Development of intelligent systems (RInS)

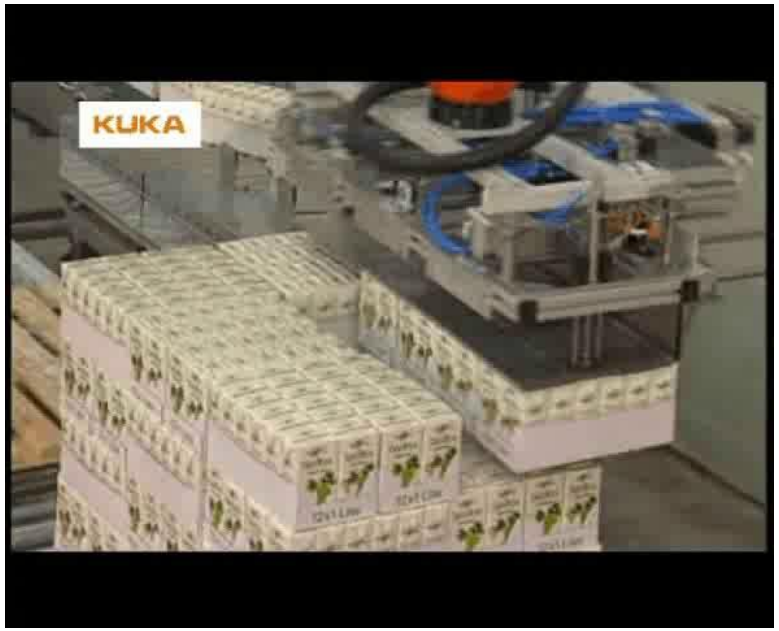
Cognitive robot systems

Danijel Skočaj
University of Ljubljana
Faculty of Computer and Information Science

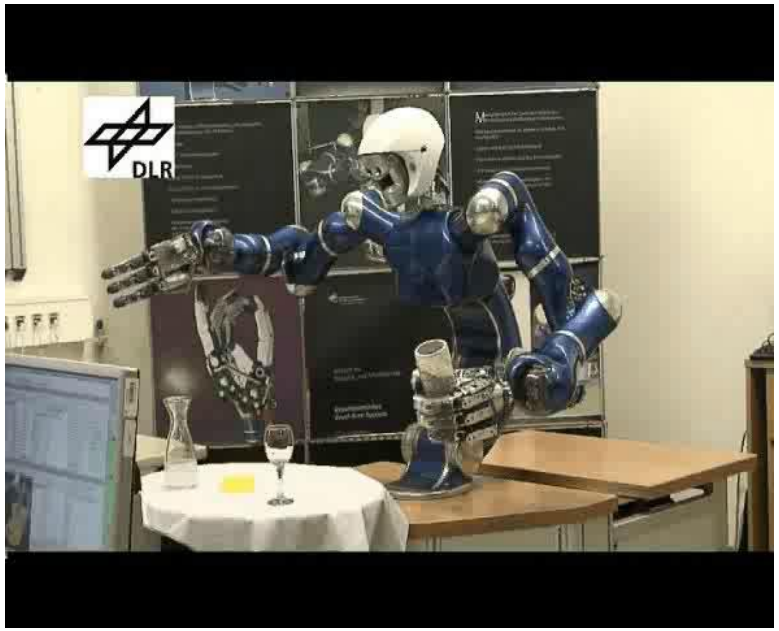
Academic year: 2023/2024

Robotics

- Routine industrial robotic system



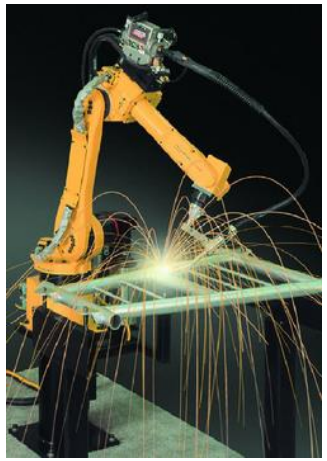
EURON video



EURON video

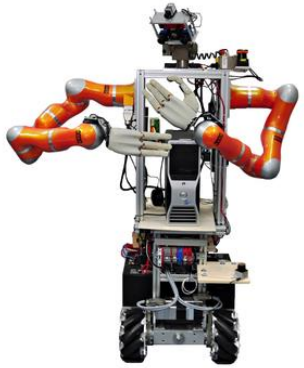
- Intelligent artificial visual cognitive system

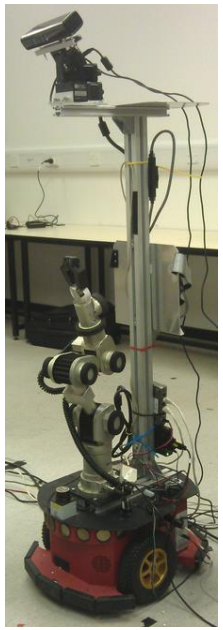
Cognitive robot systems



industrial robots

cognitive 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

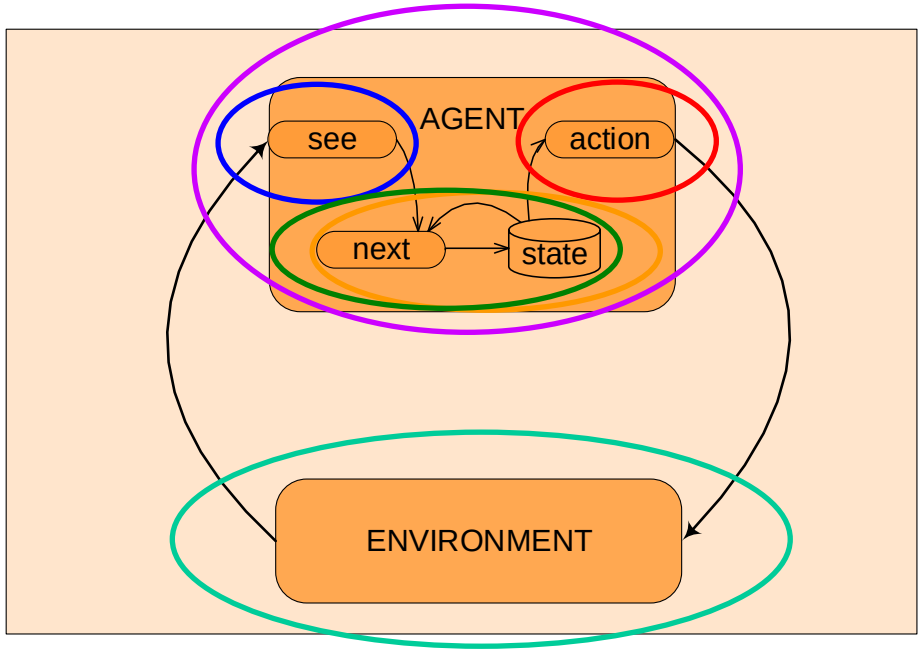
- Cognition is the ability to relate perception and action in a meaningful way determined by experience, learning and memory. *Mike Denham*
- A cognitive system possesses the ability of self-reflection (or at least self-awareness). *Horst Bischof*
- Cognition is gaining knowledge through the senses. *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,* situatidness*]*
- 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

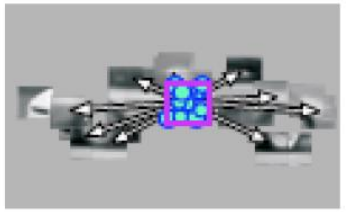
An example of a cognitive system

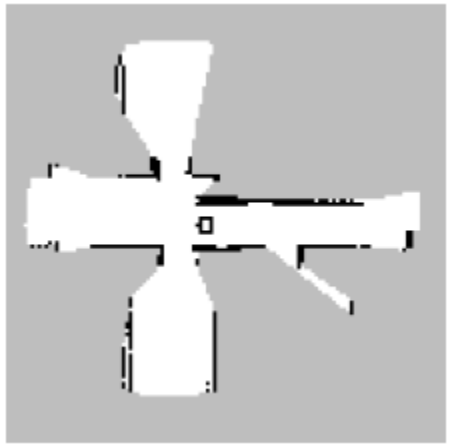
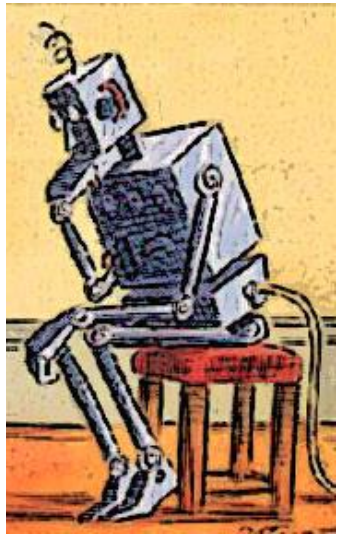
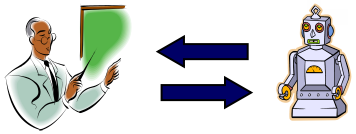
- Autonomous car
- City drive
- Competencies
  - Perception (image, 3D, collision)
  - Planning
  - Reasoning
  - Learning
  - Navigation
  - Obstacle avoidance
  - Action
  - Flexibility
  - Robustness
  - Efficiency
  - …

