



# THE AGE OF SPIRITUAL MACHINES

'A unique look at the future' Bill Gates

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decades of progress since the first electrical calculating equipment was used in the 1890 census, it was not until the mid-1960s that this phenomenon was even noticed (although Alan Turing had an inkling of it in 1950). Even then, it was appreciated only by a small community of computer engineers and scientists. Today, you have only to scan the personal computer ads – or the toy ads – in your local newspaper to see the dramatic improvements in the price performance of computation that now arrive on a monthly basis.

So Moore's Law on Integrated Circuits was not the first, but the fifth paradigm to continue the now one-century-long exponential growth of computing. Each new paradigm came along just when needed. This suggests that exponential growth won't stop with the end of Moore's Law. But the answer to our question on the continuation of the exponential growth of computing is critical to our understanding of the twenty-first century. So to gain a deeper understanding of the true nature of this trend, we need to go back to our earlier questions on the exponential nature of time.

## THE LAW OF TIME AND CHAOS

*Is the flow of time something real, or might our sense of time passing be just an illusion that hides the fact that what is real is only a vast collection of moments?*

— Lee Smolin

*Time is nature's way of preventing everything from happening at once.*

— Graffito

*Things are more like they are now than they ever were before.*

— Dwight Eisenhower

Consider these diverse exponential trends:

- The exponentially *slowing* pace that the Universe followed, with three epochs in the first billionth of a second, with later salient events taking billions of years.
- The exponentially *slowing* pace in the development of an

organism. In the first month after conception, we grow a body, a head, even a tail. We grow a brain in the first couple of months. After leaving our maternal confines, our maturation both physically and mentally is rapid at first. In the first year, we learn basic forms of mobility and communication. We experience milestones every month or so. Later on, key events march ever more slowly, taking years and then decades.

- The exponentially *quicken*ing pace of the evolution of life-forms on Earth.
- The exponentially *quicken*ing pace of the evolution of human-created technology, which picked up the pace from the evolution of life-forms.
- The exponential *growth* of computing. Note that exponential growth of a process over time is just another way of expressing an exponentially quickening pace. For example, it took about ninety years to achieve the first MIP (Million Instructions per Second) for a thousand dollars. Now we add an additional MIP per thousand dollars every day. The overall innovation rate is clearly accelerating as well.
- Moore's Law on Integrated Circuits. As I noted, this was the fifth paradigm to achieve the exponential growth of computing.

Many questions come to mind:

What is the common thread between these varied exponential trends?

Why do some of these processes speed up while others slow down?

And what does this tell us about the continuation of the exponential growth of computing when Moore's Law dies?

Is Moore's Law just a set of industry expectations and goals, as Randy Isaac, head of basic science at IBM, contends? Or is it part of a deeper phenomenon that goes far beyond the photolithography of integrated circuits?

After thinking about the relationship between these apparently

### THE LAW OF TIME AND CHAOS

In a process, the time interval between salient events (i.e., events that change the nature of the process, or significantly affect the future of the process) expands or contracts along with the amount of chaos.

#### THE LAW OF INCREASING CHAOS

As chaos exponentially increases, time exponentially slows down (i.e., the time interval between salient events grows longer as time passes).

#### THE LAW OF INCREASING CHAOS AS APPLIED TO THE UNIVERSE

The Universe started as a singularity, a single undifferentiated point with no size and no chaos, in an early epochal events were extremely rapid. The Universe grew greatly in chaos as time went on. Thus time slowed down (i.e., the time interval between salient events grew exponentially longer over time).

#### THE LAW OF INCREASING CHAOS AS APPLIED TO THE LIFE OF AN ORGANISM

The development of an organism from conception as a single cell through maturation is a process moving toward greater diversity and thus greater disorder. Thus the time interval between salient events grows longer over time.

#### THE LAW OF ACCELERATING RETURNS

As order exponentially increases, time exponentially speeds up (i.e., the time interval between salient events grows shorter as time passes).

#### THE LAW OF ACCELERATING RETURNS AS APPLIED TO AN EVOLUTIONARY PROCESS

An evolutionary process is not a closed system, therefore, evolution draws upon the chaos in the larger system in which it takes place for its options for diversity, and Evolution builds on its own increasing order.

- Therefore:
- In an evolutionary process, order increases exponentially.
  - Time exponentially speeds up.
  - The returns (i.e., the valuable products of the process) accelerate.

#### THE LAW OF ACCELERATING RETURNS AS APPLIED TO THE EVOLUTION OF LIFE-FORMS

The time interval between salient events (e.g., a significant new branch) grows exponentially shorter as time passes.

#### THE EVOLUTION OF LIFE-FORMS LEADS TO THE EVOLUTION OF TECHNOLOGY

The advance of technology is inherently an evolutionary process. Indeed, it is a continuation of the same evolutionary process that gave rise to the technology-creating species. Therefore, in accordance with the Law of Accelerating Returns, the time interval between salient advances grows exponentially shorter as time passes. The "returns" (i.e., the value) of technology increase exponentially over time.

