Towards a Scientific Foundation for Engineering Cognitive Systems

- A European Research Agenda, its Rationale and Perspectives -

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figures

foci & features

facts

futures & frontiers

follow-up

	Programmes	# projects	M€
pre 1998	Various AI initiatives		
1998-2002	Cognitive Vision	8	18
2002-2006	Cognitive Systems, Robotics	45	133
2006-(2013)	Cognitive Systems, Interaction, and Robotics	94*	419*
		147	**570**

* up until 2012

Objectives, rationale, and research questions

The overarching objective (presumably of public research funding anywhere in the world):

to boost economic growth through science-based innovation.

What does this mean for the

Cognitive Systems and Robotics (CSR) programme?

Technical systems that operate **robustly** and **flexibly** in complex **environments** (i.e., capable of responding intelligently and largely autonomously to gaps in their knowledge and to situations or contexts that have not been specified in their design)**.**

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Progress towards systems with these characteristics can only be achieved by developing and adopting **new engineering principles** and approaches, based on largely common but as yet not fully explored **scientific grounds**.

key term: environment:

a "world" arising from an environment is determined by the (types of) signals and data an entity operating in it is fit to process.

Environments

1. (“Type 1”) “Common Sense” environments: 3+1 D, (to us) visible light, audible sounds, touchable objects, ..., “natural” or “civilized”;
   but: machines may reach, see, hear, smell, ..., do more or different things;
2. (“Type 2”) natural environments at various scales, not directly or fully accessible through our own (bodily) senses and actuators (for instance: our own bodies, the deep sea, outer space, etc.)
3. (“Type 3”) “Artificial” environments: external representations of Man’s (and machines’) perceptions and reflections; e.g., “Digital Content spaces”, the Web.
4. (“Type 4”) Technical systems embedded in Type 1&2 environments;

Environments - focus on:

1. (“Type 1”) “Common Sense” environments: 3+1 D, (to us) visible light, audible sounds, touchable objects, people (!)..., “natural” or “civilized”; **but:** machines may reach, see, hear, smell, ..., do more or different things;
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common traits: “open-ended”, dynamic, surprises ...

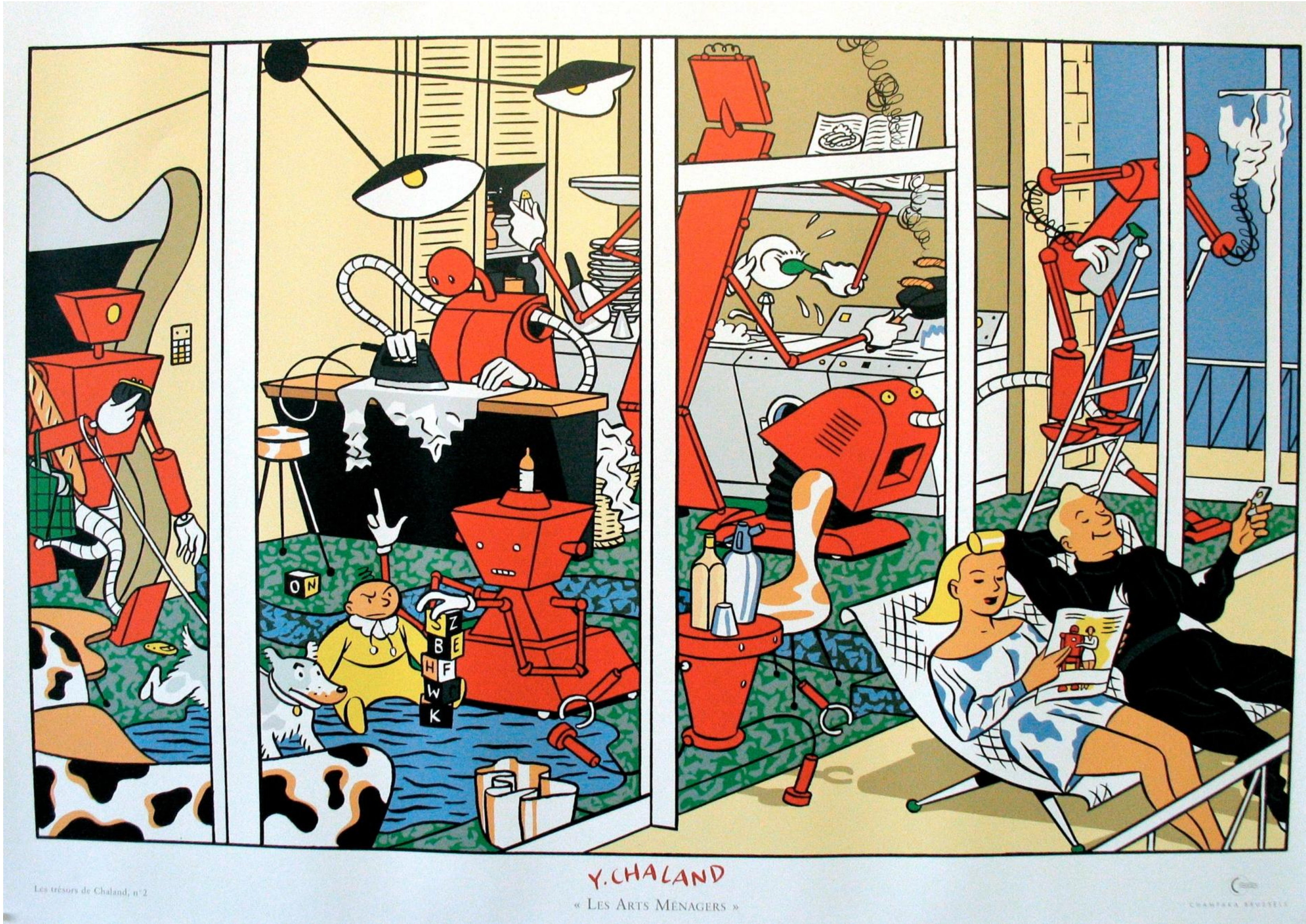
The programme's main focus rephrased:

to ...