Google self-driving car

Requirements of cognitive systems

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

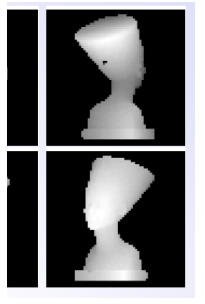



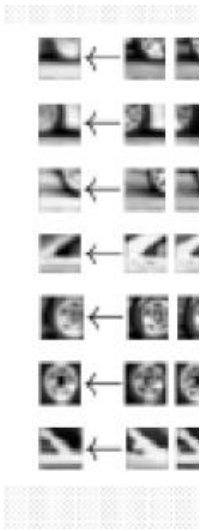





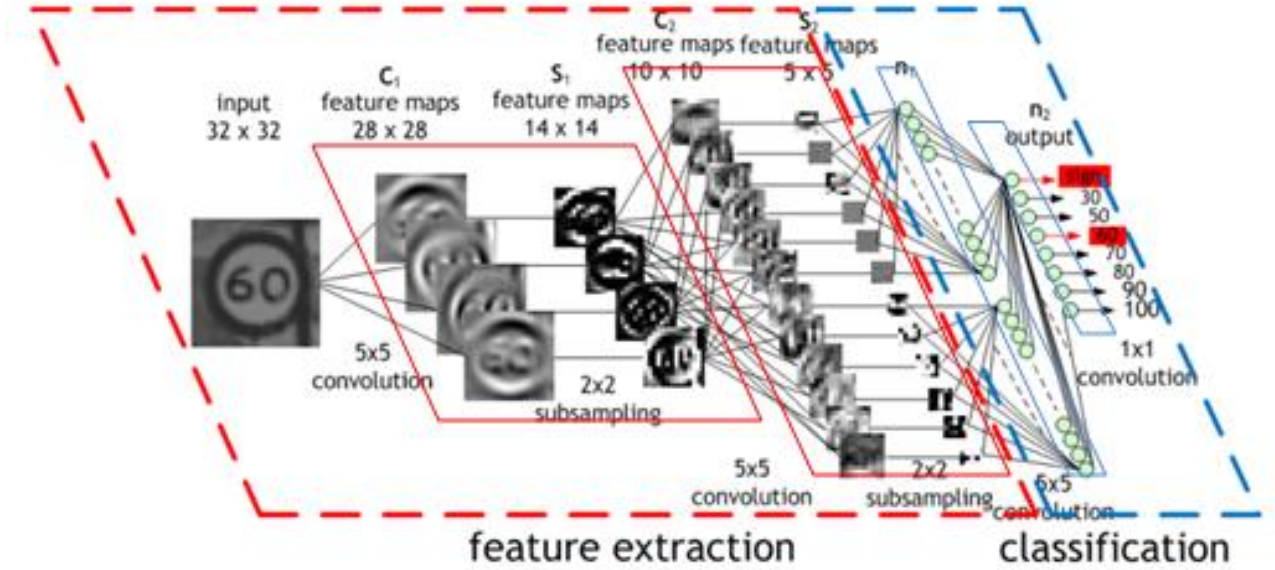
Perception

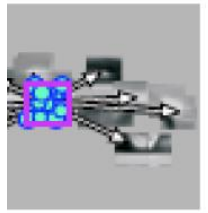
- Perception
  - Visual information (image, video; RGB, BW, IR,…)
  - Sound (speech, music, noise, …)
  - Haptic information (haptic sensors, collision detectors, ect.)
  - Range/depth/space information (range images, 3D models, 3D maps, …)
  - Many different modalities – very multimodal system
- Attention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

