Aussois 2012

Experimental Geotechnology:

paradigm shifts in the information age

J. Carlos Santamarina
Georgia Institute of Technology

See manuscript:

Santamarina, J. C. (2006). "Geotechnology: Paradigm Shifts In The Information Age." ASCE Geotechnical Engineering in the Information Technology.

The pdf is available at pmrl.ce.gatech.edu under "Publications"

Remember …?

Black & white TV

Neil Armstrong moon walk (7/20/69)

33 and 45 music records

$5^{1/4}$ discs

telegrams (Western Union discontinued service on 1/27/06)

secretaries typed reports and papers

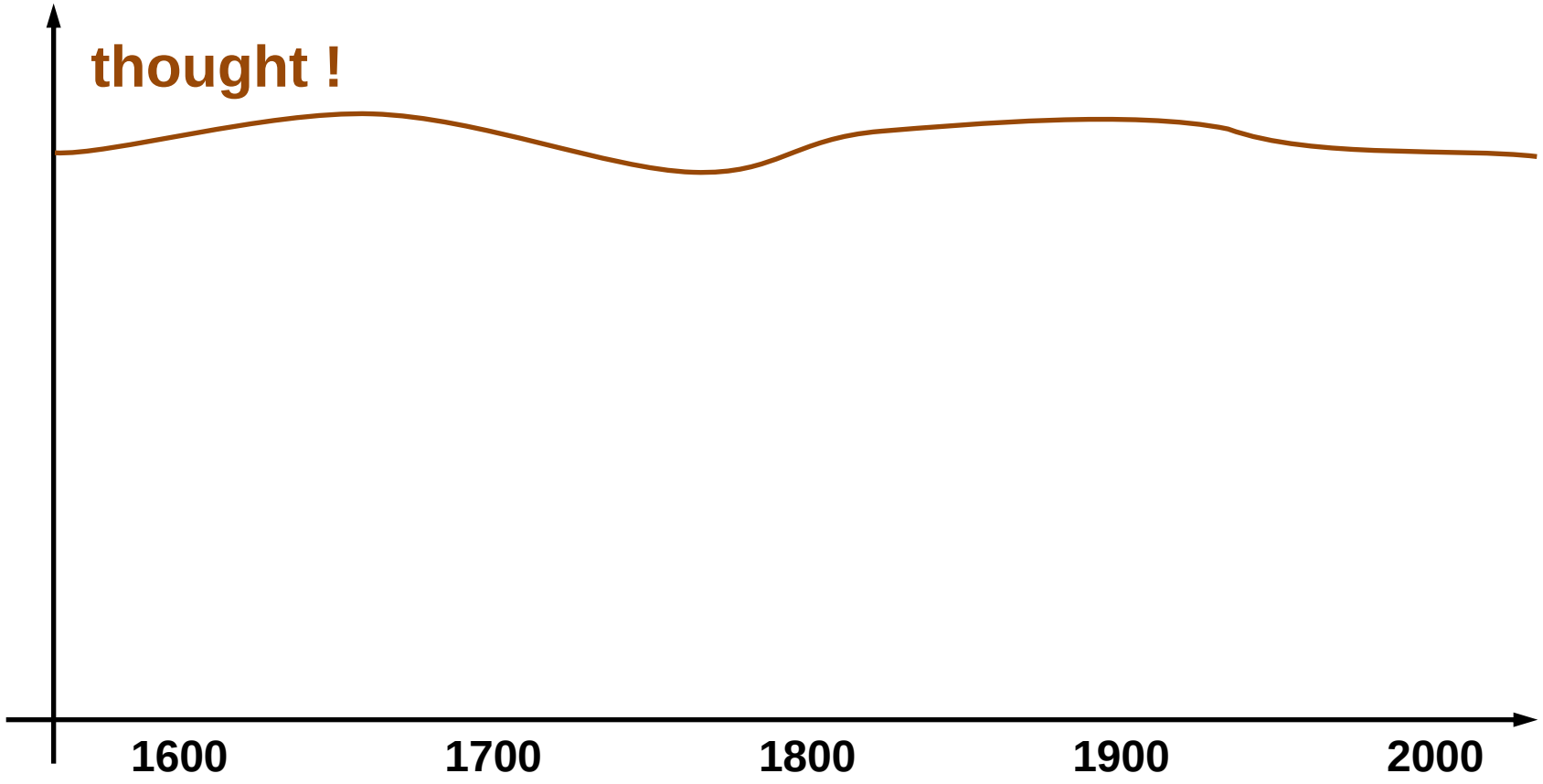
The first time you…

watched color TV … sent FAX … sent e-mail

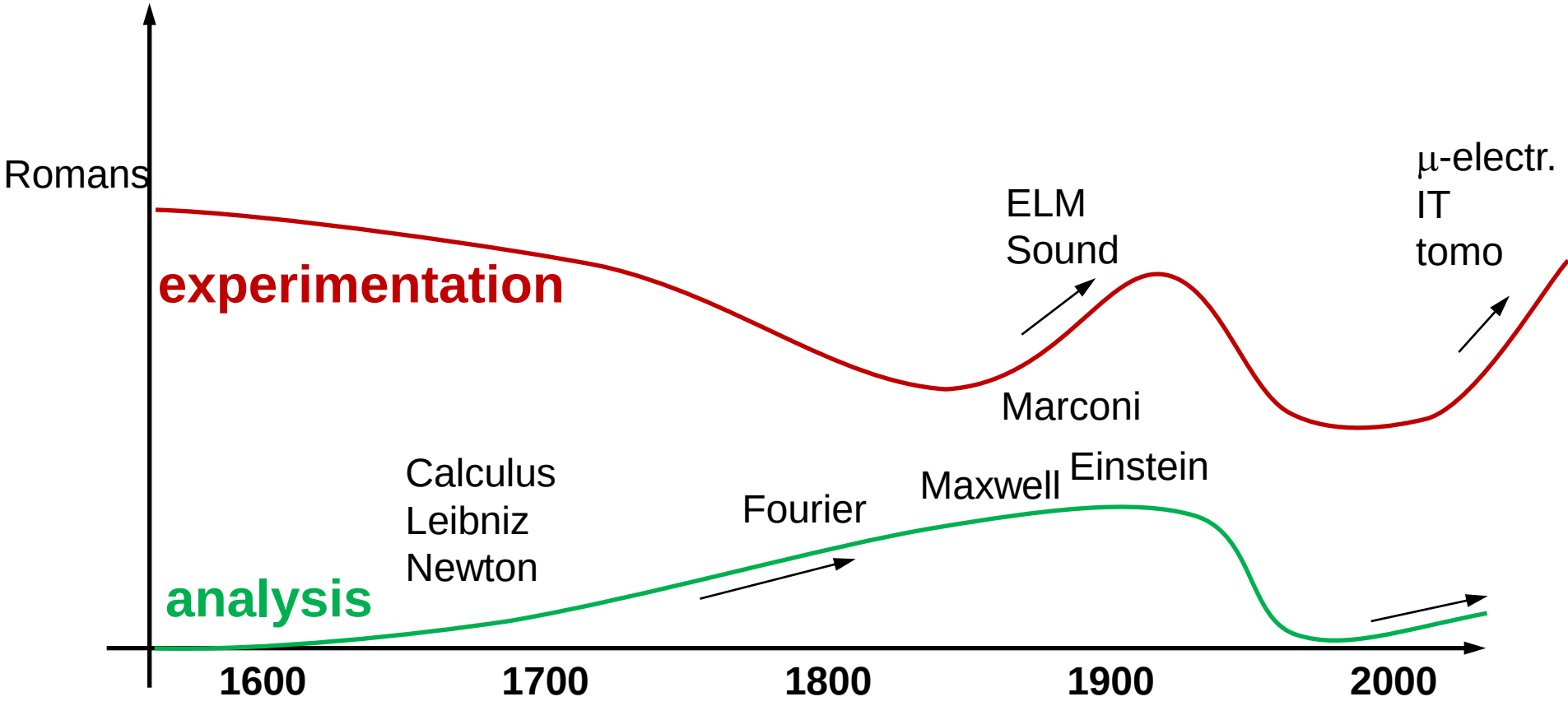
learned about CAT scan, PET scan, MRI, sonogram

used internet, cell phones

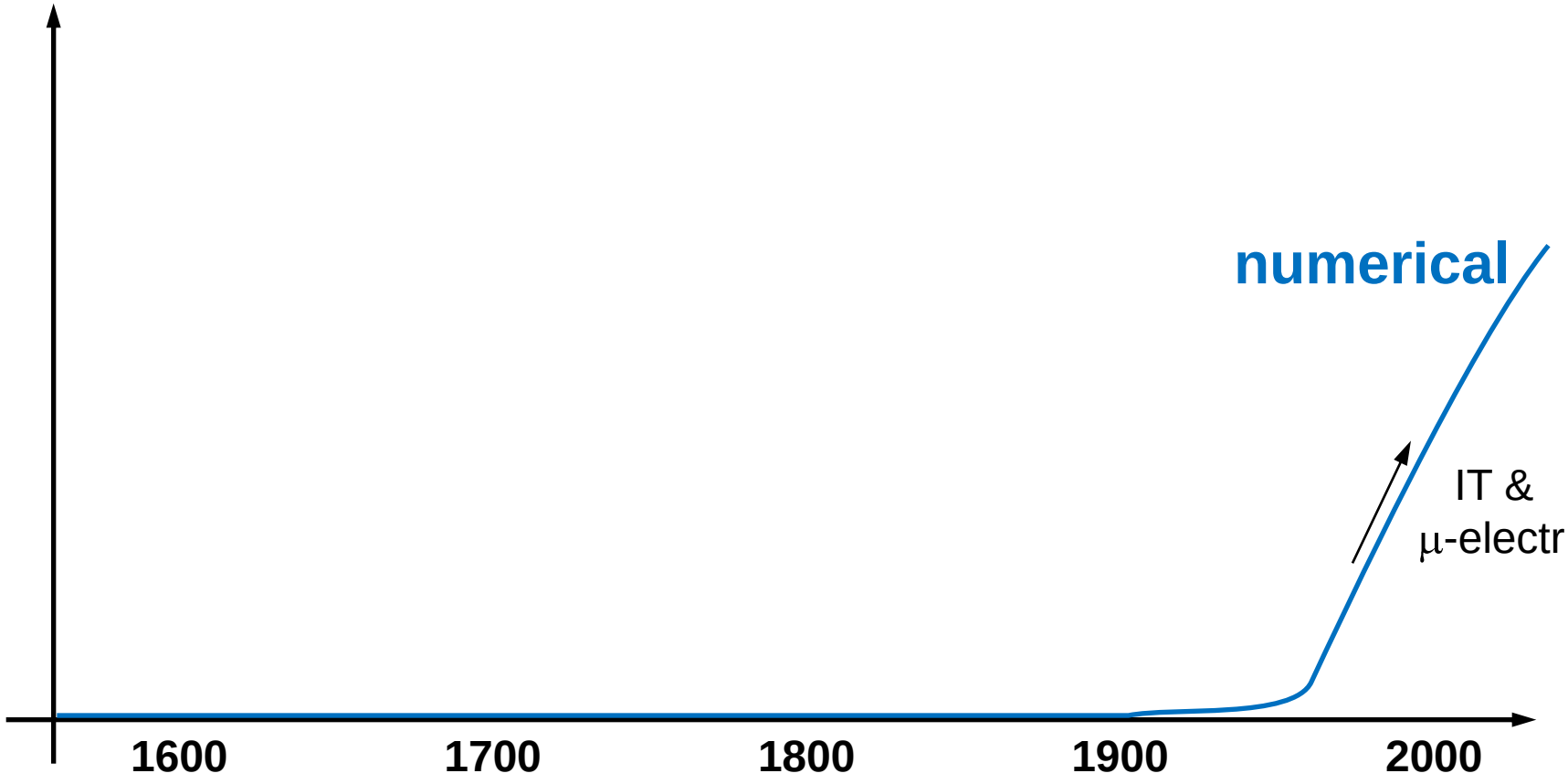
Knowledge Generation: Relative Role of…



Knowledge Generation: Relative Role of…



Knowledge Generation: Relative Role of…



Emergent Technologies - Synergism:

microelectronics

computers

data storage and display

sensors

digital data analysis

inverse problem solving

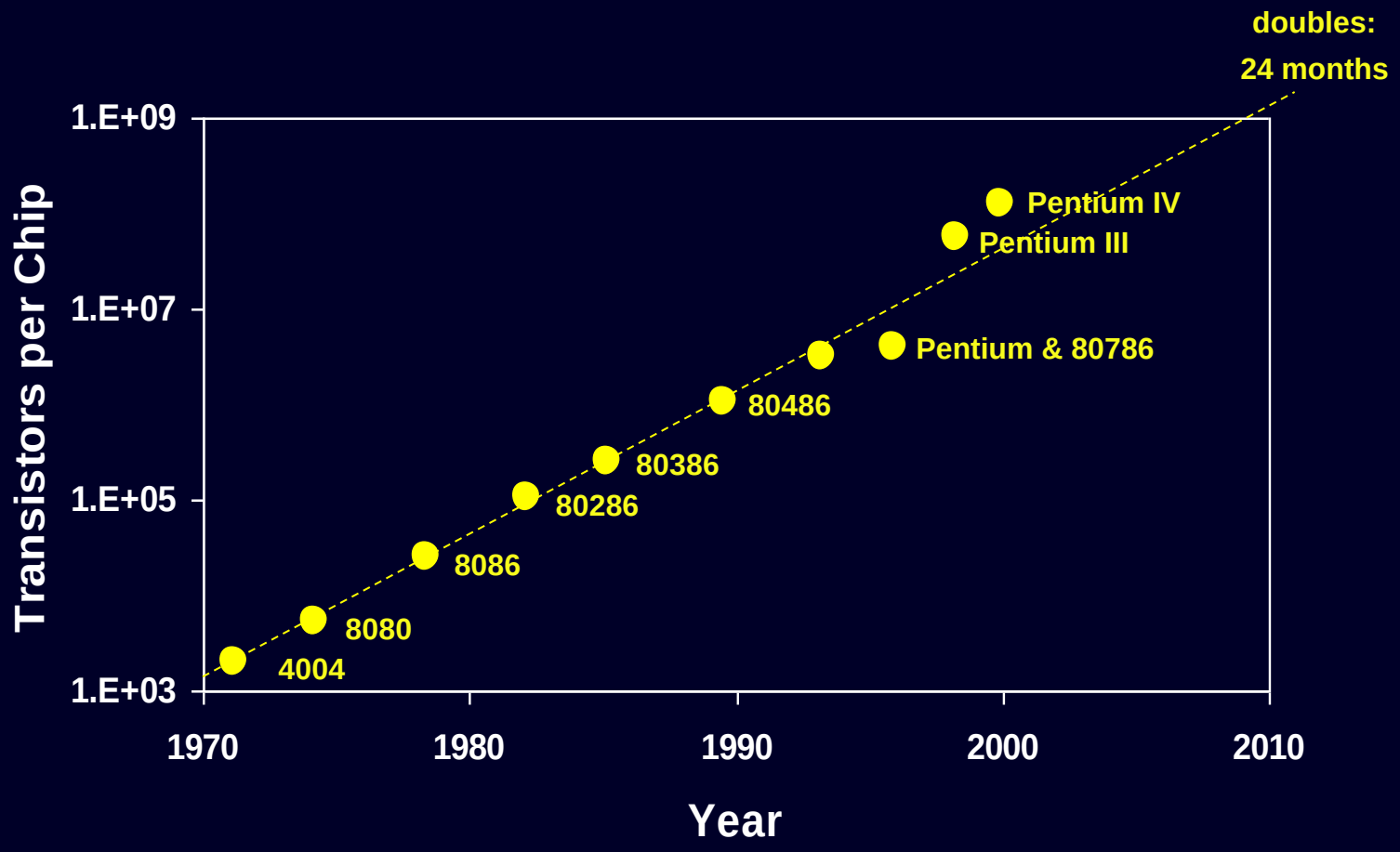
numerical methods

communications (cell phones - internet)

Interwoven History

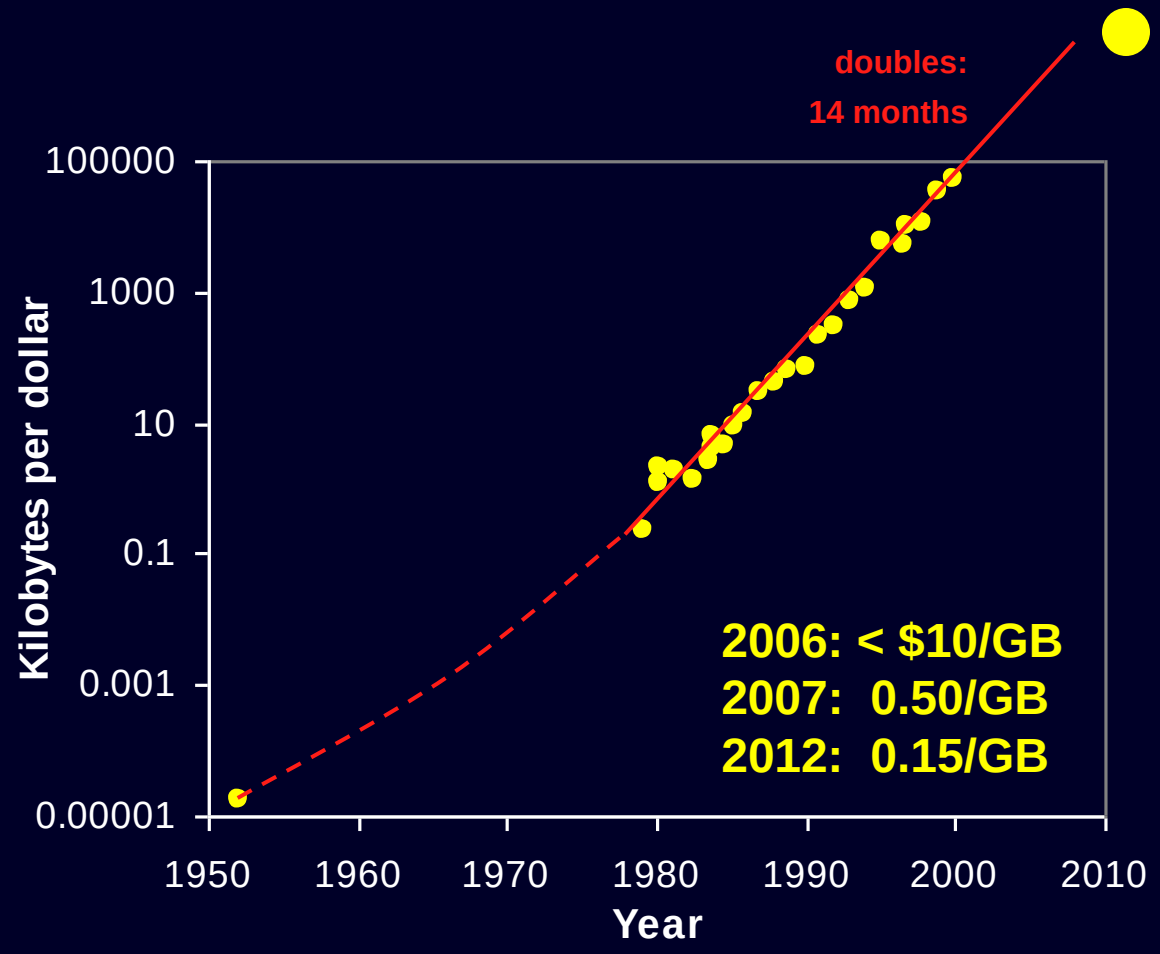
1910's	Fredholm: generalized inverse
1920's	Consumer electronics (radios, electronic phonographs)
1930's	Car radios and portable radios
1940's	Digital computer Transistor at Bell Labs Digital signal processing starts
1950's	Sony pocket-size transistor radio Integrated circuits at Texas Instruments Feynman: nano-technology
1960's	Computers emerge Growth of digital signal processing: FFT algorithm
1970's	Microprocessors: computers = chip Consumer electronics begin transition to digital Computerized tomography
1980's	Personal computers & CD players, commercial cellular phones Texas Instrument: single-chip digital signal processor Micromachining
1990's	Digital memory and storage IBM Deep Blue defeats G. Kasparov (1997) World wide web
2000's	Submicron electronic devices More than 30 nano-technology research centers in the US.

