Embedded Systems for Impedance Imaging

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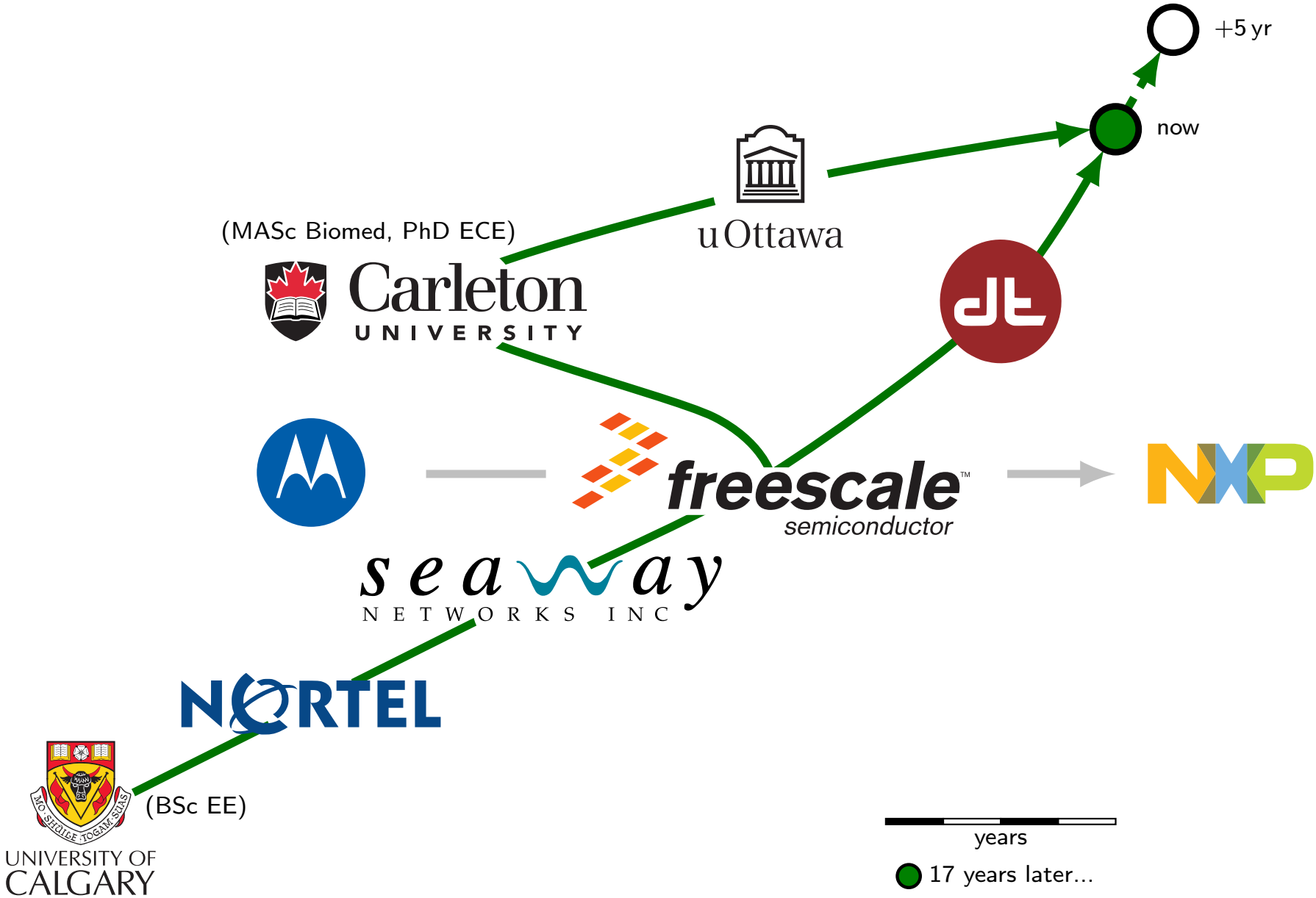
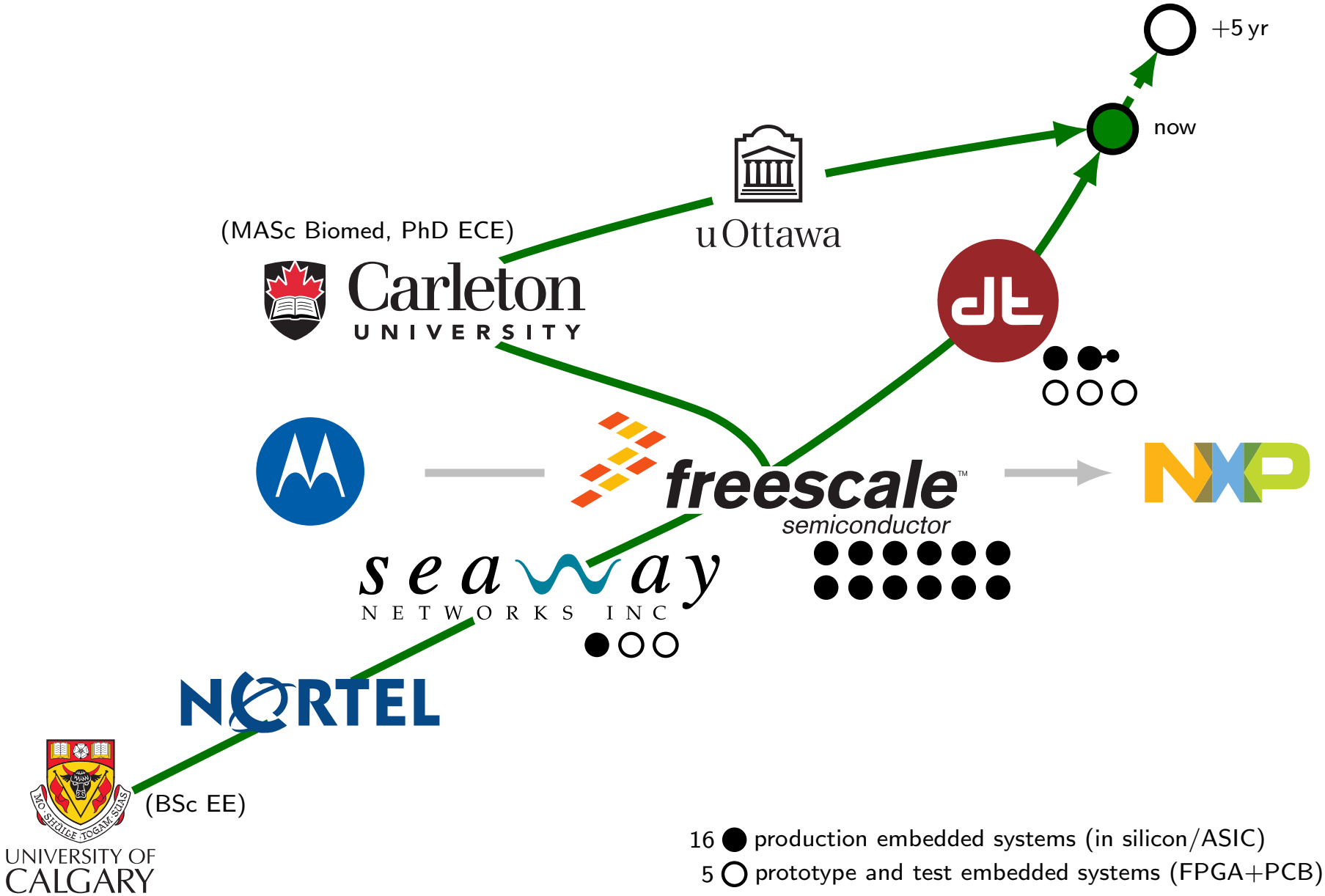
Feb 27, 2018

Wikipedia, public domain


+5 yr
now
(MASc Biomed, PhD ECE)
Carleton UNIVERSITY
uOttawa
freescale semiconductor
NXP
seaway NETWORKS INC
NORTEL
(BSc EE)
UNIVERSITY OF CALGARY
years
17 years later...


+5 yr
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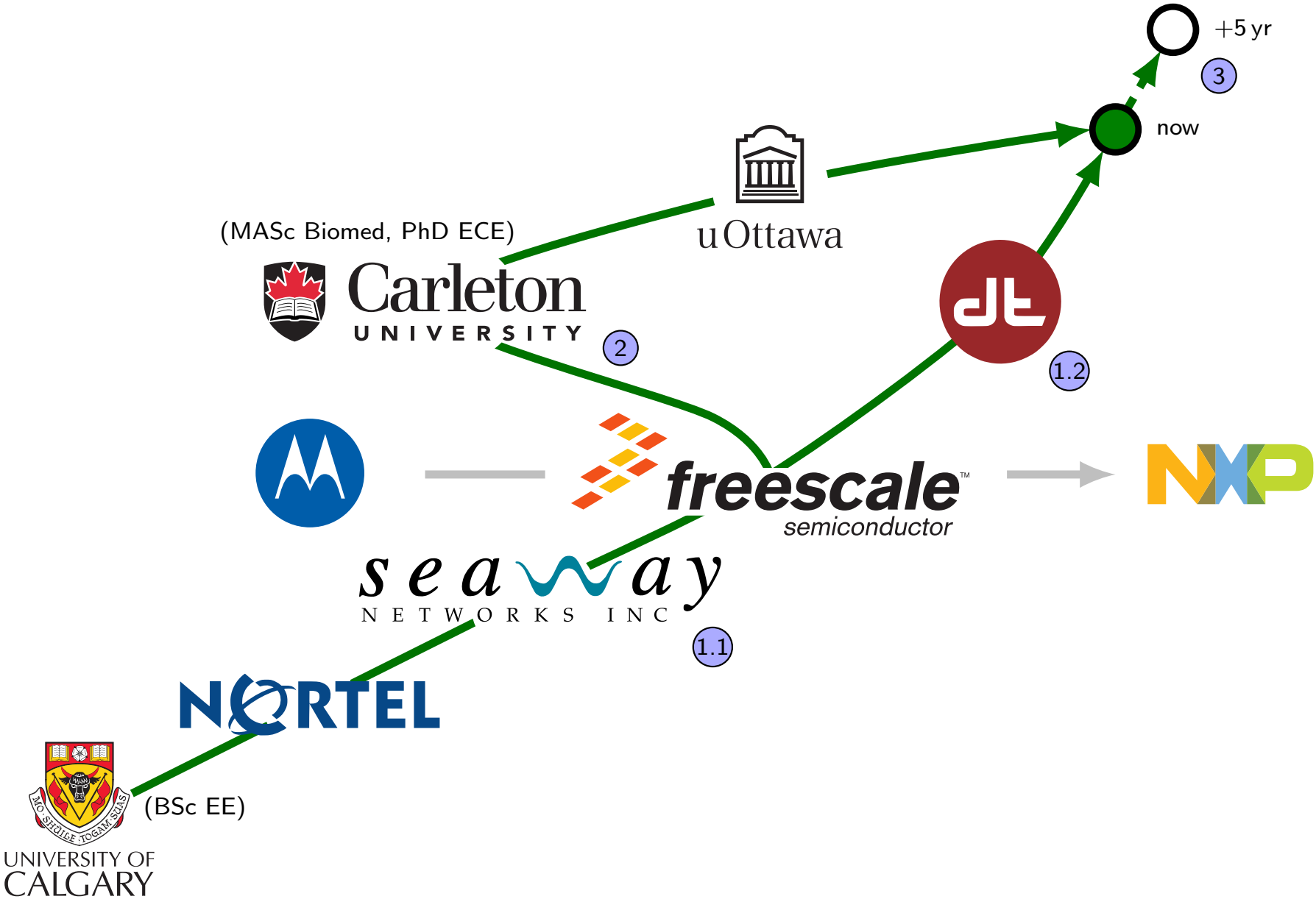
NXP
seaway NETWORKS INC
NORTEL
(BSc EE)
UNIVERSITY OF CALGARY
16 production embedded systems (in silicon/ASIC)
5 prototype and test embedded systems (FPGA+PCB)


