

Development of intelligent systems (RInS)

Cognitive robot systems

Danijel Skočaj

University of Ljubljana

Faculty of Computer and Information Science

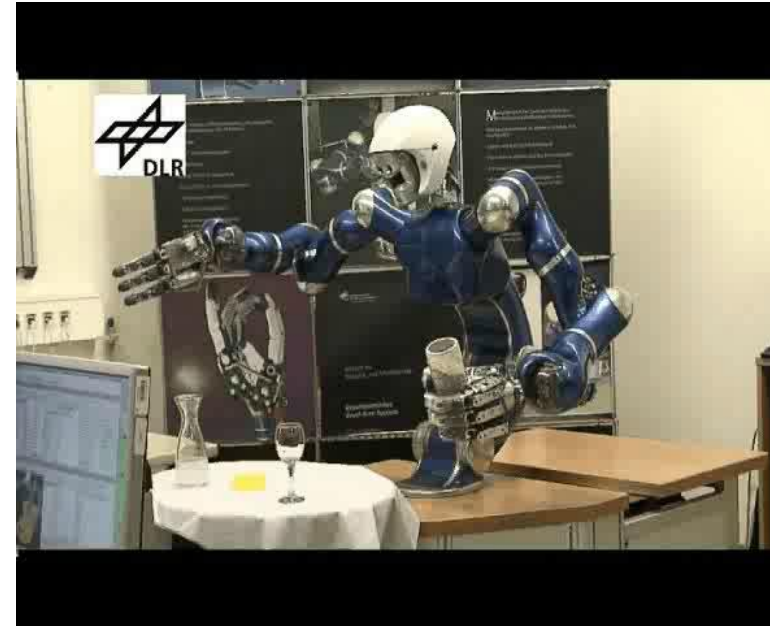
Academic year: 2025/2026

Robotics

- Routine industrial robotic system



EURON video

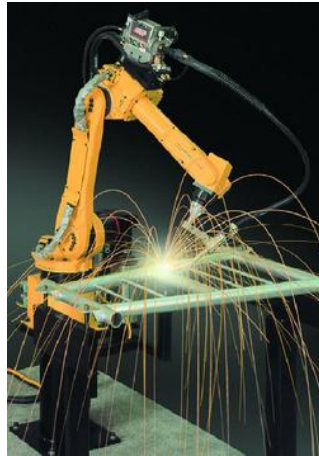


EURON video

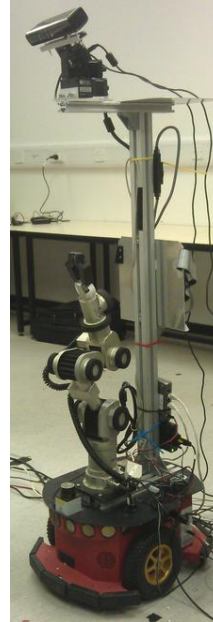
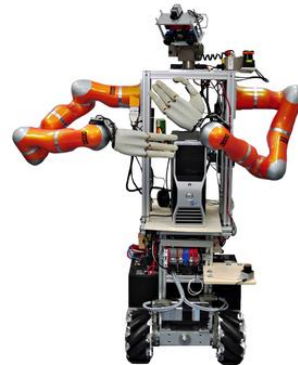
- Intelligent artificial visual cognitive system

Cognitive robot systems

cognitive robots



industrial robots



SF

human



perception

action

attention

goals

planning

reasoning

communication

learning

Cognitive robotics

- Wikipedia:

Cognitive robotics is concerned with endowing **robots** with mammalian and **human-like cognitive capabilities** to enable the achievement of complex goals in complex environments. Robotic cognitive capabilities include **perception processing, attention allocation, anticipation, planning, reasoning about other agents**, and perhaps reasoning about their **own mental states**. Robotic cognition embodies the **behaviour of intelligent agents** in the **physical world**.

- A cognitive robot should exhibit:
 - knowledge
 - beliefs
 - preferences
 - goals
 - informational attitudes
 - motivational attitudes (observing, communicating, revising beliefs, planning)

Researchers' definitions

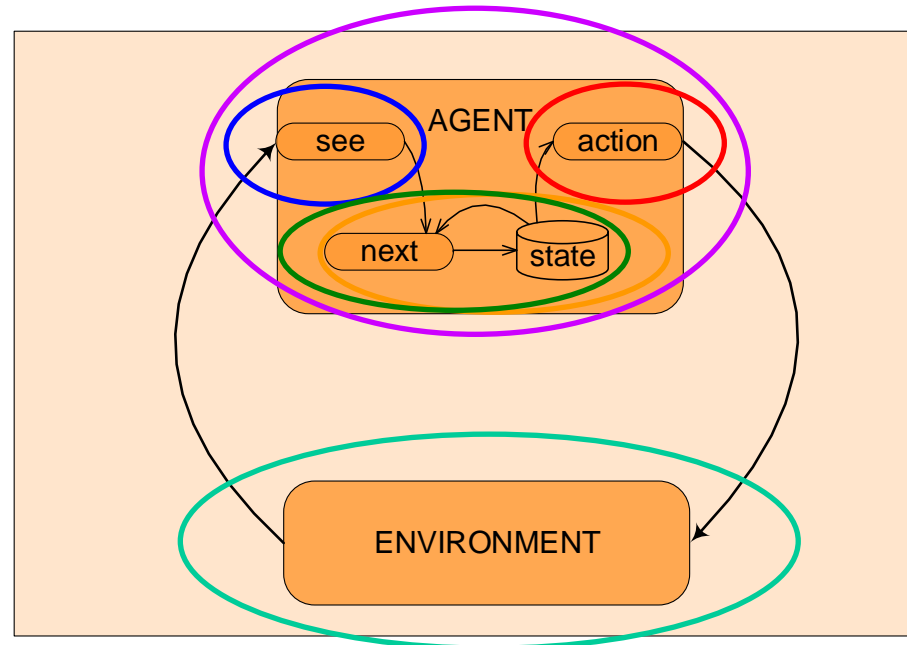
- Cognition is the ability to relate perception and action in a meaningful way determined by experience, learning and memory. *Mike Denham*
- A cognitive system possesses the ability of self-reflection (or at least self-awareness). *Horst Bischof*
- Cognition is gaining knowledge through the senses. *Majid Mermehdi*
- Cognition is the ability to ground perceptions in concepts together with the ability to manipulate concepts in order to proceed toward goals. *Christian Bauckhage*
- An artificial cognitive system is a system that is able to perceive its surrounding environment with multiple sensors, merge this information, reason about it, learn from it and interact with the outside world. *Barbara Caputo*
- Cognition is self-aware processing of information. *Cecilio Angulo*
- Cognitive Systems are ones that are able to extract and (most importantly) represent useful aspects of largely redundant, possibly irrelevant sensory information in a form that is most conducive to achieving a particular high level goal. *Sethu Vijayakumar*
- A cognitive system is a system that can change its behaviour based on reasoning, using observed evidence and domain knowledge. *Bob Fisher*
- Cognition is when I know what I am doing, when I can judge how good or bad it is, and explain why I am doing it. *Markus Vincze*
- Cognition is the ability to plan, reason, adapt and act according to high level motivations or goals and using a range of senses, typically including vision, and may be communicate. *Patrick Courtney*
- A cognitive system is an autonomous anti-entropy engine. *David Vernon*

Researchers' definitions

- Cognition is the ability to relate **perception** and **action** in a **meaningful** way determined by experience, learning and memory. *Mike Denham*
- A cognitive system possesses the ability of **self-reflection** (or at least self-awareness). *Horst Bischof*
- Cognition is **gaining knowledge** through the **senses**. *Majid Mermehdi*
- Cognition is the ability to **ground perceptions** in concepts together with the ability to **manipulate** concepts in order to **proceed** toward **goals**. *Christian Bauckhage*
- An artificial cognitive system is a system that is able to **perceive** its **surrounding environment** with multiple **sensors**, merge this information, **reason** about it, learn from it and **interact** with the outside world. *Barbara Caputo*
- Cognition is **self-aware** processing of information. *Cecilio Angulo*
- Cognitive Systems are ones that are able to extract and (most importantly) represent useful aspects of largely redundant, possibly irrelevant **sensory information** in a form that is most conducive to achieving a particular **high level goal**. *Sethu Vijayakumar*
- A cognitive system is a system that can **change its behaviour** based on **reasoning**, using **observed evidence** and domain knowledge. *Bob Fisher*
- Cognition is when **I know** what **I am doing**, when I can **judge** how good or bad it is, and **explain** why I am doing it. *Markus Vincze*
- Cognition is the ability to **plan**, **reason**, adapt and **act** according to high level **motivations or goals** and using a range of **senses**, typically including **vision**, and may be communicate. *Patrick Courtney*
- A cognitive system is an **autonomous anti-entropy** engine. *David Vernon*

Main emphasis

- Perception
- Action
- Reasoning, planning
- Goals
- Autonomy, self-awareness
- Environment



An example of a cognitive system

- Household robot Robi
- My command: "Fetch me a beer".



Example

- Sequence of actions:
 - The robot has to be attentive and has to listen for my command. [*attention, motivation*]
 - It has to hear me and understand my command. [*perception, speech recognition, communication*]
 - It has to set the corresponding goal and aiming at fulfilling it. [*goal, proactive behaviour*]
 - It has to know where the beer is located, it had to previously learn that. [*learning*]
 - He has to plan how to fetch the beer. [*planning*]
 - He has to plan the most appropriate path to the refrigerator, based on the map, which had to be previously built. [*navigation, map building*]
 - He has to move along the planned path. [*action – moving*]
 - On the way, it has to continuously monitor its path. [*perception, action*]
 - It has to avoid obstacles. [*perception, replanning, reactive behaviour*]

Example

- When arrives in front of the refrigerator, it has to position itself appropriately. [*embodiment, situatedness*]
- It has to know how to open the refrigerator. [*recognition of object affordances*]
- It has to search for the beer in the refrigerator (it has to learn in advance the corresponding appearance). [*perception, categorisation, learning*]
- It has to plan how to grasp the beer. [*planning*]
- It has to grasp the bottle suitably. [*action, visual servoing, haptic control*]
- It will take the reverse path and return to me. [*planning, navigation, action, perception, recognition*]
- Robi: "Here is your beer". [*communication*]

Cognitive systems

- Cognitive assistant
 - Explores the environment and builds the map
 - Learns to recognize objects
 - Understands object affordances
 - Knows to interpret verbal and nonverbal communication with persons
 - Detects new situations and reacts correspondingly
 - Operates robustly in real time in unconstrained domestic environment
- Basic functionalities are built in; they are further developed and extended by learning

Willow Garage



An example of a cognitive system

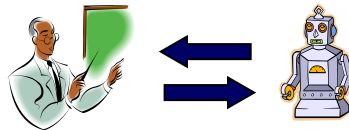
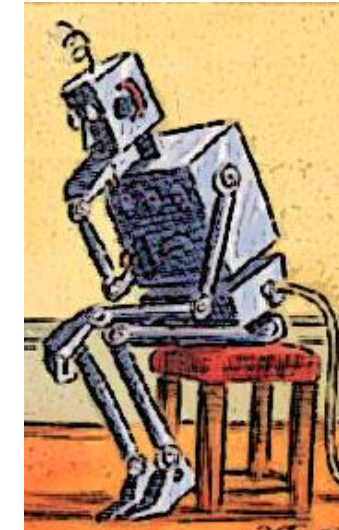
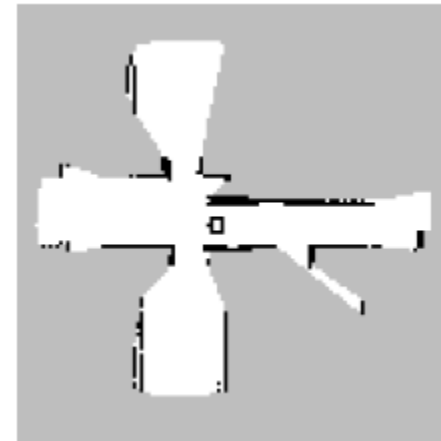
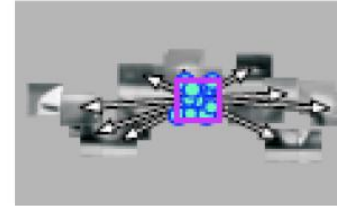
- Autonomous car
- City drive
- Competencies
 - Perception (image, 3D, collision)
 - Planning
 - Reasoning
 - Learning
 - Navigation
 - Obstacle avoidance
 - Action
 - Flexibility
 - Robustness
 - Efficiency
 - ...

