Towards Acting, Learning, Reasoning "Co-Bots"

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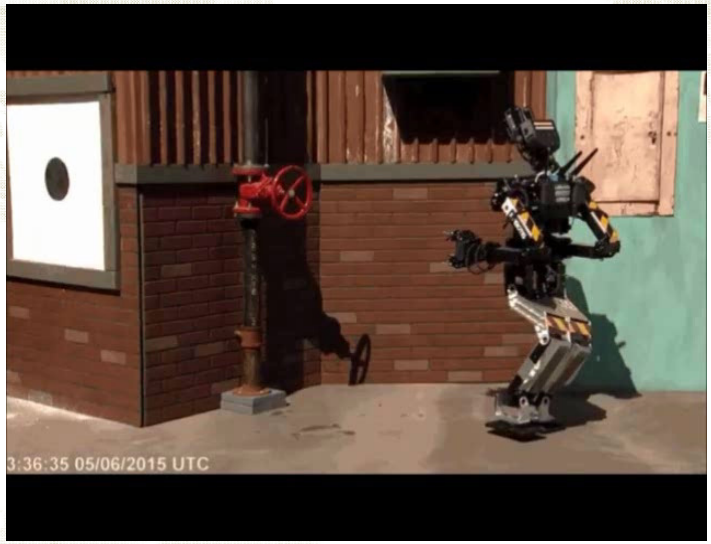
Genova, Italy

Towards Acting, Learning, Reasoning "Co-Bots"

Co-Worker

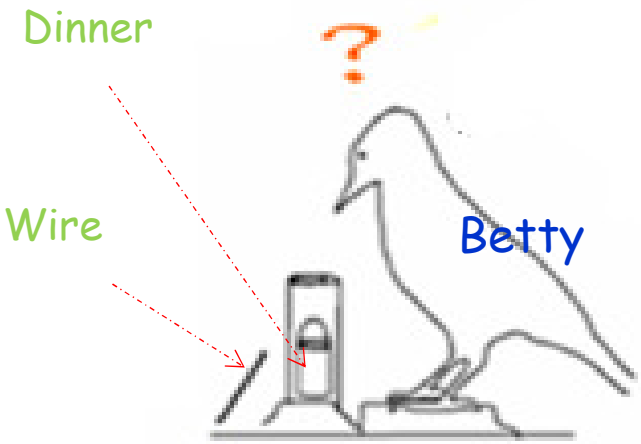
Co-Inhabitant

Co-Explorer



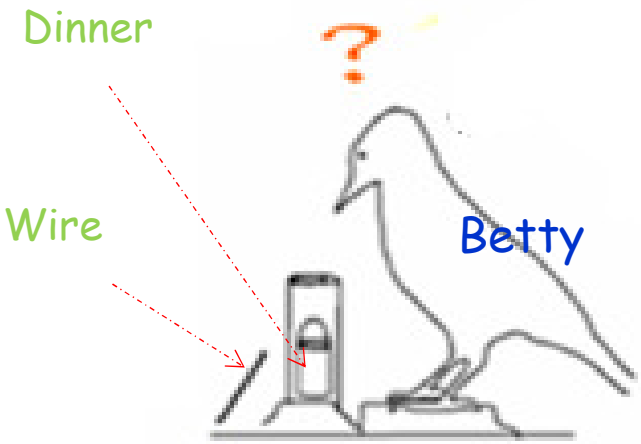
2015 DARPA Disaster zone Challenge (Lot of things to be Done!!!)

Necessity is the mother of invention: The Story of Betty



Alex Kacelnik's Lab, Oxford

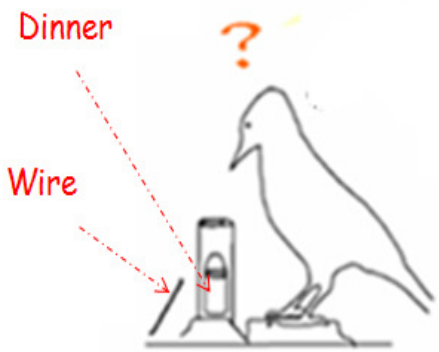
Necessity is the mother of invention: The Story of Betty

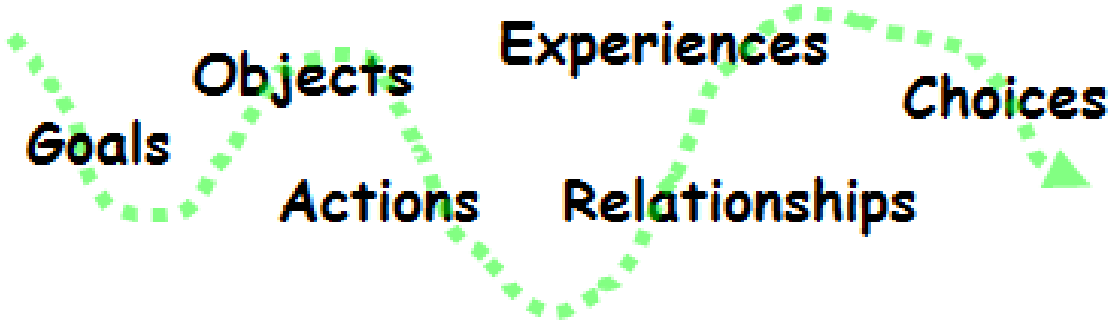


Alex Kacelnik's Lab, Oxford

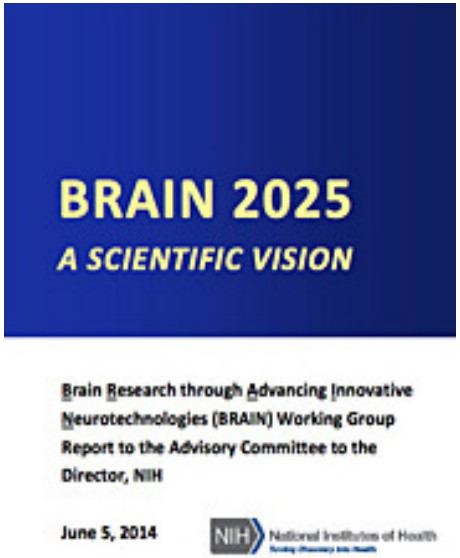
- Perception (Beyond labelling….. Understanding the scene)
- Inference (The goal is not Achievable)
- Memory (Recall of a specific past learnt experience: playing with Wires, Twigs)
- Fine Manipulation (Creating a hook tool and Using it as an extension of its body)
- Knowledge of Cause-Effect relations (Pulling the basket with a Hook Tool)
- **Integration: The Magic glue**

The unstructured real world is full of such situations…





A Converging point for many disciplines of research and innovation

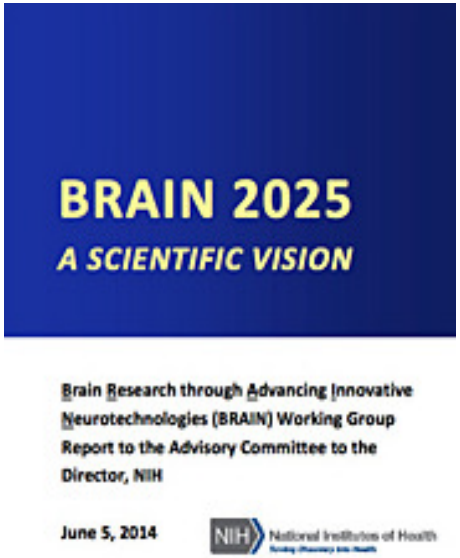


http://www.braininitiative.nih.gov/2025/

Neurosciences

- What neural computations take place in the brains of primates, humans when they exhibit cognitive goal oriented behaviors in unstructured environments
- And why and how some of these functions are lost in diverse cognitive disorders (dementia, schizophrenia, ASD)…

A Converging point for many disciplines of research and innovation



http://www.braininitiative.nih.gov/2025/

http://sparc-robotics.eu/roadmap

Intelligent Autonomous Systems

- What cognitive architectures would enable artificial agents to exhibit robust, flexible and goal oriented behaviors in unstructured dynamic environments…
- How does it connect to emerging trends from brain science and can we causally explain loss of cognitive functions (ex: through virtual lesions)

A Converging point for many disciplines of research and innovation

http://www.braininitiative.nih.gov/2025/

http://sparc-robotics.eu/roadmap

http://www.effra.eu/

End User Applications (Society,Economy)

- Co-Worker (Productivity of SME, Quick Switchover to new tasks, Customization N=1, Employee health)
- Co-Inhabitant (Beyond Vacuum cleaners- Elderly Care, Assistants)
- Co-Explorer (Separating humans from direct line of action)

My Personal research landscape.....

"What I cannot build, I do not understand" - Richard Feynman

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FACTORIES OF THE FUTURE
Multi-annual roadmap for the contractual PPP under Horizon 2020

Prepared by EFFRA

http://www.braininitiative.nih.gov/2025/

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http://www.effra.eu/

Co-Bots are invaluable integrating platforms to bridge disciplines…

- Understand Natural cognition (by building one….)
- Develop Cognitive technologies (for diverse end users)

My personal catalogue for future Co-Bots (Co-worker, Co-inhabitant)

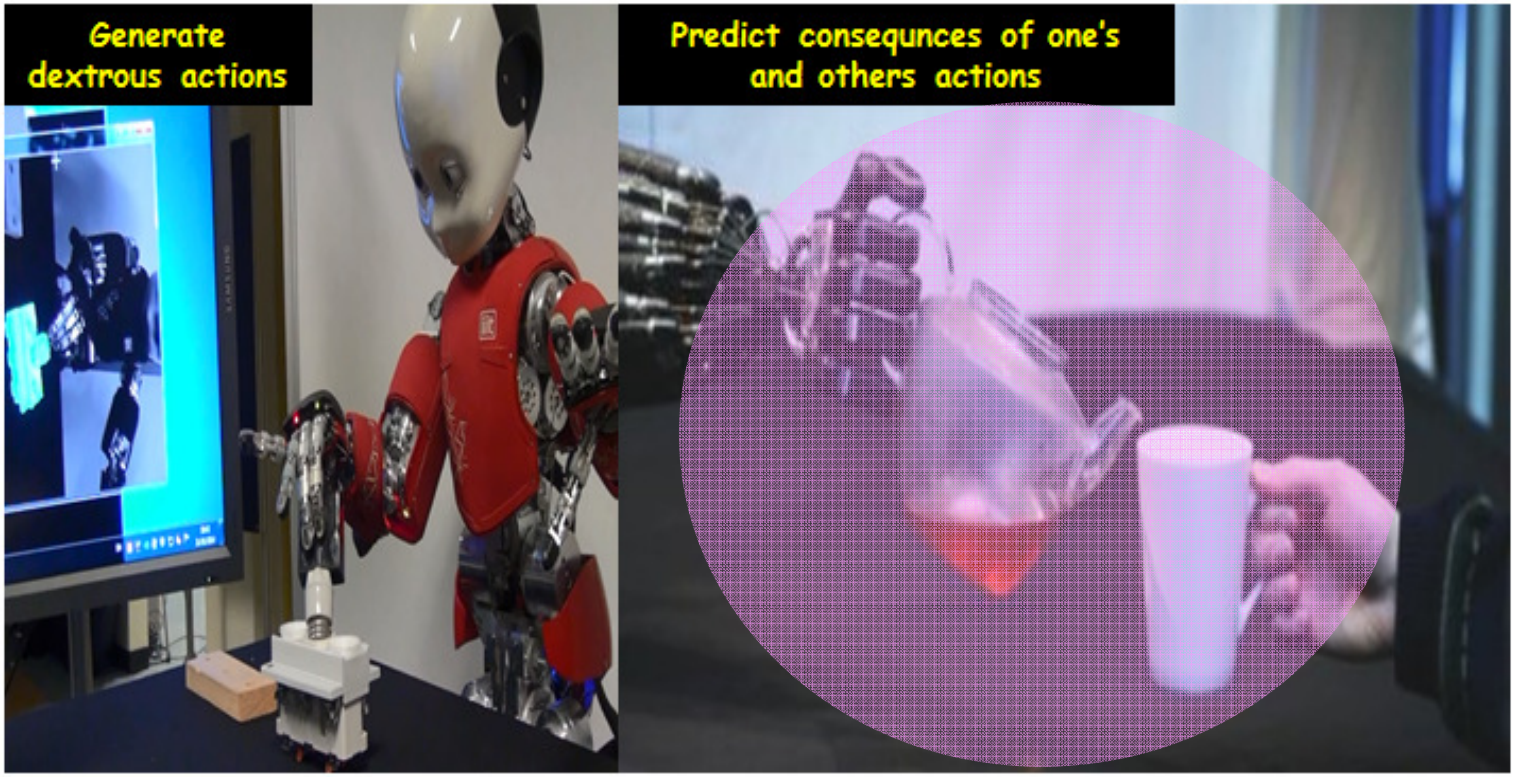
In the rest of my talk, I will discuss 3 potential research directions .....

