Two Views of Child as Scientist: Humean and Kantian

(we are all children)

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Based on work done with Jackie Chappell concerning animal cognition, work with the CoSy team on requirements for human-like robots, and discussions with Dean Petters about babies.
See http://www.cs.bham.ac.uk/research/projects/cosy/

These slides are available on my 'talks' website and Birmingham CoSy web site:

http://www.cs.bham.ac.uk/research/cogaff/talks/
http://www.cs.bham.ac.uk/research/projects/cosy/

A closely related talk presents a (possibly) new theory of vision
http://www.cs.bham.ac.uk/research/projects/cosy/papers/#pr0505

Prologue: Hume and Kant

Some background to this presentation: an abbreviated approximate history

David Hume was one of the great empiricist philosophers who thought that every concept has to be derived from experience of instances — a mistaken but often re-invented theory recently revived in connection with the label ‘symbol grounding’ criticised in http://www.cs.bham.ac.uk/research/cogaff/talks/#grounding.

He also argued that we do not experience any kind of causal connection apart from co-occurrence or sequential occurrence. So he concluded that ‘causes’ means approximately ‘is regularly correlated with’, since nothing stronger than co-occurrence is ever experienced, though learnt correlations often lead to strong ‘feelings’ of expectation. But we do not experience one thing ‘making’ another happen.
See Hume’s A Treatise of Human Nature and his Enquiry Concerning Human Understanding.

This is now a very popular interpretation of causation, usually elaborated using ideas of Bayesian probability.

Immanuel Kant responded that (a) concept empiricism is false, because in order to have any experiences you need concepts, so they cannot all come from experience, (b) to make sense of our experiences as referring to an external world with properties that we do not directly experience we need a notion of causation as involving necessity not merely correlation, and (c) he thought we had ways of understanding necessity that Hume had not recognised e.g. the ability to discover synthetic necessary truths in mathematics (arithmetic and geometry).

Although the vast majority of thinkers seem to side with Hume rather than with Kant, I think they are all missing some deep facts about human and animal knowledge about the environment, and requirements for intelligent robots. The use of Humean causation may be widespread in many animals but Human intelligence requires something deeper, closer to Kant, involving understanding of structures and structural changes.

This presentation introduces some of the ideas and some of the evidence, though there is still much work to be done showing how the required mechanisms can actually work in brains or in other machines.

The ideas are developed further in a theory of perception presented in
http://www.cs.bham.ac.uk/research/projects/cosy/papers/#pr0505

The Child as Scientist: 1

Yogurt can be food for both mind and body in an 11 month baby.

Video available at

http://www.jonathans.me.uk/josh/movies/josh23_0040.mpg

Hypothesis

Alongside the innate physical sucking reflex for obtaining milk to be digested, decomposed and used all over the body for growth, repair, and energy, there is a genetically determined information-sucking reflex, which seeks out, sucks in, and decomposes information, which is later recombined in many ways, growing the information-processing architecture and many diverse recombinable competences.

HOW ???

There is more discussion of this video in
http://www.cs.bham.ac.uk/research/projects/cosy/papers/#pr0603

The Child as Scientist: 2

- The idea that an infant, or possibly an older child, is like a tiny scientist investigating the world is often reinvented.
- It is obviously false if taken literally, for instance, because there are many conceptual, representational and mathematical tools used by scientists that are not available to a child, not even highly talkative and competent four-year-olds.
- A currently popular view, exemplified by work of Alison Gopnik and colleagues

  online here http://ihd.berkeley.edu/gopnik.htm

  is that young children (or at least their brains!) have the prerequisites for making causal inferences consistent with causal Bayes-net learning algorithms, which deal with conditional probabilities.
- On that view the concept of cause is viewed as concerned with correlations – Humean causation with probabilities replacing universal correlations.
- Another view, implicit in Kant's critique of Hume, points to a deterministic, notion of causation concerned with structures and their interactions. On this view understanding causation is, at least in some cases, akin to proving, or at least understanding, mathematical theorems as in geometry.
- I suggest that the probabilistic/correlational (Humean) kind of causality is what most animals have, but humans and maybe a few others also have something deeper: a Kantian, deterministic, structure-based understanding of causality – the sort that drives deep science. We are mathematicians, not just scientists.

Alison Gopnik's Work

Alison Gopnik

Alison Gopnik and Laura Schulz (2004)
'Mechanisms of theory formation in young children' in *TRENDS in Cognitive Sciences* Vol.8 No.8
http://ihd.berkeley.edu/gopnik_tics.pdf

Their conclusion

> **"Although much more research is necessary .... it seems that infants and young children can detect patterns of conditional probability, understand the nature of their own and others interventions, and to at least some extent, integrate conditional probability and intervention information spontaneously and without reinforcement."**

There are different theses here:

- **Children learn spontaneously (through play and exploration)**
- **To some extent they are like young scientists discovering how things work**
- **Their understanding of causality involves learning conditional probabilities as expressed in Bayesian nets (a topic of much recent research in AI).**

The first two points relate closely to a theory Jackie Chappell and I have been developing (in relation to the biological altricial/precocial distinction).

http://www.cs.bham.ac.uk/research/cogaff/talks/#ijcai-05
http://www.cs.bham.ac.uk/research/cogaff/05.html#200502
http://www.cs.bham.ac.uk/research/cogaff/05.html#200503

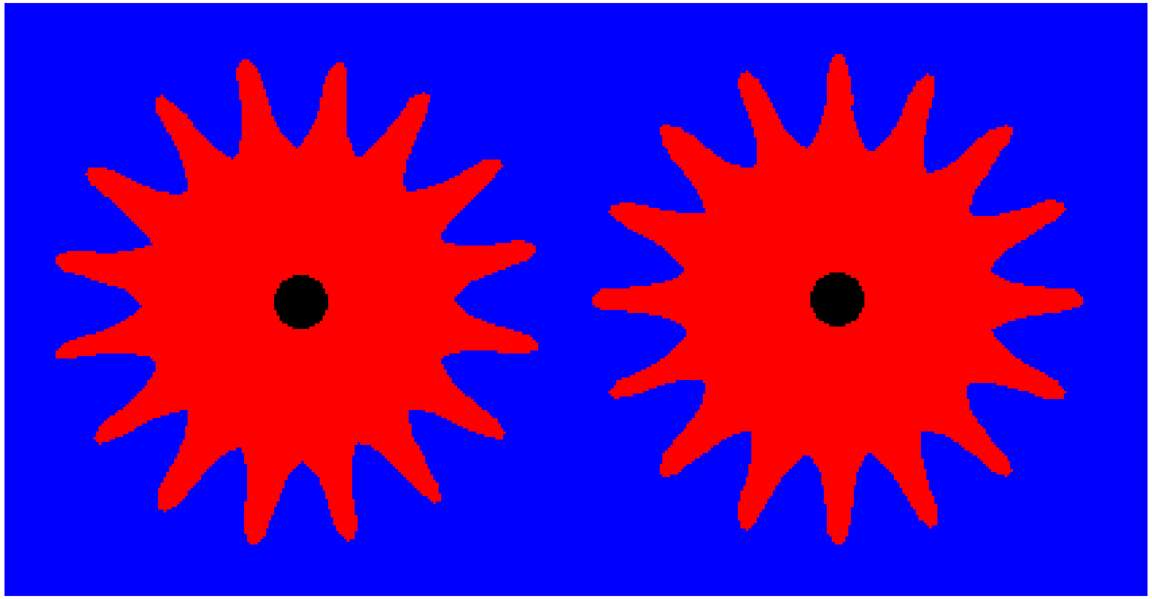
The third point leaves out an important kind of causal understanding, which I think occurs in some altricial species, and which is my main topic: i.e.

