Advanced Sensors and Detectors

An Emerging Initiative

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10th Argonne – UChicago – Fermilab Collaboration Meeting,
Fermilab, December 1,2 2011

Premise

- **“Multi-disciplinary is a really key missing part of society …… We've gotten so good at getting deep …… but don't know how to talk, let alone build anything together.”**

Interview of ‘The Atlantic’ with Joi Ito, director of MIT Media Lab, Sept. 13, 2011

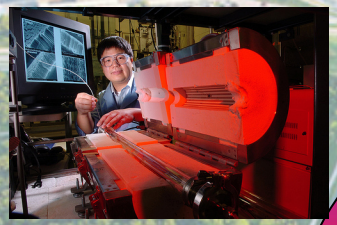
the Atlantic

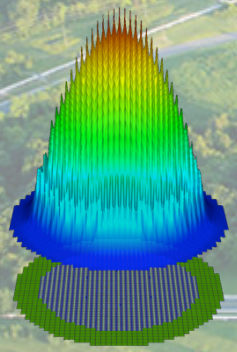
ɹɐuǝ disciplinary

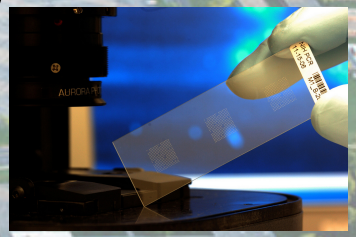
From: http://www.media.mit.edu/

Uniquely Argonne

Beyond Serendipity ...







HEP
NE
ES
IAD

PHY
LCF
DIS
MCS

Applied Science

Basic Science

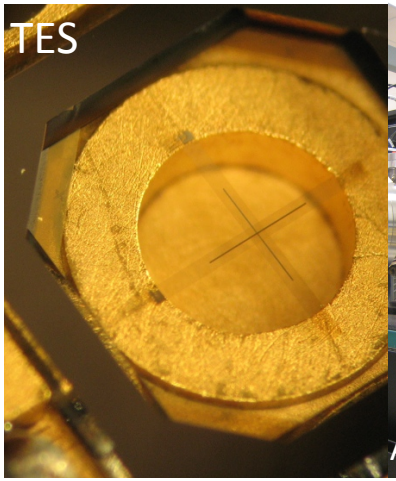
CNM
APS
EVS
ASD
BIO

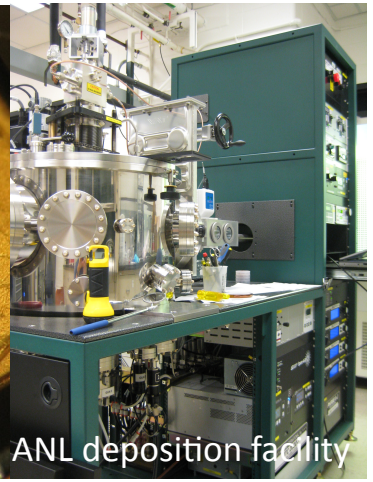
AES
CSE
MSD
XSD

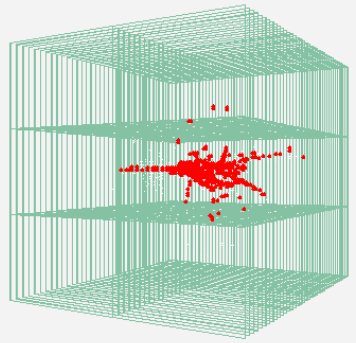
... Truly Multidisciplinary

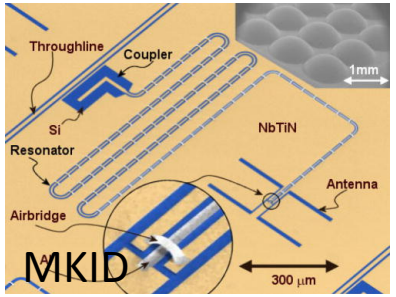
Current Projects

- Transition Edge Sensor Development for Cosmic Microwave Background radiation: study of origin of the universe (Argonne – UofC)
- Digital Hadron Calorimeter ASIC development and readout: most detailed image of hadron showers, large data volume (Argonne – Fermilab)
- ASIC development (QIE) for LHC experiments (ATLAS/CMS)
- Development of Microwave kinetic inductance detectors for CMB and APS applications: CMB polarization, X-ray spectroscopy (Argonne – UofC)



