Challenges & Opportunities for Nanoscience & Nanotechnology: Physical Science +

Leverage

- **More than a decade of the National Nanotechnology Initiative**
- **Decades of semiconductor manufacturing technology**
- **Over a century of synthetic chemistry**
- **Informatics, sparsity**
- **Communication & collaboration across fields**

Challenges

- **Insufficient measurement, theory, and simulation tools**
- **Complexity and heterogeneity in structure and function**
- **Sustained support for long-range development**

Biotechnology revolution – inspiration and guidance

David Shrigley
Nature is Boring

Lessons for Nanoscience & Nanotechnology

Scientific Tools that Target Scientific, Technological, and Other Important Problems Have Tremendous Impact and Leverage

Discover new and potentially useful phenomena and properties by design
- **Materials Genome Initiative, Theory, Simulations**

Understand (and use) heterogeneity of structure and function

Tools: *cf.*, the last three years of the Human Genome Project
- **BRAIN Initiative**
- **Microbiome Initiative**
- **Precision Medicine**
- **Brain-Inspired Computation**

Precision Materials and Connections
- **More on this shortly- preserve properties, use materials and process efficiently**

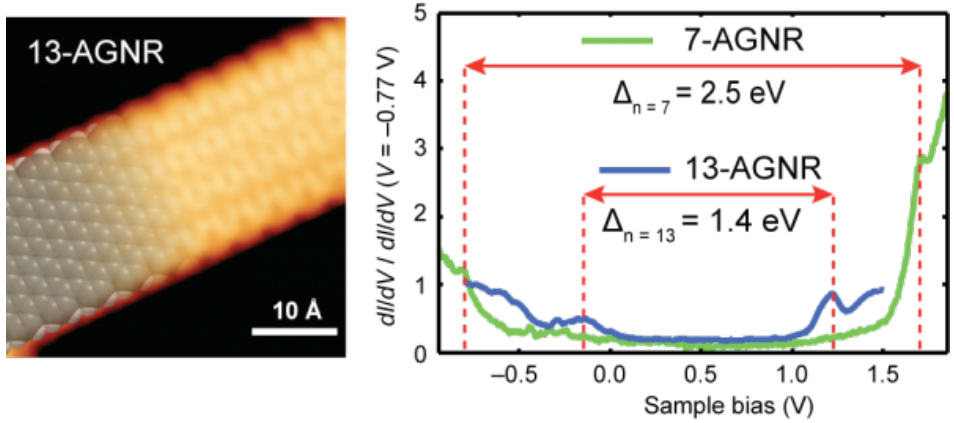
Heterostructured Materials Create New and Tailor Properties
- **New properties by our ability to assemble**
- **Scale-up strategies once targets are identified**

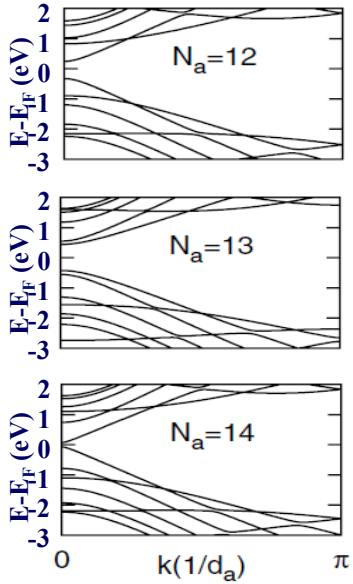
Alivisatos *et al.*, *ACS Nano* 7, 1850 (2013)
Bitteen *et al.*, *ACS Nano* 10, 6 (2016)

