Nexus Geostructural Research Institute

NEXUS

Geotechnical Engineering in the Information Age

adapting to a fluid and data-rich world

Gyeol Han & J. Carlos Santamarina

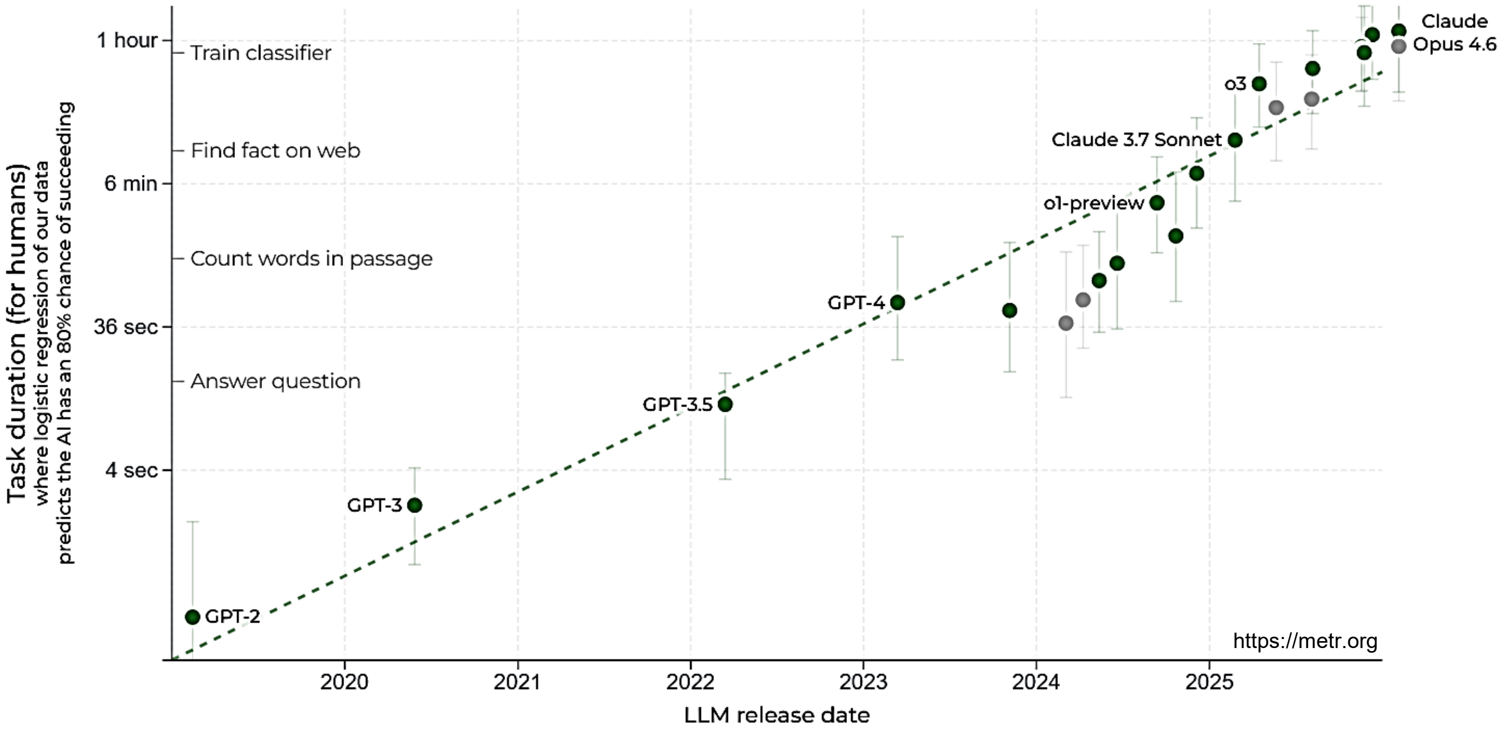
May 5 2026

Rapid Growth

Introducing ChatGPT

Nov 30, 2022

We've trained a model called ChatGPT which interacts in a conversational way. The dialogue format makes it possible for ChatGPT to answer followup questions, admit its mistakes, challenge incorrect premises, and reject inappropriate requests.

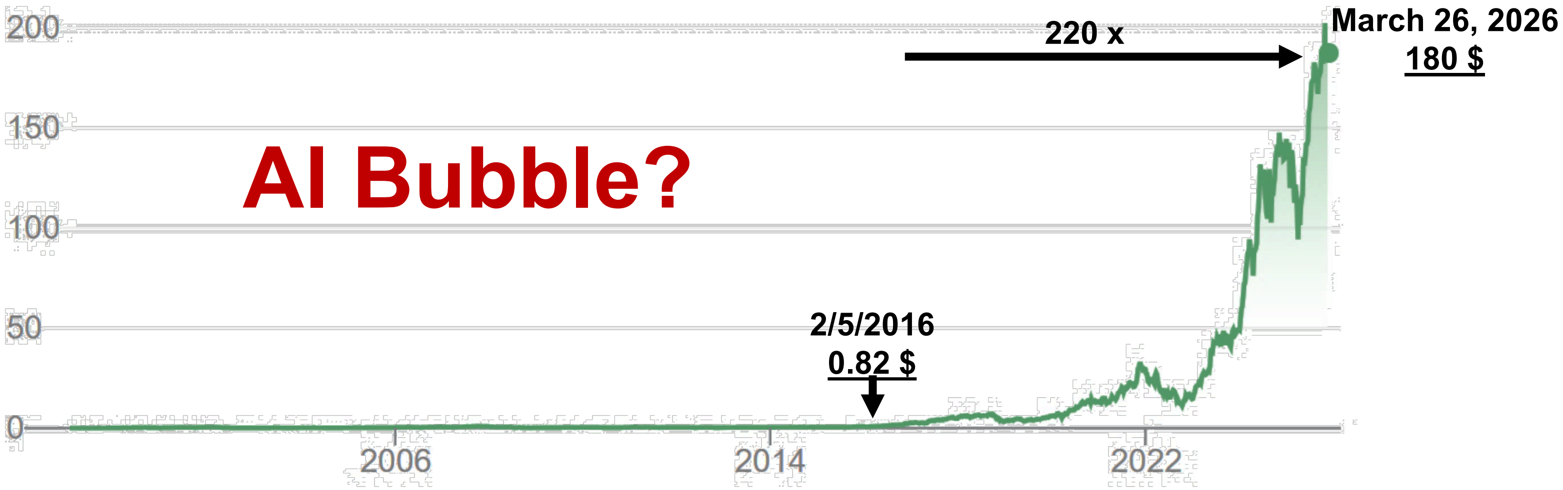


The duration of tasks that AI can complete is doubling every seven months

Economic Impact

Data Centers

NVIDIA



NVIDIA: the largest publicly traded company in the world (most days)

Concerned…?

