New title: 31 Jan 2024

How a physical universe can produce new forms of intelligence without an intelligent designer

Some alternative possible titles:
- Vertebrate hatching, insect metamorphosis, and intelligence
- How minds with brains evolved from brainless synapse-ancestors
- The biochemical/biophysical (not neural) basis of natural forms of intelligence
- Varieties of informed control since earliest proto-life forms emerged on planet Earth

Extra titles added 8 Mar 2024. Updated 29 Mar 2024

ABSTRACT

Updated 4 Apr 2024

There are many unobvious connections relating
- varieties of intelligence that have existed on our planet
to all of:
- physics, chemistry (especially biochemistry), biology, neuroscience, psychology, computation,
epistemology, metaphysics, and other branches of philosophy, including philosophy of biology,
philosophy of psychology, philosophy of mind, philosophy of science, philosophy of mathematics,
and the various histories of those branches of science and philosophy.

Below I try to show that these topics are also related to physical forms of control used in the earliest life-forms on this planet, long before animals and additional forms of control in later forms of life were produced by evolution. Biological evolution is an amazing bootstrapper. But it makes use of unobvious aspects of fundamental physics, in particular its generative powers.

Partly inspired by Karl Popper’s notion of three worlds summarised below, I’ll present a branching hierarchy of powers of the universe produced from an initial set of powers by processes "recursive boot-strapping" that repeatedly extend those powers.
The most familiar examples of such extensions are provided by the history of human technologies, but we can now see those extensions as relatively new instances of types of process extension that have been occurring since long before humans and other animals existed on this planet. I’ll present a draft incomplete abstract specification of the mechanisms, which may be refined later. The mechanisms and processes analysed by Popper can then be seen as relatively recent products of the much older mechanisms and processes of biological reproduction, development and evolution at work on this planet for millions of years.

Similar processes of boot-strapping may exist in other parts of the universe, but with very different outcomes.

The underlying mechanisms could be described as a form of intelligence in the physical universe, much more general than, and with richer potential than, intelligence of humans or other animals, which are among its products. Below I’ll offer some conjectures regarding how those processes might have produced new forms of life, with new specific forms of intelligence -- including branching forms of intelligence that have emerged through processes of biological evolution on this planet.

Unfortunately, most discussions of natural and artificial intelligence and their relationships, including many conference presentations, as well as books, journal articles, and web-sites, focus on intelligence in humans and other relatively recently evolved animals, such as nest-building birds, whales, orangutans, sheepdogs, etc., ignoring forms of intelligence, or more generally forms of information-processing, in very ancient organisms and in sub-mechanisms of current organisms, for example: biochemical mechanisms using various kinds of information in controlling processes of development, reproduction and evolution of animals, including control of amazing processes of metamorphosis in many species of insects, transforming both complex physiological structures, and behavioural capabilities (e.g. from crawling to flying) discussed below. These are all specimens of the generative powers of the universe at work.

Related News
Last updated 3 Apr 2024
I shall present some of the ideas below in an invited keynote talk at the World Congress On Organic Chemistry (WCOC 2024) taking place October 24-25, 2024, in Paris, France. My presentation, summarising some of the ideas presented below, will be given remotely. See: https://www.scitechseries.com/organic-chemistry/program/scientific-program/2024/how-minds-with-brains-evolved-from-brainless-synapse-ancestors
(The website misleadingly lists invited speakers as members of the organising committee.)

Background
Last updated 2 Apr 2024
Many years ago I started the work that led, after several changes of direction, to production of this web site. The most recent changes were based mainly on information found on the internet about biological mechanisms that might be relevant to explaining how, long before well-known ancient mathematicians such as Pythagoras, Euclid and Archimedes were born, even more ancient humans, in various continents, were able to discover and prove important geometrical theorems, including what we call Pythagoras’ theorem about right-angled triangles, re-discovered by Pythagoras. As explained below, those ancient humans discovered various diagrammatic proofs of the theorem. Over time, the research methods and explanatory ideas grew increasingly complex and increasingly difficult to explain.
Gradually (during 2022-2024) the aims of this document were extended in various ways, including trying to explain how a newly formed planet could provide mechanisms supporting evolution of brains with the required powers. That, in turn, led me to questions about how the physical/chemical features of the young planet, perhaps using material from other sources, such as comets or our nearest star, the sun, were able to produce all the life forms that exist on Earth, including physical/chemical mechanisms required for supporting many forms of reproduction, development and evolution, and also forms of collaboration and competition, leading to ever-increasingly sophisticated mechanisms used in or produced by increasingly diverse and increasingly complex forms of life, and their interactions and dependencies -- significantly extending the Darwin/Wallace theory of evolution.

For example, as explained below, human growth and development from a very early stage depends on the presence of bacteria that are not produced by the mother’s genome but are picked up from the mother’s birth canal during the process of birth.

Eventually, all that led (via pre-human life forms) to ancient humans. They spread across various parts of this planet, evolving into different races with slightly different physical features and many different competences (including very varied linguistic competences and cultures) and different types of knowledge, some of whom were able to make discoveries in geometry and topology, used in ancient engineering projects, including building temples and pyramids, transporting materials across long distances, and making various tools and transport mechanisms. using different kinds of mathematical knowledge, including knowledge of various subsets of topology, geometry, and arithmetic. Various subsets of that knowledge were also developed by other animals, including, for example, birds and insects making nests of different sizes, shapes and functions.

Some of the complex history of human intelligence is illustrated by the examples in these Wikipedia pages (among others):
https://en.wikipedia.org/wiki/Pythagorean_theorem
https://en.wikipedia.org/wiki/Archimedes

Most people who are familiar with those facts do not notice that the basic physical mechanisms involved in those processes of evolution and reproduction were also able to support many complex capabilities in other species, including insects able to collaborate in construction and maintenance of complex structures such as ant-hills, as illustrated in this short BBC video, https://www.youtube.com/watch?v=ZglirAfRvWg, and insects that are able to transform themselves to new life-forms with new capabilities during metamorphosis, using very complex mechanisms which I suspect may pose challenges for current theories about fundamental physics, discussed below.

There is an even richer history, nowhere completely summarised, as far as I can tell, which is the history of all the many types of biological mechanisms, substances, and processes that have existed on this planet and the roles they have had in the species in which they occurred. A few researchers, including especially Lynn Margulis, referenced below have thought and written about some of this history, though I suspect much is still waiting to be discovered.

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.

I don’t regard this four-fold division as sufficiently rich to capture the major transformations in mechanisms involved in producing, sustaining, and modifying forms of life. I hope it will later be replaced by a new systematic collection of labels covering, for example, products of evolution that extend the powers of biological evolution by making use of increasingly complex and powerful physical/chemical processes. The possibility of such mechanisms always existed, but the realisation of different increasingly complex possible mechanisms required many new physical mechanisms to be assembled by earlier products of biological evolution, all depending ultimately on features of the physical universe that have always existed, though increasingly complex and varied derivatives could be produced by processes occurring at different times in different parts of the universe, repeatedly using general features of the universe in combination with previously produced derived mechanisms in many different evolutionary/developmental trajectories. I suspect some of those processes depend on basic features of the universe that have always existed but have not yet been identified by human scientists. They may or may not be consistent with currently accepted "fundamental" physical theories.

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 feature of biological evolution, 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.

The history of all the details of life on this planet could not possibly be summarised completely in a single document, but perhaps we can make progress towards a useful partial history including key features of the early universe that supported all the later developments, and also possible developments that have not yet been realised on this planet, but may have been elsewhere in the universe, some of which could also occur in the distant future on our planet.
During development of the above ideas, this document has gradually grown into a progress report on a large and varied collection related sub-projects of different sorts.

I hope the numbers of researchers working on these topics will continue to grow and eventually will form a well integrated collaborative research community.

Link to Table of contents, still under construction.

**Added 17 Feb 2024**

For almost all the topics mentioned below there are other online sites providing more detailed information. But I have not encountered any other web site attempting to cover all these topics, apart from sites like Wikipedia that attempt to include information about everything that has been thought by competent internet users to be important.

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**Thanks**

People who have helped me via discussions or by sending information or suggestions, or whose online work has helped me, are mentioned below. I may have missed some because of my failing memory (age 87 since October 2023). I invite anyone not already mentioned below who has assisted my research in the past to contact me at the email address above if you would like to be added to the list of helpers below. Please provide a link to your personal web site if you have one.

I have been helped by researchers in many different disciplines, including former teachers, students, colleagues, and online acquaintances with shared interests, some explicitly thanked below. There are probably many others to whom I owe thanks, but whose influence I have not noticed, or forgotten, especially since brain decay (Alzheimers disease) started a few years ago.

I welcome new contributions, suggestions, criticisms, etc. though there may come a time when factors beyond my control prevent me from responding to such messages. I don't mind being sent a reminder if I have not responded to a message -- which may accidentally have become "buried out of sight" in my large collection of messages still waiting to be read!

**Apologies**

Updated 5 Feb 2024

This is work in progress, still being revised and extended, a process that is likely to continue for a long time, as I continue to discover, or receive references to, relevant items online and add references to them, along with comments, below.

So normal modes of publication, requiring information to be frozen at some point in time are not appropriate. For example, many references and important new ideas have been added since I started investigating what is known about control of insect metamorphosis in 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 and poor design of this document. That is partly a consequence of the inappropriate original layout of the document, which I did not expect to grow so large and complex. Perhaps there is no good design for a document containing so much diverse, constantly changing, information! Another factor impacting on the design is the (possibly misguided?) goal of attempting to include aspects of autobiography, explaining how key new ideas presented below developed and who and what contributed to that process.
A further factor is the complexity and diversity of the physical/chemical mechanisms underpinning biological evolution, reproduction and development, and the fact that those mechanisms are changed both by long term evolutionary processes and also by much shorter species-specific developmental processes in individual organisms, some of which later produce new species. For example, processes of metamorphosis in insects include several unobvious kinds of complexity, involving highly complex and intricate "actions at a distance" described and discussed below.

Yet another factor contributing to the complexity of this document is the constantly changing availability of relevant online information, some of which does not fit naturally into the pre-existing structure of this web site.

Documenting key features of all the mechanisms referenced, including updating the documentation when new features, or new information about the mechanisms, turn up, is a very challenging, never ending, task.

Some of the flaws in this document may be caused by my (creeping) dementia. I have been aware of memory problems for several years but towards the end of 2022 was diagnosed with Alzheimer’s disease, for which I have been prescribed Memantine, though I have no idea whether it is helping me. Fortunately the dementia has somehow not removed my ability to continue extending and revising this extremely complex web site presenting a large amount of material from many different research fields, much of it added since June 2023 when I first noticed some of the control complexities in insect metamorphosis.

It is difficult to provide adequate information for readers with different interests and backgrounds, most of whom will be familiar with at most a small subset of the subject matter collected here. I believe most (perhaps all?) current scientific educational procedures do not provide abilities required for understanding all the complexities of biological processes of evolution, reproduction and development.

I shall continue exploring alternative ways of presenting some or all of the information in this document. In most cases if an item is moved to a different part of the web site all existing links to it will continue working, though I may sometimes make mistakes. I am grateful for reports of bugs in this document.

Health and other factors permitting, I may try to produce a new, more appropriate, design at some future time. In the meantime, I am trying to provide navigational aids below, in the Table of contents, including notes about recent additions and other changes. Everything is somewhat messy because of the complexity and diversity of the subject matter and the history of construction of this document. Perhaps there are people who could produce (or have already produced???) better presentations of all this information. If so, please let me know, using the email address above!

If you save a copy of this document it is likely to become out of date soon, as information here is frequently corrected or extended. So it is better to save this link to the web site, instead: http://www.cs.bham.ac.uk/research/projects/cogaff/misc/metamorphosis.html

Video presentation on insect metamorphosis
Challenges to fundamental physical theories
What life forms, forms of evolution, forms of reproduction, forms of development, etc., are possible depends on a variety of features of fundamental physics. However, working out how those features explain the more complex processes can be a challenging task, as illustrated by the discussion of insect metamorphosis, below.

I shall try to indicate some possible challenges to current theories about fundamental physics, on which I am not an expert, so I welcome comments from theoretical physicists. I have already had a great deal of help in the past from Anthony Leggett, a distinguished theoretical physicist with whom I have interacted at various times since we met as students in Oxford around 1960, though he has not seen recent versions of this document, much expanded since I began to speculate about the pre-history if synapses in June 2023.

Location of this document:
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/metamorphosis.html
Despite the file name, this is about far more than metamorphosis - partly because the document has been through multiple phases of metamorphosis!

Browsable Table of Contents (Still under construction)

This table of contents is incomplete and is likely to continue being expanded and reorganised, and the collection of items referenced is also likely to change.
The order in which items are listed in the table of contents is not the same as their order in the document.
Some items may later be moved to new locations in this document, where they are more relevant as a result of other changes to the contents of the document.

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Note on intelligence and consciousness in sub-mechanisms, not whole organisms

Note on widely believed but false assumptions

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Intelligent, conscious(?), subsystems of organisms

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APPENDIX 1: Is physical space/time discrete?

A new question about action at a distance

Why are assembly mechanisms "intelligent"?

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How David Hume inadvertently inspired Kant

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Beyond Kant: Forms of spatial intelligence in biological reproductive mechanisms

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Karl Popper’s three worlds

Leo Caves, on Popper, Whitehead, Biology and Category Theory

Useful comments, questions, and publications by Dennis de Champeaux

Hamid Ekbia Has sent me useful comments and references


Aaron Turner’s "BigMother" project, partly related

What does Chat GPT6 think about all this?

