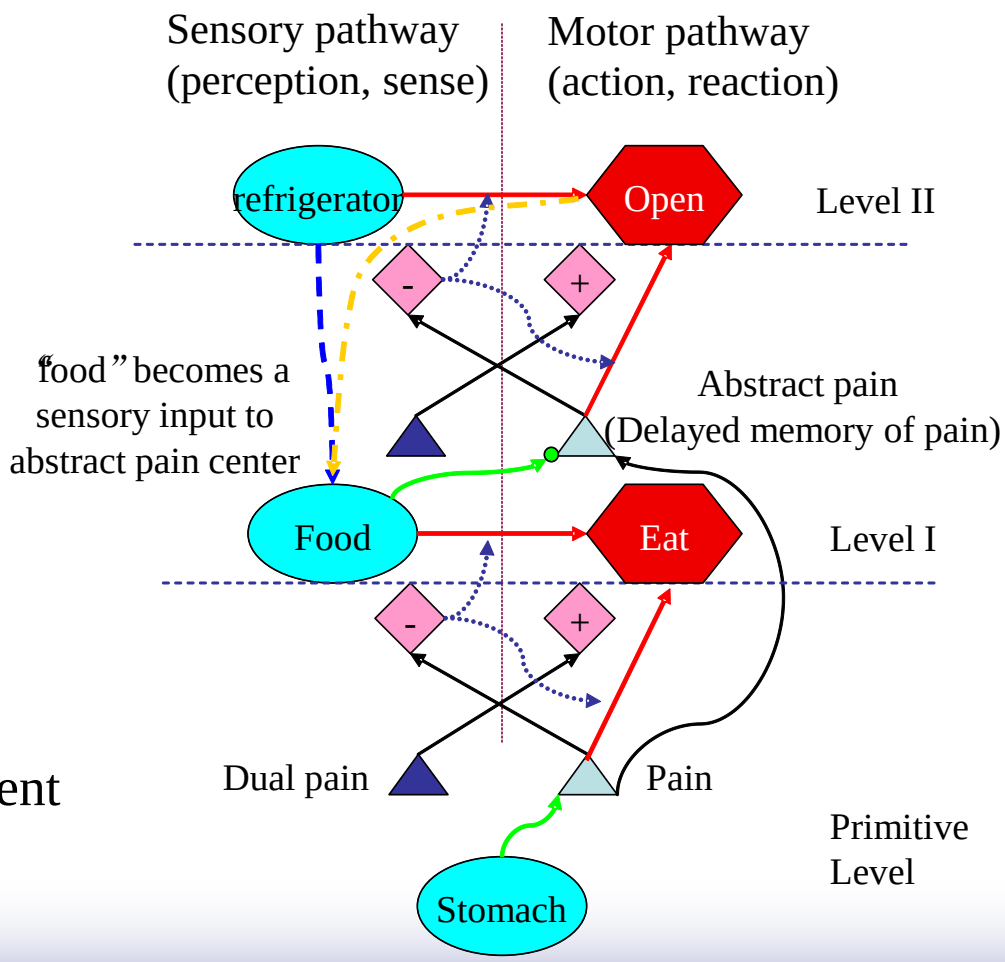
Pain-center and Goal Creation for ML

- Simple Mechanism
- Leads to a hierarchy of complex goals
- Pain comparators release reinforcement signals:
  - Pain increase - inhibitory
  - Pain decrease - excitatory
- Forces exploration



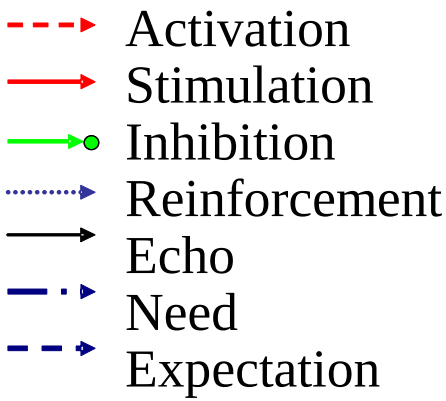
Abstract Goal Creation for ML

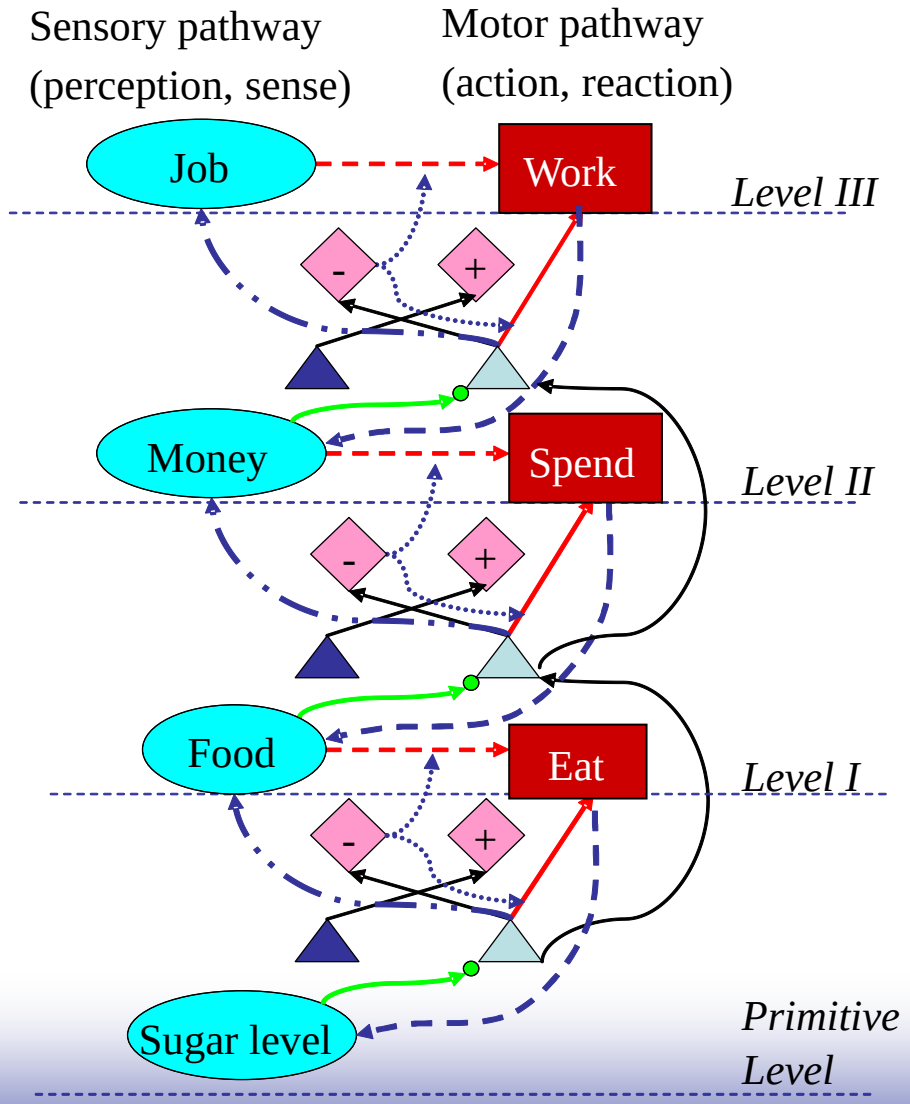
- The goal is to reduce the primitive pain level
- Abstract goals are created if they satisfy the primitive goals