Tristan Harris *(Google, Netflix: The Social Dilemma)*

- Social control by algorithms
- Recursive self improvement RSI ➔ AI explosion?

Netflix 2020
YouTube, November 27, 2025

Geoffrey Hinton *(Turing Award & Nobel Prize)*

- AI could become uncontrollable
- China is focused … will lead policy to control AI

WS, October 9, 2025

Joshua Bengio *(Turing Award – the most cited scientist)*

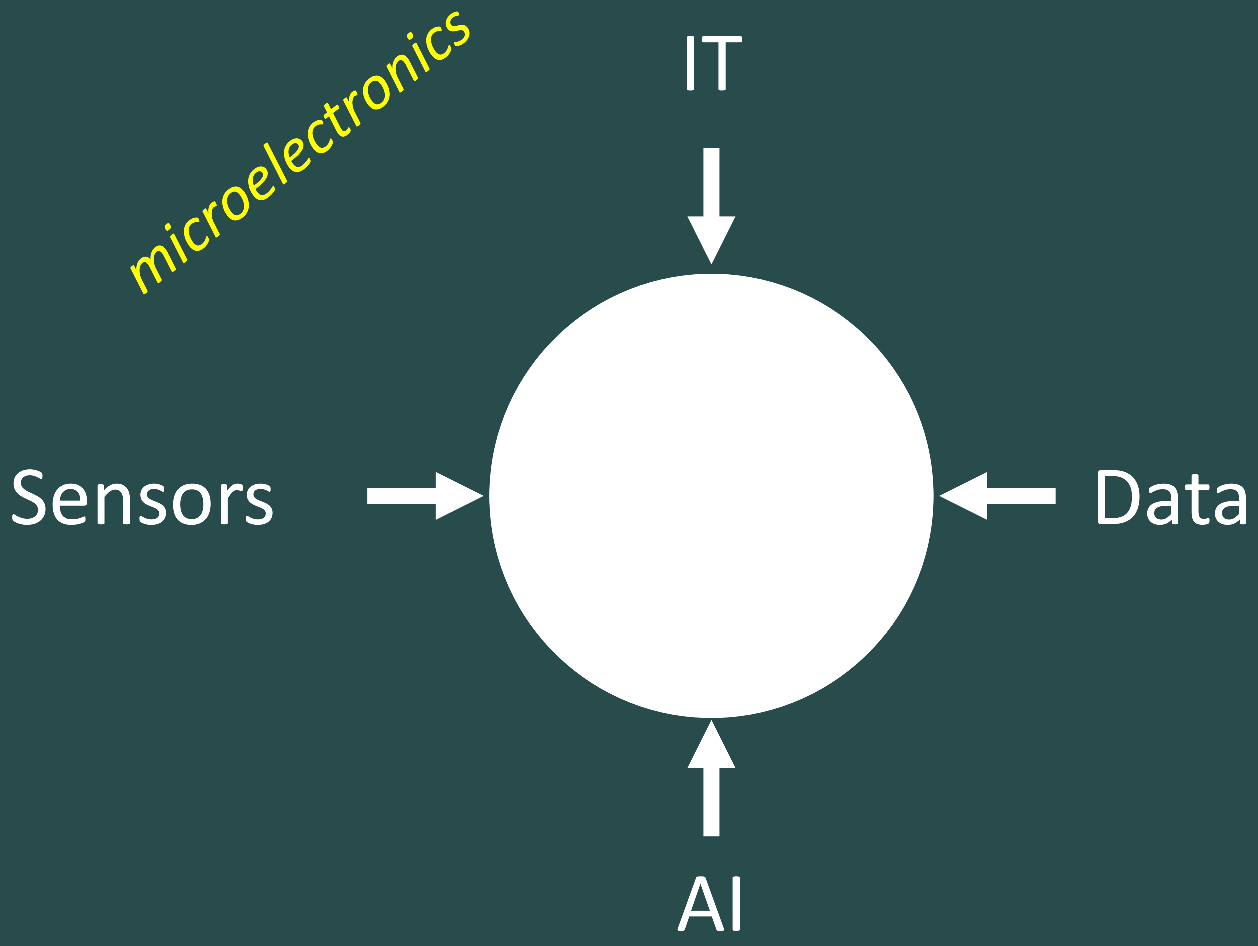
- Signs of "AI agency": deceive, self-protect
- His goal: guardrails against bad AI actor

TED talk, May 2025

Yann LeCun *(Turing Award, Facebook/Meta)*

- Critic of AGI alarmism … not an existential threat
- LLMs: constrained by language ➔ New architecture: learns from videos

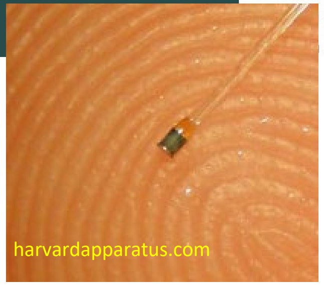
FT, January 2, 2026



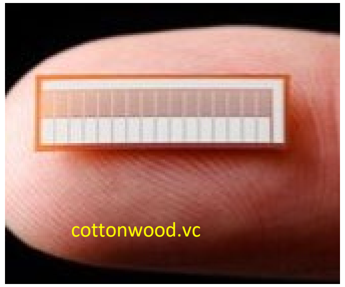
Convergence

(1) Sensors

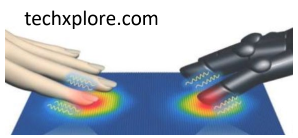
Pressure the Bourdon tube
sub-mm sensor

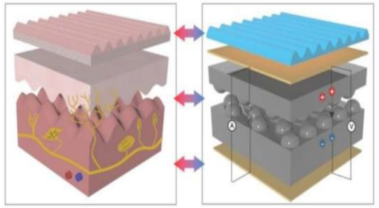


Smell electronic noses 1 sensor/mm^2
our nose: 100-to-1000 chemoreceptors/mm^2 in

