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Aquila: An Open-Source GPU-Accelerated Toolkit for Cognitive Robotics Research

Martin Peniak and Anthony Morse

Agenda

- What is Cognitive Robotics?
- The iCub humanoid robot
- GPUs and robotics
- Aquila - past, present and future

Cognitive Robotics

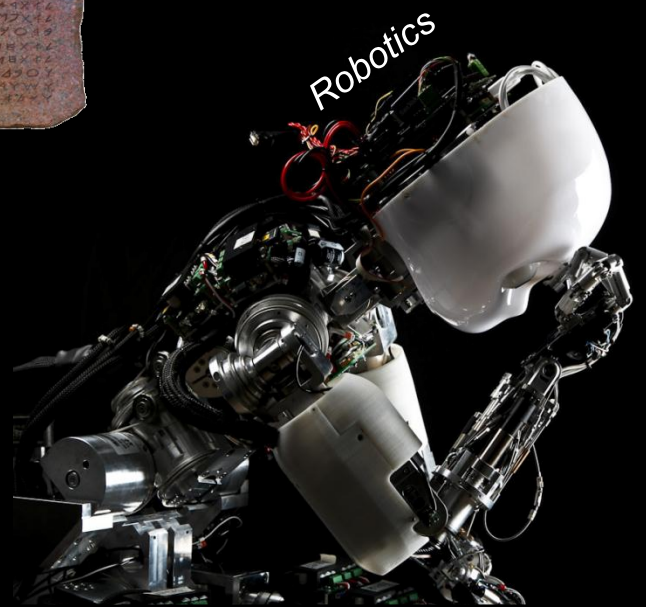
Cognitive Robotics

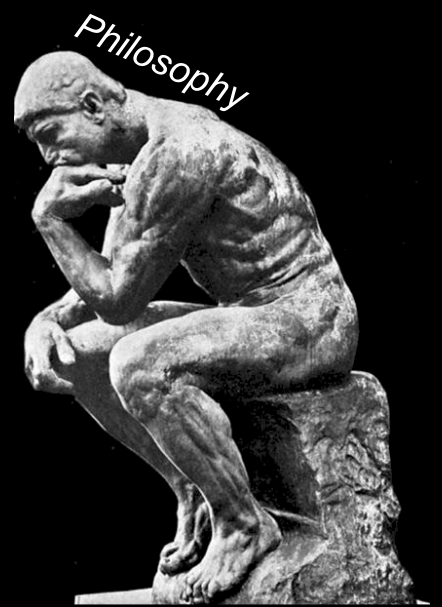
- Cognitive Robotics draws from classical robotics, artificial intelligence, cognitive science and neurobiology to elucidate and synthesize aspects of action-oriented intelligence.

Linguistics

Computer Science

Psychology

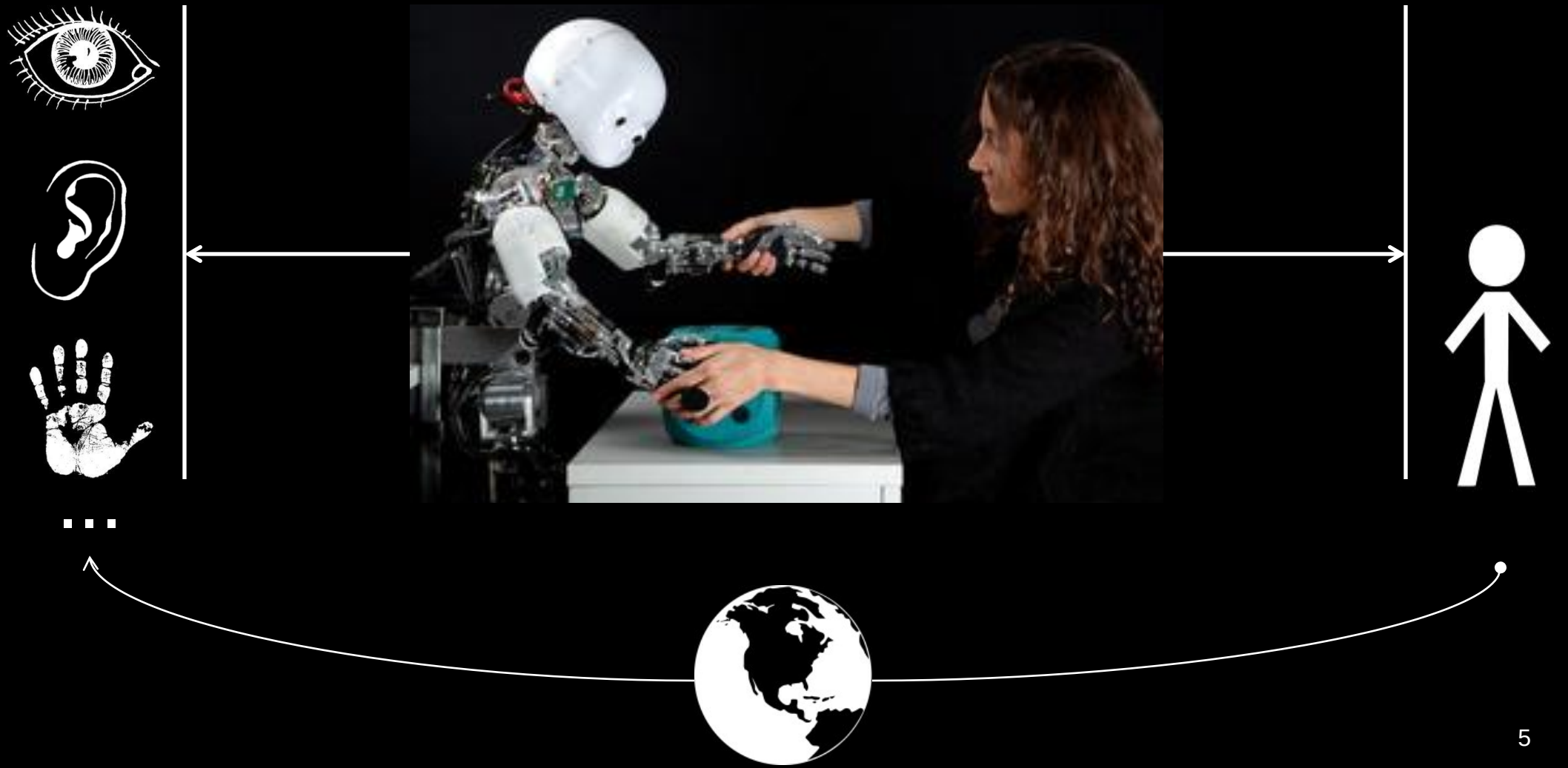




AI

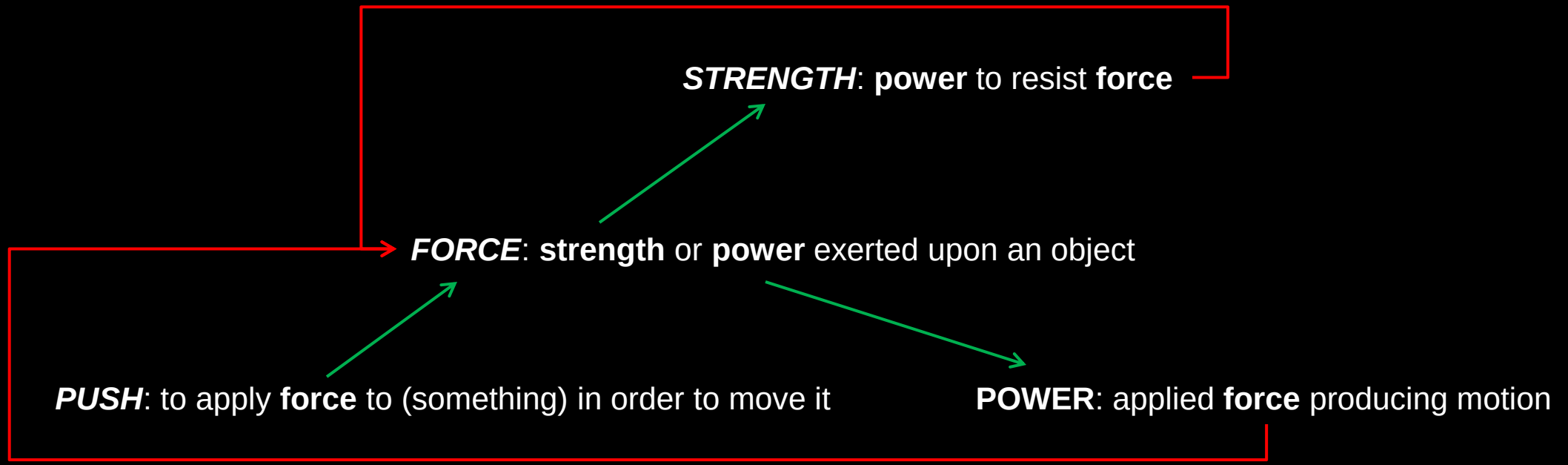
Neuroscience

Cognitive Robotics



Ungrounded Symbol Systems

- **Computers can easily be pre-programmed to memorise a dictionary, but cannot fully understand the language they use**



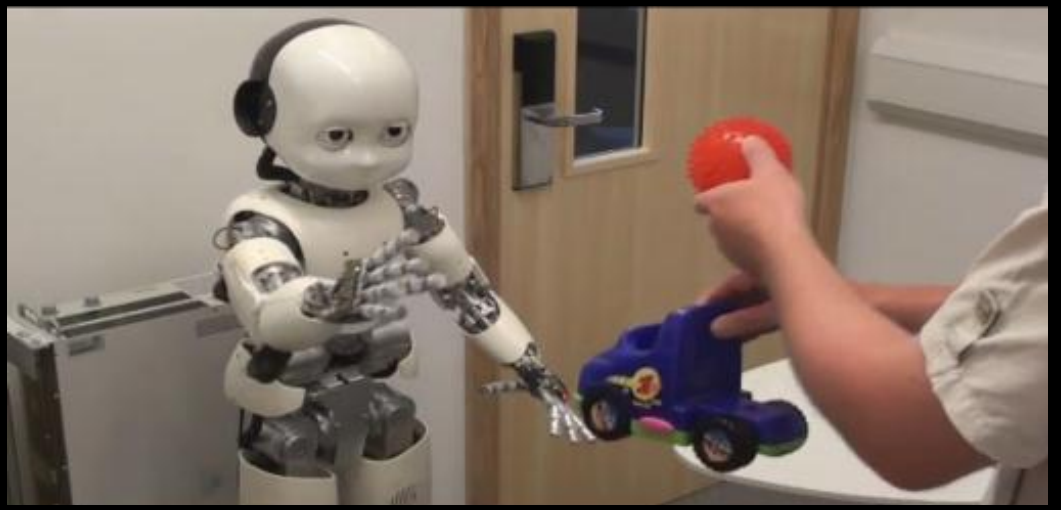
Example of self-referential, amodal network of word definitions in Webster's Dictionary (Roy 2005) Chinese Room (Searle 1980)

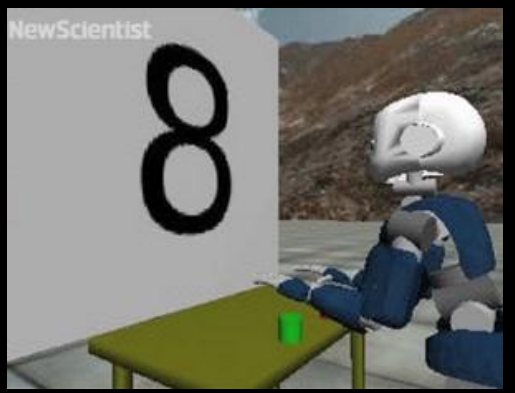
Cognitive Robotics

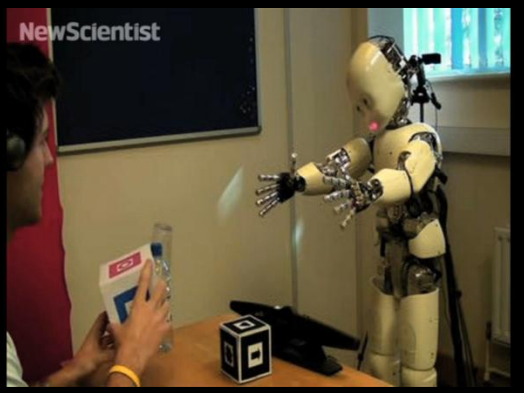
- An objects identity or category, it’s meaning lies in the profile of dynamic interactions that it affords

