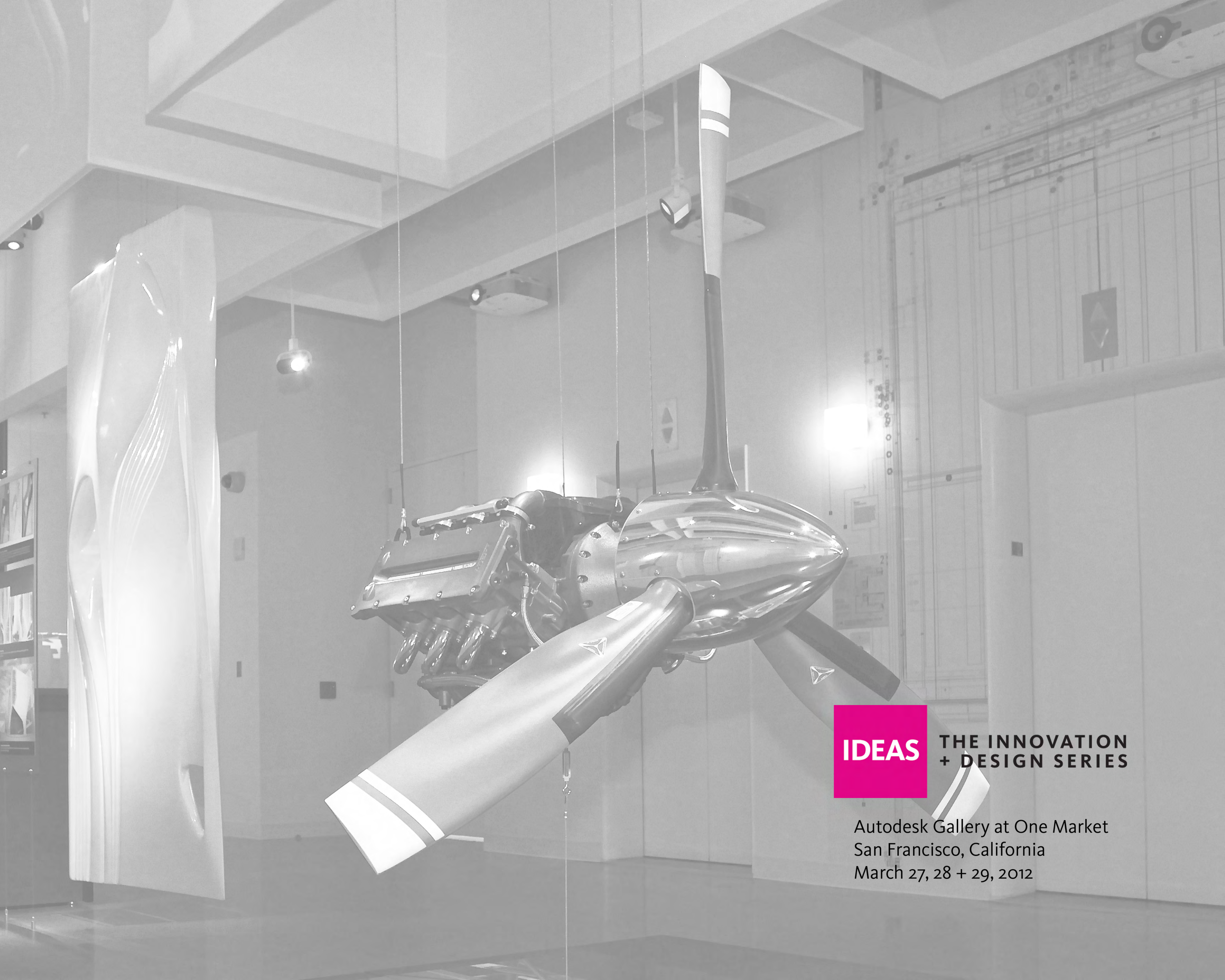
Autodesk®

IDEAS

IDEAS: The Innovation + Design Series

Transcendent of specific products or disciplines, IDEAS is an exclusive gathering of thought leaders for the purpose of exploring design - as a systematic approach to problem solving and innovation, encompassing form, function, and performance - and its impact on corporate and societal success.



IDEAS THE INNOVATION + DESIGN SERIES

Autodesk Gallery at One Market
San Francisco, California
March 27, 28 + 29, 2012

Small is the New Big:

Designing Our Future at the Nanoscale, Humanscale, and Beyond

Imagine it's the year 1977 and a diverse group of visionaries meet to speculate on the impact of the "personal computer". Could they have imagined how the exponential growth of computation, connectivity, and miniaturization would power a globally connected network of technologies that would define, transform, and create industries? Consider the myriad of decisions over the past two decades that might have been better informed from being part of such a forum.

Flash forward to today, where advancements in programming matter at the nanoscale, and synthethic biology in particular, promise imminent disruption to industries even more quickly and dramatically than ever imagined or experienced before. When and where will the big breakthroughs occur? How might these innovations change the way we approach the science and art of design? And how might humanscale engineering breakthroughs, including simulation and optimization, be applied to facilitate a spec-driven, repeatable process for the nanoscale?

In consideration of these questions and more, Autodesk **IDEAS** has brought together an eclectic group of present-day visionaries, including scientists, academics, engineers, architects, designers, and entrepreneurs to explore the promise and potential of bio/nanotechnology today, and ideate the implications and opportunities for tomorrow.

The one billionth-scale is reshaping how we
imagine, design + create
for the humanscale and beyond.

IDEAS_05
The Promise of Synthetic Biology & Programmable Matter

EXECUTIVE SUMMARY

On March 27th and 28th, thirty leaders in Synthetic Biology, Programmable Matter and Design Technology met at the IDEAS Innovation+Design Summit to discuss tools, trends and implications of these emerging technologies.

The participants - an eclectic group of researchers from different industries - presented a wide range of topics through the course of the two day workshop. Subjects ranged from synthetic biology to programmable matter, and from self assembly to large structures.

The participants shared their work in the form of condensed presentations followed by questions and discussions. This visual report contains a description of the key ideas presented in the Summit.

It also contains an analysis from the IDEAS team of a framework of design which strives to bring together the emerging technologies and workflows with traditional design methodologies.

Still in its infancy, the promise of Synthetic Biology and Programmable Matter is profound, potentially addressing the grand challenges of the world, from producing sustainable energy and abundant healthy food to access to clean water and new ways of manufacturing things.

For more information about IDEAS, contact ideas@autodesk.com.

The IDEAS team.

New Paradigms and Processes will Enable People to Transform Industries

THE BIG IDEA - AN ANALYSIS

Synthetic Biology and Programmable Matter apply computational technologies to enable design at the nano scale and beyond. Relatively uncharted and full of promise, these emerging domains of study will inspire designers to rethink the way they approach their work as well as reconsider the nature of the problems they can address. The wildly diverse tools and technologies will have a broad impact which can be summarized into the following sentence: new paradigms and processes will enable people to transform industries.

NEW

Several technologies continue to grow at exponential rates, compounding their power while lowering their cost. Most dramatic beyond raw computational power is the capacity to read and write genetic material. The application of computation to biology is a primary driver for emerging design approaches.

PARADIGMS

These advances in design, computational and biological tools are providing designers with new frameworks and approaches to design. Eight domains of design were subsequently identified.

AND PROCESSES

The essence of design is an iterative process that combines exploration, discovery, analysis, prototyping, production and measurement. However, the the way design occurs within each design paradigm can be significantly different from others.

ENABLE PEOPLE

As digital, physical and biological tools become more powerful, available at a lower cost, they become democratized, allowing more people from different disciplines to do the creative work of design.

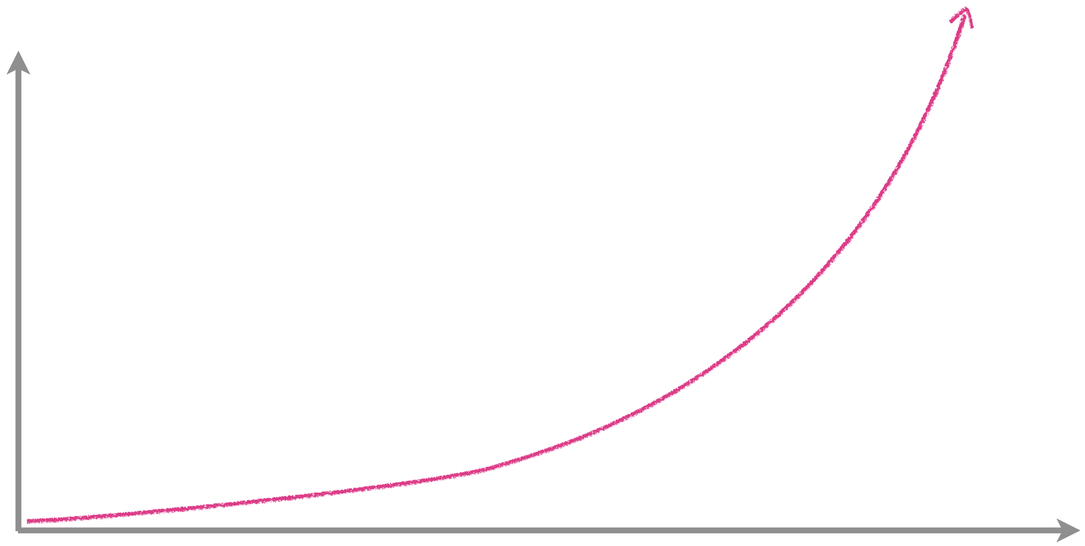
TO TRANSFORM INDUSTRIES

The resulting impact of new technologies, paradigms and processes will equip more people to transform entire industries, from energy production, food, building and healthcare.

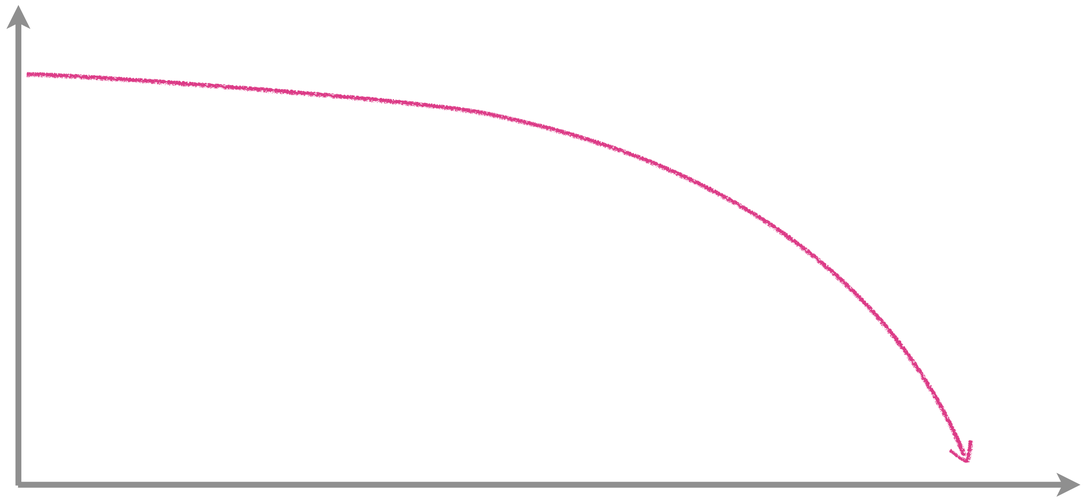
We are at the beginning of a massive transformation of the approaches to design and fabrication.

New Paradigms and Processes will Enable People to Transform Industries

NEW TECHNOLOGIES CREATE EXPONENTIAL GROWTH
Exponentially growing technologies exhibit compounding development. Generally built on information technologies, their growth accelerates as faster and more powerful computers build faster and more powerful computers. This accruing growth is generally represented as an ever steeper curve.



COST OF PRODUCTION
One consequence of this growth is lowering cost of production. Most significant is the change of genomic reading and writing, which are changing faster than Moore's Law.



New technologies provide more capacity to digitally scan, modify and fabricate objects of all kinds.