Precise Materials by Design

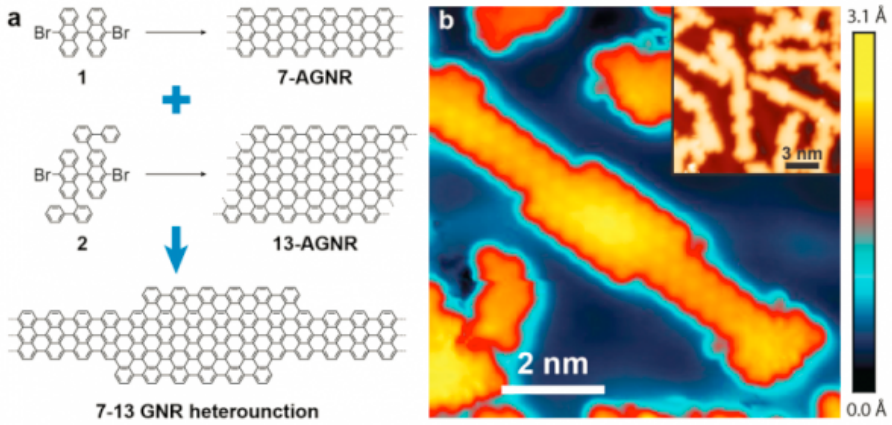
We can design materials *and* connections to be perfect

Contacts are chemical, physical, and electronic connections





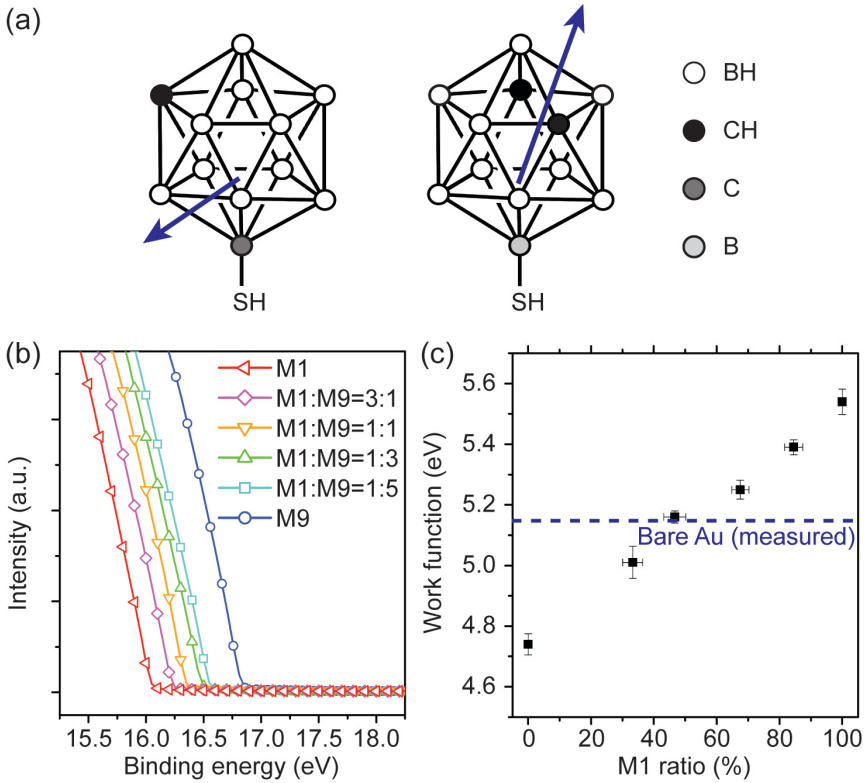
Son *et al.*, *PRL* 97, 216803 (2006)



Chen, Fischer, Crommie *et al.*, *ACS Nano* 7, 6123 (2013)
Chen, Fischer, Crommie *et al.*, *Nature Nano* 10, 156 (2015)

