iCORE
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Molecular devices: The next technological revolution

Robert A. Wolkow
From an essay commissioned by the Canada Foundation for Innovation

For many years, scientists have imagined schemes for creating "molecular devices" [1]. What they had in mind were the smallest imaginable structures–built of only a few molecules–yet having the potential to underpin powerful computers, new communications tools and fantastic medical diagnostic devices. Their ideas were not entirely science fiction – sound principles were applied and much of the thinking still stands up today.

Unfortunately, one seemingly insurmountable problem stood in their way. No one could think of a way to actually make the proposed molecular units. However, in the past several years, some extraordinary developments have made it possible to start realizing the dream of manipulating matter on the molecular scale. The key advance was the invention of the scanning tunneling microscope (STM) by Gerhard Binnig and Heinrich Rohrer at the IBM labs in Switzerland [2].

The STM is a deceptively simple tool and not much like a conventional microscope at all. It doesn't use lenses and there is no eyepiece to look through. In fact, the STM is a closer cousin to the record player with the sharpest needle you can imagine–just a single atom wide at its point. Under computer control, the tip gently scans over a surface, detecting every tiny hollow or miniscule bump. As the tip moves across the surface, a topographical map appears on the computer screen, point by point and line by line. Within minutes, a detailed map of the surface is complete. The importance of the STM is widely recognized–Binnig and Rohrer were awarded a Nobel Prize for their work in 1986.

In the mid-1980s, the basic STM technology was transferred from Zurich to the IBM Research Center in Yorktown Heights, NY. Some very smart scientists in the NY lab seized on the technique and quickly made adaptations and improvements. Soon after, I was hired to work at the NY IBM lab – I rushed there early in 1987, even before I had defended my thesis or graduated.

I was instantly fascinated by the STM technique. It was quite a time. The excitement of STM's potential was coupled with long hours, intense focus, frequent setbacks, and occasionally, bursts of discovery. On weekends my wife sometimes joined me in the lab. While I worked away, she read the Sunday New York Times or drawing on some innate technical ability (and not, presumably, her Arts degree) expertly electrochemically etched STM tips for me. After adding a few new features of my own to the STM, I successfully recorded the first ever atom-by-atom view of a surface chemical reaction.

From today's perspective, we can see that the STM is causing a revolution in science. It has become a powerful, enabling and widespread tool. Scientists around the world have contributed to the steady advance of the technique and to its increasingly diverse applications. As a result, problems that were utterly impossible to solve when I was a student are now routinely handled. Mature areas of study have been rejuvenated and new fields of study have emerged.

The excitement spills over into the popular press in the form of fantastic claims related to the coming age of "molecular machines" or "nano-technology." Unfortunately, there is a danger that enthusiasm – including financial backing – will dry-up before we realize the true potential of these new possibilities. To avoid building unrealistic expectations, we must encourage more scientist-public discourse.

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Official Launch

Dr Robert A. Wolkow, iCORE Chair
Nanoscale Information and Communication Technologies
April 11, 2003, 12:15 - 1:30 pm
Government House, Edmonton, AB

10 emerging technologies that will change the world

A top ten list created by the Massachusetts Institute of Technology (MIT) points to emerging technologies that will "change the world."

"In labs around the world, researchers are busy creating technologies that will change the way we conduct business and live our lives. These are not the latest crop of gadgets and gizmos: they are completely new technologies that could soon transform computing, medicine, manufacturing, transportation, and our energy infrastructure," according to Nicolas Negroponte in the February issue of MIT's *Technology Review*.

Half of these are also iCORE's target research areas. The top ten are:

Wireless Sensor Networks
Injectable Tissue Engineering
Nano Solar Cells
Mechatronics
Grid Computing
Molecular Imaging
Nanoimprint Lithography
Software Assurance
Glycomics
Quantum Crypotgraphy

Alberta's fastest growing companies still in ICT

Despite the perception that the dot.com sector has gone bust, over half of Alberta's fastest growing companies are in the information and communications technology (ICT) sector, says iCORE president and CEO Dr Brian Unger, who has been calling attention to the fact after analyzing a statistical report in the February issue of *Alberta Venture*. Unger says the findings came as a surprise.

