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A New Economic Era in Computer Science: DNA Vs Quantum Computing

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Abstract

The increasing rate of growth both of science and technology in our era, renders the forecasts for the development course of each technology, very significant for the strategic development designer of any organism, either this concerns an enterprise or a state or a union of states. Such a technology is the computer technology, which is currently to the limit of its current possibilities and is being prepared to pass into a new era and create a new economic environment. The silicon technology, because of its constructional restrictions, cannot maintain the existing growth rate for more than one decade. “Spintronics” or “molecular electronics” can constitute transient technologies, but the radical change will be the transition from serial to parallel calculating process.

Aim of this work is to constitute a useful tool for the forecast of development of the subversive technologies that will bring us to a new era of computer science. DNA computing and Quantum computing are considered as such technologies. The use of such a forecast may result in dramatic changes in the economic map of the companies engaged in information technology, since it will allow an early placement of them in upcoming competitive race.

Keywords: DNA Computing; Quantum Computing; Forecast; S-Curve Model; Hyperbolic Tangent Model.

1. Introduction

The revolution that was introduced by the computer growth changed the form of our world, importing us inter alia in a society of information via the internet. The possibilities of distribution of information were increased astonishingly with visible results in every sector of our life; from sciences, through the increase of scientific publications, and education, in all her rungs, to the very operation of our society and democracy.

The growth of computational science was described until today by an empiric rule, known as “Moore’s law”. According to this rule, the computational power is doubled every two or two and half years. This controversial rule functioned with very good results roughly for half a century. However, the projection of its validity for the next years, forecasts a limit around 2023 (Georgalis & Aifantis, 2013). That time point coincides with the theoretical forecasts for the possibility of lithography development, which constitutes the main tool of completed circuits incision (Tennant & Bleier, 2011). According to this logic, when the etching reaches in dimensions smaller than 6-7nm, insuperable obstacles are presented, owing to phenomena of electron leakage, quantum tunneling phenomena etc.

Therefore, the inevitable prospect that is brought about is the transition into a new era in the calculation science. Such transient prospects are presented by technologies known as "spintronics" (Verdaguer & Robert, 2013), which uses the spin of electrons, where the dextral rotation can express the element of zero (0) in binary system and the levorotatory as one (1).Transistors of a single molecule (molecular electronics) follow the same doctrine (Vuillaume, 2008). Nevertheless, all these technologies follow the basic logic of the existing one: the serial treatment, where the total of likely calculations coincides with the logic of one after the other calculation (Nguyen, 2006). The inversion of this logic is provided by the import of parallel treatment. In that case, the calculation of likely solutions of a problem results simultaneously, with obvious profits in the computational speed as well as in the energy and constructional cost (Lehtonen et al, 2014). Representatives of this parallel treatment of data are two technologies of completely different logic that are being developed at this moment; the DNA computing and Quantum computing. The knowledge of the development course of these two technologies is of fundamental importance for the analyst, who will determine the accession and the course of the organism which finances him in the corresponding technology. Possibly, the competitive race that follows will determine which technology will prevail and, consecutively, who will come out gained from the competitors that will have been included in time in this race. So, an appropriate forecasting tool is needed, so that the strategic policy-makers of the big agencies decide about it.

2. The S-Curve Model

Perhaps, the most critical element that characterizes a model is its accuracy. There are more accurate and less accurate models. What should one choose depends on the type of information needed from the model, through which we make the prediction. A very accurate model possibly reduces other important properties, especially its generality (Geroski, 2000). Due to a model high accuracy only a specific part of the phenomenon and not its entirety can be described. In general, we would say that science - in our case the strategic management - often merely limits the accuracy for the sake of generality as opposed to technology that seeks the greatest possible precision, since it is engaged to specific problems.

This case, however, concerns an entire, completely new science sector and, as nothing similar has been attempted until today, the prediction is expected to have a margin of error, which nonetheless will not reduce its value whatsoever. This is because when it comes to the development of an entire new scientific field, what is important is the trend and not the precise prediction. Thus, to select a proper management strategy, prediction is the key (Burgelman et al, 2006). In this effort it has been observed that the evolution of science - but also the evolution of technology and of many other biological phenomena - follows an exponential growth due to the positive feedback, which comes from the increasingly improving ways of recording and managing information and the better communication manners, so that the best results exported from one stage of the evolutionary process are used to create the next. Each development cycle is faster, based on the results of the previous one. In addition, discoveries and inventions created by the very evolution intensified and created an even faster development (Schumpeter, 1935; Bester, 2000). In the current globalized market, the long-term economic success is increasingly dependent on the generation, management and exploitation of knowledge. Investment in R & D is needed to produce knowledge and, in turn, the industrial innovation needs knowledge to produce wealth. In this way, the loop is closed and the R & D can be supplied with further private capital. The ability to unleash the potential of this knowledge through nanoelectronics is crucial for giving new impetus to industries that are no longer competitive due to strong international competition, as well as to develop new knowledge-intensive industries. The global industry nowadays operates in a highly competitive environment. For reasons related to the global economic crisis, many industries may be under-capitalized and may devote only limited resources for R&D and innovation. Banks and venture capitalists are very selective when offering risk capital, particularly in the areas they see as areas of high technological risk, uncertain commercialization time or such that could have adverse effects in moral perspective, health or environment. In this way, patents are needed to prove ownership of the knowledge and new entrepreneurs need not only be at the forefront of computational science, but also combine this fact with insight, related to strategic management and business planning (Porter, 1980; Dussange & Romanantsoa, 1987).