New Paradigms and Processes will Enable People to Transform Industries

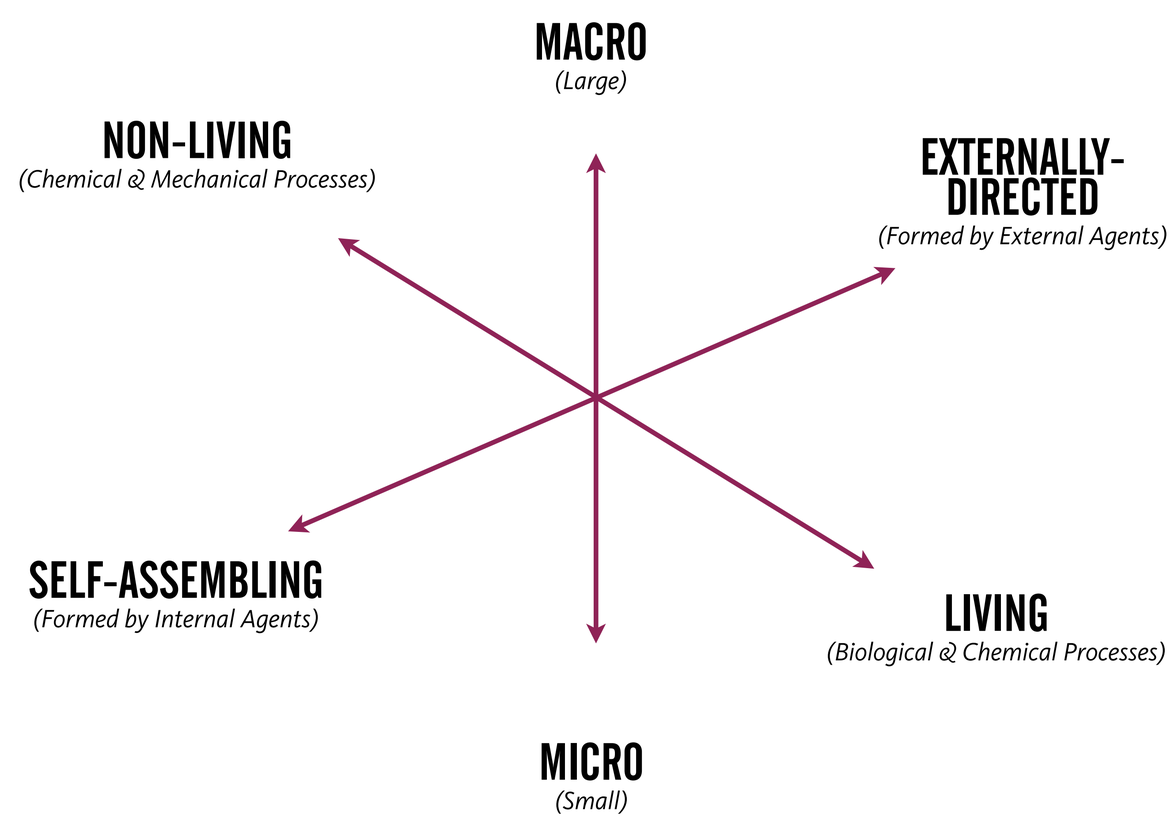
PARADIGMS
The impact of these emerging technologies to digitally record, manipulate and fabricate objects is expanding the designers' reach into several domains: spatial, fabrication method and nature of material.

SIZE: Macro vs Micro
New tools are allowing designers to extend their capability of design from the setting of everyday objects (shoes, cars, furniture) and larger objects (buildings and cities) to smaller objects (medical devices and nanobots).

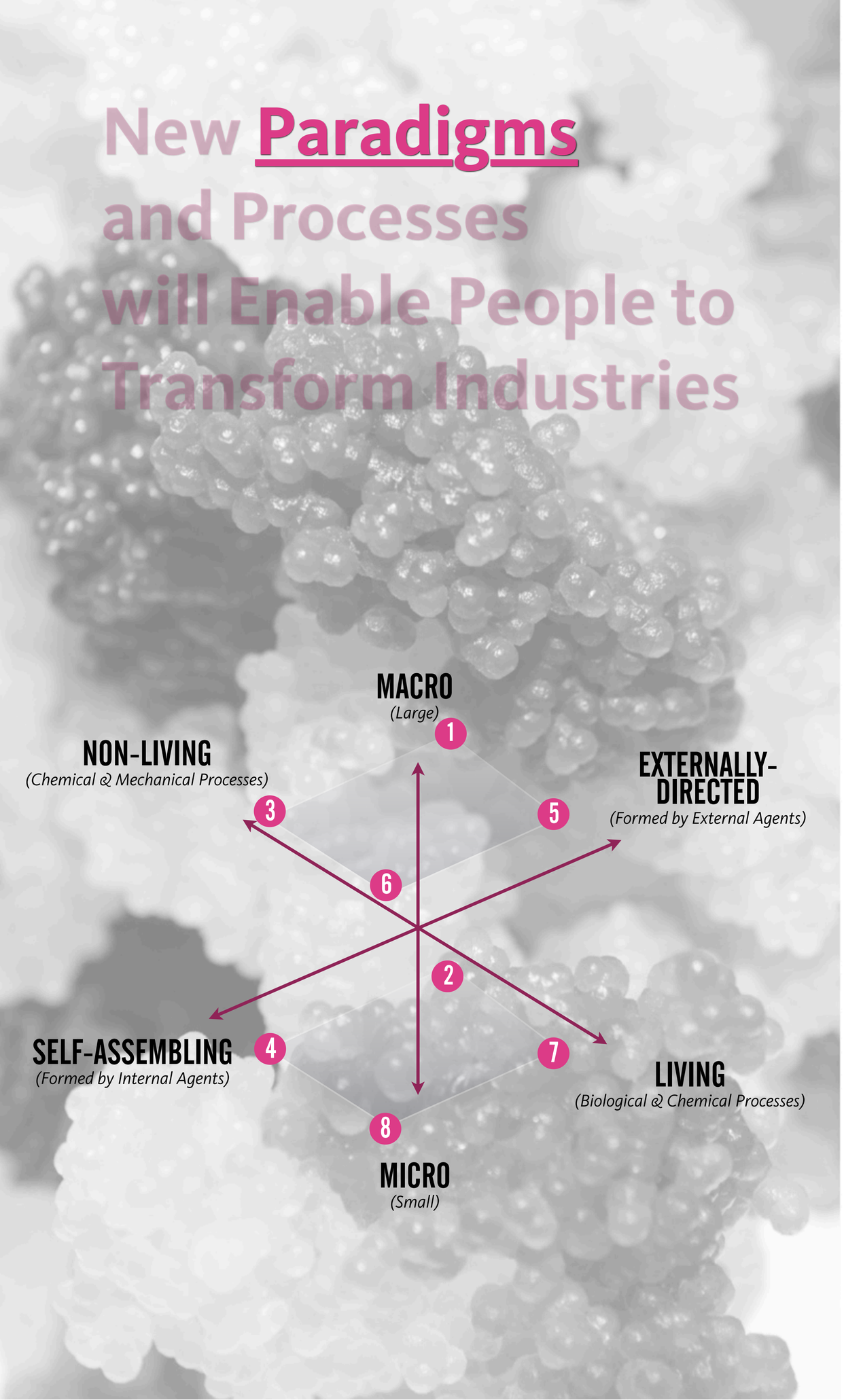
FABRICATION: Self-Assembling vs Externally Directed
New approaches to fabrication broaden the designer's options for physical production. Directed fabrication includes familiar manufacturing processes of additive assembling and subtractive sculpting. Self-assembly changes the approach entirely as the designer is no longer an external director. The designer can create the conditions for complex objects to spontaneously self-assemble from simpler objects.

NATURE: Non-Living vs Living
New technologies enable designers the capacity to manipulate at the molecular level, using techniques ranging from inanimate chemistry to animated living biology. Advances in synthetic biology equip designers with the ability to read, manipulate and fabricate DNA, introducing the possibility to design biological processes.

These three capability can be arranged on a three dimensional matrix.



New Paradigms and Processes will Enable People to Transform Industries



EIGHT FUNDAMENTAL DOMAINS

The combination of the three dimensional frameworks produce eight unique domains of design.

1. **Macro Non-Living Externally Directed**
   The most familiar design paradigm, this domain includes the world of visible objects - from consumer products to buildings and cities.

2. **Micro Non-Living Externally Directed**
   This domain focuses on the miniature, microscopic and nanosized objects including medical devices, digital processor chips and nano objects.

3. **Macro Non-Living Self-Assembling**
   Inspired by the work of Skylar Tibbits, large structures can be assembled by mimicking chemical processes: magnetic shapes snap together into patterns.

4. **Micro Non-Living Self-Assembling**
   As demonstrated by CADNano, it is possible to build complex nanostructures from a collection of self assembling smaller structures.

5. **Macro Living Externally Directed**
   This is the domain of traditional design and management of living creatures from crop to animal management.

6. **Macro Living Self-Assembling**
   Nature's ecosystems operate at this domain, spontaneously creating and evolving interconnected systems of material and energy exchange.

7. **Micro Living Externally-Directed**
   Emerging robotic technologies can directly deposit cells into a lattice creating living tissue, which may be used to regenerate or replace organs.

8. **Micro Living Self-Assembling**
   All known forms of living creatures are coded by DNA. Genome Compiler provides tools to be able to program DNA at a high level.

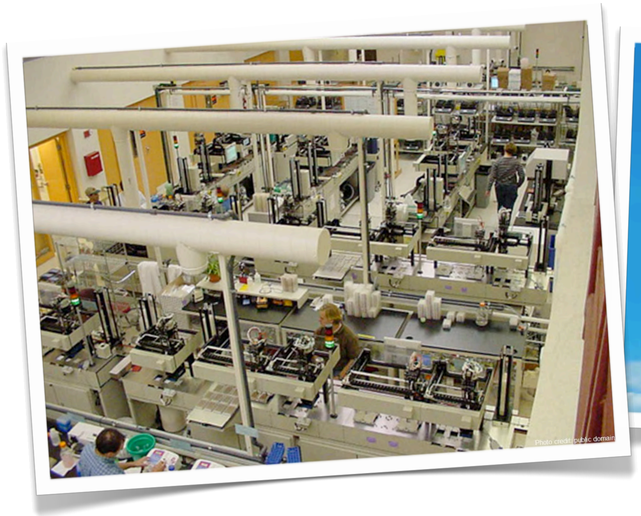
New Paradigms and Processes will Enable People to Transform Industries

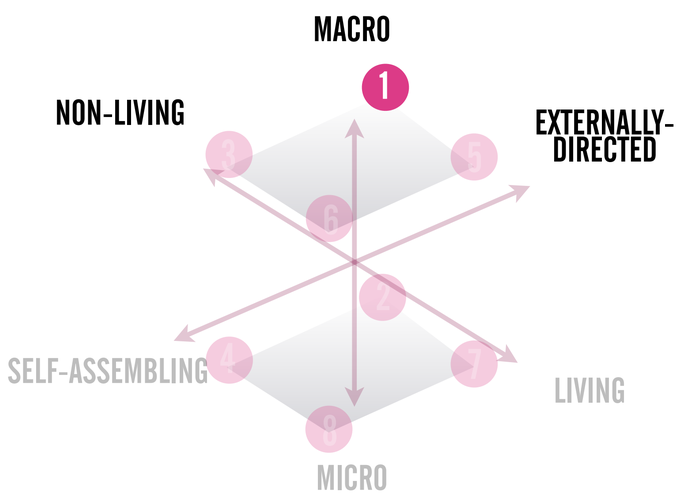
1 Macro Non-Living Externally Directed

The most familiar design paradigm, this domain includes the world of visible objects - from consumer products to buildings and cities.

Established Approaches
Objects in this domain are generally visualized by a designer who sketches, models, visualizes, simulates, prototypes and fabricates an object for mass consumption. Increasingly, robotics are used for manufacturing.

Emerging Approaches
New tools allow designers to rapidly scan, modify and print objects of all sizes as well as engage in a collaborative design process using computational and crowd sourced methods.





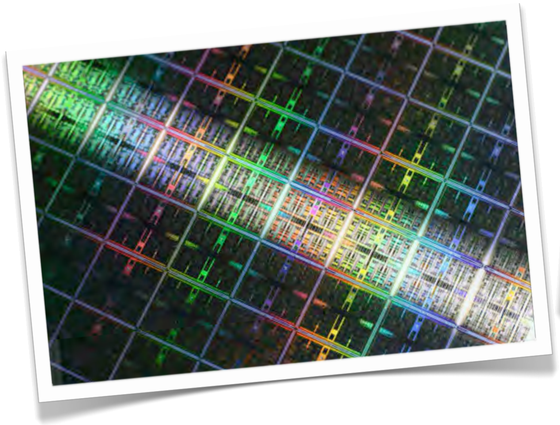
New Paradigms and Processes will Enable People to Transform Industries

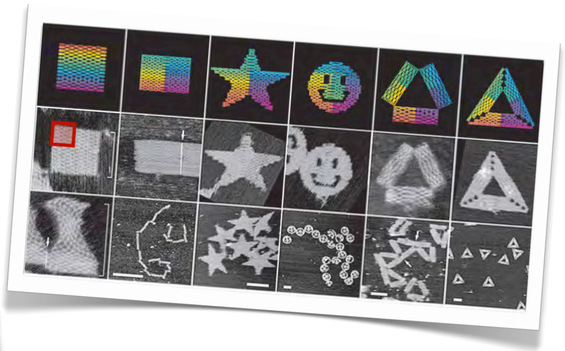
2 Micro Non-Living Externally Directed

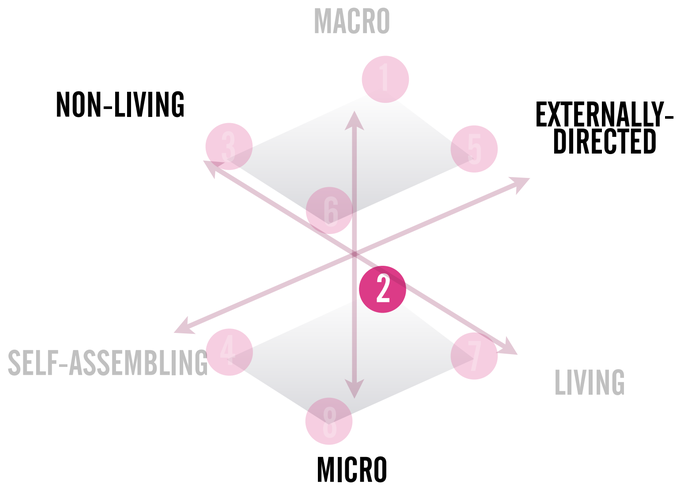
Miniature, microscopic and nanosized objects including medical devices, digital processor chips and nano objects are the realm of this domain.

