Research Goals and Problems viewed after 37 years combining AI and Philosophy in the context of psychology and biology and 10 years of philosophy of mind and mathematics, before that.  
A fairly arbitrary selection from the observations I could make.

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These slides will be made available online here:
http://www.cs.bham.ac.uk/research/projects/cosy/papers/

See also the euCognition Research Roadmap project:

My slides have too much detail for presentations. They are intended to make sense if read online.
Background

• ERCIM: is an EU-funded European Research Consortium for Informatics and Mathematics - aims to foster collaborative work within the European research community and to increase co-operation with European industry.
  http://www.ercim.org/

• One of its projects is INTERLINK: International Cooperation Activities in Future and Emerging ICTs, a 30 month project (1/10/2006 - 30/3/2009) aimed “at advancing Europe’s knowledge in a number of critical Science & Technology areas, at promoting European solutions and knowledge world-wide, and at influencing the way research in these areas would evolve internationally”.
  http://interlink.ics.forth.gr/

• It is divided into three working groups, one of which is Group 3: Intelligent and Cognitive Systems, whose objectives include fostering world-wide discussion among researchers about cognition and cognitive systems, which “safely coexist with humans, interactively communicate with humans and usefully act in built-for-human environments”.
  http://interlink.ics.forth.gr/central.aspx?sId=84I240I746I323I344319

• Interlink organised an international workshop in Nice 10-12 May 2007, to discuss the state of the art in the three areas, including gaps in knowledge, and to make recommendations for future research.
  http://www.ercim.org/interlinkworkshops

• I was invited to the workshop and attended both the plenary meetings and the Group 3 meetings. All attendees were invited to give ‘position’ presentations, and to make the slides available afterwards. These are my slides, expanded considerably in the light of the discussions.
Some thoughts about the objectives

• There is already a large amount of research in Cognitive Systems funded under FP6, and a lot more is to be funded under FP7: see the ‘projects’ page (though EU links keep breaking as a result of reorganisation),
  So we are in danger of rediscovering wheels and/or making recommendations based on incomplete information.

• Some of the goals of Interlink are already being pursued in the FP6 euCognition network, one of whose activities is discussion of a roadmap (also mentioned in David Vernon’s presentation)

• Asking many people to spend a short time working on long term goals and milestones may produce only the “least common denominator” among existing opinions (as has often happened in the past), whereas a small high calibre group doing deep analysis of current gaps in knowledge and know-how may produce less predictable results.

• Biological systems provide important existence proofs, that we are still nowhere near understanding: I suspect evolution “discovered” and solved far more design problems than we have identified. We need to learn what those problems were, in order to expose, and attend to, gaps in our understanding.
Biological existence proofs

• Some problems solved by evolution can be discerned by looking very carefully at competences and competence-gaps of many non-human animals and also human children:
  finding tasks that one organism or child cannot perform whereas another can may help us formulate questions about what architectures, forms of representation, information, mechanisms, virtual machines, architectures etc. might explain the differences. Often, subtleties that go unnoticed in real life become evident if the same video of some behaviour is watched repeatedly. Some videos are analysed in http://www.cs.bham.ac.uk/research/projects/cosy/papers/#pr0602

• But the questions to ask may not be obvious: e.g.
  Neuroscientists need to ask what ontologies are used by different brain mechanisms. Psychologists need to ask how information is processed. All need to study diverse environments that affected evolution. All need to learn to ask questions about which virtual machines run on neural and other substrates. We need to ask how many different routes there are from genome to behaviours. We should all wonder whether the colloquial concepts used to formulate our questions are suitable for use in science or far too fuzzy and general (e.g. ‘emotion’, ‘consciousness’, ‘memory’, ‘learning’, ‘self’ — none of which was developed for scientific uses). No chemist would now use ‘water’ in the same sense as Aristotle.

• Biologists, neuroscientists, psychologists, social scientists need to learn to communicate with us and we need to learn to communicate with them.

• It is important not to adopt confrontational postures that disparage approaches that have not solved all the problems.
  NO approaches known so far solve more than a tiny subset of (often trivial) problems.
Example: over-emphasising embodiment

Yes — embodiment is important, but for human intelligence it is more important to have had embodied ancestors than to be embodied in a particular way.

