From the Quest for Fire to GATTACA: Systems and Synthetic Biology as the Next Wave of Technology Disruption in the Anthropocene

Dr. George Poste
Chief Scientist, Complex Adaptive Systems Initiative
and Del E. Webb Chair in Health Innovation
Arizona State University
george.poste@asu.edu
www.casi.asu.edu

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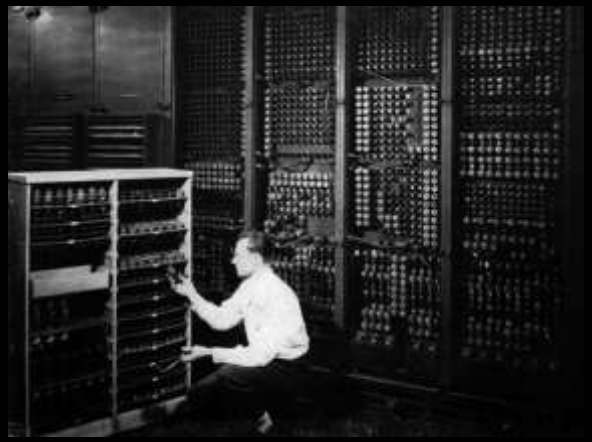
The Journey to the Anthropocene: Mastery of Increasingly Sophisticated Intellectual Challenges and Technological Acceleration

First Communication Revolution 70K YBP

Agrarian Revolution 11K YBP

Scientific Revolution 0.5K YBP

Industrial Revolution 0.25K YBP



Digital Revolution 0.1K YBP

Molecular Biology Revolution 0.05K YBP

Systems and Synthetic Biology as the Next Major Wave of Technological Disruption in the Anthropocene

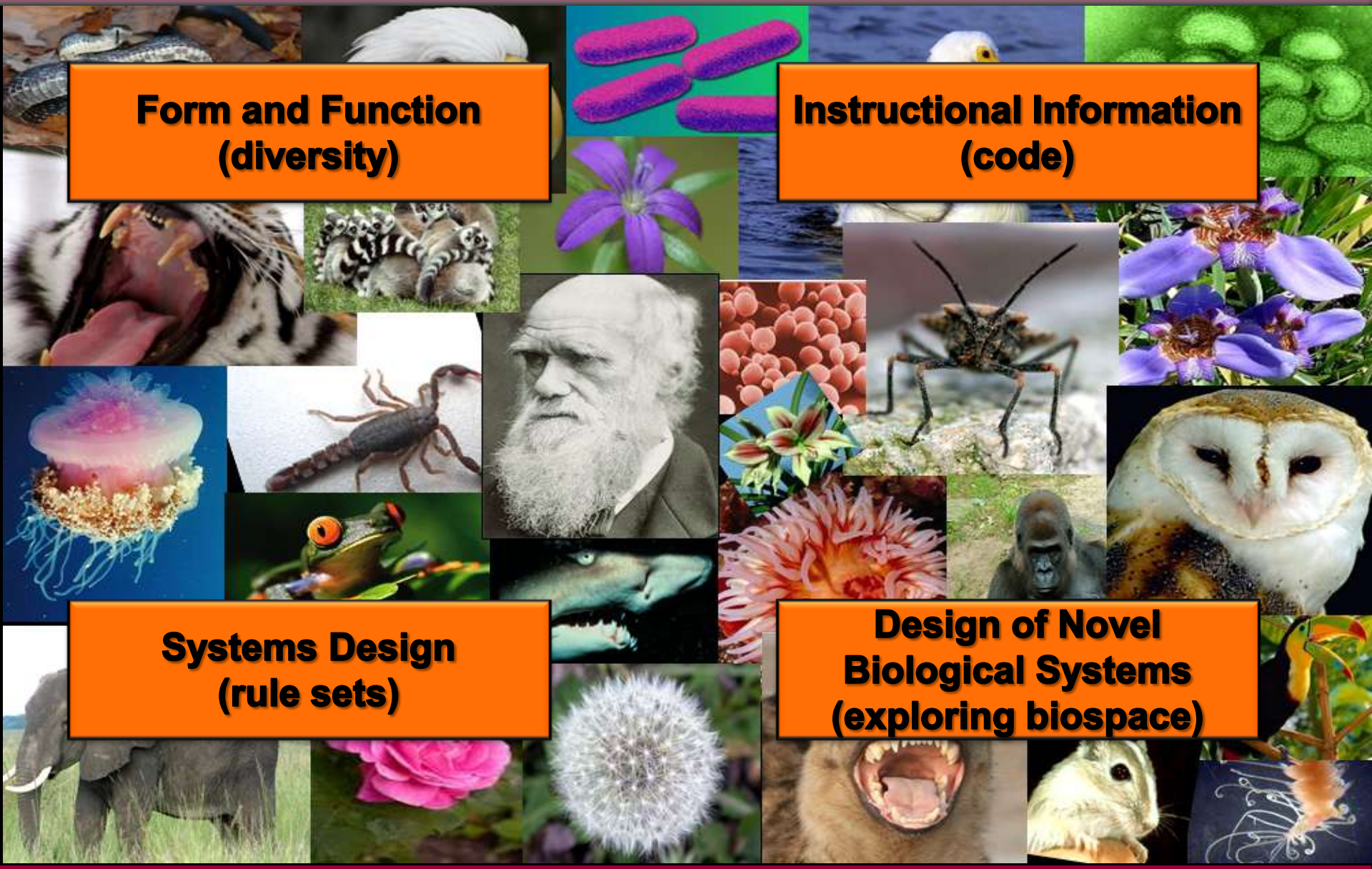
Understanding the Instructional Rules for Construction and Control of Complex Biological Systems