+5 yr
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uOttawa
(MASc Biomed, PhD ECE)
Carleton
UNIVERSITY
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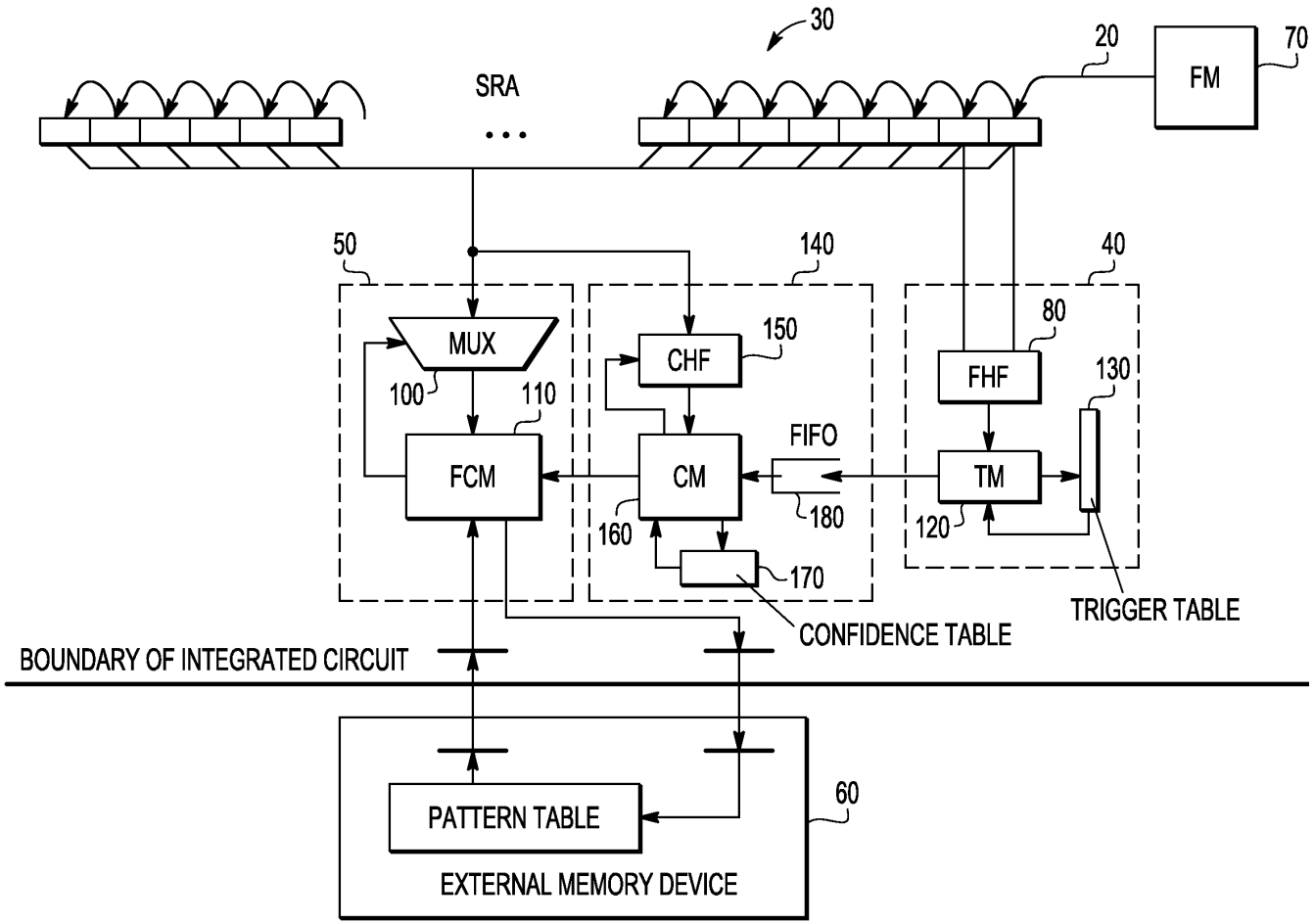
freescale
semiconductor
NXP
seaway
NETWORKS INC
1.1
NORTEL
(BSc EE)
UNIVERSITY OF
CALGARY

Highspeed Pattern Matching

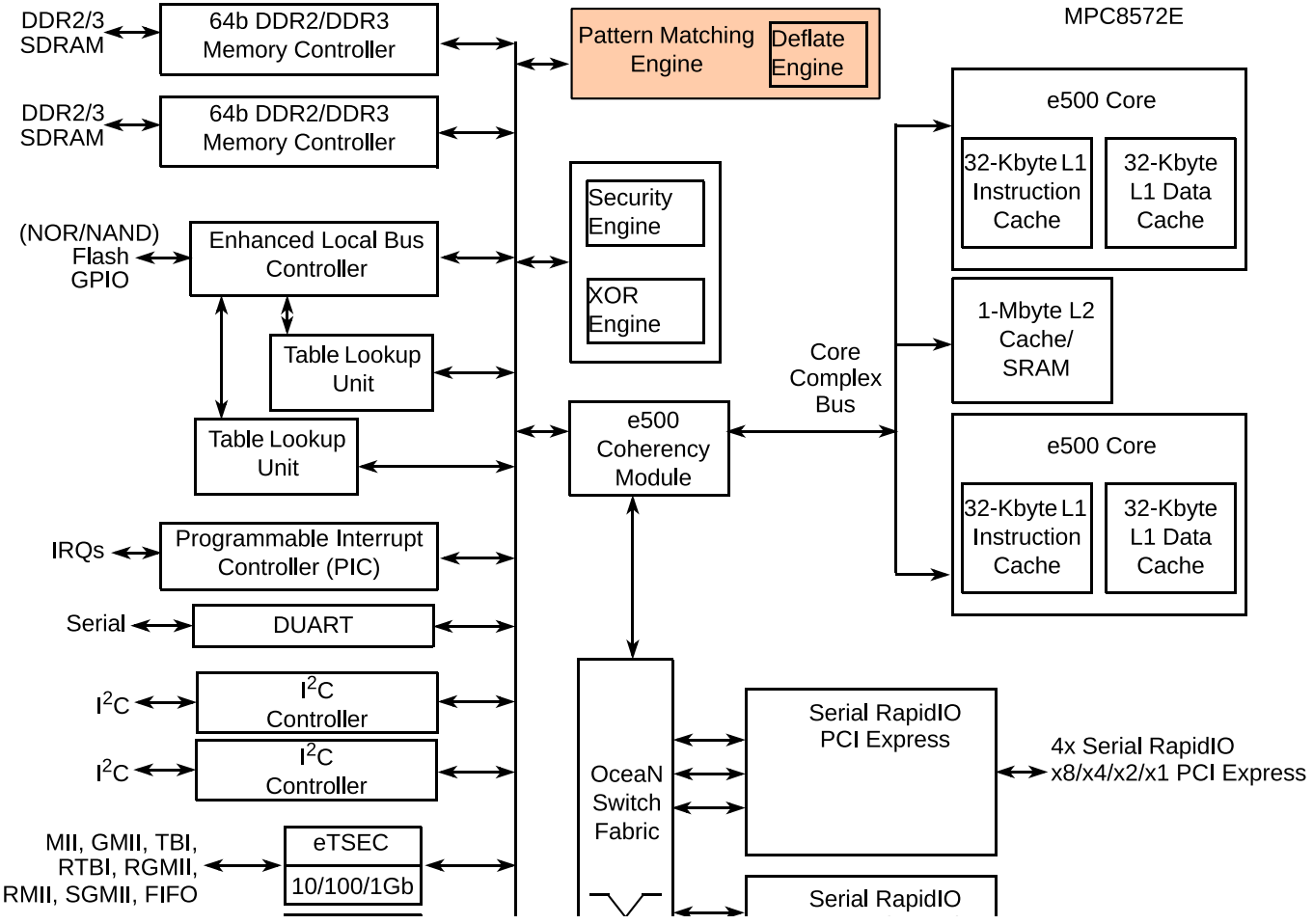


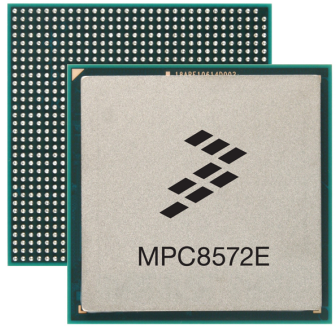
10k patterns, full Perl regex compiled to HW database, 3.2 Gbps (SNORT, spam)

