Article

A Predictable Pattern of Shortcuts in Evolution

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Abstract: The concept of cosmic evolution expands the concept of evolution of humans from purely biological evolution to include the evolution of stars and planet Earth and complex prebiotic molecules, and also the cultural evolution, or technological development, of humans to the present day. The pattern of period-doubling systems, where intervals between successive bifurcations shortens by a factor equal to 4.66920… (the Feigenbaum Constant δ) appears to match known events in evolution that coincide in time with new methods of passing on information. These advances seem to coincide with innovatory shortcuts, speeding up evolution. This paper presents a speculative conjecture of a new law or principle of evolution, unifying the stages of the development of intelligent life.

Keywords: evolution; cosmic evolution; self-organising systems; complexity; period-doubling systems; Feigenbaum Constant

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1. Introduction

The concept of cosmic evolution expands the concept of evolution of humans from purely biological evolution to include the evolution of stars and planet Earth and complex prebiotic molecules, and also cultural evolution, or technological development, of humans to the present day [1]. Astrophysicist E.J. Chaisson points out similarities between all stages of cosmic evolution, being all examples of self-organising systems of increasing complexity driven by flows of energy, and suggests that there may be a unifying law or principle that can explain all three. This paper proposes such a universal law.

2. Information Transfer

According to the concept of Cosmic Evolution, there are three kinds of evolution: physical, biological, and cultural.

1. **Physical evolution** started at the beginning of the universe and involved the creation of basic particles, then stars, then elements which spontaneously joined together in ever more complex molecular structures. Eventually some of these molecules became self-replicating and later became incorporated into the first self-replicating cells [3] [4].
2. **Biological evolution** is based on cells which contain information – in the form of DNA – which is used to make the proteins that cell needs. There is also a mechanism for making copies of the DNA. The cells multiply by growing larger and dividing into two cells, and the DNA is passed on to both cells. Cells evolve when the DNA mutates, changing the traits (physical form and behaviour) of the cell.
3. **Cultural evolution** is what we have today, where instead of passing on information via DNA, we pass it on to each other and to future generations by spoken or written word. This can include useful information about what behaviour to adopt to prosper in the world, in the same way that DNA contains useful information about how create an organism with the combination of traits (physical form and behaviour) to survive and prosper. The advantage of cultural evolution is that we don't have to wait to evolve biologically, which is much slower. Knowledge is the DNA of our society.

So we have 3 forms of evolution, and, at least in the last two - biological and cultural evolution – the passing on of information is essential.

2.1. DNA enabling Self-Replicating Cells

If we look at the first living cells, we have noted that there is information transfer in the form of DNA (or something similar). But there is another, more important innovation in living cells, namely the cell's ability to self-replicate. Soon after the first cell evolved and divided into two, both of these cells could also grow and divide and very soon there could have been millions of identical cells. With many copies of a cell, evolution could proceed in parallel, with many cells mutating in different ways at the same time. In this way, cell division acted as a kind of shortcut in evolution.

But the self-replicating cells needed DNA. DNA worked as a blueprint for the cell, containing instructions on how the cell can grow by manufacturing things needed by the cell, and also how the cell can divide into two cells which are both identical to the original cell. Each cell has many copies of the DNA, so that when the cell divides, both resulting cells contain the DNA. (This is a sharing of DNA rather than a transfer, but it is equivalent to DNA transfer if we arbitrarily designate one of the cells as the original cell and the other cell as the new cell.)

The main point here is that as each new cell is created, it needs a copy of the DNA instructions in order to function. In other words the information transfer innovation *enables* the shortcut innovation.

1) **Evolutionary shortcut:** Self-Replication.
2) **New way to transfer information to enable the shortcut:** DNA.

(One could argue that the passing on of DNA is part of the process of self-replication and not a separate innovation. The counter-argument would be that perhaps it does not matter whether there are two separate innovations or whether they are two aspects of the same innovation, as long as both aspects are present.)

2.2. Sexual Reproduction enabling Trait Accumulation

For the next 3 billion years, cells evolved. But they still self-replicated and passed on DNA to new cells in the same way. The sexual reproduction was invented. This turned out to be a new shortcut in evolution.

With self-replication, cells could evolve, but it took a long time. Suppose a cell acquires a mutation that gives the cell a useful trait, that we can call trait "A"). It passes on this mutation to its offspring when it self-replicates.

Suppose now that another cell acquires a different mutation giving it useful trait "B".

Now what are the chances of a cell getting both of these useful traits, "A" and "B"? The answer is, very low. Because there is no way for the trait "A" mutation to transfer to a cell that has the trait "B" mutation, or vice versa. So cells with trait "A" will need to wait for trait "B" to arise by mutation, which can take a very long time.

This is where sex comes in. Sexual reproduction is way of collecting good mutations into a single cell. Two parent cells (for example, one parent with trait "A" and one parent with trait "B") come together and each produce a *gamete* cell (for example, an egg or a sperm). The gametes from each parent cell fuse to produce an offspring cell (for example, a fertilised egg) which has some DNA from both parents. All things being equal, the chances of the offspring having both "A" and "B" mutations is one in four.

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

As with the first living cells, this change also involves a *new* way of passing on information. The information transfer innovation with sex is that a cell does not pass on all of its DNA but instead contributes only half a set of DNA to the gamete, so that when two gametes fuse to a single offspring cell, it will have a full set of DNA.

Again we have a *new* way of passing on information enabling an evolutionary shortcut:

1) **Evolutionary shortcut:** Trait Accumulation.

2) **New way to transfer information to enable the shortcut:** Sexual Reproduction.

(As in the case of life, the two innovations are two aspects of one process: in this case, taking some DNA from each parent.)

2.2.1 Multicellularity

It is relevant here to mention that sexual reproduction probably gave rise to complex multicellularity, i.e. collections of differentiated cells, or, in other words, plants and animals.

Simple multicellularity (collections of identical cells) existed before sexual reproduction, but there are theoretical arguments that complex multicellularity is unviable without sex. If this the case, then sexual reproduction may well have enabled complex multicellularity and complex multicellularity would have appeared at the same time as sexual reproduction. Evidence of this can be found in red algae in 1.2 billion year old rocks [6]. If this is the case, then the advent of sexual reproduction and complex multicellularity could be seen as different aspects of the same event.

2.3. Animal Teaching enables Advanced Learned Behaviour

Cultural evolution actually gives back before language and before humans. First there was the phenomenon of *social learning* 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 [7] and it covers a whole spectrum of behaviours. For example, the fact new-born rats respond positively to foods that the mother ate during pregnancy is counted as social learning [8]. There is even evidence of learning behaviour in prokaryote cells [9]. So social learning may be an inherent feature of animal or even cellular life that evolved as animals or cells evolved, learning about other members of their own species at the same time as learning about everything else in their environment. In that case, the beginning of learning may count as part of the same event as the first life, or sexual reproduction.

