Abstract, notes and references
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Why current AI and neuroscience fail to replicate or explain ancient forms of spatial reasoning and mathematical consciousness

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ABSTRACT
Most recent discussions of consciousness focus on a tiny subset of loosely characterized examples of human consciousness, ignoring evolutionary origins and transitions, the diversity of human and non-human phenomena, the variety of functions of consciousness, including consciousness of: possibilities for change, constraints on those possibilities, and implications of the possibilities and constraints -- together enabling extraordinary spatial competences in many species (e.g. portia spiders, squirrels, crows, apes) and, in humans, mathematical consciousness of spatial possibilities/impossibilities/necessities, discussed by Immanuel Kant (1781). (James Gibson missed important details.) These are products of evolution's repeated discovery and use, in evolved construction-kits, of increasingly complex types of mathematical structure with constrained possibilities, used to specify new species with increasingly complex needs and behaviours, using lower-level impossibilities (constraints) to support higher level possibilities and necessities, employing new biological mechanisms that require more sophisticated information-based control. Such transitions produce new layers of control requirements: including acquisition and use of nutrients and other resources, reproductive processes, physical and informational development in individual organisms, and recognition and use of possibilities for action and their consequences by individuals, using layered mixtures of possibilities and constraints in the environment, over varying spatial and temporal scales (e.g. sand-castles to cranes and cathedrals). I'll try to show how all this relates to aspects of mathematical consciousness noticed by Kant, essential for creative science and engineering as well as everyday actions, and also involved in spatial cognition used in ancient mathematical discoveries. In contrast, mechanisms using statistical evidence to derive probabilities cannot explain these achievements, and modern logic (unavailable to ancient mathematicians, and non-human species) lacks powerful heuristic features of spatial mathematical reasoning. New models of computation may be required, e.g. sub-neural chemistry-based computation with its mixture of discreteness and continuity Grant(2018).

This document is available at
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/mathematical-consciousness.html
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/mathematical-consciousness.pdf

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[THE REST OF THIS DOCUMENT IS A DRAFT, STILL BEING REVISED]
REFERENCES ARE BELOW
Followed by some notes on recent discoveries about sub-neural mechanisms.

Discussion

Consciousness is multi-faceted. The adjective "conscious" can be applied to a person, a group of people, a nation, a squirrel, a beetle, and (controversially) also plants and other organisms that acquire and use information about themselves or their environment.

There are also states (e.g. being conscious of), events (noticing, recognizing) and processes (becoming conscious of, making out details, losing sight of, forgetting, ignoring, etc.), and abilities that are acquired, enhanced or diminished on the basis of available or unavailable, attended or unattended, information, and many more. Possible contents of consciousness are enormously varied, including objects, processes, states of affairs, attitudes of other individuals, dangers, opportunities, constraints, discrepancies, impossibilities, necessities, e.g. geometrical or topological impossibilities/necessities. There are even states of consciousness during states of unconsciousness, e.g. in dreams.

My main concern in this talk is to point out hitherto unexplained features of ancient mathematical consciousness that are closely related to aspects of spatial perception in many intelligent species -- and pre-verbal human toddlers.

> Two non-trivial (for non-mathematicians) examples:
> 1. How many equivalence classes of simple (non-self-crossing) closed curves are there on the surface of a torus? Two closed curves are equivalent if each can be continuously deformed into the other in the surface containing both of them.
> 2. If planar cut is used to slice off exactly one vertex of a convex polyhedron (3D solid object whose surface is made up of polygons) what happens to the number of vertices, edges and surfaces in the remaining polyhedron?
> Both examples are discussed briefly in
> http://www.cs.bham.ac.uk/research/projects/cogaff/misc/turing-intuition.html#infinite
> I have a large and varied collection of examples of types of mathematical or proto-mathematical consciousness scattered among online papers, including a much expanded version of a set of notes on perceiving impossibility for a talk in Bristol in 2015
> http://www.cs.bham.ac.uk/research/projects/cogaff/misc/impossible.html (also pdf)
> a set of illustrations of Kant's ideas on mathematics:
> http://www.cs.bham.ac.uk/research/projects/cogaff/misc/kant-maths.html (also pdf),
> a summary of Turing's discussion of mathematical intuition vs mathematical ingenuity.
> http://www.cs.bham.ac.uk/research/projects/cogaff/misc/turing-intuition.html (also pdf).