J Pillar, A Boyle, T Buick, B Fong, D Lapp (2006) "Method and apparatus for network security" Patent US20070192856

J Pillar, M Schellhorn, T Buick (2005) "Data scan mechanism" Patent US8001602B2

Highspeed Pattern Matching



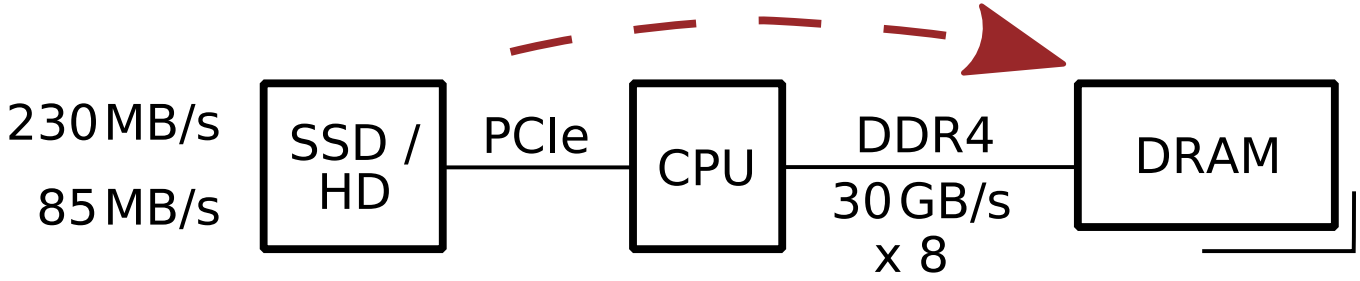


deflate = gzip, 4 x 1 Gbps ethernet, 2 x PowerPC e500 cores

NXP Semiconductors, MPC8572E PowerQUICC III Integrated Processor: Hardware Specifications, 2008

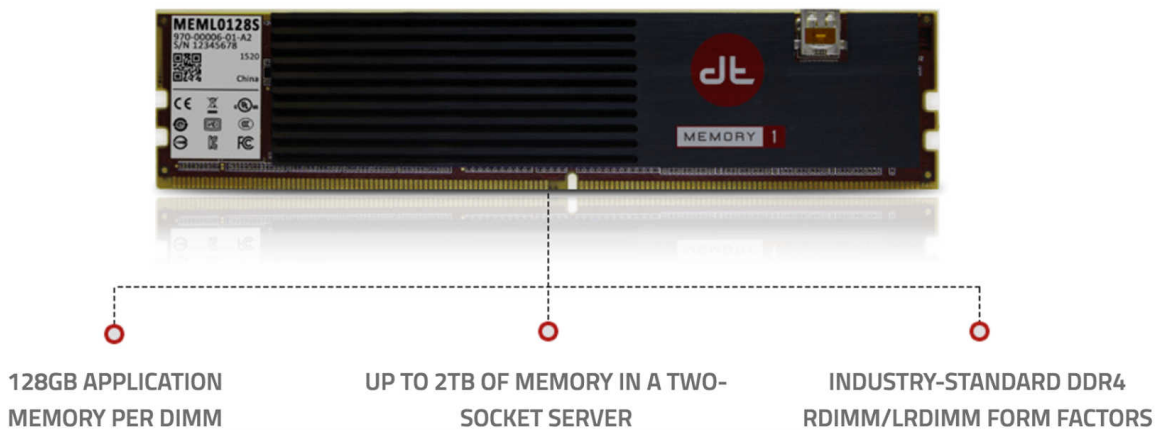
Memory Channel Storage

Max: 128 GB memory/system → 1 TB "memory"

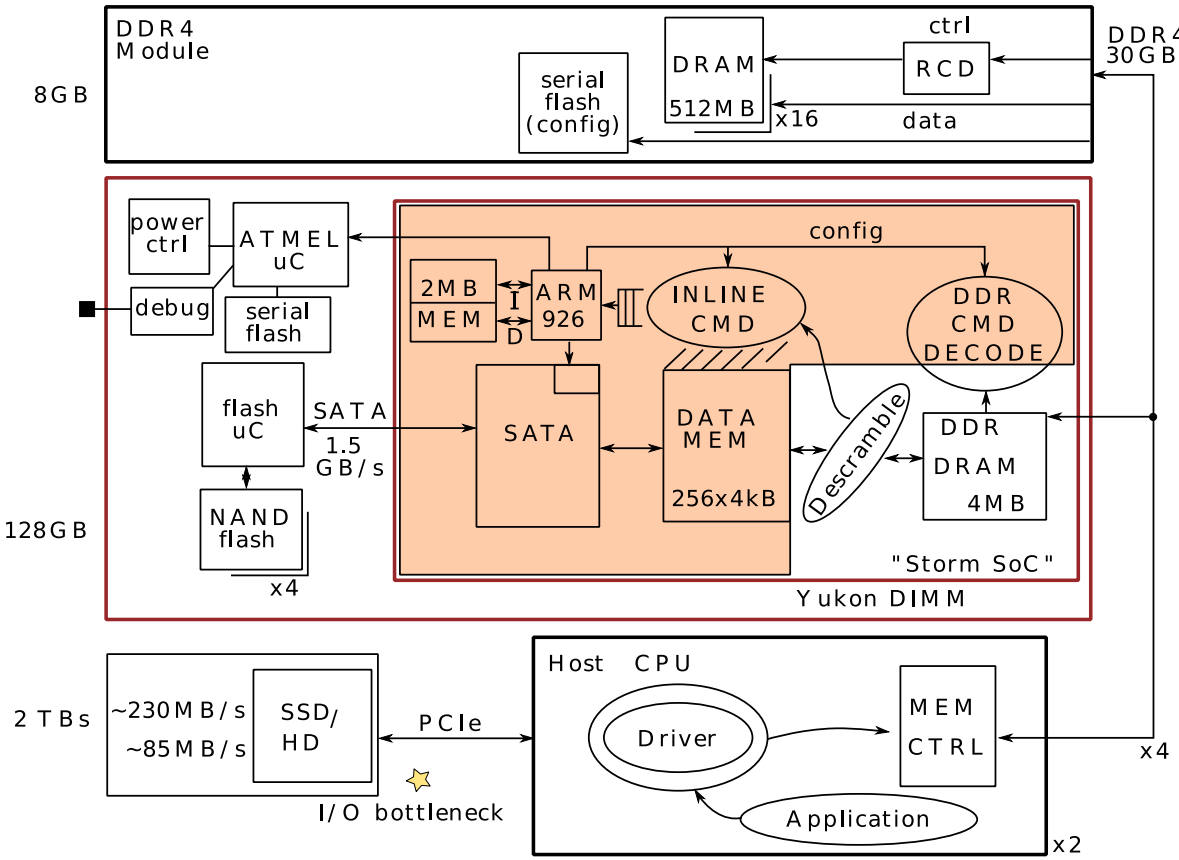


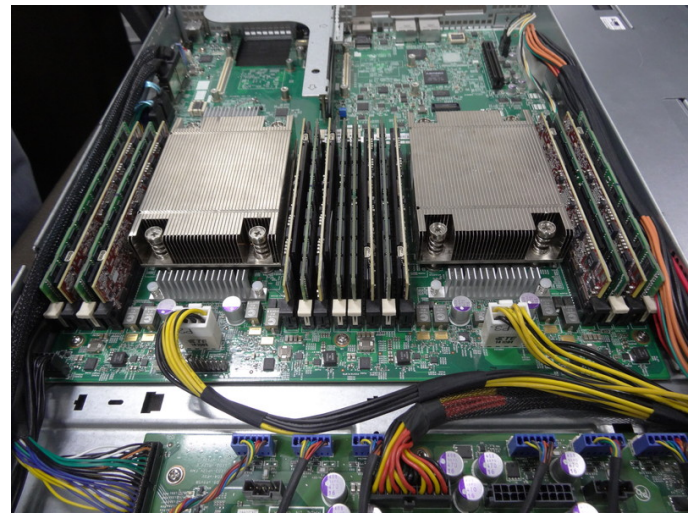
Average access time: orders of magnitude faster

Fundamentally speeding up
high performance computing on big data

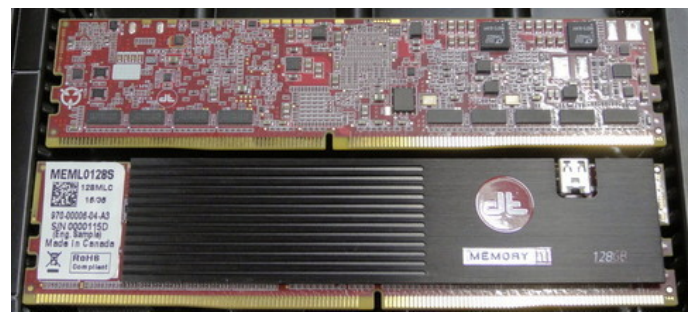


Memory Channel Storage





compare typical 8 GB DDR4 DIMM, to Diablo's "Memory1"



images retrieved Feb 24, 2017 from newegg.ca and PC Watch

Meanwhile in a parallel universe,

flickr: chingster23

Average 565 derailments per year, 80 with dangerous goods (Canada, 2010-2015)[2]
Gogama clean-up costs will be "in the millions" – MPP F. Gelinas[3]

[1] Transportation Safety Board of Canada, *Railway Investigation Report R13E0069*, Apr 2013

[2] Transportation Safety Board of Canada, *Statistical Summary - Railway Occurrences 2015*, Feb 2016

[3] M. Stackelberg, CBC News, *Ontario bills CN $350K for Gogama derailment clean-up*, Dec 2015

Mount Polley Mine, Likely, BC: spilled 4,500,000 m^3 of tailings[4] with clean up costs of \$200–500 mil.[5] (2014)
46 "dangerous or unusual occurances" 2000–2012 in BC[6]; 2–5 "major" tailings dam failures per year[7]

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[4] Indep. Expert Eng. Invest. & Review Panel, *Report on Mount Polley Tailings Storage Facility Breach*, 2015

[5] CBC News, *Mount Polley mine tailings spill*, Aug 2014

[6] G. Hoekstra, Vancouver Sun, *Liberals keeping dangerous occurrences at B.C. tailings ponds a secret*, Aug 2014

[7] M. Davies, et al., *Mine Tailings Dams: When Things Go Wrong*, AGRA Earth & Env. Ltd, 2002

What is the Systems Problem?