But something that may have arisen as a separate innovation event is Animal Teaching. 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. For example, meerkats teach their young how eat scorpions by giving them dead or disabled scorpions [10]. The young meerkats learn by imitation or emulation, and the knowledge gets passed on, again shortcutting the biological genetic route for the passing on of knowledge. So Animal Teaching would seem to count as a new way of passing on information.

But if animal teaching is passing on information, what information is being passed on? There may be some behaviours which are very useful, but are not passed in by social learning alone 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 DNA mutation, which takes a very long time.

So we have:

1) **Evolutionary shortcut:** Advanced learned behaviour.
2) **New way to transfer information to enable the shortcut:** Animal Teaching

2.4. Writing enables the Recording of Information

We know very little about the evolution of spoken language, but we do know a lot about written language. Much information is today passed on by the written word. The first writing was called Cuneiform and it was developed as a means to record trade, debt, and tax information [11]. It also enabled social elites to preserve their religious knowledge, literature, and medical texts. This is another evolutionary shortcut. Without the aid of writing, humans would have had to evolve extraordinary memory abilities which, even if possible, would take a very long time.

The two events we see here are:

1) **Evolutionary shortcut:** Recording of Knowledge.

2) **New way to transfer information to enable the shortcut**: Writing.

2.7. Movable Type Printing enables Democratisation of Knowledge (1039-1048 CE)

Another important event in the transfer of information that happened since writing was invented was the invention of the printing machine. To be more precise, the invention of movable type printing in 1039-1048 CE [12]. 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. However, the Eurocentric view of scientific development has been challenged by historian Joseph Needham and it appears that China was ahead of Europe scientifically until the 13th and 14th centuries, at which point Europe began to catch up and take the lead [13]. 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.)

If evolution is about passing on information, the printing machine was the machine to do it. Before printing, books were copied by hand, which made them very expensive and mainly owned by wealthy establishments such as religious authorities.

Printing democratised knowledge, putting into the hands of many more people. Science and mathematics, which were revolutionized 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. The changes in society amounted to another evolutionary shortcut.

The two events we see here are:

1) **Evolutionary shortcut:** Democratisation of Knowledge
2) **New way to transfer information to enable the shortcut**: Movable Type Printing Machine

2.6. The Internet enables Instant Global Knowledge Access (1967 CE)

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 allows 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 different ways.

The two events we see here are:

1) **Evolutionary shortcut:** Instant Global Knowledge Access.
2) **New way to transfer information to enable the shortcut**: The Internet.

In this case, Instant Global Knowledge Access is the application, whereas the Internet and its associated technologies are the technology used to implement it.

2.9. Summary of Innovations in information transfer

The list of information transfer innovations we have identified so far (plus the beginning of the universe) is shown in table 1.

Information Transfer Innovations	Years before 2000
i) Beginning of the universe	13.820 - 13.778 billion years [14]
ii) Inheriting DNA via cell replication	4.28 - 3.77 billion years [15]
iii) Recombining DNA via sexual reproduction	1.2 - 1.0 billion years [16] [6]
iv) Animal Teaching	unknown
v) Cultural transfer through speech	unknown
vi) Cultural transfer through writing	5,400-4,600 years (3400-2600 BCE) [17]
vii) Cultural transfer through printing	961-952years (1039-1048 CE) [12]
viii) Cultural transfer through Internet	33 years (1967 CE) [18]

Table 1. Events and dates

We don't know the dates of the events that don't leave any fossil or archaeological record, at least not directly: namely Animal Teaching, and the development of spoken language. Neither do we know if we have identified all information transfer innovations.

3. Innovations in information transfer

If, as E.J. Chaisson suggests, there is to be found a law or principle to unify the different types of evolution, perhaps we should try to look for a pattern. What sort of pattern would we want? Looking at the list, it is apparent that the interval between the events gets shorter and shorter. For instance, taking the last two intervals in our list (the interval between *vi* and *vii*, and the interval between *vii* and *viii*), the interval decreases by a factor of between 3.9 and 4.8 depending on which dates are used within the range of error.

E.J. Chaisson mentions bifurcations, which brings to mind the pattern of bifurcations in period-doubling systems, which also get shorter and shorter. The remarkable thing about period-doubling systems is that the interval between bifurcations decreases by a factor that always converges to the same number. This number is called the Feigenbaum Constant δ and is equal to 4.66920…, which lies within the range we see for the decrease factor for the last two intervals in our list, 3.9 to 4.8.

The period-doubling phenomenon is found in all kinds of scenarios, such as the growing of citrus fruit, the firing of neuron networks, and in abnormal cardiac rhythms. But can the evolution of life be such a period-doubling system? Biological systems do exhibit period-doubling bifurcations (PDB) in various circumstances, and bifurcations are associated with a sudden increase in complexity manifested in the appearance of new structures. There is a possibility that these new structures correspond to artefacts arising from new modes of transfer of information.

What happens if we try to match our information transfer dates to the Feigenbaum ratio 4.66920?

3.2. Calculation of predicted dates

The predicted age of each event is calculated from the two most accurately known dates, namely the last two events: the first prototype of the network technology used in the Internet in 1967; and the printing machine in 1039-1048 CE. Both dates - 1039 and 1045 - give effectively the same results, but 1048 is used here because it gives a slightly better fit to other known dates in evolution.

$$\text{Theoretical Age of event n, } A_n = A_{n+1} + 4.66920 \times (A_{n+1} - A_{n+2}) \quad (2)$$

Starting values:

- Age of the Computer Network in 2000, $A_{12} = 2000 - 1967 = 33$ years
- Age of the Printing Machine in 2000, $A_{11} = 2000 - 1048 = 952$ years

Figure 1 shows the result.

