Article

Issues in the Path to the Singularity: A Critical View

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Abstract

This paper examines the 2005 book *The Singularity is Near: When humans Transcend Biology* written by Raymond Kurzweil. The focus lies on the author´s views of exponential growth information technology (IT), which would result in the so called technological singularity. This work attempts to reduce the book´s essence to the main factors necessary for the achievement of artificial intelligence (AI), the main tool for the paradigm shift represented by the singularity. In line with the book, we consider that computational power is the major requirement for the development of AI. We explore three selected preconditions for the continuity of exponential trends: the continuity of economic growth, limited energy usage and the availability of enabling knowledge. The investigation on the demand side points that the trend in energy consumption on computer CPU´s has been decreasing in the last 14 years, even with increasingly more powerful processors. On the supply side, Kurzweil´s reliance on photovoltaics as a major future source of energy seems questionable due to the slow rate of improvement this technology has had during recent years. The final part of the work observes the characteristics of different types of statistical growth, and draw parallels between Kurzweil´s ideas and similar concepts used in the past.

Keywords: Singularity, critical view, Kurzweil, artificial intelligence, information technology, CPU, growth.

1. Introduction

Raymond Kurzweil is a well known inventor, businessman and writer. Kurzweil´s name is mostly associated with the piano and music synthesizer company he founded, whose products are labeled after his name. Kurzweil also launched a number of parallel companies, ranging from text-to-speech technologies to literature on life-extending nutrition.

According to his own self-description, Kurzweil embodies the definition of a futurist. Kurzweil´s predictions are based mainly in the field of Information Technology. By analyzing specific trends in this sector, he extrapolates development predictions based on the interfaces that IT-based technologies have with other sectors of the human society.

In recent years – more precisely after 2005 – Kurzweil´s name rose to the spotlight due to his feats as an author on future studies. This paper is interested in examining the potential problems for the materialization of Kurzweil´s IT development predictions, which are present on his 2005 book The *Singularity is Near: When Humans Transcend Biology.*

This paper recognizes the criticism on Kurzweil´s ideas, but refrains from taking part in this discussion. Instead, the investigation focuses solely on the conceptual merit of the energy

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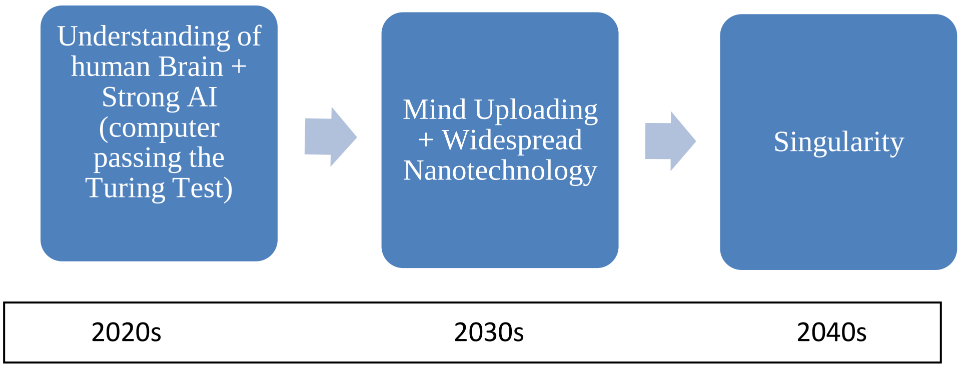
component associated to the increasing computational power hypothetically required for the attainment of strong artificial intelligence – and the singularity.

1.1 Kurzweil´s 2005 book: *The Singularity is Near*

As a follow up to two previous books on future studies, namely The Age of Intelligent Machines (1990) and The Age of Spiritual Machines (1999), Kurzweil published in 2005 an updated work entitled *The singularity if Near: When Humans Transcend Biology.* The book attempted to predict some of the main changes to the human society that will happen in the next decades, based on the observation of past and ongoing evolutionary trends in key technologies considered by the author as fundamental impact on near and mid-term future. The main difference between Kurzweil´s 1999 and 2005 books is that the later picked up on fast-changing technological developments that were happening in the early 2000´s, such as the increased understanding of the human genome, the maintenance of Moore´s law [1] accelerating computer performance and the whole debate of sustainability in energy systems. Altogether, the development trends analyzed in the book were converging, according to Kurzweil´s argumentation, to a technological *singularity*[2] which would take place near the year of 2045.

The scope of this paper is limited to the essence of the book, which is the development of ICT based on increasingly powerful computer technology. Although inputs from other fields of knowledge will be necessary for Kurzweil´s predictions to be fulfilled, it is clear in his work that the prime carrier of change is the continued exponential growth in computing power which will allow the emergence of artificial intelligence, which still according to his predictions, is likely to be the fundamental driver for the achievement of the *singularity*.

For a better understanding of the foreseen development trend in ICT envisioned by Kurzweil, follows an evolution line based on information extracted from his 2005 book.