Kantian (not Humean) causation.

Kinds of Causation: 1 (Humean)

Two gear wheels attached to a box with hidden contents.

Can you tell by looking what will happen to one wheel if you rotate the other about its central axis?



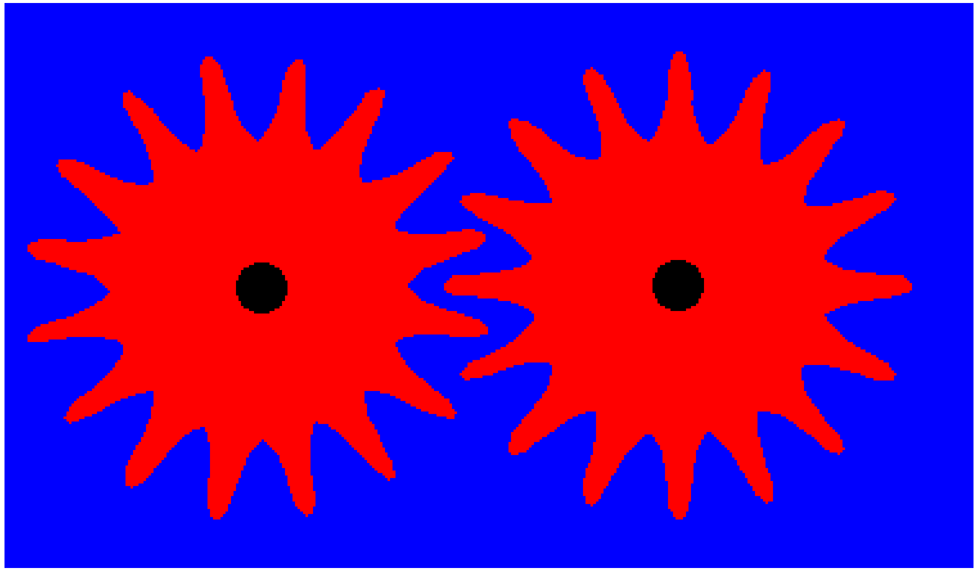
- **You can tell by experimenting: you may or may not discover a correlation – depending on what is inside the box.**
- **In more complex cases there might be a knob or lever on the box, and you might discover that which way the second wheel rotates depends on the position of the knob or lever. (Compare learning about gears in driving a car.)**
- **In still more complex cases there may be various knobs and levers, modifying one another's effects through hidden mechanisms. There could also be motors turning things in different directions, competing through friction devices, so that the fastest one wins.**

Kinds of Causation: 2 (Kantian)

Two more gear wheels:

You (and some children) can tell, by looking, how rotation of one wheel will affect the other.

How? You can simulate rotations and observe the consequences.



What you can see includes this:

As a tooth near the centre of the picture moves up or down it will come into contact with a tooth from the other wheel. If both are rigid and impenetrable, then if the first tooth continues moving, it will push the other in the same direction, causing its wheel to rotate.

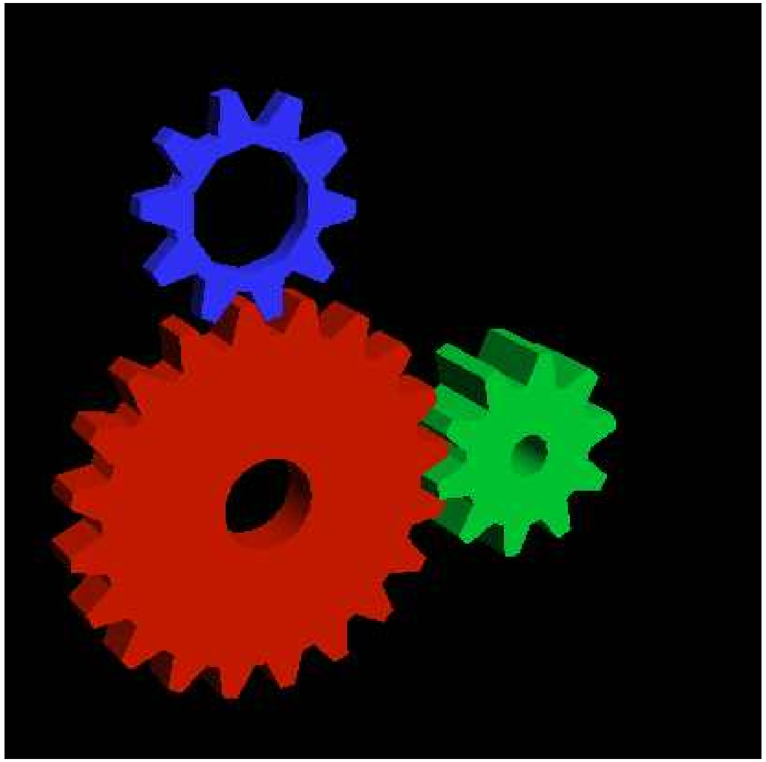
(I am not claiming that children need to reason verbally like this, consciously or unconsciously.)

NB: The simulations that you run can make use of not just perceived shape, but also unperceived constraints: in this case rigidity and impenetrability.

These need to be part of the perceiver's ontology and integrated into the simulations, for the simulation to be deterministic.

The constraints and processes using them need not be conscious, or expressed in linguistic or logical form: how all this works remains to be explained.

MORE GEARS



SHOW THE GLXGEARS DEMO

This is available on many linux systems.

If the central holes have fixed axles through them
and the blue wheel turns clockwise,
what will the others do?
What changes if one of the wheels slides along its axle while the others do not?

Humean and Kantian Causation

- When the only way you can find out what the consequence of an action will be is by trying it out to see what happens, you may acquire knowledge of causation based only on observed correlations.

  This is 'Humean causation' – David Hume said there was nothing more to causation than constant conjunction, and this is now a popular view of causation: causation as probabilistic.