Microelectronics – Moore's Law



data from Birnbaum and Akinwande

Storage



data from Kurzweil

The brain - Storage

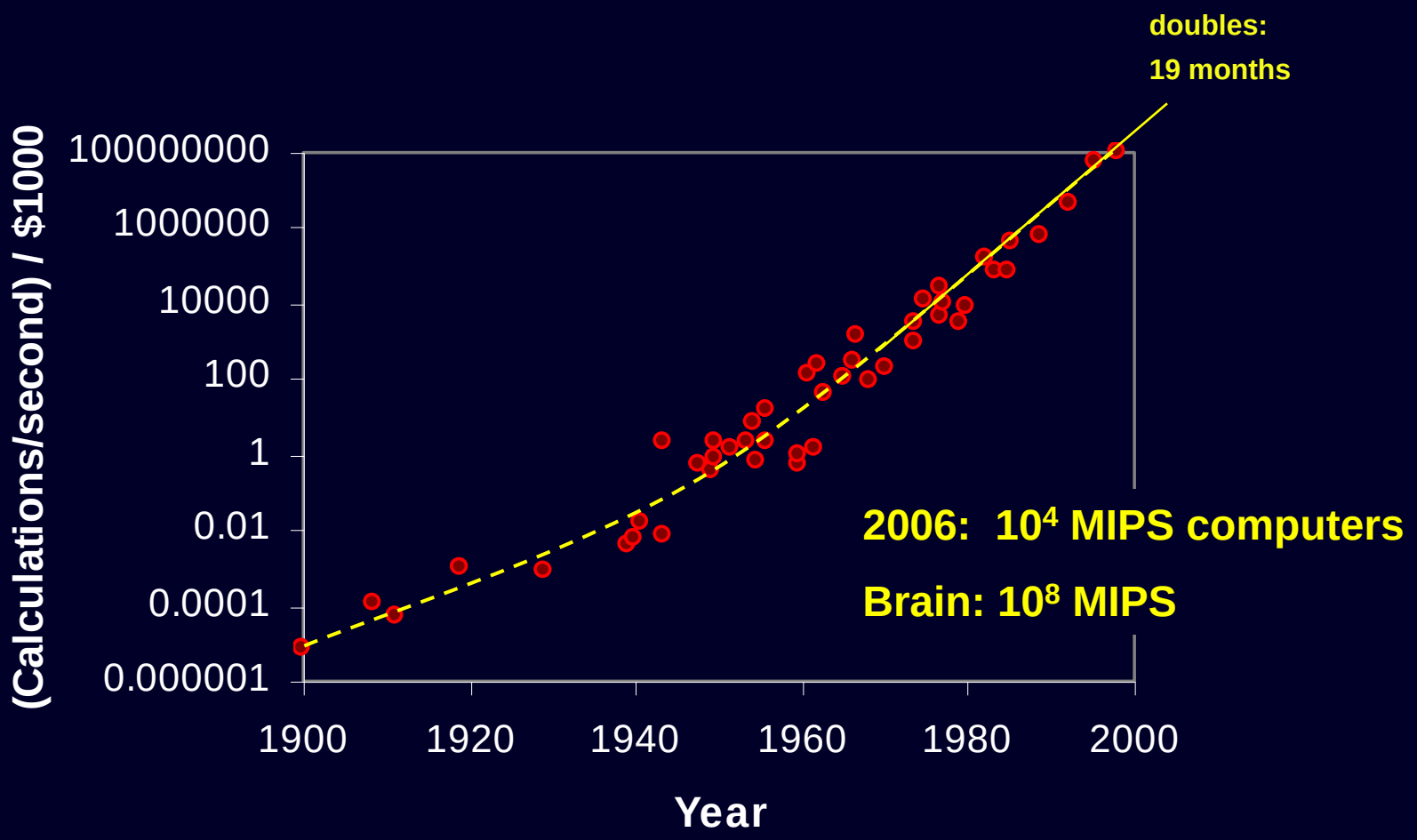
— a pianist playing Chopin 1 hr (10 kB) —

each neuron stores 1 bit	brain ~1 TB	150 $
each synapses stores 1 bit	brain ~100 TB	15,000$

— — 2006 Computer Capabilities — —

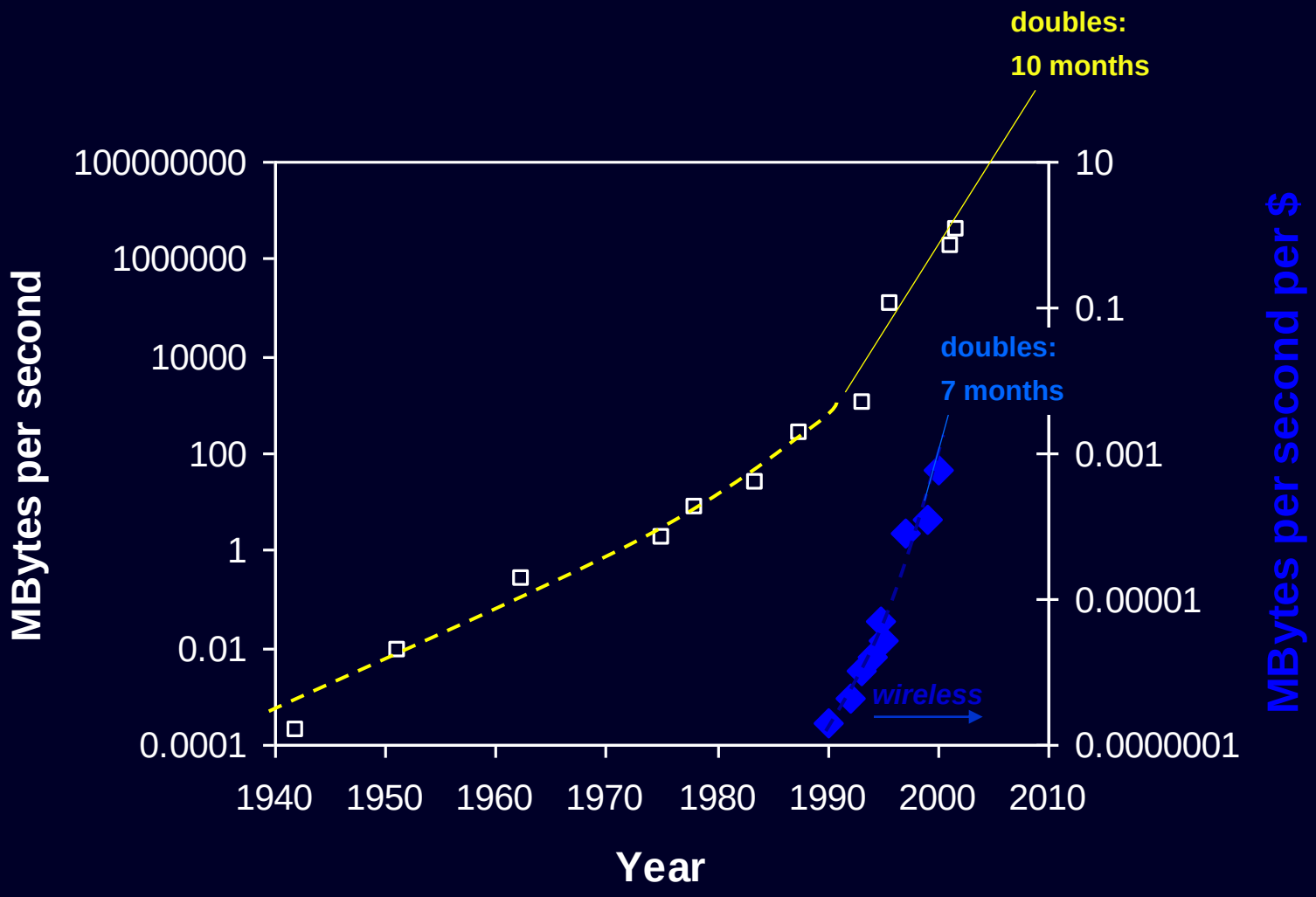
each molecule stores 1 bit	brain ~10^7 TB	1.5 billion$

Calculations per second



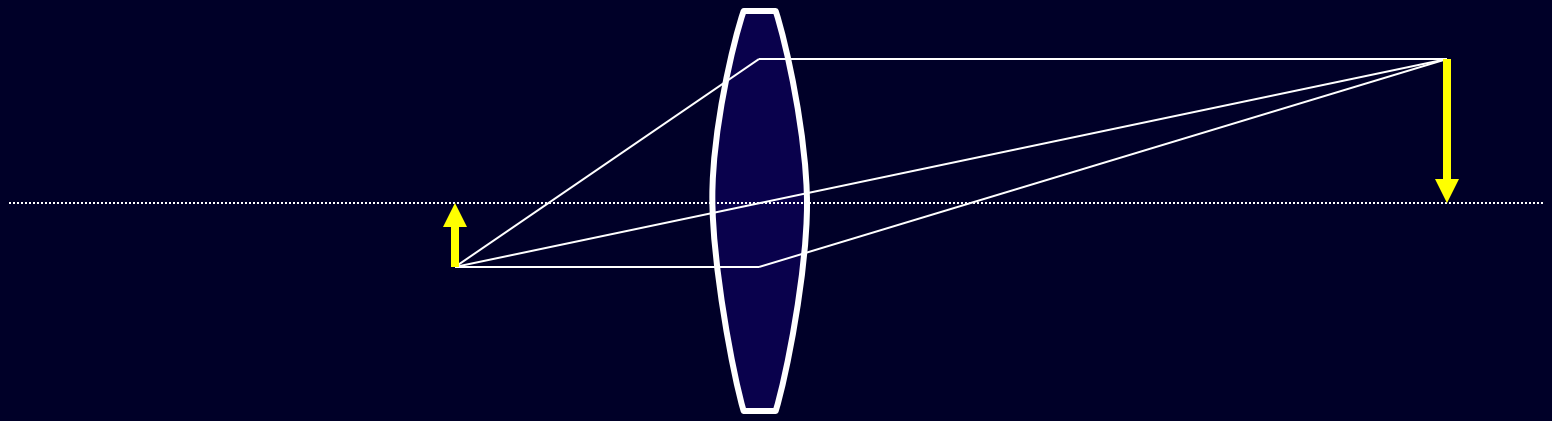
data from Kurzweil; Moravec

Communications



data from Kurzweil

Lenses: Paradigm Shifts



geocentric
(pre-Copernicus)

Galileo
Telescope

heliocentric

sterile

Leeuwenhoek
Microscope

biotic

Observations

Underlying technology: doubles every 7-to-24 months

At present rate: computers ≈ brain by 2015-2025

How is our field changing?

What are possible paradigm shifts?

Building Blocks

Sensors

Signals

Inversion

Content

Databases

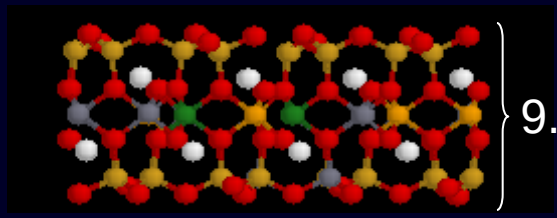
Nano and Micro Technology

Sensors - MEMS

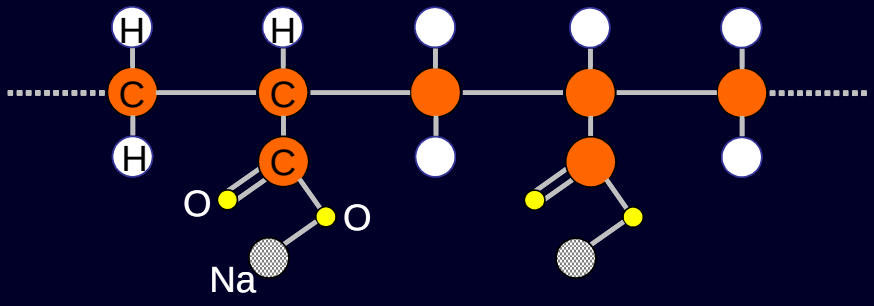
Nano-Control

Nano-manipulation (Eigler 1990)

Montmorillonite (MDL)