Google self-driving car



Requirements of cognitive systems

- Perception
- Representations
- Recognition
- Learning
- Reasoning
- Planning
- Communication
- Action
- Architecture

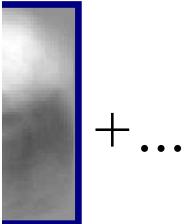
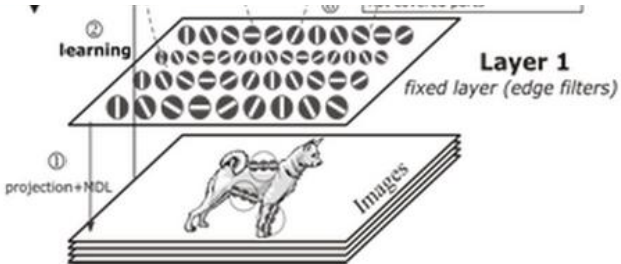
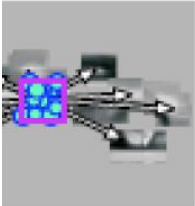
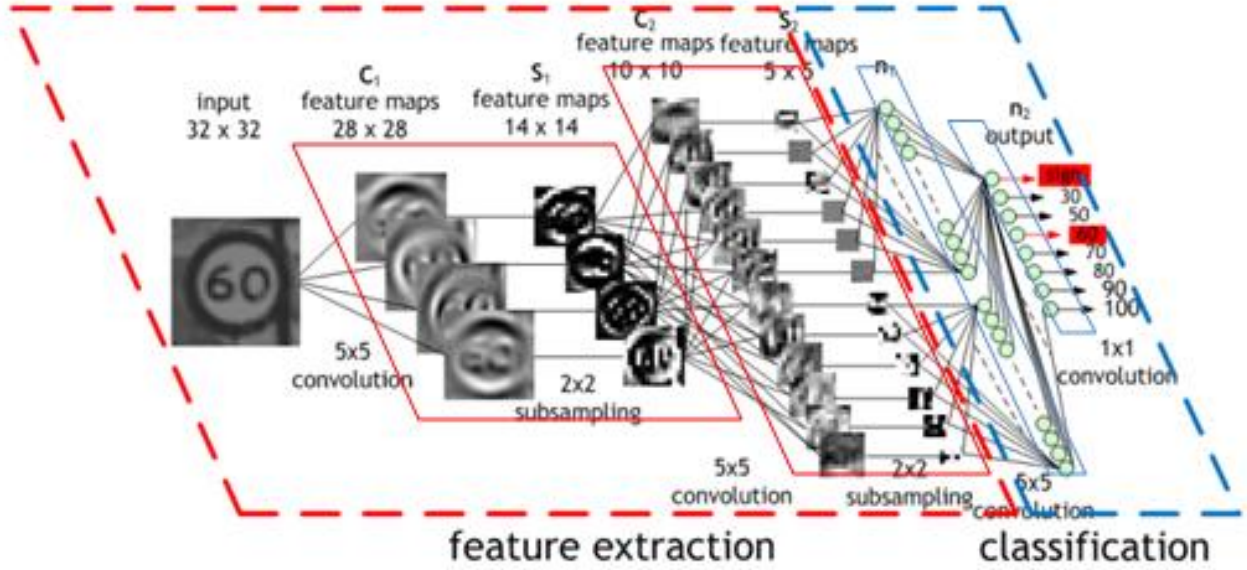
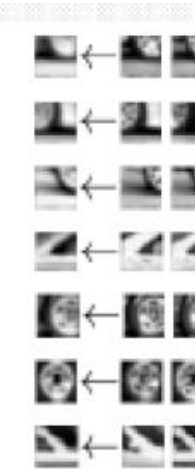
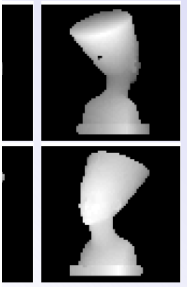


Perception

- Perception
 - Visual information (image, video; RGB, BW, IR,...)
 - Sound (speech, music, noise, ...)
 - Haptic information (haptic sensors, collision detectors, ect.)
 - Range/depth/space information (range images, 3D models, 3D maps, ...)
 - Many different modalities – very multimodal system
- Attention
 - Selective attention
 - Handling complexity of input signals

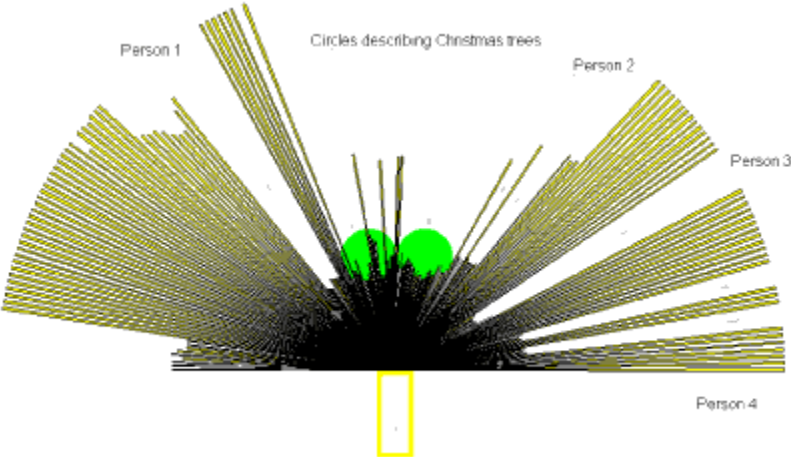
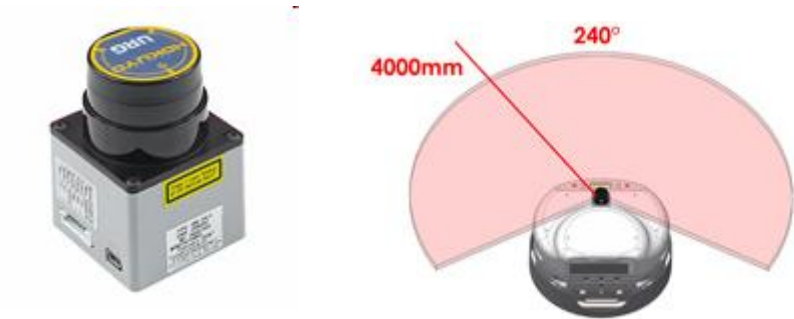


Representation of visual information

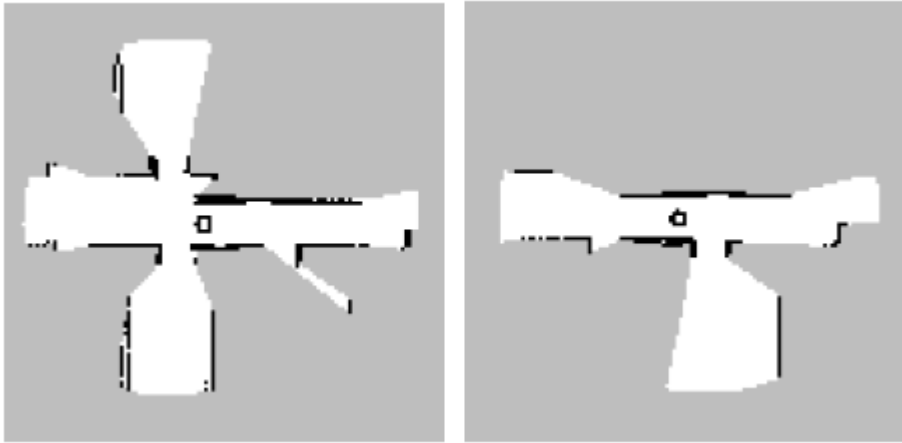
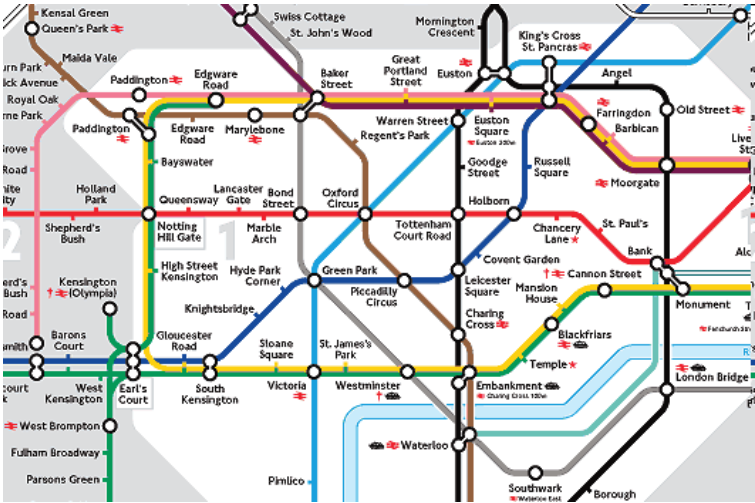


