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Shaping Our Technological Futures

Some important, long-term, social and economic challenges that we face can potentially be addressed by existing and emerging technologies. This article draws on the future technology growth trends and technology lists identified by Evans (3) in the paper "Securing Australia's Future – Future Technology Overview." Our focus is on how technological change can be channeled to address the critical challenges of our time and how we can shape the new and emerging technologies and systems to address these challenges. We include a list of basic technology advances that will, within the next ten years, underpin a large range of application technologies. We then identify some of the critical issues facing society, such as urbanization, water, and climate change, and discuss how the convergence of underpinning technologies can be shaped to address these issues. While the paths of technological change cannot always be predicted and impacts are highly uncertain, there are some clearly emerging trends, which point to real possibilities of steering technology in the direction of addressing critical societal issues.

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Critical Societal Issues

Critical societal issues, along with people's preferences and even beliefs, are some of the factors that can and have influenced the adoption of new technologies and have driven technological change. Concerns over dwindling and finite energy resources and about environmental sustainability, for example, are driving the development of renewable energy technologies. Key issues have been identified in various arenas, such as in the United Nations list of Millennium Development Goals, with significant levels of agreement. Similarly, the Carlton Connect Initiative (CCI) outlines some of these important issues: water, food and energy security, urbanization, climate change, adaptation, risk and resilience, and social equity.

The history of technology prediction indicates, however, that there are various and sometimes completely unexpected paths that technological development can take. Therefore anticipating technology change and its potential impact is not always possible. Technology forecasting, while often seen as an activity of critical importance to both industry and government, is well known to be a notoriously difficult and unreliable process. Hence, our purpose is to identify the potential of the most promising of today's existing and emerging technologies, to meet the "grand challenges" of our times.

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Underpinning Technologies

Underpinning technologies are those existing and developing technologies that are advancing in a reasonably predictable manner. Hence likely capabilities within 10–20 years can be determined with some degree of confidence. Computer performance that underpins many of technology system advances has progressed according to Moore's Law for around 50 years and recent materials technology advances such as graphene pave the way for a further 10–20 years of exponential increase in performance and exponential reduction in size and cost. Integrated circuit technology, relentlessly following Moore's Law, resulted in a high performance computer in the mid to late 1960s (occupying many tens of cubic meters volume, drawing many kilowatts of power, and costing several million dollars) being transformed by 1980 to the size of a thimble, drawing just a few watts of power, and costing a few dollars while achieving similar computing performance.

Underpinning Technology List

- Computing power and memory – excluding quantum computing – likely to experience a 10 million fold increase in integration density with a similar reduction in cost and a many-fold increase in speed resulting in today's supercomputers capability (such as, for example, the IBM Blue Gene super computer) forming the compute/memory elements in handheld consumer devices in 2025. How this massive increase in compute power will be used is unclear.
- Steadily advancing cognitive computing capability is likely to lead to a large increase in automated machine "thinking" ability that will be available for consumer devices by 2025. The IBM Watson computer is a first serious step in this direction.
- Steadily increasing capability in networking –10–100 GB/sec in the home and public transport, and 1–10 GB/s mobile.
- Near instantaneous and near-zero cost DNA sequencing.
- 3-D printing – fast, highly capable, low cost, widespread. Already 3-D printers are employed to manufacture advanced components such as turbine blades and aerospace components, orthopaedic replacement parts, and a range of electronic components.
- Increasingly capable and rapidly reducing cost of humanoid robotics and natural user interface technology within 20 years.
- Autonomous vehicles, driverless cars, UAV's, electric vehicles — low cost, safe, efficient, widespread within 15 years.
- Smaller, cheaper, more capable sensing and monitoring technology, including new nanotechnology based sensor systems, such as low-cost, chip-based biochemical analysis.
- Improved large- and small-scale alternative energy technology, better storage, wireless transfer for low power levels, energy scavenging technology for many consumer and monitoring applications, advanced power grid control and micro-grid technology (smart-grid).
- New energy technologies and more efficient use of existing gas, oil, coal [3].

