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# Introduction to Information and Communications Technology (ICT)

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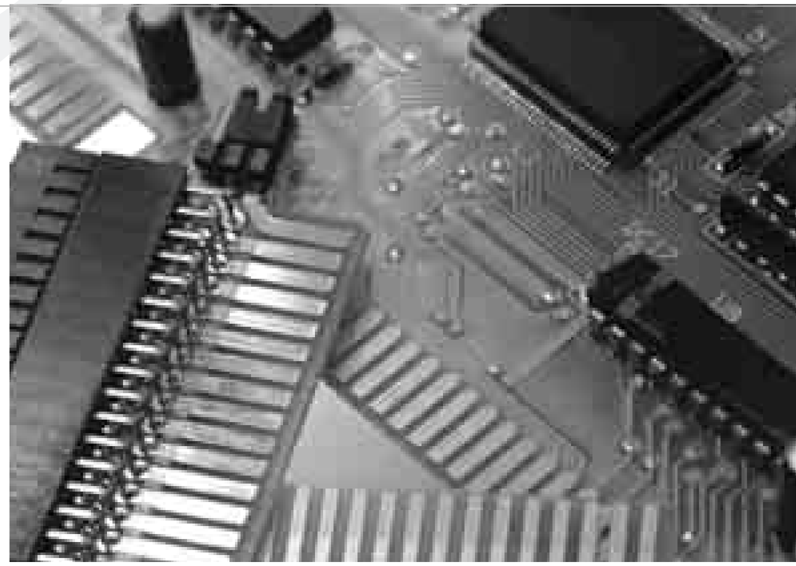
REPORT

## Table of Contents

# 1. Introduction



This chapter begins with a snapshot of the ICT sector and an outline of the products and services it provides. It concludes with a brief history of how ICT became a central player in the advanced economies and the patterns that will characterize its ongoing development.

Each of the subsequent chapters examines one of the core technologies on which ICT builds and a sketch of the industries and jobs involved. The concluding chapter presents an overview of how ICT jobs are expected to evolve over the coming decade.

The purpose of this document is to help inform the non-technical reader about ICT and how it is profoundly reshaping the entire economy.

## 1.1 What is Information and Communications Technology (ICT) and Why is it Important?

In the economic accounts, the OECD[1] approximates ICT as the industries that *process* (including capturing, transmitting and displaying) information with electronic systems. Industry Canada follows the OECD definition[2] in the table below.

Table 1: Revenue and Employment Profile of Canada's ICT Sector (2006)[3]

| Sector | Revenue (CDN$ Billion) | Employment |
|---|---|---|
| ICT Manufacturing | 22.2 | 89,300 |
| ICT Services | 77.7 | 407,700 |
| Software Publishing | 6.9 | 39,800 |
| Telecommunications Services | 36.4 | 119,700 |
| Cable Distribution | 7.4 | 19,500 |
| Internet Svc Providers | 2.0 | 7,800 |
| Data Processing, Hosting | 3.0 | 16,300 |
| Computer Systems Design | 22.0 | 204,600 |
| ICT Wholesaling | 39.1 | 75,100 |
| **Total ICT** | **139.0** | **572,100** |

ICT represents about 3.5 percent of employment[4] and generates 4.6 percent of Canadian GDP. However, its importance is far greater than the numbers suggest.

### ICT's Importance

ICT is a landmark development that economists term a *Technological Revolution*: a cluster of new and dynamic technologies, industries and products that massively restructure the economy over a period of about five to six decades. In modern times, the *Industrial Revolution* was the first such upheaval.[5]

Technology packs a powerful business punch, generating over half of all economic growth. Yet the epicenter of these eras of transformative growth comprises just a few closely interacting industries. In fact, four core industries drive the *Information and Communications Technology (ICT) Revolution*:

*The Industrial Core of the ICT Revolution*

- Computers;
- Telecommunications;
- Software; and
- Semiconductors (microchips).

1 Organization for Economic Cooperation and Development

2 Note that the OECD definition is a work in progress. It was first proposed in 1998, revised in 2002 and will be further modified to reflect members' recommendations.

3 *Canadian ICT Sector Profile*, Industry Canada, Strategis, <http://www.ic.gc.ca/epic/site/ict-tic.nsf/en/h_it07229e.html> (July 2007).

4 Based on total employment of 16,396,200 (March 2006).

5 Economists identify four subsequent eras of major transformation: Steam & Railways; Electricity & Heavy Engineering; Oil, Autos & Mass Production; and Information & Communications Technologies.

A hive of interconnections among these four industries has evolved a comprehensive base of design and production know-how: the *platform technology* on which the products and applications of the ICT Revolution are built.

*The Platform Technology of the ICT Revolution*

- *Microelectronics:* The design and manufacture of integrated circuits made from semiconductors;
- *Software:* The detailed instruction sets that tell the circuits what to do; and
- *Photonics & Wireless:* The generation, control, transmission and detection of electromagnetic radiation to support the operation of electronic systems.

This platform technology comprises the collective scientific, engineering[6] and hands-on know-how that generates the value added of ICT products and services. The advantages these products and services offer are so compelling that they have rewritten best practice across the entire economy. ICT applications range from advanced sectors like aerospace and biotechnology to long-established businesses like banking and retailing. The widespread application of ICT products and services has literally recreated economic activity in their image: unprecedented access to information—anytime, anywhere.

## 1.2 The Products and Services of the ICT Revolution

Above all else, ICT defines a new way of doing business; literally rewriting the rules of the game across the board: from products, to entire industries, to society itself. It is a relentless and pervasive force of change. As Marshall McLuhan observed almost half a century ago:

> "We shape our tools, and afterwards our tools shape us."

The visible agents of change that reshape the way business is done are *electronic systems*. They are the products that result from the application of the revolution's platform technology. They range from garage door openers and microwave ovens to medical imaging devices, air traffic control radars and ATMs. Worldwide, electronic systems represent about a US$1.3-trillion market that can be segmented into four major end-use markets:

Table 2: The Global Electronic Systems Market (2005)[7]

| Sub-Sector by End-Use | Revenue (US$ Billion) | Per cent of Market |
|---|---|---|
| Data Processing Equipment, e.g.: PCs, Servers, Computer Peripherals, Storage , Displays | 365 | 29 |
| Other Electronic Equipment, e.g.: Aerospace, Automotive, Industrial | 328 | 26 |
| Communications Equipment, e.g.: Handsets, Telecom infrastructure, Networking, Broadband | 290 | 23 |
| Consumer Electronics, e.g.: Appliances, TVs, Audio Visual, Game consoles, Set-top boxes | 277 | 22 |
| **Total** | **1260** | **100** |

6 Engineering disciplines are based on science, mathematics, proven models and analysis that yield predictable, reproducible results at economic cost. Software is a young field, not yet a fully developed engineering discipline.

7 Semiconductors: Technology and Market Primer 4.0, CIBC World Markets, (January 2007).

Services made possible by ICT products are the invisible agents of change—hidden in plain sight—because they are such an integral part of our daily lives. Such services range from Google® and eBay® to cell phones and GPS, from call centres to online banking, from computerized dental records and images to e-government.

As Canadian data demonstrates (see Table 1), even within the ICT sector proper, manufacturing revenues are far overshadowed by services. In fact, services of all kinds are so pervasive that in the advanced economies they represent some 70 to 80 percent of GDP. This is the real power of the ICT Revolution, a paradigm shift in the entire fabric of the economy, a decades-long transformation that has powered a quantum leap in productivity.

The ICT Revolution and the core industries that have developed its platform technology of solid-state electronics systems have roots that stretch deep into centuries past.

## 1.3 A Brief History of the ICT Revolution

The Computer industry is synonymous with the twentieth century. However, computers are modern descendents of the 5,000 year old abacus. The telecommunications industry also has a long—and separate history—until its intertwining with the computer industry in the second half of the twentieth century. Twenty-five centuries ago, Greek armies used an 'optical telegraph' to relay signals from hilltop to hilltop using combinations of five torches. In modern times, Napoleon's armies used a line of fifteen semaphore stations to relay massages 180 km from Paris to Lille. In fact, military applications were a key driver behind the twentieth-century emergence of ICT: *the marriage of computing and telecommunications*.

The essence of the ICT Revolution is the marriage of computing and telecommunications.

The other driver—and vital connecting link between the once separate industries of computing and telecommunications—was *electronics*. The electric telegraph opened the era of instantaneous long-distance communications in the 1830s. Combined with railways, beginning in the American Civil War, it the led to the emergence of modern warfare based on rapid movement and communications.

By the 1870s, the world's major cities were connected by telegraph in a 'Victorian Internet.' In 1876, the telephone extended instant communications to voice. 'Wireless telegraphy' (radio) conquered the North Atlantic in 1901 and was monopolized by the American government as a key weapon of naval warfare when it entered World War I.

By the late 1920s, electronics was first applied to computers. While advanced mechanical computers had been built as early as 1832, it took until 1951 for electronic computers to become a commercial reality. They were the product of the enormous electronics advances of World War II that saw the invention of vacuum tube computers in both the United Kingdom and the United States as part of the war effort.

However, vacuum tube electronics was only the humble beginning. It was the new field of *solid-state electronics*, marked by the pivotal inventions of the transistor (1947) and the integrated circuit (1959), that set the stage for what economic historians now call the *Information and Communications Technology Revolution*.

The invention that changed the world was the *microprocessor* (1971), literally a programmable computer on a chip. On a sliver of silicon smaller than a fingernail, it held as much computing power as the first mainframes—massive machines that filled entire rooms. More importantly, microprocessors made computing affordable, reliable—and ultimately commonplace.

In 1971, the microprocessor triggered the ICT Revolution.

Today, microchips are a US$248-billion global business (2006): the *semiconductor industry*. They are the building blocks of the solid-state electronic systems that have created new industries, from cell phones to software, and rewritten the rules of the game in long-established ones, from banking to retailing.

The companion ICT platform planks of *photonics, wireless* and *software* appeared almost simultaneously with that of microelectronics. All three augment the power and impact of the microprocessor.

While software had begun in the late 1940s as part of developing practical applications for mainframe computers, it only evolved into a stand-alone business by the early 1970s—enormously facilitating the widespread business application of computers.

Wireless in the form of mobile telephony had been successfully deployed by AT&T beginning in 1946; however, it remained a niche market in the shadow of AT&T's telephone monopoly. It was not until 1973 that Motorola's public demonstration in New York City signaled the coming mass market arrival of the cell phone – made portable and practical by the microprocessor. The first U.S. commercial cellular service was launched by Ameritech in 1983. By 1987, cell phones had grown so fast they used up the limited spectrum made available to them by the U.S. Federal Communications Commission (FCC).

Photonics was the final component of the ICT puzzle to fall into place. It made possible the high-speed economic transmission of huge amounts of data on which the information economy depends. In 1970, the twin breakthroughs of practical lasers and low-loss glass fibre sparked a worldwide effort to develop fibre optic transmission systems, the heart of the Internet. First generation transmission systems began to be deployed in 1978, and the 'seed' of the Internet—a backbone linking supercomputing centers—was planted in the U.S. by the National Science Foundation in 1985. By 1990, backbone transmission speeds were upgraded and the fledgling network expanded to sixteen sites. The term 'Internet' first came into use to indicate connectivity to this backbone.

*In Summary*

Recent economics research indicates that *platform technologies* like ICT fully unfold over decades as they spread across the economy in a process of diffusion and assimilation. The process is well enough understood that economists can now outline the broad pattern of developments that characterize economic revolutions. The four major phases of the ongoing ICT Revolution are summarized below.

## The Lifecycle of the ICT Revolution

The platform technology is built around a *breakthrough innovation: the microprocessor*. It marked a major discontinuity that opened up a whole new frontier of design and product possibilities. It fired the imagination of entrepreneurs, engineers and investors. Its inspired application was fueled by falling microchip prices, rapid performance improvement and widespread availability.

In the **Introductory Stage** (approx. 1971–1984), pioneering producers of microchip products, like pocket calculators and the first personal computers, gained experience, and markets gradually learned what the new technology was 'for.'

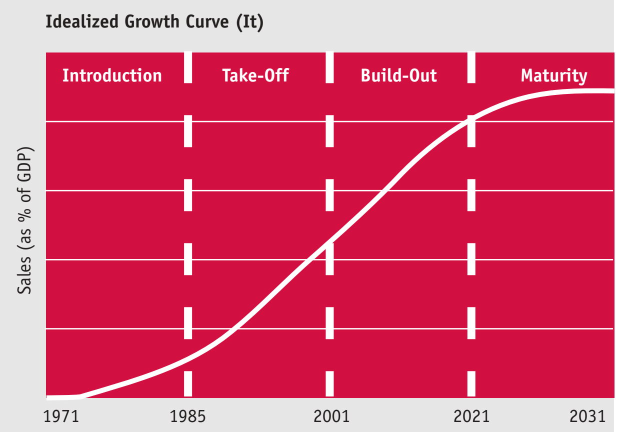
In the **Take-off Stage** (approx. 1985–2000), process innovation in chip-making—the enabler of the ICT Revolution—drove falling prices that sparked accelerating double-digit growth as major applications like PCs and cell phones resonated with users.

In 2008, the revolution is now in the **Build-Out Stage** (approx. 2001–2021). Radical innovation is over, replaced by incremental improvements that sustain steady but unspectacular single-digit growth toward the (now) discernable outline of full market penetration—all technologies no matter how advanced ultimately fill the needs of finite markets. The major market applications are now well established. Technology is becoming a *supporting actor* as marketing and distribution increasingly take the lead in heightened competition for remaining markets. Products and markets are undergoing *increasing segmentation* as a result.

In the **Maturity Stage** (approx. 2021–2031), market growth will further decline toward the overall rate of economic expansion. The platform technology will 'hit the ceiling' of its physical performance limits and remaining opportunities for improvement will be increasingly realized with new inputs from younger industries.

These four stages of the ICT lifecycle are *distinguishable by their characteristic growth performance*. This is shown below in Figure 1.

Figure 1: The Four Stages of the ICT Revolution




- **Introduction:** Slowly, pioneering producers gain experience and markets gradually learn what the technology is 'for.'
- **Take-Off**: Significant price and performance improvements spur accelerating double-digit growth.
- **Build-Out**: Marketing and distribution overshadow technology in competition for remaining markets. Growth slows to single digits.
- **Maturity**: Inputs from younger industries help sustain innovation as growth further declines toward the overall level of economic expansion.

In the following pages we look in more depth at each of the technologies that are major planks, both today and tomorrow, in the ICT platform: microelectronics, photonics, software, wireless and nanotechnology. We briefly outline each component technology: What it is and the major markets it serves. Each chapter concludes with a profile of some leading Canadian companies in the field and typical jobs.

We begin with microelectronics, literally the 'structural steel' on which the edifice of the ICT economy is built.