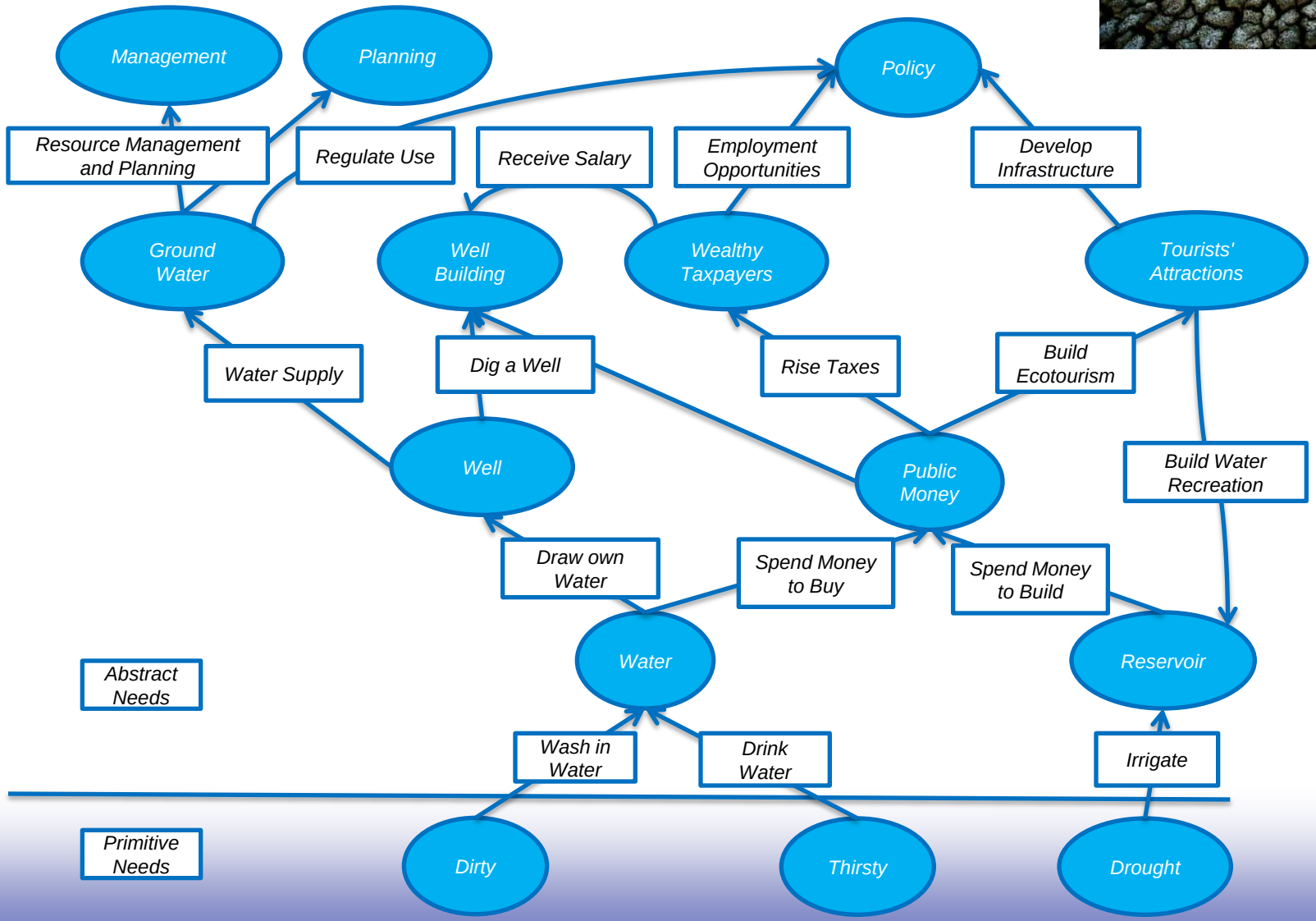
Abstract Goal Hierarchy

- Hierarchy of abstract goals is created if they satisfy the primitive goals





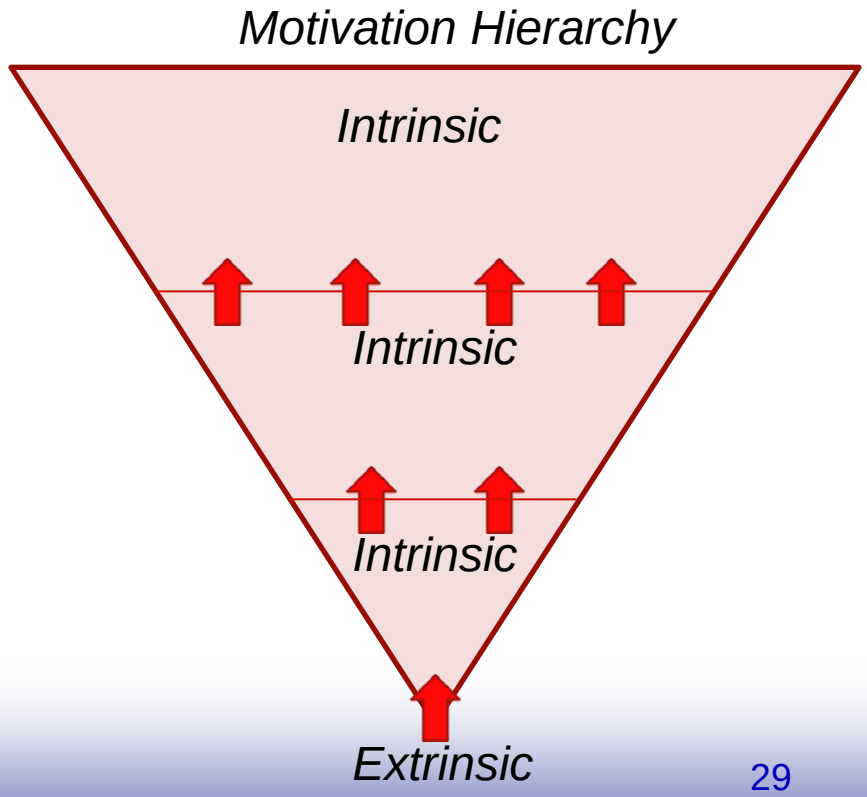
Abstract needs



Motivated Learning

- Controlled by underlying "primitive" motivations
- Builds on motivations to create additional "abstract" motivations

