Department of Defense Basic Research

13TH ANNUAL

SCIENCE & ENGINEERING TECHNOLOGY CONFERENCE /

National Defense Industrial Association

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Office of the Assistant Secretary of Defense for Research and Engineering

April 17, 2012

Why DoD Invests in Basic Research

(from the DSB Task Force Report on Basic Research)

- **Basic research probes the limits of today's technologies and discovers new phenomena and know-how that ultimately lead to future technologies.**

- **Basic research funding attracts some of the most creative minds to fields of critical DOD interest.**

- **Basic research funding creates a knowledgeable workforce by training students in fields of critical DOD interest.**

- **Basic research provides a broad perspective to prevent capability surprise by fostering a community of U.S. experts who are accessible to DoD, and who follow global progress in both relevant areas, as well as those that may not seem relevant — until they are.**

High Priority Topics in DoD Basic Research

- Metamaterials and Plasmonics
- Quantum Information Science
- Cognitive Neuroscience
- Nanoscience and Nanoengineering
- Synthetic Biology
- Understanding Human and Social Behavior

Metamaterials and Plasmonics

Engineered design of basic properties and transport of energy/information in materials & structures

- **Enabled capabilities**
  - Nanoscale Subsurface Spectroscopy
  - Plasmon-enhanced Detectors & Imagers
  - Phased Antenna Arrays
  - Microvascular Autonomic Composites
  - Novel Coatings (ex. Ice free, water repellent)

- **Select breakthroughs**
  - Sub-wavelength Elements, Plasmonics, Photonic Crystals, Metamaterials
  - Self-sensing & Self-healing Materials
  - Biologically Inspired Structures
  - Computational & Fast-algorithm Tools

- **Key research challenges:**
  - Efficiently convert optical radiation into localized energy, and *vice versa*.
  - Enhancing local photophysical processes
  - Precise assembly & fabrication of hierarchical 3-D photonic
  - Integrating plasmonics with nanostructured semiconductor devices

Quantum Information Science

Manipulate and control nature down to the precision of a single quantum.

- **Enabled capabilities**
  - **Quantum computing:** solving currently intractable problems
  - **Quantum communication:** practical ultra-secure communication
  - **Quantum simulation:** developing new classes of materials for new applications
  - **Quantum sensing, metrology and imaging:** sensitivity/precision/resolution beyond best possible with classical means
- **Key research challenges**
  - Maintaining quantum coherence over time
  - Discovering new algorithms that fully exploit QIS for additional new capabilities
  - New techniques to control quantum systems
  - New materials, fabrication for long coherence time

Polynomial-Time Algorithms for Prime Factorization and Discrete Logarithms on a Quantum Computer*

Peter W. Shor†

Abstract

A digital computer is generally believed to be an efficient universal computing device; that is, it is believed able to simulate any physical computing device with an increase in computation time by at most a polynomial factor. This may not be true when quantum mechanics is taken into consideration. This paper considers factoring integers and finding discrete logarithms, two problems which are generally thought to be hard on a classical computer and which have been used as the basis of several proposed cryptosystems. Efficient randomized algorithms are given for these two problems on a hypothetical quantum computer. These algorithms take a number of steps polynomial in the input size, e.g., the number of digits of the integer to be factored.

Keywords: algorithmic number theory, prime factorization, discrete logarithms, Church's thesis, quantum computers, foundations of quantum mechanics, spin systems, Fourier transforms

AMS subject classifications: 81P10, 11Y05, 68Q10, 03D10

Select breakthroughs

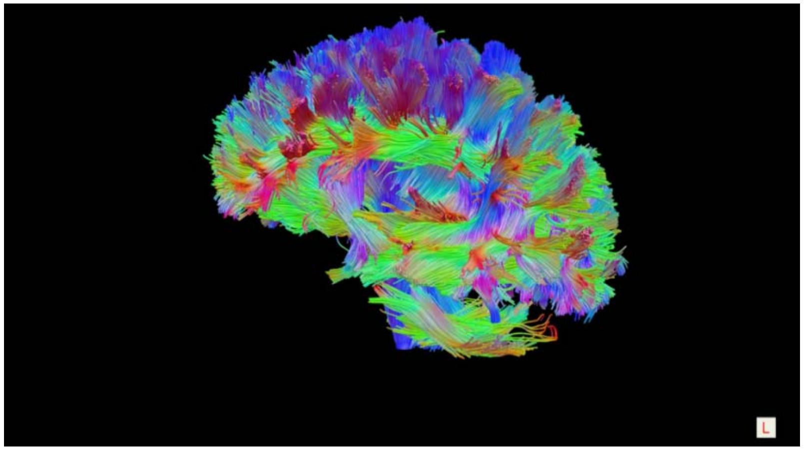
- **Quantum factorization algorithm** (Shor 1995): solve intractable problems
- **Quantum gas microscope** (Greiner 2010): observation of an ensemble of atoms in a lattice with down to a single atom resolution

Cognitive Neuroscience

More deeply understand and more fully exploit the fundamental mechanisms of the brain.

