Article. 12,544 words

A Feigenbaum cascade of generalised Darwinian processes in evolution

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Received: date; Accepted: date; Published: date

1. *Abstract*

The concept of cosmic evolution expands the concept of evolution from purely biological evolution to include, on the one hand, physical evolution of the universe from the Big Bang to stars and planet Earth and complex prebiotic molecules, and on the other hand the cultural evolution and technological development of humans to the present day. The author proposes that the tools of chaos theory, which are routinely used in the study of population dynamics, be applied to cosmic evolution. Population dynamics as a subject is very close to evolutionary theory. Concentrating on how the process of transmitting information to future generations changes, as biological evolution gives way to cultural development and technological advancement, there are indications that the advance of evolution follows a pattern of period-doubling bifurcations universally found in population dynamics and generally known as the "period-doubling route to chaos".

Keywords: evolution; chaos theory; cosmic evolution; complexity; period-doubling; Feigenbaum Constant delta;

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2. *Introduction*

2.1. *Different kinds of evolution*

When we think of evolution, we generally think of biological evolution. However, there are other kinds of evolution, both before and after biological evolution. First, there was physical evolution, which started at the moment the universe was created and which included the evolution of stars and planets and eventually the evolution of complex molecules that were precursors of life. This was followed by biological evolution, then development of culture and technology. The unification of theories is considered desirable in most branches of science, and the unification of physical, biological, and cultural evolution into a single theory of cosmic evolution is no exception[1].

2.2. *A common thread: information transfer*

If there was a single theory of cosmic evolution, what would it look like? First, it would need to accommodate the different processes of evolution - physical, biological and cultural. Though different, we would also expect the different processes to share one or more aspects. One aspect that would seem to be shared by biological and cultural evolution is the transfer of information to future generations. Biological evolution transfers information in the form of DNA. Cultural evolution transfers information in the form of spoken and written language.

The type of information transfer that is transferred to future generations it that which is useful for living. It can take many forms. DNA for defining organisms, skills for catching food, visual symbols (writing) for advanced education.

2.3. *Push*

A lot of energy goes into transferring information to the next generation. This reflects the importance of the information. For example:

- Almost every cell in our bodies contains a copy of our entire genome.
- It takes about a year for parents to teach a young New Caledonian crow how to make tools to retrieve food[2].
- Human education never really ends as knowledge is replicated for mass usage.

2.4. Landmark innovations

Every new form of information transfer is initiated by a landmark innovation in evolutionary history. For example:

- The first self-replicating life initiates information transfer via DNA
- The invention of spoken language initiates information transfer via speech
- The invention of writing initiates information transfer via written words

Some types of information transfer (DNA and written words) are preserved and can be found and dated. Others (spoken language) are not preserved. Those forms that are preserved are relatively easy to find because they are long-lived phenomena that are abundant in the palaeontological and archaeological records.

2.5. Acceleration

Considering the whole history of the universe, the impression we have is that there is acceleration in development. For example, it took 3 billion years of single-celled life before life on Earth moved on to multicellular plants and animals, whereas much human cultural evolution has occurred on a timescale of a few thousand years.

2.6. Speed

It is difficult to reason about the acceleration of evolution without knowing something about the speed of evolution. The currently dominant narrative of evolution is that it proceeds in fits and starts, with long periods of stasis, largely decided by changes in the environment. However, research indicates that the rate of evolution is hardly affected by environmental changes. and that, while environment affects abundance, it has little effect on speciation or extinction [3]. Evolution seems to be not primarily governed by adaptation to changing environment, but by internally generated genetic change such as mutation.

Borttaget: there is

Borttaget: that

2.7. Acceleration and Chaos Theory

Darwin created his theory of Natural Selection after reading Thomas Malthus' writings on population and competition for resources. It might be fruitful for evolutionists to look at the study of population again. In Population Dynamics, which is closely related to the study of evolution, diagrams of the population level of a species commonly show instabilities in the form of so-called bifurcations at decreasing intervals. The intervals are not usually in the time dimension, but could be made so if a variable that changes with time is used as the bifurcation parameter. Decreasing intervals in the time dimension is a characteristic of acceleration. The phenomenon of decreasing intervals results from applying Chaos Theory to Population Dynamics, and is called the Feigenbaum Attractor. The Feigenbaum attractor is found in various physical chaotic systems such as dripping taps, convection patterns in water and mercury, and nonlinear electronic circuits. In all such chaotic systems, the intervals decrease by the same factor, 4.66920…, a number known as the Feigenbaum universal constant Delta.

Chaos theory is normally applicable when a relatively simple operation on a system is repeatedly applied. The evolution of life is just such a system, consisting of a simple operation, mutation, iterated many times.

2.8. Investigation

The aim of this study is to find out whether Chaos Theory, and especially the Feigenbaum Attractor, can be related to the transfer of information that is a common factor in biological and cultural evolution, and form the basis of a theory of cosmic evolution that unites them.

3. Methods

The methods used were experimentation with matching the universal Feigenbaum constant Delta, 4.66920…, to the intervals between the starting dates of various mechanisms of information-transfer found in the history of evolution, and searching the literature for evidence to confirm or reject the suggestions.

4. Results

4.1. Transfer of information

An initial list was made of different mechanisms for transferring information to the next generation.

- **1) DNA**. Essential to self-replicating life is the transfer of information to each replicated organism. This information telling cells how to self-replicate is stored in DNA, and copies are made for made for each cell when cell division takes place.
- **2) Sexual reproduction** involved a change to reproduction so that DNA comes from two parents instead of one, allowing organisms to combine traits.

  The next stage of evolution can be characterised as culture-led because the changes begin as cultural behaviour, but they lead to biological changes, often before the next change. In culture-led and technological evolution we can identify further important changes in the transfer of information to future generations, namely:
- **3) Teaching by demonstration** (transferring information in the form of skills),
- **4) Spoken language** (transferring symbolic information)**,**
- **5) Written language** (storing symbolic information),
- **6) Printing machines** (replicating stored information), and
- **7) the Internet** (online information).

These are summarized in table 1.

We do not know the dates for Teaching by Demonstration or Spoken Language because we have found no traces of them in the palaeontogical or archaeological record. But we have dates for the rest of the events, and in particular we have fairly accurate dates for the last three events, which are shown in table 2.

According to the best data we have, printing was invented somewhere between 3639 years and 4448 years after the invention of writing. And the Internet was invented 919 to 928 years after Printing was invented (in China).

(Note: all dates used are the date of the first working example of the phenomenon described.)

If we compare these consecutive intervals, the first interval is between 3.92 and 4.84 times larger than the next interval. The ratio of shrinking intervals in the Feigenbaum Attractor is 4.66920…, which is between 3.92 and 4.84, so the ratio fits the Feigenbaum ratio within the margins of error. Therefore this data is a possible candidate starting point for matching the Feigenbaum Attractor to the rest of evolutionary history.

The last event is the invention of the Internet. The second last event is the Printing Machine, invented sometime between 1029 CE and 1048 CE in China. Further dates back in time were calculated by simply multiplying the interval between dates by the Feigenbaum constant 4.66920. This was done for various years between 1029 CE and 1048 CE. It was found that the year 1048 CE gives the best fit to other dates for information transfer in evolution.

4.2. New events

The result was a new list with, in total, 13 events. Four of the new dates given by the Feigenbaum ratio seem to match the following innovation events:

Additional events:
- **Tools made with tools** *(improved versions of found tools)*
- **Composite tools** *(improved versions of found tools)*
- **New inventions** *(things with new functions, rather than improved versions of found tools)*
- **New livelihoods** *(i.e. something other than hunting, gathering and scavenging.)*

There are 3 more dates which did not match any known date in evolution. This is not necessarily a problem, because we don't know the date of everything due to of lack of archaeological or paleontological evidence. As it happened there were 3 events where there is circumstantial evidence that their dates could match the 3 unmatched Feigenbaum dates, namely:

Undated events:
- **Teaching by demonstration**
- **Using tools** *(i.e. using found objects as tools)*
- **Making tools** *(improved versions of found tools)*

All 13 events are shown in figure 1 and table 3. The table shows dates and times of events and intervals between them. Each event is described in detail below.

4.3. Tools significant

The fact that the initial list contained of new forms of information transfer and that the Feigenbaum ratio "filled in" the list with important events in tool development implies that the teaching of each of the seven stages of the tool development counts in some way as a separate, independent means of transmitting information, not unlike opening a new information channel.