... strengthen the **scientific foundation** for engineering artificial cognitive systems - i.e., *artificial systems that perceive and (inter-)act, based on a suitable understanding of their environment*.

=> an **enabling technology** for a variety of applications involving interaction within **"real world"** (**type 1 & 2**) environments pertaining to, for instance,

… robotics, assistive technologies, multimodal man-machine interfaces, …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Y. CHALAND
« LES ARTS MÉNAGERS »
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CHAMPAKA BRUXELLES

What should a scientific foundation for engineering such systems support?

Generic and specific answers ...

Generic:

How would we live today if there were no science?
(modern engineering impossible without science)

Specific: as a given technology evolves ...

General but specific for CSR research:

What (if anything) do we need to understand about cognition as a biological phenomenon in order to specify, design and build artificial cognitive systems?

birds vs. aeroplanes

AI (mainstream) vs. Cybernetics

so far: only natural CS

... nouvelle / new AI (Brooks et al, Cog, ...)

required: conceptual framework, meaningful terms, commonly understood, allowing for falsifiable hypotheses, ...

a sort of “physics of cognition” and its mathematical underpinning?

(science in the sense of “Naturwissenschaft”?)

natural cognition:

- The **emergence**, **evolution** and **development** of cognitive capabilities in living organisms
- the **physical structures and functions** underlying cognitive capabilities and processes
- the **mechanisms of recognising** objects, actions and situations, and of **generating and adapting behaviour**
- the types, levels and dynamics of **internal representations**

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- The **emergence**, **evolution** and **development** of cognitive capabilities in living organisms
- the **physical structures and functions** underlying cognitive capabilities and processes
- the **mechanisms of recognising** objects, actions and situations, and of **generating and adapting behaviour**
- the types, levels and dynamics of **internal representations**
- the role and instantiations of **memory and learning**
- **goal-setting mechanisms** and the development of strategies for achieving goals
- the nature and role of **emotion and affect**
- **self-awareness**, **consciousness**, intentionality and **Theory of Mind**
- the role of **language**

engineering questions (the artificial):

- Which artificial cognitive systems need what **form of embodiment** and why?
- Can (some of the) ***cognitive toil*** inherent in perception-action cycles, be **offloaded** onto physical processes that are peculiar to **"the shape of things"**, the material things are made of, and the way they are put together?
- Which sorts of **memory** (mechanisms) are required, and what are the **modes and mechanisms of learning** needed in an artificial cognitive system?
- What form and degree of **autonomy** is desirable and achievable?

