Some background information:

I am trying to present new ways of thinking about the many complex relationships between mechanisms of biological evolution and mechanisms of reproduction and development in a huge variety of species, some very ancient and others relatively recently evolved (e.g. mammals), including mechanisms operating across different time-scales, such as mechanisms for representation and use of information relevant to evolution, reproduction, various stages and types of development, and selection and control of actions, including internal actions such as creating goals, considering reasons, modifying stored information, and many more.

The ideas are inspired by research results and publications of researchers in a very wide variety of disciplines. Examples include the many forms of interdependence between species, such as crucial forms of cross-species collaboration required for many internal processes. Many of the facts are highly counter-intuitive. E.g. digestion of food in humans requires collaboration with bacteria. I was surprised to learn that a newborn human infant cannot digest its mothers milk without help from bacteria picked up from the mother during the birth process. The child’s genome does not provide all the required digestive mechanisms! One of many sources of information about this is here:


The work reported below grew out of earlier research on forms of mathematical cognition, begun around 1959, when I was a research student, and had been inspired by Immanuel Kant’s claim that David Hume’s two acceptable forms of reasoning had omitted a third, more complex form of spatial reasoning used in many ancient mathematical discoveries. Exploring Kant’s alternative over many years eventually (June 2023) triggered new ideas about the origins and functions of synapses in brains -- ideas that are partly inspired and/or supported by biological research results cited below. However, I have not found anyone else who has explicitly made the claim below that the earliest ancestors of existing mammals were single celled ancestors of their synapses, some of which later evolved neurons to support the functions of synapses as organisms became more complex!

This document has undergone a great deal of metamorphosis since it was originally created. The changes include, but go far beyond, discussion of metamorphosis! So the file name ‘metamorphosis.html’ is now potentially misleading, but any other short file name would also be misleading. So the file name will not be changed in the near future!

There are some inconsistencies of spelling below, because quoted items include words that are spelled differently in British English and American English, e.g. "signalling" (British) and "signaling" (in a quotation below!).
Updates and reorganisation are likely to continue for some time!

VERTEBRATE HATCHING, INSECT METAMORPHOSIS, AND INTELLIGENCE
Title changed from Metamorphosis, 4 Aug 2023

Possible alternative titles:
Evolution and development of biological mechanisms of evolution and development
(Added 8 Oct 2023)
Do synapses connect neurons, or do neurons connect synapses?
(Added 30 Aug 2023)

Apology:
No short title can capture the scope of this document. In it, I have been trying, with much re-writing, to summarise recent attempts to understand evolution of various kinds of spatial intelligence implicitly involved in mechanisms of biological evolution and development, i.e. intelligence in biological mechanisms, not just intelligence in whole organisms, the normal focus of research investigating biological intelligence.

Added: 23 Oct 2023
Because these investigations led to a surprising view of the importance of synapses, alternative possible titles for this document include:

  Are animals descendents of ancient ancestors of their synapses?

  Are animals relatively recently evolved forms of life that enable collections of single-celled synapses to reproduce, develop and collaborate?

  Should we regard synapses, or perhaps collections of cooperating synapses, as intelligent?

Note on intelligence and consciousness
Most discussions of intelligence attempt to answer questions about properties of whole organisms or machines, e.g. in talking about the intelligence of an octopus or a rabbit, or discussing what kinds of machines can be intelligent.

This document, however, is mainly about intelligence in mechanisms, including biological mechanisms that are components of organisms rather than organisms.

For example, human digestive systems have a type of intelligence insofar as they perform complex information-based tasks related to consumption of food, decomposition of components, and use of the products of decomposition.

Much of the discussion below is about forms of intelligence in mechanisms of evolution, reproduction and development of organisms. These are not entities that can be presented with tests for intelligence, as one might do with a human or other animal, or a robot. However all the examples include making use of information in performing some task or serving some biological function, such as reproduction, development, or digestion of food.
Such tasks involve decisions based on various kinds of information e.g. information about components of food being digested, information about partly or completely assembled physiological structures, and information in the genome, or derived from the genome during earlier stages of development.

Such abilities to use information can be regarded as as examples of consciousness, although they are not normally included in discussions of consciousness. Most discussions of the nature of consciousness or criteria for consciousness refer to abilities of whole organisms or machines, not abilities of mechanisms within organisms, some of which were produced during earlier stages of development.

For example, the discussion of consciousness in the recent, much praised, book by Anil Seth referenced below does not (as far as I can tell from some partial reading) attempt to answer any of the questions about intelligence in developmental mechanisms discussed in this document. Presumably none of the reviewers noticed that lack, or would have regarded it as relevant.

I suggest that the examples of biological intelligence mentioned below involve forms of consciousness, e.g. because the mechanisms make use of information about what is happening in the organism in order to decide what to do next, and using information involves a form of consciousness, or proto-consciousness. That's not true of processes that are merely products of causes acting on the organism, or parts of the organism, e.g. being poisoned by an unwittingly swallowed chemical, or becoming infected by breathing in a polluted atmosphere, without any defensive response being triggered.

**Note on Sleep-Walking**

Added 24 Oct 2023

There are some well known facts about consciousness that tend to be ignored in many scientific and philosophical discussions about consciousness. A striking example is "Sleep-walking", a combination of a form of consciousness during unconsciousness, which involves much more than walking.

For example, online searching produces examples showing that a sleep-walker can do things like walk to a door, notice that it is shut, grasp and rotate the handle, open the door and then walk through the doorway. A superb short video on sleep-walking is available here: [http://www.pbs.org/video/what-happens-in-the-brain-when-you-sleepwalk-dp7xeh/](http://www.pbs.org/video/what-happens-in-the-brain-when-you-sleepwalk-dp7xeh/) provided by Heather Berlin and colleagues.

Such examples are ignored in many publications on consciousness. I don't know whether any scientists or philosophers have produced good explanations of such possibilities, e.g. detailed explanations of how the mechanisms work, how they evolved, how they might change during development of individuals (presumably human babies are incapable of such behaviours), and whether they occur in other species.

**Apologies**

This is work in progress, still being revised and extended, a process that is likely to continue for a long time. So normal modes of publication, requiring information to be frozen at some point in time are not appropriate.

Many references and important new ideas have been added since June 2023, and more are likely to be added in future.

I apologise for gaps, errors, inconsistencies, and wasteful repetitions that need to be pruned!
I also apologise for the complexity of this document, although that is mainly a consequence of the complexity and
diversity of the physical/chemical mechanisms underpinning biological evolution, reproduction and development!

There may also be some challenges to current theories about fundamental physics (on which I am not an expert).

Notes:
- Some of the key ideas offered below about biochemical processes are relevant in a variety of different contexts. I may
  try later to find a better way to introduce the ideas in all those contexts without repeating so much detail. If I ever
  succeed I’ll remove this note!
- The processes of transcription used to include quotations from other publications are not totally reliable. So, please
do not quote text in this document attributed to another author without first checking the original.

Author: Aaron Sloman
http://www.cs.bham.ac.uk/~axs
Emeritus/Honorary Professor of Artificial Intelligence and Cognitive Science.
School of Computer Science
University of Birmingham, UK
a.sloman-At-bham-ac-uk
Brief CV below

Thanks
Some of the people who have helped me via discussions or by sending information or suggestions,
or whose online work has helped me, are mentioned below. I apologise to the many others I have
interacted with over many years, who have also contributed.

Background
This document presents several new ideas about the importance of synapses and how
single-celled precursors of synapses could have been our oldest ancestors!

The new ideas emerged unexpectedly from the latest in a long series of attempts, begun over 60
years ago, to understand mechanisms that have enabled humans to make important discoveries
about topology and geometry starting centuries before well-known ancient mathematicians such as
Euclid, Archimedes and Pythagoras were born. For example, Pythagoras’ theorem about areas of
squares on sides of a right-angled triangle was discovered in several different countries, using
different proofs, long before Pythagoras was born! Some links to the history of geometry are
provided below.

Since switching my research focus from Mathematics to Philosophy of Mathematics in 1959 I have
been trying to understand the biological mechanisms underlying spatial intelligence in humans and
other animals, especially the mechanisms that enabled discoveries about geometrical and
topological necessity and impossibility to be made by the ancient mathematicians mentioned
above.

There are related, but simpler, spatial reasoning mechanisms and competences in other animals
such as elephants, apes, dolphins, weaver-birds, and many other species that can interact
intelligently with their physical environment, including interacting with other animals, for various
purposes.
The abilities of ancient mathematicians to make discoveries about geometric or topological necessities and impossibilities are related to even more ancient spatial reasoning abilities used in taking decisions about actions to achieve desired goals and to prevent unwanted side-effects. For example, after a painful experience, a child may work how to push a door shut without crushing fingers between door and door-frame, or how to push shut a partly pulled out drawer in a chest of drawers, without jamming fingers: don’t push while fingers are folded over the top edge of the drawer! A more complex example described below is getting a table through a doorway whose width is less than both the length and width of the table top.

Less obvious and more difficult to observe are the sophisticated coordinated muscle movements in and around the mouth of a human infant when sucking milk from a nipple. To my surprise an internet search revealed a product, named "Willow, The Smart Robot Breast Pump", also described as "Bionic Breasts", described here in 2017:


It is impressive but not as impressive as the much smaller versions produced by biological evolution, directly linked to sophisticated swallowing mechanisms!

Some human spatial reasoning abilities seem to be shared with other intelligent animals, including squirrels, apes, many nest-building birds, and aquatic mammals. Octopuses also have manipulative competences based on surprisingly sophisticated spatial reasoning abilities.

Impressive achievements are observable when animals build nests, catch and devour prey, and in some cases create and use tools to achieve various goals. Of course, not all animals, and not even all species of dogs, have equally impressive spatial reasoning abilities, as shown when some of them try, and fail, to get through a narrow gap while holding a long thin object horizontally in the mouth. I don’t know how well the origins and mechanisms of such species differences are understood by biologists.

For reasons explained below (originally presented by Kant around 1781) currently fashionable theories in psychology and neuroscience cannot explain such competences. As a result, AI systems based on such theories, cannot model or replicate the phenomena.

**Intelligent, conscious(?), subsystems of organisms**

There are even more sophisticated, but not widely recognised, forms of intelligence that are used not by "whole animals" but by biological mechanisms of reproduction and development: intelligence displayed in biological processes of chemical construction, disassembly and reconstruction that we cannot directly observe but which we would probably describe as highly intelligent if we were able to observe the processes without knowing who or what was controlling them.

For example, the hatching processes that transform the contents of a new-laid egg into an animal that emerges from the egg with both enormously complex internal physiology and also a collection of unlearnt competences available for use shortly after hatching, is a process that we cannot observe. But it must be far more sophisticated than processes we can observe, including processes that require complex forms of spatial intelligence, such as construction of a weaver bird’s nest, using intricately interwoven long thin leaves, illustrated in this collection of videos:

http://www.youtube.com/watch?v=YePKbjODrto.
Although the construction of those nests is impressive, the complexity achieved by the hatching processes inside a weaver bird’s egg, is much greater. None of the nests comes close to matching the complexity of a new hatchling’s physiology. And a newly created nest does not possess anything remotely like the behavioural competences of a newly hatched bird!

Mechanisms that are in some ways even more complex are required to explain the amazing processes of metamorphosis in insects, presented in the remarkable video included in this website: http://www.wired.com/story/how-insect-brains-melt-and-rewire-during-metamorphosis/

Those processes include disassembling some of the previously constructed physiological structures, then rearranging physical particles to produce both new physiological structures (such as wings and a proboscis) and also new cognitive competences, required for flying, feeding and mating, in an animal that previously could not do much more than crawl over plants eating some of their material, while growing in size.

To understand the differences in complexity between processes required for hatching and processes required for metamorphosis, consider the difference between (a) building a robot that can disassemble a house and then use all or most of the materials to construct a new house and (b) building a "metamorphosis machine" that can disassemble parts of a house and, while continuing disassembly, starts reusing bricks, pipes, beams, cables, and other substructures to change the house to have a different number of rooms, stairs, corridors and new plumbing facilities with new functions, all while the occupants of the house continue using the house for shelter, etc.

Some of the rebuilding during insect metamorphosis seems to require disassembling objects down to the level of sub-atomic particles that are reassembled to provide new structures with new functions -- all done while the organism remains alive, but inactive.

**Features of fundamental physics required for insect metamorphosis**

The phenomena of insect metamorphosis demonstrate that the physical universe includes mechanisms that make possible processes with the following combination of features:

- Minute (microscopic/sub-microscopic) scales of structures and processes: everything is very much smaller than apparatus in physics laboratories. E.g. in some cases the containing cocoon is smaller than a human thumb.

- Complexity of initial structures: e.g. physiological structures in organisms before metamorphosis.

- Complexity of new physical structures created by the processes: including new body parts (visible and invisible) in insects emerging from a cocoon or pupa after metamorphosis, e.g. with newly acquired wings and a proboscis for sipping nectar from plants.

- Complexity of new behavioural competences created by the processes: e.g. ability to fly, ability to find and use new sources of food, ability to mate, etc.

- Intricacy of control requirements during concurrent disassembly/assembly: e.g. because of the complexity of previously developed physiological structures that are disassembled, the need to ensure that only the right subset of structures is disassembled while the rest are preserved, and the complexity of the new physiological structures and control mechanisms created during metamorphosis, such as wings and flight-control mechanisms.
- Very low energy requirements, and small range of temperatures and energy transfers.

- Remote control of processes during both hatching and metamorphosis, possibly using unknown forces to co-ordinate different concurrent processes of chemical disassembly of older structures and assembly of new ones, e.g. producing wings that use new wing materials, along with new muscles, nerve-fibres and blood vessels, replacing old parts of the body, all achieved without the use of space-occupying physical manipulators.

A huge amount is already known about the physics and biochemistry of evolution and reproductive/developmental processes in many organisms, including details of processes related to the structure of DNA and the roles of RNA. I have tried to focus on some less well understood, more abstract, features of the processes, such as remote control of complex disassembly and assembly processes using abilities to make use of remotely sensed information about changes occurring during those processes.

A new question:
Does control of "action at a distance", without physical grippers and sensors providing feedback, require greater intelligence than control using physical manipulators?

Hatching, metamorphosis and fundamental physics

Hatching processes in vertebrate eggs are able to use (partially unknown) features of fundamental physics mentioned above to transform a large amount of relatively unstructured chemical egg-matter enclosed in a shell into an animal that emerges with extremely complex and varied, intricately interconnected, physiological structures and mechanisms, and important behavioural competences ready for use without any training,

Insect metamorphosis poses additional requirements, for mechanisms providing even more complex uses of biochemical information, and control of significantly more complex biochemical processes, after the insect has been interacting with, and feeding itself in, the environment, for some time, before metamorphosis begins.

The additional requirements for control of metamorphosis in insects seem to pose new challenges for fundamental physical theories.

It is possible that my understanding of current theoretical physics is flawed and there already exist explanations for such mechanisms and processes. However, I have not found any references to such mechanisms by physicists, although theoretical physicist Anthony Leggett has conjectured that some forms of communication between identical twins may also require unknown physical mechanisms. However, I think the facts about insect metamorphosis are much better supported by empirical evidence!