- *Unlike in RL, ML focuses on intrinsic rewards and creating mission related new goals and motivations.*



Reinforcement Learning

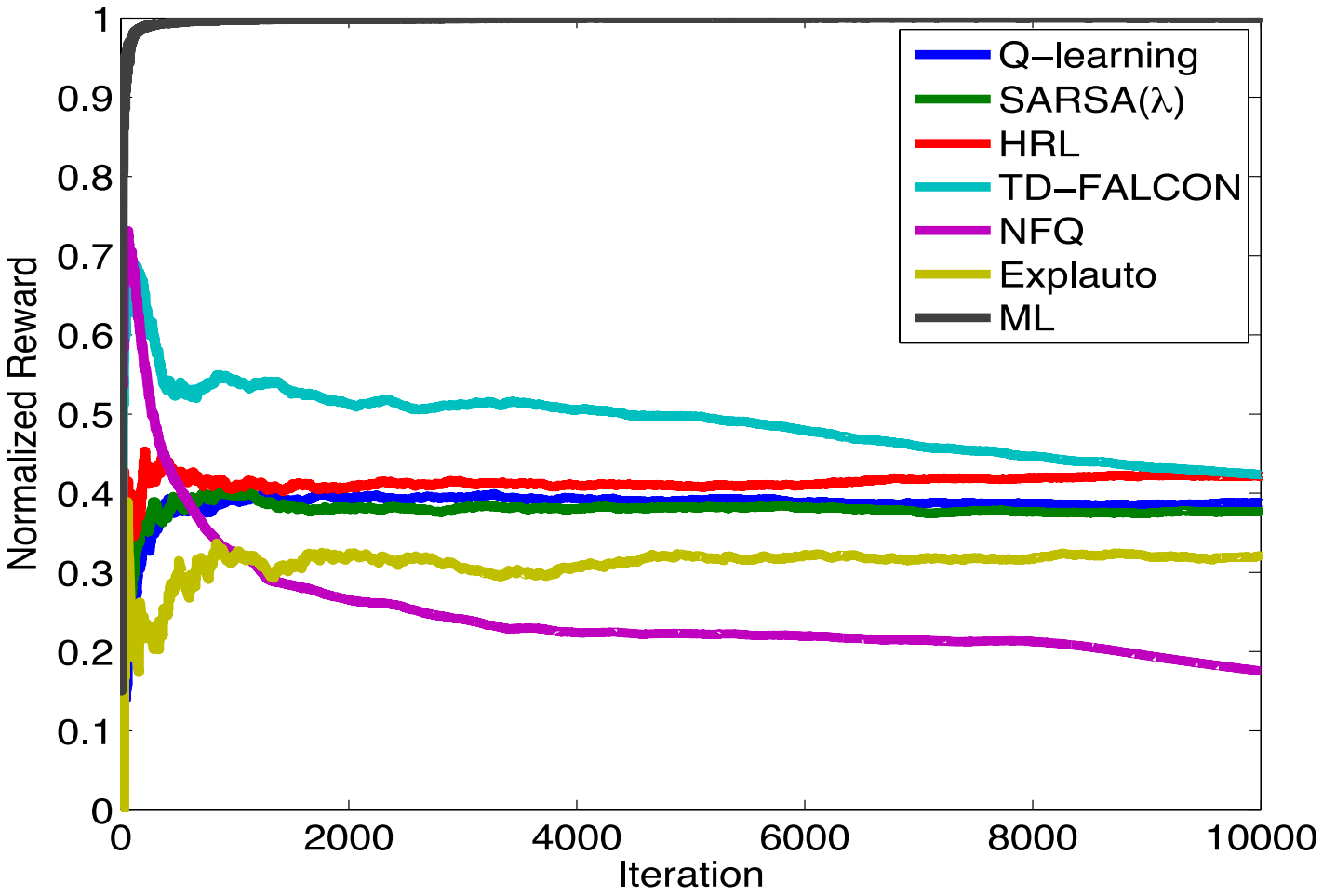
- Single value function
- Measurable rewards
  - Can be optimized
- Predictable
- Objectives set by designer
- Maximizes the reward
  - Potentially unstable
- Learning effort increases with complexity
- Always active