3. DNA Computing

It is the next step in building computers and requires the use of completely new materials. The DNA molecules, the material of our genes, have the ability to carry out calculations incomparably faster than the fastest computer of our era. The fact that the material is present in each cell makes it endless and very cheap. The research these days, seeks to incorporate DNA molecules in a chip so that it eventually creates the so-called biochip (Cervantes-Salido et al, 2013). Researchers have already managed to use these particles to perform complex mathematical operations. Regarding the storage capacity, it is incomparably greater than that of the existing ones. As an example we can mention that in 1cm^3 of DNA material, data of tens of terabytes can be stored.

The outset of research in the new technology was attributed to Leonard Adleman (1994), who introduced the high computing capacity of DNA. Adleman likened the form of information storage in the genes to the analogous of a hard drive in a computer. In his article, he described the use of DNA molecules as a solution to the "Hamilton's Path" problem or more simply "the traveling salesman problem". The reasoning in DNA computing is that the DNA helices can express some of the parameters of the problem with the appropriate encoding, through the combination of the four bases that form them – Adenine (A), Thymine (T), Cytosine (C) and Guanine (G).

Mathematically this means that we have a total of four bases, E= {A,T,C,G}, which can encode incomparably more information than the current binary set. Any sequence of these four bases may portray as either one parameter or a combination of parameters. Should DNA molecules be mixed in a test cube, they will be joined in all the possible combinations, with each combination representing a possible answer. In a minimum period of time, the possible responses are taking shape, while the wrong answers (the incorrectly shaped molecules) can be removed with appropriate chemical reactions.

Research is focusing on the two major shortcomings of the method, at this time. The first is that the removal of the wrong molecules requires significant time and the second that the procedure requires human intervention. A possible reply to the auto nomination of the process can be given through the creation of appropriate enzymes, which are biological catalysts and will have the role of the software that is used to achieve the desired calculation (Zhang et al, 2008).

The next big step was made by M. Ogihara & A. Ray (Ogihara & Ray, 1997), researchers from the Univ. of Rochester, who developed DNA logic gates. As known, logic gates are fundamental building blocks in the processing procedure, since they convert the binary code of serial signals, which are the input signals to the processor, so that it is processed into output signals. Instead of using electrical signals to carry out logical processes, the DNA logic gates are based on the code of macromolecules. They detect tracks of genetic material as input signals and they join them together to create the output signals. For example, the genetic portal "AND" joins chemically two input signals- that is to say, two DNA fragments- in order to create a chain that will serve as the output signal.

The new computer generation will change the current image of computers through the miniaturization that will lead to the enormous increase of the storage capacity with minimal power consumption. Still, the most important benefit is the dramatic increase in computing capacity through the parallel processing of data. In contrast to the serial logic of the existing technology and thus the achieving one goal every time doctrine, in the parallel processing we can take simultaneously all the possible answers for each question (Kruse et al, 1994).

Regarding the biochips, the solution seems to be the hybrid systems of electronic and biological components. In this direction, the development of MEMs (Micro- Electro Mechanical Systems) and NEMs (Nano- Electro Mechanical Systems) will help (Li et al 2003). The development of such systems apart from the obvious outcomes, will result in non-toxic equipments and also self-powered -in terms of energy, since they will consume energy derived from consuming their own DNA molecules.

4. Quantum Computing

The idea of introducing the quantum theory in computer science has been assigned to P. Benioff (1982). He is considered to be the first who implemented the quantum mechanics in the Turing machine, which is the basic idea in every known computer. The Turing (1936) machine’s bits, where each bit is a position in a long stripe which can take the value of 0 or 1 or be left blank and where a reading machine is reading this tape in order to give the instructions to the computer to carry out the program, in quantum computers they are simply converted into so-called qubits. Therefore, the quantum computers are not limited to two situations, but encode information in quantum bits, the aforementioned qubits. Specifically, the classical Turing machine's stripe exists now in quantum state and the same applies to the reading head. The symbols in every position do not only take the values 0 and 1 but may also be simultaneously the superimposition of 0 and 1, i.e. to be simultaneously 0 and 1 and all their values between (Wittek, 2014).

