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Frontiers of research and future directions in information and communication technology

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ABSTRACT

Information and communication technology (ICT), characterized by continual innovation and rapid technological change, is having a tremendous impact on society. Research and development in ICT are being conducted throughout the technology sector, and fundamental research is being carried out in many university departments of electronics, computer science, and engineering. This paper deals with frontiers of research and trends in selected areas of ICT, including computer hardware, microelectronics, and semiconductor devices and materials—areas that are leading the innovations in ICT. It briefly describes emerging technological developments, and concludes with advances in software engineering.

1. Introduction

The convergence of the fields of information technology (IT) and telecommunications has produced the term "information and communication technology" (ICT), with "communication" including the field of telecommunications. ICT research is conducted under a number of umbrellas and fields including computer science and engineering (computers, computation, communication, and information science), and electronics engineering (robotics and artificial intelligence), all related to ICT. Publications in these broad fields appear in numerous journals, including those produced by the Institute of Electrical and Electronics Engineers (IEEE) and the Association for Computer Machines (ACM).

The remainder of this article is a brief discussion of what I see as the current status of research and future directions in the areas of information and communications, which are driving the advances in ICT.

2. Advances in computer hardware

Research and development in computer hardware are leading to significant reductions in the size of components and subsystems. This is due not only to the ability to incorporate more transistors on chips, but also to the switch from conventional servers to *blade* servers in computer installations. For most IT departments, blades are a huge improvement over conventional rack-mounted units. This compact and slim computer (hence the name "blade") typically uses the same Intel or AMD processors and Windows or Linux operating systems as most other servers, but blades consume much less power and take up much less room. This will have an impact on the size of mainframe computers and supercomputers, as they will require less area.

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3. Microelectronics and semiconductor devices and materials

For the past four decades, the productivity and performance of microelectronics have advanced at exponential rates unmatched in technological history. The number of transistors per microchip has skyrocketed by a factor of about 100 million, while the cost of a chip has remained virtually constant. Microelectronics has become the principal driver of the modern information revolution, and the ubiquitous microchip has had a profound and pervasive impact on our daily lives.

Microelectronics is in rapid transition to nanoelectronics. For instance, the physical laws governing metal oxide semiconductor field effect transistors (MOSFET) behavior support the projection that device dimensions that began at 25 μm in 1960 can be scaled down from the 0.25 μm range to the 0.025 μm or 25 nm ranges after 2020.

Since microelectronics are integral to many current and future technology developments, research in design, modeling, fabrication, and testing of solid-state devices is ongoing in many university and industrial laboratories. This research includes semiconductor electronic devices, photonics and optical devices used in data storage systems, and the increasingly complex area of optical networking. Semiconductor research is also being conducted into the use of materials other than silicon, such as epitaxial germanium–silicon junctions and devices, nitride semiconductors, and optoelectronic materials and devices.

Another important area of research is electronic design automation (EDA), which has been active for over 25 years. However, advances in EDA alone cannot maintain the progress of integrated circuit (IC) designs. Frontier research is being conducted to develop silicon components created in tandem with design automation tools. These new technologies will facilitate implementation of a silicon system that can be manufactured. Work in this area includes analog and mixed-signal IC design; low-power architectures and circuits; designing for manufacturability; circuit-level modeling, optimization, and synthesis; verification and system design; computer architecture; and hardware–software co-design.

In the real world, advances in productivity and performance do not increase endlessly. Consequently, the paramount questions now facing microelectronics are: How much longer can we expect these advances to continue? What lies beyond the profound and pervasive impact that microelectronics have already delivered to society?

4. The transistor laser

The transistor has spawned a $300 billion per year semiconductor industry. The transistor makes possible a lifestyle that includes cellphones, PCs, digital cameras, MP3 players, medical imaging systems, set-top boxes, supercomputers, and the Internet. Now it promises to emit light, and with that comes the possibility of speedier broadband communications in both telecommunications networks and within and between chips. A team at the University of Illinois at Urbana-Champaign [1] has an extraordinary prototype transistor that can switch on and off more than 700 billion times per second, faster than any other transistor in the world. It is made from indium phosphide and indium–gallium–arsenide, the same type of compounds used in today's light-emitting and laser diodes.

This discovery will be followed by a more powerful kind of device, a transistor laser. It will put out both electrical signals and a laser beam that can be directly modulated to send optical signals at the rate of 10 billion bits per second. With some further modification, the transistor laser will eventually send 100 billion bits per second or more.

5. Silicon chips

The truth of Moore's Law—the number of transistors that can be placed on an integrated circuit is increasing exponentially, doubling approximately every 2 years—has been demonstrated relentlessly. Data rates have soared, Internet traffic continues to swell, and wired and wireless technology expands constantly to cover continents. Users now expect fast, free-flowing bandwidth whenever and wherever they connect with the world. Within the next decade, the circuitry now found in a rack of today's servers—which are able to churn through billions of bits of data per second and handle all the data processing needs of a small company—will soon fit neatly on a single silicon chip. However, as newer, faster microprocessors emerge, the copper connections that feed the processors in computers and servers will prove inadequate to handle such large amounts of data. At data rates approach 10 billion bits per second, microscopic imperfections in the copper or irregularities in a printed circuit board begin to weaken and distort the signals, even when traveling distances as short as 50 cm.

New board materials and new techniques will provide some performance gains, but also will cost more. Researchers are now replacing copper with optical fiber and electrons with photons. This process is called silicon photonics, and it will result in affordable optical communications. Manufacturers will be able to build optical components using the same semiconductor equipment and methods they now use for ordinary integrated circuits, thereby dramatically lowering the cost of photonics.

Meanwhile, performance gains will be significant: integrated onto a silicon chip, an optical transceiver could send and receive data at 10 billion or even 100 billion bits per second. This kind of bandwidth will, in turn, dramatically alter the ways computers are used. With optical interconnects in and around desktop computers and servers, it will be possible to download movies in seconds rather than hours and conduct ultra-fast searches through gigabytes of image, audio, or text data. Multiple simultaneous streams of video arriving on PCs will open up new applications in remote monitoring and surveillance, teleconferencing, and entertainment.