THE META-CONFIGURED GENOME (2019 VERSION)
(Multi-layered, multi-stage, parametrised, epigenesis)
An introductory presentation, including a short video.
Including some background information and plans for further development.

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NOTES

This is: http://www.cs.bham.ac.uk/research/projects/cogaff/movies/meta-config/
A pdf version is available at
http://www.cs.bham.ac.uk/research/projects/cogaff/movies/meta-config/meta-config.pdf
It is part of the Turing-inspired (Turing, 1952) Meta-Morphogenesis (M-M) project, introduced here:
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-morphogenesis.html

A.S. is directly responsible for the contents of this document.
J.C. was the source of the key biological idea, e.g. in Chappell and Sloman (2007), extending ideas in an earlier joint paper at IJCAI 2005. A comment by Peter Tino (October 2019) about the complex biochemistry of gene transcription probably underlying the meta-configured genome mechanisms, prompted a separate (tentative) document about requirements for molecular mechanisms (Sloman, 2019-dna).

Background information and discussion of implications, with further links relating to these ideas, is provided below -- after the introductory video.

Video and Summary of the Meta-Configured Genome (MCG) Hypothesis
A short (4.5min) video presentation, starting with the introduction below, then attempting to explain some of the complex multi-stage developmental processes summarised in the diagram below is available here:

WEBM (13MB)
(MP4 and OGV formats available if needed)

Introduction
Text of the introductory part of the video (with minor edits):

This is a highly compressed (work-in-progress) introduction to the meta-configured genome theory developed in collaboration with Jackie Chappell in Biosciences at Birmingham.

It replaces the familiar distinction between altricial and precocial species with a space of types of complexity in genome-expression.

I'll describe simple forms of gene expression, and then add several layers of complexity, including types of gene expression that produce parametrised, i.e. incompletely specified, structures that obtain their parameters from results of earlier gene expression. This allows environments, including social environments, to add multiple layers of sophistication to competences produced at different stages in the evolutionary history of a species, during later stages of development of individuals, but not on the basis of conventional learning. (This is crucial when learning from mistakes is impossible, because mistakes are likely to produce death or serious injury!)

This renders old debates about types of "modularity" (especially innate modules) in human brains or minds, out of date, since they ignore important types of multi-layer parametrised modules, and the roles of parametrised genetic specifications, without which human languages, and many human competences, including ancient mathematical competences, would have been impossible.

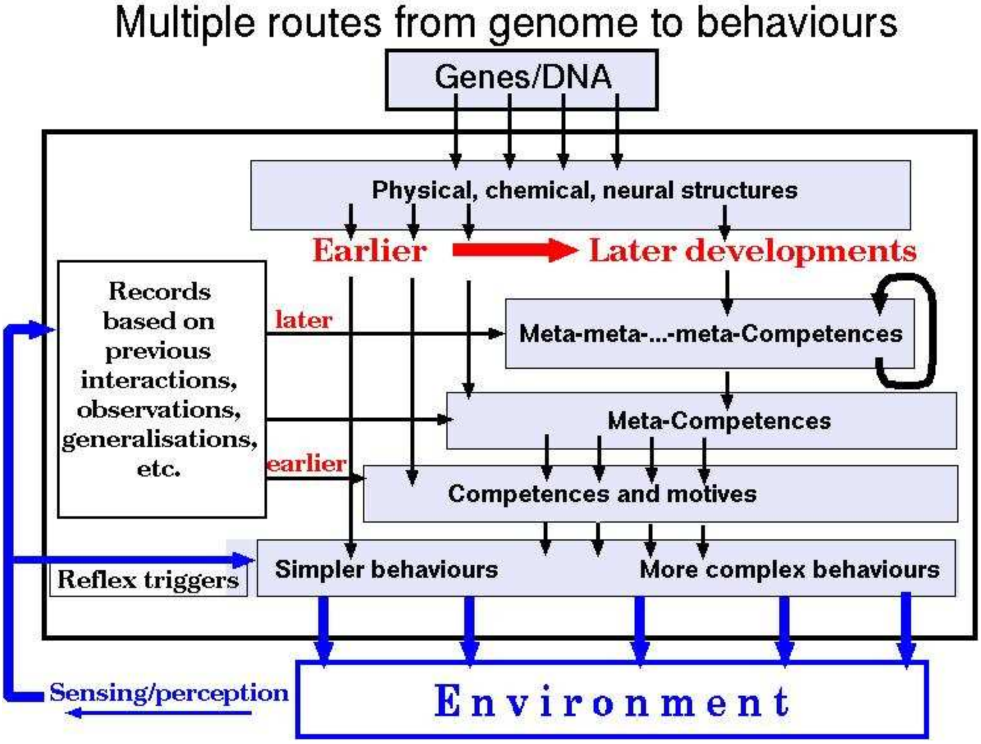
An illustrative list of layers of increasing sophistication is presented. The ideas are still at an early stage of development and little is known about implementation details, which, in humans, are likely to depend on sub-neural forms of chemical computation, that are not concerned with correlations and probabilities, but with structures and structural relationships and changes in compositional processes. Some of these ideas are familiar to theoretical linguists.