Revisions still in progress

Warnings for readers

Intelligence and consciousness in sub-mechanisms, not only whole organisms

Confusions about "self" or "selves"

False beliefs about evolution of language

David Haussler’s Reverse Evolution Machine

Research on optogenetics

Optogenetics is a technique in neuroscience in which genes for light-sensitive proteins are introduced into specific types of brain cells in order to monitor and control their activity precisely using light signals. It is claimed that this allows researchers to control how nerve cells communicate. I cannot yet judge the importance of the optogenetics research in detail, but it is potentially relevant to the issues presented here.

Contactless Signalling in many species
Cell cycle: Making waves to coordinate the entry into mitosis
Noam Chomsky and various others emphasized "productivity" of thoughts, etc.

Note on Gregory Bateson and information.

SOME COMMON CONFUSIONS

Thanks to Former colleagues and students (in semi-random order below!)
Margaret Boden
Max Clowes
He was an important personal influence in my switch to use of AI concepts and tools.
David Hogg
Luc Beaudoin
Nick Hawes
Ron Chrisley
Matthias Scheutz
Early help from R.M.Hare
Mateja Jamnik
Mary Pardoe
Clare MacCumhaill
Anna Ciaunica
Aviv Keren
Daniel Dennett
Carlos Gershenson
Warning about Rupert Sheldrake
Brief CV for A.S.

Note on personal history

Note on my time at Sussex University

Older (simpler) Evo-Devo document

Katrin Hammerschmidt, et.al. on the evolution of multicellularity

Homeobox and hox genes

Cladogenesis and Anagenesis

Openai.com

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

Scientists at Fermilab close in on fifth force of nature Is this relevant?

APPENDIX 2: Additional relevant items

Note:

This table of contents may grow larger to include relevant items not yet listed.
If you can’t find something you were looking for, try a text search.

Some background information:
(Still being revised!)

Note on document history

Skip-document-history

This web site (a draft, incomplete, work-in-progress document) has undergone a great deal of metamorphosis since it was originally created! The changes include, but go far beyond, discussion of metamorphosis. As a result, the name ‘metamorphosis.html’ is now potentially misleading, but any other short name would also be misleading. So the name is unlikely to be changed soon!
Some readers will recognize that much of my thinking about these topics is influenced by the claims made by Lynn Margulis about "symbiogenesis", referenced below.

This work substantially extends and is partly inconsistent with earlier work for which, in 2020, I was awarded the 2020 K.Jon Barwise Prize by the American Philosophical Association (APA): https://www.apaonline.org/page/2020Prizes-S#Barwise
The work that led to that award is now out of date!

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, including some very ancient (e.g. single-celled) organisms and other more recently evolved species, e.g. mammals and other vertebrates.

These bio-evo-devo mechanisms are also related (in unobvious ways) to a host of questions in different disciplines, including philosophy of mind, philosophy of science, philosophy of mathematics, neuroscience, psychology, linguistics, and a collection of biological, biochemical and biomedical research and application areas. There are likely to be implications for practical activities, such as education, treatment of brain disorders, various other kinds of medical treatment, development of new tools to support those activities, and implications for interplanetary or possibly even intergalactic travel (not discussed here)!

The mechanisms discussed below facilitate, or modify, changes of various kinds in products of evolution, including changes in spatio-temporal relationships (directions, distances, shapes, relative speeds of translation or rotation), changes in physical forces, changes in bonds between particles, i.e. chemical bonds that can be formed, strengthened, weakened, or released, changes in functional roles of various parts of organisms, and changes in biological species and their relationships. This is an illustrative list: I am not claiming to have covered all the mechanisms or all the biological functions that need to be explained.

The explanatory mechanisms include abilities to create, store, transmit, modify, or use information of many kinds, including information about new products of biological processes, and information about possibilities for and constraints on changes. The mechanisms are relevant to explaining powers of biological evolution and development, as well as helping with human engineering.

The mechanisms are also relevant to design of materials for education of teachers, psychologists, therapists, and philosophers whose work focuses on biological phenomena.

Some of the naturally occurring mechanisms discussed are physical, including many chemical mechanisms that don’t merely change spatial relationships (e.g. directions and distances between components of organisms) but also produce or remove chemical bonds between particles.

Contactless causation in biological processes
Some mechanisms operate across spatial and temporal distances, including very small or zero length distances (e.g. involving contact). The contactless causes operate across gaps in space or time or both, including gravitational, centrifugal, electrical and magnetic forces. There are also many contactless forms of causation involved in perception and signalling capabilities in a wide variety of animals including insects and cross-species forms of communication used for example by plants to attract pollinators or deter predators, as illustrated in this very useful video presentation by two amazing young scientists, added 28 Feb 2024:
I suspect that some of the biological phenomena reveal gaps in current physical theories. E.g. it may turn out that not all details of control of processes of chemical decomposition and reorganisation during insect metamorphosis summarised below can be explained by current theories in physics. Compare the discoveries by ancient humans regarding irregularities in observed motions of bodies visible at night, and the discovery of magnetism, used for navigation not only by humans but also other animal species, as illustrated and explained here: https://en.wikipedia.org/wiki/Magnetoreception. (Added 28 Feb 2024)

**Note on the role of Fungi**

Updated 28 Feb 2024

Previously this document did not mention Fungi, despite their great importance in evolution of many non-fungal forms of life, pointed out, for example, by Lynn Margulis in her work on evolution of forms of life). See, for example, David Moore’s *Fungal Biology in the Origin and Emergence of Life*, Cambridge University Press, 2013: https://davidmoore.org.uk/root_06.htm

End of background information

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**Biological processes involving information**

Influences of biological changes include changes in use of information, e.g., storing, copying, or using information specifying changes in structures, processes, and relationships, over different spatial and temporal scales, for instance using information relevant to:

- reproduction, control of various stages and types of development, selection and control of actions, including internal actions such as creating, comparing and selecting goals, considering reasons, modifying previously stored information, taking decisions about what physical actions to perform and what internal information processing actions to perform. The physical processes controlled by using information include consumption of new matter, growth of organs, distribution of nutrients, distribution of important chemicals produced by relatively central glands, disposal of waste material (e.g. carbon dioxide and other chemicals), inhalation of oxygen, use of products of digestion of food for many different purposes, correction or partial correction of results of abnormal processes (e.g. during reproduction), and repair, or partial repair, of externally caused damage of various sorts with various causes.

All those information-using processes are examples of use of intelligence.

Most of those topics are ignored by researchers on intelligence (including me in the past), because intelligence is normally thought of as an aspect of a whole organism, e.g. a human or other intelligent animal that is capable of forming complex goals and then devising means to achieve them, using pre-existing intelligent design capabilities.

In contrast, this document includes discussion of intelligence used in *subsystems* of organisms, e.g. digestive systems, disease-resistance systems, mechanisms controlling various stages of hatching in eggs, mechanisms controlling metamorphosis in insect cocoons, and many more.

One of the "high level" aims of this project is to explain how the biochemical mechanisms that are available in earlier states of the physical universe have the potential at later stages, to create increasingly complex new physical structures, including creating intelligent mechanisms. These are...
forms of intelligence (e.g. intelligence in plants) that are involved in control of internal or external processes but do not require explicit future goals, or abilities to predict future developments. For example, a very young oak tree, or pine tree uses various kinds of intelligence in various subsystems, e.g. roots, stem, branches, leaves, but it does not have the sort of intelligence that might be attributed to a human, a non-human animal, or an intelligent designer!

A similar comment can be made about the intelligence of a partly hatched animal inside an egg or the intelligence of an insect or part of an insect while transforming itself inside a cocoon.

The evolution, development, and functions of affective mechanisms
Added 6 Apr 2024
A lot of my work in the past has been concerned with affective states, processes, mechanisms, and their biological functions, but without sufficient regard for their evolution until very recently. Examples of the older work are listed here
http://www.cs.bham.ac.uk/research/projects/cogaff/misc/emotions-affect.html
Many of the other topics referenced here involve what might be described as "implicit motivation" including ancient mechanisms of reproduction and development.

How a physical universe can produce new forms of intelligence without an intelligent designer
Perhaps the topic being discussed should be labelled "blind intelligence", attributed to physical/chemical mechanisms that repeatedly produce new increasingly complex products, including new intelligent assembly mechanisms, and increasingly complex forms of blind intelligence, but without using the kind of intelligence that starts from explicit goals and finds means to achieve them.

Processes using such blind, or partly blind, intelligence can operate over very different time-scales, including both rapid formation of motives in an organism that immediately trigger actions, and also long term multi-stage developments of increasingly complex goals, mechanisms, organisms and species. The latter processes require evolutionary time-scales.

The mechanisms proposed below repeatedly produce new complex products that were not pre-specified in explicit goals or intentions, but nevertheless require forms of intelligence (or "know-how") to be used in their production: increasingly complex forms of blind intelligence are products of simpler forms of blind intelligence.

The implicit goals achieved in this way result from repeated production of mechanisms that can generate both new goals and new mechanisms to achieve them.

As a result, over time, the physical universe can produce very complex mechanisms achieving very complex goals, starting from a state in which neither those mechanisms nor those goals existed. This document does not offer suggestions as to whether the universe had a beginning or has always existed (whatever that may mean!), and what requirements a beginning state must satisfy in order to produce what we now know exists. An older survey of mechanisms involved in production of motives, and other forms of affect, was mentioned above.

I hope this complex (contorted??) summary is intelligible, though I do not expect it to be easy to understand! It has been revised several times. There will be further revisions!
Examples of products of evolution and development presented in this document, including new goals and new mechanisms, are only a sample, not a complete list.

This document provides an indication of the diversity and complexity of physiological processes using biochemical mechanisms, in a wide variety of organisms, over a wide variety of time-scales. It is likely that many more special cases will be discovered in future, and errors and omissions will have to be corrected as a result!

Intelligent selection of actions, whether internal to organisms or actions in the environment, requires abilities to detect that certain options will fail, and others will succeed, and that the possible outcomes in other cases are not yet predictable, although likelihoods may be partially ordered.

Explaining how all this is possible involves describing the evolutionary mechanisms that create all the above mechanisms. Over time, and in different ways in different parts of the physical universe, such evolutionary mechanisms (helped by their physical and biological environments) create new evolutionary mechanisms as organisms become more complex and later stages of evolution produce more complex developmental transformations. This involves mind-boggling recursion, producing steadily increasing complexity and diversity of mechanisms and products!

The ideas presented here are inspired by research results and publications of researchers in a wide variety of disciplines. Most of the researchers (and disciplines) consider only a small subset of the biological phenomena, for example: studying learning in humans or other animals without considering the evolutionary and biochemical developmental mechanisms that produce or are used by those learning processes.

I have learnt from many researchers. One of them is William Bechtel referenced below. After we met and talked at a conference in Edinburgh in 2018, his ideas helped to stimulate some of the key thoughts presented here, though I don’t know whether he would endorse results of that stimulation!

Varieties of intelligent subsystems in organisms

Background information is available above. We normally discuss only intelligence of complete organisms, but there are also many mechanisms within organisms that use various types of intelligence, which differ at different stages of reproduction, development and behaviour of the organisms, in unobvious ways.

There are also forms of intelligence that are shared across individuals, when two or more organisms collaborate in tasks that individuals cannot perform alone, including hunting, mating, learning by playing, swarming, and building structures, e.g. insect hives, ant-hills, etc.

Later examples of intelligence include many forms of interdependence between species, including unobvious but crucial forms of cross-species collaboration required for many internal processes, such as disease resistance that results from eating other organisms, and other examples, many of which are highly counter-intuitive.

E.g. digestion of food in humans requires collaboration with bacteria. I was surprised to learn, and I suspect many readers will be surprised to learn, that a newborn human infant cannot digest its mother’s milk without help from bacteria picked up from the mother’s birth canal during the birth process, because the child’s genome does not provide all the required digestive mechanisms. One of many sources of information about this is here:
I hope this work can help to contribute to the hopes and objectives mentioned in this short video produced by the MIT media lab:
https://www.media.mit.edu/groups/media-lab-research-theme-future-worlds/overview/

History of this research
The research reported here 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 (detailed below) that David Hume’s two acceptable forms of reasoning (empirical reasoning based on sensory evidence and logical reasoning in which consequences are derived from definitions of terms), did not include forms of spatial reasoning used in ancient mathematical discoveries, such as diagrammatic proofs of Pythagoras’ theorem. I later learnt (as mentioned above) that many different diagrammatic proofs of that theorem (and other geometric theorems) had been discovered in several different countries, centuries before well-known ancient mathematicians such as Pythagoras, Euclid and Archimedes were born!

Further information below: The Kant-Hume disagreement and History of geometrical discoveries.

In June 2023, results of exploring Kant’s ideas and their implications, at various times between 1959 and 2023, unexpectedly 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. The new ideas included the following new conjectures, which I have not seen mentioned elsewhere.

Key new conjectures
Here are some of the key new conjectures:
(Updated 30 Dec. 2023)

Main new conjecture: The earliest ancestors of existing vertebrate species were single-celled organisms that were ancestors of current brain synapses!

Further details: Later evolutionary changes (somehow) enabled collections of those single-celled synapse-ancestor organisms to combine and share resources in more complex organisms, in which ancestors of neurons somehow evolved to allow the synapse-ancestors to communicate and collaborate. Those neuron-ancestors had a secondary role, supporting the biological functions of collaborating synapse-ancestors.

Further evolution enabled organisms to become even more complex, through cell-division and differentiation. Some of the resulting new species used ancient precursors of neurons to transmit information, to support both communication between the synapse-ancestor cells that had become linked for mutual benefit, and also to support monitoring and control (by synapse ancestors) of other organs that evolved later.