Cognitive Robotics

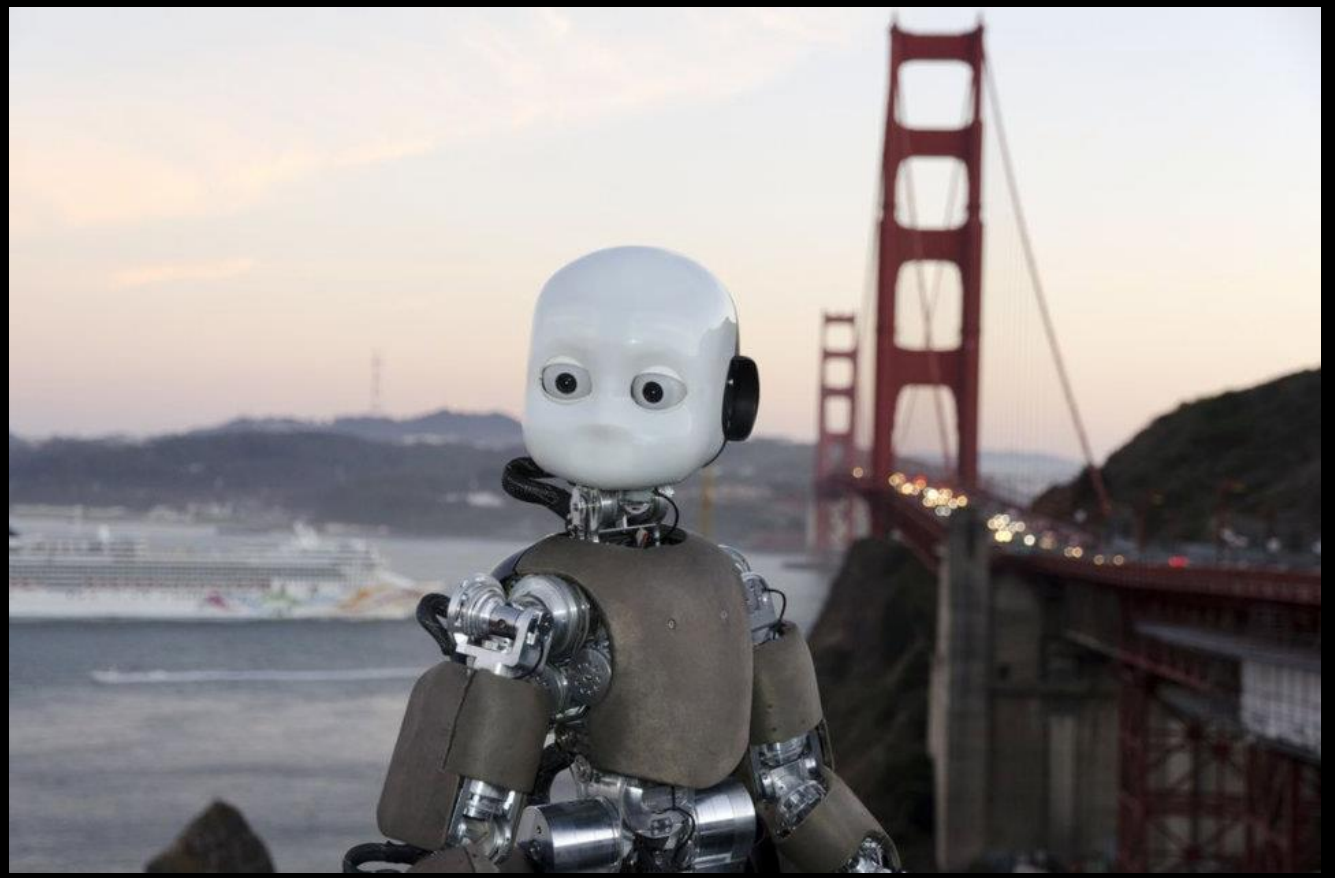
- Replicating child psychology experiments
- Testing psychological theory
- Finding common processes underlying disparate phenomenon
- Prompting new questions and investigations
- Developing technology







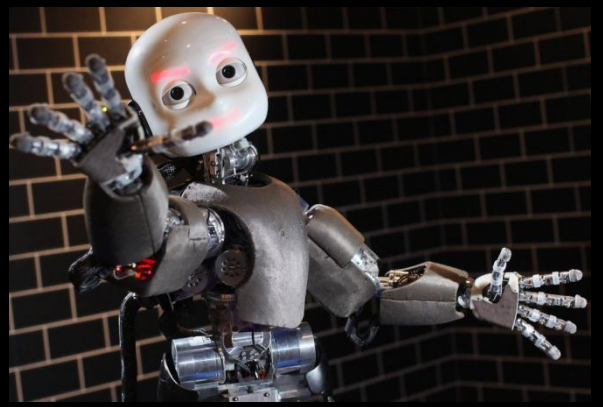
iCub humanoid robot

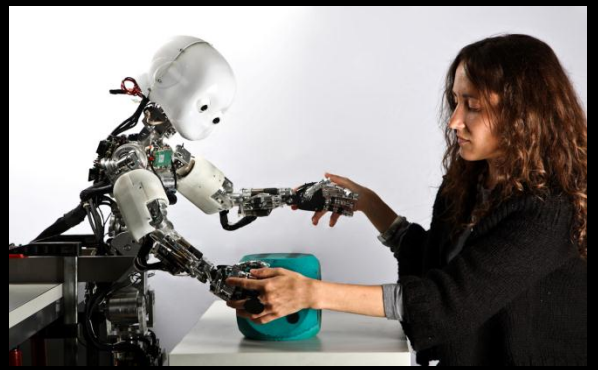


- The dimensions are similar to that of a 3.5 year old child
- 53 degrees of freedom
- Came from the European Framework 6 project: RobotCub (www.robotcub.org)
- There are now 20 iCubs in different labs in Europe and 1 in the US
- Continued design - v2.0 to come out soon
- Various ongoing project outcomes are distributed via an open-source software repository and via hardware upgrades
- A free iCub simulator is available

iCub humanoid robot

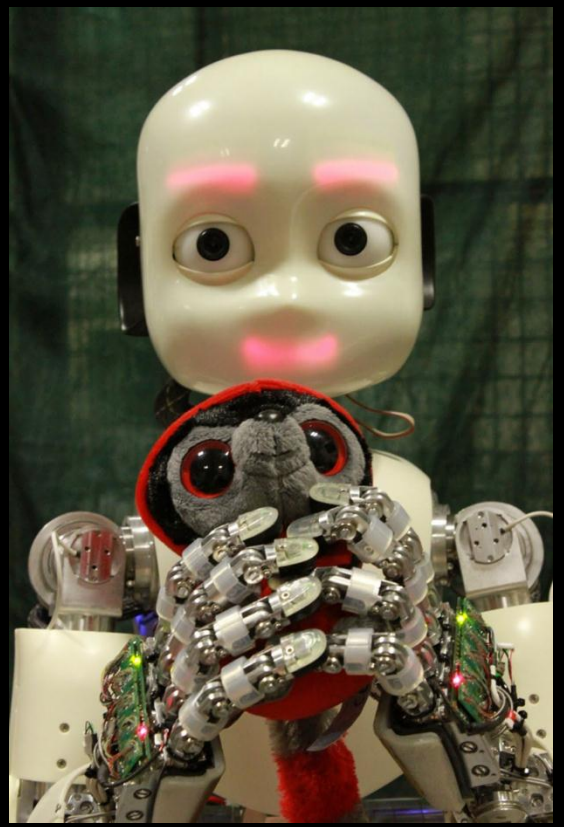
Touch sensitive skin and compliant actuation