Critical Issues and Technology Convergence

Slowly but steadily these new technologies are coming together in a larger ensemble of systems that open up new social and economic possibilities. In this section we identify some of the critical societal issues and how technology and system convergences can be shaped to address these issues.

Smart Cities

The problems associated with increasing urbanization, such as eroding urban ecology and air quality, and the increasing pressure on infrastructure and services, can be addressed through the following technology convergences.

Smart and Agile Power Systems + Extensive Sensing + Analytics + Networks + Autonomous Electric Vehicles = Safe, Green, Sustainable (Smart) Cities.

Impacts include:

- Improved urban ecology, biodiversity and air quality;
- The development of smart "traffic light" grids that predict traffic flow;
- Smart and agile energy systems – "personal power" generation, storage, and sharing;
- Low-cost-effectiveness – reducing the relative cost of infrastructure, improved access, and social equity;
- Data-driven decision making – strengthened governance and improved planning and design.

The following system and technology convergences will also be a feature of these "smart cities."

Computing Power + Robotics = Further Automation Of Manual Work

Cyclic Economies, Increased Re-Cycling

Hand-in-hand with these developments is also the possibility for enhanced and wide-scale surveillance of human activities.

Water Sustainability

Improved water sustainability, waste water treatment, drinking water, ecological health of urban waterways, and system management can be achieved through the convergence of smaller, cheaper, and more capable sensing and monitoring technology, with analytics and networks.

Extensive Sensing + Analytics + Networks = Improved Water Productivity, Sustainability And Safer Drinking Water

Much of the data that will underpin evidence-based practice will be derived from next-generation sensor networks that provide near-real-time environmental information, and much more rapid evaluation of environmental responses to water. Stewardson (11) assesses that there is an urgent need to increase our capacity to integrate remotely sensed (satellite and airborne platforms) with ground data in model-based assessments to evaluate the contribution of environmental water.

Climate Change

Some of the key issues related to climate change, adaptation, risk mitigation, and enhancing resilience can be tackled through green power development, smart grids, and improved quality of response, based on the following technology convergences.

Renewable Energy Sources + Sensing + Networking + Analytics + Extensive Distributed Energy Sources = Green Power (Smart Grid)

Extensive Sensing + Analytics + Networking = Improved Quality Of Response, Enhanced with Robotics And Uavs

During the relief operations conducted in the aftermath of typhoon Haiyan in the Philippines in 2013, the fastest way to re-electrify devastated communities was through small-scale renewable energy technologies solutions, such as solar lanterns and off-grid solar-powered minigrids. Assessments of early warning efforts conclude that the warning systems were inadequate resulting in unnecessary loss of lives (8).

Impacts include:

- Improved energy efficiency and reduced demand;
- Accelerated transition to renewable energy;
- Informed decision-making and enhanced risk management and assessment from centre to on-ground emergency services – reduced loss of lives and negative impacts.

Food Security

Malnutrition and childhood mortality in the developing world can be addressed through the cost-effective agricultural applications of nanotechnology (1).

The underpinning nanotechnology, in convergence with analytics and RFID technology, can have significant impacts on food security and agricultural production.

Nano-Technology + Analytics + RFID Technology = Improved Food Security

Crop health can be monitored using nanosensor arrays. Sensors applied to the skin of livestock or sprayed on crops can help detect the presence of pathogens. It involves little land or maintenance, it is productive and inexpensive, and it requires only modest amounts of materials and energy.

Impacts include:

- Improved crop protection;
- Improved food quality;
- Increased agricultural productivity – decreasing malnutrition and child mortality, overall improvement in health outcomes.

> **There are some clearly emerging trends, which point to real possibilities of steering technology in the direction of addressing critical societal issues.**

Health

Fast DNA Sequencing + Analytics = Personalized Medicine

DNA sequencing is on the path to becoming an everyday tool in life-science research and medicine. Institutions are beginning to sequence patients' genomes in order to customize care according to their genetics. This type of personalized medicine will lead to substantially improved outcomes and lower health-care costs. Instead of costing hundreds of millions of dollars and taking years to sequence a single human genome, now a population-scale sequencing platform recently has been created that can sequence over 18 000 genomes per year at a cost of approximately $1000 per genome. Sequencing is no longer something only big companies and international consortia can afford to do. Now, thousands of bench-top sequencers sit in laboratories and hospitals across the globe.