4.4. The 13 innovation events in detail

Here is a description of the 13 events in more detail.

- *Event number:* **1**
- *New phenomenon:* **Beginning of the universe**
- *Search space:* **Atoms/molecules**
- *Information transmission to next generation:* **(Not applicable – no living organisms)**

Starting from a state of low complexity, the state of the universe increased in complexity through various processes until organic molecules developed and, after about 10 billion years, self-replicating life.

- *Event number:* **2**
- *New phenomenon:* **Self-replication**
- *Search space:* **DNA-defined cellular traits**
- *Information transmission to next generation:* **DNA copying**

Cells replicate themselves by growing and dividing into two cells. Each cell has copies of the genetic code which contains all the information the cell needs to grow and replicate itself.

- *Event number:* **3**

- *New phenomenon:* **Sexual Reproduction and Complex (i.e. differentiated cell) multicellularity**
- *Search space:* **DNA-defined multicellular traits**
- *Information transmission to next generation:* **Sexual Reproduction**

Multicellularity with differentiated cells (e.g. muscle cells, brain cells, etc) – known as *complex multicellularity* – is probably necessary for intelligent life to evolve. Plants and animals are multicellular. However, multicellularity is apparently not viable without sexual reproduction. Not all evolutionary biologists are in agreement about this, but there is evidence that sex and multicellularity evolved at the same time in red algae found in 1.2 billion year old rocks [4]. If this is the case, then sexual reproduction and complex multicellularity could be seen as different aspects of the same innovation.

Sexual reproduction also seems to evolve faster than simple self-replication (which is basically cloning). With self-replication, useful mutations occur, but often in different cells. There is no mechanism for the mutations to move into the same cell, so each cell has to evolve the same mutations on its own. Sexual reproduction combines genes from 2 parents, which is a way of collecting good mutations into a single cell.

In addition, the genes used in sexual reproduction are all genes that come from fit individual organisms, increasing the chances of fit offspring.

99% of all species today reproduce sexually, so it is clearly advantageous [5].

- *Event number:* **4**
- *New phenomenon:* **Teaching by demonstration**
- *Search space:* **Novel behaviours**
- *Information transmission to next generation:* **Teaching**

Cultural evolution goes back before language and before humans. *Social learning*, whereby young animals learn from their elders seems date back to the beginning of sexual reproduction or even earlier[1]. Teaching, on the other hand, is a deliberate act which is more in keeping with the theme of deliberately pushing knowledge to the next generation (c.f. passing on DNA during Self-Replication, and shuffling genes for the benefit of offspring during Sexual Reproduction).

Teaching is any deliberate behaviour or change in behaviour in order to pass on information, such as performing a task more slowly in order to demonstrate it to another of the species. For example, meerkats teach their young how eat scorpions by giving them dead or disabled scorpions [9]. The young meerkats learn by imitation or emulation, and the knowledge gets passed on, shortcutting the biological genetic route for the passing on of knowledge. So Teaching would seem to count as a new way of passing on information.

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[1] Social learning *is a process whereby young animals learn from their elders. Social learning is very widespread, as most species interact with their young at the beginning of their lives [6] and it covers a whole spectrum of situations, including learning prior to birth. For example, the fact that new-born rats respond positively to foods that the mother ate during pregnancy is counted as social learning [7]. There is even evidence of social learning in other sexually-reproducing forms of life such as plants and microbes [8]. So social learning may be an inherent feature of sexually-reproducing life, or even self-replicating cell s, with juveniles learning about other members of their own species at the same time as learning about everything else in their environment. That implies that social learning evolved slowly as multicellular animals evolved that the beginning of learning may count as part of the same innovation as the first sexual reproduction or the first cells. There is no sudden evolution of social learning and insofar as social learning affects evolution, it can perhaps be considered to be "factored in", in the same way that multicellularity also seemed to appear with sexual reproduction.*

However, if teaching is passing on information, what information is being passed on? Firstly, this is teaching of *learned* behaviour, not genetically programmed teaching. In addition, it presumably teaches behaviours which are not passed on by social learning because opportunities for observation are rare, or because learning the behaviour is difficult or dangerous. Such a case may be the meerkats' handling of scorpions. If the meerkats did not actively teach the behaviour, the behaviour may not get passed on. This is an evolutionary shortcut, because new useful behaviours can be passed on directly through teaching instead of through genetic code mutation, which takes a long time.

While the teacher would have taught by demonstration, the pupil would have learned from the teacher by imitation, which is considered to be a symbolic means of communication. Animals already have a talent for this, probably because they have practised social learning.

We do not know when teaching first appeared, but the predicted date, 264 million years ago, was about the time when Cynodonts emerged, which were descendants of pelycosaurs ("mammal-like reptiles"), had mammal-like skulls and were ancestors of modern mammals. Some cynodonts are thought to have engaged in parental care [10]. Some cynodonts were mammals, and modern mammals have been observed teaching their young [9]. Parental care is thought to date back even further to 520 million years ago [11], but that is not the same as teaching. That the first teaching could have happened 264 million years ago with the cynodonts or their immediate ancestors, the Therapsids, is not implausible.

- *Event number:* **5**
- *New phenomenon:* **Tool use**
- *Search space:* **Found tools**
- *Information transmission to next generation:* **Teaching tool use, Tool Transfer**

The use of tools is undoubtedly important in evolution. In effect, a tool is added to the body. It instantly extends the body without waiting for biological evolution [12]. The tools in question would basically be sticks and stones that happen to be lying around on the ground and used without modification for a useful purpose.

56.6 million years ago, the first monkey had evolved. Monkeys use tools today [13], and it is not implausible to suggest that they were the first to use tools 56.6 million years ago.

Chimpanzees have been observed teaching their offspring how to place nuts on a so-called anvil stone and crack them open using a stone of suitable size and weight [25]. While they are learning, young chimpanzees are allowed to use their mother's tools. This is called "tool transfer" and even without additional teaching, it fulfils all the criteria to qualify as teaching on its own because 1) it has a "cost" (giving up the tool to the pupil), and 2) the pupil learns from practicing with the tool [26].

- *Event number:* 6
- *New phenomenon:* **Making tools**
- *Search space:* **Made tools**
- *Information transmission to next generation:* **Teaching tool-making & Referential Gestures**

This is the time of the first great apes or hominids. Great apes have been observed making tools [16], so it is reasonable to suggest that they may have made tools back when they first evolved. Tools are made by humans, great apes and corvids. Humans, great apes, and ravens (members of the corvid family) are also the only animals that use referential gestures [13] [17]. It is not unlikely that there is a connection between these two facts, namely that referential gestures are needed to teach tool-making.

- *Event number:* **7**
- *New phenomenon:* **Tool-made tools**
- *Search space:* **Objects made with tools**

- *Information transmission to next generation:* **Tool-on-tool teaching (using "Tool-made tool language)**

2.6 million years ago was not the first time that stone tools were made. Stone tools made with the "bipolar" technique using with an anvil stone have been dated to 700,000 years earlier [18]. However, the freehand knapping technique marks a significant advancement.

A tool is an extension of the body. When a tool is held in the hand, it has to be incorporated into mind's "body schema" so that the working tip of the tool can be moved as if it were a part of the body [12]. Modern humans can do this easily, but our ancestors may not have been as proficient.

With the freehand knapping technique, a stone is held in each hand, without the support of an anvil stone. One stone was hit with the other to break off flakes. The movement of each hand has to be coordinated with the other hand. The method provides complete manual control over the tool being used and the object being made, and they both become extensions of the body.

Although it required greater dexterity, early humans clearly found that this technique gave better results, because they used it from then onwards (although the bipolar anvil technique continued to be used for certain types of stone and smaller stones that were difficult to work with the freehand technique) [19]. The freehand technique required improved perceptual abilities, learning capacities and bimanual dexterity compared with the bipolar technique [20]. The complete control involved eventually led to very finely made stone tools, such as spear heads.

Experiments have shown that teaching modern humans the freehand flaking technique is more effective if gestures are used during teaching, and even more effective if spoken language is used [21]. Thus it may be that some form of language had evolved which enabled hominins to teach the freehand technique to others. We can call this the "Tool-made tool teaching language" Modern humans, with more advanced innate tool abilities, can learn the freehand knapping technique without language, but this may not have been the case for early hominins. It has been suggested that hominins at this time engaged in social foraging which demanded increased cooperation and communication, and that they may have developed gestures as a means of communication [22].