# 2. Microelectronics

Microelectronics is the business of designing and producing microchips. As outlined in Chapter 1, it is a US$248-billion global business (2006). Microelectronics produces the building blocks from which electronics systems are built.

## 2.1 The Anatomy of Electronics Systems

Electronics systems, e.g., a PC, are built around the motherboard—a master circuit board that provides the electrical connections to bring together the tasks performed by smaller circuit boards. For example, in PCs, these circuit boards handle supporting jobs like sound output, external memory storage and control of video displays. The circuit boards provide mechanical support and electrical interconnections for the microchips and electronic components mounted on them. It is the circuits formed by these component parts that ultimately carry out the electrical signal processing that lies at the heart of electronics systems' applications.

Microchips are tiny electronic circuits that are created by a combination of chemical and photolithographic processes on the surface of thin crystals of silicon. The most advanced chip-making processes (2008) currently make production runs where the smallest circuit features measure only 45 nm.[8] The workhorse components of these circuits are tiny on/off switches (transistors) that are created by laying down very thin overlapping layers of materials. Whereas the microprocessor chip (Intel's 4004) that announced the ICT revolution had some 2000 transistors, today's advanced microprocessors have *billions*, e.g., Intel's Itanium 2 (2006) has 1.72 billion transistors.

The most remarkable achievement of microelectronics production technology is that these huge numbers of transistors and their supporting components are created, *complete with the 'wiring' (interconnect) that combines them into functioning circuits*. The resulting marvels of engineering are called integrated circuits (ICs), typically referred to as microchips or just chips.

Microchips are the basic building blocks of electronic systems

The complexity of integrated circuits is both immense and achieved at the unimaginably small scale of viruses.[9] Just four Itanium 2 microprocessors have about as many transistors (6.88 billion) as there are people on earth[10]—and they work in unison to accomplish useful tasks like storing and processing information in the form of electrical signals that flow through them. An overhead view of a microchip (stripped of its protective packaging) is shown below in Fig. 4. This is the Intel 4004 chip that launched the ICT Revolution almost 40 years ago. This tiny chip packed as much calculating power as ENIAC, one of the first electronic computers—that had the footprint of a modern bungalow.

Figure 2: The Intel 4004 Chip (1971)

*Intel 4004 (1971)*

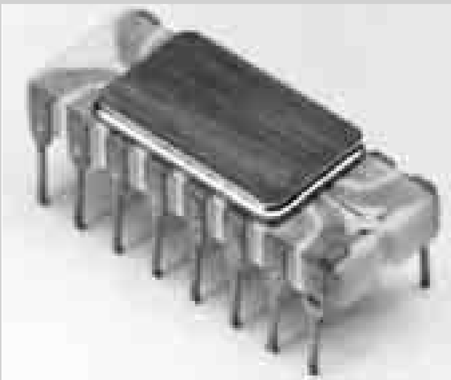
- Silicon chip: about 0.6"cm tall
- Note bond wires 0.025 mm (the short white lines around the edges of the chip). These connect sub-circuits of the chip to the protruding pin connections.
- Blocks of transistor circuitry are visible
- 2,250 transistors in all
- No storage included: this was provided by a separate chip.

[8] One nanometer is one-billionth of a metre.

[9] Most viruses are in the range of 10 to 100 nm.

[10] About 6.7 billion (2008).

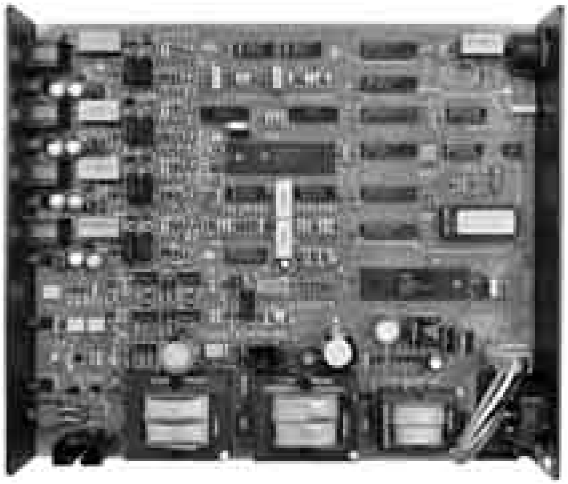
Figure 3: Intel 4004 Chip



*Intel 4004 (1971)*

The 4004 chip is again shown to the right, this time complete with its protective package and protruding pins that provide the electrical connections needed to mount it on a circuit board. A typical circuit board is shown below in Figure 4. The black rectangles are chips. The modern Intel motherboard would mount a number of these smaller circuit boards.

Figure 4: Typical Circuit Board



## 2.2 What Microchips Do

There are just a few major categories of microchip, each designed for specific tasks in electronic signal processing:

**Analog Chips:** These process electrical signals—quite literally—as 'waves' of voltage. An example is chips that process human speech (e.g., speaking into a telephone). When we talk, our vocal chords create sound waves of varying frequency (pitch). The resulting waves are much like those at the seashore. The chip reproduces them as a time-varying wave of voltage, exactly 'copying' the waves of human speech. This copy of speech as an electrical signal can then be processed by electronic systems, e.g., 'piggy backed' onto a radio wave and transmitted as an electromagnetic signal to a distant receiver. The disadvantage of analog is that all such copies are degraded by noise—an ever-present reality in electronic systems—adding unwanted random waves. Also, with analog signal processing, only limited modifications (like amplification or filtering out selected frequencies) are possible.

**Digital Chips:** They also process electrical representations of real-world signals like speech—but with a twist: Rather than reproduce an electrical copy of the signal, they measure the 'height' of the wave many times per second. They then code the results of each measurement as a string of ones and zeros. With a sufficient large number of measurements to the desired degree of accuracy, e.g., six digits, the signal is coded as a long sequence of voltage 'spikes,' e.g., a 'one' could be represented by a signal value of five volts and a zero could be represented as a signal value of two volts.

While digital sounds like a roundabout way of representing signals, it has enormous advantages. It is practically impervious to 'noise.' It would take major difficulties to confuse a one with a zero. The wave can be represented to any degree of accuracy by measuring more frequently and more precisely. An unlimited number of copies can be made with no loss of quality. Most important, all forms of information, sound, pictures, numbers and words can be represented electronically as streams of ones and zeros, *the common language of computing*.

Today many chips are *mixed-signal*, with both analog and digital signal processing (e.g., a cell phone chip).

**Digital Logic Chips:** The most common example is the microprocessor chip that is the 'brains' of a PC or laptop.

It applies the mathematics of logic to process digital signals to accomplish practical tasks like word processing, creating presentations or running spreadsheets.

**ASICS (Application Specific Integrated Circuits):** These are simply digital logic chips that have been purpose-designed to excel at a particular application. For example, engine management chips in a car measure a set of engine operating variables to optimize engine performance. Anti-lock braking chips sense when the wheels are losing their grip on the road and momentarily release the brakes to prevent loss of control—all within fractions of a second.

**FPGAs (Field-Programmable Gate Arrays):** These are general-purpose logic chips that can be configured by the user to carry out complicated tasks like recognizing specific shapes or acting as sensors.

**Memory Chips:** They are designed to store data either permanently or temporarily. **SRAM** and **DRAM** chips lose memory without power (volatile memory). In contrast, non-volatile memory holds its information even when the power is off, e.g., **Flash**, **ROM** and **EPROM**.

**Optoelectronics Chips:** They transform electrical signals into light, or vice versa.

**MEMS (Microelectromechanical Systems) Chips:** These chips combine logic with the ability to accomplish physical work, e.g., to control the flow of fluid in ink-jet printers.

## 2.3 Markets Served

Our focus is on the end-use electronics systems markets for microchips. There are six key markets[11] for microchip applications:

**Computing:** This application includes both personal computing and data processing. The equipment ranges from PCs and servers, to PC displays, hard disk drives, optical storage and multifunction peripherals that include printing, faxing, scanning and copying. This application centres on users working on a single PC or server with locally-stored data, including interacting with peripherals.

**Networking:** The local area network connects multiple computers, peripherals and data storage devices. The equipment is used in an environment like a small business, a single corporate branch or a home office. Equipment that is used to send information over longer distances is covered in the following section on telecommunications/data communications.

**Telecommunications/Data Communications:** This is simply networking on a larger scale over longer distances. A third party like a telephone or cable company provides the networking service. Such networks are called WANs (wide-area networks). The equipment market they represent is generally divided into three segments: access, metro and long-haul.

*Access networks* connect individual business and residential customers to local networks. *Metro area networks (MANs)* take these local signals and connect them with other access networks to serve intra-city/regional transport needs. *Long-haul networks* provide connections for city-to-city or country-to-country transport.

**Photonics** plays an important role in addition to electronics systems, and the equipment involved is addressed in greater detail in the following chapter on photonics.

**Wireless:** This centres on the now common cell phone and its supporting equipment that enables network service. Wireless is presented in detail in Chapter 5.

**Consumer Devices:** This market centres on a collection of devices that provide audio and video entertainment. Most consumer electronics devices have had little computing power. They have long been analog systems with limited

[11] *Semiconductors: Technology and Market Primer 4.0*, CIBC World Markets (January 17, 2007).

digital control elements. However, consumer electronics is being rapidly digitized. There are seven key markets:

*Digital Set-top Boxes:* These have grown rapidly in recent years as digital cable TV has replaced analog cable service. Satellite TV has been digital from the start. High-definition content and IPTV (digital television service delivered by Internet) are further stimulants to growth.

*Digital TVs:* Television is undergoing significant change. Besides high-definition content and new display technologies , there are new services like on-demand TV and digital video recording. This will drive rapid growth.

*DVD (Digital Video Disc) Players and Recorders:* DVD is among the fastest growing consumer electronics technologies, driven by the superior quality of DVD movie viewing.

*Digital Cameras:* These were among the first consumer products to go digital. Combined with the rise of photo-capable printers, photography has been transformed from film to the digital world.

*MP3[12] and Portable Media Players:* These popular units have changed the entertainment industry: business models that will allow content providers to ensure that users pay have yet to evolve—and video is about to follow suit.

*Video Game Consoles:* This is an important market that has consolidated to just three suppliers: Sony, Nintendo and Microsoft. Today's units are full-featured multimedia computing platforms, essentially specialized PCs.

*Flash Memory Cards:* These are accessories for equipment like digital cameras, MP3 players and other handheld digital devices that require data storage.

*Automotive:* This is a classic example of a mature product that is adding value by drawing on the younger technology of microelectronics, primarily in areas like engine control, safety, comfort and entertainment. Examples include GPS navigation, remote keyless entry.

## 2.4 Some Canadian Companies

Canada's microelectronics industry is concentrated on microchip design. Like many other established industries, it has evolved from vertical integration to horizontal specialization, characterized by 'upstream' specialists in design and 'downstream' specialists in manufacturing.

**Chipworks:** Founded in Ottawa in 1992, Chipworks is a 'reverse engineering' company. They analyze the design and composition of the market's newest semiconductor chips to provide comprehensive competitive technical analysis. Their expertise ranges from chip de-layering and materials characterization to circuit analysis and patent claim interpretation.

**PMC-Sierra™:** is a leading provider of broadband communications and storage semiconductors for metro, access, fiber to the home, wireless infrastructure, storage, laser printers, and fiber access gateway equipment. Major product families include:

- Servers and Storage Devices
- Wireline and wireline Infrastructure

Figure 5: The Changing Microelectronics Industry Value Chain

| Phase I: 1960s Full Integration | Phase 2: 1970s Traditional | Phase 3: 1980s Fabless | Phase 4: 1990s Chipless |
|---|---|---|---|
| Specification & Integration | Specification & Integration | Specification & Integration | Specification & Integration |
| Sales & Distribution | Sales & Distribution | Sales & Distribution | Sales & Distribution |
| Silicon Intellectual Property | Silicon Intellectual Property | Silicon Intellectual Property | Silicon Intellectual Property |
| Fabrication | Fabrication | Fabrication | Fabrication |
| Manufacturing Tools | Manufacturing Tools | Manufacturing Tools | Manufacturing Tools |
| **Internal** ← | | | → **External** |

[12] MPEG-1 Audio Layer 3 is a digital audio encoding format that uses data compression.

- Fiber to the Home—Passive Optical Networks
- Digital Home and Business Solutions to support core VoIP, IPTV, Media, and Data services.
- Voice over IP Devices
- Processors for applications from Internet routing equipment and enterprise switches to network printers and set-top boxes.
- Laser and Multi-Function Printer Chips.

**Tundra Semiconductor Corporation:** Tundra, based in Ottawa, Ontario, is a global leader in *system interconnect* providing world-class customer support, leading-edge semiconductor solutions and design services to the world's foremost communications, networking, storage system and information technology vendors. Interconnect chips help to manage the large internal data flows that are essential to the internal operations of electronics systems.

## 2.5 Typical Jobs

The job descriptions in this section are for actual positions recently advertised by Canadian microelectronics design companies. They are intended to provide the reader with a realistic sample of the kind of work carried out in Canadian microelectronics.

### *Applications Engineer, Software*

The Applications Engineering Team provides technical support for users of a wide range of semiconductor products. This involves both software development and debugging of hardware to help customers. It includes assisting customers to integrate chips into their electronic systems and undertake test activities related to customer inquiries.

*Responsibilities:*

— Investigate and resolve customer issues. Replicate customer issues in the laboratory using customer software, analysis tools, and test platforms.

— Develop software to assist customers with successful implementation of products: e.g., device drivers, chip initialization code, embedded RTOS (real time operating systems), BSPs (board support packages).

— Develop technical expertise and applications knowledge on designated products to assist customers.

— Assist with the development of customer documentation including user manuals and application notes.

— Support new product development through review of customer specifications and participation in product verification.

— Develop product demonstrations for use at tradeshows and customer sites.

*Requirements:*

— A Bachelor's degree in Computer Engineering, Electrical Engineering or equivalent.

