RESEARCH AND DEVELOPMENT (R&D) INSTITUTES STUDY

[Comparative study of four world renowned scientific/industrial Research and Development (R&D) Institutes:
Fraun Hoffer Institute, Germany
Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
Massachusetts Institute of Technology (MIT), USA
and National Research Council (NRC), Canada]

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Chapter 1: Mandate[1]

Fraunhofer

Fraunhofer (Fraunhofer-Gesellschaft[2] – henceforth 'FG') was founded in Munich in 1949. It was established in order to be a part of the development of Germany's research infrastructure, in the post war era.[3] FG was named after Joseph von Fraunhofer (1787 - 1826), who was a researcher, inventor and entrepreneur.[4] FG started as a non-profit organization, whose main aim was to raise funds (from government, private establishments, and individual donors) for research projects that were relevant to industry. Its earliest activities were centered around the industries in Bavaria, which were predominantly focused on - mining, the iron and steel industry, and mechanical engineering.[5] In 1950s, it also received funds from programs such as the Marshall plan and the European Recovery Program.[6]

In 1972, FG adopted what is known as the 'Fraunhofer model'. Under this model, FG was to focus on contract research work (i.e. research funded by private sources). This meant that research and development (henceforth 'R&D') work had to be oriented strictly in accordance with the market. The state supported FG, but the support was supposed to be proportionate to the funding that FG was able to acquire through private sources.[7] Adoption of this model was also intended to transform the FG into an 'umbrella organization', which would have various autonomous/semi-autonomous applied research institutes operating underneath its banner.

In 1967, the Institute for Oscillation Research was set up within the FG. This organization later became the Fraunhofer Institute for Information and Data Processing; hence it was FG's earliest foray into the Information Technology (henceforth 'IT') sector.[8] This was followed by the Institute for Solid State Technology in 1974. By 1982, FG established several institutes (like the Fraunhofer Institute for Microelectric Circuits) which were conducting researches exclusively in the field of the hardware/mechanical technology for electronic communication - which later on would form the foundation for one of FG's key area of expertise: the IT sector. By 1991, FG established Fraunhofer Institute for Computer Graphics Research, which marked

[1] Mandate, vision, strategy and, key performance indicators (metrics) such as research outcomes, impacts (financial - revenues for companies using the technologies produced, number of new employees hired by companies using the technologies, revenues for the research organization, products licensed, number of papers published by staff).
[2] 'society'
[3] http://www.fraunhofer.de/en/about-fraunhofer/chronicle/1949-1954.html
[4] http://www.fraunhofer.de/en/about-fraunhofer/joseph-von-fraunhofer.html
[5] http://www.fraunhofer.de/en/about-fraunhofer/chronicle/1949-1954.html#!tabpanel-5
[6] http://www.fraunhofer.de/en/about-fraunhofer/chronicle/1949-1954.html#!tabpanel-4
[7] http://www.fraunhofer.de/en/about-fraunhofer/chronicle/1972-1982.html#!tabpanel-11
[8] http://www.fraunhofer.de/en/about-fraunhofer/chronicle/1966-1971.html#!tabpanel-5

FG's entry into the software/programming aspect of IT; while evolving from its previous thrust on hardware and physical electronics.[9]

CSIRO

The origins of CSIRO, or the Commonwealth Scientific and Industrial Research Organisation, can be traced to the early years of World War I. In early 1910s, the Australian Government wanted to establish a national-level 'scientific laboratory' in Australia, and hence it made the Advisory Council of Science and Industry. By 1926, the Advisory Council paved the way for the Council for Scientific and Industrial Research (CSIR). [10] The mandate of the CSIR was to carry out scientific researches, in order to develop primary and secondary industries in Australia — i.e. farming, mining and manufacture. Another important mandate of the Council was to collect information about the state of scientific research in Australia; undertake research; review existing science researches all over the world; and collect and disseminate information to various Australian scientific organizations and universities. CSIR began its operations from technical colleges in Melbourne and Victoria.[11]

During the 1930s and 1940s, CSIR was conducting researches in the areas of - animal pests and diseases; plant pests and diseases; fuel problems, especially liquid fuels; preservation of foodstuffs, especially cold storage; and forest products. During World War II, CSIR assisted Australian Government with defense technologies, such as the radar. This was CSIR's (and later, CSIRO's) very first venture into the field of microelectronics and Information Technology (*henceforth* ***'IT'***).[12] In 1949, CSIR was renamed as CSIRO (i.e. the Commonwealth Scientific and Industrial Research Organisation); and it expanded its research areas to include - building materials; wool textiles; coal; atmospheric physics; physical metallurgy; and assessment of land resources. During this period, CSIRO conducted researches on applying early IT and computing technologies, in the fields of atmospheric physics, radio astronomy and land resources. In the 1950s, CSIRO expanded its research expertise in the areas of – environment; human nutrition; conservation; urban and rural planning; and water.[13]

CSIRO's present day IT researches can be traced to the Biometrics Section of CSIR, which was established in 1941. In 1944, the Biometrics Section was renamed as the Mathematical Statistics Section, which progressed to become the Division of Mathematical Statistics in 1954. CSIRO started exclusive work in IT and computing sciences, with the formation of the Computing Research Section in 1963, which later became the Division of Computing Research in

[9] http://www.fraunhofer.de/en/about-fraunhofer/chronicle/1983-1989.html#!tabpanel-4
[10]http://www.csiro.au/Organisation-Structure/Flagships/Digital-Productivity-and-Services-Flagship/About-DPAS.aspx
[11] www.tfrc.csiro.au/openday2005/csiro_history.pdf
[12]http://www.csiro.au/~/media/CSIROau/Corporate%20Units/Corporate%20Communications/Brand%20%20Marketing%20Communication/AnnualReport2000-1_AboutCSIRO_pdf%20Standard.pdf
[13] http://www.csiro.au/Portals/About-CSIRO/Who-we-are/History/CSIROHistoryOverview.aspx

1967. In 1985, the Division of Computing research was transferred to the newly formed Division of Information Technology (which subsequently became the Information Communication Technology Centre).[14] [15]

MIT

MIT, or Massachusetts Institute of Technology, is a private research university. It is located in Cambridge, Massachusetts (USA); and it has five schools, one college, and 32 academic departments. MIT focuses on scientific, engineering and technological education as well as research.[16] MIT was founded by William Barton Rogers and his associates. Rogers was a professor of natural philosophy at the University of Virginia; and his vision for MIT was to build an institution for technical and scientific education. In 1861, the charter of MIT was presented to the Commonwealth of Massachusetts; and by 1865, MIT accepted its first batch of students. Rogers became MIT's first president and his mandate for the Institute was to establish a new kind of independent educational institution, which will be relevant to an increasingly industrialized USA.[17]

The origins of researches and education in the field of information technology (*henceforth 'IT'*) can be traced to the Department of Physics and Electrical Engineering at MIT. Electrical engineering (*henceforth 'EE'*) was originally taught in the Physics Department. By 1882, EE became a separate degree, and a separate department by 1902. By 1975, EE department realized the growing field of computing; hence it renamed itself as Department of Electrical Engineering and Computer Science.[18]

By the beginning of the Second World War, MIT scientists pledged their support to the Allied effort. For their part, MIT physicists worked on wartime projects at the MIT labs; as well as, provided technical education to the military officers. A significant achievement of the MIT physicists was the radar technology. The invention was a radio tube known as a cavity magnetron, which could be used to reflect radio waves to detect planes and boats at a distance. Similarly, by 1930s, Karl Compton, the President of MIT, had been involved in the research and development (*henceforth 'R&D'*) of microwave technology for defense purposes. All these scientific and technological developments later gave rise to the electrical engineering and computer science divisions of MIT.[19]

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[14] http://www.csiropedia.csiro.au/display/CSIROpedia/Mathematics%2C+Informatics+and+Statistics+%282009-%29

[15] http://www.csiro.au/Organisation-Structure/Flagships/Digital-Productivity-and-Services-Flagship/Resources.aspx

[16] Entrepreneurial Impact: The Role of MIT, 2009. Retrieved from www.kauffman.org/mit

[17] http://web.mit.edu/facts/origins.html

[18] http://web.mit.edu/annualreports/pres12/2012.04.05.pdf

[19] http://web.mit.edu/physics/about/history.html

During the period between the World Wars, almost every member of the MIT Physics Department was involved in some form of war work. For example, MIT Physicists developed high-voltage x-ray machines that could be used to examine castings and munitions for defects; their cyclotrons generated radioisotopes for medical purposes; and few scientists were allegedly involved with the secretive 'Manhattan Project'.[20] Other members of the department worked on camouflage (specifically light-scattering paint, which made day time bombing raids safer); guided bombs and missiles; and noise reduction inside tanks. Most of MIT's present day computing researches can be traced back to these scientific innovations during the war period. To illustrate: MIT scientists developed the hydrophone – a device that could detect submarines for the Navy. Later, this technology gave rise to a rigorous understanding of statistics, for tackling anti-submarine warfare. This statistical innovation evolved into what is now known as Operations Research.[21] [22]