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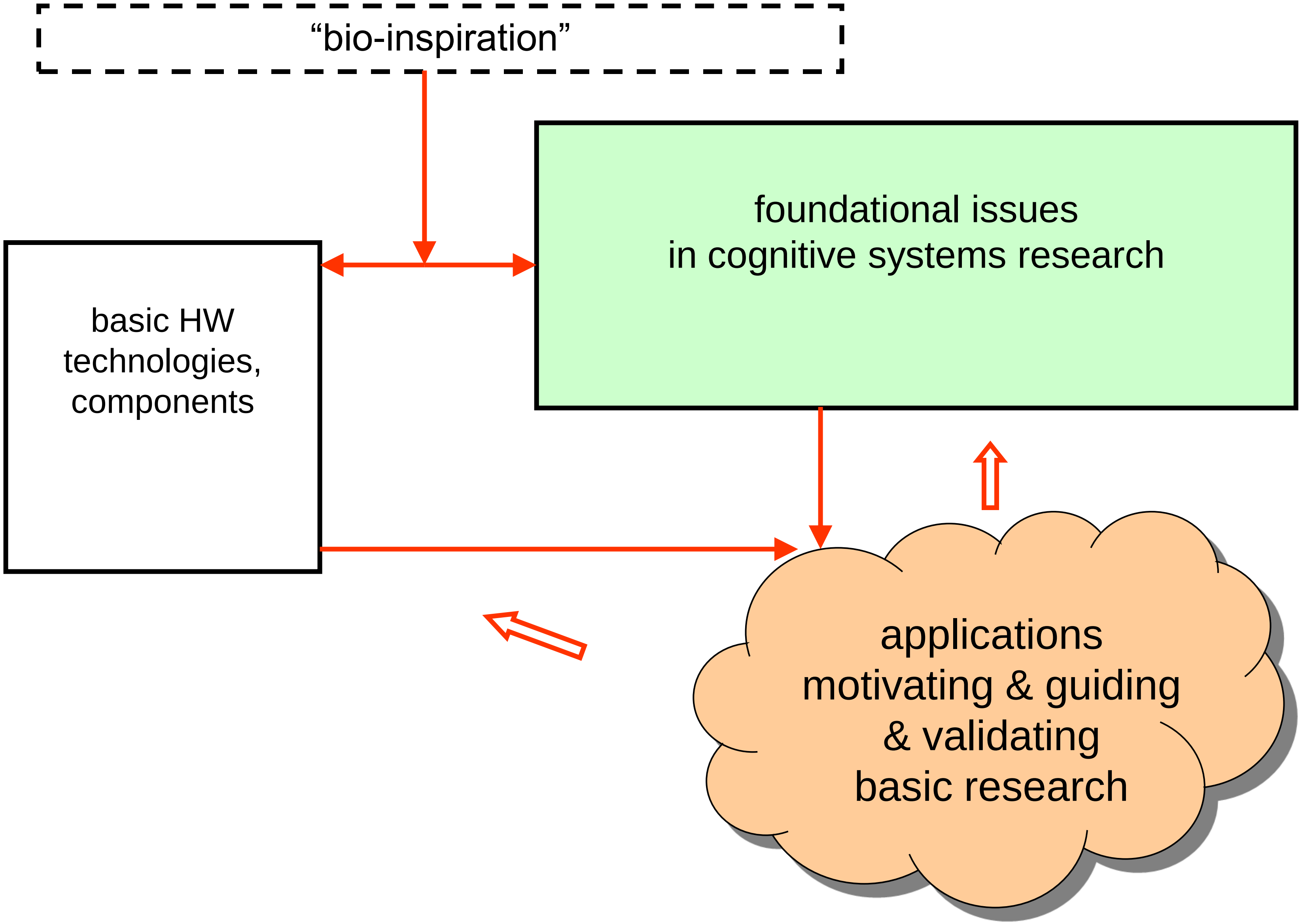
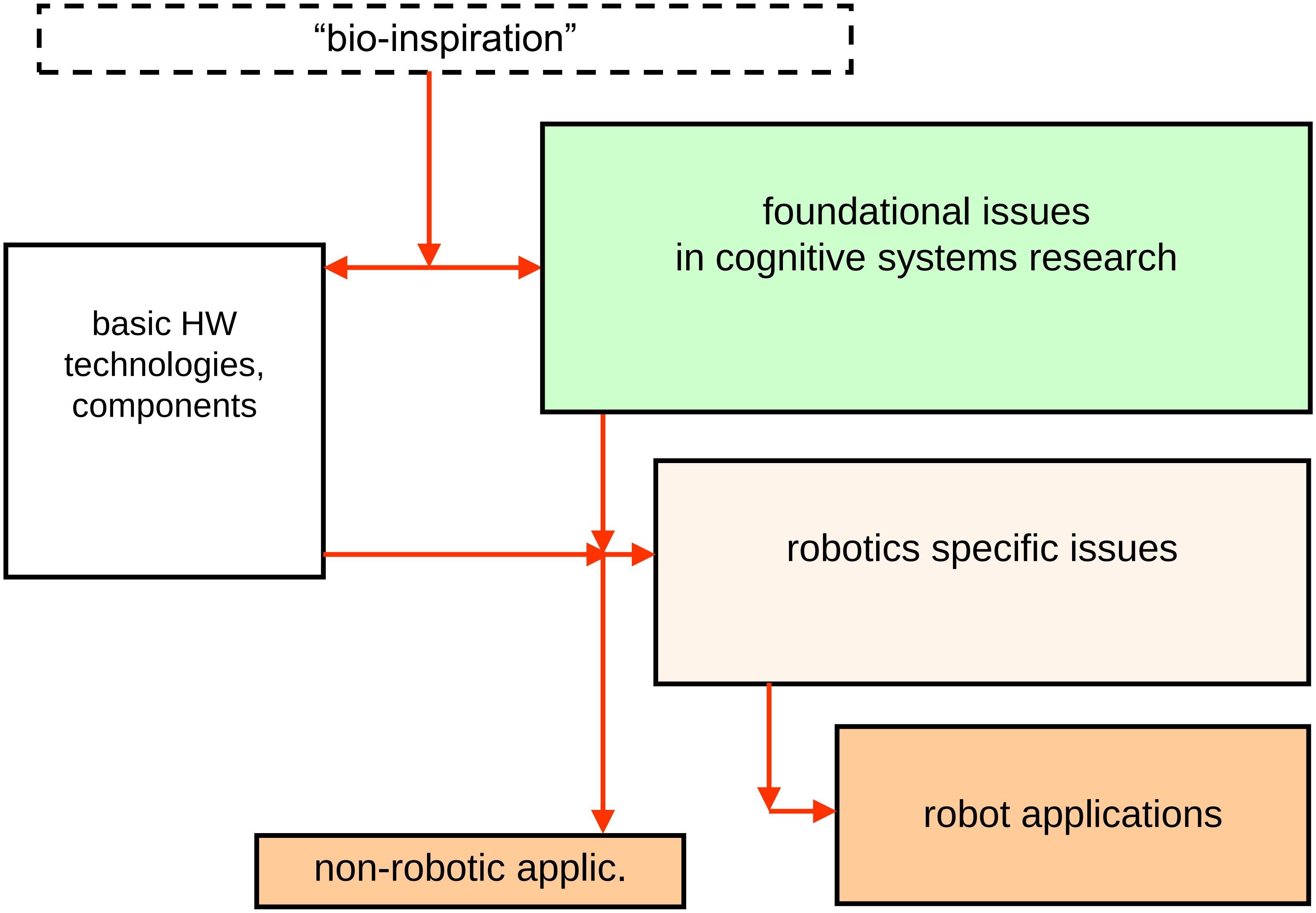
- Which sorts of **memory** (mechanisms) are required, and what are the **modes and mechanisms of learning** needed in an artificial cognitive system?
- What form and degree of **autonomy** is desirable and achievable?
- To what extent can natural cognitive traits such as **affect**, **consciousness** or **Theory of Mind**, be modeled and used in artificial systems?
- For an artificial system to be (or to become) cognitive, does it necessarily have to be **self-X**? (X ∊ {monitoring, modifying, debugging, configuring, controlling, understanding, aware, organising ...})
- **Where does design end** and (semi-)autonomous evolution, development, self-organisation and learning begin?
- How does all this (representations, concurrent processes, memory, autonomy, self-X ...) boil down to **integrating architectures** (“anatomy & physiology”) for artificial cognition?


"bio-inspiration"
foundational issues
in cognitive systems research
basic HW
technologies,
components
applications
motivating & guiding
& validating
basic research