In various evolutionary trajectories, synapse clusters linked by neuron ancestors somehow evolved abilities to grow additional structures performing new functions, e.g. sensing objects in the environment, moving in the environment towards useful entities and away from obstructions and dangers, and manipulating some of the objects, including consuming some of them, in order to make use of some of their chemical constituents, by disassembling some of their complex molecules and re-using the components to form new structures -- processes which required
additional newly evolved biochemical mechanisms.

A result of all that evolutionary history followed by multi-stage development during reproduction, is that biochemical processes in synapses, collaborating with the aid of neurons, now have important but unrecognised roles in intelligence of many current animal species, including humans.

Moreover, it is now evident that during insect metamorphosis processes, some ancient products of biological evolution achieve complex disassembly and reassembly of physiological structures in cocoons or pupas -- processes that involve much less energy consumption, and a much smaller range of temperatures and pressures, than any mechanisms designed by human engineers to create complex new machines by disassembling and reassembling physical structures.

All this contrasts with the "standard" view of neurons as the main mechanisms of intelligence, aided by synapses that allow neurons to influence one another or collaborate.

My conjectures about the roles of synapses and their implications are very speculative and are also still too vague/imprecise. I hope that further research, or work already done by other researchers but unknown to me, will make it possible to add many more detailed and precise claims about chemistry-based mechanisms of intelligence and the roles of synapses in intelligence.

One of the themes emerging from this research is that the biosphere can be thought of as "the greatest ever experimental researcher", constantly exploring new combinations of previously acquired knowledge and expertise, constantly making new discoveries and using them, while also producing many false starts and failed experiments, i.e. forms of life that did not survive, for various reasons. Moreover, the evolutionary mechanisms that produce new physical structures and extend forms of intelligence sometimes produce "mistakes". Conjoined twins are a spectacular example.

If we think of the biosphere as a giant organism it is the largest, most successful, most intelligent, and increasingly intelligent, organism on the planet, and perhaps in this galaxy, or even in the universe, if there's no other similar biosphere?

Added 18 Dec 2023

Expressed more modestly, this is a claim that long before evolution produced organisms that humans would be inclined to describe as intelligent, it produced mechanisms that enabled ancient organisms to perform biochemical tasks during reproduction and development that, despite involving sub-microscopic disassembly and assembly processes, surpass the complexity of tasks performed by human-designed "intelligent" machines operating on assembly lines in factories. The human-designed mechanisms do not disassemble parts of previously functioning complex machines and reassemble the components to produce new machines with some entirely new components and entirely new behavioural capabilities, as in post-metamorphosis flying insects.

**Did synapses evolve before neurons?**

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 ancient synapse-like mechanisms and other more recently evolved mechanisms in ancient animal bodies, including sensors and muscles. So, instead of synapses connecting neurons, neurons originally connected ancient precursors of synapses, allowing them to collaborate. As more complex organisms evolved, neurons also linked the precursors of synapses to increasingly many 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. The work of Tibor Ganti proposes requirements for the earliest organisms reproducing sexually using DNA.

Note on plant intelligence
Added 10 Nov 2023
There has been relevant work on "plant intelligence" and collaboration between animals and plants, e.g. by Paco Calvo and colleagues referenced below.

Gaps and errors in this document and in related work
Updates and reorganisation are likely to continue for some time!
If the date of last update (top of the page) is more than two days ago please refresh the page (e.g. using Ctrl-R in several Web browsers) as there may be important new information, and portions of the document may have been re-written.

As I learn more about research related to the ideas presented in this document I become increasingly aware of gaps that still need to be filled, and the likelihood of confusions and errors that I have not (yet) noticed. I shall try to remember to add information here about gaps and possible errors that I do notice in the contents. It is likely that the list of gaps in our understanding will grow substantially as I learn more and think more about mechanisms and processes of evolution, reproduction and development of biological organisms and mechanisms. I may also include notes on non-trivial errors or omissions in other published work.

Revisions still in progress
(There are some inconsistencies of spelling below, because quoted items include words that are spelled differently in British English and American English.)

Because this is likely to be my last major research document, on account of (slowly) progressing dementia, described below, I have been adding links to more or less closely relevant autobiographical background information that would not be included in a normal research report.

Apology for inadequate title
(Apology updated 8 Dec 2023)
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. That change in the focus of research led to inclusion of a huge amount of additional material concerning mechanisms of evolution, reproduction and development, including mechanisms for producing new mechanisms -- a constant feature of biological evolution,
whose implications I did not notice for many years. I was not alone!

**Previous title for this document, and possible alternative titles**

**Vertebrate Hatching, Insect Metamorphosis, and Intelligence**

(Title changed from older title "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)

**Further alternative possible titles**

Added: 23 Oct 2023

Because these investigations led to a surprising view of the importance of synapses, alternative possible titles, or sub-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?*

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**Warnings for readers:**

- 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, or providing a qualifier something like "as reported by Sloman in ..." with a link to this document. I shall try, over time, to reduce the number of errors and omissions.

**Disclaimer about synapse conjecture**

I am not suggesting that the earliest 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 *Carroll (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:

https://www.youtube.com/watch?v=qsn4z7bNble "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 above.

The conjectures also have connections with the ideas of Tibor Ganti about the earliest forms of life using sexual reproduction, 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 below.

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 insect metamorphosis, partially disassembling and 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 and re-construction processes.

I searched for, but could not find, explanations of how those chemical processes used in metamorphosis were controlled. I began to suspect that the best candidate mechanisms would be variants of the chemical processes already identified in synapses, which, in the light of information about 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 I do not recall Grant making those specific claims, in anything I read.
Intelligence and consciousness in sub-mechanisms, not only whole organisms

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

In contrast, this document is mainly about intelligence in mechanisms, including biological mechanisms that are components of organisms rather than whole organisms: we can refer to forms of consciousness that occur when components of organisms acquire and use information in performing their biological functions.

For example, animal 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 such sub-mechanisms involved in evolution, reproduction, development and functioning of organisms. These mechanisms 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 of forms of intelligence mentioned in those contexts include processes that make use of information in performing tasks or serving biological functions, such as reproduction, development (including growth of new organs), digestion of food, disposal of waste products, etc.

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 of components of organisms to use information can be regarded as examples of consciousness and intelligence, although they are not normally included in discussions of consciousness or intelligence. As mentioned above, most discussions of the nature of consciousness or criteria for consciousness refer to abilities of whole organisms or machines, whereas this document discusses forms of intelligence and consciousness in mechanisms within organisms produced during various stages of development, including mechanisms that produce new mechanisms with new forms of intelligence.

These are not questions and topics that are normally addressed in publications on consciousness. For example, the discussion of consciousness in the recent, highly praised, book by Anil Seth referenced below does not (as far as I can tell from partial reading) attempt to answer any of the questions about intelligence in developmental mechanisms discussed in this document. Presumably none of the reviewers praising the book noticed that lack, or would have regarded it as relevant to an evaluation of the book, or the author. (I have written to him about this!)

I suggest that the examples of biological intelligence discussed here involve forms of consciousness, 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, even if what uses the information is only a relatively small part of an organism or machine.
Note on widely believed but false assumptions
Added 27 Nov 2023. Updated 5 Jan 2024
One of the problems facing researchers interested in various aspects of evolution, including evolution of mechanisms underlying intelligence, is that there are widely held but mistaken beliefs that can cause inappropriate questions to be asked, and important evidence to be ignored. This can lead to serious distortions in theories and research methodologies. An example is the wide-spread mistaken belief that spoken languages evolved before sign languages. Why that is an error is explained below.

Another error is the belief that trainable neural networks that derive conclusions from statistical evidence can explain all forms of spatial and mathematical intelligence, ignoring the fact that there are forms of human (and non-human) spatial intelligence involving discovering that something is impossible, i.e. its negation is necessarily true, which cannot be achieved by statistics-based reasoning. As Immanuel Kant noticed around 1781, necessity is different from a very high probability and impossibility is different from a very low probability. So trainable neural networks cannot provide abilities to discover that Pythagoras’ theorem is necessarily true because they cannot establish that counter-examples (in a planar surface) are impossible, as explained below. See also
https://www.cs.bham.ac.uk/research/projects/cogaff/misc/toddler-theorems.html#primes

Online demonstrations by Tadashi Tokieda
Additional examples are presented in the brilliant online demonstrations of reasoning about geometric and topological necessity and impossibility by Tadashi Tokieda, using forms of reasoning that, as far as I know, cannot be replicated either by artificial neural networks or other existing computer-based models:
https://www.youtube.com/watch?v=3vNoRvr6OzA
https://www.youtube.com/watch?v=D15L0E1zHJ0
and a recent (2023) lecture in Oxford that I have just discovered but not yet watched all of it:
https://www.youtube.com/watch?v=8p02DtmyQhU
He is one of the most spectacular teachers regarding varieties of topological and geometric discoveries, making no use of any standard formal methods of reasoning, e.g. in these two "elementary" videos:
https://www.youtube.com/watch?v=SXHHvoaScto
https://www.youtube.com/watch?v=Wj5foqm5MfM

He also has many other 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.
Can current physical theories explain how brains perform such tasks?

Note on consciousness during sleep-walking
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 an action such as opening a closed door while sleep-walking, which requires a form of consciousness of the state of the door while a person is asleep and unconscious.

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:
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. I welcome suggestions for additional references to be added to this document.

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

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 about statistics-based neural network mechanisms cannot explain those spatial reasoning competences that provide discoveries about spatial impossibility and necessity. So AI systems based on such theories, cannot model or replicate the phenomena discussed here, including abilities of ancient human mathematicians and spatial reasoning abilities of other highly intelligent animals, including elephants and apes.

Modified: 28 Feb 2024

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

Examples of hatching and metamorphosis (illustrated in videos and other references in this document) show that 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 normally observe. However this amazing video shows stages of hatching in a real, partially opened egg (but not the molecular processes producing the changes): [https://twitter.com/HowThingWork/status/1640995937685319684](https://twitter.com/HowThingWork/status/1640995937685319684)

The unobservable biochemical control processes 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: [https://www.youtube.com/watch?v=YePKbjODrto](https://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 come 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 than hatching processes are required to explain the amazing processes of metamorphosis in insects, presented in the remarkable video included in the website referenced above. 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:
  insect-parts are 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 insects before metamorphosis are very complex, despite their small size.

- Complexity of new physical structures created by metamorphosis 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, making use of "co-operative" changes in some plant genomes, illustrated by the research of Paco Calvo referenced below.

- Complexity of new behavioural competences created by insect metamorphosis:
  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 also because of 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. My comments focus on 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.

**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 previously talked about the need to move particles between locations, in a hatching egg, or in an 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, which I had read and posted comments on several years ago.

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!

**A new question about action at a distance:**

Does control of "action at a distance", without physical grippers and sensors applying forces and providing feedback, require greater intelligence than control using physical manipulators which apply forces and provide feedback?

**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, apparently without any form of physical feedback to assist control, 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 greater challenges for fundamental physical theories than requirements for control of disassembly and assembly of matter in eggs of vertebrates, where no previously assembled complex physiological structures are disassembled and the components used to assemble new complex structures. The matter that is disassembled in hatching eggs of vertebrates is relatively amorphous, unlike insect components that are disassembled during metamorphosis.

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 are assembly mechanisms "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. For example, 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: 
[https://www.youtube.com/watch?v=LWOb8k0kbXY](https://www.youtube.com/watch?v=LWOb8k0kbXY)

and this one showing transformation of a dragonfly: 
[https://www.youtube.com/watch?v=pMq5IY4XUkc](https://www.youtube.com/watch?v=pMq5IY4XUkc)
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. ($$ add links here $$)

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, e.g. in car factories.

**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
are related to points made by Immanuel Kant around 1781. David Hume had claimed in a famous
statement about types of knowledge and the mechanisms that made them possible, 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. Hume’s first alternative is compatible with the powers of neural networks, but not his
second, since logical and arithmetical reasoning can establish that certain propositions are
necessarily true or necessarily false, and necessity is not a degree of probability.

**Kant’s reaction to Hume**

Kant had read Hume’s work and stated that it had awakened him from his “dogmatic slumbers”!
But he also criticised Hume’s criteria for permissible kinds of knowledge by presenting examples of
discovering that something is topologically or geometrically impossible, or necessarily true, which
could not be based EITHER on a process of collecting data and deriving probabilities, because
necessity and impossibility cannot be derived from very high and very low probabilities OR on a
process of logical derivation from definitions of terms, since those ancient discoveries occurred
long before logicians had developed logic-based formal reasoning systems, and they were based
on forms of spatial (geometric or topological) reasoning. So, in addition to being non-empirical (a
priori) and necessary truths they were also synthetic, not analytic, in Kant’s terminology, though he
pessimistically thought the mechanisms used were too mysterious for us to understand (“forever
concealed in the depths of the human soul”).

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. For readers who are unfamiliar with these ideas, more examples of such geometric and topological discoveries are available here: https://www.cs.bham.ac.uk/research/projects/cogaff/misc/impossible.html

Because necessity and impossibility are not points on probability scales, Kant's observations imply that statistics-based neural networks cannot explain ancient non-probabilistic 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 had offered an early specification of logicist explanations/models of mathematical reasoning, namely derivation from definitions of terms, using only logical methods of reasoning. Although Kant agreed with Hume’s criticisms of beliefs presented in religious texts, and accepted his endorsement of logic-based reasoning mechanisms where available, he thought the logic-based mechanisms endorsed by Hume could not account for many ancient geometric and topological discoveries, and other discoveries such as the impossibility of a right-hand glove fitting a left hand.

There is no evidence that such logic-based reasoning was used either by the most ancient mathematicians making geometric and topological discoveries, or by intelligent non-human animals taking decisions based on reasoning about what is or is not spatially possible in some situation, e.g. a bird building a nest, an animal trying to carry a long thin object through a narrow gap, or a squirrel working out how to defeat a "squirrel-proof" bird-feeder (search the internet for examples of squirrels succeeding).