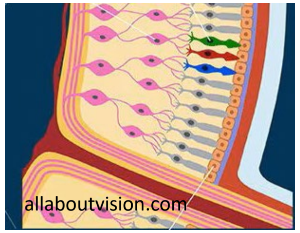


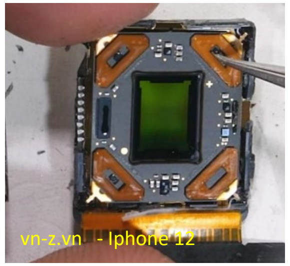
Tactile Pressure-sensitive skins: ~ 1sensor/mm^2
Similar to our skin (fingertips: ~250 receptors/mm^2)





Vision Photodetectors 1 μm size in cellphones cameras
Photoreceptors 3 μm size in our retina



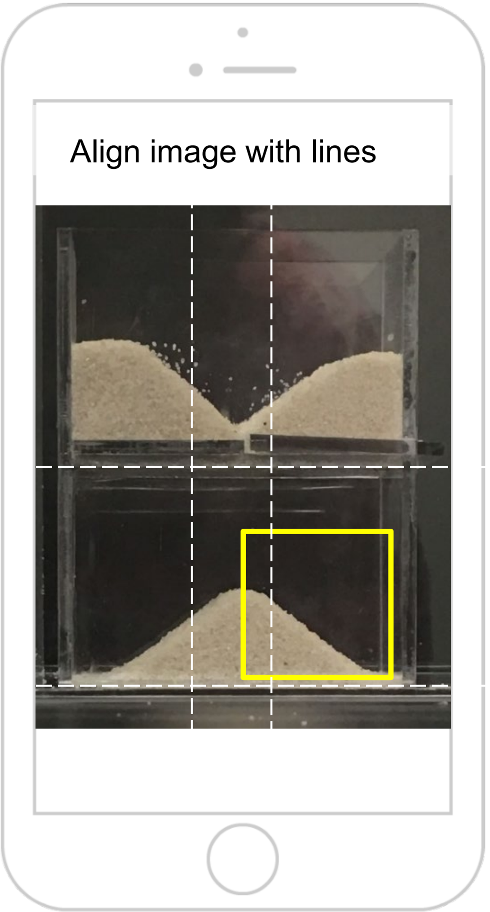


Developments in sensing systems: truly remarkable in last decades

Example: Shape + Size + Friction (Coarse-grained)