Our claim is that the key ideas are not restricted to evolution and development of linguistic competences, but are more generally applicable -- e.g. to spatial reasoning abilities underlying ancient mathematical competences.

Please watch the above video before reading on:

After the above introduction, the video attempts to explain how different parts of the genome are activated/expressed at different times, making use of previously stored information gained during earlier phases of gene expression -- as summarised (less clearly) in this diagram:

Figure EPI: Summary of The Meta-Configured Genome
A more complex theory of epigenesis



Explained in more detail in the video:
Cascaded, staggered, developmental trajectories, in complex organisms, in which later processes of gene expression (down arrows more to the right) use "parameters" acquired from results of earlier processes (down arrows more to the left) in increasingly complex ways.
(These ideas were proposed by Chappell and Sloman (2007),
extending ideas in an earlier paper at IJCAI 2005 in Edinburgh).

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(Still liable to change)

Background Ideas -- Inspired by Immanuel Kant

(This section provides some of the high level motivation behind the idea of a Meta-Configured Genome, presented in the video (above).

One of the sub-goals of the M-M project is to explain how spatial reasoning mechanisms in minds of ancient mathematicians (and other spatially intelligent animals, including squirrels, some nest building birds and pre-verbal human toddlers!) work. Some suggestions about mechanisms, based ultimately on chemical processes underlying biological evolution and mechanisms of genome expression, as summarised in the Meta-Configured Genome theory presented above, are referenced below.)

Ancient mathematicians, such as Archimedes, Euclid, Pythagoras, Zeno, and many more, made profound discoveries, e.g. in geometry and topology, that are still in constant use world-wide by scientists, engineers, architects, and mathematicians. (Though unfortunately no longer taught to all bright students at school or university, in many countries, since about the middle of the 20th century, when seriously flawed educational decisions were taken in several countries.) Immanuel Kant identified the problem around 1781 but his ideas summarised in Sloman(2018) (and defended in my 1962 DPhil thesis), have been ignored or mistakenly rejected for over half a century.

Researchers who claim to have implemented geometrical or topological reasoners that model such discovery mechanisms using either logic-based theorem provers combined with suitable axioms and definitions, or trainable neural nets trained on many test cases fail to understand two points made by Immanuel Kant (1781), namely that the ancient discoveries were neither *analytic*, i.e. derived using only definitions and purely logical reasoning, nor *empirical*, e.g. based on statistical evidence acquired (e.g. by a neural network) from collections of tests or experiments. (Kant's distinctions were summarised in Sloman(1965).) The ancient discoveries were about *possibilities* (e.g. possible geometrical constructions or arithmetical operations), *impossibility* (e.g. no number can be the largest prime; no power of 27 can be divisible by 28) and *necessity* (i.e. being incapable of being false, e.g. every even power of 6 must be divisible by both 4 and 9, and no planar convex polygon can have an even number of sides and an odd number of angles. [How do you know?]).

No statistics-based neural network can *represent* impossibility or necessity, let alone *establish* it as mathematicians regularly do with proofs of various sorts. (The ability to establish necessity does not have to be *infallible*: mathematicians can and do make mistakes, then later notice the errors and in many cases correct them, sometimes with great difficulty, as documented by Lakatos (1976).)

The required mechanisms have not yet been replicated in AI or explained in psychology or neuroscience, and the requirements are currently ignored or misunderstood by most philosophers of mathematics, psychologists, neuroscientists and AI researchers. (They have not read and understood Kant, and checked out his claims in personal experience of making even simple mathematical discoveries -- a serious flaw in current educational practices!)

Our work identifies a (gradually emerging!) new direction in which to seek such explanations -- namely trying to understanding evolutionary origins and the mechanisms they produce rather than doing laboratory tests on humans and other animals. This is one of the key strands of the (Turing-inspired) Meta-Morphogenesis project mentioned above, begun in 2012 -- the Turing centenary year.

Ultimately, this search will take us into aspects of fundamental physics involved in the mechanisms of genome replication and gene expression, extending Schrödinger's profound insights in (1944), helping to inspire the discovery of the structure of DNA a few years later. But our theory has not yet reached that stage of development. So we focus only on well-known facts about human and non-human forms of intelligence and the kinds of consciousness they support, and ask how such mechanisms could have been produced, and extended, over time, in a physical universe, in which the vast majority of biological processes depend on chemical mechanisms.

This presentation of the theory introduces new (Oct-Nov 2019) speculations about the (bio) chemical details underlying Meta-Configured Genomes. The theory is still too vague/abstract, though some more detailed but still incomplete thoughts and questions about the biological mechanisms are presented in (Sloman, 2019-dna).