Established Approaches
Precise machine and chemical processes allow for the mass production of microstructures.

Emerging Approaches
Advances in scanning tunneling electron microscopes allow the manipulation of individual atoms.







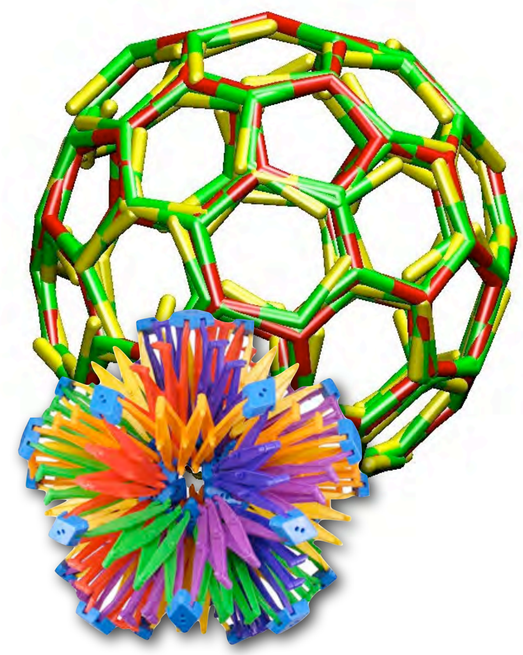
New Paradigms and Processes will Enable People to Transform Industries

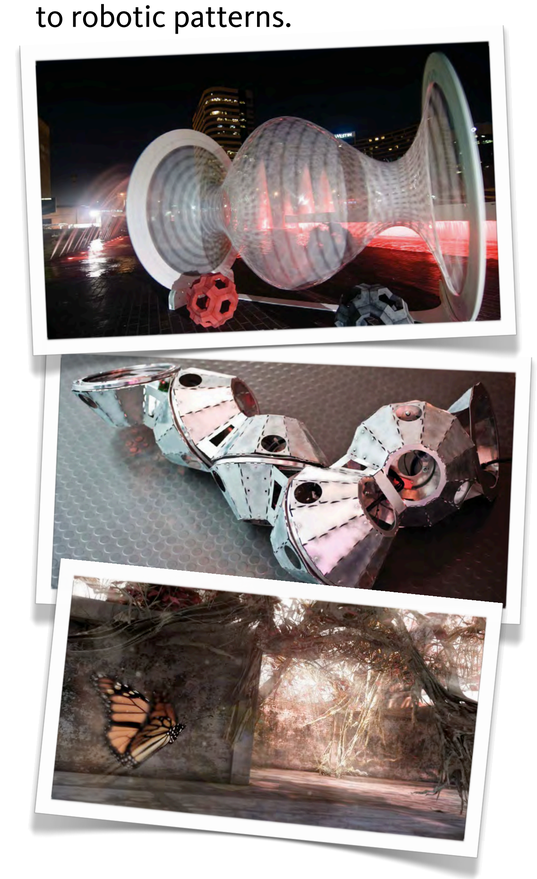
3 Macro Non-Living Self-Assembling

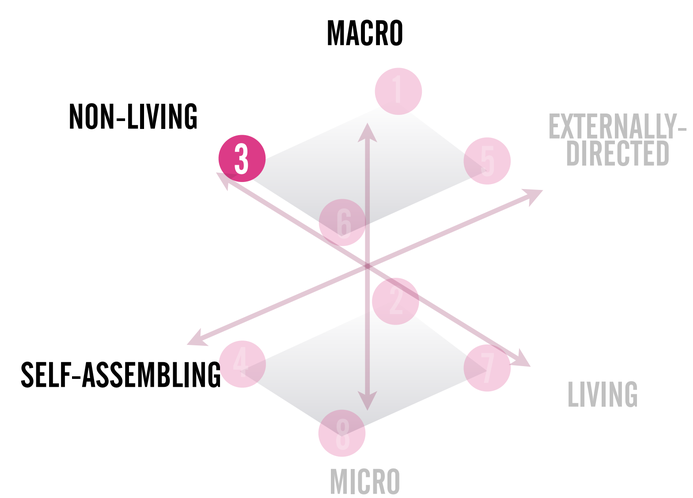
Large structures can be self-assembled from smaller components by mimicking chemical processes: magnetic shapes snap together into patterns when contained and absorb added energy.

Established Approaches
Simple shapes can be assembled into simple larger structures such as Hoberman spheres.

Emerging Approaches
The combination of specific object shapes with magnetic elements and energy produce emergent complex shapes. This principle can be applied to robotic patterns.







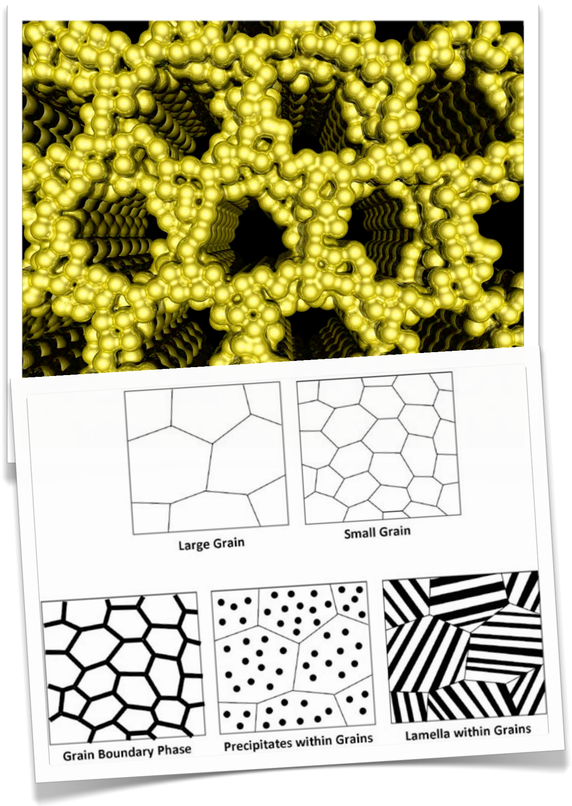
New Paradigms and Processes will Enable People to Transform Industries

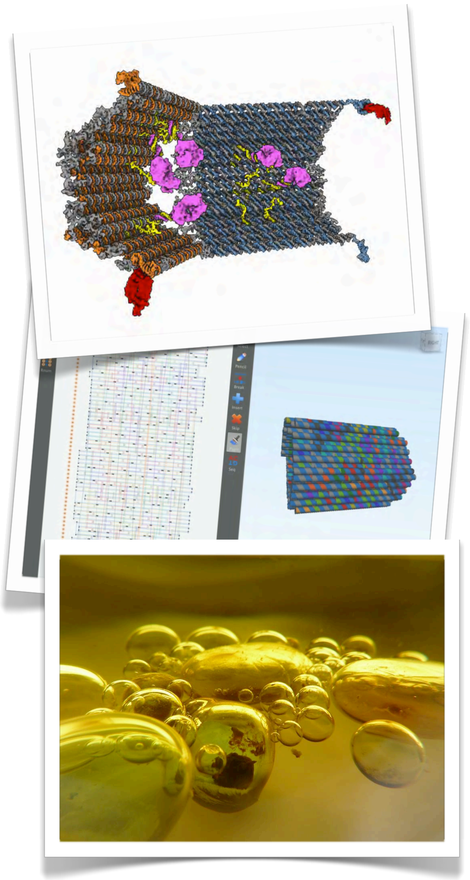
4 Micro Non-Living Self-Assembling

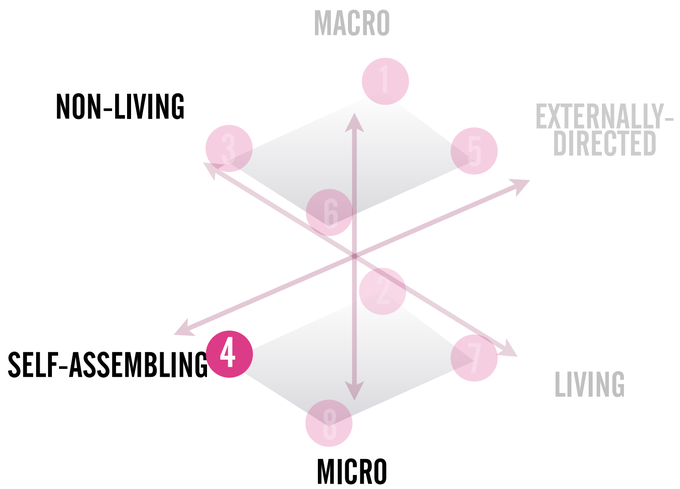
As demonstrated by CADNano, it is possible to build complex nanostructures from a collection of self assembling smaller structures.

Established Approaches
Precise machine and chemical processes allow the creation of new materials from nanoparticles.

Emerging Approaches
Programming DNA to create Origami enables an entirely new approach to design at the nanolevel.







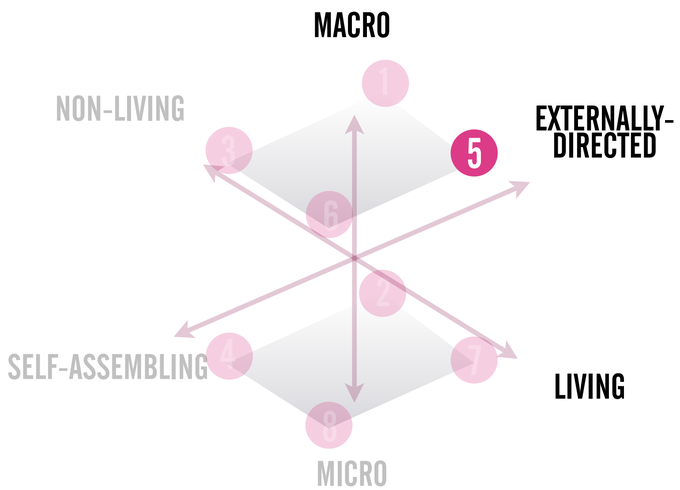
New Paradigms and Processes will Enable People to Transform Industries

5 Macro Living Externally Directed

This is the domain of traditional design and management of living creatures from crop to animal management.

Established Approaches
Humanity has a long history of managing landscapes and food sources through direct intervention.

Emerging Approaches
New practices create a system based view of management, applicable in organic and urban agriculture.



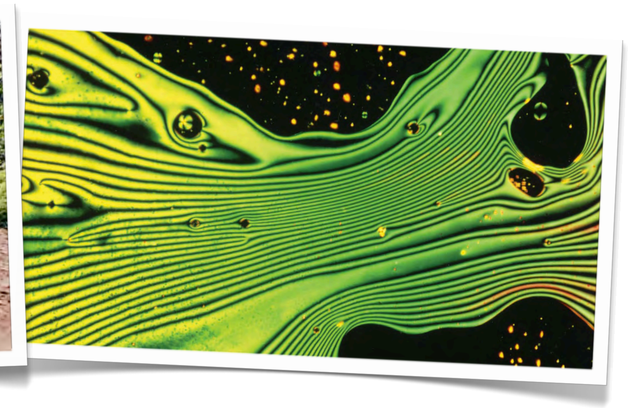
New Paradigms and Processes will Enable People to Transform Industries

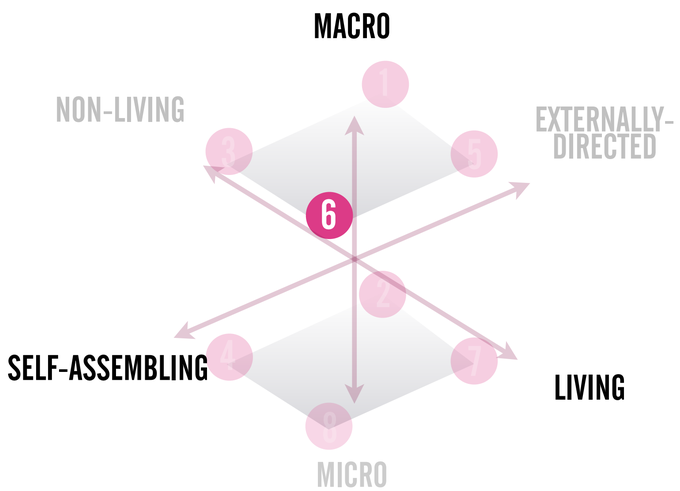
6 Macro Living Self-Assembling

Nature's ecosystems operate at this domain, spontaneously creating and evolving interconnected systems of material and energy exchange.