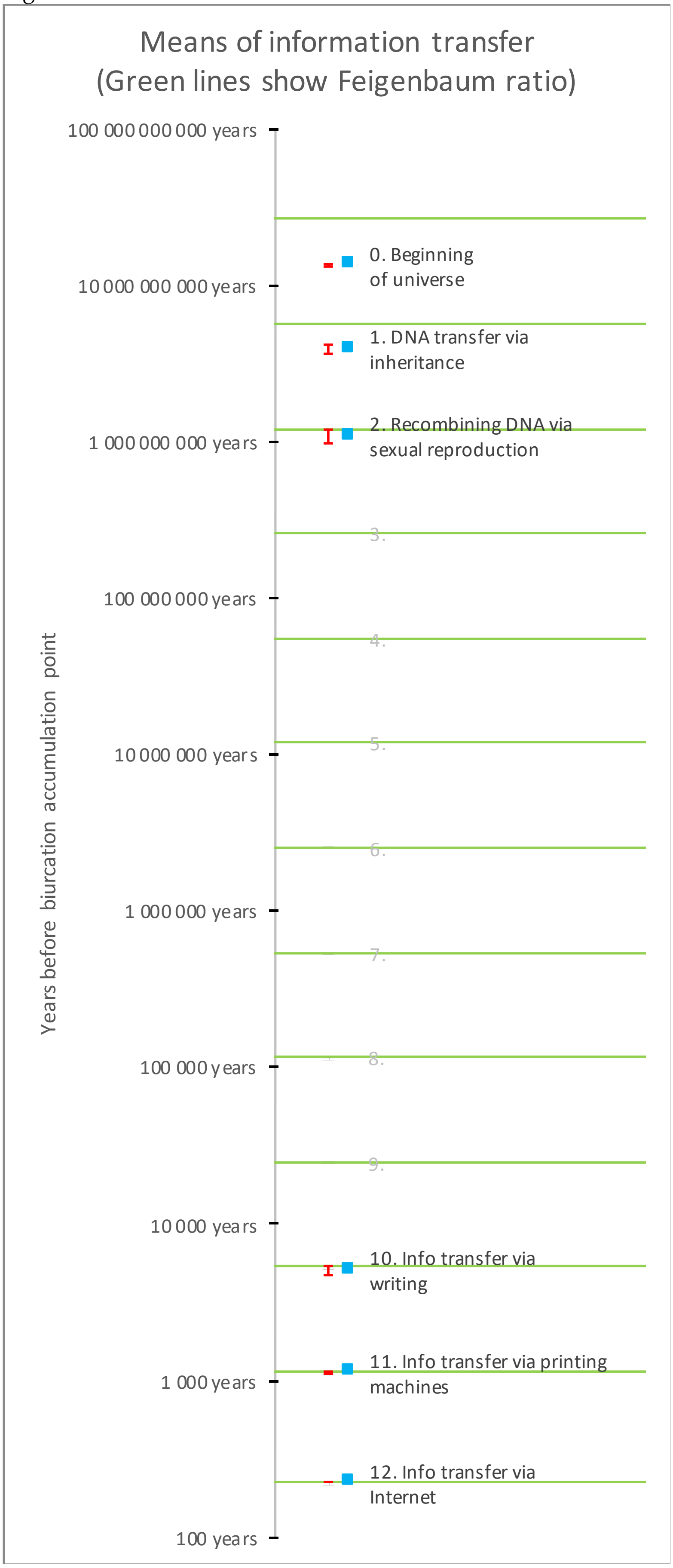

Figure 1. Events with known dates superimposed on a grid (the green lines) representing the Feigenbaum ratio 4.66920. The graph uses a logarithmic scale so that constantly decreasing intervals of the Feigenbaum ratio are all stretched to the same length. The number of years is relative to the bifurcation accumulation point, which for this series is the year 2217. The red marks are error bars showing the uncertainty in known dates.

3.2. The pattern fits?

Figure 1 shows a pattern that results from fitting those events from our list that have known dates to the pattern of the Feigenbaum ratio. The diagram uses an expanding logarithmic scale so that constantly decreasing intervals of the Feigenbaum ratio are all expanded to the same length. The distance between the green horizontal lines represents the Feigenbaum Constant 4.66920. We can note the following points:

- The last three events fit conform to the Feigenbaum ratio.
- Event 2 (Information transfer via sexual reproduction) is very close to the pattern.
- Events 0 and 1 (beginning of the universe, and self-replicating cells) don't match the grid (the green Feigenbaum lines). This is actually standard behaviour for period-doubling bifurcations. In most period-doubling systems the ratio starts off with a different value, but rapidly converges to the Feigenbaum Constant. That is exactly what we see happening here. By event 2 we are close to the grid and will stay close to the grid if it is a normal case.
- We have seven empty positions in the middle. But we can try and fit other events to the dates given by the Feigenbaum ratio.

3.3. Predicted Events

The Feigenbaum ratio suggests that there are seven significant dates. These are shown in table 2 together with significant evolutionary events close to the predicted dates.

	Date predicted by PDB pattern (years before 2000)	Closest events to predicted age and their possible significance (years before 2000)	Difference between known and predicted age
3	264 million years	260 million years. Cynodonts (mammal precursors) [19]. Animal Teaching?	+1.5%
4	56.6 million years	60 million years. Earliest Monkeys [20]. Tool use?	0
5	12.1 million years	11.9 million years. Earliest Great Apes [21]. Tool-making?	0
6	2.60 million years	2.60 - 2.55 million years. Freehand technique for using a tool to make another tool [22]	0
7	556,000 years	500,000 years. Composite tools [23]	+11.1%
8	119,000 years	135,000 - 100,000 years. First new invention: bead jewellery [24].	0
9	25,300 years	32,000 - 18,000 years. First domestication (the dog) [25].	0

Table 2. Additional events which correspond to the dates suggested by the PDB pattern. The initial deviation from the Feigenbaum constant for the first few events is normal for bifurcations in period-doubling systems. The percentage differences between ages of predicted and actual dates are measured from the Accumulation Point, estimated to be in 2217.

4.1. Event dated 264 million years ago. Animal Teaching?

This 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 [26]. Some cynodonts were mammals, and modern mammals have been observed teaching their young [10]. Parental care is thought to date back even further to 520 million years ago [27], but that is not the same as parental teaching. This date of the first animal teaching is not known but that it should have happened 264 million years ago with the cynodonts or their immediate ancestors is not implausible.

4.2. Event dated 57 million years ago. Teaching of Tool Use?

The use of tools is undoubtedly important in evolution. A tool is, in effect, an addition to the body. It instantly extends the body without having to wait for biological evolution [28]. 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.

57 million years ago is the time of the first higher primates or monkeys. Monkeys use tools today [29], and it is not implausible to suggest that they were the first to use tools 57 million years ago. For it to be a valid event for our purposes, it needs to be a new way of teaching.

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 [30]. While they are learning, young chimpanzees are allowed to use their mother's tools. This is called "tool transfer" and on its own it fulfils all the criteria to qualify as teaching [31]. This clearly a new form of teaching, because tools did not previously exist.

The two events we see here are:

1) **Evolutionary shortcut:** Tool Use.
2) **New way to transfer information to enable the shortcut**: Tool Transfer.

In this case, the two events are related but clearly separate, as Tool Use does not involve Tool Transfer once it is learned.