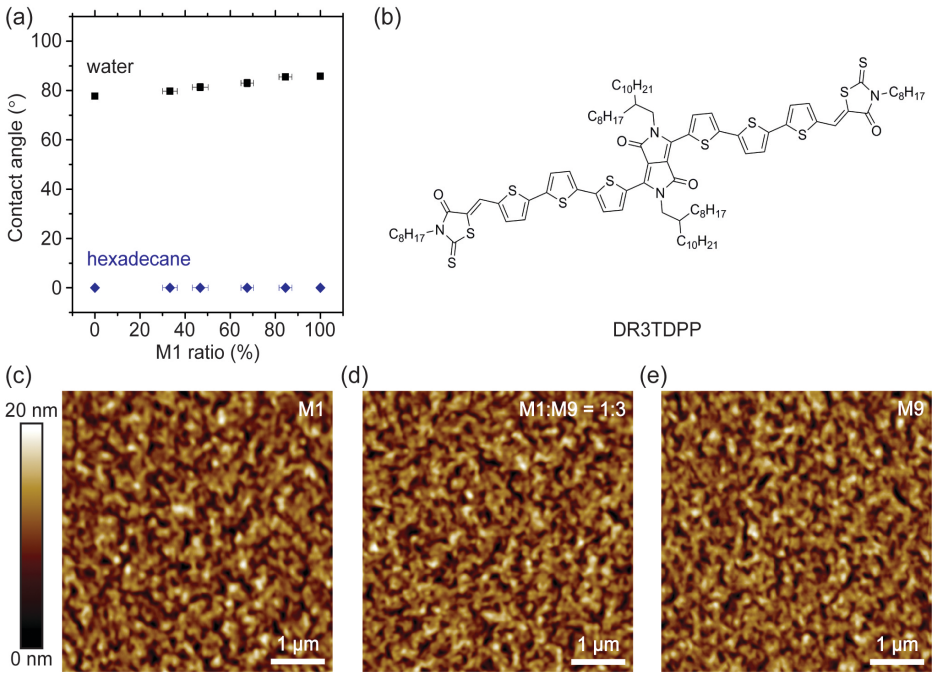
Control Interfacial Energy in Organic Electronics with Mixed Carboranethiol Monolayers

Adjust work function independently of wetting of polymer layer



Mix M1/M9 monolayers to adjust band alignment

***cf.* Marder**



Water contact angle shifts with mixture. Hexadacane and polymer layer wetting unaffected byM1/M9 ratio.

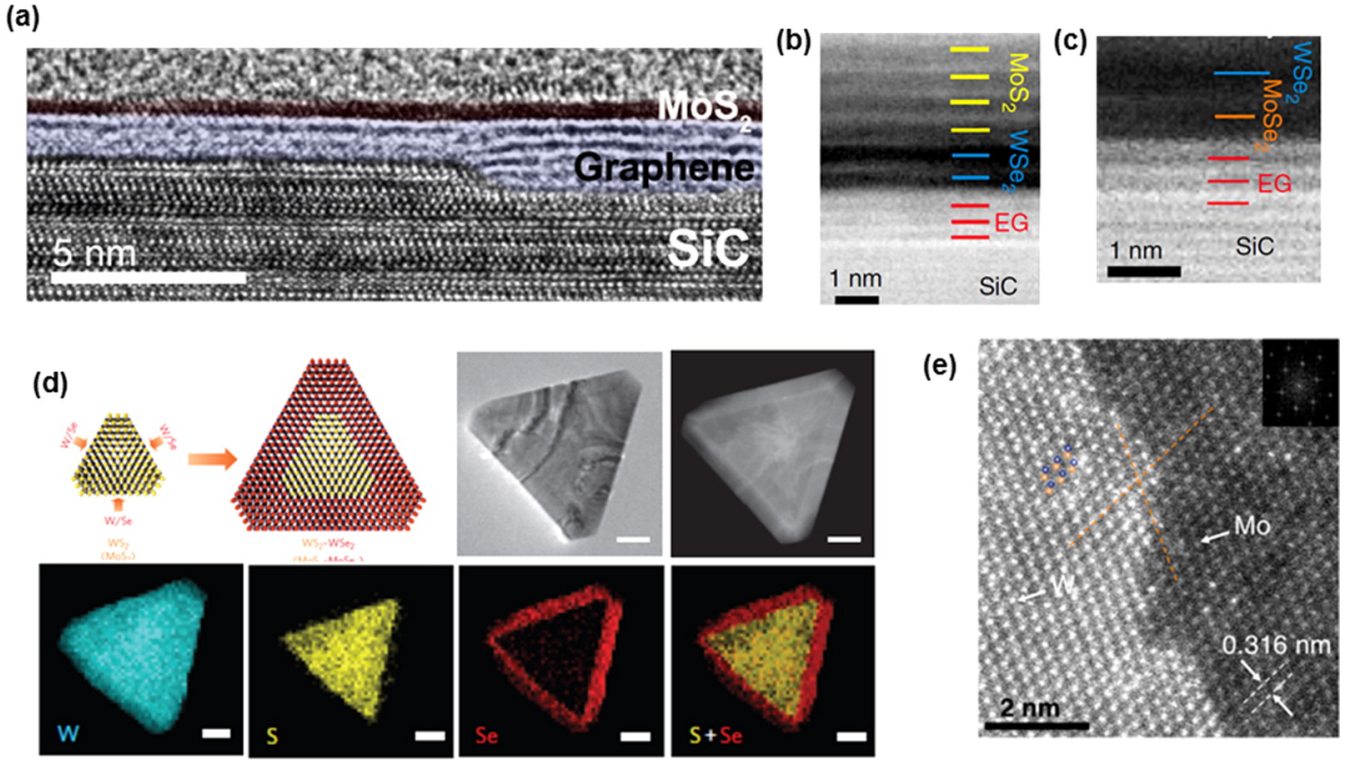
Kim *et al.*, *Nano Letters* 14, 2946 (2014)