In both hatching and metamorphosis, processes in developing organisms use complex biochemical mechanisms that create:

- new physical/physiological structures

and also
- new behavioural capabilities:

Some of the capabilities used shortly after hatching or shortly after metamorphosis, cannot be based on learning in the environment, and cannot be controlled by trained neural networks, since newly hatched animals and animals emerging from a cocoon, have had no opportunity to train their neural networks while acting in the environment using the newly acquired physiology.

Moreover, trainable neural mechanisms in brains do not exist in the early stages of assembly of a new organism in an egg. Complex biochemical assembly mechanisms of the sorts discussed below are required to create neural mechanisms during later stages of hatching. Those assembly processes cannot use neural mechanisms that have not yet been created!

So neural networks are not required for, and cannot explain, important kinds of intelligence used in biological evolution and development, including construction of neural systems!

No human designed assembly mechanisms that I know about come close to matching the achievements of mechanisms produced by biological evolution, including

-- efficiency of uses of matter and energy,

and

-- minute sizes and amounts of matter in the biological mechanisms, compared with the sizes of human-designed machines for assembling or modifying structures.

Of course, it is possible that there are (secret?) laboratories unknown to me where human engineers have created machines comparable in size, capabilities and power requirements to the biological mechanisms. Possible, but unlikely!

Why "intelligent"?
The assembly mechanisms in eggs and cocoons, etc. are intelligent insofar as they control complex collections of concurrent coordinated biochemical actions, which assemble a collection of complex functional physiological structures that perform a variety of important biological tasks within the organism, at various stages in the life of the organism, before, during and after metamorphosis, in the case of insects. I suspect no human would be able to control such processes if given an array of relevant sensor readings and a collection of devices (knobs, levers, buttons, wheels, etc.) for controlling details of the assembly.

However, I am not claiming that the goals of the assembly mechanisms and their products are explicitly specified in some portion of the machinery, or that individual actions are selected by assessing their relevance to achievement of the goals. Instead, the assessment and selection processes in hatching and metamorphosis use complex unknown mechanisms that must have been "discovered" during the evolutionary history of the species, after which specifications for those mechanisms were stored in the genome and used during development.

Perhaps the labels "effective", "efficient" and "competent" are more appropriate than "intelligent" in the above contexts.

I suspect that no human designed mechanisms (including mechanisms developed in unknown secret laboratories!) come close to matching these biological mechanisms in respect of the above combinations of features.
Note:
Any human-designed robot rearranging small physical objects to form structures comparable in complexity to physiological structures assembled during hatching would be described as highly intelligent, because of its ability to use non-space-occupying mechanisms to move multiple minute physical components in parallel through already cluttered spaces to where they are needed in the developing organism.

All this challenges widely believed theories claiming that trainable neural networks explain all forms of intelligence. No neural network is available to control creation of a neural network in a new organism!

There are many online videos showing aspects of insect metamorphosis, e.g. this one showing a multi-legged Hawk-moth caterpillar crawling along and feeding on plant leaves then being transformed by metamorphosis into a moth with wings and only six legs: http://www.youtube.com/watch?v=LWOb8k0kbXY

Because of the need to explain how metamorphosis mechanisms preserve so much previously created structure and functionality, while creating new structures with new functionality, the processes of metamorphosis seem to pose even stronger challenges than explaining the hatching processes that occur in eggs of vertebrates, discussed in previous documents and workshop/conference presentations.

However, both the in-egg vertebrate hatching processes and the transformations during insect metamorphosis exceed the complexity of automated assembly processes achieved by machines that humans have designed. The biological processes seem to require far greater kinds of intelligence, in addition to occupying much smaller spaces, using far less energy, and far smaller temperature ranges than human-designed assembly systems.

Inadequacies of trainable neural networks
Many researchers believe that the main mechanisms underpinning human intelligence, including ancient forms of mathematical intelligence, are neural networks that collect statistical evidence, from which they derive probabilities.

That belief also drives massive efforts to design artificial intelligent machines by giving them trainable artificial neural networks and then training them on large amounts of data collected from observations of human question answering and decision making behaviours and/or records of robot interactions with the environment while learning to achieve various goals, in some cases also supplemented by massive amounts of information, with many difference sources, made available on the internet.

However, such beliefs about the powers of neural networks are seriously mistaken, for reasons that were pointed out by Immanuel Kant around 1781. Kant had read David Hume’s claims in his famous statement about types of knowledge and the mechanisms that made them possible. Kant thanked Hume for waking him from his “dogmatic slumbers”. Hume claimed that real knowledge could be obtained only by two means: either empirical data collection, providing statistical information from which probabilities could be derived, or logical and arithmetical reasoning.
Kant also criticised Hume by presenting examples of discovering that something is topologically or geometrically *impossible*, or *necessarily true*, which could not be based on a process of collecting data and deriving probabilities, because necessity and impossibility cannot be derived from very high and very low probabilities. They also could not have been derived from definitions of terms merely by use of logical reasoning, since those ancient discoveries occurred long before logicians had developed logic-based formal reasoning systems. I.e. they were synthetic, not analytic, in Kant’s terminology.

I don’t know whether Kant had noticed that there are intelligent non-human animals (e.g. squirrels and others mentioned above) that also seem to be able to detect spatial impossibilities or necessities and use those abilities in selecting actions. There is no reason to believe that non-human intelligent animals are able to use forms of logic-based formal reasoning proposed by human meta-mathematicians.

Kant did not use the labels "topology" or "topological" though he gave examples of what would now be called topological discoveries, e.g. the impossibility of a right hand glove fitting a left hand, without first being turned inside out. More examples of such geometric and topological discoveries are presented here, for readers who are unfamiliar with these ideas: [http://www.cs.bham.ac.uk/research/projects/cogaff/misc/impossible.html](http://www.cs.bham.ac.uk/research/projects/cogaff/misc/impossible.html)

In his criticisms of Hume, Kant unwittingly also refuted neural-net based theories of mathematical intelligence long before they had been proposed! However, he was pessimistic about human abilities to understand how human mathematical minds worked. He suggested that the mechanisms involved might lie "forever concealed in the depths of the human soul".

Kant’s observations imply that statistics-based neural networks cannot explain ancient mathematical discoveries in geometry and topology, many of which, as mentioned above, were made centuries before famous ancient mathematicians, such as Pythagoras, Euclid, and Archimedes were born.

Hume offered an early specification of logicist explanations/models of mathematical reasoning, namely derivation from definitions of terms, using only logical methods of reasoning. But that form of reasoning could not account for Kant’s geometric and topological examples.

There is no evidence that such logic-based reasoning was used either by ancient mathematicians or by intelligent non-human animals taking decisions based on reasoning about what is or is not possible in some situation, e.g. a bird building a nest or an animal trying to carry a long thin object through a narrow gap.

Kant called the truths that provable by use of logic and definitions "analytic" and the others "synthetic". He claimed that there are synthetic necessary mathematical truths, and that humans had already discovered many of them. Some of those discoveries are made while attempting to achieve practical goals, failing, and reasoning about why they had failed.

He understood that necessity and impossibility are not extremes of probability. Despite this, many thinkers nowadays mistakenly believe that neural networks that derive probabilities from statistical data can explain intelligence in humans and other animals, including ancient forms of mathematical intelligence.
I suspect that is in part a consequence of poor forms of mathematical education developed since mid 20th century, a view shared by Benoit Mandelbrot who discovered fractal geometry, mentioned below. He held opinions that were related to Kant’s ideas. A few decades ago I attended a lecture on fractals in which Mandelbrot criticised current forms of mathematical education that ignore ancient forms of spatial reasoning used in many mathematical discoveries, including his own discoveries. I don’t know whether he was aware that he was implicitly endorsing claims made around 1781 by Kant.

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**Beyond Kant:**

**Forms of spatial intelligence in biological reproductive mechanisms**

This document extends the above ideas by proposing that biological processes of evolution, reproduction and development make use of forms of spatial intelligence, implemented in the biochemical mechanisms used in production of organisms with increasingly complex physiological mechanisms and competences, including mechanisms used in their own development. A new-laid egg obviously does not contain any of the body-parts of the animal that will emerge from the egg. Less obvious is the fact that the new egg does not contain most of the mechanisms that will be used to assemble the animal: those mechanisms have to be produced during the hatching process. But producing those mechanisms from the chemical contents of the new-laid egg will require use of other mechanisms that do not exist when hatching begins.

So the hatching process must produce increasingly powerful increasingly varied mechanisms for producing new assembly mechanisms, in addition to producing all the contents of the animal that emerges from the egg. The complex, hard to understand, diagram referenced below is my crude attempt to depict some of that complexity in hatching processes of eggs of vertebrates.

But the mechanisms involved in insect metamorphosis require additional kinds of complexity, as I’ll try to explain.

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**The need for biochemical information processing mechanisms**

The ideas presented here challenge popular theories about intelligence, consciousness, and how brains work, by assigning a key role to biochemical information-processing mechanisms in synapses, contradicting currently fashionable ideas about the roles of neural networks in human intelligence and inflated claims about the powers of artificial neural network mechanisms.

These ideas also challenge logic-based theories of intelligence. Wikipedia [http://en.wikipedia.org/wiki/History_of_logic](http://en.wikipedia.org/wiki/History_of_logic) provides interesting pointers to the extremely complex history of logic, including predecessors of Aristotle, who is sometimes thought of as the founder of logic. Over many centuries in many different parts of the planet, there has been a vast amount of work on formal, symbolic, logic-based, reasoning, including development since mid 20th century of computer-based (digital) mechanisms (e.g. theorem-provers), with increasingly powerful capabilities.

But there is no evidence that biological brains contain such (logic-based, formal) reasoning mechanisms (apart from the brains of human mathematical logicians!), so those mechanisms cannot explain ancient human mathematical capabilities used centuries before well known ancient mathematicians mentioned below were born. Moreover, logic-based reasoning mechanisms cannot explain older spatial reasoning capabilities in highly intelligent non-human animals mentioned...
earlier.

**Biological mechanisms with implications for fundamental physics**

The next few paragraphs have been re-written several times -- and further re-writing is still in progress -- with possible temporary inconsistencies and unnecessary repetitions!

*Insect metamorphosis compared with vertebrate hatching*

In June 2023, while thinking about processes of insect metamorphosis and their evolution, I formed a new conjecture: that millions of years before humans and other intelligent animals evolved, single-celled organisms existed that were precursors of synapses, and biological evolution later began to produce chemistry-based mechanisms in those organisms that enabled them to collaborate using precursors of neurons to share information. Could ancient single-celled organisms that were precursors of synapses also be the earliest precursors of animals?

New variants of the oldest synapse-like cells might have grown precursors of neurons as attachments that could form links between those cells, forming ancient structures composed of collaborating synapses linked by neurons, contradicting the standard theory that neurons are linked via synapses that enable the neurons to collaborate in calculating probabilities derived from statistical records.

Recollecting a conference talk around 2008 on the complexity of chemical information processing in synapses, by Seth Grant, in Edinburgh, whose work is referenced below, led me to wonder whether related mechanisms were involved both in the earliest pre-cursors of current animals, and also in processes of insect metamorphosis.

His 2008 talk included a claim that synapses perform far more complex information processing than neurons. He even made the surprising claim that the computational power of a single synapse was comparable to the power of the internet! (I don’t know whether he would still make that claim in 2023!)

The work of Grant and his colleagues seems to me to provide support for a new conjecture that, instead of thinking of synapses as connecting neurons that do the main information-processing in brains, we should think of neurons as connecting collections of synapses that actually do the main information-processing.

The work of Tibor Ganti referenced below about the earliest single-celled organisms capable of reproduction, suggests that such organisms required complex chemistry-based mechanisms both for interacting with substances in their (liquid) environments and for reproduction. Additional chemical mechanisms must have evolved later to support forms of collaboration, followed by evolution of multi-celled organisms and use of sexual reproduction.

Much, much later, insects used extended versions of those chemical mechanisms in amazing processes of metamorphosis, transforming both physiological structures and cognitive competences in the insect.

Chemical mechanisms that evolved relatively late might have enabled variants of those ancient synapse-like mechanisms to form pairs or larger groups, linked by newly evolved neurons, and to acquire additional mechanisms, including outer coverings, and appendages for interacting with
objects in the environment, such as food sources, obstacles, and perhaps shelters from various sources of danger.

Were such collections of linked synapse-precursors the earliest animals?

In that case, the earliest ancestors of animals would have been single-celled synapse-like organisms, without animal bodies, which somehow later began to collaborate, forming more complex organisms, in which neurons somehow evolved as mechanisms to facilitate such collaboration between proto-synapses by sharing information, and perhaps also helping to hold the cells together!

(The above lines of thought occurred while I was wondering what sorts of mechanisms made it possible to control reorganisation of chemical matter inside a cocoon or pupa, while the organism remained alive, though inactive -- a formidable task.)

Perhaps very much later descendents of those early collaborating synapses developed, as yet unknown, chemical information processing mechanisms providing capabilities required for forms of intelligence identified by Immanuel Kant (referenced below), for reasoning about possible and impossible changes in the spatial environment, and necessary consequences of such changes. So a new challenge is to explain how chemical mechanisms in synapses can be used for such reasoning.

The rest of this document is a first crude attempt to fill out some of the details of that new conjecture, including the idea that precursors of synapses were single-celled life forms, long before neurons existed, and that precursors of neurons somehow evolved when neuron-like structures began to be used initially to hold collaborating clusters of "synapse-like" cells together and to enable them to share information, and then, after further evolution, to send control information from synapses to more recently evolved body parts, and also to transmit information from external and internal sensors back to synapses.

Additional organs could have evolved later, e.g. for sensing and interacting with the environment and for providing many new internal functions, all connected by neurons and other mechanisms, e.g. blood vessels, tendons, etc.

So the very ancient synapse-like organisms, connected by neuron-like structures, somehow began collaborating
- to acquire and share information, e.g. about sources of food, competitors and other threats, obstacles and opportunities,
and
- to select and control interactions with the environment.

The remainder of this document adds details to those conjectures.

Despite their complexity, the ideas presented here are bound to be over-simplified and are likely to include errors and gaps. I welcome correction of factual errors and suggestions for improvement and/or extension of these ideas and also suggestions for improved presentation!
As the ideas developed, it became clear that I was discussing extremely complex chemical mechanisms, possibly also including still unknown features of the physical universe, needed to fill gaps in the theory. I shall try to spell out some conjectured details of the mechanisms involved in the evolution of collaborating networks of synapses, and to relate them to some (possibly wildly incorrect) speculations about fundamental, not yet understood, features of the physical universe.

Processes of reproduction and development in complex biological organisms need to make use of information about partly constructed biochemical structures and processes, many of which are more intricate and more complex and involve much smaller structures than any machinery designed so far by human engineers. The sensing and controlling processes use much smaller amounts of energy than any comparably complex construction or control mechanisms designed by humans.

This raises a new question: whether those mechanisms make use of physical mechanisms not yet identified by physicists.