Representation of space

- Metric information

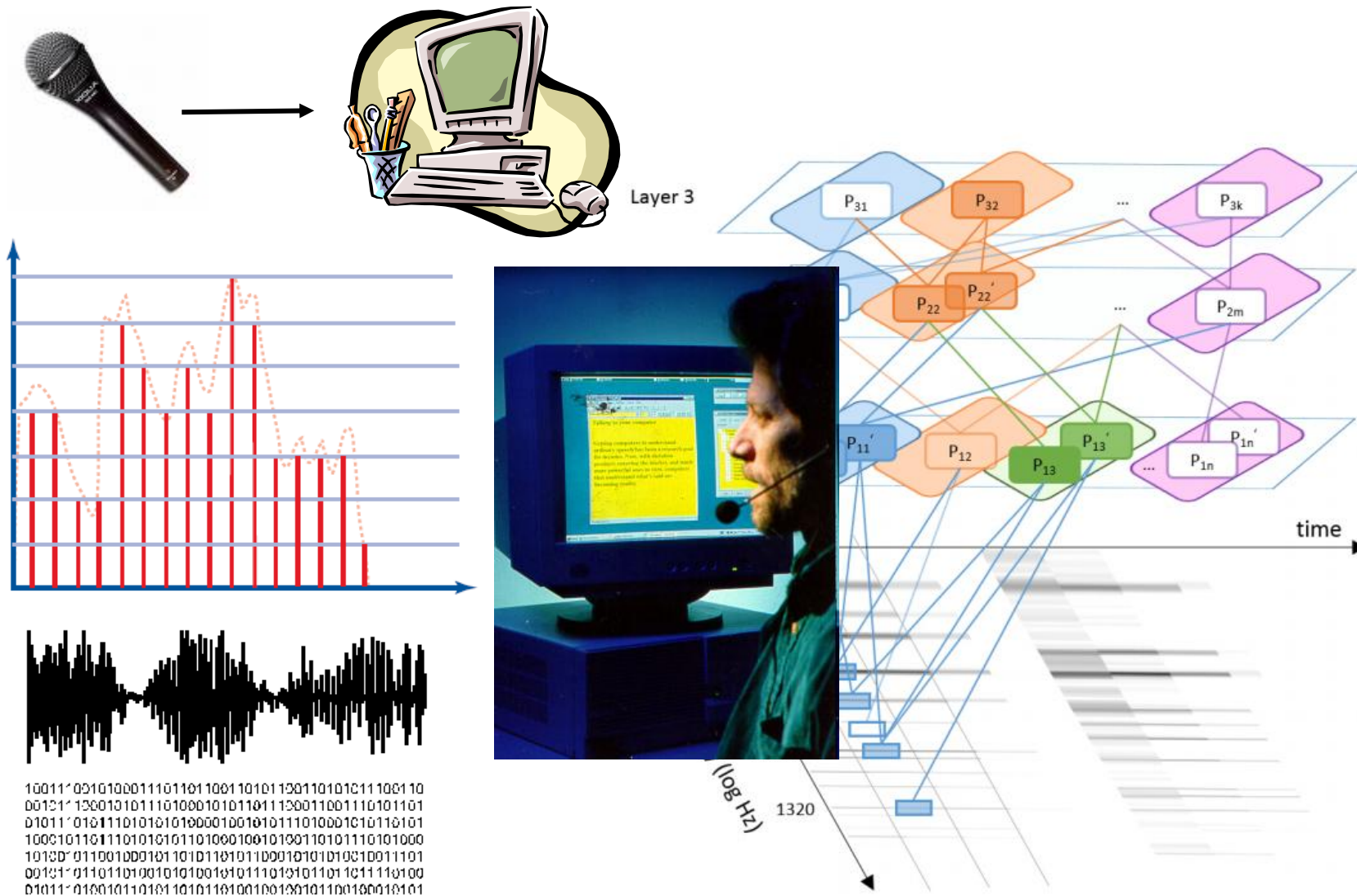


- Topological map

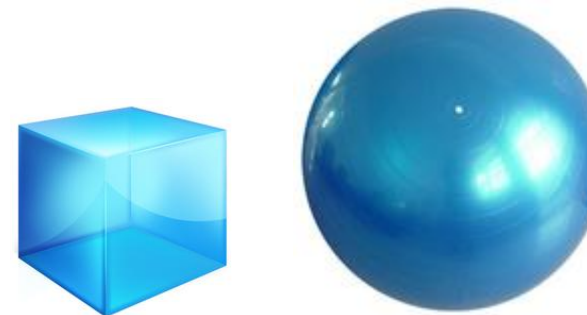
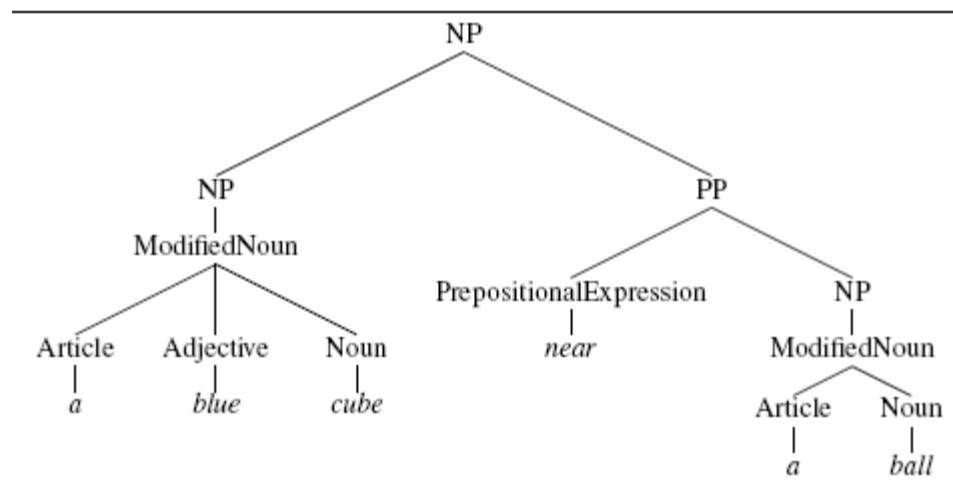


- Hierarchical representation

Representation of audio



Representation of linguistic information



$S \rightarrow \text{Command} \mid \text{Statement} \mid \text{Question} \mid S \text{ Conjunction } S$
 $\text{Command} \rightarrow VP$
 $\text{Statement} \rightarrow NP VP$
 $NP \rightarrow \text{Pronoun} \mid \text{Modified_Noun} \mid NP \text{ RelClause} \mid NP PP \mid NP$
 $\text{Conjunction } NP$
 $\text{Modified_Noun} \rightarrow \text{Noun} \mid \text{Article Noun} \mid \text{Adjective Noun} \mid \text{Article}$
 Adjectives Noun
 $\text{Noun} \rightarrow \text{Noun_Singular} \mid \text{Noun_Plural}$
 $PP \rightarrow \text{PrepositionalExpression } NP$
 $\text{RelClause} \rightarrow \text{RelPronoun } VP$

Representation of knowledge

1. Natural language

- understanding the meaning of the individual words
- *Spot is a brown dog and, like any dog, has four legs and a tail.*

2. Formal language

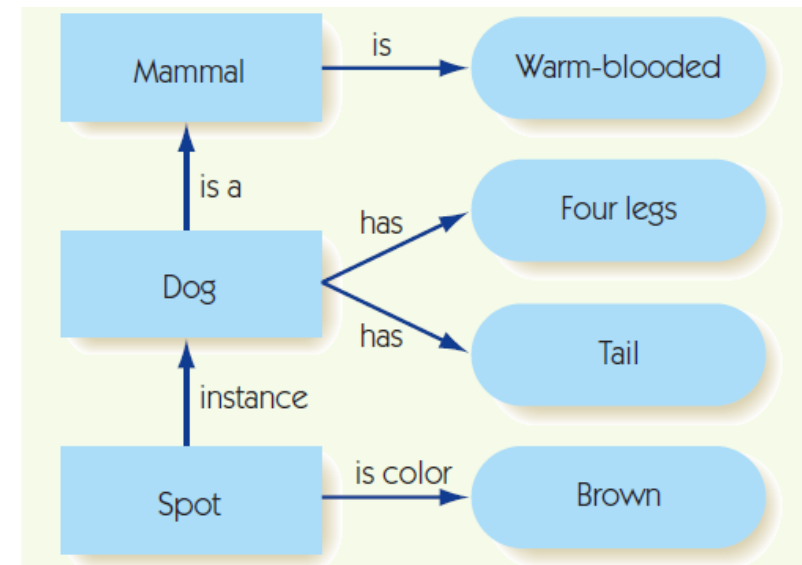
- Formal logic
- "Spot is a brown dog" : $dog(Spot) \text{ AND } brown(Spot)$
- "Every dog has four legs": $(\forall x) dog(x) \rightarrow four\text{-legged}(x)$

3. Graphical representation

- Knowledge is represented with nodes and edges
- Semantic nets

4. Ect.

- appropriateness, efficiency, scalability, suitability



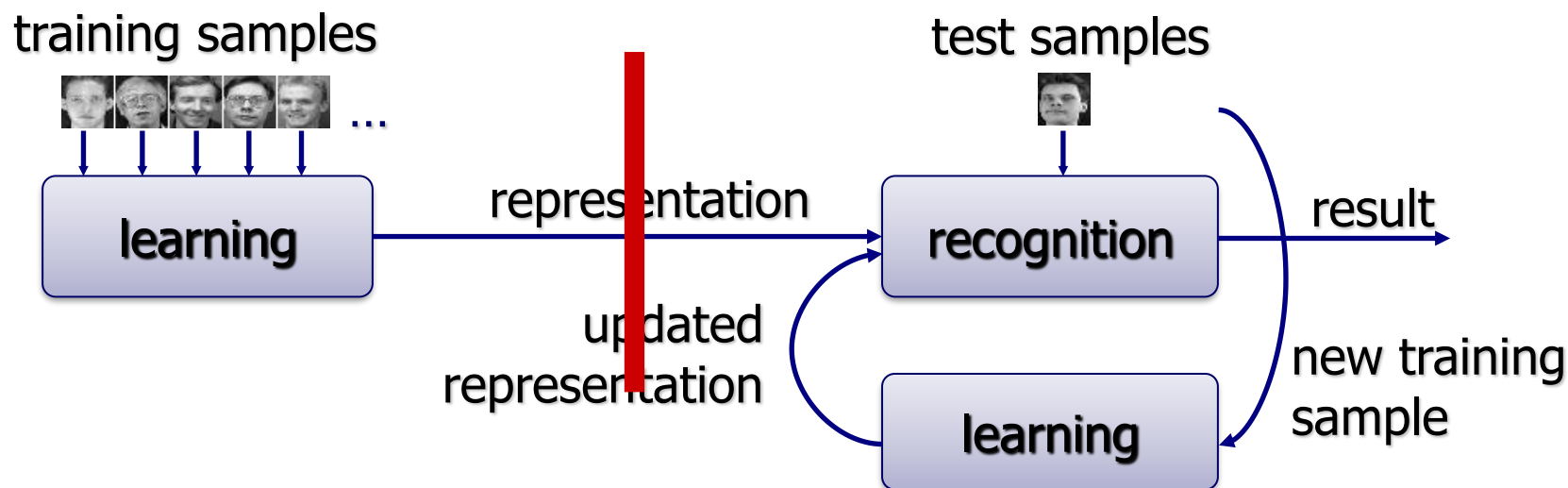
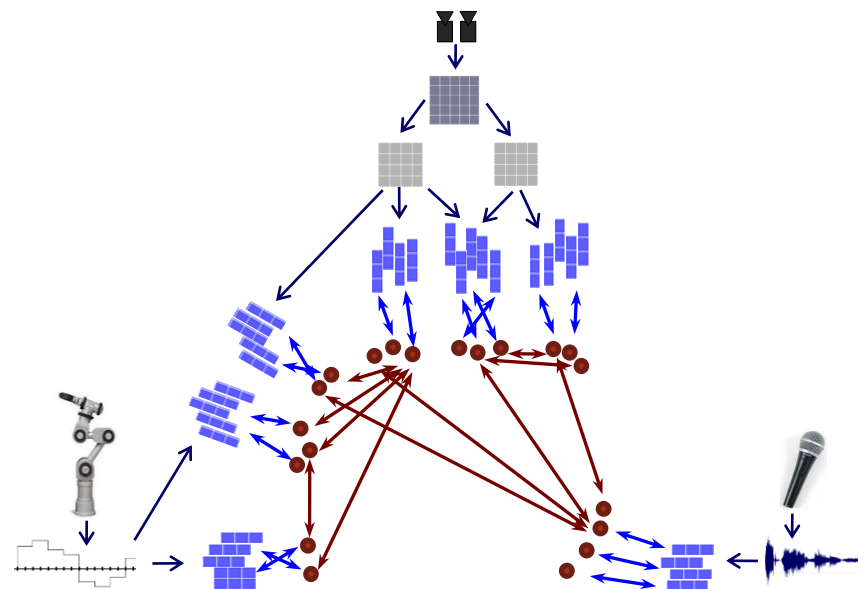
Recognition