- *Event number:* **8**
- *New phenomenon:* **Assembly techniques**
- *Search space:* **Composite tools**
- *Information transmission to next generation:* **Composite tool teaching and "composite tool teaching language")**

The prime candidate for this innovation is the earliest known stone-tipped spear from 550,000-450,000 years ago [23][24][25]. The significance of this spear is that it is the first known example of a composite tool. It had a wooden shaft and a sharpened stone tip attached to the shaft using a method known as hafting. From this point onwards, early humans had the ability to conceive of a human-made object made of more than one component and were able to construct one. This is a significant skill as most things made by humans today are composite objects.

Note that this is not a new tool, because spears had already been in use for a very long time, but making a tool by making separate parts and joining them together is a new and important principle for making things.

Just as with the freehand tool technique, it may have been that a new language innovation was required to teach the making of composite tools.

- *Event number:* **9**
- *New phenomenon:* **Creating new objects to solve problems**
- *Search space:* **New inventions**
- *Information transmission to next generation:* **Teaching use of inventions, and "Invention Teaching Language"**

Boats, clothes, beads, harpoons, sewing needles, mortars and pestles, cloth, flutes, rope, pottery. These are just some of the new things that humans started to make, beginning around 119,000 years ago. It seems that humans suddenly gained the ability to invent new things. It is significant that everything that humans had made until this point were copies of the first tools used, which were originally twigs and sharp sticks that were found lying around. The previous pinnacle of human technology - the stone-tipped wooden spear - was a just superior version of a sharp stick that was first found and used perhaps tens of millions of years before.

New inventions are considered to be associated with the Upper Palaeolithic Revolution [26], but the first inventions came earlier and the archaeological record agreed with the bifurcation-predicted date of 119,000 years ago.

This new ability for invention did not seem to require much advance in manual techniques so much as a new creativity or problem-solving ability. These new inventions would also possibly require new cognitive abilities to use and to explain to others, and may have been associated with new language abilities. A significant change in language associated with the Upper Palaeolithic Revolution has been proposed [27].

Of the earliest inventions here the date of the first bead necklace (135,000-100,000 years ago [28]) is used for this innovation, because the although the dates for the other earliest inventions - boats and clothes – fit the bifurcation pattern, evidence is circumstantial and without actual artefacts.

- *Event number:* **10**
- *New phenomenon:* **Language and Organisational skills**
- *Search space:* **New livelihoods**
- *Information transmission to next generation:* **Teaching of "Complete Language"**

The Neolithic Revolution supposedly began 12,000 years ago with the domestication of sheep and various plants and led to the first agricultural civilisation. However, the date predicted by the bifurcation pattern was 24,900 years ago. This agrees with the date of the first animal to be domesticated, which was the dog (32,000 - 18,000 years ago [29]). Dogs appear to have been an integral part of the Neolithic revolution [30]. It is believed that humans and dogs worked in a mutually beneficial partnership, initially in hunting [31], but later with herding. This partnership may have been important in the move away from hunting, scavenging, and gathering, to organise new livelihoods leading to agriculture and civilisation.

This innovation also seems to have come from crossing a cognitive threshold that may have been associated with an advance in language. This seems to have enabled the capacity to invent new livelihoods. Communication must have been important to make these new livelihoods work. At some point language seems to have given humans to the capacity for logical reasoning and problem-solving. From experiments we know that some kinds of problems can only be solved with the aid of language [32]. Certainly, some kind of logical reasoning and problem-solving ability must have been necessary for humans to abandon scavenging, hunting and gathering (which for tens of millions of years was the only thing they knew how to do) and invent new ways of living, ending up with civilisation and the specialisation of labour.

- *Event number:* **11**
- *New phenomenon:* **Information Storage (Writing)**
- *Search space:* **Handwritten works**
- *Information transmission to next generation:* **Teaching of reading and writing**

We know very little about the evolution of spoken language, but we do know a lot about written language. Much information is now being passed on by written words. The first writing was called Cuneiform and it was developed as a means to record trade, debt, and tax information [33]. It also enabled the recording of religious knowledge, literature, and medical texts. Without the aid of writing, humans would have had to evolve much increased memory abilities which, even if possible, would take a long time to evolve.

The written word is not just communication: it is a shared memory and reference. A handwritten document is a persisting object that can record things that two or more people have agreed upon. Such a document enables agreements to be made, accounts to be opened, and laws to be reliably documented. It became an essential part of society.

The invention and use of new kinds of documents became the main source of variation and innovation in human society, taking over the role of the main driver of evolution of intelligent life on Earth. Various types of handwritten documents quickly became established, such as contracts, accounts, and descriptions of laws. Such documents enabled the organisation of groups of people on a larger scale and led to what we know of as cities and civilisation and an even greater degree of labour specialisation.

Writing is a form of information technology. The gestural and vocal parts of spoken language are translated into visual symbols on clay tablets or paper-like sheets of papyrus. Where spoken language is ephemeral, written language is persistent. Information in written form does not have to be remembered in detail. It can be referred to when necessary. It effectively forms a storage medium that extends the storage capacity of the mind.

- *Event number:* **12**
- *New phenomenon:* **Information replication (Movable Type Printing)**
- *Search space:* **Printed works**
- *Information transmission to next generation:* **Replication of knowledge**

An important innovation in the transfer of information that happened after writing was invented was the invention of a machine to replicate information. To be more precise, the invention of movable type printing in 1039-1048 CE . This was perhaps the first machine to handle symbols. Movable-type printing had small printing blocks for each character which could be assembled together in a frame and used to print text onto paper. The moveable type made the process of composing a page of text very quick compared with the previous technique of carving wood blocks for printing. Movable type printing was invented in China and later spread to Europe. The 400-year delay before it spread to Europe could be thought to have slowed European development. When movable type printing arrived in Europe, it was an instant success and may have made up for lost time by incorporating new technological developments that had taken place in the meantime.

Before printing, books were copied by hand, which made them very expensive and mainly owned by wealthy establishments such as religious authorities.

Printing had the effect of democratising knowledge, putting into the hands of many more people. Science and mathematics, which were revolutionised by the invention of writing, were again boosted by the ability of printing to spread accurately replicated knowledge, without the errors often caused by hand-copying.

- Event number: **13**
- *New phenomenon:* **Online Information (Internet)**
- *Search space:* **Web pages and services**
- *Information transmission to next generation:* **Search and delivery of knowledge**

If we were to look for other, more recent examples of ways of transferring information, the Internet comes to mind. The Internet is a store of information as well as a communication channel. It contains search functions that allow us to find information far more quickly than before, and also to find other people whom we might be interested in exchanging information with and instantly communicate with them in a variety of ways.

4.5. Generalised Darwnism

Examination of the information transfer events reveals that they are all part of generalised Darwinian processes. Darwinism is a theory of biological evolution that states that organisms evolve and adapt to their environment through an iterative process. This process can be conceived as an evolutionary algorithm that searches the space of possible forms (the fitness landscape) for the ones that are best adapted, by natural selection of inherited variations. Generalised Darwinism can differ from Darwinism in the various ways, including the process of evolution, that is

- **Variation** (the search space for the solution and the means of generation of variation to explore it (for example, mutation, or something else),
- **Selection** (natural selection, sexual selection or artificial selection),
- **Inheritance** (the means, format and content of the inheritance).
- **Subject** (the organism or species, perhaps including cultural artefacts such as writing)

Table 4 shows the 13 events interpreted as different forms of Generalised Darwinism.

4.6. Identifying Generalised Darwinian Processes.

It is important to be sure that we have identified all the generalised Darwinian processes that are to be found, and conversely that we have not included evolutionary events that are not generalised Darwinian processes.

Table 5 shows a list of all evolutionary changes that produced new forms of information transfer, indicating which were a) part of a new generalised Darwinian process and were used as a new mechanism for inheritance as a primary means to push essential knowledge such as biology, skills, or pure information to future generations, and b) were not.

We have a fairly good idea from the palaeontological and archaeological records what human ancestors were doing at various times. For example, we know when they started doing various things, like making tools, and we know how many millions of years they did that. We are also reasonably sure that while they were making tools, they also taught their offspring to make tools.

As an example of something not used to transfer knowledge, we also know that cave paintings or pieces of rock art were made during a certain period. However, while making tools enabled us to evolve more quickly, it seems unlikely that rock art had such a large effect. Rock art had no adaptation advantage that we know of and does not seem to have been part of a generalised Darwinian process that gave any significant adaptation advantage. As a means of storing knowledge or communicating, rock art on its own is ambiguous in meaning. (It is telling that archaeologists do not know the meaning of rock art to this day.) The meaning could only be conveyed if it was presented in spoken words or text. Rock art is thought to have been used in rituals. Nevertheless, the art techniques developed for rock would have been useful later when writing was invented.