Before expanding those ideas about biological evolution, I'll give some background information about views on the nature of mathematical discovery, and then combine the biology with a new (half-baked) theory about mechanisms of mathematical cognition that evolved from conjectured ancient biochemical information processing mechanisms.

Synapses, Kant, and explanations of human mathematical abilities
In 2008, when I heard Seth Grant, mentioned above, talk about synapses, it had become fashionable in some research communities to claim that intelligence in humans and other animals was based on the operation of systems of neural networks that were trained on statistical data from which they computed probabilities that could be used in making predictions, explaining observations, and selecting actions to achieve desired goals -- unaware that Kant’s arguments had already refuted such claims in 1781 as explained Immanuel Kant

Inspired by Kant and the work of Seth Grant I recently began to suspect that ancient chemical mechanisms in synapses were also evolutionary precursors of chemical mechanisms involved in consciousness, including types of mathematical consciousness, that evolved much later, such as consciousness of geometric and topological impossibility and necessity.

That suspicion somehow led me to the conjecture above that it is more accurate to say that neurons are used to connect synapses, enabling the synapses to collaborate, than that synapses are used to connect neurons, enabling them to collaborate! However, both alternatives are too simple: much elaboration and refinement is required.

Some speculative evolutionary history
Very early organisms included cell structures containing interacting chemicals surrounded by a membrane that allowed transfers of chemicals to and from the environment, providing sources of energy and materials for growth and reproduction, and also waste disposal. Somehow, evolutionary processes enabled some of those structures to benefit by collaborating with others, sharing information about the contents of the environment, and perhaps collaborating in acquiring food and coping with obstacles, dangers, and competitors.
As collections of collaborating synapse-like cells grew more complex, additional mechanisms, including information-sharing mechanisms, might have evolved to enable them to interact more effectively with their environments, using increasingly complex sensors, along with motors possibly composed of cell-clusters, all held together in membranes that were precursors of structures like external skin and shells -- all evolved from collections synapse ancestors connected by nerve fibres holding cells together and sharing information between them.

Over time, the numbers of components in more recently evolved organisms increased, requiring increasingly complex and varied mechanisms for acquiring various kinds of food and sharing nutrients among components. This required use of more kinds of information, including information about locations of food, obstacles, dangers, etc. It also required mechanisms for internal distribution of nutrients and disposing of waste, and also information-processing mechanisms for controlling all those mechanisms, including controlling mechanisms for combining forces applied to external objects, such as food, obstacles, competitors and predators.

The above line of thought suggests that the earliest precursors of the neural networks that are now used in animal brains evolved as mechanisms for combining and integrating collections of ancient collaborating biochemical information processing cells, namely the precursors of synapses, performing processes of sensing, perceiving, control of behaviour, learning, and reasoning, including detection, acquisition and use of food, and escaping from predators or other sources of danger!

**Did synapses come first?**

If the above conjectures are correct, the popular view that synapses provide connections between neurons needs to be replaced by a view of neurons as having evolved to provide connections between synapse-like and other mechanisms around the body, including sensors and muscles. So, instead of synapses connecting neurons, neurons connect synapses, allowing them to collaborate. Neurons also linked them to other parts of primitive ancient animal bodies.

A corollary of this idea is that brains did not originally evolve to control the behaviours of bodies. Instead, bodies with limbs, mouths, external sensors, etc. evolved after the evolution of movable containers for ancient organisms composed of collections of (proto-)synapses. Such containers allowed their contents to avoid harm, obtain nutrients, and manipulate and process food items.

So body parts evolved as additions to the earliest brain-like organisms!

The earliest precursors of those collaborating synapses would have been single-celled organisms that absorbed chemicals from their environment, enabling them to grow and reproduce.

**Note:**

I am not suggesting that such clusters of synapses were enclosed in a skull! It is more likely that the early clusters were enclosed in a flexible membrane that had evolved from the membranes enclosing the earliest single-celled creatures.

I have tried searching for the occurrences of "bone" and "skull" in several books on life and evolution including those referenced below, but hardly any of them include significant information, or any information, about the evolution and uses of bone tissue. Notable exceptions are books authored or co-authored by Sean B. Carroll, e.g. *Shubin, Tabin and Carroll (1997)* and *Caroll (2005)*. However, those publications don’t explicitly address my questions about connections.
between evolution of physiological structures and evolution of information-processing capabilities, including spatial intelligence.

Sexual reproduction using double-stranded DNA may have evolved much later than the earliest forms of spatial intelligence, both as a mechanism that enabled sharing information about useful mechanisms and behaviours, and as a mechanism for increasing the diversity of new designs based on previously evolved biochemical mechanisms.

[I am not satisfied with the above explanation. I shall try to find a better way to formulate these conjectures.]

There seems to be divergence of opinions on many aspects of early evolution. One conjectured account of evolution of some aspects of sexual reproduction relevant to this discussion is available in an online video:

http://www.youtube.com/watch?v=qsn4z7bNb14 "How Sex Became a Thing".

As far as I can tell, my conjectures about evolution of animal synapses as derived from single-celled organisms have never previously been proposed, although the conjectures were partly inspired by reports on chemical information processing mechanisms in synapses by Seth Grant and his colleagues referenced below.

There are also connections with the ideas of Tibor Ganti about the earliest forms of life, mentioned above, and even closer connections with ideas about "symbiogenesis" proposed by Lynn Margulis, whose work I think I first encountered around 2008, mentioned again below.

The newest ideas about evolution of synapses presented here were triggered in June 2023 when I first noticed gaps in ideas that had been presented in my earlier papers and talks between 2020 and January 2023 on hatching processes and mechanisms in vertebrate eggs, and their implications for biological evolution.

The earlier papers and talks included arguments about the nature of spatial intelligence, including abilities to make use of information about spatial impossibility or necessity, going back to my 1962 DPhil thesis defending Kant’s philosophy of mathematics, mentioned above.

Talks since late 2020 also presented examples of chemistry-based self-assembly mechanisms in eggs of vertebrates which produce hatchlings that emerge not only with very complex physiological structures, but also with significant genome-based forms of spatial intelligence used very soon after hatching. Those examples were used as evidence supporting the claim that chemical mechanisms might provide more powerful forms of spatial intelligence than neural nets, as well as potentially supporting Kant’s claim that there are non-empirical and non-logic-based forms of reasoning about spatial necessity and impossibility.

A new development occurred in June 2023, when I first realised that processes of metamorphosis transforming previously assembled physiological structures in an insect, and providing both new physiological structures and new forms of intelligence (e.g. abilities to fly to obtain food) provided new evidence of the powers of chemical information in controlling chemical construction processes.
I searched for, but could not find, explanations of how those chemical processes used in metamorphosis were controlled. I formed a suspicion that the best candidate mechanisms would be variants of the chemical processes already identified in synapses, which, in the light of information about the computational powers of synapses presented by Seth Grant, mentioned above, might be capable of controlling both chemical transformations of body structures, and also chemical transformations of behaviour control mechanisms in brains, including control during metamorphosis, although Grant did not make those specific claims.

The power of chemical information-processing
All this points to the powers of chemistry-based information processing as far richer than the powers of neural networks collecting statistical data and deriving probabilities.

The chemistry based mechanisms are also very different from the logic-based formal mechanisms developed during the 19th and 20th centuries, partly inspired by the work of ancient logicians.

I now conjecture that chemical mechanisms in synapses are the basis of forms of spatial intelligence in humans and many other intelligent animals, including apes, squirrels, aquatic mammals and many species of nest-building birds. Finding support for that conjecture will require extending the research on chemistry-based forms of information processing, discussed below, using much older features of the physical universe than neural networks. I'll start with some more detailed conjectures.

Two conjectures:
(a) Complex chemical mechanisms related to those involved in insect metamorphosis had key roles in ancient forms of reproduction, using features of fundamental physics, conjectured below, that may not yet have been noticed by physicists, and which may require revision of current theories about fundamental physics.
(b) Currently unknown chemical mechanisms related to those reported by Grant, are used not only in controlling processes of metamorphosis in insects, but also in previously-unrecognised key processes in human and non-human forms of consciousness and spatial intelligence. At present I don't have detailed ideas about how those chemical processes work, but will present examples of what they achieve.

The roles of speed-control mechanisms
An important aspect of the connection between evolutionary and developmental processes is the role of control of relative speeds of processes of gene expression. A useful overview of relevant work by Stephen Jay Gould, can be found here:

Evolution and Development for the 21st Century
which includes the following (slightly re-formatted here):
"More than anyone else, the Harvard paleontologist Stephen Jay Gould (left) drew attention back to embryos as evolutionary time capsules. In his landmark 1977 book Ontogeny and Phylogeny, Gould documented the history of scientific research that had led to so much confusion. But he also demonstrated that the wealth of cases could be organized by some simple principles. Imagine that the timing of development is controlled by two knobs like you’d find on a radio. One controls the rate at which an organism grows. The other controls the rate at which it changes shape over time. Random mutation may end up changing the settings of each knob, thereby speeding up or slowing down the rate at which a species’ embryos develop. These kinds of adjustments can alter the entire body of an organism, or individual organs."

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Important gaps in this work
There are many gaps in the ideas presented below, including the need to explain forms of social interaction, types of empathy, abilities to acquire and use information about or to speculate about or to influence, states of mind of other individuals.

The work of Mike Ferguson at Dundee University is also relevant, though I have so far read only a subset.

Recent related work. since 2020
In my talks and online documents produced between 2020 and January 2023 reasons were given for thinking that biochemical mechanisms whose details have not yet been discovered are needed to explain forms of intelligence that cannot be explained by popular theories about the powers of neural networks mentioned above.

Alternatives to statistics-based neural network mechanisms, not yet noticed or understood by psychologists or neuroscientists, must be available in human brains, for reasoning about spatial structures and processes that led to ancient mathematical discoveries in geometry and topology, including discoveries about spatial impossibility and necessity made centuries before well known ancient mathematicians, such as Pythagoras, Euclid and Archimedes were born. I shall try to specify some of the features needed by such mechanisms below.

(Some of that early history of mathematical discovery is referenced below.)

Some background for what follows:

Necessity and impossibility are not degrees of probability
As explained above, insofar as ancient mathematical discoveries were concerned with spatial necessity and impossibility they could not have been based on mechanisms that merely collect statistical evidence and derive probabilities. Kant pointed this out long ago in his criticism of Hume.

I suspect that many proponents of mistaken theories about powers of neural networks did not have the good fortune to be taught ancient methods of spatial reasoning using diagrams, that were normally included in school mathematics classes up to around the middle of the 20th century, before use of formal, logic-based, symbolic reasoning mechanisms began to dominate mathematical education, which was also before theories about learning based on neural networks became fashionable.

Evolution of mechanisms that make use of spatial necessity and impossibility
I shall try to show how, long before humans existed, discoveries about possible and impossible spatial structures and processes, and forms of control, were made, and used implicitly, not by humans or other animals, but by ancient evolutionary processes, which produced mechanisms for creating, manipulating and modifying increasingly complex spatial structures in organisms of many types.

I am not claiming that any form of intelligence existed in that ancient universe, only that chemical mechanisms capable of being used very much later to create intelligent organisms existed, which were first used by blind, unintelligent (purposeless), mechanisms of biological evolution and development that produced increasingly complex but unintelligent primitive organisms.
Those mechanisms, and their products, were combined in later evolutionary and developmental processes in ways that eventually produced what we call intelligent organisms, on at least one planet. We (humans) may never know whether such mechanisms have produced, or will produce, organisms using similar forms of intelligence, in currently unknown parts of the universe.

That was not a process in which some intelligent agent selected the goal of producing intelligent agents and used appropriate means to achieve them. An analogy: a malicious individual who understood the mechanisms that produce hurricanes might be able find a way to set up mechanisms to create hurricanes to harm inhabitants of some terrain. But that does not mean that hurricanes, or mechanisms that create hurricanes, are intelligent.

Similarly, production of intelligent organisms by biological evolution, using mechanisms that can create intelligent systems, was not an intelligent process. The process made use of chemical mechanisms that had been used much earlier in processes that produced much simpler, unintelligent organisms, such as bacteria!

As noted above, Kant conjectured around 1781 that the mechanisms underpinning ancient mathematical discoveries of spatial impossibilities and necessary relationships, including ancient discoveries in geometry and topology, would "lie forever concealed in the depths of the human soul", whereas I now conjecture that they will turn out to be based on currently undiscovered biochemical mechanisms conjectured above, i.e. mechanisms with a very long evolutionary history, starting long before evolution produced humans and other animals with spatial intelligence. This potentially provides new justifications for Kant’s ideas and for claims I have been making since defending Kant in my DPhil thesis in 1962, as explained below.

How evolution evolves
Why evolutionary tree diagrams are seriously misleading

Biological evolution is often represented as a uniform process producing a tree-structured collection of forms of life, as shown here by Wikipedia http://en.wikipedia.org/wiki/Phylogenetic_tree using trees whose branches diverge and become more numerous over time, but never merge.

Use of such tree diagrams hides the fact that in species that use sexual reproduction, every individual brings together two evolutionary histories, the histories of two parents, each of whom also combines two histories. So each individual member of such a species has multiple backward branching ancestors.

Tree diagrams also ignore the fact that many species, including humans, make essential use of other products of evolution. For instance the bacteria that are essential for human digestive processes have different evolutionary histories from humans. A new human infant has to collect bacteria living in its mother during the birth process and from mother’s milk, not during gene expression in the womb! There’s no way to represent the evolution of such cross species cooperation in standard evolutionary diagrams.

Moreover, biological evolution has repeatedly produced mechanisms that extend the abilities of evolution itself, to make and use new discoveries, and in doing so it frequently combines different products of earlier evolution, a feature that cannot be represented in tree-structured diagrams, whose branches never merge. My thinking about that was partly inspired by ideas of Lynn
Margulis, in her theory of *symbiogenesis*, briefly summarised below.

For a long period in the history of our planet, evolution was not capable of producing humans. There are several reasons why it was not possible for humans to evolve a few centuries after life first began on this planet, apart from the time needed to evolve all the detailed components of modern human genomes. Other factors obviously included the need for other organisms that humans could consume as food, and the organisms on which those organisms depend.

Less obviously, as pointed out by Lynn Margulis, mammal bodies, including human bodies, make essential use of other organisms that are not by-products of the mother’s genome, and are not consumed as food, including bacteria used in digesting food. So humans could not have evolved before those organisms.

Diagrams showing tangled networks can give more accurate representations of evolution than diagrams showing only tree structures, but are more difficult to create and to read, including this unpleasantly complex diagram used for several of my talks in 2022: [http://www.cs.bham.ac.uk/~axs/fig/evo-devo/evo-devo-final.jpg](http://www.cs.bham.ac.uk/~axs/fig/evo-devo/evo-devo-final.jpg), produced before I began to think about processes in which different evolutionary lineages are combined, producing new, more complex species. That diagram was inspired by a suggestion by Susan Stepney at York University after one of my zoom presentations. However, it does not include the ancient evolutionary processes combining previously evolved single-celled and multi-celled organisms, producing new forms of reproduction and development, discussed here.