At different stages of evolution of birds and mammals, the problems brains had to solve changed, and entirely new kinds of functionality developed: we do not yet have a good characterisation of the variety of functions. H-Cogaff (below) is a partial answer – which overlaps with Minsky’s partial answer in “The emotion machine”

I.e. our brains and minds are to a large extent products of our evolution – and that gives us powerful capabilities to achieve the results of what our ancestors learnt without having to repeat all the processes by which they learnt: that’s why badly deformed, or congenitally blind or deaf children can, via their own routes, become adult humans. (E.g. Alison Lapper, the artist. http://www.alisonlapper.com/)

(That’s partly because mirror neurons should have been called “abstraction neurons”: i.e. they are involved in using amodal exosomatic ontologies – like the ontology used by Jim Crowley’s “intelligent room” – which can share an ontology with us despite having a very different “body”.)
Two views

Annette Karmiloff-Smith (1994):

“Decades of developmental research were wasted, in my view, because the focus was entirely on lowering the age at which children could perform a task successfully, without concern for how they processed the information”

Precis of: Beyond Modularity: a Developmental Perspective on Cognitive Science, in Behavioral and Brain Sciences journal, 17,1. pp 693-706,
http://www.bbsonline.org/documents/a/00/00/05/33/index.html

Ulric Neisser (1976):

“we may have been lavishing too much effort on hypothetical models of the mind and not enough on analyzing the environment that the mind has been shaped to meet.”

(Thanks to Erik Hollnagel for the reference)

These are not incompatible: we need to combine them!

Sloman and Chappell in BBS (to appear)
Commentary on Eva Jablonka and Marion Lamb: Evolution in Four Dimensions
http://www.cs.bham.ac.uk/research/projects/cosy/papers/#tr0703
Don’t expect a question to have one answer

We need to remember that there are many species, often solving the same problem (e.g. locomotion, perceiving the environment, obtaining nourishment, replicating genes) in very different ways.

Don’t ask what architecture an intelligent robot will need: different answers depend on details of the environment and the task requirements and whether and how they change over time – i.e. different niches require different designs.

Don’t ask how to implement ‘emotions’ or ‘consciousness’: colloquial labels name diverse sets of phenomena arising out of different sorts of mechanisms.

A. Sloman and R.L. Chrisley and M. Scheutz, (2005),
The architectural basis of affective states and processes, in Who Needs Emotions?: The Brain Meets the Robot, Ed. M. Arbib and J-M. Fellous, OUP, pp. 203–244,
http://www.cs.bham.ac.uk/research/cogaff/03.html#200305

Don’t ask what sort of innate capacities a robot needs: nature shows us that there are complex nature/nurture tradeoffs with many different solutions.

A. Sloman and J. Chappell, (2005), The Altricial-Precocial Spectrum for Robots, Proceedings IJCAI’05,
http://www.cs.bham.ac.uk/research/cogaff/05.html#200502

J. Chappell and A. Sloman, (to appear)
Natural and artificial meta-configured altricial information-processing systems, International Journal of Unconventional Computing,
http://www.cs.bham.ac.uk/research/projects/cosy/papers/#tr0609
Varieties of individual development trajectories: Cognitive epigenesis

Individual trajectories (i-trajectories) through design space involve various combinations of learning and development, based on various combinations of genetically provided competences, including competences that provide new competences, at different levels of abstraction (meta-competences).

Sometimes development of a new competence or meta-competence requires ontology extension: of different sorts – how are they achieved?

This is just a summary – explained in more detail in Chappell and Sloman to appear in IJUC, Sloman and Chappell to appear in BBS and other online papers:

http://www.cs.bham.ac.uk/research/projects/cosy/papers/#tr0609
Natural and artificial meta-configured altricial information-processing systems

Other papers also at http://www.cs.bham.ac.uk/research/projects/cosy/papers/

NB: All boundaries are somewhat fuzzy.
Environment affects all embedded processes.
For most species only the two leftmost routes are used.
Importance of exosomatic ontologies

Exosomatic ontologies can represent things independently of how they are sensed or acted on. ‘Concept empiricism’ (recently reinvented as symbol-grounding theory) deems that impossible. But Kant (in 1780) argued otherwise against Hume.

Use of exosomatic (not just amodal or multimodal) ontologies is a significant feature of human information processing.

- This is commonplace in science: genes, neutrinos, electromagnetic fields, and many other things are postulated because of their explanatory role in theories, despite never being directly sensed or acted on.
- Does this also occur during learning in infants and hatchlings that discover how the environment works by playful exploration and experiment?
- Are ‘ontologies’ that refer beyond the sensor data also set up in the genome of some species whose young don’t have time to go through that process of discovery but must be highly competent at birth or hatching? (precocial species)
- Could the portia spider perform her amazing feats if she had only representations of her sensory and motor signals?


- Is there anything in common between the different ways ontologies get expanded in biological systems (e.g. in evolution, in development, in social processes)?
- This relates to questions about what a genome is, and about varieties of epigenesis.

[http://www.cs.bham.ac.uk/research/projects/cosy/papers/#dp0606](http://www.cs.bham.ac.uk/research/projects/cosy/papers/#dp0606)
(Critique of sensorimotor cognitive theories)
More complex behaviours need to be specified in terms of the competences they require.

Behaviour type XXX has features requiring competence of type YYY

NB: My claims — e.g. ‘These linguistic and planning behaviours require mechanisms with recursive capabilities and compositional semantics’ — must be open to testing and refutation.