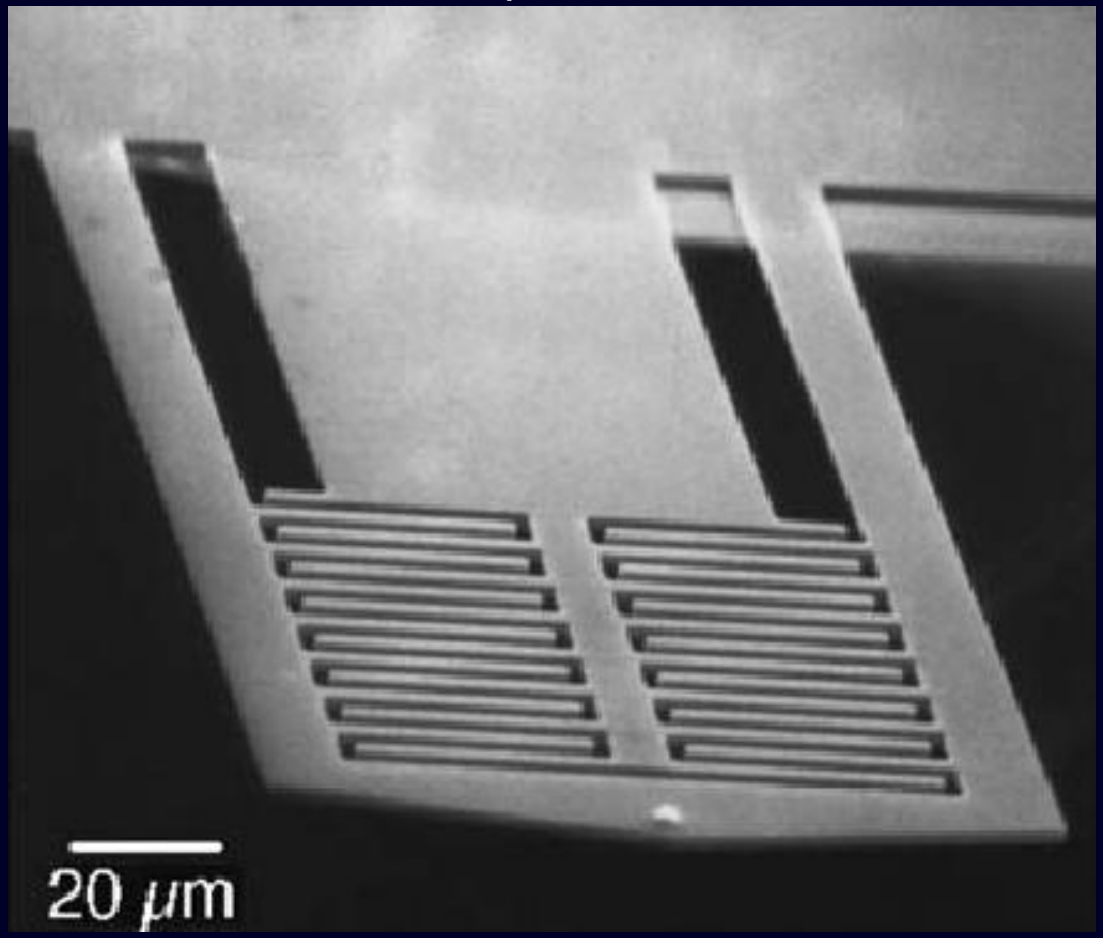


Surface control NaPAA



Micro-electrical mechanical systems MEMS

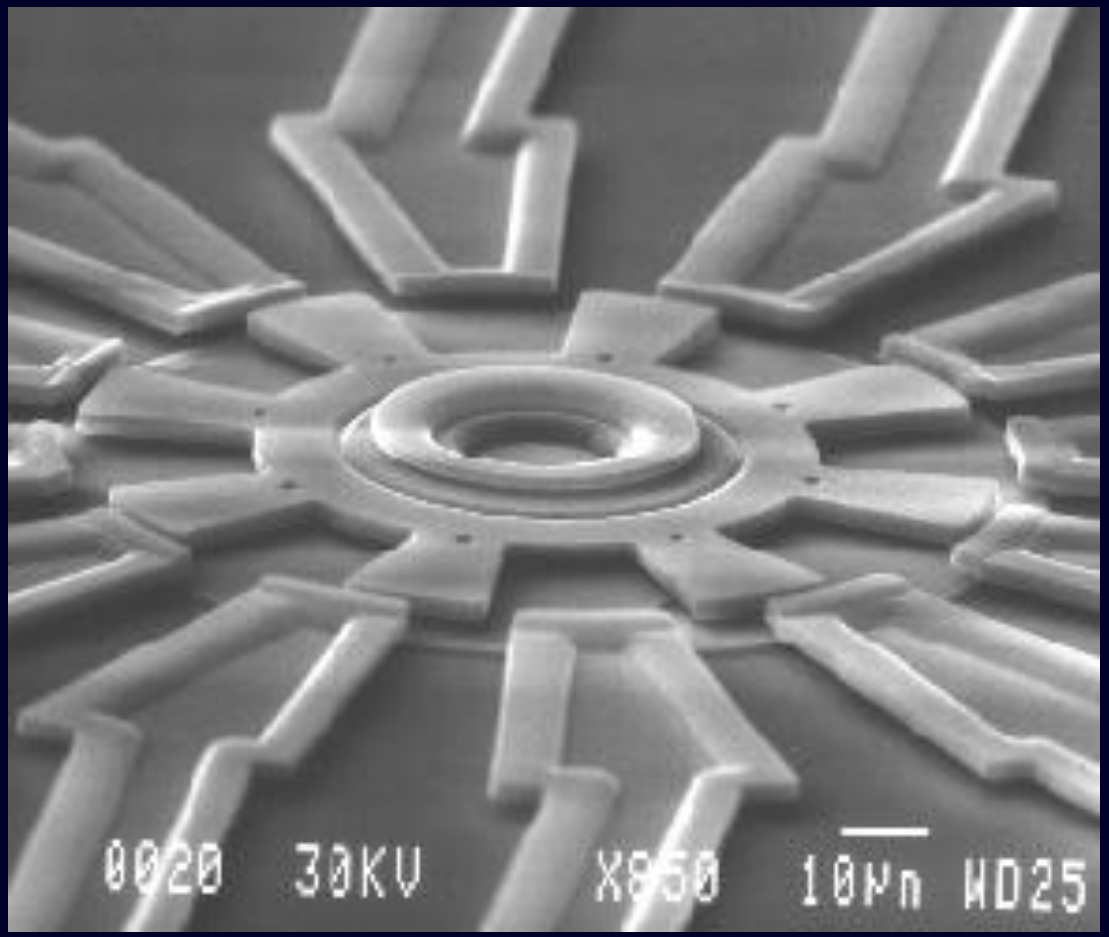
Cantilever displacement sensor



Yaralioglu et al

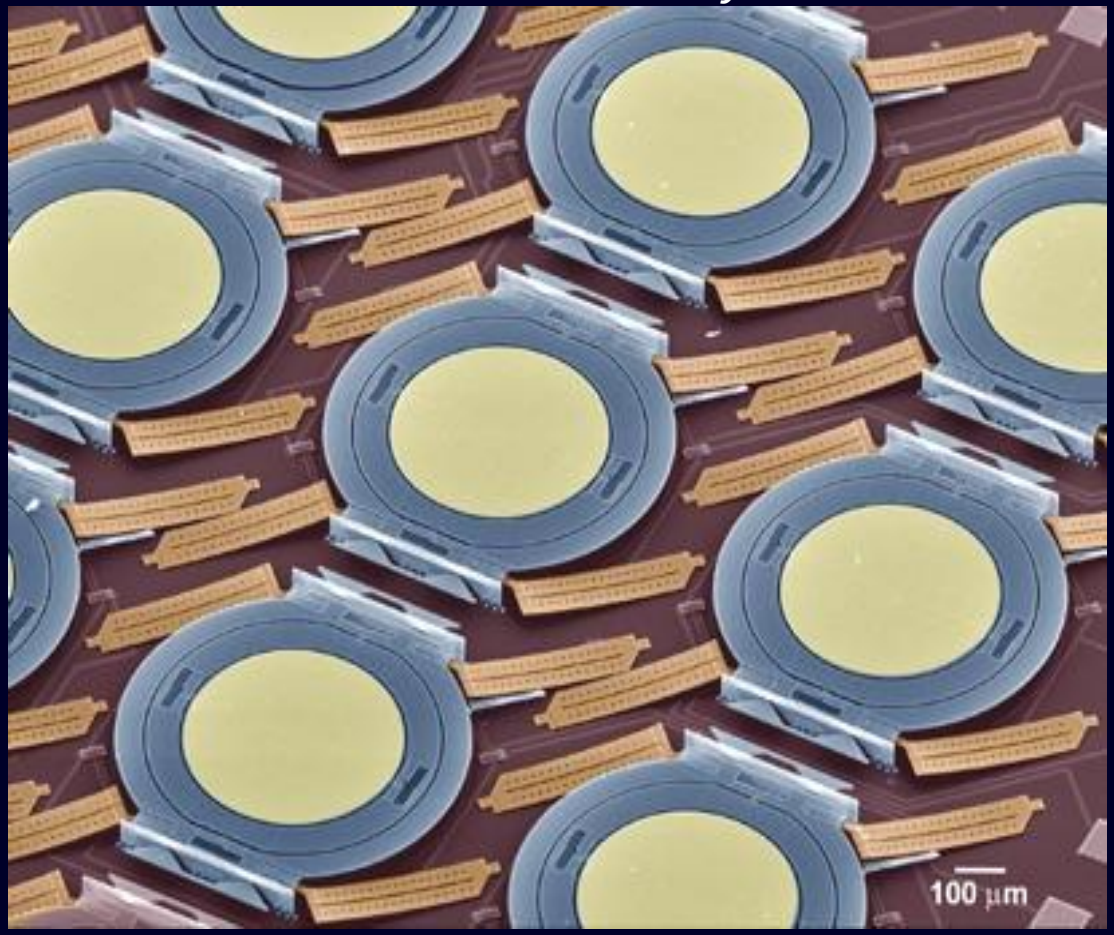
Micro-electrical mechanical systems MEMS

Motor



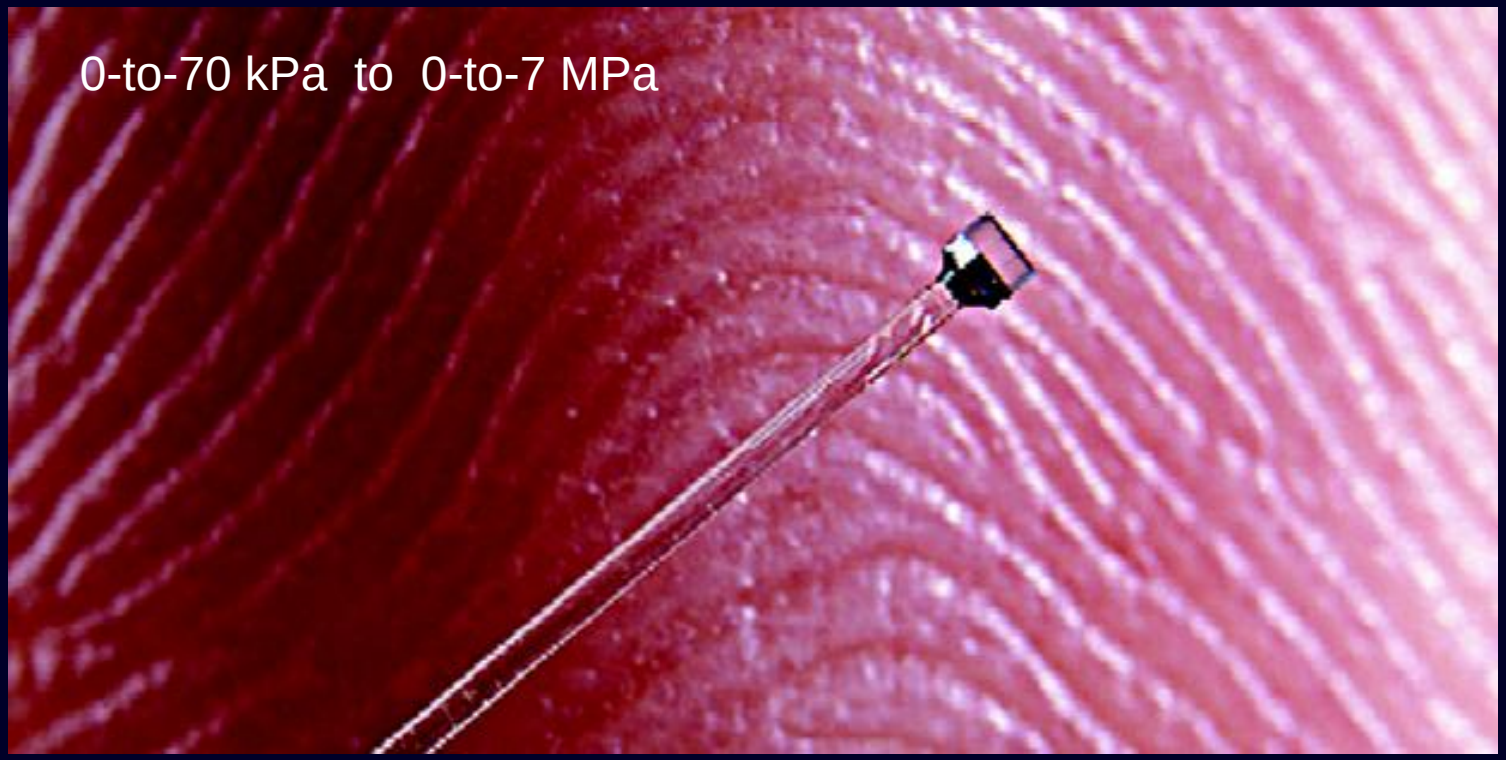
Micro-electrical mechanical systems MEMS

Micro-mirror array



Bell Labs

Fiber optic based pressure transducer



Salinity T Depth GPS Pitch Roll Compass

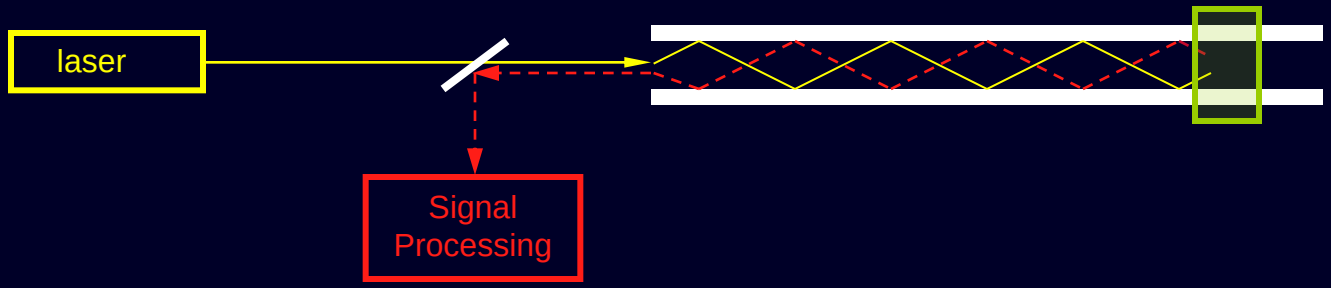
Memory size: 128,000

Battery life: *up to 5 years*

Depth: *down to 2000m*

http://www.star-oddi.com

Distributed Optical Sensors



Strain (Dowding)

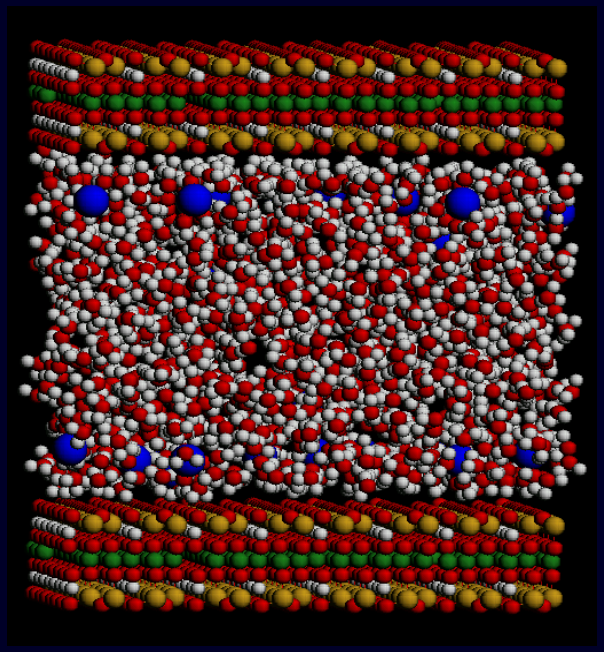
Pore fluid chemical properties

Moisture content (Brillouin)

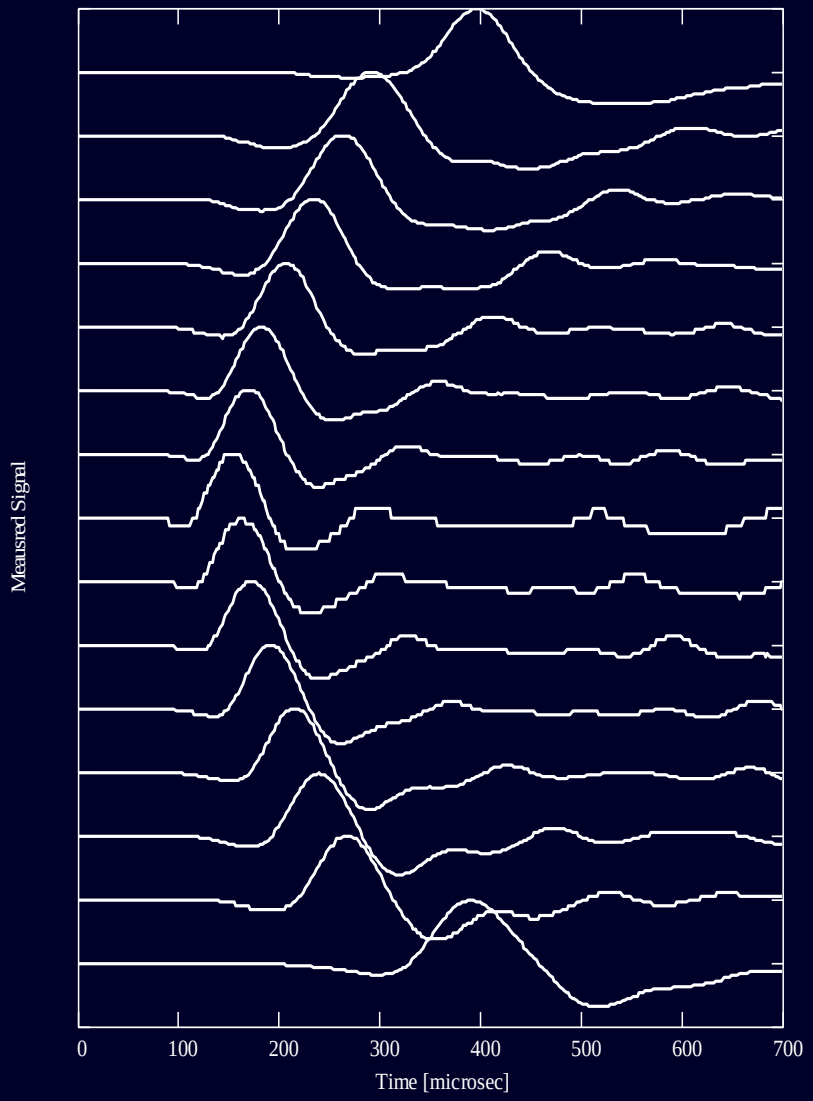
Temperature (Raman)

30 km … every 1 m … 1°C resolution

Soil = innate sensing system



(N. Skipper – UCL 2002)



Sensors: Current Research

miniaturization (micro and nano-sensors)