Motivated Learning

- Multiple value functions
  - One for each goal
- Internal rewards
  - Cannot be optimized
- Unpredictable
- Sets its own objectives
- Solves minimax problem
  - Always stable
- Learns better in complex environment than RL
- Acts when needed

http://www.bradfordvts.co.uk/images/goal.jpg

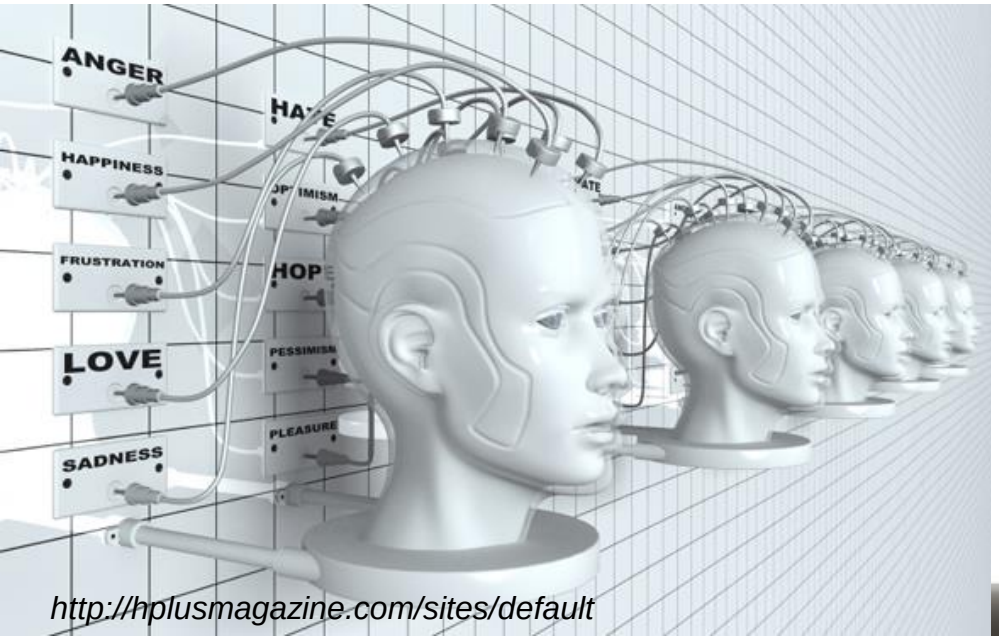
Average Reward in Reinforcement Learning vs Motivated Learning



Machine Consciousness

Consciousness is attention driven cognitive perception, motivations, thoughts, plans, and action monitoring.

A machine is conscious IFF besides ability to perceive, act, learn and remember, it has a central executive mechanism that controls all the processes (conscious or subconscious) of the machine;



http://hplusmagazine.com/sites/default

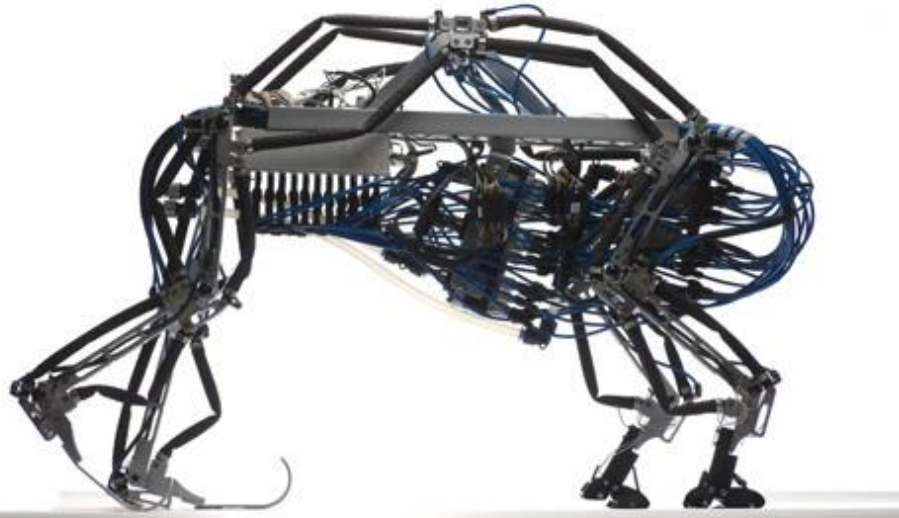
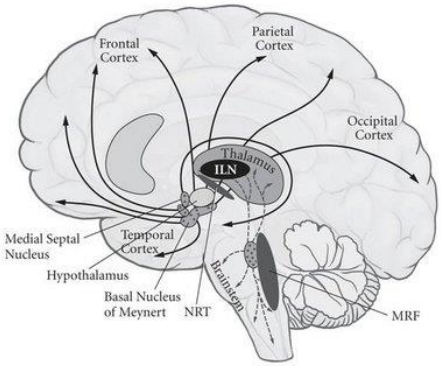