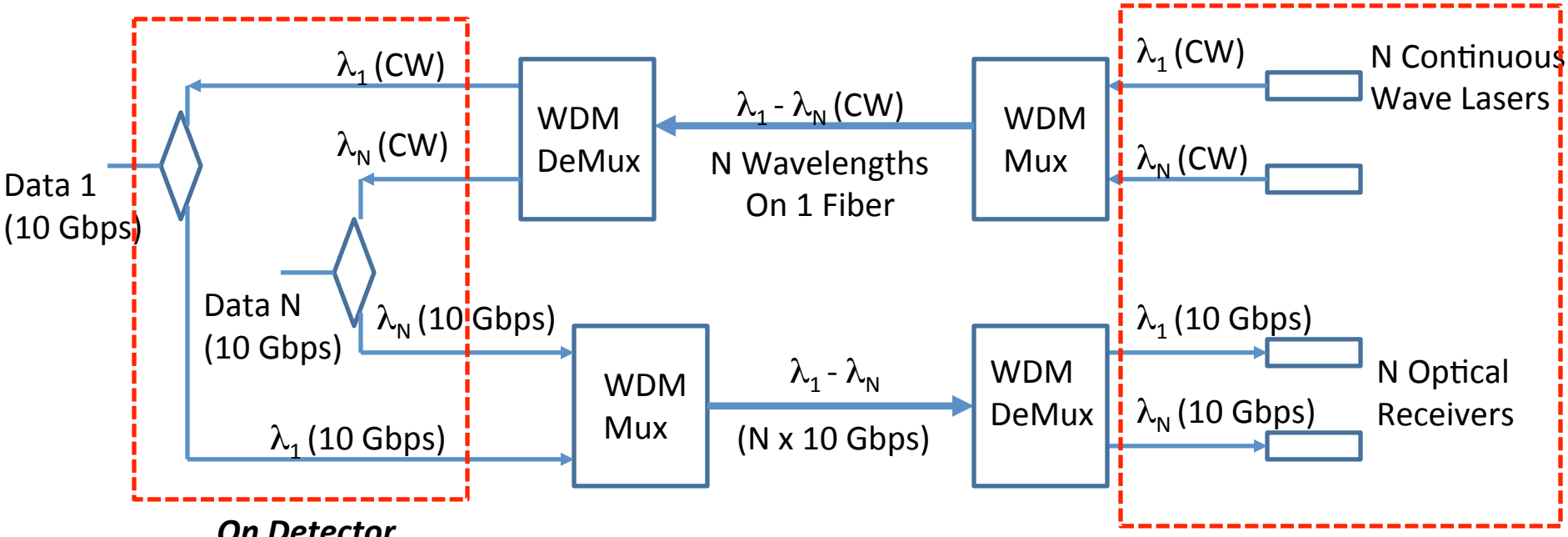


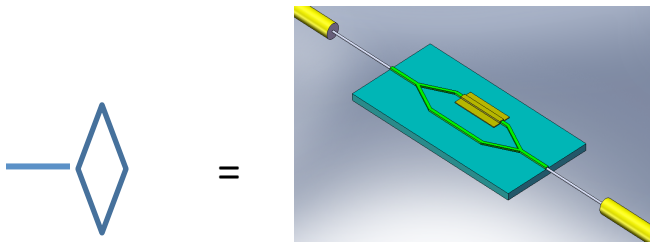




Optical Modulators

- Optical modulators for reliable, low-mass, low power, radiation hard, high volume, flexible data transmission: 10 – 60 Gb/s (Argonne – Fermilab – UofC – Vegawave)





Mach-Zehnder Intensity Modulator

WDM = Wavelength Division Multiplexing

Radiation test at 10^{11} protons/cm^3 without any single event upsets @10Gbps

Status Quo

- Many individual efforts ongoing; all quite successful
- Interdisciplinary aspect enables and enriches program
  - LAPPD would not be possible without the successful interaction between the many divisions at Argonne
  - Potential to be a transformative technology

- **Identify an opportunity for a major strategic initiative within the context of ANL – FNAL – UC, that capitalizes on the individual strengths.**