distributed sensors, arrays, networks

optimal sensor location

inter-sensor wireless communication

embedded systems

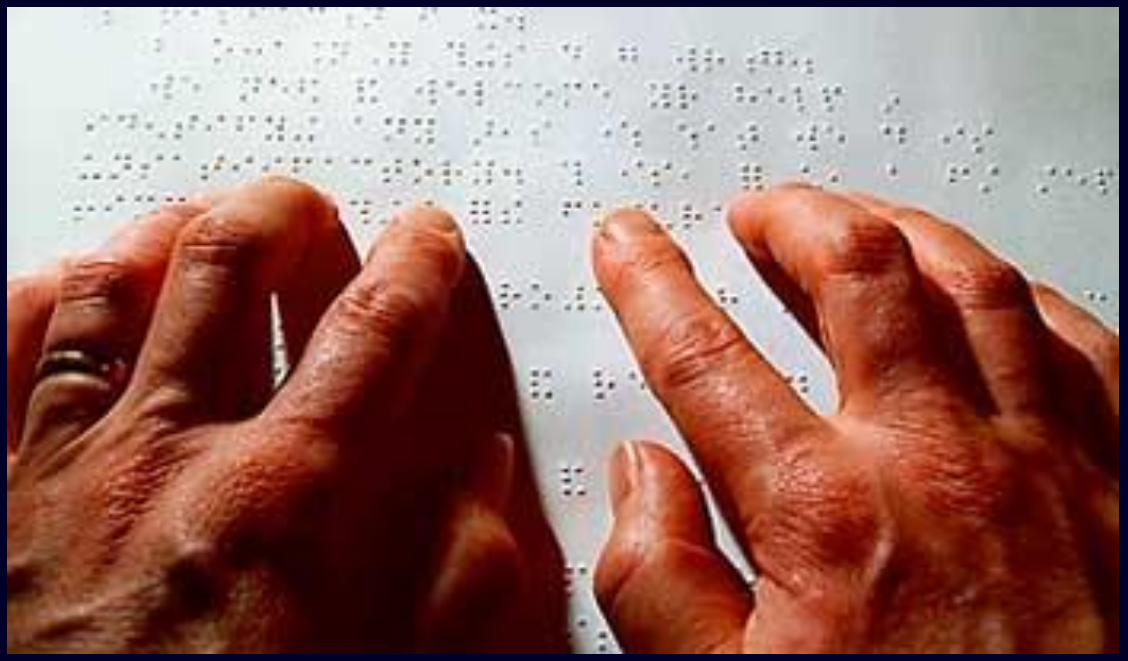
intelligent sensor systems

distributed processing

Data Fusion

From multi-sensor data to information

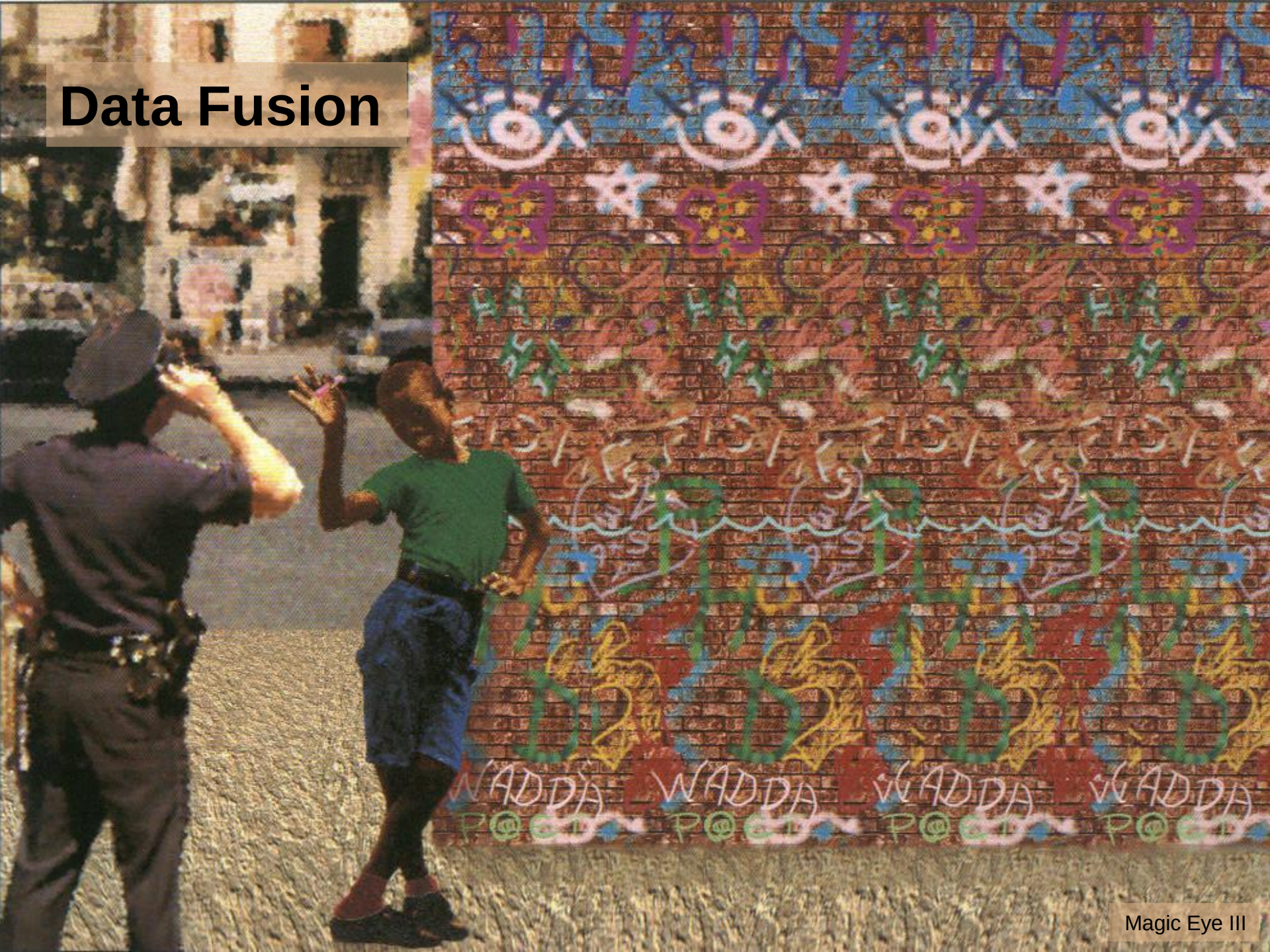
Data Fusion: Same Mode



Fuse multi-sensor data to gain new information

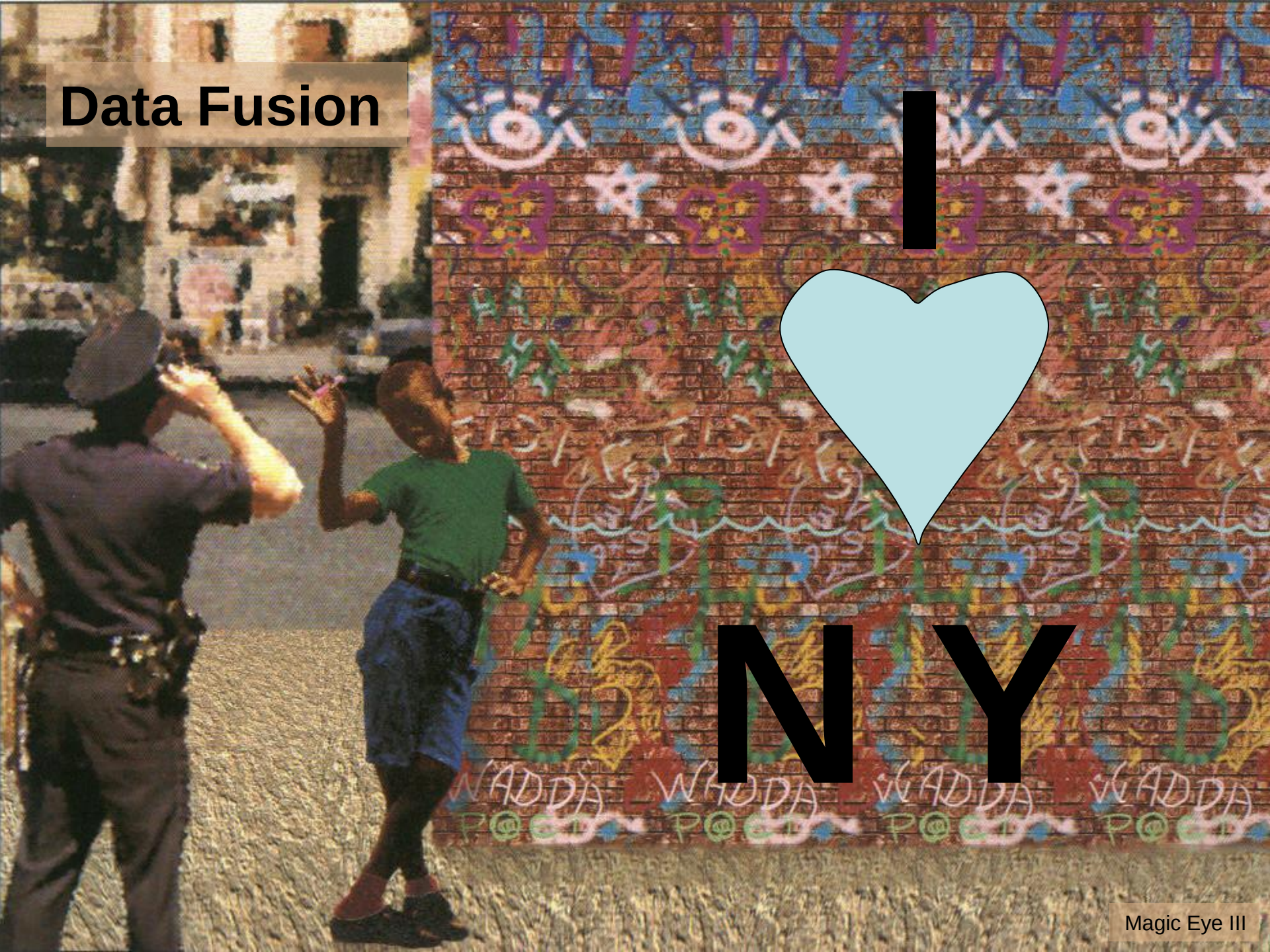
http://www.pc.rhul.ac.uk/zanker/teach/PS1061/L6/braille.JPG

Data Fusion



Magic Eye III

Data Fusion



Magic Eye III

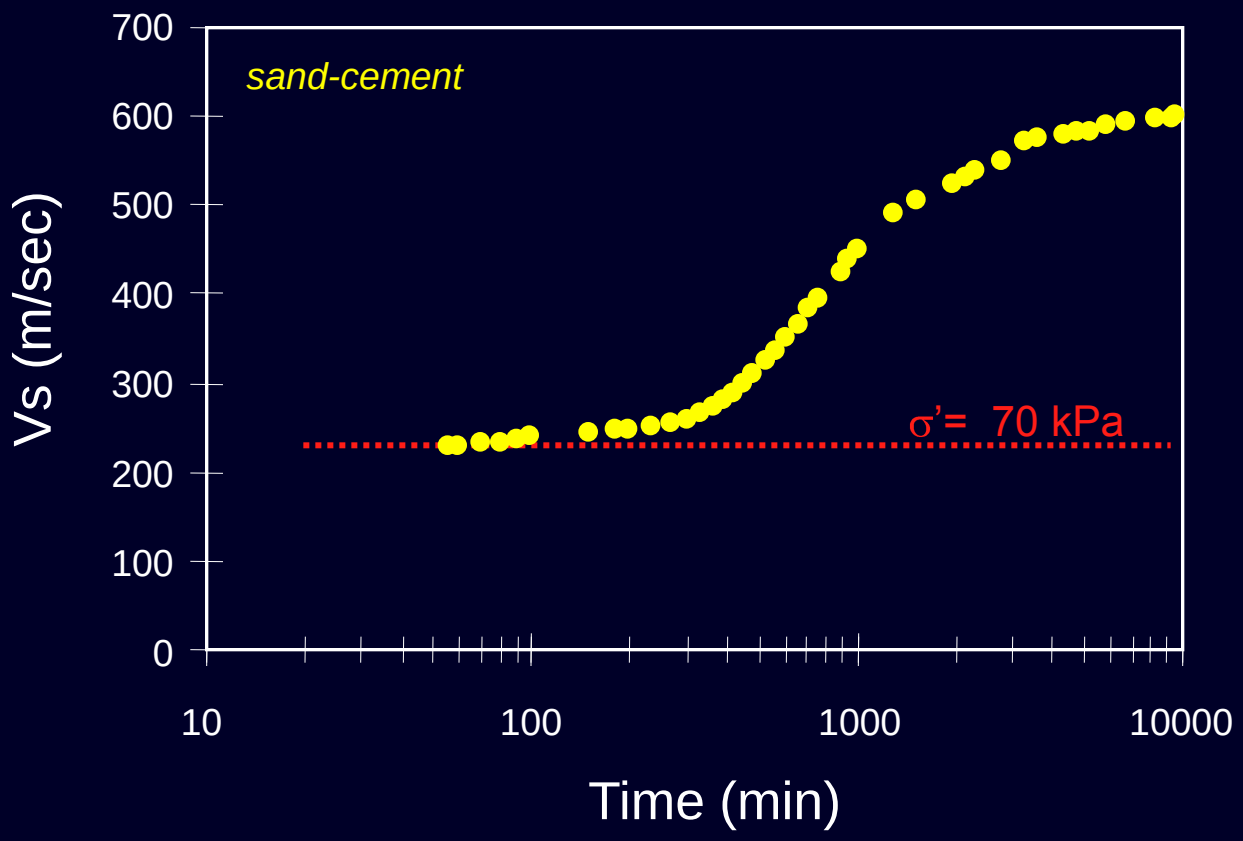
Data Fusion: Multi Mode

Navigational

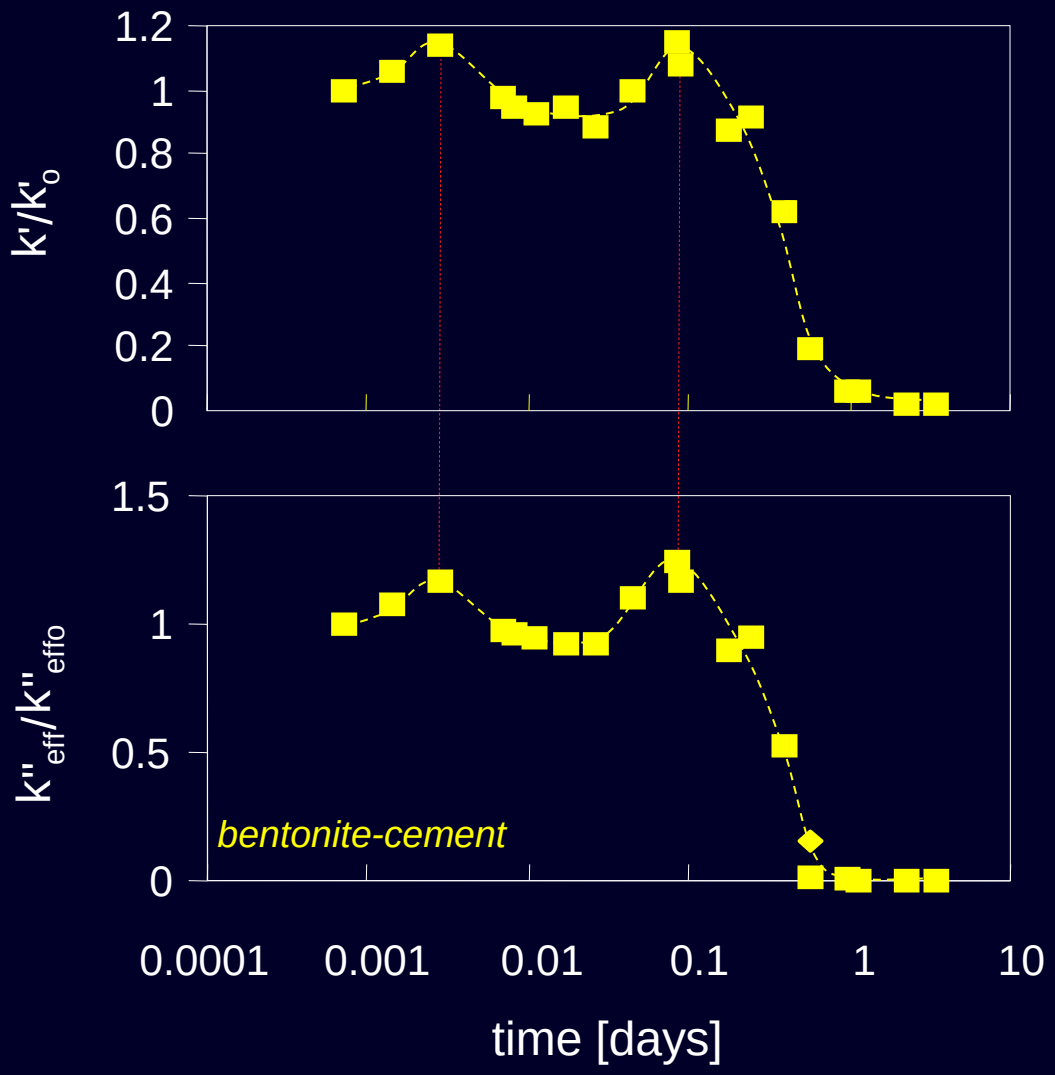
Homing in

sunsite.tus.ac.jp/multimed/pics/animals/bat.jpg

Cementation - Elastic waves



Cementation - Electromagnetic waves



Data-fusion in geotechnology

- boundary deformations → ε_{vol} field

$$\varepsilon = C_c' \log \sigma_f' / \sigma_o'$$

- travel time S-waves → V_s field

$$V_s = \alpha \left[\frac{\sigma_{\square}' + \sigma_{\perp}'}{2\text{kPa}} \right]^{\beta}$$

- electrical resist. → σ_{el} field

$$\sigma_{elec}^{soil} = n\sigma_{elec}^{fluid} = f\ C_c, \sigma', \sigma_{elec}^{fluid}$$

travel time EM waves → V_{EM} field

$$V_{EM} = \frac{c}{\sqrt{\kappa'}} = f\ w\ = f\ C_c, \sigma'$$

Fuse multi-modal sensor data to gain new information

Observations

Signal processing = information extraction

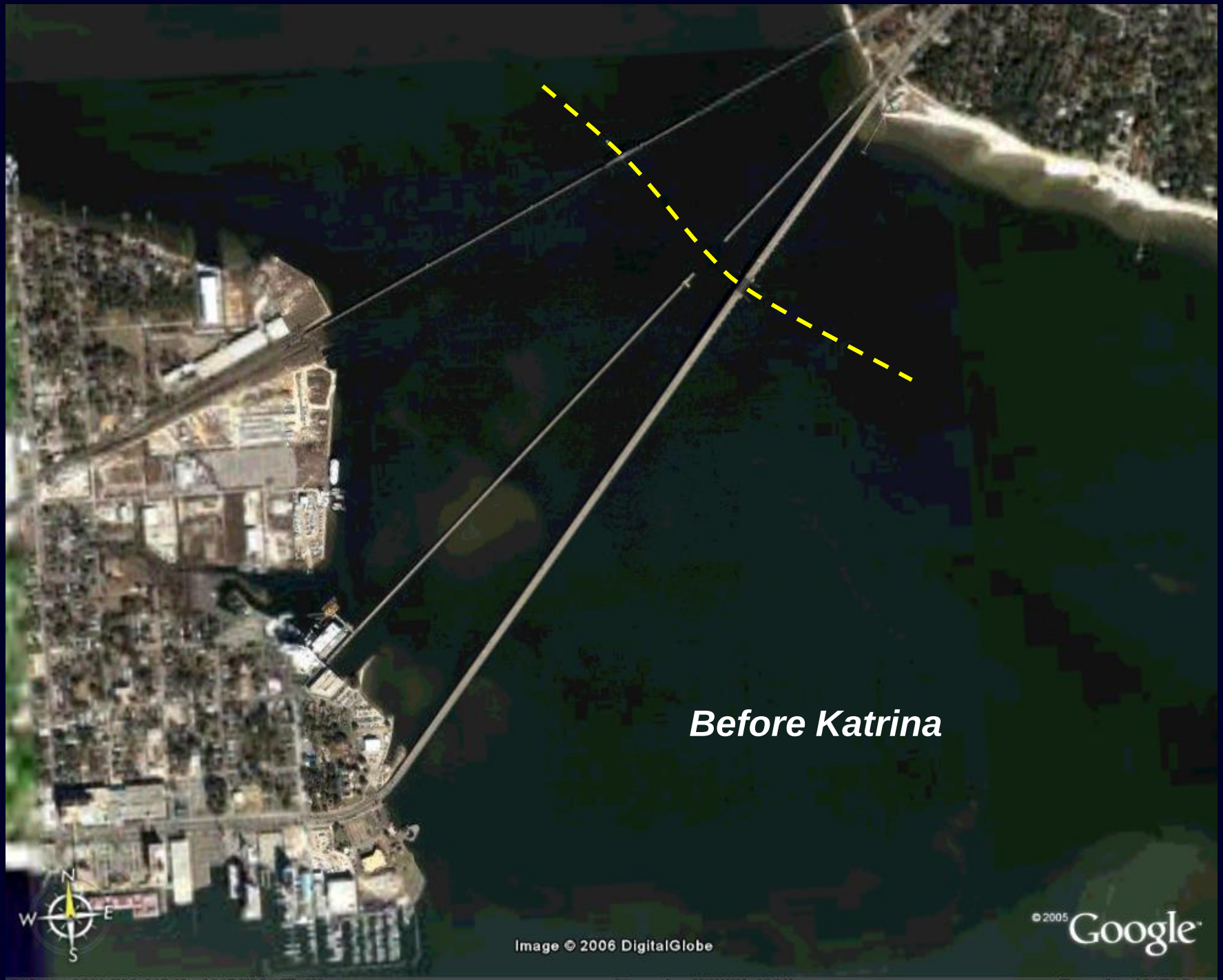
- noise control
- similarities between signals
- simple algorithms may be sufficient

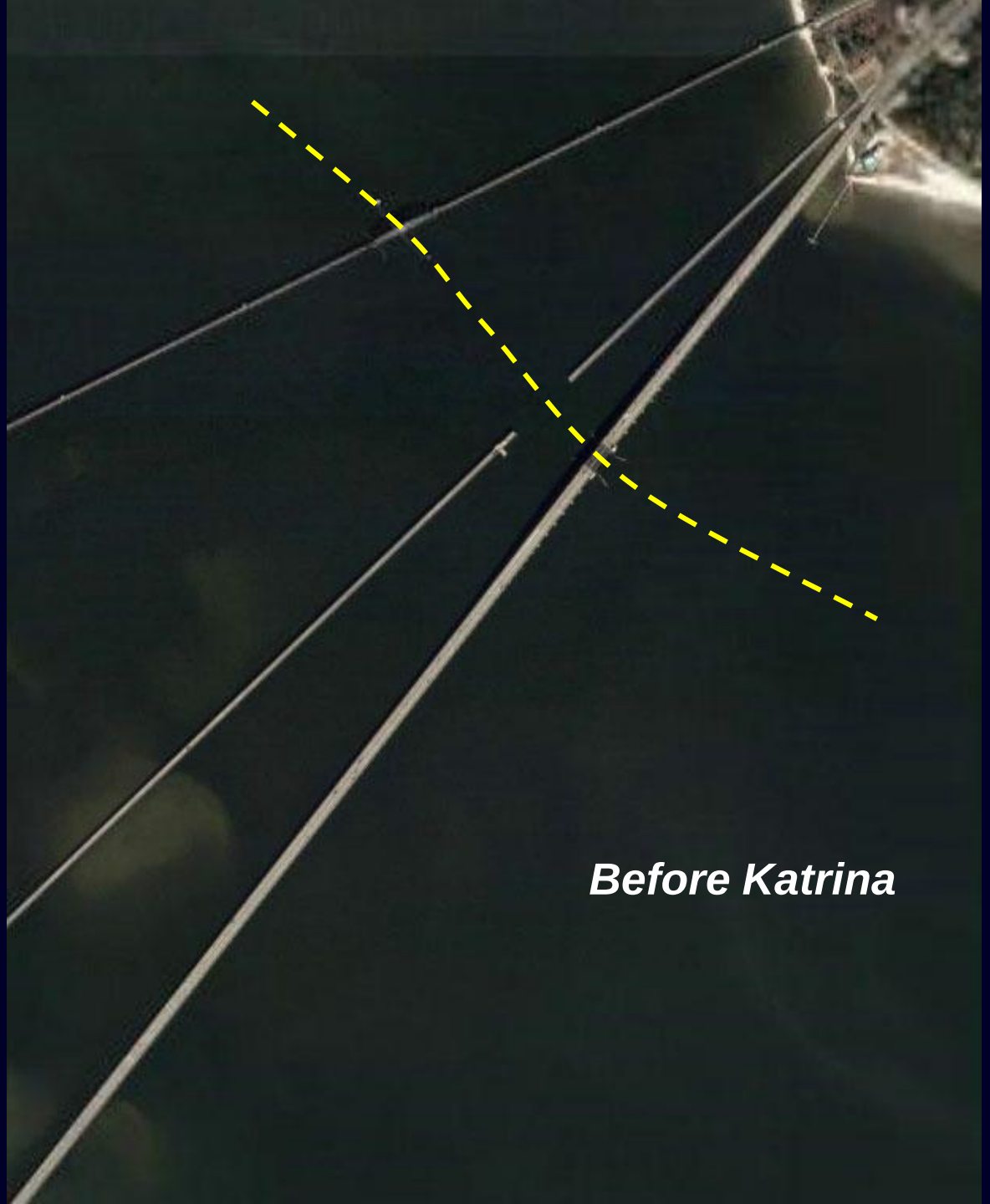
Data fusion = new information from:

