Co-Robotic Systems for GeoSciences Field Research

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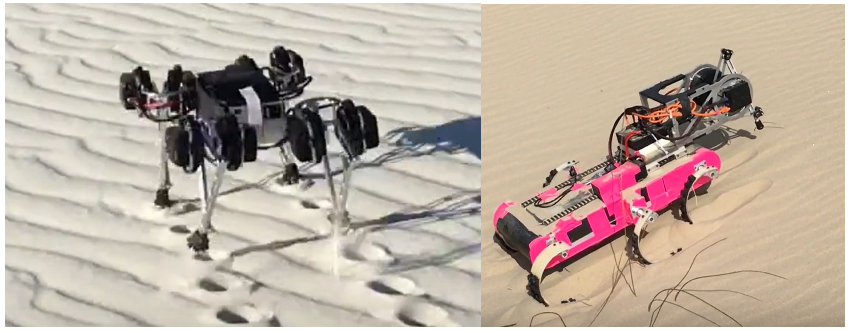
Task Overview

Heterogeneous teams of field-ready robots



Novel sensing and measurements

Optimizing collaborative sampling strategy

Desertification and sediment loss

Complexity and variability

Models of soil erosion and transport

Human hypothesis exploration

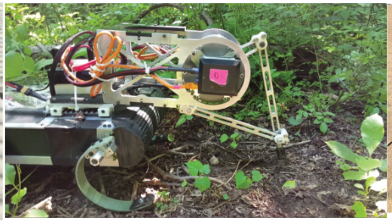
Challenges

- Locomotion challenges
  - Deformable terrain (sand, gravel, leaf litter)
  - Obstacles (rocks, boulders, fallen branches)
  - Entangling vegetation (grass, stems)

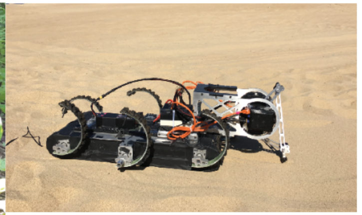
- Geoscience challenges
  - Spatial and temporal variation of soil erodibility
  - Environmental controls of soil erodibility

Gypsum dunes
(White Sands, NM)

Hillslope-River
(Wissahickon, PA)



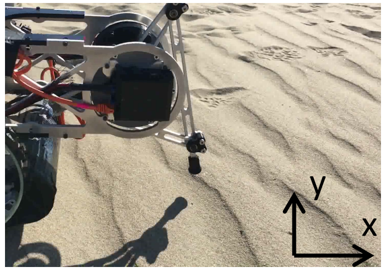
Quartz sand dunes
(Oceano, CA)

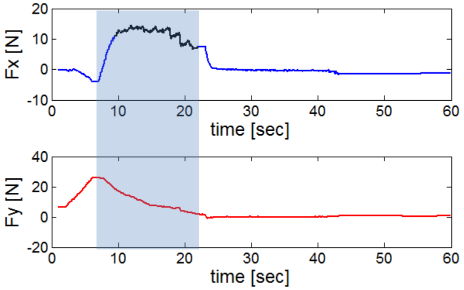


- Decision-making challenges
  - How do experts make decisions about where to collect data?
  - How do experts resolve uncertainty and conflicting information?

Novel Approaches

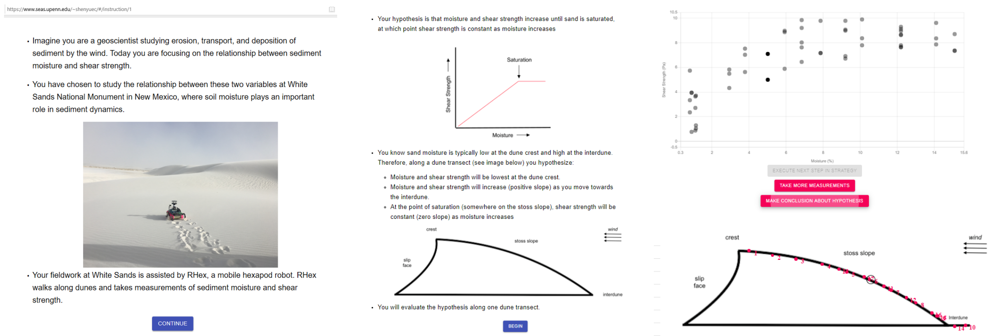
- **Make every step an experiment**! Direct-drive robotic leg for precise measurements of soil erodibility and environment-aided locomotion
- **Heterogeneous robot team** to help human scientists isolate and model dependence of soil erodibility on different environment controls
- **Web-based decision making scenario** to explore human sampling strategies, increase autonomy, and enhance scientific practice