4.3. Event dated 12.1 million years ago. Teaching Tool-making?

This is the time of the first great apes or hominids. Great apes have been observed making tools [32]. If teaching tool use is a significant new way to pass on information, then perhaps teaching toolmaking is too. Teaching the making of tools is a three-part process, usually in the following sequence: 1) Demonstration of how to use the tool; 2) Repeated tool transfer until the tool use is mastered; 3) Demonstration of how to make the tool [33]. Whether this qualifies as a new way to transfer information has not been established.

The two events we see here are:

1) **Evolutionary shortcut:** Making Tools
2) **New way to transfer information to enable the shortcut**: Teaching Tool-Making

4.4. Possible new levels of language?

We believe that language developed at some time during the period when the next 4 events occurred. We know that language developed after the making of tools, because the animals that make tools today do not have any significant form of language. We know that language had already developed the time Writing was invented. But 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 Upper Palaeolithic Revolution [35]. The PDB pattern suggests that that there are four important events during this period, and it is not impossible that there were up to four levels of language that evolve step-wise. Each new level of language would ideally represent a new level of information than can be transferred to other individuals, and thus qualify as a new means of transferring information. We are talking about the development of spoken language, but it is possible that the earlier forms of language could be gestural, or a mixture of spoken and gestural language. We can call these languages Language I, II, III, and IV, where Language I may be entirely or partly gestural, and the rest spoken.

At this stage in evolution, language development co-evolved with both tool use and brain size [36].

4.5. Event dated 2.6 million years ago. Language I in Teaching enables Freehand Tool Technique?

This is 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 [37]. But the Freehand Knapping technique marks a significant advance.

A tool is an extension to 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 [28]. (We modern humans are used to doing this, but to a hominin that has not done it before, it may be a bit like learning to cut your hair in the mirror.)

With the Freehand Knapping technique, a stone is held in each hand, without the support of an anvil stone, and one stone is hit with the other to break off flakes. In this situation, both stones are effectively being used as tools. The working tip of the one stone (the "hammerstone") is used to hit a specific place (effectively the working tip) of the other stone (the "core"). Without external support, the movement of each hand has to be coordinated with the other hand.

This is the first time that coordinated use of two tools together is used, and although it required greater dexterity, early humans obviously found that it gave better results, because they used it from then onwards. The freehand technique gives greater control over the resulting flakes, 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 [38].) Freehand required improved perceptual abilities, learning capacities and bimanual dexterity compared with the bipolar technique [39]. The improved control given by the freehand technique eventually led to very finely made stone tools, and was a large contribution to the dexterity we have today as a species.

Experiments have shown that teaching modern humans the freehand flaking technique is more effective if gestures (which are a form of language) or spoken language are used during teaching [40]. So it may be that some form of language had evolved which enabled hominins to teach this technique to others. 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 co-operation and communication, and that they may have developed gesture as a means of communication [41].

The two events we see here are:

1) **Evolutionary shortcut:** Freehand Technique for Maximum Dexterity.
2) **New way to transfer information to enable the shortcut**: Language I (perhaps Gesture) used in Teaching.

4.6. Event dated 556,000 years ago. Language II in Teaching enables the Making of Composite Tools?

The prime candidate for this event is the earliest known stone-tipped spear from 500,000 years ago [23]. This is slightly less old than predicted by the Feigenbaum Constant, but it is possible that spears existed earlier and have not yet been found. 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 by 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.

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.

The two events we see here are:

1) **Evolutionary shortcut:** Composite tools
2) **New way to transfer information to enable the shortcut**: Language II used in Teaching.

4.7. Event dated 119,000 years ago. Language III in Teaching enables the spread of new inventions?

Boats, clothes, beads, harpoons, sewing needles, mortars and pestles, cloth, flutes, rope, pottery. These are just some of the things that humans started making 119,000 years ago. And that was just the beginning. It seems as though humans were suddenly hit with an 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 basically twigs and sharp sticks that were originally found lying around. The pinnacle of human technology - the stone-tipped spear - was a just superior version of a sharp stick they had been using for probably tens of millions of years.

New inventions are considered to be associated with the Upper Palaeolithic Revolution [42], but the first inventions came earlier and the archaeological record (the objects above) agrees with the pattern-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, perhaps the result of crossing a new cognitive threshold. These new inventions would also possibly require new cognitive abilities to use and to explain to others, and would also be likely to be associated with new language abilities. A significant change in language associated with the Upper Palaeolithic Revolution has been proposed [35].

Of the earliest inventions here I will use the date of the first bead necklace (135,000-100,000 years [24]) for this event, because the evidence for the other earliest inventions - boats and clothes - is circumstantial and without actual artefacts.

The two events we see here are:

1) **Evolutionary shortcut:** Era of New Inventions
2) **New way to transfer information to enable the shortcut**: Language III used in Teaching.

4.8. Event dated 24,900 years ago. Language IV in Teaching enables New Lifestyles?

The Neolithic Revolution supposedly began 12,000 years ago with the domestication of sheep and various plants and led to the first agricultural civilisations. But the date predicted by the PDB pattern is 24,900 years ago. Indeed, the first animal to be domesticated was the dog (32,000 - 18,000 years [25]) and dogs appear to have been an integral part of the Neolithic revolution [43]. It is believed that humans and dogs worked in a mutually beneficial partnership, initially in hunting [44], but later with herding. This partnership may have been important in the move away from hunting, scavenging and gathering, to organising new lifestyles leading to agriculture and civilisation.

This event also seems to have come from crossing a cognitive threshold that may have been associated with an advance in language. It seems to have enabled a capacity for inventing new lifestyles. Communication must have been important to make these new lifestyles work. At some point language seems have given humans to the capacity for logical reasoning and problem-solving. We know from experiments that some kinds of problems can only be solved with the aid of language [45]. Certainly, some kind of logical reasoning and problem-solving ability must have been necessary for humans to abandon 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 division of labour.

The two events we see here are:

1) **Evolutionary shortcut:** Era of New Lifestyles
2) **New way to transfer information to enable the shortcut**: Language IV used in Teaching.

4.9. List of shortcuts

Table 3 shows the shortcuts.

