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Aaron Sloman Draws Together

VIRTUAL MACHINERY AND EVOLUTION OF MIND (PART 2)*

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1 Introduction

Darwin's critics could not understand how natural selection could produce minds and consciousness. They (and even some of his defenders) pointed out that his evidence, such as gradual changes in animal forms, supported only the hypothesis that natural selection produces *physical* forms and behaviours. Nobody could understand how physical mechanisms can produce mysterious and externally unobservable mental states and processes, referred to by Huxley as 'The explanatory gap'.[1] Since Darwin's time, the problem has been re-invented and re-labelled several times, e.g. as the problem of 'Phenomenal Consciousness' (Block, 1995) or the 'Hard Problem' of consciousness (Chalmers, 1996). The topic was touched on and side-stepped in (Turing, 1950). It remains unclear how a genome can, as a result of physical and chemical processes, produce the problematic, apparently non-physical, externally unobservable, personal experiences (qualia) and processes of thinking, feeling, wanting, and artistic, mathematical or scientific creation.

The facts about virtual machinery used in complex computing systems, presented in Part 1, suggest ways in which biological evolution may have taken advantage of virtual machines to produce self-monitoring, self-modifying, self-extending information-processing architectures, some of whose contents would have the core features of qualia, including non-definability in the language of physics. This suggests a way for Darwin to answer the criticism that natural selection can produce only physical development, not mental states and consciousness, though this type of explanation was not available in Darwin's time. On the basis of what we have learnt recently, we can now conjecture that evolution produced 'mysterious' aspects of consciousness if, like engineers in the last six or seven decades, it produced solutions to increasingly complex problems of representation and control – solutions based on increasingly abstract, but effective, mechanisms, including self-observation capabilities, implemented in non-physical virtual machines which, in turn, are implemented in lower level physical

*This is the second of three linked papers in this Volume. Part 1 is in Part I of the volume. The final part, Part 3, on Meta-Morphogenesis, is in Part IV of the volume.

[1]For more detail and quotations from critics, see (Sloman, 2010a).

mechanisms. For this, evolution would have had to produce far more complex virtual machines than human engineers have so far managed, but the key idea might be the same.[2]

Part 1 presented Universal Turing Machines as theoretical precursors of technology supporting networks of interacting running virtual machines (RVMs) sensing and controlling things in their environment. Such RVMs are *fully implemented* in underlying physical machines (PMs) but the concepts used to describe the states and processes in some RVMs (e.g. 'pawn', 'threat' and 'win' in chess VMs) are not *definable* in the language of the physical sciences. We now develop the biological versions of these ideas, potentially explaining how self-monitoring, self-modifying RVMs can include some of the features of consciousness, such as qualia, previously thought by some to be inexplicable by science, paving the way for a theory of how mind and consciousness might have evolved, and how robots might have qualia. Unlike capabilities of earlier machinery, there is no close relationship between information processing capabilities and physical form or behaviour.

2 Epigenesis: bodies, behaviours, and minds

Turing was interested in both evolution and epigenesis and made pioneering suggestions regarding the processes of morphogenesis – differentiation of cells to form diverse body parts during development. As far as I know, he did not do any work on how a genome can produce *behavioural competences* of the complete organism, including behaviours with complex conditional structures, so that what is done depends on internal and external sensory information, though he briefly considered learning, in (Turing, 1950).[3]

It is understandable that physical behaviours, such as hunting, eating, escaping predators, and mating, should influence biological fitness and that evolution should select brain and other modifications that produce advantageous behaviours. But there are *internal* non-behavioural competences whose biological uses are not so obvious: thinking, reminiscing, perceiving with enjoyment, finding something puzzling and attempting to understand it. It is not obvious how biological evolution could produce mechanisms that are able to support such mental processes. Though it is clear that once such mechanisms were produced, some of them might enhance biological fitness.

Many species develop behavioural and internal competences that depend on the environment during development (e.g. which language a child speaks, and which mathematical problems are understood), so the genome-driven processes must create some innately specified competences partly under the influence of the genome and partly under the influence of combinations of sensorimotor signals during development (Held & Hein, 1963; McCarthy, 2008). For humans at least, the internal processes of competence-formation go on long after birth, suggesting that the genome continues producing, or enabling, or constraining effects (including changes in sexual and parental motivations and behaviours) long after the main body morphology and sensory-motor mechanisms have developed.

(Karmiloff-Smith, 1992) presents many examples where *after* achieving behavioural competence in some domain, learners (including some non-human species) re-organise their

[2] It is not yet clear whether the biological virtual machinery can implemented in the kind of discrete technology used in computers as we know them. New kinds of computers may be required.