- **Enabled capabilities**
  - Deeper understanding of human information processing, learning and decision making
  - New interfacing with engineered systems and displays
  - Performance under stress
  - Ameliorate/ prevent PTSD and TBI

- **Select breakthroughs**
  - Advances in brain imaging; e.g. fMRI, Diffusion Tensor Imaging, and digital EEG.
  - Advances in correlation of brain-structure to function
  - Massively parallel computation enabling brain signal analysis



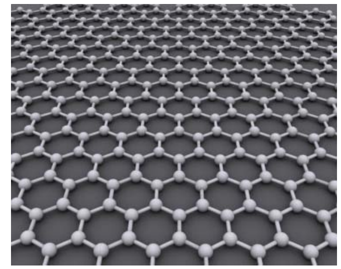
Map of brain interconnectivity as measured by Diffusion Tensor Imaging (DTI)

- **Key Research Challenges**
  - Solving the inverse problem of predicting human behavior from brain signals
  - Translating clinical measurements & analyses to uninjured personnel
  - Developing models incorporating individual brain variability

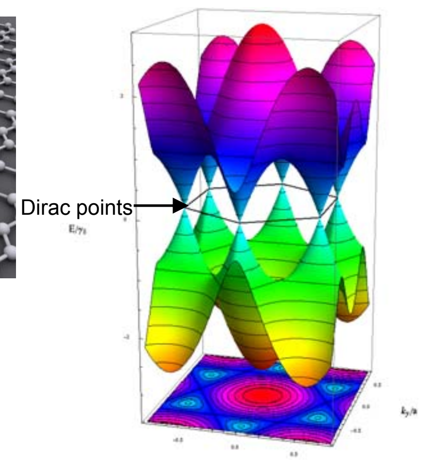
Nanoscience and Nanotechnology

Discover and exploit unique phenomena at nanometer dimensions to enable novel applications

- **Enabled capabilities**
  - Electronics & Sensing: Multi-spectral focal plane arrays, ubiquitous embedded sensors, curvilinear electronics, ultra-low voltage devices
  - Power and Energy: Fuel-cells, portable electronics, mobile power, thermoelectrics
  - Coatings: Photoactive, self-cleaning films
- **Select breakthroughs**
  - Nano-particle coating & functionalization
  - Catalysts for energy-harvesting
  - Graphene and carbon nanotubes
- **Key research challenges**
  - Low defect density graphene over large areas
  - Production and reproducibility of single chirality nanotubes and bilayers of graphene, each layer individually biased to form new condensed state



Graphene monolayer



Graphene Bandstructure with Dirac points

Synthetic Biology

The promise of engineered biology for a multitude of applications.

Enabled capabilities

- Bio-production including bio-fuels
- Bio-sensors
- Tissue regeneration
- New and faster ways to produce vaccines
- Algae-based food production
- Clean water as a bio-based capability

Key research challenges:

- Modeling and simulation to address complexity of pathways
- Automation of trials
- Selection of appropriate host cell compatible with synthetic genome
- Regulation and societal acceptance

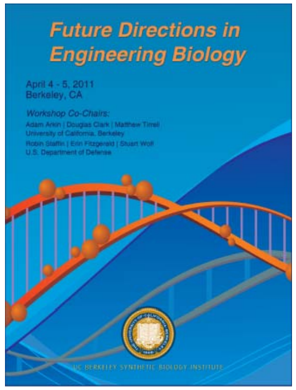
Understanding and Modeling Social Behavior

- **Why fund social science**
  - **Expanded possibilities:** social science is evolving from a primarily observational science to a more analytical science
  - **Understanding the environment:** detection of radical actors and regime disruptions is limited by our understanding of the cultural and political environments where those threats develop
  - **Inform DoD strategy and operations:** Deeper understanding of global populations and their variance will yield more effective strategic and operational policy decisions

