Impact of Computing on the World Economy: A Position Paper

Frederic Harris
University of Nevada at Reno
fred.harris@cse.unr.edu

Gordon Lee
San Diego State University
glee@mail.sdsu.edu

Stuart Rubin
Spawar Systems Center
stuart.rubin@navy.mil

T. C. Ting
University of Conecticutt
ting@engr.uconn.edu

Billy Gaston
Anautics, Inc
billy.gaston@anautics.com

Gongzhu Hu
Central Michigan University
hu1g@cmich.edu

Abstract

As computing technologies continue to rapidly advance since the last two decades, the knowledge economy has become an important part of the overall world economy. In addition to its significantly contribution to economy growth, computing technologies also have profound impact on many aspects of society. A panel discussion was held at the 21st ISCA International Conference on Computer Applications on Industry and Engineering (CAINE 2008) in Honolulu, November 12–14, 2008, where the panelists and the audience exchanged views and ideas on this important issue. This position paper summarizes the panel discussion.

1 Technology and the New Economy

Ubiquitous computing is here to stay and it has become one of the main fibers of social, cultural, and economical life. It is an enabling technology that can increase the productivity in a wide range of applications and economical activities. The concept of "computing" has been continuously evolving. In early 80's, it was the marriage of computing and communication technologies that created the era of Internet-based information resources that affect and penetrate into our daily activities in information accessing. Now, it is the polygamy of computing, communication, storage, sensory and displaying technologies that can impact almost all social, cultural, and economical development as well as our daily life. Action-oriented-intelligent user/system interactive logic and system will be greatly improved for easy use as well as to augment our intellectual capabilities.

At the individual's level, the impact of computing puts opportunity into the homes and hands of many ordinary people and assists in solving everyday problems, thus enhancing the lives of many on a global scale. This idea can be seen with the inception and widespread use of the telephone, computers, databases and the Internet. The telephone provides a platform for local communication; the computer provides computing power to the individual; the database systems provide a local place to store and organize data efficiently; and the Internet provides a wide-scale platform for the aforementioned solutions where the best of each solution's capability can be leveraged and used globally. The world has experienced enhanced global communication, data organization and retrieval, and computing. These technologies have greatly affected the economy of countries able to properly leverage them without extreme restrictions. They have enabled individuals, small groups, and small countries to have a voice by providing just as much access, visibility and opportunities as big businesses and advanced countries.

1.1 Computing and Economy Growth

Computing, as a general term for digital technologies, has greatly contributed to the economic growth in the last twenty years. According to an analysis of 110 economies in the world by Harvard economists Jorgenson and Vu [9], the annualized growth of the world economy, measured in GDP, was 2.5% during the 1989-1995 period and 3.45% for 1995-2003, a 38% increase. They included three main categories as the factors responsible for economic growth: capital deployment, effective use of labor, and total factor productivity (TFP). The contributions to the overall economic growth are shown in Table 1.

It is seen in this table that the capital deployment (including Information Technology and non-IT capital) contributed almost 50%, while the othe two major factors, labor and productivity, contributed about 20-30% and 25%, respectively. The contribution of IT capital deployment almost doubled from 0.27% to 0.53% during these periods, while the impact of non-IT capital and labor to economic growth remained pretty much flat.

Table 1. Contribution to the world economy growth.

Period	GDP growth	Source of Growth			
		capital		labor	TFP
		IT	non-IT		
1989–95	**2.50**	0.27	0.91	0.89	0.53
1995–03	**3.45**	0.53	1.03	0.89	0.99

The growth in total factor productivity (TFP) is the output growth of an economy not accounted for by the growth in input, that was also almost doubled during these two periods. It has been well documented [2, 4, 6] that such rapid growth in productivity is impacted by the advancement of Information and Communication Technologies (ICT) in a significant way.

Undoubtedly, computing technologies will continue to make computers, communication links, and storage device run faster and to be more available. However, the focus will be more on information and knowledge processing in wide range of applications in almost all social and economical fields. The productivity and impact of computing should be measured on the outcome of the increased economical productivities of all applications.