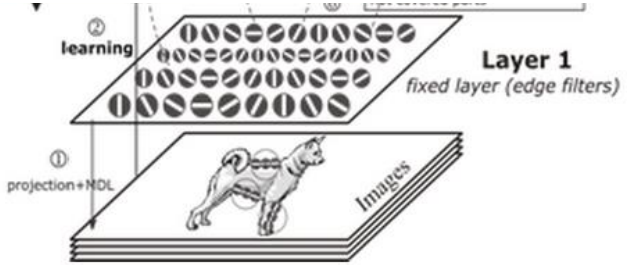
Representation of visual information

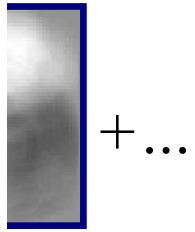






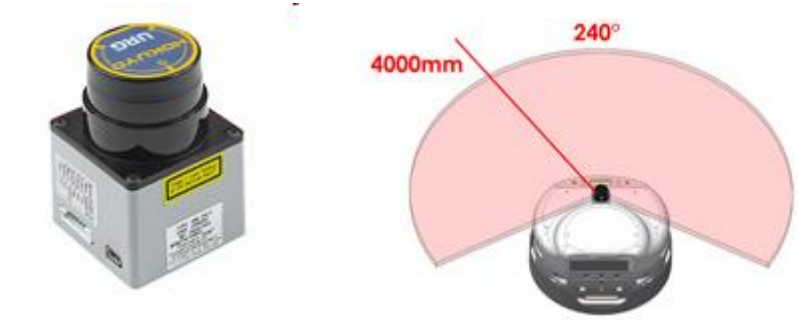


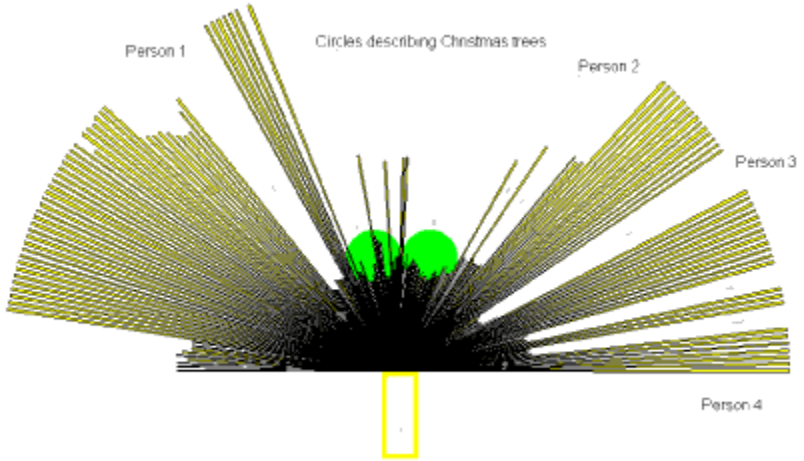




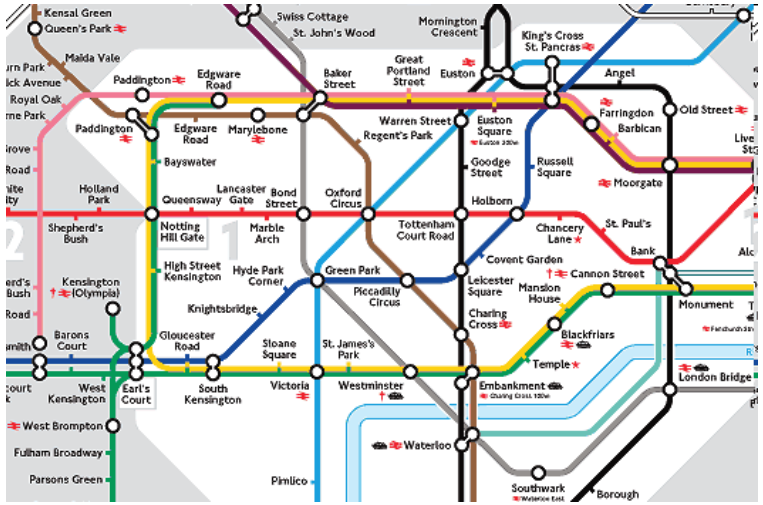
Representation of space

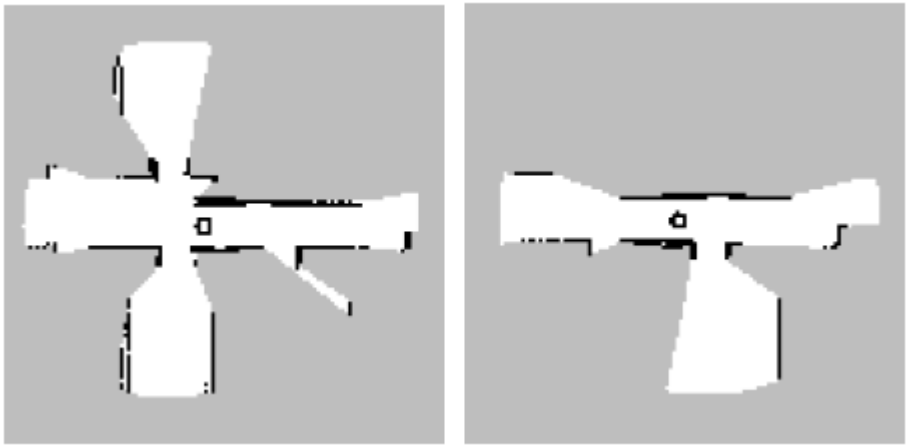
- Metric information





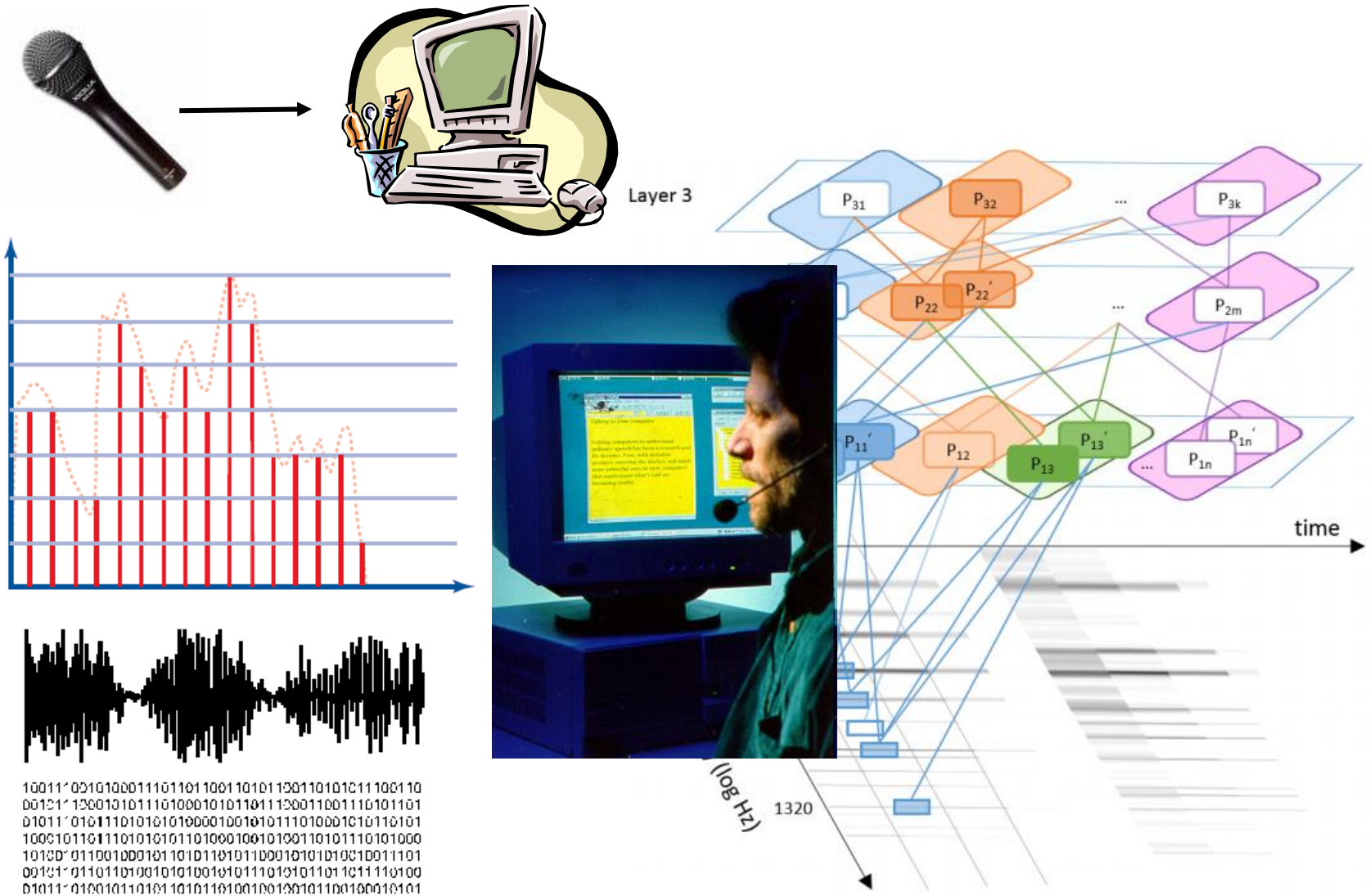
- Topological map



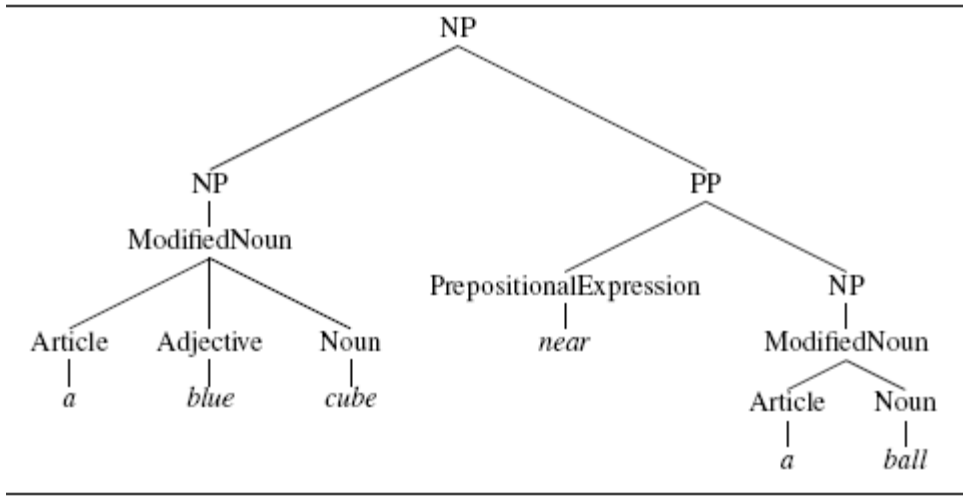


- Hierarchical representation

Representation of audio



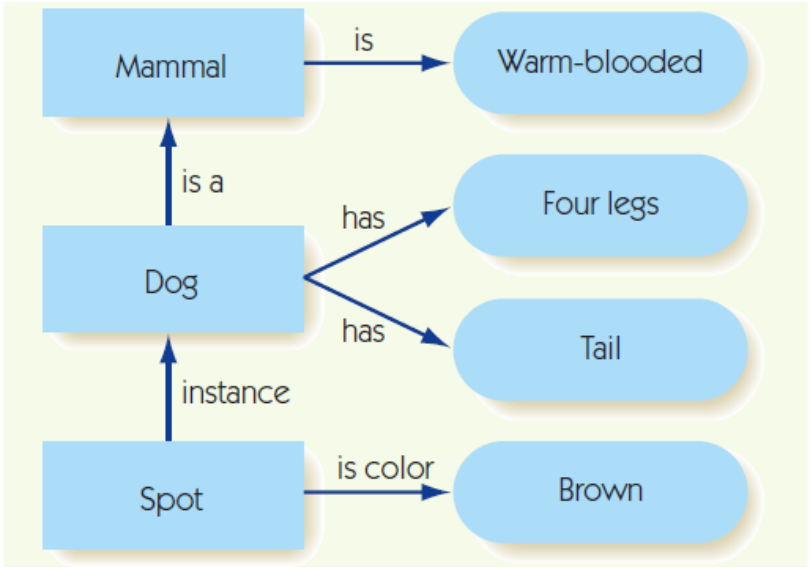
Representation of linguistic information



S → *Command* | *Statement* | *Question* | *S Conjunction S*
Command → *VP*
Statement → *NP VP*
NP → *Pronoun* | *Modified_Noun* | *NP RelClause* | *NP PP* | *NP Conjunction NP*
Modified_Noun → *Noun* | *Article Noun* | *Adjective Noun* | *Article Adjectives Noun*
Noun → *Noun_Singular* | *Noun_Plural*
PP → *PrepositionalExpression NP*
RelClause → *RelPronoun VP*

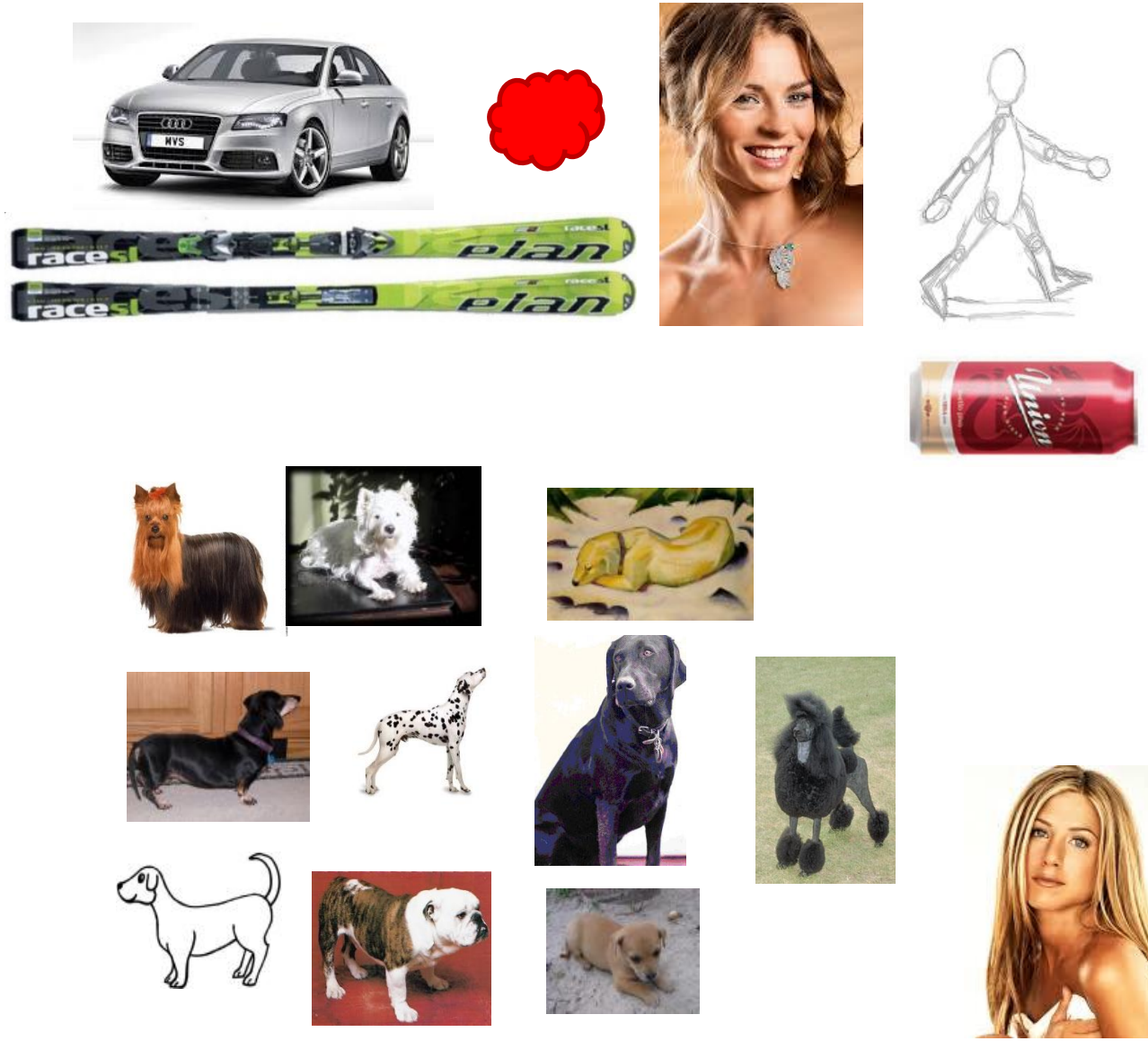
Representation of knowledge

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) AND brown(Spot)*
   - "Every dog has four legs": *(∀x) dog(x) -> four-legged(x)*
3. Graphical representation
   - Knowledge is represented with nodes and edges
   - Semantic nets
4. Ect.
   - appropriateness, efficiency, scalability, suitability