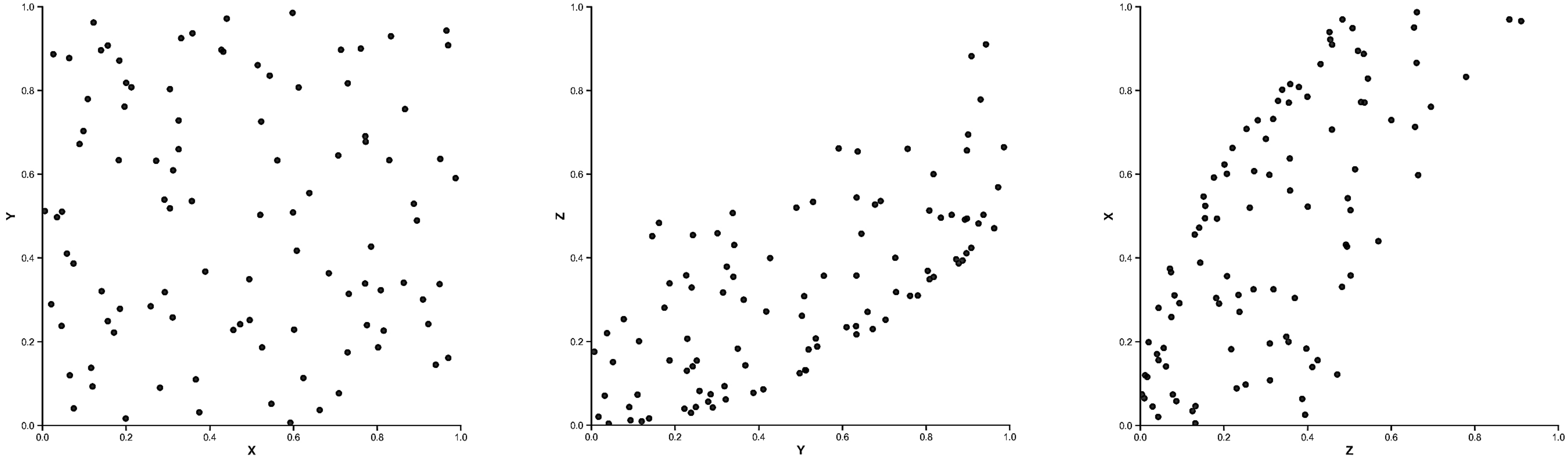
Particle size and shape

CV Friction Angle



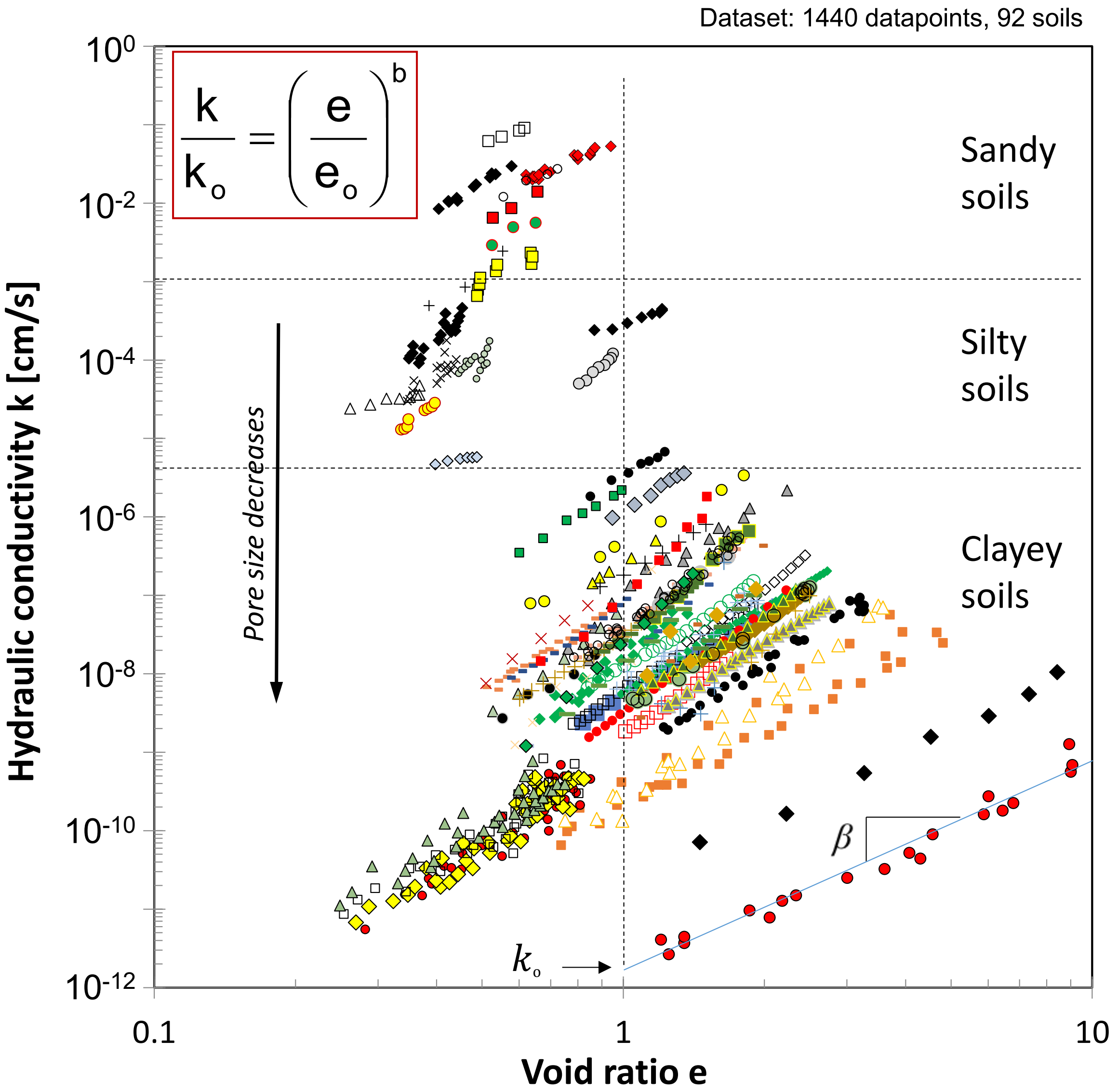
(2) Data …. Dimensionality

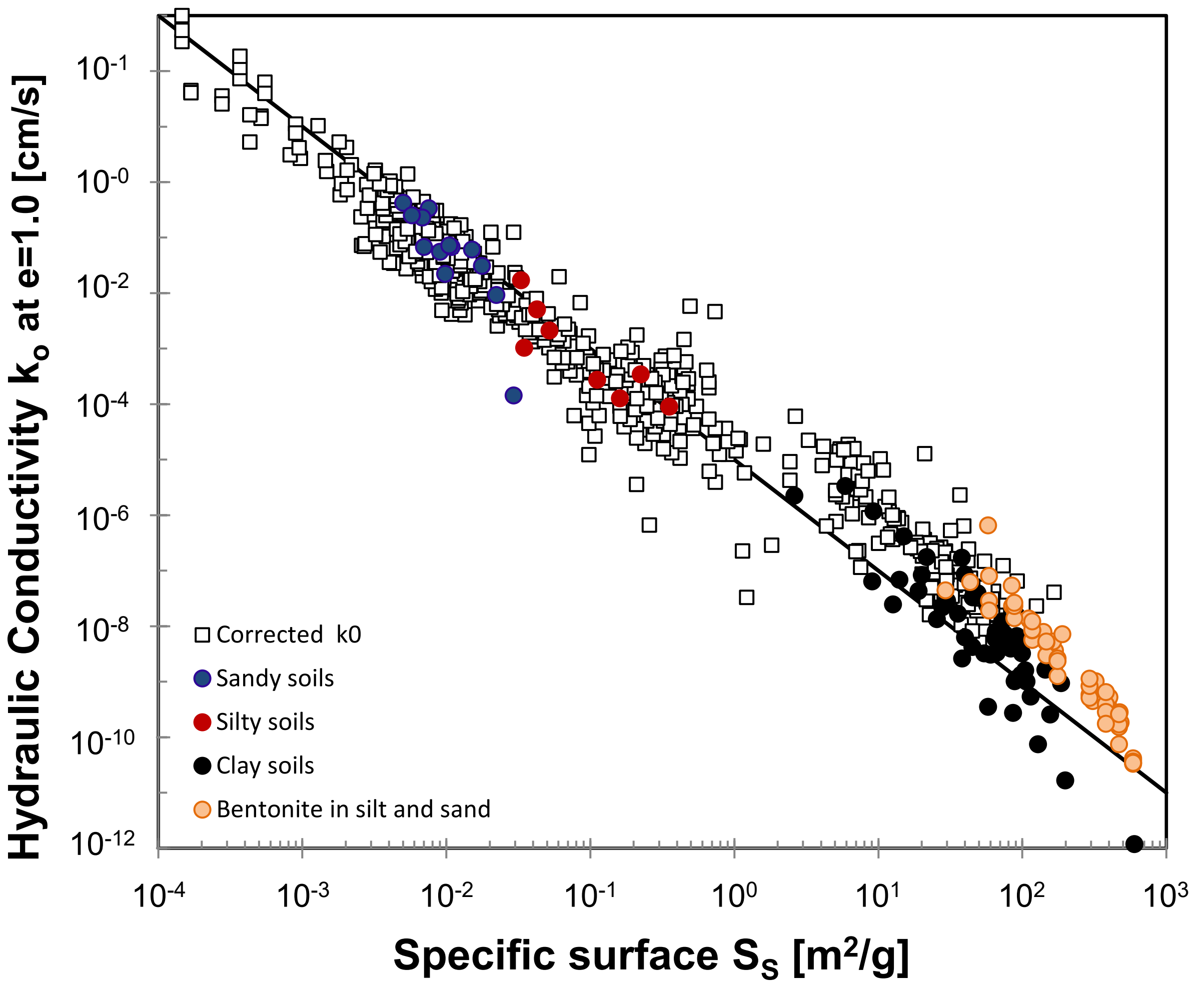
number of variables that describe observation