1.2 Network Readiness

As the world economy becomes more knowledge-based, connectivity has been recognized as a critical factor not only to the economic growth but also a key component of general public infrastructure. For example, the *Ten Principles for Digital Excellence* suggested by the Chicago Digital Access Alliance (CDAA) includes the notion of "universal access to high-speed connectivity is a public right and necessity" [1]. Countries around the world have made great efforts and investment to enhance the networking infrastructure. According to the *Executive Summary* of the Global Information Technology Report 2007-2008 [5] at the 2008 World Economy Forum, one of the benchmarks of a nation's ability to foster economic growth is unified communication, that is, the networking infrastructure at the national level. The report shows a close correlation between the network readiness index of a country and its economic strength and competitiveness in the world economy. Countries with high rankings in the network readiness index are those developed countries in Europe, North America, and some Pacific regions. Several countries with fast economic growth in recent years (such as Brazil, China, India) also see their network readiness indexes rising as the governments of these countries increased capital investment in their communication networks.

A government's vision of ICT is fundamentally critical to the country's economy future. The World Economic Forum conducted an extensive *Executive Opinion Survey 2006–2007* that posted a questionnaire item "The government has a clear implementation plan for utilizing information and communication technologies for improving the country's overall competitiveness (1 = strongly disagree, 7 = strongly agree)." The survey statistics was included in the Global Information Technology Report 2007-2008 [7], from which we list the top ten countries with highest score (among 127 countries/regions) in Table 2.

Table 2. Importance of ICT to government vision for the future.

Rank	Country/Region	Score
1	Singapore	6.28
2	Portugal	5.73
3	Malta	5.70
4	United Arab Emirates	5.65
5	Malaysia	5.62
6	Denmark	5.51
7	Korea	5.50
8	Qatar	5.46
9	Estonia	5.40
10	Iceland	5.37

The U.S. is ranked 28 and the BRIC nations (Brazil, Russia, India and China) ranked 75, 103, 21, and 25, respectively.

Obstacles exist for the advances of ICT. Legal and regulatory changes will continue to lag behind that can hinder the speed of development. Potential abuses and security and privacy concerns may threaten and hinder the effective use of computing for social and economical development activities. So does the lack of focused efforts, funding, and government cooperation. The research community, particularly universities and colleges, need to make more efforts to apply their research results to real world applications rather than letting the results sit on shelves in libraries. Further research-oriented meetings and conferences should make such events more visible to investors, industry and government officials.

1.3 E-Skills

Networking is only a "hardware" measure of the economy-enabling technology; an even more critical measure is a skilled labor force that is capable of using the technological infrastructure to strive for innovation and achieve higher productivity. ICT is now regarded as a general purpose technology not only for ICT-producing industries but more importantly for the ICT-using sectors [4].

The term *e-skills* has been used to refer to the general knowledge and skill set related to computing and information technology in this digital world. Today's new knowledge-based economy requires a labor force with e-skills to sustain the economic growth. In [11], Bruno Lanvin, the Director INSEAD e-Lab, emphasized that "whether or not e-skills are available in sufficient numbers and quality will determine how countries succeed or fail as knowledge societies." However, such availability of e-skills is very much lacking today. The *Global IT Report 2007-2008* indicated that our economies fall short of providing the necessary volume and levels of e-skills, and the gap between the existing education systems and the requirements of the knowledge-intensive economy is growing. The President of the European Commission, Mr. Jose-Manuel Barroso, recently warned [3], "There is some urgency. Already today, millions of vacancies in Europe are unfilled because there are not enough people with the right skills to fill them. For example, in one of Europe's key industry, advanced network technology – which includes mobile telecommunications, one in six vacancies cannot be filled. Only three years ago, this was one in twelve vacancies. This is a fast-growing sector for employment, and we cannot let this situation get worse."

Similar situation also exists in other countries such as the United States. The Digital Skills Working Group Institute for a Competitive Workforce at the U.S. Chamber of Commerce categorizes digital skills in three levels: literacy, fluency, and mastery. It claimed that "a growing proportion of U.S. jobs require at least a basic level of digital literacy, with many of the best jobs demanding increasing levels of digital fluency." [8].

Actions must be taken to to address this problem of lack of e-skilled workers. Education is the key.