Table 5 attempts to classify all means of communication according to whether or not they were part of a new Generalised Darwinian process.

4.7. Table of Generalised Darwinian processes

The following points are worth noting from table 4:

- **Push:** At each stage the mechanism of inheritance involves information being pushed from the sender to the receiver, rather than being pulled by the receiver from the sender. This incurs a costfor the sender.
- **Passing on the information-transfer mechanism itself:** As well as passing on a particular skill, what also has to be passed on is the mechanism for passing on the skill. For example, Parent A taught by demonstrating to offspring B skills for killing, say, a scorpion. Offspring B needs to know not only how to kill a scorpion, but also how to teach it by demonstration to their own offspring
- The mechanism of inheritance is different at every stage – here is the list:

- 1. None
- 2. Cell Binary fission
- 3. Fertilisation
- 4. Demonstration technique
- 5. Tool transfer (giving the tool to the pupil)
- 6. Referential gestures (found only in tool-making species, are apparently needed for teaching tool-making).
- 7. "Tool-made tool language" (proposed)
- 8. "Composite tool language" (proposed)
- 9. "Invention language" (proposed)
- 10. Complete language (needed for teaching organisational skills)
- 11. Reading/ writing skills
- 12. Printing machine technology (only needed by a few people, because of the division of labour in event 10)
- 13. Internet technology (only needed by a few people, because of the division of labour in event 10)

These are the methods used to pass on selected information at the various stages. From event 7, language skills may have been needed and would have had to have been taught first, before the tool skills that were selected for passing on. New languages for stages 7, 8 and 9, have been proposed to coincide with the corresponding tool development.

- **Cognition:** Although there is no definitive "ladder of cognition" we can nonetheless see that selection of what to pass on to the next generation occurs at ever higher cognitive levels to match the cognitive level of the current stage of evolution. In ascending order (from table 4):
  - 1. No selection (no life)
  - 2. Natural selection
  - 3. Sexual selection (selection of whole individual for mating)
  - 4. Learned skill selection (selection of what to teach one's offspring)
  - 5. Selection of tool use (to teach one's offspring)
  - 6. Selection of tool-making (to teach one's offspring)
  - 7. Selection of tool-made tools (to teach one's offspring)
  - 8. Selection of composite tools (to teach one's offspring)
  - 9. Selection of new inventions (to teach one's offspring)
  - 10. Selection of livelihoods (to teach one's offspring)
  - 11. Information Storage (Teach reading & writing and/or some other skill)
  - 12. Information Replication (Teach reading & writing + perhaps some books)
  - 13. Online Information (Teach reading & writing + some future thing)

  (It is not clear whether stages 11, 12 and 13 represent new cognitive levels.)
- **Processes do not replace, but add to existing ones:** All the old processes are still in play, although perhaps not as significant. For example, DNA mutations still occur in humans, but the biological effect on the adaptability of the species is currently negligible compared with the impact of all the other processes.

4.8. Tools

The importance of tools

The definition of a tool is an object used to extend the ability of an individual to modify features of the surrounding environment. The importance of tool use is that it is a way to instantly extend the physical body. Physical extensions to the body otherwise have to evolve biologically. Picking up a tool is obviously much quicker.

Tools and body schema

To manipulate an object with a tool, the tool must be incorporated into the tool user's *body schema*, which is a collection of processes by which the *working surface of the tool* can be placed at the intended position and angle by moving the *held part of the tool* with (usually) the hand or fingers.

Tool use and tool transfer

Tool use coincides with **Tool Transfer**. Tool Transfer is when a parent teaching the use of a tool to a youngster gives the youngster the tool. This qualifies as an act of teaching in and of itself, according to the criteria of what constitutes teaching, and being different from teaching by demonstration, it would seem to be a new way of transferring information. Clearly, teaching the hands-on feel and use of a tool can really only be done by giving the tool to the pupil. If the tool is seen as an extension of the body, then Tool Transfer is equivalent to handing a body extension directly to a pupil. This can be compared with biological information transmission, where DNA hands over instructions for growing body parts.

4.9. Tools and Language

We know that language had already developed by the time Writing was invented. However, we know very little about the development of language, as no trace was left apart from the end result.

It seems unlikely that spoken language developed fully in one step, and it is often proposed that it developed in two steps: for example, a primitive language and then a more sophisticated language for the so-called "Upper Palaeolithic Revolution" [27]. There are many different theories of language development and none have explained in any detail how language evolved. The bifurcation pattern suggests that there were several important innovations during this period.

Tool-making and referential gestures

Tool-making coincides with **Referential Gestures**. Referential gestures occur when an individual intentionally brings an object to the attention of another individual. Only humans, great apes and corvids (crows and related birds such as ravens) use referential gestures, and are also the only animals to make tools. Therefore it is likely there is a connection between the two. Gestures qualify as a language and referential gestures could perhaps be seen as a "tool-making language", used to pass on the making of tools to others.

Tool steps = language steps?

For events 7, 8 and 9 we do not know the mechanism for the transfer of skills. This is because there are no animals that we know of that are these stages of cultural evolution, and we do not know how language developed. The preceding event 6 has referential gestures, which counts as a language. The following event 10 is most likely a complete language equivalent to what we use today. This points towards 7, 8 and 9 having different levels of language for information transfer. If this is the case, each new level of language probably encodes a new kind of information that can be transferred to other individuals, giving them new abilities (e.g. in tool development) and thus qualify as a new means of transferring information.

For events 7, 8 and 9, the new language levels can be classified as:

- 7. A **"Making Tools With Tools" Teaching Language**
- 8. A **"Making Composite Tools" Teaching Language,** and
- 9. A **"Making New Inventions" Teaching Language**

Brain size also co-evolved with language and tools [34]. The fact that language developed during this period suggests that language may have been required for the tool innovations to be passed on, and that without tool innovations, language would not have developed.

4.10. Culture-led evolution

There seem to be two ways in which culture appears to affect biological evolution in what may be called culture-led evolution:

- Apparent presence of genetic assimilation of taught skills.
- Co-evolution of culture and genetics

Genetic assimilation

Behaviours which have been taught by parents can become instinctive behaviours, that is passed on genetically by the process of genetic assimilation. (There is more than one theory regarding how genetic assimilation works. Perhaps random mutations that happen to correspond to taught behaviour are strongly selected for.) An example is New Caledonian Crows, that are taught to make tools by their parents. If a crow is separated from other crows at birth, it still knows how to make tools, but the tools made are not as sophisticated as those taught by parents. The innate knowledge to make tools could be a result of the genetic assimilation of taught skills by the bird's ancestors. Genetic assimilation may make it relatively difficult to find taught behaviours in animals today.

Co-evolution of culture and biology

The tool stages were also a period when humans evolved an upright stance, walking on two legs, and parts of the brain became larger. These seem to be the result of co-evolution. The adoption of the use of tools and language by a group strongly favours the natural selection of certain physical characteristics and larger brains, the biological costs of which are more than outweighed by the increasing returns in combination with the use of tools.

4.11. Event groups

The Generalised Darwinian events fall into 4 chronological groups:

- **Event 1: Physical:** No information is passed on.
- **Events 2 to 3: Biological**: The information passed on is instinctive procedural knowledge.
- **Events 4 to 10: Culture-led**: Transition to declarative knowledge; up to seven levels of taught knowledge, each with corresponding cognitive level, and each perhaps genetically assimilated before the next level.
- **Events 11 to 13: Information technology**: Knowledge is stored externally to the mind. Not every individual needs to know everything from here on, because of information storage and labour division.

4.12. Feigenbaum cascade explained by Population Dynamics?

The study of evolution has much in common with the study of Population Dynamics. Populations of species in ecosystems are studied using mathematical formulae to simulate on a computer the effects of births, deaths and eating habits upon the population numbers. The population of each generation is calculated from the population of the previous generation. This calculation can be run many times to simulate many generations to determine the long-term population trend.

The mathematics of population dynamics

Population Dynamics uses the logistic mapping, like the one below, repeated endlessly.

$$x_{n+1} = a.x_n(1 - x_n)$$

where n is the generation, x_n is the population at generation n, and a is the birth rate.