Kant called the Hume-endorsed truths that are 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 and proved many of them (by reasoning, i.e. non-empirically). He also added the above glove example, and several others.

In his comments on 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: as noted above. Some of those discoveries, not taught in mathematics classes, are made by young children and other intelligent animals 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. Although artificial neural network mechanisms can achieve impressive and useful results based on discoveries of high or low probabilities, they cannot overcome the limitations noticed by Kant.
See also the note on inadequacies of Bayesian Nets.

I suspect that current popular but mistaken beliefs about what neural networks can do are 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.

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**Beyond Kant: Forms of spatial intelligence in biological reproductive mechanisms**

This document extends Kant’s ideas by proposing that not only humans, but also 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 mostly unstructured chemical contents of the new-laid egg will require use of other mechanisms that do not exist when hatching begins.

So the hatching processes within the egg 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 have been trying 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 [https://en.wikipedia.org/wiki/History_of_logic](https://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 even older forms of spatial reasoning capabilities in highly intelligent non-human animals mentioned above.
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.

**Relevant work by Seth Grant and colleagues**

Another key influence is the work of Seth Grant and colleagues in Edinburgh on the chemistry-based information processing functions of synapses, which I first encountered when he gave a talk on the complexity of chemical information processing in synapses at a conference on brain mechanisms in Cambridge (UK) in 2008. His 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!)

As I had already concluded (influenced by Kant’s critique of Hume, mentioned below) that the statistics-based reasoning mechanisms used by neural networks could not explain abilities to discover examples of mathematical necessity or impossibility, e.g. the theorems in Euclidean geometry, I suspected that chemistry-based reasoning in synapses might have the required powers. However, at that time I did not suspect that related mechanisms might be involved both in the earliest pre-cursors of current animals, and also in processes of insect metamorphosis.

A problem for the claim that information is stored in synapses is that the chemistry in synapses is dynamic. That problem is discussed and a (complex) answer proposed in the following video discussion between Seth Grant and Ginger Campbell in 2023:

https://www.youtube.com/watch?v=vWuSpIAZW9s.

See also this talk:

https://www.youtube.com/watch?v=vBHUFQwGAe8

The synaptic origins of brain complexity.
Presented to The Academy of Medical Sciences, 20 March 2020.
Further details: https://ow.ly/pBln50xDeEG

The work of Grant and his colleagues seems to me to provide (unintended) 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 sexual 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 may have evolved later to support forms of collaboration, followed at a later stage by evolution of multi-celled organisms using sexual reproduction allowing different products of evolution to be combined in new ways.

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 below.

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!

**The power of chemistry-based 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. The details are partly inspired by the work of Seth Grant on synapses and Tibor Ganti on *The Principles of Life*, leading to conjectures linking *Synapses, Kant, and explanations of human mathematical abilities*. 
Two conjectures about chemical mechanisms:
I conjecture (a) that 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 and (b) that 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 have provided various examples of what they achieve, including control of reproduction and development and also enabling discoveries in geometry and topology by ancient human mathematicians including multiple rediscoveries of Pythagoras’ theorem mentioned above.

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: https://evolution.berkeley.edu/the-history-of-evolutionary-thought/1900-to-present/evolution-and-development-for-the-21st-century-stephen-jay-gould/

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."

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. Also mentioned above: 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". In contrast, I conjecture that those ancient mathematical reasoning abilities 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 mentioned below.

How evolution evolves
Why evolutionary "tree-shaped" 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 https://en.wikipedia.org/wiki/Phylogenetic_tree using trees whose branches diverge and become more numerous over time, but never merge.

Such tree diagrams ignore 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, another 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.

Moreover, one of the major themes of this document is that evolution was producing what could be called "increasingly intelligent" mechanisms involved in processes of reproduction, development and evolution, long before it produced humans. Some of those products are now being used by
humans in biochemical engineering projects!

**Non-tree-structured gene-expression diagrams**

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: [https://www.cs.bham.ac.uk/~axs/fig/evo-devo/evo-devo-final.jpg](https://www.cs.bham.ac.uk/~axs/fig/evo-devo/evo-devo-final.jpg).

It was 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.

**Sophistication of 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**

Updated 31 Mar 2024

The ideas above, are related to ideas about "meta-configured genomes" developed in collaboration with Jackie Chappell after she came to Birmingham in 2004, following her PhD work in Oxford. 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 gene expression make use of parameters (items of information) acquired from *interactions with the environment*, including members of the same and other species during earlier stages of gene expression.

These processes include development of and uses of mechanisms concerned with generation, comparison, and selection of goals or motives, either for the whole organism or for parts of the organism, and in some cases groups of collaborating organisms, such as insects building hives or ant-hills, mentioned above.

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 explains how later stages of gene expression in an individual can be substantially influenced by features of the environment that were produced by ancestors of that individual. One of the consequences is 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, using the same general human genome features combined with some recently evolved ancestor-derived genome features. In all those cases gene expression processes can also be influenced by environmental features produced by ancestral individuals with the same main genome features interacting with their environment.

This might be perhaps be expressed as follows: In some species (meta-configured) gene expression processes produce results that can modify gene expression in other members of the species, including gene-expression in descendants born much later.
I think these ideas have not yet been included in the theories produced by Mike Levin and his collaborators, although there seem to be some partial overlaps. (There may be more overlaps than I have noticed!)

Another consequence of a meta-configured genome is the ability of older members of a species to develop very different competences in different locations where they interact with other members of their species in environments that have been changed by their ancestors. Examples include differences in spoken, signed and written languages in different human communities.

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!

**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 including an invited talk in January 2023 presented online using zoom, at the Tokyo conference mentioned below. Those talks suggested that hatching processes and mechanisms in eggs of vertebrates might pose challenges to current theories about fundamental physics.

The January 2023 talk presented those ideas using an earlier, simpler, version of this "evo-devo" document: https://www.cs.bham.ac.uk/research/projects/cogaff/misc/evo-devo.html part of which is replicated below.

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!
Insect pupation/metamorphosis: a brief summary, possibly challenging current theoretical physics.

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 all the relevant aspects of current physical theories may be insufficient for this assessment -- partly because I lack some of the required mathematical expertise. I hope readers who have the required expertise will be able either to endorse my claims or point out where I have gone wrong.

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: [https://home.cern/science/engineering/cryogenics-low-temperatures-high-performance](https://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. I find the achievements of biological evolution hundreds of millions of years ago stunning.

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: https://youtu.be/bki2kI8aQvg.
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.

**Newly hatched avocets provide another type of example**

Recently hatched avocet chicks leave their mother to walk towards nearby water in which they catch food, in this 35 second videoclip from a BBC Springwatch programme in June 2021: [https://www.cs.bham.ac.uk/research/projects/cogaff/movies/avocets/avocet-hatchlings.mp4](https://www.cs.bham.ac.uk/research/projects/cogaff/movies/avocets/avocet-hatchlings.mp4).

**Sea turtle example**

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.

More information about hatching processes: Chicken embryo development

*Poster_Chick_Embryo_Dev_English.pdf*

https://www.poultryhub.org/chick-embryo-development-animation

(Scroll down to see the video showing the 21 day process.)

Photographs of chick embryo stages (jpg):

https://www.cs.bham.ac.uk/~axs/fig/chicken-egg-devel.jpg

apa-stuff.d/Poster_Chick_Embryo_Dev_English.pdf

DAY 1: Appearance of embryonic tissue.
DAY 2: Tissue development very visible. Appearance of blood vessels.
DAY 4: Eye pigmented.
DAY 5: Appearance of elbows and knees.
DAY 8: Feather tracts seen. Upper and lower beak equal in length.
DAY 9: Embryo starts to look bird-like. Mouth opening occurs.
DAY 10: Egg tooth prominent. Toe nails visible.
DAY 11: Cob serrated. Tail feathers apparent.
DAY 12: Toes fully formed. First few visible feathers.
DAY 14: Embryo turns head towards large end of egg.
DAY 15: Gut is drawn into abdominal cavity.
DAY 16: Feathers cover complete body. Albumen nearly gone.
DAY 17: Amniotic fluid decreases. Head is between legs.
DAY 18: Growth of embryo nearly complete. Yolk sac remains outside of embryo. Head is under right wing.
DAY 19: Yolk sac draws into body cavity. Amniotic fluid gone. Embryo occupies most of space within egg (not in the air cell).
DAY 20: Yolk sac drawn completely into body. Embryo becomes a chick (breathing air with its lungs). Internal and external pipping occurs.

A video showing hatching processes:

https://www.youtube.com/watch?v=PhOqP_GasVs

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 advice about this from more knowledgeable readers!

**A useful summary of varieties of insect metamorphosis**
Added 23 Mar 2024
https://australian.museum/learn/animals/insects/metamorphosis-a-remarkable-change

**Metamorphosis (in holometabolous insects) 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.

**Added 9 Feb 2024**
For more information see this very detailed 2023 paper, by
**James W Truman. Jacquelyn Price, Rosa L Miyares, Tzumin Lee**
Metamorphosis of memory circuits in Drosophila reveals a strategy for evolving a larval brain
https://elifesciences.org/articles/80594

Extract from the paper:
"The neurons of direct developing insects acquire their mature phenotype by the time of hatching and their anatomy and connections change very little through nymphal growth and adulthood (Kutsch and Heckmann, 1995). By contrast, in holometabolous insects, the form and function of many larval neurons are radically different from their adult form and function (e.g., Truman and Reiss, 1976; Levine and Truman, 1985; Roy et al., 2007). At metamorphosis, they lose their larval specialisations and finally acquire their mature, adult phenotypes."

A paper on neuronal changes during insect metamorphosis by R.B. Levine
And this discussion of evolution of DNA
https://www.ncbi.nlm.nih.gov/books/NBK26876/
Molecular Biology of the Cell. 4th edition

(I apologise for any inaccuracies, and repetitions in my summary. Minor inaccuracies should not affect the main implications of these facts.)

**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 structures produced by developmental processes are disassembled and replaced by new mechanisms, including new physical structures enabling motion, such as wings, and new control mechanisms needed for actions after metamorphosis, such as 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 new structures and processes, and their 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?

Information about insect metamorphosis
Further information about mechanisms and processes of metamorphosis in insects:
https://www.britannica.com/science/metamorphosis
and
Conceptual framework for the insect metamorphosis from larvae to pupae by transcriptomic profiling, a case study of Helicoverpa armigera (Lepidoptera: Noctuidae)
Published August 2022
An earlier paper of mine (2021) discussed some of the above topics in a little more detail: https://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-specified 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', https://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, unlike behaviours of young humans and some non-human species, e.g. apes and elephants, which can detect spatial necessity and impossibility, 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.

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.

After metamorphosis they also have new feeding behaviours, e.g. in some cases flying to obtain nectar from flowers, which they suck in using a long proboscis, which did not exist before the cocoon phase. See also:
https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/insect-eggs

Information about insect metamorphosis in Quanta Magazine
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 at least 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. The transformation tasks also seem to be 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 processes.

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, though related, way in 2012, in a paper on creativity of evolution: https://www.cs.bham.ac.uk/research/projects/cogaff/evo-creativity.pdf, and later when 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: https://cucats.org/event/21. I was then unaware of the dance-band (Esoteric) that had named one of their albums "Metamorphogenesis".

I had completely forgotten about those uses 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 significantly extend the original 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! They are "two sides of the same coin": necessary truth is impossibility of falsehood, and impossibility is necessity of untruth.

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 https://www.cs.bham.ac.uk/research/projects/cogaff/misc/trisect.html

Challenges for current theories?
Do the above biochemical mechanisms pose challenges for current theories about fundamental physical structures and mechanisms? Or 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.

Note added 9 Nov 2023
One of the consequences of those early experiences has been my frequent use of the concept "construction-kit" in discussing biological processes.

A relatively recent example is this paper:
https://www.cs.bham.ac.uk/research/projects/cogaff/misc/construction-kits.html
Construction kits for evolving life
(Including evolving minds and mathematical abilities.)
The scientific/metaphysical explanatory role of construction kits:
Fundamental and derived kits, concrete, abstract and hybrid kits, meta-construction kits.
All with deep mathematical properties, creating products with mathematical properties.

That document also refers to:
Jasmin Fisher, Nir Piterman and Moshe Y. Vardi, 2011,
The Only Way is Up: On A Tower of Abstractions for Biology
Proc. 17th International Conference on Formal Methods
Eds. M. Butler and W. Schulte, pp. 3--11, Springer-Verlag Berlin, Heidelberg, 978-3-642-21436-3,

Added 6 Feb 2024
See also Vardi’s online lecture 12, Jan, 2024:
World Logic Day Moshe Vardi Lecture: What Came First, Math or Computing?
https://www.youtube.com/watch?v=CiD2Hm4GmpQ
And his earlier presentation in 2021, "World Logic Day Webinar, From Aristotle to the iPhone"
https://www.youtube.com/watch?v=wOQuW6QFdos

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 1962 DPhil thesis (defending Kant) is available here, in various formats:
(Now only of limited historical interest!)

The Kant/Hume Disagreement about varieties and sources of knowledge
David Hume and Immanuel Kant (from Wikimedia)
David Hume famously criticised theological and related metaphysical discussions by claiming that there are only two significant kinds of knowledge, namely

(a) empirical knowledge about "matters of fact", based on observation of how things are e.g. "Some animals have tusks and a trunk", and

(b) knowledge about definitional "relations between ideas" and their logical consequences, often called "analytic" knowledge. e.g. "No bachelor uncle can be an only child", whose truth can be derived using logical reasoning and the definitions of "bachelor" (unmarried male) and "uncle" (brother of someone with at least one child, or husband of someone who is the sister of someone with at least one child).