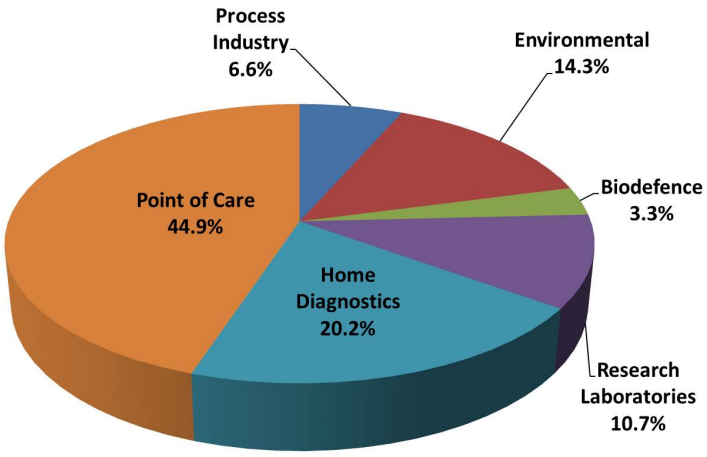
LAPPD project reach

Biosensors

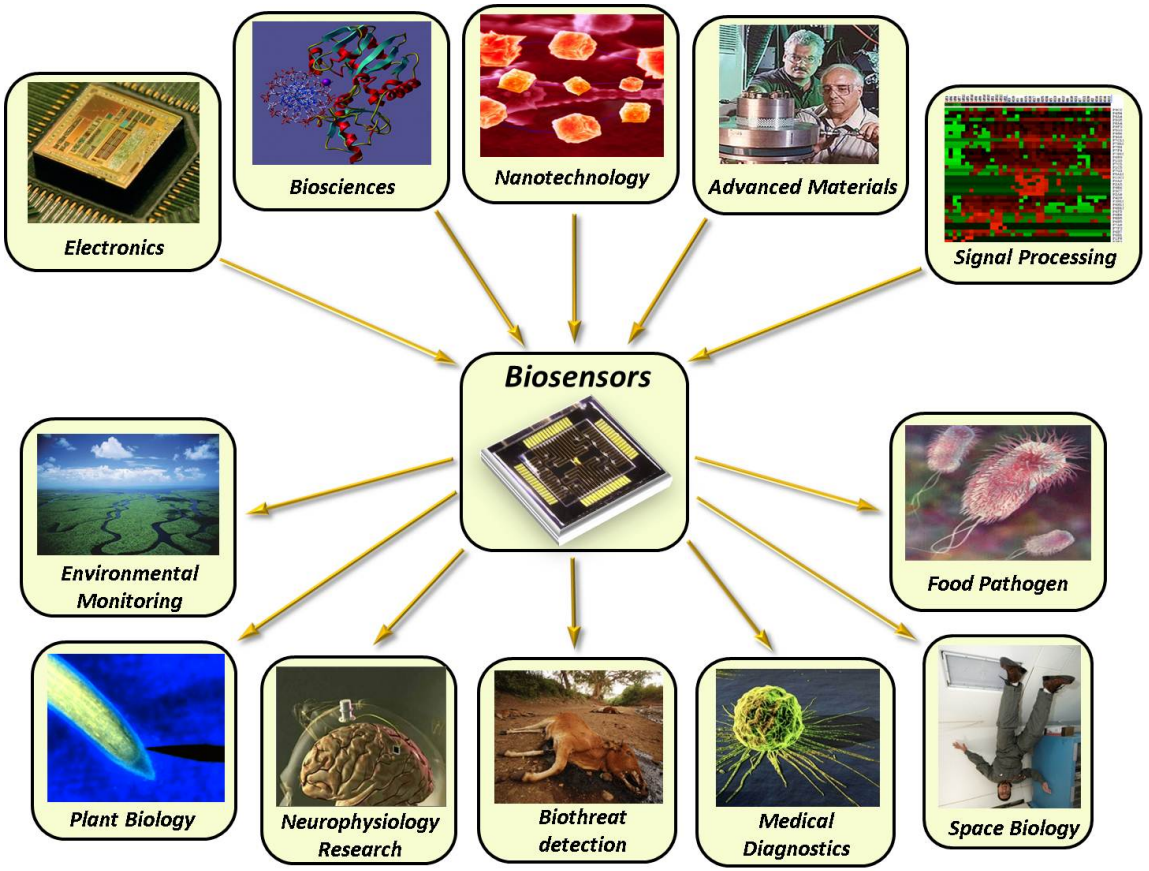
- Biosensors are “Sensors that use a biological recognition element e.g. antibodies, enzymes for sensing the target of interest”

Projected Biosensor Market

2016 > $14Billion

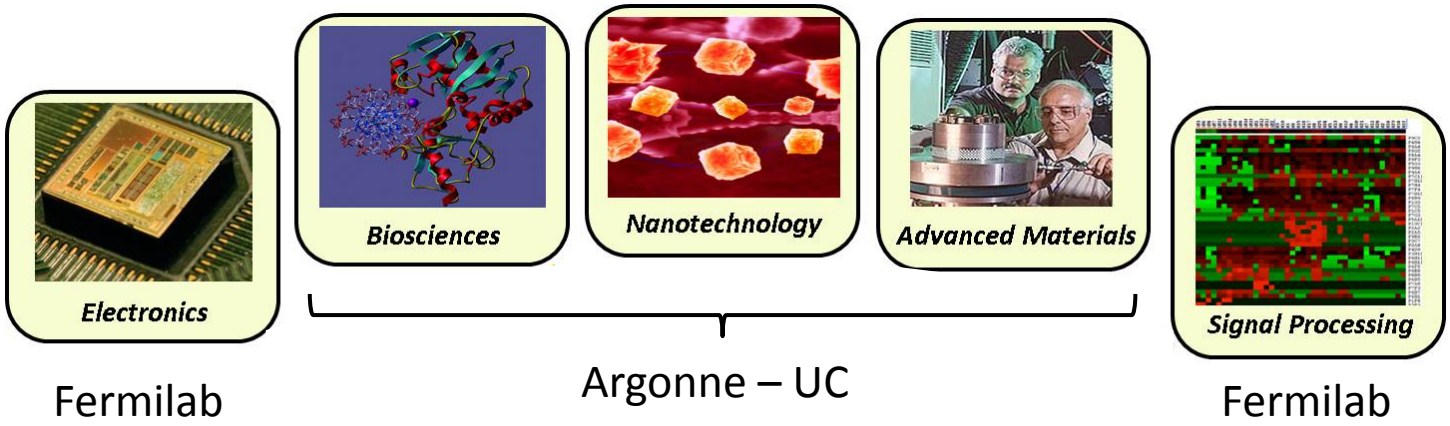


Frost and Sullivan



Can we be a technology leader ?