**Evolution of spatial control and reasoning competences**

Many "discoveries" about possibilities and limitations of spatial processes were made and used by self-extending biological processes long before human mathematicians, scientists, engineers and architects existed. Those discoveries produced new types of organism with new spatial reasoning powers and also extended the powers of biological evolution and the powers of reproductive processes in those species! But those organisms did not know what they were doing, just as trees don’t know what they are doing, or why they are doing those things, e.g. when they grow branches or when chemicals produced in one part of a tree are transmitted to other parts.

So, long before humans existed and began to discover ways of extending their powers of reasoning and discovery, "blind" biological evolution began (blindly) to extend the mechanisms it used.

Those prehistoric "discoveries" by biological evolution led to evolution of new types of biochemical mechanism controlling reproduction and development, used in the development of many non-human species, including development in insects before and during metamorphosis.

That required production of new, increasingly complex, physiological mechanisms that were capable of performing increasingly complex tasks, including increasingly complex self-assembly tasks. Those increases in complexity and "blind intelligence" occurred both in evolutionary processes and in individual developmental processes, such as hatching processes in eggs of vertebrates and metamorphosis in insects.

**Evolution of mechanisms required for insect metamorphosis**

In the evolution of insects that use self-transforming metamorphosis (e.g. transforming a crawling insect to a flying insect), developmental mechanisms previously used to enable assembly of
physiological structures were extended to include chemical *disassembly* of previously constructed physiological structures, and re-use of some or all of the chemical components to build new structures, within a cocoon or pupa.

*A human would need to be highly intelligent to be able to design and build such mechanisms.* Biological evolution on this planet achieved that a very long time ago without being driven by any explicit prior motivation, and without using any intelligence. That evolutionary transition would have been impossible if the required chemical mechanisms had not already existed.

There must be a vast collection of possible evolutionary trajectories that have never been actualised anywhere in the universe, and never will be. For example, there is a huge (infinite?) class of possible languages for communication that could in principle have evolved in human communities, but never will evolve.

*However, a subset of the physically possible varieties of metamorphosis were produced by blind biological evolution, a long time ago, not because evolution seeks new designs, but because interactions between organisms and chemically rich and changing environments happened to trigger new processes during reproduction of previously evolved organisms, and a subset of those processes produced something new that was able to survive, and a subset of those new variants were more complex in their physiology and/or behaviours than any of their ancestors.*

Evolution of varieties of metamorphosis seems to have been an unnoticed aspect of the key idea of evolution by natural selection, independently developed by Charles Darwin and Alfred Wallace, before anything was known about the chemical mechanisms involved in reproduction and evolution, such as the importance of the double helix in DNA.

**Biochemical mechanisms required for metamorphosis**

No products of human engineering come close to matching insect metamorphosis in all the following respects:

-- complexity of initial states,
-- complexity of transformations to new states,
-- complexity of final structures,
-- small amount of space used (not much larger than a typical human thumb),
-- small amounts of matter involved,
-- variety of types of matter used,
-- variety of types of matter produced
e.g. bones, muscles, blood vessels, blood cells, skin, nerves, wings, etc.
-- low energy requirements,
-- sophistication of new behavioural competences produced, including flying, feeding, and mating.

Increases in complexity of such mechanisms and processes can occur both during evolution of increasingly complex species -- requiring increasingly complex assembly mechanisms in more recently evolved species, and also during reproduction of individual organisms, where later stages of reproduction require more complex mechanisms than earlier stages of development of the organism.

In such cases, earlier stages of reproduction must be capable of (repeatedly) producing new more complex mechanisms used in later stages of reproduction. That was the main theme in my presentations of increasingly complex ideas about hatching processes, between 2020 and 2023,
crudely summarised in the evo-devo diagram linked above.

For example, hatching processes in eggs start off using relatively simple biochemical decomposition and combination mechanisms, but as they produce more complex physiological structures in the developing organism, inside the egg, the hatching processes also extend the powers of the hatching mechanisms, as required for later stages of hatching.

Across generations the processes and mechanisms became more varied and more complex. Many recently evolved egg-laying species use more complex hatching processes, and more stages of in-egg development than their egg-laying ancestors.

So, neither biological reproduction (in complex species such as insects and vertebrate animals) nor biological evolution is a uniform process. And there is no reason to believe that further increases in complexity and variety of life forms and reproductive mechanisms are impossible.

Moreover, if there are any other parts of the universe in which forms of life have evolved using the same basic chemical mechanisms combined in different ways, the evolutionary trajectories may have been very different in the vast majority of them, because of differences in physical details on different planets, or in different galaxies.

Evidence on this planet shows that the physical universe includes chemical mechanisms that are capable of repeatedly producing increases in variety and complexity of chemical mechanisms of reproduction over millions of years, resulting from accidental interactions between products of evolution and entities in their environments, including other products of evolution, as well as products of non-biological processes, such as earthquakes, volcanic eruptions and asteroid impacts.

The same underlying physical mechanisms could produce very different evolutionary trajectories in different parts of the universe.

**Implications for theoretical physics**

Despite centuries of advances in scientific understanding on this planet, there is no reason to assume that all the relevant fundamental features of the universe that have important roles in biological evolution and development have already been discovered by human scientists.

**Early evolution of spatial intelligence**

If humans ever design machines capable of performing assembly tasks that are comparable to the forms of assembly used in biological reproduction mechanisms, i.e. transforming a relatively unstructured collection of chemicals into an animal with a complex physiology and behavioural competences required for survival, those machines will be thought of as highly intelligent machines -- far more intelligent than anything designed so far by humans to perform physical assembly tasks.

But we don’t normally think of biological processes of reproduction, development and evolution, which have produced such machines, as intelligent.

Perhaps we should, in which case we can look for varieties of evolved intelligence, especially types of spatial intelligence, in biological reproduction processes that existed millennia before humans and other animals regarded as intelligent, evolved. No kind of deity is required: there is clear evidence that the physical universe happens to have features required to support such evolutionary processes. This type of intelligence also does not involve intentions or predictions, although some
of the products have those capabilities.

Moreover the uses of such forms of intelligence (competences) need not have been driven by any form of explicit motivation. E.g. one of the consequences of forms of life moving from water to land was evolution of very tall trees. But that did not require any of the products of evolution involved in that process to be motivated to produce tall trees. Likewise the fact that the mechanisms of evolution were capable of producing humans and did produce humans does not imply that there was ever any motivation to produce humans before any existed.

Of course, humans have found ways of channelling the powers of biological evolution to produce desired new organisms, including new foods, and new types of medication, though such developments can also produce unwanted consequences, some of them disastrous.

A later development -- Meta-configured genomes
The ideas above, are related to ideas about “meta-configured genomes” developed in collaboration with Jackie Chappell after she came to Birmingham in 2004. The meta-configured genome theory extended Waddington’s ideas about species that have species-specific "epigenetic landscapes", referenced below.

The meta-configured genome (M-C-G) mechanism is not in competition with the mechanisms of hatching or metamorphosis discussed here. Rather it is a feature of relatively recently evolved developmental mechanisms based on multi-layered genomes, where layers that are expressed at relatively late stages of development make use of parameters (items of information) acquired from interactions with the environment, including members of other species during earlier stages of gene expression.

This allows later stages of gene expression (after birth or hatching) to be deeply influenced by aspects of the environment, including environmental features that are products of earlier generations of the same species! (There are many examples on this planet, including uses of sign languages by deaf people and some of the non-deaf people they interact with, and many specialised notations such as musical notations and more recently computer programming languages.)

This also allows members of different species to influence each other’s development -- which may produce either cooperation or competition, or a mixture of both.

The meta-configured genome theory helps to explain the constantly growing diversity of human languages (including technical and scientific formalisms), engineering competences and achievements, artworks, mathematical discoveries, and scientific theories: all of which are still developing in different ways around our planet. But that is not the focus of this paper!

It now seems to me to be possible that some species combine both meta-configured genomes and mechanisms of metamorphosis during individual development, e.g. an insect that either before or after metamorphosis uses information about aspects of the environment that were modified by its ancestors. Perhaps there is a species of ant that develops different sorts of ant-hills in different parts of this planet, illustrating this point.
Humans achieve that sort of diversity without using metamorphosis!

**Increasing complexity of biological processes**

During evolution of self-extending processes, the processes of reproduction can become increasingly complex. So an animal hatching in an egg of a recently evolved species may go through a larger variety of increasingly complex and increasingly varied changes, within the egg, than its ancestors did.

Between January 2021 and January 2023 I presented a series of increasingly ambitious talks illustrating some of those evolutionary changes producing more complex developmental processes and mechanisms in eggs of vertebrates, and suggested that requirements of those mechanisms might indicate gaps in current theories about fundamental features of the physical universe.

The ideas were extended several times during 2021 and 2022, as I noticed more complex and varied features of hatching processes, generating additional requirements for explanatory mechanisms -- and also making it increasingly difficult to present the ideas in the time available for a conference talk! A summary of the ideas about hatching and evolution was presented in an invited talk for a Tokyo-based online workshop in January 2023.

Six months after that event, in June 2023, thinking about metamorphosis in insects generated further, even more complex, new ideas not included in my earlier presentations or online documents. Previously unnoticed differences between hatching processes in vertebrate eggs and processes in insect metamorphosis, raised new questions for theoretical physicists, biologists, neuroscientists, and philosophers. This, still evolving, document was a result of that process!

**Detecting impossibility/necessity**

A related point: many forms of intelligent action require abilities to detect that certain structures or processes are impossible, or impossible before the current configuration has been changed, and that some of the possible processes will necessarily have certain consequences, such as bringing items together, or keeping them apart.

High calibre human engineers and architects have such abilities, whereas statistics-based neural networks cannot make such discoveries because statistical reasoning is incapable of establishing impossibility or necessity, a fact noted by Immanuel Kant in 1781, as explained below.

I suggest that

constraints on tasks of biological mechanisms for deciding what can be done and what needs to be done next during processes of disassembly and assembly of complex physical structures that are parts of larger structures in biological organisms

are related to

requirements for mechanisms for making ancient discoveries in geometry and topology, concerning which spatial processes are possible or impossible in various conditions and discoveries about necessary consequences of certain processes.

These requirements were pointed out by Immanuel Kant in 1781 as explained below.
I now think the key mechanisms in humans underlying such discoveries are biochemical, and I suspect that those human reasoning mechanisms are related to, and are perhaps recent descendents of, very ancient biochemical mechanisms involved in controlling reproductive processes in many species, including developments during hatching processes in eggs of vertebrates and processes in pupae, or cocoons, of insects that undergo metamorphosis during development, mentioned above.

I also suspect that simpler versions of those mechanisms are used in many non-human animals with high levels of spatial intelligence, e.g. squirrels and other animals mentioned above.

My claims need to be “fleshed out” by specifying brain mechanisms that can perform such tasks -- a challenge for future research on brain biochemistry! As remarked above, the work of Seth Grant, is relevant, but would need significant new developments to answer my questions. Such developments, unknown to me, may already have occurred!

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**Background to the new ideas in this document**

Between 2020 and January 2023 the ideas about hatching processes in vertebrate eggs, presented in invited talks, were repeatedly extended as I noticed new features and constraints, reported in a series of increasingly complex and ambitious invited presentations during 2021 and 2022, and most recently in an invited talk in January 2023 presented online using zoom, at the conference hosted in Tokyo mentioned below. Those talks suggested that hatching processes and mechanisms in eggs of vertebrates might pose challenges to current theories about fundamental physics.


Several months later, in June 2023, I began to think about processes in insect metamorphosis that seem to pose stronger challenges to current theories about the physical universe than the previously described facts about hatching processes in eggs of vertebrates. I have tried to explain those challenges in this document. However, it is possible that the challenges are illusory because of my limited understanding of current theoretical physics!

The facts summarised above imply that the processes of metamorphosis in insects add significant complexities, described below, to the requirements for mechanisms able to explain hatching processes in eggs, discussed in previous talks and documents.

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**Insect pupation/metamorphosis: a brief summary**

In some insect species, after a period of feeding and growth, with no wings, the insect constructs a case (a pupa or cocoon) around some or all of itself, within which parts of its body are decomposed, and as mentioned above, the products of chemical decomposition are used to assemble new structures such as wings, a proboscis, and other new body parts, and also to produce new behavioural competences requiring modified brain structures, such as the ability to fly, feed on nectar in flowers, mate, and (in females) to lay eggs. All these changes in an insect are produced by processes of chemical disassembly and reassembly referred to as **metamorphosis**. Those changes differ across species, but those differences in details will be ignored here.
During early development of such insects complex physiological structures are created, then later, during metamorphosis, parts of the insect are disassembled and some of the resulting components used, possibly in combination with other physical particles available in the body of the insect as a result of feeding, to create new, very different, structures, in roughly the same space. Some insects also re-use chemical components to form a temporary external structure, a cocoon or pupa, enclosing some or all of the insect during metamorphosis.

Deciding what to do when, and how to control a complex collection of chemical disassembly and assembly processes conducted in parallel in a context that is constantly altered by preceding actions, seems to require a great deal of intelligence, including abilities to detect if something has gone wrong and requires modification. (The occurrence of developmental abnormalities indicates that these control processes are not infallible. Such developmental abnormalities and errors may be important drivers of biological evolution.)

I suggest that all this poses deep challenges to current scientific theories. Neither current neuroscience, nor current AI can explain or model these mechanisms. I shall try to explain why they may also be problematic for current theoretical physics, though my understanding of current physics may be insufficient for this assessment.

A fact worth emphasising:
The processes of metamorphosis occur at naturally occurring temperatures and pressures, in very small (insect-sized) spaces, unlike the processes and mechanisms in modern fundamental physics research establishments, as reported here:
http://home.cern/science/engineering/cryogenics-low-temperatures-high-performance

Note: I am ignoring many detailed differences of physiological structures and processes across insect species -- on which my knowledge is currently very meagre. For example, there are several thousand different species of dragonfly. The achievements of biological evolution hundreds of millions of years ago are amazing.

Implications of insect metamorphosis

There are very many types of insect, with different shapes, sizes, habitats, behaviours, lifespans, mode of reproduction, etc. In some insect species, partial disassembly and reassembly of parts of an individual happen approximately in parallel, within a space only slightly larger than the insect, during metamorphosis in a pupa or cocoon, in a process lasting up to a few weeks, producing new physical structures (e.g. wings) and new behavioural capabilities (e.g. flying).

These transitions require extraordinarily complex control of many concurrent sub-microscopic processes in that space, involving huge numbers of physical particles, whose locations within the organism and their chemical bonds are altered.

These processes raise questions about fundamental features of the physical universe that make such processes possible.

Like many other researchers, I have known many of the facts for many years, without asking the questions posed below or noticing the implications. I am probably not alone in that respect. A vast amount of literature about metamorphosis in insects is available online. So it is possible that some of my questions are answered and conjectures supported or refuted in documents that I have not
yet found. It is also possible that nobody else has thought about, or written about, the same
detailed questions!