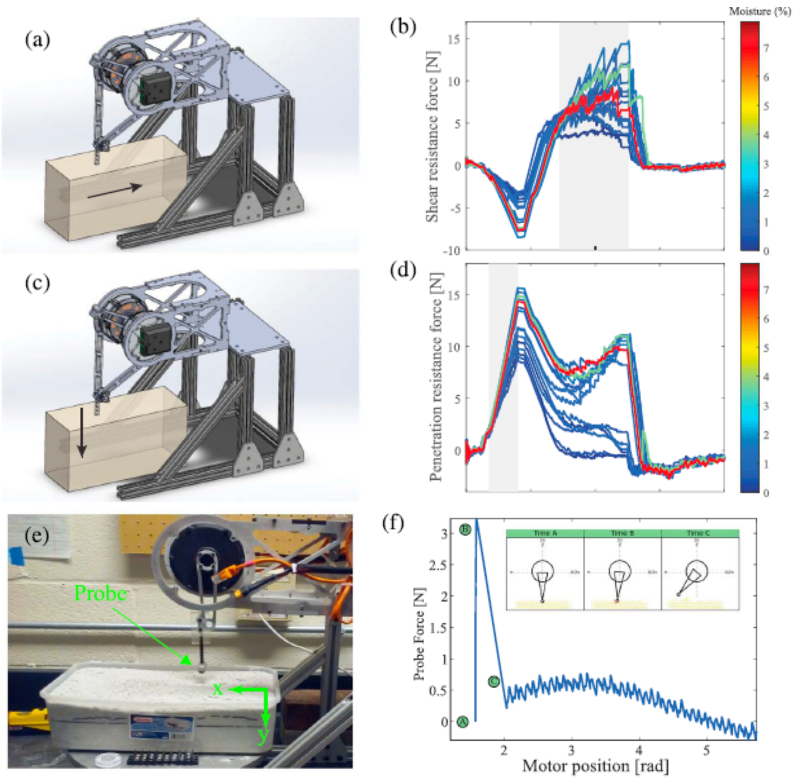
Minitaur: rapidly "scouting" spatial variation of soil erodibility

RHex: performs comprehensive measurements of environmental controls



Results – I. Integrating proprioceptive sensing information to understand environment properties

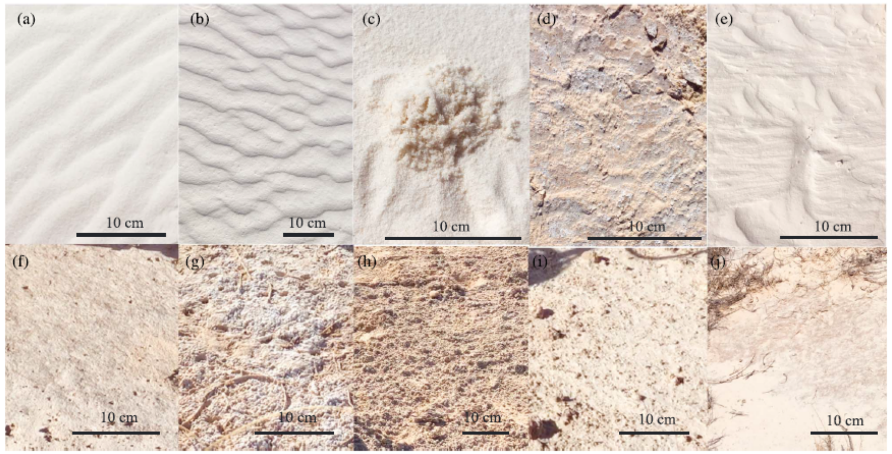
Developing different leg-soil interaction protocols to isolate soil binding mechanisms