- However if you don't need to find out by trying because you can work out consequences of the structural relations (e.g. by running a simulation that has appropriate constraints built into it) then you are using a different notion of causation: Kantian causation, which is deterministic, structure-based and generative: it supports understanding of novel situations, and designing new actions and machines.

- I claim that as children learn to understand more and more of the world well enough to run deterministic simulations they learn more and more of the Kantian causal structure of the environment.

- Typically in science causation starts off being Humean until we acquire a deep (often mathematical) theory of what is going on: then we use a Kantian concept of causation.

  (At first sight Quantum Mechanics refutes this. But

  (a) the QM wave function is deterministic, and

  (b) a well specified statistical mechanism can also have determinate properties that follow from its structure.)

The ability to do causal reasoning in different domains has to be learnt.

The ability to work out consequences requires learning to build simulations with appropriate structures, appropriate permitted changes, and appropriate constraints.

What is appropriate depends on what is being simulated: simulating the rotation of a rigid gear wheel (e.g. one made of steel) is not the same as simulating the rotation of something soft and malleable, e.g. putty or plasticine.

Appropriate constraints ensure the right counterfactual conditionals are true as the simulation runs.

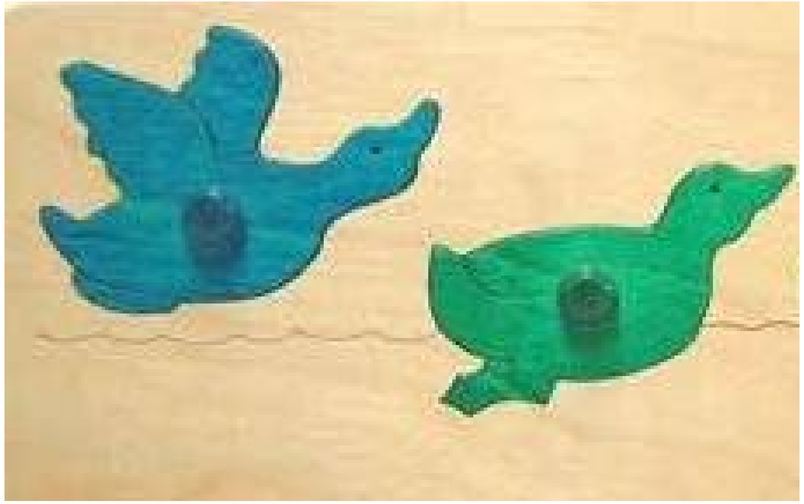
The detailed representational, algorithmic, mechanistic and architectural requirements to support such learning, and the growth of the ontology involved, require much deeper analysis than I can give at present.

Part of the point of the CoSy project is to investigate these issues, especially the requirements for human-like competence, which we need to understand before we can build designs or implementations, though the process of designing and implementing can help the process of understanding requirements.

For more detail on a theory of vision as involving running of simulations see
http://www.cs.bham.ac.uk/research/projects/cosy/papers/#pr0505

We cannot do it all from birth

Causal reasoning adults find easy can be difficult for infants.



A child learns that it can lift a piece out of its recess, and generates a goal to put it back, either because it sees the task being done by others or because of an implicit assumption of reversibility. At first, even when the child has learnt which piece belongs in which recess there is no understanding of the need to line up the boundaries, so there is futile pressing. Later the child may succeed by chance, using nearly random movements, but the probability of success with random movements is very low.

Memorising the position and orientation with great accuracy will allow toddlers to succeed: but there is no evidence that they have sufficiently precise memories or motor control.
Stacking cups compensate for that partly through use of symmetry, partly through sloping sides, so they are much easier.

Eventually a child understands that unless the boundaries are lined up the puzzle piece cannot be inserted. Likewise she learns how to place shaped cups so that one goes inside another or one stacks rigidly on another.

Conjecture: each such change requires the child to extend its ontology for representing objects, states and processes in the environment, and that ontology is used in a mental simulation capability. HOW?

Thanks for the images

‘Dizzy Ducks Toddler jigsaw’ from

http://www.borngifted.co.uk

‘Stack Up Cups’ from

http://www.wwsm.co.uk/toys//products/RC2341.gif

http://www.eden-rc2.com/thefirstyears/pages/product.asp?sec=371&prod=Y2341

A succession of stages

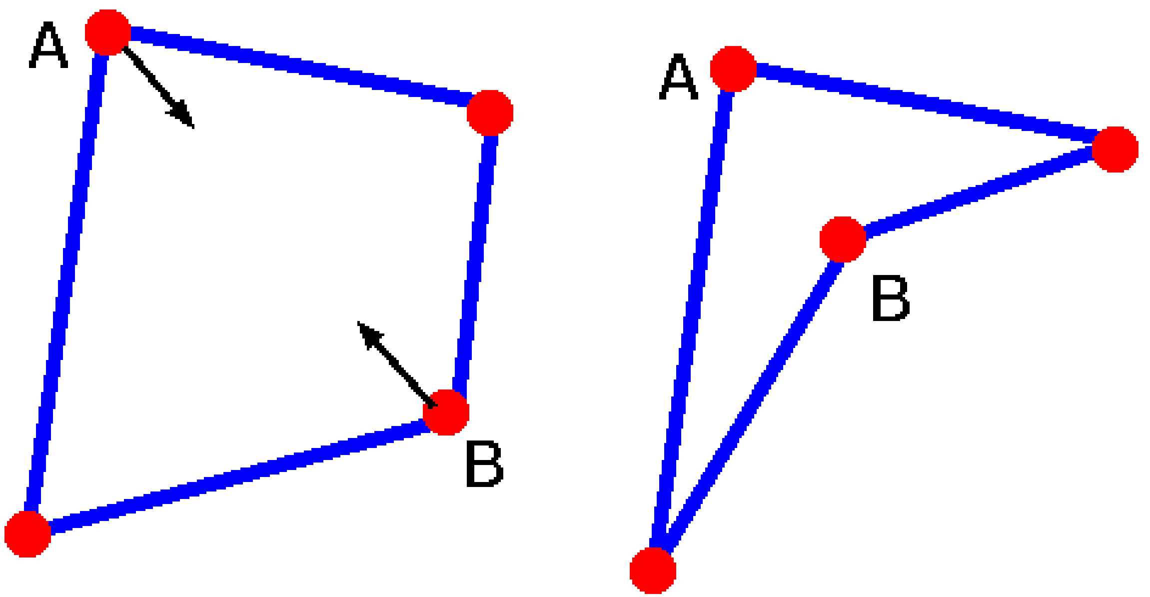
- The process of extending competence is not continuous (like growing taller or stronger):
- The child has to learn about
  - distinct new kinds of objects, properties, relations, process structures, e.g. for rigid objects, flexible objects, stretchable objects, liquids, sand, treacle, plasticine, pieces 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 recent acquisitions.
- The word ‘stage’ can mislead: there is no fixed 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.
- I don’t know how many different things of this sort have to be learnt, but it is easy to come up with hundreds of significantly different examples.
- Things available to be learnt keep changing from one generation to another: provision of new kinds of playthings based on scientific and technological advances is a major form of communication across generations.