Heterogeneity and Complexity in Materials

Identify target (hetero)structures with optimized properties – theory

Synthesize/assemble and measure test structures

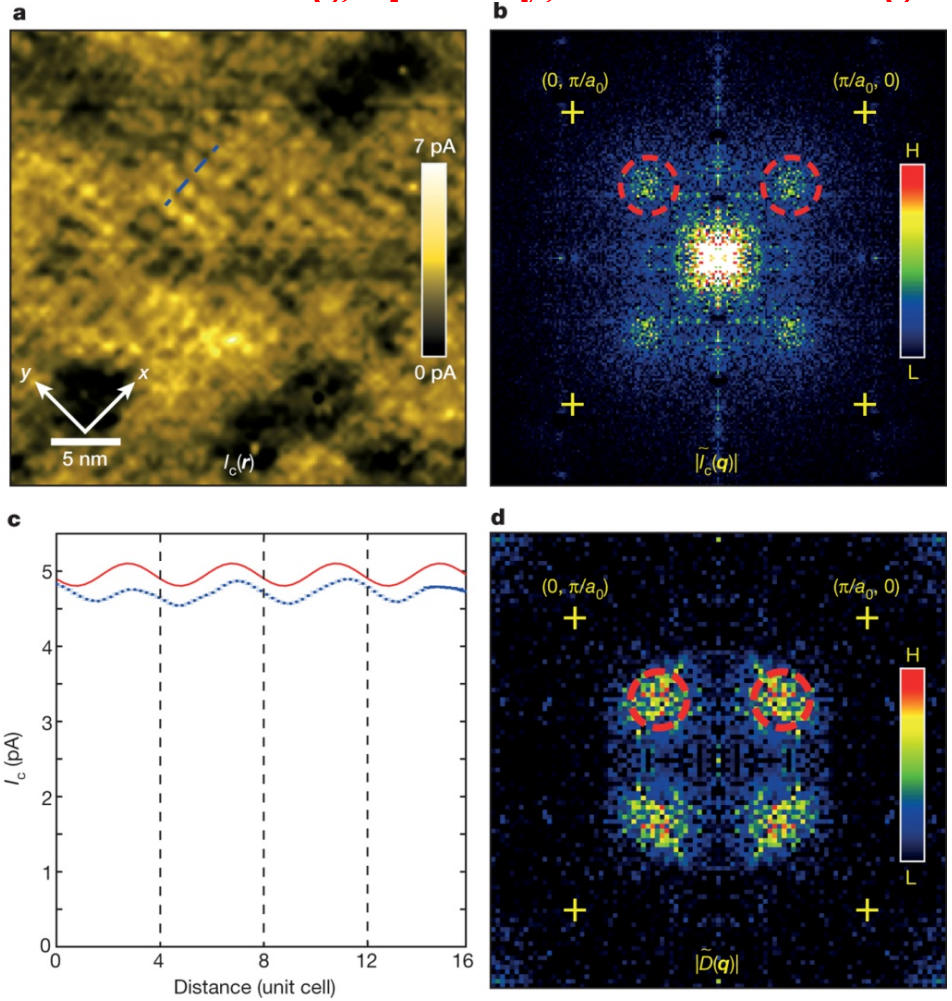
Engineer the means to produce such structures - nanomanufacturing