NRC

The National Research Council (NRC) of Canada is a 'Crown Corporation', which is operated by the Federal Government of Canada, and guided by the office of the Minister of Industry. In 1916, the Canadian Govt. formed the Honorary Advisory Council for Scientific and Industrial Research, in order to fund scientific researches in Canadian universities (via fellowships, scholarships, etc); in addition to, carrying out studies to ascertain the status of scientific work in Canada, by doing a statistical evaluation of the work force and budgets involved in technical projects. Soon after, this Advisory Council was replaced by the NRC; and by 1928, NRC had its own national laboratory at Ottawa; and thereafter, 54 scientists and research engineers by 1935. NRC's initial mandate was to strengthen the Canadian economy and industry, through scientific and industrial research.[23] [24]

Even though NRC began as an advisory body to the Canadian Govt., very soon NRC's mandate was to identify solutions for the challenges that are distinctive to Canadian environmental, industrial and scientific contexts. For e.g. in the 1920s, NRC's scientists developed a cement that was resistant to sulfates in water. Damage caused by sulfates, to concrete structures, was resulting in severe building and infrastructural damages in western Canada. The scientists also developed a concrete curing process which made it resistant to corrosion, during the harsh winters of Canada. Furthermore, the engineers of the NRC were

[20] http://hdl.handle.net/1721.3/59022

[21] http://libraries.mit.edu/mithistory/research/schools-and-departments/school-of-science/department-of-physics/

[22] http://web.mit.edu/physics/about/history.html

[23] http://www.nrc-cnrc.gc.ca/eng/education/innovations/discoveries/NRC90/1916.html

[24] http://actionplan.gc.ca/en/news/government-canada-launches-refocused-national

also spearheading construction-related standardizations, like developing building codes that are specific to Canada.[25]

During the periods of World Wars 1 & 2, the mandate of NRC was influenced by demands of the war, and it led to the emergence of NRC as the key research and development (R&D) organization of Canada. NRC made numerous and significant efforts to assist the wartime strategies of Canada and its allies. To illustrate: NRC's researchers examined the effects of mustard gas; use of penicillin to prevent wound infection; uses of typhus vaccines; plastic surgery; tuberculosis cure; burn treatments; and so on. One of the prominent inventions was the first motorized wheelchair, which was developed to assist disabled veterans. Other major innovations of NRC, during the war era, pertained to atomic energy.[26] [27]

In the NRC, the origins of researches in Information Technology (IT) can be traced to inventions, such as the pacemaker, which utilized microelectronics.[28] By the 1960s, with the experimentations on computer animation, more direct researches in IT sciences began at the NRC. Global developments, like the interest of Disney studios (USA) in making animated and 3-dimensional cartoon movies, prompted NRC's forays into computer graphics, which eventually led to the development of a revolutionary graphics-technology called - key-frame animation.[29]

Space explorations and related technologies (in particular, the 'Canadarm' in 1980's) is another arena that was directly responsible for the growth of the IT sector within NRC. NRC's scientists developed several computing systems for the functioning of the 'Canadarm', as well as for numerous other parts of NASA's shuttles. For e.g.: NRC invented the 'Space Vision System' for guiding the Canadarm, and other manipulating devices on the shuttle. Consequently, in 1990, NRC established the Institute for Information Technology (NRC-IIT) for conducting high-end researches, exclusively in the field of IT.[30]

The NRC-IIT collaborated with government agencies, industries, and universities, for developing IT innovations that would not only be commercially viable, but also support Canada in healthcare and education. Since the 1990s, NRC-IIT has been developing IT innovations, which had a wide range of applications; such as - artificial intelligence; intelligent internet; human-computer interaction; computer vision; and, processing of natural languages. Other mandates of the NRC-IIT comprised of – providing federally-funded R&D platforms (as well as finished IT products) to Canadian IT industries (especially small and medium); advanced

[25] http://www.nrc-cnrc.gc.ca/eng/education/innovations/discoveries/concrete.html
[26] http://www.nrc-cnrc.gc.ca/eng/education/innovations/discoveries/wheelchair.html
[27] http://www.nrc-cnrc.gc.ca/eng/education/innovations/discoveries/war.html
[28] http://www.nrc-cnrc.gc.ca/eng/education/innovations/discoveries/NRC90/1916_history.html
[29] http://www.thecanadianencyclopedia.com/articles/national-research-council-of-canada
[30] http://www.nrc-cnrc.gc.ca/eng/education/innovations/discoveries/astronauts.html

infrastructure for prototype manufacture (for e.g. microchips); and, licensing as well as patenting of IT products.[31]

The legal foundation of NRC's existing mandate comes from the National Research Council Act (1985) of the Canadian Government. According to this Act, the NRC is responsible for an assorted set of activities, related to science and technology in Canada. For instance – NRC's is the guiding agency for all matters affecting scientific and industrial research in Canada, especially the ones that involves natural resources, or methods and processes used in industries, or technologies related to industrial waste. Similarly, this Act makes NRC, the nodal agency for - standards and methods of measurements (like length, volume, etc); physical constants and fundamental properties of matter; along with, providing certifications to scientific and technical apparatuses, which are used by the Government and the industries of Canada.[32] [33]

[31] http://www.cdmn.ca/partners/national-research-council-institute-for-information-technology-nrc-iit-fredericton-moncton/
[32] http://www.laws.justice.gc.ca/eng/acts/N-15/page-1.html
[33] http://www.laws.justice.gc.ca/PDF/N-15.pdf

Chapter 2: Vision & Mission

FRAUN HOFFER

Currently, FG is an 'application-oriented' research organization. By 'application oriented', FG refers to - shaping technology, designing products, and, improving methods and techniques. FG undertakes researches for the private as well as the public sector. The main goal of FG is to apply innovative research findings in industrial and social contexts. The broadest categorization of FG's research fields are - health, security, communication, energy and the environment. FG's activities relating to IT falls under the field of 'Communication'. One of the directives of FG, behind conducting researches for the private sector - especially the one's based in Europe, is to provide them with technological innovations and unique solutions, in order to give them the competitive edge vis-à-vis other private corporations of the world.[34]

FG operates with both public, as well as, private funding. In 2012, its annual research budget was 1.9 billion Euros (CAD 2.6 billion). 30% of FG's budget originates from federal and local governments. The rest 70% is derived from the private sector, in forms of research contracts.[35] FG utilizes public funding to do 'pre-competitive' research. This forms the foundation for the 'competitive' or contract-based (i.e. privately funded) research projects, which are conducted for the market and customers. The earnings from the private sector enable FG to be highly self-sufficient in terms of its budget.

FG's research work can be generally divided into 2 subtypes - (a) contract research & (b) application-oriented basic research.[36] 'Contract research', which is funded by commercial establishments, is aimed solely at the market requirements of the customer. FG develops products and processes right up to their commercial viability. This comprises of only those R&D projects where scientific expertise can be converted to practical utility; and where the end result can be mass produced, leading to commercial gains. Apart from large enterprises, these projects enormously help small and medium enterprises, who might not be able to run their own R&D operations. [37] For 'application-oriented basic research', FG uses funding by the German federal ministry of education and research, for undertaking advanced researches. These R&D activities do not have any immediate production feasibility or commercial value, yet they are undertaken for their future potential.[38]

With respect to its Vision, FG has identified 6 sectors (health, security, energy, communication, the environment and mobility), which FG forecasts as the most imperative,

[34] http://www.fraunhofer.de/en/about-fraunhofer/mission/research.html
[35] http://www.fraunhofer.de/en/about-fraunhofer.html
[36] http://www.fraunhofer.de/en/about-fraunhofer/business-model/contract-research.html
[37] http://www.fraunhofer.de/en/about-fraunhofer/business-model/contract-research.html
[38] http://www.fraunhofer.de/en/about-fraunhofer/business-model/contract-research.html

from the perspective of people's needs in the future.[39] In the sector of 'Communication' (which encompasses most of FG's activities in IT), FG envisions researches in sensors and wireless communications, which they identify as the key to the future. Using IT, FG aims to transform ordinary objects (like clothes or houses) into active entities that would adapt to the user. For instance, FG wants to develop houses, which would use artificial intelligence to ensures safety or optimize energy use.[40]

