Beyond Moore’s law: disruptive technology, opportunities and policy challenges
Part I

From Moore’s law and beyond: the economic and societal impact of High performance Computing (HPC)
Moore’s law

Fig. 2 Number of components per integrated function for minimum cost per component extrapolated vs time.
An sustained *tour de force* in design and engineering

In 1978, a commercial *flight* between New York and Paris cost around $900 and took seven hours. If the principles of Moore’s Law had been applied to the airline industry the way they have to the semiconductor industry since 1978, that flight would now cost about a penny and take less than one second.

A chip-making tool under development superimposes magnetically levitated images within a tolerance of 1/10,000 the thickness of a human hair — a feat equivalent to driving a car straight for 400 miles while deviating less than one inch.

An incredible story of sustained innovation
Impact on Technical computing

• Similar linear growth for HPC
  – Outperforms Moore’s law
  – Today’s phones are yesterday’s SC

• Global recognition of economic and societal impact of HPC
  – “Outcompute to outcompete”
  – Increased investments
  – “HPC: Europe’s place in a global race”
National Supercomputing Center in Wuxi (China)
Sunway TaihuLight

10,649,600 cores, 93,015 Pflops, 15.4MW
Growth through innovation

• Linear trend misleading
  – Frequent paradigm change
  – Increased complexity

HPC Vs.

• HPC resources increasingly accessed through “the Cloud”
  – Cloud just a “delivery mechanism”
  – HPC remains HPC, and more difficult to debug/optimise in the cloud

Performance Development

- Single CPU
- Vector
- MPP
- Multi-core
- Many-core
The era of Quantum Computing
Evolution vs. Revolution

Many people believe that quantum computing is one of several technologies that will enable the “fifth generation” of computers.

FIRST GENERATION (1940–1956) Vacuum tubes
SECOND GENERATION (1956–1964) Transistors
THIRD GENERATION (1964–1971) Integrated circuits
FOURTH GENERATION (1971–present) Microprocessors
FIFTH GENERATION (present and beyond) Quantum computers

www.ichec.ie
The era of Quantum Computing
Evolution vs. Revolution

• A genuinely disruptive technology
• Best suited to optimization, sampling and machine learning across multiple industries
• Will co-exist with conventional systems
  – “As such, it is unlikely classical computing will be replaced any time soon by quantum computing.”
• “consistent enterprise use [...] still two to five years out [adiabatic] ... 5 to 10 [gate model]
• “Nonetheless, the number of qubits in today’s adiabatic quantum computers is currently keeping pace with Moore’s Law”

Source: Innovating with Quantum Computing: Enterprise experimentation provides view into future of computing, Accenture Labs www.accenture.com/labs
The future has already started...

- Deep Learning
- Autonomous vehicles
- Blended Reality
- Wearable Computing
- Neuromorphic Computing
- Earth Observation
- Quantum Computing
- Industry 4.0
- Precision everything
The future has already started...

What do all these technologies have in common?

They all require Programming for Performance

They all require High-Performance Computing techniques
Part II

Scale of opportunities for Ireland Inc.
Setting the Scene

• Significant (unparalleled?) opportunities
  – Most require **agile** and **multi-disciplinary** approaches
• Digital transformation
  – Convergence of key technologies
  – Growing role of technologists
• Favourable policy environment internationally

Europe's future is digital: EU countries commit in Rome to go deeper and further on digital (22/03/2017)

_As part of the celebrations of the 60 years of the Treaties of Rome, the Commission will bring Ministers together tomorrow to progress on high-performance computing, connected mobility and industry digitisation. Initiatives to support digital skills will also be discussed._

Quantum Computing

• QC ecosystem (IE connections)
• Accenture Labs & 1Qbit - 150 test cases**
• Early adoption expected in
  – FSI: Risk optimisation and fraud detection
  – Health: Protein folding, drug discovery
  – Manufacturing: supply chain and purchasing
  – Resources: utility system distribution optimisation

• IE has one of the most respected Centres internationally in Performance Engineering – ICHEC
**Low precision NNs are the “Driver”**

**Big Data is the “Fuel”**

**Inexact Computing is extending the lifetime of the “Moore’s Law era”**

**Massively Parallel Low Precision processors are the new “F1 car”**

Deep Learning: No Longer Just a Game

- DeepMind AI playing GO (2015)
- DeepMind AI detecting eye disease with NHS

- NVIDIA GPU
- Google TPU
- Intel NERVANA
- Movius@Intel FATHOM

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1990s
First automated DNA sequencer

2000s
Human Genome Project completed

2010s
The 1000 Genomes Project
Need integration of **infrastructure** (HPC, data, lab equipment), **institutions** (clinics, research labs, infrastructure solution providers, data protection oversight), and **expertise** (medicine, biology, statistics, bioinformatics, computational science).
Case study: Google’s DeepMind

• Collaboration with NHS’ Royal Free Hospital
  – Training to spot age-related macular degeneration diabetic retinopathy
  – Neural nets vastly improve speed and accuracy of diagnostics
    • Potentially saving the sight of thousands

• 2nd Collaboration with Moorfields Eye Hospital (2016)
  – Largest depository of Optical Coherence Tomography scans in the world
  – Shared c. 1m anonymous digital eye scans, along with related info
Is legislation “keeping up”?

• Controversy re. authority of RFH to share patients’ records
  – arrangement “is the standard NHS information-sharing agreement set out by NHS England’s corporate information governance department and is the same as the other 1,500 agreements with 3rd-party organisations that process NHS patient data.”

• 2nd Collaboration with Moorfields Eye Hospital (2016)
  • Shared c. 1m anonymous digital eye scans, along with related info

• Balance between right to privacy and public interest
  – UK’s Caldicott principles:
    • 7th principle - “The duty to share information can be as important as the duty to protect patient confidentiality”
Part III

Strategic approach (please)
Are we ready?

• A robust platform
  – Innovation-driven policies
  – Strong industry links (IDA/EI)

• Some key structural issues
  1. Prioritisation-based policies can lead to silos and under-funding for platform S&T
     • Counter-productive to a number of emerging domains
  2. Chronic under-investment in (national) infrastructure
     • Benchmarking HPC & Data Mgt infrastructure (per capita)
     • Implication re. lack of national Data Mgt platform for Earth Observation, Deep Learning, Precision Medicine, Climate Modelling, etc.
  3. Infrastructure also about software and more importantly people
  4. Role and importance of technologists not understood
     • Access to opportunities and parity of esteem
Key recommendations

1. Introduce top down approach to national infrastructure funding
   - Cross-departmental/cross-agency initiative required
   - Robust (near-mission critical) and multi-disciplinary

2. Introduce programme supporting HPC technologists
   - Significant opportunity through training & education
   - Need to bring parity of esteem (i.e., eligibility criteria and review)

3. Strengthen processes for policy implementation
   - International Strategic Advisory Network
   - Create a position of CTO to the Government