Convergence – An Emerging Research Paradigm
Examples from NSF

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GUIRR Workshop on Convergence
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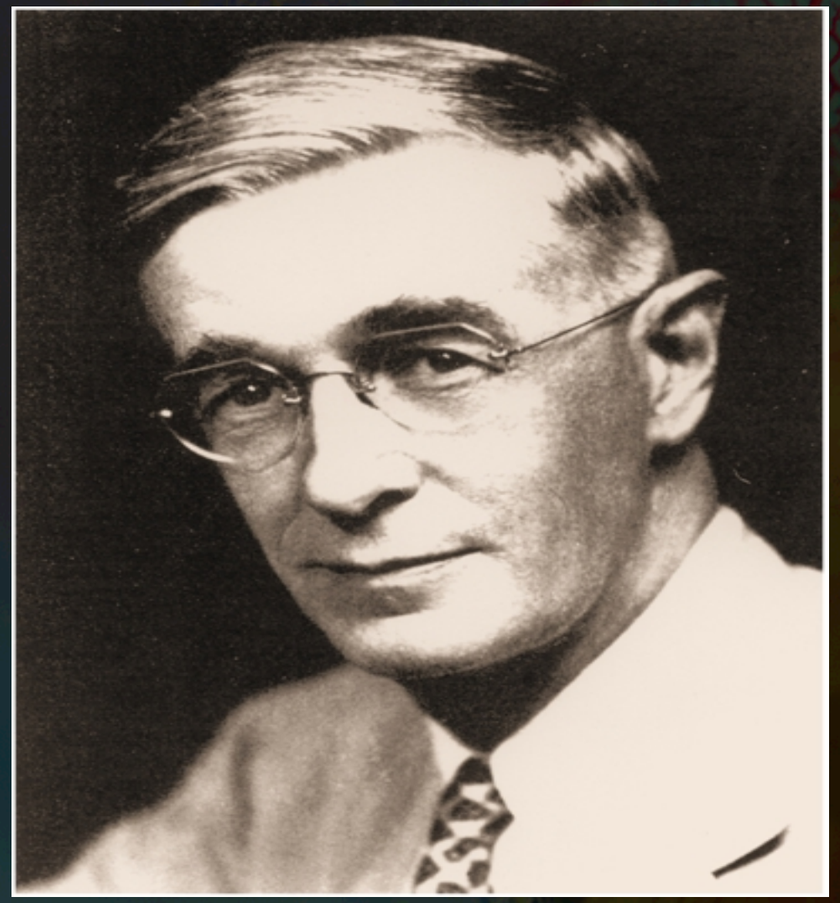