**Different varieties of disassembly and reuse**

Disassembling a house built by humans and using the old materials to build a new (identical, or
altered) house does not raise the same questions. For example, there is nothing mysterious about
how a collection of bricks, planks, water pipes, electric cables, beams, roof-tiles, and other
materials obtained from the original house can be moved around, possibly cut into smaller pieces,
or joined to form larger structures, and used, possibly with additional new components, to
assemble a new structure by adding a subset of items at a time to the new growing structure.
That’s roughly how the original house was constructed.

But no mechanisms known to human construction engineers can cause very large numbers of very
small components of a building to move concurrently through space, to form a new building
occupying approximately the same location as the original building, with some parts of the original
building decomposed and the matter used to create new parts required in the new building, along
with control mechanisms for the new parts, all done at temperatures and pressures that are not
harmful to living organisms, using only small amounts of (chemical?) energy, in a space
comparable in size to a human thumb!

That sort of concurrent disassembly and reassembly is what happens to an insect during
metamorphosis, though unlike human constructions, insects before and after metamorphosis are
active organisms, sustaining themselves by feeding in a complex environment, and they remain
alive during the processes of reassembly, with enduring and partly functioning physiological
components.

**How is all that possible?**

What physical mechanisms, used in a process of metamorphosis can cause trillions, of particles in
an insect to move, in different directions, along different routes, to new locations where they
acquire new but pre-specified relationships (e.g. new chemical bonds and new spatial
relationships) through many stages of reassembly, involving much concurrency, forming new
physiological structures (such as wings), and also creating new brain mechanisms and neuronal
connections to control the new structures (e.g. while flying, feeding, mating, etc.)?

All the physiological transformations occur within approximately the same space as was previously
occupied by the original insect, and they occur while the insect remains alive, though inactive.

How are those processes controlled? How are all the many different forces and resulting motions
*coordinated*, so that all the rearranged particles move to the right places at the right times, and
without collisions, apart from occasional errors. (As mentioned above, some developmental "errors"
may be sources of important evolutionary developments.)

A sub-sub-question: is it possible that currently known forces (gravitational, electrostatic,
electromagnetic, ... forces) are not the only causes/controllers of motion, or change of motion, of
physical matter??
The requirements for coordinating so many concurrent, co-located multi-directional movements of physical particles, while preserving important features of the whole object constituted by those particles, have implications for the structure of physical space-time.

For example, is all this possible if space-time is discrete, not continuous? If it is discrete, then simultaneous linear motion, or simultaneous motion of linked particles along smooth curves will not be possible for all components. As a result, relationships of distance and direction between particles will constantly change discontinuously, as parts are translated in different directions and also rotated. I have attempted to explain why discreteness may have these implications in the appendix below. However, Tony Leggett pointed out that the discontinuities may be insignificant if the minimal distances between locations in discrete space-time are sufficiently small, compared with distances between particles.

20 Jul 2023: Another example: Starfish embryos
Some time ago, Leo Caves kindly sent me this information showing crystallogenesis and large-scale wave motion of starfish embryos: http://youtu.be/bki2kl8aQvg.
It seems to be very relevant, though I am not yet sure exactly how this relates to the other examples of self-organisation discussed here.
Further information found via Leo Caves is linked below.

Note added: 12 Jul 2023
I have just stumbled across this paper by Ethan Siegel:
Even In A Quantum Universe, Space And Time Might Be Continuous, Not Discrete
I have not yet taken in all of it, and cannot judge its importance!

A question for any physicist, or philosopher of physics, reading this:
Through evolution of metamorphosis in insects, nature (the physical universe) has provided us with some low cost, low energy, small scale, widely available, laboratories that raise deep unanswered questions about the nature of the physical universe.

Are there any microscopic or sub-microscopic, non-space-occupying, physical mechanisms that are known to be capable of reliably moving many physical particles already within a living organism, concurrently, non-randomly, in different directions, through the same space, so as to produce new, very different, physiological structures, with new capabilities, occupying approximately the old space, which is still mainly occupied by many older (pre-metamorphosis) physiological structures, some of which are preserved while the chemical contents of other structures are disassembled and re-used for the new physiological structures, as happens when metamorphosis changes an animal’s structure and capabilities by rearranging a significant subset of its constituent physical particles?

My internet searches have not revealed any other examples apart from insect metamorphosis, though what I have found, e.g. in papers or presentations on fundamental physics, by prominent theoretical physicists, seems not to allow for the possibility of such highly coordinated processes of concurrent disassembly and reassembly of a large variety of richly interconnected complex physical mechanisms all occurring roughly within the originally occupied space.
Are the mechanisms used in insect metamorphosis beyond what current theoretical physicists can explain?

If so, that may be partly because known mathematical formalisms and reasoning mechanisms are incapable of coping with such processes, just as the forms of mathematics known to Newton and Leibniz, two great past mathematicians, were incapable of specifying, and reasoning about, computational structures and processes discovered or invented during the 20th century.

Related earlier presentations

Since 2020, I have given a sequence of increasingly complicated talks presenting ideas that emerged while thinking about hatching processes in vertebrate eggs, which I claimed challenged current fundamental physical theories.

However, the facts about insect transformations during metamorphosis significantly extend those challenges, sharpening the questions about fundamental features of the physical universe.

At the time of my Tokyo talk in January 2023, mentioned above, I had not noticed the relevance of insect transformations in a pupa/cocoon to the ideas presented in the talk. As far as I can tell (on the basis of internet searches) nobody else has noticed those connections and questions, although the basic facts about metamorphosis are very widely known!

Previous ideas and questions related to reproduction and development in vertebrate species

The January 2023 talk, and earlier talks since 2020, discussed hatching processes in eggs of vertebrate egg-laying species, including tortoises, alligators, lizards, and various bird species, among many others.

Those talks focused on developments within vertebrate eggs, during hatching, emphasising increasingly species-specific multi-stage developmental processes occurring inside eggshells, reorganising the physical/chemical contents of eggs, to assemble a vertebrate animal inside the shell, and provide it with competences used later, after hatching; competences which many researchers in psychology, neuroscience, AI and philosophy (mistakenly) think must somehow be learnt by neural network mechanisms that collect statistical data during actions performed in the environment, and use the data to derive probabilities, used in taking decisions about actions.

In contrast, I conjectured that biological evolution had produced mechanisms that collect information about spatial structures and processes and then draw conclusions about necessity or impossibility of geometrical and topological consequences, as opposed to high and low probabilities.

I now suspect that the (ancient) human reasoning mechanisms that discover geometrical and topological necessities and impossibilities are related to the biochemical mechanisms that control in-egg or in-cocoon disassembly and reassembly processes without having to collect statistics and derive probabilities on which to base control decisions.
If so, then perhaps ancient forms of geometrical and topological information processing, implemented using physical (biochemical) mechanisms not yet known to science, were being used in biological control mechanisms long before humans evolved.

During 2022 and in my January 2023 talk about hatching mechanisms, I suggested that such ancient chemical control mechanisms are used by in-egg developmental processes in vertebrate species.

Those hatching processes manipulate chemicals provided in the egg by the mother, which are decomposed and the constituents used during hatching to create increasingly complex, increasingly species-specific, physiological structures, until the foetus is ready to break out of the shell.

Those chemical assembly mechanisms in eggs provide not only new physiological structures and mechanisms, but also complex species-specific behavioural competences ready for use after hatching, i.e. without requiring any training of neural networks, commonly assumed to be required for such competences.

A newly hatched chick does not have to be trained to walk and peck at food. In the evo-devo.html document mentioned above, several examples are presented of post-hatching behaviours that are not products of learning by training neural networks after hatching.

For instance, eggs of sea-turtles are abandoned by the mother after she lays them and covers them on a sandy beach, where the turtles hatch some time later and, without any training, make their way out to sea to locations inhabited by adults, where they can find food. Of course, not all succeed, but enough have succeeded for the species to survive for hundreds of millions of years.

In addition to providing physiological structures and behavioural competences for the animal that emerges from the egg, the early in-egg processes, which must be products of early evolution, also have to produce more recently evolved in-egg assembly mechanisms needed for later stages of assembly of more recently evolved features of the new animal during the hatching process.

During evolution of egg-laying vertebrates, earlier forms of gene expression have to be modified to trigger and control later forms of gene expression, through several layers of evolved gene-expression processes, as depicted (obscurely?) in the diagram referenced above.

**Even more complexity**

I now realise that despite the complexity of the diagram, referring to processes of evolution and development in vertebrate egg-laying species, it does not include the additional complexities of metamorphosis in egg-laying insects. I had not thought about insect metamorphosis when creating the diagram. I shall not try to modify the already over-complex diagram to accommodate insect metamorphosis! But I must now attempt to modify the theories I presented about evolution of spatial reasoning competences.

In talks I gave up to January 2023 I suggested that multi-stage in-egg assembly processes provide challenges for theories proposed by theoretical physicists.
I am now asking whether the processes of disassembly and reassembly of an insect in a pupa or cocoon provide even stronger challenges to current physical theories.

**How insect reproduction adds new complexity**

The reproductive processes of insects whose development includes metamorphosis are in some respects more complex than processes of development in vertebrates, despite the fact that most newly hatched vertebrates are much larger and far more complex than insects, and typically have far more intelligence.

As explained above, many insects, after first hatching, then growing as a result of feeding in the environment, go through an egg-like pupal stage, in which physiological *disassembly* as well as *reassembly* occurs, followed by a process of “hatching” out of the pupa/cocoon!

The use of both disassembly and reassembly of complex structures (in new forms) during insect metamorphosis makes insect reproductive processes more complicated than hatching processes in eggs of vertebrates, despite the resulting insects being much smaller than (most?/all?) newly hatched vertebrates.

The insect disassembly and reassembly (metamorphosis) processes also raise new questions, discussed below, that I suspect may challenge current fundamental physical theories.

I would welcome help from more knowledgeable readers!

**Insect metamorphosis in more detail**

After hatching from an egg, an insect typically sends some time feeding in the environment and growing in size, after which it undergoes metamorphosis, in which amazingly complex transformations occur, changing both its physical/physiological structures and its behavioural competences.

During metamorphosis, parts of the insect are chemically decomposed, and the resulting chemical constituents are used both to grow a surrounding *pupa* or *cocoon*, within which many (but not all) previously built physiological structures, are disassembled, and the resulting chemical constituents are used to assemble a new, very different, organism inside the pupa, with new physical structures and also new behavioural competences.

For example, an insect that previously could only crawl on supporting surfaces may emerge from the pupa with wings and the ability to fly.

This involves dramatic physiological transformations: chemically decomposing many previously grown anatomical structures (e.g. the grub’s outer covering, its mouth, and also control mechanisms in its brain) and re-assembling many of the chemical constituents to produce, in roughly the same space, both new physical structures and entirely new behavioural capabilities, e.g. flying and mating, and also abilities to find and consume new sources of food, e.g. flying to flowers and using a newly formed proboscis to suck nectar.

For more details see this paper on neuronal changes during insect metamorphosis by R.B. Levine


And this discussion of evolution of DNA

http://www.ncbi.nlm.nih.gov/books/NBK26876/
Comparing hatching and metamorphosis
The metamorphosis processes in insects contrast with the hatching mechanisms in eggs of vertebrates discussed in presentations between 2020 and January 2023, crudely summarised in the complex diagram referenced above.

Hatching processes in eggs of vertebrates convert relatively unstructured egg-material to add new physiological structures to the developing embryo, while also repeatedly extending the in-egg assembly control mechanisms (using non-space-occupying virtual machinery) that initiate and control later stages of hatching, eventually producing a fully formed young animal that breaks out of its shell and can almost immediately start moving in the environment and picking up and consuming food for the first time.

The newly hatched animal has these competences without requiring time or opportunities to train its neural networks in order to provide them.

Different egg-laying vertebrate species (e.g. chickens, avocets, alligators and sea turtles) have very different post-hatching behaviours, as well as differences in shape, size, outer covering, and other physiological structures.

Despite the enormous complexity of hatching processes in eggs of vertebrates, they do not include insect-like disassembly of major, previously assembled structures, combined with assembly processes that replace previous competences with new competences using the new physiology, e.g. in insects that emerge from a pupa with new physical structures (e.g. wings in some cases) and also related new abilities e.g. abilities to fly to plants and suck nectar from them. No such transformations occur after hatching in vertebrates.

In an insect, the types of intelligence required before and after metamorphosis are very different, as illustrated by very different feeding behaviours.

Specifications for the later mechanisms and structures in insects (i.e. the mechanisms used during and after metamorphosis) must somehow have been encoded in biochemical structures from the earliest stages of development in those insects, but those specifications are left unused during the grub stage.

However, after metamorphosis, as described above, some of the genetic specifications previously used to produce mechanisms that control behaviours (e.g. feeding behaviours) and development of the newly-hatched grubs are no longer used, and some of the early physical products are replaced by new mechanisms, including new physical structures enabling motion, such as wings, and new control mechanisms needed for flying, feeding and mating.

What sorts of biochemical mechanisms can produce very different physical morphologies and very different physical competences, at different developmental phases in the same animal?
As remarked earlier, the complexity and sophistication of all that machinery surpasses products of human engineering design, especially in view of the sub-microscopic complexity of the structures and processes, and the very low energy requirements compared with energy required for operation of human designed machines.

This raises many questions about the mechanisms involved, including questions about how various sorts of information somehow provided in the genome are accessed when needed and put to use.

Can current theories in fundamental physics explain all those phenomena, including both the transformations during metamorphosis, and the behavioural competences of organisms at various stages?

**Challenges to physical theories**

I tentatively suggest below that the dramatic chemical disassembly and reassembly processes occurring in insect pupae may provide stronger challenges for current theories in fundamental physics, than the challenges posed by in-egg hatching processes in vertebrates, discussed in my talks until January 2023.

**One of the challenges not yet discussed is the role of catalysis.**

I have talked about the need to move particles between locations, in the hatching egg, or in the organism undergoing metamorphosis.

But specifying target locations is not enough: the particles that are moved must have old chemical bonds released, and new bonds formed in new locations. In some cases, previously unused particles may be bonded to form larger structures that then have to be moved to target locations, where they will form multiple new bonds.

The requirement to control not only motion to target locations but also bond formation adds a lot of complexity that wasn’t previously obvious to me, though it should have been especially because it is a key point in Schrödinger’s *What is life?*, where he emphasises the roles of catalysts in controlling formation and release of bonds.

So a discussion of either hatching or metamorphosis has to mention the need to create catalysts to be used as tools, or mediators in disassembling old structures and assembling new ones, in addition to creation of new body parts. How, when, and where are the catalysts constructed in these processes?

Are there catalysts that can operate over relatively long distances, compared with the sizes of the particles that they cause to form or release bonds?

Note: There are more varieties of insect development than mentioned in this document. I probably lack important knowledge about some relevant examples!