Competences lead to ideas about architectures. There are too many different, arbitrary, terminologies, diagrammatic conventions, preferred architectures. We need a common vocabulary for talking about architectures. A first draft example is the CogAff schema.

Requirements for subsystems can refer to

- Types of information used (ontology used)
- Forms of representation (continuous, discrete, Fregean, diagrammatic, distributed, dynamical...)
- Uses of information (controlling, describing, planning, teaching, questioning, instructing...)
- Types of mechanism (many examples have already been explored – there may be lots more ...).
- Ways of putting things together in an architecture or sub-architecture

Architectures vary according to which of the boxes contain mechanisms, what those mechanisms are required to do, which mechanisms are connected to which others, what sorts of connections there are, what sorts of learning can occur, whether the architecture grows itself....
Varieties of functionality in human-like systems.
An architecture for a collection of requirements.

We can use this to derive different architectures for different organisms/robots, depending on which requirements are important: a space of possibilities.

There are partial implementations of designs meeting different subsets of these requirements, using our SimAgent toolkit.

The architecture, and the more general CogAff scheme are described in more detail in many papers and presentations in the Birmingham Cogaff web site.

This overlaps a lot with Minsky’s Emotion Machine architecture but we use different principles of subdivision.

The Cogaff web site is here:
http://www.cs.bham.ac.uk/research/projects/cogaff/
Two conjectures

A: The most general capabilities of humans, which are those provided by evolution, and which support all others, develop during the first few years of infancy and childhood. We need to understand those in order to understand and replicate the more ‘sophisticated’ and specialised adults that develop out of them.

Attempting to model the adult competences directly will often produce highly specialised, unextendable, and probably very fragile systems – because they lack the child’s general ability to accommodate, adjust, and creatively re-combine old competences.

B: There are many aspects of human cognition that evolved originally to meet requirements for 3-D vision and action — including intricate manipulations of 3-D structures — using exosomatic ontologies. The mechanisms and forms of representation are now used for many other purposes, and can be used by people who have been blind from birth or who were born without limbs.

Embodiment of your ancestors is more important for development of your mental competences than your own embodiment.
Key points

- We need to understand the environment that shaped human evolution in order to understand design requirements.

- Most of the rich collection of features of the environment determining requirements for cognition have never been described:
  - spatio-temporal structures, relationships, processes, including multi-strand relationships and multi-strand processes
    - Vision is mostly concerned with getting information about processes.
    - Structures are processes in which all velocities are zero.
    - http://www.cs.bham.ac.uk/research/projects/cosy/papers/#pr0505
  - kinds of stuff and their causal powers – in many and varied configurations and processes
    - sand, rock, wood, water, mud, meat, bone, skin, fur, string, cloth, wind,...
  - different levels of complexity perceived and produced
  - two kinds of causation accessible: Humean (correlational, statistical), Kantian (structure-based, deterministic)
  - using meta-semantic competences of varying sophistication to represent information users: others and self.

- Humans do not scale up – but they do ‘scale out’. Why not both?

ERCIM Interlink Position Presentation Slide 13 Last revised: May 16, 2007
More Key points

- We need to understand how humans are a special case of something more general.
- Humans combine mechanisms that evolved at different times to meet different requirements (many shared with other animals).
- Vision has many more functions than have been noticed and the mechanisms proposed must explain them all.
- The evolution of language was at first mostly internal, to support perception, prediction, reasoning, planning in several species – only after that were the mechanisms used for external communicative functions (Sloman 1979, Sloman and Chappell in BBS).
- There are complex, unnoticed, tradeoffs between nature and nurture, with different epigenetic mechanisms for different competences (the precocial-altricial spectrum).
- We need to understand more varieties of information-processing mechanism than have so far been developed.
How to develop a research roadmap

Observe feats of humans (e.g. young children, playing, exploring, communicating, solving problems) and other animals (e.g. nest-building birds, tool makers and users, berry-pickers and hunters). These provide many existence proofs, not of specific mechanisms, but of a wide variety of possible behaviours for intelligent embodied individuals i.e. requirements to be met by our designed systems.

Use those observed behaviours to develop and document a partially ordered network of more or less challenging scenarios – ordered by dependency, complexity, difficulty and variety of competences each scenario requires.

Things we would like human-like machines to be able to do one day

Scenarios higher up and more to the right use richer ontologies, and more complex combinations of competences, often including highly trained reflexes, as well as deliberative processes, and sometimes meta-semantic abilities to represent things that represent. They also involve more complex motivations e.g. intellectual, aesthetic and moral preferences.

We should plan more of our research by identifying long term requirements in great detail and working back through less demanding requirements.
Many scientists and philosophers focus all their efforts at one level of design – physical, digital electronic, neural, cognitive, social, or whatever, or at most two levels, e.g. neural and behavioural — such research is too narrow minded and doomed to get things badly wrong.