Bhimanapati, Robinson, *et al.*, *ACS Nano* 9, 11509 (2015)

New Tools Enable New Measurements

Combine multimodal measurements
Including compressive sensing, sparsity, informatics – generalize methods

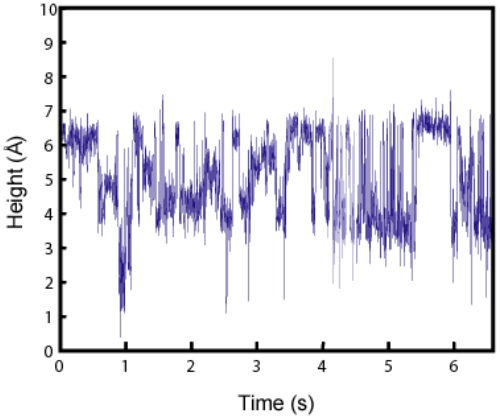


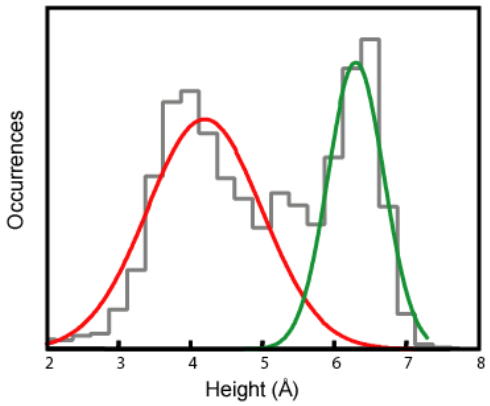
***e.g.*, Visualizing the Cooper-pair density wave in $Bi_2Sr_2CaCu_2O_{8+x}$**

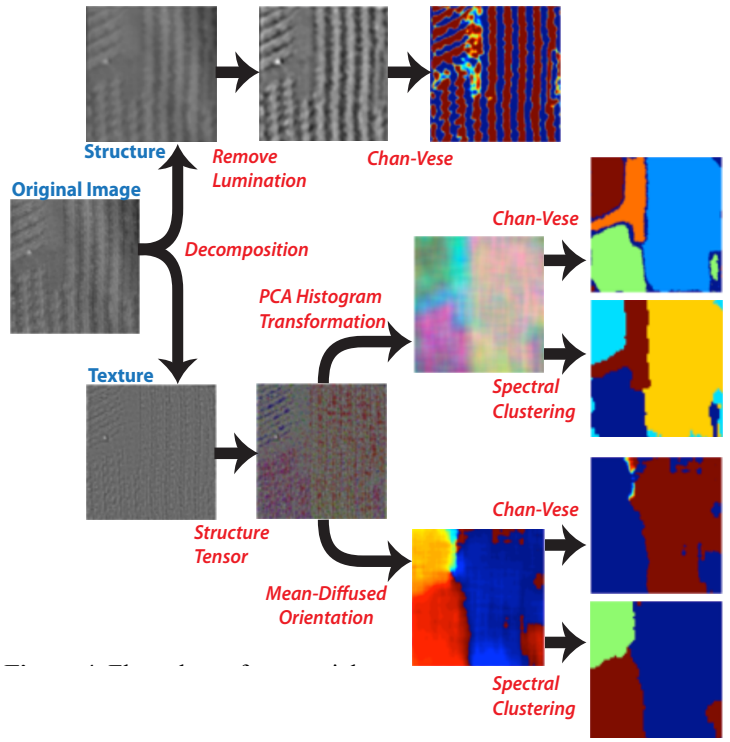
Hamidian, Davis *et al.*, *Nature* (2016). DOI: 10.1038/nature17411

