



Department of Defense Basic Research

**13TH ANNUAL
SCIENCE & ENGINEERING TECHNOLOGY CONFERENCE /
National Defense Industrial Association**

**Dr. Robin Staffin
Director for Basic Science
Office of the Assistant Secretary of Defense for Research and Engineering
April 17, 2012**

UNCLASSIFIED



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



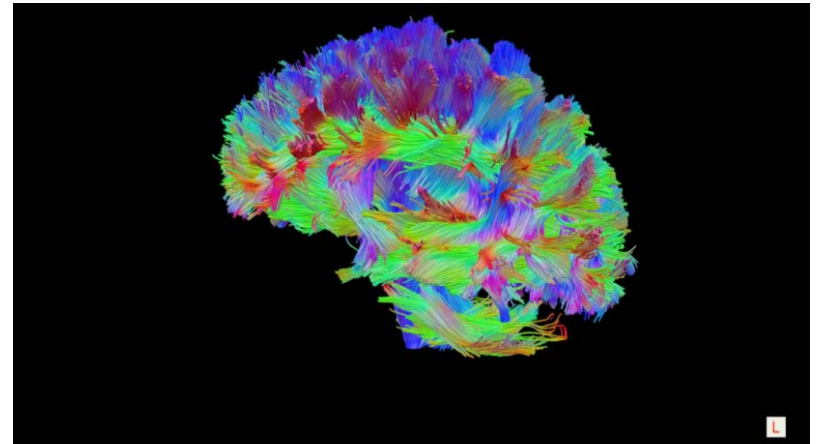
More deeply understand and more fully exploit the fundamental mechanisms of the brain.

- **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**

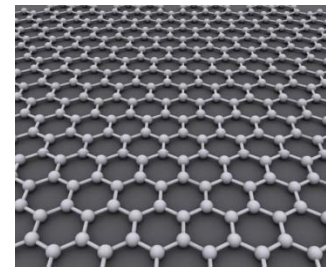
- Electronics & Sensing: Multi-spectral focal plane arrays, ubiquitous embedded sensors, curvilinear electronics, ultra-low voltage devices
- Power and Energy: Fuel-cells, portable electronics, mobile power, thermoelectrics
- Coatings: Photoactive, self-cleaning films

- **Select breakthroughs**

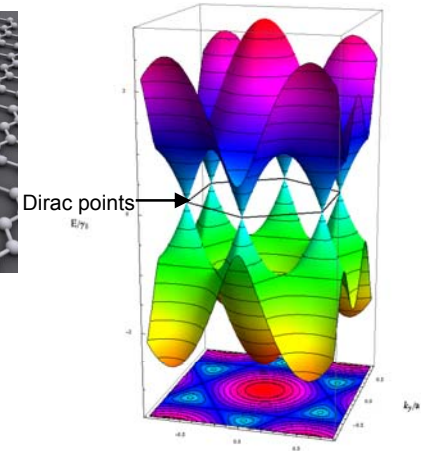
- Nano-particle coating & functionalization
- Catalysts for energy-harvesting
- Graphene and carbon nanotubes

- **Key research challenges**

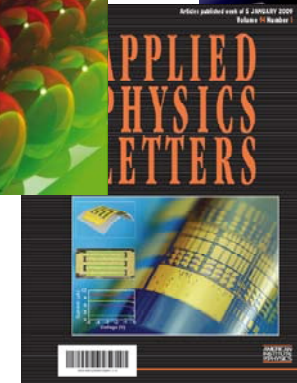
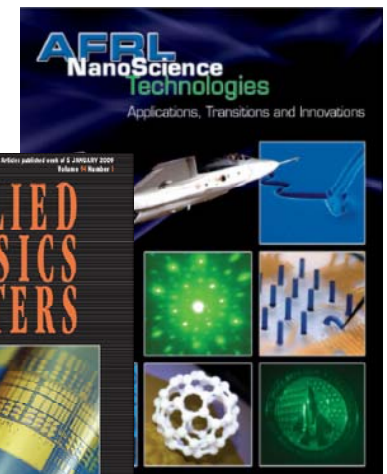
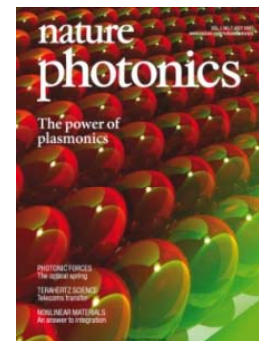
- Low defect density graphene over large areas
- Production and reproducibility of single chirality nanotubes and bilayers of graphene, each layer individually biased to form new condensed state