Established Approaches
People have manipulated ecosystems for millennia, striving to improve food production and aesthetics.

Emerging Approaches
New design techniques apply biomimicry to create more complete self-sustaining systems.





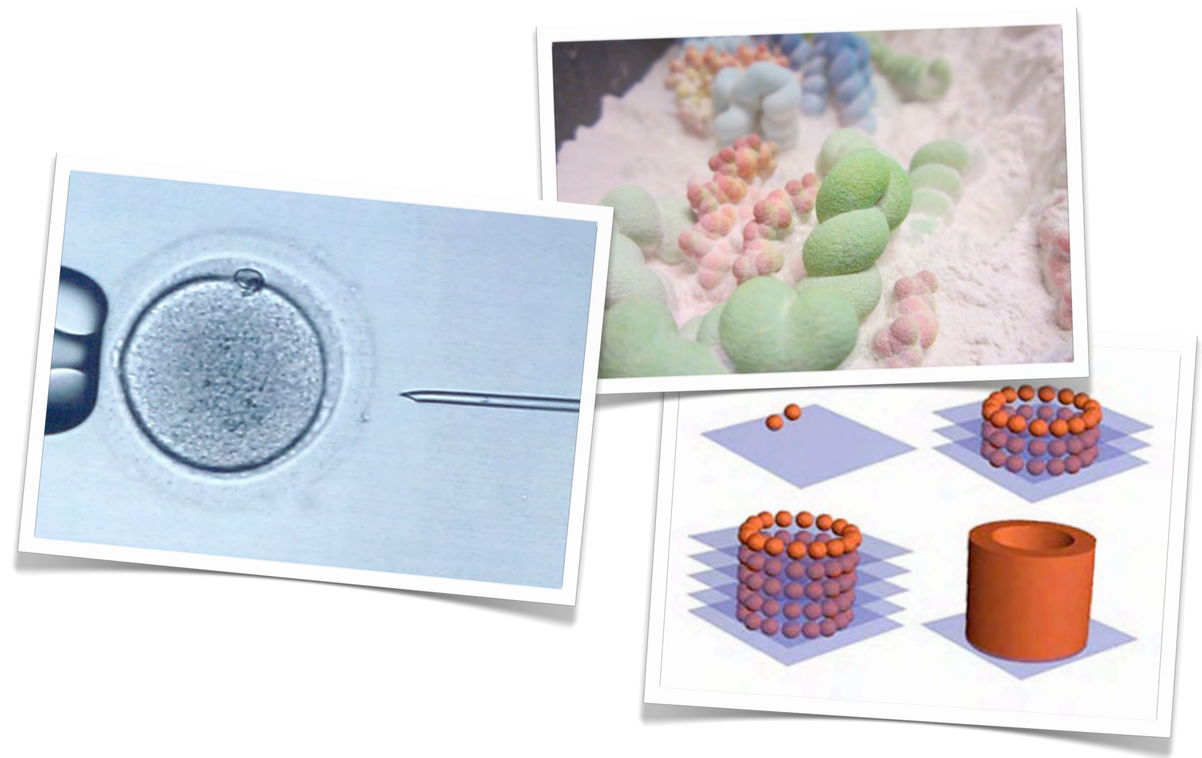
New Paradigms and Processes will Enable People to Transform Industries

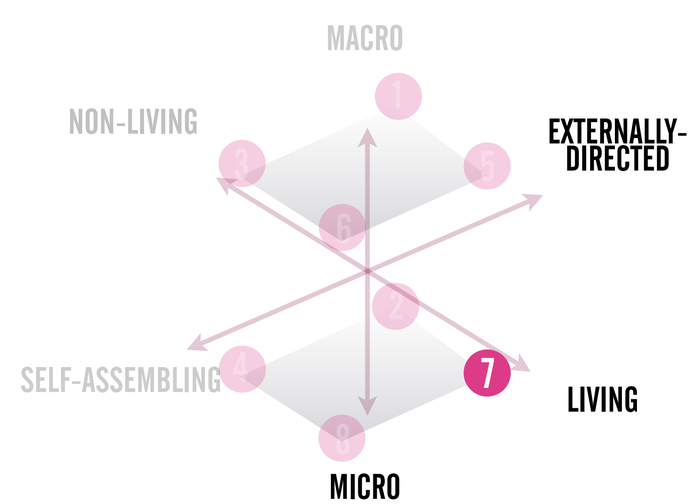
7 Micro Living Externally-Directed

Emerging robotic technologies can directly deposit organic components - from nuclei, organelles and even cells - into larger biological systems. With biological processes and metabolisms taking over, this direct manipulation produces a transformed biological system.

Established Approaches
Biologists have used microfluidic pipettes - tiny syringes - to manipulate cells for research and therapeutics.

Emerging Approaches
New techniques add 3D printing and microrobotics to produce repeatable mass production.



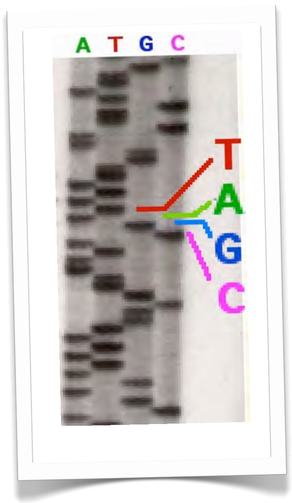


New Paradigms and Processes will Enable People to Transform Industries

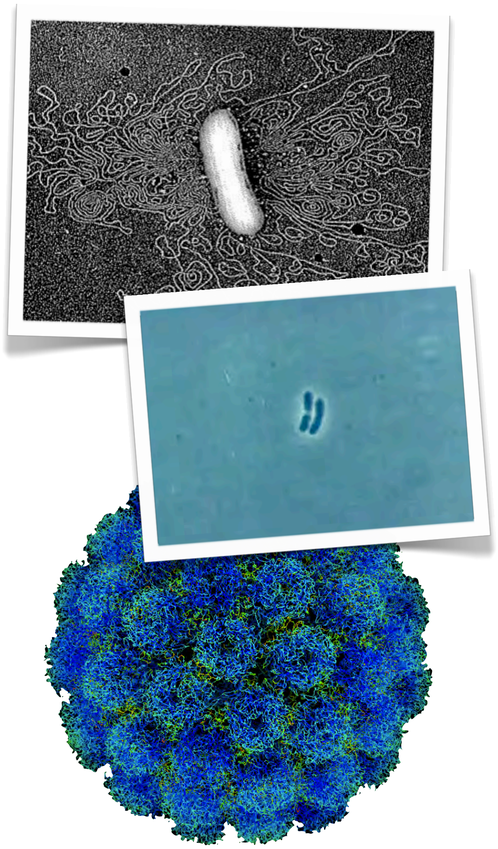
8 Micro Living Self-Assembling

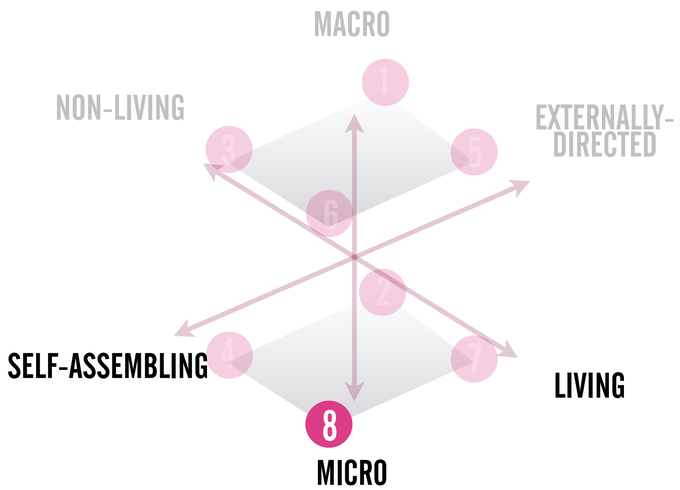
Perhaps the most significant emerging design paradigm is the capacity to read, understand and write DNA, using software that creates its own hardware.

Established Approaches
DNA reading has evolved from slow manual 2D chromatography to a series of faster sequencing methods.



Emerging Approaches
New techniques add digital tools to complete a read - understand - modify - write system.

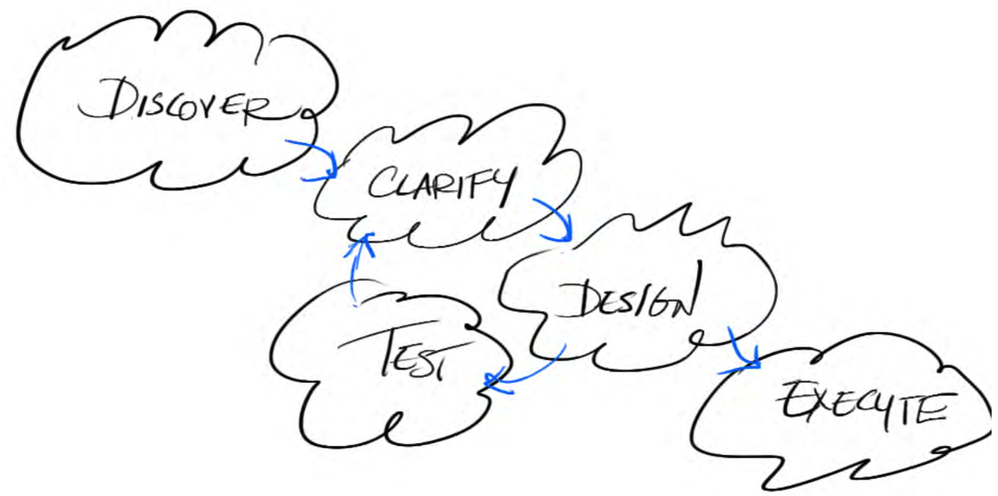




New Paradigms and Processes will Enable People to Transform Industries

DESIGN PROCESSES

Common to most design methods are a series of activities - methods to promote discovery and insight, techniques to clarify goals and processes, approaches for iteratively prototyping, visualizing, simulating, testing, executing, and measuring. Most design methods strive to discover and implement elegant solutions addressing an entire ecosystem, satisfying multiple objectives simultaneously.



While this framework may seem to be the foundation of all design, differing design paradigms can emphasize or change the order these activities. For example, in the domain of self-assembling microscopic, it's virtually impossible to visualize and simulate the results. Design optimization focuses on tools for filtering and testing, rather than previsualizing. Designers can take advantage of these emerging practices by equipping themselves with new tools as well as additional mindsets.

TOOLSET

Most design tools can be put into the categories of scanning or capturing an object or situation, understanding that representation, modifying and improving it, and fabricating the result. The simple version is called scan, modify, print. In the domain of biological science, it is referred to as read, understand and write.

MINDSET

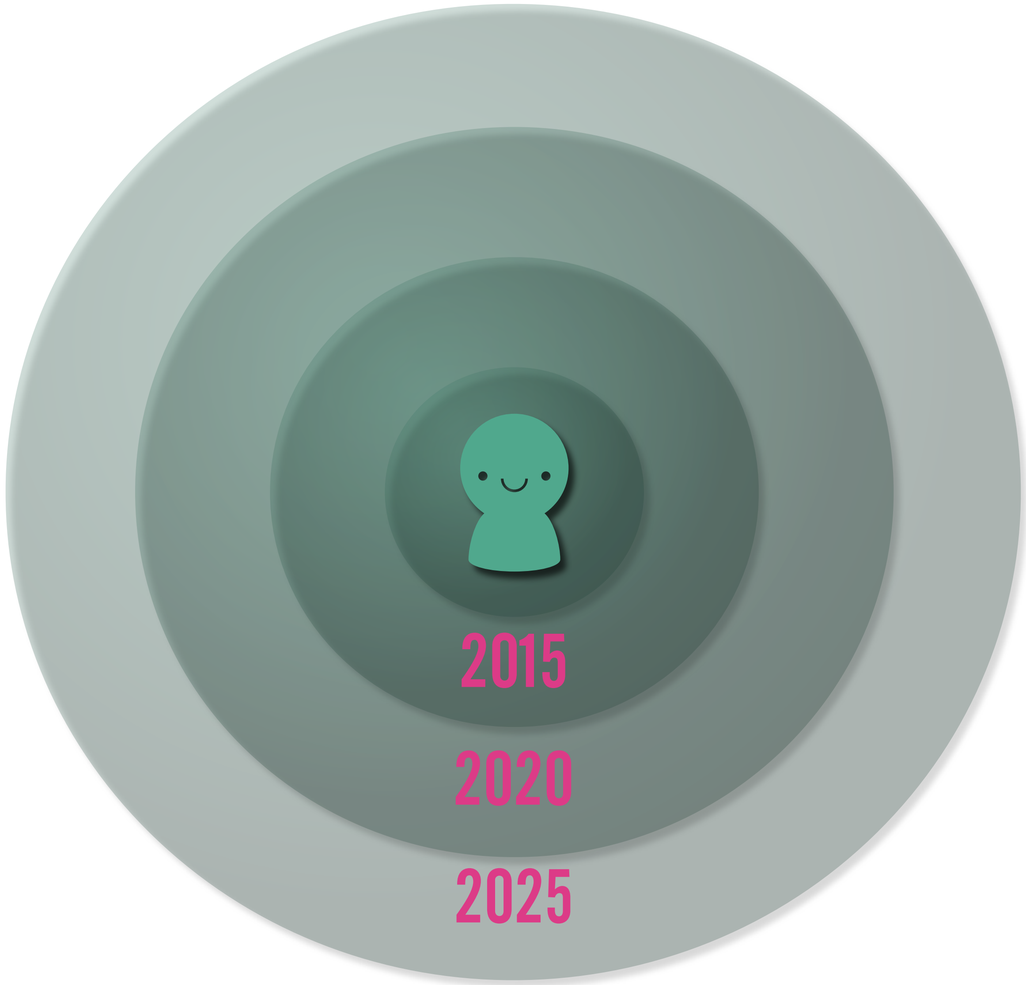
With new tools come new approaches. Design approaches now have become more sophisticated allowing designers the ability to address larger, more holistic issues and strive to reach a wider range of meaningful goals including sustainability, longevity, human experience, social equity, environmental stewardship and profitability.