Moreover, there can be discrepancies between the contents of consciousness and what exists, giving rise to errors, illusions, and false beliefs. So X's being conscious of Y may be useful or harmful to X, depending on whether Y is false or illusory, and how X's consciousness is used in taking decisions or controlling actions. False information can sometimes be very useful to the provider, e.g. camouflage.

This diversity of types, contents, and functions of consciousness is ignored by most philosophers and mis-described in many attempts to define consciousness, e.g. the dreadful recent focus on uses of "What it's like (or feels like) to be...", inspired by Nagel(1974).

The physical sciences long ago generalised the notion of force far beyond the cases that are directly experienced by humans when they feel or apply forces or make machines do so. A striking example was Newton's concept of gravitational force acting between planets, but others included unfelt atmospheric pressure on the surface of a hand, and the centrifugal force related to rotation of the earth. Likewise, a deep science of consciousness will relate the concept to a much wider variety of phenomena than humans normally think of when reflecting on consciousness, which is why there are scientists working on plant consciousness, or even microbe-consciousness, and engineers attempting to give various kinds of consciousness to man-made machines -- so far achieving only pale imitations of biological consciousness.

All these cases involve information: the content of consciousness is always information of some sort -- including potential information (something that may or may not be a footprint) and false information (e.g. hallucinations and false recollections).

> A general feature common to all these cases is the use of semantic information content of some sort. This is not Shannon information, which is essentially syntactic, but semantic information, familiar for much longer and used, for example, by Jane Austen, the novelist, over a century before Shannon, as explained in Sloman(2013-18).

A scientific study of consciousness must be part of a scientific study of types of information, types of information-user, types of information-use and types of information content relevant to various aspects of living and non-living information-using machines. That potentially includes a study of all forms of life, and perhaps also cases of proto-life, that use information. The simplest life forms use simple kinds of information for various kinds of self-maintenance including acquisition of nutrients and excretion of waste products, as well as control of growth, reproduction and in some cases motion Ganti(2003).

There are enormously varied types of consciousness involving information, and this is reflected in the fact that "conscious" can occur in many different contexts, referring to many different things that can be conscious, and followed by "of" or "that" indicating what they are conscious of, and sometimes indicated by other verbs or adjectives indicating what type of state or process or ability is being attributed (e.g. noticing, recalling, seeing, hearing, feeling, wondering whether, being unsure or undecided, etc.).

Biological evolution is more creative than anything else on this planet, and is directly or indirectly involved in the production of everything else that is creative, including humans and other animals, and perhaps future intelligent artefacts. The (metaphysical) creativity of evolution involves multiple layers, including for example creative construction of new construction kits of many kinds, including construction kits for creating construction kits (long before humans started designing and building construction kits or using natural resources as construction kits for making tools, clothing, buildings, weapons etc.). See also:
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/construction-kits.html.
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/creativity.html

One aspect of evolution's creativity is repeated discovery and use of mathematical abstractions, for example control mechanisms used in organisms whose details (size, weight, strength, reach, moments of inertia, etc.) change during development but are used continually. There are also mathematical aspects of perceptual mechanisms, including the roles of rates of change in controlling bodily processes using negative feedback -- long before human scientists discovered and made use of it in homeostatic control mechanisms, such as the Watt governor and fantail windmill mechanisms.

Many animals control their actions by making use of mathematical relationships in their sensory information as pointed out in Gibson (1979), though he and his admirers over-stated the case by ignoring uses of perception to acquire information not needed for immediate control. Nevertheless there is an enormous variety of ways in which perceptual information can be used directly or indirectly, immediately after acquisition or later on, in controlling actions, including selecting goals, making plans, and adjusting orientations, forces, speeds, etc. while acting. These are examples of online uses of information in control. Collecting perceptual information for other purposes, e.g. planning one or more sequences of actions in advance of execution and then evaluating them in deciding what to do, or storing the information for future use can be described as offline intelligence. Both involve perceptual consciousness, and are found both in pre-verbal human toddlers and many other animals. (Some psychologists who misunderstand these distinctions mistakenly refer to a distinction between perceiving "where" vs perceiving "what".) Most of these capabilities are not yet matched in current robots.