This division between empirical and analytic knowledge is sometimes referred to as Hume’s "fork".

Hume claimed that supposed types of knowledge that are neither of type (a), i.e. empirical, nor of type (b), i.e. analytic, are "mere sophistry and illusion", including theological claims and possibly other metaphysical claims.

Kant criticised Hume by pointing out that there are significant discoveries, including ancient mathematical discoveries in geometry and topology (though he did not use the label "topology"), that are in neither branch of Hume’s "fork", i.e. they are not of type (a) or type (b). And they are not spurious claims. Moreover currently fashionable neuroscience claiming that brains collect statistical evidence and derive probabilities cannot explain how brain mechanisms make it possible to discover those necessary truths, such as Pythagoras’ theorem -- discovered several times in several countries using several different proofs centuries before Pythagoras was born.

Those ancient discoveries were not based solely on empirical observation and they were not discovered merely by deriving logical consequences of (explicit or implicit) definitions of the concepts used. Such knowledge is therefore neither empirical nor analytic: it is non-empirical (a priori) and synthetic. It is not about contingent truths or falsehoods but about necessary truth or falsehood, but not mere definitional truth or falsity.
Examples illustrating Kant’s claim include many different proofs of Pythagoras' theorem, mentioned above, and other discoveries in geometry and topology made centuries before well known ancient mathematicians such as Pythagoras were born.

A non-geometrical example of a necessary truth is the discovery that one-to-one correspondence between sets is necessarily a transitive relation: if S1 and S2 are in one to one correspondence and S2 and S3 are in one to one correspondence, then necessarily S1 and S3 are also, a fact that is implicitly presupposed by our uses of natural numbers.

I don’t think any psychologist or neuroscientist knows how brains recognize such examples of necessary transitivity. Kant thought it would be impossible for humans to understand the mechanisms making such discoveries possible. As mentioned above, he suggested that the mechanisms might lie "forever concealed in the depths of the human soul".

Training a neural network cannot produce such a discovery because trained neural networks merely derive probabilities from statistical evidence: and that cannot lead to recognition that something is necessarily true or necessarily false (impossible). Something completely different must be going on in brains of young children and ancient mathematicians who acquire that understanding -- perhaps using chemical mechanisms in synapses as suggested above, rather than statistics-based neural forms of information processing, It is not surprising that in 1781 Kant was not able to think of such an explanation.

I suspect that if he had lived two centuries later he might have proposed reasoning mechanisms supported by brain chemistry in synapses -- in opposition to the currently fashionable "neural network" mechanisms that merely collect statistical evidence and then derive probabilities from the data. Such neural networks are constitutionally incapable of producing proofs of necessity or impossibility. Instead they are restricted to discovering high or low probabilities. In this document and others I have suggested that the required mechanisms make use of chemistry-based information in synapses, but at present I suspect nobody understands how such mechanisms work. The people who know most about synapses have probably never encountered Kant’s questions. (I am not claiming that I understand the detailed synapse based mechanisms, though I do claim that they have very ancient origins.)

This document extends ideas presented to a 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 (messy) web site mentioned above, which has been considerably expanded since then.

**THANKS to other researchers:**
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 University of Illinois Urbana Champagne (UIUC):
Tony (an old friend since we were students around 1960, as explained in the background note below) was invited to respond to my talk at the January 2023 workshop mentioned above, 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: https://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 added since June 2023, triggered by thinking about differences between hatching processes in vertebrate eggs and the amazing processes that occur during insect metamorphosis in a cocoon or pupa.

Background note: Help from Anthony Leggett
Tony Leggett has been a friend since our student days. We met in Oxford around 1960, where we both had R.M.Hare as our "personal tutor". I came to know Tony because Hare invited his personal tutees to a week-long holiday in Anglesey where we all went for walks with Hare and his family during the day, and had philosophical discussions in the evenings. Later, after we had both left Oxford and Tony had switched to Physics, we met again and renewed our friendship, at Sussex University, where Tony had become a member of the Physics group. Our Sussex interaction included co-tutoring a group of students from science and arts/humanities subjects, as part of the Sussex Arts/Science scheme. That friendship included reading and commenting on some of each other's draft research publications.

Tony also provided support and encouragement during development of earlier versions of the ideas presented here, including providing comments to be read out after my presentation for the online workshop mentioned above, based in Tokyo in January 2023. His support does not mean that he agrees with my conjectures! Moreover, he has not seen recent versions of this document (much revised since June 2023), and has not yet commented on its new claims.

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Jackie Chappell
I am also grateful to Jackie Chappell (School of Biosciences, University of Birmingham).
https://www.birmingham.ac.uk/staff/profiles/biosciences/chappell-jackie.aspx
We began to collaborate soon after she moved to Birmingham in 2004. This collaboration led to the Meta-Configured Genome (MCG) project, mentioned above. The key idea that some details of later stages of gene expression are influenced by information gained during earlier stages (contradicting Waddington's idea of fixed species-specific epigenetic landscapes) came from her, though collaborated in developing some of the details reported in MCG publications.

Our collaboration provided important background ideas influencing some of the more recent ideas about evolution, reproduction and development summarised above.

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Challenges of drosophila metamorphosis
A very detailed (and impressive) online article which I have so far only skimmed at speed (added 9 Feb 2024):
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
https://elifesciences.org/articles/80594

Nicole King
Added 28 Sep 2023
Her talks 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
   https://www.ibiology.org/ecology/choanoflagellates/
   Choanoflagellates and the Origin of Animal Multicellularity Part 2
2: The origin of animal multicellularity (2015??)
   https://www.youtube.com/watch?v=1v6cqSkiHik
3: AbSciCon 2022: Plenary: Dr. Nicole King,
   A History of Hypothesis on the Origin of Animals
   https://www.youtube.com/watch?v=_ZV0rrH2qRc

Gordana Dodig-Crnkovic
Added 15 Dec 2023
Professor of Computer Science, Malardalen University
Professor of Interaction Design, Chalmers University of Technology
https://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.
A plenary keynote talk by her was presented in October 2023
(includes an ‘active’ clickable link to download her PDF presentation).

Professor Susan Stepney, York University
https://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 mentioned in *Quanta Magazine*. 
Related work by Geoffrey Hinton
Added 9 Nov 2023
Geoffrey Hinton is very well known for his work related to natural and artificial neural networks, partly summarised here:
While finishing off his Edinburgh University PhD thesis in the 1970s, he worked on one of my projects at the University of Sussex. We got on very well, but disagreed about the capabilities of neural network mechanisms which derived probabilities from statistical data, which I've always argued cannot account for ancient abilities in humans and other animals to discover and make use of spatial and topological impossibility or necessity, e.g. the fact that it’s impossible for any 2-D plane to pass through more than four of the vertices of a cube, and also impossible for any point in space to lie in more than three of the faces of the cube, or to lie on more than three of the edges. One of his examples drew my attention to these impossibilities, though as far as I know he has never pointed out that statistics-based neural networks cannot discover such impossibilities: impossibility is nothing like a very low probability.

Mike Ferguson, at the University of Dundee, UK
has a relevant presentation here:
https://www.youtube.com/watch?v=2KsuYjXneXA
"From textbooks to applications of GPI anchored proteins" presented at ICCB2018:
The talk starts after about 50 seconds. There is a useful option to display an auto-generated textual transcript of the talk. I have not yet taken in all the details of the presentation!

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.

Related work by William Bechtel
Added 22 Dec 2023
There is work by William Bechtel that is relevant to my claims about the importance of biochemical information processing in synapses and their ancient ancestors, and the secondary roles of neurons, which must have evolved later.

In a message to me on 19 Jan 2021, he wrote:

"As I said in an earlier email, I think we come to some common ground in different ways. For me, increasingly chemistry is the medium in which control and hence information processing/cognition are grounded. In part, organisms with only chemistry to work with need to take in many sources of information and use them appropriately to regulate basic production mechanisms (those procuring energy and performing work to make or move the organism). The basic production mechanisms are the easy part, controlling them is the hard part."
The introduction of neurons doesn’t change the story very much, except for allowing signals to be sent over long distances relatively quickly. The action is at the synapse, and there chemistry reigns”.

I had completely forgotten that message until I rediscovered it recently. My recent thinking about synapses may have been deeply, but unconsciously(!), influenced by Bechtel’s ideas. See also https://mechanism.ucsd.edu/~bill/index.html

He recently co-authored, with Linus Ta-Lun Huang, Philosophy Of Neuroscience https://www.cambridge.org/core/books/philosophy-of-neuroscience/8EB23CCDB2E9D414EDA36CB8A5B8F62A

However, I have so far not found any explicit mention of the idea proposed here, that the oldest ancestors of animals were single-celled ancestors of synapses, and that organisms with neurons connecting synapses and other structures evolved from those ancestors later. My search process in that book may have missed something relevant: it is not a short book and I have not read most of it!

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Added 6 Feb 2024

Related work by Joseph LeDoux

Added 7 Feb 2024


also
https://www.amazon.co.uk/Synaptic-Self-How-Brains-Become/dp/0142001783

The author and I interacted at conferences many years ago. I now suspect that there are things I could have learnt from him (as with Seth Grant, mentioned above, whom he also cites), but our interactions were unfortunately not sufficiently deep or extended. He also relates his science to musical performances. I am now trying to learn more about his work, and may add more links here later.

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Other references:

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Being You: A New Science of Consciousness
By Anil Seth (2021)
Published by Faber & Faber, with multiple glowing references.
https://www.amazon.co.uk/Being-You-Inside-Story-Universe/dp/0571337708

I have 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 relevant to this document.
Anil Seth 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.

Cognitive Design for Artificial Minds (2021)
Antonio Lieto
Added here 5 Apr 2024
Published by Routledge, April 2021, Also available on Amazon Kindle
I have started reading the Kindle edition, after reading a collection of very positive reviews. I may add more comments later. At the very least it seems to be a very useful introductory overview of some of the main strands in AI and Cognitive Science though it is highly compressed: only 119 pages.

Note on (irrelevance of?) Bayesian Nets
(Modified 11 Jan 2024)
There is a huge amount of research on forms of intelligence based on Bayesian networks, including the recent book by Anil Seth mentioned above, which includes much discussion of Bayesian nets, proposed as explaining various aspects of brain function. However, insofar as Bayesian mechanisms collect statistical evidence from which they derive relative probabilities, they are incapable of explaining abilities to discover that some spatial structure or process is impossible, e.g. a process that causes linked rings to become unlinked without changing the structure of any of the links, or to discover that some generalisation is necessarily true, e.g. that spatial containment is necessarily transitive, no matter what the sizes, shapes and locations of the containers are. Impossibility and necessity are not extremes on a scale of probabilities.

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=tS2rLRYIFR8
(There are many more online demonstrations of surprising properties of mobius strips with different numbers of twists.)
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 shall 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 researchers, especially colleagues and former students -- too many to list here -- who have helped me during development of the above ideas over many years, by providing comments, questions, challenges, refutations, and references to related work. 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 on evolution, reproduction and development
I was deeply influenced especially by his 1945 book *What is life*. See [https://www.cs.bham.ac.uk/research/projects/cogaff/misc/s/schrodinger-life.html](https://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 (and colleagues)
Last updated 23 Mar 2024
The very impressive work of Mike Levin at Tufts university is related to the ideas presented here. For details, see [https://as.tufts.edu/biology/levin-lab](https://as.tufts.edu/biology/levin-lab)
Additional information about his work and collaborative activities is here: [https://www.liebertpub.com/doi/full/10.1089/soro.2022.0142](https://www.liebertpub.com/doi/full/10.1089/soro.2022.0142)
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.

I don’t yet know whether he has written anything discussing the complexities of control involved in creating new physiological structures and new competences during insect metamorphosis. He has written about a different, also interesting question not discussed in this document: whether individuals that have undergone metamorphosis can have access to information (memories about the environment) acquired prior to metamorphosis.

Two recent papers, added 30 Mar 2024 Appear to be relevant (not yet read fully!)
Collective intelligence: A unifying concept for integrating biology across scales and substrates
Patrick McMillen & Michael Levin Communications Biology volume 7, Article number: 378 (2024) [https://www.nature.com/articles/s42003-024-06037-4](https://www.nature.com/articles/s42003-024-06037-4)

An older paper, of which he is one of the authors, is also potentially relevant to the problems discussed here:

Abstract: Summary

Spatiotemporal patterns of cellular resting potential regulate several aspects of development. One key aspect of the bioelectric code is that transcriptional and morphogenetic states are determined not by local, single-cell, voltage levels but by specific distributions of voltage across cell sheets. We constructed and analysed a minimal dynamical model of collective gene expression in cells based on inputs of multicellular voltage patterns. Causal integration analysis revealed a higher-order mechanism by which information about the voltage pattern...
was spatiotemporally integrated into gene activity, as well as a division of labor among and between the bioelectric and genetic components. We tested and confirmed predictions of this model in a system in which bioelectric control of morphogenesis regulates gene expression and organogenesis: the embryonic brain of the frog Xenopus laevis. This study demonstrates that machine learning and computational integration approaches can advance our understanding of the information-processing underlying morphogenetic decision-making, with a potential for other applications in developmental biology and regenerative medicine.