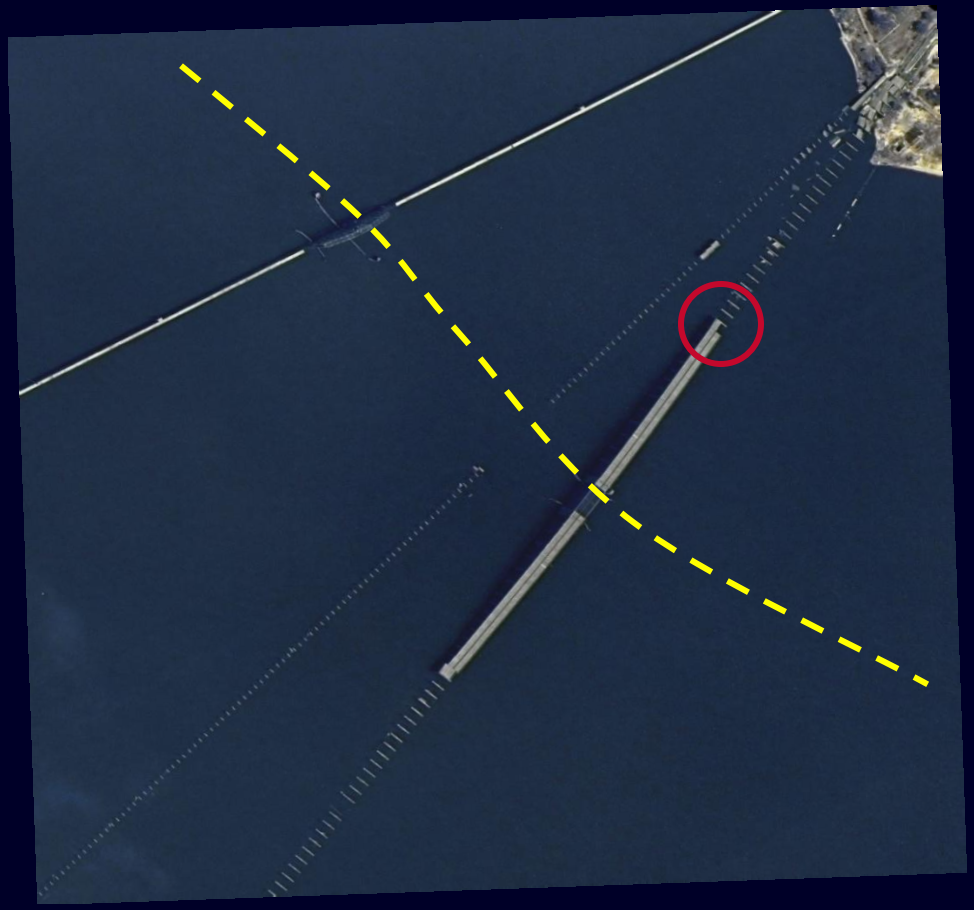
- multiple-sensors
- multi-modal sensors
- spatially distributed sensors
- concurrent or time-shifted data streams

Signal Processing

From signals to information


Before Katrina
Image © 2006 DigitalGlobe
©2005 Google
Pointer 30°24'00.89" N 88°51'01.27" W
Streaming 100%
Eye alt 10072 ft

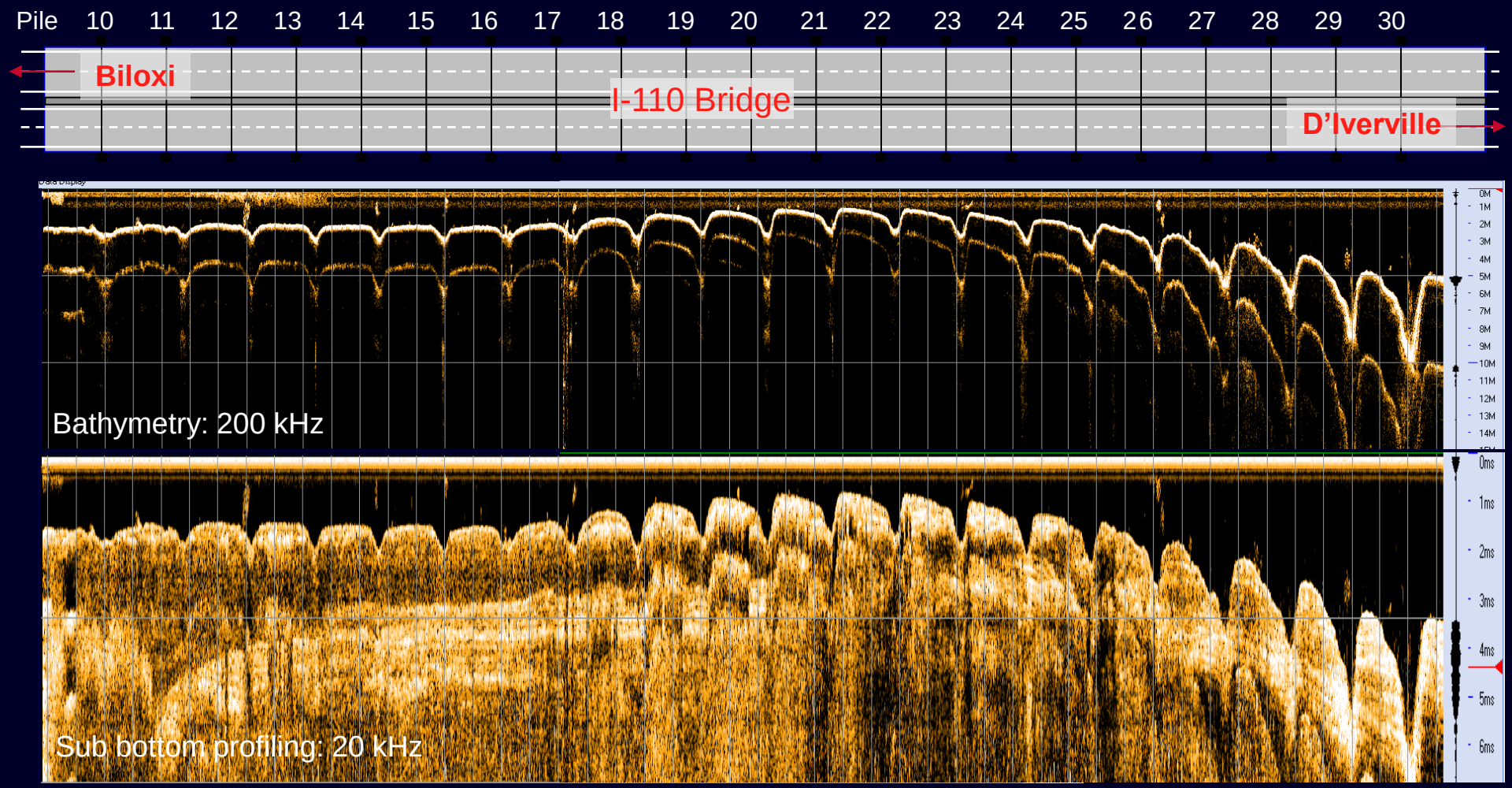

Before Katrina



After Katrina

NSF - D. Fratta

Massive data → Display → Information

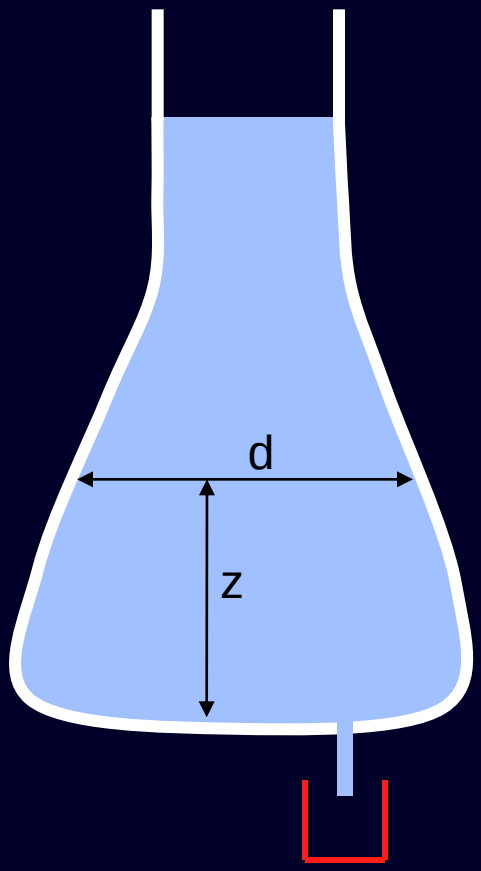


Massive data → Processing → Information

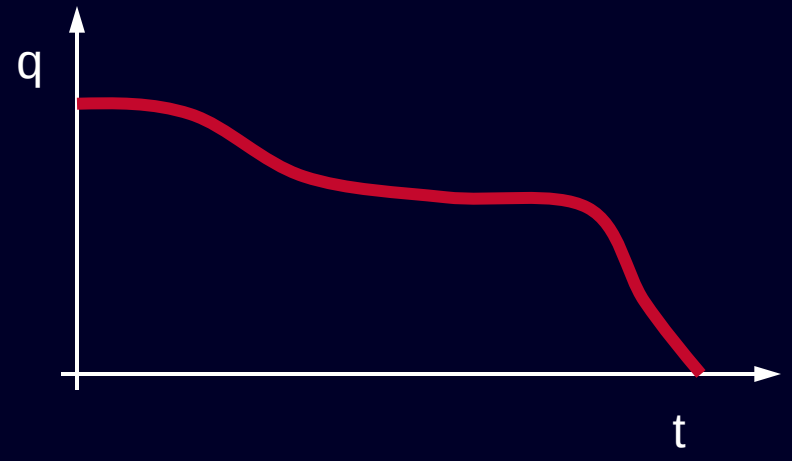
Inversion

Sensing at boundaries … learning about the body

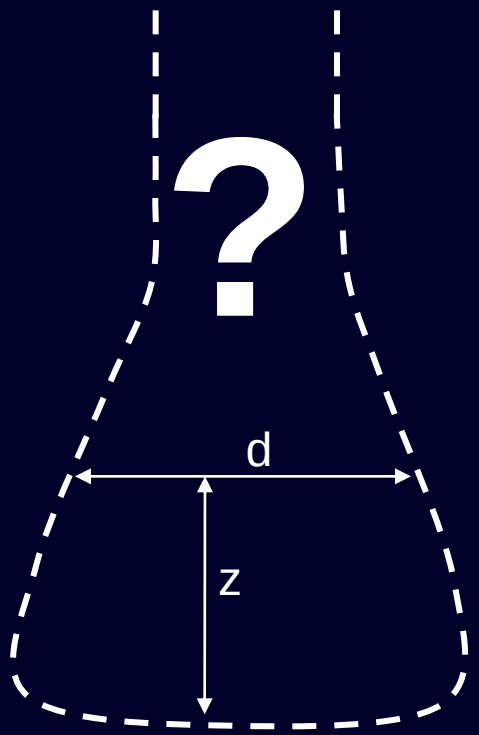
From CAUSE to EFFECT



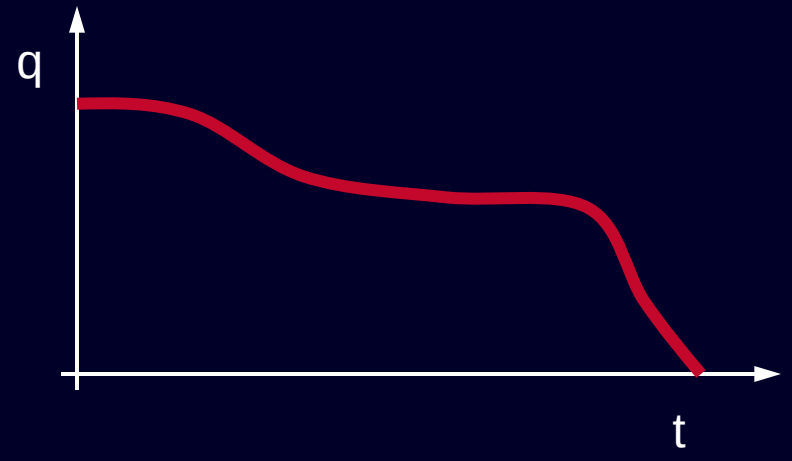
forward



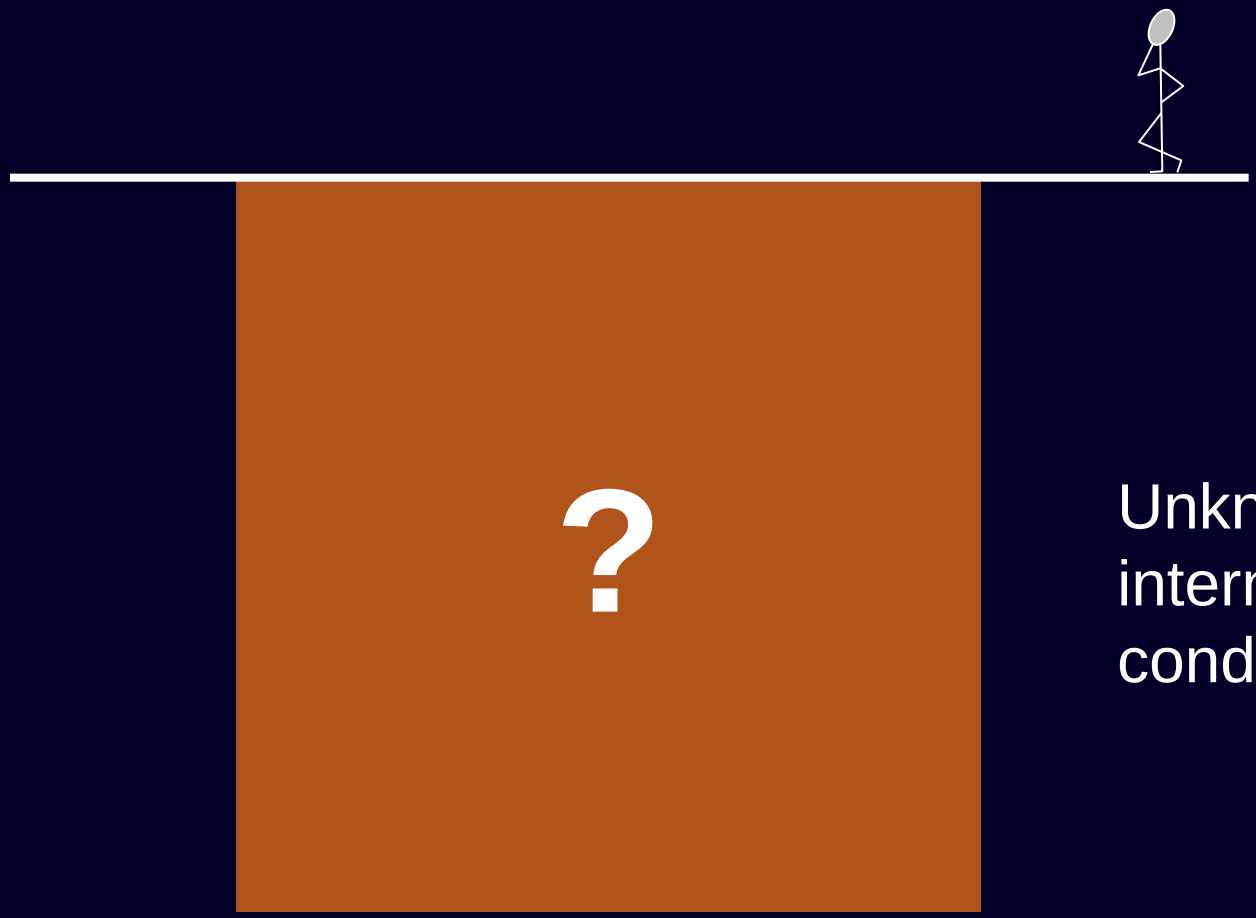
From EFFECT back to CAUSE



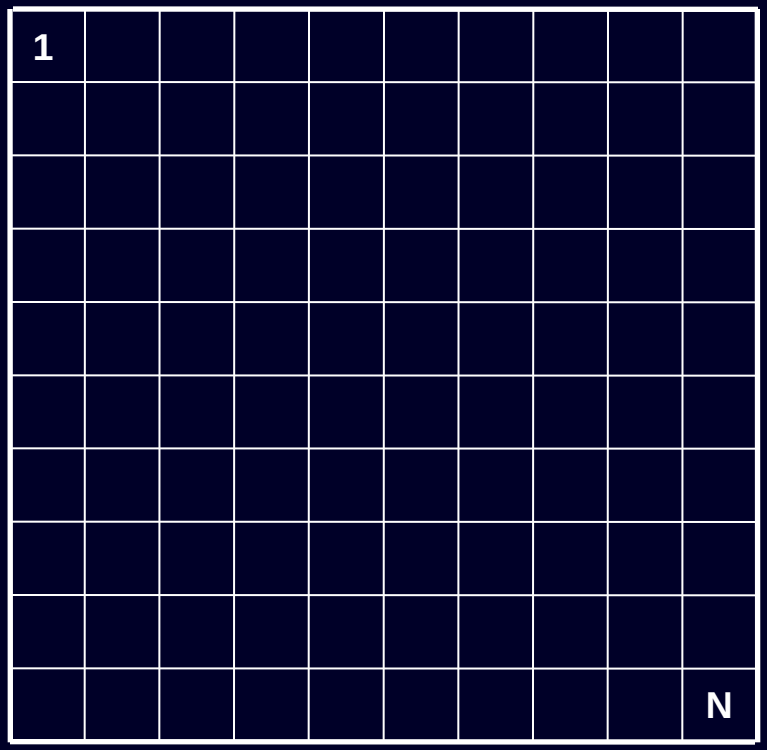
inverse



Tomography



Unknown internal conditions



invert

$$\begin{bmatrix} t_1 \\ \dots \\ t_i \\ \dots \\ t_M \end{bmatrix} = \begin{bmatrix} h_{1,1} & \dots & h_{1,k} & \dots & h_{1,N} \\ \dots & \dots & \dots & \dots & \dots \\ h_{i,1} & \dots & h_{i,k} & \dots & h_{i,N} \\ \dots & \dots & \dots & \dots & \dots \\ h_{M,1} & \dots & h_{M,k} & \dots & h_{M,N} \end{bmatrix} \begin{bmatrix} 1/V_1 \\ \dots \\ 1/V_k \\ \dots \\ 1/V_N \end{bmatrix}$$