Design tools and approaches have become more accessible.

New Paradigms and Processes will Enable People to Transform Industries

THE DEMOCRATIZATION OF DESIGN

As design tools continue to be more powerful, simpler to use, more accessible - and driven through social, mobile and cloud-based technologies - more people, from different disciplines, in varying geographies across the world will be engaged in the work of design. Likely, the definition of design will change as design disciplines overlap and merge.



From mass market customization to the maker movement, more people will be involved in the work of design.

New Paradigms and Processes will Enable People to Transform Industries

THE TRANSFORMATION OF INDUSTRIES

The new paradigms and processes of emerging design technologies, driven by a new classes of designers has the potential to radically transform industries. Since these design methodologies as driven by exponential growth, they can revolutionize the way people work as has the computer and telecommunications industry. But rather than just moving information, the revolution in the scan, modify, print workflow will change the way thinkgs are designed, made, distributed and consumed.

	FROM	TO
MANUFACTURING	Traditional treat, beat, heat and distribute methods.	Custom 3D printing to serve local and personal needs.
AUTOMOTIVE	Automotive manufacturing in select urban centers.	3D printing of vehicles and parts in regional centers.
AEROSPACE	Massive government or highly capitalized private ventures.	Distributed low capitalized centers.
AEC	Over the wall design, build, operate models.	Integrated Information Modeled holistic solutions.
FINANCE	Interconnected opaque economic systems.	Interconnected transparent economic systems.
HEALTHCARE	Disconnected manual systems of data management.	Personalized systems of data-driven healthcare.
ENERGY	Fossil-fuel based systems of energy based production.	Glucose based sustainable systems of energy.
FOOD	Unsustainable system of monoculture agriculture.	Sustainable methods of food design and production.

The following is a visual synthesis of the experience of **IDEAS.**

IDEAS THE INNOVATION + DESIGN SERIES

Reception

Tuesday, March 27th, 2012

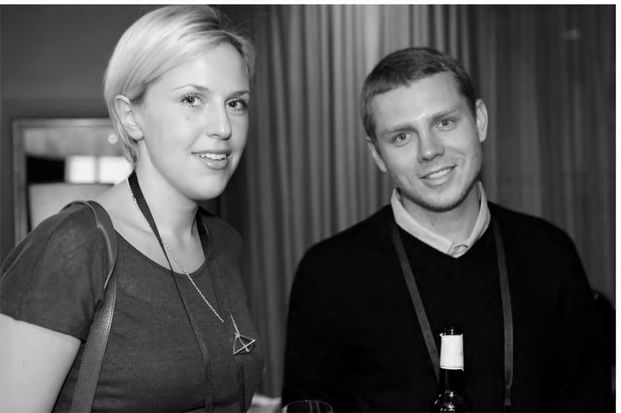
IDEAS

Maurice Conti

Jonathan Knowles

MOON OF MANAKOORA
MOON RIVER

IDEAS



Chris Rivest

IDEAS THE INNOVATION + DESIGN SERIES

Presentations

Wednesday, March 28th, 2012

Agenda

Setting the Stage

CAD/CAM for Bacterial and Human Genomes, Nanobots, Nanopores, and Mirror Life
George Church
Harvard Medical School

Self Design
Gary Wolf
Quantified Self/*Wired Magazine*

The Cost of NOT Acting
Juan Enriquez
Excel Venture Management

Reap, Mod, Fab with Biology

The 4B Year Gap
Drew Endy
Stanford University

Integrating BioCAD Tools into the Synthetic Biology Wet Lab
J. Chris Anderson
University of California at Berkeley

Synthetic Yeast
Patrick Cai
John Hopkins University

Navigating Biological Space Using Machine Learning and Gene Synthesis
Claes Gustafsson
DNA2.0

Democritizing the Tools of Creation
Omri Drory
Genome Compiler

DIYbio: Extraordinary Biotechnologies for Everyday Life
Jason Bobe
Personal Genome Project

Printed Organs and Plants as Robots

Additive Biology
Keith Murphy
Organovo

Death and Life as the Stuff od Design
Daisy Ginsberg
Stanford University
University of Edinburgh

Encoding Design

Nanoscale Construction Using DNA
Shawn Douglas
Wyss Institute at Harvard University

Directed Self-Assembled Peptoids
Babak Sanii
Lawrence Berekeley National Lab

Self-Assembly and Computational Construction
Skylar Tibbits
MIT

Towards Big Bio Bricks
Rachel Armstrong
University of Greenwich
TED Fellow

Multi-Scale and Multi-Objective Design
David Benjamin
Columbia University

Trends and Implications for the Future

Whether to Design or Evolve?
Steve Jurvetson
Draper Fisher Jurvetson

The Promise of Synthetic Biology
Andrew Hessel
Singularity University

Biosecurity
Marc Goodman
Singularity University

Future Design Paradigms
Carlos Olguin
Autodesk, Inc.

IDEAS
THE INNOVATION + DESIGN SERIES

George Church
Professor of Genetics
Harvard Medical School

In 1984, George Church developed the first direct genomic sequencing method - molecular multiplexing, barcode tags - which led to automation and software used for the first commercial genome sequence(the pathogen heliobacter) in 1994. This multiplex cycled solid-phase sequencing evolved into polonies(1999), ABI-SOLID(2005), open-source Polonator.org(2007), and Complete Genomics, Inc.(2008). Innovations in DNA reading, writing, and cell/tissue engineering has led to consumer-directed genomics(23andme, Knome), synthetic biology(SynBERC, Joule, LS9), and new ethics, safety, and security strategies. George founded PersonalGenomes.org, which provides the world's only open-access source for human genomic, environmental and trait data(GET).

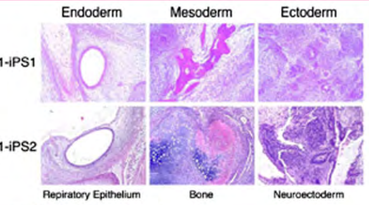
CAD/CAM for Bacterial and Human Genomes, Nanorobots, Nanopores, and Mirror Life

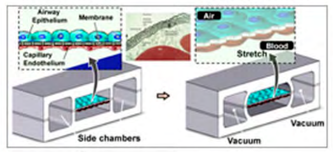
As a pioneer in genomic sequencing and synthetic biology, George provided a series of provocations exploring the impact of our emerging capacity to read, understand and write genetic code: Can we design nature? What is the interface to biological machines?

George focused on the new CAD/CAM tools for genes with the potential to prevent and cure HIV as well as provide immunization to PGP. With the advant of a $1000 human genome in 2102, new worlds of possibility emerge, including designing and producing a mirror world of biological processing.

CAD/CAM for Genomes, Nanopores, & Mirror life
28-Mar-2012 Autodesk IDEAS

CAD/M Personal tissue engineering





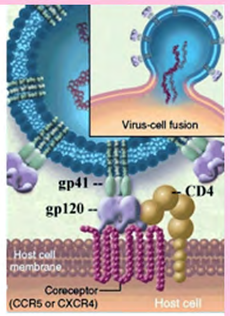
Reconstituting organ-level lung functions on a chip. Huh, Ingber, et al. Science. 2010

WYSS INSTITUTE

Human genome CAD/M prevent/cure HIV #1

Rare CCR5 double gene KO

Sangamo Phase 2 clinical trial



2007 Leukemia & AIDS:
Timothy Ray Brown

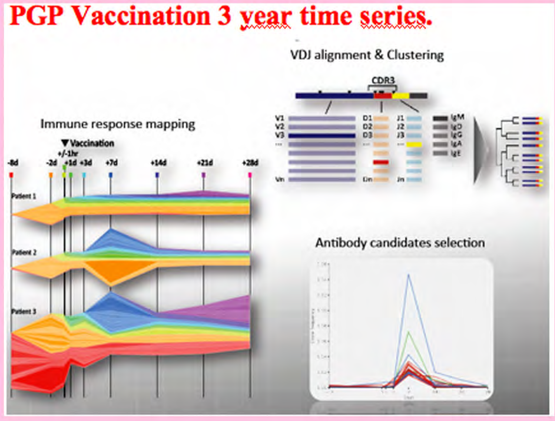
Human genome CAD/M prevent/cure HIV #2:

Rare neutralizing antibodies

"unusually long, 28-amino acid CDR3… towers above the antibody surface"
Peichala et al. PNAS 2010

Antibody-based protection against HIV infection by vectored immunoprophylaxis
Balazs, Baltimore, et al. Nature 2012

PGP Vaccination 3 year time series.

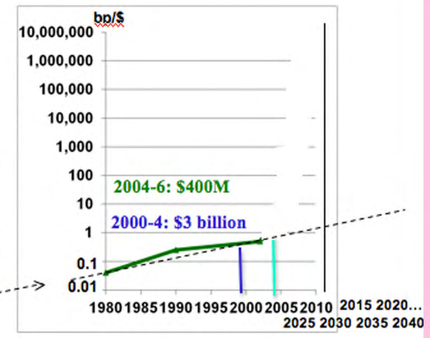


$1000 Genome

When?

2040

Moore's law 1.5x/yr for electronics

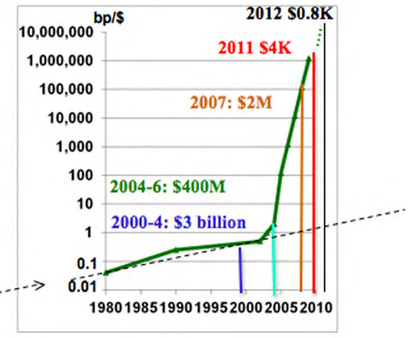


Factors of 10/yr

$1000 When?

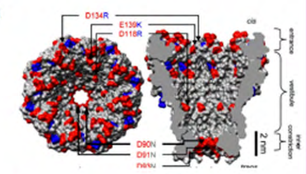
2012

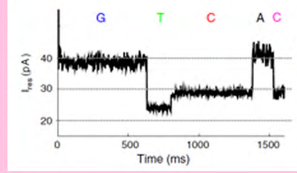
Moore's law 1.5x/yr for electronics



CAD/M Nanopore

ONT & Genia

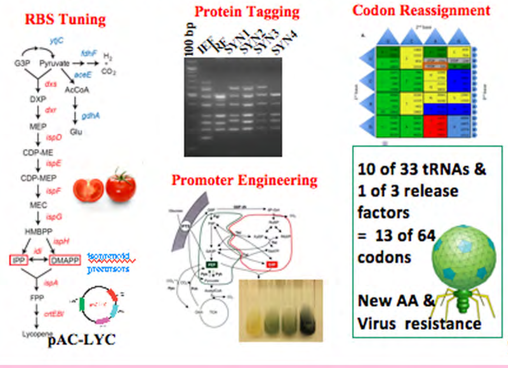




14bp-GGG-14bp-TTT-14bp-CCC-
14bp-AAA-14bp-CCC-14bp-polyA

2010: PNAS Derrington, Gundlach et al.