If the speculations are correct, a fully developed version of the theory, showing how biochemical mechanisms, all implemented ultimately in physical mechanisms, on which they build new powers, can themselves subsequently be the basis of (physically, chemically, and metaphysically) novel biological phenomena, including various increasingly complex novel forms of biological information processing (e.g. used for intelligent control of actions, and eventually, in humans, used for language development) that rely on increasingly complex biological mechanisms, without which they could not exist, and which, in turn, depend on properties of physical matter, which are not available in Newtonian mechanics. I.e. if Newton's theory described all forms of causation, life could not exist. (Not even rocks could exist since Newtonian particles could not form a large rigid structure -- his physics did not include chemical bonds!)

This is implicitly a metaphysical theory (as well as a scientific and epistemological theory) -- metaphysical insofar as it explains how a purely physical world can become the basis for a world including various kinds of information-users of steadily increasing metaphysical abstractness and complexity. In the terminology of Wilson(2017) we are talking about complex forms of *metaphysical causation* as grounding psychological phenomena in biological phenomena which are grounded in physical phenomena. I used to think that the required competences could be implemented in digital computers using new AI techniques, but it now seems that ancient mathematical forms of consciousness depend on brains using chemical information processing which is not restricted to digital information processing: some of the molecular changes during gene expression, for instance, are inherently spatial and continuous although they also involve discrete changes produced by catalytic mechanisms then create or remove chemical bonds, processes of the sorts shown to be required in reproductive mechanisms, in Schrödinger (1944).

There are many complex details not mentioned here, including evolution's essential use of not just the original physical construction kit but increasingly complex novel construction kits produced by evolution and used for producing (and maintaining or repairing) increasingly complex (and in some cases increasingly abstract) mechanisms Sloman (2014-18).

Biological requirements
Many ancient spatial competences, in humans and other intelligent species, required abilities to detect changes in spatial relationships including changes in relative size, distance, orientation, and topological changes, e.g. containment within or connections between perceived regions of the environment. Not all animals with eyes and brains have the same kinds of spatial awareness, and there may not be a common ancestor e.g. for eyes of insects, molluscs, and vertebrates and they represent spatial structures and processes in different brain mechanisms, with different evolutionary histories.

In humans, and apparently other intelligent animals, spatial perception provides information not only about what light patterns hit their retinas and the locations, shapes and surface properties of objects from which received light has been reflected, but also information relevant to processes that can or cannot occur in the environment and also information about actions the perceiver can or cannot perform: this goes far beyond Gibson's affordances (Gibson 1979, Sloman 2009).

More recently evolved mechanisms provided individuals with abilities to become conscious of spatial possibilities, impossibilities and necessities derived from spatial structures and relations. Such abilities are of use in practical decision making and control of actions.

To explain those abilities we need a theory of the nature of various forms of spatial consciousness (e.g. in humans at various stages of development, and in other organisms with varying kinds of spatial intelligence, used in controlling actions and in selecting and achieving practical goals, e.g.: making a stable nest using semi-rigid twigs (corvids), or hanging nests woven from a large number of long thin leaves (weaver birds), or squirrels getting nuts from "squirrel proof" bird-feeders, or tree climbers rejecting impossible routes through tree branches, where errors can be fatal, e.g. for orangutans as described below. These requirements rule out use of purely statistics-based trial and error learning! Strong but not conclusive evidence is not of much use to dead infants.

Two crucial features of such intelligence are not wasting time by failing to understand relative distances or sizes, or relative difficulty of motion or grasping; and not risking life, by failing to recognize serious dangers, e.g. avoiding actions likely to be fatal or lead to serious injury. A particularly important feature of natural intelligence is ability to detect and "prune" impossibilities, to avoid attempts that will necessarily lead to failure, injury or death.

This involves being able to detect necessary consequences of available changes, e.g. in order to reject possible actions that will necessarily fail disastrously to achieve desired objectives, or to select actions that will necessarily succeed -- e.g. will successfully make a gap too small for a certain object to move, or escape, through, or make one large enough to serve an important purpose. Betty, the crow mentioned below, clearly seemed to understand the difference between moving a straight piece of wire and moving a curved piece of wire in the vicinity of the otherwise unreachable handle of a bucket of food. Moreover, although this was not mentioned in the original published reports, the online videos show that she clearly understood several different ways of using features of the environment to transform a straight piece of wire into a bent or curved piece of wire. Achieving her goal of obtaining food did not remove a tendency to think of, test, and use alternative means of achieving the same goal in the same sort of situation.

Are there impossibility detectors (or necessity detectors) in brains?
Obviously action selection involves detection of possibilities. Intelligent action also requires ability to decide that something is impossible, or will necessarily succeed. What sorts of brain

mechanisms can make such forms of consciousness possible? The mechanisms may be too complex to be studied directly but we may get clues by investigating precursor mechanisms, starting from information processing mechanisms in the very earliest life-forms and trying to identify ancient evolutionary transitions producing increasingly complex forms of information processing many of which may still be in use, though not directly observable.