As far as I can tell, however, the authors (like many psychologists and neuroscientists) have not noticed that the mechanisms they mention cannot detect types of spatial impossibility or necessity. Attempting to understand how that is possible became a key feature of my research (inspired by learning about Immanuel Kant’s work) before I switched from mathematics to philosophy around 1959. This issue is important not only in relation to explaining mechanisms underlying ancient forms of mathematical intelligence, but also abilities to control behaviour effectively in complex physical environments, e.g. a female orangutan feeding in a tree while carrying a very young infant, or making a safe nest for the night by manipulating branches while holding an infant. Such actions require deep geometric and topological insight. If such competences required much trial and error learning, training neural networks, the animals would probably not live long enough to acquire such competences: too many would die as a result of errors. (This comment is relevant to much research in psychology and neuroscience based on conventional trainable neural network theories.)

Daniel Dennett
Added 23 Aug 2023, last updated 23 Mar 2024
I have interacted with, and learnt from Daniel Dennett over many years, though I am not sure that he has fully understood, or shared my interest in, the mechanisms involved in many ancient and not so ancient discoveries about spatial/topological necessity and impossibility, with properties described by Immanuel Kant in 1781, briefly summarised in the discussion of Kant and Hume above.

A colleague drew 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: https://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, which led to my conjecture that synapses are descendent 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 any of the ideas leading to my speculation that those mechanisms for controlling spatial manipulations during metamorphosis pose (a) pose challenges for current theories of fundamental physics, or (b) that they are related to
the "Kant-conjectured" mechanisms that enabled ancient forms of reasoning about spatial impossibility or necessity.

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

Tomas J.Ryan and Seth G.N.Grant (2009)
The origin and evolution of synapses
*Nature Reviews Neuroscience*(Vol. 10, Issue 10)
[https://go.gale.com/ps/i.do?p=AONE&u=googlescholar&id=GALE|A209639268&v=2.1&it=r&sid=googleScholar&asid=89bc030f](https://go.gale.com/ps/i.do?p=AONE&u=googlescholar&id=GALE|A209639268&v=2.1&it=r&sid=googleScholar&asid=89bc030f)

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 signalling 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
[https://doi.org/10.1177/2398212818810685](https://doi.org/10.1177/2398212818810685)

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 behaviours, 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?? Not if ancient ancestors of synapses were single-celled organisms making choices and controlling their own behaviours, such as consuming nutrients absorbed from the environment and excreting waste products, and at a later stage dividing to form "offspring" and interacting with other similar individuals when reproducing. Compare the ideas of Tibor Ganti

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!

Books and Lectures on theoretical physics by Carlo Rovelli
Added 8 Feb 2024
An overview: https://www.cpt.univ-mrs.fr/~rovelli/
https://www.youtube.com/watch?v= rVnJhBdiQw
"Carlo Rovelli presents Anaximander and the Nature of Science, in February 2023,"
In this interview plus discussion, Rovelli emphasises the importance of combinations of different approaches based in different disciplines, which is also a key theme of my work presented here.
Added: 11 Feb 2024
I have just come across this 2022 interview in which Rovelli explains why he likes to link physics with philosophy:
https://www.youtube.com/watch?v=ZSv0cMfxsqk

From the website: Carlo Rovelli joins Perimeter Institute Teaching Faculty member Lauren Hayward and journalist-turned-science communicator Colin Hunter in a conversation about the quest for quantum gravity, the importance of unlearning outdated ideas, etc.

Stuart A. Kauffman
Although I don’t claim to understand his work fully, it seems to be very relevant to the ideas presented here. He praises Immanuel Kant, but unless I have missed something, he does not seem to be aware of Kant’s claims about human abilities to discover examples of necessity or impossibility that are not derivable from statistical data and are not merely discovered to be logical consequences of formally represented axioms and definitions. Kant was reacting against David Hume’s claim, mentioned below, that those two are the only valid sources of knowledge.

Much of my own work, e.g. Chapter 2 of my 1978 book, has involved elaborating and defending Kant’s claims about human abilities to reason about what is and is not possible, including establishing that there are types of necessity and impossibility that are based neither on direct empirical observation nor on reasoning about probabilities derived from statistical evidence. Kant suggested that the mechanisms providing those human abilities would lie "forever concealed in the depths of the human soul", whereas I suggest that they might be explained by biochemical mechanisms (not yet identified) in synapses as mentioned above.

It is possible that I have missed something, but I don’t recall reading anything that addresses my questions about ancient forms of mathematical reasoning in these (deep and relevant) publications by Kauffman:
A World Beyond Physics: The Emergence and Evolution of Life. (2019)
EROS AND LOGOS (Online Article: 2020)

Kauffman was recently (2023) interviewed by Kuhn about whether the world is self-organising:
https://www.youtube.com/watch?v=YpnuAJGaShE
In this interview he seems to have become semi-mystical about the limitations of scientific explanation. He rightly claims (as I have been doing for many years, e.g. in my 1978 book referenced below) that there are deep facts about the nature of the universe that explain what is possible, by specifying possibility spaces, without specifying exactly which possibilities will be realised, though they do specify consequences for different possibilities, although some of the consequences are creation of new, richer, possibility spaces. The fact that not all the specific consequences are specified by the laws does not justify any form of mysticism!

In an interview with Kuhn (27 July 2021) https://www.youtube.com/watch?v=BCY7zz-CITw
Kauffman mentions fundamental features of the physical universe that specify for various states of a physical system which new possibilities can be realised, without specifying which will be realised. A more recent interview with Kuhn (15 July 2023), discusses the question "Is the World Self-Organizing?" https://www.youtube.com/watch?v=YpnuAJGaShE
Like almost all(??) researchers in this area, Kauffman does not seem to be aware of the evidence (mentioned in various links in this document) indicating (a) that the earliest forms of biological
information processing (proto-intelligence??) made use of biochemical mechanisms in single-celled ancestors of synapses and (b) that neurons performing various functions supporting communication and coordination between subsystems were later products of biological evolution.

As far as I can tell, Kauffman has also not noticed the problems of using current physical theories to explain the complex disassembly and reassembly processes that occur in insect metamorphosis summarised above. I find this surprising, given his very broad research interests and capabilities, and the breadth and depth of his publications. If it turns out that he has written about those features of metamorphosis I'll add links here.

At one stage I hoped that Kauffman’s ideas might help to answer questions about how brain mechanisms make it possible for humans and other intelligent animals to discover both possibility spaces in the physical environment, i.e. classes of structures and structure-changing processes that can exist, and also limitations on those possibilities including ancient discoveries regarding geometric and topological necessity or impossibility by humans and also discoveries by other intelligent animals regarding possible and impossible actions in the physical environment, and the necessary consequences of possible actions, but so far I have not found any reference to those capabilities, despite his references to Immanuel Kant, who seems to have been the first person to raise these questions, though he thought the answers might lie forever concealed in the depths of the human soul.

**Research on plant intelligence by Paco Calvo**

His ideas on plant intelligence, related to the above discussion, are presented with Natalie Lawrence in this video discussion: https://www.youtube.com/watch?v=1DsFsyWa7r8

(However, they don’t explicitly raise the questions I have been discussing.)

A related publication:

**P. Frazier, P. Calvo, David N. Lee** (2021)
The Neuro-Power of Movement in Plants
https://api.semanticscholar.org/CorpusID:239993444

Many examples of coevolution and mutual dependence of plants and animals are discussed in

**Paco Calvo, 2017, What Is It Like to Be a Plant?**
*Journal of Consciousness Studies* 24, 9-10, pp. 205-227,
https://www.ingentaconnect.com/content/imp/jcs/2017/24/F0020009/art00012

https://doi.org/10.1038/41710


**Conrad Waddington’s Epigenetic Landscape Idea**

A useful overview of Waddington’s work can be found in this online article:

Aaron D. Goldberg, C. David Allis, Emily Bernstein,

(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):
https://en.wikipedia.org/wiki/Pythagorean_theorem
and

According to this Wikipedia article https://en.wikipedia.org/wiki/Antikythera_mechanism the Antikythera device, apparently used to predict motions of celestial objects decades in advance, including eclipses, also provides evidence of use of sophisticated mathematical reasoning about physical processes in a complex mechanical engineering design, between 205 BCE and 87 BCE, i.e. long before the work of Newton and Leibniz.

Karl Popper’s three worlds
Last updated 4 Apr 2024
Work in progress: This is an incomplete draft, and probably has important omissions and some errors.
The ideas about biological evolution, reproduction and development in this document can be contrasted with Karl Popper’s ideas about three worlds. It is impossible to do justice here to the breadth and depth of Popper’s writings. Some of his books are listed here: https://www.thriftbooks.com/a/karl-popper/366643/. He famously contrasted the physical world (World 1) and the world of human thoughts beliefs and feelings (World 2), then later added a third world of products of human activities including engineering and architectural creations, and the collections of concepts, theories and techniques used by humans in their science-based interactions with the environment both as engineers, architects, system developers and as users of the creations (World 3).

In more detail: World 1 is the physical world containing physical objects, properties, processes and their interactions as studied in physics and chemistry, including physiological processes in living organisms. World 2 contains mental states and processes, including sensations, thoughts, beliefs and feelings in humans and other animals. These are products of biological evolution, made possible by features of world 1, including the physics and chemistry involved in forms of life.

World 3 was added later, to accommodate products of human thought and informed actions, including the contents of books, libraries and other creations that explicitly store and communicate knowledge, and 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.

See also: https://en.wikipedia.org/wiki/Popper%27s_three_worlds. (Better reference needed?)

I am not sure that experts on Popper would agree with my summary above, or with my claim that Popper’s world 1 has features that made possible not only the world 2 contents of human minds, and contents of minds of other intelligent animals, but also made possible processes in which biological evolution created mechanisms that acquired and made use of information about what was possible in the physical world.

My claim is that long before humans existed, the physical mechanisms made it possible for evolutionary mechanisms and developmental mechanisms produced by earlier evolution, to create new biochemical mechanisms to be created that extended the powers of evolutionary and
developmental mechanisms, in ways that also extended the biochemical mechanisms available during development. This is partly analogous to the ways in which technology developed by humans constantly extends the abilities of humans to extend their technology: so long before humans existed evolution was repeatedly making use of positive feedback loops that had been produced by earlier evolutionary processes, to create new mechanisms!

These evolutionary/developmental processes have been speeded up since humans developed abilities to pass on new knowledge to other humans through newly created communicative processes, which in turn were repeatedly enriched/extended through positive feedback mechanisms since the 1950s, accelerated by the Dartmouth conference described here https://en.wikipedia.org/wiki/Dartmouth_workshop and other developments.

Similarly biological evolution used and produced mechanisms enabling the powers of evolution to be constantly extended, which in turn constantly extended the complexity of products of evolution, long before humans (and perhaps other intelligent organisms in other parts of the universe) began to design create and use new physical mechanisms with new properties. However, no human-designed machines come close to matching the powers of biochemical mechanisms that produce processes of metamorphosis in insects in very small spaces using a small range of temperatures and consuming very little energy!

My claim about products of evolution is partly analogous with what Popper wrote about products of human activity, but refers to processes that repeatedly increased the creative powers of biological mechanisms of reproduction and evolution, long before humans existed.

This included extending the information-processing capabilities of products of evolution, and extending the types of information that can be used by information-using biological mechanisms, including mechanisms of reproduction and development.

Evolution achieved these extensions (unwittingly) 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 networks formed by merging previously branched trees or networks. For example, sexual reproduction combines the evolutionary ancestry of a male and a female, a type of 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]

I now suggest that human intelligence and its products (including Popper’s worlds 2 and 3), are among the products of the biological mechanisms related to the mechanisms discussed above. Other products include the mechanisms involved in processes of insect metamorphosis as well as the mechanisms involved in the evolution and development of those metamorphosis mechanisms.

I don’t regard this four-fold division as sufficiently rich to capture the major transformations in mechanisms involved in producing, sustaining, and modifying forms of life. I hope it will later be replaced by a new systematic collection of labels covering, for example, products of evolution that extend the powers of biological evolution by making use of increasingly complex and powerful physical/chemical processes. The possibility of such mechanisms always existed, but the realisation of different increasingly complex possible mechanisms required many new physical mechanisms to be assembled by earlier products of biological evolution, all depending ultimately on features of the physical universe that have always existed, though increasingly complex and varied derivatives could be produced by processes occurring at different times in different parts of the universe, repeatedly using general features of the universe in combination with previously produced derived mechanisms in many different evolutionary/developmental trajectories. I suspect some of those processes depend on features of the universe that have always existed but have not yet been identified by human scientists. They may or may not be consistent with currently accepted “fundamental” physical theories.

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 feature of biological evolution, 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.

Benoit Mandelbrot on Fractal Geometry
Added 18 Mar 2024
Mandelbrot was a highly creative mathematical genius. Some of his opinions were partly related to Kant’s ideas about mathematical knowledge. 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.

However, he has also argued that that Kant’s ideas could not explain some of the more recent advances in mathematics, in his 1982 paper below. 

Benoit Mandelbrot (1982), "A crisis of intuition as viewed by Felix Klein and Hans Hahn and its resolution by fractal geometry":

Benoit Mandelbrot, Fractal Geometry: IBM,  
https://www.ibm.com/history/benoit-mandelbrot?mhsrc=ibmsearch_a&mhq=the%20father%20of%20fractals
The ‘father of fractals’ provided a new system for measuring and understanding nature.


This wikipedia entry is also relevant: https://en.wikipedia.org/wiki/Fractal

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**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 (https://www.bbc.co.uk/news/56643677) 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. ....

In an experiment ... the researchers found that they (the muons) might be behaving in a way that can’t be explained by the current theory, which is called the Standard Model, because of the influence of a new force of nature.