- Connecting Action generation/Simulation
- Connecting Cumulative learning vs. Prospective Memory
- Configurable Cognitive architectures

....push the SoA towards next gen Co-Bots

1. Dexterous Actions (and predicting consequences of potential actions)

The dual process of Generating dexterous actions and Predicting potential consequences of ones/others actions must seamlessly alternate during any goal oriented Co-Botic Behavior



Manipulation

DARPA

AMAZON

KUKA

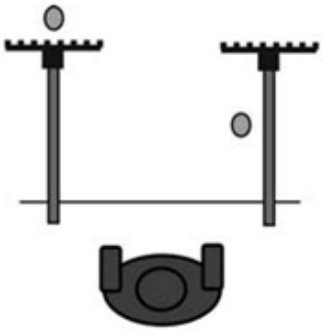
MBZ Robotics challenge (UAE)

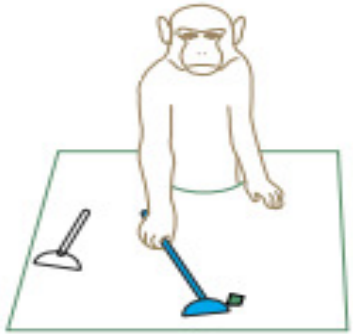
…….That could come for free

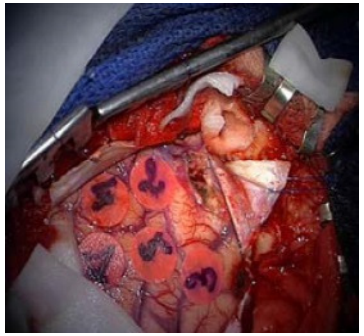
Action generation, Prediction and Understanding are closely interlinked

Neuroscience

Two sides of the same coin?







- Mirror neurons
- Motor Imagery (FMRI)
- Tool Use studies in Animals
- Direct Intercortical simulation of the parietal lobe

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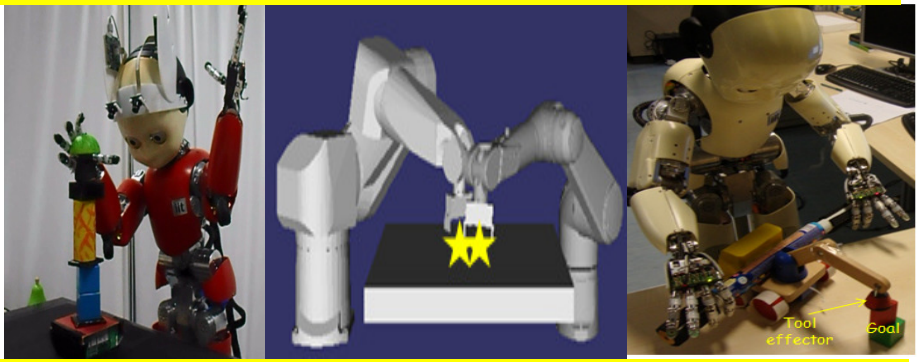
Practical Problems

Runtime Configurability

To different body+tool chains as task proceeds



To different combinations of task constraints

Right pose to enable further manipulation

Obstacles

Internal limits of motion (safety)

+

Swiftly Learning new motor skills

+

Imitating to Complementing

Unifying "Action generation, Simulation and Understanding" in Co-Bots

Nina: I am perfect…..
Tomas Leroy: Perfection is not to be in absolute control but to let go…
The black swan (Aronofsky 2011)

Body as a Configurable middle ware

Our Body is a medium to interact with the world
(and also simulate potential interactions…..)

- **Body Schema in the parietal lobe ..that is activated in different contexts…**
- **Body Schema (Internal Body Model) for Cobots ?**

The Passive Motion Paradigm (PMP)

…Both Real and Imagined actions are realized through a passive "animation" of a ' plastic and configurable' internal body model configured runtime based on the intended task/goal..

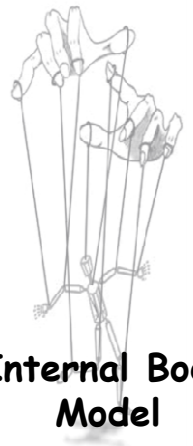
Theoretical basis

Passive Motion Paradigm: An alternative to Optimal control, Mohan and Morasso, F.Neurorobotics 2011
When Pliers become fingers in the monkey motor system, Rizzolatti et al, PNAS,2009
Getting ahead; Forward models and their place in cognitive architecture, Pickering and Clark, Trends in Cog Sci, 2014

A "Configurable, Growing" Internal Body Model for any Co-bot

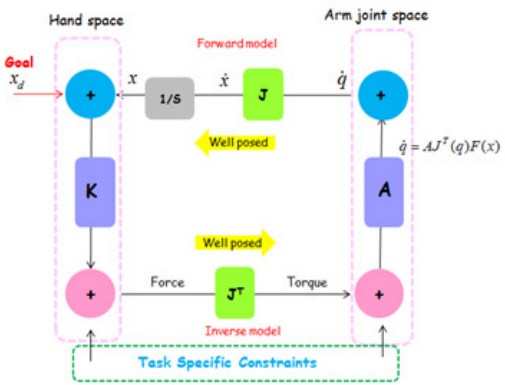
Assembled on the Fly

Goal

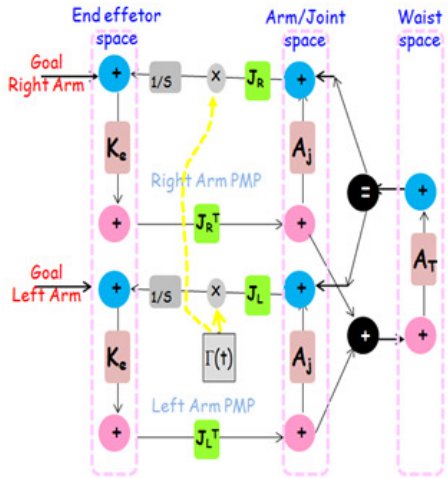


Internal Body Model

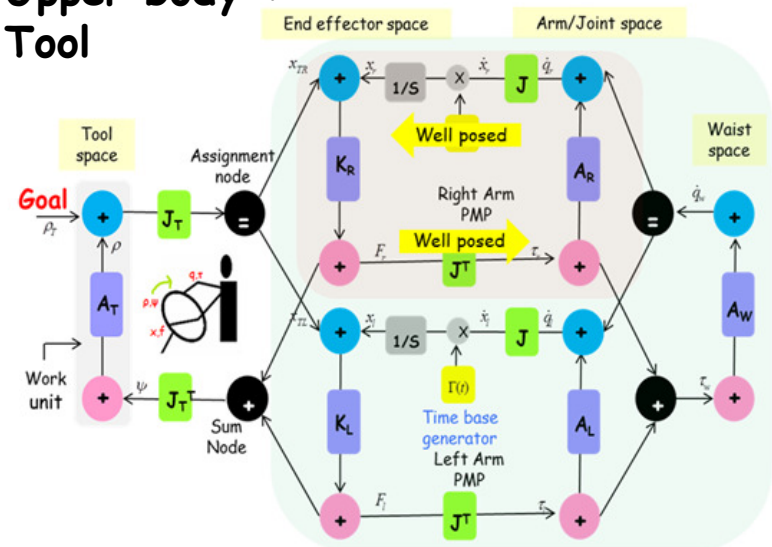
Single Arm



Upper body



Upper body + Tool



Like electrical circuits
(Two kind of nodes: Force and Position, two types of connecting links Geometric and Elastic)

Three step process

- Configure
- Animate (couple to the goal: Attractor)
- Use (Generate motor commands, or perform forward simulation)

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When Pliers become fingers in the monkey motor system, Rizzolatti et al, PNAS,2009
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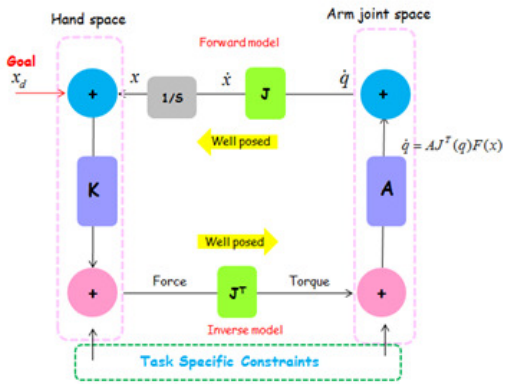
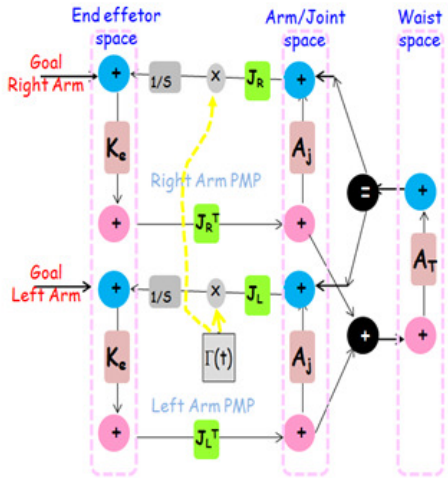
A "Configurable, Growing" Body schema for any Co-bot