"bio-inspiration"
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technologies,
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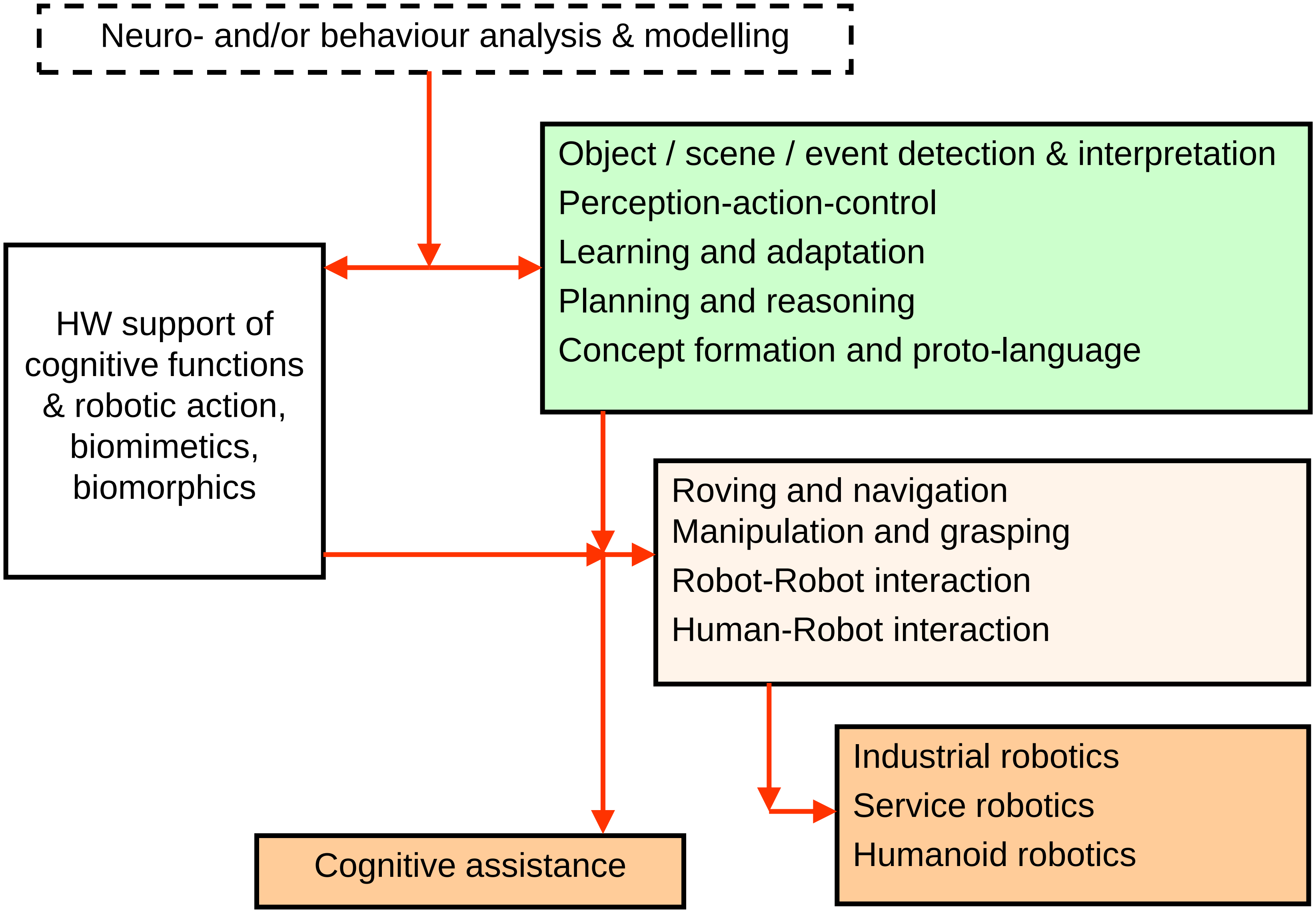
robotics specific issues
robot applications
non-robotic applic.


Neuro- and/or behaviour analysis & modelling
Object / scene / event detection & interpretation
Perception-action-control
Learning and adaptation
Planning and reasoning
Concept formation and proto-language
HW support of cognitive functions & robotic action, biomimetics, biomorphics
Roving and navigation
Manipulation and grasping
Robot-Robot interaction
Human-Robot interaction
Industrial robotics
Service robotics
Humanoid robotics
Cognitive assistance

"Knowledge has to precede application."
(Max Planck)

the "knowledge box" ...

e.g., as in the above lists

But: "*Leicht beieinander wohnen die Gedanken,*
doch hart im Raume stoßen sich die Sachen."
(Schiller, Wallenstein's Death:
Thoughts share their space with ease, yet things in space do bump with force onto each other)

in the yellow box for instance

Structuring the set of CSR projects

- platforms and environments
- cognitive competencies
- methods, models, paradigms

platforms and environments

robots:

from assembly lines to “unstructured” environments

from NC machines to and autonomous rovers providing all sorts of services

industrial, commercial, custom built

sensor networks:

monitoring and control

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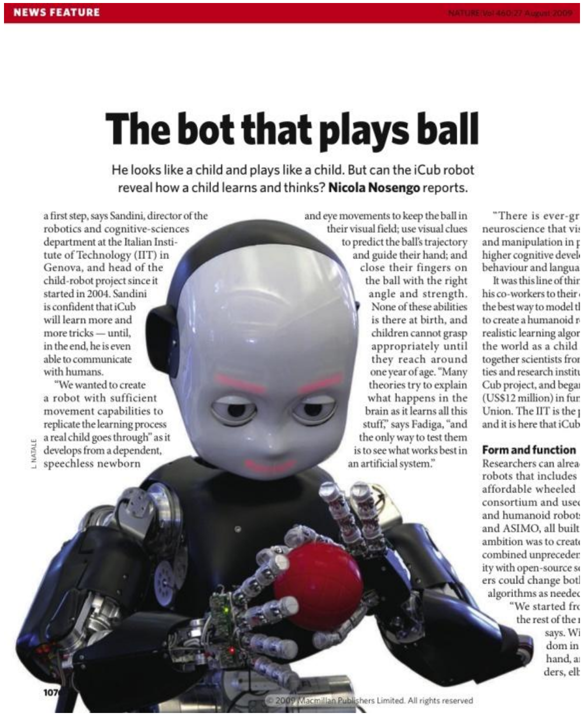
NEWS FEATURE

NATURE Vol 460 27 August 2009

The bot that plays ball

He looks like a child and plays like a child. But can the iCub robot reveal how a child learns and thinks? **Nicola Nosengo** reports.

a first step, says Sandini, director of the robotics and cognitive-sciences department at the Italian Institute of Technology (IIT) in Genova, and head of the child-robot project since it started in 2004. Sandini is confident that iCub will learn more and more tricks — until, in the end, he is even able to communicate with humans.