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**Information about insect metamorphosis**

For more detailed information about mechanisms and processes of metamorphosis in insects see, for example:

http://www.britannica.com/science/metamorphosis

and

*Conceptual framework for the insect metamorphosis from larvae to pupae by transcriptomic*
An earlier paper of mine (2021) discussed some of the above topics in a little more detail: http://www.cs.bham.ac.uk/research/projects/cogaff/misc/make-chick.html

Comparing insect metamorphosis with processes in slime moulds

Many researchers have investigated other self-organising biochemical mechanisms, e.g. in slime moulds. In many ways they are much simpler than vertebrate egg-layers mentioned above. They also don’t seem to undergo transformations comparable to metamorphosis in insects. Slime mould transformations involve shape changes, location changes, and re-distribution of matter within the organism. They don’t seem to produce new physiological structures and entirely new competences, like the post-hatching competences of newly hatched vertebrates, or the post metamorphosis competences of insects. (It is possible that I have missed important facts about them.)

Insect transformations in cocoons, etc.

As reported above, insect grubs emerge from eggs, and consume matter in the environment, until substantial growth has occurred, and then, in many species, the insect grows a pupa (i.e. a cocoon or chrysalis or similar structure), surrounding itself (or parts of itself), in which parts of its physiology are disassembled and the chemical products are reorganised, resulting in a new animal that emerges with major new body parts (e.g. in some cases wings, and a proboscis for feeding) and also important new capabilities.

The post-pupal stage uses new control information that provides new types of behaviour after emerging from the pupa, e.g. flying, sucking nectar from flowers, and mating -- in some cases mating while flying. Later, female insects find a location to deposit the resulting eggs, and in some cases even provide food ready for the hatchlings when they emerge.

Those competences obviously cannot result from training neural networks, for which there are no opportunities. The competences must be supplied by biochemical transformations of information encoded chemically in the original egg from which the grub or caterpillar emerged.

So, as a result of metamorphosis, insects typically acquire both entirely new physiological structures and mechanisms and also important new behavioural competences, all of which must have been pre-specifed biochemically in the genome. But the specifications of post metamorphosis behaviours remain unused until activated by metamorphosis mechanisms. How, exactly?

I don’t know how much is known about this. My impression is that although the changes in observable structures and behaviours produced by metamorphosis are well known, and described in detail in many publications, there is little or no understanding of the lowest level physical mechanisms producing those structure-changing and behaviour-changing biochemical transformations in a cocoon/pupa.
My talks during 2022 raised similar doubts about the physical mechanisms controlling biochemical transformations during hatching of vertebrate eggs, which do not involve metamorphosis.

Gaps in current scientific knowledge.
I have not found explanations of how chemical processes in eggs of *vertebrates*, e.g. ducks, chickens, avocets, alligators, sea turtles, and many more, can produce the kinds of post-hatching intelligence required for finding and consuming various kinds of food shortly after hatching, or for going out to sea in the case of newly hatched sea-turtles, and in many cases interacting with conspecifics (e.g. young chicks following their mother)

I have also not been able to find explanations of the details described above in processes of metamorphosis in insects.

All those competences are much more complex than the competences of (e.g.) shape-changing slime moulds, and similar organisms which have received a lot of attention because they can be used in impressive demonstrations.

The mechanisms used by slime moulds seem to be well understood, unlike the mechanisms in newly hatched vertebrates, or the mechanisms producing new behaviours after metamorphosis in insects. The internal complexity and forms of chemical reorganisation in slime moulds are very much simpler than the processes of hatching in vertebrate eggs and the processes of metamorphosis in insects.

Slime moulds and similar organisms have far fewer constituents and they do not use complex feeding organs like those in insects or vertebrate hatchlings. I previously thought they did not have different sexes and could not reproduce by mating, but have recently discovered that I was mistaken!

This recent paper by Mirna Kramar and Karen Alim, provides evidence of primitive spatial intelligence in an invertebrate species: 'Encoding memory in tube diameter hierarchy of living flow network', http://dx.doi.org/10.1073/pnas.2007815118). But it does not offer, or refer to, explanations.

However, the behaviours of such organisms do not include detection of spatial necessity or impossibility, as shown in behaviours of young humans and some non-human species, e.g. apes and elephants, although all are also capable of errors.

Diversity of insect phenomena
There are very many insect life forms, varying in many different respects, including evolutionary age, stages of development, shapes, sizes, habitats, feeding behaviours, ... etc. These two summaries provide more information:


I offer no generalisations about reproduction and development in all, or most insects, or claims about the proportions of insects with these properties.

The examples I have cited merely provide existence proofs of certain phenomena, whose possibility seems to reveal gaps in our current understanding of fundamental physics.

**Note**
I was surprised to learn recently that insects evolved later than the earliest vertebrates, though the complexities of insect metamorphosis make that less surprising.

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**Reflections on the above ideas**

In several earlier presentations I considered only reproductive processes in eggs of vertebrate species, noticing increasingly complex details during that period and adding increasingly complex diagrams representing evolution and development in the evo-devo.html web site.

During June 2023, I suddenly realised that even more surprisingly complex forms of reorganisation, mentioned above, must occur in insects transforming themselves within a pupa (e.g. a cocoon/chrysalis), including decomposing some of the physiological structures developed previously while the grub or caterpillar was steadily increasing in size and complexity by feeding on vegetable or other matter in its environment.

In vertebrate eggs, discussed earlier, the hatching processes also decompose and reorganise biochemical matter, but there is no decomposition of complex structures assembled previously during hatching. (Unless I have missed something!)

In contrast, in the pupa of some insects a significant proportion of the chemical matter previously assembled during the earlier processes of feeding and development is decomposed and the newly separated chemical constituents are then re-assembled, still within the pupa, to produce a new very different organism, e.g. with new body-parts (such as wings and proboscis), new feeding and digestive mechanisms, new forms of motion (e.g. flying, in many cases) and new abilities to mate (in some cases while flying!), and then, in the case of females, laying eggs, and in some species leaving food for the larvae when the eggs hatch.

**More detailed information about insect metamorphosis**

The following web site presents much detailed information on varieties of insect metamorphosis and the complexities of the transformations involved:

Why Insect Memories May Not Survive Metamorphosis *Quanta Magazine*

These discoveries about insect metamorphosis seem to me to be as important for the development of physical theory as ancient discoveries of magnetism.

The complex Evo-Devo diagram referenced above represents some of the complexity of interactions between evolution and development in vertebrate species, but it does not include the far more complex varieties of disassembly and reassembly that can occur in an insect’s pupa or cocoon.
Comparison with machines designed by humans
The transformations in eggs of vertebrates, and invertebrate pupae, etc., mentioned above, seem
to me to be far more complex, and more intricate, than any of the processes created in laboratories
or factories by physicists, or engineers, including I suspect, biochemical engineers, and also more
complex than any tasks performed by human-designed robots.

Current robots cannot perform the combination of disassembly followed by reassembly in a new
form with new competences, achieved by metamorphosis mechanisms in insects, using physical
mechanisms that are much smaller than human-designed robots.

Moreover, current robots cannot perform manipulations at sub-microscopic scales. I suspect that is
also true of robots developed in secret research laboratories!

If similar decomposition and re-composition tasks were somehow performed by robots they would
be regarded as highly intelligent machines! But no robot developed so far could do so much
disassembly and reassembly of complex structures in a space as small as even the largest animal
egg -- an ostrich egg.

Compared with processes in human-designed AI systems, the biological transformations described
above have far more parallelism, and far more variety in the substances and their transformations.

I suspect that assembly processes in vertebrate eggs have far more stages of increasing
complexity between the initial state and the latest hatching state than any objects assembled by
human designed robots. And the increases in complexity during hatching in a vertebrate egg, e.g.
producing birds and reptiles, exceed what happens in insect reproduction processes.

But assembly processes in vertebrate eggs don't include the kinds of combination of disassembly
and reassembly that occur during insect metamorphosis.

I expect experts reading this who have specialised biological knowledge will be aware of additional
cases that are equally complex and difficult to explain, or perhaps more so!

What neural network theories cannot explain
The facts about results of hatching processes in eggs of vertebrates, including the abilities of
biochemical assembly processes inside eggshells to produce animals with sophisticated
species-specific behavioural competences, refute currently popular ideas about the need for
animals (including humans) to acquire behavioural competences by training neural networks while
acting in the environment.

Those fashionable ideas ignore the fact that competences of newly hatched animals must have
been produced by biochemical assembly processes that occurred in the eggs, prior to hatching.
Many such competences are used by newly hatched animals before they have had time to train
neural networks.

Moreover, the competences used within the egg during hatching, to produce increasingly complex
in-egg assembly processes, cannot depend on trained neural networks, since neural networks do
not exist during early stages of in-egg physiological development, and after they begin to develop,
the under-developed neural networks lack the powers required to control complex assembly
As hatching processes proceed there are increasingly complex in-egg processes of construction of new, increasingly complex, increasingly interrelated, physiological mechanisms in the new animal being assembled in the egg, for example, bones -- including the skull, brain, spine and jointed limbs -- muscles, tendons, heart, blood vessels of various sorts, including capillary networks, and also lungs, digestive system, glands of various types, ducts, and species-specific outer coverings, e.g. scales, feathers, shells, or skin.

Obviously those chemical construction processes in eggs cannot be controlled by neural networks that do not yet exist. Moreover it would not be possible to train a neural network in a developing egg to control hatching processes by letting it assemble many eggs and providing positive and negative rewards.

Instead, the abilities required for in-egg chemical construction processes at later stages of hatching must themselves make use of biochemical assembly mechanisms that are provided in the egg either by the egg-laying mother, or by biochemical assembly mechanisms created during earlier stages of hatching.

**Note:**
Despite a degree in mathematics and physics in 1956 my knowledge of current theoretical physics is very patchy, based partly on what I've been able to learn more recently, e.g. from online presentations by theoretical physicists, such as Perimeter Institute videos.

What I have learnt suggests that the current fundamental physical theories are not able to explain the biological phenomena summarised above. I have searched for, but have not found reports of research on insect metamorphosis by physicists.

I'll welcome suggestions for improving the above discussion, including correction of any errors.

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**Further background information**

In the January 2023 talk I discussed implications of the fact that those in-egg hatching processes repeatedly produce new physiological structures and also

> new in-egg control mechanisms required for later stages of hatching,

and somehow eventually produce

> the competences required for post-hatching behaviours, including finding food and following a parent, or moving out to sea, in the case of sea-turtles whose mothers abandon their eggs after laying them and leaving them covered on a sandy sea shore.

I tried to summarise those ideas in the complex and messy diagram referenced [above](#).
Note
In their complexity and intricacy the microscopic and sub-microscopic biochemical achievements described above, produced by biological evolution, which could be labelled "meta-morphogenesis mechanisms", surpass what humans, and machines so far constructed by humans, can do when manipulating small physical objects to create larger objects.

However, many other aspects of human intelligence, e.g. making discoveries in geometry and topology, studying distant astronomical objects, and designing and building skyscrapers are obviously not matched by processes in eggs or pupae!

Note on the label "Meta-Morphogenesis":
"Meta-morphogenesis" is a label I first used in a different way many years ago, in commenting on Alan Turing’s ideas in his paper "The chemical basis of morphogenesis", e.g. as described in this document summarising a talk presented in Cambridge in 2012 [http://cucats.org/event/21](http://cucats.org/event/21).

I had completely forgotten about that when I started using the label in connection with hatching processes in eggs, late in 2020. There are connections between the old use and my use here. The new ideas presented here can be thought of as an extension of the Meta-morphogenesis project.

Further comments
Since the 1970s I have criticised very popular ideas about learning and intelligence in neural networks that collect statistical data acquired by sensors and then derive probabilities, ideas that are accepted as explaining human intelligence by many researchers in many disciplines, but are seriously mistaken.

Mechanisms computing probabilities derived from large amounts of statistical data, are constitutionally incapable of supporting ancient mathematical discoveries in geometry and topology about impossible spatial configurations or transformations, and also discoveries about necessary truths about properties and relationships of shapes or consequences of spatial constructions.

Necessity and impossibility are not high and low degrees of probability!

So no amount of statistical data collection and computing of probabilities could justify ancient mathematical discoveries about spatial necessity or impossibility, e.g.
(a) the discovery that certain diagrammatic operations using straight-edge and compasses on a planar surface will necessarily bisect an angle, and
(b) the discovery that it is impossible to obtain an odd number by adding any collection of even numbers, no matter how large and varied the collection is.

Contrast (b) with the result of swapping 'odd' and 'even'!

Note
Surprisingly many highly intelligent researchers seem not to have noticed that discoveries about impossibility and necessity cannot be made by artificial or biological neural-net-based learning mechanisms that collect statistical evidence for or against a hypothesis and then derive numerical probabilities.
I suspect this is a result of poor forms of mathematical education in many countries since mid 20th century that discarded older forms of education including uses of diagrammatic proofs in geometry.

Many ancient topological and geometric discoveries involving necessity and/or impossibility were reported in Euclid’s *Elements* (some of which had been discovered centuries earlier, e.g. in India and China), but there are other discoveries Euclid either did not know about or deliberately excluded, such as the ancient discovery of the *neusis* construction, which can be used to trisect an arbitrary angle of less than 180 degrees, in a planar surface, as explained in http://www.cs.bham.ac.uk/research/projects/cogaff/misc/trisect.html

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**DO THE ABOVE BIOCHEMICAL MECHANISMS POSE CHALLENGES FOR CURRENT THEORIES ABOUT FUNDAMENTAL PHYSICAL STRUCTURES AND MECHANISMS? AM I JUST CONFUSED ABOUT THIS?**

**The main question**

What kinds of physical (biochemical) processes could provide all the highly complex forms of control required to decompose a large amount of matter within an insect pupa, and also control the reorganisation of that matter to construct, in very small spaces (very small compared with human designed mechanisms), a variety of interconnected and inter-penetrating physiological substructures, with many different shapes, sizes, materials, physical properties, etc., many of which have to be assembled in parallel, not necessarily with perfect reliability, but sufficiently reliably for many such organisms produced by chemical decomposition and re-composition processes to exist, including species that have evolved increasingly complex and varied physiological structures and behaving capabilities over time?

A well known fact is that during pupation larval structures break down, and adult structures such as wings appear. What is not mentioned in the online documentation that I have found is that structures must be modified to replace old competences (e.g. crawling and feeding on certain kinds of matter) with entirely new competences such as flying, using new food sources, such as plant nectar, and mating, followed by different male and female behaviours.

Perhaps the (surprising) fact mentioned above that insects evolved later than vertebrates, is related to the greater biochemical complexity of metamorphosis processes than processes involved in vertebrate development?

Schrödinger’s book *What is Life*(1944) referenced below (including comments and questions), discusses some of the requirements for fundamental physics to support biological reproduction, including the importance of catalytic mechanisms, but without considering the specific kinds of complexity mentioned here (unless I have mis-remembered or mis-read!).