- Recognition of
 - objects
 - properties
 - faces
 - rooms
 - affordances
 - actions
 - speech
 - relations
 - intentions,...
- Categorisation
- Multimodal recognition

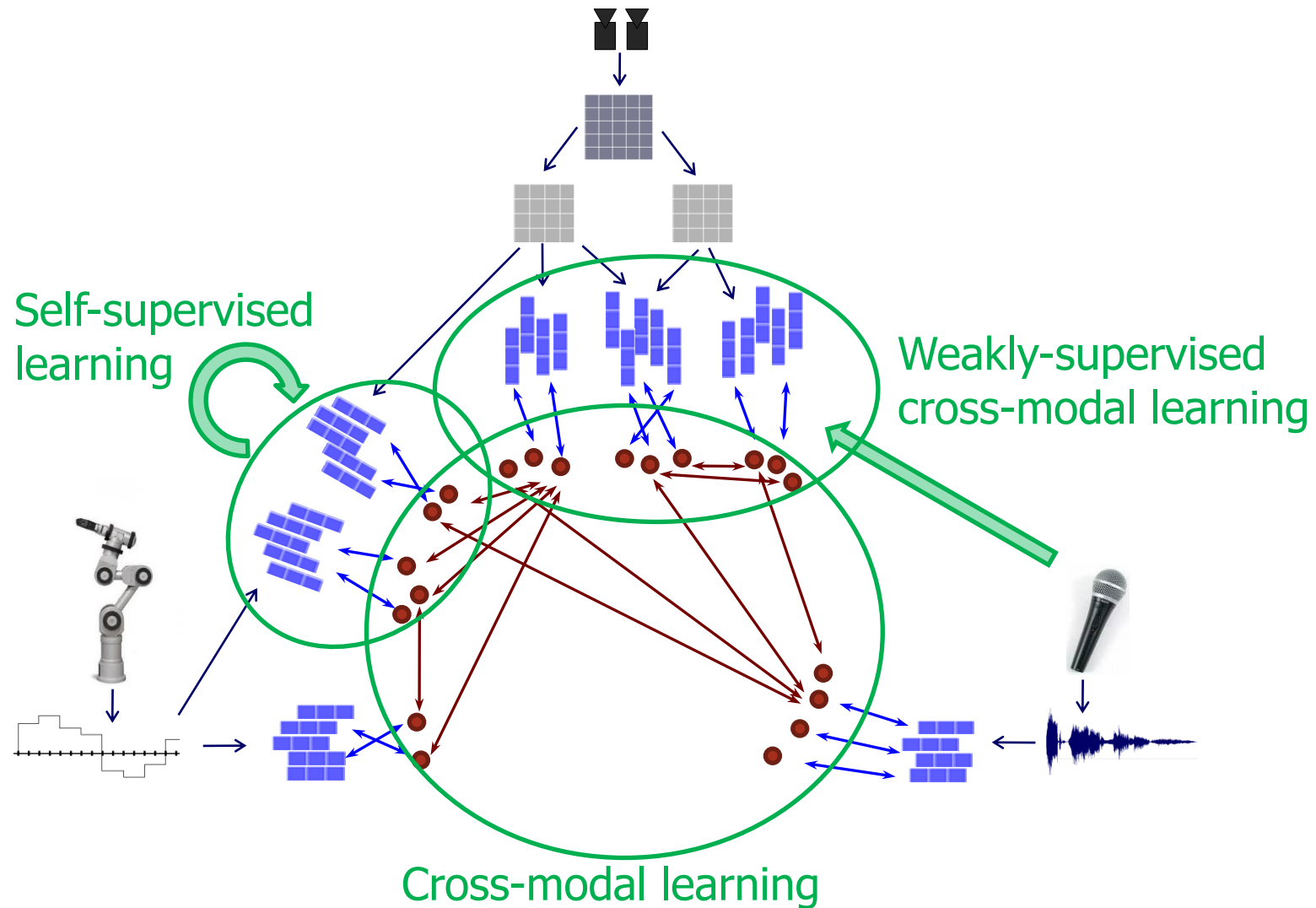


Learning

- Building representations
- Continuous learning
- Different learning modes
- Multimodal learning
- Forgetting, unlearning
- Robustness
- Nature:nurture

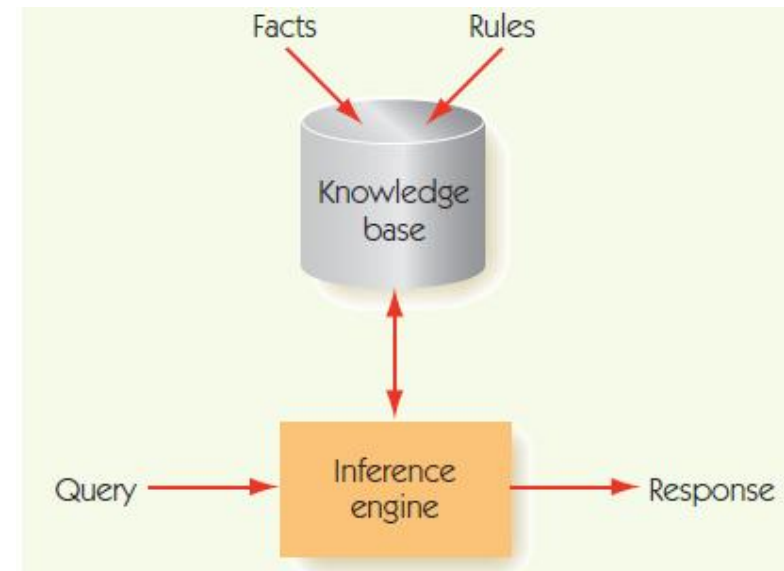
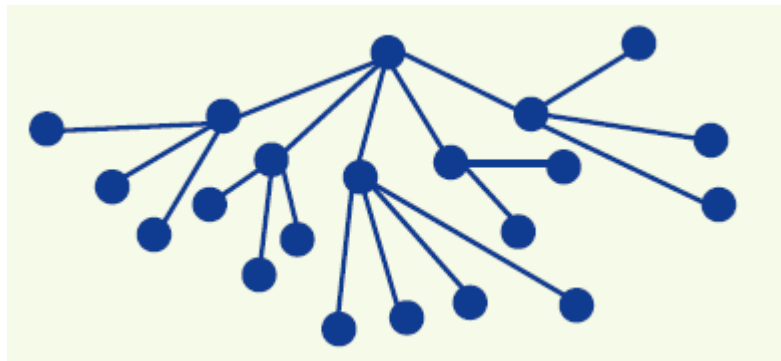
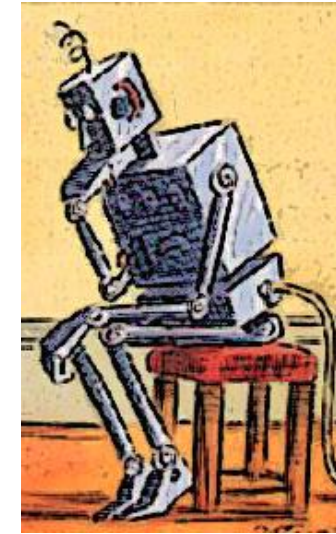


Multimodal learning



Reasoning

- Reasoning
 - In unpredictable environment
 - With incomplete information
 - With robot limitations
 - In dynamic environment
 - Considering different modalities
 - Self-awareness, introspection, knowledge gap detection and communication
 - Expert systems



Planning

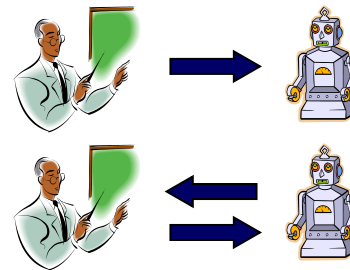
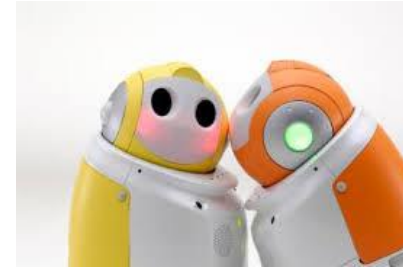
- Planning
 - In unpredictable environment
 - With incomplete information
 - With robot limitations
 - In dynamic environment



```
(:action move
:parameters (?a - agent ?to - location ?d - door)
:variables (?from - location)
:precondition (and
  (pos ?a : ?from)
  (doorstate ?d : open)
  (entrance ?d ?from) (entrance ?d ?to))
:effect (pos ?a : ?to))
```

Communication

- Communication
 - With human
 - With other (different) agents
 - In time and space
 - Transfer of knowledge
 - Clarification
 - Coordination
 - Taking initiative in the dialogue
 - Verbal and nonverbal communication
 - Symbol grounding
 - Semantic description
 - Learning language
 - syntax
 - ontology building
 - Learning using language