This reasoning leads to the conclusion that, in contrast to the existing serial computers which run one calculation each time, the quantum computer could run simultaneously many calculations, using the ability of parallel processing. Therefore, it provides a simple way to reach defined conclusions based on vague, ambiguous, inaccurate or incomplete information. It approaches the control problems, emulating the way in which a person would take decisions, and that is why it is considered an excellent choice for many applications control systems.

Certainly, in the use of quantum computers a major problem appears. When the qubit is in superimposition mode and we try to "read" it, the externally applied force places it into one of the two states: 0 or 1. Substantially, we are changing its value in our attempt to use it. A solution to this problem seems to be given by the quantum phenomenon of the "entanglement". Based on this, measurements can be made in the situation of qubit indirectly, so that the reliability of the system is maintained (Menon, 2014).

5. A Comparative Study of the Two Technologies

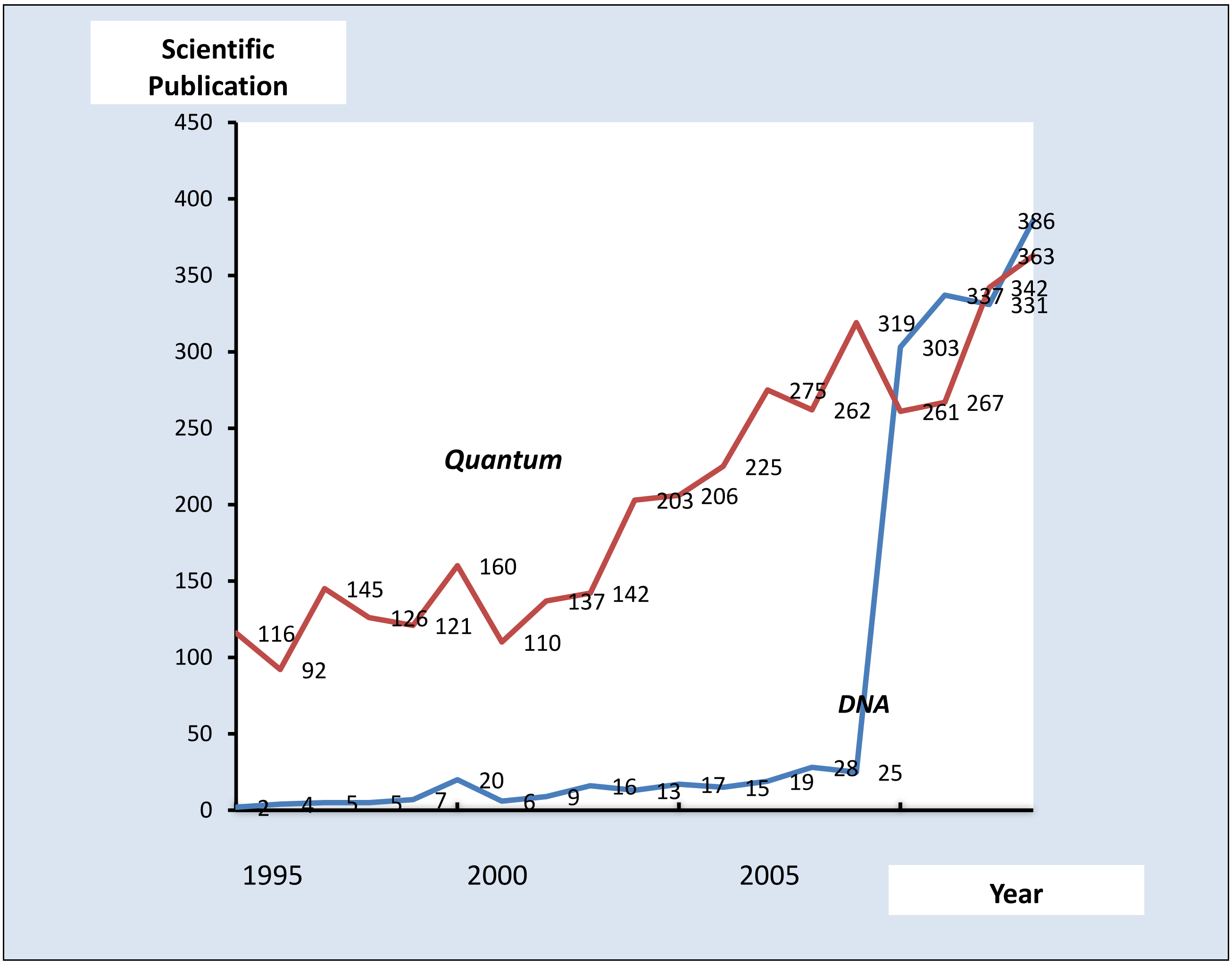
From the brief presentation of these two technologies in development, it appears that they both have great advantages and disadvantages. Both of them promise revolutionary changes in computer science with the introduction of a new concept in computational logic.