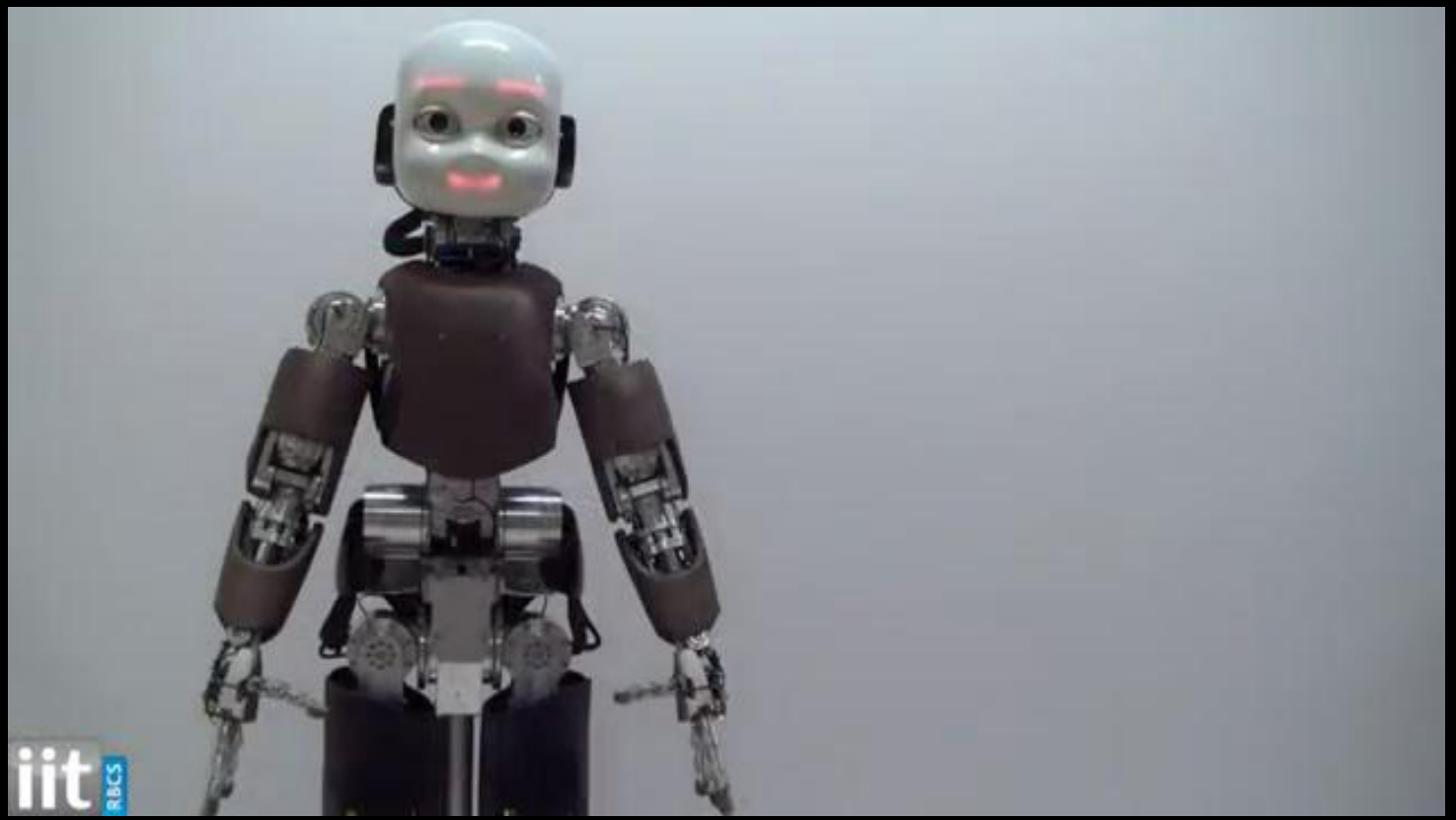




iCub humanoid robot

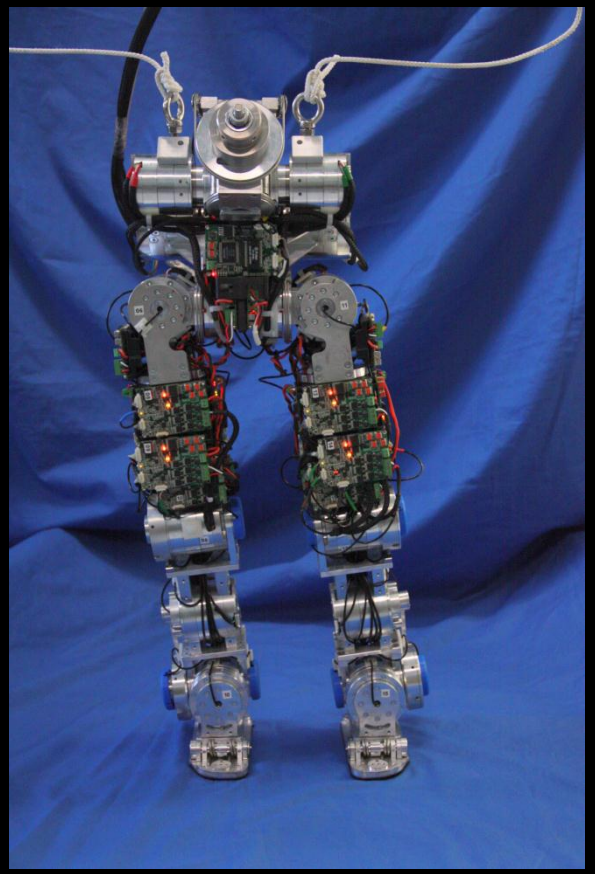
Dexterous hands for object manipulation

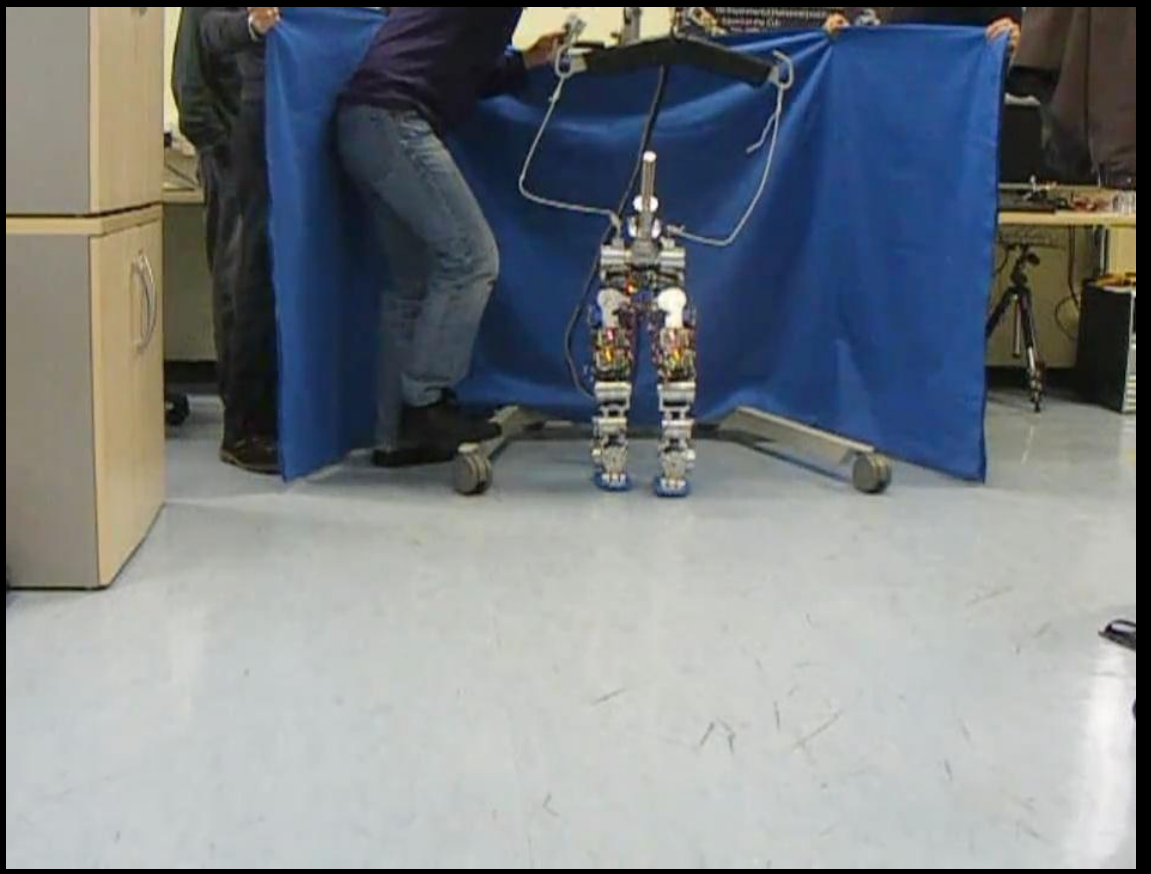




iCub humanoid robot

Almost walking

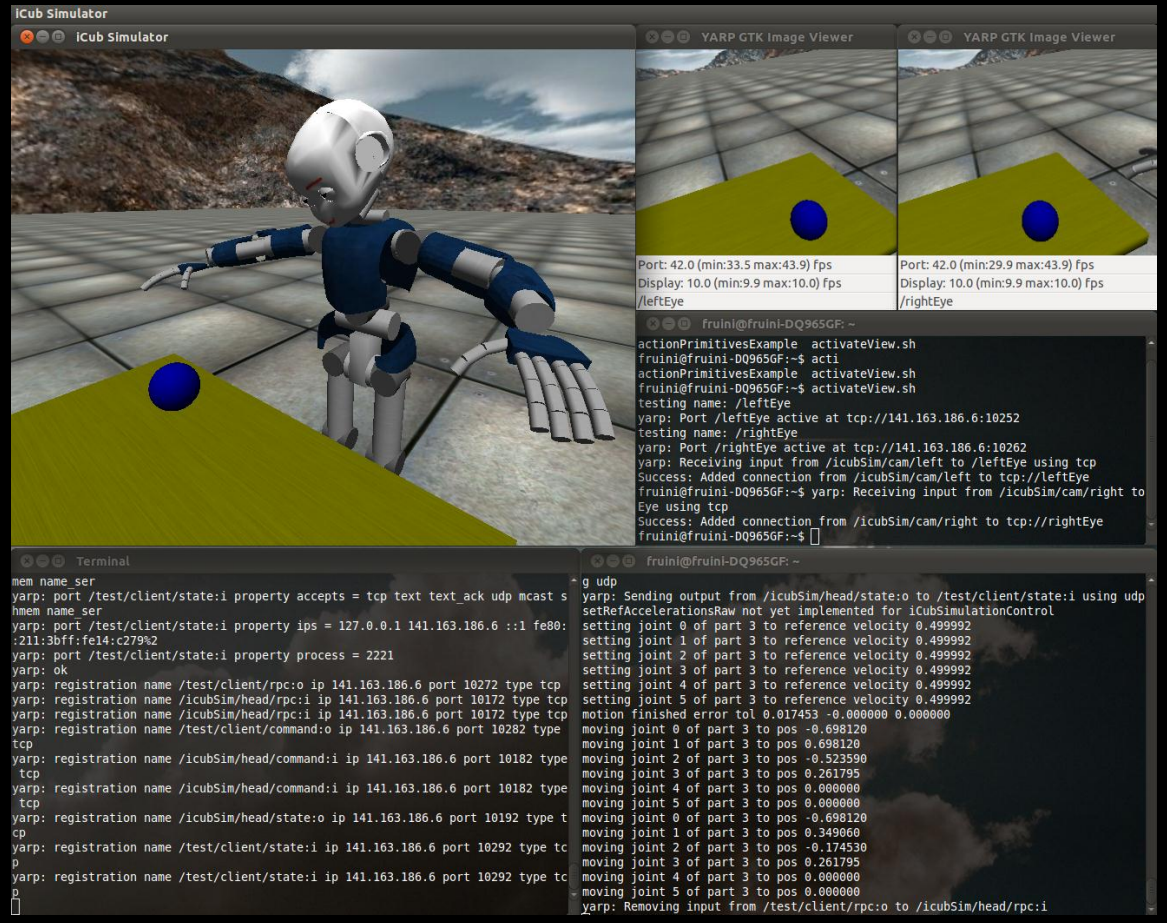




iCub humanoid robot

Simulator

- Open-source
- Developed as part of a joint effort with the European project iTalk
- Widely adopted within cognitive robotics community



V. Tikhanoff, P. Fitzpatrick, F. Nori, L. Natale, G. Metta, and A. Cangelosi, “The icub humanoid robotsimulator,” In International Conference on Intel ligentRObots and Systems IROS, Nice, France, 2008

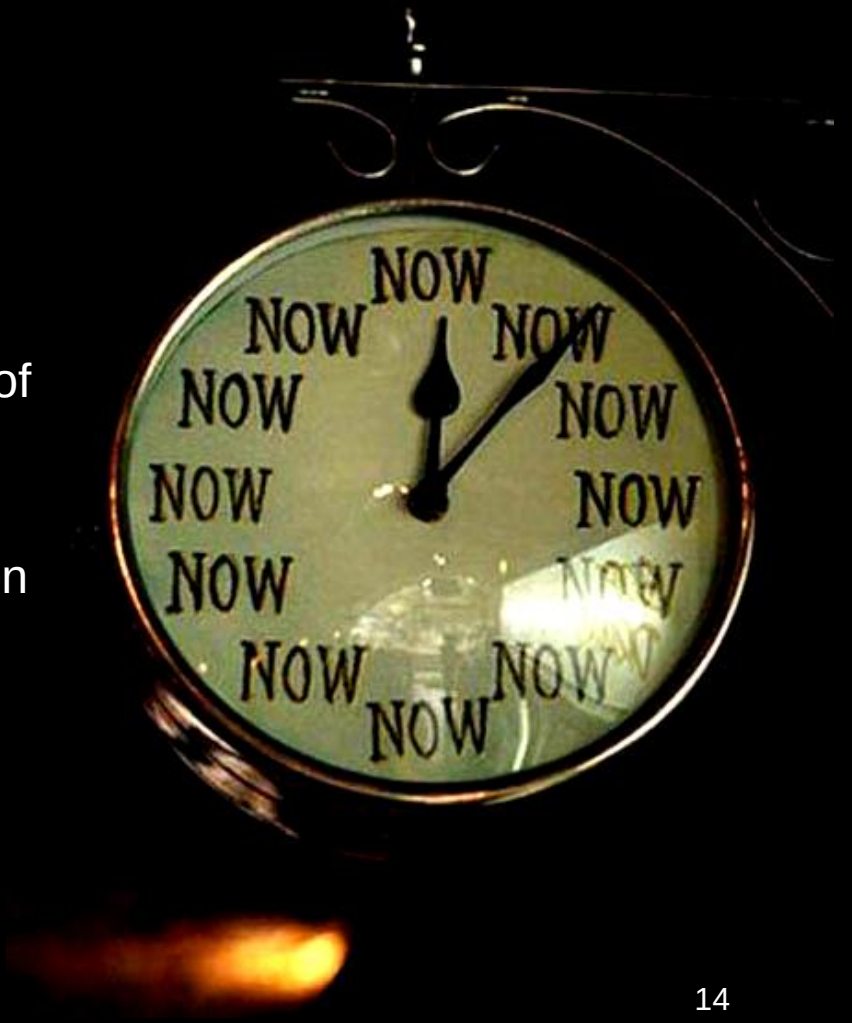
GPUs in robotics

It's all about real time

- Motion compliance < 1 ms
- Vision (30fps) < 33 ms
- Vision (60fps) < 16 ms

We typically take 33 ms as the cut-off time. 1 complete cycle of everything critical MUST be completed in that time.