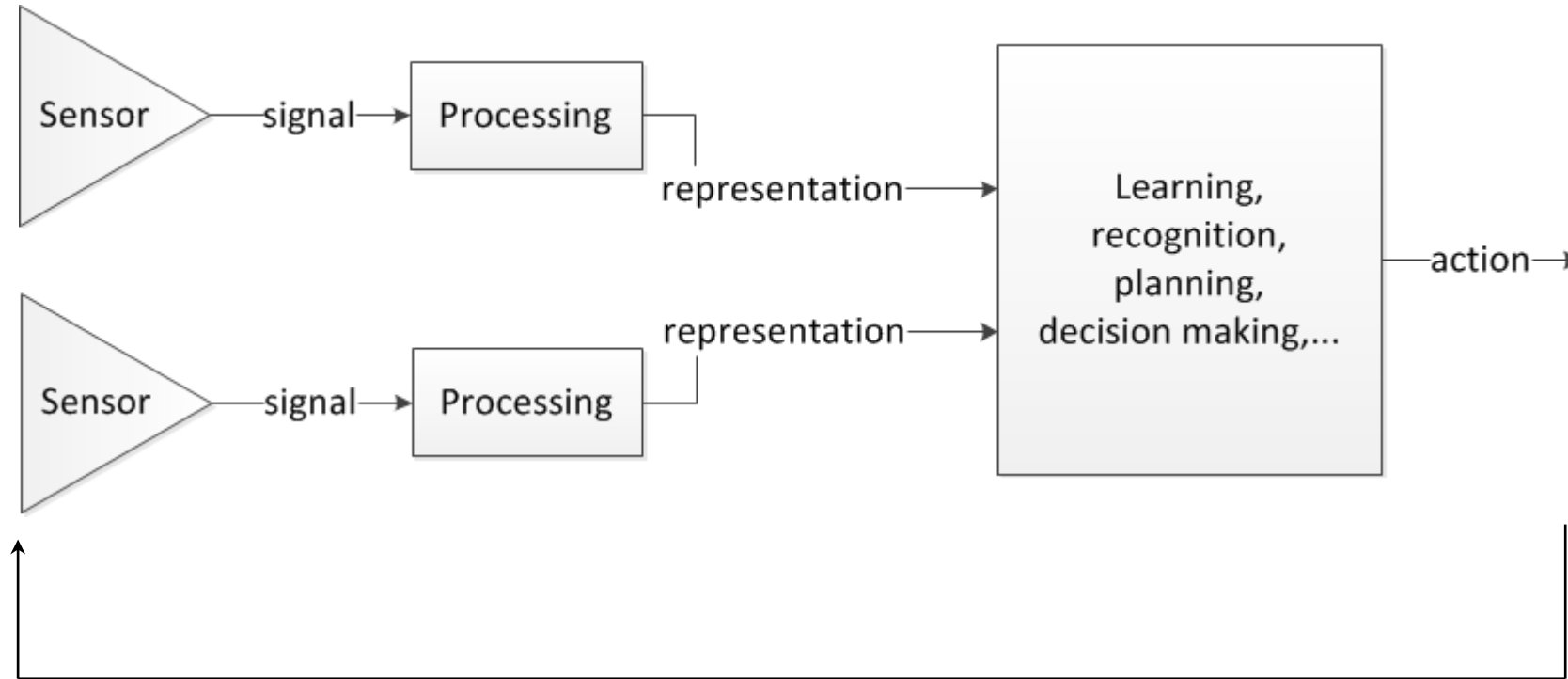


Action

- Object manipulation (manipulator)
 - Moving around in space (mobile robot)
 - Other: sound, light signals, other grippers, ect.
-
- Embodiment
 - Situatidness

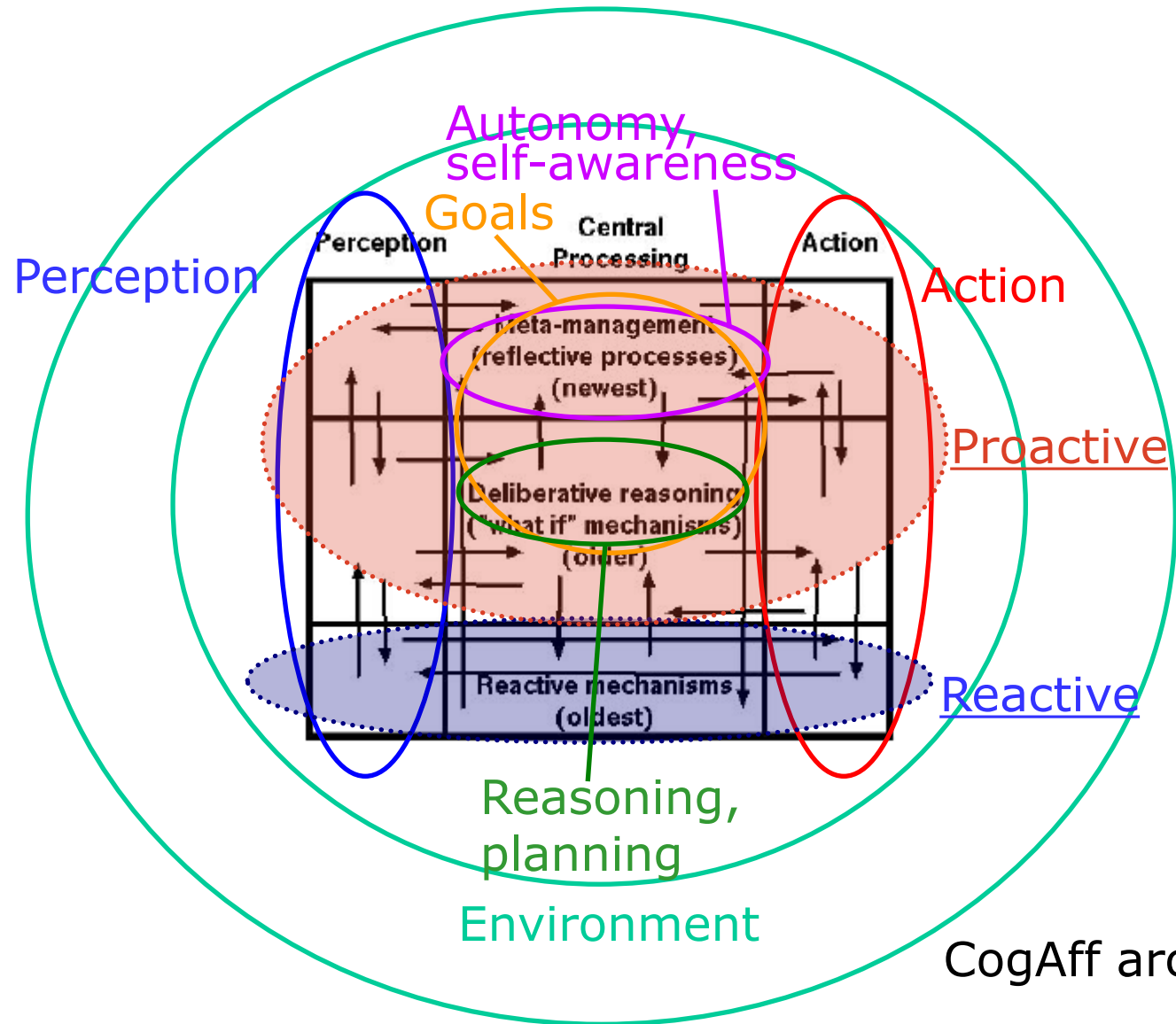


Perception – action cycle



- Large abstraction of the real world

Architecture



CogAff architecture

Examples – PR2



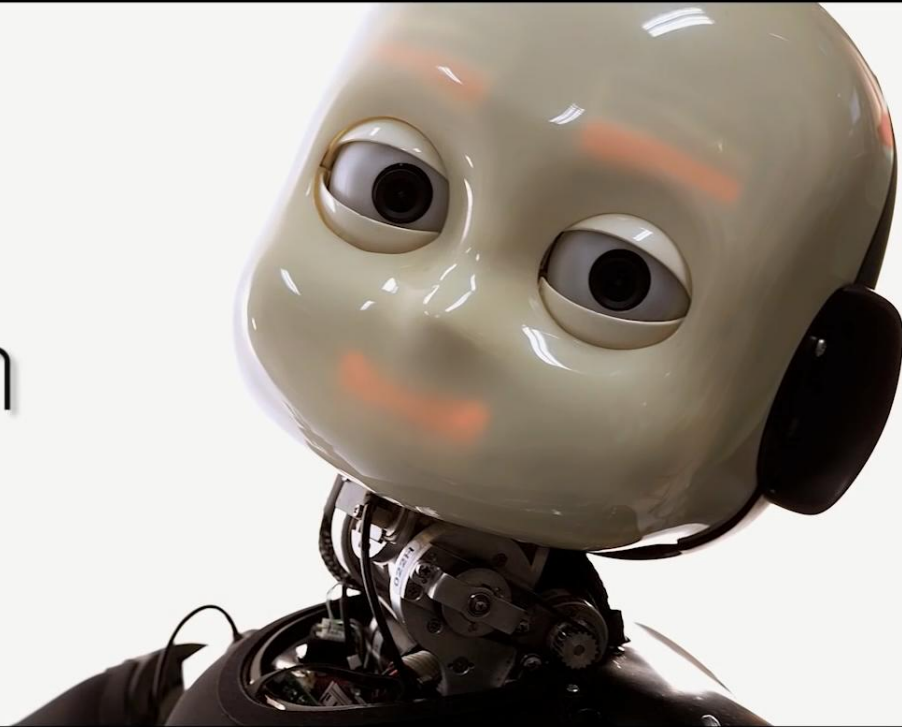
U Tokyo, TUM
Willow Garage
UC Berkley



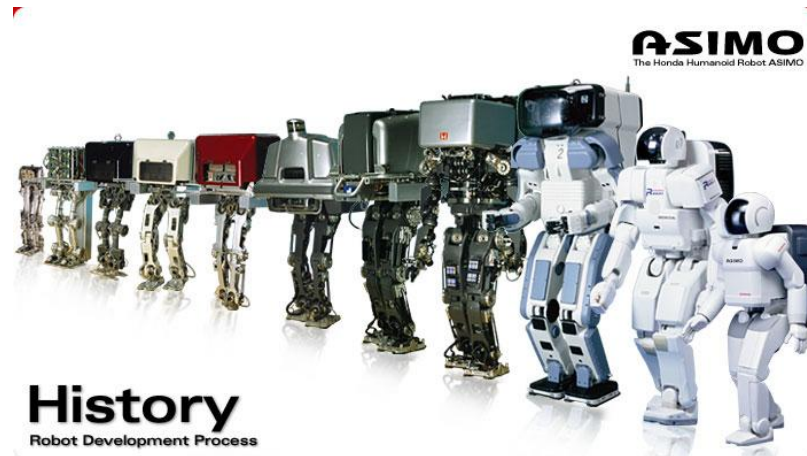
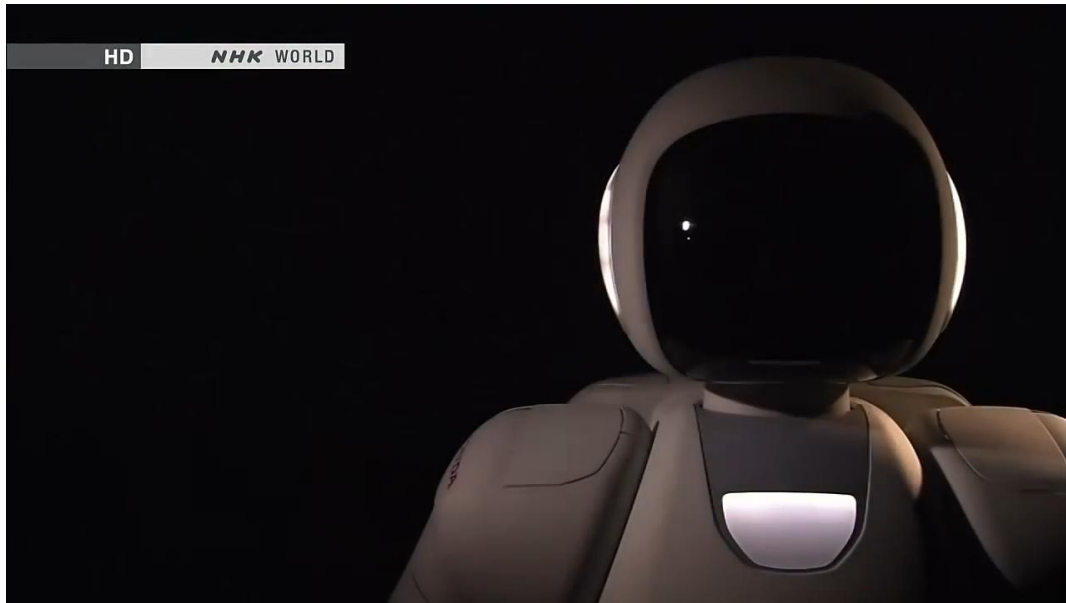
Examples - iCub