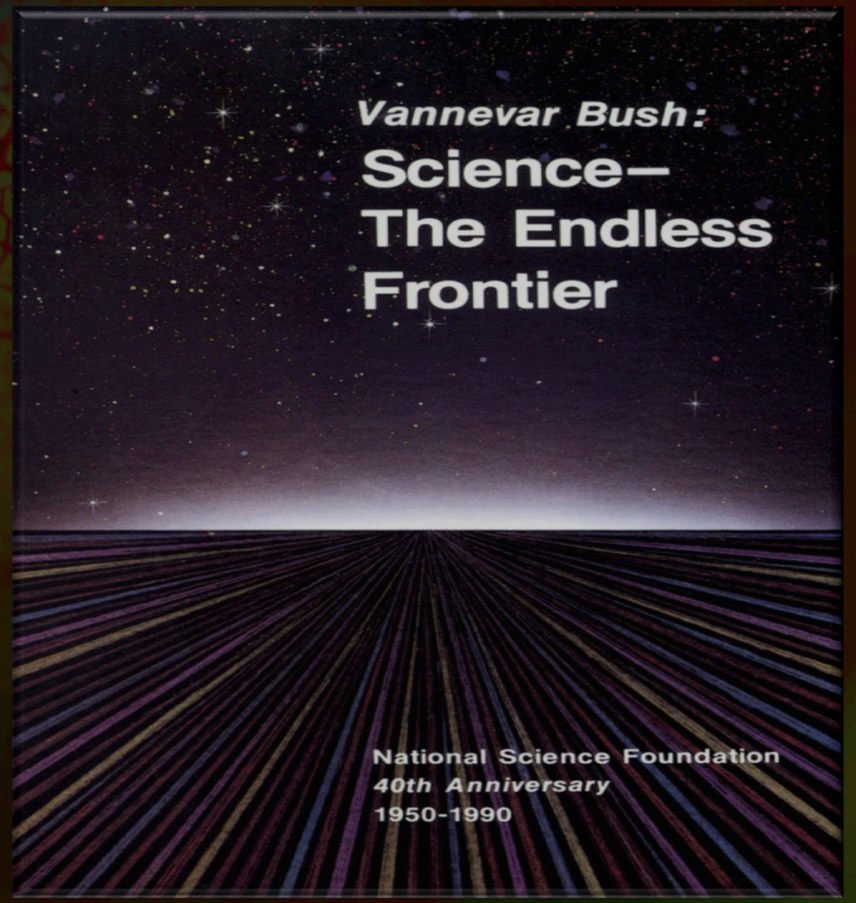

"to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…"
NSF Act, 1950

Image courtesy MIT Museum

Larger Context

- Economic growth and full employment in a sustainable manner
- Globalized world – flows of components, products, services, knowledge, and people
- Mega problems and grand challenges: food, energy, water, health, security, education, infrastructure, …
- Stubborn long-standing issues in STEM talent, diversity, and education

Tissue Engineering meets 3D Printing

- 3D printing technology
  - NSF support for geometric modeling, additive manufacturing in the 1980s and 1990s
- Tissue engineering
  - Combination of clinical medicine, engineering and science
  - NSF support goes back to late 1980s
- Additive manufacturing enables printing of scaffolds for tissue engineering
  - Unanticipated convergence of two very different research directions

Novogen MMX Bioprinter

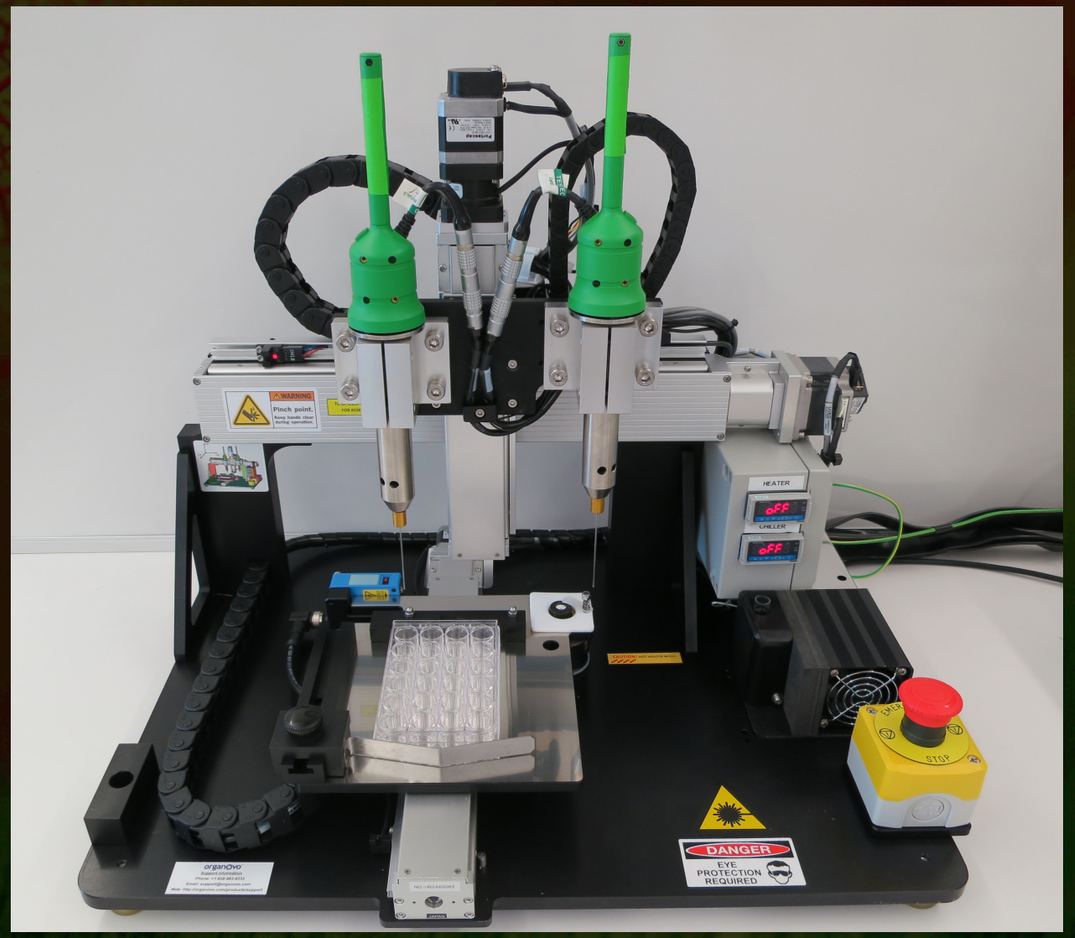

Image Credit: Organovo, Inc.