What an external observer needs, however, is to have a comprehensive view about which of the two technologies would most likely prevail. Data in Tab. I in Appendix clearly show that the technology of quantum computing involves a much greater number of publications, which indicates the corresponding tendency of the scientific community to deal with it, because of the greater familiarity with the theoretical background which rules it and is known for many years.

However, the technology referred to the DNA computing, is a completely new approach to the computer science, which incorporates an additional disadvantage: it requires the pairing of two scientific areas which are hardly related, namely biotechnology and computer science.

Moreover, only the biotechnology sector is in itself a new science with less than twenty years of a history and therefore both its familiarity and its spread cannot be compared to those of quantum-mechanics. The impressive growth in both the biotechnology and molecular computing appears in Fig 1; where we have an impressive leap forward shortly after 2007. This undoubtedly shows the interest of the scientific community to DNA computing.

Fig 1: Comparison of the Number of Scientific Publications on DNA Computing (Blue Line) to the Quantum Computing (Red Line)



Logically, the next step was to try to define the growth tendency of the two technologies using both the model of sigmoidal curves and hyperbolic tangent.

6. Forecasting DNA and Quantum Computing Evolution Via the S-Curve Model

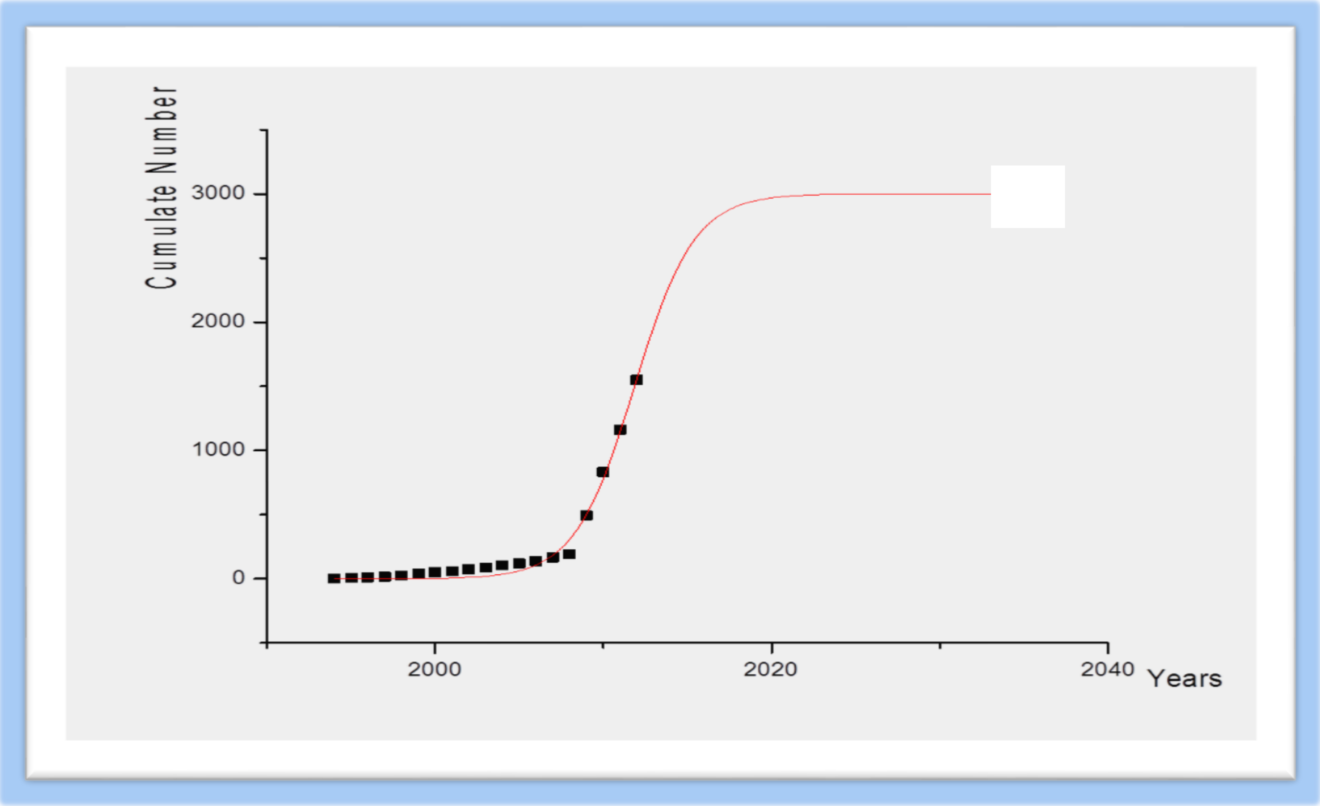
The data are related to the course of evolution of DNA computing, a case with particular characteristics, because it is about a completely new technology, which began to grow substantially after 2005. Initially for the technology of DNA computing, we admeasured the scientific publications in reputable scientific journals in two ways. One was the mensuration of the articles that involved in their titles exactly the term "DNA computing", i.e. were exactly about the subject that we are studying, and the second was the admeasurement of the articles which referred to terms relevant to the new technology, such as "DNA computing", the "parallel processing", "fuzzy logic" etc. The application in the mathematical model gave remarkably similar results, shown in the following Table 2 and in Fig 2. We used the Origin 9.1 Program to extract a forecast with the S-curve model.