IIT

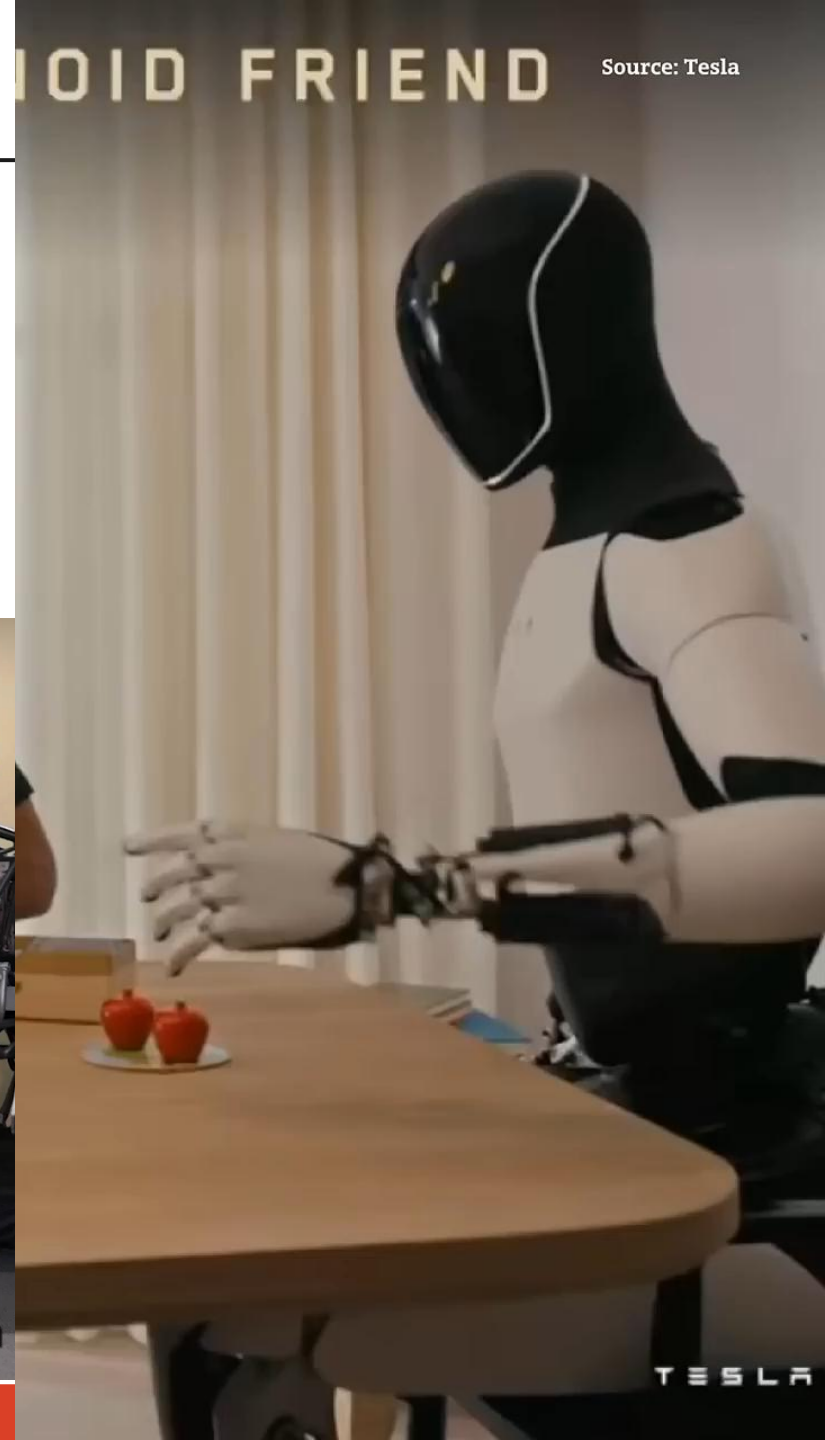
THE iCub PROJECT:
living 10 years with
a humanoid robot



Examples - Asimo

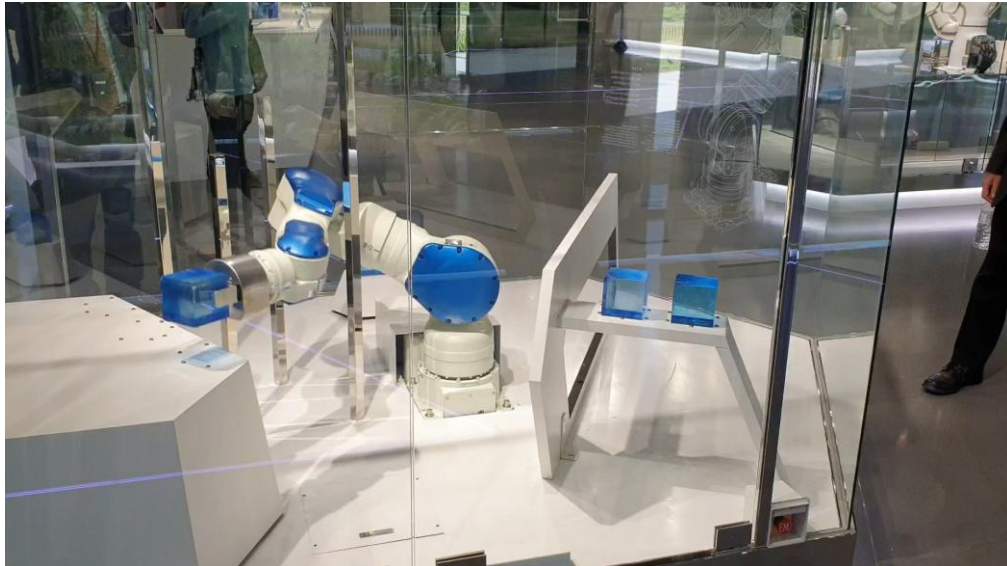
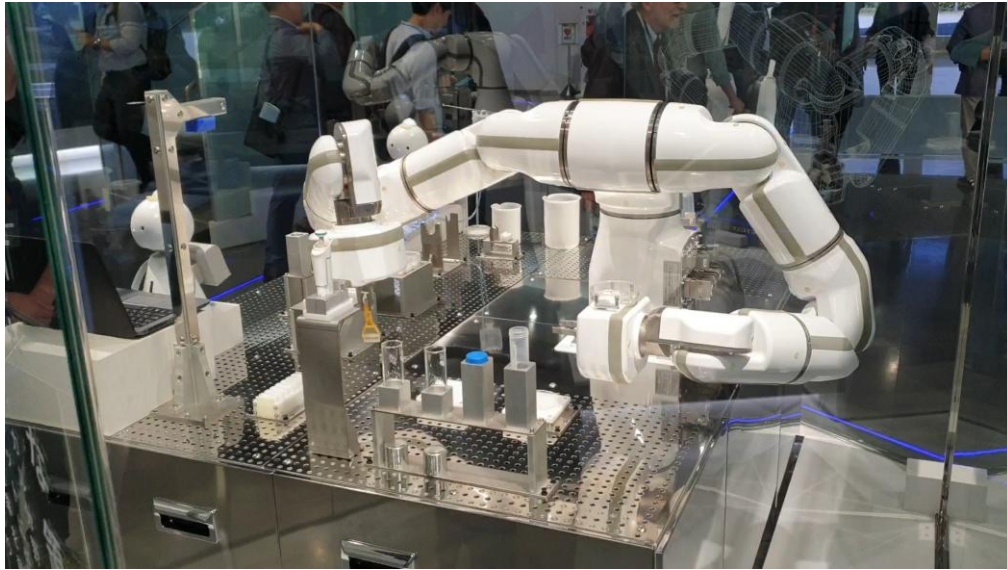