“We wanted to create a robot with sufficient movement capabilities to replicate the learning process a real child goes through” as it develops from a dependent, speechless newborn

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to create a humanoid r
realistic learning algor
the world as a child
together scientists fro
ties and research instit
Cub project, and bega
(US$12 million) in fu
Union. The IIT is the
and it is here that iCub

Form and function

Researchers can alrea
robots that includes
affordable wheeled
consortium and use
and humanoid robot
and ASIMO, all built
ambition was to creat
combined unpreceden
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algorithms as neede
“We started fr
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iCub / project RobotCub
Start: 2004-09-01
End: 2010-02-28
11 partners (Univ Genoa+10)
Funding: 8.5 million euro

Platform:
- HW – 53 dof iCub robot
- SW – YARP (revamped)
- all open source !

Sensors:
- vision, sound, touch,
- proprioception, vestibular

Examples (function)

Manipulation, grasping, assembly

DEXMART (http://www.dexmart.eu/)
FIRST-MM (http://www.first-mm.eu/)
GeRT (http://www.gert-project.eu/)
GRASP (http://www.csc.kth.se/grasp/)
HANDLE (http://www.handle-project.eu/)
STIFF (http://stiff-project.eu/)
THE (http://www.thehandembodied.eu/)
TOMSY (http://www.tomsy.eu)

DARWIN (http://www.darwin-project.eu/)
Goal-Leaders (http://www.goal-leaders.eu/)

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other

ROBLOG ("Cognitive robot for unloading containers", http://www.roblog.eu/)

Project ROBOSKIN ("Skin-based technologies and capabilities for safe, autonomous and interactive robots", http://www.roboskin.eu/)

Examples (environment and function)

roadscapes and driver assistance

- DIPLECS (http://www.diplecs.eu/)
- RADHAR (http://www.radhar.eu/)

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DIPLECS (http://www.diplecs.eu/)
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(deep) sea and underwater operations

Co3 AUVs (http://robotics.jacobs-university.de/projects/Co3-AUVs/)
CoCoRo (http://cocoro.uni-graz.at/)
FILOSE (http://www.filose.eu/)
NOPTILUS (http://www.noptilus-fp7.eu/)
TRIDENT (http://www.irs.uji.es/trident/)

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the sky and aerial inspection and monitoring

AIRobots (http://www.airobots.eu)
sFLY (http://www.sfly.org/)

Examples (environment and function) (cont.)

Urban environments and services

EUROPA (http://europa.informatik.uni-freiburg.de/)
IURO (http://www.iuro-project.eu/)
V-CHARGE (http://www.v-charge.eu/)

Examples (environment and function) (cont.)

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the human body

outside: COGNITO (http://www.ict-cognito.org/)
inside: ACTIVE (http://www.active-fp7.eu/)
I-SUR (http://www.isur.eu/)
ROBOCAST (http://www.robocast.eu/)

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industrial orientation of robotics research

BRICS ("Best practice in Robotics", http://www.best-of-robotics.org/)
ECHORD ("European clearing house for open robotics development", http://www.echord.info/)

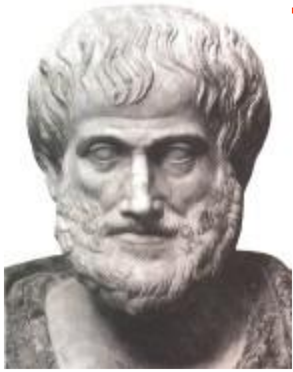
Cognitive competencies

Making the artificial system act deliberately and purposefully, and explicitly understand its world (“high level”)	e.g., concepts, plans, reasoning, communication, language, ... (“symbolic”)
Maintaining the artificial body in its environment (“low level”)	e.g., autonomic control of “service-sustaining” processes (“sub-symbolic”)

Αριστοτέλης

Περὶ Ψυχῆς

Cognitive competencies



REASON

LOCOMOTION

NUTRITION

Making the artificial system act deliberately and purposefully, and explicitly understand its world ("high level")

e.g., concepts, plans, reasoning, communication, language, ... ("symbolic")

?

Maintaining the artificial body in its environment ("low level")

e.g., autonomic control of "service-sustaining" processes ("sub-symbolic")

MIND THE GAP!

low-level "autonomic control"

- implementation in analog circuitry, of autonomic, insect-inspired robot control (cricket, fruitfly, stick-insects)
  - SPARK I&II (http://www.spark.diees.unict.it/ and http://www.spark2.diees.unict.it/)
  - EMICAB (http://www.emicab.eu/)

low-level “autonomic control”

- implementation in analog circuitry, of autonomic, insect-inspired robot control (cricket, fruitfly, stick-insects)
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- sensory-motor coordination in complex multi-degree of freedom machines
  - ECCEROBOT (http://eccerobot.org/, - compliant skeleton)
  - AMARSi (http://www.amarsi-project.eu/, reserv. computing)

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material and energy supply (rodents)

ICEA (FP6, http://www.aslab.upm.es/public/projects/ICEA/)

Synthetic Forager (http://specs.upf.edu/sf/)

+ more from the robotics list

high-level (up to “human-likeness”)

at least 2 sub-levels:

- (elementary) cognitive capabilities to establish and recognise patterns in sensor-generated data;

prerequisites for

- operations like conceptualisation, scene interpretation, reasoning, planning, intelligent control, complex goal-oriented behaviour, and communication.