Photo: www.spectrum.ieee.org/.../biorobot11f-thumb.jpg

Motivated Learning Embodied Cognitive Architecture MLECOG



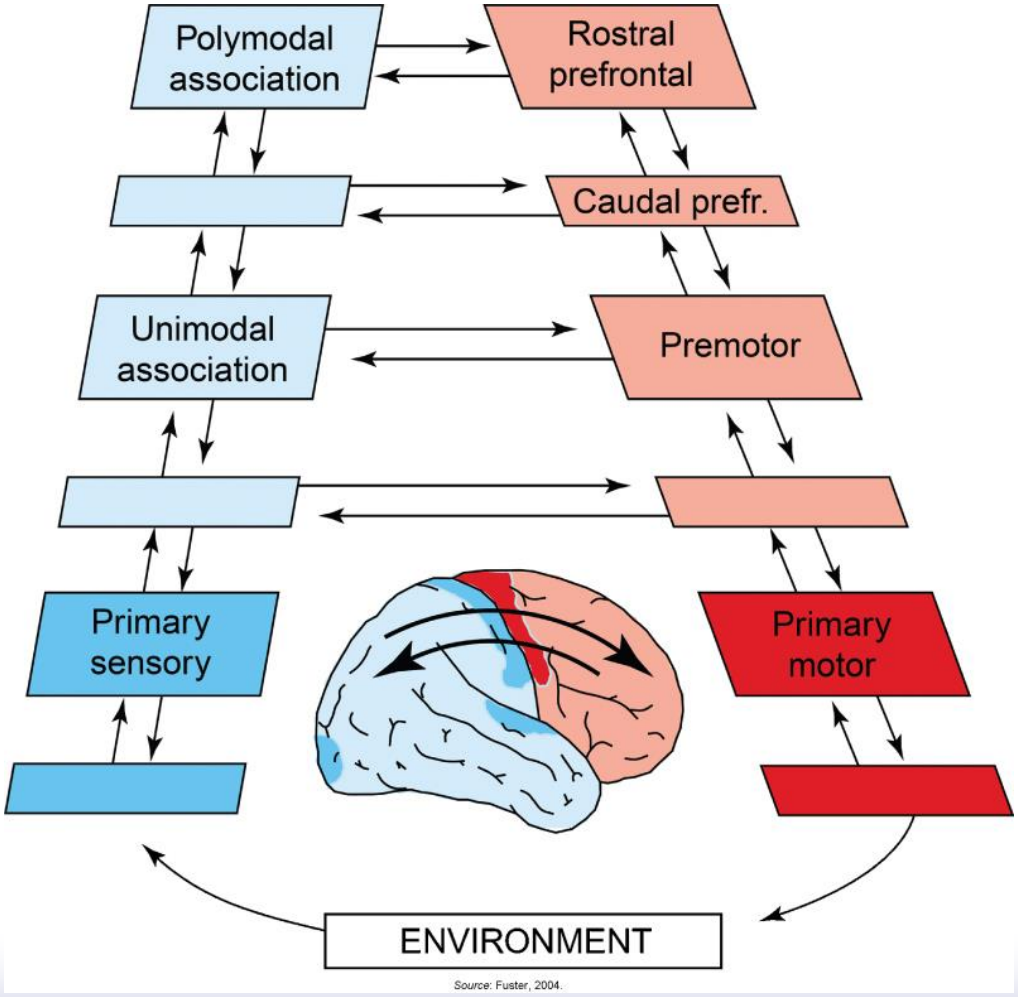
Episodic management
Scene building
Action planning
Working memory
Mental saccades
Attention focus
Action evaluation
Action monitoring
Memory attention switching
Sensory attention switching
Motivations and goal creation
Procedural memory and spatial orientation
Episodic memory
Semantic memory
Cognitive motivations, rewards, and emotions
Motor control
Long term memory
Subconscious pains, rewards, and emotions
Visual saccades
Cognitive agent
Sensory-motor area
Sensory processing
Motor processing
Sensory inputs
Motor outputs

Inspiration: human brain

Photo (brain): http://www.scholarpedia.org/article/Neuronal_correlates_of_consciousness

Sensory and Motor Hierarchies

- Sensory and motor systems appear to be arranged in hierarchies
- Association between various levels of the sensory and motor hierarchies.



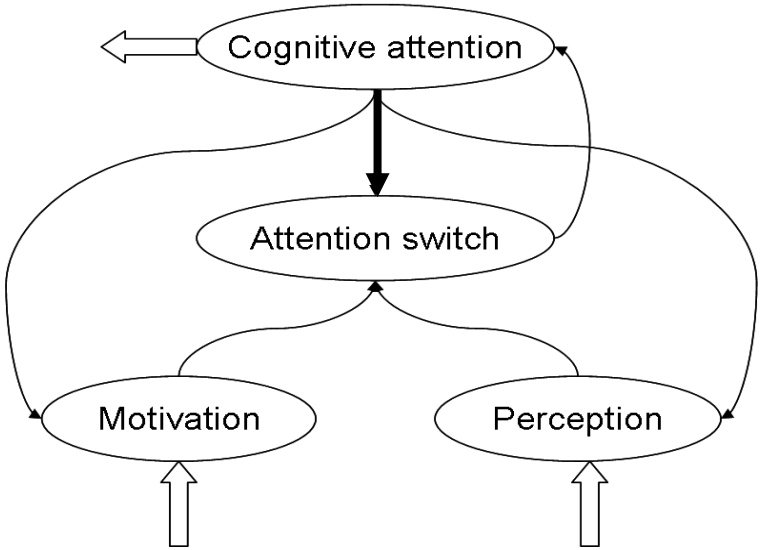
Functions of the Working Memory

1. Planning, setting goals and initiating actions
2. Monitoring outcomes and adapting to errors
3. Mental effort in pursuing difficult goals
4. Motivations
5. Initiating speech and visual imagery
6. Recognizing other's people's goals
7. Engaging in social cooperation and competition
8. Feeling and regulating emotions
9. Storing and updating working memory
10. Thinking
11. Conscious experiences
12. Sustained attention in the face of distraction
13. Switching attention
14. Decision making and changing strategies
15. Planning and sequencing actions
16. Unifying the syntax and meaning of language
17. Resolving competition between plans