  CONJECTURE:

  in the first five years a child learns to run at least least hundreds, possibly thousands, of different sorts of simulations, using different ontologies – with different materials, objects, properties, relationships, constraints, causal interactions – some opaque and Humean others transparent and Kantian.

Simulating motion of rigid, flexibly jointed, rods

A Kantian example: on the left, what happens if joints A and B move together as indicated by the arrows, while everything moves in the same plane? Will the other two joints move together, move apart, stay where they are. ???



- **What happens if one of the moved joints crosses the line joining the other two joints?**
- **This task is harder than the gears task (why?).**
- **We can change the constraints in our simulations: what can happen if the joints and rods are not constrained to remain in the original plane?**
- **What has to develop in a child before such tasks are doable?**

Cloth and Paper: Learning never ends

You have probably learnt many subtle things unconsciously, some as an infant or toddler, some later on, about the different sorts of materials you interact with (e.g. sheets of cloth, paper, cardboard, clingfilm, rubber, plywood).

That includes different ways in which actions can and cannot distort their shape.

Lifting a handkerchief by its corner produces very different results from lifting a sheet of printer paper by its corner – and even if I had ironed the handkerchief first (what a waste of time) it would not have behaved like paper.

Most people cannot simulate the precise behaviours of such materials mentally but we can impose constraints on our simulations that enable us to deduce consequences.

In some cases the differences between paper and cloth will not affect the answer to a question, e.g. in the folding examples, coming later.

Pushing and pulling

As toddlers learn to push, pull and pick things up, they find that some things 'hang together': if you move a part other parts move. But the growing ontology, and mechanisms for representing actions and their perceived effects need to allow for things that hang together in different ways.

If a group of bricks is lying on the floor, pushing a brick on the boundary towards the centre can make the whole group move, whereas pulling it in the opposite direction moves no other brick.

On the other hand if you push the edge of a blanket towards the centre most of the blanket does not move, whereas if you pull the edge away from the centre the blanket follows (in an orderly or disorderly fashion, depending on how you pull, with one or two hands, etc.).

A sheet of paper the same size as the blanket will typically behave differently: pushing and pulling will move the whole sheet, but the effect of pushing will be different from pushing a pile of bricks (in what ways?) and the effect of pulling will be different from pulling the blanket (in what ways?).

What they have in common includes the fact that if a toy is resting on the blanket or sheet of paper, pulling the edge towards you brings the toy closer too, whereas if you pull too fast, or if the toy is on the floor near the far edge, pulling will not have that effect. Why not?

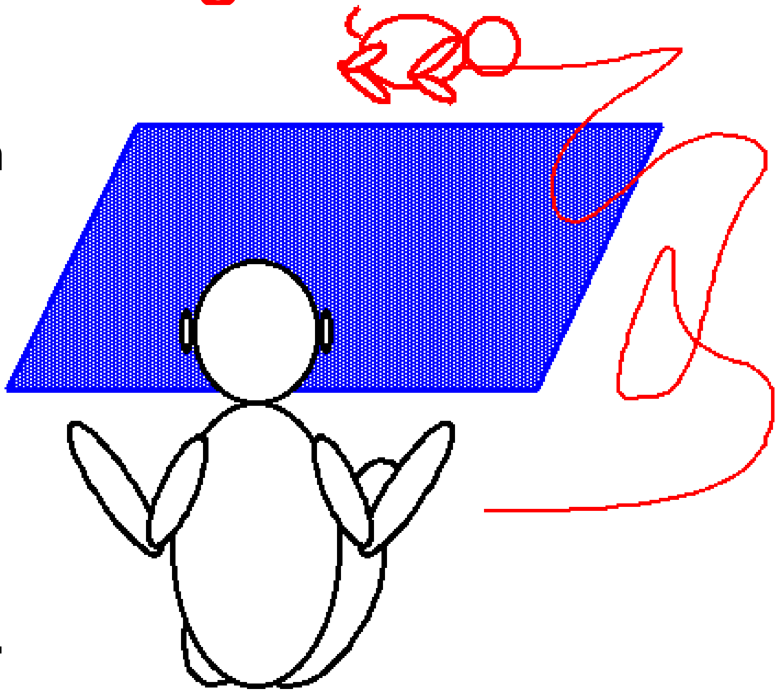
The child's ontology has to allow not only for different kinds of stuff (cloth, wood, paper, string, etc.), but also different ways in which larger wholes can be assembled from smaller parts: which requires a grasp of relations of different kinds, including 'multi-strand relations', and the 'multi-strand processes' that occur during changes in multi-strand relations, as discussed in
http://www.cs.bham.ac.uk/research/projects/cosy/papers/#tr0507

Some of the understanding of causation in such processes may start off Humean (i.e. using only conditional probabilities) and then as the ontology is enriched to include properties like *rigid, flexible, impenetrable, elastic, inextensible,* and these are combined with shape and spatial relations, the understanding can become more Kantian, i.e. structure-based, generative and deterministic, supporting more creative exploration and discovery.

Blanket and String

If a toy is beyond a blanket, but a string attached to the toy is close at hand, a very young child whose understanding of causation involving blanket-pulling is still Humean, may try pulling the blanket to get the toy.

At a later stage the child may either have extended the ontology used in its conditional probabilities, or learnt to simulate the process of moving X when X supports Y, and as a result does not try pulling the blanket to get the toy lying just beyond it, but uses the string.



However the ontology of strings is a bag of worms, even before knots turn up.

Pulling the end of a string connected to the toy towards you will not move the toy if the string is too long: it will merely straighten part of the string.