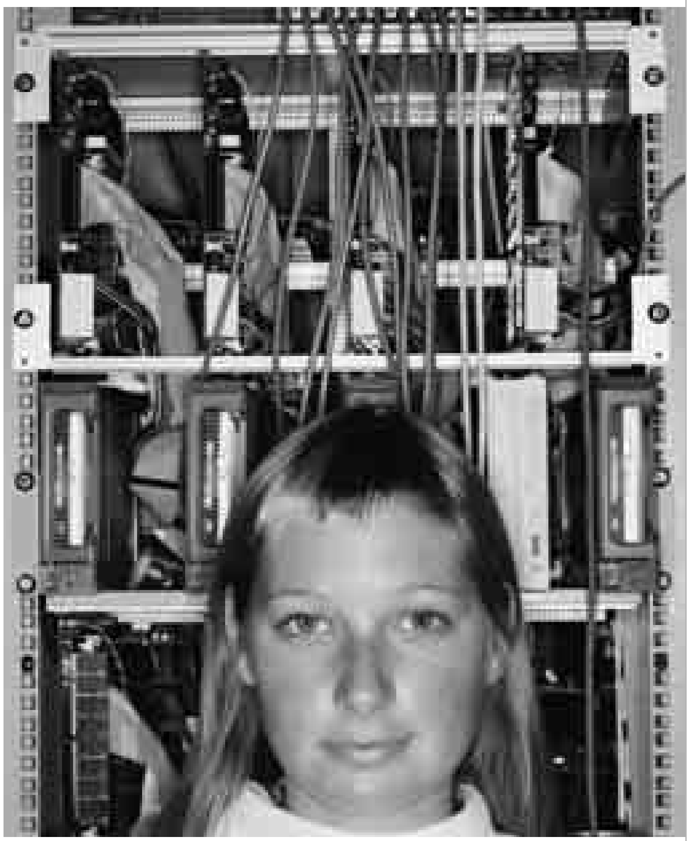
— Minimum 5+ years experience with embedded software design.

— Proficiency in C and/or C++ (software programming languages).

— Excellent debug and troubleshooting skills in both hardware and software environments.

— Familiarity and expertise in use of analysis tools including PCI (peripheral component interconnect), logic analyzers, and in-circuit emulators.

— Software development and systems integration experience with PCI, PCI Express, RapidIO or Ethernet.



*Hardware Design Engineer*

The hardware design team collaborates with other cross-functional teams to participate in the creation of circuit board designs, including design requirements and specifications, schematic design capture, design reviews and hardware design verification.

*Responsibilities:*

— Designing circuit boards and systems.

— Assisting with the testing of new chip designs.

— Creating reference designs for customers.

— Aiding chip design teams to develop specification for new designs by utilizing system level knowledge.

— Developing detailed designs of evaluation boards including schematic entry and component selection.

*Requirements:*

— Electrical Engineering degree.

— A minimum of 3 years experience in PCB design or development.

— Systems level knowledge in the datacom, telecom and storage fields.

— Experience in high speed digital design, preferably including embedded processor design.

— Knowledge and/or experience with FPGAs (field programmable gate arrays), Verilog[13], and Hardware Verification Languages, system-level design and bus-oriented systems.

[13] Verilog is a hardware description language (HDL) used to model elec

# 3. Photonics

Photonics is a relatively new discipline. The term 'La Photonique' was coined by French scientist Pierre Aigrain in 1967. Analogous to electronics, photonics comprises all the ways photons are put to work, from their generation and manipulation to their transmission and detection:

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*Photonics is putting light to work through:*

- *Generation*, e.g., lasers and LEDs (light-emitting diodes)
- *Manipulation*, e.g., lenses and mirrors
- *Transmission*, e.g., optical fibres, free space optics
- *Detection*, e.g., photo sensors, spectroscopes

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Photonics is a very broad synthesis of disciplines. Mastering the photon (the basic unit of light) stretches from chemistry and electrical engineering to materials science, nanotechnology, optics and physics.[14]

Much as electronics is applied far beyond the narrower boundaries of ICT, photonics applications reach across many sectors of the economy.

## 3.1 A Brief History of Modern Photonics

Modern photonics was opened up by two breakthrough developments that, together, realized the potential of light as a signal carrier for telecommunications. The first was a highly coherent light source—the laser, demonstrated in 1960. While ordinary light sources emit photons in all directions in a mixture of colours (wavelengths) and phases (wave crests and troughs are randomly aligned), laser light, in stark contrast, is extremely ordered. It is *in-phase* (the wave crests and troughs are highly aligned) and largely *monochromatic* and *unidirectional*.

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Laser light differs from ordinary light: it is highly in-phase, unidirectional and monochromatic.

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The second breakthrough was glass fibre that could transmit laser light with very little loss, similar to the way a copper wire offers little resistance to the flow of electrons. In 1970, the simultaneous developments of low-loss glass fibre and a practical laser that could operate continuously at room temperature led to a worldwide effort to develop fibre optic communications systems.[15]

First generation light wave systems began to be deployed by 1978. In fact, the enormous transmission capacity of fibre-optic telecommunications systems made the modern Internet possible. The seed of the Internet was planted in 1985 when the U.S. National Science Foundation (NSF) funded a high-speed network to link supercomputer centres it funded to assist university research. The universities soon found the network useful for other purposes, and traffic on the new network grew dramatically. By 1990, the network backbone was expanded and upgraded—and the term 'Internet' was first defined as connectivity with this backbone.[16]

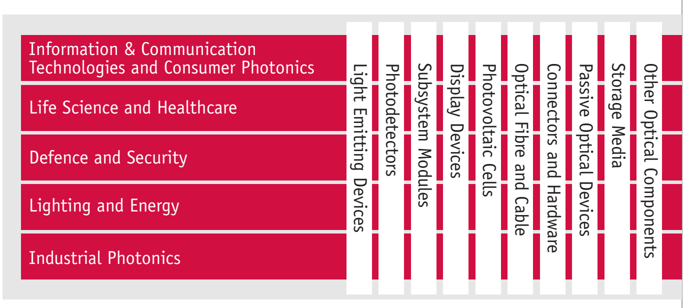
By 1995, the Internet had grown from university research tool to commercial reality. While commercial operators had appeared in the early nineties, they still relied on the NSF backbone. However, in 1993 the U.S. government announced the formation of NAPs (Network Access Points), where private operators could exchange their data traffic. This new architecture became the Internet on April 30, 1995. Its flexible structure enabled the Internet to handle the explosive growth it has known ever since.

*Beyond Information and Communications Technology*

While ICT is a major application of photonics and the focus of this chapter, it is important to note that photonics is a young, dynamic field. In fact, its commercial applications are still emerging; they are about where microelectronics was some 30 years ago.

Photonics, like microelectronics, enables applications far beyond the ICT sector. The many components that are the products of photonics technology and the major sectors in which they are applied are shown in Figure 6 below:

Figure 6: Photonics: A Pervasive Discipline Applied Far Beyond the ICT Sector




*Source: Photonics: U.K. A Strategy for Success, Dept. of Trade and Industry (July 2006)*

A brief summary of applications in these other sectors of Life Sciences & Healthcare, Defense & Security, Lighting & Energy and Industrial Photonics is presented in the table on the next page.

[14] *Towards a Bright Future for Europe*, Photonics 21, EU Commission (April 2006).

[15] *Fiber Optic Communication Systems*, G.P. Agrawal, John Wiley & Sons, New York (1992).

[16] *Telecom Factbook*, Pecar and Garbin, McGraw-Hill (2000).

Figure 7: Major Photonics Applications beyond ICT

| Materials and Process Equipment | Components | Modules | Service Providers | Content and Applications | Enabled Products | End User |
|---|---|---|---|---|---|---|
| • Silicon | • Lasers | • LCDs | • ISP | • Telecomm | • Computers | • Business |
| • GaAs | • Fibre | • PDP | • Telecoms | • VoIP | • Phones | • Consumer |
| • InP | • Filters | • LED Arrays | • Cable | • Video | • TVs | • Government |
| • InGaN | • LEDs | • Back Lights | • Laser | • TV | • Cameras | • Military |
| • Polymer | • Detectors | • Imaging | • Laser Processing | • Email | • PDAs | • Education |
| • Etching | • Connectors | • Telecomm | • Energy Generation | • eCommerce | • Weapons | • Medical |
| • MEMS | • Switches | • Optical Media Heads | • Medical Treatment | • Surveillance | • Lighting | |
| • Phosphors | • Mux/Demux | • Solar Cell | | • Pictures | • Printers | |
| • LCD | • Optic | | | • Games | • Photocopiers | |
| • Crystals | | | | • Sensing | • Renewable Energy | |

*Source: Photonics: U.K. A Strategy for Success, Dept. of Trade and Industry (July 2006)*

## 3.2 The Anatomy of Photonic Communication Systems

The laser and low-loss optical fibre are at the heart of modern light wave communications systems.

**Optical Fibre:** These are thin, ultra-pure strands of highly transparent glass that act as 'pipes' to channel the flow of light. They work because of a phenomenon called total internal reflection: the walls of the glass fibre act as if they were mirrors when light beams enter almost parallel to the walls. As the light beam travels along the fibre, it is reflected again and again off the walls with very little loss of signal strength.

**The Laser (Light Amplification by Stimulated Emission of Radiation):** Lasers generate the light beams that are used by the Internet to carry vast quantities of information. Digital outputs from electronics systems are transformed into brief pulses of laser light that represent the ones and zeros carried by the electronic signal.

The same semiconductor materials science on which microelectronics is built supports photonics as well. The materials from which both transistors and lasers are built are designed to have specific electronic properties. Solid-state lasers generate photons whose wavelengths are determined by the precisely engineered electronic energy levels of the semiconductors from which they are fabricated.

**Communications versus Computing:** While electronics systems are superior to photonics systems for processing information, photonics systems are much better for transmitting large quantities of information. A simple measure of telecommunications economics is how many signals you can 'cram' together on the same (expensive) transmission link. When many electronic signals are bundled together in a transmission line, their inherent negative charge causes them to repel each other (causing problems). Because photons have no charge, light waves can be packed together very densely to carry massive amounts of information.

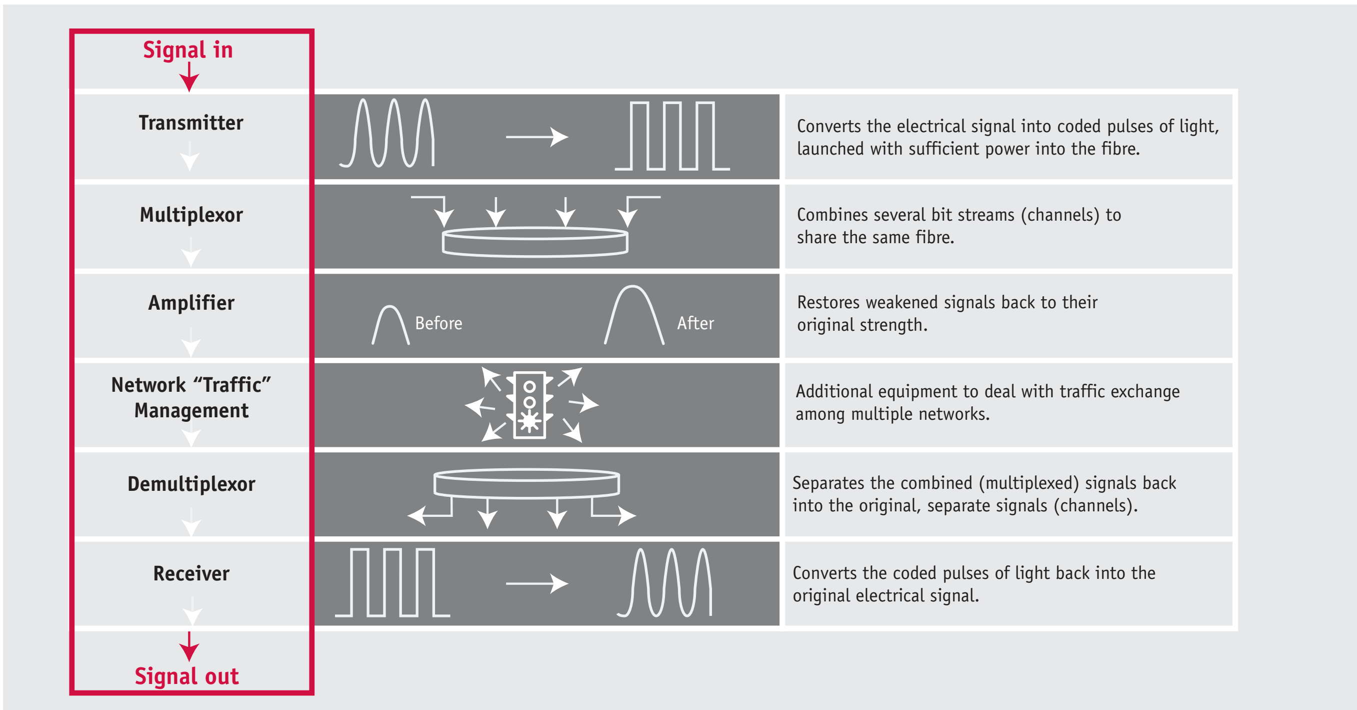
Another economic measure of communications system performance is how far the signal can travel before it needs regeneration. The original Napoleonic light wave systems (using semaphore signals) required the expensive measure of building and manning stations every 16 km. Even second generation light wave systems (early 1980s) needed signal regeneration after approximately 20 km.

This is because the light pulses lose information by attenuation (light energy is absorbed by the fibre), modal dispersion (the light spreads out beyond the original sharp pulse) and chromatic dispersion (refraction spreads out beams of mixed wavelengths). The limit on transmission distance is imposed by attenuation and dispersion. The solution is signal regeneration at periodically spaced repeaters: the degraded light signal is converted back into the original electrical stream of ones and zeros that are used to regenerate a fresh stream of laser pulses. However, regeneration is expensive (just like the original semaphore repeater stations).

Figure 8: Fibre-Optic Network Overview

The network transmits voice and data signals, coded as pulses of light, from sender to recipient.

The basic subsystems that work together to accomplish this are outlined below.




*Source: D.R. Senik & Associates Inc.,* Introduction to Photonics *(2004)*

The invention of optical amplifiers in the early 1990s began revolutionizing fibre-optic communications. They amplify the optical signal directly, versus reconversion to electrical mode and subsequent relaunch as a light signal.

While a detailed treatment of fibre-optic communications is beyond the scope of this brief chapter, the main elements of a fibre-optic network are outlined above.

## 3.3 Markets Served

Our focus is on the ICT product applications of photonics. There are four major applications areas.

**Displays:** Flat-panel displays have made significant inroads into the market for CRTs (cathode ray tubes), surpassing the number of CRT units sold in 2005. They are commonplace, from cell phones to laptop computers and TV screens. LCDs (liquid crystal displays) have become the dominant technology for flat-panel displays.

**Optical Communications:** The fundamental application is the Internet market that consists of the following three key segments:

*Optical Network equipment:* This comprises primarily the hardware for metro (intra-city) and long-haul (inter-city or inter-country networks). This equipment consists mainly of transport and switching applications.

*Fibre and Cable:* This is the glass fibre that is the physical wiring providing network connections.

*Optical Components:* These are the 'nuts and bolts' that go into building network links, mainly laser diodes, transceivers, pumps and passive devices.

— Laser diodes are used to generate laser light.

— Fibre-optic transceivers both receive and transmit light signals.

— Pump lasers provide the energy to strengthen weakened signals.

— Passive devices, unlike the components above do not add energy to signals; they merely modify it in some way. For example, a filter removes particular wave lengths (colours). Connectors physically couple one fibre to another.