Micro Computed Tomography

Observations: Inversion Ubiquitous in Geo

Measured Values	Inverted Values
triaxial F-δ	constitutive model parameters
oedometer u(t)	C_v k
pollutant c(z,t)	location and timing of leak
$V_{Rayleigh}(\omega)$	$V_s(z)$ from SASW
settlement f(t)	C_v C_s
$\delta_h(z)$ along a pile	$k_h(z)$ along the pile
ground vibration	evolution of G during event

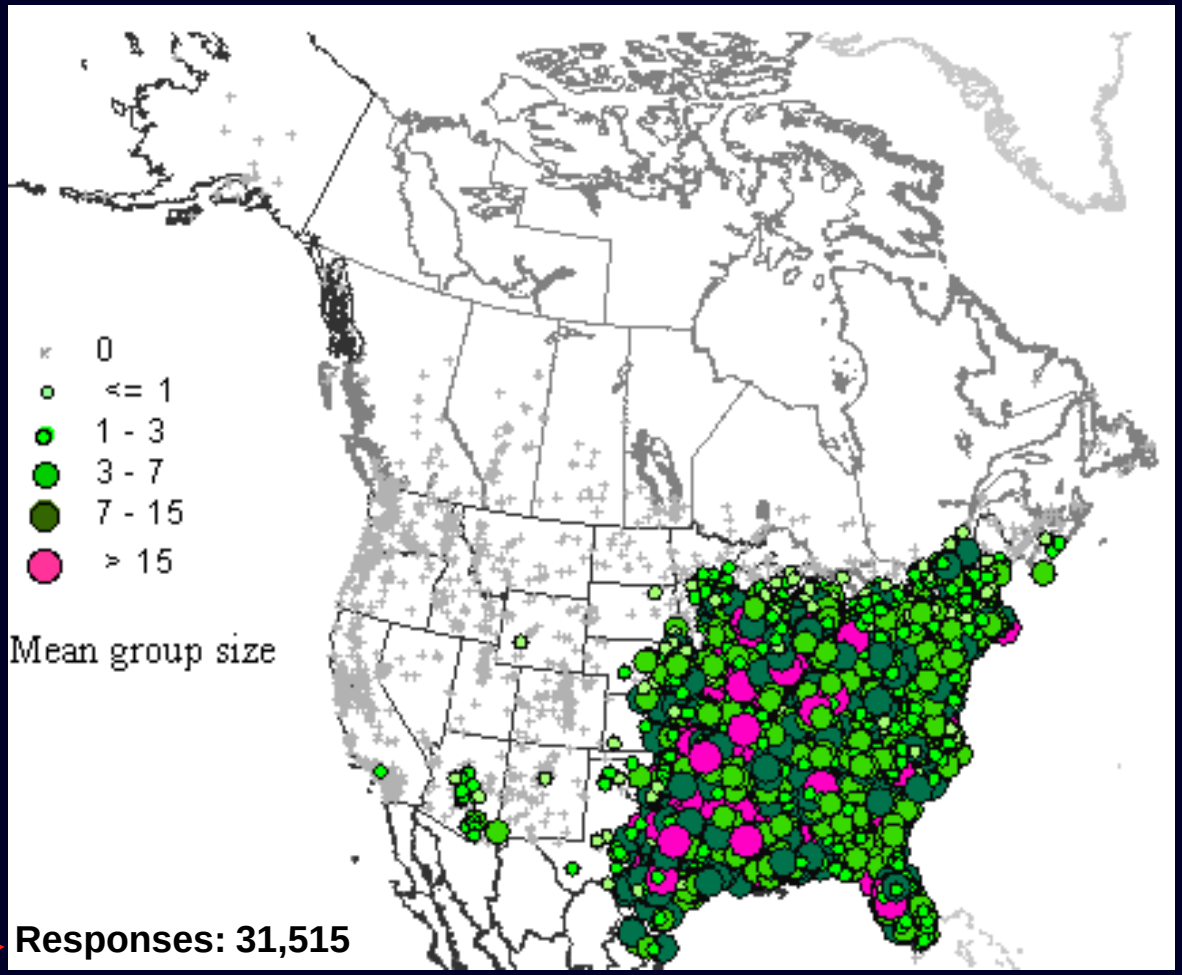
Conceive all experiments within inverse problem solving framework

Distributed Content Development

many + internet = collective intelligence

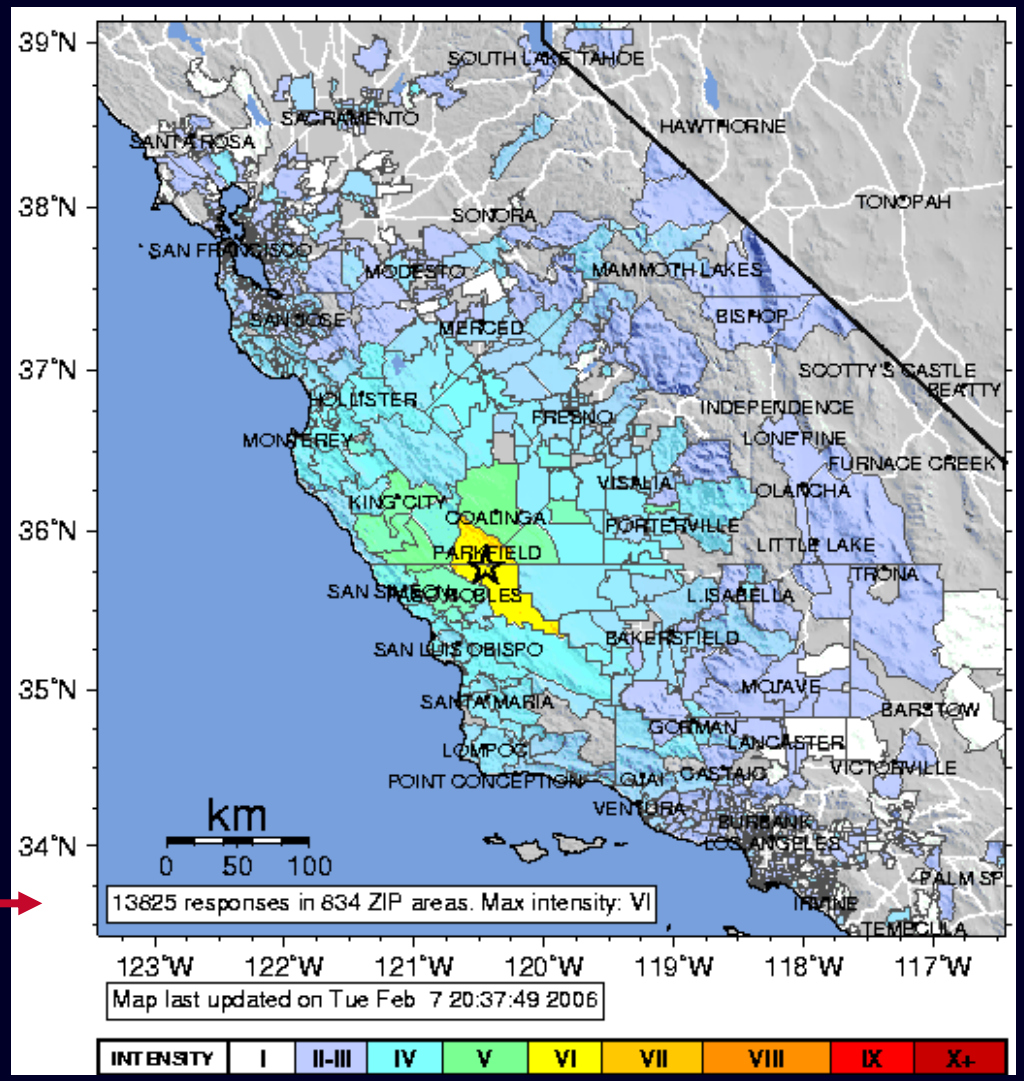
Great Backyard Bird Count

Northern Cardinal (2/17/06 - 2/20/06)



Responses: 31,515

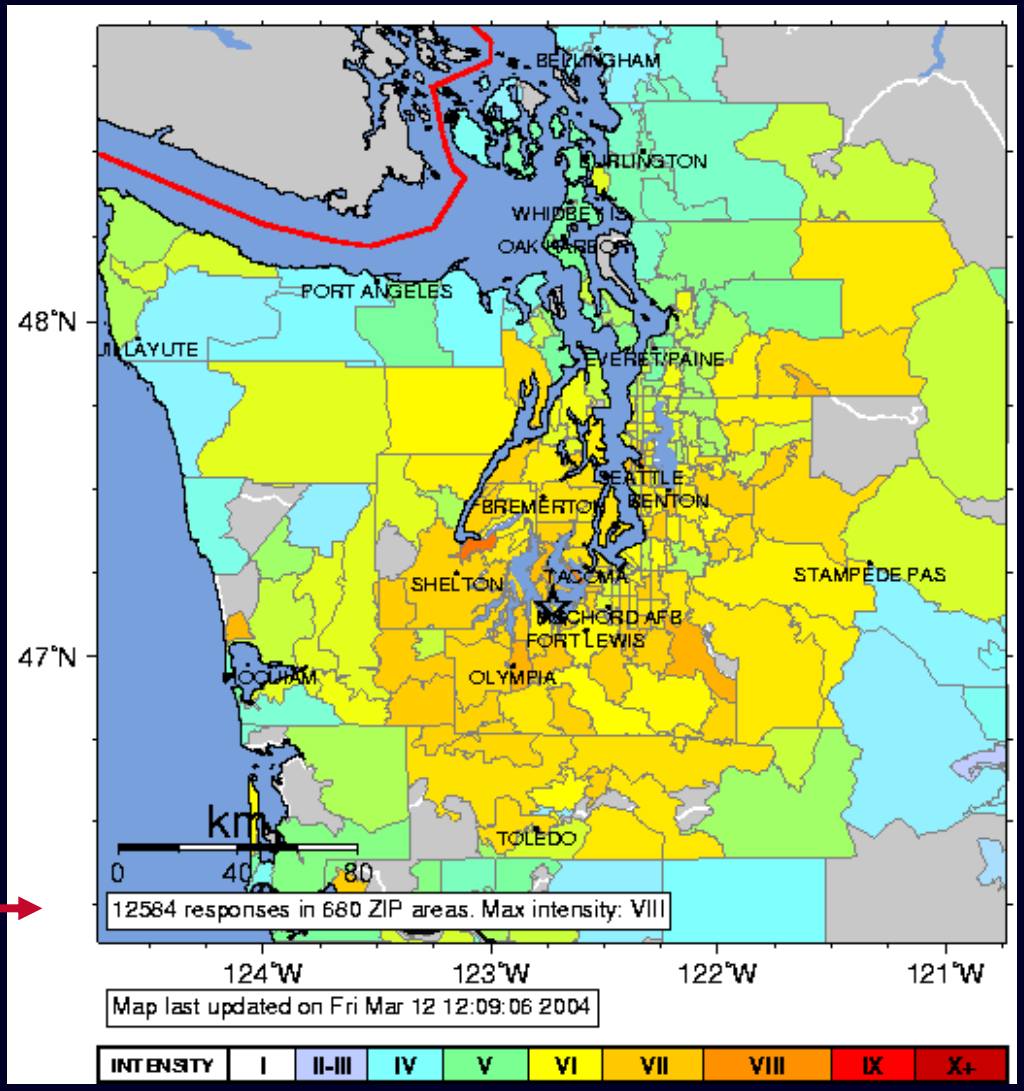
Community Internet Intensity Map



Parkfield

9/28/04

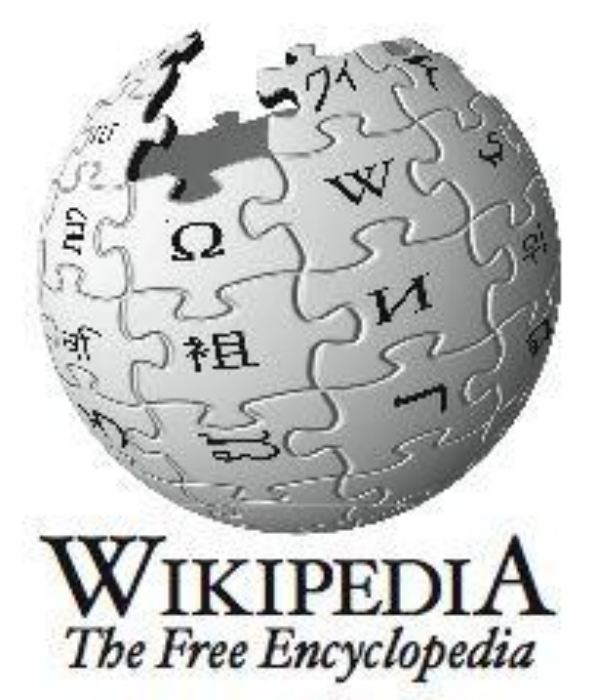
Community Internet Intensity Map



Nisqually

2/28/2001

Wiki-Geo-Pedia?



"Thousands of people, all over the world, from all cultures, working together in harmony to freely share clear, factual, unbiased information… [with the] simple and pure desire to make the world a better place."

Wikipedia Founder Jimmy Wales

Observations

- Distributed sensing
  - Many not necessarily "sophisticated sensors"
  - Specific task / protocol
  - Proper data gathering / transfer
- Distributed content development
  - Unprecedented opportunities
  - Development of large databases
  - New information…
    - new understanding…
      - new questions…

Databases

From data to knew understanding

To identify the critical parameters

Risk of heart complications (Database: 10,682 patients - 7 hospitals)