Scene analysis and interpretation

- GARNICS (http://www.garnics.eu/)
- IntellAct (http://www.intellact.eu/)
- SCOVIS (http://www.scovis.eu/)
- SEARISE (http://www.searise.eu/)
- SCANDLE (http://scandle.eu/)
- TACO (http://www.taco-project.eu/)
- VANAHEIM (http://www.vanaheim-project.eu/)

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- VANAHEIM (http://www.vanaheim-project.eu/)

Man-machine co-operation and communication

- ALIZ-E (http://www.aliz-e.org/)
- CHRIS (http://www.chrisfp7.eu/),
- CORBYS (http://corbys.eu/)
- EFAA {http://efaa.upf.edu/)
- HUMAVIPS (http://humavips.inrialpes.fr/)
- HUMANOBS (http://www.humanobs.org/)
- JAMES (http://james-project.eu)
- NIFTi (http://www.nifti.eu/)
- ROSETTA (http://www.fp7rosetta.org/)
- SPACEBOOK (http://www.spacebook-project.eu/)

Language acquisition

- ALEAR (http://www.alear.eu/)
- ITALK (http://www.italkproject.org/)
- ROSSI (http://www.rossiproject.net)

systems capable of adapting their behaviour to changing or entirely new features of their environment

- CogX (http://cogx.eu/)
- XPERIENCE (http://www.xperience.org/)

methods, models, paradigms

focus on / Type of environment	low-level competencies	high-level competencies	minding the gap	L E A R N I N G
1				
2				
3				
4				

L E A R N I N G

Learning

"perceived as the gateway to understanding the problem of intelligence" (Poggio & Shelton, 2000)

"If you invent a breakthrough in artificial intelligence, so machines can learn, that is worth 10 Microsofts.“ (New York Times, 2004)

Poggio, T. & Shelton C.R. (2000). Learning in brains and machines. Spatial Vision, 13(2,3), pp 287-296.
New York Times. (2004 March 1). Microsoft, Amid Dwindling Interest, Talks Up Computing as a Career. Retrieved from http://www.nytimes.com/2004/03/01/business/microsoft-amid-dwindling-interest-talks-up-computing-as-a-career.html?pagewanted=print&src=pm.

“ML-born” projects:

ComPlacs (http://www.complacs.org/)

MASH (http://mash-project.eu/)

PinView (http://www.pinview.eu/)

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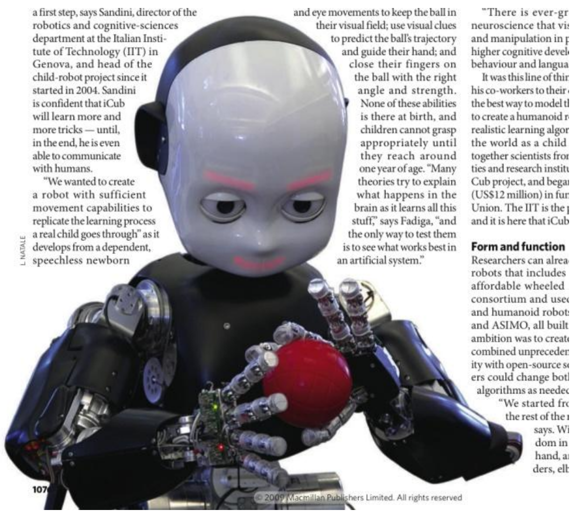
There is more demand for learning

- DIPLECS: "Dynamic interactive perception-action **learning** in cognitive systems"
- NOPTILUS: "Autonomous, **self-learning**, optimal and complete underwater systems”
- HUMANOBS: "Humanoids that **learn** socio-communicative skills by cbservation”
- NeuralDynamics: "A neuro-dynamic framework for cognitive robotics: scene representations, behavioural sequences, and **learning**”
- RoboEarth: "Robots sharing a knowledge base for world modelling and **learning** of actions"
- ROSETTA: “Robot control for skilled execution of tasks in natural interaction with humans; based on Autonomy, cumulative knowledge and **learning**”
- XPERIENCE: Robots bootstrapped through **learning** from experience"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realistic learning
the world as a child
together scientists
ties and research
Cub project, and
(US$12 million) in
Union. The IIT is the
and it is here that iCub

Form and function

Researchers can
robots that includes
affordable wheeled
consortium and
and humanoid
and ASIMO, all built
ambition was to
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algorithms as
"We started
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Project RobotCub:

Learning in developmental robotics

Discovering the manipulation abilities of its own body:

- **Learning** to control one's upper and lower body (crawling, bending the torso) to reach for targets.
- **Learning** to reach static targets.
- • Learning to reach moving targets.
- **Learning** to balance in order to perform stable object manipulations when crawling or sitting.

Discovering and representing the shape of objects:

- **Learning** to recognize and track visually static and moving targets.
- Discovering and representing object affordances (e.g. the use of tools).

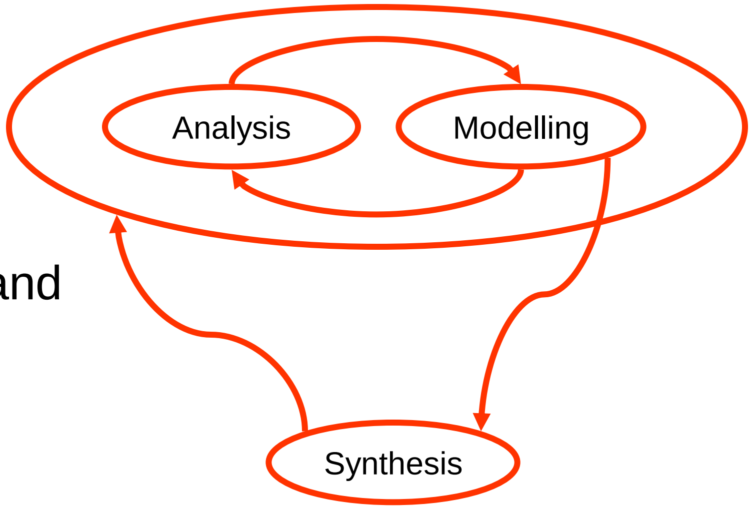
Recognizing manipulation abilities of others and relating those to one's own manipulation abilities:

- **Learning** to interpret and predict the gestures of others.
- **Learning** new motor skills and new object affordances by

projects that focus on general cognitive competencies (rather than specific robot skills):

the “analysis - modelling - implementation” triad:

1. analysis of natural cognition
   (> neuroscience, psychology, ...),



2. abstract modelling of cognitive processes and architectures
   (> mathematics, “algorithmics”),

3. implementation (“synthesis”) of cognitive machines or of cognitive processes in machines and other systems, based on abstract models
   (> engineering - hardware & software).