#### TECHNOLOGY BEGETS COMPUTATION

Computation is the essence of order in technology, in accordance with the Law of Accelerating Returns, the value—power—of computation increases exponentially over time.

#### MOORE'S LAW ON INTEGRATED CIRCUITS

Transistor die sizes are cut in half every twenty-four months, therefore both computing capacity (i.e., the number of transistors on a chip) and the speed of each transistor double every twenty-four months. This is the fifth paradigm since the inception of computation—after mechanical, electromechanical (i.e., relay based), vacuum tube, and discrete transistor technology—to provide accelerating returns to computation.

diverse trends for several years, the surprising common theme became apparent to me.

What determines whether time speeds up or slows down? The consistent answer is that *time moves in relation to the amount of chaos*. We can state the Law of Time and Chaos as follows:

*The Law of Time and Chaos: In a process, the time interval between salient events (that is, events that change the nature of the process, or significantly affect the future of the process) expands or contracts along with the amount of chaos.*

When there is a lot of chaos in a process, it takes more time for significant events to occur. Conversely, as order increases, the time periods between salient events decrease.

We have to be careful here in our definition of chaos. It refers to the quantity of disordered (that is, random) events *that are relevant to the process*. If we're dealing with the random movement of atoms and molecules in a gas or liquid, then heat is an appropriate measure. If we're dealing with the process of evolution of life-forms, then chaos represents the unpredictable events encountered by organisms, and the random mutations that are introduced in the genetic code.

Let's see how the Law of Time and Chaos applies to our examples. If chaos is increasing, the Law of Time and Chaos implies the following sublaw:

*The Law of Increasing Chaos: As chaos exponentially increases, time exponentially slows down (that is, the time interval between salient events grows longer as time passes).*

This fits the Universe rather well. When the entire Universe was just a 'naked' singularity – a perfectly orderly single point in space and time – there was no chaos and conspicuous events took almost no time at all. As the Universe grew in size, chaos increased exponentially, and so did the timescale for epochal changes. Now, with billions of galaxies sprawled out over trillions of light-years of space, the Universe contains vast reaches of chaos, and indeed

requires billions of years to get everything organized for a paradigm shift to take place.

We see a similar phenomenon in the progression of an organism's life. We start out as a single fertilized cell, so there's only rather limited chaos there. Ending up with trillions of cells, chaos greatly expands. Finally, at the end of our lives, our designs deteriorate, engendering even greater randomness. So the time period between salient biological events grows longer as we grow older. And that is indeed what we experience.

But it is the opposite spiral of the Law of Time and Chaos that is the most important and relevant for our purposes. Consider the inverse sublaw, which I call the Law of Accelerating Returns:

*The Law of Accelerating Returns: As order exponentially increases, time exponentially speeds up (that is, the time interval between salient events grows shorter as time passes).*

The Law of Accelerating Returns (to distinguish it from a better-known law in which returns diminish) applies specifically to evolutionary processes. In an evolutionary process, it is order – the opposite of chaos – that is increasing. And, as we have seen, time speeds up.

### Disorder

I noted above that the concept of chaos in the Law of Time and Chaos is tricky. Chaos alone is not sufficient – disorder for our purposes requires randomness that is relevant to the process we are concerned with. The opposite of disorder – which I called 'order' in the above Law of Accelerating Returns – is even trickier.

Let's start with our definition of disorder and work backward. If disorder represents a random sequence of events, then the opposite of disorder should imply 'not random.' And if random means unpredictable, then we might conclude that order means predictable. But that would be wrong.

Borrowing a page from information theory,<sup>21</sup> consider the difference between information and noise. Information is a sequence of data that is meaningful in a process, such as the

DNA code of an organism, or the bits in a computer program. Noise, on the other hand, is a random sequence. *Neither noise nor information is predictable.* Noise is inherently unpredictable, but carries no information. Information, however, is also unpredictable. If we can predict future data from past data, then that future data stops being information. For example, consider a sequence which simply alternates between zero and one (01010101 . . .). Such a sequence is certainly orderly, and very predictable. Specifically because it is so predictable, we do not consider it information-bearing beyond the first couple of bits.

Thus orderliness does not constitute order because order requires information. So, perhaps I should use the word *information* instead of *order*. However, information alone is not sufficient for our purposes either. Consider a phone book. It certainly represents a lot of information, and some order as well. Yet if we double the size of the phone book, we have increased the amount of data, but we have not achieved a deeper level of order.

*Order, then, is information that fits a purpose.* The measure of order is the measure of how well the information fits the purpose. In the evolution of life-forms, the purpose is to survive. In an evolutionary algorithm (a computer program that simulates evolution to solve a problem) applied to, say, investing in the stock market, the purpose is to make money. Simply having more information does not necessarily result in a better fit. A superior solution for a purpose may very well involve less data.