Small successes can mask big gaps and errors in theories

Hubert Dreyfus: climbing trees is not necessarily evidence of progress towards a moon landing.
How to think about non-physical levels in reality
Some philosophers and scientists think only physical things exist. But there are many non-physical objects, properties, relations, structures, mechanisms, states, events, processes and causal interactions.
E.g. poverty can cause crime. Decisions can cause actions.
They are all ultimately implemented in physical systems, as computational virtual machines are, e.g. the Java VM, the linux VM. Physical sciences also study layers in reality. E.g. chemistry is implemented in physics. Nobody knows how many levels of virtual machines physicists will eventually discover.
See the IJCAI’01 Philosophy of AI tutorial
http://www.cs.bham.ac.uk/research/projects/cogaff/ijcai01
Sometimes people fail to notice important levels

Diagram on right from “Towards virtual oncology” by Georgios Stamatakos in ERCIM News April 2007

It is very common to ignore some of the levels of virtual machines in human and other animal brains.

Also there are different levels in ecosystems, with complex interacting virtual sub-machines.

The ten levels of biocomplexity:

- Ecological system level
- Population level
- Organism level
- System level
- Organ level
- Tissue level
- Cellular level
- Sub-cellular level
- Molecular level
- Atomic level

Every intelligent ghost must contain a machine.
We need new kinds of mathematics

To understand evolution

To understand spatial cognition – including human vision.

I cannot elaborate this fully, but will illustrate it with evolution viewed as a process involving multiple interacting and changing dynamical systems.

An evolving ecosystem is not one thing

- At any time there are lots of niches, each of which is not just a physical location but a collection of requirements for an organism or group, or organ, or competence, where the requirements are determined by many factors in the rest of the system.

- At any time there are lots of designs partially encoded in genomes and in developing brains, as well as in aspects of cultures and animal-made features of the environment (Dawkins: the extended phenotype)

- Those designs for organisms, parts of organisms, groups of organisms, etc. evolve in parallel with the niches against which they are “evaluated”, with much feedback at many levels of abstraction.
How to view an Ecosystem?

Diverse sets of requirements (niches) change over time.

Diverse types of designs, also change, with many instances that develop over time.

Changes in designs affect the niches for other species and for instances.

Changes in niches often (not always) lead to changes in designs.

Designs and niches change over time for altricial species.

There are different sorts of trajectories in the spaces: evolutionary, individual, social/cultural, etc.

These trajectories can involve complex feedback loops (on different time scales) between designs and niches, with multiple complex, structured, ‘fitness’ relationships, at different levels.

This can also apply to parts or aspects of organisms.

See http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk6

Don’t ask for numeric fitness functions to assign a total ordering:

There are structured relations between designs and niches.
Not all evolved designs are for complete systems

The vast majority of species have almost all the important features of adult individuals predetermined by the genome combined with physical features of environments in which viable development can occur.

However some species develop competences that are based on meta-competences, possibly several layers of meta-competences, which cause exploratory interaction with the environment to learn things that allow entirely new competences to be developed.

This is part of the important vision of evolution expounded in


Summarised here

http://www.bbsonline.org/Preprints/Jablonka-10132006/Referees/

To appear in *Behavioral and Brain Sciences*
Interacting trajectories in design space and in niche space

There are different sorts of trajectories in both spaces:

- **i-trajectories:**
  Individual learning and development

- **e-trajectories:**
  Evolutionary development, across generations, of a species.

- **r-trajectories:**
  Repair trajectories: an external agent replaces, repairs or adds some new feature. The process may temporarily disable the thing being repaired or modified. It may then jump to a new part of design space and niche space.

- **s-trajectories:**
  Trajectories of social systems.

Some e-trajectories may be influenced by cognitive processes (e.g. mate-selection). We can call them **c-trajectories** (not shown separately).

All except r-trajectories involve continuously viable fully functioning working systems at every stage.
Implications for theories of meaning

The existence of precocial species refutes ‘symbol-grounding’ theory

(One version of ‘concept empiricism’ – the theory that all meaning has to be derived by processes of abstraction from sensory experiences, which is clearly not required for precocial species that are competent at birth).

In our IJCAI paper we distinguish two sources of meaning

- the structure of a theory in which ‘undefined terms’ occur
  (where the structure limits the class of possible models/interpretations)

- links to sensing and acting (e.g. through tests and predictions)
  (where the links – e.g. Carnapian ‘meaning postulates’ further reduce the set of possible interpretations, tethering the interpretation – though there is always residual indeterminacy.)

The second picture seems to represent how terms in scientific theories get their meaning, i.e. largely from the structure of the theory, which constrains possible models. So why not concepts in toddler theories?

Compare 20th century philosophy of science after crude empiricism was shown to be wrong: Popper, Carnap, Hempel, Pap, ....

Symbol Grounding

Symbol Tethering
Example: vision is much, much, more than recognition

What competences are required in a visual system to enable a child (or a robot) to get from the first configuration to the second?