CSR programme is agnostic as far as paradigms and modelling are concerned.

It leaves room for all schools of thought:

cognitivist, connectionist, enactive, dynamicist, or any variant or hybrid.

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"I don't care if it's a white cat or a black cat. It's a good cat as long as it catches mice."(Deng Xiaoping, unsourced quote, but actually a Sichuan proverb)

"action precedes perception" insinuates enactivism, e.g., in

eSMCs ("Extending Sensorimotor Contingencies to Cognition", http://esmcs.eu/)

... attempts to bridge the “low-level” - “high-level” gap

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what else?

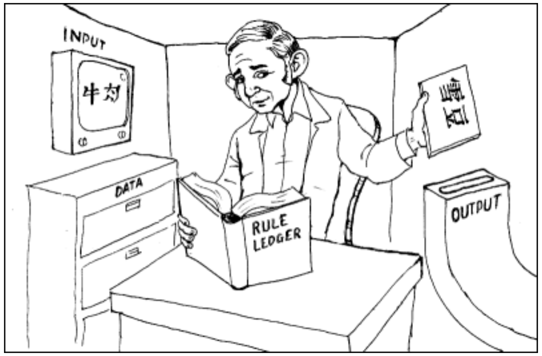
swarms and robot teams:

CoCoRo: "Collective cognitive robots" (self-organising swarm)

RoboEarth: "Robots sharing a knowledge base for world modelling and learning of actions" (http://www.roboearth.org/) (ro-ro-co)

Perspectives

The long term goal will not change any time soon …:



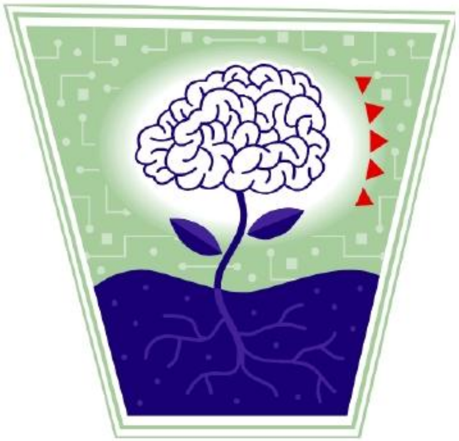
Chinese Room (or office?)

From:

Syntactic systems
(externally defined semantics, rigid and brittle,
“machines we have to understand”)

To:

Semantic systems
(intrinsic semantics,
evolution-growth-action grounded, subtle and robust,
“machines that understand the world”
that are “conscious”?)



...

“It follows that in order to produce consciousness within a mechanical brain, entirely new designs will be necessary.

These novel designs will contain as sub-systems the present type of calculator (although in a considerably improved variety) with a very significant additional feature: **these sub-systems must perform their own coding**.

The reason is obvious: as long as man does the coding, the logical principles according to which the calculator is working are located in part outside the machine: they are represented by the actions of the person who does the coding.

As long as that is the case, the calculator is not in the possession of vital information (retained by the coder) that is needed to whip the information into proper shape for the transcendental "carrier" operation.”

Quoted from: Can Mechanical Brains have Consciousness? by Gotthard Günther;
Originally published in: Startling Stories, Vol.29, no.1, p.110-116, New York **1953**
(see also: http://en.wikipedia.org/wiki/Gotthard_Günther)

Achieving understanding machines ....

machines that do the “right thing” of their own accord.

the ongoing increase in processor speed and memory capacities, self-modifying and biomorphic hardware, advances in "intelligent materials", and much more may be required; but these are most certainly no panacea.

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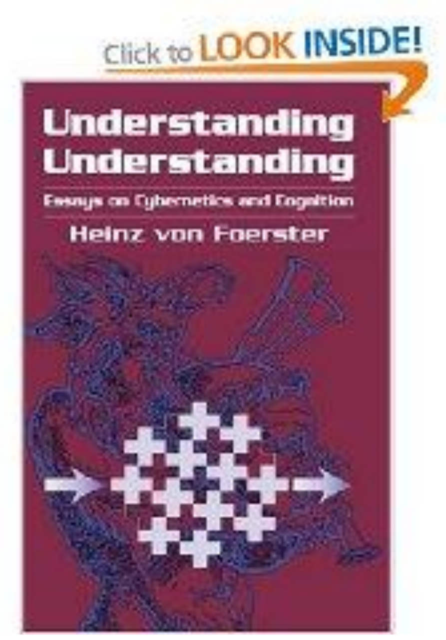
“Understanding Understanding” is the key!



e.g., understanding how we understand the world

... understanding how animals understand the world ...

... for example

Betty, Bees and Beavers

Photo courtesy of the Behavioural Ecology Research Group, University of Oxford

what body?
what mind?

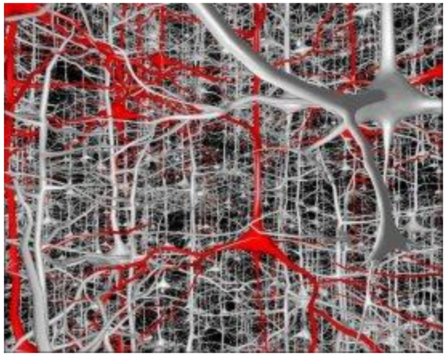
what body?
what mind?

“embodiment” – what level?