Matching Competencies



- Competencies for sensor development are well matched:

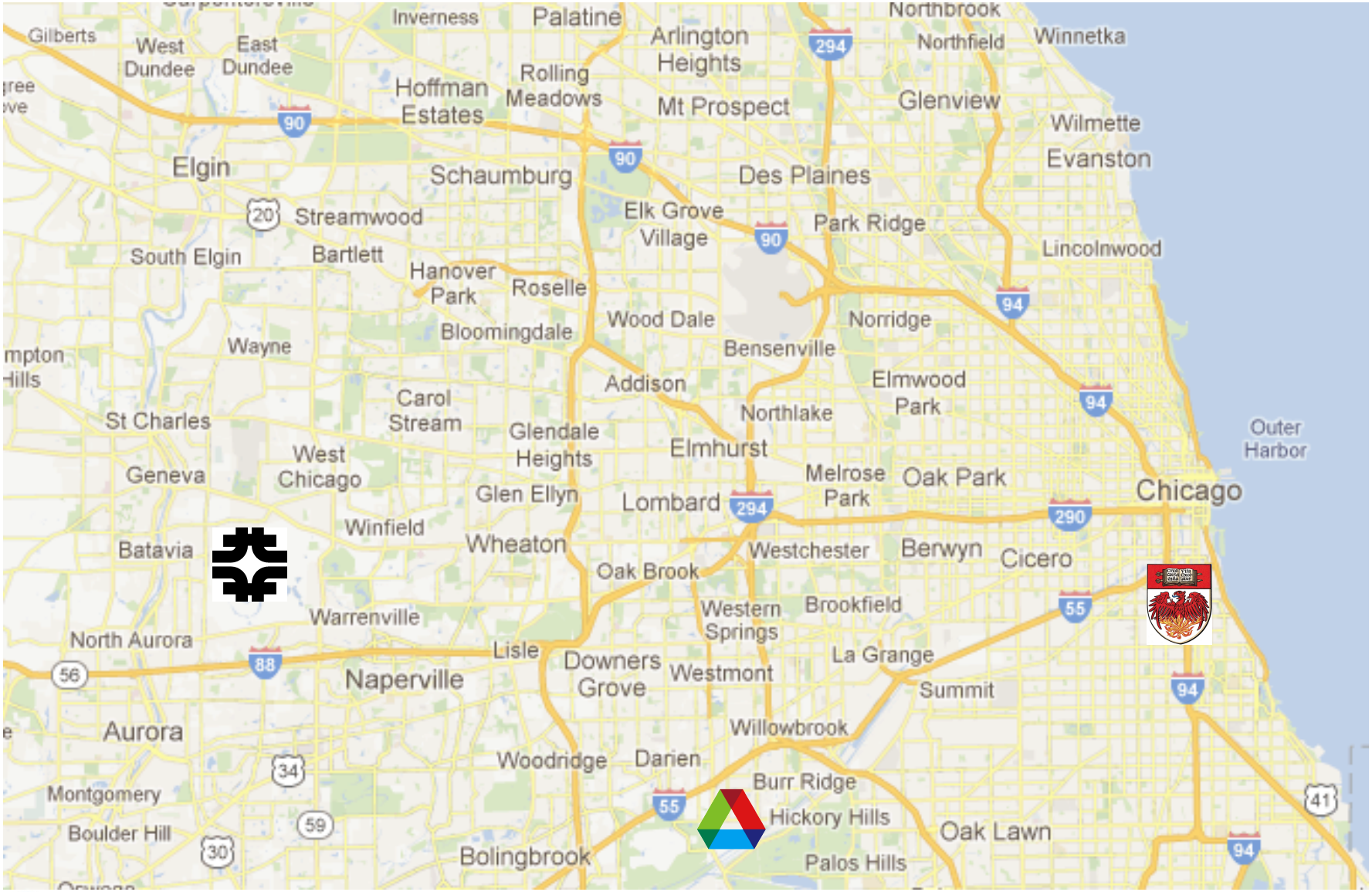
  Fermilab: ASIC Development, Electronics, Signal and Data processing

  Argonne: Biosciences, Nanotechnology, Materials Science, National Security, ...