**Exploring Biospace:
Engineering Novel Biological Functions**

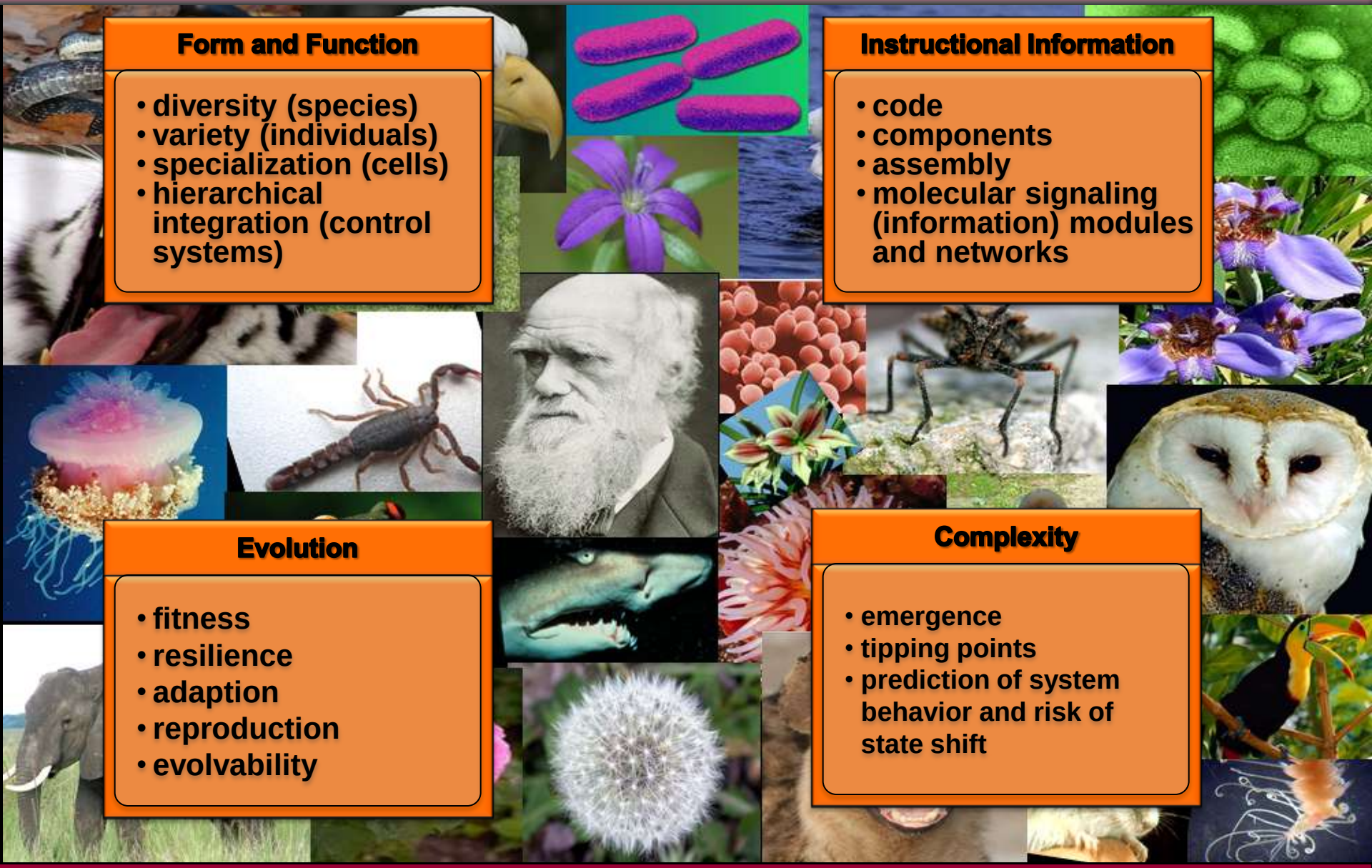
**Directed Evolution and Accelerated Evolution:
From Individual Molecules to Organisms**