Developing customized robot-borne sensors to detect environmental controls such as grain size, moisture

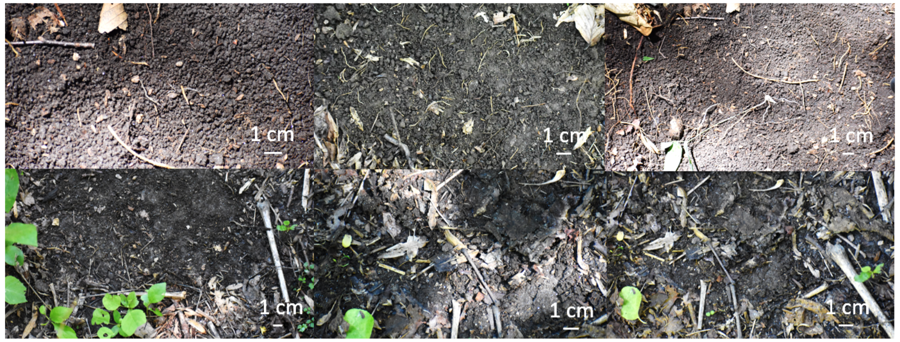
Desert system

- Soil moisture
- Compaction
- Crust development
- Bioactivity
- …



Hillslope-river system

- Grain aggregates
- Soil composition
- Bioactivity
- Soil moisture
- …

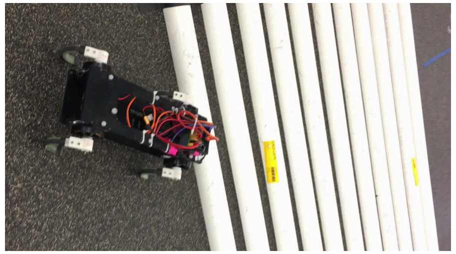


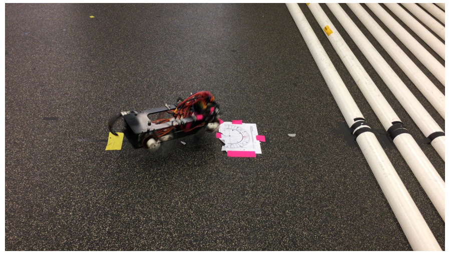
Qian, Lee, Nikolich, Koditschek, and Jerolmack., *Journal of Geophysical Research: Earth Surface* 2019

Results – II. Exploiting environment responses to improve mobility on unstructured and unstable natural terrains