  University of Chicago: Medical School, Biosciences

  Local hospitals and local industry

Regional Strength



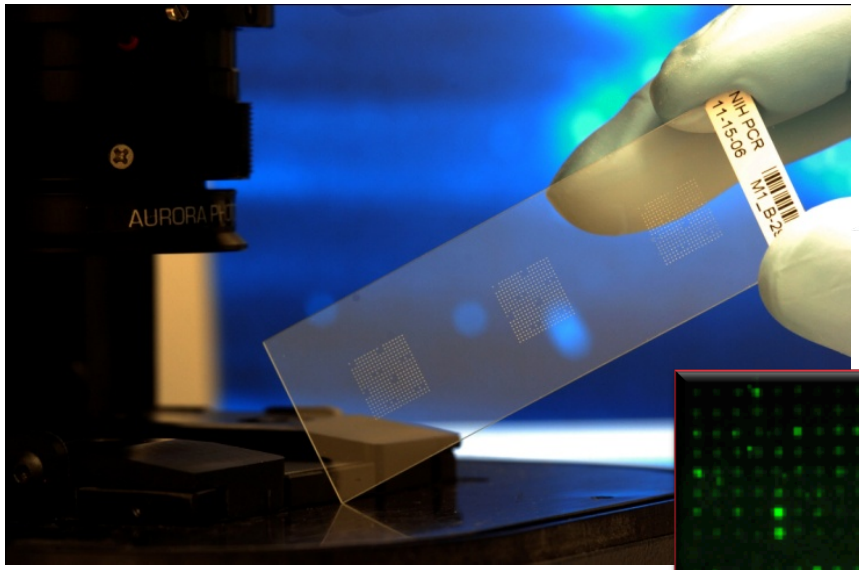
Regional Strength

Regional Strength

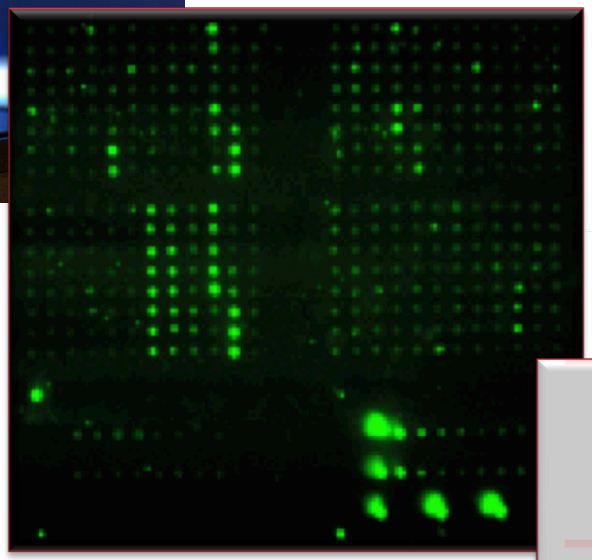
Reach …


Point-of-Care Diagnostics
Medical Imaging
Transformative Biosensors
Home Diagnostics
National Security
Environmental
Bio-threat