Mathematical consciousness.

The ability to compare items of information acquired at different times in order to take control decisions (e.g. controlling acceleration, deceleration, or direction of motion to a moving target) involves using information about information: meta-information. In many cases, mathematical relationships can be discovered and used by information users. For example moving towards some visible object causes the visual area occupied by the object to increase, and in many cases causes other objects to become occluded (i.e. made invisible) and the reverse happens when moving in the opposite direction. Moving sideways while viewing objects at various distances will cause parts of some visible objects to become invisible (occluded) and will bring some previously invisible objects into view. Moreover the rates at which things change will depend on their relative distance and the relationships of 3D orientations of surfaces to line of sight and direction of motion of the viewer. If perceived objects are also moving there will be a complex network of changes including texture flows, relative expansion or contraction of visible portions of surfaces, and possibly other factors depending on where light sources are and how shadows are cast, or objects reflected in "shiny" flat or curved surfaces (e.g. car bodies in a car park).

> **NOTE**
> Some of the phenomena normally produced by relative motion between viewer and visible surfaces can also be produced by totally different causes. For example, resting a finger gently under the lower lid of an eye and wiggling it up and down while applying pressure to the eyeball and while the other eye is closed or covered can produce some of the experienced relative changes in visual content associated with perceived objects moving in the environment. But in this case the perceived objects are not changing their spatial relationships, although visual contents are.

So how experienced contents are interpreted as sources of information can depend in complex ways on what else is going on -- a fact that is well known to stage magicians, film directors and painters.

For some organisms, e.g. some nest building birds, squirrels and various monkeys and apes, visual systems and brains seem to be able to take in and use enormous amounts of such information about spatial changes at high speed, in ways that I do not believe current neuroscience can explain, nor current AI systems match.

These animals appear not only to use their current perceptual consciousness to control their current movements, but also to take in and evaluate alternative possibilities and choose between them in achieving goals, e.g. Betty the New Caledonean crow whose hook-making and use earned fame in 2002. Look for trial 7 here: http://users.ox.ac.uk/~kgroup/tools/movies.shtml
The well known abilities of some squirrels to defeat squirrel-proof bird-feeders provide more examples.

A subtle feature of these forms of intelligence is the ability to detect that certain structures and processes make some results impossible, and others unavoidable: both involving mathematical (e.g. geometrical, topological) impossibility or necessity). Several examples are presented in http://www.cs.bham.ac.uk/research/projects/cogaff/misc/changing-affordances.html (also (PDF))

Ancient humans making tools, building shelters, catching and dismembering prey, using some parts for food and others (e.g. skins) for clothing must have had comparable spatial intelligence. But they also had abilities that eventually, via transitions that as far as I know have never been discovered, allowed them not only to reflect on spatial possibilities and impossibilities when not engaged in practical activities, but also to convey their thoughts to others and assemble their discoveries into arguments that later came to be called proofs, some of which were recorded in Euclid’s *Elements*, which, as Immanuel Kant (1781) pointed out, made use of consciousness of possibilities, impossibilities and necessary connections that were not reducible to logic plus definitions: i.e. they were *synthetic*, not *analytic*, and not merely *empirical* discoveries. Although it is possible to give robots abilities to derive some of the old conclusions from axioms and definitions expressed in logical notation, using purely logical derivations, that is not how Archimedes, Euclid, Zeno and others thought about spatial structures, and there is nothing in current AI that can match their spatial reasoning.

Deep learning mechanisms, and all proposed neural learning mechanisms that I have heard of, cannot discover necessities and impossibilities, only high and low probabilities based on statistical evidence. Logic based theorem provers can derive logical consequences of axioms and definitions but that’s not what the ancient mathematicians, squirrels, crows, and pre-verbal human toddlers do.