Q-waves in electrocardiograms

low systolic blood pressure

abnormal respiratory sound with fine crackles

exacerbation of known reduced blood flow to the heart

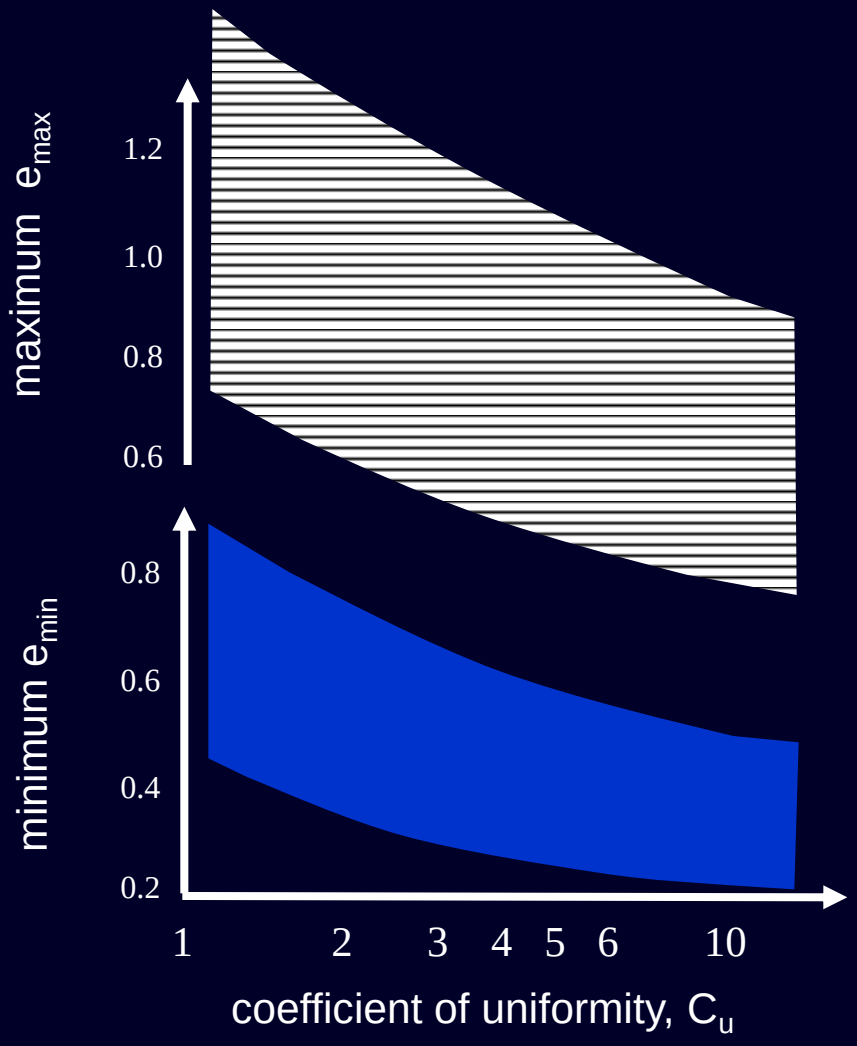
Better practice/diagnosis

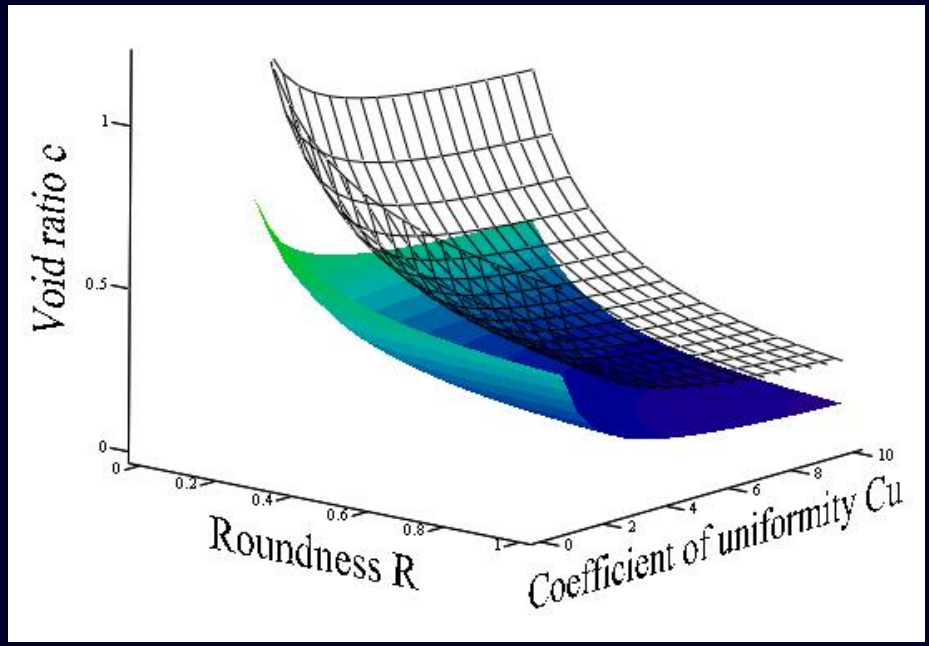
Lower cost

Enhanced understanding

Guide to further research

To identify the n^{th} control variable

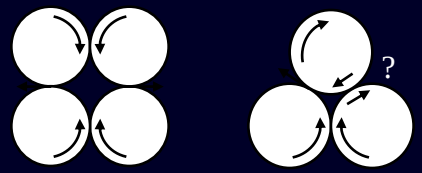


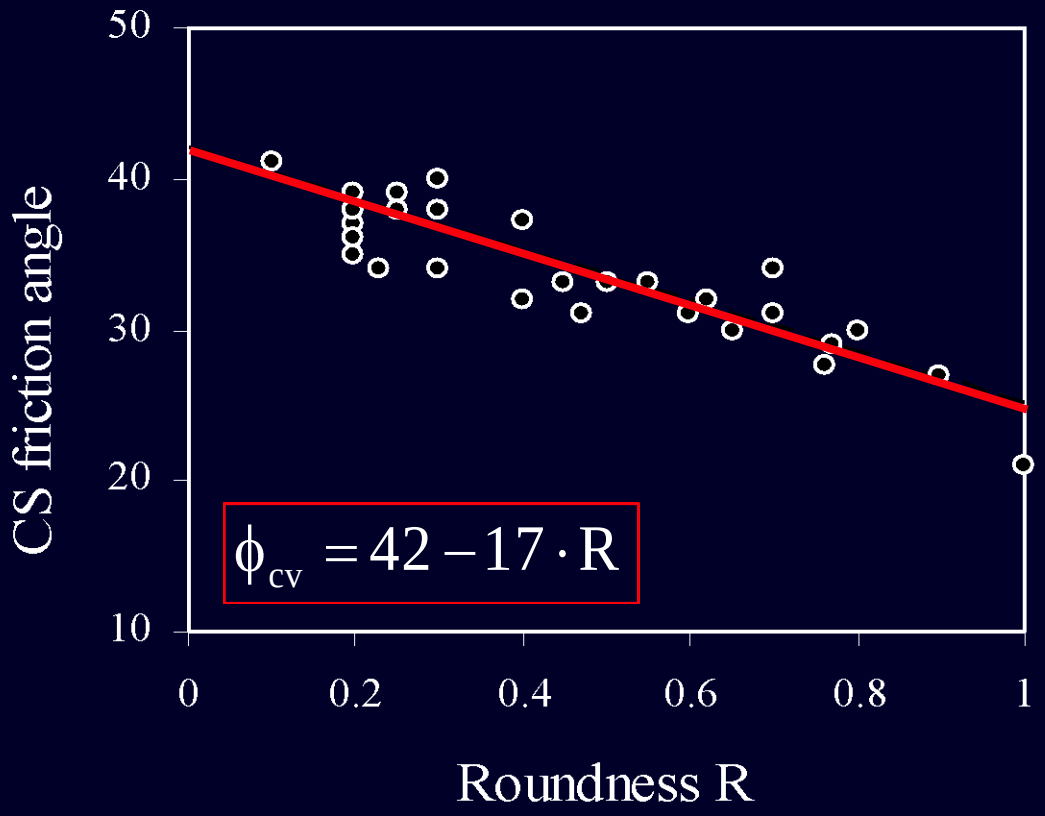


To explore causal relations

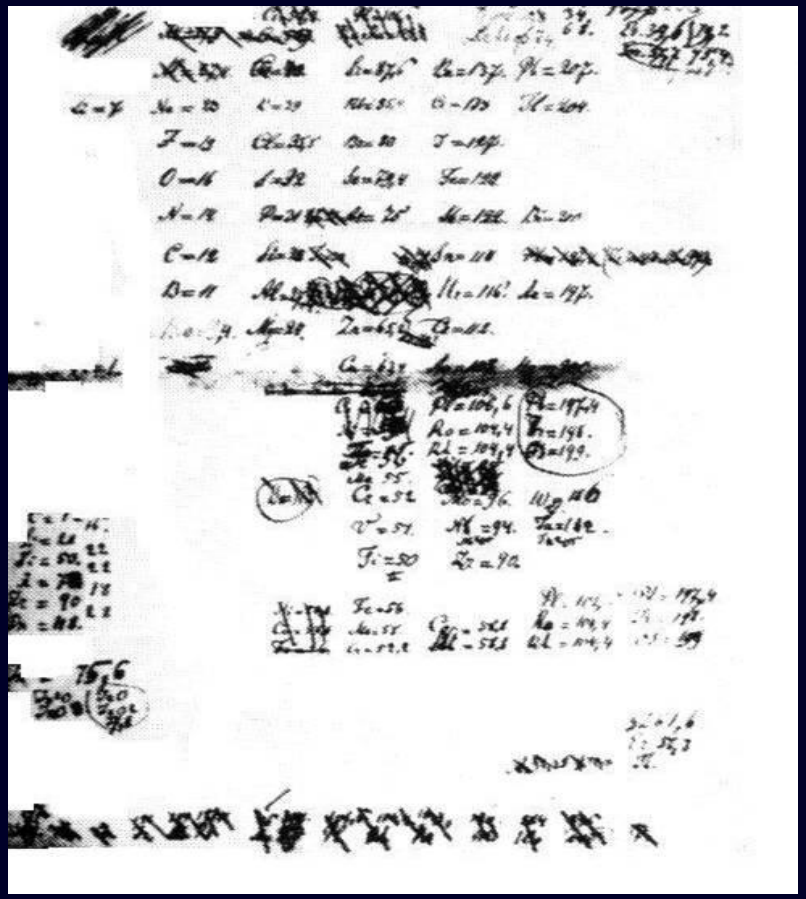
rotational frustration (e↑)

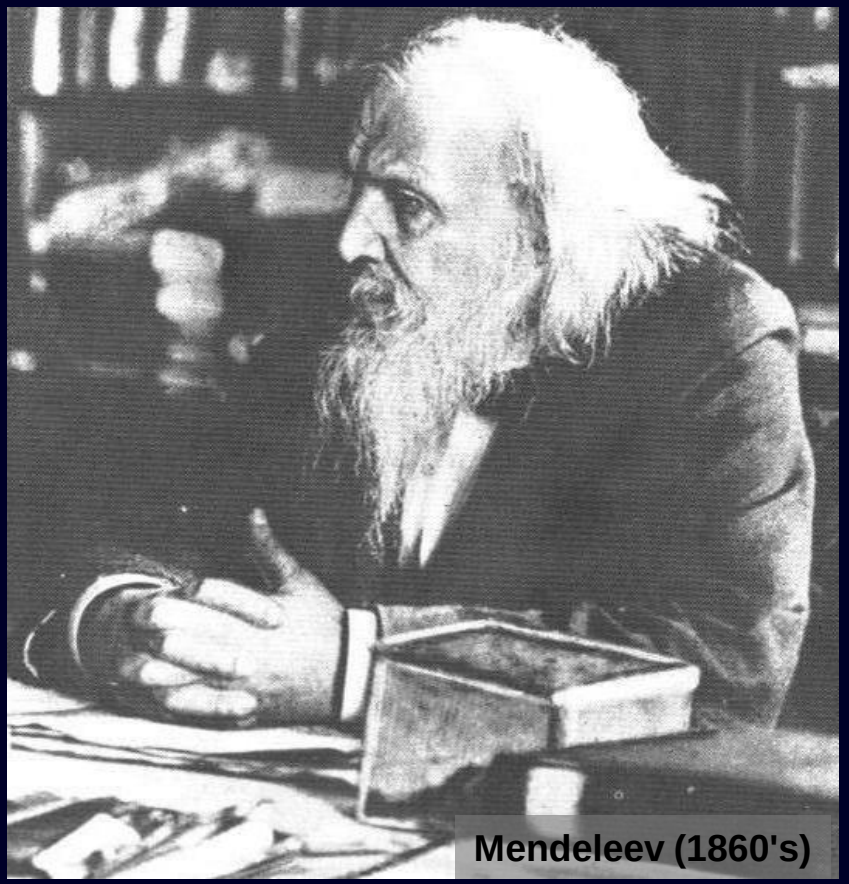
vs. chain collapse (e↓)





Spatial Systematic Organization

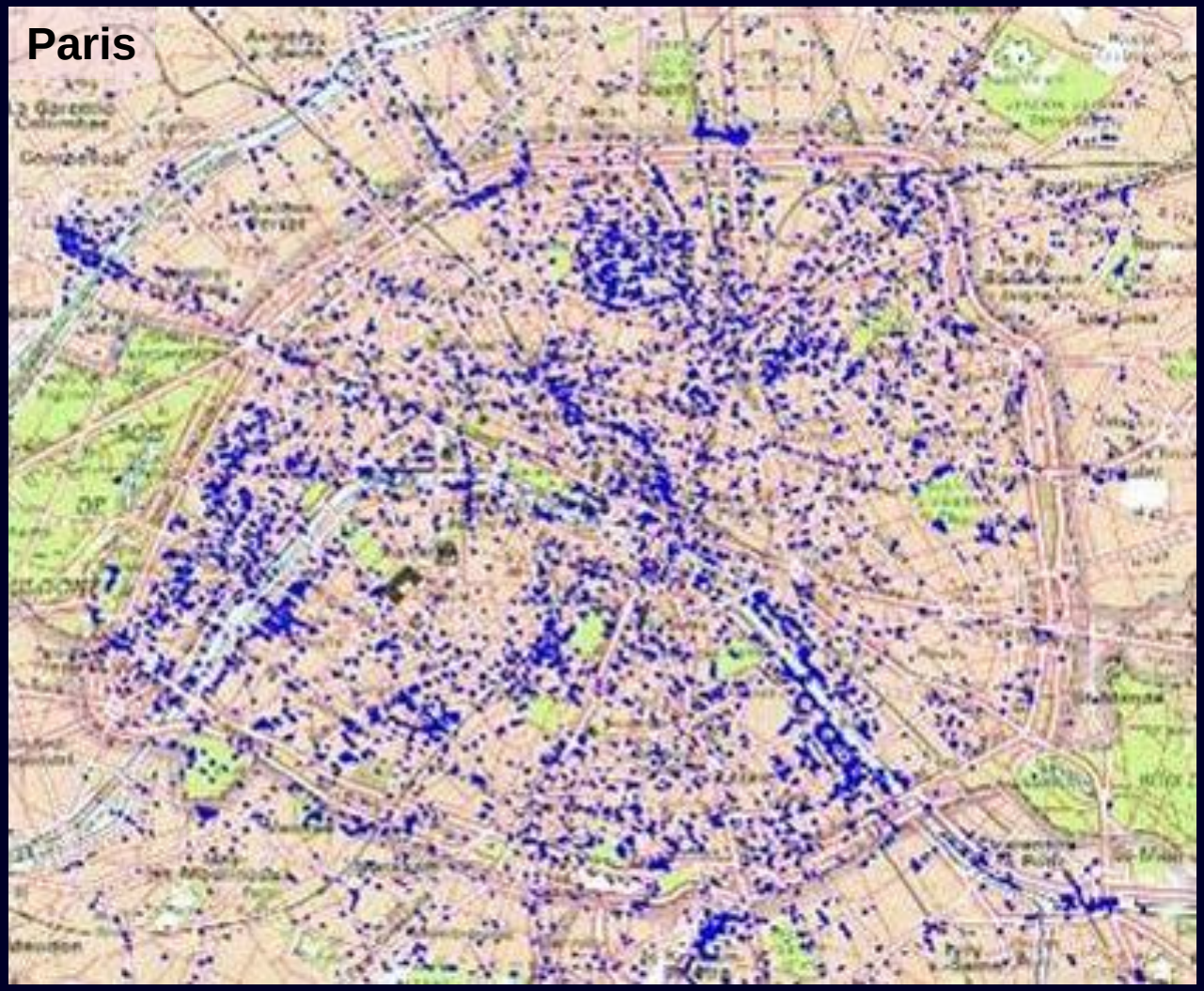




Mendeleev (1860's)

Bronowski

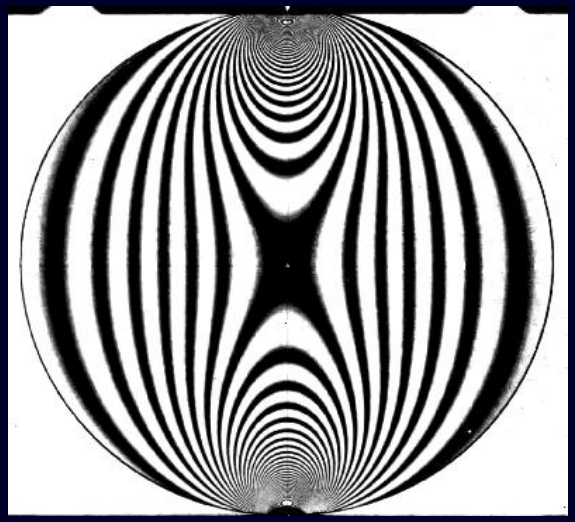
Spatial organization + analyses: GIS

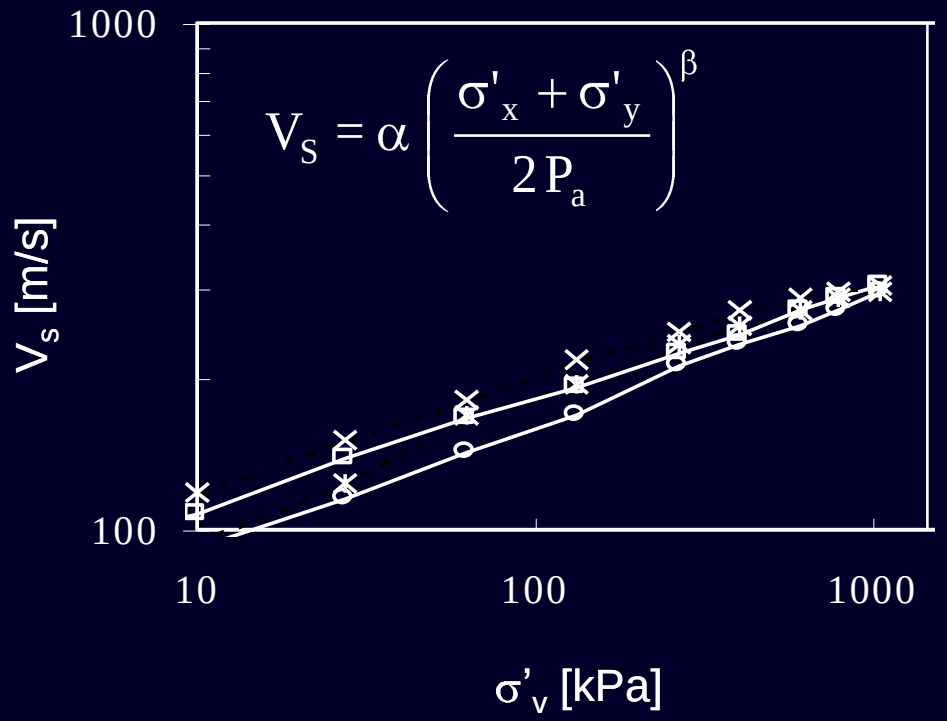


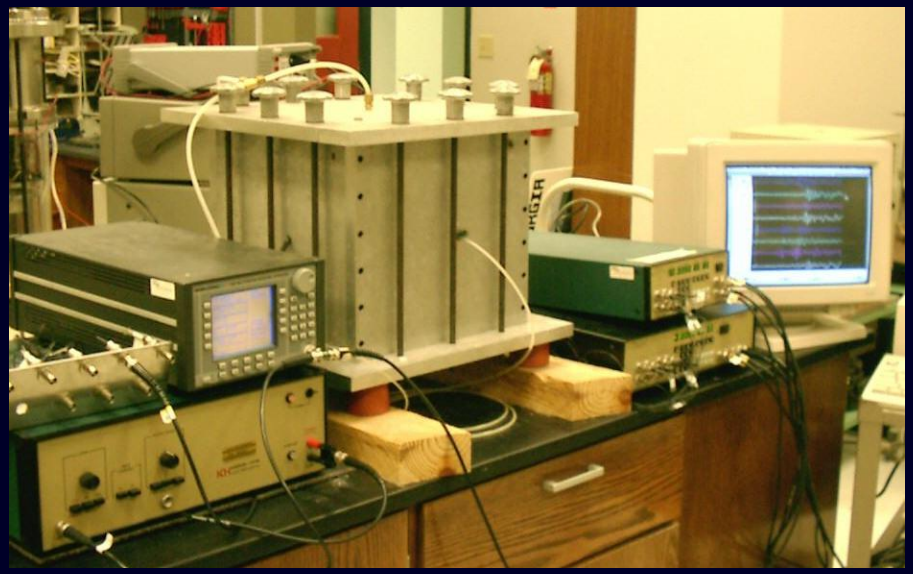
Paradigm Shifts

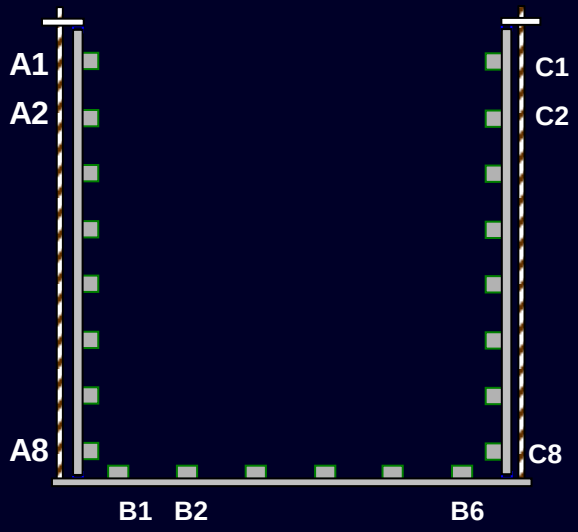
The future ain't what it used to be …
Yogi Berra

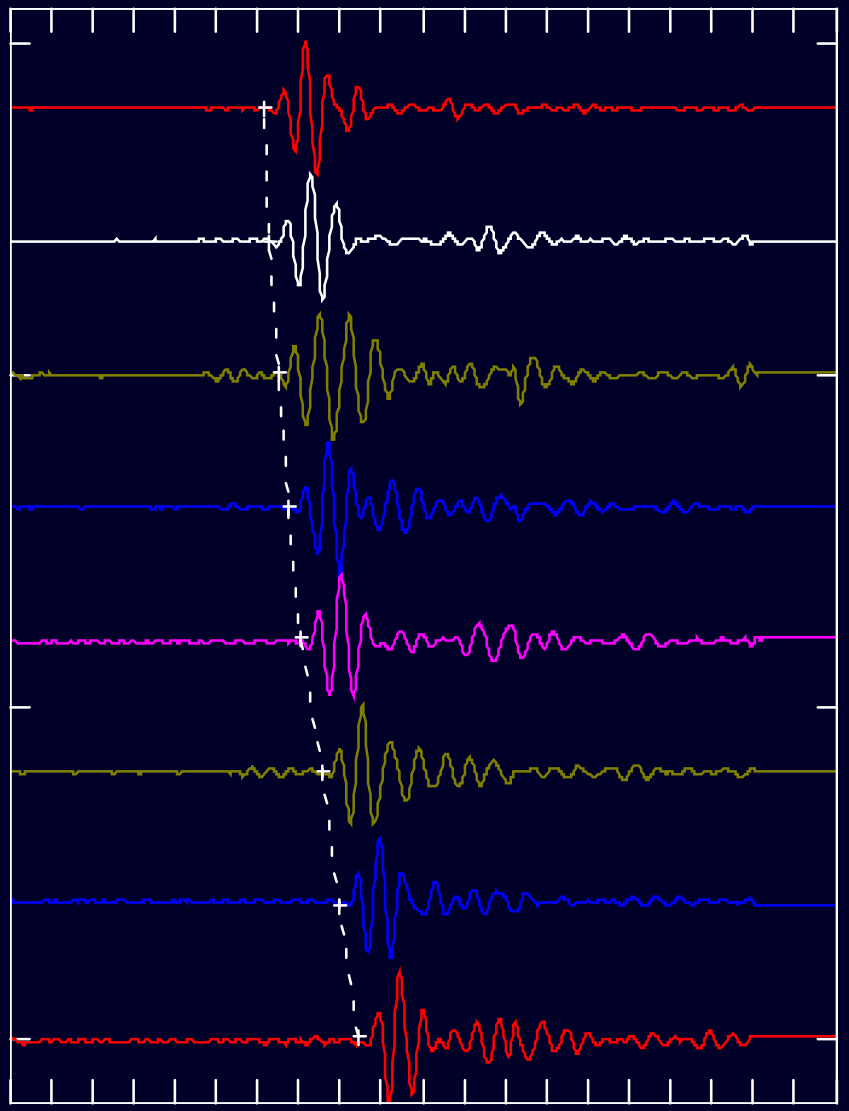
"inert soils" → "self-sensing media"