Why Genome Engineering? 4 examples



9

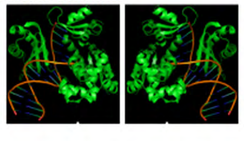
Mirror world : blow torriM

Why? resistant to enzymes, parasites, predators

How? #1: De novo Chemical synthesis (below)
#2: In vitro new peptidyl transferase + D-AA-tRNAs (next slide)
#3: In vivo: as above + 19 new synthetases

352 AA Synthetic Dpo4 *Sulfolobus* DNA polymerase IV
4 peptide bonds left to construct

L-aminoacids
D-nucleotides
(current biosphere)



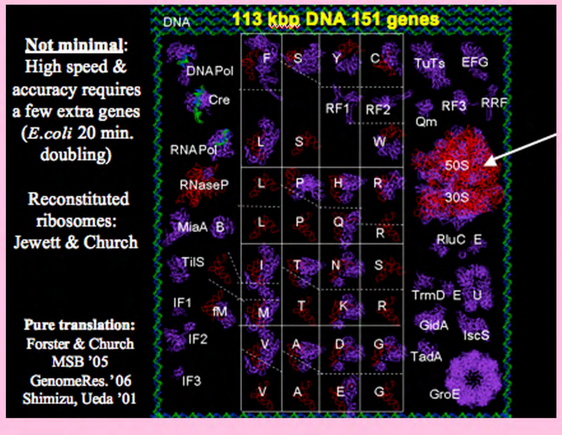
D-aminoacids
L-nucleotides
(Mirror-biopolymers)

Duhee Bang

Not minimal: High speed & accuracy requires a few extra genes (*E.coli* 20 min. doubling)

Reconstituted ribosomes: Jewett & Church

Pure translation: Forster & Church MSB '05 GenomeRes.'06 Shimizu, Ueda '01



Gary Wolf
Founder
Quantified Self

Gary Wolf is the co-founder of Quantified Self, a global collaboration among users and makers of self-tracking tools exploring "self-knowledge through numbers." He is also contributing editor at *Wired Magazine*. His work has appeared in the *Best American Science Writing* (2009) and in the *Best American Science and Nature Writing* (2009). In 2010, he was awarded the AAAS Kavli Science Journalism prize. In 2005-06, he was John S. Knight fellow at Stanford University.

Self Design

Gary continued the exploration of the intersection of computation and biology by presenting trends in measurement of human performance and behavior. A range of new devices such as NIKE+ and fitbit have received significant funding indicators that the digital health industry will grow to $4 billion by 2014.

The primary impact: biological feedback is the essence of behavioral change. Since accurate feedback can create profound benefits, a new trend of the quantified self will continue to grow.

Quantified Self

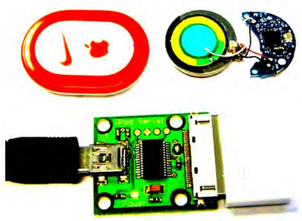
@agaricus

Computing

Personal Computing

Quantified

Quantified **Self**



DNA
EEG
EKG
EMG
GPS
GSR

sleep
mood
posture
stress
diet
microbiome

2011: $40 million investment from Kleiner Perkins, Deutsche Telekom and Yuri Milner, put Jawbone's valuation at ~$1.5 billion.

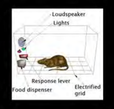
-International Business Times

[At CES] Fitbit's CEO James Park stated that … the digital health industry will be worth $4 billion by 2014.

-Brian Dolan, MobiHealthNews

SoftTech VC
Foundry Group
True Ventures
Founders Fund
Kleiner Perkins Caufield & Byers
Sculley Brothers
Greylock Partners
Band of Angels
Norwest Venture Partners
DCM
OATV

compliance



behavior change

"The Key to Success: Real-time Dynamic Personalization Combined with Machine Learning"

Elizabeth Barbeau, ScD, MPH, Chief Science Officer;
Jason Sroka, PhD Lead Machine Learning Scientist
Martin Adler , Mobile Product Manager
HEALTHRAGEOUS

Of 3 randomized, controlled trials of Weight Watchers, the largest reported a loss of 3.2% of initial weight at 2 years.

Tsai AG, Wadden TA. Systematic Review: An Evaluation of Major Commercial Weight Loss Programs in the United States. Annals of Internal Medicine. 2005;142(1):56 -66.

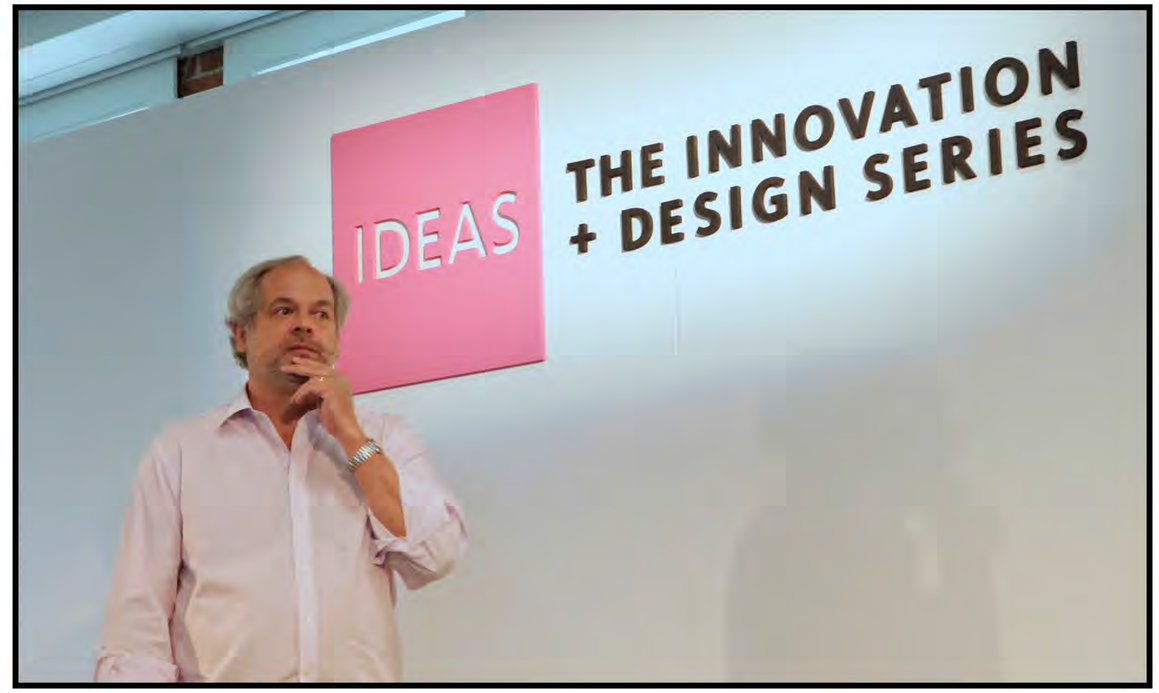
behavior change

<pause>

what are we building?

science + engineering + public use

recursion



Juan Enriquez
Managing Director
Excel Venture Managenent

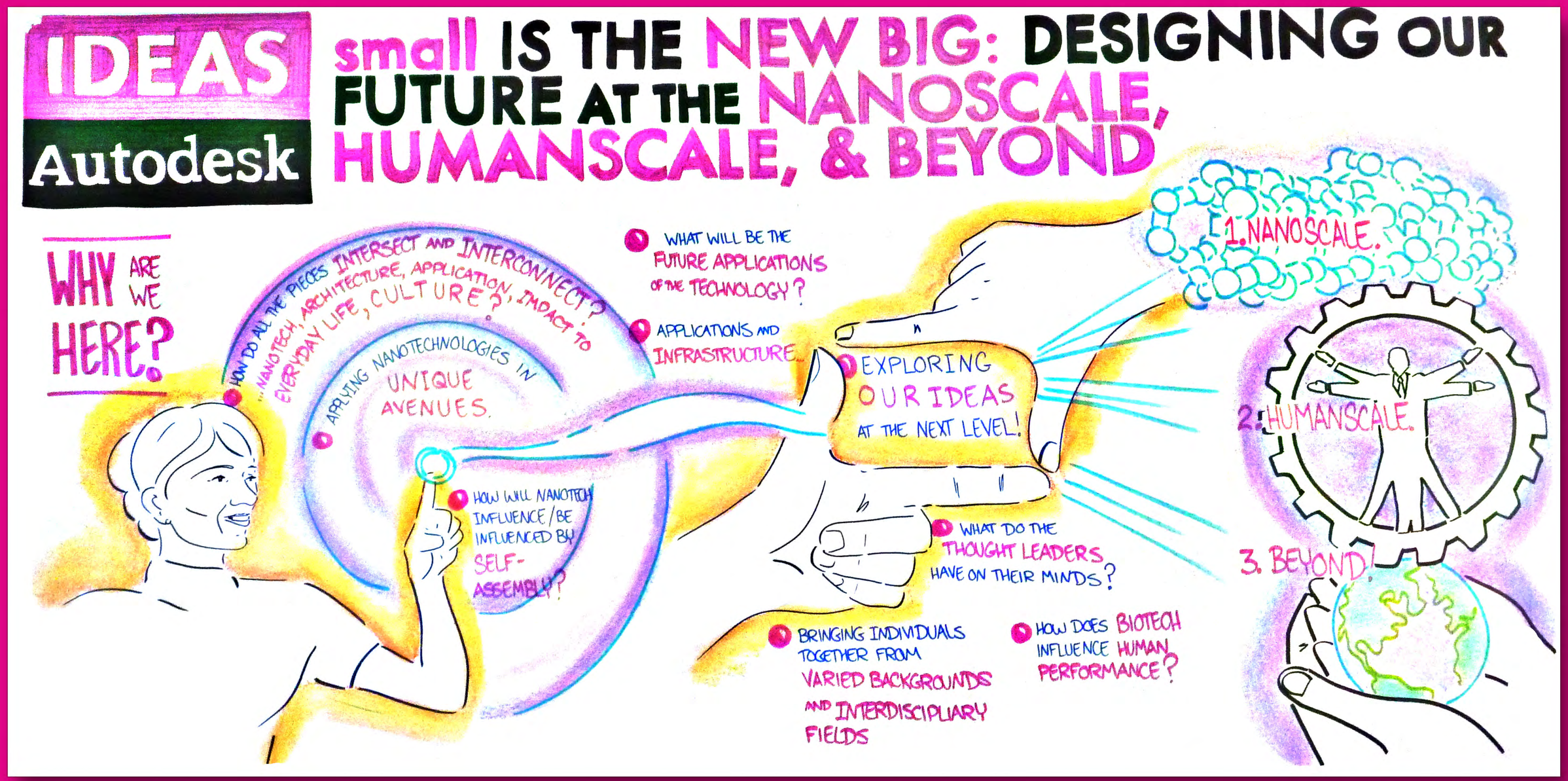
Juan Enriquez is a respected business leader and entrepreneur, and a leading authority on the economic impact of life sciences on business and society. Juan represents Excel on the boards of Shape Up the Nation, Activate Networks, Fina Technologies, Catch.com, and Sythetic Genomics.

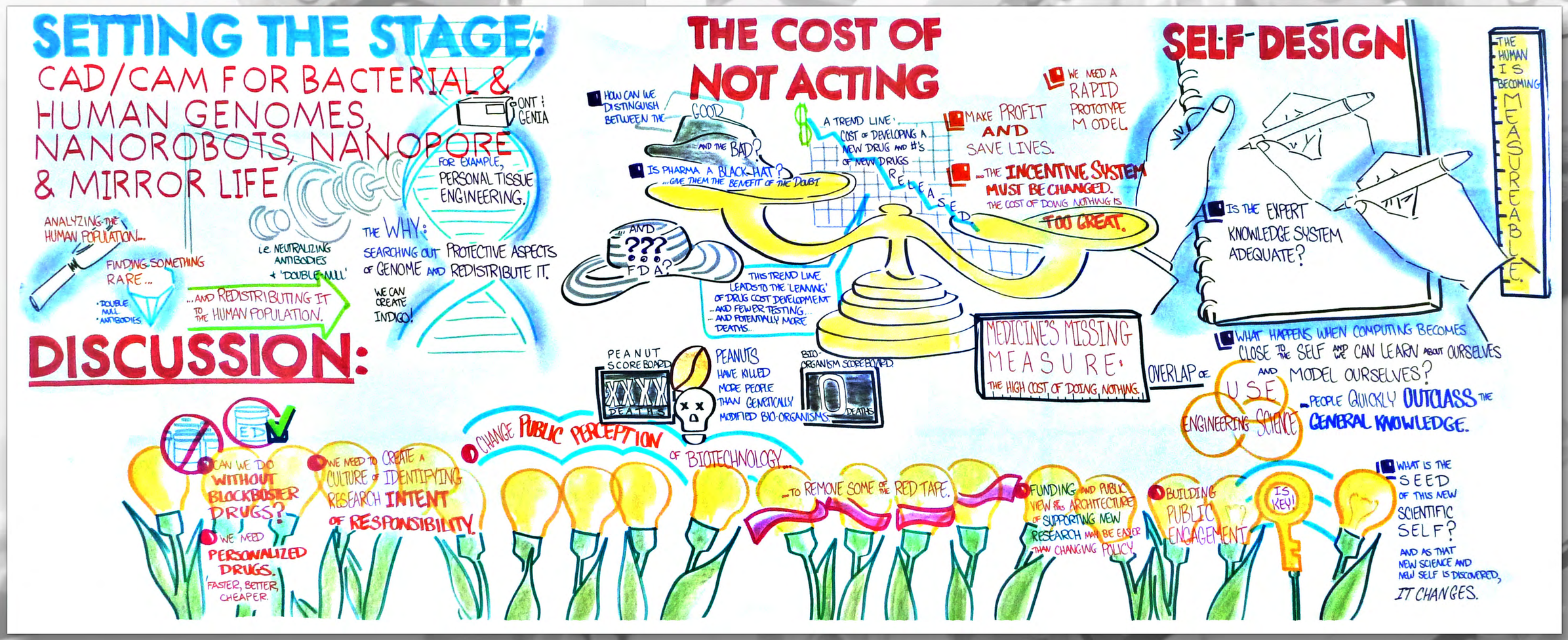
Prior to Excel, Juan was the founding director of the Harvard Business School's Life Sciences Project, with many of his innovative thoughts captured in his best--sellling book, As The Future Catches You, which provided an accurate blueprint of how a bio-based economy changes industries and corporations. His most recent publication is an eBook, Homo Evolutis: A Short Tour of Our New Species, which describes a world where humans increasingly shape their environment, themselves, and other species.