Assembled on the Fly

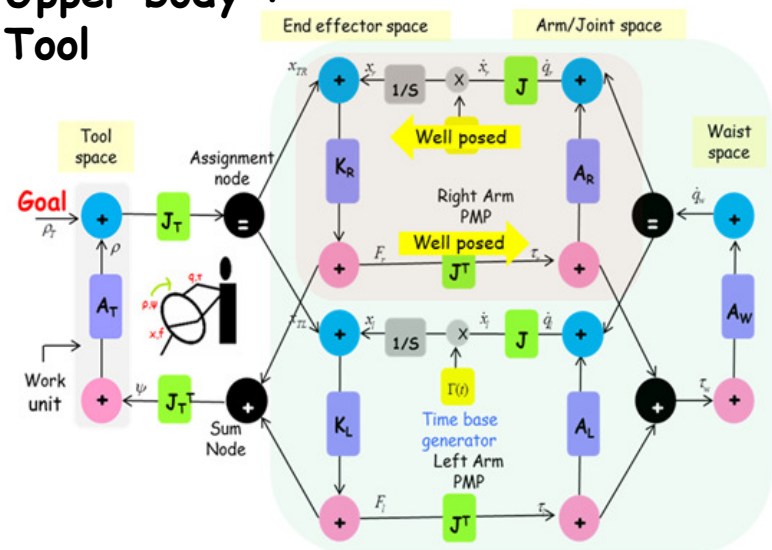
Single Arm



Upper body



Upper body + Tool



Action Generation

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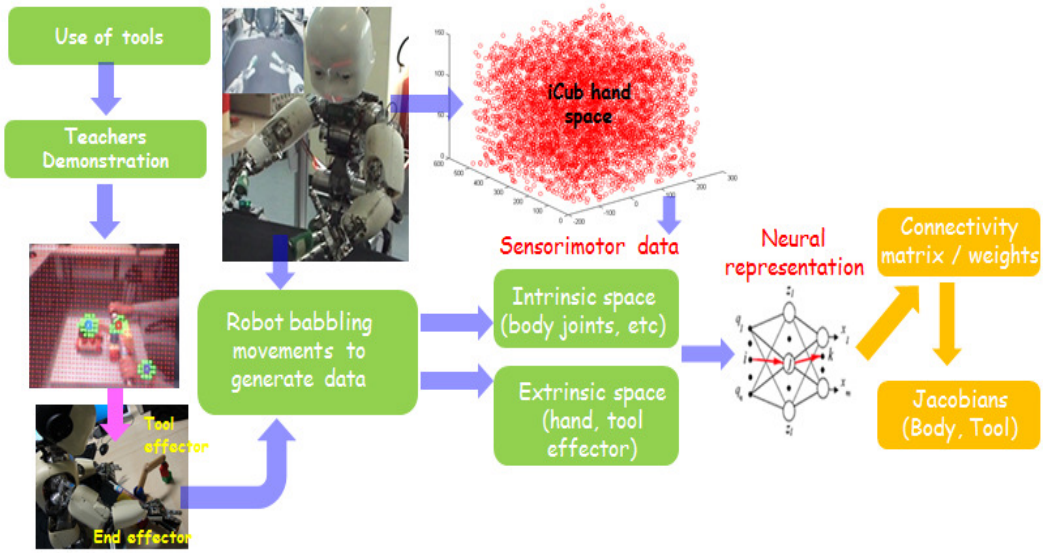
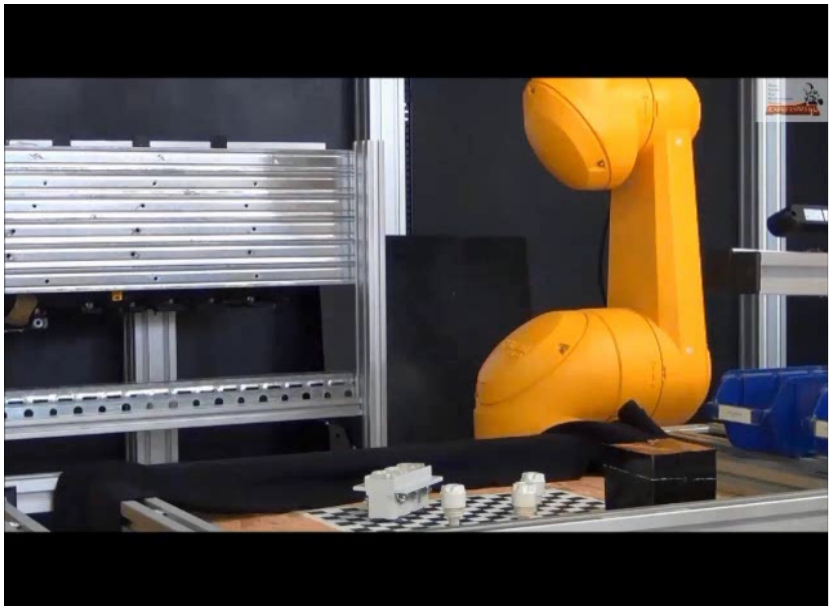
Getting ahead; Forward models and their place in cognitive architecture, Pickering and Clark, Trends in Cog Sci, 2014

Learning the Internal body model (end expanding it to coupled tools)

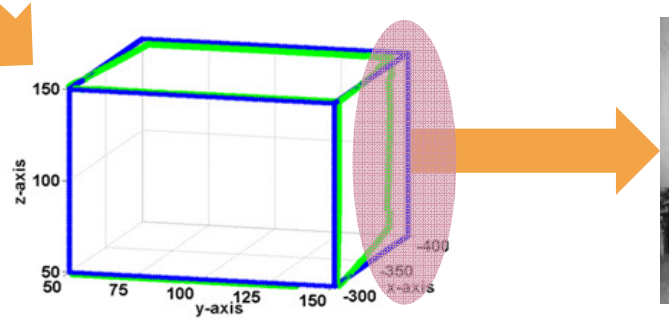
Both the Internal Body Model and extension to diverse tools can be learnt by any robot (combining exploration and imitation)

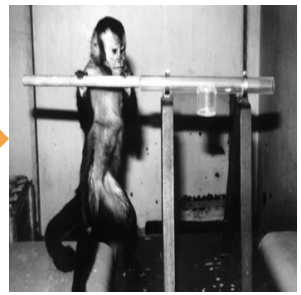
Learning and Quick Configuration or any Robot





Accuracy for Reaching in Industrial robot work cell

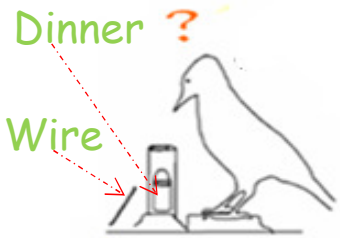




Bhat, A., Mohan, V., Morasso, P., Akkaladevi, S., Sandini, G, Eitzinger, C. (**2016**). Towards a learnt neural body schema for dexterous coordination of action in humanoid and industrial robots, ***Autonomous Robots***.

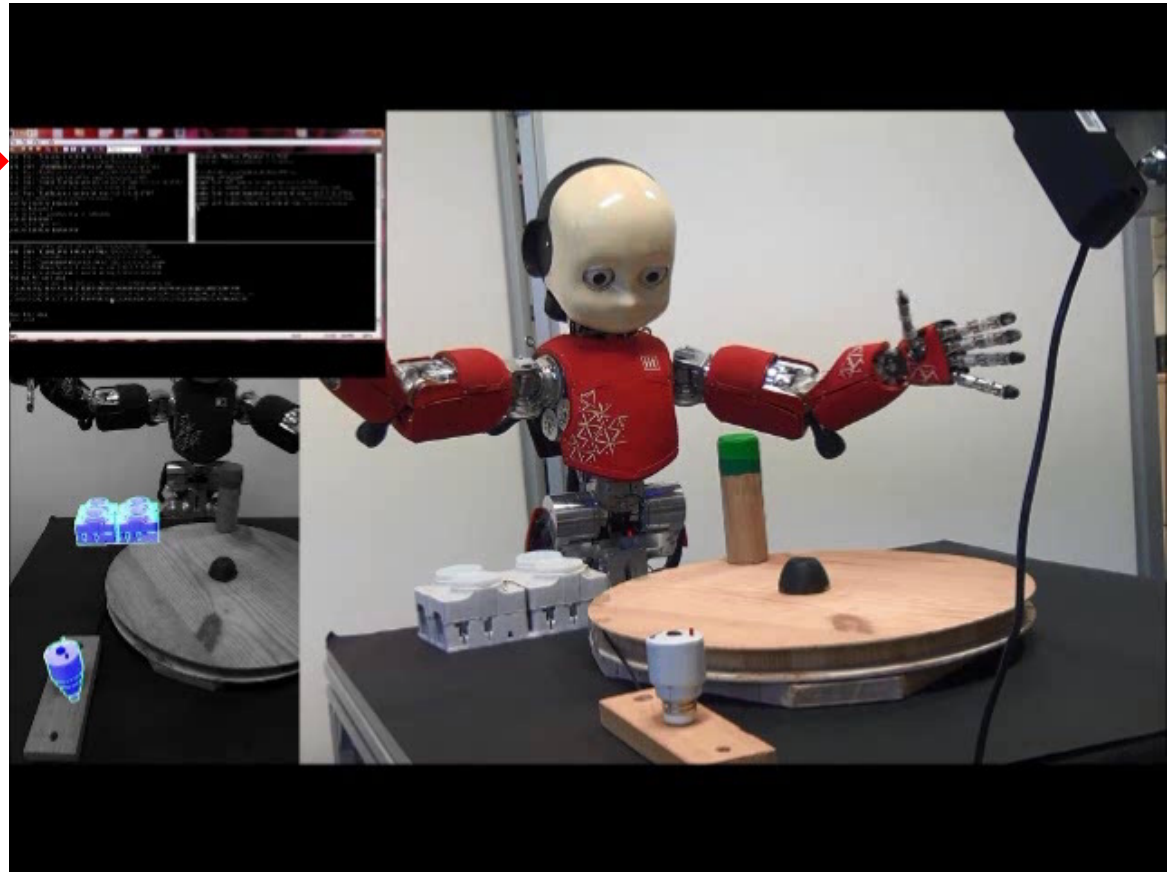
Real and imagined actions can go hand in hand.....

Real and Imagined actions can alternate, yet use the same computational middleware:
Activation of the task oriented internal Body model



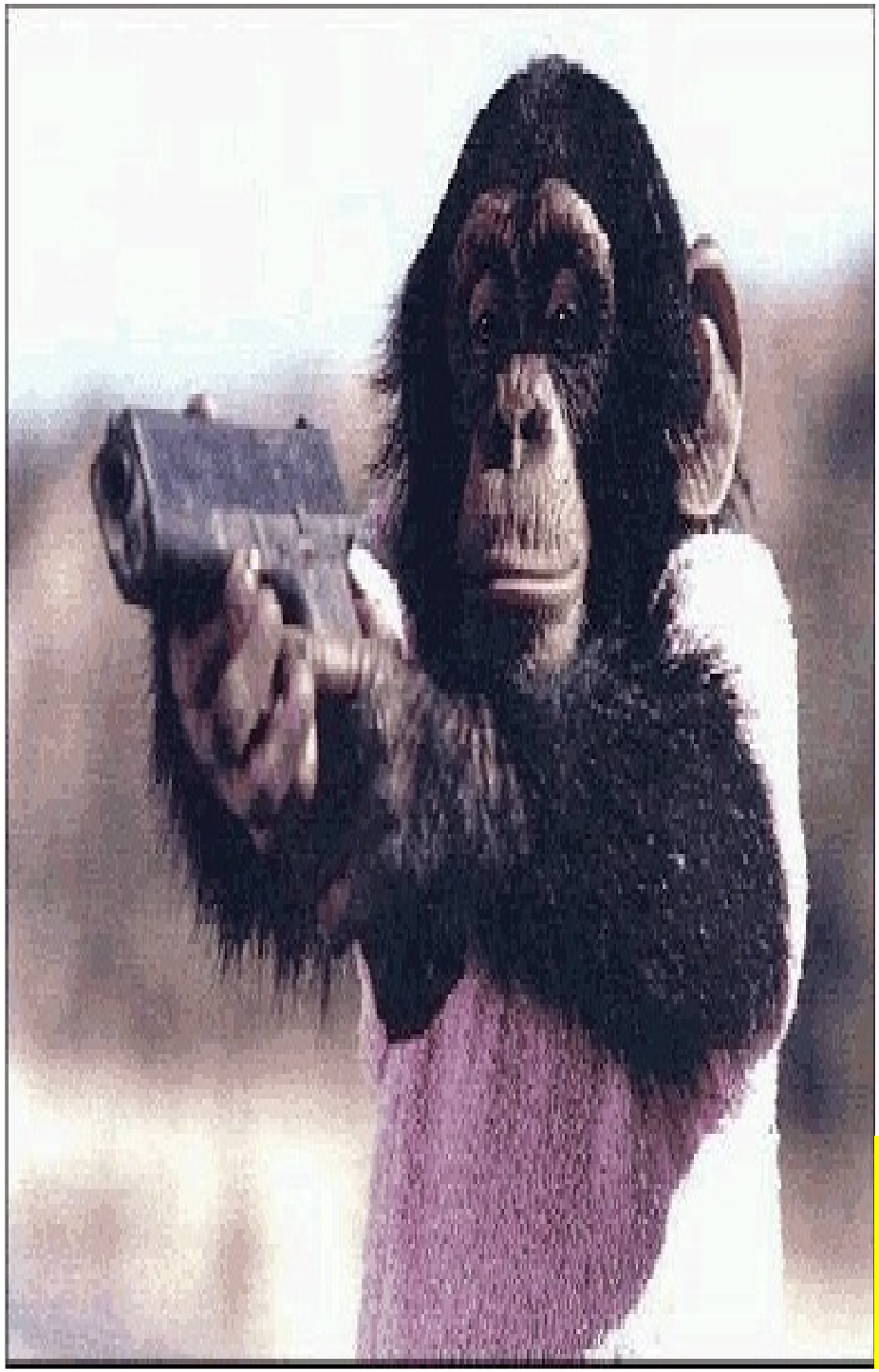
Generate-Simulate loop (mimicking Betty task)