Advanced Biomanufacturing

- The use of biological systems or the products of biological systems to generate new materials, tissue constructs, and devices, with a view towards scalability and industrialization.

2013 Workshop Vision

- To advance biomanufacturing as an emerging discipline in academic and industrial communities, as well as a technological opportunity to spur research and industry growth.

Convergence of biology, materials science, process control and engineering

A New Research Paradigm?

Definition of Paradigm

universally recognized scientific achievements that, for a time, provide model problems and solutions for a community of practitioners

Thomas Kuhn

Convergence

- Deep integration of knowledge, tools, and ways of thinking from life and health sciences, physical, mathematical, and computational sciences, engineering disciplines, and beyond
- Does *convergence* represent a new paradigm in science and engineering research?

Exemplars from NSF

The Synthetic Biology ERC (SynBERC)

Vision: engineered interchangeable biological tools that "repurpose" nature to benefit mankind.

- Integrate foundational understanding of biology into computational tools to design new biological parts and devices *in silico.*
- Biological parts and devices are made *de novo* using engineered DNA that is expressed
- Parts and devices are assembled in circuits within living cells to manufacture specialty chemicals or test drug candidates
- Work with stakeholders to minimize biorisks and environmental footprint.

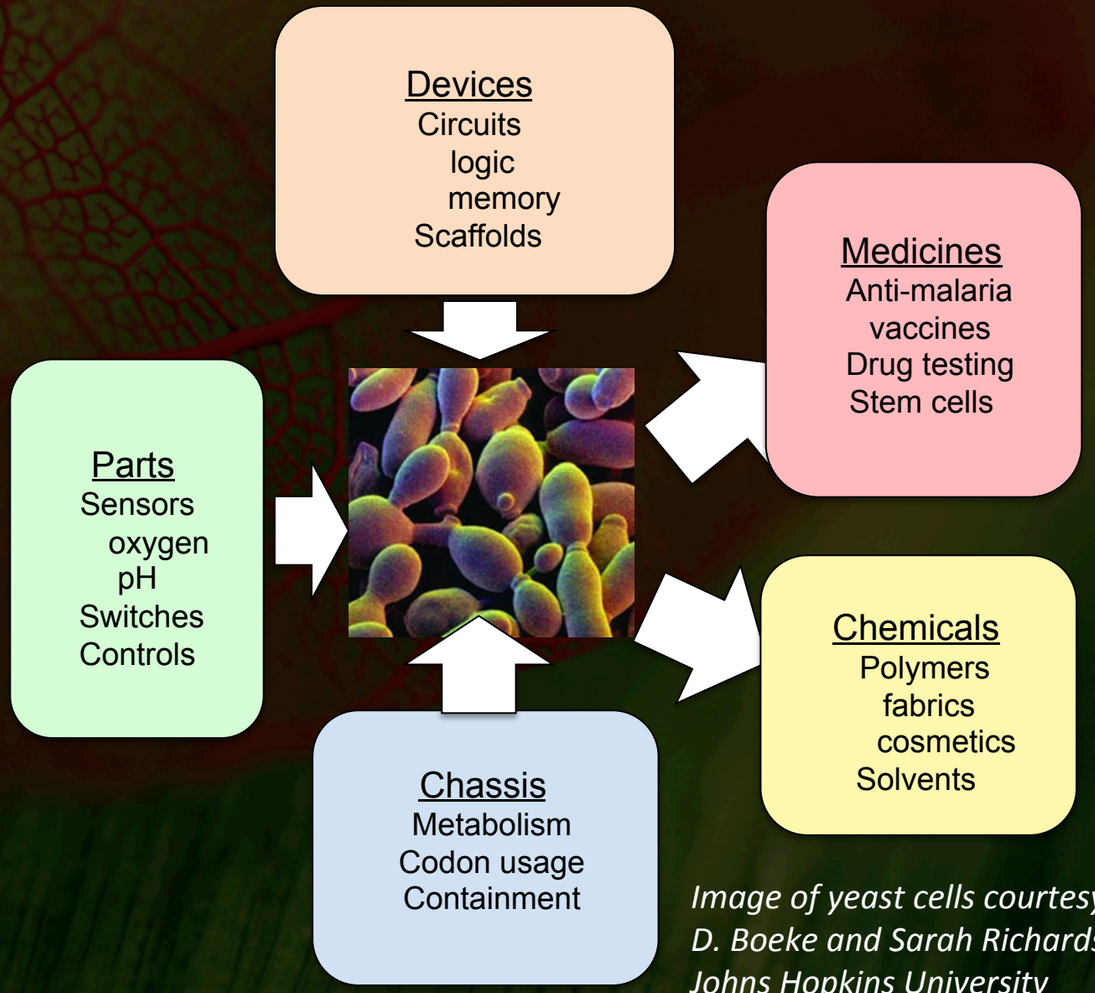

Image of yeast cells courtesy Jef D. Boeke and Sarah Richardson, Johns Hopkins University

Lead UC Berkeley (PI: Keasling); UC San Francisco, Stanford, Harvard and MIT are partner institutions.