The term $(1 - x_n)$ models the limited resources way in the higher the population, the more resources are consumed, leaving fewer resources for the following generation. This is a case of delayed negative feedback.

The simple logistic mapping, repeated, gives rise to complex results, in accordance with chaos theory. Figures 4 to 7 show how population numbers change for various birth rates .

Population dynamics and evolution

In Population Dynamics, the logistic model is often used, in which the net birth rate (births minus deaths) between generations determines the population of the species in an ecosystem. The Feigenbaum diagram in figure 7 starts with a birth rate of zero, using a definition of birth rate such that the population of living organisms is zero until the birth rate exceeds 1.0, because values below 1.0 when repeatedly multiplied eventually become zero.

If we were to draw a graph of life with *time* on the x-axis, starting with the Big Bang, we would also start with a birth rate of zero, and it is reasonable that the birth rate increases with time, as the complexity of matter increases. Thus, with time as the x-axis, we see the Feigenbaum bifurcations occurring at various times in the history of evolution.

Some adjustment to the curve for the first couple of events is perhaps necessary because the scaling of the first couple of events does not match the historical dates. However, this is the usual case with Feigenbaum cascades that they do not match at the beginning, but then rapidly converge to match the Feigenbaum constant. There is also to be considered the difference that evolution started in space, possibly at a different speed to evolution on Earth, and continued on Earth, perhaps waiting a long time before the Earth was formed.

Possible reason for population bifurcation in evolution is faster predator adaptation causing a shortage of prey.

In population dynamics, the population level bifurcates and oscillates between two levels because the birth rate is above a certain level, causing overconsumption of prey. What is the corresponding mechanism for evolution where the birth rate corresponds to complexity and increases with time?

In general, predators are more complex creatures than prey. However, there is a "cost of complexity"[35] whereby the more complex a species is, the slower its adaptation rate. Therefore, prey should be able to adapt more quickly to changing conditions than their predators. In this situation, overconsumption of prey is probably less likely to occur, and the population level is more likely to be stable. However, if the predator were to evolve by acquiring a new generalised Darwinian process listed above, then the balance may be disturbed to the advantage of the predator and result in overconsumption of prey, causing a bifurcation (instability) in the predator population level (figure 8). Further generalised Darwinian process events may cause further bifurcations.

4.13. Comparison of population dynamics and evolution

It can be useful to examine the similarities and differences between bifurcations in population dynamics and bifurcations in evolution.

- In population dynamics, each event consists of
  1) reaching a new threshold of consumption,
  2) which becomes a new source of feedback,
  3) causing a population bifurcation.

- In evolution, each event consists of
  1) completing the construction of a new generalised Darwinian process that sends new information to other individuals,
  2) which becomes a new source of feedback,
     2.1) which increases the adaptation rate
  3) causing a population bifurcation.

Adaptation rate

The main characteristic of the generalised Darwinian processes in the history of evolution is that they all increase the rate of adaptation. This rate of adaptation may slow later as the species get more complex ("cost of complexity"). The "cost of complexity" may apply just to biological evolution, or it may apply to the subsequent cultural and technological stages too.

Temporary bifurcations

Over time, species in an ecosystem will adapt, and the species that will thrive in the long term are not necessarily the ones that are fittest at any one time, but the species that adapt fastest. It is possible that changes in ecosystems may temporarily favour a particular species that is slower to adapt, giving rise to temporary bifurcations in the short term which will revert and disappear in the long term. These may appear as "noise" on the bifurcation diagram.

This description of where bifurcations arise may not agree with experiments in population dynamics because time may be needed for the species to adapt for things to settle down match predictions.

4.14. Other circumstantial evidence

There are a number of pieces of circumstantial evidence which support the idea of an evolutionary sequence as a chaotic system.

Circumstantial evidence: Self-similarity

The hypothesis of new levels of the evolution process is reminiscent of the self-similarity of fractal structures. For example, the Mandelbrot Set (figure 2) is a fractal figure generated by iteration of a mapping which is not significantly different from that of the population bifurcation diagram, but is "shown from above" in the complex number plane. Figure 2 shows the relationship between the Feigenbaum Tree and the Mandelbrot set. The Mandelbrot set shows self-similarity in the form of small copies of the Mandelbrot set within the Mandelbrot set pattern (figure 3). There are an infinite number of mini-Mandelbrot sets in the Mandelbrot set, and each one is different in size and slightly different in form. This is analogous to an infinite number of evolutionary stages.

Circumstantial evidence: Markov chain simulation of evolution

Lei Chai et al.[36] developed a model to simulate the evolution of labour division (which corresponds to event 10 in this study) and discovered that adjusting the model parameters gives rise to bifurcations. It seems likely that there would be a connection to the kind of bifurcations that are related to the Feigenbaum constant delta.

4.15. Each stage seems to build on the previous stage.

Table 6 shows the maturation of each stage and how it provides the biology, knowledge and skills needed for the next stage. The only part that does not fit this pattern is the sudden arrival of language. This could be an argument for more rudimentary language levels corresponding to the tool levels.

4.16. Future events

Evolution is still ongoing, and the bifurcation pattern predicts further dates for the future, shown in table 7. It is not certain what these events might be, but they should continue the pattern of generalised Darwinian process, and are probably forms of information technology. Theoretically there should be an infinite number of shorter and shorter events. In practice there ought to be a physical limit on how small and quick events can be. It may be that the events become less significant as they become smaller and shorter. For example, consider from a subjective point of view the amount of evolution between "Multicellularity" and "Behavioural flexibility" (where life evolved from single cells to animals with legs, eyes, and brains), and compare it with the amount of evolution between "Using tools" and "Making tools". Intuitively it seems clear that less evolution is happening at each step.

4.17. Fossil energy

Until about 100 years ago, the evolution of life on Earth has been driven by energy from the sun, and the speed of evolution has possibly been dependent on this energy, as well as the size of the Earth considered as an eco-system.

Since the middle of the 20th century, the amount of fossil fuel used worldwide has been increased significantly – perhaps not enough to alter the date of the invention of computer networks (Internet), but very possibly enough to affect the predicted dates of future events so that they happen much earlier.

4.18. Cutting edge species

Not all species evolve to the same level. But there seems to a "cutting edge" species (homo sapiens and ancestors) that has always been at the forefront of evolution, always evolving as fast as is possible (and faster than other species), evolving in a general-purpose direction and whose ancestors can be traced back to the beginning of life.

We can assume that the line on the diagram always refers to species that are ancestors of modern humans. We need to choose the variables on the diagram to compensate for the fact that the different species in our ancestry have had different numbers of offspring, different reproduction patterns, etc.

5. Discussion

5.1. Recapitulation

The hypothesis presented here focuses not on what has evolved, but how it has evolved, in what seems to be a cascade of Darwinian processes produced by some principle of complex adaptive systems not yet understood. Life started off with blind, random mutation and natural selection, exploring the search space of genetic codes, producing nothing but single-celled life for 3 billion years. Then sexual reproduction evolved, solving the problem of how to make multicellular organisms. allowing useful mutations to combine in the multicellular life forms, and changed the search space to random combinations of already-successful alleles, as well as introducing a cognitive element to evolution in the form of sexual selection. The random mutations did not stop, but continued to provide novelty to the gene pool, as mutation and recombination worked together. Likewise, natural selection continued to play a part alongside sexual selection.

Then evolution became led by culture, exploring behavioural change, moving up through tool stages, synchronised with language change and cognition as communication required the replacement of procedural knowledge with declarative knowledge. The search-space ascended through behaviour, objects that could be picked up off the ground, then made, then used to make other things, then assembled from parts, applied to new uses, and finally applied to ourselves as we learned to organise new livelihoods. During the tool phases, the tools were part of evolution, and evolved themselves, just as much as any changes in DNA that occurred during this period.

Labour became specialised as increased cooperation became possible through language, and the search space became the various specialised livelihoods. All these stages affected biology through genetic assimilation and co-evolution.

With the advent of writing, information technology took over and humans became general-purpose agents, potentially capable of anything given the right information. The search space dominating the era of the written word became the useful information that could be recorded and shared in the form of handwritten documents such as accounts, laws, and contracts (all of which spawned priesthoods still thriving today). The printing machine enabled accurate mass replication of knowledge, and the search space changing to books and articles, particularly aiding science which rigorously accumulated knowledge according to scientific methods.

Now DNA has been joined by a new kind of DNA, namely the written and printed word, which contain most of our non-instinctive knowledge of the world. These words were not produced by mutation, but be trial and error and by thinking. Not everything written is necessarily right or useful, of course, but we keep track of which books and theories are useful and which are not.