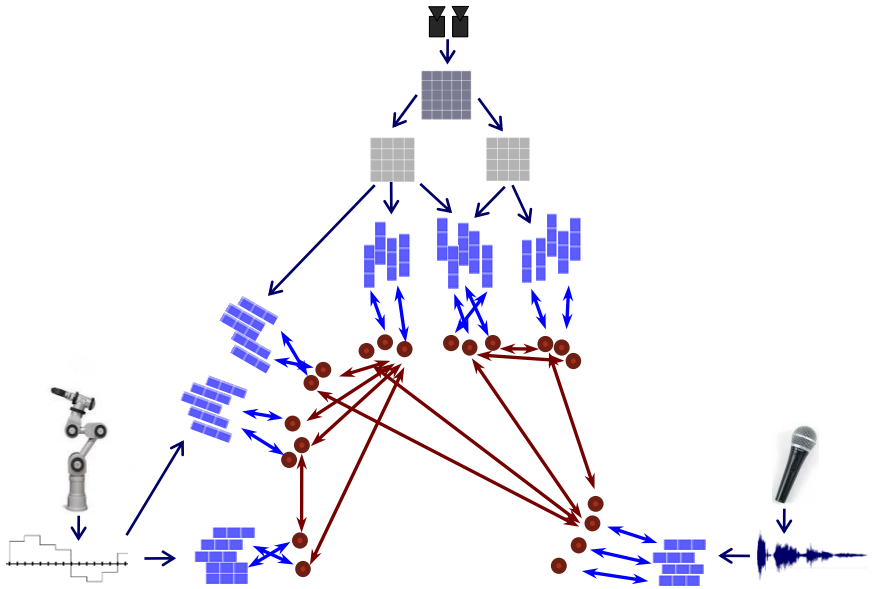
Recognition

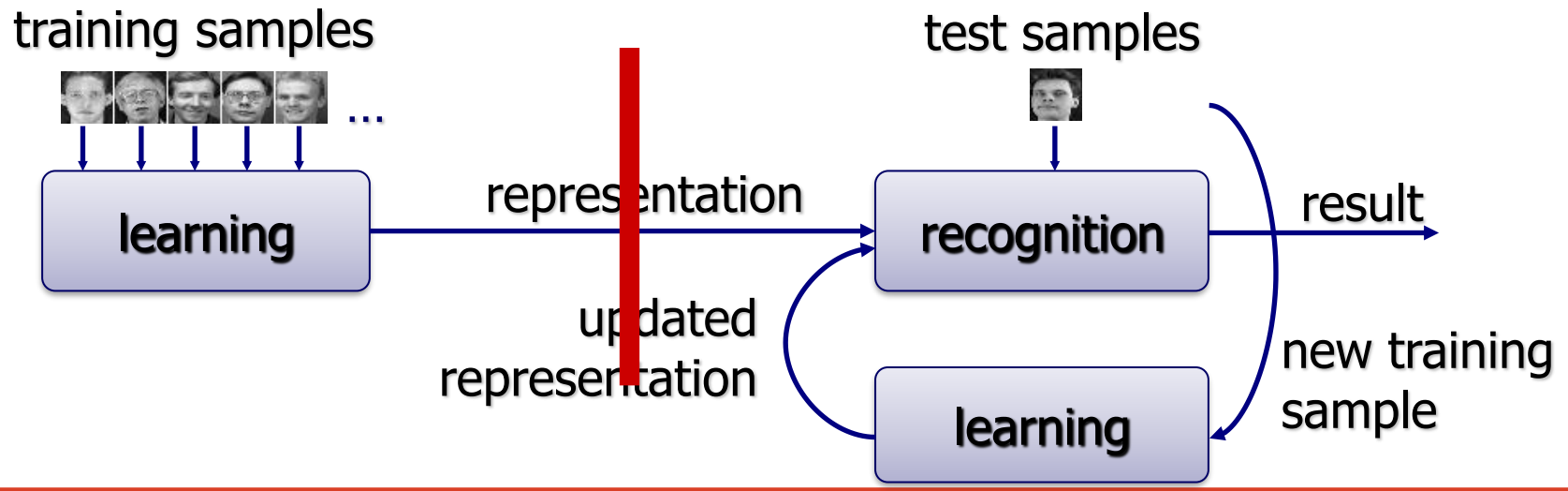
- Recognition of
  - objects
  - properties
  - faces
  - rooms
  - affordances
  - actions
  - speech
  - relations
  - intentions,…
- Categorisation
- Multimodal recognition