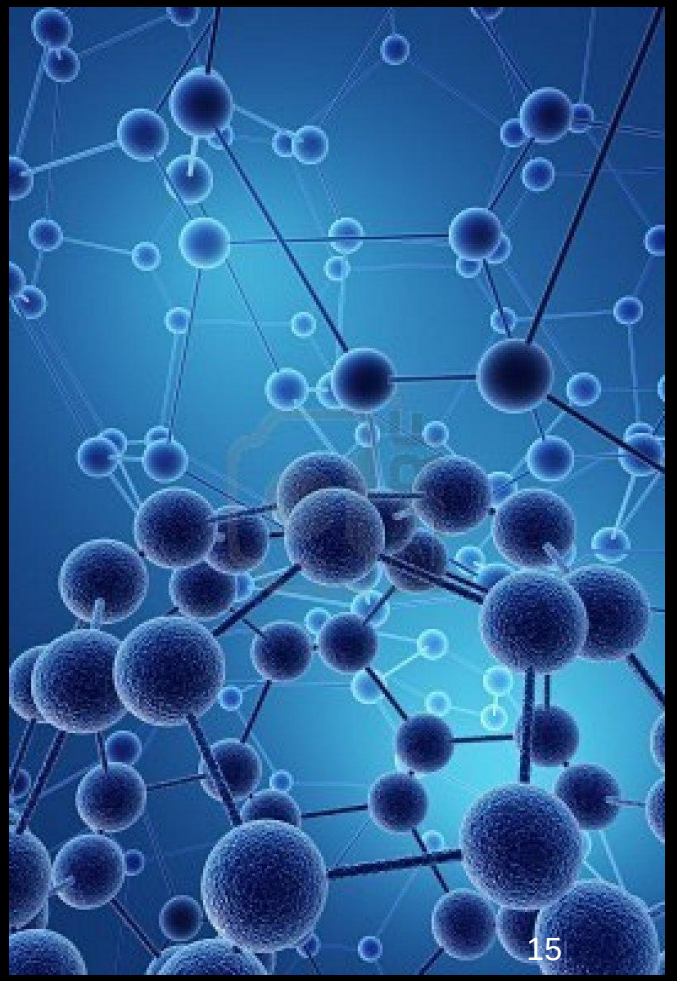
Of course some processes are not critical and their information can be used as and when it becomes available, subject to various constraints.



GPUs in robotics

It's all about real time

- Our models of learning, integrating multi-modal information, and controlling the robot are based on Neural Networks
- Each neuron within a neural network computes its own activation based on local information
- Learning algorithms continuously adapt the strength of connections between neurons
- Both processes are **inherently parallel**



GPUs in robotics

It's all about real time

- CUDA lets us build **much bigger** and **more complex** neural networks while remaining within the real time constraints
- CUDA also accelerates some of the pre-processing required (e.g. vision processing)

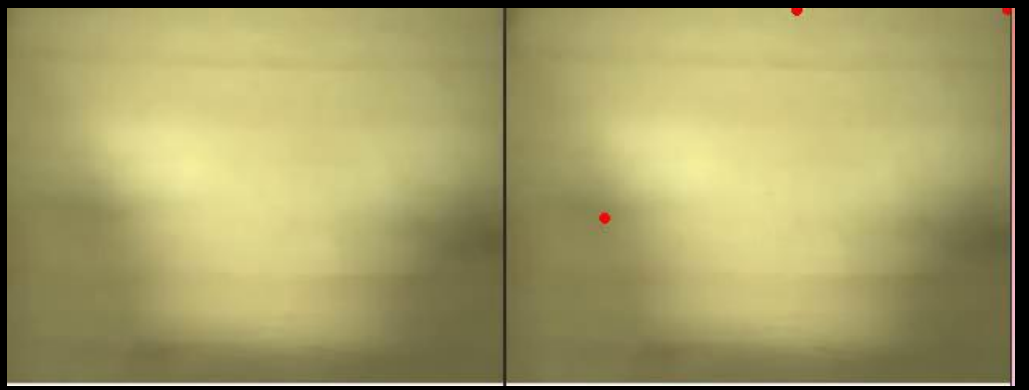
GPUs in robotics

Vision processing example

- ***Carlo Ciliberto and Vadim Tikhanoff used GPU-accelerated* SIFT-based feature extraction for iCub object recognition**

- *"In Robotics it is crucial to have systems that perform in real time since the artificial agent has to continuously adapt to (possibly sudden) changes in the environment. Clearly the CPU implementation of the SIFT detection/extraction was unsatisfactory in this regard while the GPU one allowed us to overcome this obstacle."*

- *"We did not perform a rigorous comparison between CPU and GPU implementations since the difference of computational times was so huge we did not bother. In particular we experienced times greater than 1000 ms for the OpenCV Sift detector/extractor on CPU while around 20 ms for the GPU implementation."*



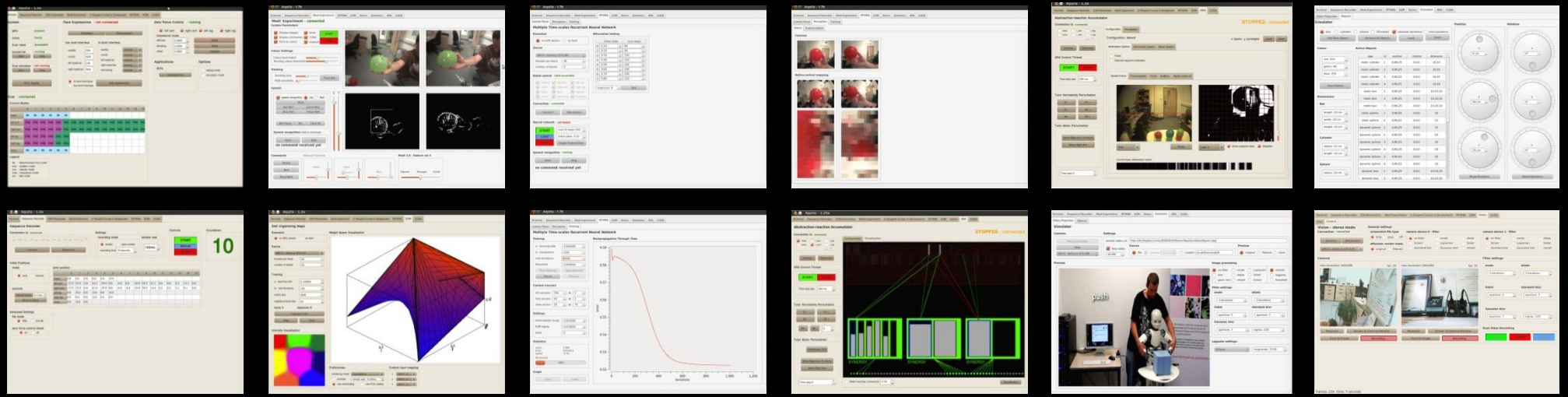
Aquila

An Open-Source GPU-Accelerated Toolkit for Cognitive Robotics Research

Aquila

History

- Project started in 2009 as a simple open-source GUI application for our research with iCub
- CUDA was adopted to accelerate growing number of interacting systems
- Several limitations have recently led to a completely decoupled redesign



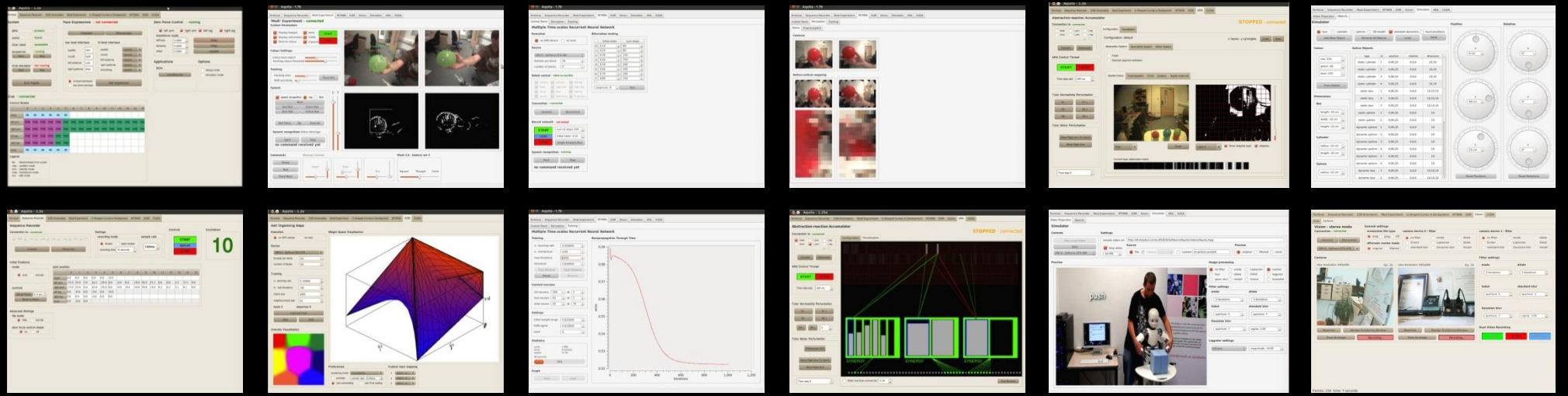
Aquila

Research with iCub made easier and more accessible

“There are many advantages using Aquila ....I am mainly using Aquila for eye tracking and the feature of video streaming using the screen in the iCub world. The biggest advantage is the ability to record the eyes and control what is displayed on the screen at the same time.”

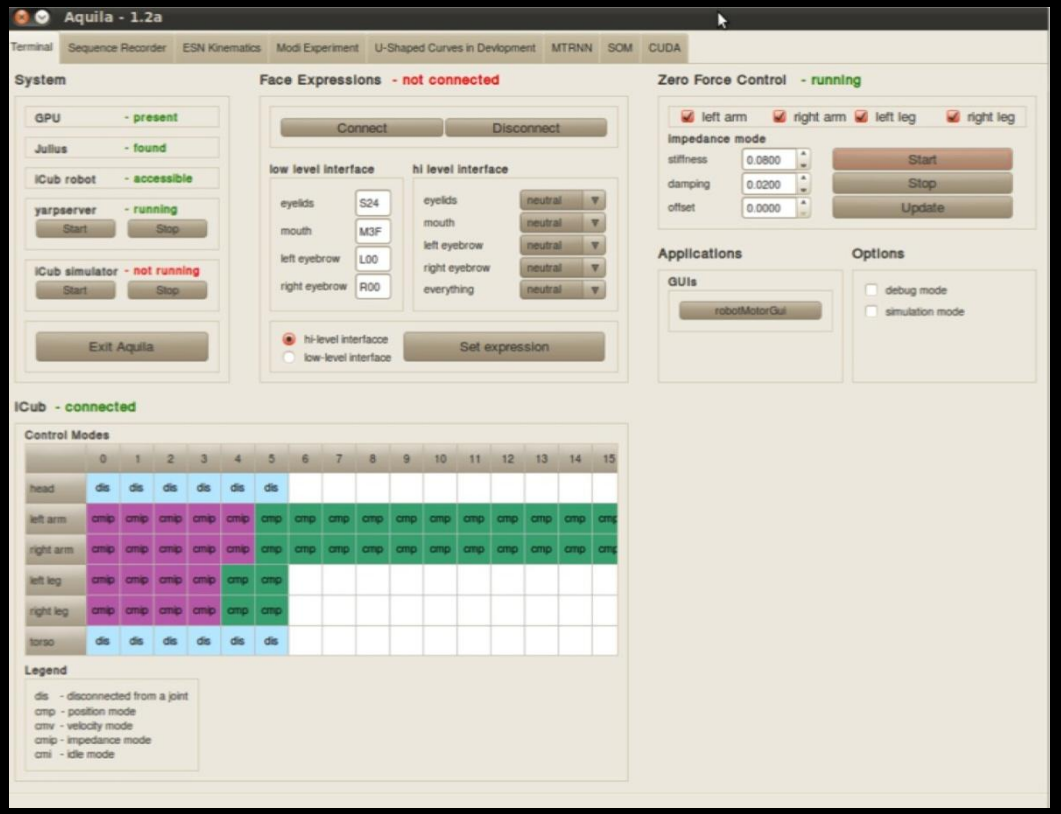
“My future goal would be to add a new eye tracking method inspired by human infants visual development system and Aquila has been a huge advantage providing the fast and user friendly experimental environment.”