According to the timeline of events in the book, in the next decades the speed of computers will continue to rise in an exponential manner, that is, Moore´s law will continue to be valid. This will be accompanied by an exponential decrease in costs per unit of processing power,

[1] Gordon Moore is one of the founders of the INTEL corporation, whose April 1965 publication in Electronics Magazine became known in the IT sector as Moore´s law. This is due to the observed trend in the electronics industry that the number of transistors in an integrated circuit seems to double every two years.
[2] Technological singularity can be defined as a moment in time where technological evolution shifts from exponential to a quasi-hyperbolic growth, resulting in major societal, identity and philosophical paradigm shifts. See: Vernor (1993), Joy (2000), Kurzweil (2005), Hanson (2008).

transmission bandwidth and storage capacities.[3] This trend, still according to Kurzweil, will allow increasingly more complex systems to be simulated. With the inputs from existing knowledge bases and ongoing inputs from neuroscience[4], this development trend in computer power will lead to a full understanding of the brain in the 2020´s. The next step will be the uptake of real-time simulation of the human brain, what will turn into the start point of up-scaled artificial intelligence, the motor of a new economic revolution.

Kurzweil´s makes usage of various empirical time series to justify the perceived evolutionary trends in ICT technologies. As an example of perceived exponential trends, he mentions the number of transistors in computer processors, the number of published scientific papers, decreasing cost per unit of computer memory, data bandwidth, *et cetera*.

This paper makes two fundamental assumptions, which are also present in the postulates of Kurzweil´s work and help as to narrow the focus of discussion:

- The *singularity* is an achievable state of technology.
- The brain is structured according to rules, which while complex, are deterministic in nature. It can be therefore understood, simulated and up-scaled.

That said, the scope of this work is limited to examining a few shortcomings in the proposed law of accelerating change (Kurzweil 2001), which is the foundation of the technological change that could make such deep transformations to occur. How would his predictions stand, if sustainability considerations are in place? In other words, can the singularity still be achieved given economic, knowledge and energy constraints?

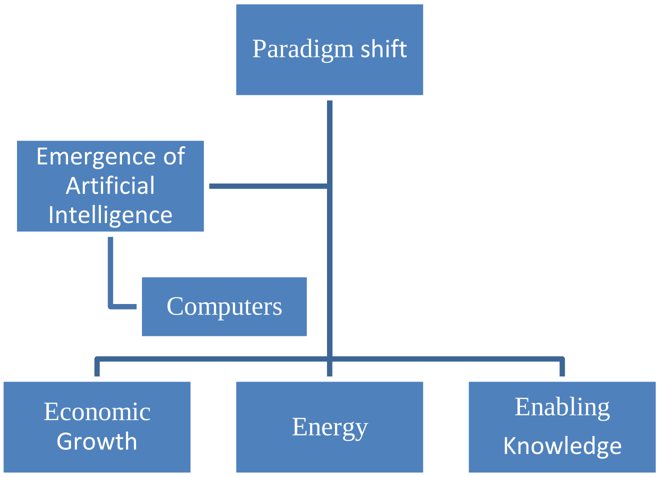
2. Requirements for the achievement of the singularity

First let us restrict the analysis to its fundamental components. Kurzweil postulates that key technologies, spearheaded by the progress in computation power, are experiencing exponential growth, what operates a multiplicator effect via spillovers to other sectors of the economy. Similarly to a schumpeterian model of business cycles, Kurzweil says that recurring cycles of *evolution* happen due to improvements based on the exponential growth. Each new improvement cycle, for example, the doubling of the number of transistors in an integrated circuit every two years, represents the creation of a refined tool that improves capacity. This continues until enough capacity and tools have been accumulated, as to allow a paradigm shift (i.e. *revolution*) to take place.

For the analysis of the research question – which factors might make it difficult to achieve the so called singularity – this paper will break this process in its constituent parts.

[3] All these three trends were plotted with empirical data in Kurzweil´s work. See Kurzweil (2005).
[4] Proposed technologies to map and simulate a virtual brain are improved brain imaging techniques with sufficient resolution and nanotech bots for brain mapping. This does not exclude, but is indeed complementary to parallel other approaches such as the accurate modeling of individual neurons, synapses, according to Kurzweil.

Mechanism of approach to the Singularity



For abstraction purposes we shall imagine that economies are essentially reduced to the classical inputs of *capital* and *labour*. These two inputs do not have a perfect substitution rate, because neither capital or labour are homogenous. In other words, capital and labor have different rates of return, for a given economic activity. Capital has been substituting low-skilled labor for centuries in human societies[5], but it is struggling to substitute highly dispersed and low energy tasks such as cleaning and cooking. The same is valid for highly skilled labor, such as researchers, interpreters and artists, all professions which so far see no threat coming from machines.

Zeira (2007) shows that grown can be achieved by capital deepening and labour being concentrated in the sectors where it still has a higher rate of return. The parallel with Kurzweil happens when capital (machines) manage to completely replace labour, even in the hardest sectors (R&D). This could fuel very fast economic growth, as machines would likely outperform humans in cognitive, precision and speed capabilities. The paradigm shift[6], or *singularity*, requires the existence of such a revolutionary growth mechanism, considered by Kurzweil to be artificial intelligence (AI). Further backtracking, AI requires the right set of enabling tools for coming into existence. Let us consider the three main factors determining the creations of these tools to be: (1) Economic growth (2) Sufficient energy supply and (3) Enabling Knowledge.[7]

2.1 Economic growth

Kurzweil´s views of the importance of technology to development are to a certain extent backed by economic growth theory (Sollow, 1957; Romer; 1990). Independently on whether technology is seen as exogenous (Sollow) or endogenous (Romer) to the economy, technology development is eventually the decisive factor determining long-term growth.