- in many different ways,
- with different variations of the first configuration,
- with different variations of the second configuration,
- using the right hand,
- using the left hand,
- using both hands,
- using no hands, only mouth...?

Can you visualise such processes – including interacting curved surfaces?

For more on this see

The problem of speed and complexity

Coming out of an underground station in a new town into a busy road: what do you see in the first second or so.

(find a suitable picture to illustrate the point.)

Perhaps we have a large collection of multi-stable dynamical systems built up over many years perturbed by both incoming retinal stimulation and internal thoughts, interests, intentions, etc.
How to see 3-D structures – one way

You probably see a clearly defined 3-D scene (though there are no precise lengths, angles or distances — only partial orderings).
Local structure in images and scenes

In the 1960s & 1970s, work by Guzman, Huffman, Clowes, Waltz, Turner, Barrow, Tennenbaum & others indicated how local image features combined with some prior assumptions about kinds of objects in the scene, could act as cues to 3-D scene fragments with specific geometrical structures.

Those prior assumptions might be false, but could be supported by more general features of the current view. E.g. if a scene appears to have many straight lines and especially if they remain straight across changes of viewpoint, the scene certainly includes many straight 3-D edges. Moreover, the surfaces joined by those edges must be planar (at least locally).

We ignore for now the fact that straight lines in 3-D space will not project into straight lines on a retina, leaving the task of identifying ‘projected’ straightness to be solved separately. (D. Philipona, J.K.ORegan, J.-P. Nadal, Is there anything out there? Inferring space from sensorimotor dependencies. *Neural Computation*.)

As the picture shows, local straightness and planarity in the scene generate very strong constraints regarding how different portions of edges, surfaces and objects are related in the scene.

Likewise when there is motion, assumed or inferred rigidity generates very strong constraints regarding both how things can change and how relatively remote scene fragments are related.

Barrow and Tenenbaum (1978) ‘Recovering intrinsic scene characteristics from images’, pointed out other forms of inference.

We don’t know how many such inferences human and other animal visual systems make but there seem to be many of them, some of which, though not all, depend on recognised objects. E.g. Gregory’s ‘hollow mask’ demonstrates how strong evidence for concavity can be overridden.

But local consistency plus constraints can produce global inconsistency – possibly undetected.
The ‘wire frame’ 3-D cube is perfectly geometrically possible. But in the Penrose, Reutersvärd and Escher pictures there is more local 2-D structure cueing specific 3-D structural interpretations, each internally consistent, but forming a globally inconsistent whole – e.g. violating transitivity anti-symmetry and irreflexivity of ‘further away’.

Sometimes various subsets (but not all) of such pictures are globally consistent.

The ‘impossible object’ pictures depend on mechanisms that are part of everyday perception of structure.

A Penrose/Reutersvärd triangle is but one of many pictures that contain geometrically possible 2-D configurations of lines, which because of various strong cues drive our visual system to 3-D interpretation of various fragments in the picture, as does the Necker cube, whether static or rotating:

http://www.cs.bham.ac.uk/research/projects/cogaff/misc/nature-nurture-cube.html
What are the implications of what you see?
Seeing cannot involve the construction of a model of the scene

A model (in the normal sense) cannot be inconsistent: but a model of this scene would have to be.
Escher’s Weird World

Many people have seen this picture by M.C. Escher:
a work of art, a mathematical exercise and a probe into the human visual system.

You probably see a variety of 3-D structures of various shapes and sizes, some in the distance and some nearby, some familiar, like flights of steps and a water wheel, others strange, e.g. some things in the ‘garden’.

There are many parts you can imagine grasping, climbing over, leaning against, walking along, picking up, pushing over, etc.: you see both structure and affordances in the scene.

Yet all those internally consistent and intelligible details add up to a multiply contradictory global whole. What we see could not possibly exist.

There are several ‘Penrose triangles’ for instance, and impossibly circulating water.

Can you see the contradictions? They are not immediately obvious.
Perceiving impossible things

What is perception of spatial structure?

Pictures of ‘impossible objects’ tell us things about the nature of vision. The ‘Penrose Triangle’ is one of many depictions of impossible 3-D objects, often presented as relevant to the study of human vision, though implications spelled out below are rarely stated.

The Swedish artist Oscar Reutersvärd discovered impossible triangles earlier, in 1934, in the lower form on the right.

Notice how each little cube looks normal: you can easily visualise grasping any of them from different directions, pulling or pushing them out of the ‘triangle’ in various ways, etc. Yet the whole 3-D configuration is geometrically impossible. Why?

What do such pictures of ‘impossible objects’ tell us about vision — at least in (some? all? adult?) humans?


http://www.psychology.soton.ac.uk/psyweb/staff/myprofile/mypublications/publications/mka/ShwairiAlbertJohnsonPS07.pdf

Compare Karmiloff-Smith’s remark, quoted previously.
The multiple functions of vision

There is a vast amount of research on visual classification and recognition. However, most of that research ignores the fact that people, and other animals can see, and manipulate things they do not recognise, e.g. strange animals or machines.