"We tend to be negative about investing in ICT because of the high-profile crashes in the sector," he says. "However, the strong growth of ICT in the toughest economic times tells a different story. It suggests that ICT will become even more central in Alberta's future."

Alberta's 30 fastest growing companies achieved $1.5 billion in revenue while employing 4,200 people in 2002. Of these 30 companies:

- 17 are developing leading edge products and services in the ICT sector, eight are in oil and gas, three in human resources, two in health-fitness, one each in biotechnology, agriculture, finance and construction (four overlap sectors).
- The oil and gas sector accounts for about 76 percent of the total revenue with ICT at 20 percent (all other sectors account for four percent), but ICT accounts for about 50 percent of the total employment.
- Eight of the top ten fastest growing R&D spenders were in the ICT sector.
- These eight ICT companies accounted for 70 percent of total R&D expenditures among the fastest growing companies in Alberta.

Dr Unger predicts that ICT will thrive because it is not only a new sector leading growth world-wide, it is an enabling technology that supports other economic drivers, in energy, agriculture, forestry, health, education or the environment.

from page 1: Molecular devices

Quantum mechanics is a good example. The theory—which is nearly 100 years old—is often portrayed as an abstract and esoteric construct. Yet is has actually led to practical, world-changing applications. One of my favourite examples is the Nuclear Magnetic Resonance (NMR) machine. When it was first developed in a physics lab 50 years ago, no one conceived it would be the foundation for the life-saving MRI (magnetic resonance imaging) machines commonly used in hospitals today.

Dare I say that we are on the verge of a technological revolution today? The practical impact of scientific upheavals like this is more or less assured—it's just that the connection to a tangible product might be convoluted and take a long time to form.

Replacing silicon as a computing engine will be a formidable task, largely because silicon has many near ideal properties. Since great technical challenges remain for molecular technology—and the main competitor enjoys towering strength—the question becomes: How do we move forward from here? It doesn't make sense for molecules to compete with silicon as a computing engine. We can easily predict the outcome if a novice fighter steps into the ring with the champion. To gain a foothold, molecules need a niche. So, why not aim at silicon's weaknesses?

Silicon-based technology is not suited to light emission or light detection, making it impotent in modern optical communications applications. Moreover, silicon can't begin to interact with molecules in the infinitely varied and sensitive ways that they interact with each other.

I suggest we build molecular devices on a silicon platform [3]. Such a silicon-molecule hybrid strategy helps get around extraordinarily challenging problems related to "wiring-up" a molecular device. As importantly, a hybrid strategy can be aimed at enhancing the capabilities of silicon rather than competing head-on.

Year by year, progress continues. At the National Research Council of Canada, we recently developed techniques that have allowed us to determine exactly how organic molecules attach to silicon surfaces. This is a key step toward our goal of hybrid silicon-organic devices. Much work remains to be done before practical hybrid silicon-molecular devices can be built, but it seems ever more likely that the necessary fabrication procedures will be developed and applications will be realized. Once these hurdles are passed, hybrid devices could be used in a wide range of areas such as telecommunications, medical diagnostics, prosthetic devices–and probably others we can't yet imagine.

Can Canada benefit from this opportunity? Yes...if we invest now.

This article originally appeared in inno'va-tion: Essays by Leading Canadian Researchers, *a collection of personal stories from 25 of Canada's brightest researchers. Abridged and reprinted with permission of the Canada Foundation for Innovation and the author.*

The book may be purchased from the Canada Foundation for Innovation at (613) 996-3176. Visit www.innovation.ca/innovation2.

[1] Molecular Level Fabrication Techniques and Molecular Electronic Devices, F.L. Carter, *J. Vac. Sci. Technol.*, B 1, 959-68 (1982).

[2] Surface studies by scanning tunneling microscopy, G. Binnig, H. Rohrer, Ch. Gerber, E. Weibel, *Phys. Rev. Lett.* 49, 57-60 (1982).