*Optical Data Storage:* Familiar storage devices include CDs (Compact Disks), DVDs (Digital Video Disks) and now Blu-Ray.[17]

The main market is data storage for PCs and work stations. Optical data storage uses direct access disks that are written and read using lasers. They offer much higher storage capacity than magneto-optic (floppy) disks. Blu-Ray is the next generation successor to CD and DVD technology.

**Consumer Products:** Photonics is used in host of applications that are covered in Chapter 2 on Microelectronics and to a lesser degree in Chapter 5 on Wireless (cell phones).

The major applications include:

— *Cell Phones:* displays, cameras and LEDs (Light Emitting Diodes)

— *Flat Panel High-Definition LCD (Liquid Crystal Display) TVs:* displays and backlights

— *Portable Music and Video Players:* displays

— *Digital Cameras:* image sensor and flash

— *Entertainment:* displays, data storage and communications.

## 3.4 Some Canadian Companies

**DALSA:** The company designs, develops, manufactures and markets digital imaging products and solutions. Its core competencies are in specialized integrated circuit and electronics technology, image processing hardware and software, and highly engineered semiconductor wafer processing.

Products include image sensor components; electronic digital cameras; vision processing hardware components; image processing software algorithms; and semiconductor wafer foundry services for use in MEMS, high-voltage semiconductors, image sensors, and mixed-signal CMOS chips.

These products are vital components in equipment for manufacturing machines for semiconductor foundries, automated machines for manufacturing electronic components and boards, digital x-ray equipment, DNA-based laboratory test equipment, industrial automated manufacturing systems, professional photography and many other industrial applications.

**EXFO:** is a recognized test and measurement specialist in the global telecommunications industry. The Telecom Division, its main business activity, offers fully integrated and complete test solutions to network service providers (NSPs), cable TV operators, telecom system vendors and component manufacturers in approximately 70 countries.

EXFO provides portable optical test solutions and is a leading supplier of protocol and copper access test solutions to enable triple-play[18] services over converged, IP networks. These test platforms host a wide range of test solutions across optical, physical, data and network layers.

The Life Sciences and Industrial Division, which leverages several core telecom technologies, offers value-added solutions in the life sciences and high precision assembly sectors, such as those required for microelectronics and optoelectronics. These solutions are based on advanced spot-curing, fluorescence microscopy and nanopositioning technologies.

**JDSU Corporation:** provides broadband test & measurement solutions and optical products for communications, commercial and consumer markets. JDSU offers test and measurement systems and services for telecommunications service providers, cable operators, and network equipment manufacturers.

In addition, the Company offers components, modules and subsystems for optical communication, display, security, medical/environmental instrumentation, decorative, aerospace and defense applications. The company's products include the following:

— *Communications Products:* Fibre-optic systems deliver video, audio and text data over high-capacity fiber optic cables.

— *Optical Communications:* Components, modules and subsystems for communications equipment providers in telecommunications and data communications.

— *Test and Measurement:* Instruments, systems, software, services and integrated solutions to help communications services providers, equipment manufacturers and major communications users.

[17] Blu-ray, is a next-generation optical disc format jointly developed by a group of leading consumer electronics, personal computer and media manufacturers (including Apple, Dell, Hitachi, HP, JVC, LG, Mitsubishi, Panasonic, Pioneer, Philips, Samsung, Sharp, Sony, TDK and Thomson).

[18] This is a telecommunications marketing term for supplying high-speed Internet access, television, and telephone, over a single broadband connection. It is a business model versus a technological innovation.

— *Commercial and Consumer Products:* To control, enhance and modify the behaviour of light, utilizing its reflection, absorption and transmission properties to achieve specific effects such as high-reflectivity, anti-glare and spectral filtering.

— *Custom Optics:* For computer monitors, flat-panel displays, projection systems, photocopiers, facsimile machines, scanners and other applications.

— *Commercial Lasers:* For biotechnology, graphic arts and imaging, semiconductor processing, materials processing and a wide variety of other laser-based applications, as well as gas cluster ion beam surface equipment used in, among other things, the semiconductor and biomedical industries.

## 3.5 Typical Jobs

Actual positions from recent job posting include the following:

### *Component Engineer*

The objective of this position is to provide structure, guidance and support in the selection of electronic components for new product development as well as maintaining the design integrity of current standard product cameras. The Component Engineer will work closely with design engineers, during the component selection process, to ensure that the highest level of product reliability and quality is maintained.

*Responsibilities:*

— Supporting project teams in the sourcing and selection of electronic components and sub assemblies.

— Ensuring selected components and subassemblies meet or exceed quality and reliability standards.

— Reviewing components for RoHS (restriction of hazardous substances) acceptability and compatibility with existing manufacturing processes.

— Working with engineering teams to qualify replacement and/or alternate components.

— Managing the obsolescence of electronic components including sourcing and recommending alternates.

— Managing the master component database including the approval of all parts.

— Working directly with component manufacturers to determine root cause and corrective actions as a result of failure analysis investigations.

— Provide mentoring to other component engineers.

*Requirements:*

– Bachelor's Degree in Electrical Engineering as well as a minimum of 2 years practical experience in selection and evaluation of electronic components as a component engineer or design engineer.

– A solid understanding of electronic component technology and manufacture, electronics supply industry and a working knowledge of design and manufacturing documentation and quality systems.

– A high degree of computer literacy, familiarity with ISO 9000 procedures, excellent communication skills and experience working with development and manufacturing engineering in a high tech manufacturing environment.

### *Process Engineering Specialist*

As part of the Manufacturing team, the Process Engineering Specialist will work with various design groups that develop specific devices. The primary contribution from this position is to assist with the definition and implementation of new processes and equipment required to introduce new products. In addition support of new equipment implementation related to global process improvement and day to day problem solving are important activities.

*Responsibilities*:

— Equipment and system level planning for device assembly of intricate optical and semiconductor devices.

— Using Statistical Process Control methods to evaluate process changes and equipment operation.

— Documentation of procedures that are clear and efficient for use by operators.

*Requirements:*

— Technologist College Diploma in manufacturing, mechanical, or electronics disciplines or a Bachelors degree in Materials Science, Physics, Chemistry (or other related science field).

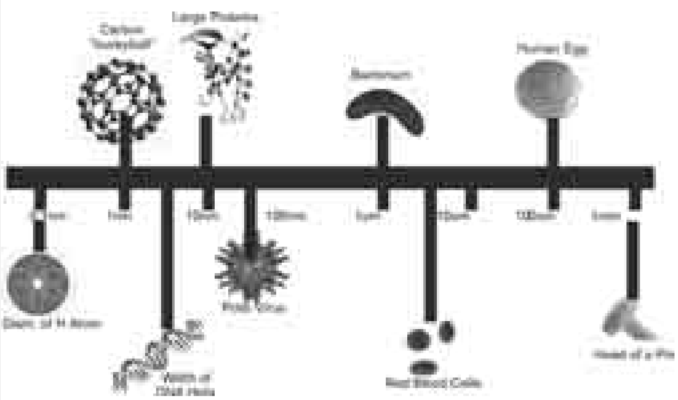
— A minimum of 3 – 6 years Manufacturing Engineering experience in a related manufacturing environment.

— A demonstrated ability to solve process and product related problems using a structured approach is a requirement of this position.

# 4. Nanotechnology

Nanotechnology exploits the unique properties of structures smaller than about 100 nanometres. At this tiny scale,[19] the laws of quantum mechanics (versus those of classical physics) begin to describe the behaviour of matter and energy. Figure 9, below, gives examples of structures that range in size from the smallest atom (hydrogen) to the head of a common pin.

Figure 9: Putting the Nanoscale into Perspective



*Source: D.R. Senik & Associates Inc.,* Nanotechnology: A preliminary Assessment of Canada's Relative Strengths (March 2005)

Classical physics explains the collective behaviour of huge numbers of atoms, e.g., the orbit of a telecommunications satellite. Quantum mechanics explains the behaviour of individual atoms, e.g., the chemical bonding of hydrogen and oxygen to form water.

However, the border between the very different realms of quantum and classical physics is not a sharply drawn line. The nanoscale is largely uncharted territory where there are too few atoms for their behaviour to follow classical physics and too many to easily describe with the still-evolving tools of quantum mechanics. Nanoscience seeks to understand this complex mix of quantum and classical behaviour, while nanotechnology seeks to apply the unique properties of the nanoscale to solve practical problems.

Moreover, the explanations that underlie disciplines ranging from chemistry and physics to biology, engineering and medicine converge at the nanoscale. "Indeed, it could be argued that evolutionary developments in each of these fields toward investigating matter at increasingly small scales has come to be known as nanotechnology."[20]

Nanotechnology is the practical application of the unique properties of structures smaller than about 100 billionths of a metre.

The following section outlines a brief history of the emerging field of nanotechnology. Although microelectronics, in particular, has mastered the routine production of structures smaller than 100 nm since 2000, the full impact of nanotechnology is yet to come. It promises to spark a new ICT revolution, much as solid state physics drove the first one.

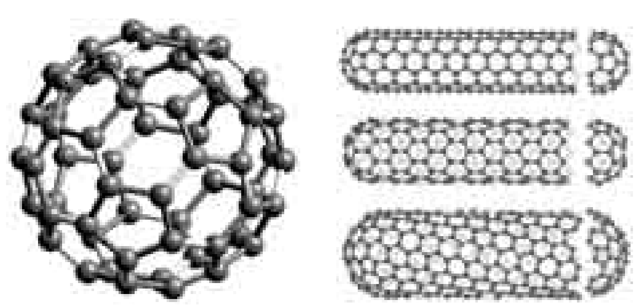
## 4.1 A Brief History of Nanotechnology

Nanotechnology is as old as civilization. Japanese sword makers unknowingly exploited nanostructure to yield the sharp, strong cutting edge of Samurai steel, and Roman glass used nanoparticles to produce colours that changed with the light. However, the idea of deliberately arranging atoms to create unique properties is just 50 years old.

American Physicist Richard Feynman's 1959 lecture, "There's plenty of room at the bottom," outlined nanotechnology a generation before it came to pass. Two subsequent landmark developments made his vision possible. First was *molecular beam epitaxy* (the deposit of layers only one molecule thick) at Bell Labs in 1969. The second was IBM's *scanning tunneling microscope* (to 'see' the position of single atoms) in 1981. Both were critical tools in exploring the nanoscale.

For example, new forms of carbon, 'buckyballs' and 'nanotubes' were discovered in 1985 and 1991. While chemically identical[21] to carbon, the spatial arrangement of their atoms gave them unique properties.

Figure 10: Buckyballs and Nanotubes



[19] One nanometer (nm) is one-billionth of a metre. To put this into perspective, the diameter of the smallest atom, hydrogen, is about 0.1 nanometers in its ground energy state. The diameter of the DNA helix is about 2 nm.

[20] *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*, The Royal Society and the Royal Academy of Engineering (July 2004).

[21] For example, both graphite and diamond are chemically identical forms of carbon. However, their properties, like hardness and optical transmission, vary enormously.

Buckyballs, being hollow spheres, have the potential of delivering therapeutic drugs. In another potential use (for strength), when compressed to 70 percent of their original size, they become more than twice as hard as diamond. Carbon nanotubes (CNTs) are ready-made molecular wires. They can be altered into a conducting, semiconducting or insulating states, making them potential (smaller) successors to silicon microelectronics. Already, CNTs are popular for their prospective electrical, thermal and even selective-chemistry applications.[22]

An early demonstration of the significant applications of CNTs was to make them function as transistors (1998). Taking 1995 as an approximate starting point for early commercial applications of nanotechnology suggests that it will reach ICT's current state of development by about 2020–2025.

## 4.2 Challenges and Applications[23]

Nanoscience and engineering address four broad research challenges:

**Basic Nanobuilding Blocks:** Fundamental structures at the nanoscale include quantum dots, nanotubes, thin films and nanoparticles, to name a few. Detailed understanding of their properties is critical to the development of applications.

**Nanostructures and Interfaces (putting the building blocks together):** Interfacial phenomena predominate. Understanding the forces at work means understanding a complex mix that includes hydrogen bonding, dispersion, dipole interactions and quantum effects.

**Nanostructure Dynamics, Assembly and Growth:** These are time-dependent properties that must be understood in order to control the production of nanomaterials and structures (e.g., self-assembly, nucleation and vapour deposition); and the resulting device dynamics (e.g., electron transport in nanotubes or molecular transport in membranes).

**Simulation and Design:** This is a daunting computational task, since nanodevices will range from about 10,000 to 100 million atoms. Mathematical models must also bridge enormous time and length scales, e.g., biological structures range in length from 0.1 nm to centimeters (a difference in scale of 10 million). The time for processes ranges from femtoseconds in quantum mechanical oscillations to microseconds for protein folding (a difference in scale of one billion times).

However, nanotechnology is now well into its *Introductory Phase* (see Chapter 1), a period when pioneering producers feel their way with new products and processes, and users learn what nanotechnology is for. Worldwide, global R&D funding almost doubled from 2003 to 2004, reaching US$10.3 billion. More importantly, from accounting for about half of R&D spending in 2003, the corporate share spending jumped to two-thirds (US$6.7 billion versus US$3.7 billion for governments and institutions.[24]

### *Applications*

A common theme has been the application of nanomaterials in incremental fashion in order to improve the performance of existing products. In 2004, four of the year's top ten nanotechnology products[25] followed this theme. They were:

— *Footwear Insoles:* Nanoporous aerogels provided from three to twenty times better insulation;

— *Mattress Covers:* Channeled nanofibres wick away moisture to provide sleeping comfort and quick drying in the laundry;

— *Golf clubs:* Titanium fullerenes (Buckyballs) make stiffer club shafts for longer drives;

— *Building Products:* Nanoparticles confer extreme water resistance to surfaces like brick limestone and concrete.

However, the most important applications of nanotechnology in ICT lie in the emerging technologies that are potential replacements of microelectronics as the 'physical medium' of computing.

While microelectronics has routinely produced integrated circuits with sub-100-nm features since 2000—Intel's current advanced production process is 45 nm—these designs ***do not*** exploit the quantum behaviour that is a fundamental feature of all nanoproducts. In fact, microelectronics designers have struggled to minimize quantum effects as the size of the workhorse component—the transistor—has shrunk.

An example is a region of the transistor called *the gate*. Its electrical properties are controlled to turn the transistor on and off. However, the electron obeys the laws of quantum physics. This means that it behaves as both a particle and a wave. At the energy levels used to operate transistors, the

22 *Physics News*, (May 21, 2002).

23 *Nanotechnology: A Preliminary Assessment of Canada's Strengths*, Industry Canada (March 2005).

24 *MIT Technology Review*, (June 2005).

25 Forbes/Wolfe, Vol.3, No. 12 (Dec. 2004). The other products were in the health sector.

electron in silicon has a wavelength of about 10 nm. As the gate shrinks to this size, the transistor (a device based on classical physics) ceases to function as an on/off switch.