Moreover much of what we see involves processes not just static objects and configurations of objects. Partly that’s because we use vision to work out what actions are possible, prior to deciding what to do, and then to help control actions that result. This implies that vision includes seeing what is possible, as opposed to what exists or is happening. That includes seeing empty spaces.

That’s a part of what is involved in perceiving affordances.

For more on the non-recognition functions of vision see

- [http://www.cs.bham.ac.uk/research/projects/cogaff/06.html#0604](http://www.cs.bham.ac.uk/research/projects/cogaff/06.html#0604)

- [http://www.cs.bham.ac.uk/research/projects/cogaff/81-95.html#7](http://www.cs.bham.ac.uk/research/projects/cogaff/81-95.html#7)
  On designing a visual system: Towards a Gibsonian computational model of vision (1989)

  A challenge for vision researchers

- [http://www.cs.bham.ac.uk/research/projects/cosy/papers/#pr0505](http://www.cs.bham.ac.uk/research/projects/cosy/papers/#pr0505)
  A (Possibly) New Theory of Vision

- [http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk7](http://www.cs.bham.ac.uk/research/projects/cogaff/talks/#talk7)
  When is seeing (possibly in your mind’s eye) better than deducing, for reasoning?

  On seeing changing binary pixels as a rotating wire-frame cube.
Another example: Ontologies for getting at something
Understanding varieties of causation involved in learning how to get hold of a toy that is out of reach, resting on a blanket, or beyond it.

Some things to learn through play and exploration

Toy on short blanket  **Grab edge and pull**
Toy on long blanket  **Repeatedly scrunch and pull**
Toy on towel  **Like blanket**
Toy on sheet of plywood  
  **Pull if short(!!), otherwise crawl over or round it**
Toy on sheet of paper  **Roll up?**
  (But not thin tissue paper!)
Toy on slab of concrete  **Crawl over or round**
Toy at end of taut string  **Pull**
Toy at end of string with slack  **Pull repeatedly**
String round chair-leg  **Depends**

Elastic string  **??????**

See this discussion of learning orthogonal recombinable competences
http://www.cs.bham.ac.uk/research/projects/cosy/papers/#dp0601

It takes a lot of learning to develop all the visual and reasoning competences required for seeing and understanding these affordances – including visualising what would have happened if you had done something different, or if someone else were to move something.

Our spatial and visual competence goes far beyond actually doing.
Two notions of causation: (Humean & Kantian)

Understanding causation is one of the requirements for competence.

Consider two gear wheels attached to a box with hidden contents. Can you tell simply by looking, without actually turning anything, what will happen to one wheel if you rotate the other about its central axis?

Only in the lower case. (How do you tell?)

Seeing what must happen if....

A child, and an intelligent robot able to find out how things work in the environment, will learn the difference between causation that is merely correlational (Humean) and causation that is based on intelligible structure and is therefore also deterministic (Kantian).

Invent more examples to fit both cases.

Which other animals learn about Kantian causation?

Watch ‘clever or funny animals’ TV shows!

Why will robots need this?

For more on this see

http://www.cs.bham.ac.uk/research/projects/cosy/papers/#pr0506

Two views of child as scientist: Humean and Kantian
Some more abstract competences

Besides being able to see, hear, feel, manipulate, use, and react to processes involving configurations of objects in the environment, humans can also learn about, think about, reason about, be puzzled about, communicate about, prove things about, many kinds of abstract entities, including:

- Games – including their rules, and many entities that can be involved in games, e.g. goals, threats, illegal moves, etc.
- Numbers
- Calculations
- Proofs
- Stories
- Plans
- Strategies
- Values
- Theories and explanations
- Their own and other people’s goals, beliefs, desires, hopes fears, puzzles, confusions, strategies, etc.
- Social groups, social relations, social processes (e.g. revenge, punishment)

These require significant representational and architectural competences beyond those commonly required for perceiving and acting in the environment as all other animals do, including microbes and insects. E.g. meta-semantic competences and deliberative competences are needed.

See requirements for ‘fully deliberative’ architectures:

http://www.cs.bham.ac.uk/research/projects/cosy/papers/#dp0604
Making high level competences fast and fluent

Humans often learn a new competence that involves deliberately following procedures, thinking about options, either remembering rules, using charts or maps, or working out new plans. After much practice using that competence in many different contexts, the deployment of the competence because much more fast and fluent. How does that happen?

Examples:
- Learning to feed oneself, to dress and undress, tie shoelaces, wash dishes,
- Learning ones way around a building or a town
- Learning to play physical games like tennis, football, boxing, hockey,
- Learning to ride a bicycle or drive a car.
- Learning a board game like chess or othello.
- Learning to play a musical instrument.
- Learning to talk.
- Learning to read text, music, computer programs, flow-charts...
- Learning to count, to answer questions about numbers, to do calculations, to prove mathematical theorems, to think about infinite sets.
- Learning to see moods, feelings, intentions, etc. in other people.
- Learning to interact socially.