[3] In 'The Mythical Turing Test' in Part III of this volume Turing's suggestion about learning on the basis of a blank slate at birth is criticised, and compared with McCarthy's ideas.

understanding of the domain in such a way as to give them new abilities to think and communicate about the domain. After children develop linguistic competences based on known phrases they spontaneously switch to using a *generative* syntax that allows *derivation* of solutions to novel problems, instead of having to learn empirically what does and does not work. (Craik, 1943) pointed out the value of such mechanisms in 1943, suggesting that they could be based on working mental models.[4] (Grush, 2004) and others suggest that such models could work as simulations or emulations. However, when used for reasoning purposes, as opposed to statistical prediction, a decomposable information structure is required rather than a fixed executable model, for instance when proving geometrical theorems.

The mental models we use to explain, predict and produce processes in our environment include models of things like gear wheels, bicycles, electric circuits and other mechanisms that are too new to have been part of our evolutionary history. So, at least in humans, the model construction process cannot all be encoded in the genome: the specific models need information obtained after birth from the environment, along with novel ideas thought up by the individual.

So, the genome specifies not only physical morphology and physical behavioural competences, but also a multi-functional information-processing architecture developed partly in species-specific ways, at various stages after the individual's birth, partly under the control of features of the environment, and includes not only mechanisms for interpreting sensory information and mechanisms for controlling external movements, but also mechanisms for building and running predictive and explanatory models of structures and processes, either found in the environment or invented by the individual.[5] How can a genome specify ongoing construction processes to achieve that functionality? I don't think anyone is close to an answer, but I'll offer a conjecture about a feature of the process: evolution "discovered" the virtues of virtual machinery long before human engineers.

Part 1 of this series of papers outlined the benefits of virtual machinery in human-designed computing systems, and their advantages compared with specifying, designing, monitoring, controlling and debugging the *physical* machinery directly, The advantages come from the coarser granularity, the use of abstraction allowing different implementations to be compared, and the use of application-relevant semantics.

Perhaps a series of initially random changes during reproduction of organisms decoupled the control mechanisms from the physical sensors and effectors, allowing more flexibility in subsequent deployment, eventually leading to use of virtual machinery in animals because of its advantages for specifying types of competence at a relatively abstract level, avoiding the horrendous complexity of specifying all the physical and chemical details, and allowing construction of behaviour specifications of greater generality. The initial specification of behavioural competences in the genome might be far more compact and simpler to construct or evolve if a virtual machine specification is used, provided that other mechanisms ensure

[4] I have not been able to find out whether Craik and Turing ever interacted. Turing must have known about his work, since he was a member of the Ratio club, founded in honour of Craik, shortly after he died in a road accident in 1945.

[5] It is argued in (Sloman, 1979, 2008) that this requires types of 'language' (in a generalised sense of the word, including structural variability and compositional semantics) that evolved, and in young humans develop, initially for *internal* information-processing, not for external communication. We can call these 'generalised languages' (GLs).

that that ‘high level language’ is mapped onto physical machinery in an appropriate way. The use of self-monitoring processes required for learning and modifying competences, including de-bugging them, may be totally intractable if the operations of atoms, molecules or even individual neurones are monitored and modified, but more tractable if the monitoring happens at the level of a RVM.

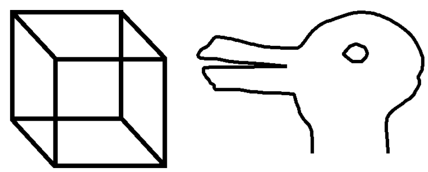
So something like a compiler is required for the basic epigenetic processes creating common features across a design, including physical forms, and something more like an interpreter to drive subsequent processes of learning and development.

3 The evolution of organisms with qualia

Part 1 showed that virtual machinery can be implemented in physical machinery, and events in virtual machines can be causally connected with other VM events and also with physical events both within the supporting machine and in the environment, as a result of use of complex mixtures of technology for creating and maintaining virtual/physical causal relationships developed over the last seven decades. The use of virtual machinery enormously simplifies the design, debugging, maintenance and development of complex systems. Finally, and perhaps most importantly, in machines that need to monitor and modify *their own* operations, performing the monitoring and modifications at the level of virtual machinery can be tractable where the corresponding tasks would he intractably complex and too inflexible and slow, if done by monitoring and modifying physical machinery.

So, biological evolution could have gained in power, flexibility, and speed of development by using virtual machine descriptions in the genome for specifying behavioural competences, instead of descriptions of the physical details. Moreover, if some of the virtual machinery is not fully specified in the genome, and has to be developed after birth or hatching by making use of new information gained by the individual from the environment, then that post-natal construction process will be simpler to specify, control and modulate, and easier to change as needed, if done at the virtual machine level rather than specifying all the chemical and neuronal changes required. And finally self-monitoring, self-control and self-modification in a sophisticated information-processing system all need to control virtual not physical, machinery.