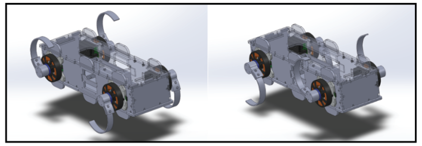
Turn obstacles into opportunities

-- use gaits to generate different dynamics from the same environment

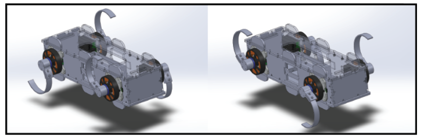


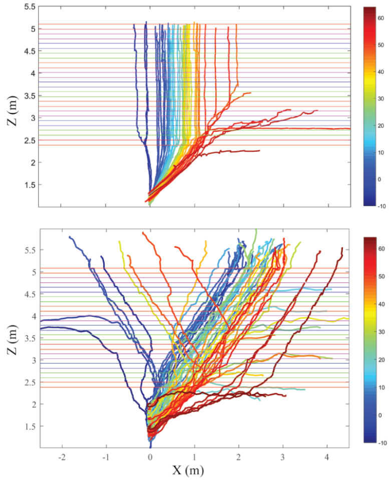


Bounding gait



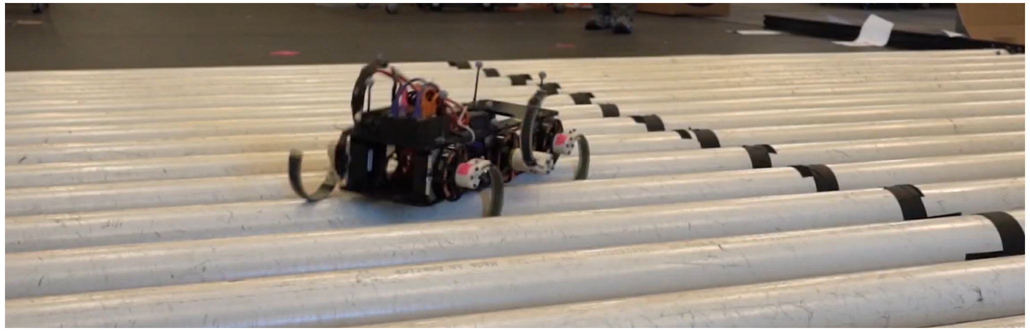
Trotting gait

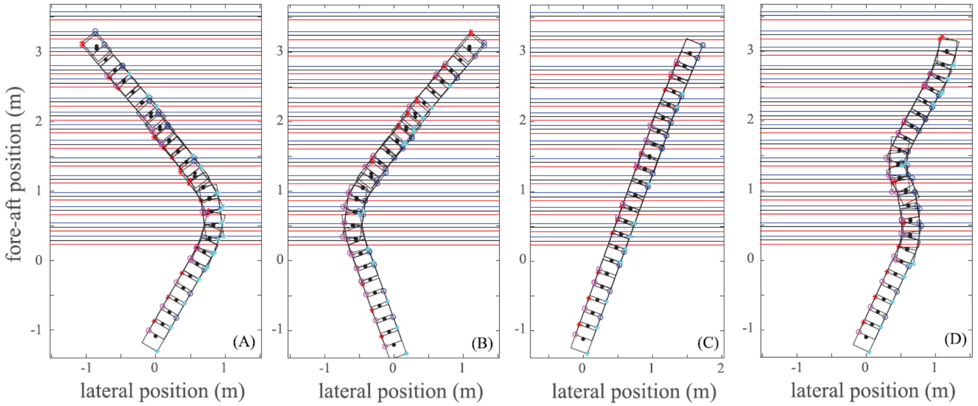




Qian and Koditschek, *IJRR* (in revision)

Robustly navigating in cluttered environments by selecting the desired obstacle collisions