Long-term remote monitoring is a

- hard systems problem, and
- vital for Canada

Long-term, reliable remote monitoring can mitigate risks and enable timely response

flickr: druclimb, Toe of the Katzie Glacier, near Vancouver, BC, 2008

Could manage *ground stability* risks with

- a tool for real-time monitoring (prediction) of movement
- robust, reliable, informative reconstructions

Tool of choice:

Electrical Resistivity Tomography
Electrical Impedance Tomography

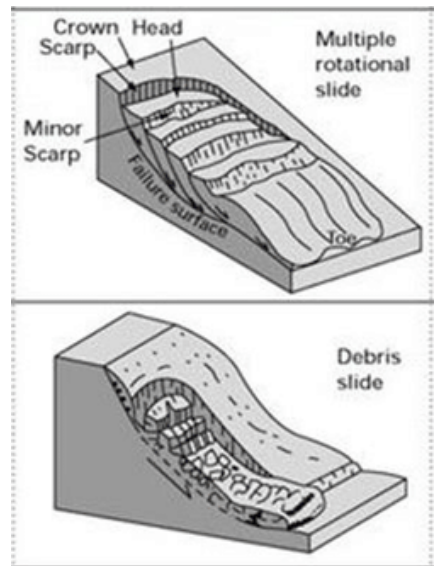


image: A Pitasi, Phd Thesis, Mediterranean University of Reggio Calabria, 2016

Could manage *ground stability* risks with

- a tool for real-time monitoring (prediction) of movement
  electrode movement & resistivity
- robust, reliable, informative reconstructions
  instrument, data, algorithm, implementation

Tool of choice:

Electrical Resistivity Tomography
Electrical Impedance Tomography

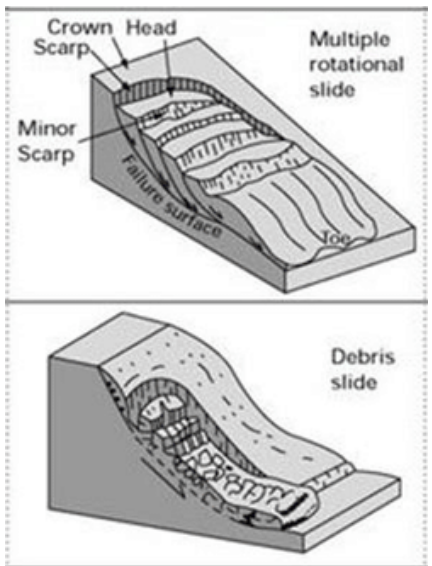
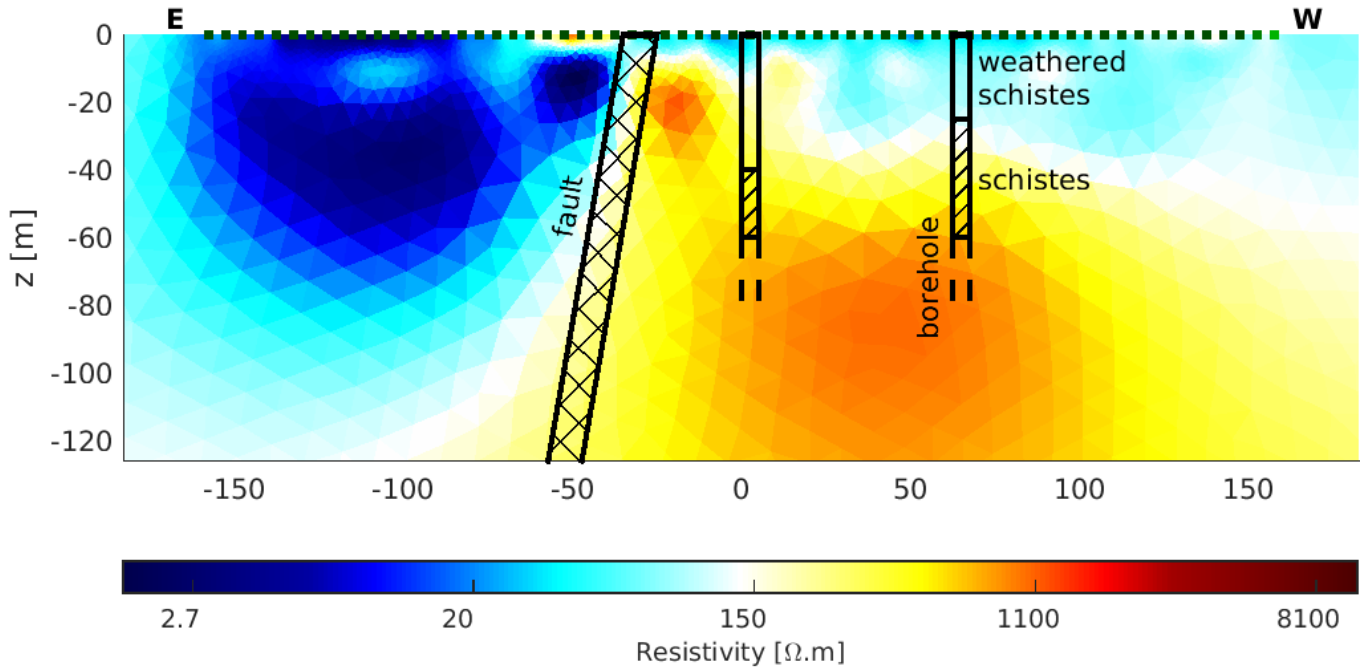


image: A Pitasi, Phd Thesis, Mediterranean University of Reggio Calabria, 2016

Electrical Resistivity Tomography



Typical ERT Survey

Pont-Péan, France

A. Boyle, *Geophysical Applications of Electrical Impedance Tomography*, PhD thesis, 2016

Electrical Resistivity Tomography

Typical ERT Survey Equipment
ABEM Terrameter LS

Guideline Geo, technical specs retrieved Feb 22, 2018

PBG Geophysical Exploration Ltd., image retrieved Feb 22, 2018

Electrical Resistivity Tomography

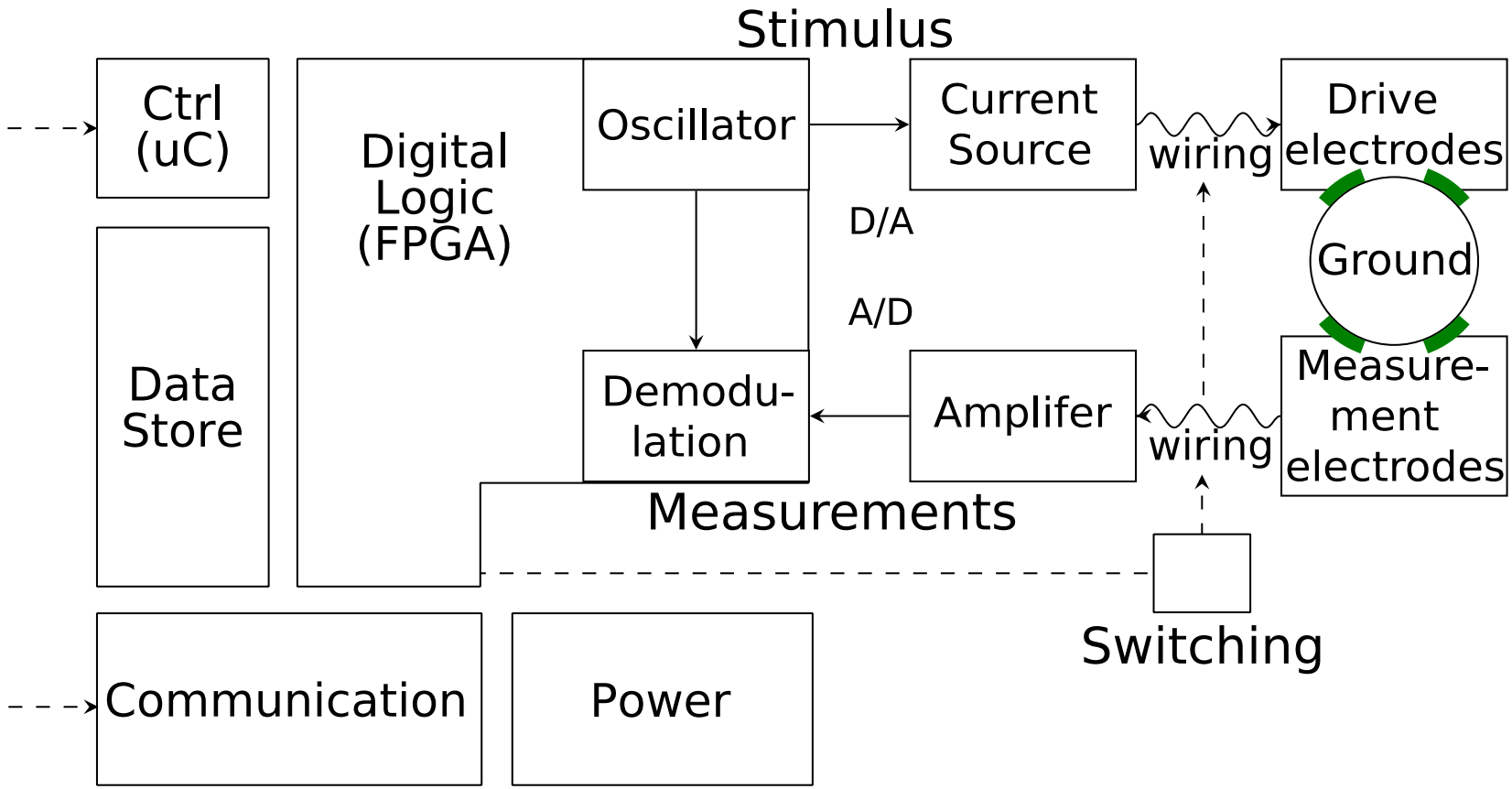
Long-term remote monitoring

slow moving landslide at Hollin Hill, UK with colleagues from the British Geological Survey
daily measurements 2008–present