Biological Diversity and Variation: "Endless Forms Most Beautiful"

“Endless Forms Most Beautiful”
Systems and Synthetic Biology and Exploring Biospace



“Endless Forms Most Beautiful”
Systems and Synthetic Biology and Exploring Biospace



Form and Function

- diversity (species)
- variety (individuals)
- specialization (cells)
- hierarchical integration (control systems)

Instructional Information

- code
- components
- assembly
- molecular signaling (information) modules and networks

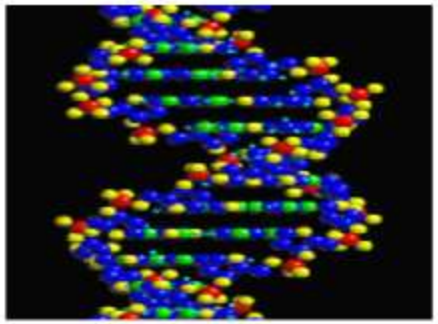
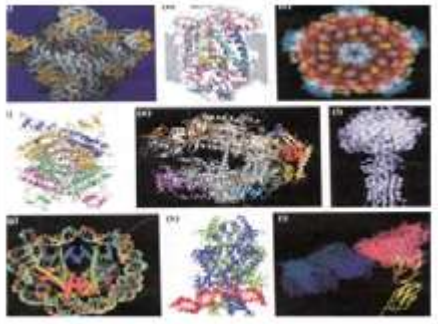
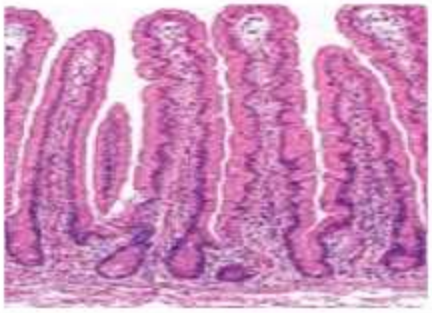
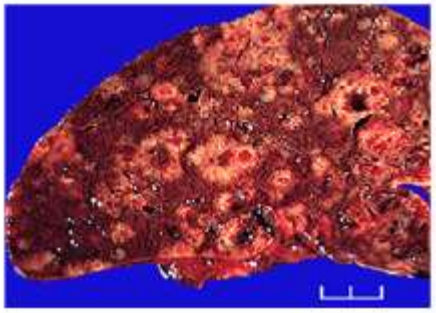
Evolution