Because brains of recently evolved intelligent species are far too complex to be studied exhaustively directly, years of diligent research may miss crucial features. But we may be able find clues about mechanisms relevant to abilities to detect possibility, necessity and impossibility without risky trial actions, if we can identify, at least in outline, the evolutionary trajectories by which those complex forms were built up, i.e. trying to find out how biological evolution, starting with one or more minimal forms of life, or prebiotic physical/chemical structures, was able eventually to produce the minds of animals with spatial reasoning abilities, including, eventually great ancient mathematicians who used spatial intelligence to make deep non-empirical discoveries that are still used by mathematicians, scientists, engineers, architects and others. A high level survey of possible evolutionary and developmental trajectories may provide clues that would otherwise go unnoticed. One of those clues is the important role played by meta-configured genomes, with functions summarised in the above video, and expanded below.

Meta-configured genomes
Conjecture: evolution of meta-configured genomes, of the sort described in the above video, was a crucial factor in the processes that produced modern mathematical consciousness. This could explain how important abilities that are not available at birth, develop several years later, without being derived by general-purpose, e.g. statistics-based learning mechanisms from evidence acquired in the intervening years. (How could the concept of impossibility and abilities to detect impossibility be acquired empirically?)

As Immanuel Kant(1781) noticed, the fact that the discoveries are non-empirical, or *a priori* does not imply that the knowledge is available from birth, or earlier. (Some of Kant's ideas are presented and defended in Sloman(2018)). The meta-configured genome theory explains why his theory might have been right, despite being incomplete (as Kant admitted), because according to the theory (a) not all the evolved capabilities in a species are available for use at birth, and (b) some of the evolved capabilities are schematic and need to be developed late, so that their general specification can be combined with information acquired by the young learner from the environment earlier.

E.g. consider how playthings of human children must have varied over thousands of years, and yet provided information about lines of sight, types of change in spatial relationships with necessary consequences (e.g. seeing more or less of a distant scene as you move left or right while looking past a vertical edge) and many types of impossibility -- some illustrated in http://www.cs.bham.ac.uk/research/projects/cogaff/misc/impossible.html (also pdf).

A crucial feature of these conjectures is that motivation is not necessarily *reward* based, and need not involve use of *probabilities*, as presupposed by theories of decision making based on "expected utility" since the mid 20th Century [Luce & Raiffa 1957] that have seriously misled many researchers in psychology, neuroscience, social science, economics, and robotics/AI.

Diversity of consciousness

An account of an alternative mode of learning and discovery should also undermine shallow, popular, recent characterisations of consciousness proposed by Nagel(1974) and others. There were deeper insights regarding consciousness in James(1879), but, like Kant, he lacked important ideas about required forms of computation.

There are many different kinds of consciousness (e.g. enjoying a smell, or a game, being puzzled by an unexpected event, recognizing the validity of a proof, finding a previously unnoticed flaw in a proof, composing a piece of music, wondering how life began, and many more), so any deep theory of consciousness must accommodate a rich variety of structured contents of consciousness, including different kinds of mathematical consciousness, such as discovery of previously unnoticed mathematical facts, wondering why they are true (i.e. being puzzled by them) and eventually understanding why they are true.

As Immanuel Kant noticed, this involves understanding relationships between different aspects of contents of consciousness, including explanatory mathematical relationships.

> For some animals, understanding impossibilities and necessities is a matter of life and death: for a young orangutan learning to climb through tree foliage like its mother, mistakes would be fatal or cause serious injury. Instead it needs some understanding before trying that some actions will fail and others will succeed assuming there is no deception at work. How is that initial understanding represented (a) in the genome, (b) in the brain, and what what brain mechanisms allow the information to how be extended and modified over time. "Visual cliff" experiments on human infants and other animals are relevant to this: https://en.wikipedia.org/wiki/Visual_cliff, although there are debates about interpretations. Our main questions are: How is the "inherited" information about such things represented chemically in the genome, and how does that information become available during later development? What changes in brains when the information is later modified and extended?
>
> There are many other animals with great spatial intelligence including honey badgers https://www.youtube.com/watch?v=c36UNSoJenI squirrels, elephants, orangutans, and the amazing portia spider:
>
>> A portia spider can sit stationary for several minutes looking around to work out a route to a point above its prey (e.g. another spider, at the centre of its web). It then follows the route even when it can no longer see the prey, making detours if necessary and avoiding branches that would not lead to the prey: "By visual inspection, they can select, before setting out, which detour routes do and do not lead to prey, and successfully perform a detour with no further visual contact with the prey". M. Tarsitano, 2006
>> Route selection by a jumping spider (Portia labiata) during the locomotory phase of a detour, *Animal Behaviour*, 72, Issue 6, pp. 1437--1442, http://dx.doi.org/10.1016/j.anbehav.2006.05.007
>> See also:
>> https://en.wikipedia.org/wiki/Portia_%28genus%29
>> https://en.wikipedia.org/wiki/Portia_fimbriata#Hunting_and_feeding