And now we have entered the Internet era, which may bring changes we do not foresee. According to the logic of the Feigenbaum attractor, the evolutionary stages seem set to continue, accelerating to the Accumulation Point, the nature of which we cannot be certain, but which will not be the end of the story.

Brief summary of results

- Physical, biological and cultural evolution has proceeded in cascade of information transfer processes matching the Feigenbaum attractor.
- In addition to the original hypothesis, these information transfer events are each part of a generalized Darwinian process, each of which has a different search space, source of variation, selection, inheritance, and cognitive level.
- The steps so far are 1) Big bang, 2) Life, 3) Sex/Multicellularity, 4) Teaching, 5) Using tools, 6) Making tools, 7) Making tools with tools, 8) Composite tools, 9) New inventions, 10) New livelihoods, 11) Writing, 12) Printing, 13) Internet.
- Language development started with steps 4, 5 or 6, and evolved in sync with physical skills until completion at step 10. Information technology then took over, with steps 11 to 13.
- Of the 13 events, gaps in the palaeontological record mean that we do not know the actual dates of 3 events and we don't know anything about details or existence of 3 postulated language events.

6. Conclusion

The results probably count as what Karl Popper called a "bold conjecture". It is difficult to judge the results because they come "out of the blue" with many aspects being new to evolution theory. The data all apparently match known facts, although facts are sometimes controversial and not universally accepted. This hypothesis is testable. If verified, it would have far-reaching effects on the theory of evolution, and on language and cognition studies. The prediction of an Accumulation Point in the relatively near future is also significant.

Author Contributions: NH wrote the paper.

Funding: This research received no external funding.

Acknowledgments: I thanks Keith Bumford for correcting the composite tool data.

Conflicts of Interest: The author declares no conflict of interest.

Data Accessibility: All relevant data are within the paper or its Supporting Information files.

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8. *Tables*

Evolutionary stages	Type of evolution	Means of passing on information to next generation
Life	Biological	Passes on a copy of the genetic code (DNA).
Sexual reproduction	Biological	Passes on a random mix of the genes of both parents.
Teaching	Culture-led	Teaching by demonstration
Spoken language	Culture-led	Teaching of and by vocal language
Written language	Information Technology	Recording of information, Teaching of reading & writing
Printing	Information Technology	Teaching from machine-replicated books
Internet	Information Technology	Virtually instant search and transmission of information

Table 1. Initial list of new mechanisms of passing on information in the history of cosmic evolution.

New means of passing on information	Date (upper & lower limit)	Years before 2000 (upper & lower limit)	Interval since previous event (upper & lower limit)	Ratio of previous interval to this interval (upper & lower limit)
Writing	3400-2600 BCE [37]	5,400-4,600 years	*(Not applicable)*	*(Not applicable)*
Printing	1039-1048 CE [38]	961-952 years	3639 to 4448 years	*(Not applicable)*
Internet	1967 CE [39]	33 years	919 to 928 years	Between 3.92 and 4.84

Table 2. Dates for the last three major changes to the way information is transferred to new generations: the invention of writing, the printing machine, and the Internet.

Innovation matching the date	Predicted date (years before 2000)	Known date – upper and lower bound (years before 2000)	Deviation of interval between dates from Feigenbaum ratio 4.66920…
1. Start of universe	26.9 by	13.78 – 13.82 by [40]	-49 %
2. Life	5.76 by	3.77 – 4.28 by [41]	-26 %
3. Sex & multicellularity	1.23 by	1.0 – 1.2 by [42] [4]	-2.5 %
4. Teaching	264 my	(No accurate date known)	0
5. Using tools	56.6 my	(No accurate date known)	0
6. Making tools	12.1 my	(No accurate date known)	0
7. Tool-made tools	2.60 my	2.55 – 2.60 my [43]	0
8. Composite tools	556 ty	450 – 550 ty [23][24][25]	-1 % *
9. New inventions	118.8 ty	100 – 135 ty [28]	0
10. New livelihoods	25.3 ty	18 – 32 ty [29]	0
11. Writing	5.24 ty	4.6 – 5.4 ty (3400-2600 BCE) [37]	0
12. Printing	952 y	952 – 961 y (1039-1048 CE) [38]	0
13. Internet	33 y	33 y (1967 CE) [39]	0

Key: by = billion years, my = million years, ty = thousand years, y = years

Table 3. Predicted dates and matching evolution events. The predicted dates are at intervals that decrease by the factor 4.66920, the Feigenbaum Constant δ. Starting at the end, the interval between the last 2 events (Printing and Internet) is 919 years. The interval before that (between Writing and Printing) is 4.66920 x 919 years = 4291 years. The interval before that is 4.66920 times bigger again. And so on. Every interval is 4.66920 times bigger than the next. 3 events are assumed to be part of the series, for which we only have circumstantial evidence of the actual dates, namely: teaching, tool-use, and tool-making. Note that there is a large error at the beginning (start of the universe, and life), which converges quickly to the theoretical value. This convergence from a different interval is normal for period-doubling bifurcations.

* The -1% deviation is because the oldest composite tool found is dated to between 450,000 and 550,000 years old instead of the 556,000 years old predicted.

	Major innovation	Type of evolution	Search space and variation	Selection (of what to pass on) at increasing cognitive level	Inheritance mechanisms *
1	**Start of the universe**	Physical	All possible molecular structures by random movement	None (no life, no transmission)	None
2	**Single-celled life**	Biological	All possible DNA base pair sequences by random mutation	Surviving genomes (Natural Selection)	Cell binary fission
3	**Sex and Multi-cellularity**	Biological	All possible allele combinations by random recombination from 2 parents.	Mated genomes (Sexual Selection)	Fertilisation
4	**Teaching**	Culture-led	All possible behaviours by trial and error.	Selected skills (artificial selection)	Demonstration technique
5	**Using found tools**	Culture-led	All possible uses of found objects as tools by trial and error.	Selected found tools (artificial selection)	Tool transfer
6	**Making tools**	Culture-led	Reductive hand-made improvements on found tools by trial and error.	Selected made tools (artificial selection)	Referential Gestures
7	**Tool-made tools**	Culture-led	Reductive tool-made tool improvements by trial and error.	Selected tool-made tools (artificial selection)	"Tool-made tool language"
8	**Composite tools**	Culture-led	Composite tools by trial and error.	Selected composite tools (artificial selection)	"Composite tool language"
9	**New invent-ions**	Culture-led	Invention of new tools for new uses, by trial and error.	Selected inventions (artificial selection)	"Invention language"
10	**New livelihoods**	Culture-led	Improvements and changes in livelihood through creative thought, trial and error.	Skills for selected livelihood (artificial selection)	Complete language
11	**Information storage (writing)**	Info tech	Invention of hand-written contracts, laws, accounts, etc. useful for civilisation by thought, trial and error.	Selected hand-written documents (artificial selection)	Reading/ writing skills
12	**Information replication (printing)**	Info tech	Accurate replication of larger documents (e.g. books) to spread knowledge and ideas.	Selected educational books (artificial selection)	Printing machine technology
13	**Online information (Internet)**	Info tech	Internet information and other services.	Selected internet services (artificial selection)	Internet technology

Table 4. Generalised Darwinian processes. Different versions of the Generalised Darwinian process appear at each bifurcation predicted by the Feigenbaum constant Delta, with new search spaces, new sources of variation, new means of selection, and new means of inheritance. The culture-led stages also affect biological evolution as cultural and biological traits co-evolve.1

* **Inheritance Mechanisms.** When passing on something in the selected column, the inheritance mechanism to pass it on must also be passed on, including the inheritance mechanisms preceding it in the inheritance mechanisms column. (up to stage 9, after which division of labour appears and not everyone has to learn printing machine technology. Many inheritance mechanisms will have been genetically assimilated and become instinctive.