Table 2: Values of the variables K, R, Xc as calculated by the program origin 9.1 with respect to the DNA computing via the logistic equation.

	Value	Standard Error
K	2988,2088	858,58913
x_c	2010,83774	0,98794
r	0,56357	0,07573

Inflection point determined about 2010, while the saturation is around 2023.

Fig 2: Forecast of Evolution of "DNA Computing"

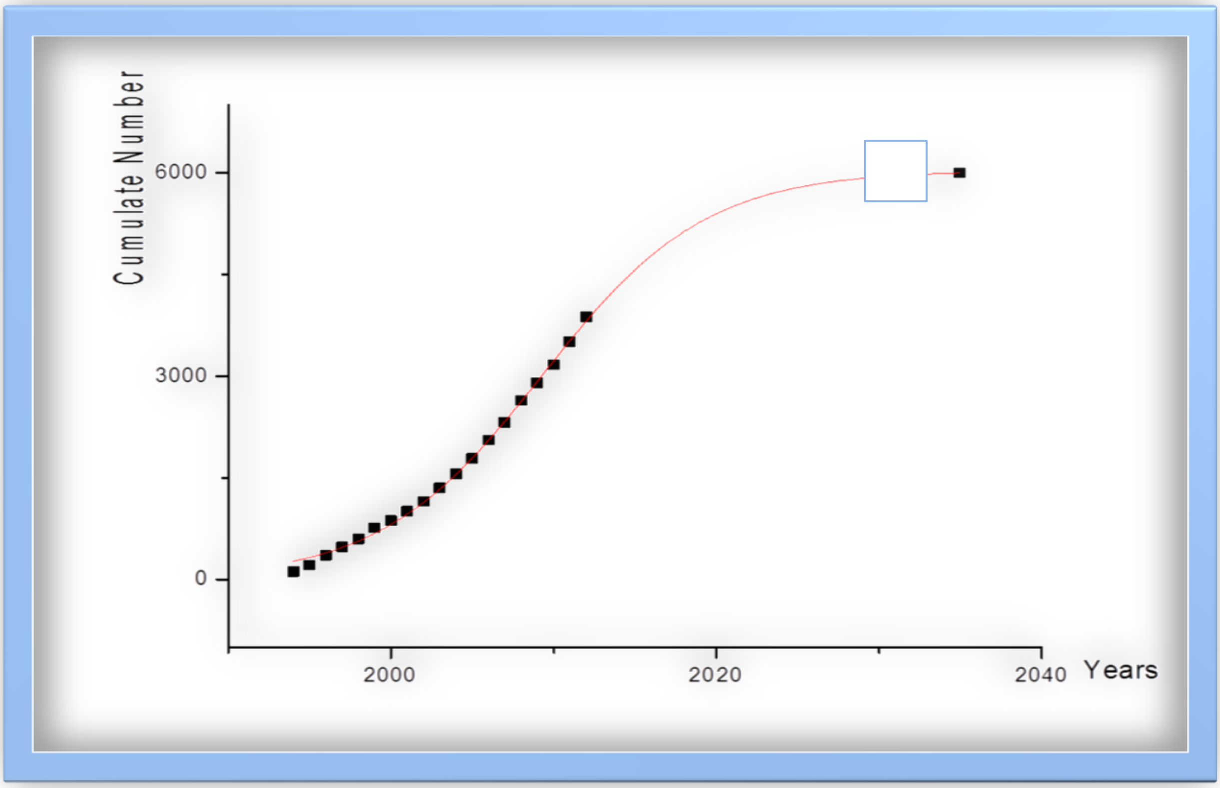


A similar procedure followed for the "quantum computing" and the results in principle are shown in table 3 and in Fig 3:

Table 3: Values of the variables K, R, Xc as calculated by the program origin 9.1 with respect to the Quantum computing via the logistic equation