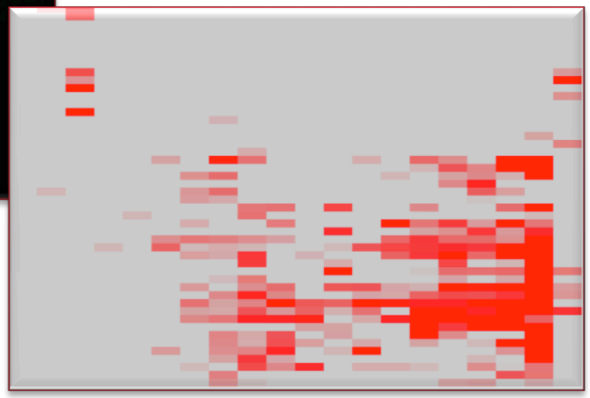
Identifying Signatures in Biosciences



Sample



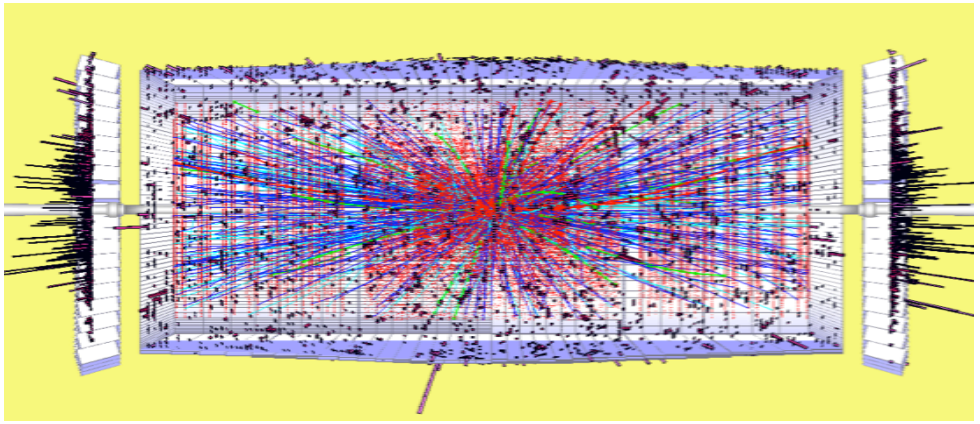
Interrogation

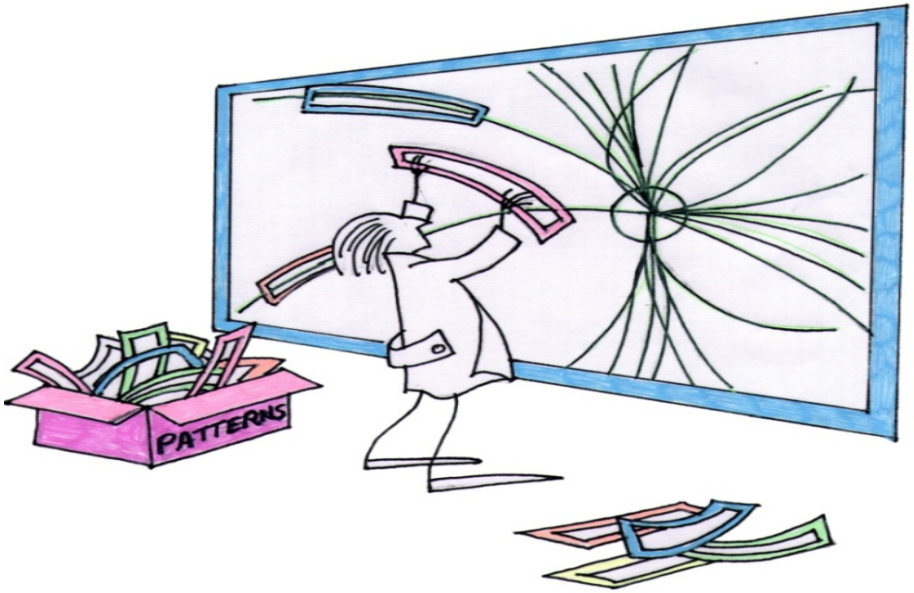


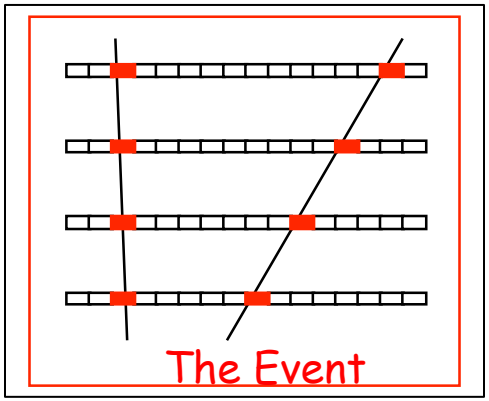
Pattern

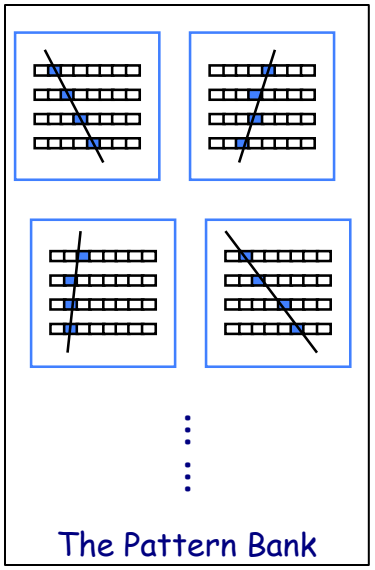
Pattern Matching Triggering

- Data presents itself as stream of hits with address
- Select events of interest using high momentum tracks:
  - Track not curved (no sagitta)
  - Track originates from collision point
- Perform hit match with patterns of interesting events









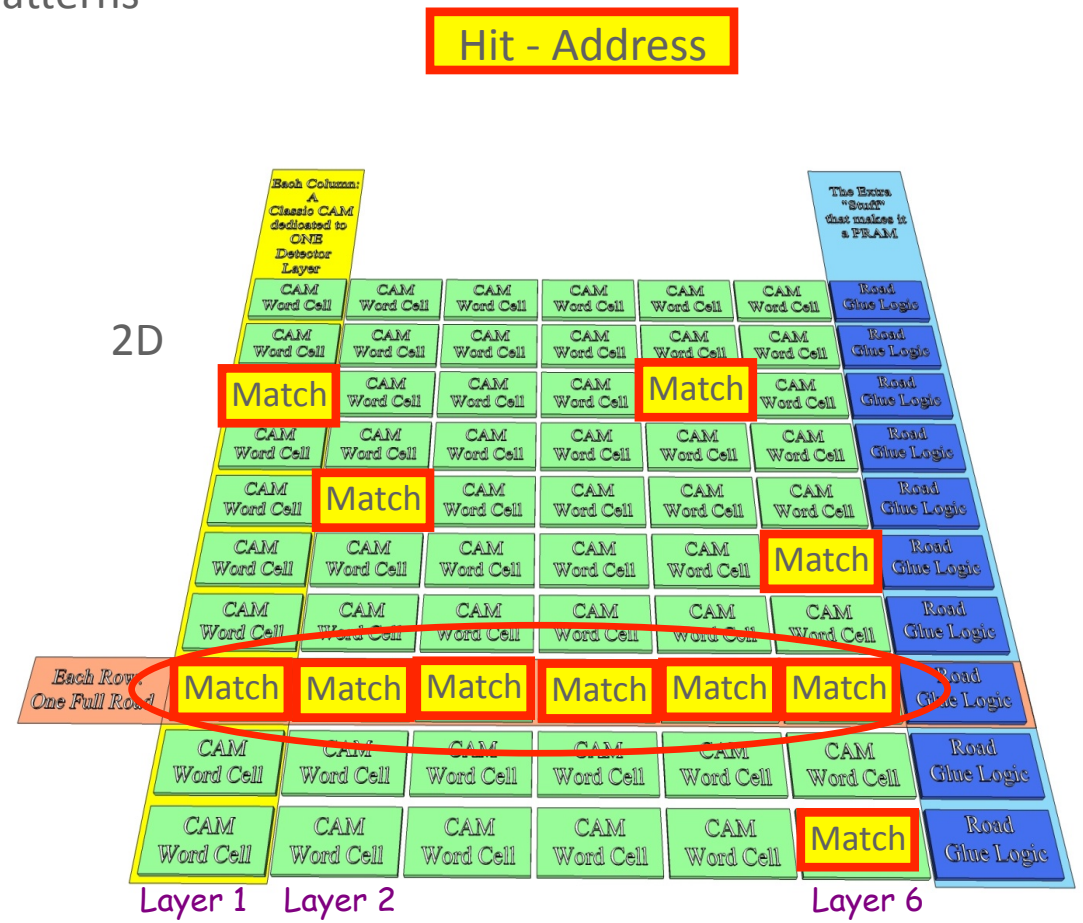
M. Dell'Orso, L. Ristori, NIM A278 (1989), 436; Nucl. Instrum. Meth. A409 (1998), 658