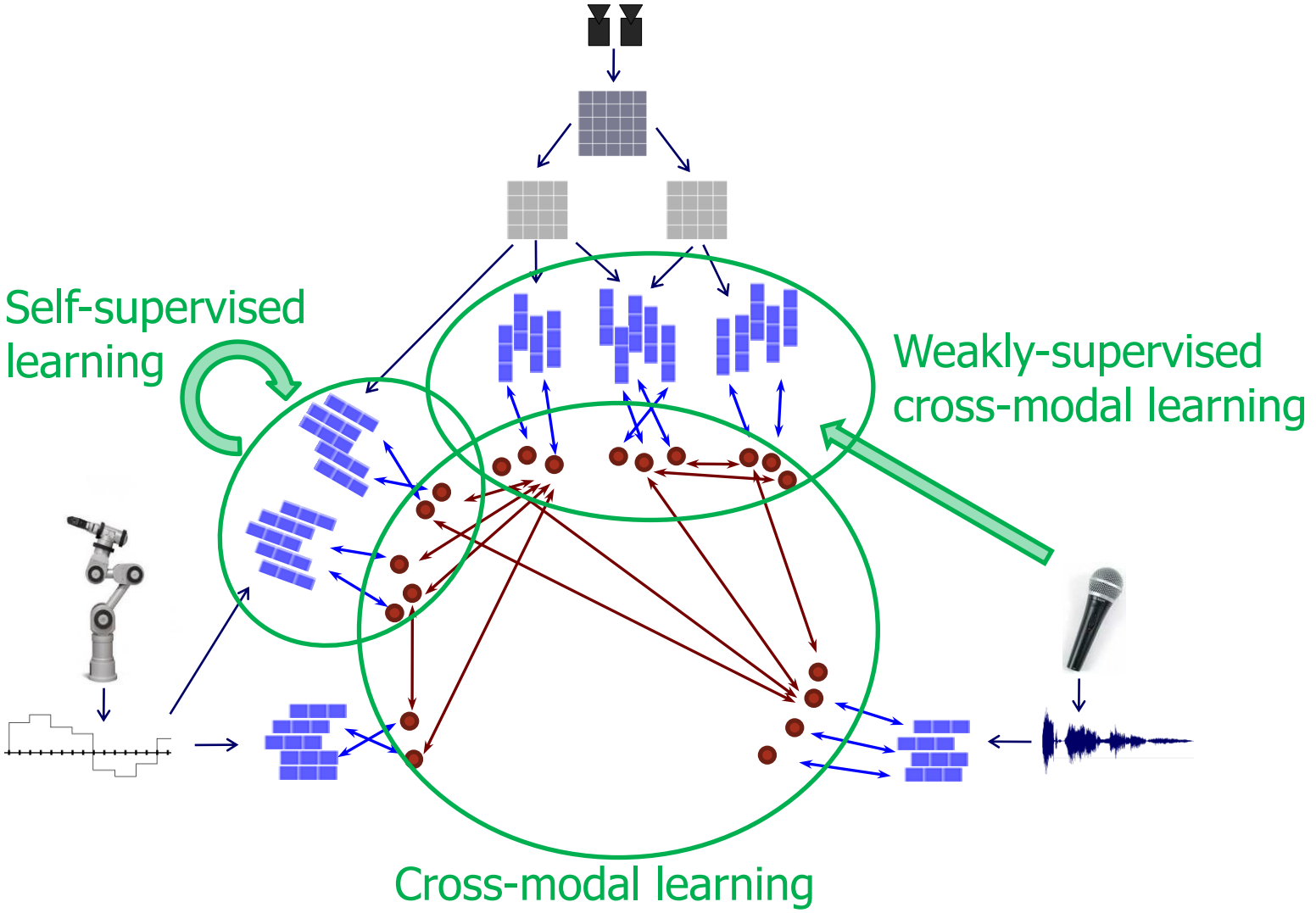
Learning

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



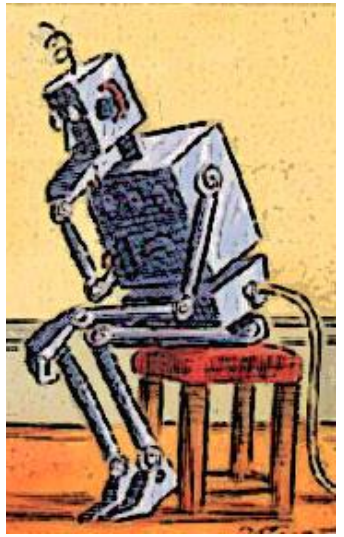


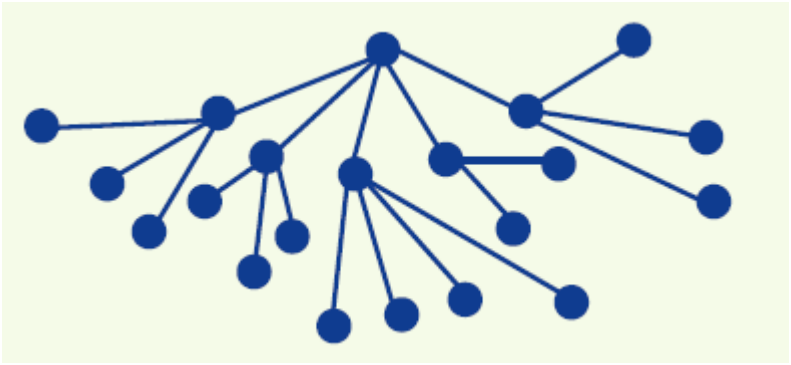
Multimodal learning

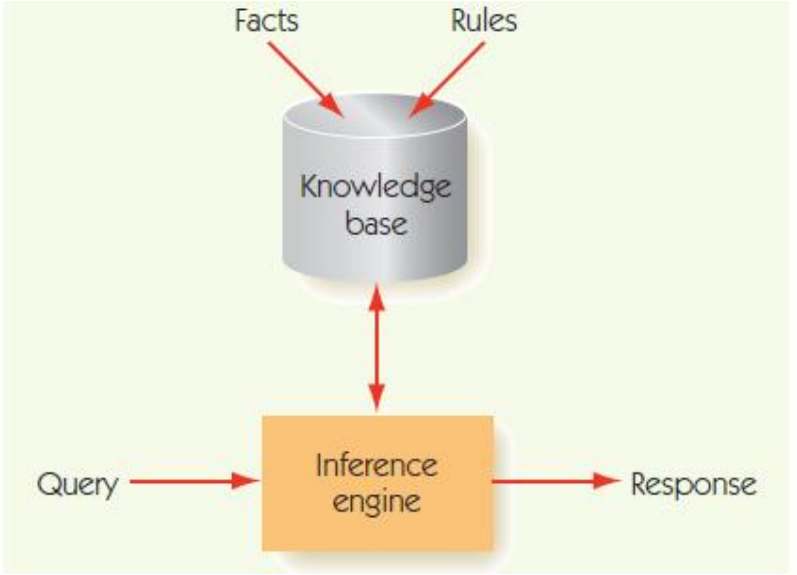


Reasoning

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







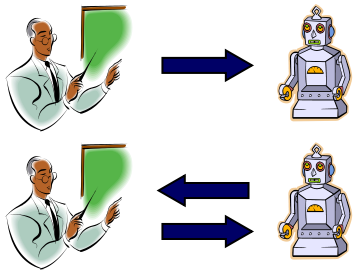
Planning

- 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.