Date (Years ago, or Date)	Information Transfer Innovations (Mechanism)	New mechanism for inheritance becomes a primary means to push essential knowledge – such as biology, skills, or pure information – to future generations
13.8 billion	1. Start of universe	No inheritance mechanism
4.0 billion	2. Single-celled life	Yes (Cell binary fission)
1,1 billion	3. Sex & multicellularity	Yes (Meosis + fertilisation)
Unknown	Social learning/Imitation	Apparently developed as part of Life or Sex. No push.
Unknown	- Hormone communication.	Signals only. Not a means of inheriting information.
Unknown	- Auditory communication.	Signals only. Not a means of inheriting information.
Unknown	- Visual communication.	Signals only. Not a means of inheriting information.
Unknown	- Olfactory communication.	Signals only. Not a means of inheriting information.
Unknown	- Electrical communication.	Signals only. Not a means of inheriting information.
Unknown	- Touch communication.	Signals only. Not a means of inheriting information.
Unknown	- Seismic communication.	Signals only. Not a means of inheriting information.
Unknown	- Thermal communication.	Signals only. Not a means of inheriting information.
264 million	4. Teaching	Yes (Demonstration)
56.6 million	5. Using tools	Yes (Tool Transfer)
12.1 million	6. Making tools	Yes (Referential gestures)
2.60 million	7. Making tools with tools	(Hypothesis needs new inheritance mechanism here.)
556,000	8. Making composite tools	(Hypothesis needs new inheritance mechanism here.)
118,800	9. New inventions	(Hypothesis needs new inheritance mechanism here.)
44,000	Cave paintings	Ambiguous to interpret without text.
Unknown	Music/Singing	Never became a primary source of information
25,300	10. New Livelihoods	Yes (Full language)
Unknown	Drawings, Pictures	Ambiguous to interpret without text.
5,240	11. Information storage	Yes (Writing)
Unknown	Courier/postal service	Never became a primary source of information
1800 BCE	Remote visual signalling (Nuragic towers)	Never became a primary source of information
800 BCE	Smoke signals	Never became a primary source of information
952 ya	12. Information replication	Yes (Printing)
1609 CE	Printed Newspapers	Not a new technology – a form of printing
1792 CE	Semaphore Telegraph	Never became a primary source of information
1822 CE	Photography	Useful complement to text, ambiguous to interpret alone
1830 CE	Cinema	Highly centralised – not free communication
1843 CE	Fax	Never became a primary source of information
1876 CE	Telephone	Never became a primary source of information
1877 CE	Sound recording	Never became a primary source of information
1888 CE	Radio transmission	Highly centralised – not free communication
1926 CE	Telex	Never became a primary source of information
1926 CE	TV transmission	Highly centralised – not free communication
1967 CE	13. Online information	Yes (Computer networks/Internet)
Early 1970s CE	Teletext	Never became a primary source of information
1971 CE	Internet email	For messaging – not a primary source of information
1989 CE	World Wide Web	Not strictly new. A hypertext app for the Internet.
1995 CE	Smartphone	Not original, a portable form of Internet terminal

Table 5. List of evolutionary changes (source Wikipedia [44][45]) that produced new forms of information transfer, indicating which were a) part of a new Generalised Darwinian process and were used as a new mechanism for inheritance as a primary means to push essential knowledge – such as biology, skills, or pure information – to future generations (marked in green), and b) were not.

Green – Generalised Darwinian process, White – not Darwinian

Stages	Stage at maturity, ready for the next Generalized Darwinian Process
1. Universe	Complex molecular processes
2. Self-replicating Life	Complex single cells
3. Sex and multicellularity	Sentient multicellular animals with learning abilities
4. Teaching by demonstration	Established culture of trying new behaviours
5. Finding and using tools	Established tool-using skills
6. Making tools	Established tool-making skills
7. Making objects with tools	Established skills at making objects with tools
8. Composite tools and assembly	Established composite tool skills
9. New inventions	Established invention culture
10. New livelihoods, language	Organisational skills, labour specialisation, civilisation
11. Writing/ Handwritten works	Established use of documents
12. Printing/ Printed matter	Widespread literacy and science
13. Internet	

Table 6. The mature state of each stage serves as a basis for the next stage.

Event number	Year of Event	Interval until Next Event
13 (The Internet)	1967	197 years
14	2164	42.2 years
15	2206	9.03 years
16	2215	1.93 years
17	2217	0.41 years
18	2217	32 days
19	2217	6.9 days
20	2217	1.47 days
21	2217	7.56 hours
22	2217	1.61 hours
23	2217	20.8 mins
24	2217	4.45 mins
25	2217	57.2 secs
26	2217	12.2 secs
27	2217	2.62 secs
28	2217	0.56 secs
(Infinite number of events here)		(Intervals approach 0)
∞	2217	Accumulation Point
(Post-bifurcation stage)	2217 onwards	Chaotic zone

Table 7. Predicted future events, with intervals and dates. The intervals are easy calculated by dividing the previous interval by the Feigenbaum Constant 4.66920. The years stated may not be exact - they are based on the date of the invention of the computer network (Internet).

10. Figures

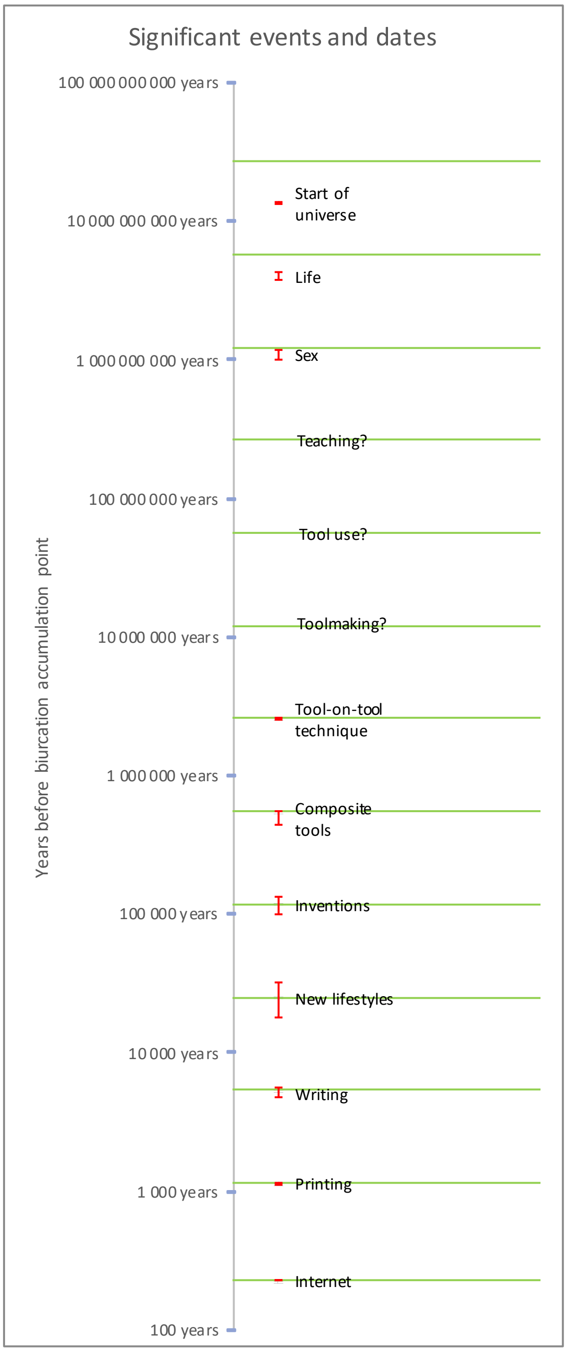
958 
Significant events and dates
Years before biurcation accumulation point
100 000 000 000 years
10 000 000 000 years
1 000 000 000 years
100 000 000 years
10 000 000 years
1 000 000 years
100 000 years
10 000 years
1 000 years
100 years
Start of universe
Life
Sex
Teaching?
Tool use?
Toolmaking?
Tool-on-tool technique
Composite tools
Inventions
New lifestyles
Writing
Printing
Internet

Figure 1. Events in evolution shown on a logarithmic time scale (measured from the Accumulation Point, where the sequence converges around the year 2217). Green lines are the dates predicted by the Feigenbaum Constant delta (= 4.66920…). The accuracy of known dates is shown by the red error bars which show the margin of error. Dates for Teaching, Tool use, and Tool-making are not known, but there is circumstantial evidence for their approximate position on the timeline. The other dates match the predicted dates within the margin of error (the green lines fall within the red lines), except for the first two dates. However, in chaos theory it is the rule rather than the exception that initial interval ratios do not match the Feigenbaum constant delta, but do rapidly converge to it, which is exactly what we see here.