That raises questions in philosophy and psychology of mathematics, about what spatial understanding is, and what sorts of mechanisms can find and use a proof about a sequence of actions that will achieve a desired result. How does such understanding differ from and share with to other kinds of consciousness -- questions that are not addressed here. The main point is that explaining the possibility of consciousness of geometrical and topological truths and the validity of mathematical arguments about them is closely related to everyday consciousness of spatial structures and processes, at various stages of development, in humans and other animals. (I believe Kant understood that.)

(Links to additional information, including a conference on consciousness at the Mathematical Institute Oxford, in Sept 2019, can be found below .
(End of background ideas)

RELATED ONLINE MATERIAL

I have assembled a draft tutorial introduction to processes making use of genetic structure in a cell, encoded in DNA, for reproduction and other purposes -- e.g. structure formation, growth, combination of structures, replication of structures, assembly of structures into whole organisms.

> (Sloman, 2019-dna): provides an incomplete and provisional summary of different apparently relevant uses of DNA in reproduction and development (especially gene expression), with links to some online video tutorials. This may be a useful early step for some people wishing to think about mechanisms capable of explaining the evolutionary and developmental phenomena, including evolution and development of forms of mathematical consciousness ignored in most theories of consciousness.

The problem of explaining mathematical consciousness is more closely related to genome expression during development of an individual organism, than to the role of the genome in reproduction. In particular, we need new insights into how the genome influences production, development and functions of information processing mechanisms,

Genome expression is far more complex, context-sensitive, and variable than genome replication (structure copying), and provides rich and varied opportunities for the environment to play a role -- sometimes a delayed role, if information acquired when triggered by a genome is not used till a later stage of gene-expression occurs, as explained in above.

In his little book *What is Life?*, (1944), Schrödinger explained the crucial role of quantum mechanisms in making reliable reproduction possible (later shown by Crick, Watson, and Franklin to be based on the double helix structure). As far as I know Schrödinger did not mention the equally important role of quantum mechanisms in the production and use of chemical structures in gene expression within developing individuals, a process that is far more complex and variable, and more extended in time, than production of a new viable fertilised egg. I have tried to give more (still sketchy and provisional) information in (Sloman, 2019-dna).

One way to summarise my main thesis:

> A huge amount of recent and current research attempts unsuccessfully to show that neural networks in brains account for important results of gene expression that require quite different mechanisms, e.g. mechanisms supporting compositionality and discovery of impossibilities and necessities -- which is impossible for neural networks that merely compute *probabilities* from statistical evidence (observed relative frequencies).

At the conference on Models of Consciousness in Oxford in September 2019 https://models-of-consciousness.org/ two of the talks related to this problem were by Roger Penrose and Stuart Hameroff, both available online: Penrose and Hameroff.

This work is partly inspired by Immanuel Kant's philosophy of mathematics (1781), defended in my 1962 Oxford DPhil thesis.

A very brief summary of the distinctions on which Kant based his claims about mathematics (in opposition to David Hume) is here:
A. Sloman, 'Necessary', 'a priori' and 'analytic', *Analysis*, 26,1, Oct 1965, Pages 12-16,
http://www.cs.bham.ac.uk/research/projects/cogaff/62-80.html#1965-02

A closely related online paper (written 2018-19) is referenced below.

Some examples (videos and photos not included in my presentation above):
Here are some online examples illustrating research done on spatial intelligence of New Caledonian Crows when Jackie Chappell was at the Oxford Behavioural Ecology Lab:

http://users.ox.ac.uk/~kgroup/tools/movies.shtml
The Trial 7 video was referenced in world-wide news headlines in 2002.
Notice the variety of different techniques Betty used to make hooks for the task:
having found a method that worked, she continued exploring alternative methods.

http://users.ox.ac.uk/~kgroup/tools/crow_photos.shtml
More pictures showing Betty and Abel (another crow) solving problems.

It is sometimes suggested that if such animals solve related problems in their natural habitat then that reduces the interest or importance of their abilities. However, that additional information does not explain what brain mechanisms are involved, what information they use, and how they use it.