	Value	Standard Error
K	5991,80392	429,48938
x_c	2009,22949	0,74302
r	0,2007	0,00902

Fig 3: Forecast of Evolution of "Quantum Computing"



In the case of Quantum computing the saturation time is about 2031. That is particularly important because it shows that this technology tends to be completed in terms of investigation several years later compared to its competitor. We also have an indicator of reliability for our estimates using the analysis of Debecker & Modis (1994). On the basis of the presented tables, we have: The maximum of publications for the DNA computing results from the fitting of the sigmoidal K=2988, while from the data that we have so far the corresponding figure is 1548. Hence 1548/2988 =0.52 or 52%. We assume an annual uncertainty at 10%. Table 5 shows a value K=2988 ± 12% with a reliability indicator of 90%.

In the same way, we are counting on the Quantum computing: K=5992 with value of up to date data: 3872. So 3872/5992=0,646 or 64,6%. With an annual uncertainty proportional to the previous case (10 %), with the help of table 6 of Debecker & Modis, K=5992 ± 9,8% and reliability index also of 90 %.

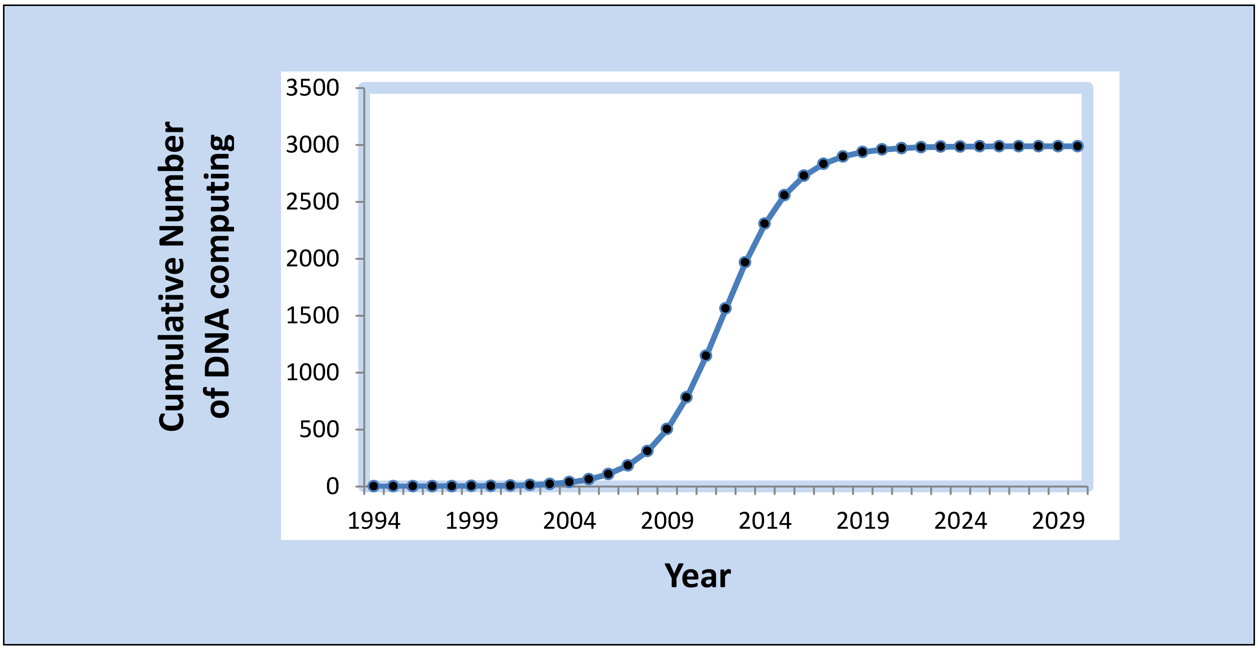
7. Forecasting DNA and Quantum computing evolution via the Hyperbolic Tangent Model.

We will use another mathematical model, so we can compare the results with those of sigmoidal curves. That model is called the Hyperbolic Tangent model. In Tab. II in Appendix are shown all data of DNA computing, as described above. In this case, we used the hyperbolic tangent model via the Microsoft Solver Program. The results obtained are shown in Table 4 and in Fig 4:

Table 4: Determination of DNA Computing Parameters Via the Solver Excel

Parameters	*Values*
r/2	0,282
b	-0,518
K/2	1494,117

Fig 4: Forecast of the DNA Computing Development Via the Hyperbolic Tangent Curve



From the comparison to the corresponding study with the model of sigmoidal, results once again largely a coincidence of forecasts. The maximum K value is determined by the model of the excessive tangent to K/2=1494,117 i.e. K=2988,234 and from the adjustment of the sigmoidal to K=2988,209, while the value of r also fully coincides. In the time course we have a minimum difference, as the adaptation of the sigmoidal leads to saturation in 2021, whereas with the model of hyperbolic tangent the corresponding time point is placed in 2025, within the limits of a normal statistical error.