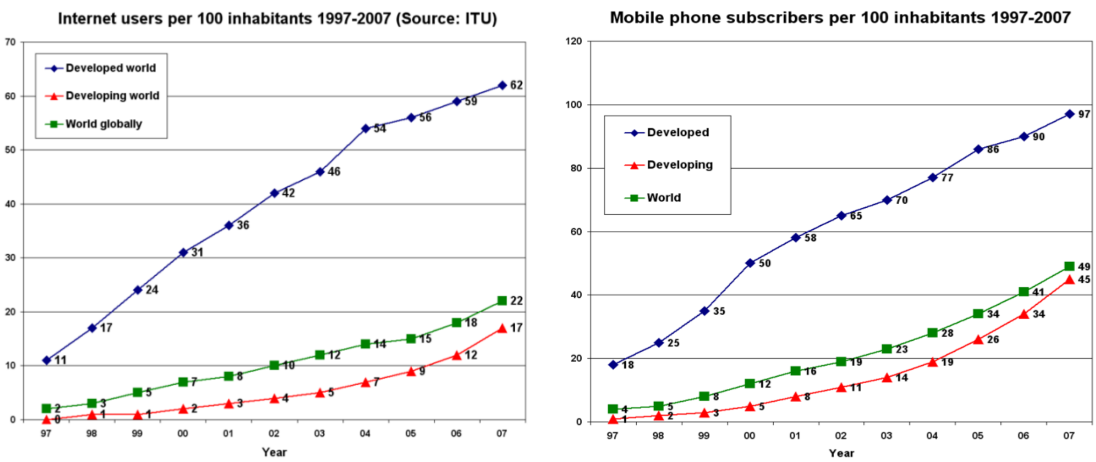
[5] Maybe the best example of large-scale labour substitution by capital is the Industrial Revolution. It shall be noticed that the large availability of energy due to the steam technology made machines more cost-effective than labourers at many manufacture lines.
[6] See Kuhn (1962)
[7] There are numerous other specific factors that could be considered (such as nanotechnology, genetic engineering, medicine and life extension, etc). For simplification and modeling purposes we will consider only the three main aggregate, keeping in mind that there are strong correlations among them.

The importance of economic growth is an established consensus in economic theory, and often the final goal of government policy due to numerous benefits it unlocks. Growth and spillovers have been obvious elements in the modern computer industry. Fueled by the increase in average incomes worldwide during the 1980s, joint the advent of the personal computer, the IT industry experienced unheard levels of demand during the 1990s and 2000s, even managing to overcome sector-specific problems and continuing to grow.[8] Given the present structure of the computer industry, there is a heavy dependence in economies of scale and standardization of products.

This leads us to an interesting aspect of the computer industry: Each new generation of computer technology requires increasingly larger investments to reach the market (Sumner and Krazit 2005). Given that continuous, exponential innovation is the main mechanism in Kurzweil´s predictions, a sustained economic growth seems necessary to allow firms to continue technology-oriented investments. These, in the same circular logic, would then be able to maintain the pace necessary to feed an exponential growth in the sectors leading to the singularity (e.g. computer processing power).

There are however limits for the growth of IT markets: The share of ICT products per household is high in developed countries and smaller in lower income regions of the world. However, there has been a rapid growth in ICT sectors in the developing world (Graph 1)

Graph 1 – Growing markets for ICT in developing countries



Source: International Telecommunication Union

Assuming that developing countries open to trade tend to grow faster than developed countries (catch-up effect), and that the computer markets are highly international, we can deduce that the market for computers – on all its forms – is driven by two major driving mechanisms: (A) – The speed with which the digital divide is bridged; (B) – The seasonal replacement of computers in IT-saturated markets.

The growth in the computer industry is fueled by both (A) and (B), in other words, the untapped market potential of developing countries plus the replacement of existing IT capital in highly developed markets such as Sweden (where small percentual growth potential remains).

[8] One example is the Dot-com market bubble which sharply depreciated shares of IT firms in 2000.

The absolute amount of resources spent on ICT products in developed countries like Sweden could be seen as a theoretical limit for computer markets; with the entire world population enjoying ICT in the same standards as Sweden, there will be no more accelerated growth due to fading catch-up effect in developing countries. Instead, the ICT demand will be determined by the frequency of replacement of existing hardware – a highly significant, but not exponentially-growing market.

One extra issue that could affect the growth necessary for the singularity to be achieved should be mentioned. *The Singularity is Near* has been published before the *Stern Report* from 2006 and the IPCC 4th assessment report of 2007 . As a matter of fact, not much focus has been given to the potential that global temperature increases could have in de-accelerating the international economy. If ongoing and near-future initiatives to mitigate climate change fail to curb temperature increases, considering Stern and IPCC forecasts to be valid, an economic de-acceleration could occur. This could mean by consequence that the ICT industry might be affected and forced to scale back technology investments, jeopardizing Kurzweils scenarios.