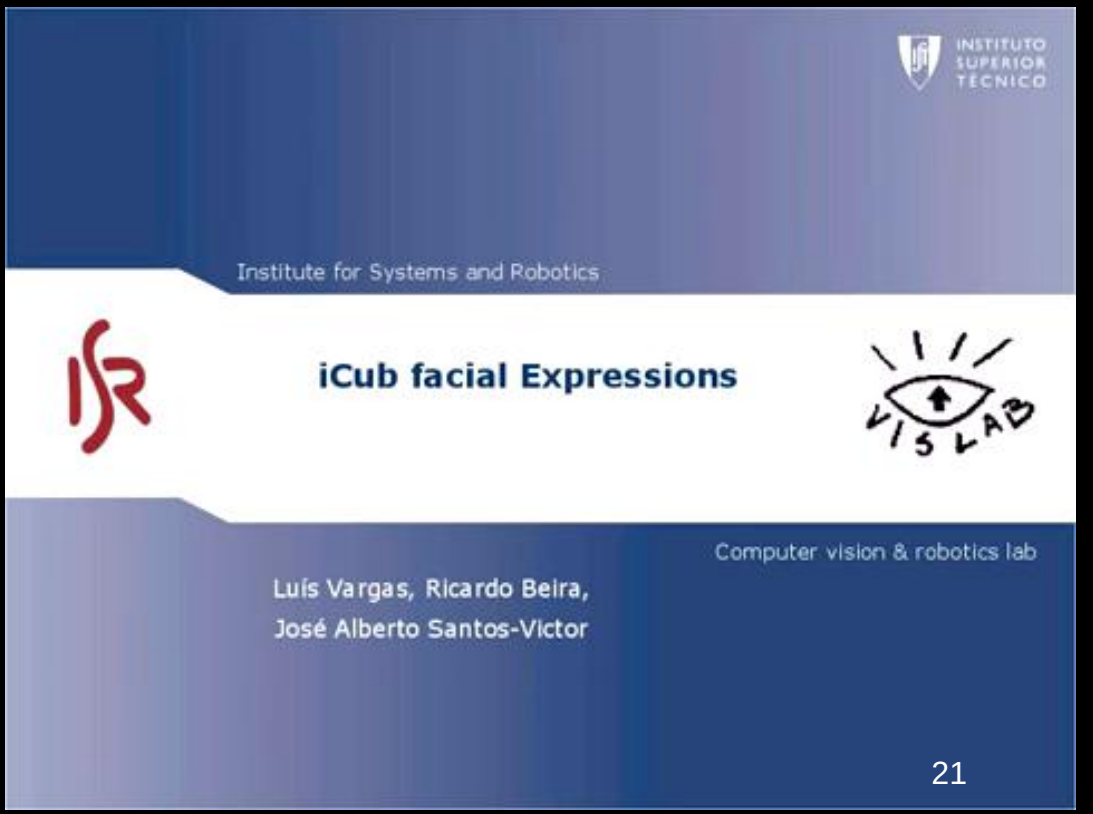
Neda Hantehzadeh, Southern Illinois University of Carbondale



Aquila
Terminal

- Interfaces to iCub face expression and force control modules
- ICub connection visualisation

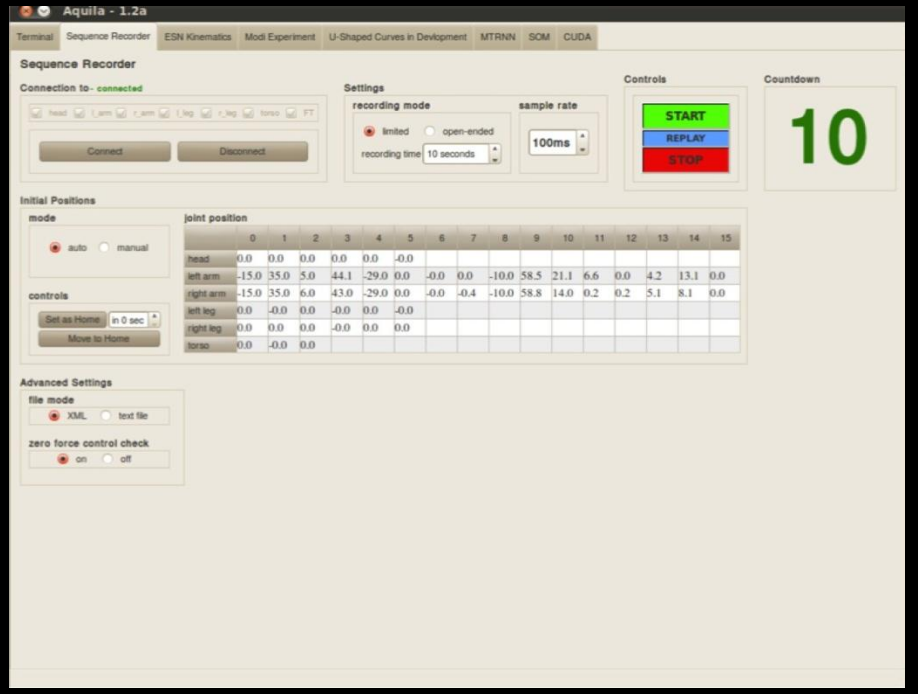


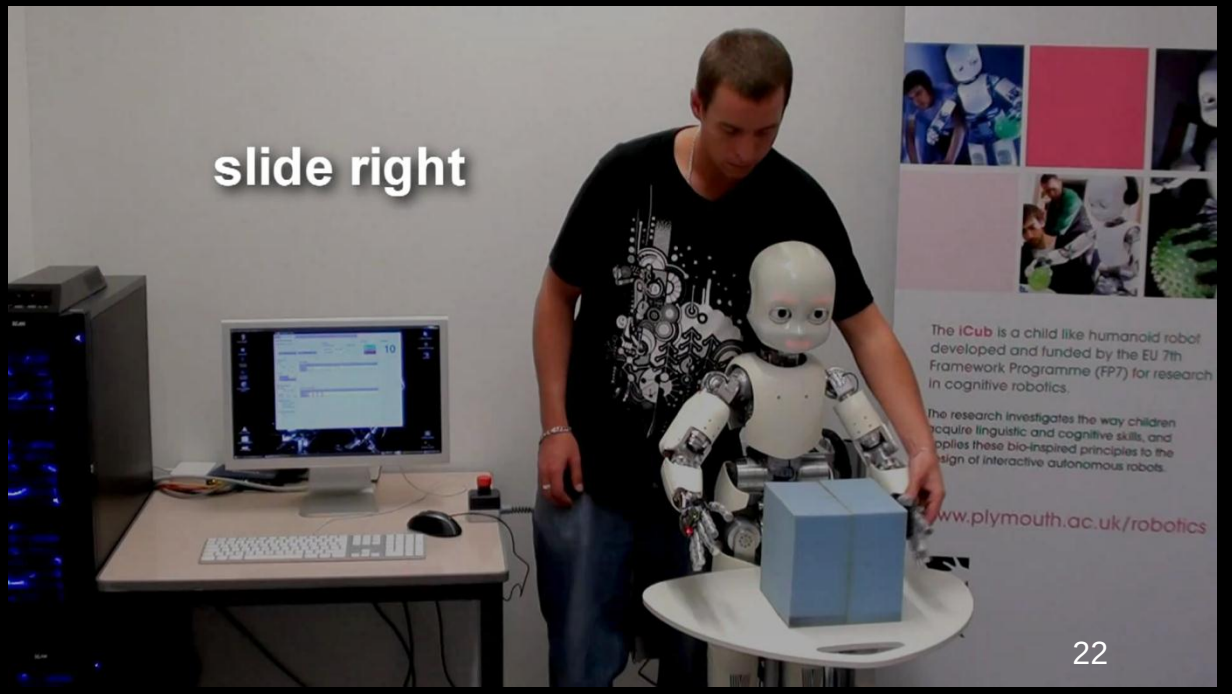


Aquila

Sequence Recorder

- Records, saves and replays sequences
- Works with force control module
- Set a home position, force threshold monitoring
- Different options: timing, custom output formatting, etc.

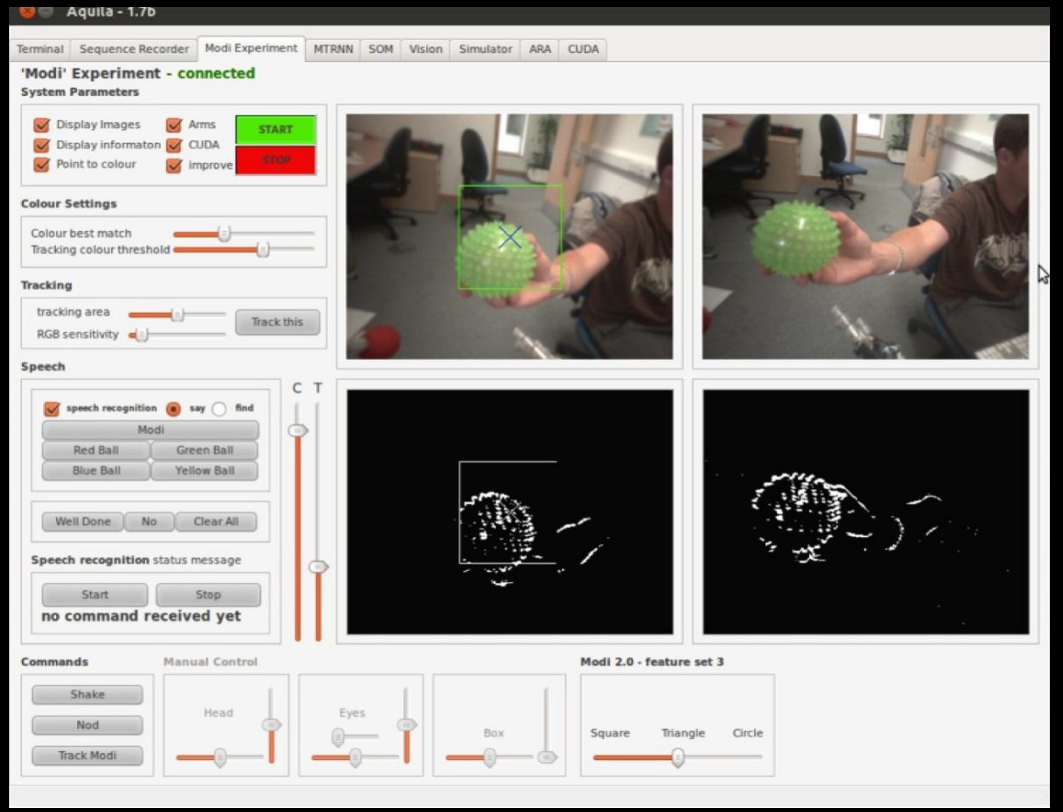




Aquila

Epigenetic Robotics Architecture

- Learning of names and objects through body association
- Research provided a number of predictions directly inspiring a number of follow up experiments in child development closing the gap between robotics and psychology

