Towards a Scientific Foundation for Engineering Cognitive Systems
- A European Research Agenda, its Rationale and Perspectives -

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| 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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Technical systems that are more effective in improving their performance and more natural in dealing with people (- where dealing with people is a requirement).
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Technical systems that are more **effective** in improving their performance and more **natural** in dealing with people (- where dealing with people is a requirement).

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;

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;

    **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, ...
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**
Marking out the domain CSR projects are expected to explore 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
- 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
Marking out the domain CSR projects are expected to explore

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?
Marking out the domain CSR projects are expected to explore

**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?
- 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**? \((X \in \{monitoring, modifying, debugging, configuring, controlling, understanding, aware, organising ...\})\)
- **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"

foundational issues in cognitive systems research

basic HW technologies, components

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

Cognitive assistance

Industrial robotics
Service robotics
Humanoid robotics
“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
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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**iCub / project RobotCub**
**Start:** 2004-09-01  
**End:** 2010-02-28  
11 partners (Univ Genoa+10)  
**Funding:** 8.5 million euro

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**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/)
Examples (function)

Manipulation, grasping, assembly

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

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/)
Examples (environment and function)

roadscapes and driver assistance
  DIPLECS (http://www.diplecs.eu/)
  RADHAR (http://www.radhar.eu/)

(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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roadscapes and driver assistance

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RADHAR (http://www.radhar.eu/)

(deep) sea and underwater operations

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TRIDENT (http://www.irs.uji.es/trident/)

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.)

Urban environments and services

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

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/)
Examples (environment and function) (cont.)

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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/)
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<th>Cognitive competencies</th>
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<td><strong>Making the artificial system act deliberately and purposefully, and explicitly understand its world (&quot;high level&quot;)</strong></td>
<td>e.g., concepts, plans, reasoning, communication, language, ... (&quot;symbolic&quot;)</td>
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<td><strong>Maintaining the artificial body in its environment (&quot;low level&quot;)</strong></td>
<td>e.g., autonomic control of &quot;service-sustaining&quot; processes (&quot;sub-symbolic&quot;)</td>
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Cognitive competencies

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

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

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

SPARK I&II (http://www.spark.diees.unict.it/ and http://www.spark2.diees.unict.it/)

EMICAB (http://www.emicab.eu/)

sensory-motor coordination in complex multi-degree of freedom machines

ECCEROBOT (http://eccerobot.org/, - compliant skeleton)

AMARSi (http://www.amarsi-project.eu/, reserv. computing)
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/)
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AMARSi (http://www.amarsi-project.eu/, reserv. computing)

material and energy supply (rodents)
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/)
Scene analysis and interpretation

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• SCANDLE (http://scandle.eu/)
• TACO (http://www.taco-project.eu/)
• 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

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<th>focus on</th>
<th>Type of environment</th>
<th>low-level competencies</th>
<th>high-level competencies</th>
<th>minding the gap</th>
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LEARNING
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)

“ML-born” projects:

ComPlacs (http://www.complacs.org/)
MASH (http://mash-project.eu/)
PinView (http://www.pinview.eu/)
“ML-born” projects:

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

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 observation"
- 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"
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 observing others.
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.
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.

"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
"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

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 ...:
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?](http://en.wikipedia.org/wiki/Gotthard_Günther) by 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.
Achieving understanding machines ....
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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.

“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?

ECCE, http://eccerobot.org/

iCub, RobotCub consortium, IIT

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”
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).

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."

Thank you!

PS: [http://www.cognitivesystems.eu](http://www.cognitivesystems.eu)

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