2.2 Energy Demand

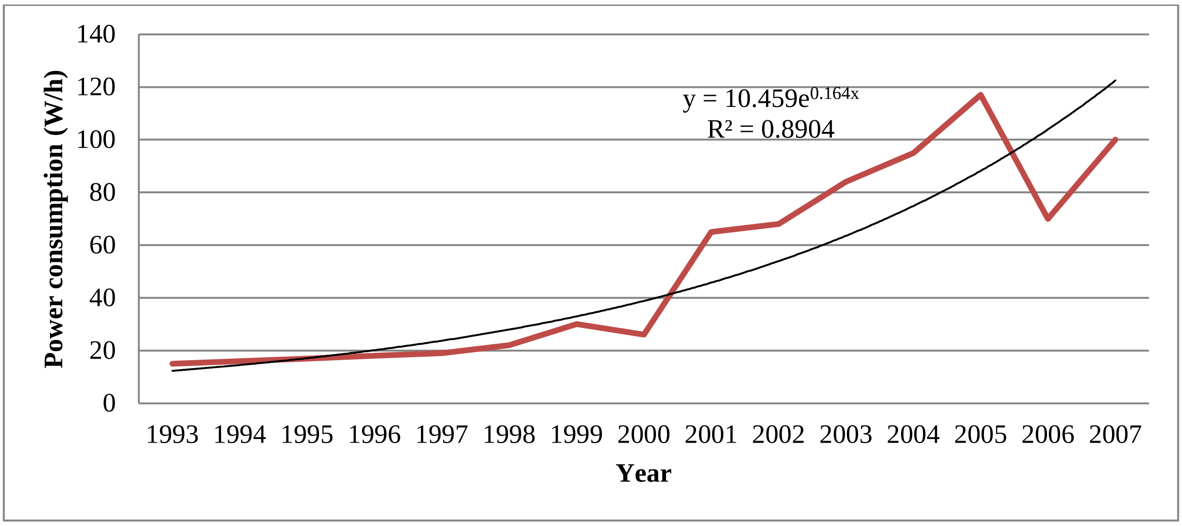
There has been some debate on whether computer power can sustain its observed growth as of 2009. Let us look into energy considerations in this section.

Today the dominant architecture in the supercomputer industry is basically the same as in the consumer segments. Supercomputers are built by massive parallelization of consumer-grade parts. Mainly after the Pentium 4 series of microprocessors, limitations in serial processing (e.g. overheating issues when clock speeds go above 3-4 gigahertz per core) became evident. However, there seems to be a creative trend in the computer industry which circumvents the overheating problem. Instead of faster single processors, the computation cores are now being assembled in parallel architecture, using multiple processors with better memory allocation. This allows even slower processors – considering clock speeds – to display better net performance.

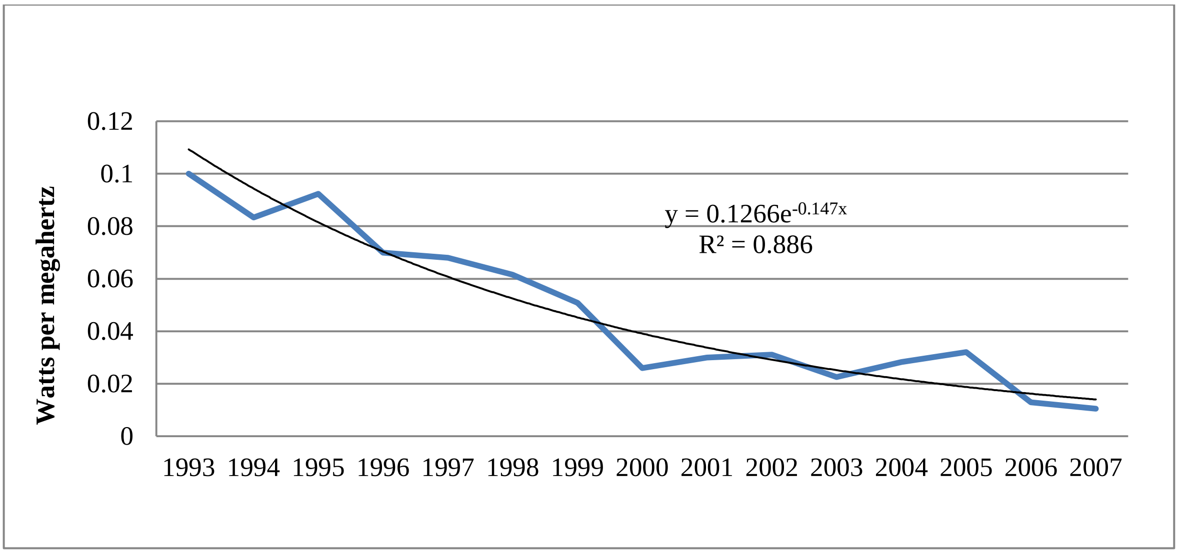
How about the power consumption of computer processor? Kurzweil´s work has not performed a demand-side analysis of energy aspects. If an exponential increase in power demand for every new generation of processors is verified to be taking place, this could result in severe difficulties for a continuous exponential growth in the sector.

