GeoCongress 2006 - Geotechnical Engineering in the IT Age

Geotechnology: Paradigm Shifts in the Information Age

J. Carlos Santamarina
Georgia Institute of Technology
Information Technology - Synergism:

- microelectronics
- computers
- data storage and display
- sensors
- digital data analysis
- inverse problem solving
- numerical methods
- communications (cell phones - internet)
## Interwoven History

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1910's</td>
<td>Fredholm: generalized inverse</td>
</tr>
<tr>
<td>1920's</td>
<td><strong>Consumer electronics</strong> (radios, electronic phonographs)</td>
</tr>
<tr>
<td>1930's</td>
<td>Car radios and portable radios</td>
</tr>
</tbody>
</table>
| 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

Transistors per Chip

Year


1.E+03 1.E+05 1.E+07 1.E+09

data from Birnbaum and Akinwande
Storage

2006: < $10/GB

data from Kurzweil
The brain - Storage

- Each neuron stores 1 bit
- Brain: ~1 TB
- Cost: 10,000 $

- Each synapse stores 1 bit
- Brain: ~100 TB
- Cost: 1 million $

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2006 Computer Capabilities

- Each molecule stores 1 bit
- Brain: ~10^7 TB
- Cost: 100 billion $
Calculations per second

2006: $10^4$ MIPS computers
Brain: $10^8$ MIPS

doubles: 19 months

data from Kurzweil; Moravec
Communications

- Data from Kurzweil

2.29.09

- MBytes per second per $ doubles: 10 months
- MBytes per second per $ doubles: 7 months
- Wireless
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 in 10-to-20 years

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

Micro-mirror array

Bell Labs
Fiber optic based pressure transducer

0-to-70 kPa to 0-to-7 MPa

www.fiso.com
Distributed Optical TDR Sensors

- Strain (Dowding)
- Pore fluid chemical properties
- Moisture content (Brillouin - Pamukcu)
- Temperature (Raman - SENSA)

30 km ... every 1 m ... 1°C resolution
Soil = innate sensing system

(N. Skipper – UCL 2002)
Signals → Information

Water Level [m]

Days

7/1/05 9/30/05

Pilots Station, Louisiana – NOAA
Before Katrina
After Katrina
Massive data → Display → Information

Bathymetry: 200 kHz
Sub bottom profiling: 20 kHz

Pile 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

Biloxi → I-110 Bridge → D’Iverville

NSF - D. Fratta
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: Multi Mode

Navigational

Homing in

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

www.moorhen.demon.co.uk
Cementation - Elastic waves

\[ \sigma' = 70 \text{ kPa} \]
Cementation - Electromagnetic waves

- $k'/k'_o$
- $k''_{eff}/k''_{effo}$

(time [days])

(bentonite-cement)
Observations

Signal processing = information extraction
- noise control
- similarities between signals
- simple algorithms may be sufficient

Data fusion = new information from:
- multiple same-mode sensors
- multi-modal sensors
- spatially distributed sensors
- concurrent or time-shifted data streams
Inversion

Sensing at boundaries ... learning about the body
From CAUSE to EFFECT

forward
From EFFECT back to CAUSE
Tomography

Unknown internal conditions
\[ \begin{bmatrix} t_1 \\ t_2 \\ t_3 \\ t_4 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} & 0 & 0 \\ 0 & 0 & h_{2,3} & h_{2,4} \\ h_{3,1} & 0 & h_{3,3} & 0 \\ 0 & h_{4,2} & 0 & h_{4,4} \end{bmatrix} \begin{bmatrix} 1/V_1 \\ 1/V_2 \\ 1/V_3 \\ 1/V_4 \end{bmatrix} \]
Micro Computed Tomography
## Inversion: Ubiquitous in Geotechnology