I have not found anyone else who has discussed exactly this topic, or who has proposed mechanisms capable of explaining such metamorphosis processes. Roger Penrose is one of the people who tries to relate biological processes to fundamental physics, but as far as I can tell, neither he, nor his collaborator Stuart Hameroff, has thought about the problems I’ve raised. Hameroff writes a lot about the importance of microtubules, but does not seem to me to explain *how* they perform the tasks for which he claims they are crucial. (I apologise if I have missed something in his publications.)
Neither, as far as I recall, attempts to answer questions about how newly hatched, or newborn, organisms (whether vertebrates, newly hatched insects, or post metamorphosis insects) are provided with the information required to control behaviours (e.g. moving around, feeding, following parents, mating, etc.) in their post-hatching or post metamorphosis environments. Examples include the abilities of new-born horses or deer to run with the herd a few hours after birth, when chased by predators. Horses and deer cannot carry their infants, as members of primate species do.

A huge (and rapidly increasing) amount of biochemical research, for scientific or medical purposes or both, has been going on in since early/mid 20th century, much of it related to the questions raised here but without addressing my questions, as far as I can tell from literature searches.

I wonder whether any theoretical physicist has thought about the processes/mechanisms of control required for hatching processes mentioned above, whether in vertebrates or insects?

I also wonder whether those requirements might rule out some current theories in fundamental physics, but I lack the knowledge that would be required to support such a claim.

Some personal history
I think my ability to raise these questions is partly a consequence of the fact that as a child, between the ages of 5 and about 9, I played with increasingly complex meccano sets, given to me as presents by an aunt (who was a schoolteacher), as a result of which I had a lot of first hand experience of discovering the importance of getting the right order in which components are connected (e.g. by nuts and bolts) and also the need to have some joints left loose until other connections are made after which the screws can be tightened.

The physiological structures in a living animal are far more varied and complex, with far more constraints on possible assembly sequences, than structures built using a human designed construction kit.

But I suspect there are overlapping requirements, including requirements to control the order in which components are assembled, and the need in some cases to interleave assembly of structurally related components, e.g. different parts of a crane, with tower, rotating cab at the top, and jib that can be raised and lowered during such rotation, like cranes that load objects from a quayside into an adjacent ship, or vice versa.

Immanuel Kant’s contribution
I am not an expert on Immanuel Kant, but I agree with his claims (in his Critique of Pure Reason (1781), and his earlier (1783) Prolegomena to Any Future Metaphysics That Will Be Able to Present Itself as a Science) about requirements for mechanisms capable of explaining human mathematical competences, including geometric and topological reasoning competences, leading to discoveries of spatial impossibility or necessity.

Kant’s arguments also rule out statistics-based neural network mechanisms, as explanations for such competences. Statistical reasoning can never prove something to be necessarily true, or impossible, since necessity and impossibility are not extremes of probability, as explained above.
His ideas had a deep influence on my 1962 Oxford DPhil thesis, and subsequent work, including triggering my switch from studying mathematics to studying philosophy of mathematics, as a student in Oxford around 1958.

My DPhil thesis is available here: http://www.cs.bham.ac.uk/research/projects/cogaff/sloman-1962/ (Now only of limited historical interest!)

This document reports ideas developed since my invited talk to a Tokyo based conference in January 2023.

The 14th International Workshop On Natural Computing, Tokyo, Japan

My talk "Recently hatched ideas about hatching and intelligence" presented ideas about interactions between evolution and development of egg-laying vertebrate species, e.g. many bird and reptile species. The presentation used an earlier version of the following (messy) web site, which has been considerably expanded since then: http://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo.html

THANKS:
N.B. The order of the following list is not an indication of importance, or amount of help received, etc.

Anthony (Tony) Leggett, is a theoretical physicist at UIUC:

http://physics.illinois.edu/people/directory/profile/aleggett
http://en.wikipedia.org/wiki/Anthony_James_Leggett
http://royalsociety.org/people/anthony-leggett-11804/

He has been a friend since our student days. We met in Oxford around 1959 (where we both had R.M.Hare as our "personal tutor"), and he provided support and encouragement during development of earlier versions of these ideas, including providing comments to be read out after my presentation for the online workshop mentioned above, based in Tokyo in January 2023.

I am not claiming that he agrees with my conjectures! He has not seen the latest version of this document, and has not commented on its claims.

He was invited to respond to my talk at that workshop, but was not available at the time of the event, so, on the basis of our discussions since 2020, and some of my previous conference presentations and online documents, he prepared some comments which were read out by the conference chairperson, now available here: http://www.cs.bham.ac.uk/research/projects/cogaff/misc/tony-leggett-talk-notes.txt

I thank him for his interest in my work and his useful pointers and encouraging comments.

This document is in part a response to his comments, but it also introduces complex new ideas not included in my January 2023 conference presentation, or earlier presentations or correspondence. I have now posed new questions for theoretical physicists, triggered six months after that conference, as a result of thinking about differences between hatching processes in vertebrate eggs and the processes that occur during insect metamorphosis.
I am grateful to Jackie Chappell
School of Biosciences, University of Birmingham.
http://www.birmingham.ac.uk/staff/profiles/biosciences/chappell-jackie.aspx
We began to collaborate soon after she moved to Birmingham in 2004, which led to the Meta-Configured Genome (MCG) project, mentioned above. Our collaboration provided the background to some of the above ideas.

Added 28 Sep 2023
Talks by Nicole King on the origins of animal multicellularity provide evidence related to claims in this document.
(If short of time, go to talk 3 (2022), below!)
1: Two talks in September 2014
   Choanoflagellates and the Origin of Animal Multicellularity Part 1
   http://www.ibiology.org/ecology/choanoflagellates/
   Choanoflagellates and the Origin of Animal Multicellularity Part 2
2: The origin of animal multicellularity (2015??)
   http://www.youtube.com/watch?v=1v6cgSkiiHik
3: AbSciCon 2022: Plenary: Dr. Nicole King,
   A History of Hypothesis on the Origin of Animals
   http://www.youtube.com/watch?v=_ZV0rrH2qRc

Gordana Dodig-Crnkovic
Professor of Computer Science, Malardalen University
Professor of Interaction Design, Chalmers University of Technology
http://gordana.se/
Since 2013 she has provided useful comments and questions related to my work and involved me in important events and publications for which she was wholly or partly responsible. She also introduced me to several other researchers with relevant interests, who provided useful comments and criticisms. Her insights and suggestions contributed significantly to some of the work reported here.

Professor Susan Stepney, York University
http://www.cs.york.ac.uk/people/susan
I am grateful for her encouragement and suggestions, including her suggestions regarding diagrams combining self-extending evolutionary and developmental processes, mentioned above.

Alan Reed, previously a member of the University of Birmingham, kindly sent me the information about varieties of insect metamorphosis linked above.

Mike Ferguson, at the University of Dundee, UK, has a relevant presentation here:
http://www.youtube.com/watch?v=2KsuYjXneXA
From textbooks to applications of GPI anchored proteins
Mike Ferguson, at ICCB2018
The talk starts after about 50 seconds.

Another Mike Ferguson
For several years another of the many individuals on the internet called "Mike Ferguson" has been sending me very useful comments, criticisms, suggestions and links to related research, for which I am very grateful.

Unfortunately there is no publicly accessible link to him or his work, to add here.

Other references:

A relevant online article which I have so far only skimmed at speed:
_Metamorphosis of memory circuits in Drosophila reveals a strategy for evolving a larval brain_
James W Truman, Jacquelyn Price, Rosa L Miyares, Tzumin Lee
In Elife, Jan 25, 2023
http://elifesciences.org/articles/80594

Being You: A New Science of Consciousness
By Anil Seth (2021)
Published by Faber & Faber, with multiple glowing references.
http://www.amazon.co.uk/Being-You-Inside-Story-Universe/dp/0571337708
I have just acquired the Amazon Kindle edition of this book and have sampled its contents. I wondered whether there might be any overlap between the topics it discusses and the topics discussed here. As mentioned above, the parts of the book that I have so far sampled make no mention of consciousness in biological processes of reproduction, development and evolution, though I have found one mention of digestion as an intelligent process, implicitly suggesting that the gut has a form of consciousness -- an example that might have been included in this document. He also allows that there are many different kinds and levels of consciousness across processes of reproduction, development and evolution, without claiming [as far as I've been able to tell after partial reading] that the processes of reproduction, development and evolution themselves involve forms of consciousness, as I am suggesting.

Note on Bayesian Nets (Added 28 Oct 2023)
Further reading of the book revealed a lot of discussion of Bayesian nets, which are proposed as explaining various aspects of brain function. However, I have no evidence that my brain uses Bayesian nets. One reason I regard them as biologically implausible is that (unless I have misunderstood something) they are constitutionally incapable of explaining ancient forms of mathematical reasoning that make it possible to discover that some spatial structures and processes have necessary consequences (i.e. alternatives are impossible) e.g. it’s impossible to produce two paper loops by cutting a paper Mobius strip, with a single twist, down the middle, as illustrated here:
https://www.youtube.com/watch?v=tS2rLRyIiFR8
What brain mechanisms are involved in understanding the kinds of necessity and impossibility involved? There’s a lot more to be said about this, and related mathematical discoveries. I may add a link to more details later.
I am not aware of any mechanisms proposed by neuroscientists (or anyone else!) that explain how we can understand why processes involved in production of mobius strips have their consequences. They are certainly not mere statistical regularities.

I am grateful to many other colleagues and former students -- too many to list here -- who have helped me during development of the above ideas over many years. They are listed as co-authors (sometimes first authors) in many publications and online documents on my web sites.

An additional (semi-random) subset of relevant researchers
I apologise to the many others not mentioned here!
The order of items in the following list is not significant.

Erwin Schrödinger
I was deeply influenced especially by his 1945 book *What is life*. See [http://www.cs.bham.ac.uk/research/projects/cogaff/misc/s/schrodinger-life.html](http://www.cs.bham.ac.uk/research/projects/cogaff/misc/s/schrodinger-life.html) including his comments on the importance of catalysis in processes of reproduction.

Mike Levin
The very impressive work of Mike Levin at Tufts university is related to the ideas presented here. For details, see [http://as.tufts.edu/biology/levin-lab](http://as.tufts.edu/biology/levin-lab)

However there are types of complexity in reproductive processes discussed above that are not considered by Levin (as far as I can tell), including the ability of hatching processes in eggs to produce hatchlings (e.g. sea turtles, or avocets) with complex behavioural competences ready for use without requiring training of neural networks. Perhaps I’ve missed something important in his many publications.

Added 23 Aug 2023

Daniel Dennett
A colleague has just drawn my attention to a discussion between Mike Levin and Dan Dennett which seems to be closely related to my conjecture that it’s not synapses that connect neurons, but neurons that connect synapses. Their discussion is available here: [http://aeon.co/essays/how-to-understand-cells-tissues-and-organisms-as-agents-with-agendas](http://aeon.co/essays/how-to-understand-cells-tissues-and-organisms-as-agents-with-agendas)

However, it is not clear to me whether
- they are merely discussing two ways of understanding the roles of neurons and synapses in current brains.
  or whether
- they are raising the same questions as I am about the evolutionary history of synapses and neurones, including my conjecture that synapses are descendents of ancient single-celled organisms that began to develop collaborative relationships millions of years ago, thereby eventually, and very surprisingly, producing all modern animals, including animals with spatial reasoning mechanisms with capabilities that Kant had postulated in his criticism of Hume’s categorisation of types of knowledge as either empirical or based on combinations of definitions plus logical deductions, mentioned [above](#).

It is also not clear to me whether either Levin or Dennett shares my speculation that those mechanisms for controlling spatial manipulations during metamorphosis and mechanisms for spatial reasoning about spatial impossibility or necessity pose challenges for current theories of
fundamental physics.

I have been impressed by and have learnt from the writings of Dan Dennett, and interactions with him over many years (since about 1978), though as far as I know he has never shared my interest in the biological underpinnings of abilities to discover impossibilities and necessary connections in ancient forms of geometric and topological reasoning, supporting Kant’s claims about the limits of both empirical/statistical reasoning and logical/algebraic forms of reasoning.

**Lynn Margulis**


I hope to find a link to a video recording of her presentation which I attended at a conference about her work in Oxford, in 2009. Some of the other talks on that occasion are available here: [http://www.voicesfromoxford.org/historic-post-lynn-margulis/](http://www.voicesfromoxford.org/historic-post-lynn-margulis/)

More on her contribution to modern ideas about biological evolution: [http://evolution.berkeley.edu/the-history-of-evolutionary-thought/1900-to-present/endosymbiosis-lynn-margulis/](http://evolution.berkeley.edu/the-history-of-evolutionary-thought/1900-to-present/endosymbiosis-lynn-margulis/)

**Seth Grant**


For several decades he and his research group have been investigating biochemical brain mechanisms that seem to me to be closely related to my recent claims about hatching and metamorphosis. E.g. See

Seth G.N. Grant (2018)
Genes to Cognition Program,
Centre for Clinical Brain Sciences,
The Synaptomic Theory of Behavior and Brain Disease
Edinburgh University, UK.

One of the claims (page 4) is:

"Thus, the evolutionary studies support the view that the most fundamental building blocks of the behavioral repertoire are multiprotein signaling complexes and not the excitable neuron of the connectionist theory."

Seth G. N. Grant (2018)
Synapse molecular complexity and the plasticity behaviour problem
*Brain and Neuroscience Advances*, Vol 2, pp 1--7

Seth G.N. Grant (2019)
Synapse diversity and synaptome architecture in human genetic disorders

Grant writes:
The purpose of this article is to outline a new molecular and synaptic theory of behavior called
the 'synaptomic theory', named because it is centered on the synaptome -- the complement of
synapses in the brain. Synaptic theory posits that synapses are structures of high molecular
complexity and vast diversity that are observable in maps of the brain and that these
synaptome maps are fundamental to behavior. Synaptome maps are a means of writing or
storing information that can be retrieved by the patterns of activity that stimulate synapses.
Synaptome maps have the capacity to store large amounts of information, including multiple
representations within the same map. The dynamic properties of synapses allow synaptome
maps to store dynamic sequences of representations that could serve to program behavioral
sequences. Synaptome maps are genetically programmed and experience-dependent, thereby
storing innate and learned behaviors, respectively. Although learning occurs by modification of
the synapse proteome, it does not require long-term potentiation (LTP) of synaptic weight or
growth of new synapses, and the theory predicts that LTP modulates information recall. The
spatial architecture of synaptome maps arise from an underlying molecular hierarchy linking
the genome to the supramolecular assembly of proteins into complexes and supercomplexes.
This molecular hierarchy can explain how genome evolution results in the behavioral repertoire
of the organism. Mutations disrupting this molecular hierarchy change the architecture of
synaptome maps, potentially accounting for the behavioral phenotypes associated with
neurological and psychiatric disorders.

Comment:
The above suggests that synapses store information that is used by other mechanisms, e.g.
mechanisms that formulate goals, make choices, control actions, etc., whereas my conjecture now
is that synapses themselves (in collaboration) make choices, control actions, derive conclusions
from evidence, reason about options, etc.
Is that a crazy suggestion??

In principle, the research reported here should be extendable to help explain both processes
involved in insect metamorphosis, and processes involved in reasoning about spatial impossibility
and necessity in intelligent animals, but it will require non-trivial extensions, including answers to
new questions about the roles of biochemical control mechanisms that evolved long before animal
brains had synapses!