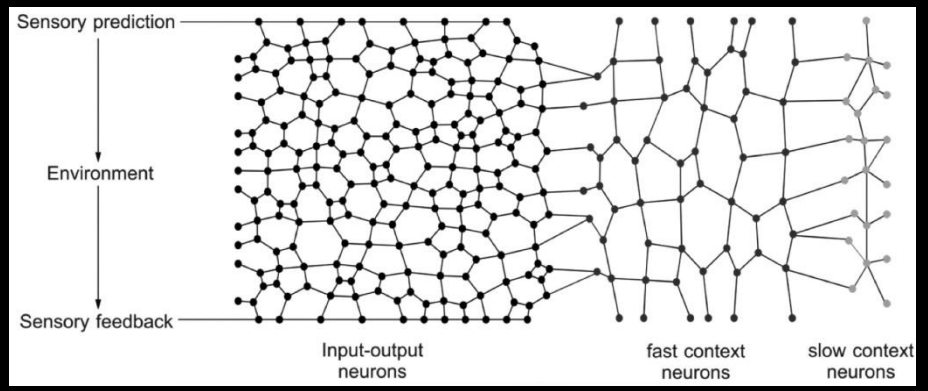


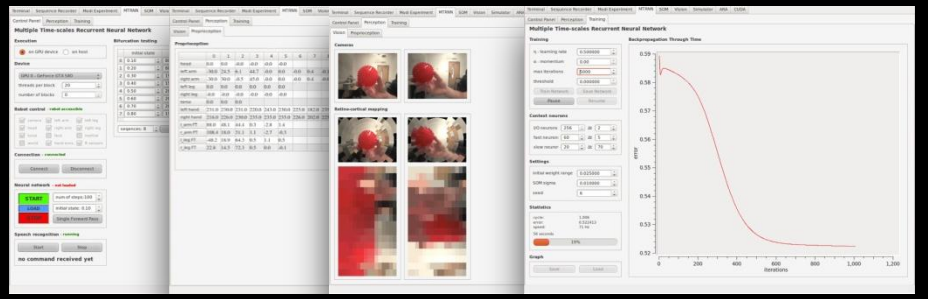
Morse, A.F., Belpaeme, T., Cangelosi, A., & Floccia, C., (2011) Modelling U Shaped Perfromance Curves in Ongoing Development. Proceedings of the Cognitive Science Conference 2011

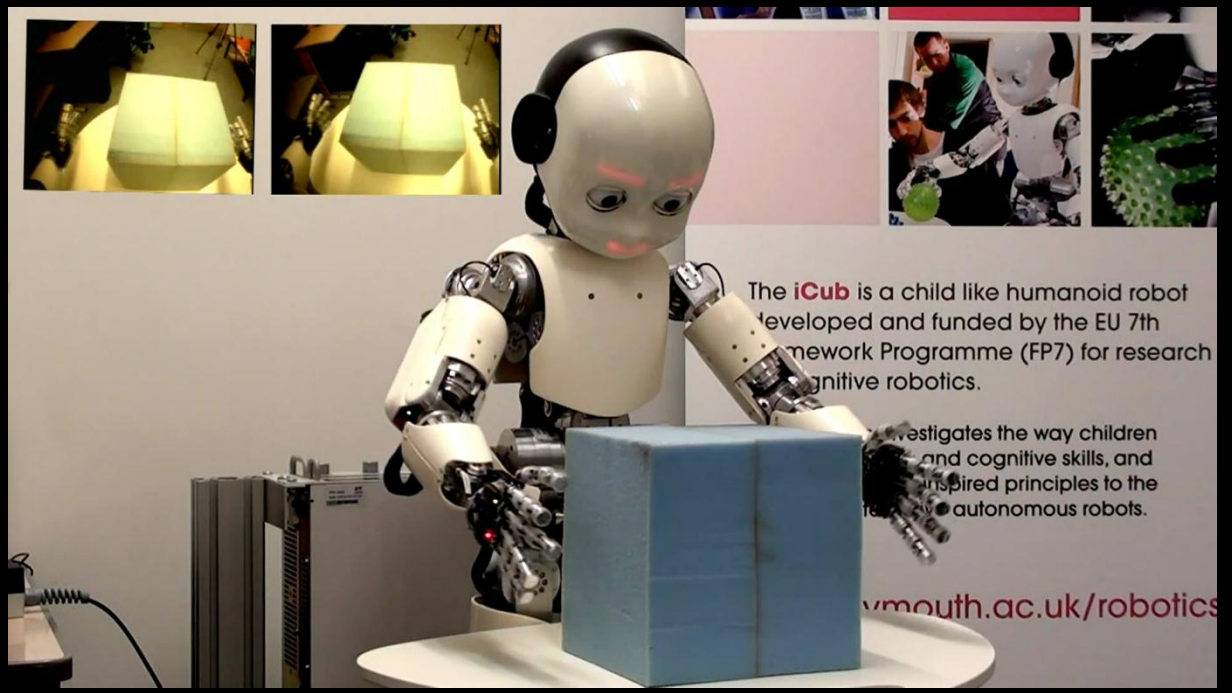
Aquila

Multiple Time-scales Recurrent Neural Network

- Humans are good at learning complex actions
- Constant repetition of movements with certain components segmented as reusable elements
- Motor primitives are flexibly combined into novel sequences of actions
- Human motor control system known to have motor primitives implemented as low as at the spinal cord and hi-level planning and execution takes place in primary motor cortex





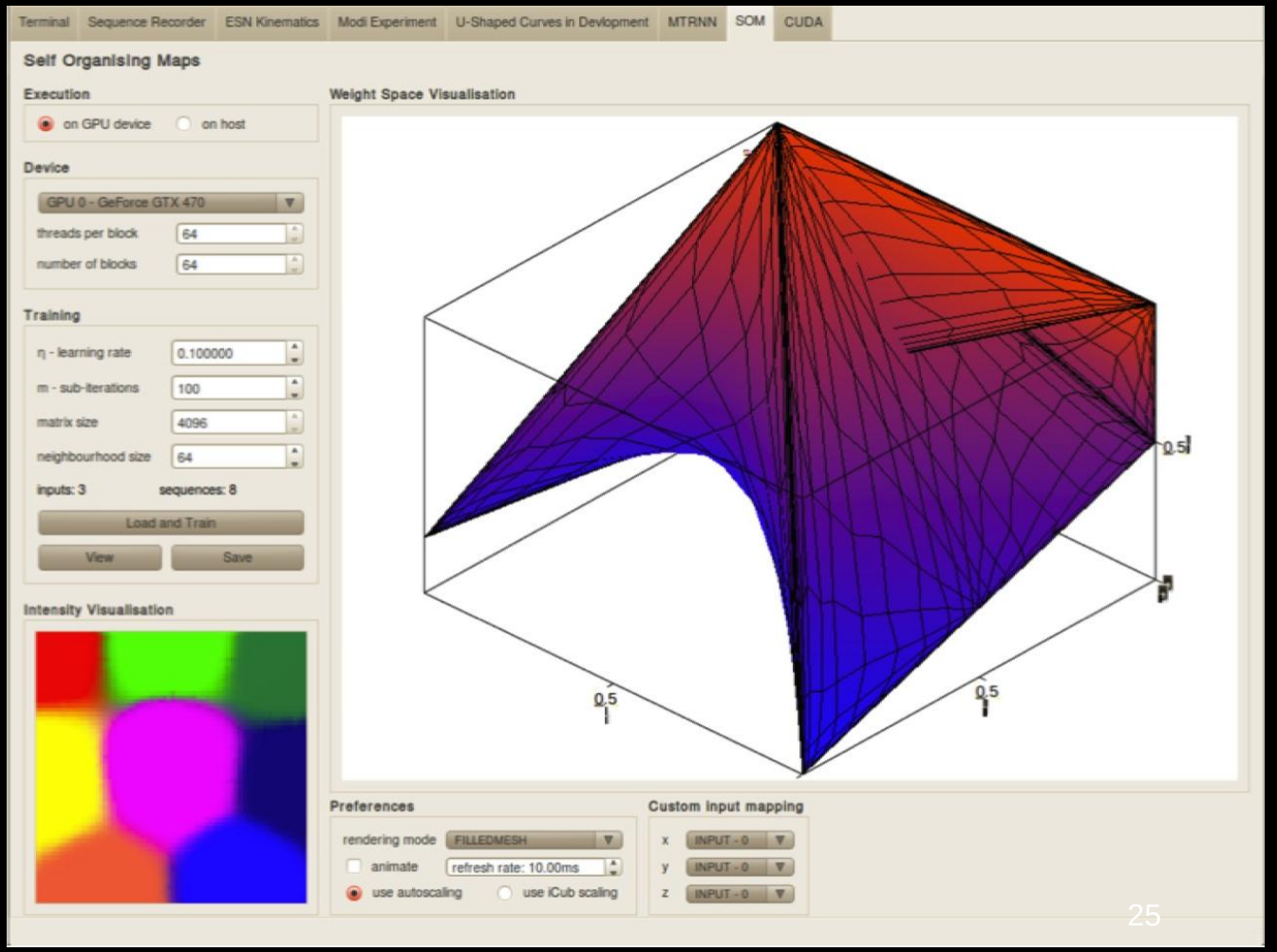


M. Peniak, D. Marocco, J. Tani, Y. Yamashita, K. Fischer, A. Cangelosi (2011). Multiple Time Scales Recurrent Neural Network for Complex Action Acquisition. International Joint Conference on Development and Learning (ICDL) and Epigenetic Robotics (ICDL-EPIROB) 2011. Frankfurt, Germany, August 24-27, 2011.

Aquila

Self-organising Maps

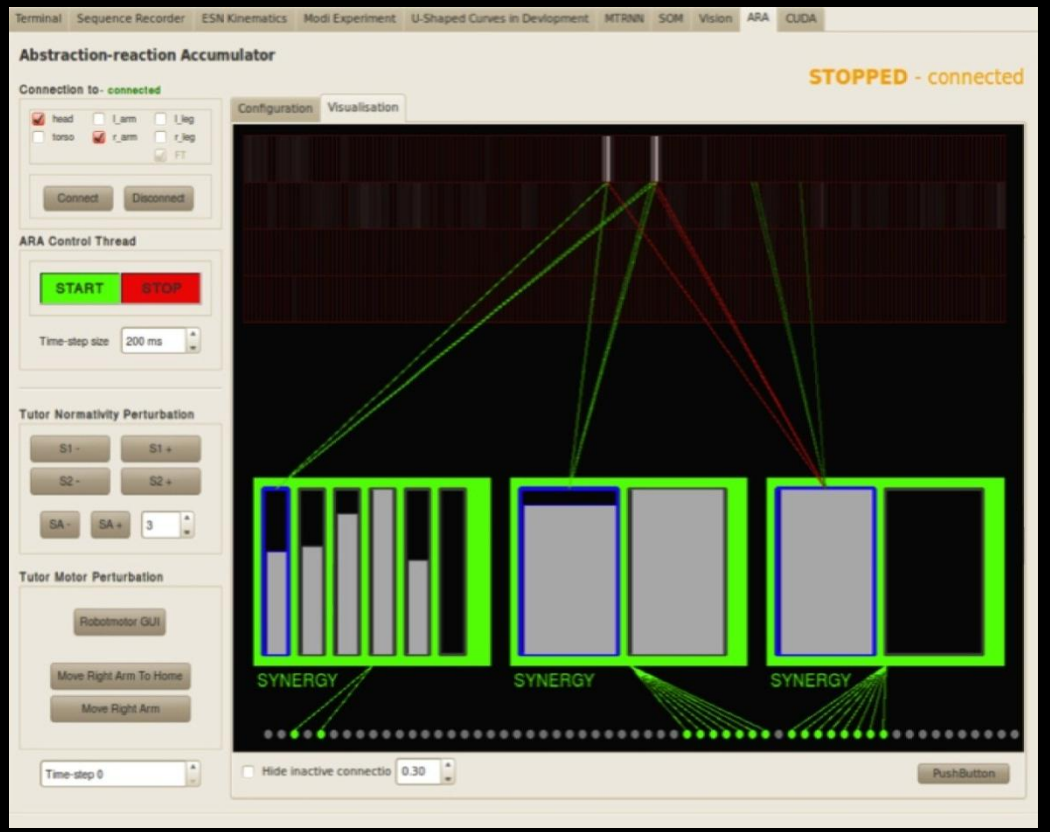
- Also known as Kohonen maps
- Type of artificial neural network that is trained using unsupervised learning
- Representing multidimensional data in much lower dimensional spaces – typically one or two dimensions
- This process, of reducing the dimensionality of vectors, is essentially a data compression technique known as vector quantisation
- Example: 3D colour input (rgb values) represented by a 2D map