In the IT sector, FG plans to develop innovations in 3 contexts – home, outdoors and office – in future. In the context of homes, FG is attempting to remove all wire-based transmissions and make video/audio signals completely wireless. Furthermore, the signals would be of extremely high quality. For 'outdoors' FG intends compress video data, so that video streaming (for e.g.: live broadcasts) to mobile devices becomes exceedingly easy. For 'offices', FG is planning to develop mechanisms, whereby one could fully access corporate networks, from any location in the world.[41] Apart from these applications, FG envisions utilization of IT technologies in other contexts. For example, in the 'Mobility' sector - software and microelectronics in cars would automatically detect traffic jams and avoid those routes. Likewise, in the 'Environment' sector – the usage of dedicated digital devices (like PDAs) in disaster management.[42]

CSIRO

Presently, CSIRO is part of the Australian federal Government; and it derives its authority from the Science and Industry Research Act (1949) of the Australian Constitution. Under this Act, CSIRO's vision and mission is to carry out scientific researches that would benefit Australian industry and the community. CSIRO is accountable to the Minister for Innovation, Industry, Science and Research.[43] CSIRO has divided its research focus into 11 broad areas, which it terms as the National Research Flagships. These areas or 'Flagships' are - Climate Adaptation; Energy; Food Futures; Future Manufacturing; Minerals; Preventative Health; Sustainable Agriculture; Water; Oceans; Bio-security; and, Digital Productivity and Services. The flagship - Digital Productivity and Services (*henceforth* ***'DP & S'***) – comprises of activities that relate to IT sector. Under the National Research Flagships program, CSIRO has formed large-scale multidisciplinary research partnerships with Australian Universities, publicly funded research institutions, private sector, and, international organisations.[44] [45]

[39] http://www.fraunhofer.de/en/about-fraunhofer/future-needs-research.html
[40] http://www.fraunhofer.de/en/about-fraunhofer/future-needs-research.html#!tabpanel-4
[41] http://www.fraunhofer.de/en/about-fraunhofer/future-needs-research.html#!tabpanel-4
[42] http://www.fraunhofer.de/en/about-fraunhofer/future-needs-research.html#!tabpanel-3
[43] http://www.csiro.au/Portals/About-CSIRO/How-we-work/Governance/Governance-Overview.aspx
[44]http://www.csiro.au/~/media/CSIROau/Corporate%20Units/Executive%20Team%20ET/CSIROStrategicPlan2011-15.pdf
[45] http://www.csiro.au/Portals/About-CSIRO/How-we-work/Strategy/Our-Strategy-Overview.aspx

The vision - behind the promotion of 'DP & S' and allied IT-related activities – are the significant changes that are taking place in the production output of Australia. Australian economy has traditionally been dependent on mining and natural resources. However, after the emergence of new and stronger markets (like India and China); the shift in the world economy from basic products (like natural resources) to consumer products; and the financial turmoil, for instance, the banking crisis of 2008 – Australian government has decided to invest in the IT sector.[46]

Consequently, the vision of CSIRO for 'DP& S' researches is twofold - (1) to maintain a competitive edge in the natural resource industry in an increasingly complex and resource-limited world; and, (2) move the economy from the over dependence on the natural resources sector. Furthermore, as the bulk of Australian population moves towards service-based industries, the Govt. of Australia deems that a digital economy is essential for Australia's economic growth. It wants the IT sector to answer the upcoming challenges to Australian society – such as, rising health costs; the budgetary challenges driven by an aging population; and pressures on the infrastructure.[47] Under the 'DP & S flagship', CSIRO has been conducting researches in the IT sector, for applications in 3 fields – (a) government and commercial services; (b) health services; and (c) smart and secure infrastructure. In the field of (a) 'Government' – CSIRO's mission is to use IT technologies for raising the productivity of Australia's government and its various units. Through the usage of IT innovations, Australian government aims to save AUD[48] 1.4 billion (CAD 1.43 Billion) per annum.[49]

In the field of (b) 'health services' – CSIRO's mission has been to partner with Australian government's health department; and aspire at saving AUD 1 billion per year through innovative IT technologies. For the same, CSIRO has developed systems for using Australia's national broadband infrastructure for healthcare services; applied IT technologies for productivity in health service delivery and sustainability in the health system; and, has developed an e-Health architecture.[50] In the area of (c) smart and secure infrastructure – CSIRO has created electronic and physical infrastructure, which provide benefits of more than AUD 1.6 Billion per annum. CSIRO's mission has been to provide innovative researches in the following segments: broadband communications; smart wireless technologies; and security and privacy of Australia's online infrastructure.[51]

A decade ago, as part of the vision and mission of CSIRO with respect to IT, Information and Communication Technology (*henceforth* ***I & CT***) was earmarked as one of the five emerging

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[46] http://www.csiro.au/Organisation-Structure/Divisions/ICT-Centre.aspx
[47] http://www.csiro.au/Portals/About-CSIRO/How-we-work/Strategy/Our-Strategy-Overview.aspx
[48] Australian Dollar
[49] http://www.csiro.au/Portals/About-CSIRO/How-we-work/CSIROs-service-charter.aspx
[50] http://www.csiro.au/Outcomes/Health-and-Wellbeing/Technologies.aspx
[51]http://www.csiro.au/Organisation-Structure/Flagships/Digital-Productivity-and-Services-Flagship/About-DPAS.aspx

sciences (the other being: complex systems science, socioeconomic integration, novel biotechnologies, and, nanotechnology). CSIRO was focusing in the areas of - grid computing; tele-collaboration and 'smart-spaces'; and systems of embedded communication devices. In 2000s, CSIRO's mission was to form partnerships with small to medium enterprises (SMEs), which was then deemed to play a key role in driving growth in Australia. Hence, CSIRO formed collaborations with institutions like the Australian Information Industry Association (AIIA), for the promotion of IT industries.[52]

MIT

Currently, the vision and mission of MIT is to advance knowledge, along with, educating students in science and technology.[53] At present, the involvement of MIT with IT is through two main routes – [1] education, and [2] research. The educational aspect is run by the Electrical Engineering and Computer Science (*henceforth 'EECS'*) Department; which is the largest department at MIT, and it imparts IT education to approximately 300 graduate and undergraduate students each year. The mission of MIT's EECS department is to produce graduates who are capable of taking a leadership position in the broad aspects of electrical engineering and computer science.[54] [55]

The research component in the field of IT is performed by over sixty laboratories and research centers of MIT. Out of these sixty, some centers are directly involved in IT related researches [such as: The Learning and Intelligent Systems Group; Communications and Networking Research Group; Computation for Design and Optimization (CDO); and so on]. Other centers, for instance - Center for Biological and Computational Learning; Operations Research (O R) group – conduct researches that draw on, as well as, inform the researches in IT sciences at MIT. The vision and mission of these centers and laboratories are diverse; and they perform researches in topics varying from – genetics, to warfare, to predictive technologies, to medicine. [56] [57] [58]

Over the last decade, MIT has been growing increasingly sensitive to the demands of life sciences and medicine, which has resulted into the calibration of its engineering departments towards taking on the challenges in the field of human health. Thus, currently, a major element of the vision of the EECS is to engage in clinically related technology development.[59] As a result, the EECS has developed an interdisciplinary undergraduate major, involving IT, electrical

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[52]http://www.csiro.au/~/media/CSIROau/Corporate%20Units/Corporate%20Communications/Brand%20%20Marketing%20Communication/AnnualReport%202001-2%20AboutCSIRO%20pdf%20Standard.pdf
[53] http://web.mit.edu/facts/mission.html
[54] http://cbcl.mit.edu/
[55] http://web.mit.edu/orc/www/
[56] http://lis.csail.mit.edu/new/
[57] http://web.mit.edu/aeroastro/labs/cnrg/
[58] http://computationalengineering.mit.edu/education/
[59] http://web.mit.edu/ogc/pdf/AnnualReport2010.pdf

engineering and clinical medicine. Another vital constituent of MIT's IT vision is the development of educational programs in advanced robotics. Consequently, the EECS encourages student-run programs such as - robot challenges, humanoid robots, web programming, and video game agent design.[60]

Around a decade ago, the vision and mission of EECS was - to provide education, which would enable students to understand the basic principles that underlie modern electrical, electronic and computational technology.[61] Their mission was to train students in IT sciences, so as to apply their understanding of science and engineering principles to the solution of problems arising in their work careers; and, be sensitive to the environmental, social, safety and economic context of their work. The EECS taught the students the common core of both electrical engineering and computer science. After this foundational education, students then proceeded to specializations.[62]