While microelectronics producers have managed to work around this, physics will ultimately require designs that will embrace quantum effects: "We are beginning to reach the fundamental limits of the materials used in the planar CMOS[26] process that has been the basis for the semiconductor industry for the past 30 years."[27]

The five most important nanotechnologies that have the potential to replace microelectronics (very likely leading to a new ICT revolution) are the following:

Table 3: Contenders to Replace Microelectronics as the Physical Medium of IT 'Hardware'

| Technology | Essential Features |
|---|---|
| DNA Computing | Exploiting nature's information storage medium (the base pairs along the DNA helix) to do simultaneous computations at the molecular level. |
| Light Computation | Encoding information in photons in order to perform logical operations through the interaction of laser beams. |
| Molecular Electronics | Using single atoms and molecules to replace conventional integrated circuit components. |
| Quantum Computing | Exploiting the inherent superposition of quantum states with 'qubits' that simultaneously represent ONE and ZERO (enormously increasing computing power). |
| Reverse Engineered Circuitry | For realizing massively parallel computers based on nature's design for neural circuitry. |
| Spintronics | Using electron spin to represent ONE and ZERO in order to do computations and store information (greatly reducing the size of current devices). |

Time will (soon) tell. The world's first quantum computer was introduced by a Canadian company in 2007.[28]

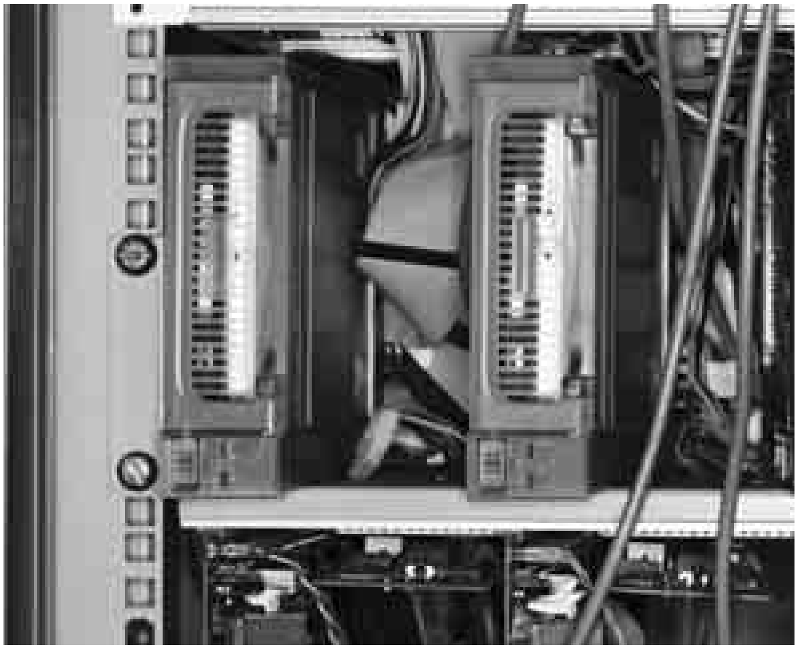
## 4.3 Canadian Companies

While Canadian companies are represented across a whole range of industries, our focus here is on the ICT sector:

**ADTEK Photomask:** is a merchant photomask manufacturer that has been providing services worldwide for over 25 years. It uses state-of-the-art writing tools to provide a full range of optical, e-beam and laser-write photomasks to the microelectronics, optoelectronics, photonics, MEMS, medical, nanotechnology and semiconductor industries.

**D-Wave:** was spun out of the University of British Columbia in 1999 to commercialize superconductor-based, quantum computer processors.

D-Wave is the first company to announce the development of a commercial quantum computer and has twice publicly demonstrated prototype systems running real-world



[26] Complementary Metal Oxide Semiconductor.

[27] *International Technology Roadmap for Semiconductors*, < http://www.sia-online.org/pre_release.cfm?ID=298 > (2003).

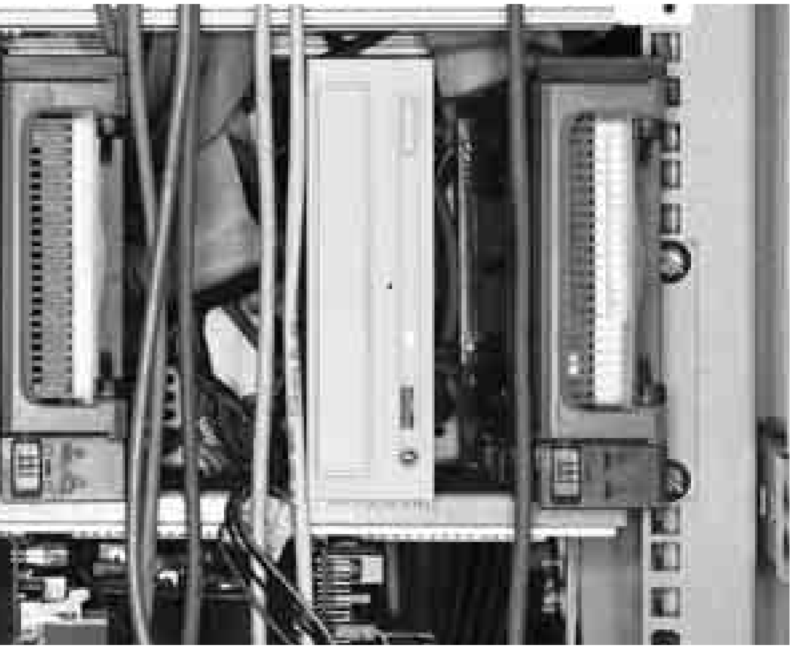
[28] "Orion's Belter," *The Economist*, (Feb. 2007).

applications. The D-Wave machine is intended to be deployed as a co-processor, which will provide acceleration to applications executing on classical digital computer systems.

D-Wave's system will be available for on-line access in early 2009 and will be useful for accelerating high value applications involving discrete optimization, pattern matching, machine learning and constrained search with preferences. Such applications are found throughout the operations research, life sciences, finance, travel, chemical and petrochemical industries. Applications in quantum simulation and electronic design automation will follow soon thereafter.

D-Wave secured $17-million financing led by international investment and underwriters on February 04, 2008, strongly supported by existing investors.

**Design Workshop Technologies:** Founded in 1988, the company creates computer-aided design software for the microelectronics, MEMS, photonics and nanolithography industries. The company specializes in the physical layout and verification of IC and of photonic integrated components:



— *Point Solutions:* to answer specific physical layout and verification needs. These needs are often dictated by specific methodological or technological constraints.

— *Task Automation:* Circuit layout is a long and thorough process that can benefit significantly from automation. Clients have successfully used DWT tools to automate their work.

— *Physical Verification:* is an essential element of design flow, the last step in quality control before a design is manufactured. Effective tools can deliver significant cost savings.

— *Design and Layout*

## 4.4 Jobs

Nanotechnology jobs are just emerging. For example, as of autumn 2006, the University of Waterloo's Nanotechnology Undergraduate Engineering Program had taken in its second class of 100 students. At full capacity, there will be 500 students in the program, built upon a foundation of dedicated nanotechnology courses, laboratories, facilities, faculty, students and work experience.

A total of 62 courses are offered, of which 48 are dedicated nanotechnology courses. Twenty-nine of these 48 new courses have labs designed to specifically prepare students for a nanotechnology career in research or industry. These labs include new undergraduate clean room facilities for IC fabrication, nanoelectronics and nano-instrumentation. All nanotechnology students will graduate with two years of work experience. This is achieved through relevant, full-time employment over two four-month and two eight-month co-op work terms.

The Nanotechnology Engineering honours degree program is designed to provide a practical education in key areas of nanotechnology, including the fundamental chemistry, physics and engineering of nanostructures or nanosystems, as well as the theories and techniques used to model, design, fabricate or characterize these technologies. Emphasis is placed on training with modern instrumentation techniques as used in the research and development of these emerging technologies. The university awards a Bachelor of Applied Science (B.A.Sc.) degree in Nanotechnology Engineering to graduates.

# 5. Wireless

As its name suggests, this technology allows communications through empty space. Unlike photonics that uses glass fibres to guide light, and electronics that uses wires to conduct the flow of electrons, wireless sends electromagnetic energy through thin air.

Wireless (also called radio) is a form of electromagnetic radiation, waves of electric and magnetic energy that travel through empty space at the speed of light. X-rays and ultraviolet radiation are very short electromagnetic waves. Waves that are hundreds of nanometres in length are visible light. Radio waves are much longer, up to hundreds of thousands of metres. However, radio waves from about 0.1 to 10 metres in length are prized by users for their ability to penetrate obstacles like buildings and trees. In the communications business, these wavelengths are referred to as 'prime spectrum.'

The business of wireless has a long history, dating back to the early years of the twentieth century. The development of wireless is briefly outlined below.

## 5.1 A Brief History of Wireless

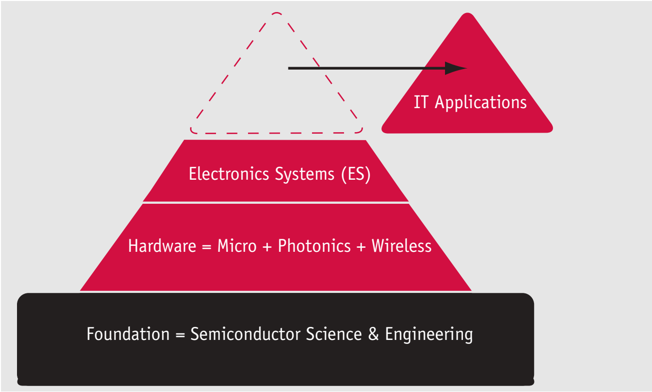
Wireless has created not one but two major industries since it emerged in the late nineteenth century. The first was radio broadcasting that grew out of Marconi's invention of 'wireless telegraphy,' first demonstrated to the British patent office in 1896. The second is wireless cellular telephony, still unfolding since its beginnings following World War II.

While the radio broadcasting industry had matured by 1945, with four national networks in the U.S. and 95 per cent of all homes with radios, the cell phone industry was only beginning. Mobility was the new capability that launched the era of mobile personal communications.

The mobile era began with the Detroit Police Department's pioneering use (1928) of one-way radio communications to dispatch patrol cars. Two-way mobile AM radio communication was the next advance (1933); however, these primitive electronics systems took up most of the trunk and had reception difficulties. FM radio (improved signal quality and resistance to interference) became the standard for most police systems in the 1940s.

The breakthrough that opened the door to cell phones was AT&T's successful radiotelephony pilot in 1946. It was the first to use mobile radio to connect users through the public telephone system. However, it was seen as a minor sideline to AT&T's telephone monopoly. It also faced regulatory constraints that viewed mobile personal communications

Figure 11: Wireless in the Context of ICT




*Source: D.R. Senik & Associates Inc., Introduction to Wireless (November 2005)*

as a misuse of limited radio spectrum for the privileged few. Even forty years later (1987) when microelectronic succeeded in making cell phones truly portable and markets took off, regulators were unyielding. The additional radio spectrum came from innovations in transmission technology.

By 2001, worldwide wireless subscriptions had surpassed the number of main telephone lines. In 2005, wireless cellular telephony had grown to become a half-trillion-dollar global business.

## 5.2 Wireless Communication Systems

Almost from radio's very beginnings before World War I, regulation has played a central role in its development. This is because the only way to prevent interference between two radio signals was to broadcast them on different wavelengths. In the United States, licensing operators from 1912 onward was a first solution. However, the huge boom in 1920s radio broadcasting—radio equipment sales exploded from $60 million in 1922 to $843 million in 1928—resulted in the *Communications Act* of 1934.[29] Ever since, governments have decided on the best use of the airwaves, licensing specific wavelengths to users, 'in the public interest,' from radio and TV to local government (e.g., police and emergency services), the military and education broadcasters.

Wireless cellular communications is an innovative network architecture that works around the relatively small radio spectrum allocated to cell phones. By limiting the range of the cell phone's radio signal, the same wavelength can be used over and over again in areas that are separated by a short distance. This significantly increases the number of simultaneous calls that a given wavelength can carry.

[29] Canada has closely followed U.S. practice.

The service area is divided into small cells, each served by cell phone towers.[30] Calls between cell phones are picked up by the nearest tower, then relayed through the public telephone system to the tower nearest the intended receiver. If cell phone users are on the move, sophisticated software switches their connection link as they pass from one cell into the next.

The brains of the cell phone network is the *mobile switching centre*. It is connected to every tower in the system by either a high-capacity telephone line or a microwave link. It fields all incoming calls, verifies that service is being requested by a valid subscriber and dispatches them accordingly. It maintains subscriber data, call billing and routing information.

The technology and equipment that serves wireless cellular telephony is outlined below.

### *Handsets*

Cell phones are the most widespread communications devices on earth. There are a good example of the interwoven nature of ICT. They combine wireless with microelectronics (chip sets that carry out the work of radio communications and signal processing), photonics (cell phone displays and built-in cameras), software (memory to carry phone book entries and generate advanced graphics) and plain old electronics (batteries and power amplifier to increase signal strength). The main components of the cell phone are:

*RF (Radio Frequency) Block:* This chip set handles radio signals. A transceiver both generates and receives the short wavelengths that carry the cell phone's radio signal. It translates between the analog signals used in the handset and the digital signals used in radio transmissions. A power amplifier boosts the signal strength for transmission by the antenna.

*Baseband and Audio Processing, Power Management:* The audio subsystem generates and receives information from voice:

— A codec (coder/decoder) chip converts voice signals: from analog into digital when it receives them from the microphone and vice versa when it sends incoming messages to an amplifier that generates an analog audio signal for the speaker.

— A digital baseband processor chip encodes the digitized voice signal into the format[31] used by the wireless network for transmissions. It also extracts the digital voice signal from messages received over the network.

— A power management subsystem controls power consumption by optimizing the use of limited battery power to the handset components.

### *Application Processor and Memory:*

— The Application processor runs the cell phone system software and controls the overall operation and functions of the cell phone. Less advanced cell phones typically integrate this function with the baseband processor chip.

— Flash Memory is used to store system software, phone book entries and other user data.

— SRAM (static random access memory) is used for digital baseband and application processor memory.

— Multimedia and Connectivity ICs (integrated circuits). In advanced cell phones, these chips provide additional functions like:

- Cameras
- Advanced Graphics
- Bluetooth: a short range radio transmission standard that allows replacing wires to create personal networks within a radius of about ten metres. This standard provides a way to connect and exchange information between devices such as mobile phones, laptops, personal computers, printers, GPS receivers, digital cameras and video game consoles.
- GPS (Global Positioning System)
- Entertainment, e.g., FM radio, mobile TV, MP3 Audio, MPEG-4[32] Video.