A related, more familiar, biological concept: Morphogenesis
There are genetically programmed changes during development that are more spectacular than the (often subtle, and hard to detect) changes in cognitive competences discussed here. In particular, genetically programmed changes of physical structure, including quantitative changes in size, weight, strength, and chemical properties of various body parts are well known, including dramatic examples of morphogenesis in insects and frogs from a larval stage (e.g. grubs or caterpillars to butterflies and moths, as illustrated in these -- and many other -- online videos
https://www.youtube.com/watch?v=Jl5ONrFHhfE
https://www.youtube.com/watch?v=71uJzE51T8M,
and changes from tadpoles to frogs
https://www.youtube.com/watch?v=1QBqp068jkI)

Clearly all those changes of physical structure and possibilities for physical action must also be accompanied by changes of the information processing mechanisms and the processes concerned with control of the movements/behaviours of those new physical parts, including switching from swimming in water or crawling on physical surfaces to flying using newly formed wings in butterflies and moths.

There are also cases of dramatic changes of behaviour at a certain stage of development that are not based on changes in physical form, e.g. changes from individual foraging to swarming behaviours in locusts, presented by David Malone in the "Jekyll and Hyde" video here: https://www.bbc.co.uk/programmes/p00zv0wk/clips
(I wish he did not follow the dreadful fashion among TV producers of adding totally unnecessary background noises making it hard for many people of my age (and younger as well as older) to make out what is being said
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/bbc-learning.html.)

The Meta-configured Genome hypothesis generalises those ideas to include changes in forms of information processing that occur in stages, and where later stages make use of information acquired during earlier stages, generalising the familiar notion that in morphogenesis later stages of physical development make use of physical materials acquired during earlier stages (including much feeding and digesting behaviour). Physical morphogenesis can be very spectacular, whereas information-processing morphogenesis involves intricate internal changes in information-processing mechanisms implemented in physical mechanisms, that are sub-microscopic and totally unobvious to those who study perceptible developmental changes.

These comments are also relevant to plants, insofar as they change not only their physical forms during a lifetime, but also the forms of control of physical materials during growth and seasonal changes, as well as reproductive behaviours.

Mathematical consciousness at Oxford Models of Consciousness conference

The material presented here overlaps with and extends my talk at the conference on Models of Consciousness at the Oxford Mathematical Institute in September 2019. A video recording of the talk is included among the videos of the conference presentations (32 invited and accepted talks): https://www.youtube.com/channel/UCWgIDgfzRDp-PmQvMsYiNlg/videos The conference booklet is available at https://models-of-consciousness.org/booklet/MoC19_Conference_Booklet.pdf

The Oxford talk related the Meta-Configured Genome thesis to problems of explaining how brains make possible the ancient, deep, kinds of mathematical discoveries leading up to (and beyond) Euclid's **Elements** and how they (brains of humans and other intelligent animals) solve related practical problems based on recognition of spatial possibilities, impossibilities and necessities.

It summarises David Hume's and Immanuel Kant's differing views on the nature of knowledge, including mathematical knowledge, and suggests that Kant is closer to the truth about the special features of mathematical discoveries, including the ancient discoveries leading up to and beyond Euclid's *Elements*.

Notes on varieties of consciousness and their evolution

After the video recordings of talks at the Oxford conference were made available, I added some notes in the Comments section, extending the ideas in my talk. Those notes (with additions) are now split between this document and a separate document available here (on this site).

The notes include a section on "Branching evolved forms of consciousness" (including varieties of spatial consciousness) available here, challenging assumptions shared by most (?) who write about the nature of consciousness.

It does not seem to be widely understood that there are more varieties of consciousness than can be captured within the currently fashionable (but seriously misleading) slogan that there is a "hard" problem of conscious related to "what it is like (or feels like)" to be in some state. I think William James over 140 years ago, had a fairly deep understanding -- expressed in his (1879) -- of the reasons why there must be varied forms of consciousness produced by biological evolution, not captured by most recent discussions of the nature of consciousness (e.g. I felt that that biological variety was ignored by most speakers at the Oxford conference on consciousness, which provoked this document.

The discussion of evolutionary and developmental branches in types of consciousness implies that most theories of consciousness are inadequate insofar as they fail to account for the variety of types of naturally occurring forms of consciousness, including mathematical consciousness and closely related forms of spatial consciousness, at various stages of development in humans and other animals, and in their evolutionary ancestors.

Work to be done

There are still many gaps. One of the most obvious is the need for a detailed account of the mechanisms producing spatial and non-spatial mathematical (or proto-mathematical) intelligence -- still lacking as far as I know. (Compare this disorganised discussion of "toddler theorems" http://www.cs.bham.ac.uk/research/projects/cogaff/misc/toddler-theorems.html.)

Also missing, as far as I know, is an account of the historical stages through which evolution arrived at some genomes that only partly specify designs, leaving gaps to be filled by previously acquired information from other sources (parameters) as new mechanisms develop.

Perhaps one of the early requirements for such mechanisms arose in species that grow in size and strength so that mechanisms are needed for controlling both the growth and the use of those mechanisms in ways that take account of changes in the size, weight, and strength of movable parts, and consequential changes in their biological uses: i.e. the control mechanisms need to take account of changes in both "inputs" to control mechanisms and "outputs" (to motor subsystems).