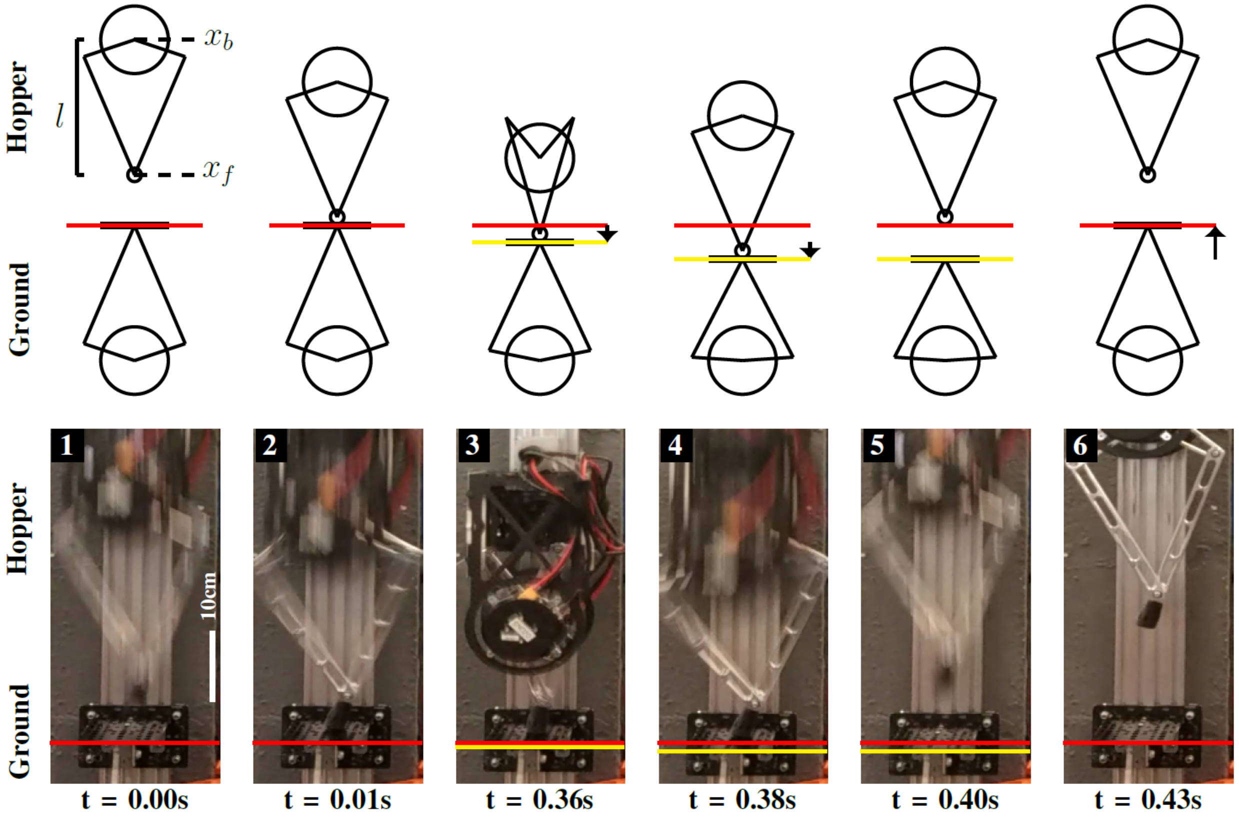




Ramesh, Kathail, Koditschek, and Qian, *IEEE RA-L 2020*

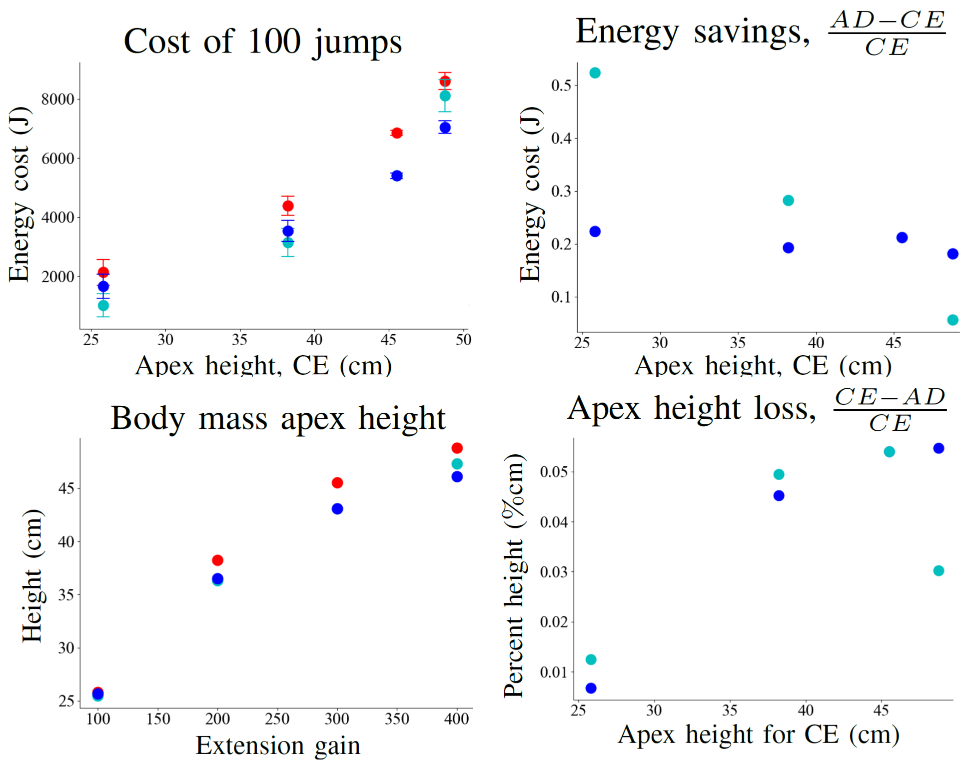
Results – II. Exploiting environment responses to improve mobility on unstructured and unstable natural terrains