The data related to the evolution of Quantum computing are shown in Tab. III in Appendix. It is also a new technology which is based though on a theoretical background - the quantum mechanics - which goes several years back. As a result the course of evolution is much more smooth than in the case of DNA computing.

Fig 5: Forecast of the Quantum Computing Development Via the Hyperbolic Tangent Curve

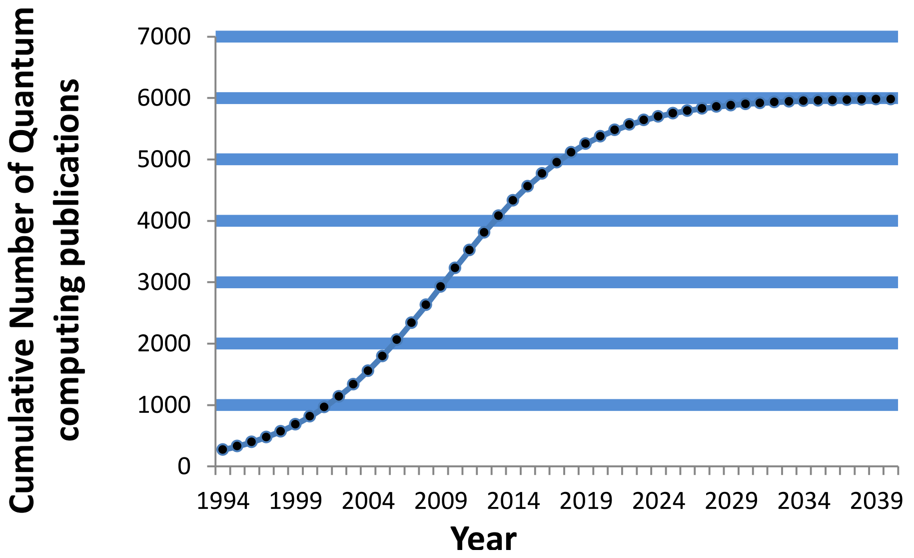


Table 5: Determination of Quantum Computing Parameters via the Solver Excel

Parameters	Values
r/2	0,100
b	0,077
K/2	2995,857

From the comparison to the corresponding study with the model of sigmoidals, results again largely a coincidence of forecasts. The maximum K value is determined by the model of excessive tangent to K/2=2995,857, i.e. K=5991,714 and by the adjustment of the sigmoidal to K=5991,809, while the value of r fully coincides (0,2007 the sigmoidal and 0,200 this one).

In the time course we have, once more, a little difference, as the adaptation of the sigmoidal leads to saturation in 2036, whereas with the model of excessive tangent the corresponding point in time is placed in 2031.

8. Conclusions

In such rapidly developing science field, anyone needs, in order to respond fairly, to develop creative and critical thinking through a process of 'lifelong learning'. This explains the phenomenon of saturation both in the model of sigmoidal curves and in that of the hyperbolic tangent. This is because, the sigmoidal curve for the scientific publications concerns a survey, which is done through the development of appropriate post-graduate, doctoral and postdoctoral programs. In conclusion, we would say that whatever the amount that a willing state will dispose, there must be a corresponding infrastructure to absorb it. However, these infrastructures are finite; they are corresponding to the training capacity provided by the research organizations of these countries (including universities). As a result, they are inevitably led to a relatively fast saturation due to their finite training capacities.

Taking into account the intellectual, scientific and technical challenges that are related to the computational sciences, investing in R & D is essential for each state or union of states if it is to remain competitive in the long term. In this sense, the support of R & D with the necessary financial resources is essential together with the existence of world-class researchers and competition between research teams in Europe.

However, the most important fact is that for DNA and Quantum computing capital investments are still low enables to design a timely strategic entrance for all interested parties in the forthcoming development race, without requiring huge capital. The question is how Quantum Computing, an older, more familiar and perhaps more mature technology than DNA Computing, seems to have been left behind; we may note the impressive growth of interest which occurred after 2005 regarding biotechnology, nanobiotechnology and so forth; an interest which is interpreted to a drastic increase in the cost of its financing and therefore to the turn of significant scientific potential in this direction. So we conclude that the main interest of the scientific community, at this time period, tends into DNA computing research. This is an important conclusion for the strategic planners of research policy of large states worldwide and for the leading technology companies, who would like to invest in this area.

Finally, the future research goal could be the study of the evolution of these technologies by introducing time delay. That is, to determine the time limits, within which anyone interested could invest without his investment being considered late.