Research Highlights

SynBERC
Synthetic Biology Engineering Research Center

- Parts: Inserted protein domains to facilitate connectivity in larger protein networks
- Devices: Showed logic gates (AND/OR/NOR) and memory circuits can activate cell pathways
- Chassis: Coordinated physical & functional activity of disparate parts in devices, chassis, and systems
- Biosafety: Reconstituted approach to risk, biosafety, and biosecurity with students, researchers, and regulators
- Curricula: 33 new courses, 2 certificate programs, 9 course modules

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Technology Highlights

- Parts: Infused modeling/design tools into industry member firms. Sent 1,500 parts to Life Technologies
- Devices: Demonstrated logic gates and sensors in member firms DSM, Inc. and Genomatica
- Chassis: Increased predictability and reduced biorisk of bacterial and mammalian cell chasses
- Biosafety: Conducted workshops and published white papers with stakeholders in government, industry, academia
- Numbers: Applications/Patents/Licenses = 72 / 5 / 4
- Spin-off companies = 5 from sponsored research

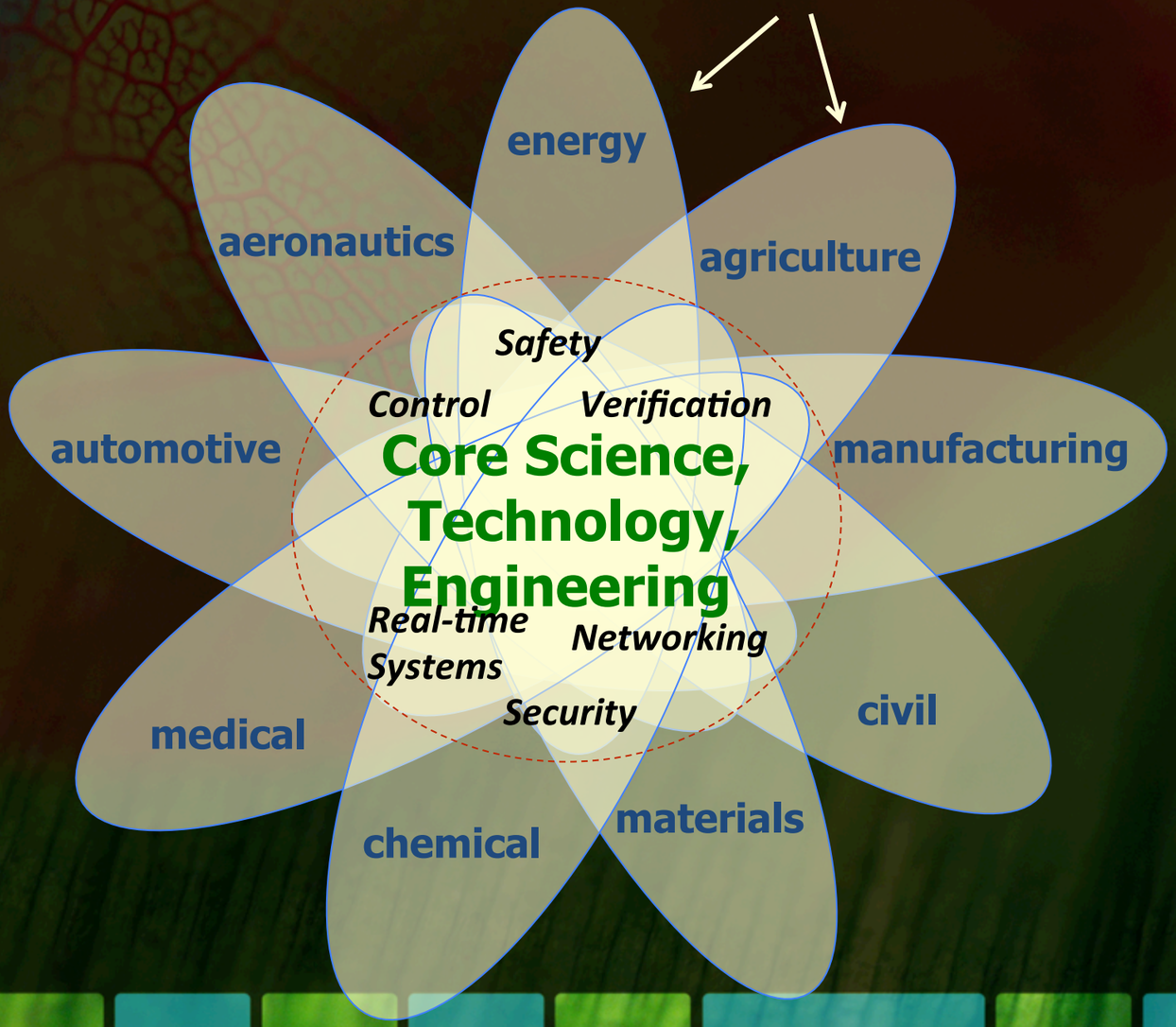
Cyber-Physical Systems (CPS)