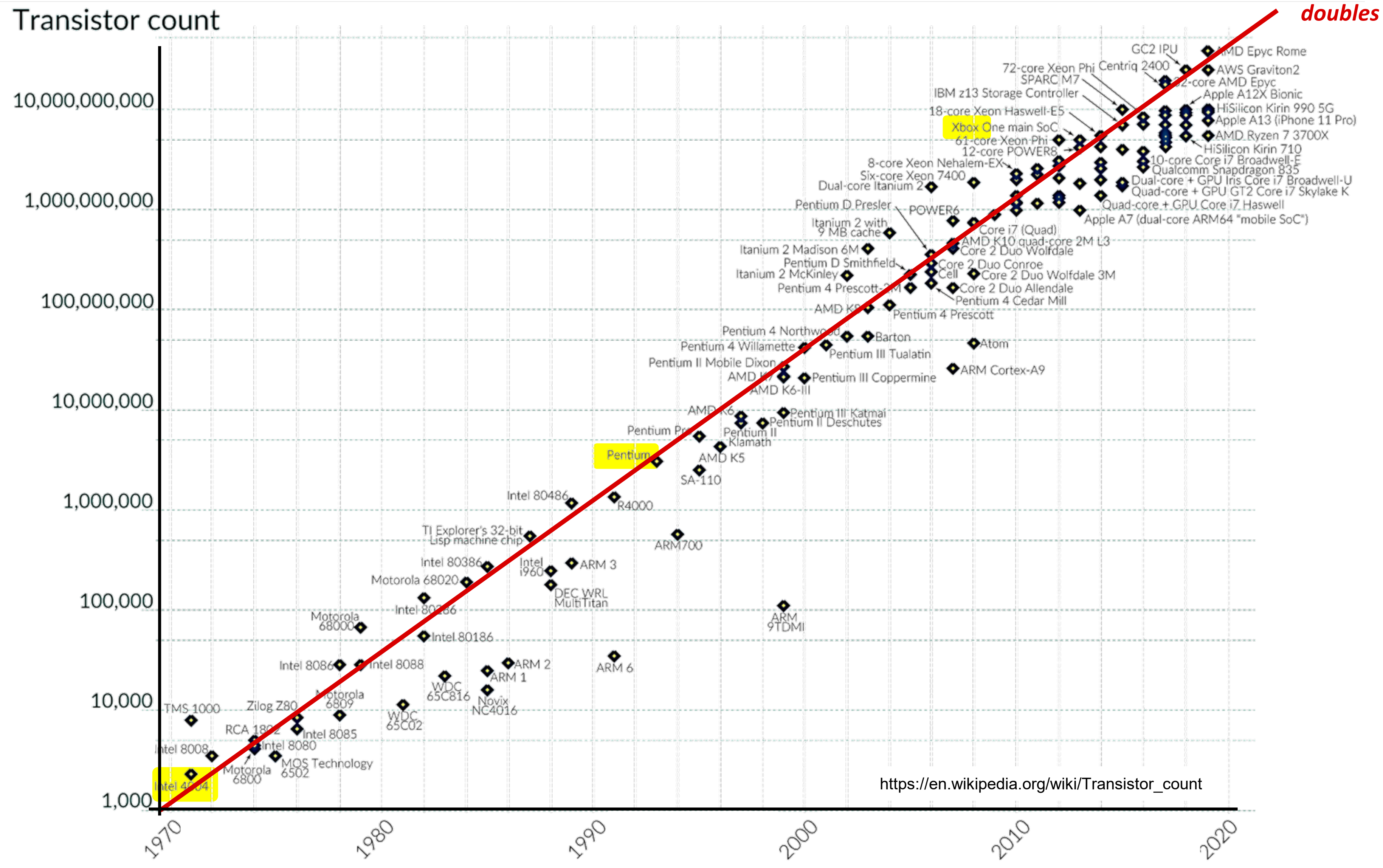
The curse of dimensionality: data sparsity ➔ far apart ➔ harder to detect patterns ➔ find key dimensions

Example: Hydraulic Conductivity





(3) IT revolution (Microelectronics)