NRC

In the early 2000s, the vision of NRC in IT was to be the lead or the highest level institution in Canada for researches in digital sciences (as demonstrated by cutting edge discoveries, like, quantum sized transistors). Another important vision of NRC was to decentralize research work in Canada, so that every corner of the country could participate in scientific innovations; and resources as well as infrastructure do not remain confined to the large centers like Toronto or Ottawa. Furthermore, NRC was also attempting to create jobs through export based industries, especially in IT sector. Late 1990s was the period of IT boom, and there was global demand for IT related technologies. NRC-IIT acknowledged this demand and actively supported industries, which created digital products. [63]

Along with the above, NRC's IT mission in early 2000s carried on with its previous mandates, such as, providing R&D services to IT companies. The aim of NRC was to assist Canadian firms in maintaining their dominance in an increasingly competitive global environment. Using its various breakthroughs in computing and digital sciences, NRC-IIT also helped in creating several start-up IT firms, so that these companies could commercialize these IT products, as well as generate employment. Last but not the least, continuing with its preexisting mission, NRC-IIT also converted federal grants into cutting edge investigation, for instance: nanotechnology, aerospace, ocean engineering – which helped in sustaining Canada's global position as a leader in advanced sciences.[64]

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[60] http://www.eecs.mit.edu/about-us/mit-eecs-department-facts
[61] http://hdl.handle.net/1721.3/59147
[62] http://www.eecs.mit.edu/about-us/mission
[63] http://www.collectionscanada.gc.ca/webarchives/20060120100152/http://www.tbs-sct.gc.ca/rma/dpr/02-03/nrc-cnrc/nrc-cnrc03d01_e.asp#Executive_Summary
[64] http://www.collectionscanada.gc.ca/webarchives/20060120100152/http://www.tbs-sct.gc.ca/rma/dpr/02-03/nrc-cnrc/nrc-cnrc03d01_e.asp#Executive_Summary

During 2010-11, NRC's vision and mission underwent significant changes. Currently, the mission of NRC is undergoing modifications, with both, addition of roles, as well as, changes and exclusion in previous agendas. NRC is calibrating its mission to the needs of the market and Canadian industry. Even though previously, industrial research was one of NRC's foci; currently and in future, it will be the central thrust. For the same, NRC plans to extensively investigate the demands of the market, and accordingly provide technological innovations and researches, which will be of commercial value.[65]

This is a shift from earlier periods, when many of NRC's innovations (like the G-suit or 'Space Vision System' or all-terrain vehicles), and studies, were not shaped by their market value. During 2011-12, NRC underwent a transformation in their working model as well, whereby it moved from being an organization for inventing and examining technology, to being a corporate or business-like entity. According to the present vision of NRC, the goals of the Council are predominantly set by market stipulations and industrial requirements. NRC aspires to be an apex research institution, centering on providing innovations and strategic solutions for Canadian industry.[66]

Within the thematic area of I&CT, at present, NRC's mission is the provision of advanced researches and products to those industries, which are involved in any aspect of computing and software. In tandem with NRC's new vision, the mission of I&CT division is to provide the IT industries, the 'complete range' R&D services, starting from – design, to fabrication, to risk evaluation, to testing, to knowledge transfer, to patenting and intellectual property, and so on. NRC's endeavor is to bridge the gap between early stages of any IT research, and the final phase of commercialization; or in other words, give all possible support to IT companies, for producing 'market-ready' IT products.[67] [68]

[65] http://actionplan.gc.ca/en/news/government-canada-launches-refocused-national
[66] Annual Report 2011-2012: 6
[67] http://www.nrc-cnrc.gc.ca/eng/reports/2011_2012/dpr.html
[68] http://www.nrc-cnrc.gc.ca/obj/doc/reports-rapports/NRC-CNRC_DPR-RMR_2011-2012_ENG.pdf

Chapter 3: Strategy

FRAUN HOFFER

At present, FG provides the following services - research & development; studies & analyses; advice & support; inspection & certification; references; and, training.[69] Contract researches conducted by FG are the most vital ones for the industrial sector. Not only FG organizes product/system R&D, it also conducts studies (e.g.: product feasibility studies, market acceptability studies, profit calculations, and so on) for industries.[70] Furthermore, it provides support services (like: demonstration of products, evaluation of software and web applications, etc.) as well as certifications for new products and systems.[71] Lastly, FG publishes its findings as well, which are used as scholarly sources by researchers and academics.[72] Furthermore, FG operates the Fraunhofer Academy, which offers customized and specialized training to scientists, managers, R&D personnel, and, university community.[73]

At present, FG's research activities are distributed into 6 distinct subject areas[74] –

1. Health, Nutrition and Environment
2. Safety and Security
3. Information and Communication
4. Transportation and Mobility
5. Energy and Living
6. Production and Environment

Out of these 6 subject areas, researches in the area of 'Information and Communication' are directly related to IT; whereas other areas, such as 'Safety and Security,' are indirectly related.

FG comprises of 66 research institutes, which are based in Europe, North America and Asia. FG has around 22,000 staff members who are mostly scientists and engineers.[75] FG's research activities are decentralized. FG's institutes follow a unified structured process, developed by FG, for doing long and short term researches; other than that these institutes are effectively autonomous.[76] FG's 66 institutes are divided into 7 groups, in order to focus on specific research subjects. These groups are –

1. Information and Communication Technology
2. Light & Surfaces
3. Life Sciences

[69] http://www.fraunhofer.de/en/range-of-services.html
[70] http://www.fraunhofer.de/en/range-of-services/studies.html
[71] http://www.fraunhofer.de/en/range-of-services/inspection.html
[72] http://www.fraunhofer.de/en/range-of-services/references.html
[73] http://www.fraunhofer.de/en/range-of-services/further-training.html
[74] http://www.fraunhofer.de/en/research-topics.html
[75] http://www.fraunhofer.de/en/about-fraunhofer.html
[76] http://www.fraunhofer.de/en/about-fraunhofer/mission/research.html

4. Microelectronics
5. Production
6. Defence and Security
7. Materials and Components

The group specializing in Information and Communication Technology (henceforth 'I & CT') comprises of institutes that do researches in the field of IT; and institutes from other groups (like Microelectronics) conduct R&D that aids researches in IT.[77] Out of the total 66 institutes, 18 are in the I&CT group (for instance - Institute for Open Communication Systems, in Berlin). Each of these institutions work on a specific number of projects. For example, presently, the Institute for Open Communication Systems is working on 11 discrete projects – ranging from application of IT in automotive to use of IT in visual computing.[78]

The I&CT group conducts IT-oriented researches in 15 distinct subjects: Image processing; Broadband communications; Cloud computing / Grid computing; Digital media (production, transmission and distribution); Display and projection technologies; e-Business; e-Government; e-Learning, edutainment and games; Embedded systems; Green-IT; IT security and security through IT; Semantic information processing; Simulated reality; Software engineering; and, usability.[79] Other allied subjects for the I&CT group are - energy and sustainability, medicine, medicine production, and automotive.[80]

CSIRO

A decade ago, in order to implement CSIRO's vision of contributing to the emerging field of IT, as well as develop SMEs in Australia – CSIRO conducted researches in the area of 'Web Services'. 'Web Services' are software applications, connected over the Internet, which may be hosted by different service suppliers, such as businesses or government departments. Using a web browser, the user interacts with one application which then shares the user's information over the Internet with other applications in the network in order to carry out the service. This technology formed the foundation for what is now known as e-commerce and e-banking.[81]

Currently, in order to fulfill its vision and mission, the strategy of CSIRO has been the partitioning of its researches into specific Divisions (or centers), which are the business units of CSIRO. These Division/centers focus on unique and specific specializations, such as - Animal, Food and Health Sciences; Astronomy and Space Science; Earth Science and Resource Engineering; Ecosystem Sciences; Energy Technology; Information Communication Technology

[77] http://www.fraunhofer.de/en/institutes-research-establishments/groups-alliances.html
[78] http://www.iuk.fraunhofer.de/en/business-areas/
[79] http://www.fraunhofer.de/en/research-topics/information-communication/information-und-kommunikation.html
[80] http://www.iuk.fraunhofer.de/index2.html?Dok_ID=12&Sp=2
[81] http://www.csiro.au/~/media/CSIROau/Corporate%20Units/Corporate%20Communications/Brand%20%20Marketing%20Communication/AnnualReport%202002-3%20AboutCSIRO%20pdf%20Standard.pdf

(ICT) Centre; Land and Water; Marine and Atmospheric Research; Materials Science & Engineering; Mathematics, Informatics and Statistics; Plant Industry; and, Process Science and Engineering.[82]