Heterogeneity in Structure and Function

How can we understand (and use) heterogeneous structure and function?
Blinking, switching, etc.
Eliminate averaging and put together efficient multimodal measurements that preserve heterogeneous information and linkages
Develop efficient algorithms for (targeted) information acquisition and assembly
How can we do the same for biomolecular structure and function?
***e.g.*, BRAIN, Microbiome**







Pathem *et al.*, *Ann Rev Phys Chem* 64, 605 (2013)
Thomas *et al.*, *ACS Nano* 9, 4734 (2015)

Understanding Functioning and Malfunctioning Neural Circuits in the Brain

Approaches:

Physical connectome

Dynamic voltage mapping

Dynamic chemical mapping

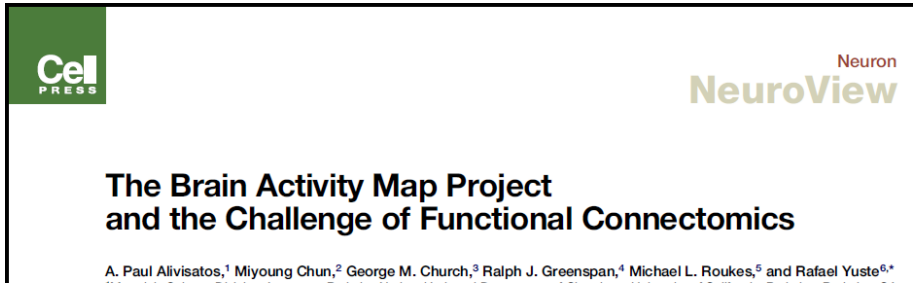
Computer simulations

Human brain:

~100 non-orthogonal chemical neurotransmitters

~85 billion neurons

~100 trillion synapses



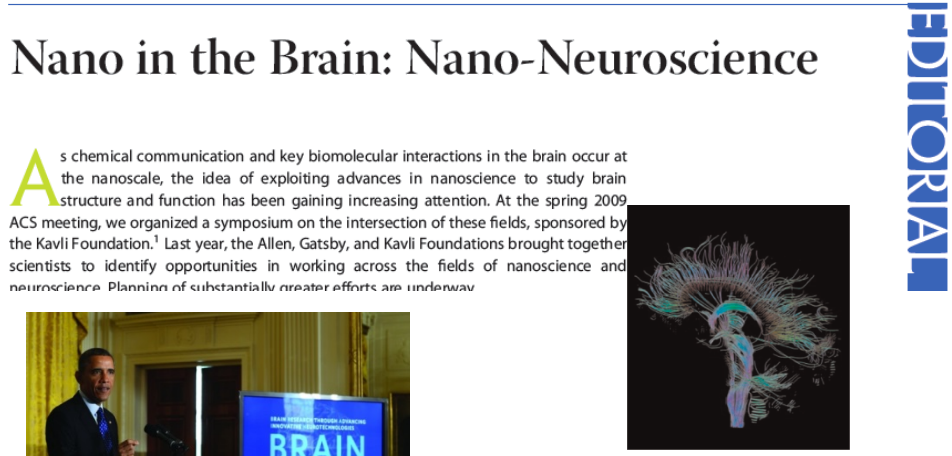
Cell PRESS

Neuron

NeuroView

The Brain Activity Map Project and the Challenge of Functional Connectomics

A. Paul Alivisatos,[1] Miyoung Chun,[2] George M. Church,[3] Ralph J. Greenspan,[4] Michael L. Roukes,[5] and Rafael Yuste[6,*]



Nano in the Brain: Nano-Neuroscience

EDITORIAL

As chemical communication and key biomolecular interactions in the brain occur at the nanoscale, the idea of exploiting advances in nanoscience to study brain structure and function has been gaining increasing attention. At the spring 2009 ACS meeting, we organized a symposium on the intersection of these fields, sponsored by the Kavli Foundation.[1] Last year, the Allen, Gatsby, and Kavli Foundations brought together scientists to identify opportunities in working across the fields of nanoscience and neuroscience. Planning of substantially greater efforts are underway