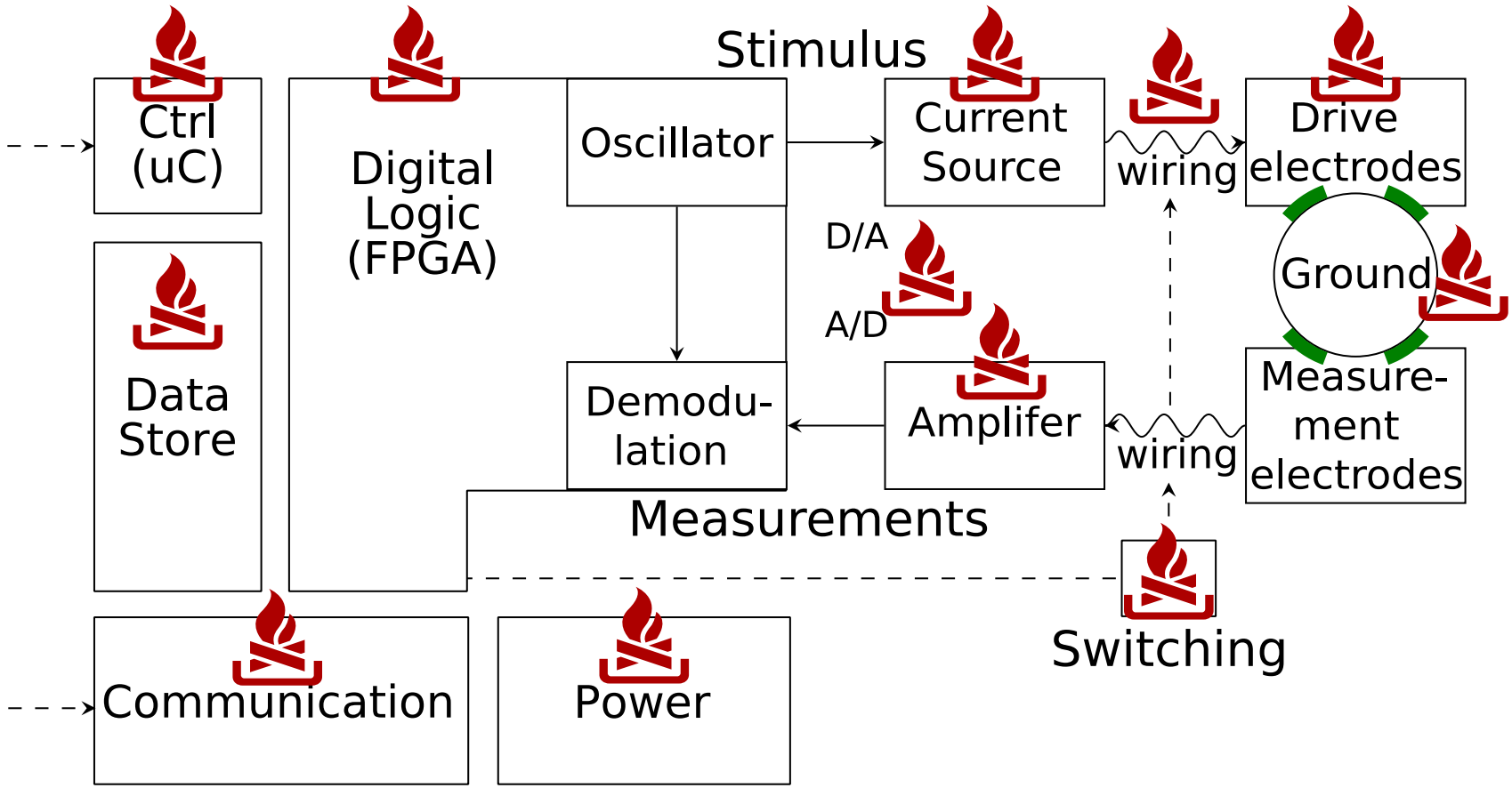
Automated Landslide Electrical Resistivity Tomography (ALERT) system

A. Boyle, 2018

Electrical Resistivity Tomography



Electrical Resistivity Tomography



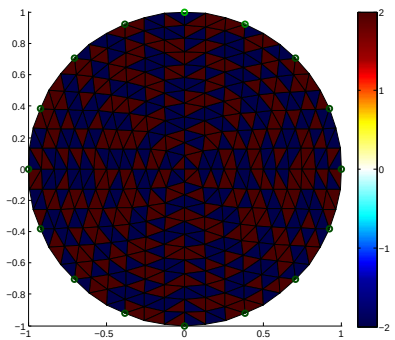
Methods

Absolute imaging problem; large conductivity contrasts
... a Gauss-Newton nonlinear iterative solver

$$\min_x ||\mathbf{Ax} - \mathbf{b}||_2^2 \tag{1}$$

$$\delta \mathbf{x}_n = -(\mathbf{J}_n^\mathsf{T} \mathbf{J}_n)^{-1} (\mathbf{J}_n^\mathsf{T} \mathbf{b}) \tag{2}$$

$$\mathbf{x}_{n+1} = \mathbf{x}_n + \alpha_{n+1}\ \delta \mathbf{x}_{n+1} \tag{3}$$



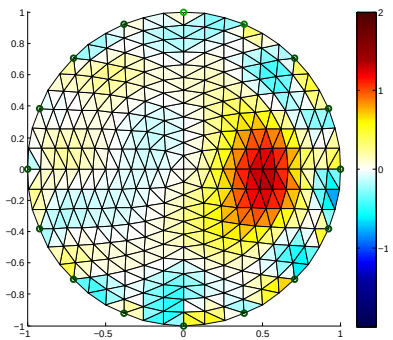
Methods

Absolute imaging problem; large conductivity contrasts
... a Gauss-Newton nonlinear iterative solver

$$\min_x ||\mathbf{Ax} - \mathbf{b}||^2_{\mathbf{W}} + ||\lambda \mathbf{R}(\mathbf{x} - \mathbf{x}_*)||^2_2 \quad (1)$$

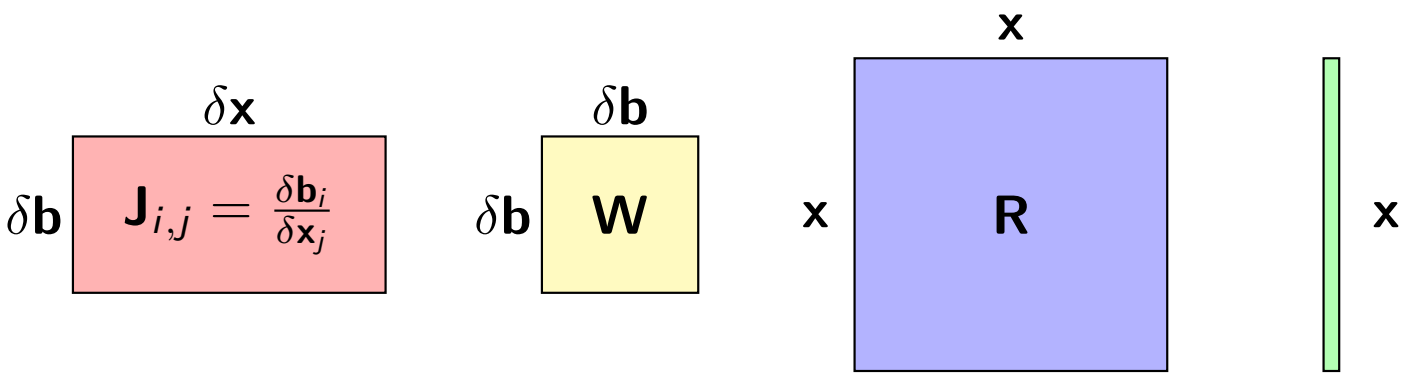
$$\delta \mathbf{x}_{n+1} = -(\mathbf{J}_n^\mathsf{T} \mathbf{W} \mathbf{J}_n + \lambda^2 \mathbf{R}^\mathsf{T} \mathbf{R})^{-1} (\mathbf{J}_n^\mathsf{T} \mathbf{W} \mathbf{b} - \lambda^2 \mathbf{R}^\mathsf{T} \mathbf{R}(\mathbf{x}_n - \mathbf{x}_*)) \quad (2)$$

$$\mathbf{x}_{n+1} = \mathbf{x}_n + \alpha_{n+1}\, \delta \mathbf{x}_{n+1} \quad (3)$$

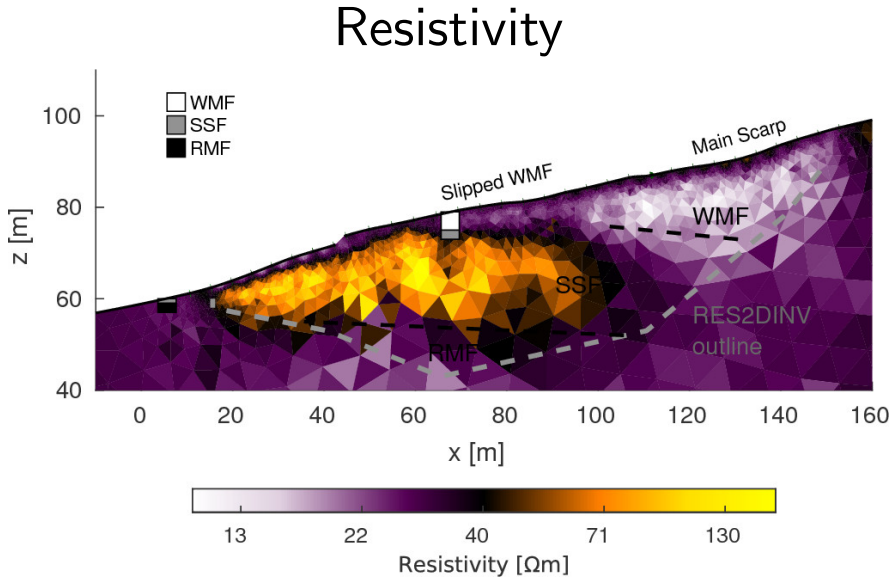


Methods

$$\delta \mathbf{x}_{n+1} = -(\mathbf{J}_n^{\mathsf{T}} \mathbf{W} \mathbf{J}_n + \lambda^2 \mathbf{R}^{\mathsf{T}} \mathbf{R})^{-1} (\mathbf{J}_n^{\mathsf{T}} \mathbf{W} \mathbf{b} - \lambda^2 \mathbf{R}^{\mathsf{T}} \mathbf{R} (\mathbf{x}_n - \mathbf{x}_*))$$