Following Harvard Business School, Juan became an active angel investor and founder of Biotechonomy ventures, which invested in BioTrove, Xcellerex, and Synthetic Genomics, a company he co-foinded with doctors J. Craig Venter and Hamilton Smith to apply life sciences to energy markets. As a business leader, advisor, and renowned speaker, Juan works directly with the CEO's of a number of Fortune Fifty companies, as well as various heads of state, on how to adapt to a world where the dominant language is shifting from the digital towards the language of life. He is a member of the board of directors of Cabot Corporation.

The Cost of NOT Acting

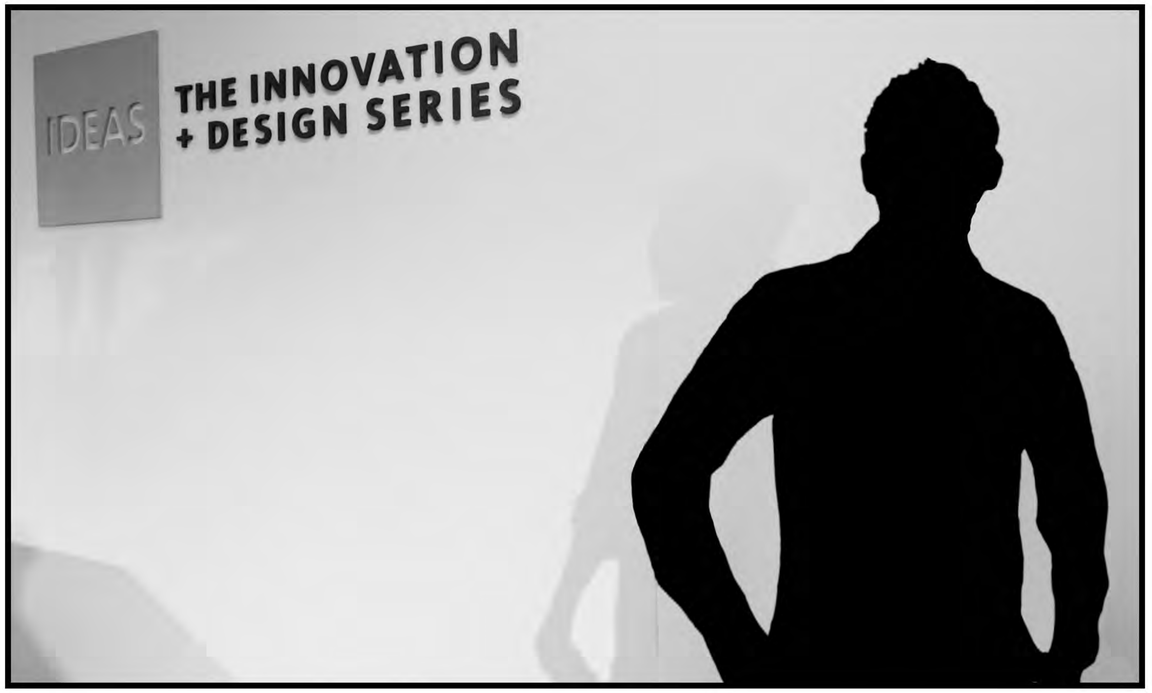
As a respected authority on the economic impact of life sciences on business and society, Juan delivered a thoughtful argument on the cost of not changing today's current drug development process. While the cost and time for new drug development is rising steeply, the pipeline for new drugs is getting thinner. The percpetion of drug companies as wearing black hats and the FDA wearing a white hat is misinformed. Heavy regulations squeeze innovation from the pharmaceutical industry, drying up new product development that could save or improve the lives of millions. What we need is a rapid prototyping model of development with a new incentive system.


IDEAS
Autodesk
small IS THE NEW BIG: DESIGNING OUR FUTURE AT THE NANOSCALE, HUMANSCALE, & BEYOND
WHY ARE WE HERE?
HOW DO ALL THE PIECES INTERSECT AND INTERCONNECT? ...NANOTECH, ARCHITECTURE, APPLICATION, IMPACT TO EVERYDAY LIFE, CULTURE?
APPLYING NANOTECHNOLOGIES IN UNIQUE AVENUES.
HOW WILL NANOTECH INFLUENCE/BE INFLUENCED BY SELF-ASSEMBLY?
WHAT WILL BE THE FUTURE APPLICATIONS OF THE TECHNOLOGY?
APPLICATIONS AND INFRASTRUCTURE.
EXPLORING OUR IDEAS AT THE NEXT LEVEL!
WHAT DO THE THOUGHT LEADERS HAVE ON THEIR MINDS?
BRINGING INDIVIDUALS TOGETHER FROM VARIED BACKGROUNDS AND INTERDISCIPLIARY FIELDS
HOW DOES BIOTECH INFLUENCE HUMAN PERFORMANCE?
1. NANOSCALE.
2. HUMANSCALE.
3. BEYOND!



Graphic Recording

Stephanie Crowley
Chrysalis Studios



Drew Endy
Assistant Professor of Bioengineering, Stanford
Vice President of Dont't Say No, BioBricks Foundation

Drew Endy teaches in the new bioengineering major at Stanford University and previously helped start the biological engineering major at MIT. His Stanford research team is pursuing one byte of programmable genetically encoded data storage. He also co-founded the BioBricks Foundation as a public benefit charity that supports the open development of free-to-use standards and technology that enable the engineering of bilogy. He also organized what has become the International Genetically Engineered Machines (iGEM) competition and the BIOFAB International Open Facility Advancing Biotechnology (BIOFAB).

The 4B Year Gap

Biological code is 4 billion years old and evolved by happenstance. Drew's thesis is that now is the time for a rewrite. Illustrating how today's biological code is virtually unreadable by people, he introduced methods to rewrite it to be more efficient and more understandable.

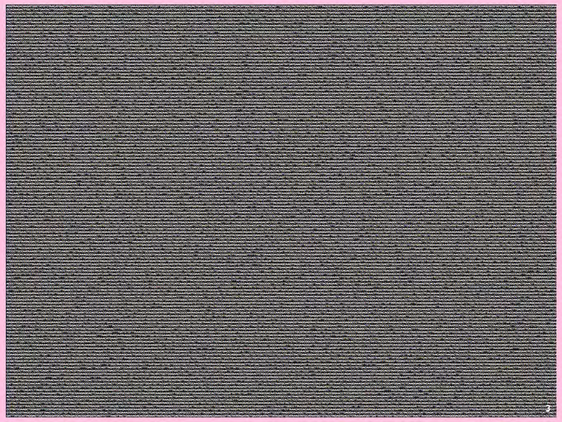
The implications of a human readable code are staggaring: the possibility of creating synthetic living systems, design and discover new living entities and create a long-term framework for learning.

"The code is ~4 billion years old,
it is time for a rewrite."

Thomas F. Knight, Jr.

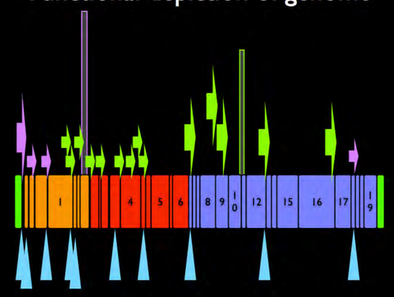
Drew Endy 28 March 2012 Autodesk

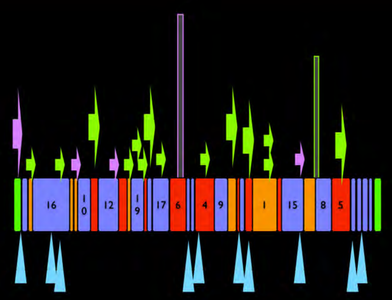
1



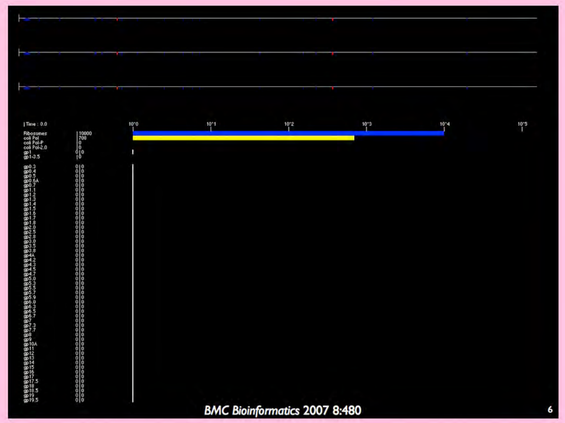
2

Functional depiction of genome





I have no idea what this genetic program will do



BMC Bioinformatics 2007 8:480

6

Natural DNA sequence

```
-------------------2.8----------------->
...acgcaaagggaggcgacatggcaggttacggcgctaaaaggaatccgaaa...
        <--3-RBS--->
```

Design & build new genome?

```
----------------2.8----------------->
acgcaaagggaggcgacatggcaggttacggcgctaaaggaatccgaaa
      <--3-RBS--->
```

```
acgcaaagggagacgacaggcaggttacggcgctaaggatccggccgcaaagggaggcgacatggcaggttacggcgctaaa
----------------2.8----------------><D28R|D29L><--3RBS------><---------------3----
```

8

Molecular Systems Biology (2005) doi:10.1038/msb4100025
© 2005 EMBO and Nature Publishing Group All rights reserved 1744-4292/05
www.molecularsystemsbiology.com

molecular systems biology

Refactoring bacteriophage T7

Leon Y Chan[1,3], Sriram Kosuri[2,3] and Drew Endy[2,*]

[1] Department of Biology, Massachusetts Institute of Technology, Cambridge, MA, USA and [2] Division of Biological Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA
[3] These authors contributed equally to this work
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Received 15.7.05; accepted 23.7.05

Natural biological systems are selected by evolution to continue to exist and evolve. Evolution likely gives rise to complicated systems that are difficult to understand and manipulate. Here, we redesign the genome of a natural biological system, bacteriophage T7, in order to specify an engineered surrogate that, if viable, would be easier to study and extend. Our initial design goals were to physically separate and enable unique manipulation of primary genetic elements. Implicit in our design are the hypotheses that overlapping genetic elements are, in aggregate, nonessential for T7 viability and that our models for the functions encoded by elements are sufficient. To test our initial design, we replaced the left 11 515 base pairs (bp) of the 39 937 bp wild-type genome with 12 179 bp of engineered DNA. The resulting chimeric genome encodes a viable bacteriophage that appears to maintain key features of the original while being simpler to model and easier to manipulate. The viability of our initial design suggests that the genomes encoding natural biological systems can be systematically redesigned and built anew in service of scientific understanding or human intention.

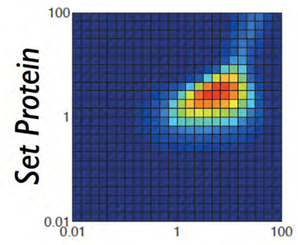
Molecular Systems Biology 13 September 2005; doi:10.1038/msb4100025
Subject Categories: synthetic biology
Keywords: bacteriophage T7; synthetic biology; refactor

I want 8 bits of data storage

01010101

"flipee"

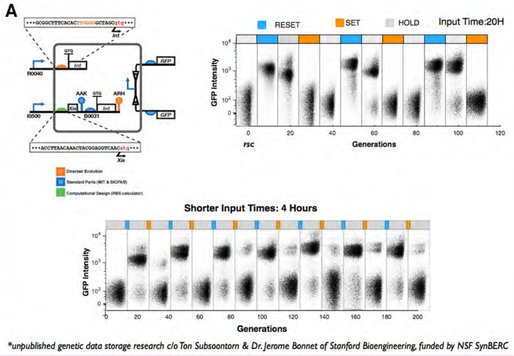
***please see Nash & Pollock (1981, 1983) thru Friedland & Lu et al. (2010+) for prior work on flipping DNA and data storage*
**unpublished genetic data storage research c/o Ton Subsoontorn & Dr. Jerome Bonnet of Stanford Bioengineering, funded by NSF SynBERC*



Precise engr. of "central dogma" needed

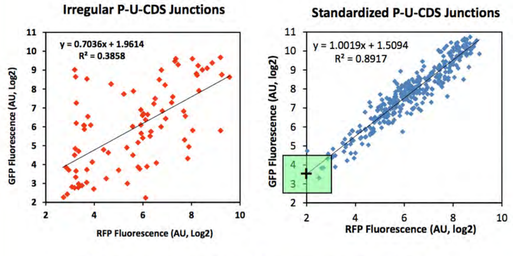
...but such tools unavailable.