csiwebcomics.com

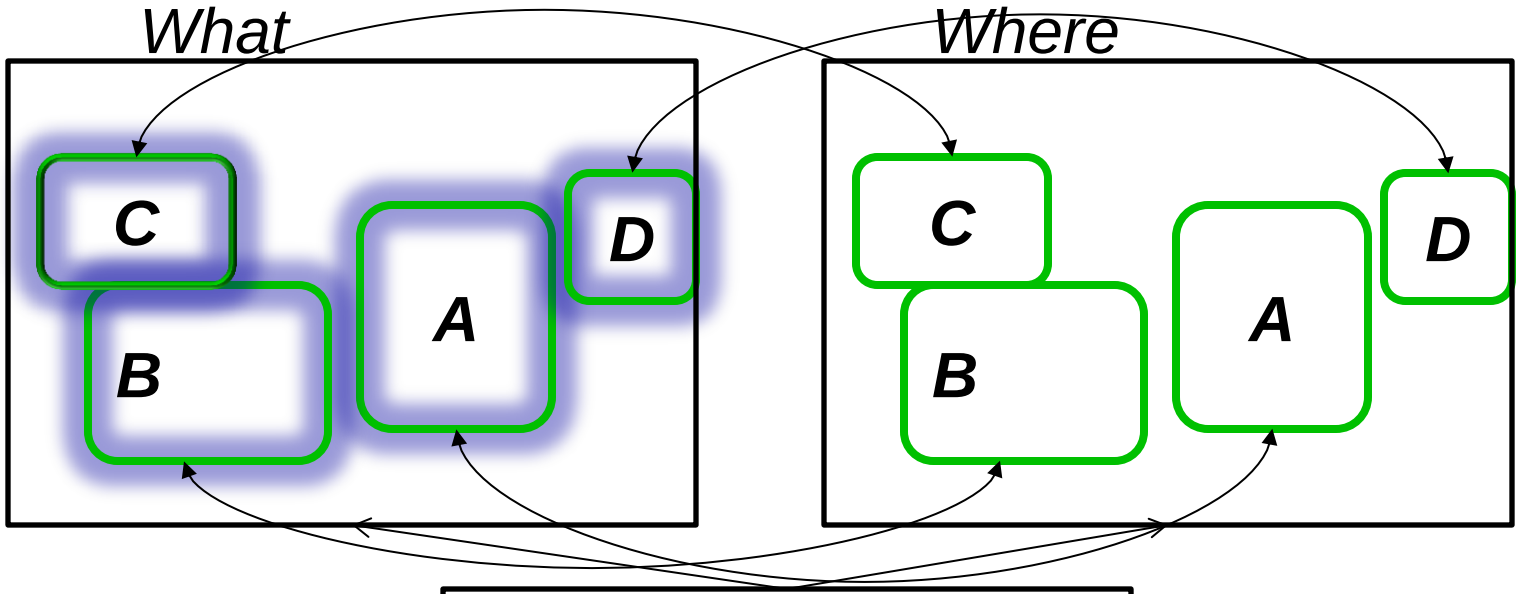
Attention Switching !!!

- *Dynamic process resulting from competition between*
  - *motivations*
  - *sensory inputs*
  - *internal thoughts*

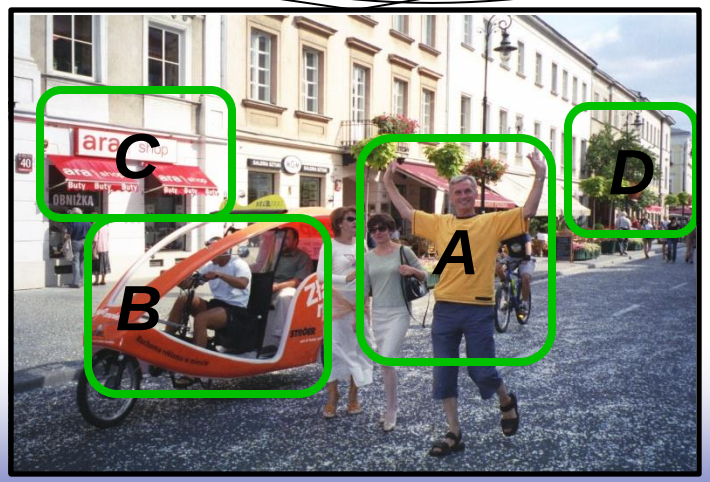


While paying attention is a conscious experience, switching attention does not have to be.

Visual Saccades



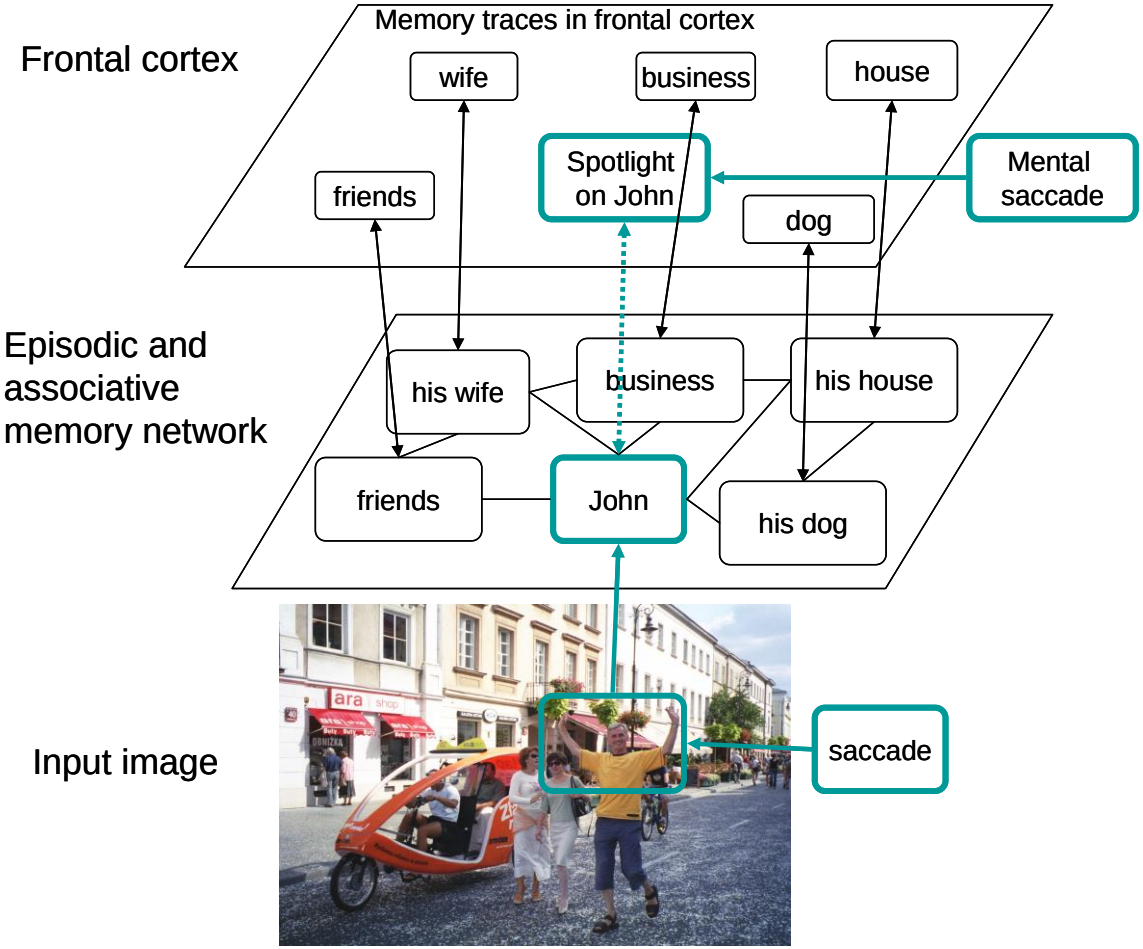
Visual saccades help to establish visual attention focus