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

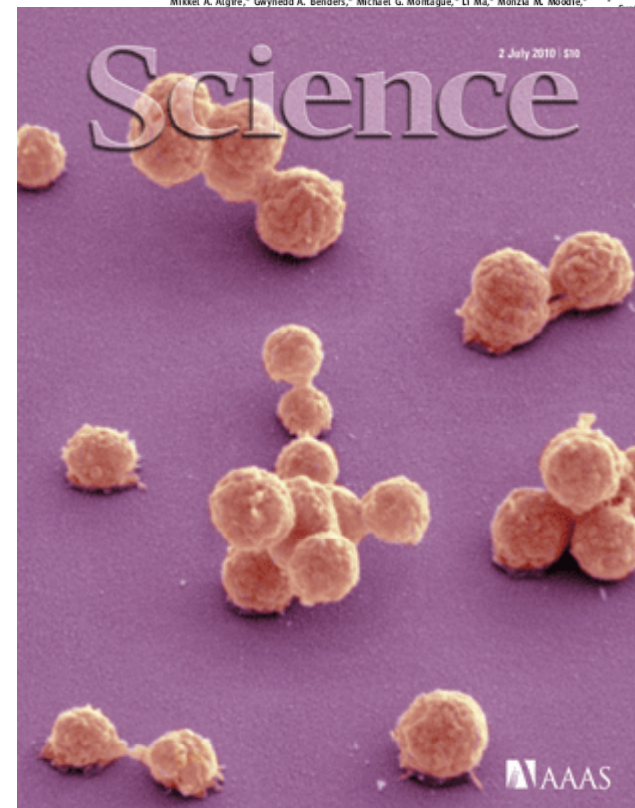
Key research challenges:

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

RESEARCH ARTICLE

Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome

Daniel G. Gibson,¹ John I. Glass,² Carole Lartigue,² Vladimir N. Noskov,² Ray-Yuan Chuang,² Mikkel A. Algré,² Gwynedd A. Benders,² Michael G. Montague,¹ Li Ma,² Monzia M. Moodie,²



create *M. mycoides* or *M. capricolum* extracts, or by simply disrupting the recipient cell's restriction system (8).

We now have combined all of our previously established procedures and report the synthesis, assembly, cloning, and successful transplantation of the 1.08-Mbp *M. mycoides* JCVI-syn1.0 genome, to create a new cell controlled by this synthetic genome.

The genome design. Design of the *M. mycoides* JCVI-syn1.0 genome was based on the complete finished genome sequences of two strains of *M. mycoides* subspecies *capri* (11). One was the genome donor used *et al.* [GenBank accession CP001621] and the other was a strain created by transfer of a genome that had been cloned and in yeast, YCPMyo1.1-*OppA* (GenBank accession CP001668) (6). This project is dependent on the accuracy of these genomes. Although we believe that both *M. mycoides* genome sequences are reliable 95 sites at which they differ. We designed the synthetic genome before both were finished. Consequently, most of the sites were designed and synthesized based on the CP001621 sequence (11). When it was available, we chose the sequence of the genome donor (CP001668) in preference (except that we kept the *lites* gene). All differences that are significant between CP001668 and CP001621 were synthesized as synthetic cassettes and CP001668 was used as a standard for genome trans-formation in yeast (8). To further differentiate the synthetic genome and the natural one, we inserted four watermark sequences (Fig. S1) in or near cassettes in regions experimentally demonstrated [watermarks 1 (1246 bp), 2 (11 bp)] or predicted [watermarks 3 and 4 (1222 bp)] to not interfere with the natural genome. These watermark sequences encode differences while limiting their translation as. Table S1 lists the differences between the synthetic genome and the natural strain. Fig. S2 shows a map of the *M. mycoides* JCVI-syn1.0 genome. Cassette and assembly intermediaries, watermarks, deletions, insertions of the *M. mycoides* JCVI-syn1.0 in Fig. S2, and the sequence of the mycoplasma clone sMmYCP255-1 submitted to GenBank (accession GCA000000000) are available. The synthetic genome assembly strategy. The cassettes were generally 1080 bp with 100 bp overlaps to adjacent cassettes (11). They were produced by assembly of chemically

Downloaded from www.sciencemag.org on January 4, 2011



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

Costly Punishment Across Human Societies

Joseph Henrich,^{1*} Richard McElreath,² Abigail Barr,³ Juan Ensminger, Alexander Bolyanatz,⁴ Juan Camilo Cardenas,⁵ Michael Gurven,⁶ Ewa Natalia Henrich,² Carolyn Lesorogol,¹⁰ Frank Marlowe,¹¹ David Tracer