Improving hopping mobility on soft, deformable terrains



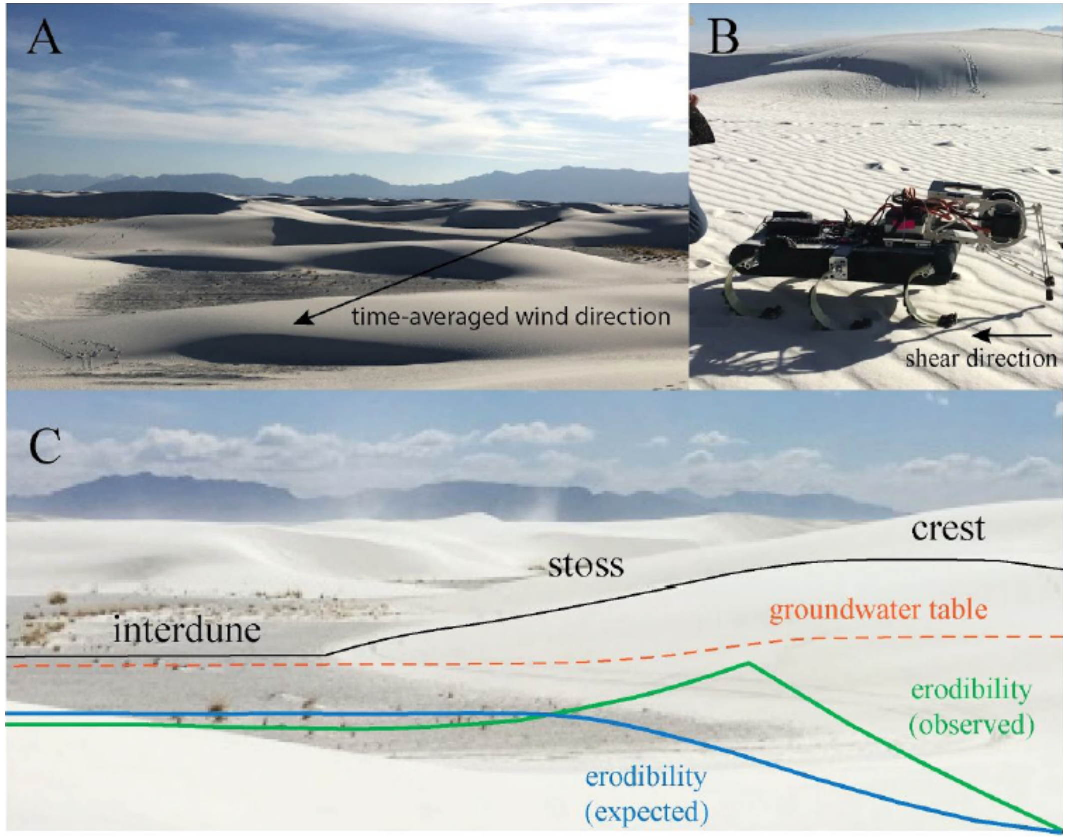
Roberts and Koditschek, *IEEE ROBIO, 2018*

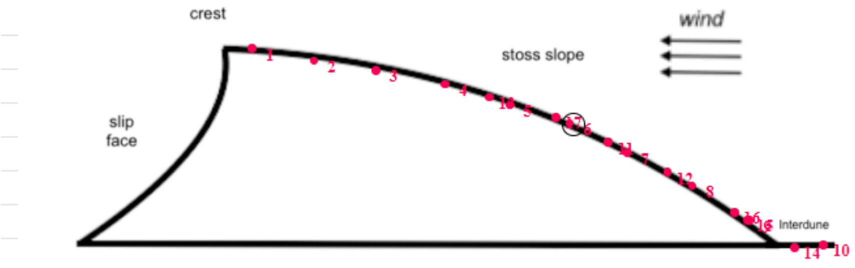
Significant energy savings in dynamic hopping with active damping controller