Associative Memory

- Associative Memory (AM) for Pattern Recognition
- Current generation of experiments:
  - 6M patterns stored, 5000 patterns per AM Chip (180 nm)
  - About 100 bits / pattern

- The Problem:
  - Need 1B patterns
  - Event hit pattern matched 25 ns !

- A Solution:
  - Extra dimensions !

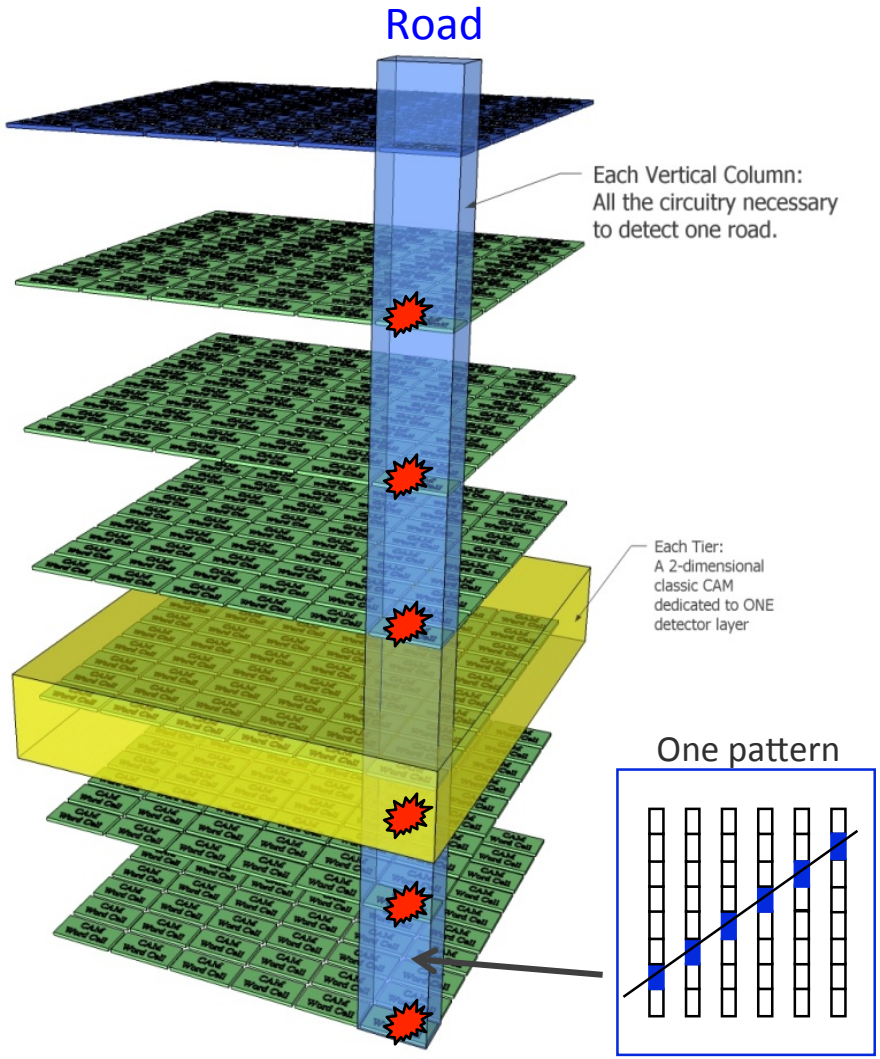


Jin Long Zhang (HEP, early career)

2D Associated Memory Layout

Associative Memory for Pattern Recognition

- Associated Memory in 3D silicon for pattern recognition



- On a 1x1 cm^2 chip, 6 tiers, 65 nm process, via pitch ~ 2 μm

4.5M Patterns can be stored !