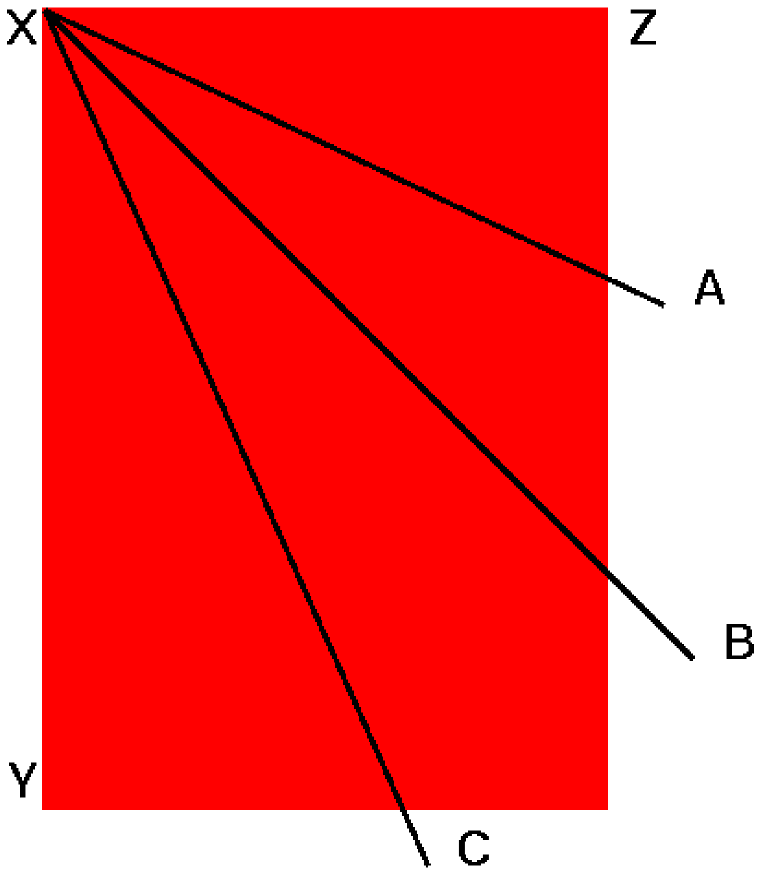
The child needs to learn the requirement to produce a straight portion of string between the toy and the place where the string is grasped, so that the fact that string is inextensible can be used to move its far end by moving its near end (by pulling, though not by pushing).

Try analysing the different strategies that the child may learn to cope with a long string, and the perceptual, ontological and representational requirements for learning them.

Example: simulating folding of a sheet of paper

You can easily imagine folding a piece of red paper (i.e. ordinary paper, not a stretchy sheet of rubber).

What will happen to the corner Z if the sheet is folded along one of the lines A, B, and C, while portion of the sheet to the left of the fold line remains flat on the table.



Will the corner Z end up inside the red rectangle, outside it or on the edge of it?

You can probably think about this in several different ways (especially if you are a mathematician).

Some ways of thinking about it involve simulating the process of folding.

Others involve visualising or reasoning about where the moved edges will end up.

A very young child cannot do this, but eventually many (in our culture) will learn to think about folding of paper, and to see the effects of folds as determined by the structure, the nature of the material (paper) and the folding process.

Other simulations use different constraints. If a cloth sheet is constrained to be flat and unstretched after the fold the same predictions will apply to it as to paper.

Visual reasoning about something unseen

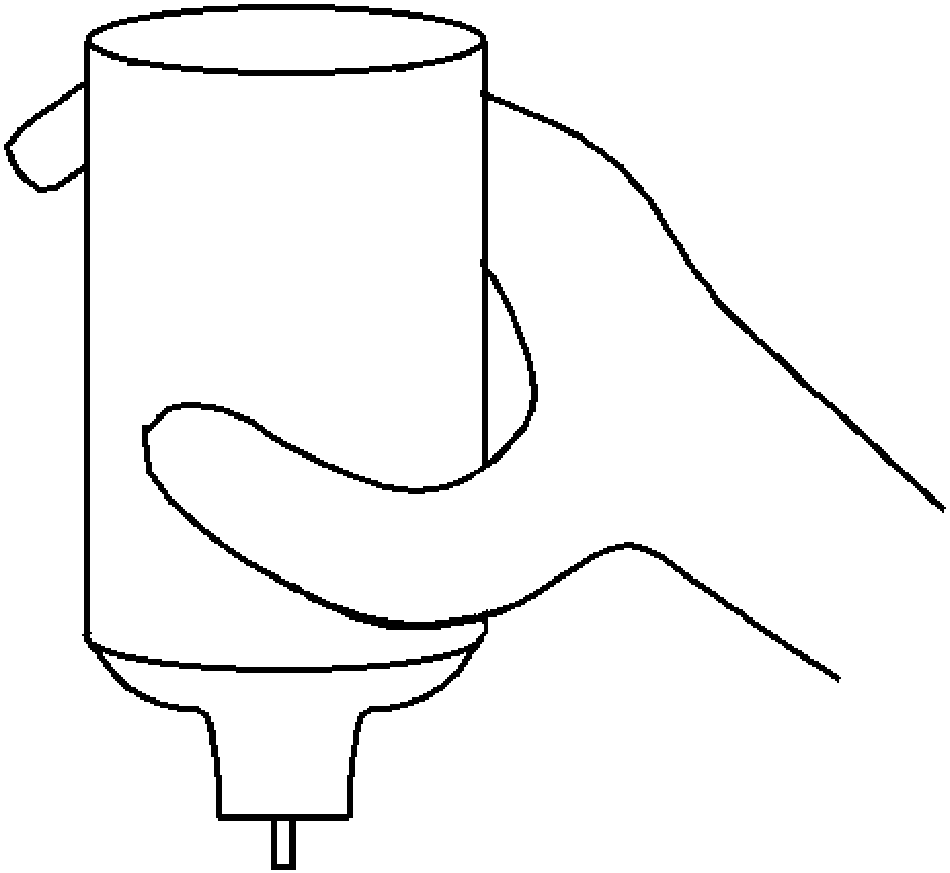
If you turn the plastic shampoo container upside down to get shampoo out, why is it often better to wait before you squeeze?

In causal reasoning we often use runnable models that go beyond the sensory information: sometimes part of what is simulated cannot be seen –

a Kantian causal learner will constantly seek such models, as opposed to Humean (statistical) causal learners, who merely seek correlations.

Note that the model used here assumes uncompressability rather than rigidity.

Also, our ability to simulate what is going on can also explain why as more of the shampoo is used up you have to wait longer before squeezing.



Biological bootstrapping mechanisms

- There are some species whose needs cannot be served by genetically determined (preconfigured) competences (using pre-designed architectures, forms of representation, ontologies, mechanisms, and stores of information about how to act so as to meet biological needs)

  why not?

- Evolution seems to have 'discovered' that it is possible instead to provide a powerful meta-level bootstrapping mechanism for 'meta-configured' species:
  - a mechanism without specific information about things that exist in the environment (apart from very general features such as that it includes spatio-temporal structures and processes, causal connections, and opportunities to act and learn, and that the neonate has a body that is immersed in that environment)
  - but with specific information about things to try doing, things to observe things to store
  - and with specific information about how to combine the things done and records of things perceived into ever larger and more complex reusable structures,
  - sometimes extending its own architecture in the process (e.g. in order to cope with a substantial extension to its ontology)
  - And including a continually extendable ability to run simulations that can be used for planning, predicting and reasoning.

So there are preconfigured and metaconfigured species, or, to be precise species with different mixtures of preconfigured and metaconfigured competences.