[3] Controlled Molecular Adsorption on Si: Laying a Foundation for Molecular Devices, R.A. Wolkow, *Annual Review of Physical Chemistry*, volume 50, (1999).

ICT Research Advisory Committee (IRAC) meets in Palo Alto
Standing (from left to right), Dr James Gosling, Dr David Jefferson, Dr Eric Manning, Dr William Pulleyblank, Dr Richard Taylor. Seated, Dr Brian Unger.

iCORE's success linked to focus, 2003 strategic plan proposes

iCORE is reexamining its current strategic plan to improve its ability to build on the success that the Alberta information and communications technology (ICT) research community has achieved over the past few years. The final draft will be reviewed by the iCORE board of directors in May.

The key strategic elements being proposed are:

(i) increasing focus with respect to awards through its flagship Chair and Professor Establishment grant program, in particular in the area of computing science

(ii) working with industry in order to expand the Industrial Chair Establishment program, to increase the leverage of invested iCORE and university department funds, in particular in electrical and computer engineering, and computer science

(iii) finding additional funds for the base budget to address (a) the expanding Graduate Student Scholarship program (b) upcoming renewals of major awards (c) continued excellent CPE and ICE awards.

The sharper program focus, coupled with ensuring that there is a successful technology commercialization ecology in Alberta, is designed to build on what has been working. Some of the related strategies under consideration are:

MAINTAINING CLEAR FOCUS
Further refining the target research areas, and placing emphasis on building early links between high quality researchers and industry.

STAYING WITH PROVEN PROCESS
Keeping a nimble, responsive and focused approach as the organization's mode of operation.

KEEPING SIGHT ON CRITICAL MASS OF EXCELLENCE
Attracting research teams and research funding to Alberta with an unwavering commitment to the critical mass of research activity that is required to support a thriving ICT industry cluster.

INCREASING PARTNERSHIPS
Continuing to develop substantial partnerships locally and internationally with researchers, universities, institutions, government programs and industry.

RESPONDING TO CHANGING ENVIRONMENTS
Participating closely with technology commercialization and economic development organizations in Alberta.

To obtain a copy of the plan after May 15, please contact iCORE at 403-210-5335 or info@icore.ca.

10 top reasons for iCORE's success

Roger Smith, Chair of iCORE's board of directors, gave comments to a life science group recently. In this discussion, he listed what he saw as ten important factors in iCORE's success:

1. Strong government support from the beginning, including the Chair of ASRA, the Minister and the Deputy Minister of Innovation and Science.
2. Clearly defined, and limited, objectives. The creation of iCORE was but one part of a comprehensive strategy.
3. Strong scientific credibility, via the participation of internationally respected researchers like James Gosling, Richard Taylor, and others, who were initially on iCORE's board and are now on the ICT Research Advisory Committee (IRAC).
4. Strong, credible, imaginative CEO who is known to ASRA, to Innovation and Science, and to others in the province.
5. Strong and diverse board inclusive of expertise from outside of the province. Government has supported restructuring of the board so it is most effective.
6. Stability in funding.
7. External validation of proposals and processes, via the Internal and External Review Committees, and the IRAC.
8. Program flexibility that allowed small changes in mandate to help achieve the primary goals, in other words, the ability to create programs that were essential complements to meeting our primary objectives.
9. Continuous involvement with universities – on the board, on committees and via workshops.
10. Ongoing efforts at building partnerships (with programs and organizations such as Canada Research Chairs, National Institute of Nanotechnology, Alberta Ingenuity, Banff International Research Station, Netera Alliance, and others).

iCORE contacts

SECRETARIAT
3608 - 33 Street NW
Calgary, Alberta
Canada T2L 2A6
www.icore.ca
info@icore.ca
tel (403) 210-5335
fax (403) 210-5337