NEUROSCIENCE

PERSPECTIVES

Science

AAAS

The Brain Activity Map

A. Paul Alivisatos,[1]* Miyoung Chun,[2] George M. Church,[3] Karl Deisseroth,[4] John P. Donoghue,[5] Ralph J. Greenspan,[6] Paul L. McEuen,[7] Michael L. Roukes,[8] Terrence J. Sejnowski,[9]* Paul S. Weiss,[10] Rafael Yuste[11]*

Nanotools for Neuroscience and Brain Activity Mapping

NANO FOCUS

A. Paul Alivisatos,[†] Anne M. Andrews,[‡,§] Edward S. Boyden,[⊥] Miyoung Chun,[∥] George M. Church,[#] Karl Deisseroth,[∇,□] John P. Donoghue,[■] Scott E. Fraser,[○] Jennifer Lippincott-Schwartz,[●] Loren L. Looger,[△] Sotiris Masmanidis,[‡,▲,*] Paul L. McEuen,[▽] Arto V. Nurmikko,[▼] Hongkun Park,[◇] Darcy S. Peterka,[●] Clay Reid,[††] Michael L. Roukes,[‡‡,§§] Axel Scherer,[‡‡,⊥⊥,*] Mark Schnitzer,[∇,∥∥] Terrence J. Sejnowski,[▲▲] Kenneth L. Shepard,[##] Doris Tsao,[¶¶] Gina Turrigiano,[□□] Paul S. Weiss,[‡,■■,*] Chris Xu,[○○] Rafael Yuste,[●,●●,*] and Xiaowei Zhuang[△△]

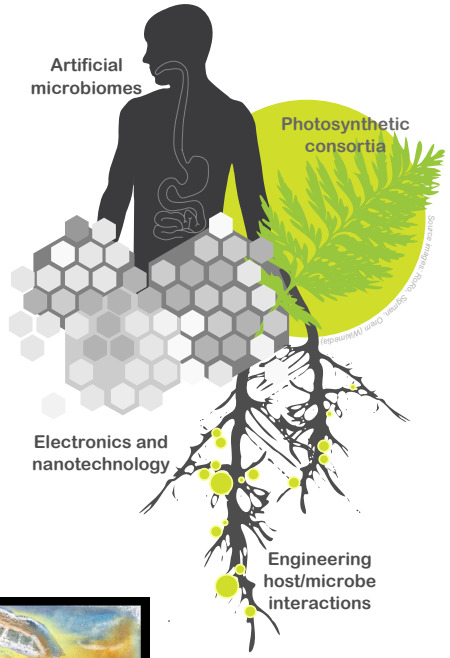
[†]Department of Chemistry, University of California, Berkeley, California 94720, United States and Lawrence Berkeley Laboratory, Berkeley, California 94720-1460, [‡]California NanoSystems Institute and [§]Department of Psychiatry, and Semel Institute for Neuroscience & Human Behavior, Department of Chemistry & Biochemistry, University of California, Los Angeles, Los Angeles, California 90095, [⊥]Media Laboratory, Department of Biological Engineering, Brain and Cognitive