### *Wireless Infrastructure*

This comprises the dedicated networks that service providers use to link cell phone subscribers through the public telecommunications/data communications networks. These networks can be segmented into two major parts:

*The Radio Access Network:* The visible element is the cell phone towers. Each cell phone tower is a base transceiver station (BTS) in the network. It has a defined range and sends and receives digital signals to and from mobile terminals in its coverall area (called a 'cell'.)

*The Core Network:* The base transceiver stations are managed by a network of base controller stations that forward traffic between BTSs and pass calls back and

[30] In practice, cells are served by multiple overlapping towers. The network switching centre selects the tower with the strongest radio link.

[31] There are many different formats as a result of the FCC's 1987 decision to allow competing transmission formats.

[32] Moving Picture Experts Group. MPEG-4 is a data compression format

forth to the core network. The core network manages the interface between the whole wireless network and the public telecommunications/data communications networks with Mobile Switching Centres.

## 5.3 Markets Served

The wireless industry applies radio communications technology in five major ways:

**Mobile Radio Telephony (Cellular Phone Systems):** This is the largest global market. This service provides two-way voice and data transmission for mobile users through radio links to the public telephone system.

**Paging:** This is a one-way message service that conveys information by radio through a tone, voice, numeric or alphanumeric signal to a pager (receiver).

**Mobile Satellites:** They provide mobile data and voice communication service over large or isolated regions, e.g., to industry users like forestry, oil and gas and utilities.

**Mobile Radio:** These are private radio networks for clients in law enforcement, rail transportation, trucking, taxi dispatch, etc.

**Fixed Wireless Networks:** There are two types.

- *High-Speed Local Multipoint Communications Systems:* They provide one-way distribution of television signals in limited geographic areas. Originally they were regarded as complementary to cable TV service, but are now seen as competitive and are licensed by the Canadian Radio-Television and Telecommunications Commission (CRTC).
- *Wireless Local Area Networks (WLANs):* These are a substitute for wired local area networks (LANs) that appeared in the early seventies as stand-alone networks connecting small work groups that shared similar job assignments and equipment. Liberation from wiring and the flexibility this offers is the major attraction of WLANs.

  LANs evolved into enterprise networks, with work groups in large organizations needing access to corporate databases and other information services. LANs were integrated into multi-building networks that connected work groups with different jobs and a more varied range of equipment.

### *Growth Markets*

Wireless technology is now middle-aged. Almost four decades have passed since Motorola's first public demonstration in New York City. Mobile cellular service is by far the dominant application, in 2007 representing a global market over a half trillion dollars. To put the dominance of cellular into perspective, it is noteworthy that the three next largest markets combined represent less than ten percent of cellular:

— *Mobile Entertainment:* This is a fast growing market. gambling (e.g., lotteries) and games are projected to be the most popular entertainment services, followed by music and sports.

— *Healthcare:* Healthcare is a huge potential market. In the OECD, countries spend on average from 8 to 10 percent of GDP on healthcare: about 9 percent in Canada and 15 percent in the United States. Key healthcare problems include manual patient charting, medication errors, ineffective and disruptive communications, lost records and costly patient monitoring. Wireless is solving these problems with electronic charting and centralized e-pharmacy checking and dispensing, multimedia communications (charts and videos), RFID[33] tracking and wireless data flow.

— *Location-Based Services:* This is increasingly being included in cell phones. It is used from tourist navigation to support of rescue teams in disaster management. It is well established in surveying and growing in vehicle tracking, railway management, traffic information and navigation solutions.

## 5.4 Canadian Companies

**Dragonwave:** The company designs, develops, markets and sells carrier-grade microwave infrastructure equipment for high-capacity broadband wireless systems for network operators and service providers. For example, Dragonwave provides microwave backhaul systems for cell phone service providers.

These products allow service providers to meet voice, video and data needs by offering high-speed, high-capacity solutions that allow service providers to rapidly expand and augment their network to support full-feature applications, such as streaming video and IPTV. As a developer of Ethernet microwave technologies, Dragonwave has developed significant intellectual property.

**RIM (Research in Motion):** RIM designs, manufactures and markets wireless solutions for the worldwide mobile communications market.

Through the development of integrated hardware, software and services that support multiple wireless network standards, RIM provides platforms and solutions

33 Radio frequency identification devices: Microchip tags that store information on whatever they are attached to and share this data when 'interrogated' by a radio signal.

for seamless access to time-sensitive information including e-mail, phone, text messaging (SMS and MMS), Internet and intranet-based applications.

RIM technology also enables a broad array of third-party developers and manufacturers to enhance their products and services with wireless connectivity to data. RIM products include the BlackBerry® wireless platform, the wireless device product line, software development tools, radio-modems and software/hardware licensing agreements.

**Sierra Wireless:** Sierra Wireless provides cellular data modems and has been an anchor player in the evolution of cellular data transmission—providing key consulting services during the evolution of the CDPD (cellular digital packet data) specification. Sierra assisted in the refinement of modulation details, simplification of the error correction algorithm and addition of power management.

Sierra Wireless modems and software connect people all over the world with mobile broadband networks that keep them in touch, informed and productive from wherever they need to be. For example, Sierra modems provide wireless access at speeds that can easily manage business needs like VPN (virtual private network) access, video conferencing, and e-mail, and more. Sierra Wireless USB modems provide fast wireless data access for desktops or notebook computers with a familiar, convenient USB connection.

The company's product portfolio addresses enterprise, consumer, original equipment manufacturer, machine-to-machine and specialized vertical industry markets. Sierra provides professional services to customers requiring expertise in wireless design, integration, and carrier certification.

## 5.5 Some Jobs

### *Hardware System Designer*

This position is responsible for the system implementation of current and next generation microprocessors and the interfaces with all subsystems. This requires close work with the various hardware and software groups to optimize performance and ensure a common interface is maintained between all products.

*Responsibilities:*

— System design and support of prototype and production hardware platforms, including implementing and debugging new technologies or subsystems into products. An in-depth knowledge of low power digital hardware design and digital audio circuitry is required, as is a comprehensive knowledge of RF circuits, Power Supply design and analog audio circuitry.

*Requirements:*

— 5 Years of Relevant Experience, Bachelor's degree in Electrical, Systems Design, Computer Engineering or Equivalent.

— Extensive Digital Design and Debugging skills.

— Experience in Low Power, Handheld electrical design and schematic capture.

— Experience in RF, Audio and Power supply design.

— Excellent electronics debugging skills.

— Ability to quickly adapt to new situations and constraints.

— Demonstrated ability to take initiative, responsibility and leadership in a team environment.

— Strong interpersonal and communication skills.

### *Customer Technical Support Specialist*

The Technical Support Team assists customers with network operating platforms. Our clients include experienced corporate Network Administrators, Government Agencies, Financial Institutions and Insurance firms. The position reports to the Supervisor, Support Operations.

*Responsibilities:*

— As part of the team, to provide professional support by troubleshooting customer issues and researching solutions.

— Participating on an inbound priority-based queue to answer telephone based inquiries (and some e-mail).

— Working in a backline capacity doing in-depth case investigations and customer follow up.

— Collecting information and performing initial troubleshooting for Server related installation, upgrade and/or post-installation issues.

— Leveraging both internal and external knowledge based systems for assisting customers.

*Requirements:*

— University or College education in a technology related discipline.

— Working knowledge of MS Windows OS (2000, XP, 2000/2003 Server).

— Outstanding comprehension and communication skills.

— 1-3 years previous support related experience dealing with customers (either face-to-face or in a technical support environment).

# 6. Software

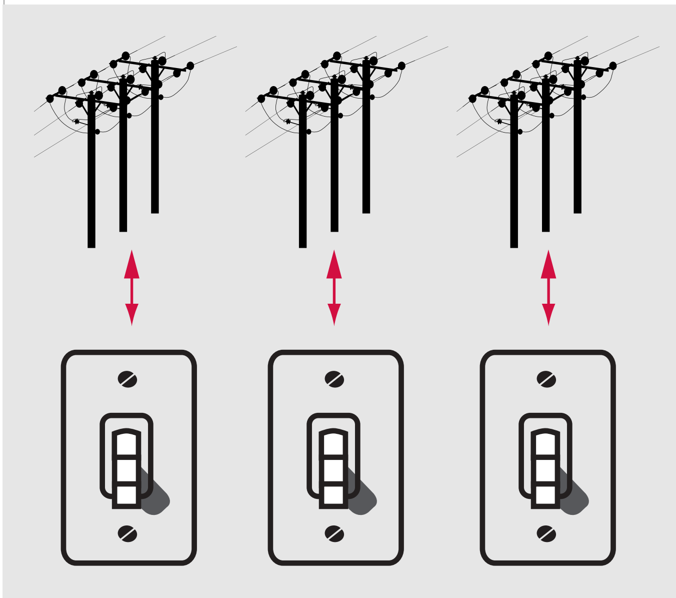
Software is the business of writing the detailed instruction sets (programs) that tell computers what to do. The term contrasts with hardware, the physical machinery of electronic systems and circuitry that actually carry out the underlying logic operations that comprise computing. Software is a global US$1 trillion industry.

## 6.1 A Brief History of Software

Software is still evolving from its beginnings in the late 1940s as the art of programming mainframe computers. The first computers had no software. Programming the computer meant literally wiring its logic circuits to accomplish the desired calculations.

The solution to this labourious task was to interconnect all of the circuits with on/off switches in order to include or isolate them as required to create the circuitry needed for a specific task.

Figure 12: The Software Solution



*Source: D.R. Senik & Associates Inc.,* The Fifth Wave: An Overview of the Technologies Driving the ICT Revolution *(September 2004)*

'Software' was the name that evolved for the coded set of instructions to activate the right switches in proper sequence to create the logic circuit for a particular calculation. Back then, programming was based on experience and intuition to get the desired results. In the intervening sixty years, it has made considerable progress toward a true engineering discipline, founded on scientific theory.

In the late 1940s, software programs were written directly in binary 'machine language,' the long strings of ones and zeros that computers represent as small pulses of voltage that are processed through their circuitry. These first generation languages had severe shortcomings. They were cumbersome to use and required detailed knowledge of the computer's circuitry, e.g., the exact location of stored data. The resulting long sequences of precise instructions would cause the computer to crash if a single bit[34] were misplaced.

By the early 1950s, second generation assembly languages used instructions like STORE, ADD and LOAD that were meaningful to programmers. Each corresponded one-to-one with a machine language instruction. The Assembler, a special program, translated these English-like instructions into machine language.

Third generation languages like FORTRAN (formula translation)[35] and COBOL (common business-orientated language) were in place by the late 1950s. As the names suggest, the grammar and vocabulary of instructions of these languages were suited to the users' general requirements.

By the early 1960s, software was generating the critical mass of know-how and applications to become a standalone business—distinct from a service 'bundled' with mainframe sales. First, the U.S. defense and space industries had extensive software needs, met by farming out contracts to small, independent companies. Second, it became evident that software development and maintenance costs were equal to hardware costs.

IBM was the first, in 1969, to launch a separate software unit—charging customers separately for hardware and software. Technology further contributed to the emergence of a separate industry with the development of C[36]—portable software, allowing software to be run on more than one type of computer.

By the late 1970s, programming technology—its job activities, software languages and hardware environment—had become sufficiently standardized to support significant market growth. As computing spread, firms such as Microsoft started to withhold the source code, thereby making software proprietary and turning it into a big business.

The 1980s saw the rise of 'shrink wrapped' software packages for PCs. Some early examples of these mass

34 Bit is short for binary digit, a one or a zero

35 Designed to work with science and engineering equations

36 C is a programming language developed at Bell Laboratories in the 1970s.

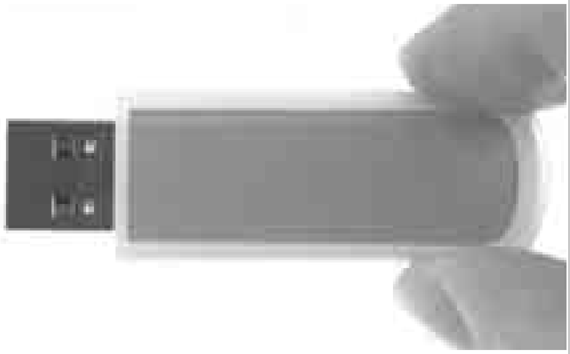
market products include WordPerfect (1982) and Lotus 1-2-3 (1983.) In the eighties, software grew at accelerating double-digit rates, from less than $30 billion (1980–81) to $100 billion in 1987. By 1995, the software goods and services industry passed the $400-billion-dollar mark.

Fourth generation languages appeared in the 1980s, a major improvement in meeting the need for customized software to enable business systems to address specific functions. Such languages, like C++ (1983), focused on the desired result versus the details of how the computer would calculate it. Just like natural languages, a wide variety of software languages have evolved to meet specific programming needs.

For example, JAVA (1995) is an *object-oriented* language. It facilitates the simulation of real-world systems with 'objects.' These are data items with an associated set of procedures to work with them, e.g., bank accounts and interest calculations. Another class of language is *special purpose*, e.g., HTML (hypertext mark-up language). It is designed for one specific task—to create documents that when viewed with a Web browser become a Web image.

Subsequent language generations have blurred into a continual process of change. Some noteworthy developments include massively parallel processing, artificial intelligence and virtual reality (high resolution graphical simulations). Now, powerful multimedia user interfaces incorporate sound, voice recognition, touch, video and TV. Combined with the Internet and the powerful connectivity of wireless, software is a major force for innovation.

As an industry, software is four decades old, now well into its long build-out phase. It is slowly becoming a commodity, marked by three fundamental developments—service-oriented architecture (SOA), open source and software-as-a-service (SaaS).



*Service-Oriented Architecture (SOA):* It is an architecture that allows different software systems to work together. SOA allows different applications (services) to exchange data and coordinate their activities. It avoids having to build new systems from scratch.

*Open Source:* The basic distinction is that source code is freely available (versus proprietary software), facilitating ongoing improvements that users share.

*Software-as-a-Service (SaaS):* It is a marketing and distribution model where a software vendor develops an application and hosts and operates the application for use via the Internet. Customers pay for use, not ownership of the software.

As a well established industry, software innovation is becoming more incremental marked by vendor concentration, intellectual property rights, installed bases, and brand loyalty.

## 6.2 Software Applications

Software can be broadly classified into *applications software, systems software* and *middleware*.

— *Applications software* refers to computer programs that perform useful tasks for the computer user, like word processing, presentations or spreadsheets.

— *Systems software* works in the background to manage the resources of the computer. It performs tasks, like allocating storage space and translating programs into machine language. The programs are written in symbolic code that is easier for people to understand. After translation, these instructions are in machine language that computers can directly execute.

— *Middleware* connects software components or applications. It allows multiple processes running on one or more computers to interact across a network, in support of complex distributed applications.