Example: Orangutans

For example, for some time during early development, young orangutans need to be able to cling safely to their mothers while they (the mothers) perform a variety of movements up, along, and between tree trunks, branches and foliage. Later the infants have to start selecting and controlling their own movements using changing topological, geometrical and dynamical opportunities and constraints as they grow in size and strength (e.g. see Thorpe *et al.* (2015)). The complexity and variability of structures and processes encountered in such environments, and the very serious risks if mistakes are made, far exceed the demands met by current industrial robots dealing with assembly, packing, dispatch, etc. (Please let me know of exceptions: in principle, future rescue robots could face similarly complex, varied and unpredictable challenges.) I would not trust any current (or near-future?) robots to put a nappy held by safety(?) pins onto a wriggling baby (unlike this one fastened by velcro and buttons (also challenging):

https://www.youtube.com/watch?v=5fvrDu3v4Lw)

Evolution of parametrised competences?

Many mobile species must meet different tasks and challenges as they grow in size, strength and reduced dependence on caring adults. Perhaps some genetically specified mechanisms that enabled parameter changes during development of an individual later evolved into mechanisms that enabled parameter changes across parent-child differences -- essential if the development environment of offspring is very different from the development environment of parents (because of climatic or other local changes, or because of migration to new territory). Such flexible mechanisms could produce considerable differences between members of the same species born into different environments, especially if differences are "stacked" during development.

Consider, for example, recent changes in childhood environments of humans, including the introduction of many computer-based and/or internet-based electronic devices: if the human genome has the right level of abstraction at different stages of development, children don't need to be born with a new type of genome to cope with the new environments. An earlier example was migration between different sorts of terrain, e.g. from warm parts of the planet to much colder regions, or from plains to steep mountainsides, or more generally changes in food sources and actions required to acquire and consume them.

Species vary in their ability to adjust developmental processes to changing environments. In extreme cases the adjustments require evolutionary time-scales because the genome has to change, instead of gene expression being changed by differences in "input parameters".

What is information?

All this work is concerned with varieties of information, including genetic information, varieties of information processing, and varieties of uses of information and information processing.

I am not using "information" in Shannon's sense (i.e. referring to syntactic or structural properties of information bearers) but in the much older, more abstract, sense of "semantic/referential content" familiar, for example, to the novelist Jane Austen, over a century before Shannon, as explained in: http://www.cs.bham.ac.uk/research/projects/cogaff/misc/austen-info.html (also PDF) --- and, of course familiar to many people centuries before Jane Austen.

Evolution produced learning mechanisms that are not reward-based

One of the important presuppositions of the Meta-Configured Genome theory is that evolution produced sources and mechanisms of motivation that are not reward-based because the mechanisms we describe require individuals to have motives generated by evolved mechanisms triggered by opportunities whose benefits (including information gained) cannot be known in advance by young learners. At that stage they can have no conception of the rewards to be gained in the (possibly distant) future. Every great author went through an early stage of learning to babble, imitating sounds heard in the environment, with no idea that this was an essential step towards writing (or understanding) great plays, poems, or novels. I suggest that many of the motivational mechanisms in young members of intelligent species use evolved motivation-triggers rather than reward-based motivation.

I call this "Architecture-based motivation", often observed in young humans and some other species whose reflex switches of attention and motivation depend on evolved mechanisms that have proved useful in ways none of the individuals can know about at the time, as explained in Sloman(2009--2015).

Related online publications/papers

For additional ideas (and both acknowledged and unnoticed gaps!) see the papers in the Meta-Morphogenesis project, including the overview, the paper on evolved construction-kits, and the paper on compositionality in biology, and others referenced in those:
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-morphogenesis.html
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/construction-kits.html
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/compositionality.html
All three papers also have pdf versions and include many links to examples and unanswered questions. All are concerned with evolutionary changes in forms of information-processing and types of information processed during individual development.

There is also an older paper on The Meta-Configured genome, which will later be reorganised to take account of recent additions in this document:
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-configured-genome.html
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-configured-genome.pdf

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Sample References

Jackie Chappell and Aaron Sloman, 2007, Natural and artificial meta-configured altricial information-processing systems, in *International Journal of Unconventional Computing*, 3, 3, pp. 211--239,
http://www.cs.bham.ac.uk/research/projects/cogaff/07.html#717

Chrisantha Fernando, 2008, Review of *The Principles of Life* by Tibor Ganti. (2003), in *Artificial Life*, 14, 4, pp. 467--470, http://dx.doi.org/10.1162/artl.2008.14.4.14404

Tibor Ganti, 2003, *The Principles of Life* Eds. E. Szathmáry, & J. Griesemer, (Translation of the 1971 Hungarian edition) OUP, New York,
http://chemoton.com/images/pdf/GantiTiborEletmu_14.pdf See also the very useful summary/review of this book by Gert Korthof: http://wasdarwinwrong.com/korthof66.htm