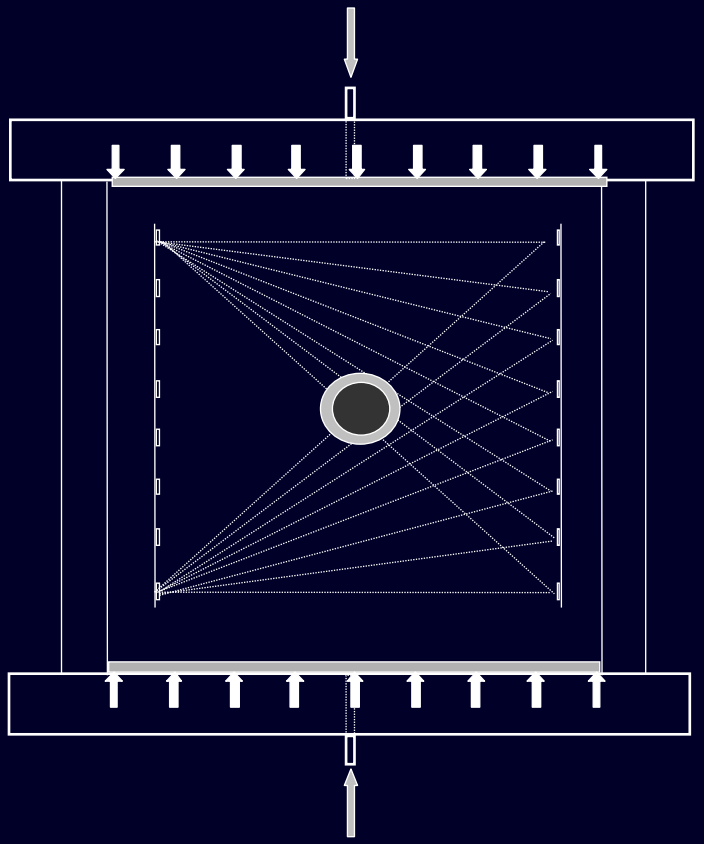


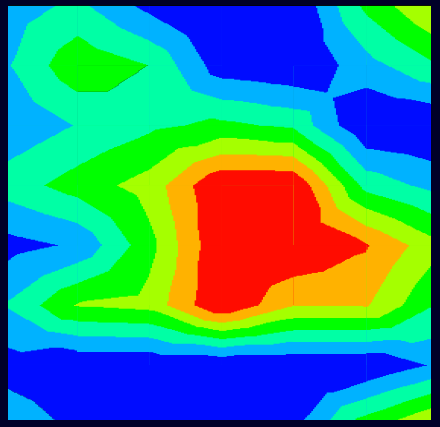


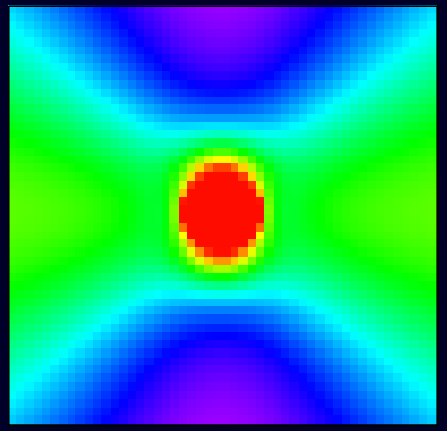


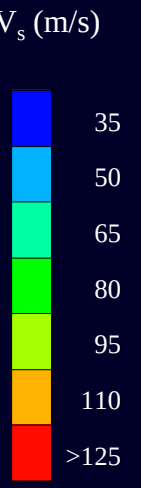

A1
A2
A8
C1
C2
C8
B1
B2
B6









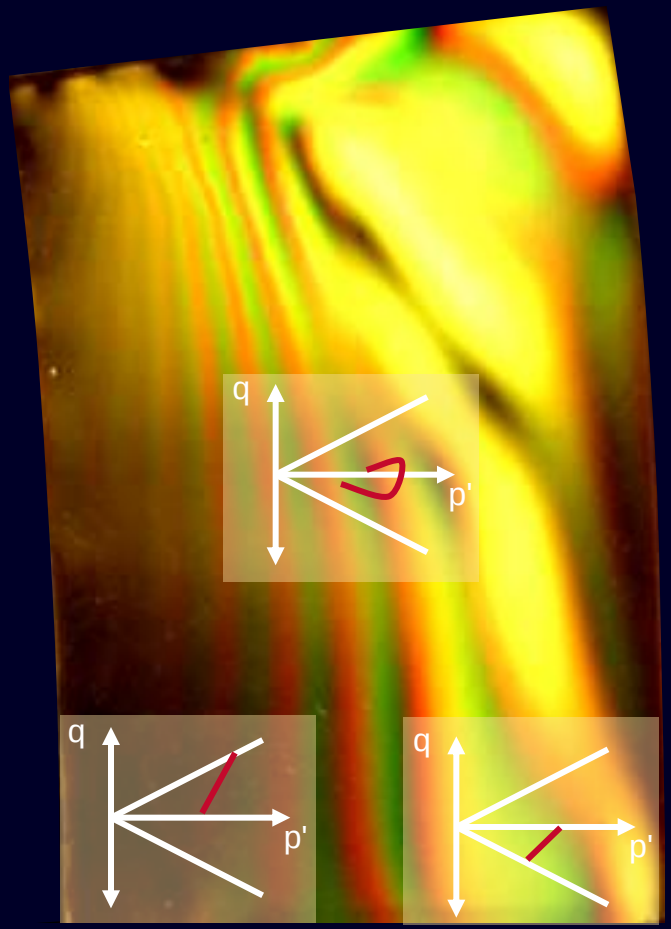


Pixel
(RLSS)

Parametric
(L-norms)

Fernandez, Lee

"n-simple tests" → "one information-rich test"

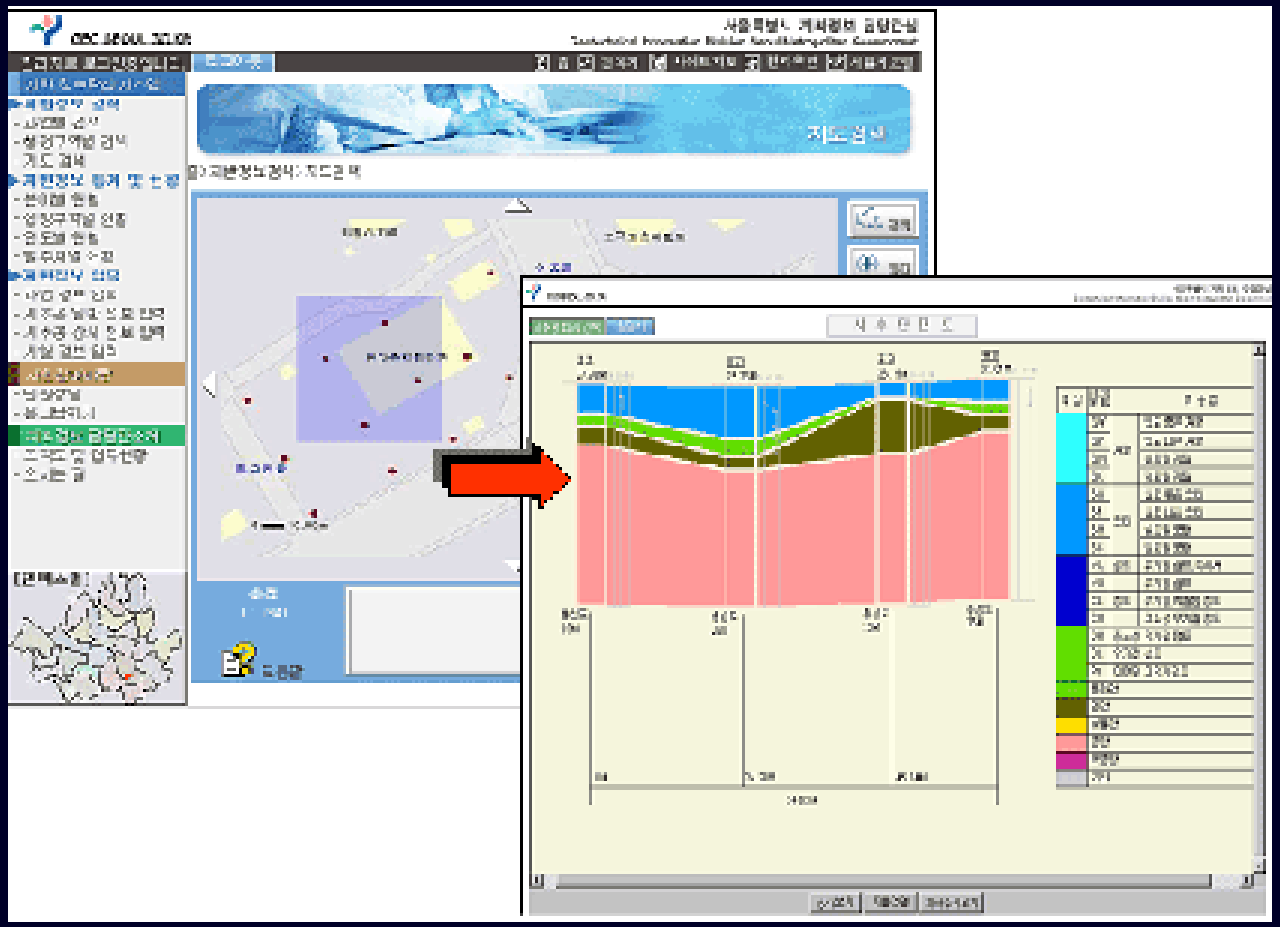


See also A. Rechenmacher: spatial variability

	Old Paradigm	New Paradigm
Philosophy	many simple tests	a few, information-rich tests
Boundaries	simplest possible	complex
Measurements	very few	many (x,y,z,t) multisensor
Interpretation	simplest inversion	comprehensive inversion
Information per test	very limited	as much as needed
Number of tests	many	one may be sufficient

"site investigation" → "model confirmation"

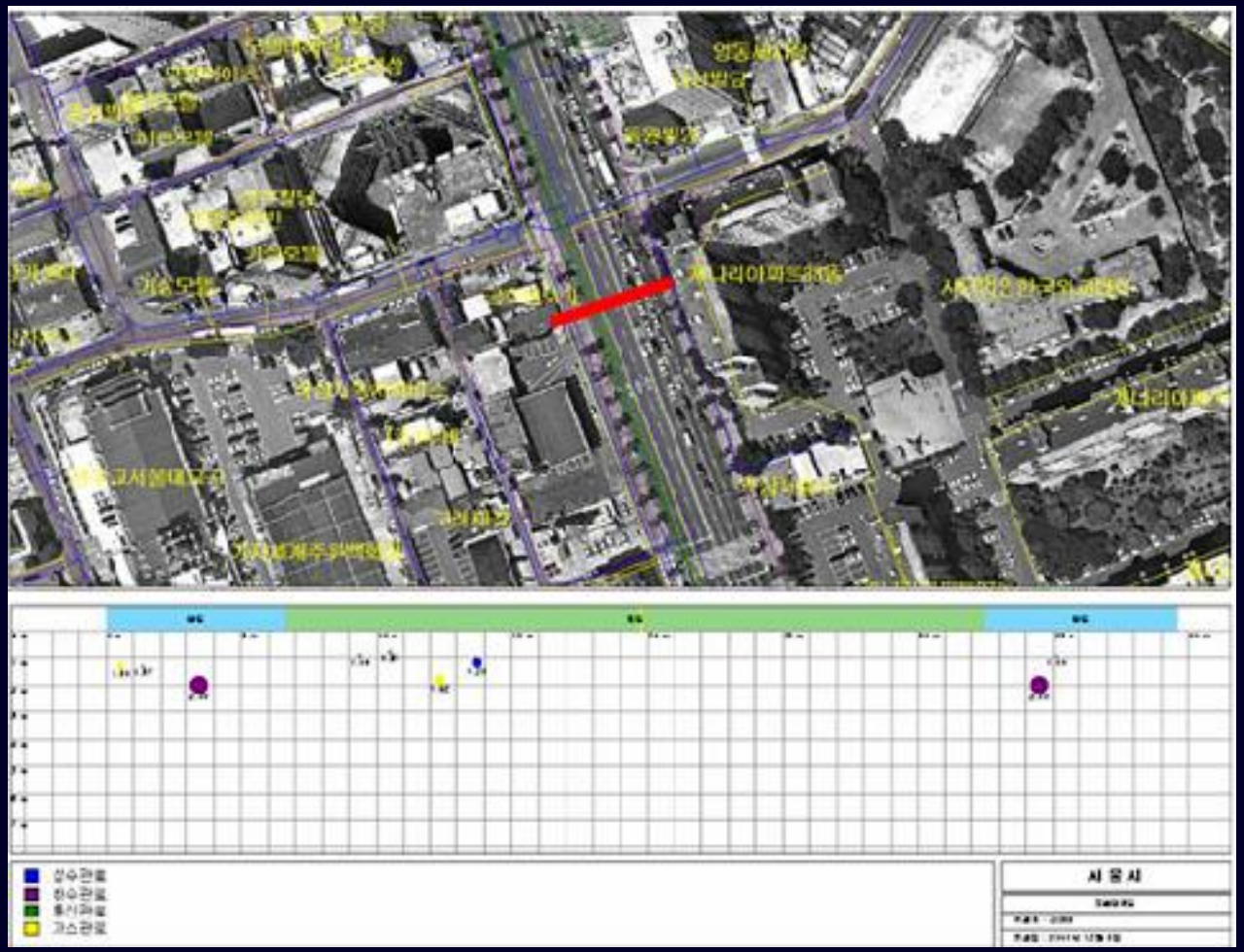
Seoul - GIS



Stratigraphy

gis.seoul.go.kr

Seoul - GIS

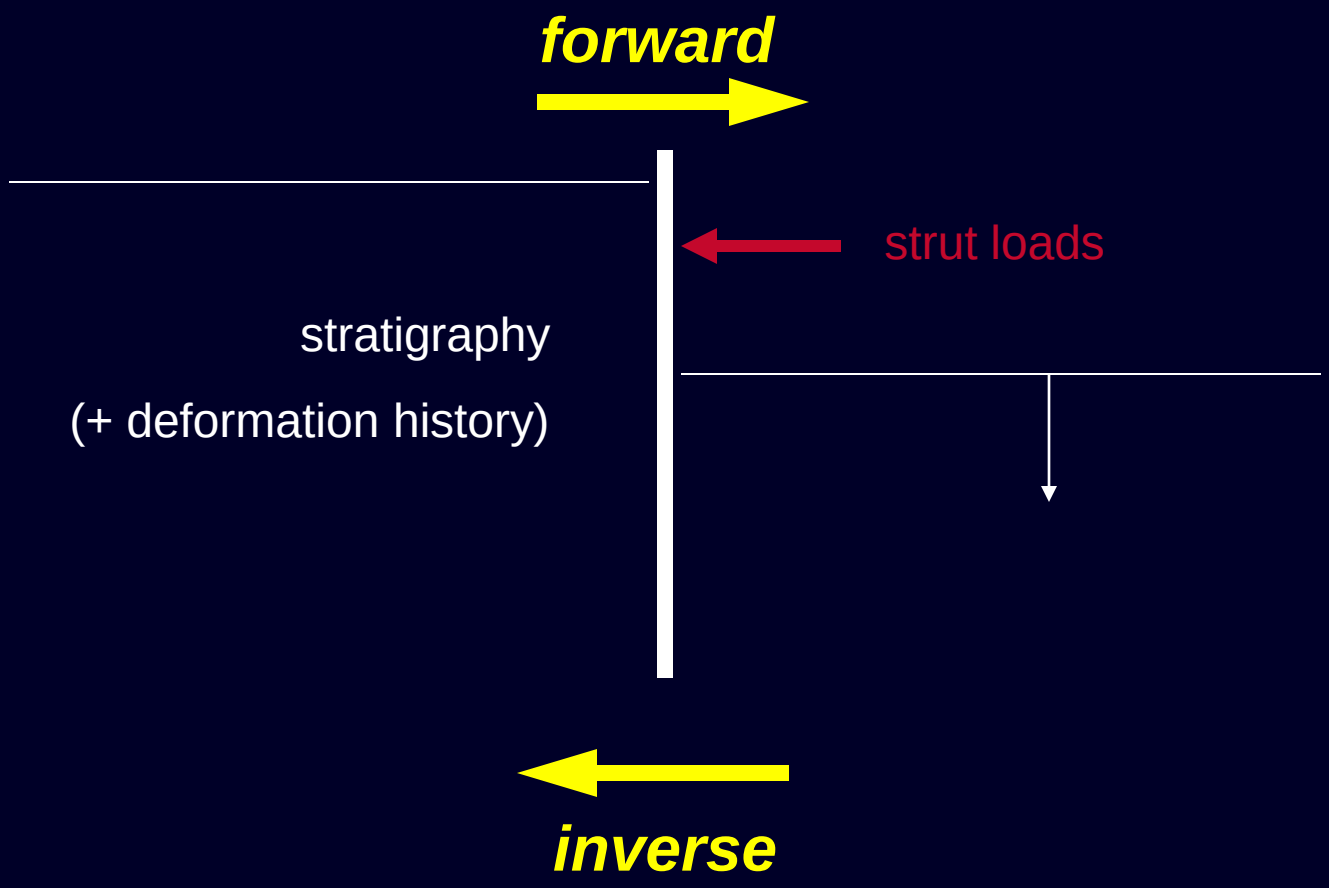


Sub-surface Infrastructure

gis.seoul.go.kr

	Old Paradigm	New Paradigm
Philosophy	"go and see"	test a model
Starting point	limited	GIS-based model of the site
Tools	minimal	extensive, multisensor
Real time optimization	none	probabilistic; spatial variability
Interpretation	simple, @office	model testing/updating, @site
Design parameters	printed correlations	based on extensive database

"design+build" → "predesign+build+monitor+adapt"



Smart, self-diagnosing, adaptive/healing

The Human Side

Our Profession and the IT age

Communications: worldwide, multidisciplinary teams

"The world is flat": outsourcing …keep technological edge

The digital divide:

- "information rich" and "information poor"
- across generations, social classes and countries
- contributes to widening the economic gap

Education in the IT age

New Study programs: "working knowledge" on..

- sensors and sensor networks
- communication systems
- databases
- signal processing & inverse problems
- application of numerical methods

Approach problem solving with renewed ingenuity

May replace current "how-to-do" training

Must not downgrade fundamental understanding

During the last 40 minutes…

You have received

6 phone calls in your cell phone

1 voice mail in your fixed phone

8 e-mails (2 spam)

etc …

etc …

etc …

"Digital Attention Deficit Disorder": a real concern !

Closing Thoughts

Unprecedented concurrent growth in various fields

Embracing IT affects: teach, learn, research, solve problems

New solutions based on fundamentals
- soils
- data and information
- measurement
- inversion

Time for best engineering skills and ingenuity
- to explore new problem solving strategies

IMAGINE geotechnology with
- inexpensive sensors, unlimited data (z,t)
- readily searchable comprehensive databases
- powerful user friendly analysis and simulation software …