2 Computing and Education

One of the great impacts of computing will be in the areas of human learning and cognitive and logical inference activities that it can and will inevitably change the way we learn, work and live. Life long learning from birth at all levels will be the focus for long term and continuous economical development of our society. In the *Recommendation of the Europe Parliament and the Council on key competences for lifelong learning* [12], "digital competence" and "learning to learn" are among the eight key competences recommended for citizens to adapt flexibly to a rapid changing and highly interconnected world.

2.1 Current Educational Situation

Many countries have put great emphases on education, particularly in fields with large gap between the availability of skilled workers and market demands, such as the STEM fields – science, technology, engineering, and mathematics. There are quite a large disparities in the quality of individual's math and science education among countries. The education system in the U.S. is lacking more and more in preparing students for the transition from high school to college and from college to industry.

According to the *Global IT Report 2007-2008* [7], the countries ranked in the top ten in math-science education in 2007-2008 are listed in Table 3. The scores in the table were based on the *World Economic Forum Executive Opinion Survey 2006–2007* survey data (1 = lag far behind most other countries' schools, 7 = are among the best in the world).

Table 3. Quality of Math and Science Education.

Rank	Country/Region	Score
1	Singapore	6.34
2	Belgium	6.29
3	Finland	6.17
4	Hong Kong SAR	5.85
5	Switzerland	5.72
6	France	5.71
7	Tunisia	5.62
8	Taiwan, China	5.59
9	Czech Republic	5.53
10	Korea	5.46

The United States is ranked 43th. There has been a coordinated effort from government, academia, and industry in the U.S. to improve and reform the education systems to put greater emphasis on the STEM education at the precollege levels to attract more young people into these fields. Several U.S. government agencies, including the Department of Education and the National Science Foundation, have been actively promoting STEM education.

2.2 The Need for Educational Reform

Educational reform is served by computer-based training, which is vital to our national economic infrastructure in the medium-term on out. Success here is contingent upon success in computational creativity. It is understood that many details and justifications are necessarily missing from this overview for the sake of brevity.

The then President candidate Barack Obama said on October 15, 2008 that no nation in history has ever maintained a strong military in the absence of fiscal solvency. One aspect of fiscal solvency is a relatively full employment, in keeping with the Phillips curve (i.e., allowing for 4 percent unemployment) [13]. But this is not the complete picture. We need to maintain and thus invest in an ever-more educated workforce to remain economically competitive in the global economy. How do we do this? It used to be held that our schools served the role of education. However in the current form of our education systems, the schools cannot effectively reach students on the current or foreseeable budget. What is needed is the introduction of affordable computer technologies to capture good instructional practice to deliver quality education to each and every individual where it is needed and when it is needed. We know that this can be done. We found from our experience that intelligence is a phenomenon of scale. That is, we can expect intelligent tutoring and training for the military and country overall will cost less per delivered instructional unit with scale – until a point is reached where it becomes the most cost-effective method for delivery.

3 Challenges in Computing

Computing will continue to impact the economy in the years to come. To sustain such impact, we will need to address some issues concerning the development of computing technologies:

(1) It should be a technology to foster more collaboration with others versus one that removes human interaction and social development, unless human life is at stake.

(2) Researchers must be careful to determine if efforts should be focused on leveraging technology to think for us, to interpret and understand for us, to instruct us, to predict/forecast the future for us. Some may deem that as creating a sort of god for mankind.

(3) One must ensure that technology must not prevent users from knowing and experiencing fundamental concepts and learning experiences. For example in speaking with a tutor for grade school students, she noted that some students experienced difficulty in trying to find the definition of a word by searching a dictionary. Apparently, the students had practiced more on typing a word in a website form and after clicking 'Submit', the definition of the work was provided. The skills necessary to traverse a dictionary were had not been grasped.

(4) The technology should enable the enhancement of communication, computing, production, and thus economic opportunities. It is important to leverage this enhancement byproduct without eliminating the fundamental skills that should be learned by an individual. It is noted that this is said cautiously, knowing that computing is changing the human society and what once was noted as fundamental in one age may be obsolete in another, which suggests that the domain of fundamental skills is in a gradual process of redefinition.