Figure 2. The Mandelbrot set, which is a bifurcation diagram shown from "above" in the complex number plane. (Image by Georg-Johann Lay, public domain)

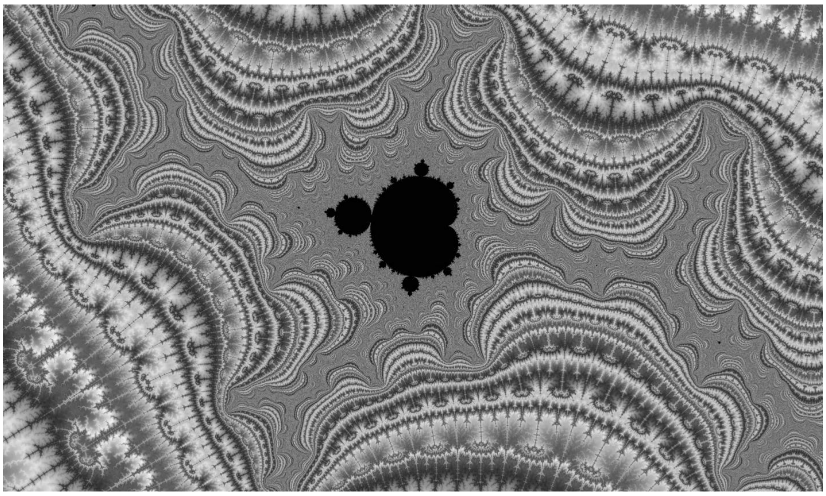


Figure 3. This mini-Mandelbrot set – of which there are an infinite number, in various sizes – is part of the detail of the Mandelbrot set. It is an example of self-similarity which is often found in iterated systems. It is analogous to generalised Darwinian processes providing alternative evolutionary paths. The Mandelbrot image is slightly asymmetrical. (This image by newbedev.com is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.)

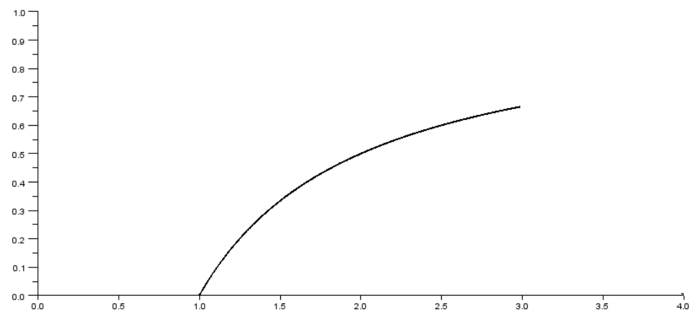


Figure 4. The population diagram shows the attractor for the population of a species for different levels of birth rate. If the species has a low birth rate, the population will not be sustainable and will die out to zero. For sustainable birth rates, the population equilibrium increases with birth rate. (Diagram adapted from an original Feigenbaum diagram by Basti Schneider, licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.)

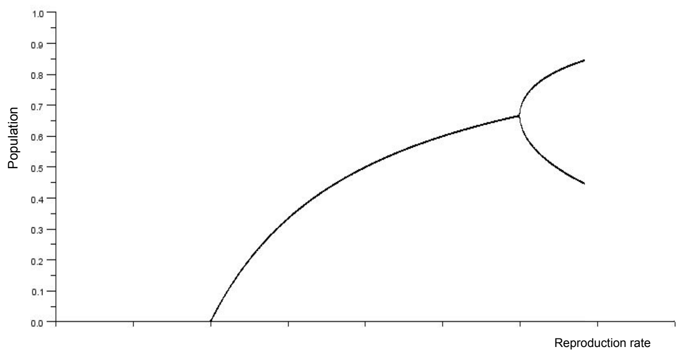


Figure 5. For still higher birth rates, the population is unstable. Note that the birth rate of a species does not normally change, so we are talking about different species. This could be, for example, because the species is too efficient for the ecosystem and eats too much, meaning there is not enough food for it the year after. The year after, the population of the species drops to a lower value. The food available recovers and the next year is back to normal. The cycle repeats and the species eats too much again. The population will in time settle down to a pattern where it oscillates between two values. s increases a bifurcation occurs, after which the population oscillates between 2 values. This is called a bifurcation. (Diagram adapted from an original Feigenbaum diagram by Basti Schneider, licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.)

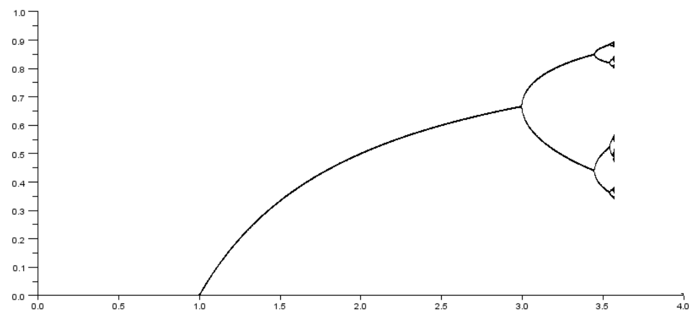


Figure 6. For other species with still higher birth rates, the population curve bifurcates again and again. The population level oscillates between 4 values, or 8 levels, and so on. (known as "period-doubling".) The birth rate interval between the bifurcations gets smaller and smaller by a factor which converges to 4.66920…, which is called the Feigenbaum constant delta. The intervals decrease to zero at the so-called Accumulation Point, at birth rate of around 3.6 on the x-axis. (Diagram adapted from an original Feigenbaum diagram by Basti Schneider, licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.)

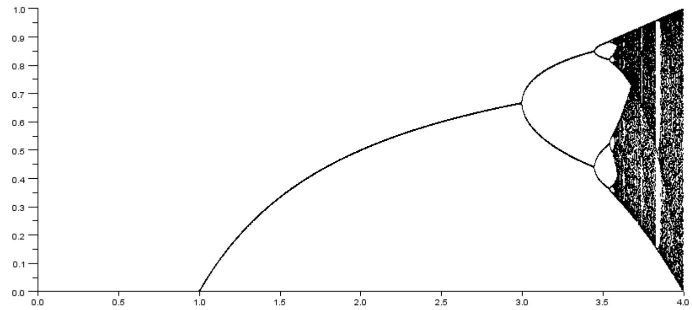


Figure 7. For still higher birth rates beyond the Accumulation Point the pattern becomes chaotic. (Diagram adapted from an original Feigenbaum diagram by Basti Schneider, licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.)

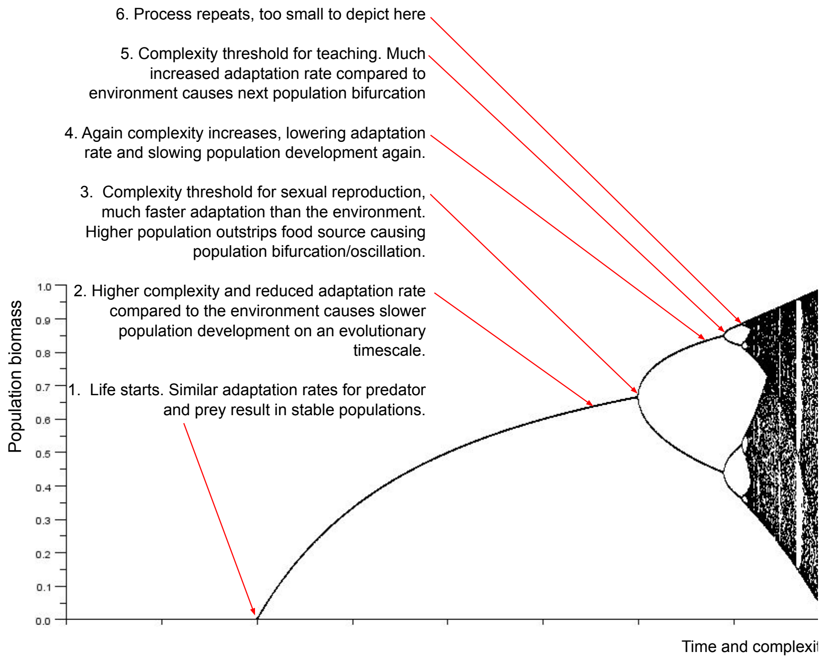


Figure 8. Suggested mechanism for population bifurcations in evolution. The curve represents all the species that at any one time are at the leading edge of evolution. The x-axis represents time, starting at the Big Bang. At each bifurcation the population increases rapidly, then more slowly as the "cost of complexity" reduces the adaptation rate as complexity increases. When a new generalised Darwinian process begins, the adaptation rate increases, causing overconsumption and a population bifurcation. (Diagram adapted from an original Feigenbaum diagram by Basti Schneider, licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.)