Conjecture: species that originally evolved with only genetically determined competences (e.g. deer running soon after birth) later evolved to start with large amounts of spare capacity that could be used to acquire new competences under the control of deliberative and meta-semantic competences. Then mechanisms developed for “compiling them” into fast fluent versions.
What’s a Research Roadmap For?
- An agreed specification of what the problems are: what we are trying to do.
- When the problem is very complex, a roadmap can break the problem down into significant sub-problems, helping with research planning.
- It can be used to specify milestones and routes through them.

Why do we need one?
- Because there have been so many past optimistic predictions that failed!
- Because even people who disagree on mechanisms, architectures, representations, etc. may be able to agree on requirements.

How can we produce one?
- NOT BY ASKING YET MORE ‘EXPERTS’ TO MAKE YET MORE PREDICTIONS!
- Instead, collect very many possible future scenarios described in great detail based on human or animal existence proofs.
- Analyse in depth requirements for achieving those details.
- Order the scenarios, and requirements (by difficulty and by dependence).

What will we gain from doing it?
- More collaboration between currently warring factions.
- More progress, avoiding dead ends
- Better ways of evaluating progress.
Here are some preconditions for progress

• Recognition that we all share a problem: how little our current systems can do, and how wrong most predictions have been.
  Many expert systems, theorem provers, planners, trainable classifiers, evolutionary problem solvers, robot learning mechanisms have proved interesting and useful. But they are ALL narrowly restricted, and PATHETIC compared with a squirrel, a raven, a human 3 year old, even leaf-cutting ants, in their ability to cope with a structured physical environment

• Willingness to try to develop a shared ontology for talking about:
  behaviours, requirements, kinds of competence, kinds of information, kinds of mechanism, kinds of representation, kinds of architecture.... (Not just our favourite ones.)

• Willingness to try to agree on some diagrammatic and notational conventions for presenting types of requirements, types of architectures and other designs.

• Avoidance of questions like ‘is it really X?’ (X=intelligent, conscious, cognitive, emotional): postpone the grand philosophical questions till we have FAR more interesting working systems.

• Willingness to examine theories and data from many disciplines.

• Willingness to teach our students to develop competences using several different approaches, instead of telling them ‘the others have failed’.

• Willingness to reclassify assumed established truths as controversial claims.

See the ‘controversies’ section of the euCognition wiki
A partially ordered network of stages

The process of extending competence is not continuous (like growing taller):

- A child has to learn about
  - distinct new kinds of objects, properties, relations, process structures, e.g. for rigid objects, flexible objects, stretchable objects, liquids, sand, treacle, plasticine, pieces of string, sheets of paper, construction kit components in Lego, Meccano, Tinkertoy, electronic kits...
  - new forms of representation, new kinds of transformations, new constraints on transformations, new applications of previously acquired information.

It is easy to come up with hundreds of significantly different examples of things to be learnt.

- There are not fixed stages: there is no order in which things have to be learnt.
- There are many dependencies but not enough to generate a total ordering – each learner finds routes through several partially ordered graphs.
- What can be learnt varies both from one generation to another and from one location to another.
- Provision of new kinds of playthings based on scientific and technological advances is a major form of communication across generations.
  
  Likewise games, stories, poems, languages, pictures, theories, ...

A collection of research milestones may also have many discontinuities, of different kinds, and will also form a partial ordering.

All this is not required for production of highly specialised robots (like robots in car factories.) Standard engineering approaches are OK for narrow objectives.
Tempting traps to avoid: DON’T:

- **DON’T**: Worry about scaling up
  
  Humans don’t scale up – they scale out. (I.e. combing old competences in new ways.) Machines can beat humans on almost any specific task. But humans can use any competence in combination with others in creative ways.

Examples ....

- **DON’T**: Focus on benchmarks.
  
  If you focus all energy on improving performance on fixed tasks, you’ll (probably) produce something that does not ‘scale out’.

- **DON’T**: Focus on forms of representation whose semantics is purely somatic
  
  i.e. concerned with sensor signals, motor signals and internal states. Much greater power, and animal competence can come from exosomatic ontologies.

  Including the ability to teach, to imitate, to help someone else...

- **DON’T**: Equate perceiving with recognising
  
  Vision enables controlling actions, perceiving structure, understanding how something works, communicating, noticing possibilities and constraints....

- **DON’T**: Ignore the details of your own environment and what you do with it.

- **DON’T**: Search for the BEST representation.
  
  For many problems, perhaps all, different forms of representation are needed for different sub-tasks – e.g. planning vs control of fast actions, vs understanding what went wrong, vs answering questions about what you did.
Don’t waste time developing quantitative measures of progress

Instead specify many intermediate, partially ordered targets, in terms of competences, behaviours, task environments, diversity, etc.