Amongst these Divisions and Centers, the Information Communication Technology (*henceforth* ***'ICT'***) Centre is directly involved with researches in the IT sector. The ICT center also provides IT-based solutions to other centers and divisions (for e.g.: Astronomy and Space Science); and the researches of the ICT Center itself is supported by others, like the Mathematics, Informatics and Statistics Division. As mentioned previously, CSIRO has been conducting researches in the IT sector, for applications in 3 fields – government and commercial services; health services; and, smart and secure infrastructure. In this context, the following are the strategies of the ICT Center for achieving the IT visions of CSIRO.[83] [84]

In the field of - 'Government' – CSIRO's strategy has been to develop computing technologies for assisting the Australian govt. on the topics of - evidence based policy making and decisions; customer centric services; and innovative services. In order to transform the Australian government into a more efficient machinery, CSIRO has been developing solutions, in particular to tackle the following challenges - harnessing big data to analyse complex interactions; understanding of long term trends; understand risk and forecast demand; business process and logistics monitoring; sophisticated models and decision tools for disaster management; and, modeling tools for risk management.[85]

In the field of - 'health services' - CSIRO's strategy has been to carry out IT researches for - utilizing broadband and mobile platforms to improve access to online health services; and connecting clinicians and patients, particularly those in rural and remote areas. This is especially pertinent to Australia, since the land mass is vast, and there are many pockets of small communities all throughout Australia. CSIRO has also been applying advanced computing on complex and non-standardised data systems that hold health information; as well as, develop tools for analyzing this data. Smarter computing tools have helped hospitals to improve productivity by reducing waiting times, and, have led to better management of hospital workflows and operations.[86]

In the field of 'smart and secure infrastructure', CSIRO's contemporary strategy is geared towards developing digital systems to achieve the following goals - wireless technologies for delivering broadband services to rural and remote areas; media content delivery and access via cloud computing; accurate positioning and mapping technologies for industry; mobile tele-presence, tele-education and training systems; and, cyber security technologies for government, industry and the public. However, the major thrust of CSIRO's IT

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[82] http://www.csiro.au/en/Organisation-Structure/Divisions.aspx
[83] http://www.csiro.au/en/Portals/Publications/Brochures--Fact-Sheets/ICT-Centre-Brochure.aspx
[84] http://www.csiro.au/Portals/About-CSIRO/How-we-work/Strategy/Our-Strategy-Overview.aspx
[85] http://www.csiro.au/en/Organisation-Structure/Divisions.aspx
[86] http://www.csiro.au/Outcomes/Health-and-Wellbeing/Technologies.aspx

researches has been in the area of broadband technologies, which is a logical evolution from its previous world-renowned innovations in LAN technologies. The Australian Centre for Broadband Innovation (ACBI) is a key organization, within the 'DP & S' Flagship, which has been facilitating new research projects in this area.[87]

MIT

In order to apply its vision and mission for IT education, and as part of its educational strategy, MIT operates 3 research labs that teach distinct subjects within IT sciences – [i] Computer Science and Artificial Intelligence Laboratory (CSAIL); [ii] Laboratory for Information and Decision Systems (LIDS); and, [iii] Microsystems Technology Laboratories (MTL). These laboratories focus on the following areas of IT - systems, communication, control and signal processing; computer science (artificial intelligence, systems, theory); and, electronics, computers and systems. Furthermore, the EECS has divided its educational focus into the following thematic areas - big data; cyber-security; multi-core processors & cloud computing; nanotechnology and quantum information processing; and, wireless networks and mobile computing.[88]

The laboratories of MIT, such as the LIDS, impart education about application of innovations in IT, for solving challenges pertaining to a diverse range of contexts. A decade ago, the educational focus of LIDS was in the subjects of – interdisciplinary fundamental research; network science (e.g. network algorithms); decision theory for teams involving cooperation and competition (e.g. dynamic mechanism design in game theory, rational decisions for large interacting networks of agents).[89] Other subjects in focus were - theoretical framework of systemic risk; cyber-physical systems (for e.g. architectural design, cross-layer algorithms); and, multi-scale/granularity modeling (e.g.: complex phenomena at multiple granularities); and, reduction/simplification of computing models.[90]

At present, the strategy of LIDS is to provide IT education in the subjects of - intelligence, surveillance, and reconnaissance systems; coordination of unmanned autonomous systems; energy information systems; biological systems and biomedical data analysis; large-scale data assimilation for the geosciences; network scheduling and routing; machine learning for recommendation systems and social media; social network analysis and characterization; and ultra-wideband.[91] Furthermore, in order to fulfill the mission of EECS with respect to application of IT sciences in healthcare, as a part of the educational strategy , there is increasing

[87]http://www.csiro.au/Organisation-Structure/Flagships/Digital-Productivity-and-Services-Flagship/About-DPAS.aspx
[88] http://lids.mit.edu/research/142.html
[89] http://lids.mit.edu/about-lids/history.html
[90] http://lids.mit.edu/images/documents/lids_history.pdf
[91] http://web.mit.edu/annualreports/pres12/2012.04.15.pdf

focus on – the linkages between circuits, signal processing, noise, etc., and the cardiovascular system, magnetic resonance imaging, ECG data, and so on.[92]

Another of MIT's current strategies, to fulfill its vision and mission for IT education, is – the Industrial Connection Program (*henceforth 'ICP'*). MIT's ICP program forms collaborations with the industry, in order to impart IT education that would suit market demands. Upon joining the ICP, companies receive customized advice and assistance in communicating information to the students about the company and its job opportunities. On the other hand, students who attend ICP events learn about industry expectations and corporate cultures; and gain a better understanding of how their own skills fit full time job opportunities. They also develop communications skills by networking with company representatives, and, gain knowledge that helps them make better decisions about their careers.

As explained before, since the First World War, MIT's researchers have been closely associated with defense oriented technologies. This trend was evident even a decade ago, especially in late 1990s and early 2000, when the strategies for MIT's IT research centers were notably guided (and funded as well) by the requirements of Defense Advanced Research Projects Agency DARPA.[93] For example, MIT's IT research gave rise to the 'Optical Networks', or internet transmission through optical fiber networks. It was initially meant for controlling aircrafts, but it later enabled local (LAN) and metropolitan area access network, with an increase in data rate but decrease in the cost of delivery per unit of information. Another instance is the Wavelength Division Multiplexing (WDM) technology, which reduced the size, cost, and complexity of electronic switches and routers in the network, while simultaneously leading to an increase in data traffic.[94]

NRC

A decade ago, in order to accomplish NRC's vision and mission of being the highest stage of IT research in Canada, NRC-IIT implemented projects on futuristic subjects like high performance computing and 'grid-based, multi-scale computation platforms.' In late 1990s, NRC-IIT recognized that, in coming years, data grids will become the most crucial computing infrastructure, which is why, in collaboration with other institutes of NRC like the Information Management Services Branch, it was involved in the testing large-scale grids, as well as models of nano-structures.[95] In order to achieve the vision of decentralizing NRC's research work, NRC adopted the strategy of creating technology clusters all across Canada (for e.g. St. John's for ocean engineering; Halifax for life sciences; New Brunswick for e-business; Edmonton for nanotechnology; and so on). These clusters also formed close collaborations with the

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[92] http://lids.mit.edu/research/144.html
[93] http://www.darpa.mil/
[94] http://hdl.handle.net/1721.3/59147
[95] National Research Council Canada: Annual Report 2001-2002

institutions of that region, like universities or industries. For illustration, the NRC-IIT at Fredericton (NB) formed collaborations with the Greater Fredericton Knowledge Park and the University of New Brunswick, which generated numerous innovations in the fields of e-Business and wireless technologies.[96]

Utilizing its state of the art discoveries in photonics, NRC's IT section helped in building new IT firms like Trillium Photonics. This strategy fulfilled NRC's mission of creating new IT companies, thereby generation jobs. In 2002, Trillium Photonics employed 42 people, was headquartered in Ottawa and had offices in Pleasanton, California. Lastly, a decade ago, NRC's strategy for providing solutions to Canada's nation-wide challenges, was in the form of joint researches within its various sectors. For instance, NRC's Genomics and Health Initiatives' (GHI) Cancer Genomics Program and NRC-IIT collaborated to develop software for data mining, which helped in the identification of genes that are involved in diseases such as cancer and Alzheimer's.[97]

As a key element of NRC's present-day strategy, the R& D activities are divided into distinct thematic areas – aerospace; aquatic and crop resource development; automotive and surface transportation; construction; energy, mining and environment; human health therapeutics; information and communications technologies; measurement science and standards; medical devices; national science infrastructure; ocean, coastal and river engineering; along with, security and disruptive technologies. As is evident, the thematic area of information and communications technologies (I&CT) comprises of researches in IT. Furthermore, thematic areas, like aerospace and medical devices, are supported by researches in IT; whereas other thematic areas, like measurement science and standards, provide inputs to the IT researches of NRC.[98] [99]