Some empirical data from a computer benchmark firm can give some insights on the trends in power consumption in the computer processor segment.[9] Observe Graphs 2, 3 and 4:

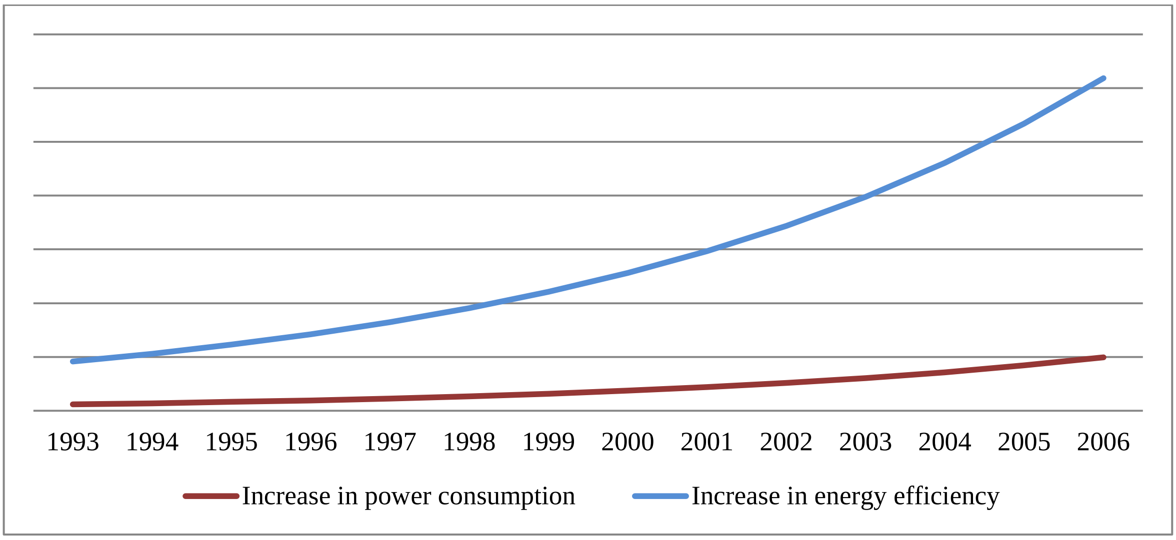
[9] Figures extracted from Tom´s Hardware Guide and Intel technical reports.



Graph 2. CPU Power Consumption: 1993 – 2007. Average of AMD and Intel processors.



Graph 3. CPU Energy-performance: 1993 – 2007. In watts per megahertz.



Graph 4. Energy efficiency increased faster than power consumption in microprocessors 1993-2007 (Plot of functions extracted from Graph 2 and 3)

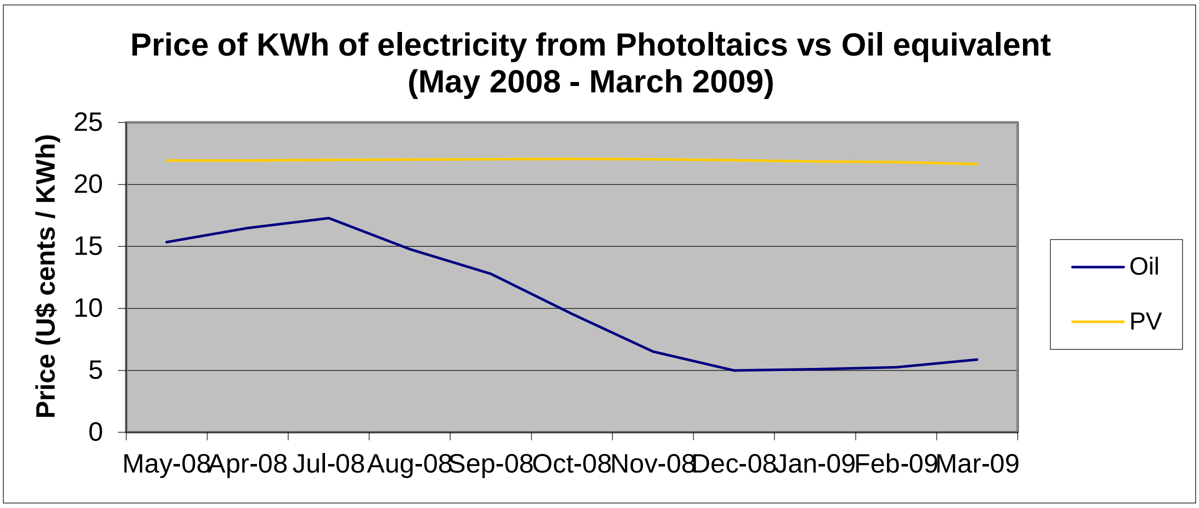
When we compare data from the most common computer processors manufactured by Intel and AMD, it seems clear that even though energy consumption per processor has increased over the period between 1993 and 2007; this has been offset by the megahertz-per-watt figures. The increase in energy efficiency – the measurement of how much processing capacity the CPU can deliver, given the same energy input – increased substantially. Graph 4 compares the weights of both trends (energy consumption vs efficiency increase). The plot demonstrates that the curves never cross each other, meaning that based on empirical data, energy efficiency has grown always faster than energy consumption per CPU. Finally, if this trend persists, energy consumption of processors is unlikely to be an impediment to Kurzweil´s argumentation.