Examples – Boston Dynamics, Tesla



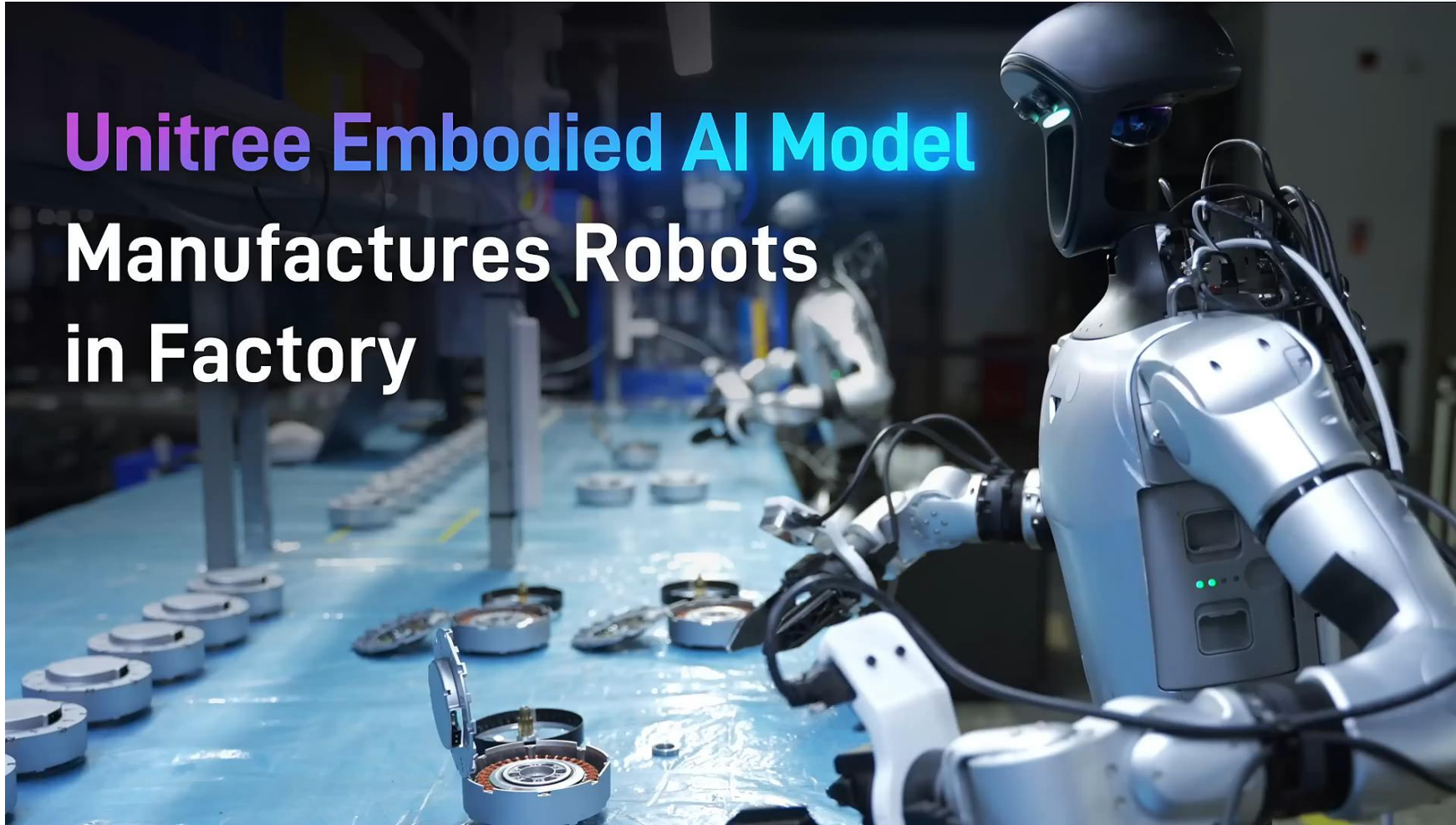
Source: Tesla

Examples - Yaskawa

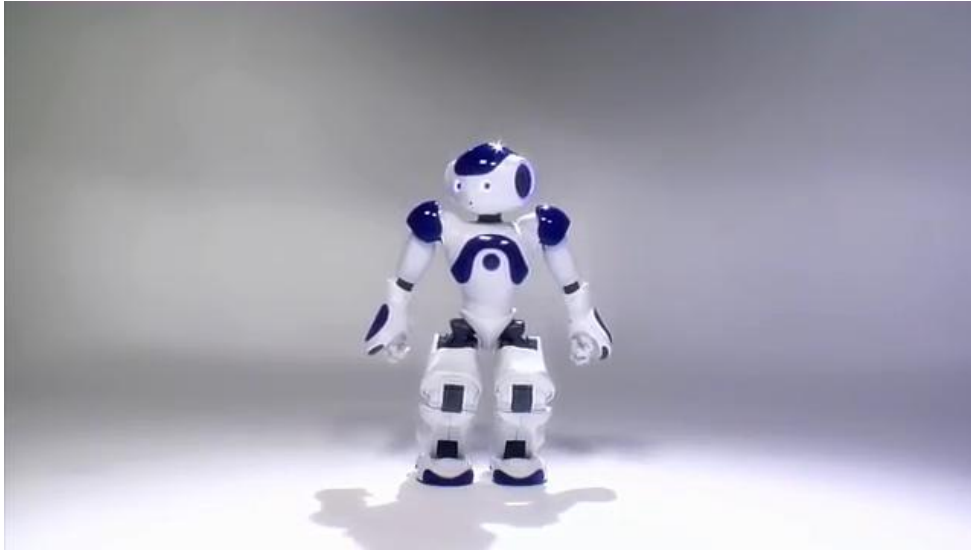


Examples Unitree

Unitree Embodied AI Model
Manufactures Robots
in Factory



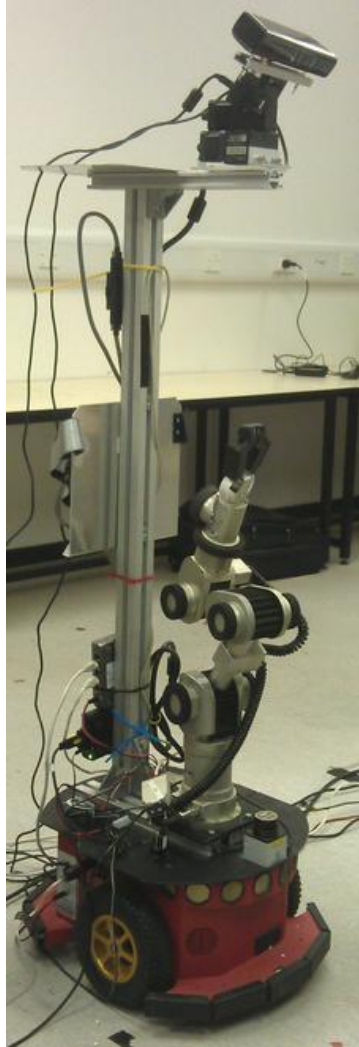
Examples - Nao



Aldebaran Robotics



Expero, FRI LUI



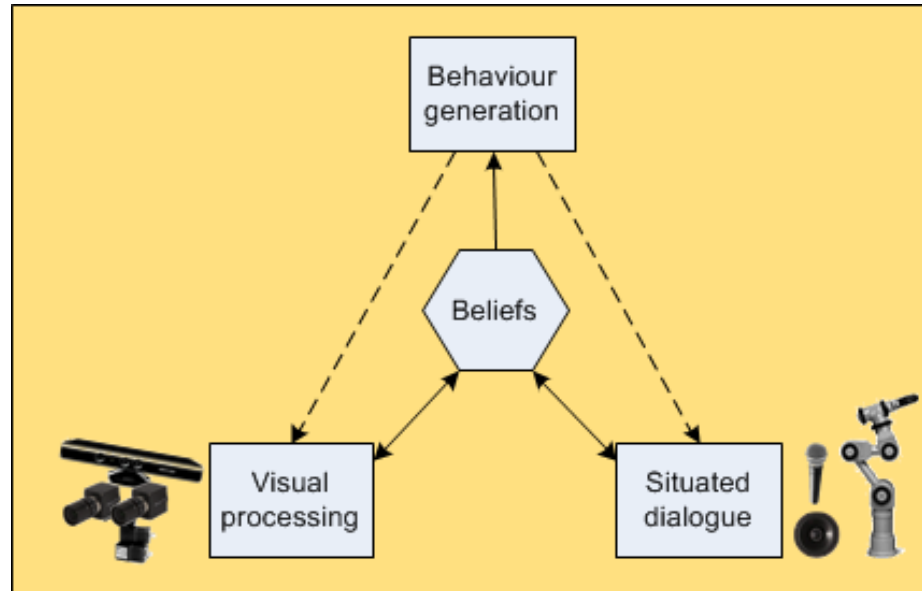
FRI, LUVSS



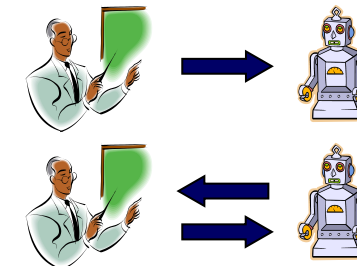
CogX, <http://cogx.eu/results/george/>

Curious robot George

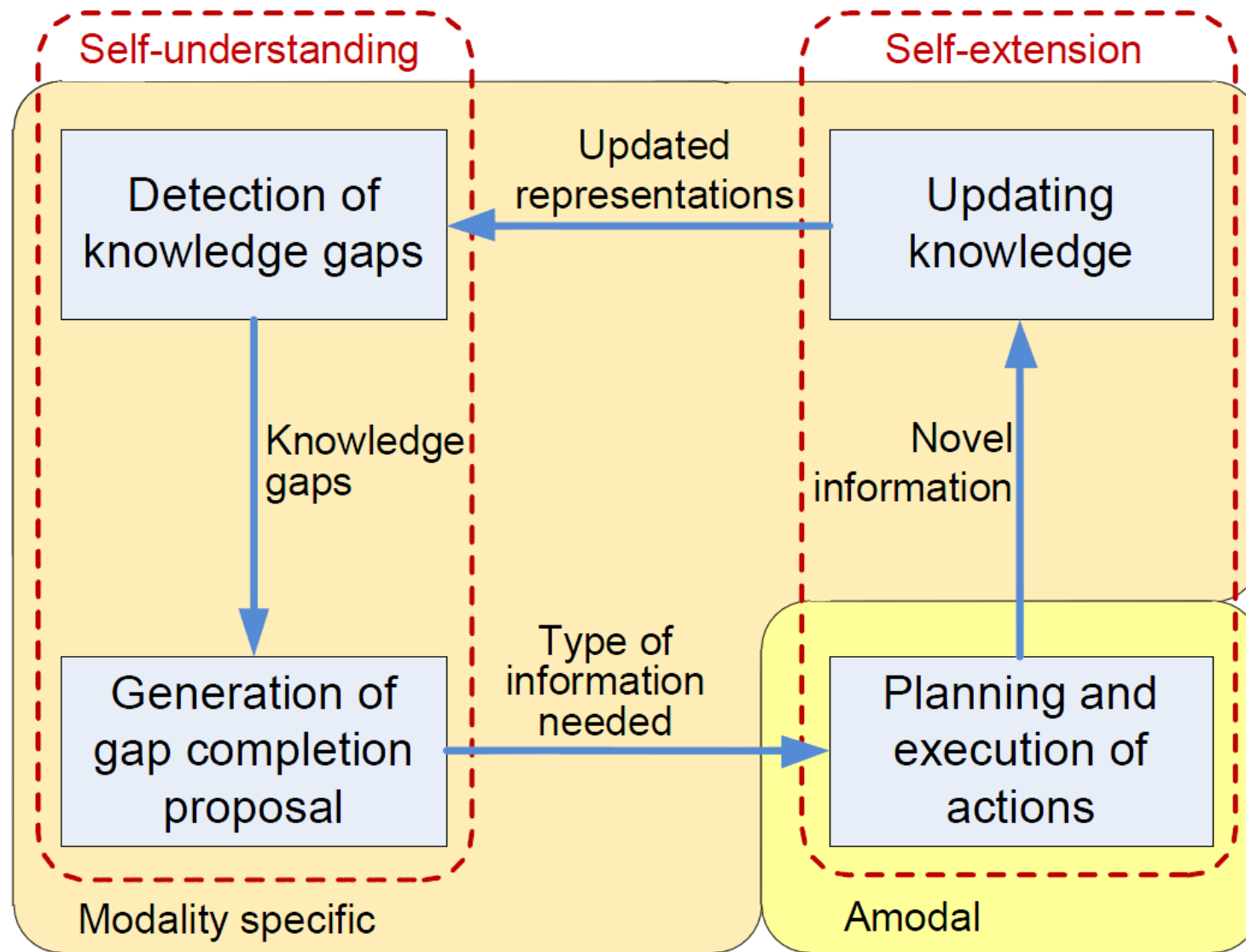
- Incremental learning in a dialogue with a human
- Curiosity driven learning
- Learning categorical knowledge