Researches within the thematic area of I&CT takes place primarily in NRC's facilities at three locations – Ottawa (ON), Fredericton (NB) and Moncton (NB). Each of these locations conducts studies in specific subjects of IT. The institutions at Ottawa (like the Canadian Photonics Fabrication Centre) specialize in photonics (i.e. devices, such as optical fibers and photonic integrated circuits, which are used for data transmission through optical methods).[100] The facilities at Fredericton and Moncton specialize in – human-computer interactions; mobile technologies; and, development of software and trainings for electronic governance and electronic business. [101] NRC's contemporary strategy is to give the leading edge to Canadian IT industries, especially in the areas of - learning technologies; semi-conductor-based photonics;

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[96] http://www.collectionscanada.gc.ca/webarchives/20060120100152/http://www.tbs-sct.gc.ca/rma/dpr/02-03/nrc-cnrc/nrc-cnrc03d01_e.asp#S2_2_2
[97] http://archive.nrc-cnrc.gc.ca/eng/programs/ghi/phase-i.html
[98] http://www.nrc-cnrc.gc.ca/eng/rd/index.html
[99] http://www.nrc-cnrc.gc.ca/eng/rd/security/index.html
[100] http://www.nrc-cnrc.gc.ca/eng/solutions/facilities/prototyping_index.html
[101] http://www.nrc-cnrc.gc.ca/eng/rd/ict/index.html

next-generation (Gallium nitride) electronics; optical testing; semiconductor foundry services; natural language processing; data and text mining; human-computer interface; decision support systems; learning and collaborative technologies; 3D interactive visualization; and cognitive modeling.[102] Furthermore, in order to fulfill its latest vision and mission of being an institution for promoting Canadian businesses, NRC's I&CT section is providing customized services, such as 'business fast-lane', 'testing' and 'designing'.[103]

In 'business fast-lane', NRC collaborates with startup IT companies, and aids them by providing NRC's infrastructure and expertise, for manufacturing of those IT products, which are 'ready' for the market. NRC's support helps in reducing the various risks that new startup companies usually face. 'Testing' is another service that is provided by NRC's IT sector, which helps new IT companies to improve their devices, as well as, the quality of production. Some of the high-end tests conducted by NRC are - stress analysis; atomic force microscopy; X-ray photoelectron spectroscopy; transmission electron microscopy; and so on. The I&CT group also provides design and modeling services to industries. The group assists or completely designs components, like circuits and microchips; along with, verifying models made by industries, for their feasibility and manufacturability. For the same, NRC uses its state of the art optical and electrical device simulation tools. [104] [105]

[102] http://www.nrc-cnrc.gc.ca/eng/solutions/collaborative/gan_index.html
[103] http://www.nrc-cnrc.gc.ca/eng/rd/ict/index.html
[104] http://www.nrc-cnrc.gc.ca/eng/solutions/facilities/prototyping/design.html
[105] http://www.nrc-cnrc.gc.ca/eng/solutions/facilities/prototyping/test.html

Chapter 4: Research Outcomes

FRAUN HOFFER

Some of the major research outcomes of the I&CT group during 2010-12 are as follows – cloud computing; early warning systems for natural calamities; complex software; chip security; and, energy grids. The I&CT group has been developing cloud computing to assist the healthcare sector. Various software models have been produced to manage specialists' information, patient records, and treatment processes.[106] For instance, this group has produced a software tool called the 'ProMiner', which conducts targeted searches for proteins and genes in humans. In the field of security, the Fraunhofer Institute for Software and Systems Engineering (ISST) from the I& CT group, has developed an early-warning system. In dangerous situations, such as storms, the defusing of unexploded bombs, or major accidents, the system can warn the local population and provide instructions on what to do, free of charge via text messages or e-mail. [107]

In the subject of complex software, one of the key achievements of the I&CT group is the development of applications for large airports like the Frankfurt airport. These applications helps the smooth flow of 53 million passengers, 2.3 million metric tons of freights and 460,000 landings and take offs (per annum) in Frankfurt. One of the institutes involved in this project is the Fraunhofer Institute for Open Communication Systems, and it has developed algorithms which would eliminate errors in the airport management systems.[108] Similarly, researchers from the Fraunhofer Research Institution for Applied and Integrated Security or AISEC (of the I&CT group) have built microchips that are resistant to counterfeiting or duplicating. This technology is imperative for financial sector and defense operations. The AISEC researches has yielded computer chips that have unique 'fingerprints', which makes them impossible to replicate; and if they are tampered with, then the chips are capable of auto destruction, thus making them highly secure devices.[109]

More than a decade ago, the most significant research outcome of the I&CT group of FG was the MPEG-2 Layer 3 (or mp3) technology. Commercial breakthrough was achieved for audio encoding techniques, which was developed by the Fraunhofer Institute for Integrated Circuits (IIS) in 1998. FG's 'MPEG-2 Layer 3' technology was employed by three satellites transmitting digital radio broadcasts to the southern hemisphere from 1999 onward. Thereafter, this technique became the de facto worldwide standard for music transmission on

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106 http://www.fraunhofer.de/content/dam/zv/en/Publications/Fraunhofer-magazine_1-2012/magazine_1-2012.pdf
107 http://www.fraunhofer.de/content/dam/zv/en/Publications/Fraunhofer-magazine_1-2012/magazine_1-2012.pdf
108 http://www.fraunhofer.de/content/dam/zv/en/Publications/Annual-Report/Annual%20Report-2011.pdf
109 http://www.iuk.fraunhofer.de/uploads/media/IUK-Profile_english.pdf

the Internet.[110] The possibility to store thousands of mp3 encoded songs on a small portable player, search them by album, artist, title, genre or even to have play lists generated automatically, was a remarkable development for music consumers as well as music industry. [111]

Other significant contributions of the I&CT group in the early 2000 were – grid computing, digital surround sound technology for domestic usage, and, copyright protection for electronic data. In the late 90s and 2000s, the World Wide Web (www) was the dominant internet protocol; however FG's Fraunhofer Institute of Industrial Mathematics had developed an exclusive grid, which connected five of FG's institutes and one from the USA.[112] This technology later on led to the expansion of cloud computing.[113] On the other hand, Fraunhofer Institute of Computer Graphics had produced digital signatures for audio and video materials. This was a noteworthy product for the movie and media industry, as it led to successful laws for anti-piracy and copyright infringement. [114]

CSIRO

In the late 1990s and early 2000s, the prime achievement of CSIRO in the field of IT, was LAN (Local Area Network). CSIRO invented and patented wireless LAN (WLAN / also known as 'WiFi') technology in the 1990s. LAN and WLAN enables working wirelessly, in homes and offices, using devices such as laptops and smart phones. Wireless network connectivity has evolved to encompass products, such as: phones, televisions, cameras, laptops, printers, routers and games consoles. Currently, CSIRO's WLAN technology is estimated to be inside three billion devices worldwide.[115]

The invention came out of CSIRO's work in radio-astronomy in early 1990s. This technology involved complex mathematics known as 'fast Fourier transforms', as well as studies on radio waves and their behaviour in different environments. Indoor environments are particularly difficult for the speedy exchange of huge amounts of data using radio waves. The main problem of wireless networking was reverberation - whereby the radio waves from the outgoing signal bounce around the surrounding environment causing an echo that distorts the signal. This obstacle was effectively solved by researchers from CSIRO, which eventually led to the rapid global expansion of wireless communications.[116] [117]

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[110] http://www.fraunhofer.de/content/dam/zv/en/Publications/Annual-Report/Annual%20Report-2011.pdf

[111] http://www.fraunhofer.de/content/dam/zv/en/Publications/Fraunhofer-magazine_1-2012/magazine_1-2012.pdf

[112] http://www.archiv.fraunhofer.de/archiv/magazin04-08/EN/publications/magazin/2004/index.html

[113] http://www.fraunhofer.de/content/dam/zv/en/Publications/Fraunhofer-magazine_1-2012/magazine_1-2012.pdf

[114] http://www.archiv.fraunhofer.de/archiv/magazin04-08/EN/publications/magazin/2004/index.html

[115] http://www.csiro.au/Outcomes/Food-and-Agriculture/Fields-of-Discovery.aspx

[116] http://www.csiro.au/~/media/CSIROau/Divisions/CSIRO%20ICT%20Centre/WLAN-factsheet-pdf/WLAN_factsheet.pdf