User Goal
Assemble Fuse Box



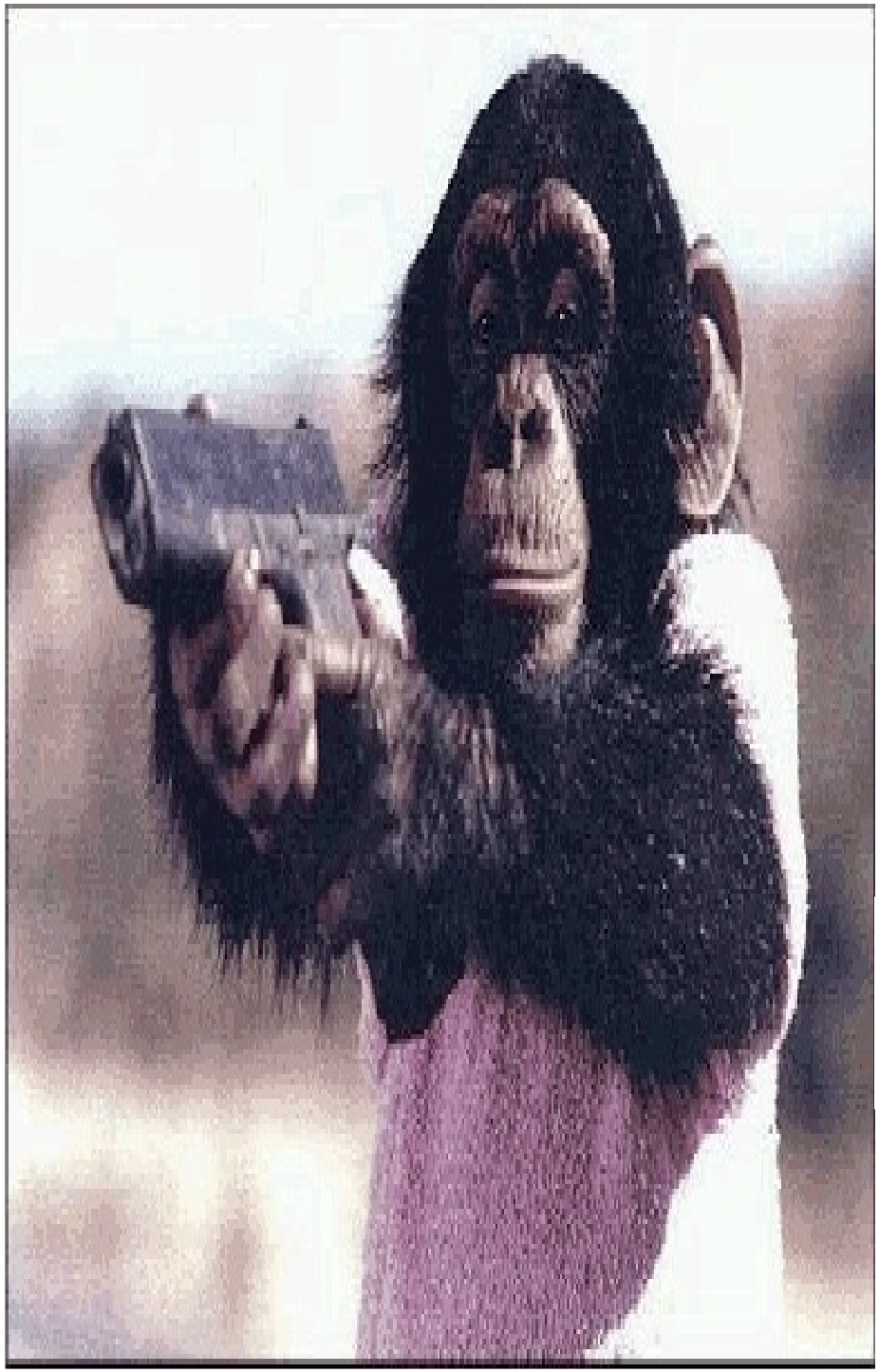
Recap
- Runtime Assembly
- Learning
- Generation-Simulation

Mohan V, Morasso P, Sandini G, Kasderidis S (2013) Inference through embodied simulation in cognitive robots. **Cognitive Computation**, vol. 5, no.1, DOI 10.1007/s12559-013-9205-4.



Generate-Simulate- Simulate Other's Actions (By analogy)

Andrew Meltzoff (2015), Body maps in the infant brain, Trends in Cognitive sciences.
Andy Clark (2016), Embodied Prediction
Mohan Et al (2016), Towards a learnt body schema for dexterous coordination of action in humanoid and industrial robots, Autonomous robots



Generate-Simulate-Simulate Other's Actions

Spin Offs + Ongoing extensions

Action Language Coupling
(in collaboration with Plymouth, Hertfordshire, Bielefeld)

Other's Action Understanding
(in collaboration with Imperial college, INSERM, Sheffield)

Industrial Assembly
(in collaboration with Profactor, FORTH, Kings College)

Whole body synergy formation under constraints

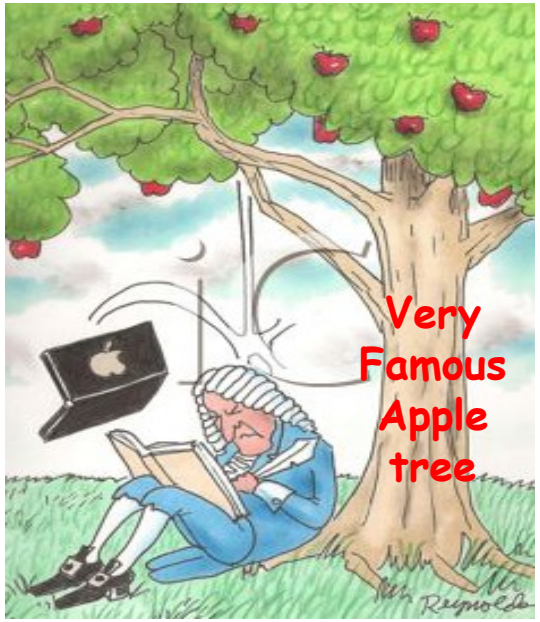
2. Memory for Co-Bots :To flexibly Connect "Past, Present and Future"

It's a poor sort of memory that works only backwards
White Queen to Alice (Lewis Carroll, 1871)

Simple Demo!

10+5=14

MEMORY

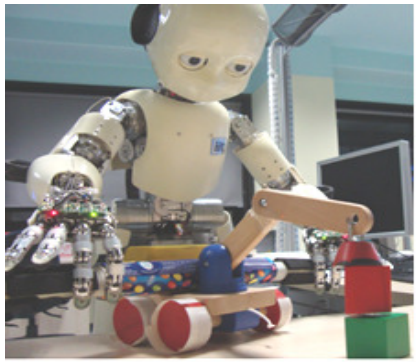


Cognitive systems learn cumulatively - On the job

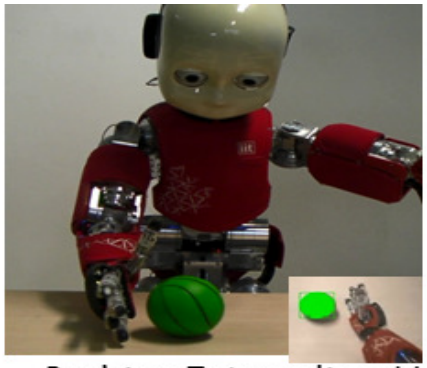
Memory is not a passive storage device, but rather an active integrative mechanism to connect-

- **Past Experiences**
- **Present Context**
- **Future Plans/Goals**

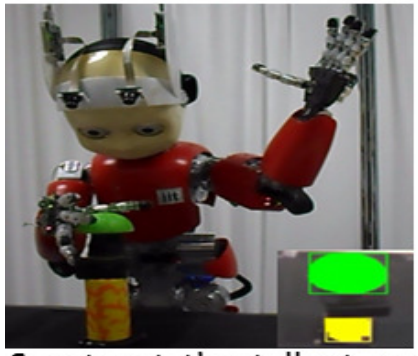
2. Memory for Co-Bots : Machine learning to Humanlike learning

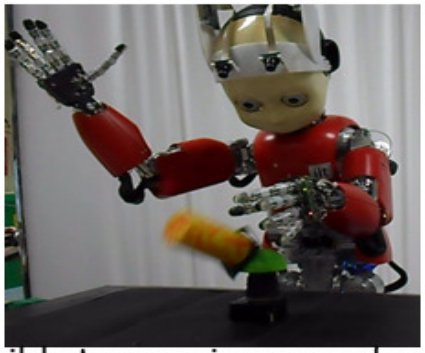


Tool Use

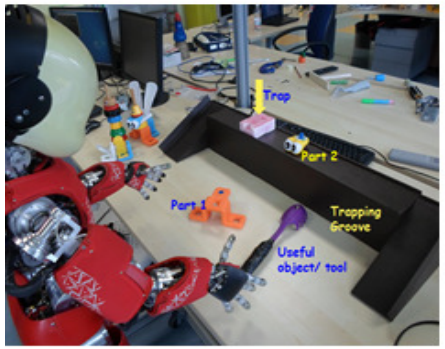


Pushing..Internalize How objects move





Construst the tallest possible tower given arandom set of objects



More complex Assembly tasks

Learning on the Job

Learning- Empower cognitive systems to learn different things, by different ways and different times

- Motor Skills
- Cause-Effect Relations

Learning Steams

- Imitation
- Interaction + Past experience
- Language based

Biomimetic Memory Framework

-Use past experiences generatively to plan goal oriented behaviors

-Discovery of the default mode network in the brain

Allen T , Fortin NJ. The evolution of episodic memory. Proc Natl Acad Sci U S A. 2013;110(2):10379–86.