An organism can perceive, think about and act on a rich and complex environment that contains enduring objects and processes at various locations at different spatial and temporal scales, and not all constantly in perceptual range. Doing this requires different sorts of information, including relatively enduring information structures and also rapidly changing perceptual contents and motor and proprioceptive signals. Relating the abstract goal of grasping a berry to the changing visual, haptic and motor signals requires machinery constructing, manipulating and using a variety of changing information contents, some concerned with what is happening in the environment, and some concerned with what’s happening in the organism: e.g. is some information incomplete, or ambiguous or capable of answering a question, or capable of being used for detailed control of actions? The contents of those information structures seem to be exactly what philosophers have been attending to for centuries and labelling as experiences, sense data, or qualia, of different sorts. Visual and haptic processes perceiving the same portion of the environment could include overlapping virtual machines dealing with different aspects of the environment processed at different levels of abstraction in parallel (Sloman, 2009). Data-structures representing visible portions and features of the environment, e.g. visible portions of surfaces with colour, shape, orientation, curvature, speeds of motion or rotation, and relationships to other surface fragments (i.e., not the specific sensory signals), will then be components of virtual machines.



(a) (b)

Figure 1: *Each of the two figures is ambiguous and flips between two very different views. (a) can be seen as a 3-D wire frame cube. For most people it flips between two different views of the cube, in which the 3-D locations, orientations and other relationships vary. In (b), the flip involves changes in body parts, the facing direction, and likely motion – requiring a very different ontology.*

Presumably, similar qualia exist in other animals that are capable of similar controlled behaviours. But in humans, and perhaps a subset of other species, there is additional machinery that can detect record, compare, and later reflect on and describe, those contents. A possible use for that would be explaining to someone else how to tell when a danger or opportunity or achievement of a goal is imminent. This introspective use of the information content is different from and requires different machinery, from the use of the sensory contents to control movements.[6]

As Fig. 1 shows, the very same low level sensory content can sometimes cause construction of more than one information structure. The ontology required to describe the change in contents differs from one ambiguous view to another. Some of the contents concern shape and information relevant to manipulation. Others concern more abstract capabilities and likely behaviours of perceived objects, like differences between a duck facing one way and a rabbit facing another way.

If the information structures created during perception and action are sometimes accessed by self-monitoring processes focused, not on what is in the environment, but on the content of what is currently being perceived, or signalled, then we potentially have an explanation of the phenomena that have led to philosophical and other puzzles about the existence and nature of sensory and motor qualia, which are often regarded as defining the most difficult aspect of mind to explain in physical or functional terms, and whose evolution and development in organisms, Huxley and others found so difficult to explain. See also (Sloman & Chrisley, 2003).

Ryle, Dennett and others identified deep confusions in talk about consciousness and *qualia*, but such things clearly exist, though they are hard to characterise and to identify in other individuals and other species. Analysis of examples, including ambiguous figures,

[6] That distinction between *having* mental contents and *detecting* them could explain evidence, e.g. by Libet, showing that initiation of motor signals can precede consciousness of the decision to move.

such as Fig. 1, helps to determine requirements for explanatory mechanisms. Such pictures illustrate the *intentionality* of perceptual experience, i.e., interpreting something as referring to something else and the different *ontologies* used by different experiences. I suggest that that is only possible within running virtual machinery, since concepts like 'interpreting', 'referring', 'intending' and 'looking' are no more definable in the language of physics than 'pawn' or 'threat'.

Many organisms can, I suspect, create and use such virtual entities without having the meta-semantic mechanisms required to detect and represent the fact that they do. As noted at the time of Darwin in Whittaker (1884), not all organisms that have qualia know that they have them! We can separate the *occurrence* of mental contents in an organism from their *detection* by the organism, which requires additional architectural complexity to support self-observation and self-description mechanisms. We need to experiment with varied ranges of increasingly complicated working examples, using different kinds of mechanism, in order to understand better some of the questions to be asked about mental phenomena in biological organisms. This is very close to Arbib's research programme described in (Arbib, 2003).

4 What Next?

Experience shows that for many thinkers belief in an unbridgeable mind/body explanatory gap will be unshaken by all this. As argued in Sloman (2010b), some cases of opposition will be based on use of incoherent concepts (e.g. a concept of 'phenomenal consciousness' *defined* to involve no causal or functional powers of the kinds described above). Designing working systems, using different robot designs to illustrate different products of evolution may help us understand the biological examples. But current achievements in AI vision, motor-control, concept-formation, forms of learning, language understanding and use, motive-generation, decision-making, plan-formation, problem-solving, and many others, are still (mostly) far inferior to those of humans and other animals, in part because designers typically consider only a small subset of the requirements for biological intelligence. Even if we omit uniquely human competences, current robots are still far inferior to other animals, in many ways. There is no easy way to close those gaps, but there are many things to try, as long as we think clearly about what needs to be explained. Turing the philosopher-engineer-biologist could have made a substantial contribution to this project. Part 3, in part IV of this volume, expands on the theme of meta-morphogenesis.

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