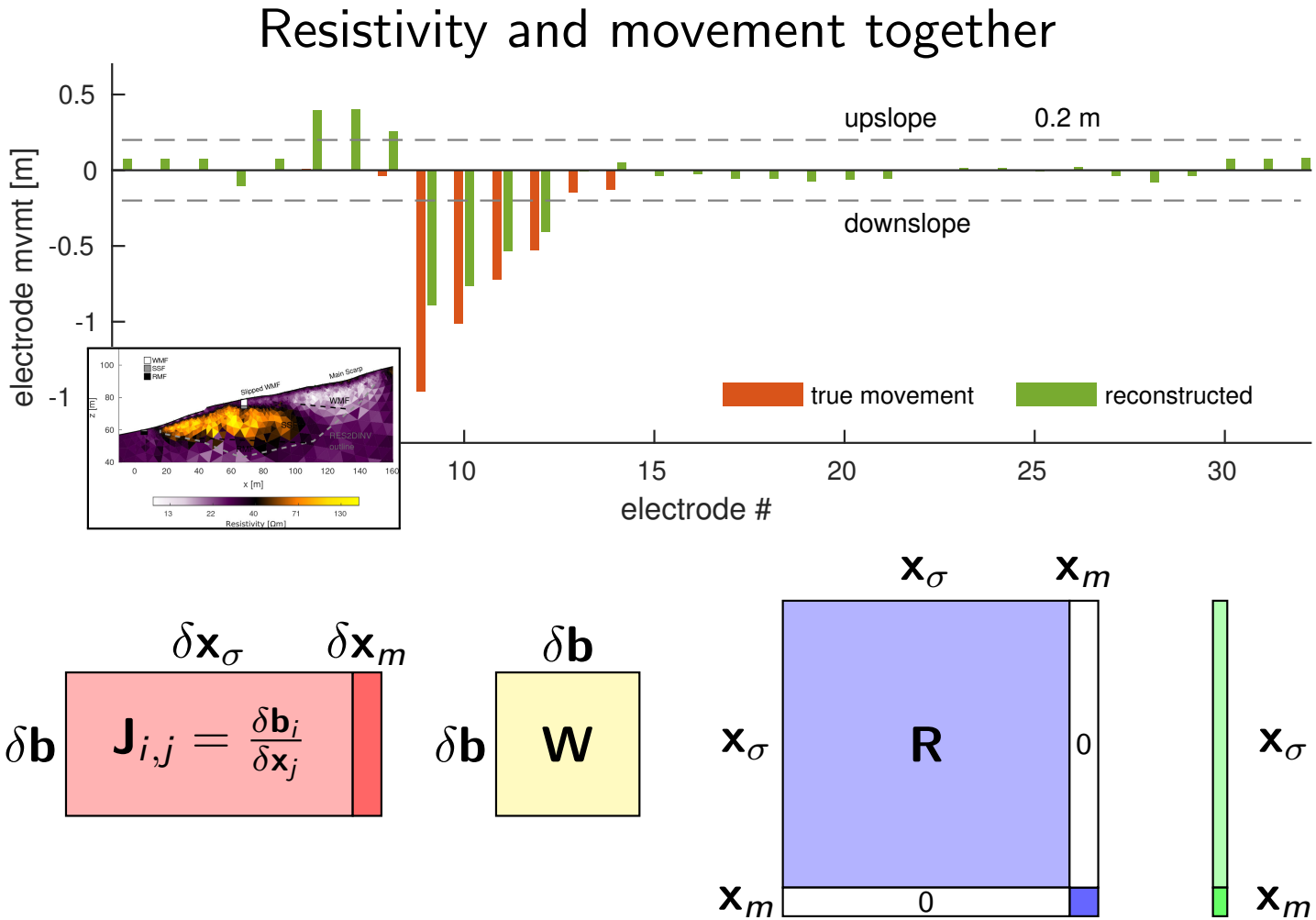
Methods



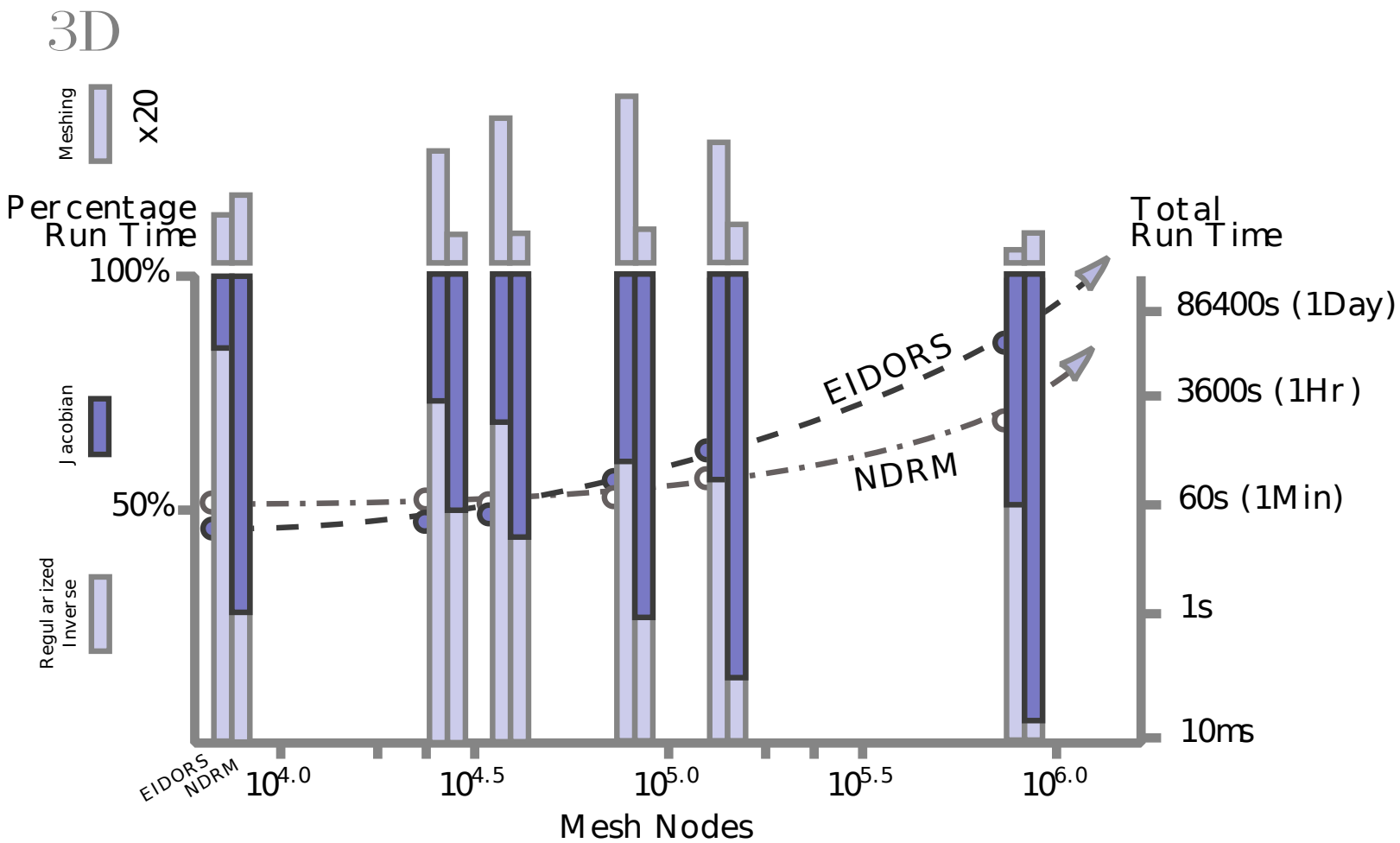
$$\delta\mathbf{b} \quad \overbrace{\mathbf{J}_{i,j} = \frac{\delta \mathbf{b}_i}{\delta \mathbf{x}_j}}^{\delta\mathbf{x}} \qquad \delta\mathbf{b} \quad \overbrace{\mathbf{W}}^{\delta\mathbf{b}} \qquad \mathbf{x} \quad \overbrace{\mathbf{R}}^{\mathbf{x}} \qquad \mathbf{x}$$

A. Boyle, P. Wilkinson J. Chambers, P. Meldrum, S. Uhlemann A Adler, Jointly reconstructing ground motion and resistivity for ERT-based slope stability monitoring, *Geophysical Journal International*, 212(2), 2018