In the 2000s, another important outcome of CSIRO's researches in IT was - privacy of personal and other sensitive information. As a result of CSIRO's 'Web Service' technologies (as explained previously), e-commerce began to play a vital role in the provision of business and government services. But privacy concerns were a barrier to people using these services. CSIRO developed models that enabled secure transfers and protocols, to ensure the user's privacy. The earliest of applications was implemented in the Commonwealth Department of Health and Ageing, Australia.[118]

Presently, the main research product of CSIRO in the IT sector is - development and testing of innovative broadband-enabled services, applications and technologies; and, their use in real world situations. The following applications are a direct result of CSIRO's IT researches - (a) smarter homes and communities - using wireless sensors and monitoring platforms to assist the elderly; (b) smart farm – sensing technologies and decision support tools on farms; (c) social TV – technologies for TV content and distribution in online format; and (d) broadband networks - design, delivery and support for broadband testing, production and networks.[119] [120]

MIT

The EECS as well as the various IT-research centers and laboratories of MIT conduct researches on the following topics - theoretical computer science; computer systems and architecture; graphics; robotics; computer vision; machine learning; computational applications in medicine; computational biology; communications; information theory; control systems; large scale systems analysis; circuits; devices; numerical computing; nanotechnology; speech and hearing; prosthetic devices; and, analog and hybrid circuits and devices.[121]

MIT's researches in the IT field have implications in a wide array of contexts. To illustrate, one of the major outcomes is a theory about biological and computational origins of human cognition, which explains the methods for language acquisition for human beings. On the other hand, another innovation applies IT technologies for enabling drivers to make appropriate choice of road routes, when they have limited information; leading to maximum efficiency for transportation networks.[122] Likewise, other researchers of MIT have developed computer programs to calculate volatility of price, supply, and demand, in power grids. These programs provide real-time feedback, enabling more flexible power grids, and consequently, better pricing for consumers.[123]

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[117]http://www.csiro.au/Organisation-Structure/Flagships/Digital-Productivity-and-Services-Flagship/About-DPAS.aspx

[118] http://www.csiro.au/Organisation-Structure/Flagships/Digital-Productivity-and-Services-Flagship/Resources.aspx

[119] http://www.csiro.au/Portals/Partner/SME-Engagement.aspx

[120] http://www.csiro.au/Outcomes/Food-and-Agriculture/Fields-of-Discovery.aspx

[121] http://web.mit.edu/facts/research.html

[122] http://web.mit.edu/annualreports/pres12/2012.04.15.pdf

[123] http://lids.mit.edu/research/143.html

Scientists of MIT are also developing computer algorithms for creating vehicles with completely autonomous maneuvering capabilities. Similar programming is also being utilized for developing control for unmanned aerial vehicles (UAVs) and mobile robots, for both defense and civilian purposes.[124] These maneuvering technologies utilize a new modeling approach to transportation networks, based on the concept of 'dynamical flow network' and game-theoretic approaches. In addition, the research centers, associated with the Communications and Networking Research Group (CNRG), have designed architectures for aerospace networks that are cost effective, scalable, and, capable of high data-rates. These innovations have applications for military communications, space exploration, in addition to, internet access for remote and mobile users.[125]

As mentioned previously, a decade ago, a significant portion of MIT's IT researches had usages in the defense sector. For example – in early 2000s, the LIDS was developing high-rate and high-performance optical communication systems (also known as 'optical fiber'), and networks, for the US defense departments. This research was aimed at reducing data loses due to atmospheric turbulence – a crucial hindrance for the military. The broader goal of this research was to produce architectural designs for efficient data communications over low-Earth orbiting satellites and other generalized satellite systems. The objective was to connect these satellite networks with terrestrial fiber as well as wireless systems. [126] Other IT researchers from the LIDS developed transmission scheduling schemes, which were based on 'channel conditions,' while transmitting satellite-based data. These innovations reduced the amount of energy needed for data transmission.[127]

Similarly, during early 2000s, many of MIT's scientists, working in the field of computing and communications, were conducting studies to aid the National Aeronautical Space Agency (NASA). For example, by using different layers of the protocol stack, several studies were conducted to examine interactions between protocols within space networks.[128] These IT studies comprised of experiments on the capacity and stability of coded packetized multiple-access channels. These studies determined the effects of such packetized channels on energy required for transmission and on data-delays during transmission. Other researchers focused on understanding the minimum number of satellites required for a constellation. They experimented with constellations of 12 for low-Earth orbiting satellites, 6 for medium-Earth orbiting satellites, and 3 for geostationary-Earth orbiting satellites.[129]

However, not all IT research outcomes of MIT were for defense purposes. Other centers of MIT, which were conducting researches in IT, were focusing on the one of the vital emergent

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[124] http://acl.mit.edu/projects/
[125] http://grandchallenge.mit.edu/technology.shtml
[126] http://web.mit.edu/annualreports/pres03/08.18.html
[127] http://web.mit.edu/annualreports/pres04/08.18.pdf
[128] http://web.mit.edu/annualreports/pres12/2012.04.05.pdf
[129] http://web.mit.edu/annualreports/pres04/08.05.pdf

technologies of late 1990s and early 2000s – i.e. networking. Concurrent to other apex research facilities all over the world (like Fraun Hoffer and CSIRO), MIT's IT centers were developing efficient, stable and architecturally simple - wide area and local area networks (i.e. WLAN); high-speed and low-speed networks; and point-to-point and broadcast communication channels. These studies were looking into networking problems, such as, wireless channels with parallel relays; splitting and successive decoding for wireless networks; routing in wireless and satellite networks; and so on.[130]

NRC

Around late 1990s and early 2000, NRC's major outcomes in IT research were in the subject of digital images. NRC and its scientists developed path breaking image processing systems that gave rise to the 'XYZ RGB' color coding technology. These highly advanced innovations enabled the spectacular visual effects in movies like the 'Lord of the Rings.' This technology involved a unique invention by the researchers of NRC-IIT, whereby every millimeter of the models were scanned using a laser, and then computer programming was used to recreated as well as animate the characters; as a result, giving them the life-like imagery.[131]

This revolutionary imaging technology has its foundation in the pioneering work of NRC in the 1980s, on the subject of virtual reality (VR).[132] By early 2000, NRC's researches in VR had diverse applications; such as, advanced simulated environments, for usages in gaming modules. NRC-IIT developed computer programs, which produced sights and sounds in tandem with a person's movements in a given environment (like a playground). This technology made gaming experiences exceedingly realistic. This 'realism' in virtual reality proved to be helpful for other critical tasks, like flying a plane or operating a construction crane. NRC's VR innovations led to the development of simulators (like flight training), which were used for training people to carry out complex and hazardous tasks. [133]

NRC-IIT also continued developing its innovative laser scanning technologies, and it led to several uses during early 2000s, such as, in designing and construction. Everything thing, from the smallest of toys to the largest of ships, could be scanned, and then 3-D virtual images could be created. This process aided the manufacturers in finding out structural defects, design problems, as well as, to make changes or modifications in the prototype of their products. This process was superior to the older process of straightaway moving to manufacture, and then end up with defective products and costly recalls. This scanning innovation was also utilized to

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[130] http://web.mit.edu/annualreports/pres04/08.05.pdf
[131] National Research Council Canada, Annual Report: 2003–2004
[132] http://news.gc.ca/web/article-eng.do?m=/index&nid=504139
[133] http://www.nrc-cnrc.gc.ca/eng/rd/ict/index.html

scan the surface of NASA's space shuttles, in order to make sure that there were no damages on the surface.[134] [135]

At present, NRC carries on its work on imaging; however its IT research outcomes have become significantly diversified. For example, the IT institutions in Ottawa have developed state of the art foundries for silicon-based materials, in order to produce base-architecture for microchips and integrated circuits. NRC also operates foundries for manipulating Gallium nitride (GaN), which is referred to as the material for future electrical technology, particularly for making semiconductors for radars and electronic warfare systems. Furthermore, this location also specializes in a technique called 'Nanoimprint lithography,' which is used to create customized microprocessor wafers, for high-powered computing systems.[136]

Another major area of outcome for NRC's IT activities - is data transmission through optical systems. With the enormous demand for internet bandwidth, super high speeds, mobile internet devices, and cloud computing, there is a global necessity for data transmission technologies that are geared for large volumes as well as high speeds. NRC's innovations in optical mediums and technologies (e.g. photonic components, optical fibers) have made noteworthy contributions in fulfilling this necessity.[137] NRC has also successfully applied photonic components in the creation of electrical grids that are smart and energy efficient.[138]