Input image

Mental Saccades

- *A visual attention spotlight is a result of a visual saccade.*
- *Perceived object activates associated areas of semantic and episodic memory.*
- *This activates memory traces in the working memory that will be used by mental saccades.*



Mental Saccades and Cognition

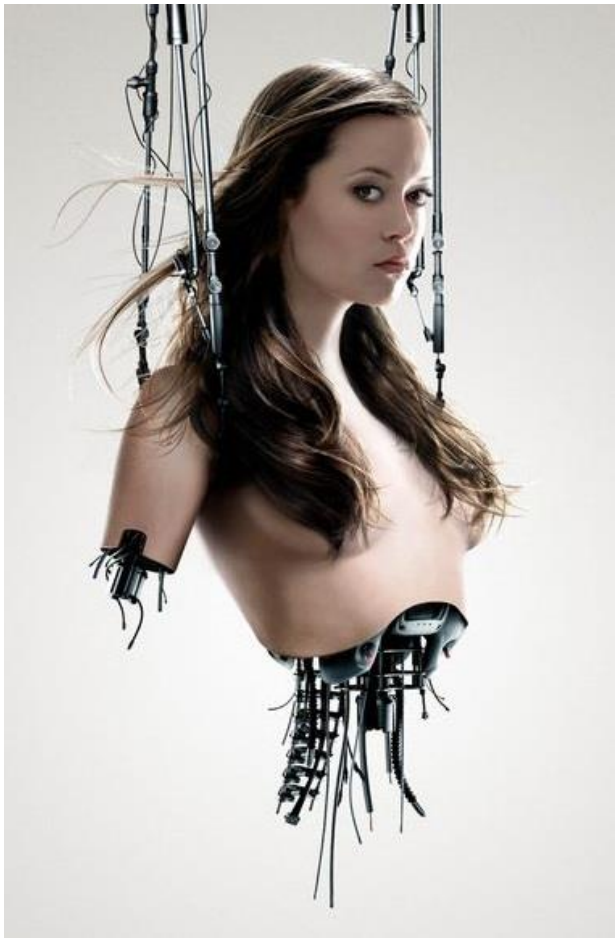
- *Self-organizing mechanism of emerging motivations and other signals competing for attention is fundamental for building cognitive machines.*
- *Motivated learning provides a mechanism for creation of abstract goals and continuous goal oriented motivation.*
- *Attention switching is a dynamic process resulting from competition between goals, representations, sensory inputs, and internal thoughts.*
- *Mental saccades of the working memory are fundamental for cognitive thinking, attention switching, planning, and action monitoring.*

Mental Saccades and Cognition

- *Motivations for actions are physically distributed*
  - *competing need signals are generated in machine's mind*
- *Before a winner is selected, machine does not interpret the meaning of the competing signals*
- *Cognitive processing is predominantly sequential*
  - *winner of the internal competition directs the cognitive thought process*
- *Top down supervision of perception, planning, internal thought or motor functions*
  - *results in a conscious experience*
    - *decision of what is observed and where is it*
    - *planning how to respond*
  - *a train of such experiences constitutes consciousness*