Recent behavioral experiments aimed at understanding the evolutionary cooperation have suggested that a willingness to engage in costly punishment situations, may be part of human psychology and a key element in understanding. However, because most experiments have been confined to students in industrialized societies, generalizations of these insights to the species have necessarily been tentative. Results from 15 diverse populations show that (i) all populations demonstrate a willingness to administer costly punishment as inequitable behavior increases, (ii) the amount of costly punishment varies substantially across populations, and (iii) costly punishment is associated with altruistic behavior across populations. These findings are consistent with a gene-culture coevolution of human altruism and further sharpen what a theory of cooperation needs to explain.

For tens of thousands of years before formal contracts, courts, and constitutions, human societies maintained important forms of cooperation in domains such as hunting, warfare, trade, and food sharing. The scale of cooperation in both contemporary and past human societies remains a puzzle for the evolutionary and social sciences, because, first, neither kin selection nor reciprocity appears to readily explain altruism in very large groups of unrelated individuals and, second, classical assumptions of self-regarding preferences in economics and related fields appear equally ill-fitted to the facts (1). Reputation can support altruism in large groups; however, some other mechanism is needed to explain why reciprocity should be linked to prosociality rather than selfish or neutral behavior (2). Recent theoretical work suggests that, subject to certain conditions, evolve, even among non-industrialized societies devoid of reputation systems, cooperation also emerges. Consistent with this, experiments have demonstrated the existence of costly punishment (3, 4, 5, 6, 7, 8, 9, 10, 11, 12), and (iii) will be consistent with the theory of costly punishment (13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100).



Population	Costly Punishment	n
Marango	●	n=25
Hadza	●	n=31
Tsimane	●	n=35
Samburu	●	n=31
Shuar	●	n=21
Isanga Village	●	n=30

RESEARCH ARTICLES

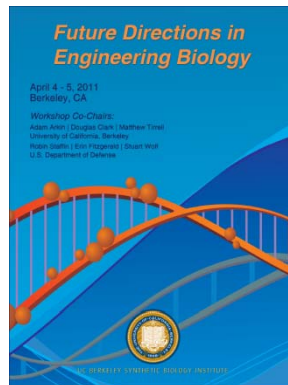
have even been...
deepenings of...
because the...
of large-scale...
like previous...
study altruism...
conducted at...
university students...
such findings...
students and/or...
ethics or...
characterized...
experimental...
desires to measure...
(6). We found...
did not explain...
societies studied...
variation in...
with...
until costly...
societies and...
it is difficult to...
forming human...
how widespread...
punishment...
is valuable...
costly punishment...
stronger norms...
because the



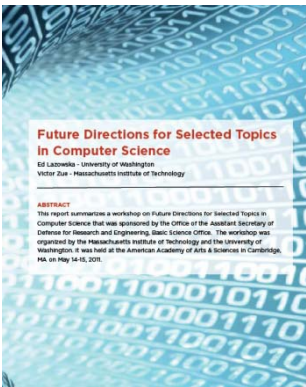
Future Directions Scientific Workshops



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
Dr. Robin Staffin - robin.staffin@osd.mil
Website: http://www.acq.osd.mil/rd/basic_research/



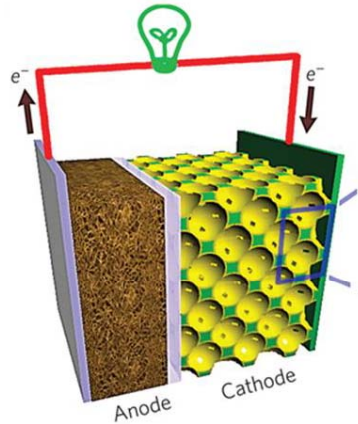
Industry and MURIs



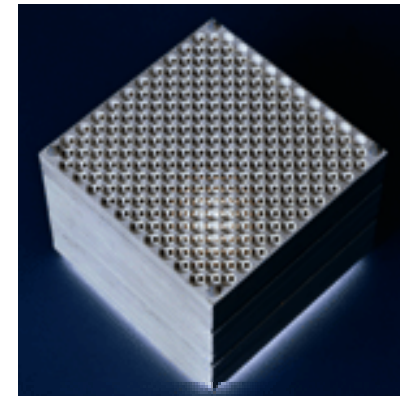
MURIs have produced large numbers of patents, start-up companies, and have shown the way for existing companies to meet DoD needs



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