2.3 Energy supply

In his reasoning, Kurzweil does not neglect the issue of the world´s pressing demands for cleaner and better energy sources. Namely mentioned in his book is the role of solar cells, which would, according to him, decrease in price and increase in efficiency providing most of the world´s energy needs by the 2020´s.

While it is true that Photovoltaics (PV) experienced fast growth in total installed capacity worldwide during recent years, it is also a fact that PV markets are highly concentrated where feed-in tariff mechanisms are in place (Costa, 2009). Less than one percent of the total European energy consumption originates from photovoltaics, and few countries concentrate the bulk of the photovoltaic surface (Germany, Spain and Italy)

The author selected information on the price of photovoltaics, comparing it to the price of fossil-based electricity. Even during months of 2008, when oil reached its peak price in recent years, photovoltaics remained uncompetitive. See Graph 5:



Graph 5. Price of kWh of electricity from photovoltaics, compared to oil equivalent. (May 2008 – March 2009). Source: Costa (2009).

Problems in the supply of silicon have kept the price of PV high in recent years, and industry forecasts are highly uncertain in regards to future price reductions (Costa 2009). Fossil based energy is still at least fourfold more economical than PV, and as of 2011 there is no strong, internationally applied carbon pricing mechanism to internalize the environmental costs and adjust this cost-benefit relation. Short term fluctuations of fossil energy (e.g. oil prices) might have a negative impact on short-term investments on desirable sources of energy (i.e. photovoltaics), slowing progress in PV development.

Apparently, Kurzweil´s bet on photovoltaics is increasingly risky. Unless great improvements in the PV sector occur, boosting conversion efficiencies and bringing down prices, the business-as-usual perspectives for PV are not in line with the prediction of a major energy source for the world´s economy.

Even if the growth in photovoltaics materialize as predicted, there are also considerations on whether electricity supply could interfaces with the transport sector. The development of better energy carriers, in the form of high capacity batteries for automotive transport has been a long-standing challenge for energy engineers, and still no efficient solution has been found. The utilization of biofuels and other alternatives could, at best, hedge some of the market against potential costs of emissions-intensive transport.

2.3 Enabling knowledge

The availability of knowledge to simulate and upscale the human brain is possibly the most sensitive aspect of Kurzweil´s analysis, given the multiple uncertainties involved. Even with continued economic growth and no energy constraints, hardware capacity is not enough to produce AI.

Neuroscience is nowadays subdivided in numerous fields, focusing on physical, biological, chemical and cognitive aspects of the brain. The scope of this work is firmly defined at analyzing the feasibility of Kurzweil´s future predictions. The author will, in this sense, refrain from touching some of the many polemic aspects that this topic can carry.

In a systematic way, it seems reasonable that the understanding of the brain is highly dependent on progress in computational neuroscience. According to Kurzweil, some specific technologies (i.e. Brain imaging techniques coupled with nanotechnology) would allow the structure of the brain to be understood and modeled with sufficient resolution, as to allow the extrapolation of Artificial Intelligence.

Kurzweil´s predictions do not exclude, however, other possible paths for the development of AI, as for example bottom-up approaches, such as individual software modules being developed in parallel, and interfacing with each other for the achievement of the same results.

In any case, there are a few interesting questions in the way of his predictions.

If Kurzweil is right, and brain scans successfully reproduce the physical and electrical structure of the human brain, there is still a problem to be solved. It is ominous in all modern artificial neural networks the fact that they work as universal approximators. That is, they are predictive, but not explanatory tools. Although predictions from neural networks can be highly useful, it is impossible to understand how a process takes place in the inner workings of a neural net. This is why artificial neural networks are also called black boxes (Benitez et al 1997). In this sense, if there are limitations to the understanding on how neural networks process information, there could be difficulties to upscale any simulated brain, condition stated by Kurzweil as necessary for the achievement of super-human intelligence.