*See the above BBC news web pages for more details.*

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**Inspiration from Tibor Ganti, 2003.**

*The Principles of Life,* (Translation of the 1971 Hungarian edition),  

This book, presents Ganti's "Chemoton" theory, specifying requirements for the earliest single-celled organisms capable of sexual reproduction. The ideas are complex and I don’t claim to
have understood all of the details. 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 Ganti’s work by Gert Korthof, who also provides a large collection of related references: https://wasdarwinwrong.com/korthof66.htm
Another tribute: https://www.chemoton.com/en/chemoton/the-chemoton-theory

Kenneth Craik’s remarks on chemical processes in Brains
His comments about the role of chemistry in brains, in his book *The nature of explanation* influenced my thinking. I cannot tell whether he would have approved of the ideas about the importance of synapses in cognition. For more information about Craik see: https://www.psychol.cam.ac.uk/news/today-7th-may-marks-75th-anniversary-fatal-accident-changed-course-psychology-cambridge

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
https://www.researchgate.net/publication/358903918_Towards_a_Process-Relational_Biology...(PDF)
(I have not yet taken in all the details so cannot evaluate this, though the ideas are clearly relevant.)

Hamid Ekbia
https://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:
*Science News*: From single cells to multicellular life: Researchers capture the emergence of multicellular life in real-time experiments. (Nov 6, 2014)
Summary:
All multicellular creatures are descended from single-celled organisms. The leap from unicellularity to multicellularity is possible only if the originally independent cells collaborate. So-called cheating cells that exploit the cooperation of others are considered a major obstacle. Now, researchers capture the emergence of multicellular life in real-time experiments.
Comment: I have not found evidence that the authors also share my conjecture in this document that the earliest ancestors of animals also happen to earliest ancestors of synapses.

Work by Katrin Hammerschmidt and colleagues
"From single cells to multicellular life: Researchers capture the emergence of multicellular life in real-time experiments"
Journal Reference:
https://dx.doi.org/10.1038/nature13884

Jonathan Bard
Added 7 Nov 2023, updated 10 Dec 2023
*Evolution: The Origins and Mechanisms of Diversity*
https://www.amazon.co.uk/Evolution-Mechanisms-Diversity-Jonathan-Bard-ebook/dp/B09NQS91MX/
(published in 2021). From a partial reading, it appears to be very relevant to the above ideas, though I have not yet had time to decide whether there are any conflicts, or whether the book answers, or even asks, all questions raised here. A close reading may reveal important
connections, in which case details may be added here later. Bard seems to have very relevant publications that are unfortunately not easily or cheaply accessible.

I prefer to read books electronically, so that I can adjust font size and search for text items. But the Kindle version did not work well, so I returned it. However I later found that his earlier book, published in 2016 can be read for a lower price and more conveniently using Google Play: A free sample is here:  
https://play.google.com/books/reader?id=_DVVEAAQBAJ&pg=GBS.PR7&hl=en_GB  
Full text (non-free):  
https://play.google.com/store/books/details?pcampaignid=books_read_action&id=kRUeDQAAQBAJ&pli=1  
I have the impression that, like many others, Bard has not noticed that for species that use sexual reproduction, the fact that each individual (normally) has two different parents implies that evolution produces networks that branch backward in time as well as forward. This has important consequences. (Did Darwin notice this?)

R.M.Hare  
Richard Mervyn Hare, usually referred to as R.M.Hare, is mentioned here partly because he introduced me to Tony Leggett mentioned above, for whom he was "Personal Tutor" in Balliol College Oxford, at a time when Tony was an undergraduate studying ancient philosophy. Hare also became my "personal tutor" in Balliol College (in 1959), after I switched from research in Mathematics to research in Philosophy of Mathematics -- as a result of reading Kant's critique of David Hume, and agreeing with the main claims of Kant about the nature of mathematical knowledge, as explained above. At that time Balliol did not have a philosopher of mathematics among its staff, so a member of another college was assigned as my formal supervisor -- a person who turned out not to be interested in my defence of Kant's philosophy of mathematics! For more information on Hare, see https://en.wikipedia.org/wiki/R._M._Hare

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  
As explained above: reacting to Hume’s claim inspired Kant’s ideas about the existence of synthetic necessary truths.

What does Chat GPT6 think about all this?  
Here is a transcript of our conversation in April 2023:  
https://www.cs.bham.ac.uk/~axs/ChatGpt6TestedOnlineBy-AS-2ndApr2023.txt
A conversation with chat.openai.com in August 2023
https://chat.openai.com/share/81309886-d093-414d-a1de-a2598ab246f3

See also: https://www.quora.com/What-is-the-need-of-metamorphosis-in-insects
(The above list may be extended later.)

My 1984 "possible minds" paper
'The structure of the space of possible minds', available online at:
Perhaps my most influential publication, partly thanks to various uses of the key ideas by Phillip Ball, often referring to my 1984 paper.

My 2022 MDPI paper needs updating
The paper: "Varieties Of Evolved Forms Of Consciousness, Including Mathematical Consciousness"
https://www.mdpi.com/1099-4300/22/6/615
Was written before the development of some of the key ideas presented here. As a result, that paper is now out of date in some important respects.

The importance of explanations of possibilities
It is widely believed that the main form of progress in science is discovery of new laws, whereas I have argued for many years that the discovery of possibilities is more fundamental and that discovering laws involves discovering constraints on previously specified possibilities, for example in Chapter 2 and other sections of my 1978 book.

Some online tutorials on ancient and recent forms of spatial thinking.
My mathematical education at school in the early 1950s included learning to find geometric constructions and proofs of theorems in Euclidean geometry, which is why I later agreed with Kant's claims that ancient mathematical discoveries were not based solely on formal logical reasoning from axioms and definitions. Unfortunately such teaching became unfashionable in the second half of the 20th century under the influence of the Bourbaki group, which promoted the educational ideas of a mythical mathematician Nicholas Bourbaki: https://en.wikipedia.org/wiki/Nicolas_Bourbaki

Also: An introduction to some more "standard" Euclidean constructions and proofs, presented by Zsuzsanna Dancso;
https://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: https://www.cs.bham.ac.uk/research/projects/cogaff/misc/trisect.html
**EXAMPLES**
Updated 27 Dec 2023

**Example: 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).

It appears that complex biochemical disassembly and reassembly processes in small enclosed spaces 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 complex objects composed of many particles are moved (translated or rotated) 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 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. I welcome comments or suggestions for improving this discussion.

APPENDIX 2: Additional relevant items

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

"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 homebox genes from Jackie Chappell.)

Cladogenesis and Anagenesis
This Wikipedia entry has information relevant to the topics about evolution and development presented above:
https://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.

**Added 26 Nov 2023**
I thank Jochen Triesch for this link to a very clever video-musical presentation of some of the issues discussed here:
https://www.youtube.com/watch?v=ydqReeTV_vk
Evo-Devo (Despacito Biology Parody) | A Capella Science. See also
https://www.acapellascience.com/

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**Former colleagues and students**
(The order of individuals named below is not significant.)
I am grateful to many past and present colleagues and students who have helped me in various ways over many years, including asking challenging questions, making important suggestions, providing new references and pointing out errors, lack of clarity, omissions, etc. There are too many individuals to list here, and probably some whose influence I have forgotten, partly because of brain-slide at age 87!

**Note on personal history (switch from research in mathematics to philosophy of mathematics)**

[This biographical note is inadequate and will later be rewritten]
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.

**Brief CV for Aaron Sloman:**
Updated: 31 Mar 2024
Born in Que Que (now KweKwe) Southern Rhodesia (now Zimbabwe) 30th October 1936. My parents mistakenly thought I would get a better education in South Africa, so at age 11 they sent me to boarding school in Cape Town, where both parents had close relatives. After leaving school I went to university in Cape Town.
First degree: BSc Maths and Physics (First Class), University of Cape Town, 1956.
Went to Oxford in 1957 to do mathematics. Became interested in philosophy and attended lectures and seminars in philosophy, including student societies and philosophy graduate seminars (originally invited by philosophy graduate students with whom I had become friendly). I discovered that I disagreed with several current opinions on the nature of mathematical discovery, then formally switched to philosophy of mathematics around 1959, inspired by Kant’s philosophy of mathematics.

My DPhil thesis attempting to defend Kant’s philosophy of mathematics was completed in 1962.
1962: Appointed lecturer (in philosophy of mathematics and science) at Hull University.
1964: Appointed lecturer (in philosophy of mathematics and science) at Sussex University.
As a result I got to know a number of major researchers in AI, and was invited by Bernard Melzer to spend 1972-3 in Edinburgh (funded by a UK research council), where I met several important AI researchers, and learnt to program using the Edinburgh AI language, Pop2 (which strongly influenced the later development of Pop-11 at Sussex university).
I became convinced of the deep relevance of computation to philosophy, and later published my

1978 Book: The Computer Revolution in Philosophy
published thanks to pressure and encouragement from Margaret Boden, later made freely available online, with many additions and revisions. here: https://www.cs.bham.ac.uk/research/projects/cogaff/crp/

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 publications referenced in the list of contents above, I became convinced of the importance of chemistry-based forms of information processing, partly as a result of collaboration with biologist Jackie Chappell (referenced above) after she joined the school of Biosciences in Birmingham, though it took me several more years to notice the significance of hatching processes in eggs (in 2020), and later on (since June 2023) the chemistry involved in metamorphosis.

Margaret Boden
I was also much influenced, and helped, by Margaret Boden, https://www.ruskin.tv/maggieb/ a colleague at Sussex university from 1965 (now seriously unwell unfortunately). In particular, without her encouragement and help I would never have published my one and only book, partly because my ideas keep changing (as new details are added), most dramatically since June 2023, as indicated in this document!

David Hogg
A former DPhil student at Sussex University, who taught me a lot about computer vision systems, while I was supposed to be supervising him. https://www.cistib.org/members/core-academics/david-hogg

Luc Beaudoin
A former PhD student. He came to Sussex University to work with me as his PhD supervisor, and followed me to Birmingham, where he became as much a research collaborator as a student. To a lesser extent this has also happened with other former students, especially after I moved to Birmingham. He has documented some of our interactions here: https://cogzest.com/2018/03/understanding-ourselves-with-virtual-machine-concepts/
I have not been able to keep up with all of his activities listed here: https://cogzest.com/

Nick Hawes
One of my former PhD students, now a Professor at Oxford University, https://eng.ox.ac.uk/people/nick-hawes/
He is Director of the Oxford Robotics Institute, which won this award in 2023: https://ori.ox.ac.uk/news/oxford-robotics-institute-wins-prestigious-queen-s-anniversary-prize/

Ron Chrisley
https://profiles.sussex.ac.uk/p476-ron-chrisley
This document (prepared for an honorary degree ceremony at Sussex University in 2006) summarises some of our interactions. https://www.cs.bham.ac.uk/research/projects/cogaff/misc/dsc.html
Matthias Scheutz
He worked with me on an externally funded research project for a while, since when we have collaborated intermittently, despite a number of differences in our interests and philosophical viewpoints!
https://engineering.tufts.edu/cs/people/faculty/matthias-scheutz

John McCarthy
He was one of the founders of Artificial Intelligence and wrote about connections between AI and philosophy. For example see this web site on AI and philosophy:
https://jmc.stanford.edu/articles/aiphil.html

We met and talked after I criticised some of his ideas at an IJCAI Conference in London in 1971, and despite our disagreements about philosophy, AI, and the possible explanatory roles of logic-based mechanisms, we got on well. He invited me to talk at a conference he organised and we also interacted a lot when I spent a month at Stanford University and when we met at conferences.

Tributes after his death in 2011: https://jmc.stanford.edu/tributes.html

Interactions with Marvin Minsky
After I met and talked with Marvin Minsky in the early 1970’s, including criticising some of his ideas, he began to encourage me, and supported my research e.g. by inviting me to take part in events he organised and citing my work, but without agreeing with my claims about mechanisms! To find out more about him see:
https://web.media.mit.edu/~minsky/
https://en.wikipedia.org/wiki/Marvin_Minsky
Together with his student Push Singh, we wrote this report published in the AI magazine in 2004:

The St. Thomas Common Sense Symposium: Designing Architectures for Human-Level Intelligence
https://scholar.archive.org/work/scwqdcnninl45r1t3hbbkbk

Eva Jablonka
I first encountered her work when I was invited to respond (with Jackie Chappell) to a summary in the Behavioural and Brain Sciences Journal (BBS) of the book (unfortunately now out of print): Evolution in Four Dimensions by Eva Jablonka and Marion Lamb
https://mitpress.mit.edu/9780262600699/evolution-in-four-dimensions/
The BBS summary, with commentaries and replies is available (but not freely available) at:
https://doi.org/10.1017/S0140525X07002361
She has several recent online presentations, e.g. this talk on the evolution of emotions:
https://www.youtube.com/watch?v=4-TVZBOeWCg
We have met and talked at some conferences/workshops where we both gave presentations, and there are some overlaps as well as differences between our ideas. More information about her is available here: https://english.tau.ac.il/profile/jablonka Click on “CV” (below picture) for additional details.
William J. Rapaport (alias Bill Rapaport)
His work comparing natural and artificial intelligence is relevant, though I don’t think he has written about biochemical mechanisms. Some of our interactions and overlaps are presented in:
https://www.cs.bham.ac.uk/research/projects/cogaff/misc/two-books.html

Information about Max Clowes
Max Clowes was mentioned as a major influence in my Brief CV above. For more information about him, see my tribute, after his early death
https://www.cs.bham.ac.uk/research/projects/cogaff/sloman-clowestribute.html

Mary Pardoe
Was a former student who discovered an interesting new diagrammatic proof of the triangle-sum theorem after becoming a mathematics teacher, described and discussed in:
https://www.cs.bham.ac.uk/research/projects/cogaff/misc/triangle-sum.html
It later turned out that her proof had been discovered earlier, by Bernhard Friedrich Thibaut (1775-1832).