Stuart A. Kauffman
His work is relevant to the ideas presented here, but I have not found anything that addresses my
questions about ancient forms of mathematical reasoning. See
A World Beyond Physics: The Emergence and Evolution of Life. (2019)
Oxford and New York: OUP
and
Stuart Kauffman (2020) EROS AND LOGOS, Angelaki, 25:3, 9-23, DOI:
http://doi.org/10.1080/0969725X.2020.1754011

Paco Calvo
His ideas on plant intelligence, related to the above discussion, are presented with Natalie
Lawrence in this video discussion:
http://www.youtube.com/watch?v=tDsFsywWa7r8
(However, they don’t explicitly raise the questions I have been discussing.)
http://doi.org/10.1038/41710


Conrad Waddington’s Epigenetic Landscape Idea
Work on the Meta-Configured Genome theory with Jackie Chappell referenced above challenged Waddington’s ideas as too simple.

For further information about the history of geometry see (for example):
http://en.wikipedia.org/wiki/Pythagorean_theorem
and

Comparison with Karl Popper’s third world
(EXTENDING THE DARWIN/WALLACE THEORY OF EVOLUTION)
World 2.5, or Realm 3.0
This work on insect metamorphosis can be contrasted with Karl Popper’s idea of a "Third world". Popper pointed out that a great deal of human knowledge is implicitly recorded and used not in written or spoken words, but in products of human activities, such as engineering and architectural creations, which he called "The third world". See http://en.wikipedia.org/wiki/Popper%27s_three_worlds.

An over-compressed summary: Popper’s worlds 1, 2 and 3 are realms of knowledge. World 1 is the original physical world, World 2 the world of living forms produced by biological evolution, and World 3 includes products of human thought and informed actions, including not only books, libraries and other creations that explicitly store and communicate knowledge but also machines, buildings and other products of human activity that both extend what humans can do and also implicitly encode useful information about what can be done in the environments in which humans live, and whose effects can alter the contents of worlds 1 and 2 as well as contributing new extensions to World 3.

In contrast, the phenomena I am discussing are products of biological evolution that extend the powers of biological evolution in various ways, including extending the information-processing capabilities of products of evolution, and extending the types of information that can be used by information-using biological mechanisms.

Evolution achieved these extensions long before humans existed, by combining products of different evolutionary processes to form new networks of organisms, i.e. not just branching tree-structures as suggested in many diagrammatic representations of evolution, but also by merging previously branched trees or networks, a process that began long before the evolution of
humans.

So biological evolution started combining products of evolution in ways that extended the powers of evolution, thereby producing and extending its own Popper-like "third world", long before humans existed and began to extend their world as described by Popper.

Since these phenomena precede and help to produce new forms of intelligence used in biological reproduction, helping to enable evolution of intelligence in precursors of humans as well as humans, they could be described as forming World 2.5. Instead, in order to avoid a clash with Popper's terminology, I suggest that we use the word "Realm", and talk about Realm1, Realm2, Realm3, and Realm4.

Realm1 is the physical world as it existed before life began, and is the same as Popper's World1. Realm2 is an extension of Realm1 (World1), containing the most primitive life forms (which may differ in different parts of the physical universe). Realm3 is an extension of Realm2.

Realm3 includes products of biological evolution (such as metamorphosis mechanisms) that encode not human knowledge, but knowledge about the world, that has been accumulated and used implicitly by biological reproductive and developmental mechanisms, which exist as by-products of earlier processes of evolution, enabling new types of life forms to exist, whose development includes metamorphosis.

Realm4 extends Realm3 to include new physical structures created by living organisms that change their physical environment in ways that benefit them and their descendents. Examples might include beaver dams and ant-hills. [TO BE EXTENDED]

Although I have not been discussing evolution of humans, I now suggest that human intelligence and its products are among the products of the biological mechanisms related to the mechanisms discussed above, that enabled evolution of insect metamorphosis.

In the long term, this messy terminology should be replaced by a new systematic collection of labels for products of evolution that extend the powers of biological evolution by making use of increasingly complex and powerful physical processes. The possibility of such mechanisms always existed, but the realisation of different increasingly complex possible mechanisms required new physical mechanisms to be assembled by earlier products of biological evolution repeatedly using the physical world in combination with previous products of evolution.

A key feature of this process, which is not captured by the use of branching tree diagrams often used (mistakenly) to depict biological evolution, is that both sexual reproduction and forms of symbiosis allow products of different branches to be combined to generate new branching networks composed of branching and merging previously evolved trees and networks, a process labelled "symbiogenesis" by Lynn Margulis, mentioned above.

I suspect that if Popper had thought about this, he might have called this World 3, and renamed his World3 as World4! But it is too late now to use those labels.

It is possible (very likely?) that evolutionary processes in different parts of the universe have produced different subsets of the multiple possible forms of branching and merging of products of biological evolution, inherent in the initial universe. I think that something like this suggestion was also made by Lynn Margulis.
Leo Caves, on Popper, Whitehead, Biology and Category Theory

*Towards a Process-Relational Biology? Relating Whitehead’s Metaphysics and Relational Biology through Category Theory*

December 2017

Found on Researchgate

http://www.researchgate.net/publication/358903918_Towards_a_Process-Relational_Biology_Relating_Whitehead%27s_Metaphysics_and_Relational_Biology_through_Category_Theory

(I have not yet taken in the details so cannot evaluate this, though the ideas are relevant.)

Mandelbrot on Fractal Geometry

Benoit Mandelbrot, Fractal Geometry: IBM,


Scientists at Fermilab close in on fifth force of nature

Extract from BBC news 10th Aug 2023

By Pallab Ghosh
Science correspondent

"Scientists near Chicago say they may be getting closer to discovering the existence of a new force of nature.

They have found more evidence that sub-atomic particles, called muons, are not behaving in the way predicted by the current theory of sub-atomic physics.

Scientists believe that an unknown force could be acting on the muons.

More data will be needed to confirm these results, but if they are verified, it could mark the beginning of a revolution in physics.

All of the forces we experience every day can be reduced to just four categories: gravity, electromagnetism, the strong force and the weak force. These four fundamental forces govern how all the objects and particles in the Universe interact with each other.

The findings have been made at a US particle accelerator facility called Fermilab. They build on results announced in 2021 in which the Fermilab team first suggested the possibility of a fifth force of nature.

Since then, the research team has gathered more data and reduced the uncertainty of their measurements by a factor of two, according to Dr Brendan Casey, a senior scientist at Fermilab.

"We’re really probing new territory. We’re determining the (measurements) at a better precision than it has ever been seen before."
Inspiration from Tibor Ganti, 2003.
The Principles of Life, (Translation of the 1971 Hungarian edition),
The ideas in this book, presenting Ganti’s "Chemoton" theory are very complex and I don’t claim to have understood all of them, or even most of them! However, the complexity of the ideas reflects the complexity of the biochemical mechanisms and processes that make life, in all its complexity and variety, possible. There is a useful summary/review of this book by Gert Korthof, who also provides a large collection of related references: http://wasdarwinwrong.com/korthof66.htm

Hamid Ekbia
http://news.syr.edu/blog/2022/12/14/hamid-ekbia-ph-d-appointed-director-of-autonomous-systems-policy-institute/
Has sent me useful comments and references, including this:
From single cells to multicellular life: Researchers capture the emergence of multicellular life in real-time experiments

Vaughan Pratt
drew my attention to the distinction between Cladogenesis and Anagenesis mentioned below.

Openai.com
This web site includes very relevant information, including many links. I shall try to find a better description to insert here later.

David Hume famously wrote:
"If we take in our hand any volume; of divinity or school metaphysics, for instance; let us ask, Does it contain any abstract reasoning concerning quantity or number? No. Does it contain any experimental reasoning concerning matter of fact and existence? No. Commit it then to the flames: for it can contain nothing but sophistry and illusion."
An Enquiry Concerning Human Understanding (1748) sect. 12, pt. 3

What does Chat GPT6 think about all this?
Here is a transcript of our conversation in April 2023:
http://www.cs.bham.ac.uk/~axs/ChatGpt6TestedOnlineBy-AS-2ndApr2023.txt

(The above list may be extended later.)

Some online tutorials on ancient and recent forms of spatial thinking.
One of the most spectacular teachers regarding the types of topological and geometric discoveries, making no apparent use of any standard formal methods of reasoning is Tadashi Tokieda, e.g. in these two "elementary" videos (among many others):
He also has many more online videos presenting visual proofs in areas of geometry and topology that go beyond Euclid, and standard school mathematics. They can be found by searching for "Tadashi Tokieda" + geometry or topology.

Also: An introduction to some more "standard" Euclidean constructions and proofs, presented by Zsuzsanna Dancso; http://www.youtube.com/watch?v=6Lm9EHhbJAY

There are many more online examples of visual proofs, including the standard ancient proofs included in Euclid’s elements (many discovered centuries before Euclid was born) presented online, and other constructions and proofs not normally included in standard geometry textbooks, including the ancient construction for trisecting an angle, and the proof of its validity, summarised here:
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/trisect.html

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**Getting a table through a doorway**

I expect most readers of this document will be aware that getting a table through a doorway whose width is less than the width of the table can be achieved by tilting the table onto its long edge and pushing two legs through the doorway then rotating the table about a vertical axis to push most of it through the doorway, and then using another horizontal rotation about a vertical axis to push the last two legs through, after which the table can be rotated back to its normal orientation. (I have not been able to find an online video demonstration of this technique!)

**APPENDIX 1: Is physical space/time discrete?**

There appear to be disagreements among theoretical physicists over whether physical space-time is continuous or discrete or some sort of mixture (e.g. one component discrete and the other continuous).

I previously argued that complex biochemical disassembly and reassembly processes in small enclosed spaces discussed above would be error-prone if space-time were discrete, because of the distortions that would be created by so many different connected components moving and rotating in different directions in discrete steps.

The following experiment illustrates the problems:

Create a 2D rectangular grid on which objects can be slid around, preferably larger than chess-board size (8x8). Create some semi-rigid 2-D objects composed of discs connected by bendable wire. Simple examples would be shapes like "A", "E", "F", "H", "K", etc., or two or more such shapes connected. The shapes could be made of discs joined by wires, i.e. discs attached to the ends of pieces of wire, including joints.

Experiment by placing such a shape on the 2D grid with every disc in the middle of a square (bending connecting wires if necessary), then move the shape by sliding it in various directions on the grid with or without rotating it on the surface. Now check whether each of the discs is still in the middle of a square, and if not, what distortions of the shape (bending the wires) are required to get
every disk back to the middle of a square. (With or without the constraint that two discs cannot be in the same square.)

Such an experiment should provide an intuitive feel for consequences of translating and rotating objects composed of many particles under the constraint that each particle must either remain where it is or move to the centre of another square. Enforcing that constraint will in many cases cause the shape to be distorted, i.e. with distances between the particles having to change and some of the angles between links having to change, in order to keep all particles in the centre of a grid location.

The problem is not restricted to rectangular grids. E.g. a hexagonal grid would have similar consequences, despite differences in the details.

This suggests that if physical space is discrete, with all physical particles constrained to have their centres located at space-time points, then shape distortions will occur if objects are moved arbitrary amounts in arbitrary directions.

What the consequences of the distortions are will depend on other features of the universe!

In earlier presentations I suggested that the facts about biochemical developments in vertebrate eggs, and the more complex processes of metamorphosis in insects, provide challenges for physical theories that state or imply that space-time is discrete?

However, Tony Leggett has pointed out to me (if I've understood him correctly) that if the minimal distances between space-time locations are very much smaller than distances between the centres of particles in biological organisms, then the distortions produced by motion (including rotation) of biochemical structures within an organism, during hatching or metamorphosis will be insignificant, and my earlier suggestions are misguided.

**APPENDIX 2: Also relevant**

The following items are also relevant to the problems and ideas discussed, but have not yet been fully integrated into this document. Items listed here may later be moved to another section of the document, or referenced more directly in other sections of this document.

**Homeobox and hox genes**

The following quotation is copied from this web site by Jennifer Harrison: [https://geneticjen.medium.com/the-difference-between-homeobox-and-hox-genes-e73d7926eca1](https://geneticjen.medium.com/the-difference-between-homeobox-and-hox-genes-e73d7926eca1)

"Every Hox gene is a homeobox gene, but not every homeobox gene is a Hox gene. The homeobox genes have diversified so much through evolutionary history that there are now distinct classes of them and the Hox genes are the most famous family of homeobox genes. The homeobox itself might be highly conserved, but the rest of DNA in homeobox-containing genes can have more freedom to evolve independently.

In us bilaterian animals, one of the main roles of the Hox genes is to specify anteroposterior identity to your body. It's a complicated system but a simplified explanation would be that the Hox genes play a role in determining which body parts grow and where on the body. By messing with their DNA, you can cause limbs to grow in the wrong places."

There’s lots more on the above web site.
For more on Jennifer Harrison see https://geneticjen.medium.com/
(I first learnt about the existence of homeobox genes from Jackie Chappell.)

Cladogenesis and Anagenesis
This Wikipedia entry has information relevant to the topics about evolution and development presented above:
http://en.wikipedia.org/wiki/Cladogenesis
Including (quoting from Wikipedia, with minor changes to fit this context):
Cladogenesis is an evolutionary splitting of a parent species into two distinct species, forming a clade.
Cladogenesis contrasts with Anagenesis, in which an ancestral species gradually accumulates change, and eventually, when enough is accumulated, the species is sufficiently distinct and different enough from its original starting form that it can be labelled as a new form - a new species. With anagenesis, the lineage in a phylogenetic tree does not split.

See the (fairly short) Wikipedia article for more details and more references.

Former colleagues and students
I am grateful to many past and present colleagues and students who have helped me in various ways, including making important suggestions and pointing out errors, lack of clarity, omissions, etc. There are too many to list here.

Note on personal history
In 1959, I switched from mathematics to philosophy of mathematics, while a graduate student in Oxford, after a degree in mathematics and physics at the University of Cape Town, in South Africa. My home, until I went to the UK, was a little town then called "QueQue", now "KweKwe", in what was then Southern Rhodesia, now Zimbabwe.

Brief CV:
First degree: BSc Maths and Physics, University of Cape Town, 1956.
Went to Oxford in 1957 to do mathematics, but switched to philosophy of mathematics around 1959. DPhil defending Kant’s philosophy of mathematics completed in 1962.
After teaching philosophy at Hull University, 1962-4, moved to Sussex University. In 1969, started learning about AI and learning to program after Max Clowes arrived at Sussex, and stretched my mind. I soon became convinced of the deep relevance of computation to philosophy, and later published The Computer Revolution in Philosophy: Philosophy, science and models of mind in 1978.

Much later, partly influenced by Kenneth Craik, The Nature of Explanation, Turing’s paper on The Chemical basis of morphogenesis, Schrödinger’s book What is Life, and other things, I became convinced of the importance of chemistry-based forms of information processing, though it took me several more years to notice the significance of hatching processes in eggs, and later on (since June 2023) the chemistry involved in metamorphosis.

I was also much influenced by Margaret Boden, a colleague at Sussex university from about 1965.