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APPENDIX

Table I: Data Of Scientific Publications for DNA and Quantum Computing, and Their Cumulative Presentation Respectively

Year	DNA computing	DNA computing Cumulative number	Quantum computing	Quantum computing Cumulative number
1994	2	2	116	116
1995	4	6	92	208
1996	5	11	145	353
1997	5	16	126	479
1998	7	23	121	600
1999	20	43	160	760
2000	6	49	110	870
2001	9	58	137	1007
2002	16	74	142	1149
2003	13	87	203	1352
2004	17	104	206	1558
2005	15	119	225	1783
2006	19	138	275	2058
2007	28	166	262	2320
2008	25	191	319	2639
2009	303	494	261	2900
2010	337	831	267	3167
2011	331	1162	342	3509
2012	386	1548	363	3872

Table. II. Cumulative Data of the Number of DNA Computing Scientific Publications and Their Statistical Analysis

Year	t	Cumulative number of DNA computing publications	Adapting data	diff	diff^2
1994	-16	2	0,13	-1,87131	3,50178944
1995	-15	6	0,23	-5,7739	33,33796171
1996	-14	11	0,40	-10,6028	112,419128
1997	-13	16	0,70	-15,3022	234,1573445
1998	-12	23	1,23	-21,7742	474,1174024
1999	-11	43	2,15	-40,8471	1668,485402
2000	-10	49	3,78	-45,2196	2044,810317
2001	-9	58	6,64	-51,3644	2638,306363
2002	-8	74	11,64	-62,3614	3888,945145
2003	-7	87	20,39	-66,612	4437,158263
2004	-6	104	35,64	-68,3639	4673,621729
2005	-5	119	62,05	-56,9502	3243,327056
2006	-4	138	107,33	-30,6703	940,6646452
2007	-3	166	183,58	17,57914	309,0263035
2008	-2	191	308,20	117,2027	13736,4718
2009	-1	494	502,28	8,27655	68,50128121
2010	0	831	782,86	-48,14	2317,459695
2011	1	1162	1147,81	-14,1861	201,2467258
2012	2	1548	1562,37	14,37225	206,5616323
2013	3		1966,66	**MEAN**	**2170,111578**
2014	4		2306,35		
2015	5		2557,80		
2016	6		2727,03		
2017	7		2833,75		
2018	8		2898,30		
2019	9		2936,37		
2020	10		2958,49		
2021	11		2971,23		
2022	12		2978,53		
2023	13		2982,70		
2024	14		2985,08		
2025	15		2986,44		
2026	16		2987,21		
2027	17		2987,65		
2028	18		2987,90		
2029	19		2988,05		
2030	20		2988,13		

Table. III. Cumulative Data of the Number of Quantum Computing Scientific Publications and Their Statistical Analysis

Year	t	Cumulative number of Quantum computing publications	Adapting data	diff	diff^2
	-16	116	269,26	153,26	23488,59
1995	-15	208	325,85	117,85	13888,46
1996	-14	353	393,51	40,51	1641,40
1997	-13	479	474,05	-4,95	24,46
1998	-12	600	569,40	-30,60	936,23
1999	-11	760	681,56	-78,4414	6153,053547
2000	-10	870	812,50	-57,5036	3306,660865
2001	-9	1007	964,02	-42,9773	1847,051048
2002	-8	1149	1137,60	-11,3992	129,9424608
2003	-7	1352	1334,14	-17,8608	319,0079023
2004	-6	1558	1553,76	-4,23601	17,94378718
2005	-5	1783	1795,60	12,60482	158,8814614
2006	-4	2058	2057,64	-0,36482	0,133093366
2007	-3	2320	2336,61	16,61054	275,9101748
2008	-2	2639	2628,14	-10,8583	117,9035784
2009	-1	2900	2926,92	26,91922	724,6446431
2010	0	3167	3227,08	60,07518	3609,027201
2011	1	3509	3522,63	13,63288	185,8554063
2012	2	3872	3807,98	-64,025	4099,194591
2013	3		4078,25	**mean**	**3206,544339**
2014	4		4329,68		
2015	5		4559,67		
2016	6		4766,84		
2017	7		4950,88		
2018	8		5112,37		
2019	9		5252,54		
2020	10		5373,07		
2021	11		5475,88		
2022	12		5562,97		
2023	13		5636,31		
2024	14		5697,76		
2025	15		5749,05		
2026	16		5791,70		
2027	17		5827,07		
2028	18		5856,34		
2029	19		5880,50		

2030	20		5900,41		
2031	21		5916,81		
2032	22		5930,29		
2033	23		5941,36		
2034	24		5950,46		
2035	25		5957,92		
2036	26		5964,03		
2037	27		5969,05		
2038	28		5973,16		
2039	29		5976,52		
2040	30		5979,28		