- Roots in Cybernetics: idea goes back to Norbert Wiener
- Computation, communications, networking elements being increasingly infused into the physical world
- Computer science disciplines converging with disciplines that govern physical (and biological) worlds at multiple temporal and spatial scales
- *Internet-of-Things or Industrial Internet*

Transportation	▪ **Faster and safer aircraft** ▪ **Improved use of airspace** ▪ **Safer, more efficient cars**
Energy and Industrial Automation	▪ **Homes and offices that are more energy efficient and cheaper to operate** ▪ **Distributed micro-generation for the grid**
Healthcare and Biomedical Systems	▪ **Increased use of effective in-home care** ▪ **More capable devices for diagnosis** ▪ **New internal and external prosthetics**
Critical Infrastructure	▪ **More reliable power grid** ▪ **Highways that allow denser traffic with increased safety**

CPS Approach

- Abstract from application sectors to more foundational principles
- Apply these principles to problems in new sectors
- Safe, secure, reliable, verification, real-time adaptation, …



Infrastructures Research: Earthquakes and Hazards

- NSF-supported approaches and successes
  - Earthquake-resistant structures (e.g., base isolation, novel materials, improved building codes)
  - George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES): unique national facilities “at scale”
  - Integration of engineering and social sciences for infrastructure management and hazard mitigation

Credit: J.K. Nakata, U.S. Geological Survey

New Paradigm for Infrastructures

"the framework of ***interdependent networks*** and ***systems*** comprising identifiable industries, institutions (including ***people*** and ***procedures***), and distribution capabilities that provide a reliable flow of products and ***services ….***"

National Infrastructure Protection Plan 2006
Executive Order 13010

Emphasis is on viewing infrastructures as systems of processes with significant human behavioral dependency and cyber components that together deliver services, in contrast with the traditional view as discrete physical elements.

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Resilient Interdependent Infrastructure Processes and Systems (RIPS)

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Convergence of Engineering, Computer Science, and *Social, Behavioral and Economic Sciences*

Directorate for Computer & Information Science & Engineering

Division of Computer and Network Systems

Directorate for Engineering

Emerging Frontiers in Research and Innovation

Division of Electrical, Communications and Cyber Systems

Division of Chemical, Bioengineering, Environmental, and Transport Systems

Division of Civil, Mechanical and Manufacturing Innovation

Directorate for Social, Behavioral & Economic Sciences

Challenges and Opportunities – *Funding Agencies*

- How do we maximize synergies between core disciplinary programs and emerging areas of convergence?
- How do we identify and catalyze new areas of convergence?
- How do we structure merit review processes to assess convergence oriented proposals?
- How do we coordinate and leverage across Federal agencies?

Challenges and Opportunities – *Academic Institutions*

- How to create flexible organizational structures to enable convergence research paradigm change?
- How do we educate students to successfully engage in the convergence revolution?
- How to modify the tenure and promotion system to encourage intellectual risk-taking inherent in convergence-style research?
- How will scientific professional societies adapt to the convergence research paradigm?

Challenges and Opportunities – *Industry*

- Technology companies have deep and critical knowledge and know-how in a variety of scientific and engineering fields
- How can the industry collaborate with government and academic institutions to realize the benefits and payoffs from a convergence paradigm?
- Is the open innovation approach synergistic with convergence-oriented research?
- Do we need new partnership models?

Closing Thoughts

- Convergence has the potential to transform the research ecosystem
- It will require organizational and cultural changes in academic, government, and industry sectors
- Successful, high impact examples will guide and accelerate its development to become a new paradigm
- Ultimate success depends on inspiring and attracting brilliant minds to see “convergence-style” research as the path to realize their dreams

QUESTIONS?

IDEAS, THOUGHTS!

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