Empiricism and Biology

- Empiricists tend to dislike Kantian theories – or more generally theories about ‘innate’ knowledge or innate cognitive competence.
- But that may be because they don’t know enough biology.
- The vast majority of biological species have most (and in many cases all) of their cognitive competences pre-programmed innately (e.g. precocial species such as chickens, deer, reptiles, fish and most non-vertebrates).
- E.g. chicks can walk around and peck for food soon after hatching and some deer can run with the herd very soon after birth.
- Many of those can also learn using adaptive mechanisms that produce relatively slow kinds of learning based on the statistics of their interactions with the environment (e.g. reinforcement learning)
- But for some species (e.g. corvids, hunting mammals, primates) that was not adequate – and evolution found an alternative strategy, better suited for neonates starting off in very varied environments, or which require complex cognitive skills in adult life that cannot be provided in the genome (e.g. because there is not enough evolutionary time or opportunity to learn).
- In both sorts of species there is genetically determined competence: but one has content determined and the other has information and mechanisms for acquiring content pre-determined: the outcomes are very different.

Biological Nativism: Altricial/Precocial tradeoffs

- **Evolution 'discovered' that for certain species which need to adapt relatively quickly to changing environmental pressures and which perform cognitively demanding tasks as adults, a kind of Kantian learning mechanism is possible that allows much faster and richer learning than is possible in systems that merely adjust probabilities on the basis of observed evidence (statistical data).**
- **The latter species, with more or less sophisticated forms of the Kantian mechanism, learn a great deal about the environment after birth and and in some cases are able rapidly to develop capabilities none of their ancestors had (like young children playing with computer games).**
- **We conjecture that this uses an information-processing architecture which starts off with a collection of primitive perceptual and action competences, and also with a mechanism for extending those competences by 'syntactic' composition, as a result of play and exploration, which is done for its own sake, not to meet other biological needs (food, protection from hurt, warmth, etc.)**
- **The meta-level features of the mechanism and the initial competences are genetically determined, but the kinds of composite competences that are built are largely a function of the environment.**
- **This requires forms of learning that are not simply adjustments of probabilities, but involve continual creation of new useful structures.**

Terminological problem

- The labels ‘altricial’ and ‘precocial’ are used by biologists with a rather narrow meaning, relating to state at birth.
- We are talking about patterns of cognitive development that seem to be correlated with those differences at birth.

  Insects, fish, reptiles, grazing mammals, chickens, are precocial (born/hatched physiologically developed and behaviourally competent),

  whereas

  hunting mammals, primates, crows, humans are altricial (born/hatched underdeveloped and incompetent), but achieve deeper and broader cognitive competence as adults, with more rapid and creative learning.

- We need new terminology for the cognitive differences.

  Perhaps a distinction between

  – preconfigured (relatively rigid) cognitive development

  and

  – non-preconfigured (relatively flexible and fast path-building?) cognitive development using metaconfigured capabilities.

  However, organisms with the latter may also include many preconfigured competences e.g. some ‘waiting’ for puberty in humans.

HYPOTHESIS

- **In nature, fluid, flexible, metaconfigured, cognitive development (using particular sorts of architectures, mechanisms and forms of representation), is generally found only in species that biologists call ‘altricial’ – i.e. born/hatched under-developed and cognitively incompetent**

  However, (a) the converse does not follow, and (b) the link is contingent:

  Are elephants exceptions?

- **This underdevelopment and incompetence at birth may not be necessarily a feature of metaconfigured artificial systems with flexible cognitive development – perhaps some machines, or animals on some other planet, can be ‘born’ fully formed and fairly competent as well as possessing the competence to learn qualitatively new things by other means than slow statistics gathering.**

- **Nevertheless there may be design features that are required by both artificial and natural rapid and flexible learners, capable of spontaneously developing new ontologies and new combinations of old competences – e.g. if brain development has to be staggered or ‘cascaded’, then at birth infants are more likely to be incompetent.**

- **We need to understand the design principles if we wish to develop machines capable of human-like understanding of the environment and rapid, flexible cognitive development.**

- **There can different competences in the same animal or robot – some more rigid (precocial, genetically determined) some more flexible (derived creatively from exploration and play).**

- **We need to understand relations between environmental and task constraints that favour different combinations of pre-configured and metaconfigured development.**

KEY IDEA

In addition to physical growth –

biological organisms also grow their own

information-processing architectures

(which are virtual machines, not physical machines,

and therefore can change their structure more radically.)

There are probably many more ways this can happen in nature or in machines than we have thought of.

Summary so far:

There is an important sub-class of animals in which competences are not all pre-configured, whose development makes use of:

- **Genetically determined actions, perceptual capabilities and representations,**
- **Genetically determined play/exploration mechanisms driving learning which extends those actions, etc., using abilities to chunk, recombine and store**
  - **new more complex action fragments**
  - **new more complex perceptual structures,**
  - **new more complex goals,**
- **Creating new ontologies, theories, competences (cognitive and behavioural),**
  - **i.e. new more complex thinking resources,**
- **Thereby extending abilities to search in a space built on larger chunks: solving ever more complex problems quickly.**
  - **(unlike most statistical forms of learning)**
- **Humans are able to apply this mechanism to itself – producing new forms of self-awareness and new forms of self-understanding, including mathematical knowledge.**

For AI systems this will require us to discover new architectures and learning mechanisms.

Two ‘altricial’ species and a pointer to a third

- **Movie: Betty, the hook-making New Caledonian crow.**

  http://news.bbc.co.uk/1/hi/sci/tech/2178920.stm

  or give to google three words: betty crow hook

- **Movie: An infant (11.5 month) yogurt-manipulator experimenting with a bit of his world made up of spoon, hands, thighs, mouth, carpet, yogurt, tub — detecting interesting happenings and trying to understand and replicate/modify them.**

  http://www.cs.bham.ac.uk/ axs/fig/yog-small.mpg

  Like Betty he later tried to learn about hooks, but went through a stage of not understanding, shown here

  http://www.jonathans.me.uk/josh/movies/josh34_0096.mpg

  (We need many more videos of such infant exploratory play to study – in humans and other animals.)

- **The key ideas are quite old – e.g. Piaget.**

- **Compare Oliver Selfridge’s program that learns to ‘count’**

  Reimplemented in Pop11 http://www.cs.bham.ac.uk/research/poplog/teach/finger
  (describes Pop-11 program written over 20 years ago on the basis of an idea described to me by Oliver Selfridge.)
  See:

  O. G. Selfridge, “The Gardens of Learning”, *AI Magazine* 14(2) (1993) 36*48
  http://aaai.org/Papers/Magazine/Vol14/14-02/AIMag14-02-005.pdf

  Partly like Case-based or Explanation-based learning.

Selfridge's metaconfigured Finger/Count program

RUNNING THE POP11 VERSION.

```
Initial state
Counter: 20
             v
    [] [] [] [] [] [] []
  0 1  2  3  4  5  6  7
```

There is a 'finger' adjacent to a row of blocks. It has two actions

- **goright**
- **goleft**

and a 'counter' that has two actions

- **increment**
- **decrement**

Actions can be composed in various ways

- **in sequences**
- **loops**

Loops terminate when either the finger or the counter hits a 'boundary'.