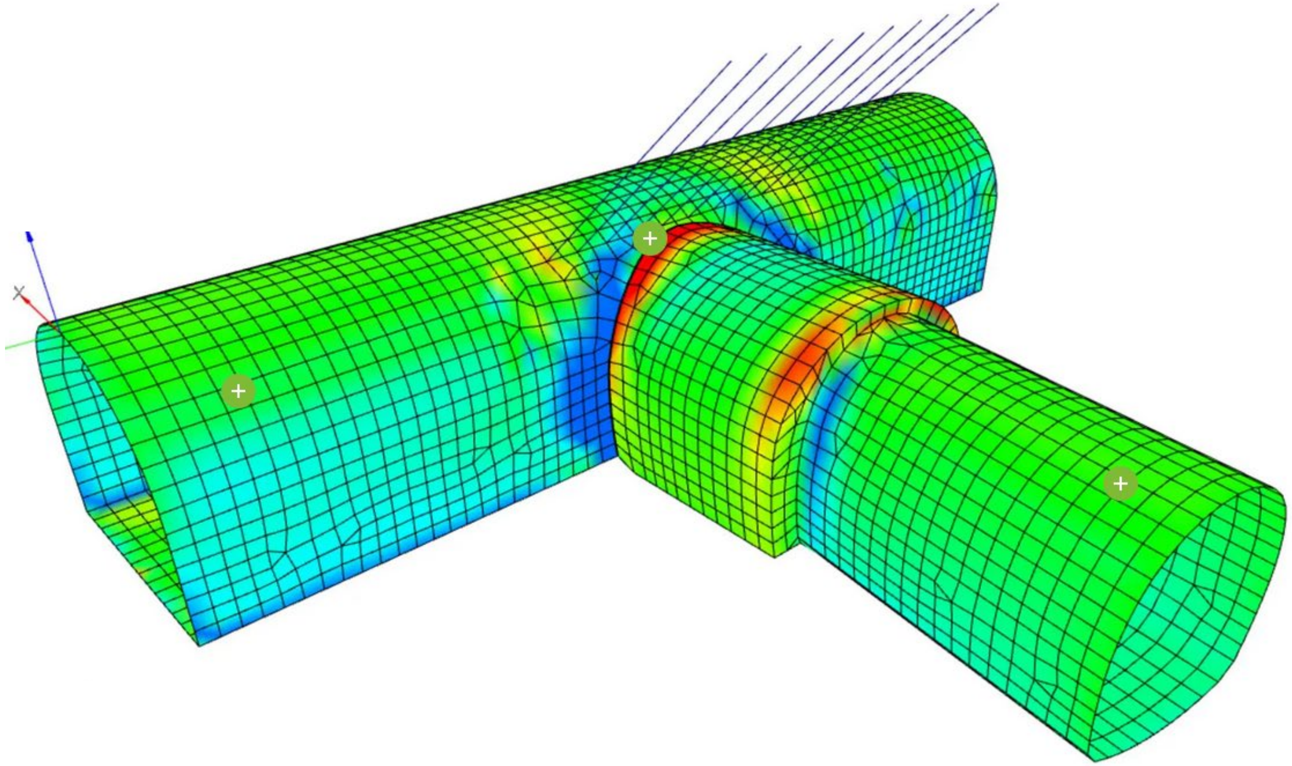


Brain ~ 10^9 synapses per mm^3

2026 Processor ~10^9 transistors per mm^3

Example: Digital Twins = Peck XXI

Bentley.com



Westatix.com

(4) AI = A Gradual Paradigm Shift !

1980's: Expert Systems

our understanding → rules → prediction

EXPERT SYSTEMS FOR GEOTECHNICAL ENGINEERS

By J. C. Santamarina[1] and J. L. Chameau,[2] Associate Members, ASCE

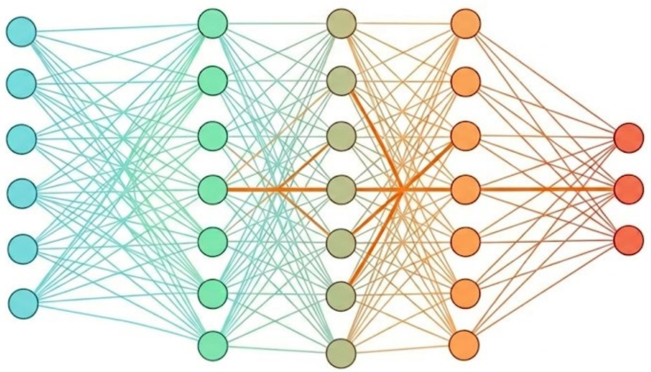
February 10, 1987. This paper is part of the *Journal of Computing in Civil Engineering*, Vol. 1, No. 4, October, 1987. ©ASCE, ISSN 0887-3801/87/0004-0241/$01.00. Paper No. 21897.

NAME : DRIVE-2
IF : piles can be driven
AND
concrete can be used
THEN : use precast concrete piles
IMFA : 0.95

2020's: NN ➔ LLM

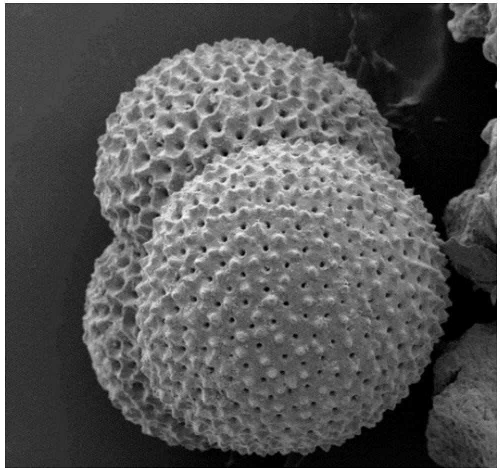
data → training → patterns → prediction

1943	First neuron model	McCulloch & Pitts
1958	Perceptron: First learning NN	Rosenblatt
1982	NN for associative memory	Hopfield
1986	Backpropagation	Rumelhart, Hinton, Williams
2017	Transformer	Google (Vaswani et al)



NN: high-dimensional data, sparse in n-D, unclear causal relationships, lack of well-established physical models

Example: Identifying Soil Grains & Rocks



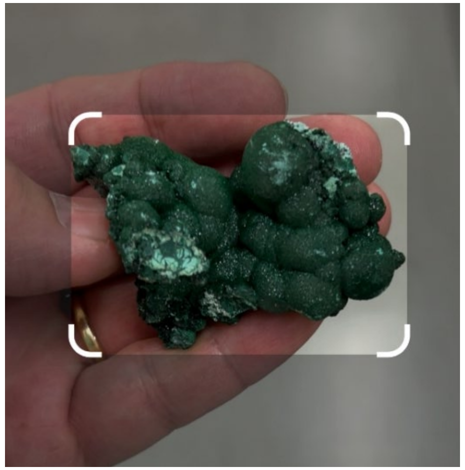
Gemini

This structure is a **planktonic Foraminifera test (shell)**

The particle exhibits several distinct features that are diagnostic for this organism:

Morphology: It consists of multiple spherical or globular chambers that are arranged in a **trochospiral** (coiled) fashion, which is typical of planktonic foraminifera. The overall size (a few microns) refers to the scale of the small features, while the entire organism shown is likely in the range of 100 to 500 microns.

Surface Texture: The surface of the chambers is covered in a dense, regular pattern of **pores** (the small holes) and **pustules** (the small bumps or spines). This porous texture is characteristic of the CaCO3 (calcium carbonate) wall structure of many planktonic foraminifera.



Google Lens

The image displays a specimen of Malachite, a vibrant green mineral known for its distinctive botryoidal (grape-like) or stalactitic formations. Here's some information about Malachite:

Composition and Appearance: Malachite is a copper carbonate hydroxide mineral with the chemical formula $Cu_2(CO_3)(OH)_2$. Its striking green color is due to the presence of copper.