Disruptive Transformation Technologies

Disruptive technologies, such as 3-D printing, autonomous vehicles, wearable Internet, and energy storage, can transform how we address all of these issues. Disruptive technologies hold the potential to transform the way certain activities are conducted, from some industries disappearing and new ones emerging, to the total transformation of mass consumption and production. A number of people are predicting that the extremely flexible manufacturing potential of 3D printing could even play a role in disaster response.

The technology pioneers describe the potential of 3D printing to create a total self-producing environment, using recycled materials, printing out its own energy sources, linked to food production at one end and system production at the other (9). Not only the creation of a self-contained production loop, but an entire system that lives off recycling of surplus products, such as plastics and other materials. Some feminists also reflect optimism about how these technologies provide a tool for challenging traditional notions of gender identity, transforming gender relations, and the relationship between women and technology.

The "Dark Side"

The old battle line between "personalization" or "decentralization" verses "centralized control" appears to be further reinforced with the anticipated technology progression. Trends towards smaller and increasingly low-cost technologies (the impacts of Moore's Law), aid their uptake and distribution, and hence the personalization and decentralization of these emerging technologies and systems. The technologies that enable increasing personalization (and consequential increasing expectations of personalized attention) also bring the clear ability of observing detailed personal information and the possibility of this information being available to others. The contradictions are growing sharper between trends towards personalization and decentralization of technology on one hand and increasing centralization and control by governments and states on the other. Is the future an Orwellian-type "surveillance society" or a more horizontally networked "global village"? Many of the technology "dark-side" prophecies and fears, related to privacy issues, the loss of personal control, and even enslavement of society by technology, are based on this aspect of coming technologies [2], [4], [7], [10].

And what are the gender ramifications of disruptive technologies? We are told that women may soon bid farewell to existing methods of birth control and welcome a new type of contraception in the form of microchip implants. An M.I.T. startup backed by the Bill Gates Foundation plans to start pre-clinical testing for the birth control chip this year and pave the way for a possible market debut in 2018. The fingernail-size microchip implant – each measuring 20 x 20 x 7 millimeters – holds enough 30-microgram daily doses of levonorgestrel – a hormone already used in several contraceptives – to last for 16 years. Women who received the implant under the skin of buttocks, upper arm, or abdomen would also get a remote (wireless) control that allows them to halt or restart the implant whenever they like. The technology includes secure encryption to prevent outsiders from blocking or reprogramming the implants wirelessly. As an added precaution, the remote control can only communicate with the microchip implant across a distance equivalent to skin contact [5].

Can this new application for microchips potentially revolutionize the level of control women have over their reproductive functions? Or is this another example of intervention and control over women's bodies, by what has been considered to be by many feminists, a "patriarchal" scientific establishment? Has the optimism among some feminists, influenced by the dawn of the digital age and the development of information and communication technology, with its potential to empower women and transform gender relations, been realized? Thirty years since the publication of Donna Harroway's "Cyborg Manifesto," in 1985, it will be important to assess the gender ramifications of disruptive technologies.

Real Possibilities

While the paths of technological change cannot be predicted and their impacts are uncertain, there are some emerging trends, which point to real possibilities of steering technology in the direction of addressing the critical issues facing humanity. Planning, policy, laws, and regulation, for instance, can spawn the development of new technologies as a positive force for change in a given direction. Hence governments can and do have an important role to play and "smart" policy and planning can spawn technology change. Government subsidies and support for R&D, for example, was the backbone for the development of oil, gas, nuclear, and today's renewable energy industries.

While the ambiguous nature of technology change needs to be acknowledged, such as trends towards reduced privacy, the impact of robotization on employment, or the "weaponization" of technologies, we can also aspire to an alternative future: a child in a slum has her environment transformed by 3D printing, and has access to complex medical treatment provided by a low-cost robotic surgical machine, available at the local health clinic, powered by very efficient solar systems. The possibilities are endless. Despite what the pessimism of the moment might suggest, we have far more going for us, to believe in the possibility of change for the better.

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