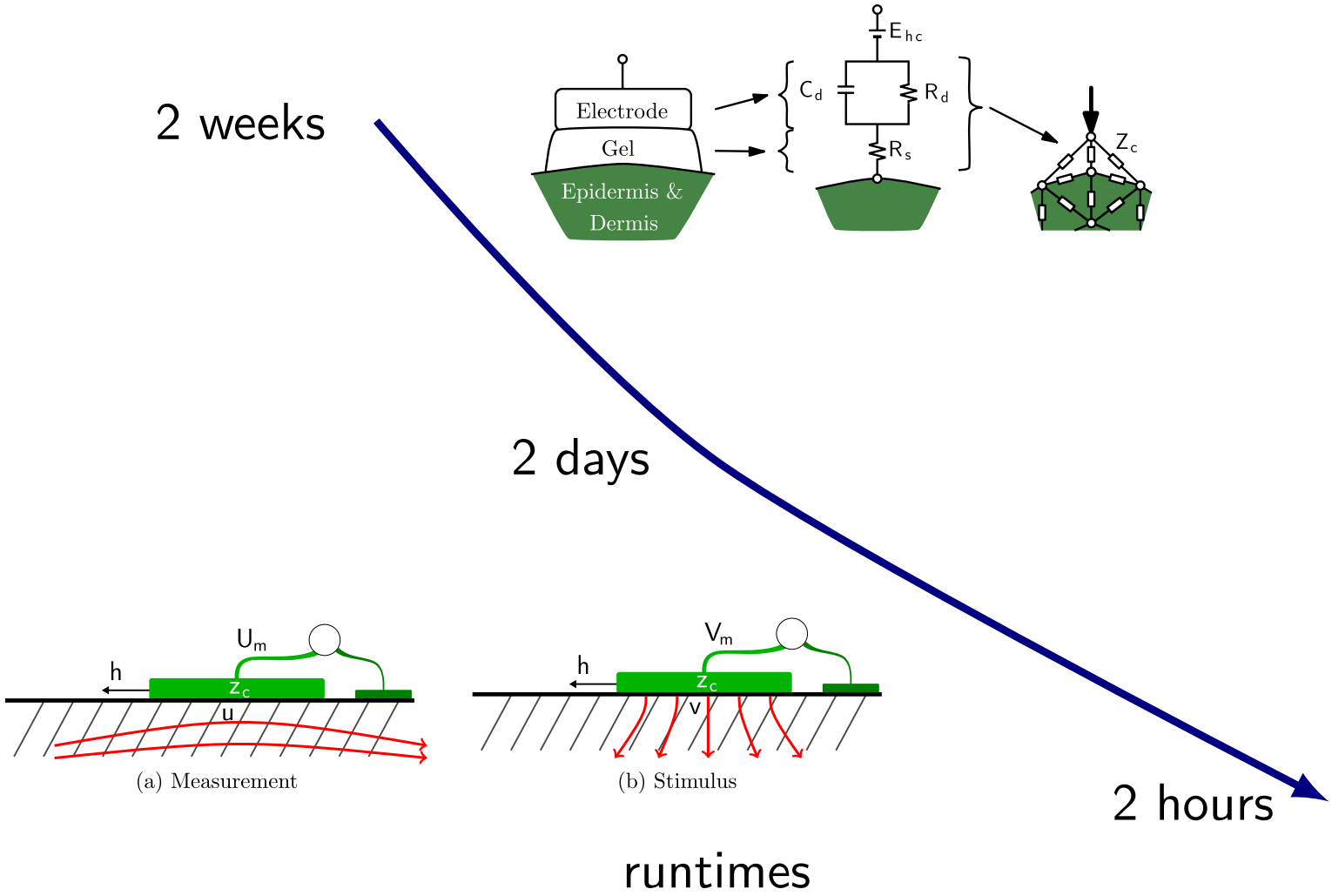
Methods



A Boyle, P Wilkinson J Chambers, P Meldrum, S Uhlemann, A Adler, Jointly reconstructing ground motion and resistivity for ERT-based slope stability monitoring, *Geophysical Journal International*, 212(2), 2018



A Boyle, A Borsic, A Adler, Addressing the Computational Cost of Large EIT Solutions, *Physiological Measurement*, 33(5), 2012



(a) Measurement

(b) Stimulus

A Boyle, A Adler, Impact of Electrode Area, Contact Impedance and Boundary Shape on EIT Images, *Phys. Meas.*, 32(7), 2011

A Boyle, M Crabb, M Jehl, W Lionheart, A Adler, Methods for Calculating the Electrode Position Jacobian for Impedance Imaging, *Phys. Meas.*, 38(3), 2017

Visions of the North,

M Lundberg, The Lure of the Aurora Borealis, What's Up Yukon, Lewes Dam, 2016

My vision...

A Canadian Centre of Excellence
in
Systems Engineering Solutions for Remote Monitoring

My vision...

A Canadian Centre of Excellence
in
Systems Engineering Solutions for Remote Monitoring

Embedded systems for long-term remote monitoring

- timing
- power
- data quality
- communication
- location
- calibration

- movement
- damage
- failure
- repurposing
- updates

through open collaboration and development.

A Boyle, A Adler, An Embedded System for Impedance Imaging of Permafrost Changes, *18th Int. Conf. on Biomed. Appl. of Electrical Impedance Tomography*, Dartmouth, USA, 2017

Giant Mine, NWT (1948–2004: 220,000 kg gold), 5 km from Yellowknife: 237,000 m^3 of arsenic trioxide dust (As_2O_3 is highly carcinogenic and water soluble) will be stored in frozen underground chambers for the indefinite future