- fitness
- resilience
- adaption
- reproduction
- evolvability

Complexity

- emergence
- tipping points
- prediction of system behavior and risk of state shift

The Economy of Biological Organization: Defining the Common Building Components for Biological Systems and Combinatorial Assembly to Generate Functional Diversity

common genetic (digital) code in all life forms	tool box of protein motifs for combinatorial assembly (“molecular lego”)	assembly of structurally and functionally diverse proteins	networks of protein interactions and complex molecular signaling patterns
			
			
complex organism design	stable networks and information fidelity (health)	dysregulated networks and altered information patterns (disease)	therapeutic modulation of perturbed networks

Understanding the Rule Sets for Regulated Information Flow and Processing in Dynamic Biological Systems

“It”
(hardware/wetware)

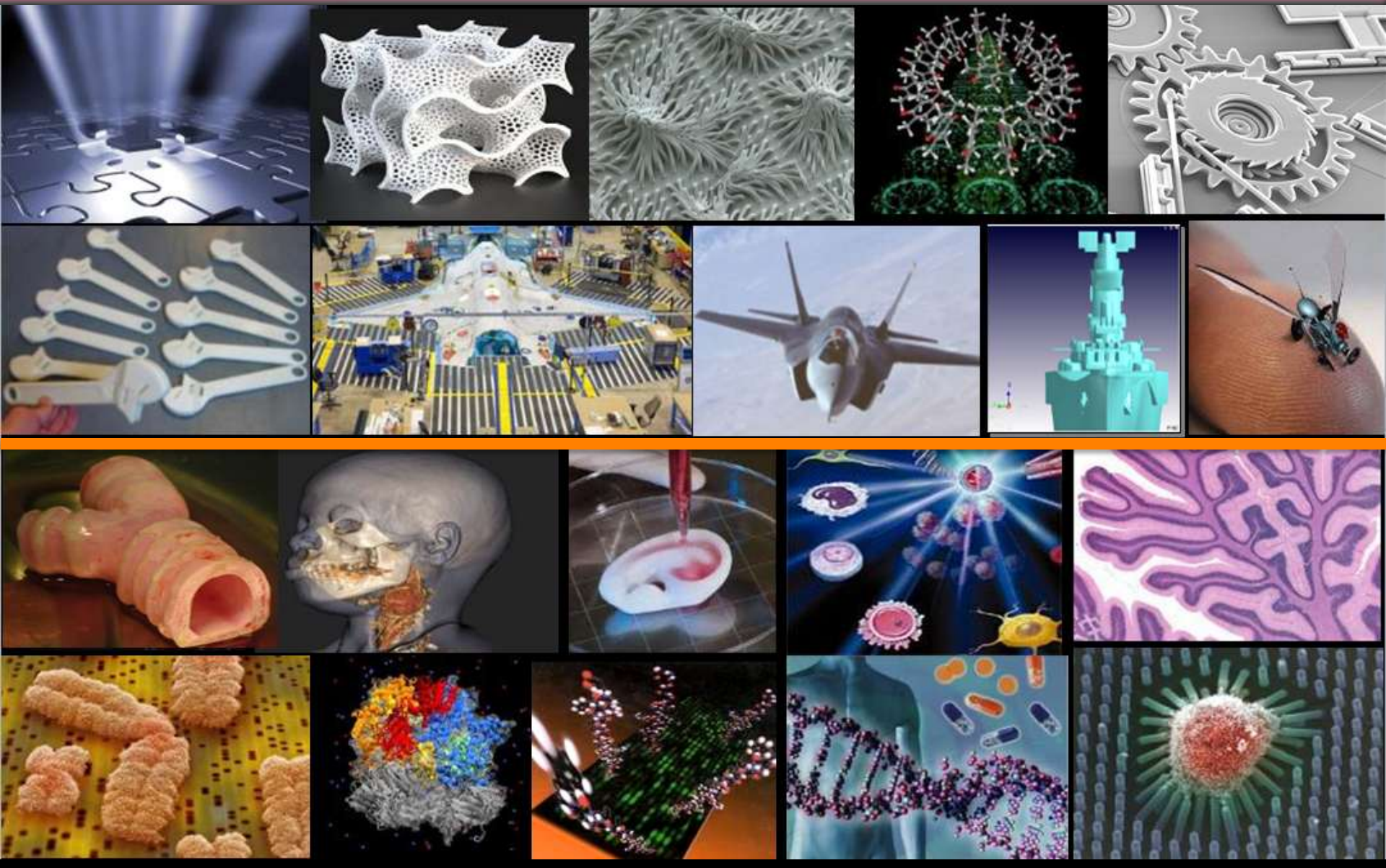
“Bits”
(software and encoded design)