Example snapshots of the program working

```
Initial state
Counter: 20

            v
    [] [] [] [] [] [] []
  0 1  2  3  4  5  6  7
```

The program asks for a goal state and I type in '1 1'.

```
Target finger position and target counter value? 1 1
```

It then searches for a combination of moves that will produce a state with both counter and finger registering 1 — but it fails.

```
.............................................................
.............................................................
I give up on this one
```

Each dot represents a tested combination of actions.
It gives up after trying 120 different systematically varied actions.

After carefully selected training examples

Because successful chunks are stored as new action units, the set of available 'basic actions' increases:

```
(1) [goright increment]
(2) [[repeat goleft] [repeat decrement]]
(3) goleft
(4) goright
(5) increment
(6) decrement
```

After a few example tasks it gets to this collection:

```
(1) [[repeat goleft] [repeat decrement] [repeat [goright increment]]]
(2) [goright increment]
(3) [[repeat goleft] [repeat decrement]]
(4) goleft
(5) goright
(6) increment
(7) decrement
```

Now it can always solve the 'counting' problem

No matter what the starting configuration, if given the 'count blocks' goal (same target number for finger and counter),

it always solves the problem using only one stored action.

E.g. I give it the goal 17 17 in this configuration

```
Counter: 20
                                               v
    [] [] [] [] [] [] [] [] [] [] [] [] [] [] [] [] []
  0 1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17

Target finger position and target counter value? 17 17
.
Plan was: [[repeat goleft] [repeat decrement] [repeat [goright increment]]]
```

A single complex action reliably solves the problem which previously was found too difficult.

The program was not (like precocial animals) pre-configured with the ability to solve this class of problems. But it was metaconfigured with the ability to configure itself to solve such problems, given a carefully selected training sequence ('scaffolding' by the teacher).

Conjecture

We conjecture that rapid learning in altricial species depends on similar mechanisms, where the metaconfigured learner spontaneously attempts things without requiring a teacher.

This depends crucially on discretisation (chunking) of continuous domains, to provide ontological and representational units that are capable of being combined in ever more complex discrete structures.

> **Learn the easy things first, and some hard things become easy.**
> **It is nearly impossible to learn anything that is hard to learn.**
> **Oliver Selfridge: AI Magazine**
> **The Gardens of Learning: A Vision for AI**
> **14(2): Summer 1993, 36-48**

Limitations of the ‘Finger’ program

The program is obviously very limited

- very simple actions
- very simple kinds of perception
- no conditionals
- no parameters
- only very simple loop terminations
- very restricted kinds of goals
- it is essentially passive: goals must come from outside
- very simple ‘environment’ – e.g. no 3-D rotatable structures
- very restricted ways of composing actions
- no parallelism
- very few actions: and no neeed for action-selection mechanisms

All of these limitations could be removed in more complex programs.

Some requirements for extending the theory

Expanding this sort of mechanism to account for 'altricial' (flexible, creative, constructive, metaconfigured path-makers) will not be easy.

- **It requires a host of specialised (probably genetically determined) mechanisms including mechanisms generating playful exploratory behaviour**
- **It needs recursive (?) syntactic competence and meta-semantic competence.**

  Meta-semantic competence is needed in mechanisms that can represent systems which themselves have representational capabilities – in the same agent or in others

- **Some of the required elements seem to exist in AI developments of the last 40 years (many of them forgotten and not taught to students alas).**

  E.g. Sussman's HACKER program (MIT, circa 1973?), and various kinds of symbolic learning mechanisms, including concept learning, rule learning, mechanisms (e.g. Explanation-based learning), as well as the more statistical mechanisms that now get most attention.

- **The bootstrapping process needs**

  precocial (pre-configured) meta-level capabilities

A spectrum of competences

- **Every organism is a mixture of both kinds of capabilities:**

  pre-configured — constructed

- **Not all of the first kind are manifested at birth/hatching – many are ‘time-bombs’.**
- **Architectures for altricial species can do many things that are not directly biologically useful:**

  including (possibly dangerous) exploration of a space of possibilities.

- **Architectures can change over time.**
- **Altricial architectures are virtual machines that grow themselves.**

  But we have over-simple ideas about how: e.g. the notion of a knowledge-free, general-purpose learning system is current favourite, but inadequate mechanism.

See our (Sloman & Chappell) IJCAI paper
http://www.cs.bham.ac.uk/research/cogaff/05.html#200502

and the H-CogAff architecture described on the Cognition and Affect web site:
http://www.cs.bham.ac.uk/research/cogaff/

Implications for theories of meaning

The existence of precocial species refutes 'symbol-grounding' theory

(Otherwise known as '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

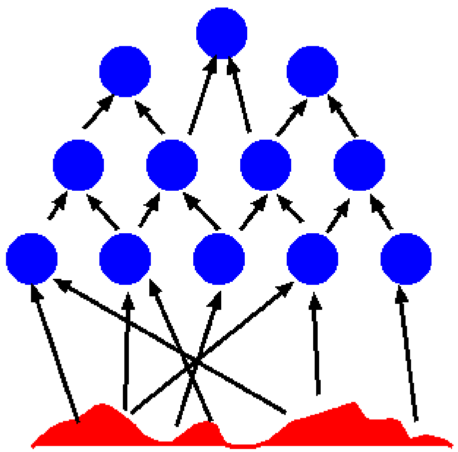
- **the structure of a theory in which 'undefined terms' occur**

  (where the structure limits the class of possible models/interpretations)

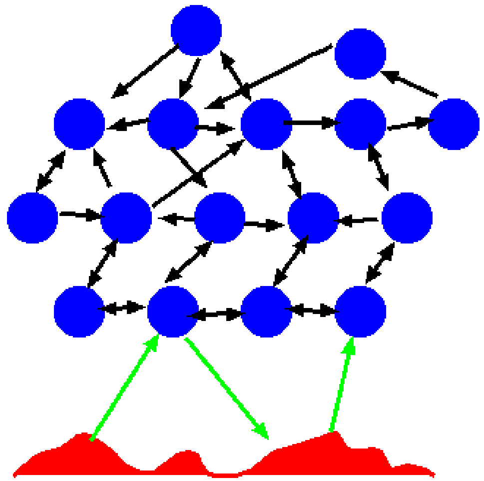
- **links to sensing and acting**

  (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 scientific theories get their meaning, so why not toddler theories?



Symbol Grounding



Symbol Tethering

How do you ‘tell by looking’?

The examples of understanding (Kantian) deterministic causation in gears, links, shampoo containers, etc. presupposed that we sometimes can understand propagation of changes through changing structural relationships.

How it is done is far from clear, and it is far from clear how to implement such things in artificial systems.