... And matched every 25 ns.
In addition: faster and less power

- Note: the third dimension could equally be in the time domain
- Pattern recognition often encountered in many different applications

Biometrics: Iris Recognition

- Iris recognition based on complex-valued 2D Gabor wavelets; Structure extracted as sequence of vectors in the complex plane, with quantized phase angles
- 256 bytes required to represent each iris pattern (+ control bits)
- Match expressed in Hamming distance

J. Daugman, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 15(11), (1993) pp. 1148-1161

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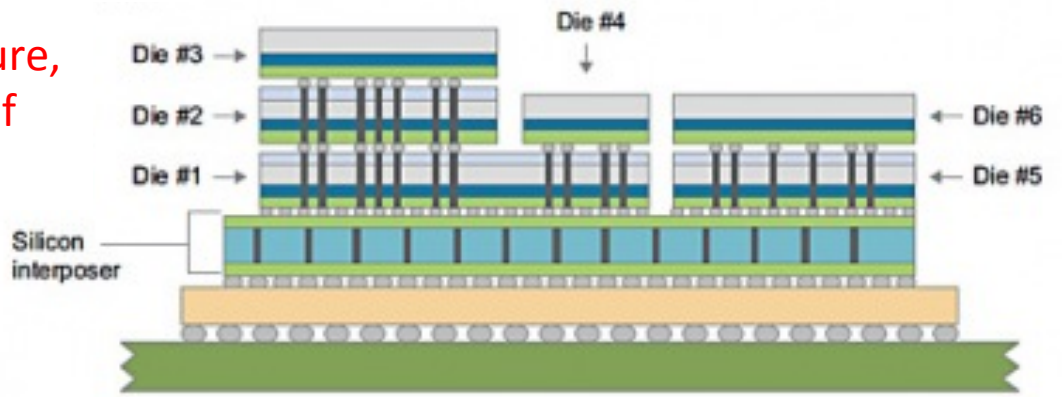
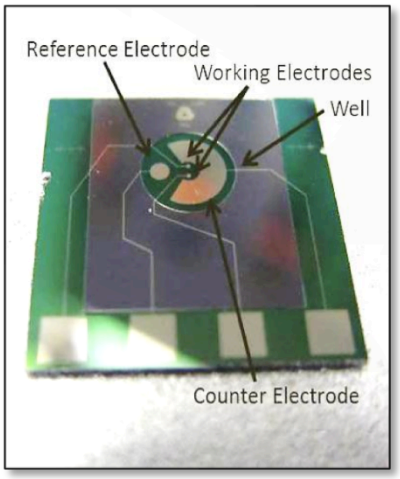
- Extending example from before: Layered Associate Memory structure, pocket-size, could hold the irises of ~ 35k people (in 1x1cm^2 chip)
- Interesting compression problem to extend population ?

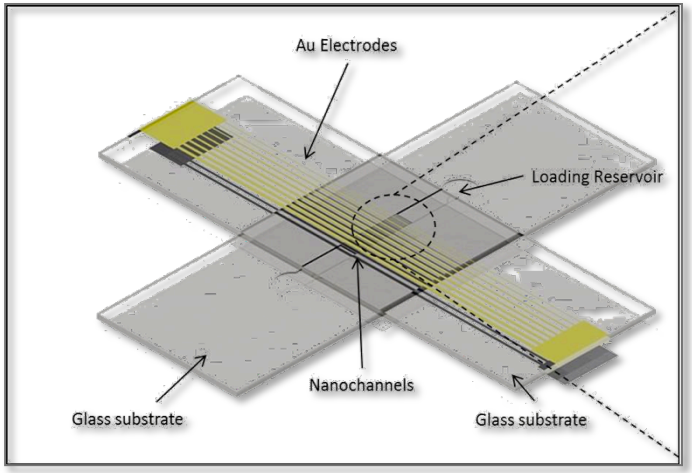


J. Daugman, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 15(11), (1993) pp. 1148-1161

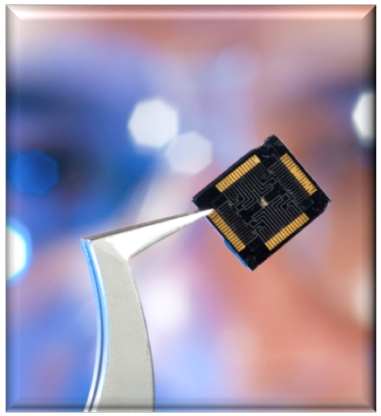
Automated Biosensors

Photo-electrochemical biosensors for cancer detection





Nanofluidic Biosensors



Develop `Lab-on-a-Chip'

Integrate electronics and processing

Proposal

- Thesis Project for the University of Chicago Business School:

  Evaluate the potential for the greater Chicago area to become a regional, if not national, center for the development of biosensors, centered at Argonne

  Develop a business plan for the development of biomedical sensors and detectors that capitalizes on the expertise of the two national laboratories and the University of Chicago in conjunction with more than ten highly regarded medical schools in the area and many small and large businesses focused on bioscience

- Planning a limited one-day workshop at Argonne in January 2012 to explore this area further

- Tremendous potential through truly interdisciplinary collaborative action