Information transfer innovation	The shortcut enabled by the info transfer	What does this shortcut replace?	End result (just before the next information transfer innovation)
Beginning of universe	(nothing)	(nothing)	Complex molecules
DNA	Self-Replication	Waiting for every living cell to evolve separately	Complex self-replicating cells
Sexual Reproduction	Trait Accumulation	Waiting for a beneficial mutation.	Multicellular life (animals & plants)
Animal Teaching	Advanced learned behaviour	Waiting to acquire successful behaviour via DNA.	Good teaching & learning ability
Teaching & tool transfer.	Find an object and use it as a tool (extension of the body)	Waiting to acquire useful physical trait via DNA	Good tool-use ability
New form of teaching?	Making tools	Waiting to find a useful tool.	Good tool-making ability
Freehand tool-on-tool technique	Hold tool and object freely in each hand for maximum control	Waiting for good results from poorly-controlled anvil-based technique	Freehand tool-on-tool technique for maximum dexterity.
Composite tools	Combine materials	Waiting to find ideal raw material	Concept of parts and assembly.
Era of inventions	Invent new tools	Waiting to find new kinds of tools	Inventions.
Lifestyle changes	Invent and organise new lifestyles.	Waiting for better times	Lifestyle change leading to agricultural civilisation.
Writing	Accurate recording of information.	Waiting to teach important information to others	Record of important information.
Printing	Democratisation of knowledge	Waiting to hand-copy important documents	Books. Widespread education.
Internet	Instant Global Knowledge Access	Waiting to find relevant information	(not yet known)

Table 3. Evolutionary shortcuts

4.10. Co-evolution

During this period of language development, we suspect that there is co-evolution of language, tool skills, and biological evolution of the body, and in particular the size of the brain. But the emergence of Australopithecus garhi, Homo heidelbergensis and Homo sapiens occurs not at the events described, but in between the events. It seems that what may have happened is that the bifurcations cause an innovation which then creates an evolutionary pressure that favours the development of certain features, primarily larger brain size, in order to fully take advantage of the innovation. The change is consolidated, setting the stage for the next innovation.

5. What do these results tell us?

From the above, we can possibly draw the following conclusions:

- Evolution is punctuated by **Evolutionary Shortcut** events, which occur *simultaneously with and are enabled by* **Information Transfer Innovations**.

- The importance of information transfer is that if an innovation evolves within a living individual, but the information needed to reproduce it cannot be passed on to other individuals, then the innovation will die with the originator.

- We can identify which evolutionary events are shortcut events because they coincide with a new form of information transfer. If an event does not coincide with a new form of information transfer, then it is not a shortcut event.

- These events (all new forms of information transfer, and their associated shortcut events) all seem to occur at predetermined times that are consistent with the PDB (Period Doubling Bifurcation) pattern and the Feigenbaum Constant 4.6692.

- Sometimes the shortcut and the information transfer seem to be different aspects of the same change, sometimes they appear to be separate. (This may be a question of how we perceive them. There may be an underlying order that we do not see.)

5.1. Other innovations in transferring information

As well as the events we have considered, a number of other new means of communication have arisen in evolution too. These should be evaluated to verify that they are *not* new ways to pass on information. These are discussed in Appendix A.

5.2. Have we missed any other events?

There are other events which are not included in the pattern, and this exclusion must of course be justified. If there is a single event that does not match the pattern, then the pattern is not valid. A number of possible events are discussed in Appendix B.

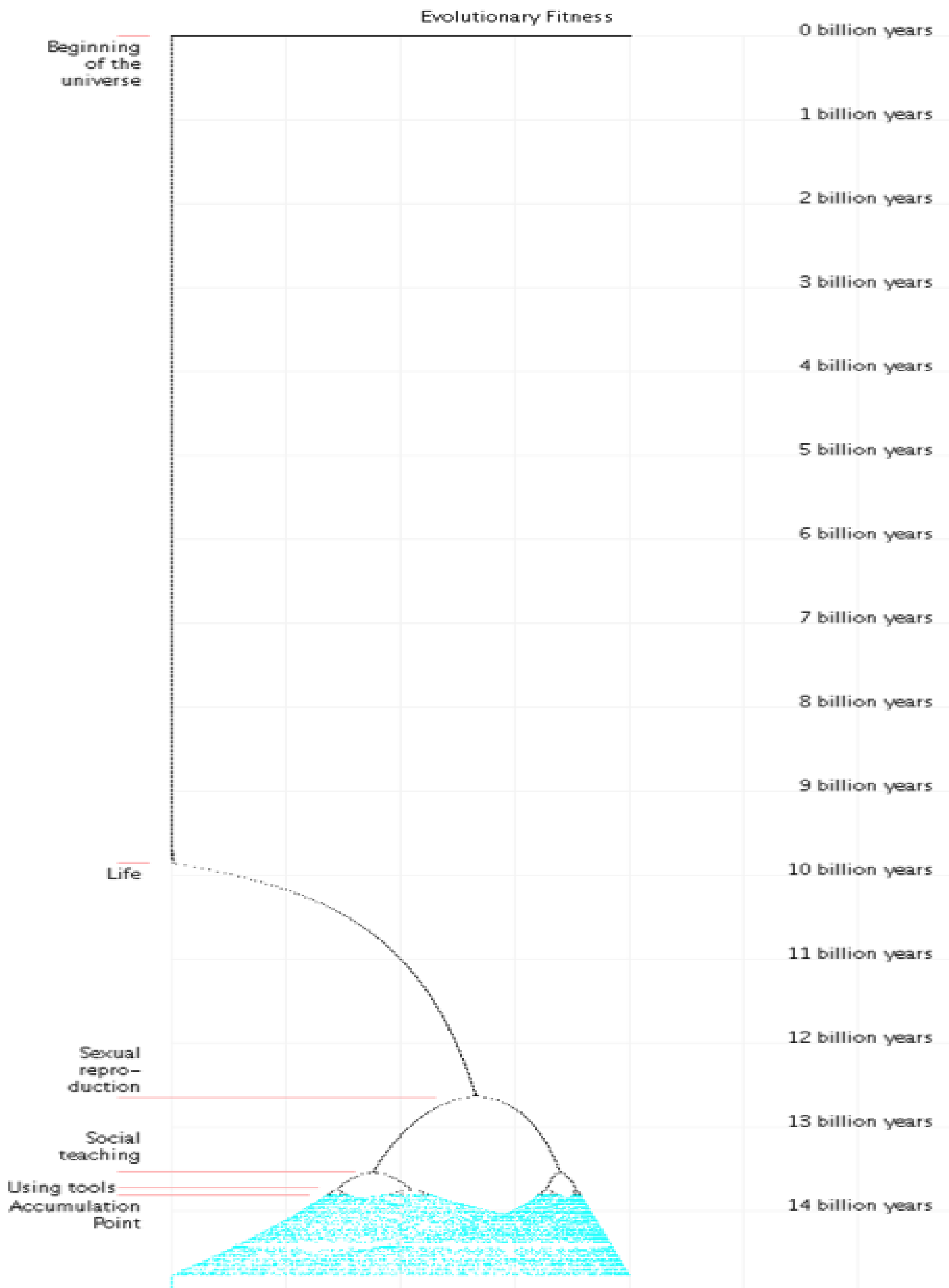

Figure 2. The bifurcation diagram for evolution on a linear time scale, with the beginning of the universe on the left. After "Using tools" the bifurcations become too small to see on this diagram. After the bifurcations is the Accumulation Point and the beginning of the chaotic stage. The blue area is the chaotic stage.