Currently, many of NRC's IT innovations are tailored towards solving challenges in the everyday lives of Canadians in general, in addition to the nation as a whole. For instance, with an increasingly aging Canadian population, care of seniors is a critical challenge for the Govt. The Govt. is attempting to tackle this issue by keeping the seniors in their homes, as long as possible, so that the healthcare system and institutionalized care system does not get overwhelmed. Here, NRC is assisting by developing computerized homes, which are tailored for seniors to live independently, with almost no or minimal support. Such homes will contain systems for remote monitoring of air temperature and humidity; control of doors and appliances like refrigerator or ovens; as well as, health status of the senior.[139] [140]

[134] http://www.nrc-cnrc.gc.ca/eng/education/innovations/discoveries/vr.html
[135] http://www.nrc-cnrc.gc.ca/eng/education/innovations/spotlight/special_effects.html
[136] http://www.nrc-cnrc.gc.ca/eng/solutions/facilities/prototyping/foundry.html
[137] http://www.nrc-cnrc.gc.ca/eng/solutions/collaborative/apc_index.html
[138] http://www.nrc-cnrc.gc.ca/obj/doc/reports-rapports/NRC-CNRC_DPR-RMR_2011-2012_ENG.pdf
[139] http://www.nrc-cnrc.gc.ca/eng/reports/2011_2012/dpr_2012/dpr_supplementary.html
[140] National Research Council Canada: Annual Report 2011-2012

Chapter 5: Impacts[141]

FRAUN HOFFER

In 2011, the I&CT group generated around €155 million (CAD 212 million) in project revenue in the business areas of - digital media, e-business, e-government, information and communication technology, energy and sustainability, medicine, production, as well as, security, financial services and the automotive sector. The group's budgeted expenditure was €215 million (CAD 294 million).[142] The 'mp3' technology license-fee revenue was €125 million (CAD 171 million), although this has been on the decline.[143] The tax revenue for the German state from mp3-related products, is estimated around 300 million Euros each year. In 2011, Germans spend around 1.5 billion Euros on mp3 players and mp3 related products.[144] . In 2011, there were around 4,000 researchers and engineers in the I&CT group of FG. [145] A decade ago, during the periods of 1998 to 2001 – due to the introduction of mp3 technology by FG, more than 10,000 jobs were created in Germany. In 2011, the Fraunhofer Institutes applied for patents for 673 new inventions. Patent application rose from 5175 in 2007 to 6130 patent applications in 2011.[146]

CSIRO

In 2002-3 (a decade ago), CSIRO had approximately 6600 staff members, located at 60 sites throughout Australia and overseas. CSIRO's revenue from Australian government was AUD 639 million; and AUD 117 million from R&D activities for the private sector. In 2002-3, CSIRO's researchers presented 142 conference papers; published 686 journal articles; produced 223 books/chapters; and 240 technical reports. Up till 2003, CSIRO had a patents portfolio of over 2002 patents, from around 779 patent families; and the revenue from these patents and other intellectual properties was approximately AUD 13 million per annum.[147] [148]

In 2012, CSIRO's total revenue was AUD 1,476 million. Out of this, AUD 228.6 million came from the wireless networking technology (WLAN) patent and licensing agreements. Australian Governments (federal and local) are the largest contributor to this revenue (about

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[141] Financial (revenues for companies using the technologies produced, revenues for the research organization); number of new employees hired by companies using the technologies; products licensed; number of papers published by staff

[142] http://www.fraunhofer.de/content/dam/zv/en/Publications/Annual-Report/Annual%20Report-2011.pdf

[143] http://www.iuk.fraunhofer.de/index2.html?Dok_ID=12&Sp=2

[144] http://www.mp3-history.com/en/the_story_of_mp3.html#!tabpanel-7

[145] http://www.fraunhofer.de/content/dam/zv/en/Publications/Annual-Report/Annual%20Report-2011.pdf

[146] http://www.fraunhofer.de/content/dam/zv/en/Publications/Annual-Report/Annual%20Report-2011.pdf

[147] http://www.csiro.au/~/media/CSIROau/Corporate%20Units/Corporate%20Communications/Brand%20%20Marketing%20Communication/AnnualReport2003-4_AboutCSIRO_pdf%20Standard.pdf

[148] http://www.csiro.au/~/media/CSIROau/Corporate%20Units/Corporate%20Communications/Brand%20%20Marketing%20Communication/AnnualReport%202002-3%20AboutCSIRO%20pdf%20Standard.pdf

49%), followed by Australian private sector (about 17%). CSIRO has around 6500 staff, undertaking and assisting research and in Australia and overseas. In 2012, CSIRO's researchers presented 461 conference papers; published 913 journal articles; produced 86 books/chapters; and 158 technical reports. CSIRO has a patents portfolio of over 3900 patents, from over 780 patent families. In between 2009 to 2012, revenue from CSIRO's patent portfolio was an average of AUD 13.7 million per annum.[149] [150]

MIT

At present, MIT has about 11,000 employees (including faculty members), out of which 1022 are professors (of all ranks).[151] The EECS had around 130 faculty members. In 2012, MIT's operating cost was approximately USD 2.7 billion, in which 49% was used by various research programs. MIT's revenue was almost USD 3 billion, with 28% coming from research activities and 22% from educational services.[152] By some estimates, till 2011, MIT alumni have founded more than 25000 companies. These firms employ about 3.3 million people and generate revenues worth USD 2 trillion per annum.[153] The Technology Licensing Office (TLO) of MIT facilitates the transfer of technology from MIT to industry. In 2012, the TLO issued 16 technology licenses to new startup companies, out of the total of 81. In 2012, these licenses generated USD 147 million for MIT. The TLO also received 199 patents.[154] A decade ago (in 2002), MIT's operating budget was about USD 1.7 billion; whereas revenues from various researches was almost USD 1 billion, out of which USD 440 million was from Lincoln laboratories. The two most major clients of MIT's researches were the US Departments of health and defense.[155] During 2003-4, MIT received 159 patents and the TLO issued 95 technology licenses. 20 licenses were given to startup companies, and the revenue from licensing was USD 37 million.[156]

NRC

At present, NRC has approximately 4,000 employees. In 2010, NRC published 746 articles in various journals and its researchers presented around 300 papers at refereed scientific conferences. However in 2012, NRC produced only 200 articles and 93 conference

[149] www.csiro.au/annualreport1112
[150] http://www.csiro.au/Portals/About-CSIRO/Who-we-are/Staff/Our-staff-overview.aspx
[151] http://web.mit.edu/facts/faqs.html
[152] http://web.mit.edu/facts/financial.html
[153] Edward B. Roberts and Charles Eesley (2009), Entrepreneurial Impact: The Role of MIT. MIT Sloan School of Management.
[154] http://web.mit.edu/annualreports/pres12/2012.08.20.pdf
[155] http://web.mit.edu/annualreports/pres03/01.02.html
[156] http://web.mit.edu/annualreports/pres04/03.18.pdf

presentations.[157] NRC's operating budget in 2011 was CAD 678, which was a decline from the CAD 832 million in 2010. In 2011, NRC's activities generated revenues worth CAD 171 million, out of which CAD 79 million was from sale of goods and services. NRC also provided CAD 91 million to more than 2000 firms and organizations, for 2317 innovation projects that created and supported 6,492 jobs.[158] In between 2009 to 2012, NRC made about 760 patent applications, out of which 311 patents were awarded. In I&CT sector, NRC was awarded 11 patents; and in 2011, revenue from industries for R&D in IT was CAD 12 million, out of which CAD 1.7 million was from fees of licenses.[159]

A decade ago, in 2002-3, NRC's researchers published around 1,133 articles in refereed journals, produced 1794 technical reports, and presented 796 papers at international conferences. NRC's studies were amongst one of highest cited materials in scientific publications. In early 2000s, NRC had around 1000 formal collaborations with Canadian industry, universities, and public organizations, which were worth CAD 286 million. In 2002-3, NRC's operating budget was about CAD 800 million, out of which 80% came from Canadian government and 20% was generated by NRC (through licensing, services, etc). NRC had about 4000 employees, as well as 1200 guest workers from Canadian and foreign universities, in addition to, the public and private sector.[160] During early 2000, NRC had 18 research institutes and 2 technology centers across Canada. NRC's institutes had between 60 to 320 staff members; and they specialized in different areas of research.[161]

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[157] http://www.ottawacitizen.com/technology/Pure+science+research+drops+sharply+National+Research+Council/8351165/story.html
[158] http://www.nrc-cnrc.gc.ca/eng/reports/2011_2012/dpr.html
[159] http://www.nrc-cnrc.gc.ca/eng/reports/2011_2012/dpr.html
[160] http://www.oag-bvg.gc.ca/internet/English/parl_oag_200403_01_e_14893.html
[161] http://www.oag-bvg.gc.ca/internet/English/parl_oag_200403_01_e_14893.html