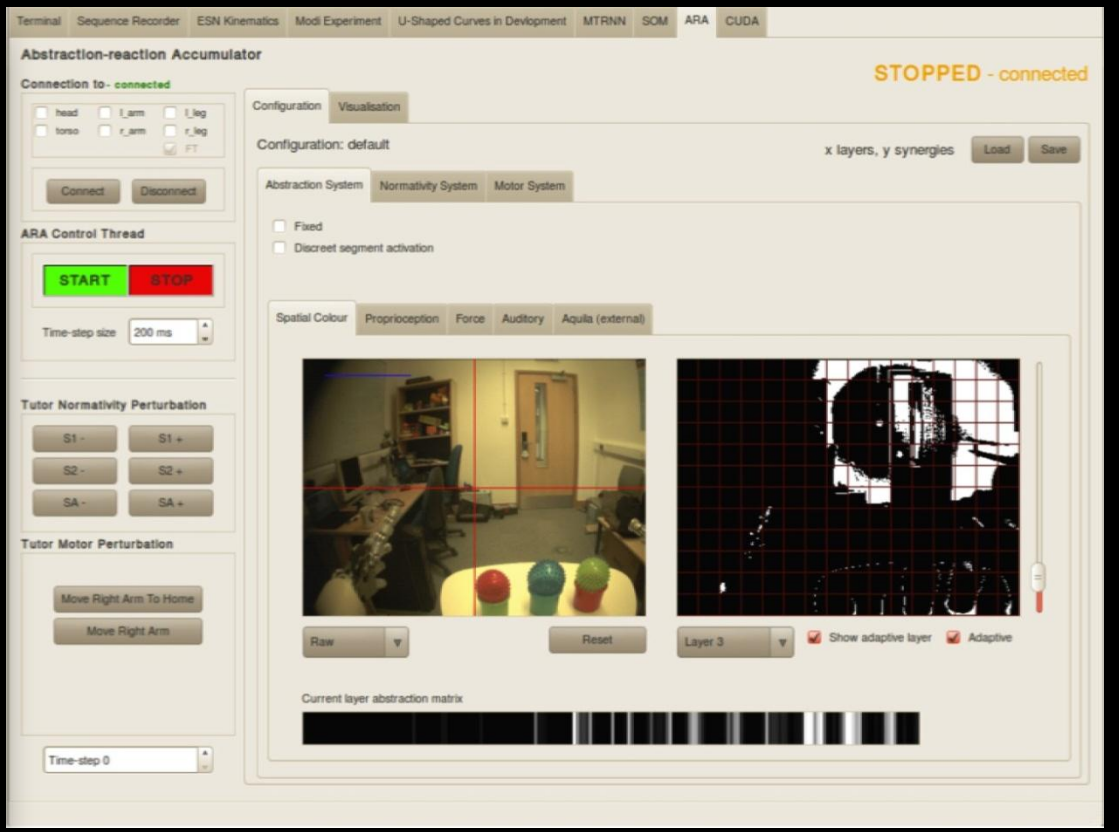


Aquila

Abstraction-reaction Accumulator

- Inspired by the early cybernetics work
- Developed by Chris Larcombe



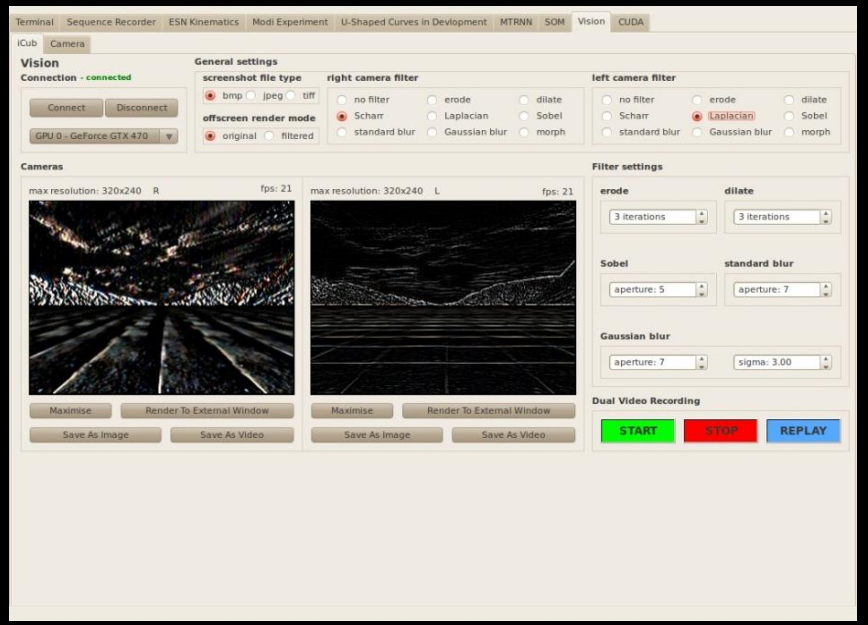


C. Larcombe, A. Morse, A. Cangelosi (2011). Learning to React to Abstractions: Accumulating Adaptations in a Humanoid Embodiment. International Joint Conference on Development and Learning (ICDL) and Epigenetic Robotics (ICDL-EPIROB) 2011.

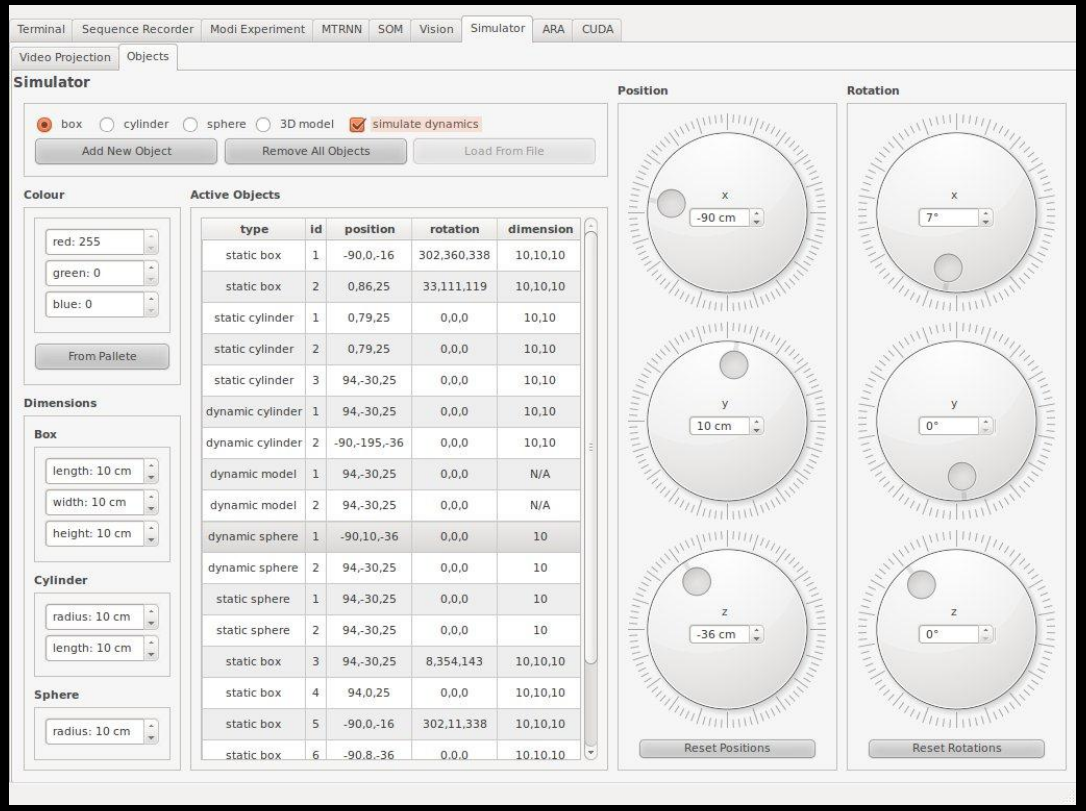
Aquila

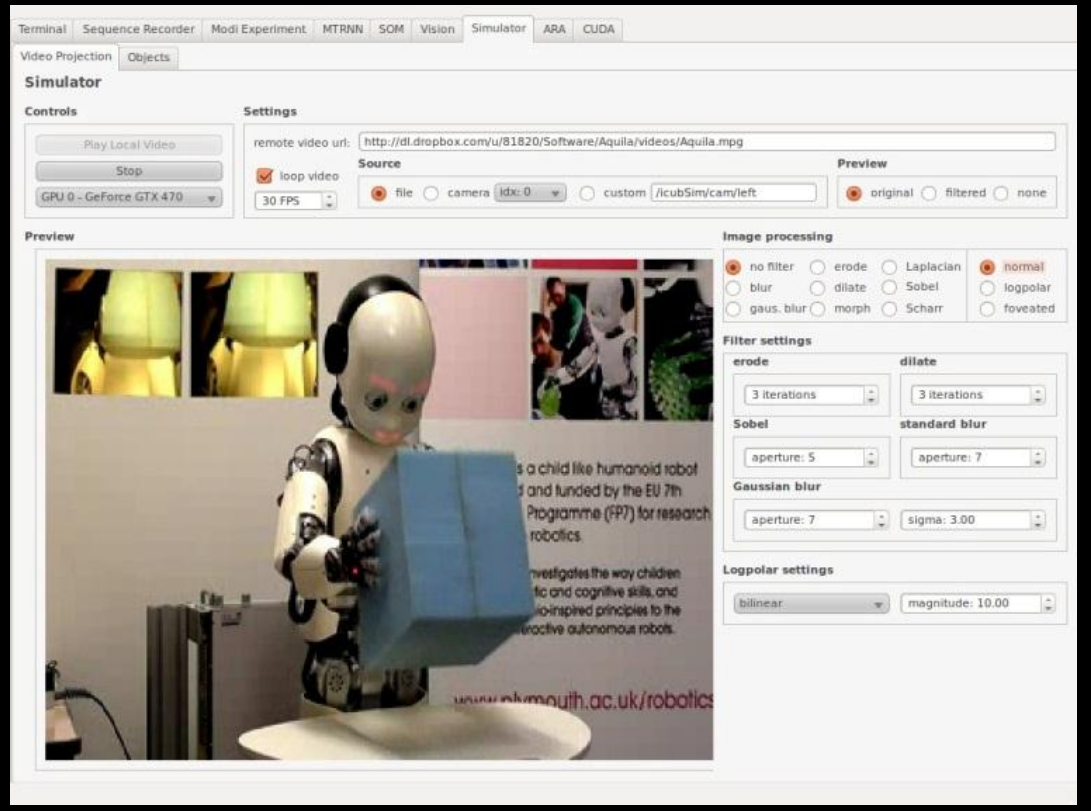
Vision

- iCub and USB cameras
- Filters and transforms
- Record frame and videos
- Kinect support for iCub teleoperation