3.1 The Next Revolution

Leverage computing power, communication, storage capability and collaboration techniques provide some insight into the next revolution in computing. All of these areas are driven by the immense need to access, analyze, process, and distribute information more intelligently. Information is the common denominator. It is sometimes said that information/knowledge is power; however, it should be said that correctly applied information/knowledge is power, assuming that the information being applied is of the necessary quality. Over the past years, steps have been initiated by a number of government and commercial entities to capture a plethora of data to address the issue of providing a more informative, preventative and predictive analysis to today's fleet management effort. A large number of such efforts consist of capturing more data. Unfortunately, whether it is historical data stored in legacy systems, current data captured by mechanics, or future data acquired by the use of sensor technology, some of the underlined issues still remain. These issues include but are not limited to making sense of the captured data, acquiring the appropriate combinations of data, making the proper relationships between data, as well as determining the relevance of said data. One of the biggest problems of data collection is determining what exactly one can keep and/or disregard. This creates a problem in an unnecessary cost of storage, which can be high when processing a large amount of data. Discovering and defining relationships between similar documents or sets of information has become a rather common and needed task within all areas of government, business and industry. Entities needing this capability range from potentially small scale systems, such as a small elementary school library book management systems, to large scale systems, such as military government information systems servicing several international logistic depots. The right information is often needed to obtain real time situational awareness, mission capability, damage assessment, and risk analysis. These issues affect all types of business and government organizations and may prove beneficial in business decisions, medical discoveries, advances in information retrieval and organization, environmental management, aircraft maintenance management and the like.

Throughout the business world, whether commercial or non-commercial, there exists the need for a solution that can capture input from disparate data sources, analyze the information, discover new information of relevance, link related information, and from said information allow the necessary personnel to make intelligible decisions. The term "necessary" is used because such a solution should possess the capability to adapt the distributed information to each end-user based on ability, role, clearance, learning capacity, and level of need. This involves some knowledge and interaction with the user. This technology should enable intelligent information access and interaction and not information overload. In specific it should provide the necessary understanding to make optimal decisions and not hinder decision making. Furthermore with such an increase in processing and computation, this computing technology will benefit from the current concentrated effort to develop clean, green energy alternatives.

3.2 Josephson/Optronic Hybrid Computing

One thing is clear – we need to innovate, or be rendered obsolete. Computing currently supports a significant percentage of the GDP growth as stated in Section 1.1; but it can contribute more if we commit to the development of faster, greener, more powerful devices. These devices can be small like PCs, but the greatest growth in power will come from the development of large computer utilities running hybrid optical and Josephson-Junction based circuits [10]. Josephson Junction devices already run at 50 to 100 times the speed of silicon circuits due to their much faster switching times, lower power, less heat production, less cross-talk, and far less parasitic capacitance. High-temperature supercomputing promises the development of Josephson chips that need run no cooler than the temperature of liquid nitrogen and can be switched/shunted with far less current. Another implication is less thermal stress at the relatively warmer temperatures. Also, liquid nitrogen is far easier to produce than liquid helium – the current gold standard for such devices. Moreover, recent advances in alloys promise the development of thermopiles that are closer to the theoretical limit for electronic heat-pumping. They can be used for the last stage of cooling because unlike silicon circuits, Josephson devices consume virtually no power and produce virtually no heat to be pumped out as a consequence.

Optronics allows for a speedup by a factor of one thousand to one million times where inexact computation is permissible (e.g., ensembles of neural networks). Much of AI works best using heuristic, fuzzy processing. For example, the Traveling Sales Problem can be solved on a PC in about a second if we relax the requirement for optimality to within one percent for about 200 cities. Conversely, optimality would take about one year on a supercomputer – and that is just for 200 cities. Clearly, one must take advantage of heuristic processing where possible to better enable domain-specific computation. Currently, the best unclassified computers operate at about 55,000 times the speed of a high-end PC. That is no small achievement. In the short-term, we should be able to up that factor to 5.55×10^6 using high-temp Josephson superconducting circuits. In the medium term, 5.55×10^9 seems plausible using optronic hybrids, and in the long-term, 5.55×10^{15} seems plausible – additionally based on a distributed computational paradigm. This is fast enough to outperform all of the combined mental facilities of the planet, given appropriate software. Such systems hold the promise of medical advances, engineering advances, and the like; but, one capability stands out among the rest – that is, the capability to revolutionize education and training.