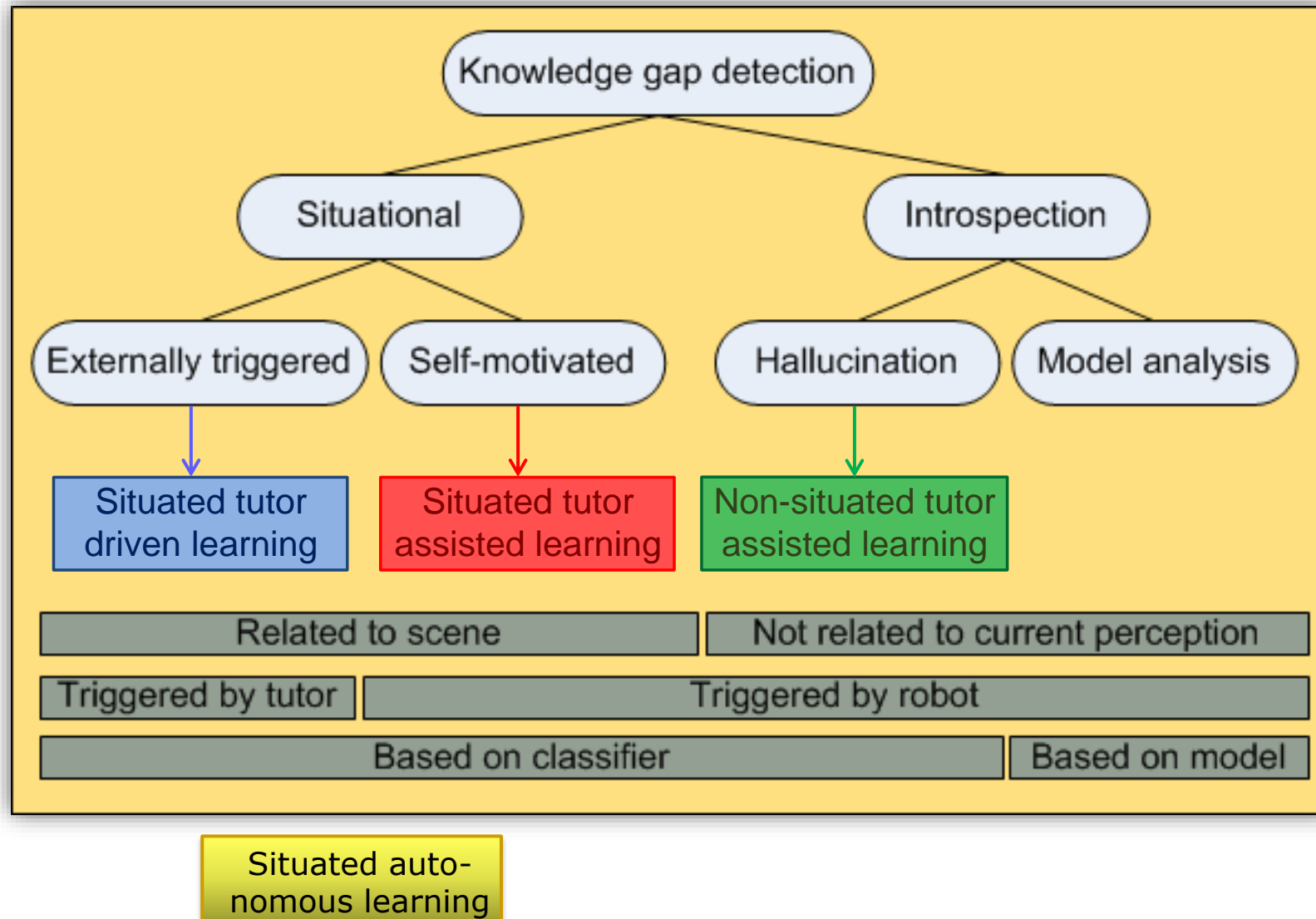
COGNITIVE SYSTEMS THAT
SELF-UNDERSTAND AND SELF-EXTEND



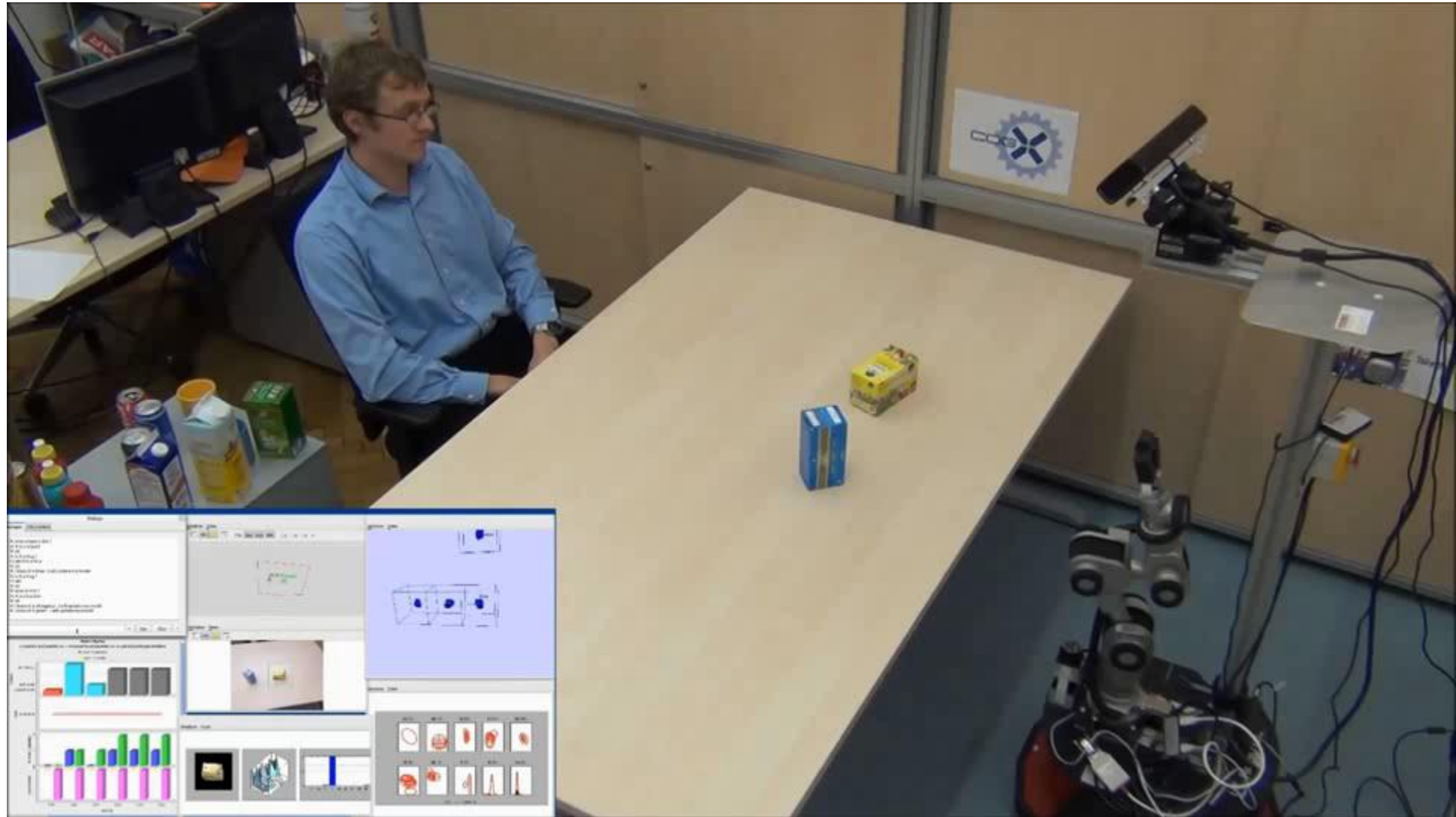
Self-understanding for self-extension



Learning mechanisms

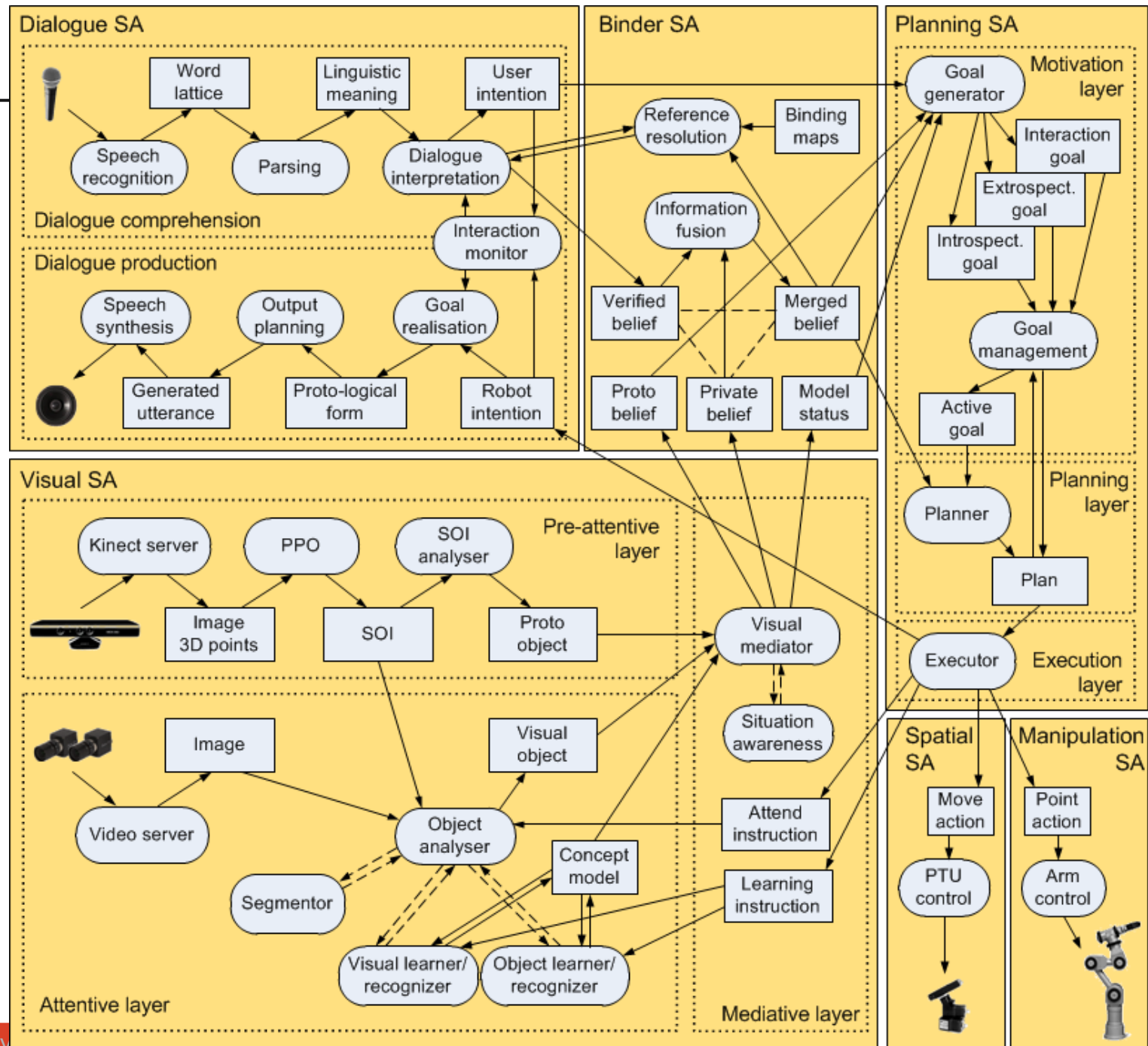


Video



<http://cogx.eu/results/george>

System



Conclusion

- Cognitive systems are
 - intelligent
 - very heterogeneous and asynchronous
 - coherent
 - multimodal
 - They continuously upgrade their knowledge by learning
 - They communicate with a human
 - They interact with the environment
 - They move around the environment
 - They are able of autonomous reasoning and decision making
- Literature: SKOČAJ, D., VREČKO, A., MAHNIČ, M., JANIČEK, M., KRUIJFF, GJ, HANHEIDE, M., HAWES, N., WYATT, J., KELLER, T., ZHOU, K., ZILLICH, M., KRISTAN, M. An integrated system for interactive continuous learning of categorical knowledge. *Journal of experimental & theoretical artificial intelligence*, ISSN 0952-813X. [Print ed.], 2016, vol. , no. , str. 1-26

Conclusion

T-60



T-30



T



T+30

