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
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)
We can design materials and connections to be perfect

Contacts are chemical, physical, and electronic connections

Chen, Fischer, Crommie et al., *ACS Nano* 7, 6123 (2013)

Son et al., *PRL* 97, 216803 (2006)
Adjust work function independently of wetting of polymer layer

Mix M1/M9 monolayers to adjust band alignment

Water contact angle shifts with mixture. Hexadecane and polymer layer wetting unaffected by M1/M9 ratio.

cf. Marder

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

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$_2$Sr$_2$CaCu$_2$O$_{8+x}$

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

**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,1 Michael L. Roukes,6* Terrence J. Sejnowski,9* Paul S. Weiss,9* Rafael Yuste10*

**Nano in the Brain: Nano-Neuroscience**

As chemical communication and key biomolecular interactions in the brain occur at the nanoscale, the idea of exploring 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. Plans of substantially new efforts are underway.

**Nanotools for Neuroscience and Brain Activity Mapping**

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

Tools for the Microbiome: Nano and Beyond

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!