Develop ways of describing shortcomings, partial matches, unwanted side-effects, costs, etc.

Don’t just produce numbers, which typically conceal information on which they are based: instead provide the information about what changes are needed to produce improvements.

Compare the outputs of test suites used when developing complex systems.
How useful would it be if the only output was “65% successful”, rather than detailed results of different tests?
Methods and tools to help build roadmaps

Many people find it very difficult to think up a systematic and comprehensive collection of future scenarios of the kind required. We have been working on a methodology to help with development of this network of roadmaps, using a 3-D ‘Grid of Competences’

Columns represent types of entity to which competences can be applied (e.g. 2-D and 3-D spatial locations, regions, routes, inert objects, mobile objects, objects that have perception, goals and actions, and more abstract entities such as beliefs, proofs, numbers, plans, concepts, questions, problems).

Rows represent types of competence that can be applied to instances of some or all of the types of entities; e.g. competences like perceiving, manipulating, referring to in thought, referring to in language, constructing, dismantling, ....

The third dimension is depth of items in the boxes representing difficulty of the competence.

The degree and kind of difficulty will affect time required to produce working systems.

NOTE:

a more complex topology than a rectangular grid is required: refinements and elaborations of the grid are topics for future research. (For more detail see the introduction to GC5 symposium in proceedings or website http://www.cs.bham.ac.uk/research/cogaff/gc/aisb06/).

For a first draft sample grid see http://www.cs.bham.ac.uk/research/projects/cosy/matrix
The Grid is Over Simple

The grid generates various types of competence applied to various types of entity.

E.g. consider the many kinds of things, of different sizes, shapes, weights, kinds of fragility, that you can grasp in different ways, using two or more fingers, two hands, your mouth, using tweezers, etc., and the subtle and complex requirements for vision in these tasks.

- Combining different subsets of the grid, at different depths, produces scenarios of varying complexity, creating milestones on the long term roadmaps/graph, defining scientific challenges that everyone will agree are hard.
- Progress can be measured by which portions of the graph have been achieved.
- Benchmarks requiring integration of different combinations of competences can be defined by people who disagree on methods and mechanisms.
- The grid is an oversimplification: some boxes need subdivisions, and other boxes will be empty.

You can refer to anything, concrete or abstract, but many things cannot be acted on physically, pointed at, disassembled, etc.

The ability to refer to some things, e.g. macroscopic physical objects, requires simpler conceptual apparatus than the ability to refer to other things, e.g. to transfinite ordinals or to the referring capabilities of symbols.

So finding the grid’s topology is a research goal.
The space of sets of requirements:  
‘niche space’ for biological and non-biological machines

Things researchers and designers need to think about:

- Types of entity
- Types of competence
- Types of combined competence-type PLUS entity-type
- Somatic ontologies: entities and abstractions internal to the individual  
  E.g. multimodal sensorimotor relationships
- Exosomatic ontologies:  
  Entities, processes, relations in the environment, or in other individuals.  
  E.g. inferred properties of materials, hypothesised causal relations.
- Abstraction ontologies:  
  Beliefs, goals, numbers, proofs, plans, theories, ...
- Types of complex competence based on combinations of simpler competences.  
  E.g. seeing or imagining or describing a hippo swallowing a fly.

Recent concerns about embodiment, sensorimotor contingencies, symbol grounding, dynamical systems, situatedness, mainly arise from a consideration of only a subset of the requirements for a human- (or chimp- or crow-) like information-processing machine, namely the subset shared with microbes, insects, fishes, reptiles, etc. using only (or mostly) somatic ontologies.
Meta-level requirements

Often requirements for advanced intelligent systems are specified using labels like ‘robustness’, ‘flexibility’, ‘creativity’, ‘autonomy’.

What do they mean?

In some sense we know what they mean – we can recognize instances and non-instances – but specifying explicitly what we are looking for is hard, partly because what we understand by each term is quite complex.

These are names for meta-requirements — analogous to higher order functions. They need to be given additional information to provide actual requirements.

E.g. a robust lawnmower is different from a robust operating system, or a robust planner.

These meta-requirements are discussed at much greater length in this discussion paper:

http://www.cs.bham.ac.uk/research/projects/cosy/papers/#dp0701
A First Draft Analysis of some Meta-Requirements for Cognitive Systems in Robots (January 2007)
That’s all for now

I could go on much longer.
But neither you nor I have time for this.
I may revise or expand this.

Many thanks to developers of Linux and other free or open-source software packages, that allow me to work the way I want instead of being forced to use interfaces designed by some company aiming to please the maximum numbers of paying customers.

Products of long term, fundamental research should as far as possible be open, freely available, and platform-independent in order to encourage exploration of diverse options.
The benefits of standardisation for products are the death of innovative exploration.