“Exploring Biospace”
(directed design of novel biological systems)

Digital Biology (Code) and Synthetic Biology (Construction): "It from Bits"

- program and assemble new biological functions and organisms based on knowledge of the 'rule sets' underlying hierarchical biological systems
- reprogramming existing biological signaling pathways and networks
- expanding the dimension of explored biospace
  - design, simulation and construction of novel functions/organisms with no known natural evolutionary counter part
  - novel biotic: abiotic combinations
- "directed evolution" and "accelerated evolution"

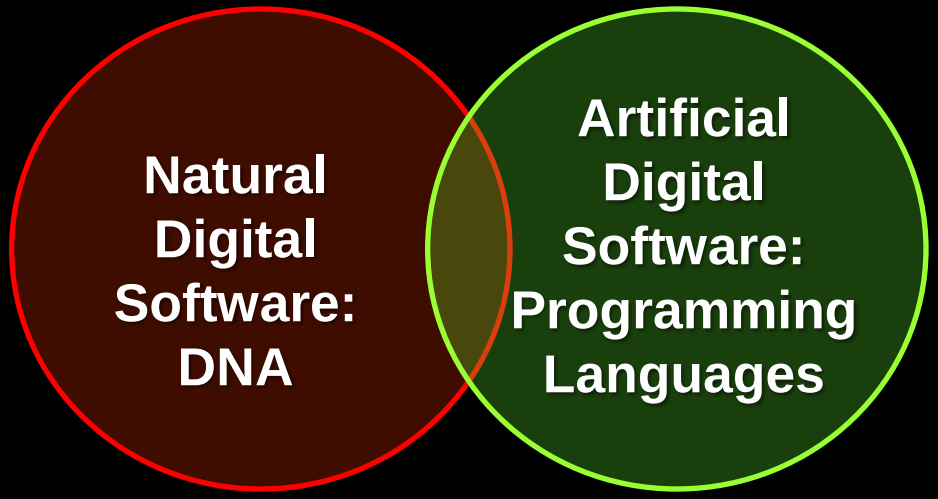
Advanced Manufacturing
Digital Programming of New 3-D Fabrication and Assembly Technologies



Programmable Matter: Computer-Controlled 3D Assembly of Structures of Increasing Complexity

- digital code for automated assembly of complex multi-scale structures
- uncoupling of design from fabrication and rise of point-of-need (PON) production capabilities
- 3D printing
  - spatio-temporal assembly at nano-/ Ångstrom-level scale
  - abiotic materials
  - biotic materials
  - abiotic:biotic hybrids
- 4D systems
  - self-assembly, repair and reconfiguration
  - dynamic adaptive behavior: repair, reconfiguration