5.3. The bifurcation diagram

Figure 2 shows the bifurcation diagram for evolution on a linear scale. The system starts to vary periodically at the point where life appears in the form of self-replication cells. The period doubles as the periodic variable bifurcates into 2 values, then 4, 8, 16, and so on. The interval between bifurcations gets rapidly smaller according to the Feigenbaum ratio 4.66920… and the interval becomes zero at the Accumulation Point. The data points to an Accumulation Point around the year 2217. At that point the system enters the chaotic stage (coloured blue). It is chaotic in the mathematical sense, meaning that very small disturbances can grow to be very large, and are difficult to predict.

4.7. Fitting the curve

To get the correct date for the start of life, the bifurcation parameter was calculated using the following equation:

$$b = t^{-0.575}, \quad (1)$$

Where t is time and b is the bifurcation parameter. This is in no way intended to be a definitive solution, merely a proof of concept that an equation can be found to fit the data.
However, this equation does not fit the date for the beginning of the universe to the data. It proved to be non-trivial to find a suitable equation to fit the curve to factual dates of both the beginning of the universe and the beginning of life. To solve this, the time between the beginning of the universe and the first appearance of life on Earth was simply stretched by a factor of approximately 5.8.

The lack of a simple equation to fit the first two data points suggests one of more of the following:

- that evolution proceeds at a different speed in space and on Earth,
  or
- that evolution halts at a certain stage until it finds a planet where life can begin,
  or
- that life was actually created in space before the Earth became a suitable habitat.

The diagram in figure 3 was generated using the standard logistic mapping:

$$x_{n+1} = bx_n(1 - x_n), \quad (2)$$

where x is the evolutionary fitness and is between 0 and 1.

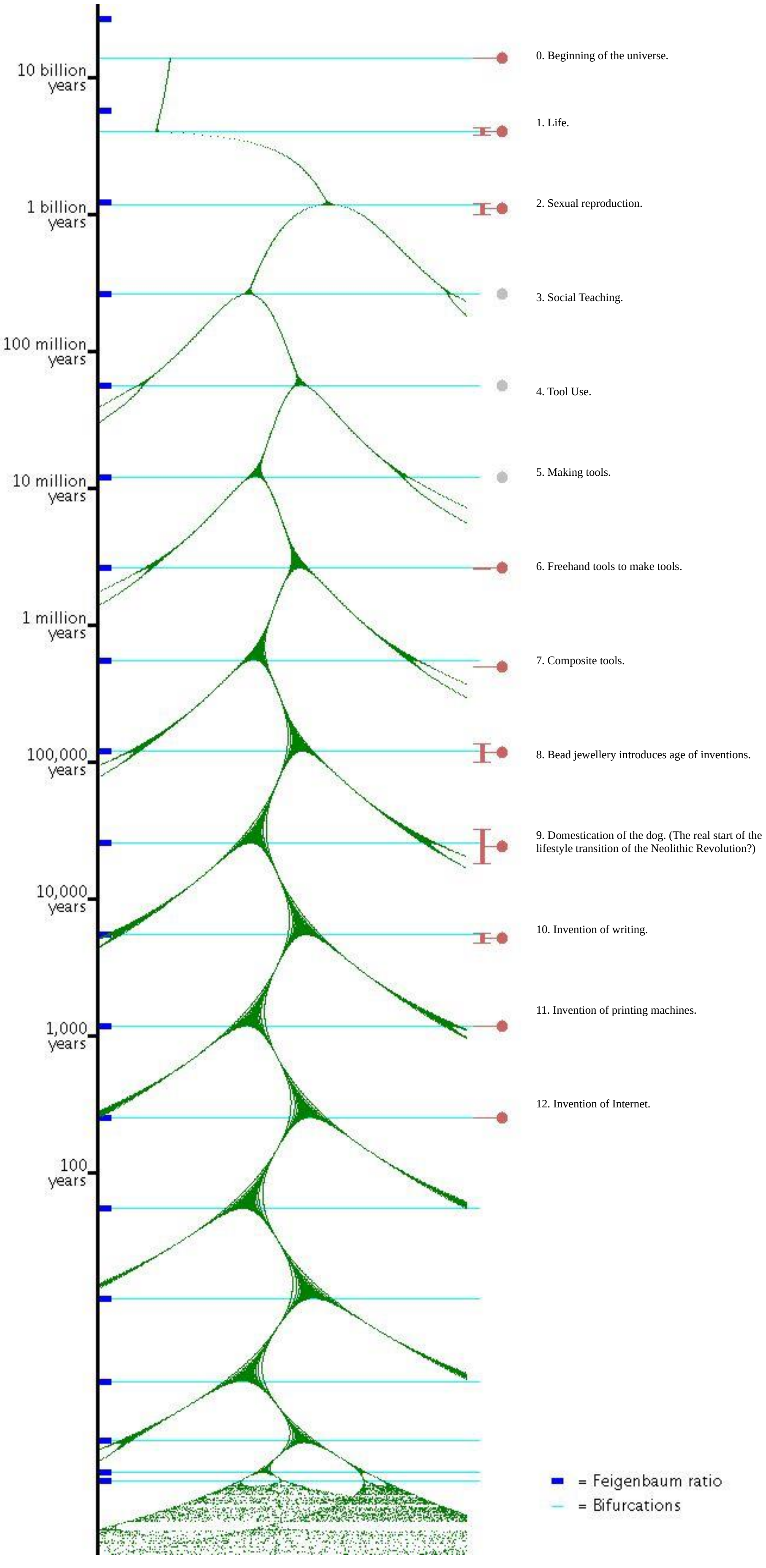
10 billion years
1 billion years
100 million years
10 million years
1 million years
100,000 years
10,000 years
1,000 years
100 years
0. Beginning of the universe.
1. Life.
2. Sexual reproduction.
3. Social Teaching.
4. Tool Use.
5. Making tools.
6. Freehand tools to make tools.
7. Composite tools.
8. Bead jewellery introduces age of inventions.
9. Domestication of the dog. (The real start of the lifestyle transition of the Neolithic Revolution?)
10. Invention of writing.
11. Invention of printing machines.
12. Invention of Internet.
= Feigenbaum ratio
= Bifurcations

Figure 3. This bifurcation diagram uses the same equation as figure 3, but with a logarithmic scale to show the bifurcations in detail, measured from just after the accumulation point, which is why we can see some of the chaotic zone at the bottom. The error bars on the red markers show the uncertainty in the known dates.