James J. Gibson (1979), *The Ecological Approach to Visual Perception* Houghton Mifflin, Boston, MA,

William James, 1879, Are we automata?, *MIND, A Quarterly Review of Psychology and Philosophy*, January, 13, 1897, pp. 1--22,

Immanuel Kant,1781, *Critique of Pure Reason*
http://archive.org/details/immanuelkantscri032379mbp

K. S. Lashley, The Problem of Serial Order in Behavior, in *Cerebral mechanisms in behavior,* Ed. L.A. Jeffress, Wiley, New York, 1951, pp. 112--131, http://s-f-walker.org.uk/pubsebooks/pdfs/The_Problem_of_Serial_Order_in_Behavior.pdf

Luce R, Raiffa H (1957), *Games and Decisions: Introduction and Critical Survey* Wiley Inc.; Chapman and Hall

Imre Lakatos (1976), *Proofs and Refutations,* Cambridge University Press.

T. Nagel, 1974, What is it like to be a bat?, *Philosophical Review* 83, pp 435--50. Duke Univ. Press, http://dx.doi.org/10.2307/2183914

V.V. Ogryzko, 2008, Erwin Schroedinger, Francis Crick and epigenetic stability, *Biology Direct*, 3, 15, http://doi.org/10.1186/1745-6150-3-15

Includes:
"A shift from the signal transduction paradigm to the epigenetic one might be useful for the study of many other protein modifications and even of interactions between macromolecules."

Erwin Schrödinger (1944) *What is life?* CUP, Cambridge,
I have an annotated version of part of this book, with additional links, here
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/schrodinger-life.html

Sloman, A. (1962). *Knowing and Understanding: Relations between meaning and truth, meaning and necessary truth, meaning and synthetic necessary truth* (DPhil Thesis), Oxford University. (Transcribed version online.)
http://www.cs.bham.ac.uk/research/projects/cogaff/62-80.html#1962

Aaron Sloman, 1965, "Necessary", "A Priori" and "Analytic", *Analysis*, Vol 26, No 1, pp. 12--16. http://www.cs.bham.ac.uk/research/projects/cogaff/62-80.html#1965-02

Aaron Sloman (2009), Some Requirements for Human-like Robots: Why the recent over-emphasis on embodiment has held up progress. In *Creating Brain-like Intelligence,* Eds. B. Sendhoff, E. Koerner, O. Sporns, H. Ritter and K. Doya, Springer-Verlag, 2009, pp. 248--277, http://www.cs.bham.ac.uk/research/projects/cosy/papers/#tr0804

Aaron Sloman, 2009--2015, Architecture-Based Motivation vs Reward-Based Motivation, Original version published in *Newsletter on Philosophy and Computers,* American Philosophical Association, Newark, DE, USA, pp. 10--13. Revised/extended version online here: http://www.cs.bham.ac.uk/research/projects/cogaff/misc/architecture-based-motivation.html (Also PDF)

Aaron Sloman (2014-18), Construction kits for evolving life, [In progress. Begun Nov 2014], http://www.cs.bham.ac.uk/research/projects/cogaff/misc/construction-kits.html

Aaron Sloman,(2018,ff), "Key Aspects of Immanuel Kant's Philosophy of Mathematics, ignored by most psychologists, neuroscientists and AI researchers studying mathematical competences" http://www.cs.bham.ac.uk/research/projects/cogaff/misc/kant-maths.html (Also PDF)

Aaron Sloman, (Sloman, 2019-dna) Steps toward a specification of a new super-Turing class (or classes) of computation, potentially relevant to explaining forms of natural intelligence so far not replicated in any version of AI or incorporated into theories in psychology or neuroscience.
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/dna-uses.html

Susannah K. S. Thorpe, Jackie Chappell, Abigail C. Phillips, Maria A. van Noordwijk and Tatang Mitra Setia, 2015 The Ontogeny of Gap Crossing Behaviour in Bornean Orangutans (Pongo pygmaeus wurmbii) July, *PLOS*
https://doi.org/10.1371/journal.pone.0130291

A. M. Turing, 1952, The Chemical Basis Of Morphogenesis,
Phil. Trans. R. Soc. London B 237, 237, pp. 37--72, (and reprinted in collections of Turing's work), usefully summarised for non-mathematicians in Philip Ball, 2015, "Forging patterns and making waves from biology to geology: a commentary on Turing (1952) 'The chemical basis of morphogenesis'", *Royal Society Philosophical Transactions B,*
http://dx.doi.org/10.1098/rstb.2014.0218

Alastair Wilson, 2017, Metaphysical Causation, *Nous*
https://doi.org/10.1111/nous.12190

Installed: 13 Oct 2019
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This document is
http://www.cs.bham.ac.uk/research/projects/cogaff/movies/meta-config/

A partial index of videos is available here
http://www.cs.bham.ac.uk/research/projects/cogaff/movies/

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