3.3 Object-Oriented Intelligence

The vast majority of intelligent tutors and trainers these days have good graphics and multimedia support. They are lacking in intelligence, however. It is our opinion that the best architecture for delivering intelligence in tutoring and training applications is to arrange all multimedia materials as small objects that are maintained in an object-oriented relational database and brought up by a simple rule-based production system. The input to this expert system can be quiz questions (even connected to simulation programs), meant to elicit student feedback. The pattern of responses serves as the context to the intelligent system. While such a system can be prototyped and will certainly work, there is a problem. If n is the number of objects in the system, then there can be n! paths through the training system and thus it becomes impractical for an expert to precognate most response patterns.

3.4 The Creative KASER

At this point, we need to introduce the KASER family of intelligent systems [14]. They have theoretically and empirically applied computational analogy to map necessarily limited supplied knowledge to an appropriate response – along with a squelchable possibility of error. We know that the cost of knowledge acquisition is the limiting factor in constructing such systems. KASERs can, for example, allow for the development of a million dollar expert system for about a thousand dollars (i.e., the square root concept). They are also amenable to massive distributed heterogeneous and parallel processing and they can learn from a trusted user. All this comes together to allow for the definition of computational architectures that allow for the delivery of educational content in a reusable, augmentable, cost-effective manner that offers to make text-based instruction all but obsolete. We can show that there will invariably be a net return on the educational dollars invested from at least a national macroeconomic standpoint. Then too there will be desirable spin-off benefits, which include: the development of KASERs, the development of faster/greener computational systems, creative design and engineering, medical discoveries, scientific discoveries, educational superstars (i.e., excellence in teaching is an under-compensated skill set), and the like – all of which may pale in comparison to the benefits attendant to the transformation of the educational infrastructure in the United States and beyond.

We are lucky – lucky because the project outlined above need not begin with a giant step; rather, it can be phased in and guided by project milestones. We have demonstrated and can further validate each of the claims made herein. Capabilities attendant with scale can be limited to smaller studies for empirical validation. The goal is to make the student an active, rather than passive learner. This idea has not loomed on the horizon as a cost-effective possibility prior to our R&D on the KASER family of engines.

The NSF has supported small studies on intelligent tutoring systems, but they essentially used COTS (Commercial off-the-shelf) – not KASERs. Most importantly, the early progenitors did not think in the large – presumably because they could see no benefits of scale here and conventional expert systems invariably experience performance degradation with scale; whereas, KASERs perform better and better with scale. An intelligent system that cannot utilize all of the processor power made available to it is fundamentally flawed. Again, Josephson/Optronic hybrid computing offers the promise of extreme processor power. The program, if stood up, needs a political bridge from the academic to the superintendent and that needs to be understood from the inception. PERT charts may be employed in this regard. You get low cost, low risk, and virtually unlimited military (training) and societal benefits with success.

4 New Directions in Computing

In the competitive world, a strong cooperation between government, academia, and industry play a vital role critical to the health and prosperity of our economies and to improve the quality of life of the citizens. Bruno Lanvin suggested five key actions to take in work force enhancement [11], as shown in Table 4.

Although the five key actions above were targeted to the European Union, we believe they are also universally applicable to other countries including the U.S. As the researchers and practitioners in the field of computing, we are an integral part of the national and international coordinated effort for the advancement of computing to sustain the economy growth. In particular, the following highlight what the research community in computing should do in the next decade.

Table 4. Key actions to enhance e-skills readiness.

Key action	Expected leader
Share a compelling e-vision	government
Strengthen e-skills	government (visibility) industry (inclusion, action)
Formulate e-curricula	industry (needs) academia (formulation) government (regulatory)
Promote math and science	academia (curricula) government (vision) industry (sponsoring)
Enhance life-long learning	industry (content, rewards) government (fiscal) academia (e-learning)

(1) Develop more focused efforts.

(2) Specifically market government and commercial businesses to come to conferences (e.g. discount registration, create incentives for teaming with universities, program committee should consist of industry partners).

(3) Team with small businesses. Small businesses are positioned to create cost effective solutions, more innovation, more enhanced/focused solutions. There is funding specifically set aside for small business and university researcher teaming.