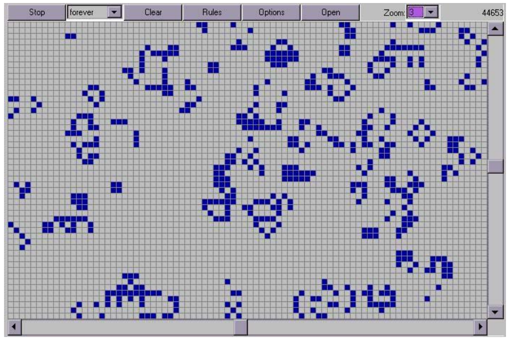
iCub, RobotCub consortium, IIT

ECCE, http://eccerobot.org/

Jules, Bristol Robotics Lab



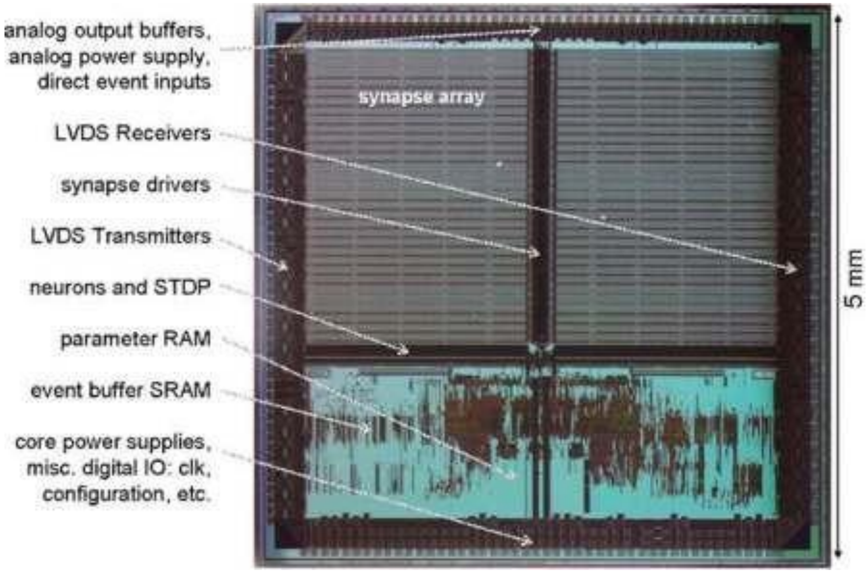
“embodiment” – what level?



FACETS

http://facets.kip.uni-heidelberg.de/

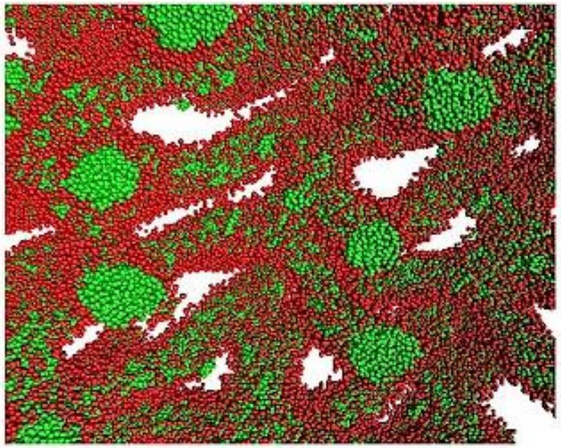
Fast Analog Computing with Emergent Transient States



PACE

http://www.istpace.org/

Programmable Artificial Cell Evolution



... can we marry the

precision, capacity and reach

of digital systems

to the

robustness, adaptivity and effectiveness

of (certain) biological systems?

(and – of course – our little human ingenuity?)

do we need new paradigms for

“mapping the world”

into the physico-chemical dynamics of suitable material structures?

ref: unconventional computing, “super-Turing”

Siegelmann H. T. (1999) Neural Networks and Analog Computation: Beyond the Turing Limit.

does
Mind-Matter Matter?

(to what a mind can do)

(the age-old question!)

A note on this question (the mind-body problem?):

"*The body is a big sagacity, a plurality with one sense, a war and a peace, a flock and a shepherd.*

An instrument of thy body is also thy little sagacity, my brother, which thou callest `spirit' - a little instrument and plaything of thy big sagacity"

(Nietzsche, 1896).

Nietzsche, F. (1896). Thus Spake Zarathustra (translated by Alexander Tille). New York and London: Macmillan.

do we have to reinvent life?

(nano-bio-cogno?)

(Ethical?) epilogue 1: “Vom Fischer und syner Fru”*

The enchanted flounder the fisher had one day encountered in the placid sea and returned to its element, thankfully gave in to the wife's every demand, promoted her from the filthy shack where she used to live, all the way to the papal throne, and made her richer and richer, and more and more powerful.

Then the woman wanted to be like God.

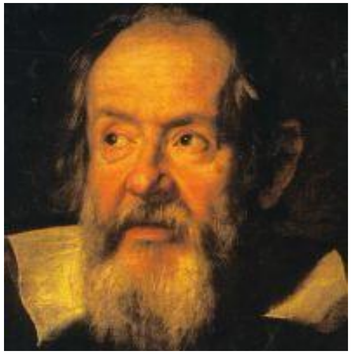
Upon hearing this the flounder told the fisherman: “Go home. She is sitting in her filthy shack again.”

And the sea was roaring like hell.

* “The Fisherman and his Wife”
http://www.pitt.edu/~dash/grimm019.html

(Ethical?) epilogue 2: Mevr Kroes quotes Sig Galilei

Neelie Kroes, the Commissioner in charge of European ICT (Information and Communication Technologies) funding, in (Kroes, 2011), quotes from Berthold Brecht's famous play "The Life of Galileo" (Brecht, 1952) the great scientist's adage:



"*I maintain that the only goal of science is to alleviate the drudgery of human life*."

And she adds: "*Sound advice indeed! We will continue to fund research whose results help create better living conditions for everyone on this planet and research that helps us to better understand ourselves and the world we live in. Both go hand in hand—and robots should take their fair share in this ICT landscape.*"

Kroes, N. (2011). Robots and Other Cognitive Systems: Challenges and European Responses. Philosophy & Technology, Volume 24, Number 3, pp 355-357.

Thank you !

PS: **http://www.cognitivesystems.eu**

PPS: Views expressed in this talk are those of the author and do not necessarily engage the European Commission.