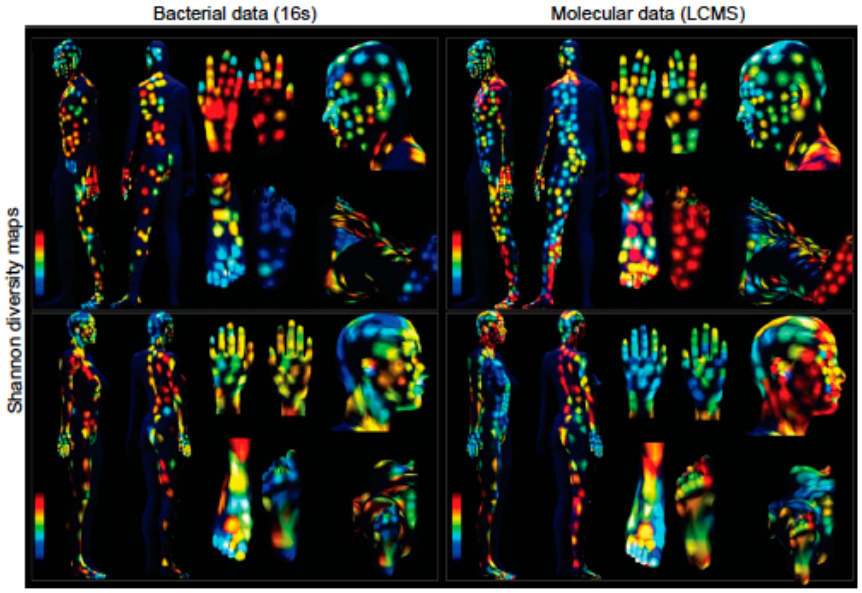
Alivisatos *et al.*, *Science* 339, 1284 (2013)

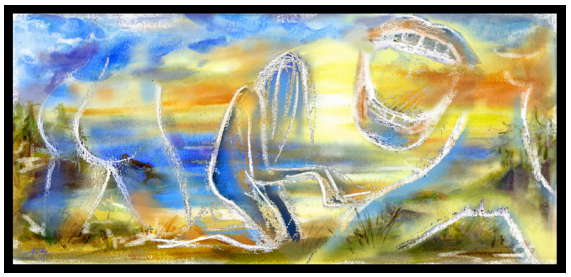
Alivisatos *et al.*, *ACS Nano* 7, 1850 (2013)

Probing and Manipulating Microbiomes

Approaches:
Sensor Arrays
Synthetic Biology
Precision Medicine
Oceanography
Atmospheric Science
Imaging
Visualization







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Tools for the Microbiome: Nano and Beyond

Julie S. Biteen,[†] Paul C. Blainey,[‡] Zoe G. Cardon,[§] Miyoung Chun,[∥] George M. Church,[⊥,#] Pieter C. Dorrestein,[¶] Scott E. Fraser,[□] Jack A. Gilbert,[■,○] Janet K. Jansson,[●] Rob Knight,[*,△] Jeff F. Miller,[*,▲,▽] Aydogan Ozcan,[▲,▼,○] Kimberly A. Prather,[●,††] Stephen R. Quake,[‡‡,§§] Edward G. Ruby,[⊥⊥] Pamela A. Silver,[#,¶¶] Sharif Taha,[∥] Ger van den Engh,[●●,▲▲] Paul S. Weiss,[*,▲,▽▽,■■] Gerard C. L. Wong,[▲,○,▽▽] Aaron T. Wright,[●] and Thomas D. Young[▲,▽▽]

Bouslimani, Knight, Dorrestein *et al.*, *PNAS* 112, E2120 (2015)
Alivisatos *et al.*, *Science* 350, 507 (2015)
Bitteen *et al.*, *ACS Nano* 10, 6 (2016)

Questions for Nanoscience & Nanotechnology: Physical Sciences

What are our new priorities?

How might we address these challenges? What new strategies do we see?

What are the gaps in our goals and objectives?

Is there something that is no longer a priority?

Where can nanoscience & nanotechnology be brought to bear in a larger context?

***e.g.*, BRAIN, Microbiome, Brain-Inspired Computation, Precision Medicine Initiatives**

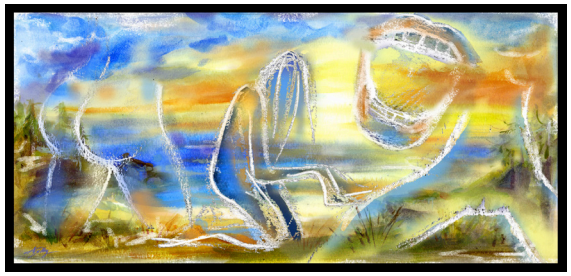
How will we know when NNI is successful?

How do we measure that success?

What about industry engagement?

Hiring students

Acquiring, developing, applying, & marketing tools



Interested in mapping future directions beyond this workshop? See me!