(4) Lobby to prevent government intervention without understanding.

(5) Much more research in security and confidentiality areas need to be emphasized.

(6) Standards and compatibility for the massively connected computational and information processing systems need more research and policy attentions for the information oriented and dependent society.

(7) Research in intelligent information processing need to focus on holistically and symbiotically for both static and dynamic data and knowledge.

(8) Software efficiency and reliability including systems as well as application software systems need to be emphasized.

(9) Intelligent and logical user/system interaction, including multi-media and sensory interfaces needs to be greatly improved and developed.

(10) Representatives from computing research and development communities need to be engaged more actively participating in policy, legal, and regulatory processes.

(11) Most importantly, we need to actively engage in the development learning strategies and activities in schools as well as in society for preparing individuals for effective use of computing and information systems for learning and working in our current and future information oriented society.

5 Summary

At *The Impact of Computing on the World Economy* panel at the CAINE 2008 Conference, the participants expressed and exchanged their views on this important topic and pointed out that such discussions need to continue and actions must be taken by all sectors of our societies, particularly on education and new computing technologies. This position paper summarized their discussions.

On the education front, we as researchers and educators need to be creative. Rote instructional presentation does not work any better than does fixed micro-managed lesson plans. Then, to cost-effectively scale human creative instruction, you need to develop computational creativity to the same level. Thus, software systems like KASER can be properly viewed as enabling the automation of the true instructional process – all of which can snowball into an improvement in American Society and concomitantly, the ever-present American Spirit. This spirit is perhaps best captured by the Walt Disney's phrase on the wall of the GE Carousel of Progress exhibit at the 1964 New York World's Fair, "If you can dream it, you can do it."

References

[1] Chicago Digital Access Alliance. Ten principles for digital excellence. `http://www.digitalaccessalliance.org/principles-for-digital-excellence`, 2007.

[2] Robert D. Atkinson and Andrew S. McKay. Digital prosperity: understanding the economic benefits of the information technology revolution. *Special Report of Information Technology and Innovation Foundation*, March 2007.

[3] José Manuel Barroso. Lisbon: a strategy for all seasons. speech at *Lisbon Council Growth and Jobs Summit*, Brussels, March 2008.

[4] Susanto Basu and John G. Fernald. Information and communications technology as a general purpose technology: evidence from U.S. industry data. *Economic Perspectives*, pages 52–67, 2008.

[5] Soumitra Dutta. Executive summary: the global information technology report 2007-2008. `http://www.weforum.org/pdf/gitr/2008/Summary.pdf`, 2008.

[6] John Fernald and Shanthi Ramnath. The acceleration in U.S. total productivity after 1995: the role of information technology. *Economic Review*, Q1:1–15, 2004.

[7] World Economy Forum. The global information technology report 2007-2008. `http://www.weforum.org/en/initiatives/gcp/Global%20Information%20Technology%20Report/index.htm`, 2008.

[8] Digital Skills Working Group. `http://www.uschamber.com/icw/strategies/digitalskills.htm`.

[9] Dale W. Jorgenson and Khuong Vu. Information technology and the world economy. In *Proceedings*. Federal Reserve Bank of San Francisco, 2005.

[10] Brian David Josephson. The discovery of tunnelling supercurrents. *Reviews of Modern Physics*, 42(2):251–254, 1974.

[11] Bruno Lanvin. E-skills, competitiveness and employability: knowledge societies next frontier. In *European E-skills 2008 Conference*, 2008.

[12] European Parliament and the Council. Recommendation of the Europe Parliament and the Council of 18 December 2006 on key competences for lifelong learning. *Offical Journal of the European Union*, L 394:10–18, December 2006.

[13] Alban William Phillips. The relationship between unemployment and the rate of change of money wages in the United Kingdom 1861-1957. *Economica*, 25(100):283–299, 1958.

[14] Stuart H. Rubin, S. N. Jayaram Murthy, Michael H. Smith, and Ljiljana Trajković. KASER: knowledge amplification by structured expert randomization. *IEEE Transactions on System, Man, and Cybernetics — Part B: Cybernetics*, 34(6):2317–2329, 2004.