Conclusion

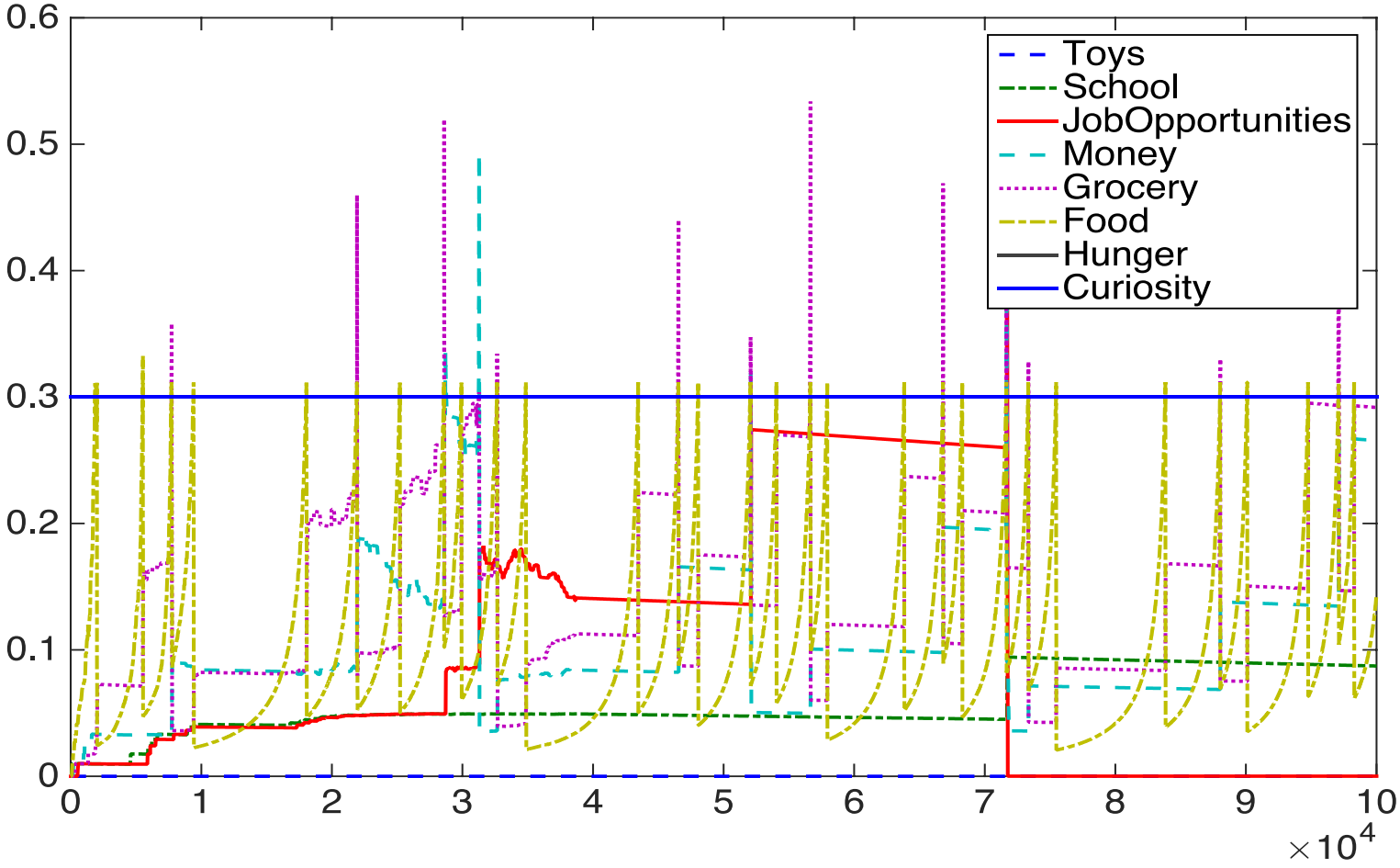
Motivated intelligent machines can be conscious



MLECOG Architecture Implementation in NeoAxis

- Neoaxis testing environment is based on Object-oriented Graphics Rendering Engine.
- The screen capture provides an overview of the environment's state, agent's action, pain that triggers its action, and pain levels.

MLECOG Pain Management in NeoAxis

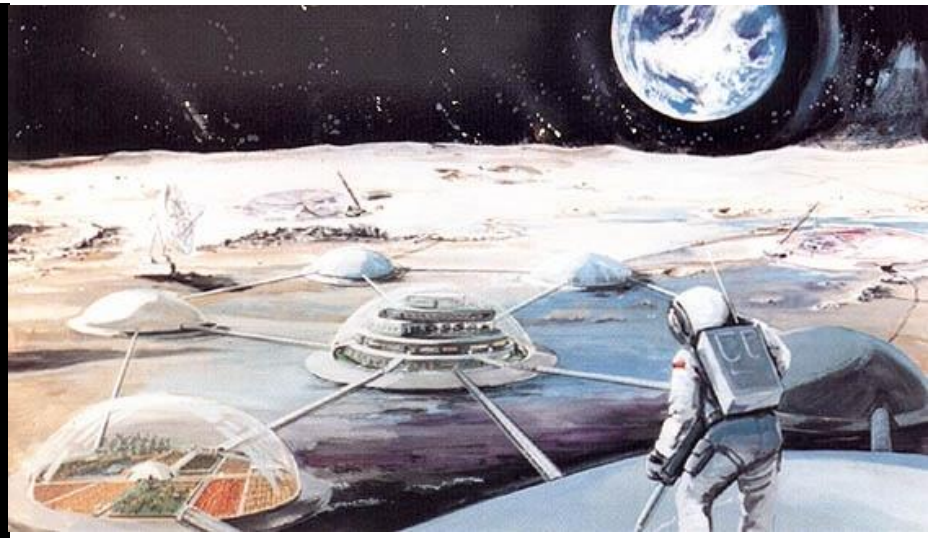


Promises of Embodied Intelligence

- To society
  - Advanced use of technology
    - Robots
    - Tutors
    - Intelligent gadgets
  - Intelligence age follows
    - Industrial age
    - Technological age
    - Information age
  - Society of minds
    - Superhuman intelligence
    - Progress in science
    - Solution to societies' ills
- To industry
  - Technological development
  - New markets
  - Economical growth

new types of Humanoid Robots are having the ability to feel materials http://www.recenttechinventions.com/

Sounds like science fiction



- If you're trying to look far ahead, and what you see seems like science fiction, it might be wrong.
- But if it doesn't seem like science fiction, it's definitely wrong.

From presentation by Feresight Institute

Embodied Artificial Intelligence

Based on:

[1] E. R. Kandel et al. *Principles of Neural Science*, McGraw-Hill/Appleton & Lange; 4 edition, 2000.

[2] Joscha Bach, *"Principles of Synthetic Intelligence", Oxford University press, 2009.*

[3] Gulio Tononi, *"Phi: A Voyage from the Brain to the Soul", Pantheon, 2012, 384 pp.*

[4] Pentti Haikonen, *"Consciousness and Robot Sentience", World Scientific, 2012.*

[5] R. Pfeifer and C. Scheier, *Understanding Intelligence*, MIT Press, Cambridge, MA, 1999.

[6] R. A. Brooks, "Intelligence without reason," In Proc. IJCAI-91. (1991) 569-595 .

[7] Bernard J. Baars and Nicole M. Gage Cognition, Brain, and Consciousness, Academic Press, 2007.

Questions?