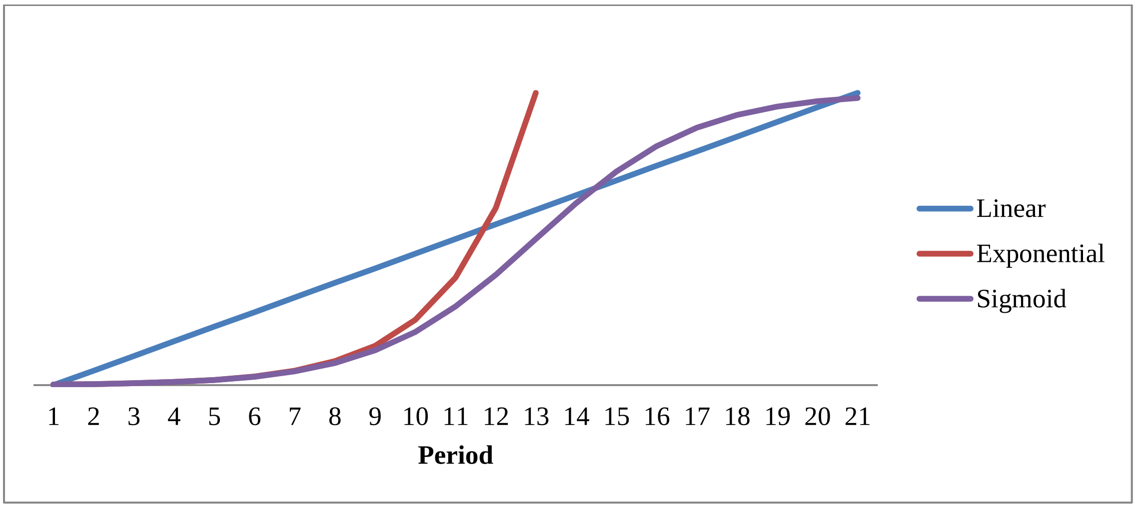
Firm behavior might also hamper the rate of progress towards a singularity. Technologies that can unlock large business opportunities might inspire anti-competitive behavior. Information asymmetries such as corporate secrecy in AI technologies could, beside monopolistic considerations, hamper the widespread usage of such technology, reducing its effective multiplicator effect throughout economies. As a consequence, the accelerated growth necessary for the *singularity* would be jeopardized.

3. Discussion

Great extent of Kurzweil´s argument is based on his interpretation of the long term evolution of life on planet earth. In his work, a centerpiece is a graph where events with different characteristics, such as the appearance of life on earth, the development of civilizations, agriculture, writing, etc are all plotted in an evolutionary logarithm graph, which is prone to criticism in two points (See: Annex 1):

- Different events / technologies are compared in the same context. The selection of relevant events is arbitrary, and even when different authors are used to reduce bias, the criteria for selection of events remains arbitrary, and prone to limitations of scientific knowledge.
- If the scope of the book is the singularity, and if ICT is the main driver of this process, so the appropriate evolutionary graph would have to be limited in time to the twentieth century (and not the entire evolution of humankind).

The discussion concerning the attainability of the singularity could easily slip into the realm of mathematical philosophy, concerning the characteristics of growth trends. Graph 6 depicts three types of statistical growth. Notice that exponential and sigmoid (S-Curve) growths remain almost identical until the 9^{th} period, but after that point, the sigmoid starts to saturate and stabilizes. The uncertainty related to future predictions in technology makes it impossible to know if growth observed now – or in the last hundred years – is been a de-facto exponential or an S-Curve, converging towards stabilization sooner or later. Simply said, this is the pitfall of adaptive expectations, or relying on past trends to forecast the future.



Graph 6. Types of growth

One interesting example of this debate happened in 2007, when a reader (Leonard Skinner) posted the following comment on Kurzweil´s company website: [10]

" When the technological singularity comes, cars will have an infinite number of tailpipes and airbags and razors will have an infinite number of blades. Ok, so that's a little silly, but still - past performance is no guarantee of future results.
As for razors and tailpipes, perhaps it may be for microprocessors"

When confronted by this criticism, Kurzweil replied:

"Exponentials continue if there is (1) a benefit or reason for it continuing, (2) the resources for it to continue, and (3) a mechanism for it to continue."

Would Kurzweil´s interpretation of exponential trends in ICT be an example of static analysis?[11] Static analysis means that a forecast has been based only in past observations. In economics the equivalent term is *adaptive expectations*. A classic example dates back to the 18th century, in the context of the ongoing industrial revolution Thomas Malthus imagined that the observed population growth would lead to a national disaster in Britain by 1850. By failing to realize the limitations of the industrial revolution in England, Malthus made his flawed predictions based on pure adaptive expectations, thus not realizing that population growth would de-accelerate. The same idea was revisited by Ehrlich (1968) predicting catastrophic population growth during the 1980´s.

As a counterargument to the static analysis criticism, Kurzweil could say that his investigation mostly reflects a form of dynamic analysis called *rational expectations*. This means that, in

[10] Discussion thread available at: http://www.sl4.org/archive/0706/16378.html (last accessed 13 August 2009)

[11] Static analysis is a pejorative term for when trends are projected into the future simplistically. One simple example is a man who has one child when he is 30 years old. Then another child when he turns 35. A static analysis would conclude that the man will have his eleventh child when he turns 100 years old, not taking into consideration other variables that might influence the trend (e.g. human behavior, aging).

addition to considering past trends, Kurzweil made efforts to avoid bias and made use of the best available information for his forecasts.

4. Conclusion

In line with Kurzweil´s answer to Leonard Skinner, there are numerous benefits that could occur in Kurzweil´s envisioned path to the singularity, which are redundant to be mentioned. In regards to resources for exponential trends to continue, there are some doubts whether economic growth in the next decades will be enough to permit increasingly more expensive generations of microprocessors to reach the markets. Additional studies could attempt to quantify the characteristic of this trend – if investments required to produce new microprocessors are also increasing exponentially.