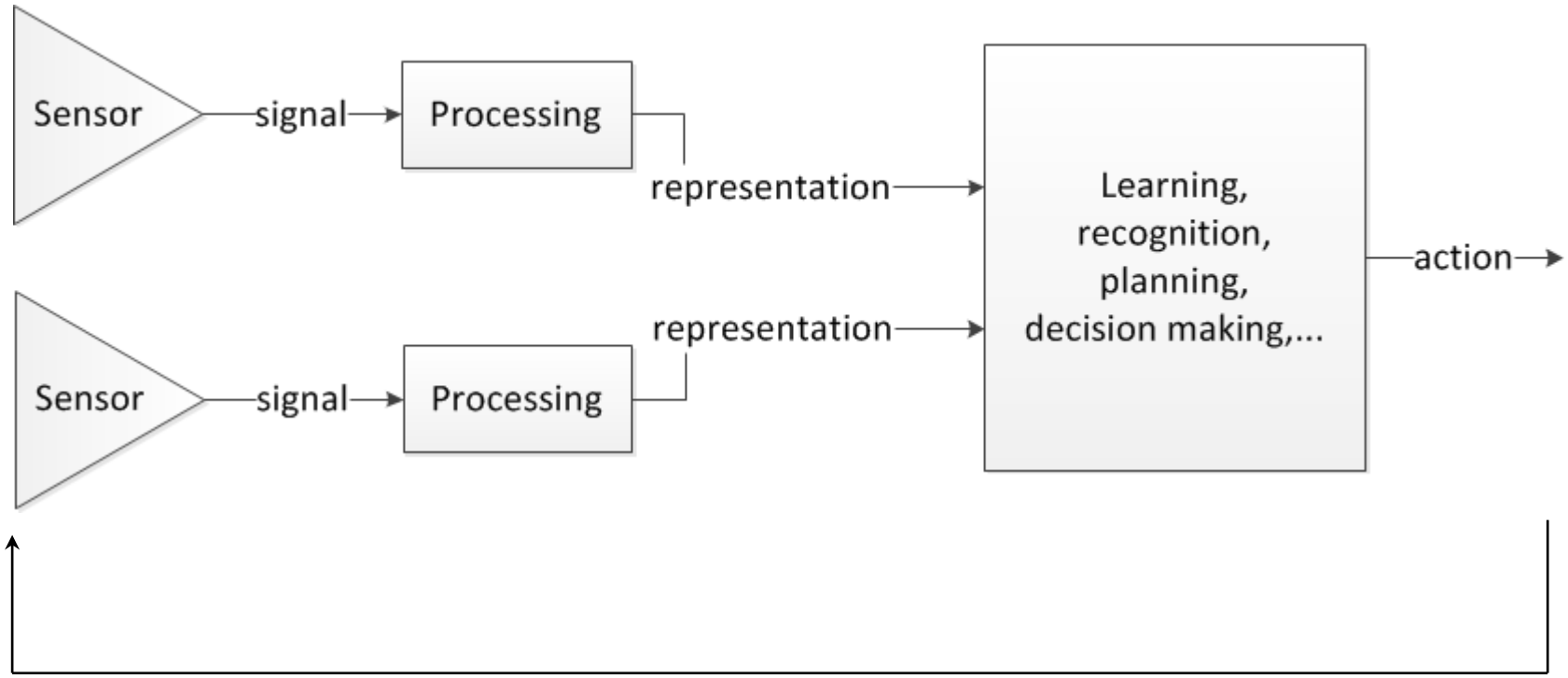
- Embodiment
- Situatidness





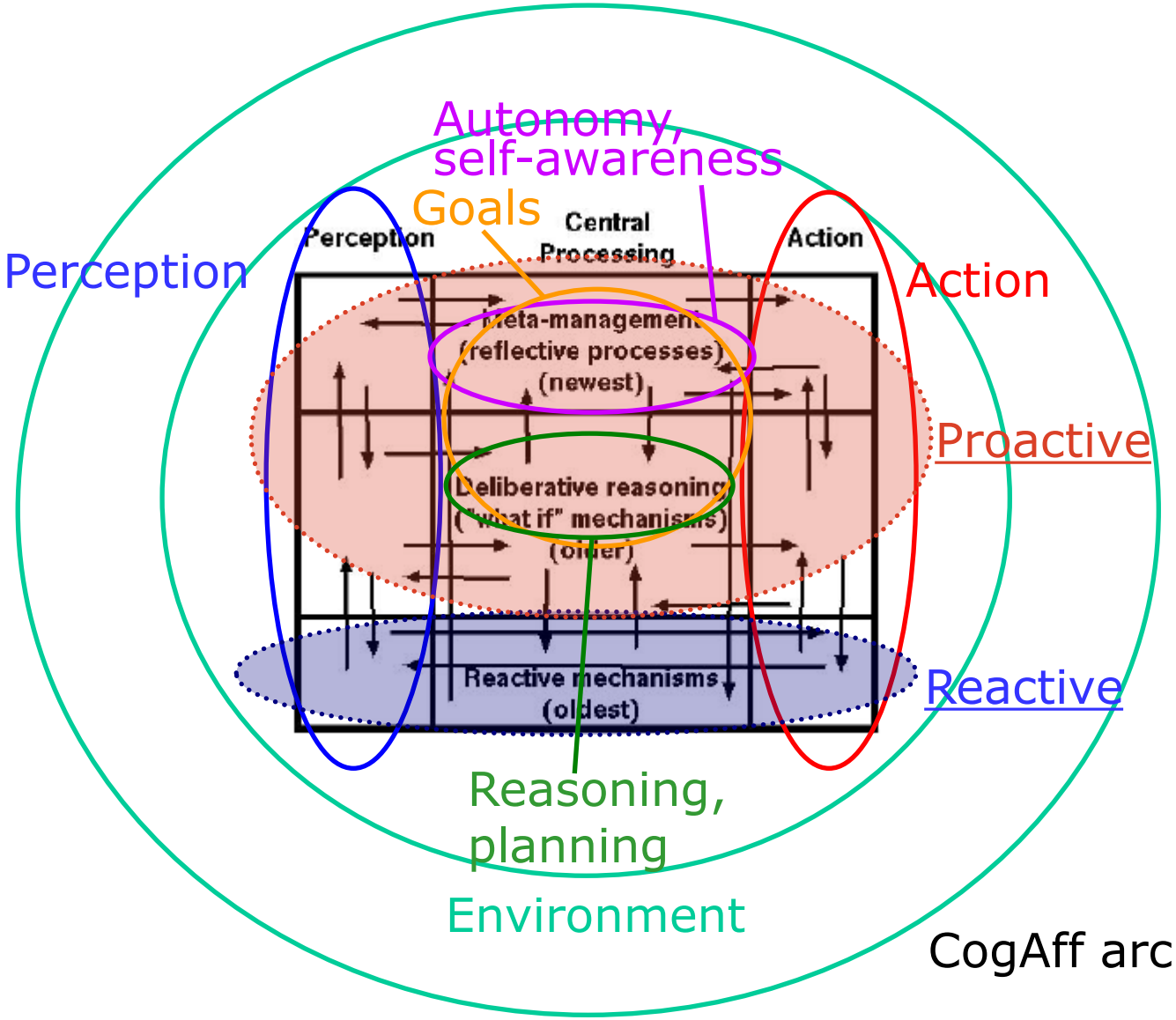


Perception – action cycle



- Large abstraction of the real world

Architecture



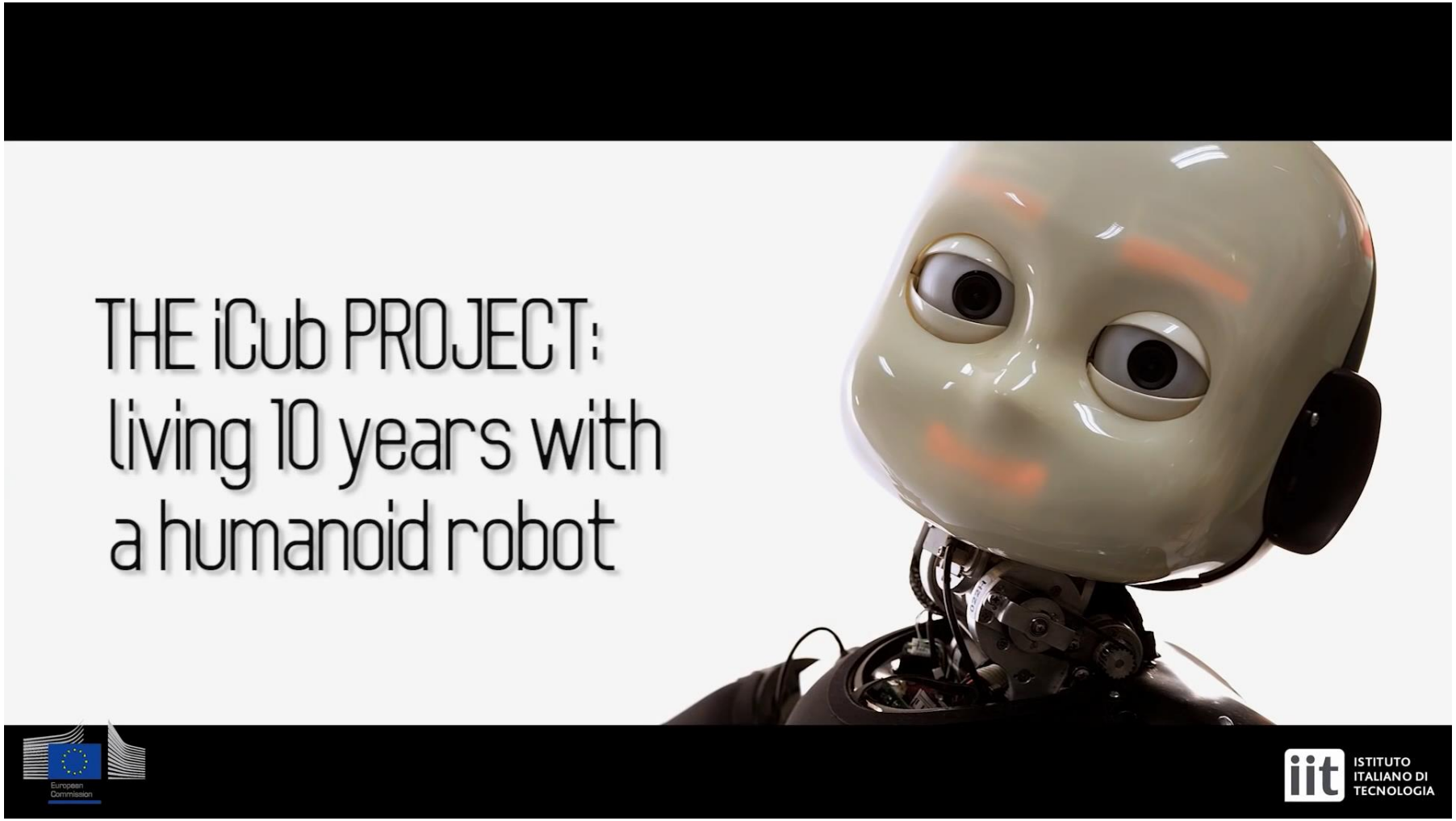
CogAff architecture

Examples – PR2

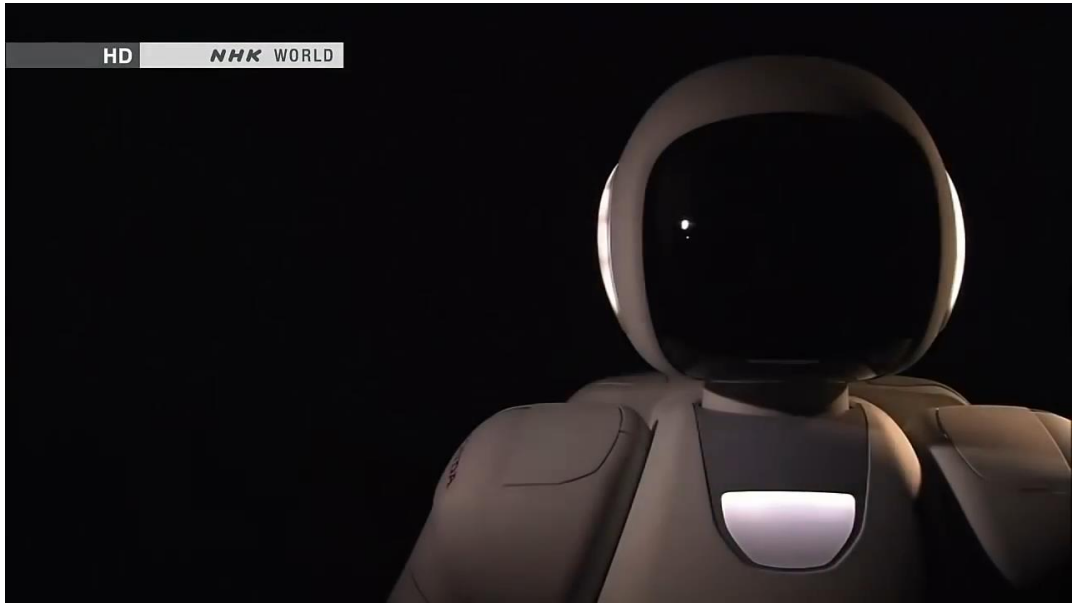
U Tokyo, TUM
Willow Garage
UC Berkley

Examples - iCub

IIT

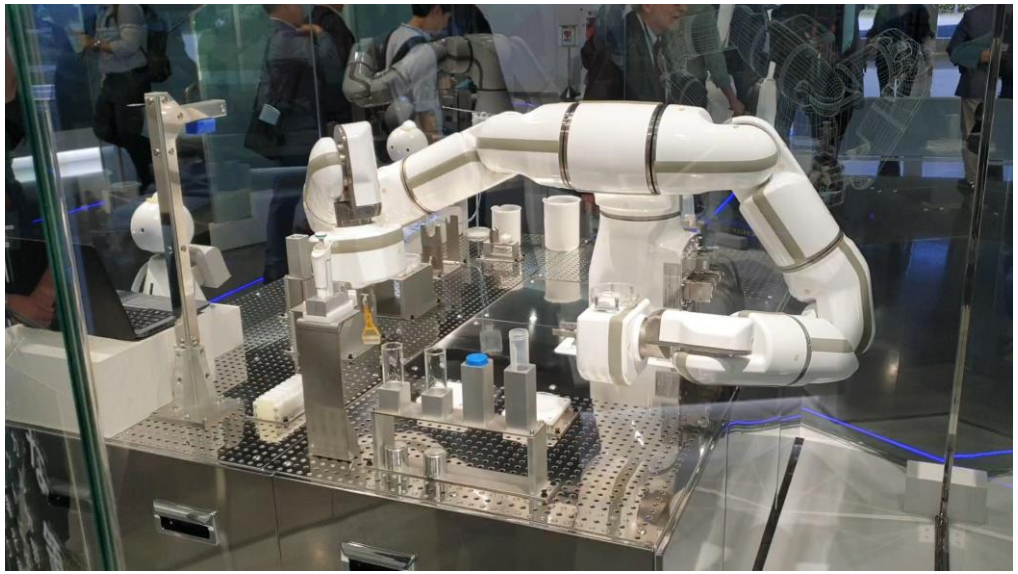


Examples - Asimo



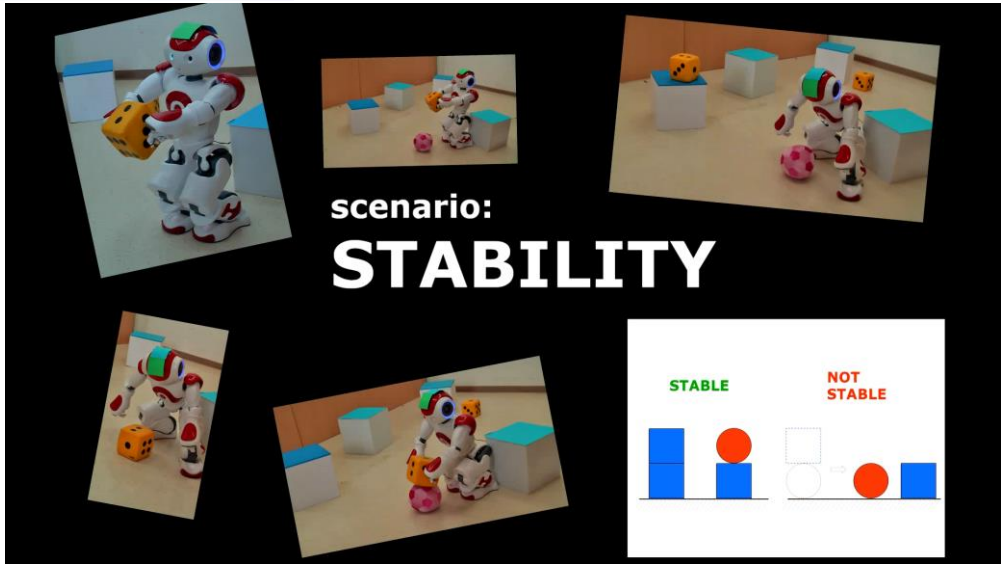