Properties: It has a relatively soft hardness of 3.5–4 on the Mohs scale, making it important to handle with care, especially in jewelry.

Historical Uses: Historically, malachite was mined in ancient Egypt and Israel for copper smelting and also used for sculptural and decorative purposes. It was even used as eye paint by ancient Egyptians and as a pigment in paintings.

Terzaghi and Peck … in 2026!

GeoTech in AI Time

A New Vocabulary

NEXUS

Data Synchronization & Adaptation

- **Data Fusion:** Integrating structurally different data formats (e.g., X-ray CT images + tabular AE sensor data) into a unified framework
- **Multi-fidelity:** Combining sparse, expensive lab data with abundant, cheap simulation data to maximize learning
- **Data Assimilation:** Updating a numerical model's internal state by merging it with field sensor observations
- **Digital Twin:** A virtual subsurface model continuously synchronized with real-world field conditions
- **Domain Adaptation:** Calibrating distribution shifts when applying a model trained on lab data to field data

Physics-AI Integration & Efficiency

- **Physics-Guided ML (PGML):** Applying multiphysics knowledge across the ML pipeline (e.g., physically meaningful feature engineering)
- **Physics-Informed Neural Networks (PINN):** Adding governing equations (PDEs) into the loss function as soft constraints
- **Physics-Constrained ML:** Hardcoding physical laws (e.g., mass conservation) into the neural network architecture
- **Surrogate Model:** A black-box approximation trained strictly on input-output pairs to rapidly bypass heavy numerical simulations
- **Latent Space:** A compressed, lower-dimensional mathematical space containing core, dominant features of the data (e.g., learned via VAEs)

Probabilities & Inverse Problems

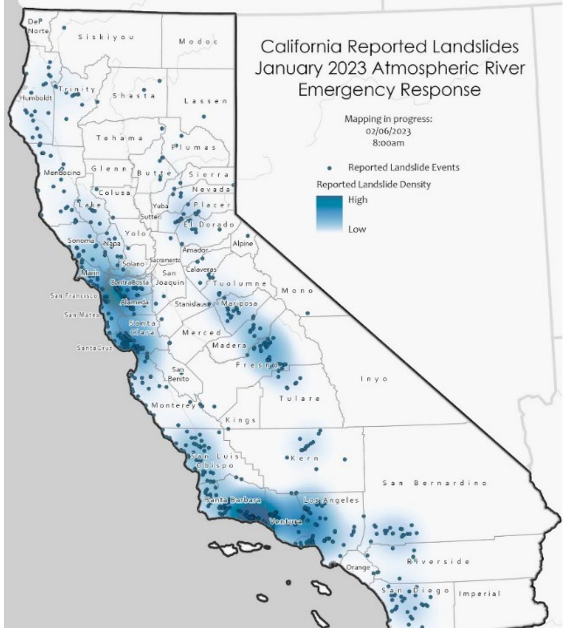
- **Inverse Modeling:** Back-calculating subsurface parameters (e.g., initial stress, permeability) from observed system responses
- **Uncertainty Quantification (UQ):** Calculating both inherent geological variability (aleatoric) and model/data limitations (epistemic)
- **Bayesian Updating:** Iteratively refining the probability distributions of rock properties as new data is collected
- **Normalizing Flows:** Transforming simple distributions into exact, complex multi-dimensional distributions without reducing dimensions
- **Explainable AI (XAI):** Post-hoc tools (e.g., SHAP) used to quantify which input variables drove a black-box model's prediction

Scientific Discovery & Autonomous Systems

- **Symbolic Regression:** Discovering explicit mathematical equations (new PDEs) directly from data
- **Scientific Foundation Models:** Pre-trained models encode physical principles into statistical latent spaces via large-scale empirical data
- **Closed-loop Workflows:** Automated research pipelines executing a continuous feedback loop (hypothesis-test-refine) without human intervention
- **Hierarchical AI Agents:** Task-specific AI networks orchestrating multi-physics and multi-scale simulations

Geotech + AI…?

Site Investigation	Automating data extraction from logs Data fusion: CPT data, geophysics, remote sensing ➔ 3D **subsurface models** &variability ➔ **Soil properties**
Laboratory characterization	Rapid index property determination ➔ index properties to **soil properties** **Information-rich multi-physics experiments -** Rapid inversion test data
Constitutive Models	Data-driven soil models Hybrid mechanics+AI models: “physics inspired data driven”
Design	Ground improvement selection GeoSystems **design & optimization & updating** (foundations, tunnels) FEM + Monte Carlo + ML (much smaller number of simulations!)
Construction Monitoring & Risk Management	Massive instrumentation with real-time **instrumentation interpretation** **Digital twins:** continuously updating models, prediction & forecasting AI-powered **observational method**
Large-Scale Geosystems	**Landslides**: geomorphology + climate + history + satellite + … **Coastal Geotech**: erosion, saltwater intrusion, contamination **Urban underground**: 3D geological models & subsurface infrastructure Forecasting geotechnical **hazards**
Daily practice	Algorithm generation for data analysis **Report** preparation (templates, standards, literature review, case histories) Checking **codes & standards** (regional to international)



State of Practice (Small-medium companies)

Informal Questionnaire 1/2026

NEXUS

Laboratory tests

- **Classical tests dominate - Advanced testing is sector-dependent**
- **Budget drives practice** Routine projects & limited budgets ➔ minimal lab testing & greater reliance on local experience.