The concept of 'complexity' has been used recently to describe the nature of the information created by an evolutionary process. Complexity is a reasonably close fit to the concept of order that I am describing. After all, the designs created by the evolution of life-forms on Earth appear to have become more complex over time. However, complexity is not a perfect fit either. Sometimes, a deeper order – a better fit to a purpose – is achieved through simplification rather than further increases in complexity. As Einstein said, 'Everything should be made as simple as possible, but no simpler.' For example, a new theory that ties together apparently disparate ideas into one broader, more coherent theory reduces complexity but nonetheless may increase the 'order for a purpose' that I am describing. Evolution has shown, however,

that the general trend toward greater order does generally result in greater complexity.<sup>22</sup>

Thus improving a solution to a problem – which may increase or decrease complexity – increases order. Now that just leaves the issue of defining the problem. And as we will see, defining a problem well is often the key to finding its solution.

#### The Law of Increasing Entropy Versus the Growth of Order

Another consideration is how the Law of Time and Chaos relates to the second law of thermodynamics. Unlike the second law, the Law of Time and Chaos is not necessarily concerned with a closed system. It deals instead with a process. The Universe is a closed system (not subject to outside influence, since there is nothing outside the Universe), so in accordance with the second law of thermodynamics, chaos increases and time slows down. In contrast, evolution is precisely not a closed system. It takes place amid great chaos, and indeed *depends on the disorder in its midst, from which it draws its options for diversity.* And from these options, an evolutionary process continually prunes its choices to create ever greater order. Even a crisis that appears to introduce a significant new source of chaos is likely to end up increasing – deepening – the order created by an evolutionary process. For example, consider the asteroid that is thought to have killed off big organisms such as the dinosaurs 65 million years ago. The crash of that asteroid suddenly created a vast increase in chaos (and lots of dust, too). Yet it appears to have hastened the rise of mammals in the niche previously dominated by large reptiles and ultimately led to the emergence of a technology-creating species. When the dust settled (literally), the crisis of the asteroid had increased order.

As I pointed out earlier, only a tiny fraction of the stuff in the Universe, or even on a life- and technology-bearing planet such as Earth, can be considered to be part of evolution's inventions. Thus evolution does not contradict the Law of Increasing Entropy. Indeed, it depends on it to provide a never-ending supply of options.

As I noted, given the emergence of life, the emergence of a

technology-creating species – and of technology – is inevitable. Technology is the continuation of evolution by other means, and is itself an evolutionary process. So it, too, speeds up.

A primary reason that evolution – of life-forms or of technology – speeds up is that *it builds on its own increasing order*. Innovations created by evolution encourage and enable faster evolution. In the case of the evolution of life-forms, the most notable example is DNA, which provides a recorded and protected transcription of life's design from which to launch further experiments.

In the case of the evolution of technology, ever improving human methods of recording information have fostered further technology. The first computers were designed on paper and assembled by hand. Today, they are designed on computer workstations with the computers themselves working out many details of the next generation's design, and are then produced in fully automated factories with human guidance but limited direct intervention.

The evolutionary process of technology seeks to improve capabilities in an exponential fashion. Innovators seek to improve things by multiples. Innovation is multiplicative, not additive. Technology, like any evolutionary process, builds on itself. This aspect will continue to accelerate when the technology itself takes full control of its own progression.

We can thus conclude the following with regard to the evolution of life-forms, and of technology:

*The Law of Accelerating Returns as Applied to an Evolutionary Process:*

- *An evolutionary process is not a closed system; therefore, evolution draws upon the chaos in the larger system in which it takes place for its options for diversity; and*
- *Evolution builds on its own increasing order.*

*Therefore:*

- *In an evolutionary process, order increases exponentially.*

*Therefore:*

- *Time exponentially speeds up.*

*Therefore:*

- *The returns (that is, the valuable products of the process) accelerate.*

The phenomenon of time slowing down and speeding up is occurring simultaneously. Cosmologically speaking, the Universe continues to slow down. Evolution, now most noticeably in the form of human-created technology, continues to speed up. These are the two sides – two interleaved spirals – of the Law of Time and Chaos.

The spiral we are most interested in – the Law of Accelerating Returns – gives us ever greater order in technology, which inevitably leads to the emergence of computation. Computation is the essence of order. It provides the ability for a technology to respond in a variable and appropriate manner to its environment to carry out its mission. Thus computational technology is also an evolutionary process, and also builds on its own progress. The time to accomplish a fixed objective gets exponentially shorter over time (for example, ninety years for the first MIP per thousand dollars versus one day for an additional MIP today). That the power of computing grows exponentially over time is just another way to say the same thing.

So Where Does That Leave Moore's Law?

Well, it still leaves it dead by the year 2020. Moore's Law came along in 1958 just when it was needed and will have done its sixty years of service by 2018, a rather long period of time for a paradigm nowadays. Unlike Moore's Law, however, the Law of Accelerating Returns is not a temporary methodology. It is a basic attribute of the nature of time and chaos – a sublaw of the Law of Time and Chaos – and describes a wide range of apparently divergent phenomena and trends. In accordance with the Law of Accelerating Returns, another computational technology will pick up where Moore's Law will have left off, without missing a beat.