Examples – Boston Dynamics

Examples - Yaskawa



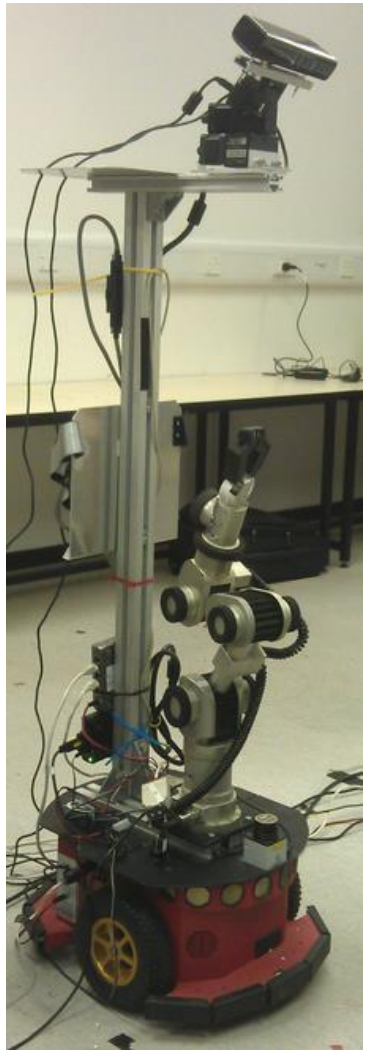
Examples - Nao

Aldebaran Robotics



Expero, FRI LUI

George

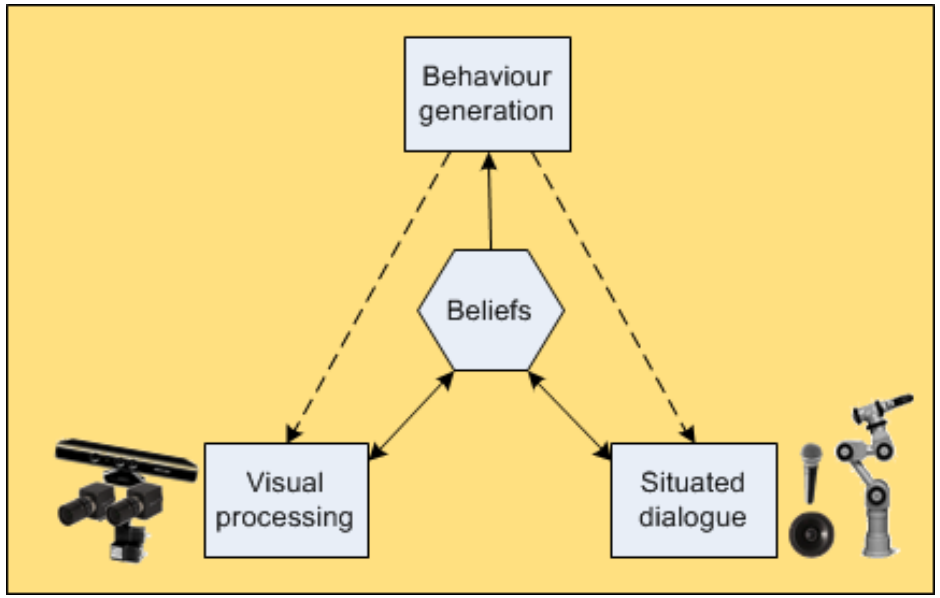


FRI, LUVSS

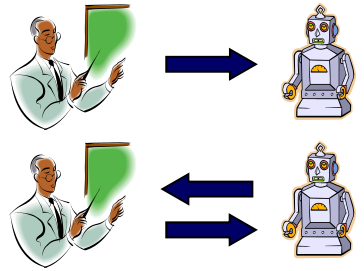
CogX, http://cogx.eu/results/george/

Curious robot George

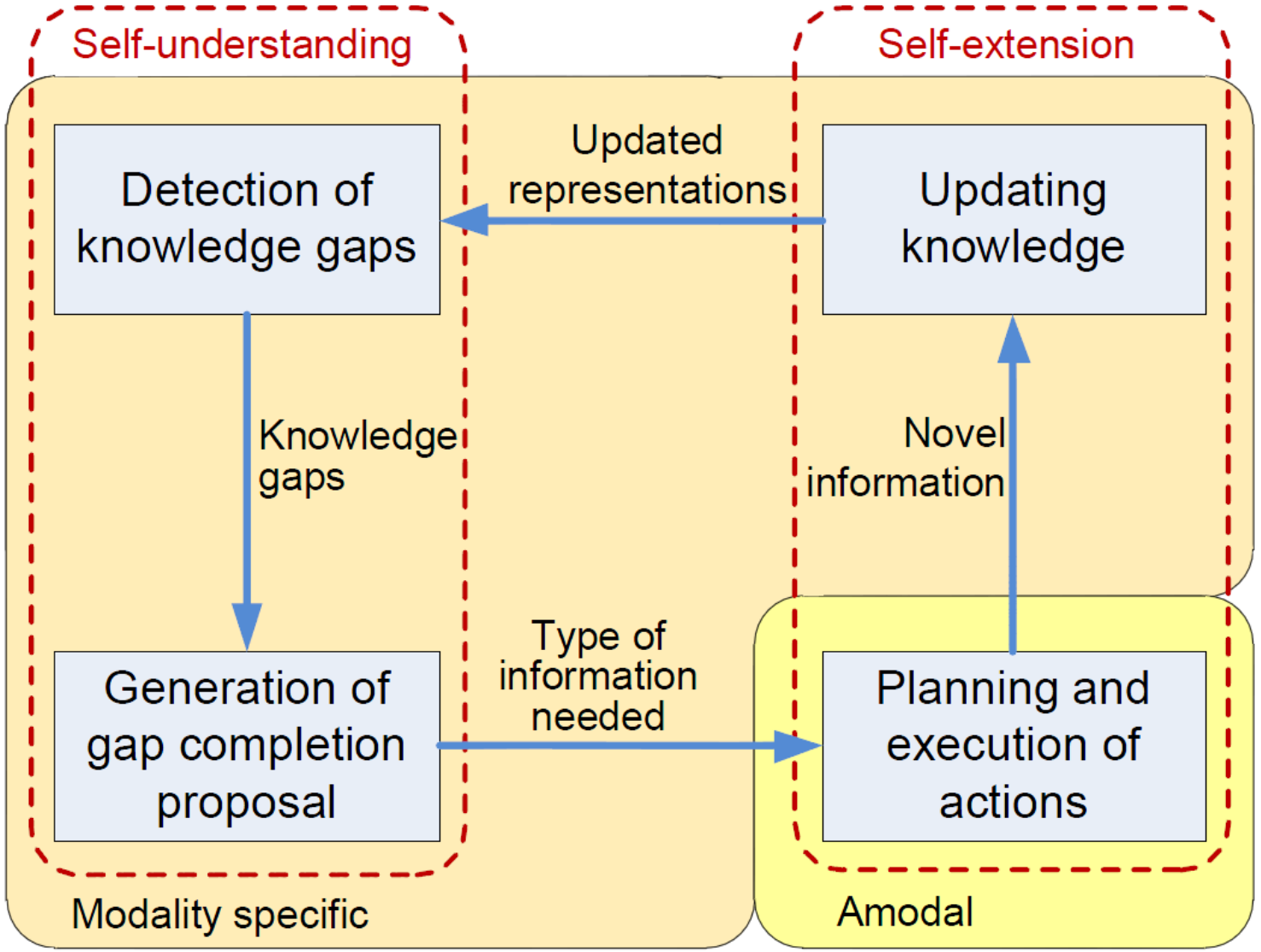
- Incremental learning in a dialogue with a human
- Curiosity driven learning
- Learning categorical knowledge