As a now well developed industry, software has made much progress toward developing a true engineering discipline of its own: Software Engineering (SE). This is a systematic, quantifiable approach to the development, operation and maintenance of software, increasingly founded on scientific theory and proven models. An important advance has been the creation of *development tools* designed to help programmers develop and implement new programs.

## 6.3 Markets Served

Software is bound up inextricably with information services. As the United States Department of Commerce dryly noted, "Information services have permeated the world economy to such an extent that defining this industry has become difficult."[37]

The largest part of this market is for professional computer services, including systems integration, computer programming, facilities management and maintenance, consulting, training and computer rentals and leasing. The market includes data processing and network services. Data processing covers data entry, credit card authorization, billing, payroll processing. Network services include electronic data interchange, electronic mail delivery, file transfer and electronic funds transfer.

### *A Canadian Perspective*

The National Research Council's Institute for Information Technology (NRC-IIT) is dedicated to R&D in software and systems technologies. Its work aims to have a profound and beneficial impact on Canadian society. NRC-IIT focuses on the following areas:

— *3D Imaging, Modeling and Visualization:* To use 3D information for the real world. Applications include industrial automation, inspection, space robotics, medicine and cultural heritage.

— *Data and Text Mining:* To enhance access to information. For example, BioIntelligence research involves discovering methods to structure and disseminate new knowledge discovered from genomics and proteomics data mining applications, then integrating it with other forms of knowledge, such as clinical documents and patient information available through medical labs, pharmaceutical companies and other medical organizations.

— *Human-Computer Interaction:* To understand physical interaction, cognitive, communication and social issues involved in the use of ICT. For example, collaborative technologies like groupware help people work on common tasks, by sharing environments and enabling people to work simultaneously or at different times.

— *Information Security, Privacy and Trust:* Focuses on addressing the challenges associated with network security and privacy for distributed systems, networks and application security. For example, this work includes:

- privacy enhancing technologies
- trust in digital communities
- secure agent deployment
- privacy for e-business applications
- security aspects of wireless and wired electronic commerce.

— *Intelligent Internet Applications:* This research falls into two main areas: rules for business logic and the electronic marketplace. The objective is to develop and apply logic tools that capture the intentions of business partners as they delegate economic activity to electronic agents.

— *Natural Language Processing:* This work develops computer-based tools for processing oral and written information, regardless of the language used. They encompass:

- multilingual text processing (e.g., machine translation, translation and revision assistance, and information retrieval);
- management of information from multilingual texts (e.g., automatic indexing and synthesis, information search from one language to another, document classification);
- support for language training (e.g., evaluation of language knowledge level, tools to assist in writing and reading, pronunciation coaching); and
- speech processing (e.g., voice recognition, biometric voice identification, text-to-speech and speech-to-text conversion).

[37] U.S. Industry & Trade Outlook, McGraw-Hill & The U.S. Dept. of Commerce/ International Trade Administration (2000)

*Software Engineering*

The goal is to advance the state of software production throughout the software lifecycle from project initiation to first delivery, product evolution and maintenance. Work focuses on:

- Integration and interoperability including commercial off-the-shelf software processes and
- Software development practices.

## 6.4 Some Canadian Companies

**Cadence Design Systems (Canada) Inc.:** Cadence develops electronic design automation (EDA) tools. These sets of software design tools that span the industry value chain from microchips up to circuit board and systems level. These tools are used by electronics companies to design and develop their products that include combinations of complex silicon and software solutions coupled with low-power, low-cost packages and miniature, high-speed printed circuit boards.

The company's Ottawa Design Centre has a worldwide mandate in all aspects of electronic design for the telecommunications industry.

**Descartes Systems Group**: Descartes provides systems solutions to meet the logistics needs of global trade and transportation organizations. Descartes offers solutions and services for two specific customer groups: transportation and logistics services providers; and manufacturers, retailers, distributors and service providers.

Descartes is a leading provider of software-as-a-service (SaaS) logistics solutions. It provides messaging services between logistics trading partners and shipment management services to help manage third party carriers and private fleet management services for organizations of all sizes to reduce administrative costs, billing cycles, fleet size, contract carrier costs, mileage driven and improve pick-up and delivery reliability.

**Open Text Corporation:** Founded in 1991 as a University of Waterloo spinoff, Open Text is the largest independent company providing enterprise content management (ECM) software solutions. These products help customers manage their critical business content from start to finish.

Specific products assist companies with the management of their content revisions, approvals to archiving and compliance with relevant regulatory requirements. A primary product, Livelink, enables corporations to manage traditional forms of content such as images, office documents, graphics and drawings, as well as to manage electronic content including Web pages, e-mail and video. These solutions allow users to gain access to view and manage all information related to a transaction or business process, without having to switch from one application to another.

## 6.5 Some Jobs

*Product Designer*

The objective is to research, identify, and solve complex software design problems in an innovative, highly collaborative environment. Product Designers work directly with program managers, product managers, architects and development leads to further software design.

The goal is to translate high level requirements into designs leading to detailed requirements that deliver compelling experiences that solve business problems. Product Design is responsible for designing the user experience framework, interaction and interface design for complex enterprise software applications.

*Responsibilities:*

- Support Program and Product Management by performing user research and developing ongoing relationships with customers.
- Capture customer stories and build an understanding of customer problems and needs.
- Analyze, synthesize and communicate customer research findings in order to highlight customer needs and help Program and Product Management anticipate market change.
- Identify and create user personas, buyer personas and associated scenarios.

— Create user experience artifacts such as wireframes, conceptual models, and low-high fidelity prototypes.

— Assist architects and product managers with assessing cross product and operational impacts of proposed development projects.

— Facilitate requirements meetings, ideation sessions, design reviews and focus groups with internal and external stakeholders.

— Maintain day-to-day contact with the development team to refine and revise requirements and implementation details, based on an agile/iterative development process.

— Validate designs with customers and other stakeholders throughout the development lifecycle.

— Mentor peers, stakeholders and teammates on customer-centered design principles and methodologies.

*Requirements:*

— 5+ years working with an experienced design team or diverse experience in areas such as development, writing, and professional or learning services.

— Degree in Computer Science, Human Factors Engineering, Cognitive Science, Interaction Design, Industrial Design, or related experience. Master's preferred.

— Strong technical background or the ability to quickly understand and articulate interactions in a complex technical environment.

### *Application Technical Architect*

This position assists in defining and building application technical architecture components for projects across several environments (i.e., Development, Integration, Test, Pre-Production, Production, Disaster Recovery) relative to the automation of interactions and exchange of information in the financial services environment.

*Responsibilities:*

— Configure, tune and administer all middleware server components.

— Ensure application technical architecture consistency and cohesion with other applications in the program and the corporate IT architecture. Investigate and promote cross-team adoption of standard tool sets and components in working towards a shared development model. Prepare technical documentation.

— Occasional support of the pre-sales team through responses to proposals, customer demos, customer requirements gathering and architecture prototypes.

*Qualifications:*

— A post-secondary degree in Computer Science or equivalent and a minimum of 3 years in enterprise software projects, with a proven track-record of success (both test and development experience), in both application and system programming.

— Advanced knowledge, understanding and hands-on experience with administering application middleware server components (e.g., Sun Java Web and Directory Server, BEA WebLogic Server, WebMethods Enterprise Services Platform, Oracle RDBMS) in a UNIX platform environment. Demonstrated experience with application clustering in a multi-tiered, high transaction volume environment.

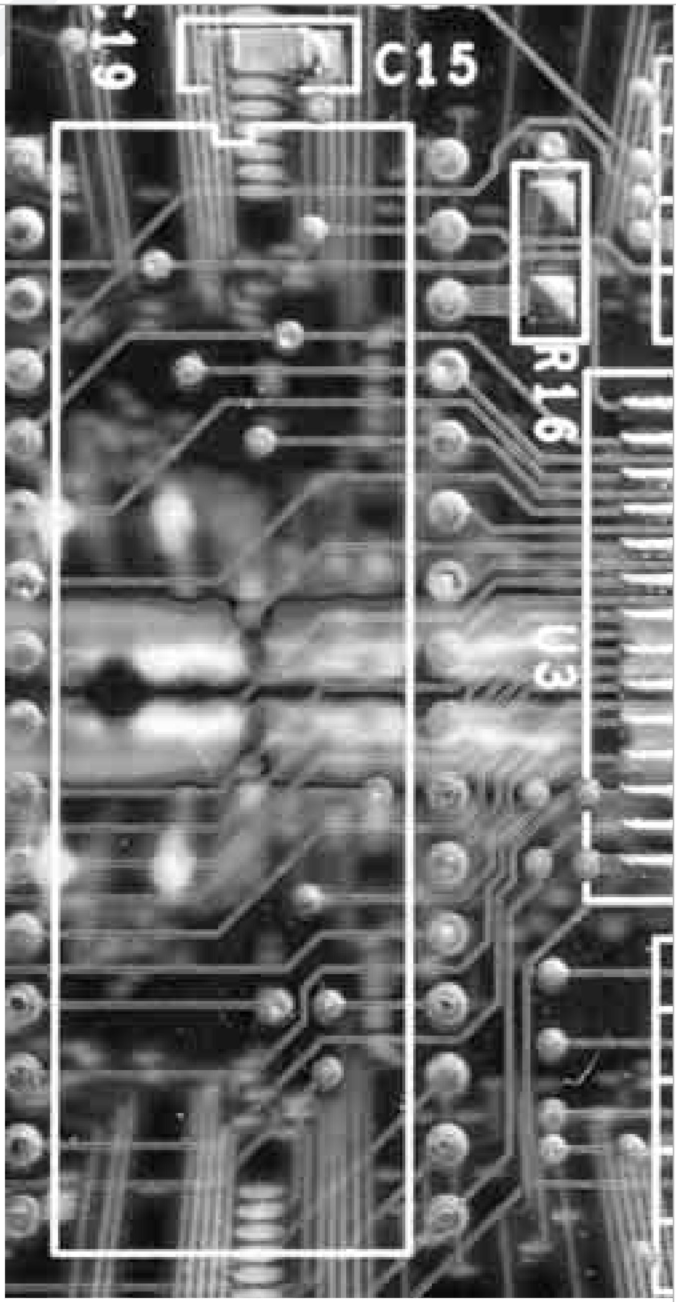
— Solid understanding of cutting-age Java application design and concepts (SOAP, J2EE, Web Services and application integration) as well as advanced knowledge of database design, data storage and transform issues, in addition to software engineering concepts and best practices.

— Working knowledge of Solaris and Windows operating systems, Oracle databases, HP testing tools, Java application analysis tools and system level performance tools.

— Familiar with multi-tiered technical architecture design (e.g., routers, switches, firewalls, protocol flows).

— Exemplary communication and interpersonal skills, organizational skills, and problem solving skills. Advanced technical writing skills with emphasis on translating "technical speak" into business language.

# 7. ICT Job Overview




## 7.1 Introduction

ICT skills are an integral part of modern life. While ICT specialists account for about 2 to 5 percent of employment in most OECD countries, together, ICT producers and users account for around 20 to 30 percent of total employment.[38] The OECD distinguishes three categories of ICT competencies.

Table 4: Defining ICT Specialists and Users

| | |
|---|---|
| ICT Specialists: | They have the ability to develop, operate and maintain ICT systems—the focal point of their job. |
| Advanced Users: | They are highly competent in using advanced, often sector-specific ICT tools. ICT systems are not the main job but a central tool. For example, an aeronautical engineering design, CFD (computational fluid dynamics) software is used to model airflow. |
| Basic User: | They utilize generic tools, like Word and PowerPoint, as part of the job. Again, ICT is an aid, not the main job. |

Increasingly, ICT specialists are expected to have other skills—like business—much as business people are now expected to have ICT skills.

OECD figures for Canada (2004) show ICT specialists accounted for 4 percent of total employment; ICT producers and users combined accounted for 20 percent of total employment.

## 7.2 Broad Developments

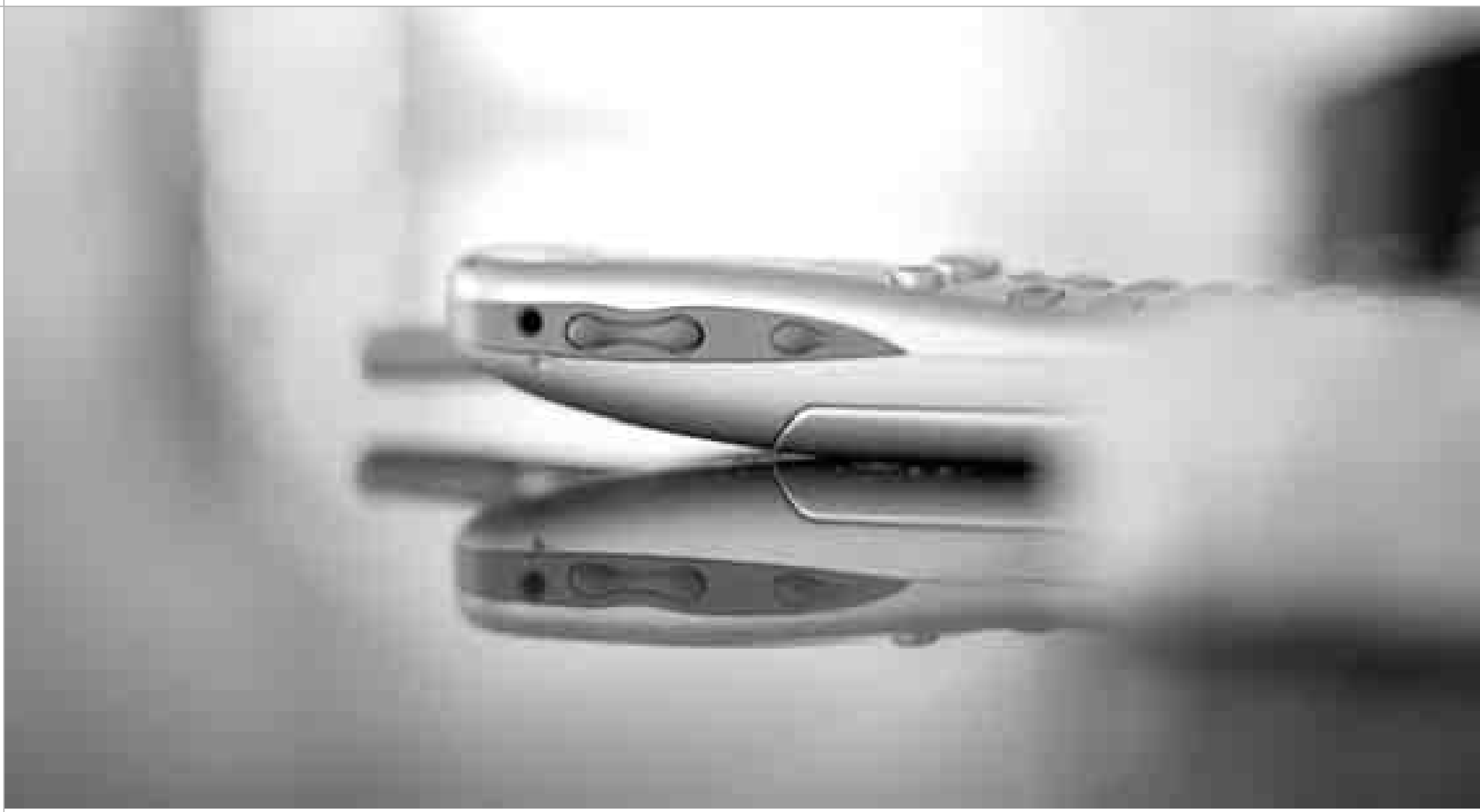
The U.S. Dept. of Labor, Bureau of Labour Statistics, reports annually[39] on the job market and career prospects for dozens of industries. The following group of five industries collectively span the ICT sector:

— Computer Systems Design and Related Services
— Computer & Electronic Product Manufacturing
— Internet Service Providers (ISPs), Web Search Portals & Data Processing Services
— Telecommunications
— Software Publishers

Computer Systems Design and Related Services along with Computer & Electronic Product Manufacturing cover the *hardware* part of ICT and overlap with the larger area of electronic systems. ISPs, Web Search Portals & Data Processing Services along with Telecommunications and Software Publishers cover the *software and services* dimension of ICT.