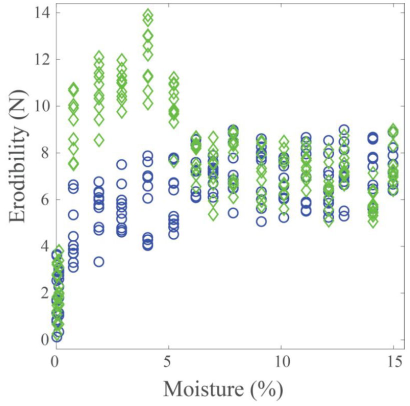


Roberts and Koditschek, *ICRA 2019*

Results – III. Optimizing data foraging by deciphering human decision-making







Wilson, Qian, Jerolmack, Shipley, Roberts, Ham, and Koditschek, *QJEP* (in review)

- **Exploring biases:** two datasets, one supports hypothesis and one does not
- **Exploring dynamic decision making:** two phases, initial strategy and measurement-based adaptation

Results – III. Optimizing data foraging by deciphering human decision-making

Experiences or biases?

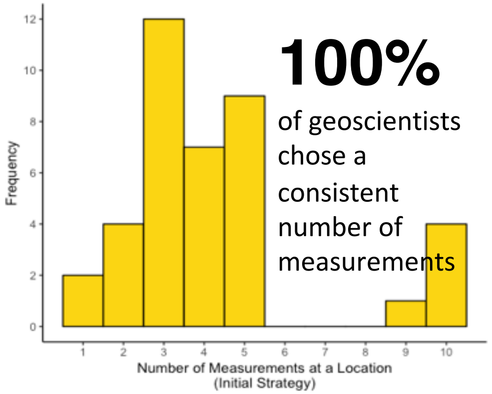
In absence of in-situ measurement feedback: Strong heuristic-based

EQUAL SPACING HEURISTIC

85% of geoscientists chose locations at roughly equal intervals

***defined as average interval discrepancy less than .08*

MAGIC NUMBER HEURISTIC



100% of geoscientists chose a consistent number of measurements

Uncertainty and conflict?

In response to incoming data that are noisy or are potentially unsupportive of hypothesis, how do experts adapt sampling strategies?

NO ADJUSTMENT

23% of geoscientists did not alter their initial data collection strategy at all

ADJUSTED STRATEGY

77% of geoscientists who adjusted waited until their initial strategy was complete before collecting more data

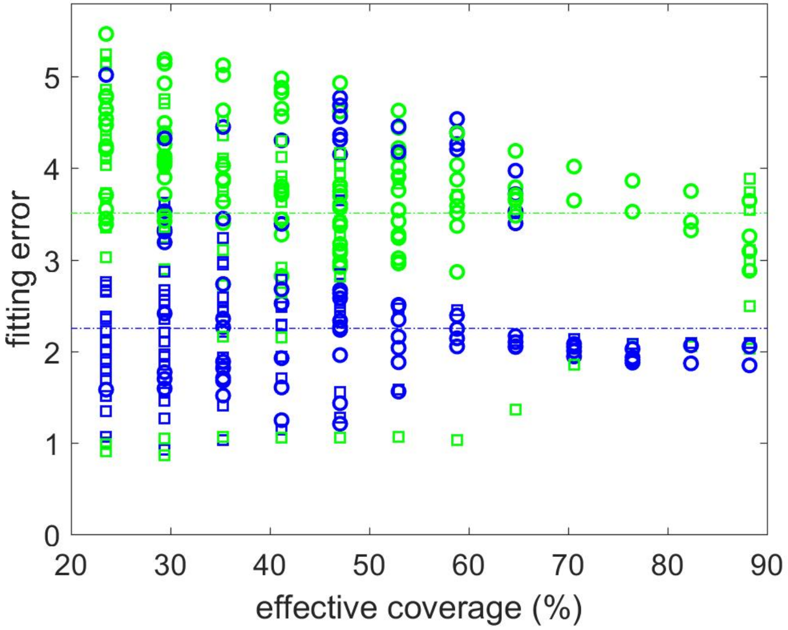
67% of geoscientists who adjusted kept using the same magic number