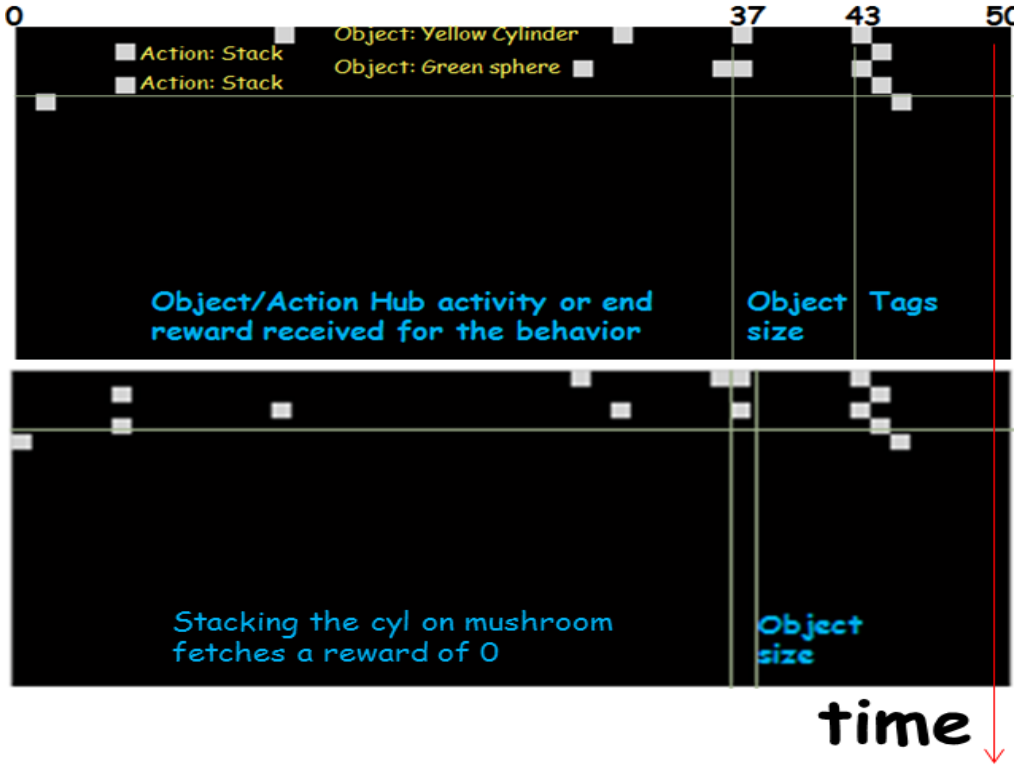
Mohan, V, Sandini G, Morasso P (2014). A neural framework for organization and flexible utilization of episodic memory in cumulatively learning baby humanoids. Neural Computation, MIT Press.

2. Memory for Co-Bots : One possible Implementation

Robot Episodic Memory structure for cumulative Encoding of experiences

- Auto Associative network (Mohan et al, 2014, Hopfield 2008)
- 1000 neurons: arranged as a 50x20 sheet, 10^6 connections
- An experience is a temporal sequence of actions, objects, rewards, body state
- One shot learning
- Experiences can emerge from exploration, user demo, language based instruction

Simple Example: Encoding experience (One shot learning)



2. Memory for Co-Bots : Remembering to Inferring

Robot Episodic Memory Structure and Encoding of experiences

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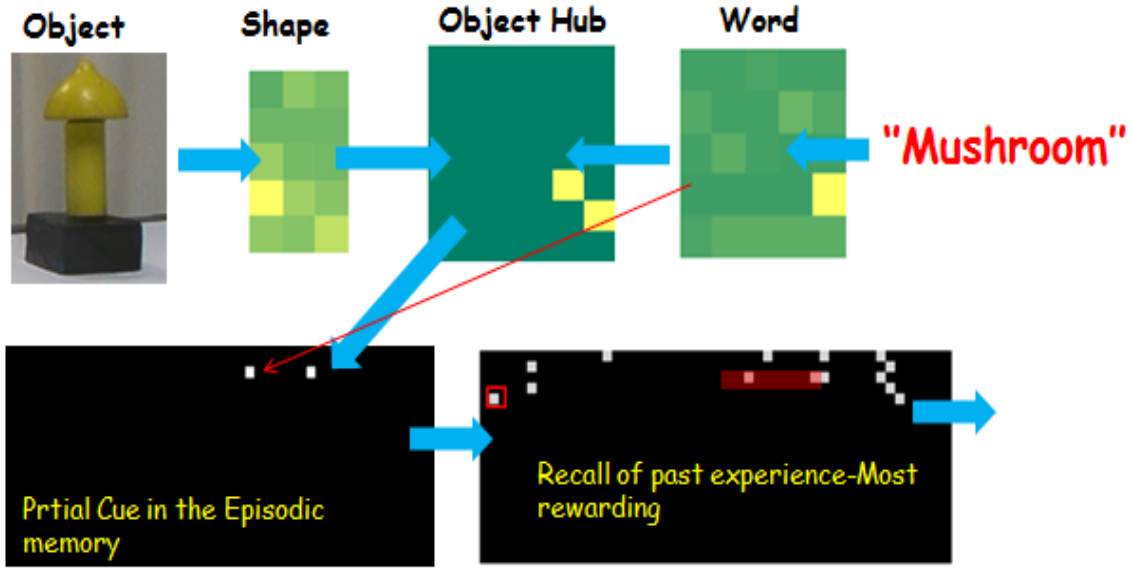
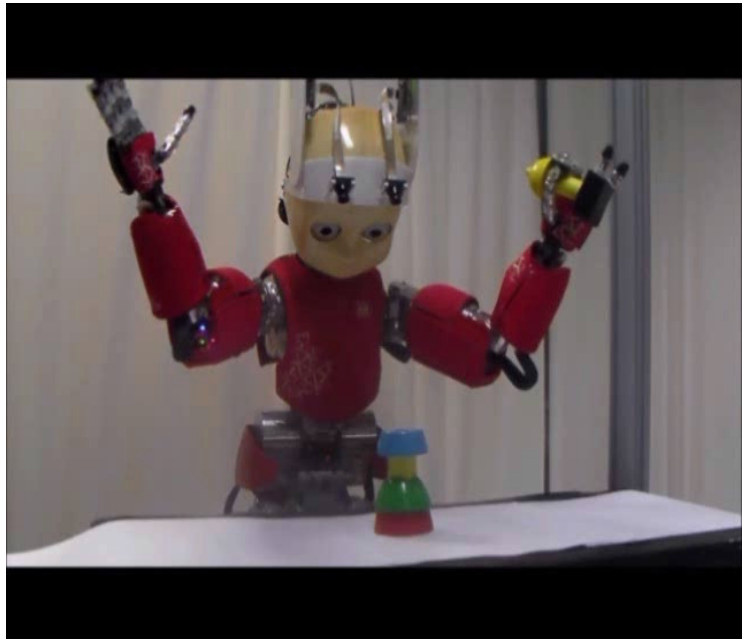
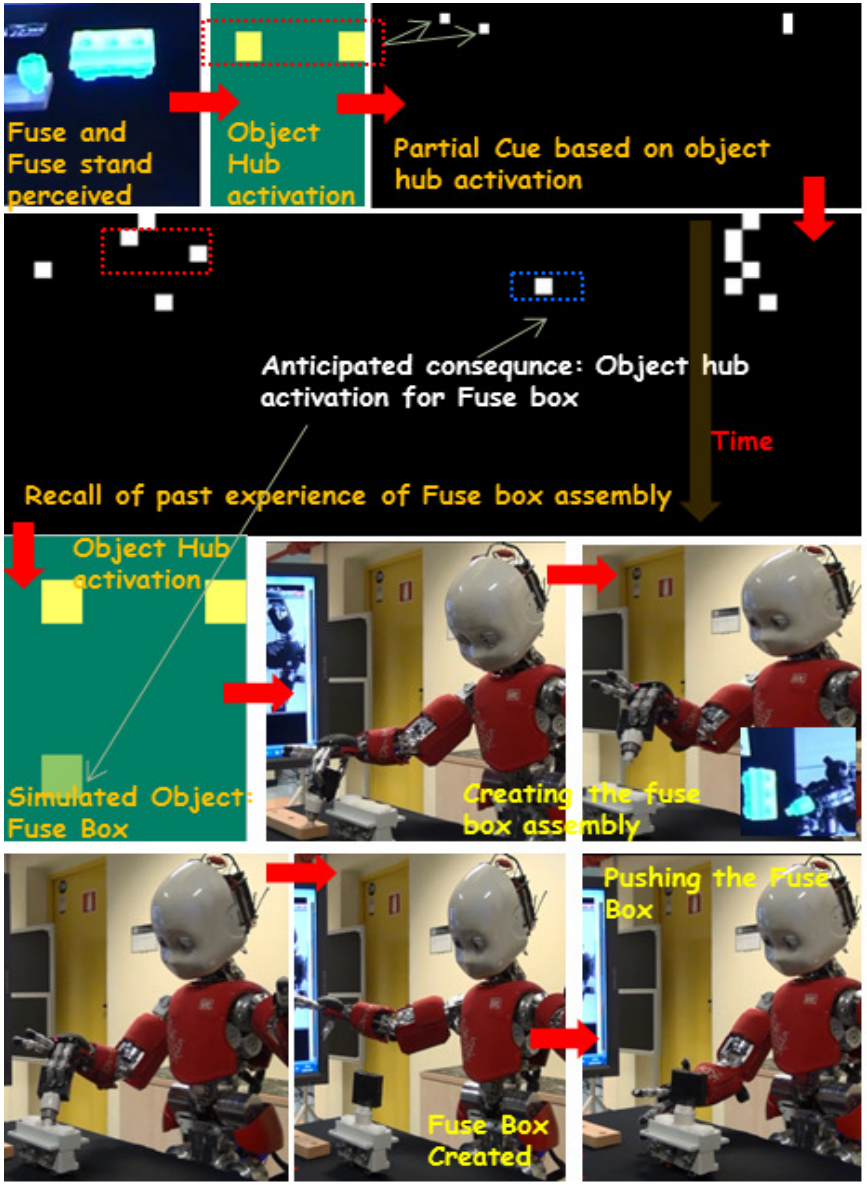
Simple Example: Multimodal Recall from partial cue in future



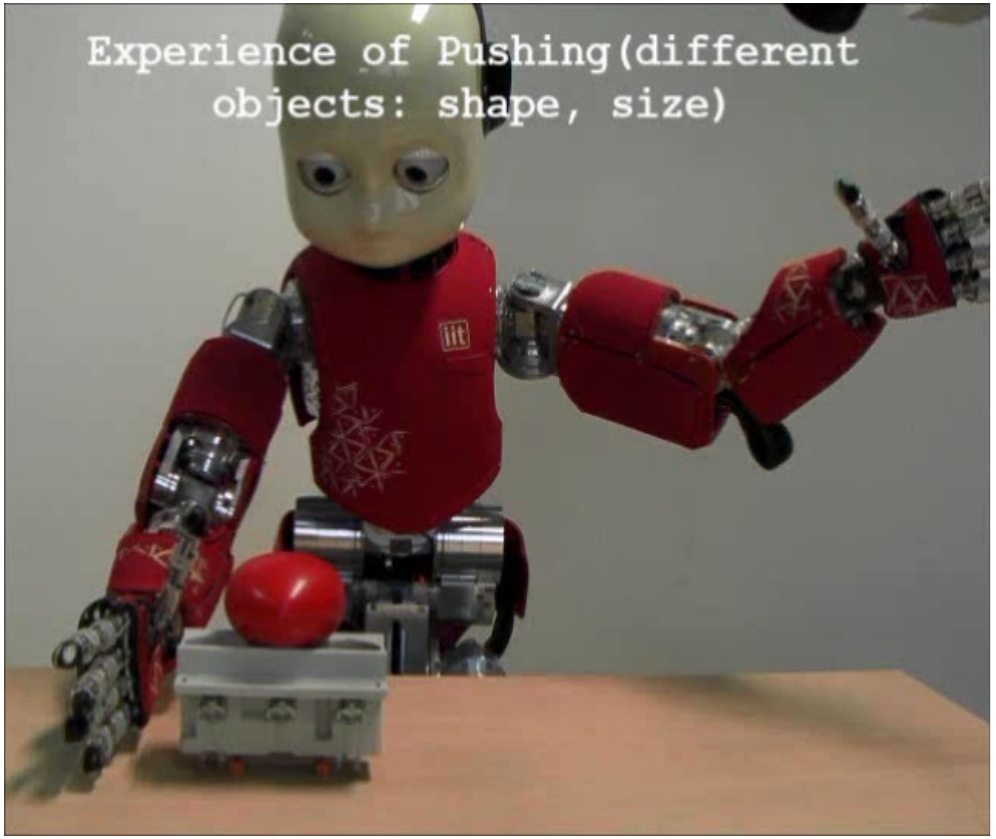


2. Memory for Co-Bots : Remembering to Inferring

User: Assemble Fuse Box



User: Assemble Fuse Box (Impossible Goal)