4.8. Bifurcations on a logarithmic scale

Figure 4 shows the bifurcation diagram for the same system as figure 3 on a logarithmic scale for most of the diagram to show the bifurcations in detail and a linear scale at the bottom to show the bifurcations converging to the accumulation point and the chaotic zone.

4.9. Future events

The pattern of information transfer thresholds stretches not only into the past, but also into the future. If the pattern continues, the intervals will shrink to zero at the accumulation point in the year 2217. To give an idea of the time intervals involved, the next dozen or so events are shown in table 4.

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

Table 4. Predicted future events, with intervals and dates. The intervals are easy calculated by dividing the previous interval by the Feigenbaum Constant 4.6692. The years stated may not be exact - they are based on the date of the invention of the computer network.

5. Discussion

5.1. Is it credible to find evolutionary events obeying a strict timetable?

Following a timetable is not the usual narrative of evolution, which commonly stresses the trial and error aspect. But Chaos Theory is fundamentally about finding order in chaos, and perhaps the most well-known example of this is the discovery of the Feigenbaum Constants themselves. It is perhaps odd to think of something consciously invented, like the printing machine, as being of the same importance as the first self-replicating cells. And yet consciousness itself has evolved and is clearly directing evolutionary development now. We are conscious of the fact that we are evolving, and we can imagine things (for example, artificial intelligence equal to human intelligence) that may be invented in the future - indeed we have to imagine them before we can invent them. But we are also aware that these things must wait until we have reached a certain level of development, that we cannot move faster than we are doing now.

Evolution increases complexity, and complexity increases the production of entropy. According to the Maximum Entropy Production Principle, systems naturally strive to increase the production of entropy, which means that evolution is constantly driven to develop at the maximum possible rate [46].

5.2. One evolution process

These results support the idea that cosmic evolution is not three separate processes, but one single process with, so far, a dozen different stages.

5.3. Each event builds on the previous event, and is a prerequisite for the next event

This is clear from looking at the events in table 3. The only occasion it is not clear is the transition from sexual reproduction to animal teaching. However, if sexual reproduction enables multicellularity, as some researchers claim, then the causal connection from sexual reproduction to sentient animals also becomes natural.

5.4. Unanswered questions

There are some unanswered questions, namely:

- What period is being doubled?
- What are the future events?

6. Summary

This paper presents a speculative hypothesis:

- That evolution has seen a number of occasions where new methods of transferring information to the next generation have evolved;
- That each such new method is closely associated with and coincides in time with a "shortcut" innovation which speeds up the process of evolution;
- That these events arise at predetermined intervals which get progressively shorter by the factor 4.66920 (the Feigenbaum constant δ), which is a well-known and very common characteristic pattern of Period-Doubling Bifurcations (PDB), often found in complex systems.

I begin by identifying such 6 events in evolution with known dates: the beginning of the universe (included as a reference point); Life itself; Sexual Reproduction; Writing; Movable Type Printing; and the Internet.

Noting that the ratio of intervals between the last 3 events agree with the Feigenbaum constant, I projected the intervals back in time, which generated 10 dates, including a fit for sexual reproduction, and approximate fits for Life and the Beginning of the Universe.

The remaining 7 dates include:

- 3 dates that may coincide with the following events whose actual date is unknown:
    - Animal Teaching, near the appearance of now-extinct precursors of mammals,
    - Tool Use, near the appearance of monkeys,
    - Tool-making, near the appearance of the Great Apes. It is not clear how the teaching of tool-making involves a new way of passing on information.

- 4 dates that agree with the actual dates of the following events:
    - The "tool-on-tool" stone-working technique,
    - Composite Tools,

  - The first new inventions,
  - The first domestication (the dog).

- I suggest that these last 4 events may be associated with language developments, in order to satisfy the condition that each event corresponds to a new way of passing on information.

- The PDB pattern also predicts future evolutionary shortcuts, culminating around the year 2217, when the pattern of evolution is to enter a new phase.

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Appendix A – Other new means of communication

As well as the events we have considered, a number of other new means of communication have arisen too. We should evaluate each of them to see whether or not they qualify as critical new ways to pass on information, and whether we need to refine our criterion.

First, it is useful to consider how knowledge is used.

The first stage is biological, where the knowledge encoded in DNA is expressed to produce a juvenile. If it is a social animal, it may be looked after while young and may learn some things by imitation. It may be taught to use tools. If they are human, they will be taught a spoken language. Later they will go to school and learn to read and write, and then learn various subjects which are taught from books and perhaps other media. They may later go to university. The Internet is a source of information during and after education. The generation of new knowledge by academics is speeded up by the Internet, but follows the same rules as before regarding references to previous research.

The production of new knowledge is generally handled by universities, where academics do research and produce research articles, scholarly books, new coursebooks, and popular books as our knowledge advances. The advance of knowledge generally proceeds through peer-reviewed articles in academic journals. Also non-peer-reviewed books may gain legitimacy as important works.

Table 5 shows all major innovations in transferring information.

Innovation	Can handle sufficient amounts of information	Generally available for input and output	Successful commun-ication innovation on its own	Must be new
1. Life	Yes	Yes	Yes	Yes
2. Sexual Reproduction	Yes	Yes	Yes	Yes
3. Animal teaching	Yes	Yes	Yes	Yes
4. Using found tools	Yes	Yes	Yes	Yes
5. Making tools	Yes	Yes	Yes	Yes
6. Freehand tool-ton-tool technique	Yes	Yes	Yes	Yes
7. Making composite tools	Yes	Yes	Yes	Yes
8. Age of invention	Yes	Yes	Yes	Yes
9. Age of new lifestyles	Yes	Yes	Yes	Yes
10. Writing.	Yes	Yes	Yes	Yes
11. Printing.	Yes	Yes	Yes	Yes
12. Internet.	Yes	Yes	Yes	Yes
Telephone, Simple mobile phone.	No	Yes	Yes	Yes
Cave paintings, art, illustration, diagrams, photography.	No	Yes	Yes	Yes
Music.	No	Yes	Yes	Yes
Postal Service.	Yes	Yes	No	Yes
Newspapers.	Yes	Yes	No	No
Telegraphy.	No	No	Yes	Yes
Fax machine.	Yes	No	Yes	Yes
Email.	Yes	Yes	No	Yes
Smartphone.	Yes	Yes	No	No
Teletext.	No	No	No	No
Radio, TV, cinema.	No	Yes	Yes	Yes
Video, Audio.	Yes	Yes	No	Yes
World Wide Web.	Yes	Yes	No	Yes

Table 5. Inventions for passing on information.