Digital Convergence

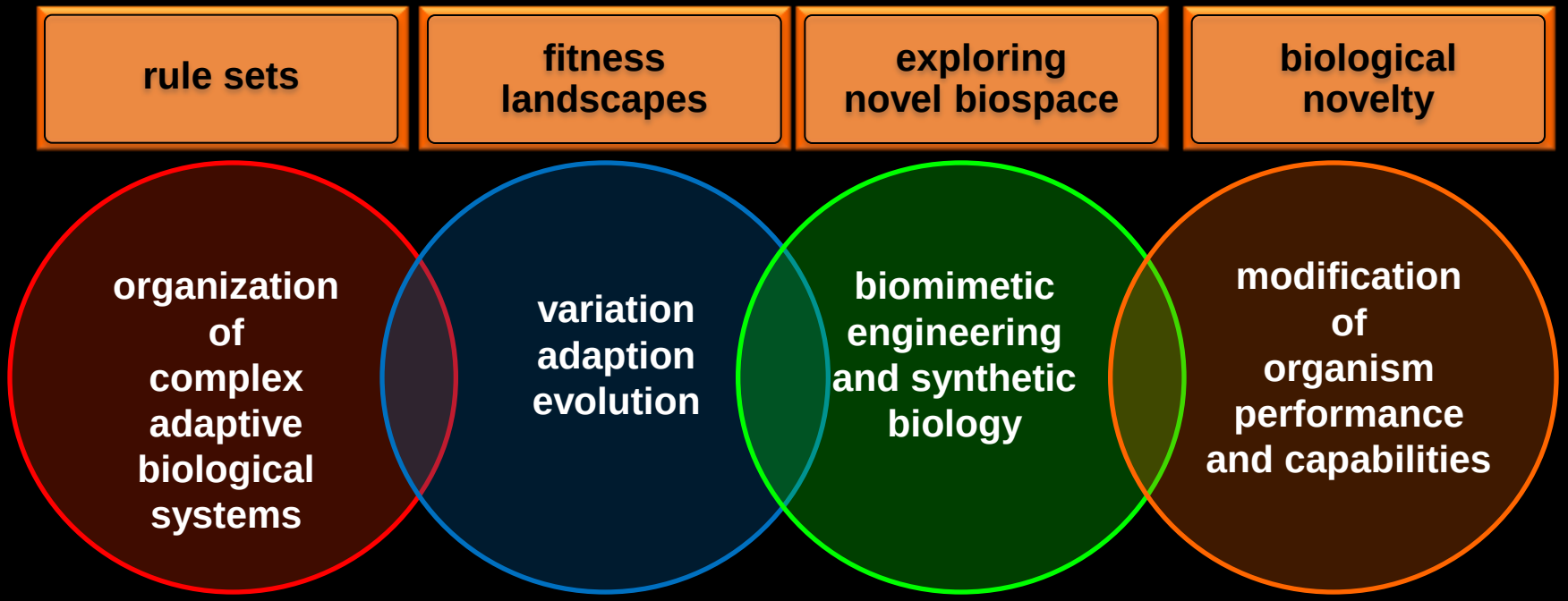


$3 – 4 \times 10^9$ years old	60 - 70 years old

Exploring Biospace
The Power of Combinatorial Interactions and Molecular Assembly

- number of theoretical possibilities for synthetic assembly (biospace) far exceed narrow molecular space sampled in evolutionary time to date
- estimated 22,000 human genes
- two genes cooperate to create a function =(22,000 x 21,999)/2 = 241,989,000 potential combinations
- 100 genes generate a complex function $=10^{65794}$ potential combinations

Mapping the Coding Information for Organizational Complexity, Diversity and Variation in Biological Systems



- form and function
- instructional codes and information content

- mapping existing biospace

- dual use applications
- ethics, oversight and regulation

- augmentation (non-heritable)
- enhancement (heritable)

Technological Progress

From Reactive Precarious Survival to Proactive Shaping of the Anthropocene

Technology Acceleration and Technology Convergence

Escalating Technical Complexity and Understanding Emergence in Complex Adaptive Systems

Complex Adaptive Systems: Increasing DDOF







- graded levels of autonomous behavior (components, system)
- escalating challenge of predicting system behavior and state shifts

Understanding Complex Biological Systems and Directed Engineering of Biological Novelty

“Oh, God help us! We’re in the hands of engineers.”

Dr. Ian Malcolm
‘Chaotician’: Jurassic Park