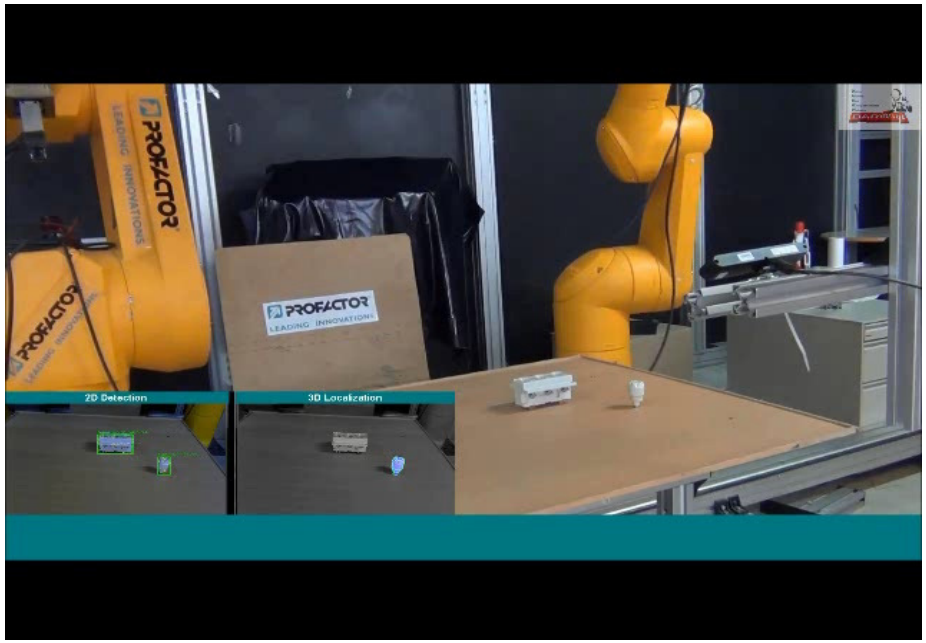


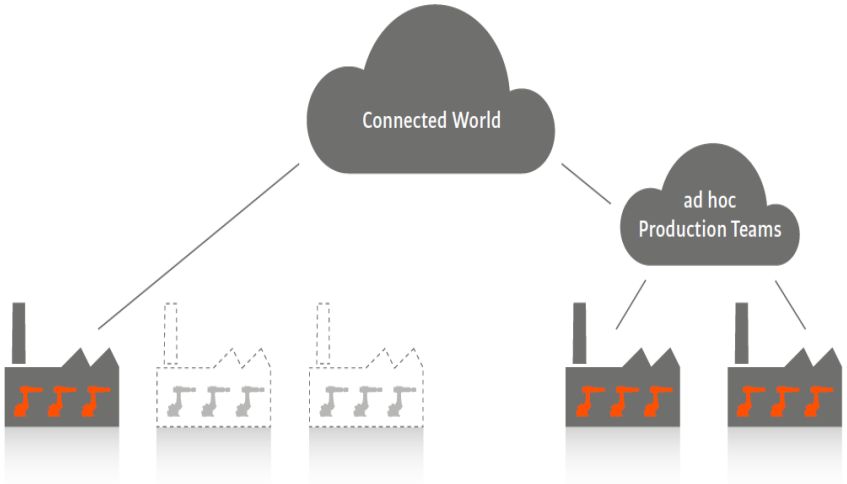
Bhat, A., Mohan, V., Sandini, G., Morasso, P. (2016). *Humanoid robot infers Archimedes' principle*: From cumulative exploration to abstraction of underlying causal relations and affordances. *Proceedings of the Royal Society Interface.*

2. Memory for Co-Bots : Bank transfer to Other robots, Cloud Based

Memories are transferrable beyond embodiments

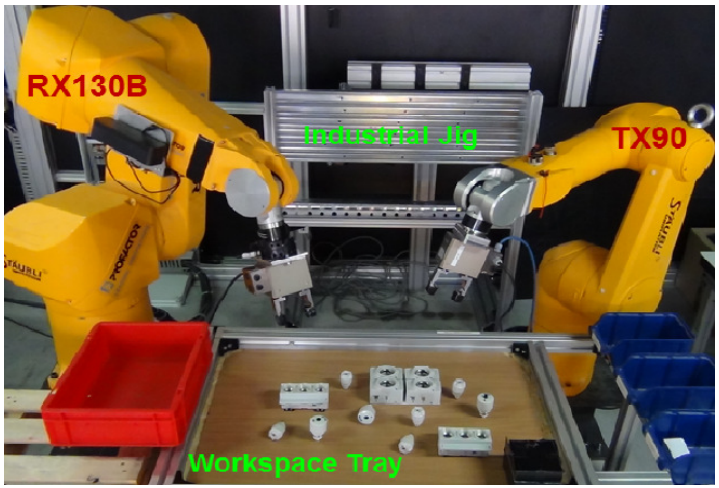
Fuse box assembly with unexpected intervention, monitoring, reasoning in industrial work cell (Co-Bot Working with an uncooperative human)





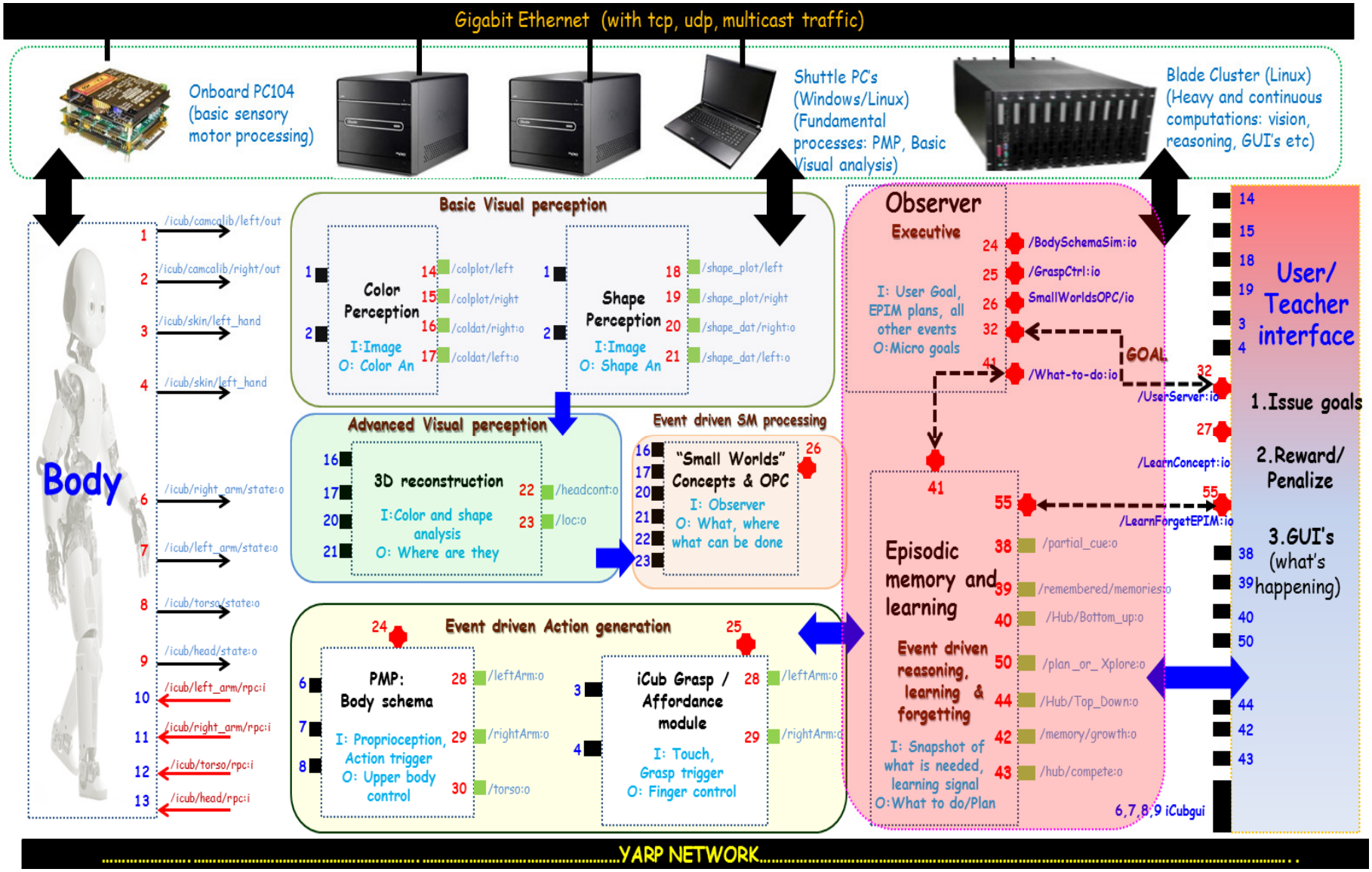
Mixed Assembly

Goals are inferred from environmental cues



roboearth.eu, robohow.eu, vishwanathanmohan.com

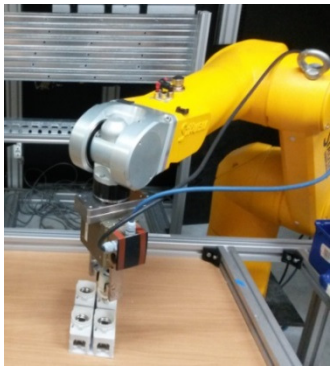
3. Plug and Play Cognitive Architectures: Big Picture



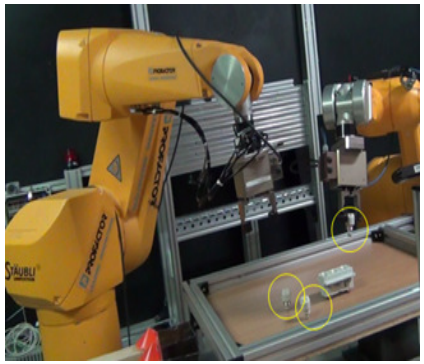
CZECH TECHNICAL UNIVERSITY IN PRAGUE · KING'S College LONDON · PROFACTOR · NOVOCAPTIS COGNITIVE SYSTEMS & ROBOTICS · FORTH Foundation for Research & Technology - Hellas

3. Plug and Play Cognitive Architectures (Last 4 Years of Engagement)

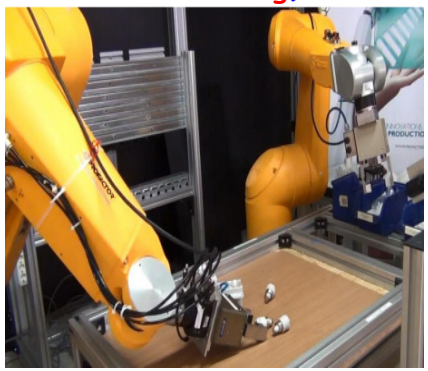
Basic Assembly on Industrial Platform (Peception-Action Loop)