Field tests

- **Practice remains largely classical** SPTs are still very common
- **Geophysics is growing but unevenly adopted** GPR, ERT, P&S, InSAR
- **Adoption is constrained by cost and logistics** Mobilization = cost., Drillers lack incentives, high-end: expensive

Multi-physics laboratory or field testing

- **Multi-physics testing is largely absent in practice** Use remains project-specific.
- **Limited experimental or coupled-modeling experience**

Use of AI

- **Adoption is minimal and at early-stage** (1) Background & writing. (2) Data management, CPT interpretation. (3) Coding
- **Big data is the main driver** Hundreds or thousands of CPTs
- **Lack sufficient curated geotechnical data** Readiness & confidence remain low
- **Training and standards are major gaps** Most companies are looking for internal “champions”

Database of material parameters

- **Data exists, but are poorly organized** Informal and decentralized; past projects used as informal reference
- **Local knowledge substitutes for databases** Practitioners often rely on regional experience
- **Limited data sharing across firms** Major contractors have large datasets, but are rarely shared

State of Practice: Large+ Companies

Based on publicly available information

NEXUS

ACS/HOCHTIEF Group (Turner, CIMIC, Dragados and FlatironDragados)

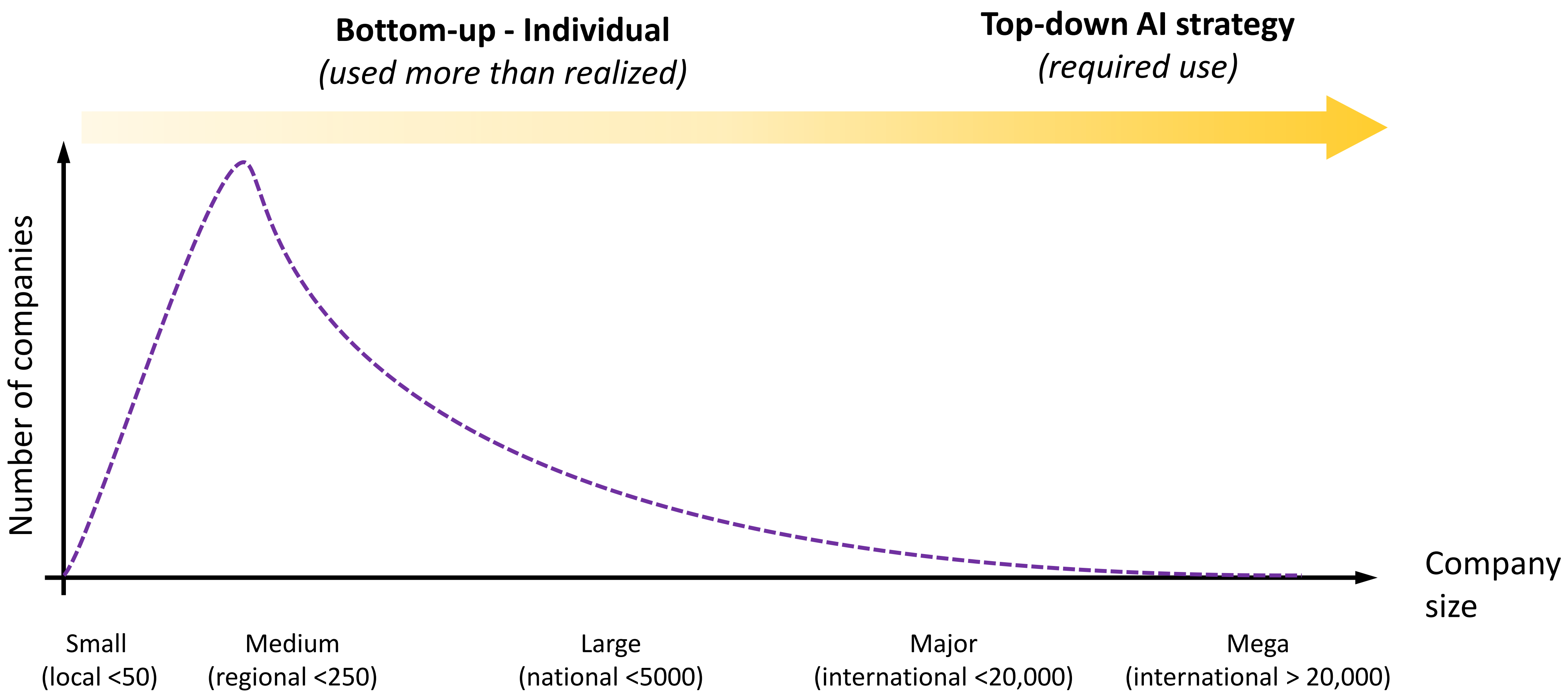
NEXTPLORE (2018) for innovation and digital solutions

Developing & deploying digital tools across infrastructure projects

Bechtel:	Digital solutions group Integrating AI, digital twins, smart construction management tools
Fugro	AI and machine learning for geotechnical data analysis and monitoring platforms. Digital twin in subsurface modelling
AECOM	Acquired AI startup Consigli (11/2025) AI for design optimization, risk analysis, and data-driven engineering
Jacobs	internal AI/digital task forces
WSP	partnered with technology leaders to accelerate digital initiatives
Geosyntec	Data science and ML. Actively recruiting

State of Practice …

NEXUS



Concerns with all: (1) misuse (2) uploading confidential data (3) guardrails…

AI in Technology Transfer? Training & Education

NEXUS

Key: how it is used ➔ *stimulate thinking, not replace it*

- Individualized tutoring
- Low cost, no language barriers
- Personalization: pace, explanations
- Immediate feedback

Requires an educational shift ➔ *greater emphasis on*

- Critical thinking
- Problem formulation
- Skepticism toward AI-generated results

Writing & critical thinking

- Higher-quality texts
- Lower originality
- More superficial understanding
- Reduced retention

Academic integrity

- Shift toward in-class assessments

Risk: digital divide

Technology advances faster than scientific evidence and our ability to adapt

Closing Thoughts

NEXUS

(1) Accumulated data
(2) Sensors
(3) IT + communications
(4) AI

Technology & AI Revolution
Concurrent with new geotechnical challenges

How to educate in AI-times?	**Stimulate minds**
Strengthen physical intuition	**Reinforce fundamentals … σ' !**
Geotechnics: moment of opportunities!	**Make time to embed technology&AI… pays off**
Caution: overreliance on data-driven	**Data are sparse & biased - Data ≠ knowledge**
Why will a client choose you? (your medical doctor)	**Trust, judgement, knowledge & technology + AI**
Engineering practice	**Informed, innovative, globally consistent**

Nexus Geostructural Research Institute (NGRI)

NEXUS
GEOSTRUCTURAL RESEARCH
INSTITUTE

Advancing geostructural systems through research and innovation to enhance the resiliency of underground and civil infrastructure