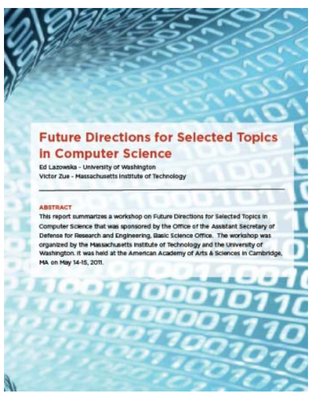
- **MINERVA Research Initiative**

Future Directions Scientific Workshops

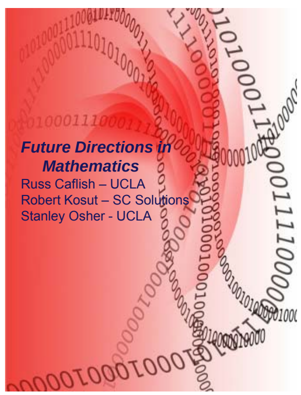
Physics and Materials Science



Engineering Biology



Computer Science



Mathematics

- ***Workshop Goals:***
  - Identify Opportunities for Future DOD Investment (Emerging Areas and Discoveries)
  - Identify areas where continuing investment justified
  - Identify International Centers of Excellence
  - Identify issues with Current Support
- ***This year's Workshops*:**
  - Cognitive Neuroscience Columbia University, March 11-13 2012
  - Engineering Sciences – Upcoming two cross-disciplinary workshops

Industrial Outreach

Industrial Outreach: Instituted

- Invited Industry to attend **MURI Annual Review** through NDIA
  - Attended by 16 major DoD contractors

    Lockheed Martin Skunk Works, Lockheed Martin Advanced Technology, Lockheed Martin Physics, Northrup Grumman, BBN, Applied Research Associates, Robotic Technology Inc, MITRE, iRobot Aerospace, Draper laboratory, Honeywell, Alion, Crane, Intelligent Automation, DGNSS Solutions, Planned Systems International
- Held **MURI 25th Anniversary Session** at NDIA Meeting
  - Attended by 50 industry managers
- Posted list of active MURI's on ASD(R&E)/Basic Science website (http://www.acq.osd.mil/rd/basic_research/muri_partners/list.html)
- Invited industry scientists to emerging areas workshops

Industrial Outreach: Proposed

- Encourage PI presentations at industry-oriented meetings and conferences
- Invite relevant industry reps to MURI and program reviews
- Proposals solicited for new "at the crest-of-the-wave" MURI topics
  - OSD approved topics

This Year's MURI Review

- Currently ***190 Active MURI Projects -*** many very relevant to Defense and Aerospace (see website below)
- Industry ***Welcome*** **at MURI Reviews**
  - Chance to meet with PIs and other performers
  - Initiate collaborations
  - Keep track of latest innovations
- Next MURI Review – ***All NDIA Invited – Save the dates***
  - *When: August 8-10, 2012*
  - *Where: System Planning Corporation – One Virginia Square, 3601 Wilson Blvd, Arlington, VA 22203*
  - *Limited number of seats – register soon at website below*

For more information contact: Director, Basic Research
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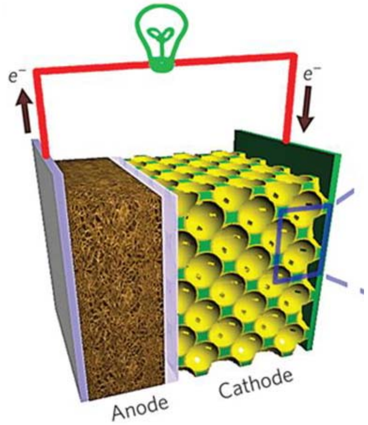
Website: http://www.acq.osd.mil/rd/basic_research/

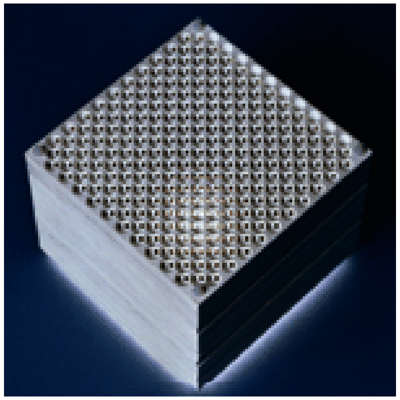
Industry and MURIs

MURIs have produced large numbers of patents, start-up companies, and have shown the way for existing companies to meet DoD needs

GE and others use better coatings for aircraft engines and surfaces



Xerion Advanced Battery ultrafast charge and discharge



Photonic bandgap materials proliferated in applications from LEDs to highly reflective mirrors for lasers

From "Sustaining US Global Leadership – Priorities for Sustaining 21st Century Defense"

- "In adjusting our strategy and attendant force size, the Department will make every effort to **maintain** an adequate industrial base and **our investment in science and technology**."

- "To that end, the Department will both encourage a culture of change and be prudent with its "seed corn," balancing reductions necessitated by resource pressures **with the imperative to sustain key streams of innovation that may provide significant long-term payoffs**."

January 5, 2012