Table 5 is discussed in the following sections.

A.1. Criteria

- **Can handle sufficient amounts of information.** For passing on tool use, imitation is enough. But many of these means of communication were invented after the invention of writing, which means that a considerable amount of human knowledge would have already been accumulated and put into writing. For any of the inventions to be significant, it must be able to easily handle large amounts of information to easily accommodate the amount of information so far amassed.
- **Generally available for input and output.** It also should be an innovation which is in general use. For example, mass media such as cinema, radio and television are generally consumed but are not available for most people to transmit what they want.
- **Successful communication innovation on its own.** It should be a new innovation that was successful in its own right. For example, recorded videos have become a popular way of spreading information on the Internet, but were not commonly used for spreading information before the Internet.
- **Must be new.** Must be a new innovation, not a slightly different version of a previous invention.

A.2. Important innovations

- **Cave paintings, Art, Illustration, Diagrams, Photography.** Art started with the first cave paintings. But pictures alone are very limited in the kinds of knowledge they convey. Out of art grew writing – a system of symbols representing spoken language and mutually understood. But art and illustration always remained as a complement to written words in order to better illustrate knowledge (for instance, in geometry), just as specific extensions to writing exist such as mathematical formulae, chemistry symbols, electronic diagrams, etc. But the first cave paintings, although a significant and essential step, did not in themselves represent a generalized new way of passing on information, due to the limitation in the kind of knowledge pictures can convey on their own.
- **Newspapers.** The newspaper cannot be considered a significant innovation in itself, because it is essentially a book, albeit with fresh information of the moment.
- **Internet and World Wide Web.** Given today's dominance of the World Wide Web on the Internet, it is easy to conclude that the Web is more important than the Internet. It is generally perceived that it was the World Wide Web that made the Internet popular. And yet the Internet was already growing exponentially before the Web, and the percentage rate of growth did not increase when the Web was introduced [47][48]. The argument that the Web was necessary to make computer networks simple enough for home users to use ignores the fact that online network services already had millions of home users before the Web [49]. The World Wide Web is an implementation of hypertext, which was first implemented in 1968 [50].
- **Email.** Email systems were common in the early 1960s, but did not become really successful until a single global network arrived in the form of the Internet.
- **Music.** Has never been a significant way to pass on information.
- **Postal Service.** Courier services must have been around since the first civilisations and before writing, and were not initially used to transfer information.
- **Telegraphy.** Mostly only used for time-sensitive information by banks, news agencies and military.
- **Fax machine.** Not in general use.
- **Radio, TV, Cinema.** These mass media are strictly limited, mainly because they are controlled by relatively few corporations who decide the content and are not generally available to most people for passing on information.
- **Teletext.** Teletext came after the Internet, so is not a new idea, and it is controlled by broadcasters.
- **Video, Audio.** These were not popular as a means of spreading information until the Internet.
- **Smartphone.** The smartphone is a combination of a phone and a computer, both of which pre-date the Internet.

Appendix B – Other possible events

There are other events which are not included in the pattern, and this exclusion must of course be justified. If there is a single event that does not match the pattern, then the pattern is not valid. A number of possible events are discussed below.

Events should fit the criteria:

- *A new way to pass on information, capable of transferring sufficiently large amounts of information for the stage of evolution, or arising at the same time as such an event.*
- *A true innovation*
- *Available for general use*

These are events to be examined:

- **Complex Multicellular life (differentiated cells)**
  This apparently appeared at the same time as, and was enabled by, sexual reproduction, and so can be considered to be part of that event and is not a different event at a different time.

- **Eukaryotes,**
  Pluricellular life (conglomerations of identical cells),
  Photosynthesis,
  The eye,
  Hearing,
  Smell, Taste, Touch, Motion.
  None of these are new ways to pass on knowledge to others.
- **Horizontal Gene Transfer.**
  Transferring genetic information via HGT may have been common in prokaryote cells from the beginning. If it was not, it would be a new kind of evolution and would break the PDB pattern.
- **Nervous system, Brain**
  Is not a new way to pass on knowledge.
  Animals developed nervous systems as part of their bodies, which then became centralized to a brain. The brain started off small and primitive and grew gradually in size. There was not any sudden creation of the brain as an evolutionary event. But the brain is very much a part of many of the evolutionary events described.
- **Proto-tools**
  Are not new ways to pass on knowledge.
  Proto-tools are not tools that are manipulated, but stationary objects, such as a large rock used as an anvil, or a bird's nest. They are not considered to be real tools because they are not picked up and used as an extension of the body to remotely manipulate the environment.
- **Civilisation**
  Is not a new way to pass on knowledge and did not occur at the same time as a new way to pass on knowledge.
  Civilisation was a new phenomenon, but is should be seen as a manifestation of the capability create civilisation through the capability to create new lifestyles, rather than as an evolutionary event in itself. It is one of the fruits of evolution, not a mechanism of evolution.
- **The wheel**
  Is not a new way to pass on knowledge.
- **Medieval technology**
  This refers to simple machines (such as the lever, the screw, and the pulley) combined to form more complicated tools, such as the wheelbarrow, windmills and clocks. They are not new ways to pass on knowledge.
  They should be seen fruits of evolution, not a mechanism of evolution.
  They are not a new ability to handle tools, because they use existing abilities.
- **The Industrial Revolution**
  This affected agriculture, manufacturing, mining, metallurgy, and transport, driven by the discovery of steam power. The industrial revolution was very significant and had a huge economic and social impact. It could match the tool criterion, but it does not represent a new ability to pass on information, because existing abilities are used.
- **Second industrial revolution**
  Harnessing of electricity to create electric motor, light bulb, etc.
  Not new way to pass on information.
- **Science**
  Science is, in a sense, what organisms been doing since they were single cells - trying to work out, by trial and error, what practical knowledge works to survive and thrive, which has led to more explicitly stated theories about the universe as our cognitive abilities have increased. No point in time can be identified where science became a "new way to pass on knowledge". But science was revolutionised by the invention of writing and of printing.
- **Mathematics**
  Studies of animal cognition have shown that simple mathematical concepts, such as numbers, are not unique to humans. Humans practiced astronomy before writing. Like science,

mathematics is not a "new way to pass on knowledge", because it is passed on via existing methods of speech and writing, although it was revolutionised by the invention of writing and of printing.

- **Scientific Method**

  Scientific method is the application of rigorous procedures to advance knowledge, but not in itself a way to pass on knowledge.

- **The Computer.**

  Why is an important invention like the computer is not a critical evolutionary event? Certainly it is important, but on its own it does not pass on information and so is simply not a part of this conjecture.

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