The answer may be closely related to a theory of visual perception, according to which seeing involves running a collection of simulations at different levels of abstraction, partly, but not entirely, driven by the visual data.

Summary available here:
http://www.cs.bham.ac.uk/research/projects/cosy/papers/#pr0505

- **The simulation that you do makes use of not just perceived shape, but also unperceived constraints: rigidity and impenetrability.**
- **These need to be part of the perceiver’s ontology and integrated into the simulations, for the simulation to be deterministic.**

KANT'S EXAMPLE: 7 + 5 = 12

Kant claimed that learning that 7 + 5 = 12 involved acquiring *synthetic* (i.e. not just definitionally true) information that was also not *empirical*. I think his idea was based on something like this simulation theory.

It is obvious that the equivalence below is preserved if you spatially rearrange the blobs within their groups:

```
ooo          o       oooo
ooo   +      o   =   oooo
o          ooo       oooo
```

Or is it?
How can it be obvious?
Can you *see* such a general fact?
How?

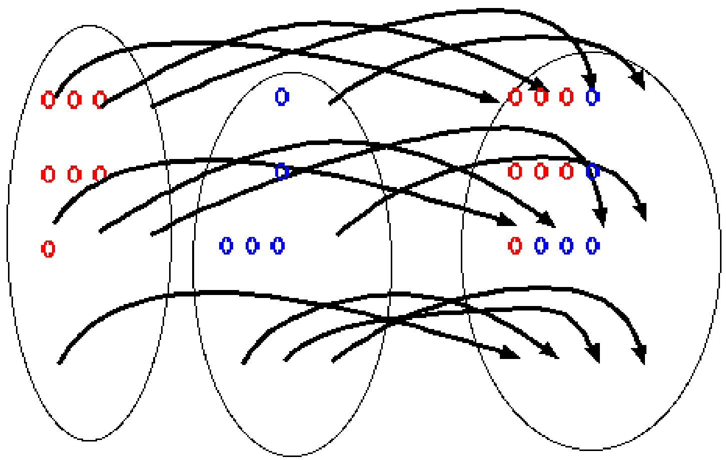
What sort of equivalence are we talking about?

I.e. what does "=" mean here?

Obviously we have to grasp the notion of a "one to one mapping".

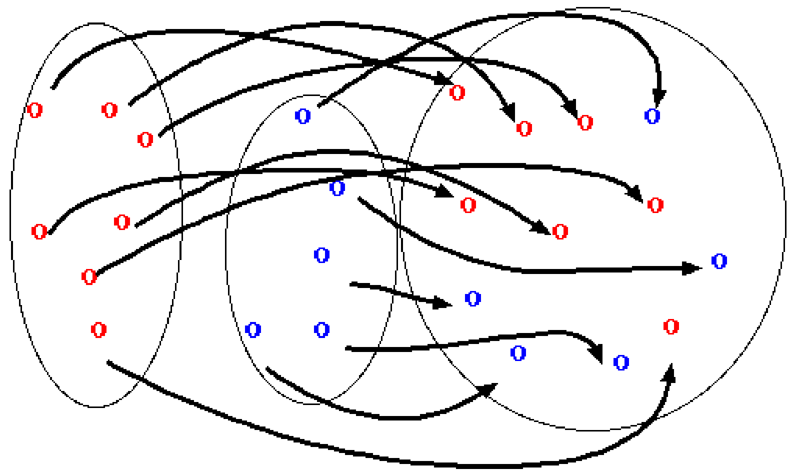
That can be defined logically, but the idea can also be understood by people who do not yet grasp the logical apparatus required to define the notion of a bijection.

SEEING that 7 + 5 = 12



Join up corresponding items with imaginary strings.

Then rearrange the items, leaving the strings attached.



Is it 'obvious' that the correspondence defined by the strings will be preserved even if the strings get tangled by the rearrangement?

Is it ‘obvious’ that the same mode of reasoning will also work for other additions, e.g.

777 + 555 = 1332

Humans seem to have a ‘meta-level’ capability that enables us to understand why the answer is ‘yes’. This depends on having a model of how our model works.

But that’s a topic for another occasion.

Different kinds of learning

- I’ve made it sound as if some kinds of learning, such as learning about structure-based causation, or about mathematics, happen only in one way,
- However there are many things that are learnt by thinking explicitly, using something like the mechanism I have been describing (and probably others), after which that competence is used repeatedly in such a way that another part of the system, a ‘reactive’ layer gets trained to do the same task by going automatically from task or problem to solution, using a stored association, instead of working out the required behaviour.
- This can allow tasks using highly trained subsystems to run in parallel, while the deliberative structure-manipulating creative learning subsystem does something else.
- There are many examples, some physical (e.g. learning to play musical scales at high speed or learning to ride a bicycle or drive a car), and some mental, such as finding out numerical facts and then memorising them so that they are instantly available.
- Much learning of language seems to have the two strands: structure based explicit and relatively slow on the one hand and fast and fluent on the other.

  The latter fools some researchers into thinking it’s all statistical.

- Thus we should never ask ‘How do humans do X?’, for there may be many different ways humans do X (walk, talk, sing, plan, see, think, learn ....).

additional points

- We need to find out how many different kinds of simulative capabilities a child, a chimp, a nest-building bird, a domestic robot, needs to acquire.
- We need to understand what sorts of forms of representation, mechanisms and architectures, can produce those developments.
- The process can involve creation of new ontologies and new forms of representation.
- There will not be a simple step: understanding causation
- Many different kinds of cognitive competence relevant to understanding different kinds of structures and processes grow during our life time.
- Different people grow different subsets (why?)
- Scientific research is just an extension of this – though too many scientists restrict their research to accumulation of correlations (like learning in precocial species?).
- When the ability we are discussing is applied to itself we get activities like mathematics and philosophy.

Conclusion

- I have been emphasizing the growth of understanding of the environment as based on a Kantian notion of causation – but only for some altricial species.
- This accounts for many of the most distinctive features of human life – and many causes of death also, when we act on incomplete or erroneous theories.
- However I am not claiming that all or even most of our information about causation is based on explanatory knowledge about the underlying structures.
- In particular, most of what a child learns about itself is Humean, including how to control its movements, then later much of how its mind works.
- Much self-knowledge, about body and mind, is incomplete, and liable to error.
- Alongside growth of insight into how physical things work a child also gradually bootstraps theories about how minds work, its own and others – child science includes psychology as well as mechanics and physics.

  Both can produce errors (including religion and superstition) that persist in adult life. The errors will depend on how good the genetically determined and subsequently developed learning mechanisms are – and how far the understanding and teaching of science and engineering have progressed in the culture.

'Know thyself' Socrates is reputed to have said.
But understanding what is probably the most complex machine on earth, including many coexisting, interacting virtual machines within it, is easier said than done.

See also: http://www.cs.bham.ac.uk/research/cogaff/talks/