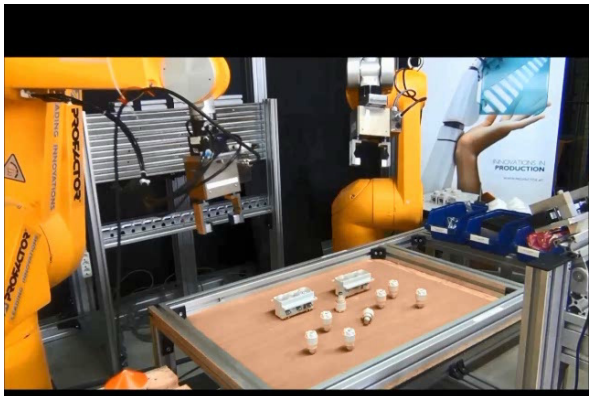


Multirobot Assembly (Peception-Action -Spatial reasoning Loop)



Recovery from Failures (Peception-Action -Spatial reasoning Loop-Top down monitoring)

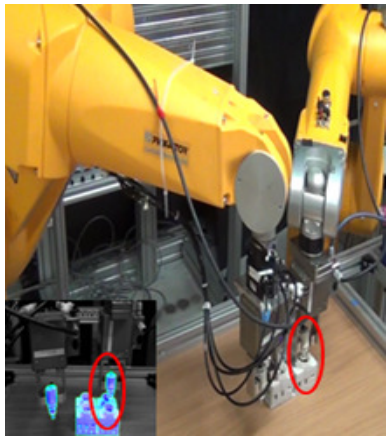




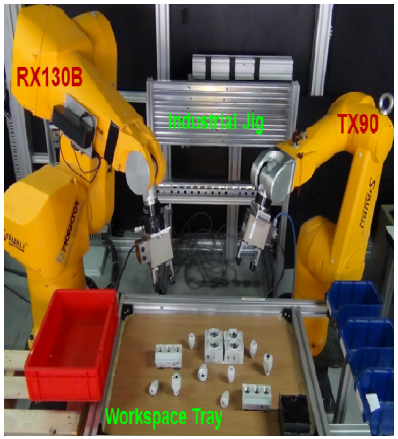
Assmbly of two fuseboxes: Parallel Operation and Collision Avoidance

Robot Cooperation (Peception-Action -Spatial reasoning Loop-Top down monitoring-Internal model based Simulation)

Quick Switchover to new tasks (Peception-Action -Spatial reasoning Loop-Top down monitoring-Internal Simulation-Online learning)



Mixed assembly (Goals are triggered by the environment)



Comaprison with Industrial Benchmark system

Demonstration Scenario	DARWIN Cognitive System (Demo specific success rate)	DARWIN Benchmark system (Demo specific success rate)
1.1	31 seconds	29.9 seconds
1.2	90%	100%
2	100%	100%
3.1	100%	100%
3.2	94%	95%
4	88%	85%
5	15 minutes	2-3 hours
6	97% (TSR: 85%)	84% (TSR: 45%)

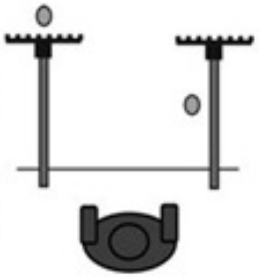
Demonstration Scenarios:

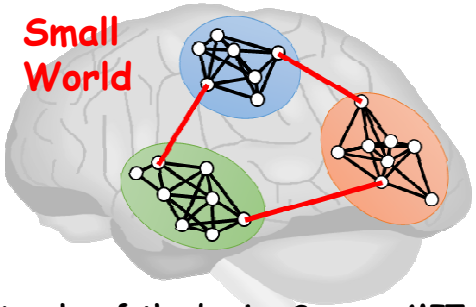
1.1 Basic assembly with fuses in upright position
1.2 Basic assembly with fuses in arbitrary position
2 Bi-manual operation of robots
3.1 Recovery from grasp failure
3.2 Recovery from insertion failure
4 Robot Cooperation
5 Change over to new task
6 Mixed Assembly
TSR: task success rate

Co-Botics is about making learning, reasoning robots that can do much more!

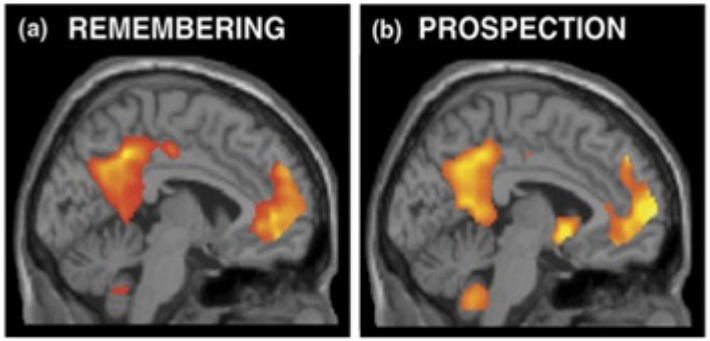
Going back to Neurosciences (Why and Why Now?)

Action Gen-Sim

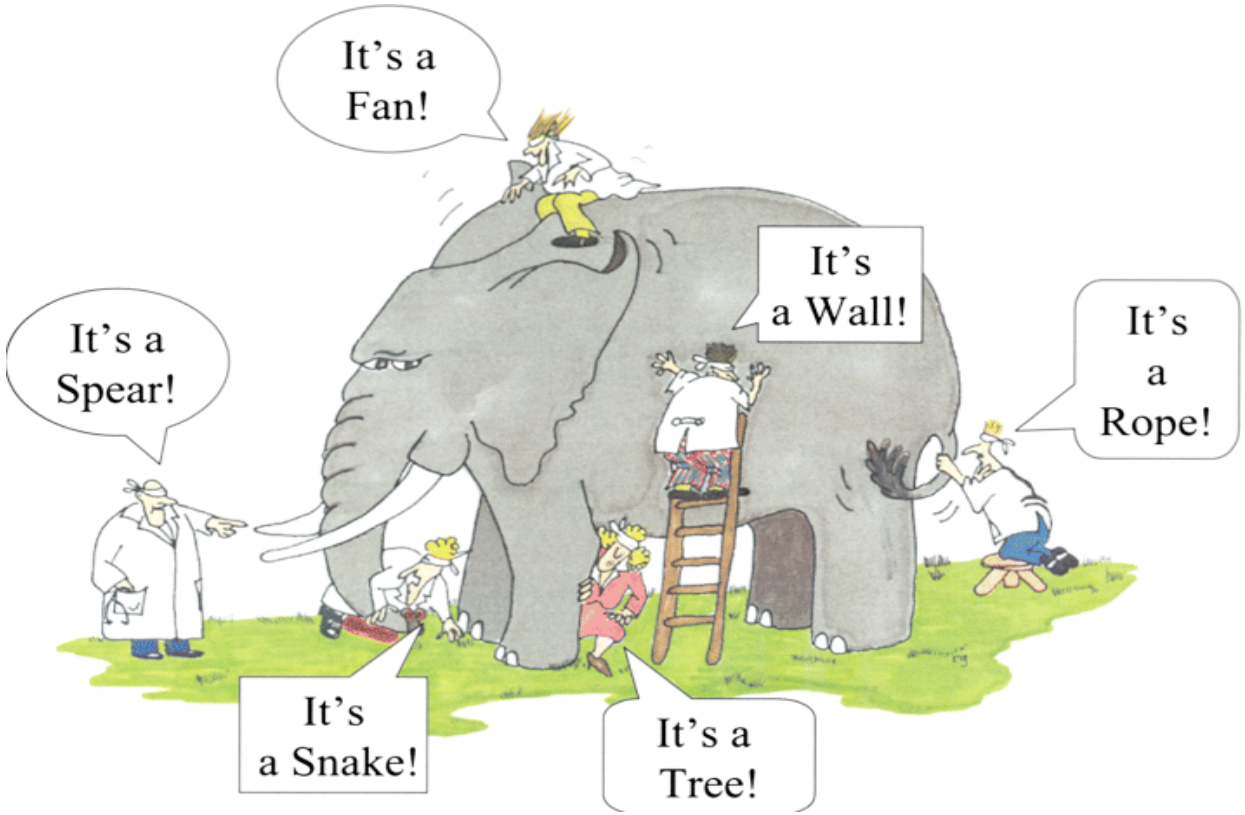




Networks of the brain, Sporns, MIT



Brain: Just like a big elephant problem



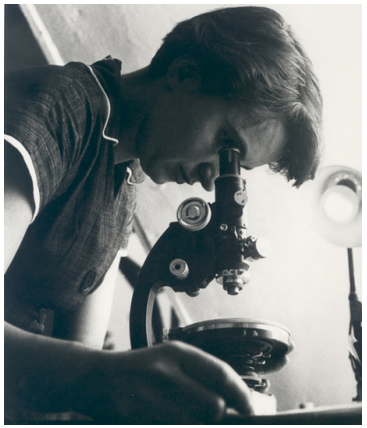
Data to Useful engineering Principles

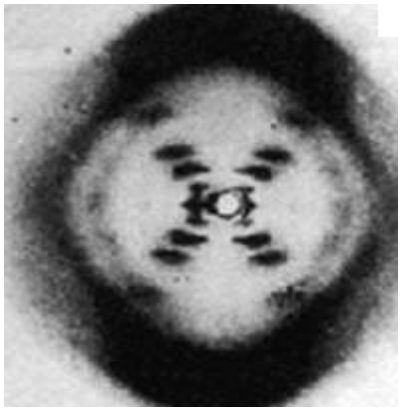
Need an Integrative approach

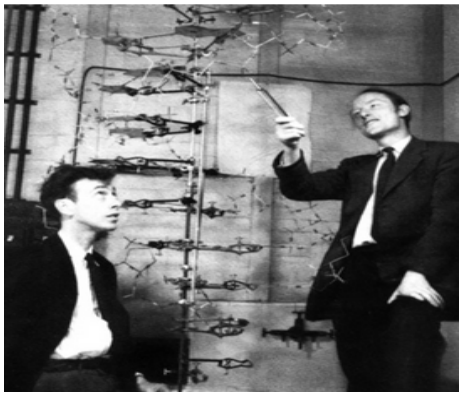
Co-Bots are such Integrative platforms

Going Back to History of Science: Role of Research Labs

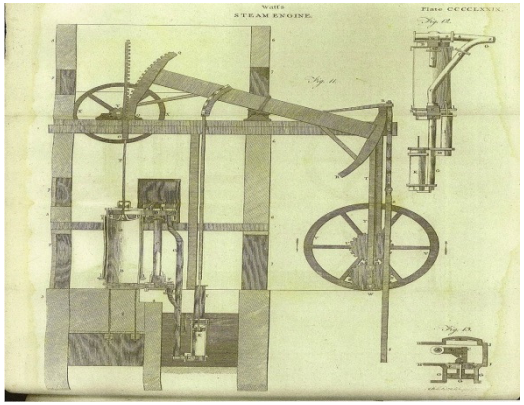
DNA- Interdisciplinary efforts







Steam engine: Application to Theory



Our quest to understand brain function and designing artificial systems exhibiting cognitive behaviors is at a crucial juncture

Research Labs and Research led education are fundamental enablers in this direction (QUB Vision 2020)

Concluding message from Charlie Chaplin's Eating Machine!!!!!