[38] *OECD Information Technology Outlook 2006* – ISBN 92-64-02643-6.

[39] Bureau of Labor Statistics, U.S. Dept. of Labor, Career Guide to Industries, 2008-2009 Ed.



The overall employment outlook for the next decade is summarized below in Table 5. An overview[40] of each of these five areas follows.

Table 5: Overall Employment, All Occupations in Five Industries Spanning ICT

| Industry | Job increase, %, 2006-2016 |
|---|---|
| Computer Systems Design and Related Services | +38 |
| Software Publishers | +32 |
| Internet Service Providers (ISPs), Web Search Portals & Data Processing Services | +14 |
| Telecommunications | +5 |
| Computer & Electronic Product Manufacturing | -12 |

## 7.3 A Job Market Summary for the Industries Spanning ICT

— **Computer Systems Design and Related Services**: This is the fastest growing area, driven by the reality that today's organizations need information and communications technologies to conduct business. However, only larger organizations have internal IT departments that manage the technology and infrastructure that run an organization's business systems. Most organizations turn to companies in the computer systems design and related services industry for help. Such companies assist with specific projects, like setting up a secure Website or software installation. They also provide contract support services like data centre management or custom programming.

*Computer specialists* comprise over half of employees. These cover eight professional and related occupations.

- *Programmers* create, test and maintain software. They also customize software packages to meet client needs.

[40] Ibid.

- *Computer Engineers* design, develop, test and evaluate software programs, systems and hardware and related equipment. *Computer Systems Software Engineers* primarily write, modify, test and develop software to meet the needs of a specific customer.
- *Computer and Information Scientists* develop solutions to complex hardware and software problems drawing on theoretical knowledge and innovation.
- *Systems Analysts* use methods like data modeling, structured analysis, information modeling and cost-benefit analysis to help organizations maximize the performance of their machines, personnel and business processes. They implement new software applications and design new systems.
- *Network Systems and Data Communications Analysts* design and evaluate network systems like LANs, WANs and Internet systems. *Web developers* are responsible for day-to-day site design and creation. *Webmasters* deal with technical issues for the site.
- *Network or Computer Systems Administrators* install and support these networks. They may also be responsible for planning and implementing network security measures.
- *Database Administrators* determine ways to organize and maintain the organization's data.
- *Computer Support Specialists* are troubleshooters. They field calls and provide technical assistance, support and advice to customers and users.

— Software Publishers: 'Publishing' refers to all aspects of producing and distributing software, such as designing, providing documentation, assisting in installation and providing support to customers. While some production is in printed form, software is produced and distributed on CD-ROMs and sold preloaded on new computers. Increasingly, software is now developed for distribution and use over the Internet.

The strong growth of software publishing reflects its central role in business. Some examples include Enterprise Resource Planning (ERP) and e-business. ERP automates a firm's business processes including human resources, manufacturing, financial management, customer relations and supply chain management. E-business refers to conducting any business process over a computer network. E-commerce, in particular, is the buying and selling of goods and services. All of this on-line business has heightened the need for computer security like firewalls and antivirus software to safeguard network and computer operations against intrusion or online crime like credit card fraud.

Computer specialists in this field comprise just over half of all jobs. They do many of the same jobs as those above in Computer Systems Design and Related Services, including:

- Programmers
- Computer Software Engineers
- Computer Support Specialists.

— Internet Service Providers (ISPs), Web Search Portals and Data Service Providers: All three services are key to Internet access and its smooth functioning in facilitating the information flows that are the lifeblood of modern economic activity.

ISPs provide the direct Internet connections that route information from one location to another, much as private services like Fedex and public ones like the post office provide fast and accurate delivery of physical mail. ISPs develop and maintain the network and business connections that underlie the Internet service we take for granted. Like telephone service or electrical utility service, ISPs work on a subscription basis. They may also offer related services like Web hosting, Web page design and consulting services for hardware and software. While ISPs route customers' data, the telecommunications industry owns the physical connections like fibre-optic cable, microwave transmission systems and telephone networks that actually carry the data—much like trucking companies deliver shipments, but government owns the road network.

Web search portals provide databases of Websites and a quick and convenient way of searching them using key words. The distinguishing feature of Web search is its use of sophisticated algorithms to gather information and rank the relevance of content sought by the user. Web portals may also offer additional services like news, maps, e-mail and local business directories.

Data service providers handle large amounts of data for clients. Web hosting involves posting content and making it accessible via Internet. Additional data hosting services include archiving old data or providing streaming music and video. Data processing includes data entry, conversion and analysis.

Computer specialists in this field account for about one-third of jobs, many the same as listed in the two categories above, including:

- *Computer Software Engineers*
- *Computer Systems Analysts*
- *Computer Support Specialists.*

- **Telecommunications:** This is a long-established industry, dating back to telegraphy (1830s), telephony (1870s), wireless telegraphy (late 1890s), radio broadcasting (1920s), photonics (late 1970s), communications satellites (1960s), wireless cellular telephony (early 1980s) and the Internet (1990s). While its employment growth is modest, is has been continually transformed—for almost two centuries—by the most advanced technologies of the day. Telecommunications includes voice, video and Internet communications. While wireline telephone communications dominated the industry at the mid-twentieth century, Internet service, and satellite and cable distribution now account for an increasing share.

  Telecommunications companies connect their subscribers to central switching offices that determine the most efficient route to transmit data. They provide the links that connect different regions as well as other countries. Voice traffic requires a small amount of network capacity; however, data, video and graphics require significant capacity (bandwidth). Consequently, telecommunications companies have been expanding and upgrading network capacity.

  Cable and other program distribution is an industry sector that provides TV and other services on a subscription or fee basis. (In the economic accounts, broadcasting is now considered a separate industry because of its focus on content, versus transmission, as the core of added value.) Direct broadcasting satellite (DBS) operators transmit programming via earth satellites to customers' receivers (minidishes.) Cable companies use fixed links like fibre-optic or coaxial cable[41] instead.

  Wireless telephony operators and their hugely popular services are covered in Chapter 5 (Wireless). Another category of telecommunications company is *resellers*. They lease transmission services from telecommunications companies and resell it to smaller customers (much like the wholesaling business does with physical goods).

  Advances in technology and changes in regulation have allowed cable companies and telephone companies to directly compete with each other. A significant change for cable companies is the capacity for two-way communication with customers, versus just one way distribution of signals. This allows offering services like

[41] Coaxial cables are often used to transmit high frequency signals like TV because almost no signal energy is lost through external electromagnetic fields.

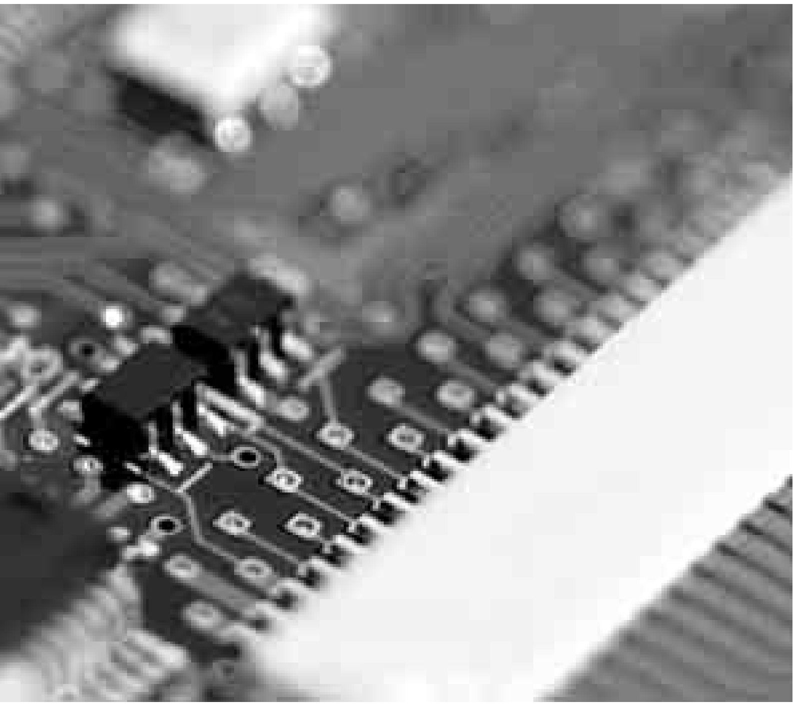
video on demand and high-speed Internet access—allowing VoIP (voice over Internet service). Telephone companies leverage their extensive wireline networks to offer high bandwidth service—like DSL (digital subscriber lines) for high-speed Internet.

Computer specialists and related occupations in this field account for about 16 percent of jobs, many shared with the categories above; these include:

- *Computer Software Engineers*
- *Computer Support Specialists*
- *Network and Computer Systems Administrators*
- *Network Systems and Data Communications Analysts.*

The industry's foundation on the physical networks at the core of its added value is reflected in the inclusion of the following jobs in the above group as well. Marketing, too, is part of this group, underlining its importance in generating competitive advantage in long-established industries:

- *Electrical and Electronics Engineers*
- *Electrical and Electronics Technicians*
- *Market Research Analysts.*



The importance of physical networks and equipment is further underlined by the 26 percent of all jobs in installing, repairing and maintaining telecommunications equipment, cables, access lines and systems:

- *First Line Supervisors/Managers of Mechanics, Installers and Repairers*
- *Telecommunications Equipment Installers and Repairers, except Line Installers*
- *Electrical and Electronics Repairers of Commercial and Industrial Equipment*
- *Electronic Home Entertainment Installers and Repairers*
- *Telecommunications Line Installers and Repairers.*

- Computer and Electronic Product Manufacturing: Like manufacturing in the advanced economies as a whole, employment is expected to decline somewhat over the period 2006-2016.

  Overall, 12 percent of jobs (order of magnitude, 1 percent annually) are expected to either be taken up by overseas producers or be eliminated by productivity improvement. This is part of the normal technology development cycle that older industries, like autos and aircraft manufacturing, have already experienced. Like telecommunications, the industry is characterized by significant research and development and a high rate of technological change.

  Computer specialists and related occupations account for about 11 percent of jobs, all shared with the categories above. These include:

  - *Computer Software Applications Engineers*
  - *Computer Systems Software Engineers*
  - *Computer Hardware Engineers*
  - *Computer Support Specialists*
  - *Computer Systems Analysts.*

  The importance of electronics systems across the entire economy is evidenced in the inclusion of engineering disciplines other than electrical and electronics. In all, this group of engineering and technical disciplines accounts for about 15 percent of all jobs:

  - *Aerospace Engineers*
  - *Electrical Engineers*
  - *Electronics Engineers, except Computer*
  - *Industrial Engineers*
  - *Mechanical Engineers*
  - *Drafters*
  - *Electrical and Electronic Engineering Technicians*
  - *Industrial Engineering Technicians.*

## 7.4 A Final Word on ICT Jobs

The ICT Revolution will continue to reshape the broad economy over at least the next quarter century. It is in the long and relatively stable *Build-Out* phase: major applications are established and overall growth, in the single digits, will gradually fill in market needs. As ICT reaches its physical performance limits, largely determined by the classical physics on which its microelectronics building blocks are founded, the ICT platform will increasingly turn to successor technologies.

Already, the younger ICT components of photonics and software are the source of more and more value added. For example, photonics has already replaced electronics—down to the distance scale of local area networks—as a better transmission solution than electronics. It is expected to further displace electronics down to the motherboard level and even the chip level as more applications demand the high-speed data transmission on which ICT improvements build. The U.S. National Science Foundation sees nanotechnology as an emerging discipline that will open up a new technology revolution.[42] This era, whose outlines are already starting to provide tantalizing glimpses of what could be, will be launched by a set of interacting developments driven by the convergence of neuroscience, ICT, biology, and nanotechnology. The explanations that underlie the separate fields of physics, chemistry, engineering, and life sciences all converge at the nanoscale. The new understanding that nanotechnology will exploit, centres on four twenty-first-century building blocks for innovation: bits, neurons, atoms, and genes.

> The basic building blocks that will be combined in unprecedented ways to shape twenty-first-century innovation are bits, neurons, atoms, and genes.

ICT will be bound up with this new era. As a source of new products, new industries and new jobs, ICT will continue to be at the forefront of advanced applications. Much as wireless went far beyond the telegraph, and computing surged past the limits of vacuum tube mainframes, ICT in the coming half century will be part of a new and challenging revolution that will maintain its importance as a major generator of value added and a large employer.

[42] *Converging Technologies for Improving Human Performance*, U.S. National Science Foundation and Dept. of Commerce (June 2002).

**The Information and Communications Technology Council (ICTC)** is a not for profit sectoral council dedicated to creating a strong, prepared and highly educated Canadian ICT industry and workforce. ICTC is a catalyst for change, pushing for innovations that will provide labour market intelligence, life-long professional development and quality education and training for the Canadian ICT industry, educators, governments and the ICT workforce. We forge partnerships that help develop the quantity and quality of ICT professionals needed to improve Canada's position as a leader in the global marketplace.

To achieve its goals, ICTC focuses on four areas that are proven building blocks of a healthy, forward-looking sector:

- **Skills Definition** – defining the skills required to be a professional in the ICT sector.
- **Labour Market Intelligence** – providing up-to-date statistics and analyses of human resource developments in the ICT sector.
- **Career Awareness** – providing programs and tools to explore the career possibilities in Canada's ICT sector.
- **Professional Development** – dedicated to continuous learning for ICT workers so they can maintain and improve their skills sets and increase their opportunities within the sector.

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