Still regarding resources, there is apparently also a trend that processing power increases much faster than energy requirements in CPU´s. This would hold Kurzweil´s argument, but must be seen with caution. The human brain is taken by Kurzweil as model to pursue, still it only consumes 20w of power-equivalent. Large supercomputers today use as much energy as what is produced by a small hydroelectric power plant, to achieve less than one human brain in net performance. In addition to this, photovoltaics, Kurzweil´s bet on photovoltaics as the future of clean energy is still far from even approaching a commercial break even. As of 2011 the bulk of energy generation originates from fossil sources.

Given the highly unpredictable nature of knowledge, the mechanism for exponentials to continue, or the emergence of the necessary technologies for the achievement of the singularity, few or no conclusions can be made for this point. However, there could be an underlying effect in line with self-fullfilling prophecies associated with Kurzweil´s books. Just as it inspired this short paper, it could focus the interest of researchers into areas that are fundamental for the singularity to be achieved. It is not unheard that popular literature can bring about strong interest in certain areas, making the mechanism for evolution to come into reality.

Perhaps a revised edition of *The Singularity is Near*, considering the potential dangers of climate change, could give another view towards the path to the singularity.

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Note: The views contained in this article reflect the views of the author only, and not necessarily those of the Royal Institute of Technology.

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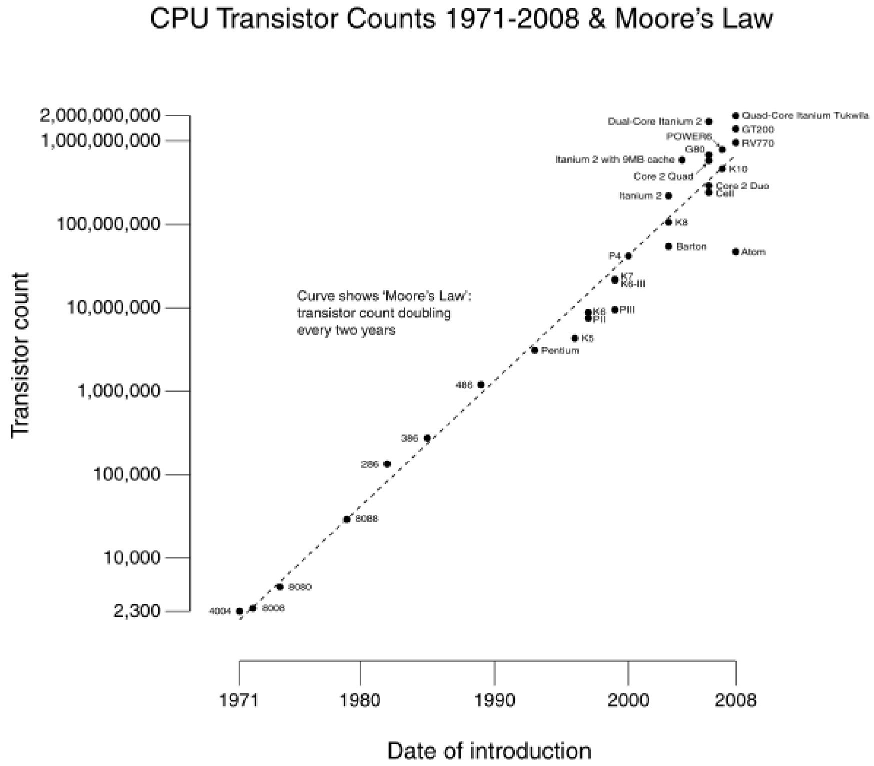
(Note: All hyperlinks were successfully assessed as of January 27th, 2011.)

Annex 1

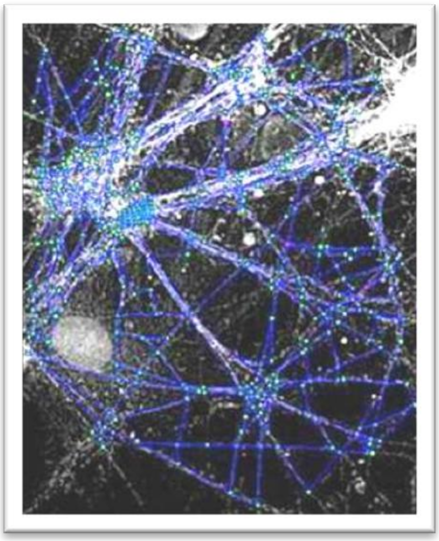
Source: Kurzweil (2005)

<u>Fifteen views of evolution</u>: When plotted on a logarithmic graph, 15 separate lists of key events in human history show an exponential trend. Lists prepared by Carl Sagan, Paul D. Boyer, Encyclopedia Britannica, American Museum of Natural History and University of Arizona, compiled by Ray Kurzweil, amongst others.

Annex 2



Source: Wiki commons



Graphical representation of the internet (left) compared to a biological neural network.

Image credits: Opte project and Physics buzz.