Wilson, Qian, Jerolmack, Shipley, Roberts, Ham, and Koditschek, *QJEP* (in review)

Results – III. Optimizing data foraging by deciphering human decision-making

from reduced vulnerability to decision biases to human-level intelligence in hypothesis-based reasoning

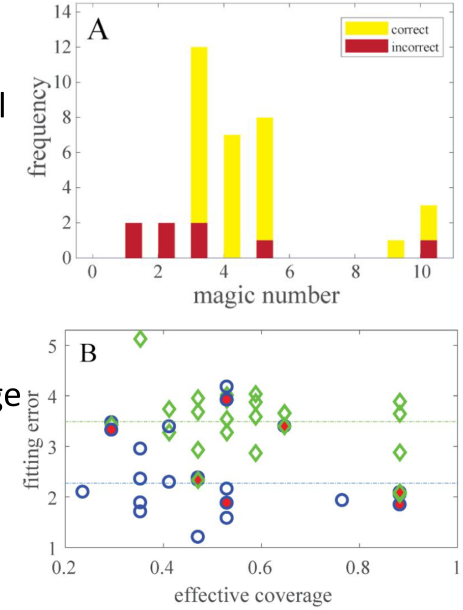
Convergence of “representative observation” in human sampling



Statistical patterns for Type I Error

Anchoring to small magic number

Insufficient coverage of variable space[1]



[1] despite potentially enough spatial coverage

Co-robots for enhanced scientific practice and training

- Robots provide statistical feedback (e.g., effective coverage, fitting error) to reduce heuristic anchoring biases
- Understanding the cognitive underpinning of adaptive data collection decisions (e.g., hypothesis testing vs. exploration) to better support human scientific agenda

Wilson, Qian, Jerolmack, Shipley, Roberts, Ham, and Koditschek, *QJEP* (in review)

Impact

Scientific impact

Peer-reviewed journal and conference publications (2019-2020)

1. Wilson, Qian, Jerolmack, Shipley, Roberts, Ham and Koditschek, “Data Foraging: Spatialtemporal data collection decisions in disciplinary field science”, *Quarterly Journal of Experimental Psychology (QJEP)* (under review)
2. Qian and Koditschek. "An obstacle disturbance selection framework: emergent robot steady states under repeated collisions", *The International Journal of Robotics Research (IJRR)* (under revision)
3. Dunne, Arratia and Jerolmack, “A new method for in-situ measurement of the erosion threshold of river channels”, *Water Resources Research* (under review)
4. Ramesh, Kathail, Koditschek, and Qian, “Modulation of Robot Orientation via Leg-Obstacle Contact Positions”, *IEEE Robotics and Automation Letters (RA-L)*, 2020.
5. Qian, Lee, Dylan, Nikolich, Koditschek and Jerolmack. (2019). Rapid In-Situ Characterization of Soil Erodibility With a Field Deployable Robot. *Journal of Geophysical Research (JGR): Earth Surface124.5 (2019): 1261-1280*.
6. Wilson, Bond, and Shipley (2019). How can geologic decision making under uncertainty be improved? *Solid Earth,* 10, 1469-1488
7. Jerolmack and Daniels, "Viewing Earth's surface as a soft matter landscape", *Nature Reviews Physics*, 2019.
8. Roberts and Koditschek (2019). Mitigating energy loss in a robot hopping on a physically emulated dissipative substrate. *Proceedings of the 2018 IEEE International Conference on Robotics and Automation (ICRA)*.
9. Gunn, Wanker, Edmonds, Ewing and Jerolmack, "Circadian rhythm of dunefield activity", *Nature Geoscience*, 2019.

Broader Impact (Education and outreach)

Educational development: 2x postdoc, 9x graduate students, 4x UG students

Outreach: GRASP lab RET; K-12 demos (x17); Industry demos (x8); Science festivals (x6); Public science talks (x9);

Exploring the unknown

Inspiring next-generation scientists and engineers