Future of Co-Bots: Some take home points

- Generate dexterous Actions (and predict consequences of potential actions of oneself and others)
- Perception (beyond labelling and rather inferring what one can do)
- *Learning on the Job (Green, Fast and Cumulatively)*
- *Memory (not passive storage element, but actively connecting past with the present context and possible future)*
- *Configurable "plug and play" cognitive architectures (use a robot like a smart phone)*
- *Domain agnostic, partially embodiment agnostic and strongly brain guided*

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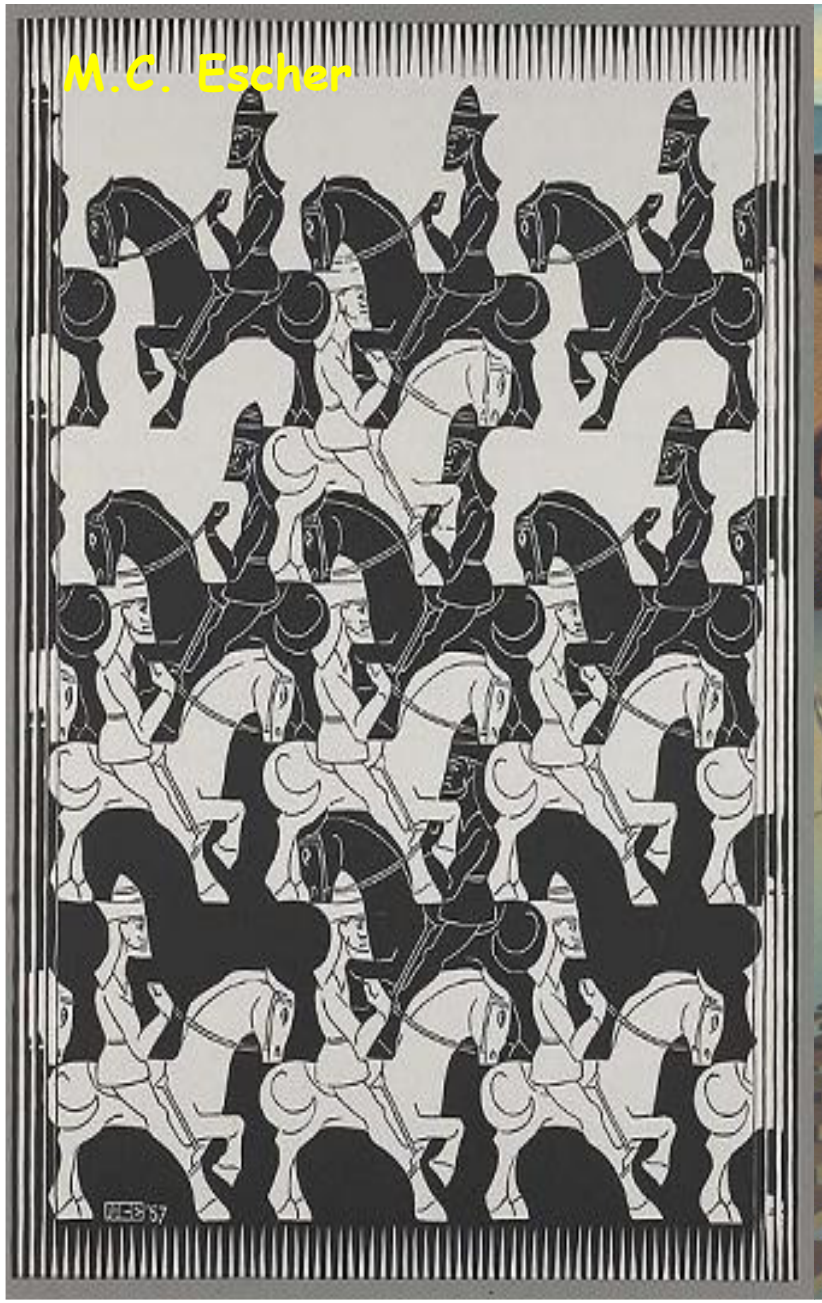
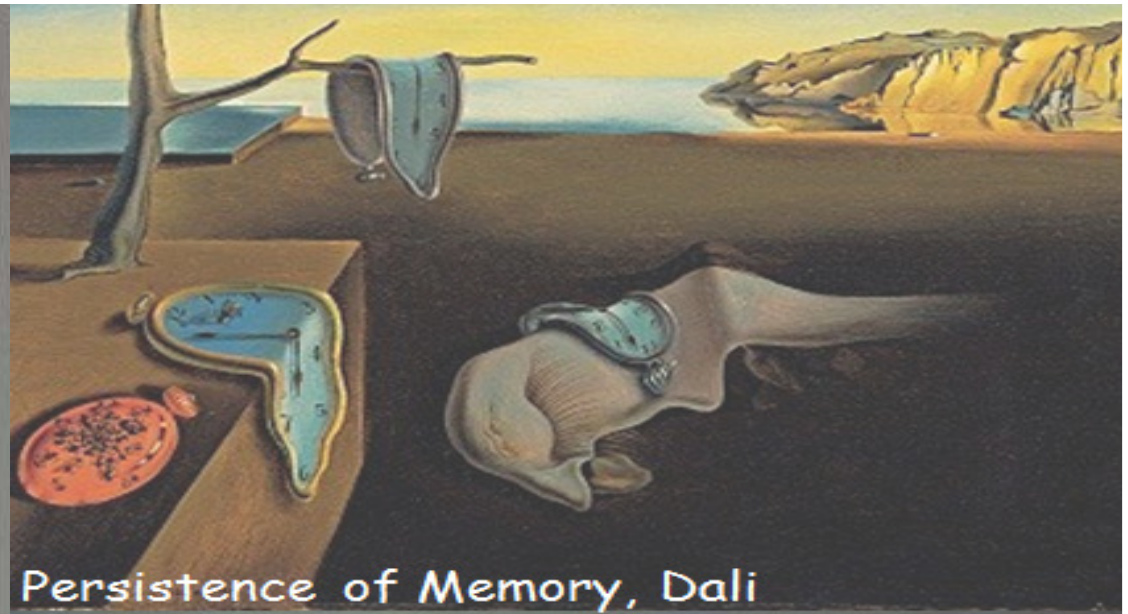
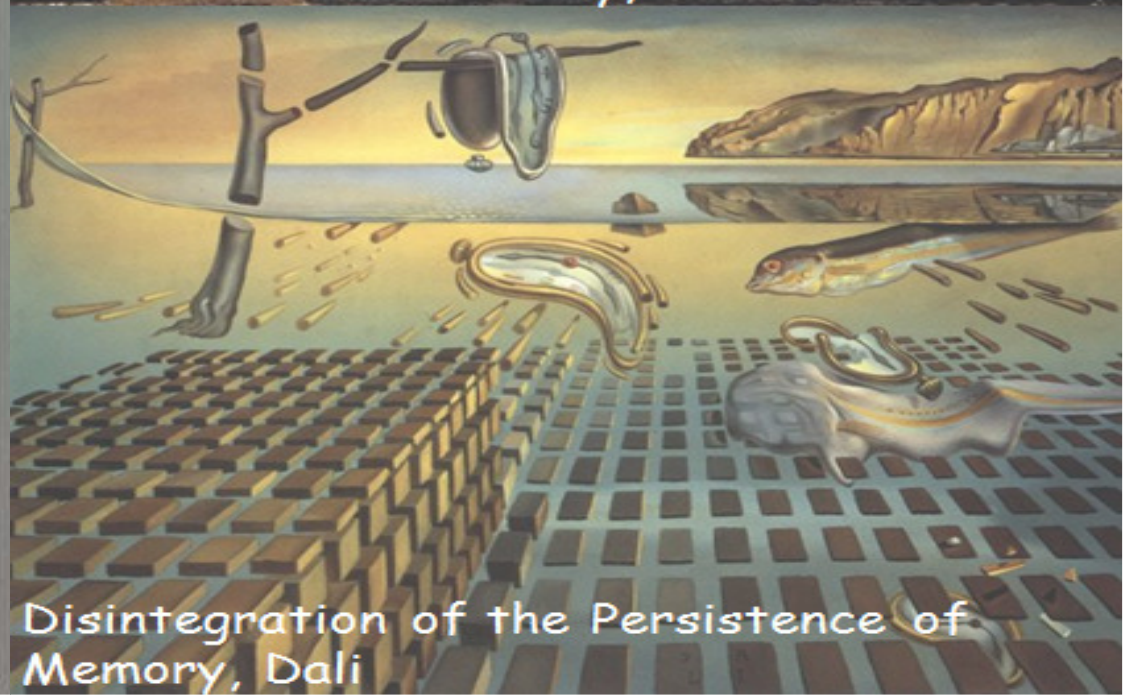
My personal roadmap

A pictorial Recap!! (Art is a lie to realize the truth ...Picasso)

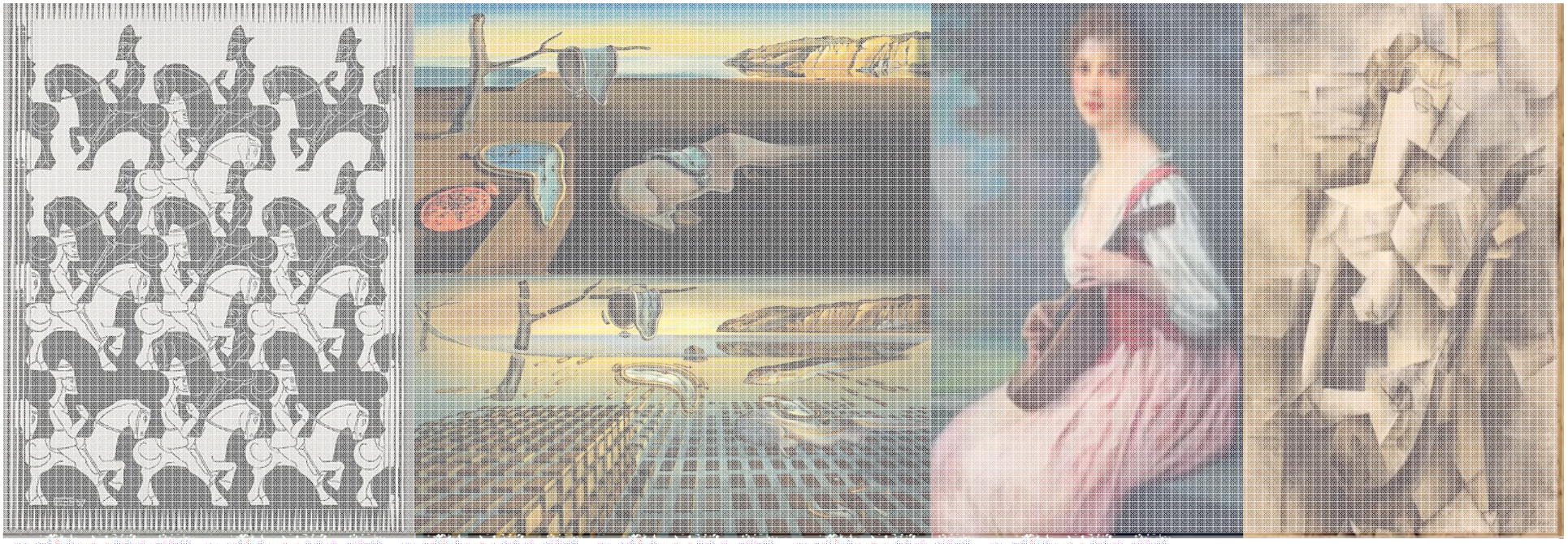




Persistence of Memory, Dali



Disintegration of the Persistence of Memory, Dali



Thank You + ?????

Further Info+ Contact + Software → www.vishwanathanmohan.com