Aquila
Simulator





Aquila

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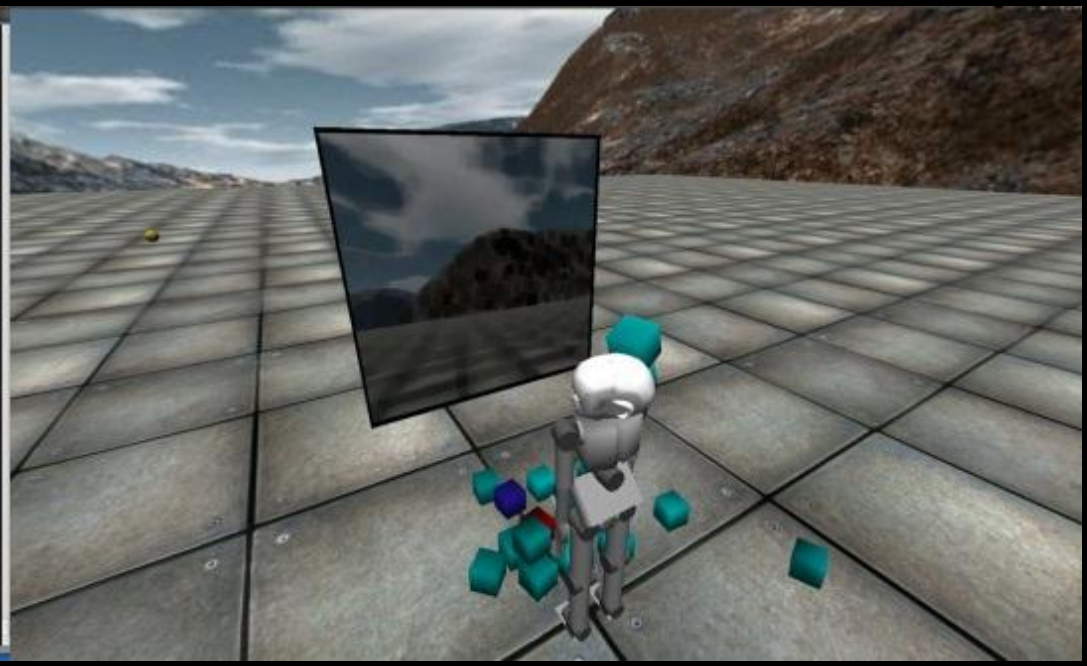
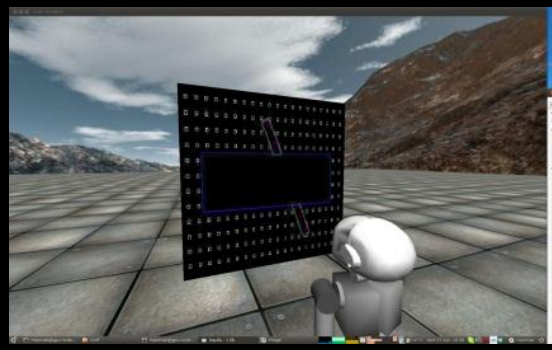
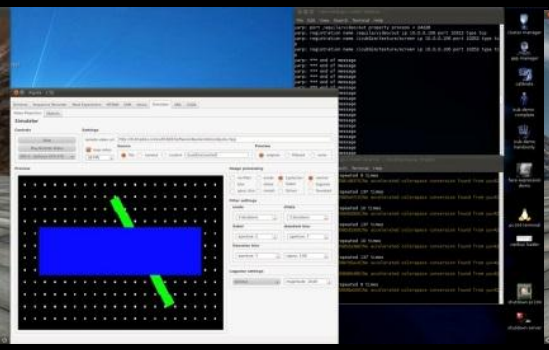
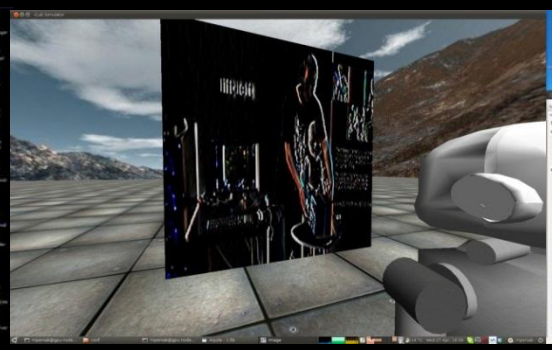
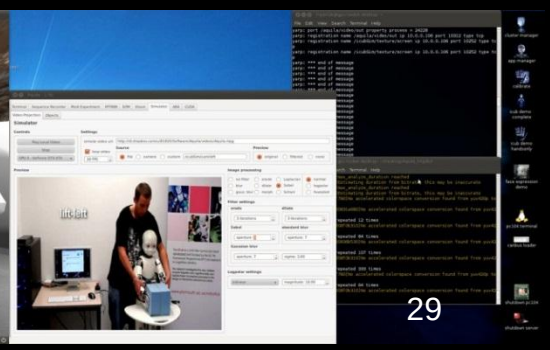




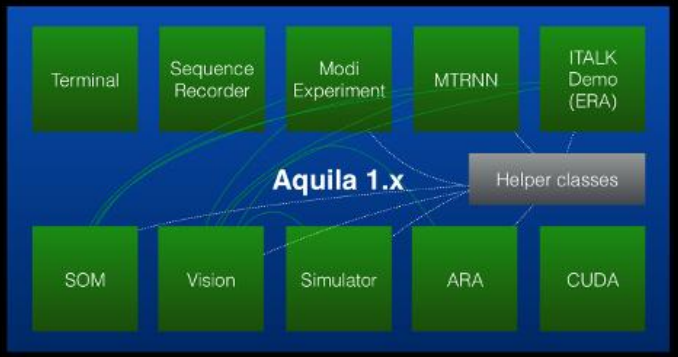






Aquila
History

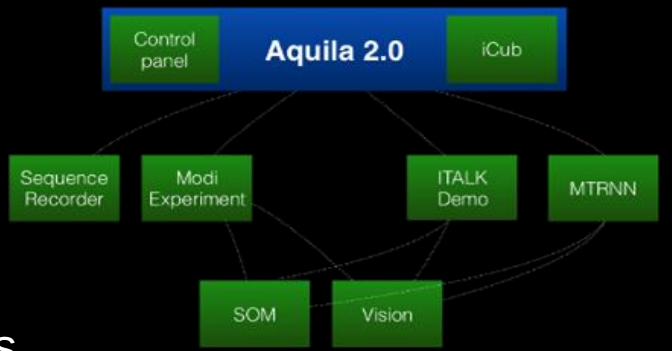
- Modules not available individually
- Compilation more difficult due to increasing number of modules
- Host machine execution only
- Linux-only support



Aquila 2.0

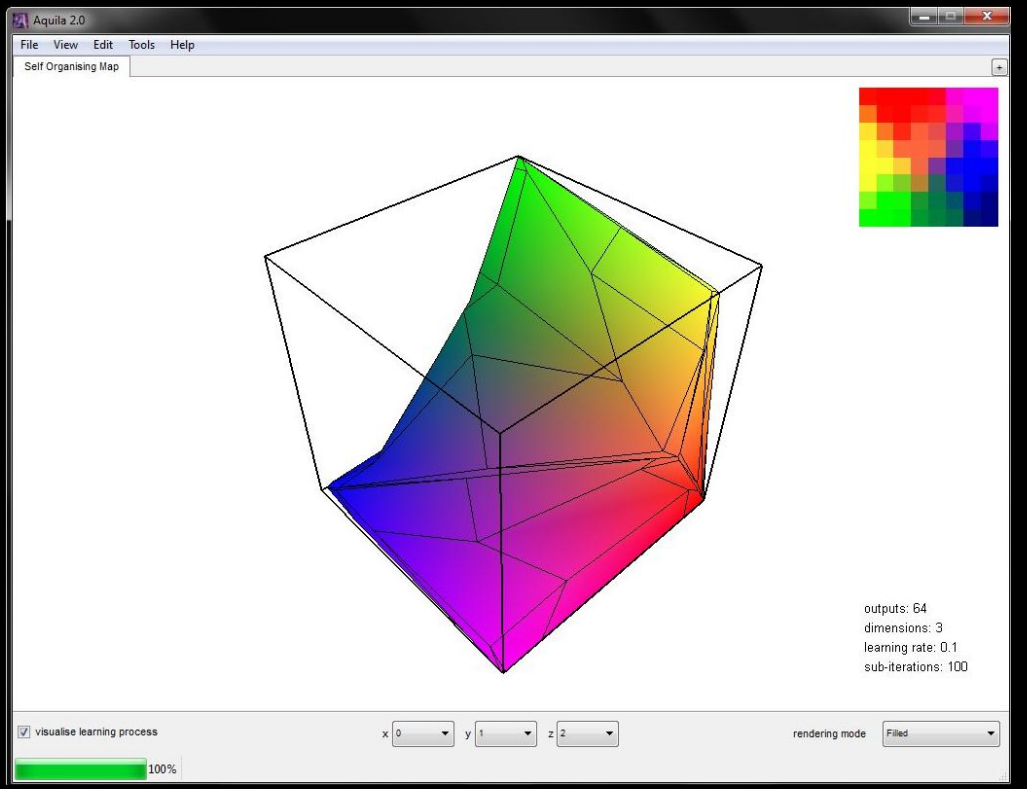
Present

- Modules
  - are independent from Aquila but can make use of its features (graphical interface, module management, etc.)
  - can run in multiple instances on different hosts and GPU devices across networks
- Linux, Windows and OSX support
- Compiles as part of the main iCub repository
- Simpler, faster and more efficient
- Better platform for developers
- Ongoing work is focused on porting the old modules



Aquila 2.0

- **Aquila 2.0**
  - detects compiled Aquila-compliant modules on the network
  - launches any of these modules on any GPU or CPU processor found on the network
  - dynamically creates their graphical user interfaces under individual tabs
- **Aquila-compliant modules**
  - run as a standalone processes
  - can be used without Aquila (terminal mode)
  - specific ports are used for Aquila interfacing



Aquila and Evolutionary Robotics

Evolutionary Robotics

- Relatively new technique for the automatic creation of autonomous robots
- Inspired by the Darwinian principle of selective reproduction of the fittest
- Views robots as autonomous artificial organisms that develop their own skills in close interaction with the environment and without human intervention
- Drawing heavily on biology and ethology, it uses the tools of neural networks, genetic algorithms, dynamic systems, and biomorphic engineering

Nolfi S. and Floreano D. [2000]. Evolutionary Robotics: The Biology, Intelligence, and Technology of Self-Organizing Machines. Cambridge, MA: MIT Press/Bradford Books

Evolutionary Robotics

- The evolutionary process is notoriously time-consuming
- GPU implementations of genetic algorithms result in better results in **much** shorter time
  - For example see: P. Pospichal and J. Jaros, "Gpu-based acceleration of the genetic algorithm," in *GECCO 2010*

Nolfi S. and Floreano D. [2000]. Evolutionary Robotics: The Biology, Intelligence, and Technology of Self-Organizing Machines. Cambridge, MA: MIT Press/Bradford Books

Current Development at NVIDIA

Aquila and Evolutionary Robotics

- Novel GPU implementation of scalable genetic algorithms
- New module that is using these algorithms to facilitate evolution of a biologically-inspired vision system
- Modules ready by the end of 2012

"Imagination is the highest form of research"
Albert Einstein

Questions?

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