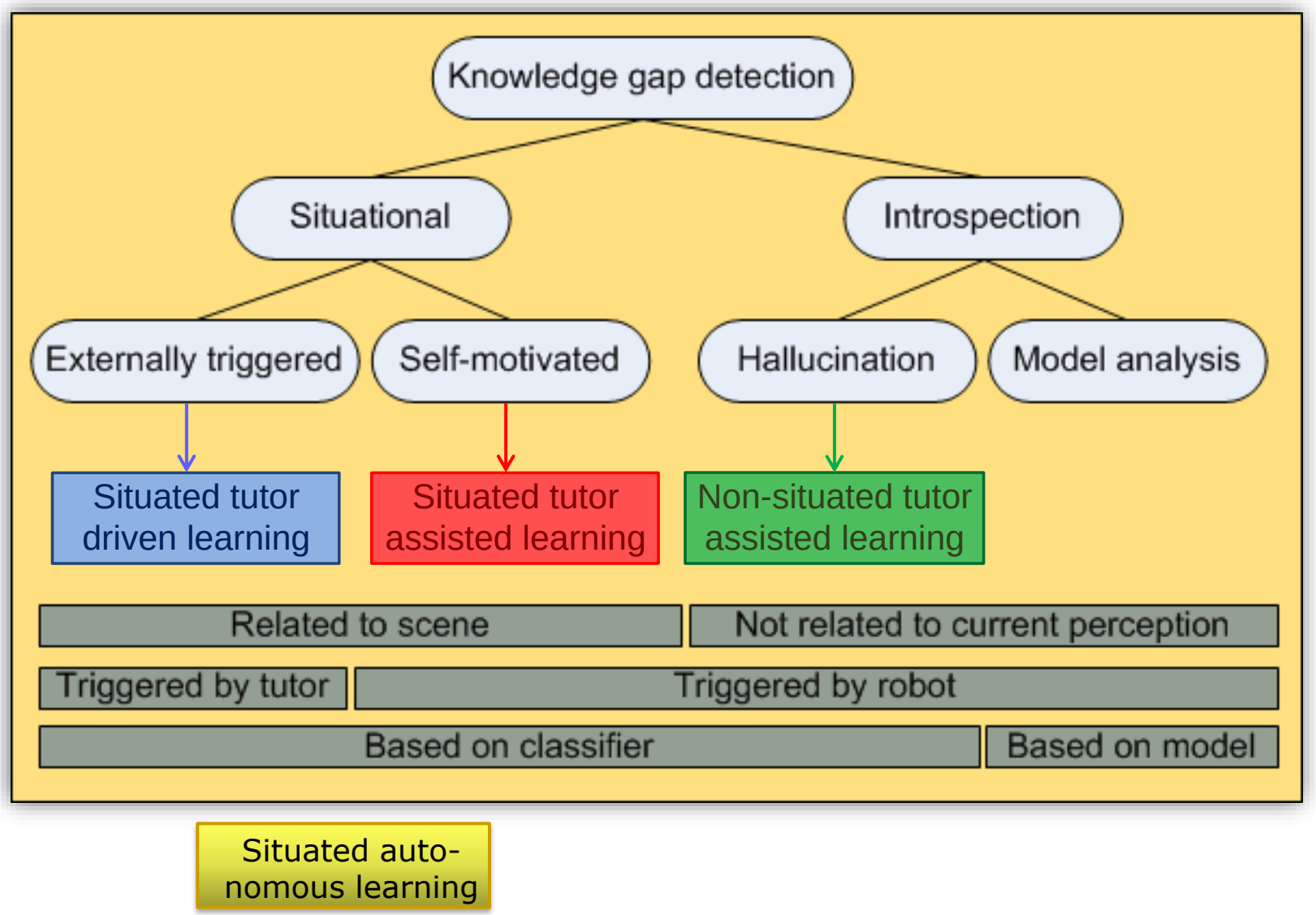
COGNITIVE SYSTEMS THAT SELF-UNDERSTAND AND SELF-EXTEND



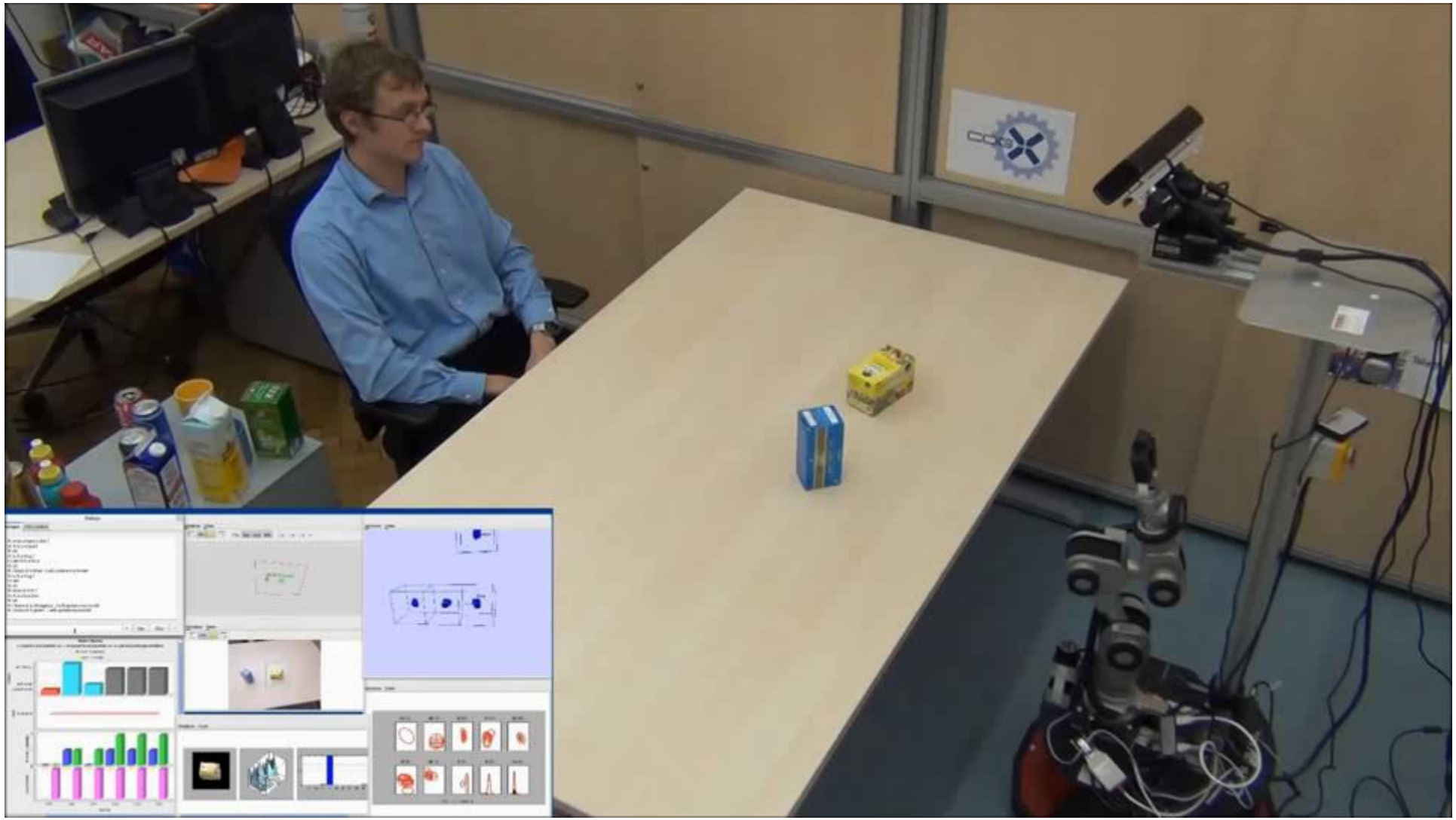
Self-understanding for self-extension



Learning mechanisms

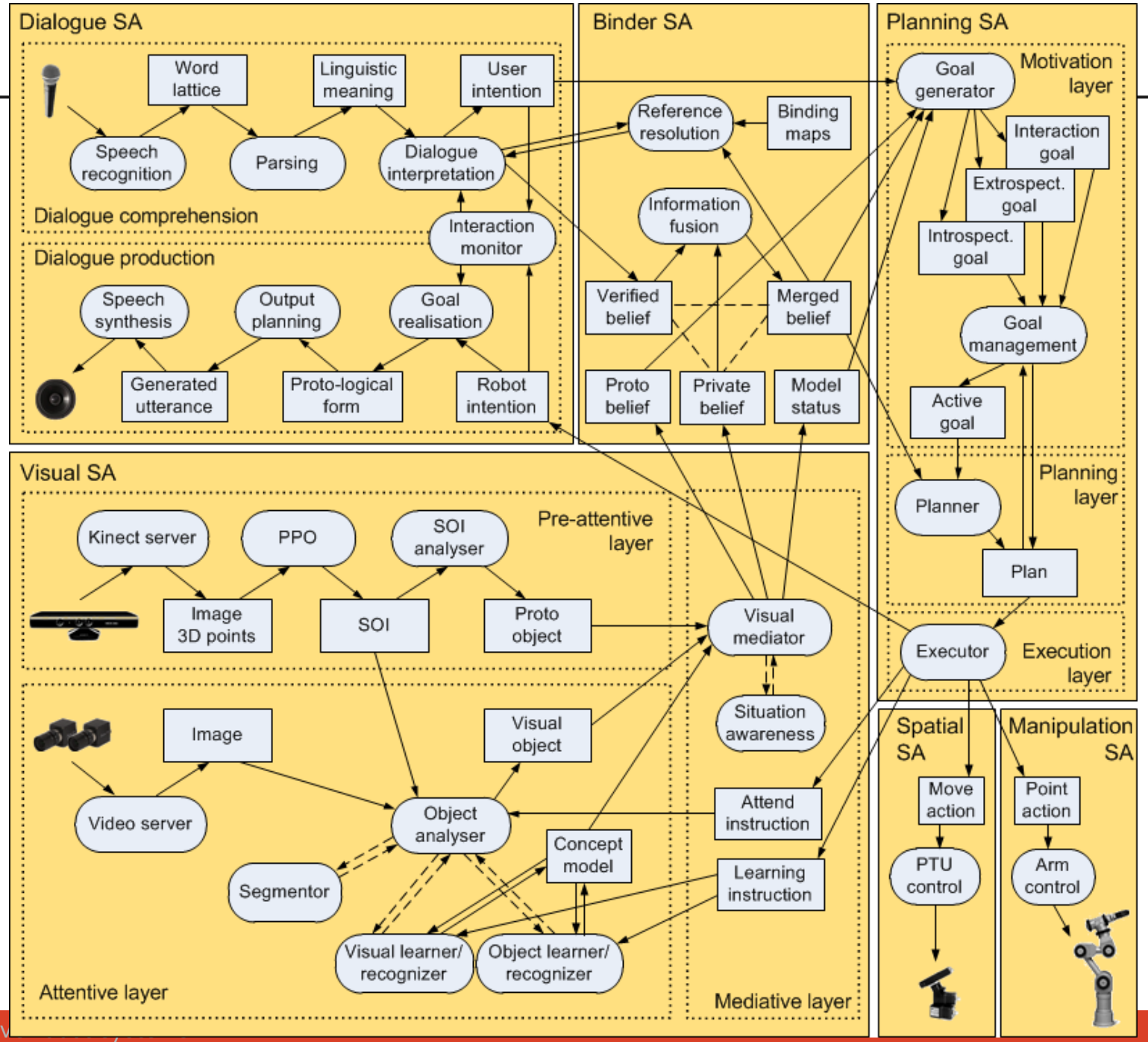


Video



http://cogx.eu/results/george

System


Dialogue SA
Word lattice
Linguistic meaning
User intention
Speech recognition
Parsing
Dialogue interpretation
Dialogue comprehension
Interaction monitor
Dialogue production
Speech synthesis
Output planning
Goal realisation
Generated utterance
Proto-logical form
Robot intention
Binder SA
Reference resolution
Binding maps
Information fusion
Verified belief
Merged belief
Proto belief
Private belief
Model status
Planning SA
Goal generator
Motivation layer
Interaction goal
Extrospect. goal
Introspect. goal
Goal management
Active goal
Planner
Plan
Planning layer
Executor
Execution layer
Visual SA
Kinect server
PPO
SOI analyser
Pre-attentive layer
Image 3D points
SOI
Proto object
Visual mediator
Situation awareness
Image
Visual object
Video server
Object analyser
Attend instruction
Concept model
Segmentor
Learning instruction
Visual learner/ recognizer
Object learner/ recognizer
Attentive layer
Mediative layer
Spatial SA
Move action
PTU control
Manipulation SA
Point action
Arm control

Conclusion

- Cognitive systems are
  - intelligent
  - very heterogeneous and asynchronous
  - coherent
  - multimodal
  - They continuous 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., JANÍČEK, 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