Mateja Jamnik
https://www.cl.cam.ac.uk/~mj201/
We had overlapping research interests and she spent some time working in our department, before she moved to Cambridge University. Her brief TedX talk illustrates the overlapping interest in spatial reasoning:
https://www.youtube.com/watch?v=uG3AZsXQ1fY
I don’t know how she would react to the claims I have been making about biological evolution, reproduction and development, and the conjectured importance of biochemical reasoning mechanisms in synapses.

Aviv Keren
Since 2015 we have had a great deal of useful correspondence related to the topics addressed here, which overlap considerably with work on his PhD thesis, and he also arranged for me to be invited to a conference in Israel some time ago. I may later add more information about him here.
https://avivkeren.wixsite.com/website
https://avivkeren.wixsite.com/website/resume

Clare MacCumhaill
Added 19 Jan 2024
https://www.durham.ac.uk/staff/clare-maccumhaill/
Clare has recently expressed a strong interest in this research, and kindly drew my attention to the connection between what I had been writing about insect metamorphosis and the ideas of Rupert Sheldrake about Morphic Resonance, whose work I had previously regarded as seriously misguided, though I had not looked at all the details linked below. The new information did not change my opinion of his work! I mention him here only to warn readers not to be fooled.

Anna Ciaunica
https://cfcul.ciencias.ulisboa.pt/equipa/anna-ciaunica/
We met at a conference in Oxford in 2012 when she was still a PhD student, and met again later at another conference. I read and commented on draft notes for her PhD thesis, trying to persuade her that quantum mechanisms were not relevant to attempts to understand consciousness. Now, many years later, I admit that she was right and I was wrong, for reasons explained elsewhere in
this document! (E.g. Search for "quantum").

Carlos Gershenson
https://tendrel.binghamton.edu
His work is related to but different from the ideas presented here. For example:
 Presents an epistemology based on information to explore "laws of information" that include physics, biology, cognition, cybernetics, etc.
In A. Minai, D. Braha, & Y. Bar-Yam (Eds.), *Unifying themes in complex systems (pp. 100--115, Vol. 7).*, Springer: https://arxiv.org/abs/0704.0304

Its Conclusion:
"Brains are not essential for intelligence. Plants, swarms, bacterial colonies, robots, societies, and more exhibit intelligence without brains. An understanding of intelligence (and life, Gershenson et al., 2020) independently of its substrate, in terms of information processing, will be more illuminating than focusing only on the mechanisms used by vertebrates and other animals. In this sense, the metaphor of the brain as a computer, is limited more on the side of the brain than on the side of the computer. Brains do process information to exhibit intelligence, but there are several other mechanisms that also process information to exhibit intelligence. Brains are just a particular case, and we can learn a lot from them, but we will learn more if we do not limit our studies to their particular type of cognition."

Additional references suggested by Carlos Gershenson:
https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2016.01478/full
Updated 17 Mar 2024
This includes discussion of Microbiota contributing to wasp reproduction processes during metamorphosis. The introduction states: "Bacterial symbionts are widely recognized as important drivers of insect physiology, development, behavior, reproduction, nutrition, and evolution...", and later: "Biologists now recognize that symbioses are shaped by complex multipartite interactions, not only between the host and its associated microbes, but also between different members of the microbial community and the environment. This understanding has led to the view of hosts as complex ecosystems".

Warning about Rupert Sheldrake on "morphic resonance"
Added 19 Jan 2024
Perhaps it's a mistake to include this!
https://www.sheldrake.org/research/morphic-resonance/introduction
Thanks to a tip from Clare MacCumhail, I looked for information about Sheldrake and found the above web site. I was not familiar with details of his work but had previously got the impression that he was seriously mistaken. His ideas about what he calls "morphic resonance" may appear to be similar to what I have been writing about forms of control of complex biochemical processes in hatching eggs and especially in processes of insect metamorphosis. Unfortunately, despite that overlap, after listening to this youtube talk by him on Science and Spiritual Practices:
https://www.youtube.com/watch?v=fiUE9jCTnOQ
I think some of his claims are seriously misguided, even if they appear at first sight to overlap with my conjectures. I may add more specific criticisms later.
The David Haussler's Reverse Evolution Machine

Professor David Haussler works in the field of computational genomics, which relies on computers to reconstruct the genome of ancient creatures for which DNA is not preserved in fossils.

By essentially running evolution in reverse, he scans the genomes of organisms that haven’t changed over very long periods of time but then suddenly change, resulting in new species that evolve differently from one another.

Gregory Bateson
I read Bateson’s book *Steps to an Ecology of Mind* many years ago. Many readers had been confused/mistaken about his reference to a bit of information as "a difference that makes a difference", which they interpreted as a definition of "information". See:
https://en.wikipedia.org/wiki/Gregory_Bateson

I tried to analyse and correct the confusions about Bateson and information in
https://www.cs.bham.ac.uk/research/projects/cogaff/misc/information-difference.html, though I felt his theory of information did not accommodate all the varieties of information and information use. The main point is that Bateson described not "information" but "a bit of information" and later "the elementary unit of information" as "a difference that makes a difference", which is not the same as the definition often attributed to him. He did this in at least two of the essays, namely in "The Cybernetics of ‘Self’: A Theory of Alcoholism" and in "Form Substance and Difference". His work may have helped to plant seeds in my mind for some of the ideas presented in this document!

Noam Chomsky and various others emphasized "productivity" of thoughts, etc.
This Youtube video https://www.youtube.com/watch?v=axuGfh4UR9Q provides a lot of information about the history of those ideas, including the need for recursion and compositionality not only in forms of linguistic expression, but also in forms of thought, reasoning, planning, decision-making.

So some time before statistics-based neural network models became highly fashionable it had already been shown that they were incapable of providing the required forms of productivity:

I’ll be grateful if someone can provide a good online text-based source of information about this, so that readers do not have to watch a video to get the information.

Dennis de Champeaux
I have had some useful email correspondence with him (initiated by him) in the last few years, related to the topics presented here. He has published several books related to these topics. E.g. search for books by him on Amazon Kindle and/or https://www.amazon.com/, https://www.amazon.co.uk/, etc.
(I shall try to provide a better source of information about him.)

Phillip Ball
https://www.cccb.org/en/participants/file/philip-ball/34436
He is a well known writer about science. He helped to publicise some of my earlier ideas (about "The space of possible minds") originally presented in 1984, by referring to them in his 2020 book, *The Book of Minds*
https://www.panmacmillan.com/authors/philip-ball/the-book-of-minds/9781529069167 and in live and recorded presentations advertising the book, e.g.
He has elaborated the ideas more recently, in ways that are closely related to the themes of this document, e.g. here https://lab.cccb.org/en/the-space-of-possible-minds/

Aaron Turner
Added 5 Mar 2024
Aaron Turner recently contacted me about his work-in-progress presented at https://www.bigmother.ai/
which seems to be related to the work I have been doing, though the aims seem to be very different. I may add further information later, when I have found time to look more closely.

Research on optogenetics
I cannot yet judge the importance of this work in detail, but it is clearly relevant to the issues presented here. See:
https://www.youtube.com/watch?v=hOKLMjuwuLo
Optogenetics: Illuminating the Path toward Causal Neuroscience
3 Oct 2019

Featured Speakers:
Edward Boyden, PhD, Y. Eva Tan Professor in Neurotechnology at MIT, Leader of the Synthetic Neurobiology Group in the MIT Media Lab, Investigator at McGovern Institute for Brain Research at MIT, and HHMI-Simons Faculty Scholar at the Howard Hughes Medical Institute
Karl Deisseroth, MD, PhD, D.H. Chen Professor of Bioengineering and of Psychiatry and Behavioral Sciences at Stanford University and Investigator at the Howard Hughes Medical Institute
Peter Hegemann, PhD, Hertie Professor of Neuroscience and head of experimental biophysics at Humboldt University of Berlin
Gero Miesenbeck, FRS, Waynflete Professor of Physiology and founding director of the Centre for Neural Circuits and Behaviour at University of Oxford
Charlotte Arlt, PhD, Research fellow in neurobiology at Harvard Medical School
Kimberly Reinhold, PhD, Research fellow in neurobiology, Harvard Medical School

Cell cycle: Making waves to coordinate the entry into mitosis
Added: 9 Mar 2024.
Zachary M. Wilmott Jordan W. Raff
https://www.cell.com/current-biology/fulltext/S0960-9822(22)01675-X
Summary:
How do very large cells coordinate their entry into mitosis? A new study shows that the bistability of the Cdk/Cyclin system allows cells to generate either "trigger waves" or "sweep waves" that drive cells into mitosis in different ways with distinct consequences.

NOTE:
I have not yet had time to look closely at this so I am not sure how useful it is, though it seems to be relevant to the main topics of this document.
SOME COMMON CONFUSIONS
Section added 27 Dec 2023, and items moved here, previously located earlier in this document.

False beliefs about evolution of language
Updated 27 Dec 2023
It seems to be widely believed that for humans spoken language was the earliest form of communication and that mechanisms supporting other forms, including written language and sign languages, evolved later. That assumption is seriously mistaken. Partial evidence that it is a mistake is the fact that deaf children brought together in Nicaragua, interacting freely, created a new shared sign language, indicating that the human genome supports the development of sign languages. See Shoshi Parks (2018) "How Deaf Children in Nicaragua Created a New Language. It happened on the playground" [link], and Donna Jo Napoli and R. Sutton-Spence. (2011). "Sign Language Humor, Human Singularities, And The Origins Of Language". Deaf Around The World: The Impact Of Language 231-250. [link]

The fact that use of spoken language evolved relatively late is related to the complexities of mechanisms linking apparatus for breathing and apparatus for swallowing. Before some animals moved from water to land there was neither need nor opportunity to breathe, and mechanisms used by spoken languages did not exist, so any communication must have been based on movement of body parts (either because the movements are visually detectable under water, or because they produce detectable pressure waves, and/or changing surface colours), or perhaps by use of electrical or chemical signals, or other mechanisms not yet known to current science. This Wikipedia entry is relevant: [link]

Confusions about "self" or "selves"
Added 27 Dec 2023
In publications, lectures, and online presentations, an assumption is frequently made that the word "self" refers to some part or aspect of an organism that is a product of processes of biological evolution and development, and which may grow more complex during development, and whose nature is difficult to describe or explain. This is a deep but very wide-spread confusion based on failure to understand that whenever anyone, X, is referring to his or her self, using words and phrases like "myself", "self aware", "selfconscious", and so on, what X is actually referring to is nothing more, and nothing less, than X. In particular it is not some "special" part of X, though what X may be saying about X can be much more complex than the form of words suggests. For more details (including a reference to related comments by David Hume, who pointed out this error long ago in his A treatise of Human Nature) see [link]

A similar form of words can be used (at least in English) for objects that nobody would believe can have a self: e.g. "The clock damaged itself on hitting the floor after the hook on which it was suspended broke". An object may be described as having self-inflicted damage, if the damage was caused by some action behaviour of the object. For example this news report states: "But as it spun around, it appears part of the frozen block may have scraped the bed, inflicting damage on itself." This does not imply that the iceberg has a self.
Oldest navigational tool?
Added: 16 Feb 2024
This web site https://www.bbc.co.uk/news/science-environment-41724022 reports on what is now thought to be the oldest known human designed navigational aid, an astrolabe discovered in a shipwreck in 2014 now thought to have been made between 1495 and 1500.

End Note
My main task now is to work out the important implications of the roles of (bio-)chemistry in cognitive mechanisms. The central role of chemistry in evolution, reproduction, development and maintenance is widely acknowledged but not its role in cognitive functions of many kinds, though I am not the first to have noticed this. Other researchers are referenced in this document, and there are probably many more I have not yet encountered.

Was Alan Turing working on related ideas shortly before he died??
Added 30 Mar 2024
I suspect Alan Turing was working on closely related ideas shortly before he died, and a side effect of that was his 1952 paper on chemistry-based morphogenesis. I suspect he had begun to develop deeper and broader ideas about the relevance of chemistry to intelligence. There may be clues in unpublished documents on which he was working at that time. I also suspect that Kenneth Craik also had related ideas, hinted at in Chapter 3 of The Nature of Explanation. He too died tragically young, killed in a road accident in Cambridge. I don’t think he and Turing ever met, though Turing may have learnt about Craik’s ideas possibly at Ratio club meetings.

Added 13 Feb 2024
This document is an unfinished attempt: still in need of reorganisation and further development of the ideas. To find relatively recent additions search for occurrences of "added" and "updated"!

NOTE ON MY DEMENTIA AND TOOLS USED TO CREATE THIS WEB SITE
Last updated 27 Jan 2024
Several years before I began working on this document I began to notice a decline in memory mechanisms, for which I partly compensated by extending my editing tools, programmed in Ved, the editor of the Poplog system, using the programming language Pop-11, which is used to implement itself and the rest of the Poplog system.
Information about Poplog and its mechanisms, including Pop-11, is available in several web sites, including https://www.cs.bham.ac.uk/research/projects/poplog/ and this more recent Poplog information site: https://www.cs.bham.ac.uk/research/projects/poplog/V16/
Waldek Hebisch has created a Poplog github site: https://github.com/hebisch/poplog
Several other contributors to development of poplog have information online about it. I don’t know how much longer these tools will suffice to enable me to continue updating this and related documents.

NOTE ON MY TIME AT SUSSEX UNIVERSITY
Important seeds leading to the work reported above (including interactions with Anthony Leggett) were planted while I was at the University of Sussex in Brighton England, between 1964 and 1991 (apart from a year spent at Edinburgh University during 1972-3). I have therefore included the following link to an interesting account of life at Sussex by Sussex Mathematician (Group Theorist)