Perhaps that is part of the reason why Turing (1939) wrote in his thesis that computers are capable of mathematical ingenuity (e.g. finding symbolic proofs by searching in a space of logical deductions) but incapable of mathematical intuition, e.g. understanding spatial impossibilities and necessary connections. (What I think he was getting at, and how it is related to Kant’s philosophy of mathematics, is summarised (here).)

There is growing evidence from the work of a small subset of neuroscientists, e.g. Grant, 2018 that far more is going on within synapses, at a chemical level, than was previously realised, including much more activity than would be required for neurons to perform the computations used in "deep learning" systems. In my talk I'll present some very sketchy ideas about how we can make progress in understanding the mechanisms involved in ancient mathematical consciousness, based on the power of chemical mechanisms to combine both discrete and continuous processes, shown in Schrödinger;s *What is Life* (1944), to be crucial for biological reproduction mechanisms to preserve complex information reliably. Perhaps the same features of chemistry are crucial also for perception, reasoning and learning in animals with spatial intelligence, and mathematicians with spatial forms of mathematical consciousness.

Conjecture: Part of what's missing in AI and Neuroscience concerns the mixture of continuity and discreteness in sub-neural chemistry: a source of vast computational power whose features have not yet been understood, though there is some evidence that Turing was thinking about this shortly before he died? Schrödinger;s *What is Life* (1944) is relevant.

As Seth Grant (2018) writes:
"... the molecular complexity of the postsynaptic proteome poses an existential crisis to the traditional view that the synapse is a simple connector that is strengthened with learning. It is, in fact, a highly sophisticated molecular computer." [There are more extracts from his paper below, after the references.]

I think the Meta-Configured genome thesis is also directly relevant
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-configured-genome.html (pdf)

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Several sample quotes from this remarkable paper are below.

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(I wrote a semi-serious spoof in 1996
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/like_to_be_a_rock/)

Much of Jean Piaget's work is also relevant, especially his last two (closely related) books written with his collaborators: *Possibility* and *Necessity*
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Some recent discoveries about sub-neural mechanisms:
A sample of relevant extracts from Grant, 2018:

"A major surprise was that virtually every class of synapse protein found in mammals had first evolved in unicellular organisms."

"Furthermore, when considering the molecular machinery of the presynaptic terminal versus the post-synaptic terminal, it was discovered that the postsynaptic protein machinery was the most ancient, having first arisen in prokaryotes."

"The synapse molecular machinery is therefore more ancient than the neuron."

"A striking fact is that these prokaryotic proteins include receptor signalling complexes, which are basic multiprotein machines used by cells to detect the external environment and trigger intracellular adaptive responses."

"These evolutionary observations indicate that the most ancient and fundamental property of the postsynaptic machinery is the integration of temporal information. It also indicates that temporal integration by signalling complexes is a basic and ancient memory mechanism."

"This raises a fascinating and simple alternative to the classical model of synaptic resistance and the LTSS model, namely, that it is temporal detection that is the fundamental property and that the adjustment of strength is a secondary and much later evolved function. It is also worth noting that the capacity to detect patterns of activity is significantly altered in synapses carrying mutations in the scaffold proteins that organise the vertebrate signalling complexes."

Comment by A.S.:
It is not just what the synapses detect that's important but also how such detection influences control. In very simple organisms control is immediate, but as organisms, their needs, and the environments they interact with become more complex, the information processing requirements become more complex, and less closely tied to requirements for immediate action, or reaction. Examples include considering and choosing between alternative actions, reasoning about actual or possible causal influences, assembling actions to achieve a novel goal, or, later still, rejecting a considered goal after working out that it is impossible to achieve.

As I believe Kant saw, at least dimly, in 1781, all of this mechanism that evolved initially for fairly direct detection and selection of means to various desired ends, was later used as the basis of mathematical discoveries about spatial structures, processes and their relationships that eventually led to the production of Euclid's *Elements* and many more mathematical discoveries in geometry and topology not included by Euclid and also not included in Hilbert's Foundations of geometry.

The Turing-inspired Meta-Morphogenesis project studying such transitions in biological information processing is available here:
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/meta-morphogenesis.html

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