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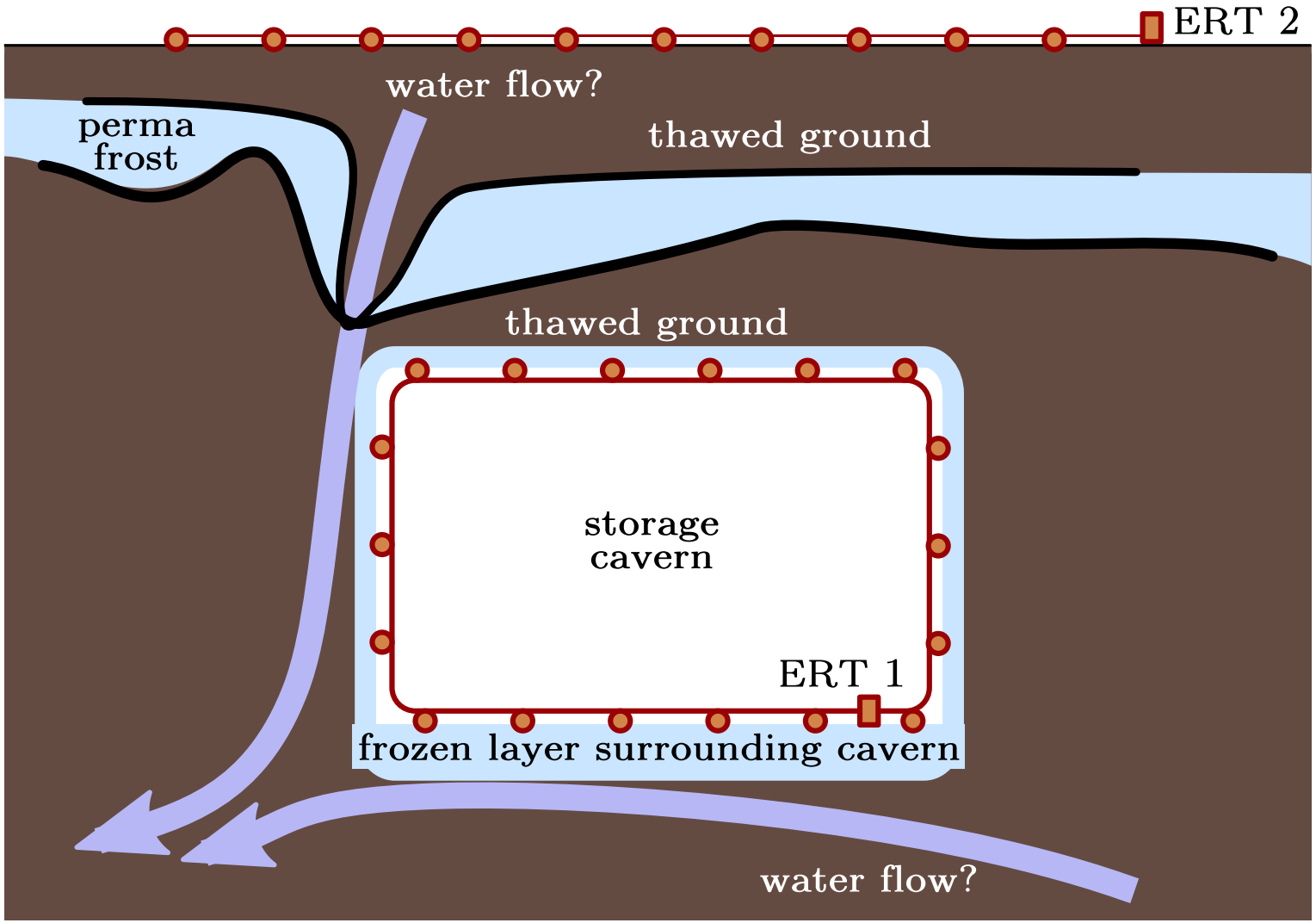
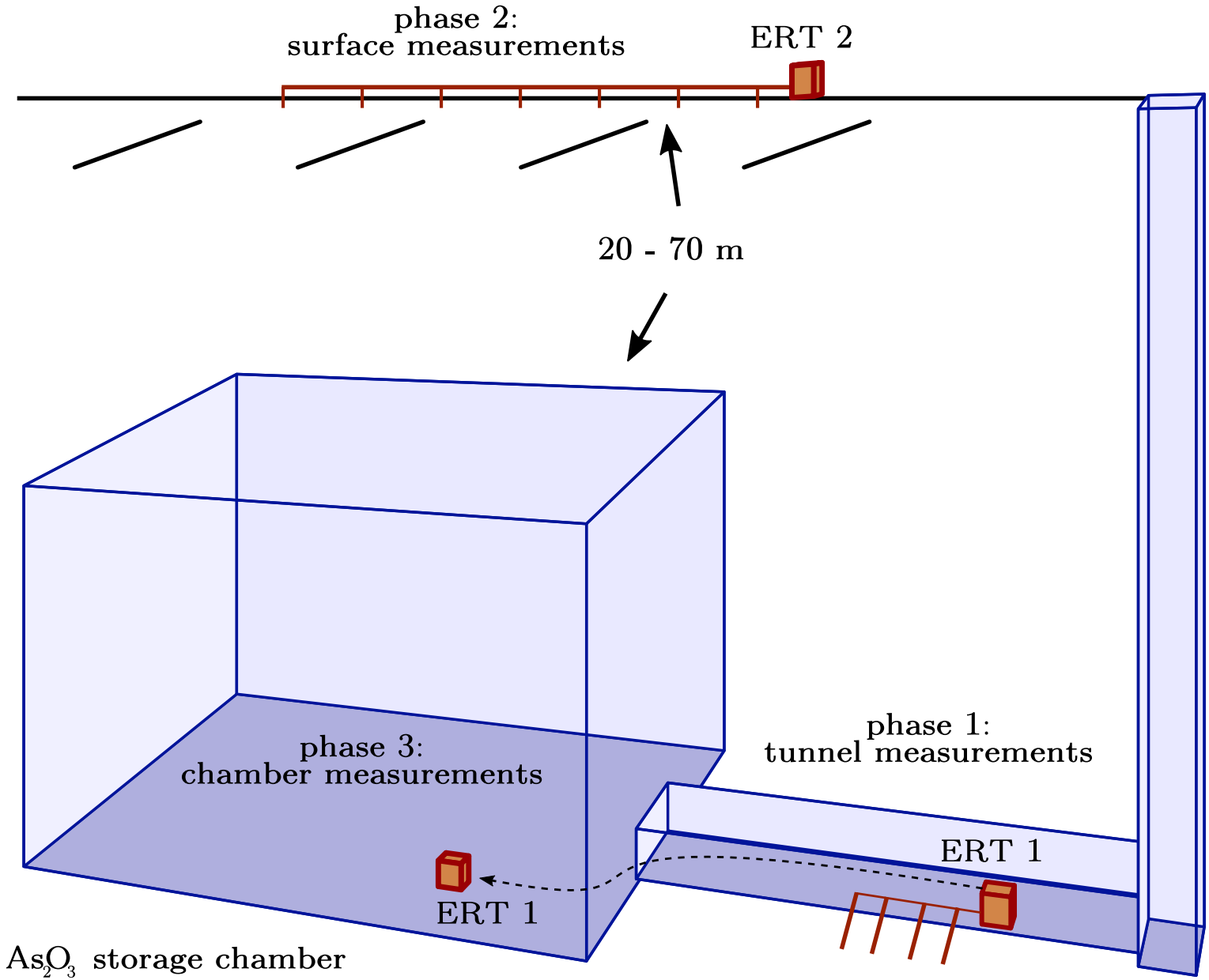
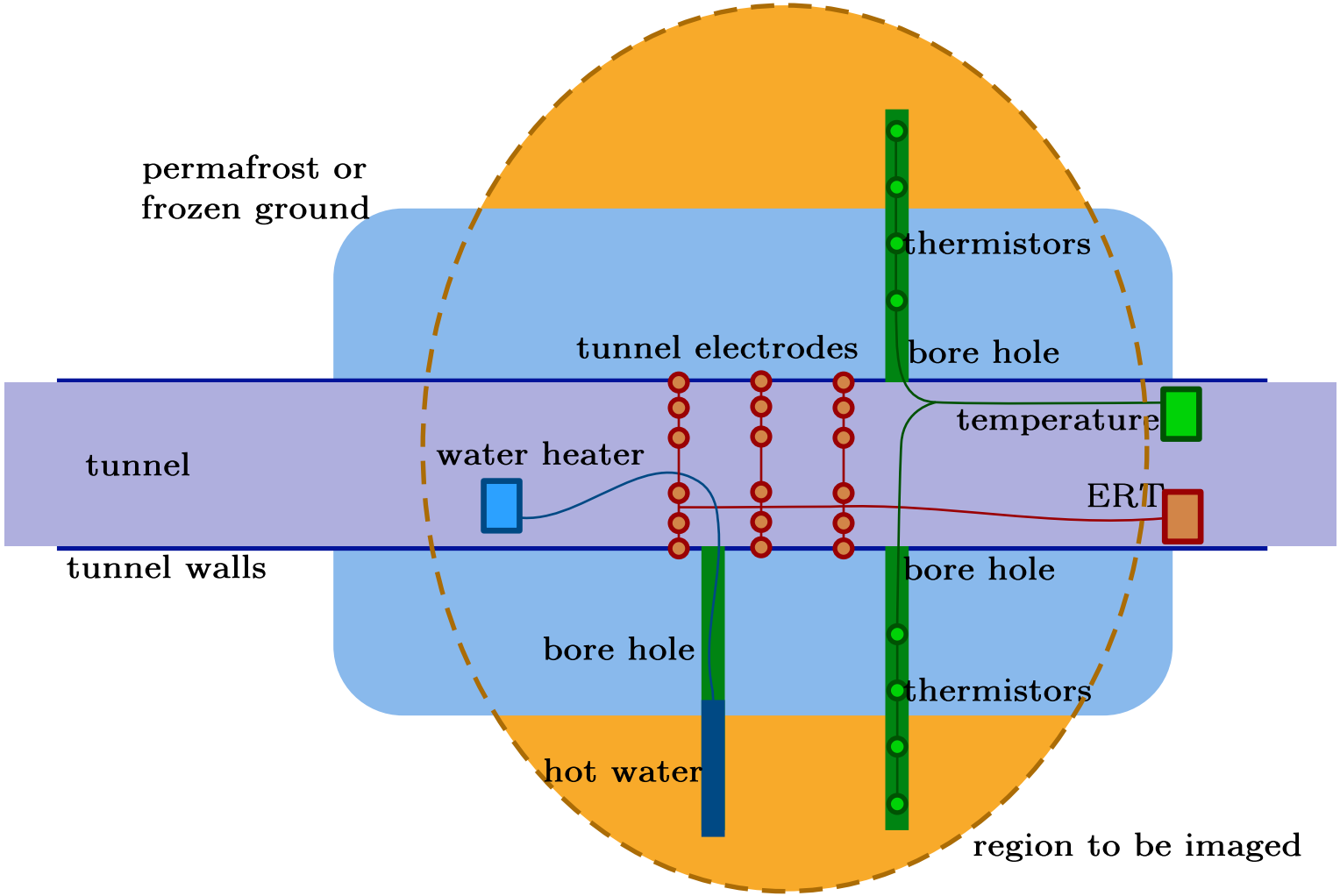
photo: Giant Mine Joint Interim Remediation Project Office, Indian and Northern Affairs Canada, Giant Mine Remediation Project, 2012


ERT 2
water flow?
perma
frost
thawed ground
thawed ground
storage
cavern
ERT 1
frozen layer surrounding cavern
water flow?


phase 2:
surface measurements
ERT 2
20 - 70 m
phase 3:
chamber measurements
phase 1:
tunnel measurements
ERT 1
ERT 1
As_2O_3 storage chamber


permafrost or
frozen ground
thermistors
tunnel electrodes
bore hole
temperature
tunnel
water heater
ERT
tunnel walls
bore hole
bore hole
thermistors
hot water
region to be imaged

Embedded Systems Directions

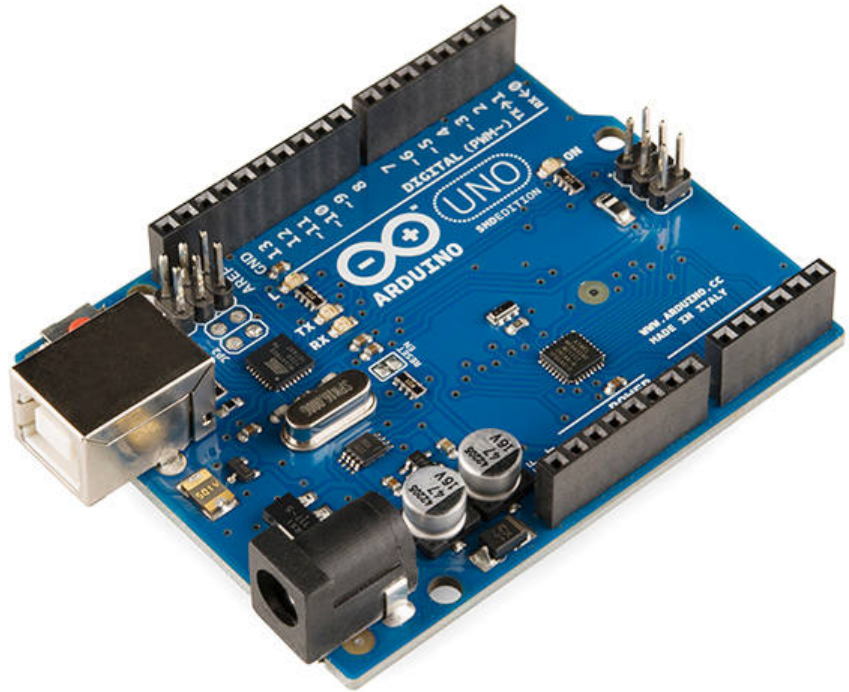
- nuisance "noise" to useful information
  - electrode area, contact impedance, boundary shape
- low frequency electrical measurements on
  - Glaciers, Permafrost and Frozen Ground
- "open hardware" embedded systems development
- integrated systems simulation
  - FEM, analog/SPICE[8], digital/Verilog, firmware/C/asm
- automated analysis of reliability and degraded performance
- modeling and "as-built" reconstruction
- embedded system design, test and debug methodologies

[8] A Boyle, A Adler, Integrating Circuit Simulation with EIT FEM Models, *19th Int. Conf on Biomed. Appl. of Electrical Impedance Tomography*, Edinburgh, UK, 2018 *(submitted)*

Open Hardware for Embedded Systems

Hardware, firmware, software

Arduino, RepRap (3D printing),
CERN Open Hardware Repo.
BitScope DSO[9]



Challenges:
tool lock-in, part obsolesence,
licensing, community

Focus on *application specific* scientific instrumentation[10]
Scientific value as reference design (trade-offs, criteria, metrics)
"collected wisdom," "best practices," "common language"
Enabling discussion across disciplines as Systems Engineering
geophysics, maths, engineering, medicine, industry/business

[9] N Jackson, Bitscope: A mixed-signal capture engine. *Circuit Cellar* 97, 1998

[10] J Pearce, Open-source Lab: How to build your own hardware and reduce research costs. Elsevier, 2014

Collaborators

- Canadian/northern projects

  NRCan, Carleton, University of Calgary, Nunavut Impact Review Board/University of Saskatchewan

- British Geological Survey

  Geophysical Tomography Team

- various groups worldwide

  Belgium, England, France, Korea, Switzerland, United States

- ... you?

Thank You