PRESIDENT AND CEO
Dr Brian W. Unger
unger@icore.ca

DIRECTOR OF PROGRAMS
Lynn Sutherland
sutherland@icore.ca

DIRECTOR OF CORPORATE RELATIONS
Fred A. Stewart
stewart@icore.ca

DIRECTOR OF UNIVERSITY RELATIONS
Dr Terry Caelli
caelli@icore.ca

DIRECTOR OF UNIVERSITY RELATIONS
Dr John Kendall
kendall@icore.ca

DIRECTOR OF COMMUNICATIONS
Mary Anne Moser
moser@icore.ca

OFFICE MANAGER
Carole Carlton
carlton@icore.ca

CONTRACTS AND COMMUNICATIONS
Betty Ann Snyder
snyder@icore.ca

President's report

In the February MIT *Technology Review*, futurist Nicolas Negroponte explored the common denominator among originators of breakthrough ideas, and concludes it is having a high tolerance for risk and failure. His description of the research climate required for this reinforces some of iCORE's efforts to foster innovation in Alberta, such as supporting interdisciplinary research, providing venues for exchange of ideas, encouraging risk and encouraging openness and idea sharing.

All of these are designed to increase the likelihood of serendipitous and unimagined results. iCORE is planning a new annual forum to foster the cross-pollination of ideas among research teams in Alberta. In the meantime, we encourage all of the iCORE research teams, and other Alberta researchers, to support diversity in research disciplines and think about how research might make leaps into other areas. We need to be able to take risks, and make sure that we don't link failure and ridicule to ideas that might seem far-fetched. After all, that must be one of the main draws of Alberta – support for a risk-taking and pioneer spirit.

Brian Unger, President, iCORE

New appointment

Nicholas Pippenger has been approved as a new member of iCORE's External Review Committee. Dr Pippenger holds a Canada Research Chair in Computer Science at the University of British Columbia and is a Fellow of the Royal Society of Canada (Academy of Science), a Fellow of the Institute of Electrical and Electronics Engineers, and a Fellow of the Association for Computing Machinery. His research interests centre in theoretical computer science, but also extend into communication theory and mathematics. He is the author of *Theories of Computability*, published by Cambridge University Press in 1997.

The External Review Committee is an arms-length group responsible for selecting external reviewers who assess the international calibre of prospective iCORE award recipients.

iCORE sponsoring events and lectures

Grid applications in Canada

Researchers requiring access to high performance computing that can only be provided by distributed machines can learn more about the emerging field of grid computing at Grid Applications in Canada.

This iCORE-sponsored event will take place on May 8 and 9 in Edmonton, at the Telus Centre. For more information or to register, visit www.westgrid.ca.

Computer science lecture series: Calgary

iCORE is one of the sponsors for a series of lectures at the University of Calgary's Department of Computer Science. Over the next year, the department is planning from four to six lectures in such fields as Visual and Interactive Computing, Quantum Computing and Cryptography, Software Engineering, and Distributed Systems and Algorithms. The Computer Science Department home page is at www.cpsc.ucalgary.ca.

ICT forum series: Edmonton

iCORE is also a sponsor of an ICT Forum Series, to be held at the University of Alberta. A forum on Wireless Systems was held in February 2003, and three more are planned. The forums will be on the topics of Large Scale Data Repository Management (May-June 2003), Data Mining and Intelligent Systems (September 2003), and E-health (December 2003). Details of the upcoming forums can be found at www.ualberta.ca/ict.

Agent-based technologies conference

The First International Conference on Agent-Based Technologies and Systems (ATS'03), also partly sponsored by iCORE, will take place in Calgary from August 27-29th, 2003. www.enel.ucalgary.ca/People/far/CFP/ATS03_CFP.html

Upcoming events

April 11 **iCORE launch**
Dr Robert Wolkow, iCORE chair,
Nanoscale Information and Communication Technologies
Government House, Edmonton, AB
12:15 - 1:30 pm

April 30 **iCORE Distinguished Lecture Series**
New frontiers in wireless technology
Dr Jim Haslett, iCORE Industrial Chair
Telus Centre 134, Edmonton, AB
4 pm, reception to follow
Multicast to Calgary and Lethbridge