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

Conceive all experiments within the 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

www.birdsource.org/gbbc
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 new 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↓)

\[ \phi_{cv} = 42 - 17 \cdot R \]
Spatial Systematic Organization

Mendeleev (1860's)
Spatial organization + analyses: GIS
Paradigm Shifts

The future ain’t what it used to be …
Yogi Berra
"inert soils" → "self-sensing media"

\[ V_S = \alpha \left( \frac{\sigma_x' + \sigma_y'}{2P_a} \right)^\beta \]

\[ \sigma_v' \text{ [kPa]} \]

\[ V_s \text{ [m/s]} \]
"n-simple tests" → "one information-rich test"

See also A. Rechenmacher: spatial variability
<table>
<thead>
<tr>
<th>Philosophy</th>
<th>Old Paradigm</th>
<th>New Paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philosophy</td>
<td>many simple tests</td>
<td>a few, information-rich tests</td>
</tr>
<tr>
<td>Boundaries</td>
<td>simplest possible</td>
<td>complex</td>
</tr>
<tr>
<td>Measurements</td>
<td>very few</td>
<td>many (x,y,z,t) multisensor</td>
</tr>
<tr>
<td>Interpretation</td>
<td>simplest inversion</td>
<td>comprehensive inversion</td>
</tr>
<tr>
<td>Information per test</td>
<td>very limited</td>
<td>as much as needed</td>
</tr>
<tr>
<td>Number of tests</td>
<td>many</td>
<td>one may be sufficient</td>
</tr>
</tbody>
</table>
"site investigation" → "model confirmation"

Seoul - GIS

Stratigraphy

gis.seoul.go.kr
<table>
<thead>
<tr>
<th><strong>Old Paradigm</strong></th>
<th><strong>New Paradigm</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Philosophy</strong></td>
<td>&quot;go and see&quot;</td>
</tr>
<tr>
<td><strong>Starting point</strong></td>
<td>limited</td>
</tr>
<tr>
<td><strong>Tools</strong></td>
<td>minimal</td>
</tr>
<tr>
<td><strong>Real time optimization</strong></td>
<td>none</td>
</tr>
<tr>
<td><strong>Interpretation</strong></td>
<td>simple, @office</td>
</tr>
<tr>
<td><strong>Design parameters</strong></td>
<td>printed correlations</td>
</tr>
</tbody>
</table>
"design+build"  →  "predesign+build+monitor+adapt"

- forward
- stratigraphy (+ deformation history)
- inverse
- strut loads
### Old Paradigm  |  New Paradigm

<p>| | | |</p>
<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
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<tbody>
<tr>
<td><strong>Sensor system</strong></td>
<td>minimal</td>
<td>spatially distributed, multi-mode</td>
</tr>
<tr>
<td><strong>During constr.</strong></td>
<td>sporadic measurements</td>
<td>continuous monitoring</td>
</tr>
<tr>
<td><strong>Interpretation</strong></td>
<td>minimal - limited use</td>
<td>continuous - extensively used</td>
</tr>
<tr>
<td><strong>Inferred infor.</strong></td>
<td>just measured data</td>
<td>comprehensive inversion</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>&quot;probably&quot; over-designed</td>
<td>known, adequate safety</td>
</tr>
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*Observational Method in the information age*
Closing Thoughts
During the last 30 minutes…

You have received
- 2 phone calls in your cell phone
- 1 voice mail in your fixed phone
- 5 e-mails (2 spam)

Your students or employees spent 10 min in instant messenger

Decision on your BlackBerry is still on hold…

"Digital Attention Deficit Disorder": a real concern!
IT revolution: it's here!

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

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

IMagine a renewed geotechnology
inexpensive sensors, unlimited data (z,t)
readily searchable comprehensive databases
powerful user friendly analysis and simulation software …
Thank you

Organizers

Comments and suggestions by:

A Bayoumi     G Cascante     GC Cho
A Fernandez    D Fratta      E Kavazanjian
HK Kim        TH Kwon       JY Lee
G Narsilio    V Rebata-Landa A Schofield
HS Shin       JR Valdes     TS Yun

The Goizueta Foundation