~3 years and ~800 D.B.T. attempts...



**unpublished genetic data storage research c/o Ton Subsoontorn & Dr. Jerome Bonnet of Stanford Bioengineering, funded by NSF SynBERC*

Meanwhile, precise & reliable gene expression

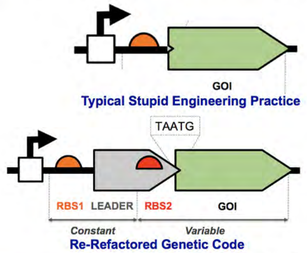


Design systems with ~10 genes at a time prior to first testing (in place of 1 gene at a time).

(biofab.org)

14

How? Re-rewrite the code...



VIVEK MUTALIK &
THE BIOFAB TEAM
(biofab.org)

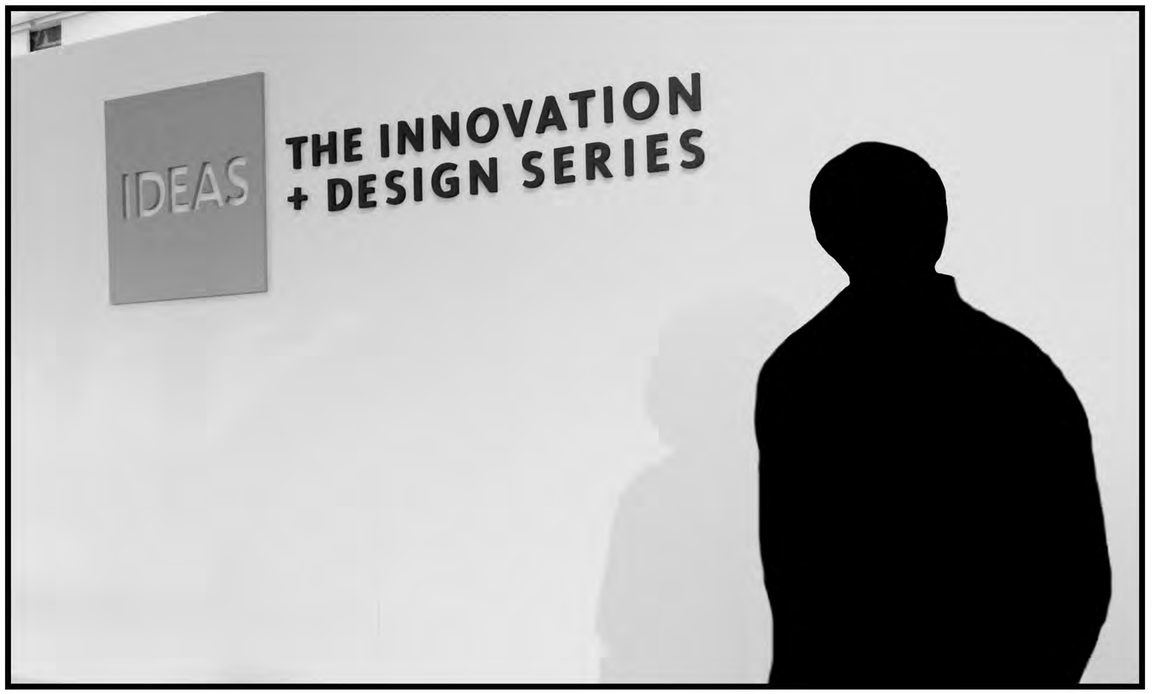
15

Design for 1-, 2-, & 3-time.

Natural living systems,
Direct generational descent,
Replication with error,
Natural selection.

Synthetic living systems,
"Decoupled" promulgation over time,
Replication with representation,
Fashioned selections,
Discover and design for the moment,
for learning, & forever.

16



J. Christopher Anderson
Assistant Professor
University of California at Berkeley

J. Christopher Anderson is a bioengineering professor at the University of California at Berkeley National Lab, where he is developing new applications and foundational technologies for synthetic biology, a ground-up approach to genetic engineering. His work includes new bioware (engineered cells), hard--ware (robotics/instrumentaion), and BioCAD software tools including Clotho and the Act Ontology. As a SynBERC (www.synberc.org) principle investigator, he shares the goal of enabling the full promise of synthetic biology by simplifying its methods, developing new education mechanisms, and addressing concerns over biosafety and biosecurity. In addition, he has led the Berkeley International Genetically Engineered Machines (iGEM) team for the past seven years.

Integrating BioCAD Tools into the Synthetic Biology Wet Lab

Chris demonstrated how to integrate BioCAD tools into a Synthetic Biology wet lab. He showed how Clotho could be used as an engineering tool to create apps.

From inception to full biological projects, it provides a system to connect to repositories of biological data, select from a collection of apps, specify, design and assemble a biological system and share with other institutions. It also provides the means to design new apps.

Anderson | Lab
Putting the engineering in genetic engineering

SynBERC

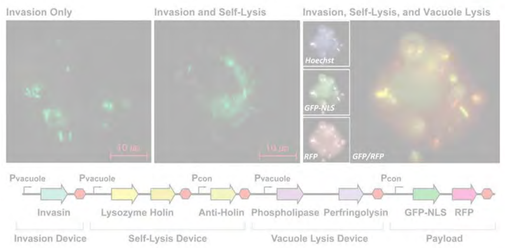
Integrating BioCAD tools into the Synthetic Biology wet lab

IDEAS: The Innovation + Design Series
Autodesk Gallery, San Francisco, CA
March 27, 2012

J. Christopher Anderson
Assistant Professor, Bioengineering
327 Stanley Hall, UC Berkeley
jcanderson@berkeley.edu

Our funders:
Autodesk, Agilent Technologies, DARPA, NSF

Payload Delivery Device



For an 18 part device:
2 years, 330 Basic Parts (**391,374bp**), 557 composite (**1,786,866bp**)

We need software!

Douglas Densmore

- Automated fabrication
- Automated verification
- Automatic design synthesis

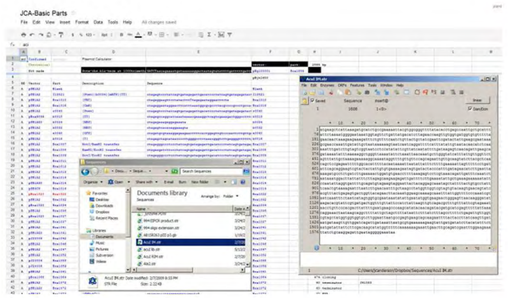
Clotho

Eugene

Automated Assembly

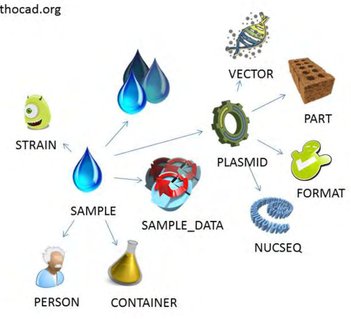
(2008-2010)

The soft data problem



CLOTHO 2.0: The data model (2010)

www.clothocad.org



The Clotho ecosystem (2011-2012)

Weiss Lab (MIT)
- Matchmaker: an automatic part assignment algorithm
- Puppeteer: software stack for robotic automation
- MamBa: mammalian export of bacterial parts

Voigt Lab (MIT)
- Cello: a workflow for specification, design, and assembly of combinational logic circuits
- Design and assembly of a library of boolean circuits

Anderson Lab (Berkeley)
- Clotho core development
- Act ontology

Silver Lab (Harvard)
- J5 wrapper development
- Purple/Chron

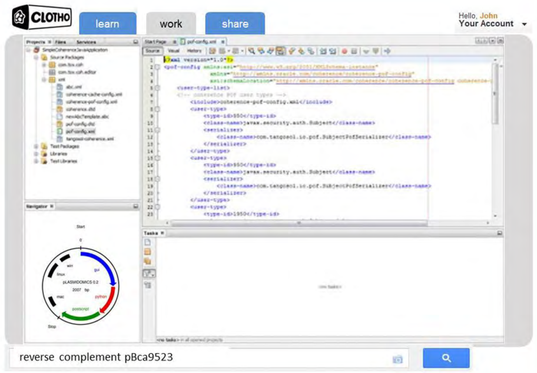
SBOL
- Hermes: part import/export

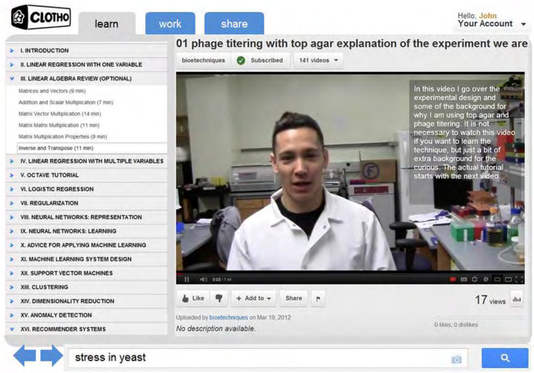
Church Lab (Harvard)
- Merlin MAGE integration

CLOTHO 3.0: In active development

Driving principles:
- Minimize the user experience
- Maximize functionality

- Support for web, Android, iPad, etc.
- Scripting in many languages
- Integration of sharing and education functionality
- Dynamic-but-typed data model
- Enhanced querying functionality
- Simplified user interface
- Workflow integration
- Un-hide some of the more powerful features of 2.0





Acknowledgements

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Wetlab Automation
Mariana Leguia
Jennifer brophy

Special Thanks
Carlos Olguin (Autodesk)
Tim Ham (ICE, JBEI)
Cesar Rodriguez (BioFAB, Genome Compiler)
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UC Team
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Jenhan Tao
Maxwell Bates
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Tim Hsiau

Berkeley iGEM Comp
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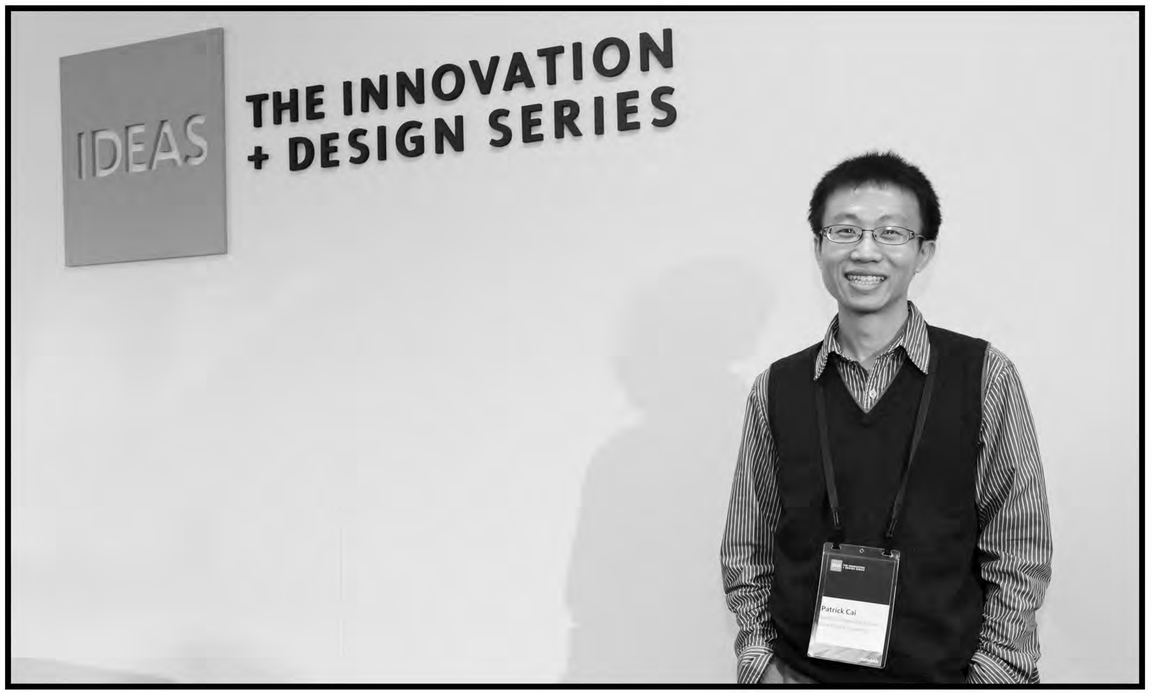
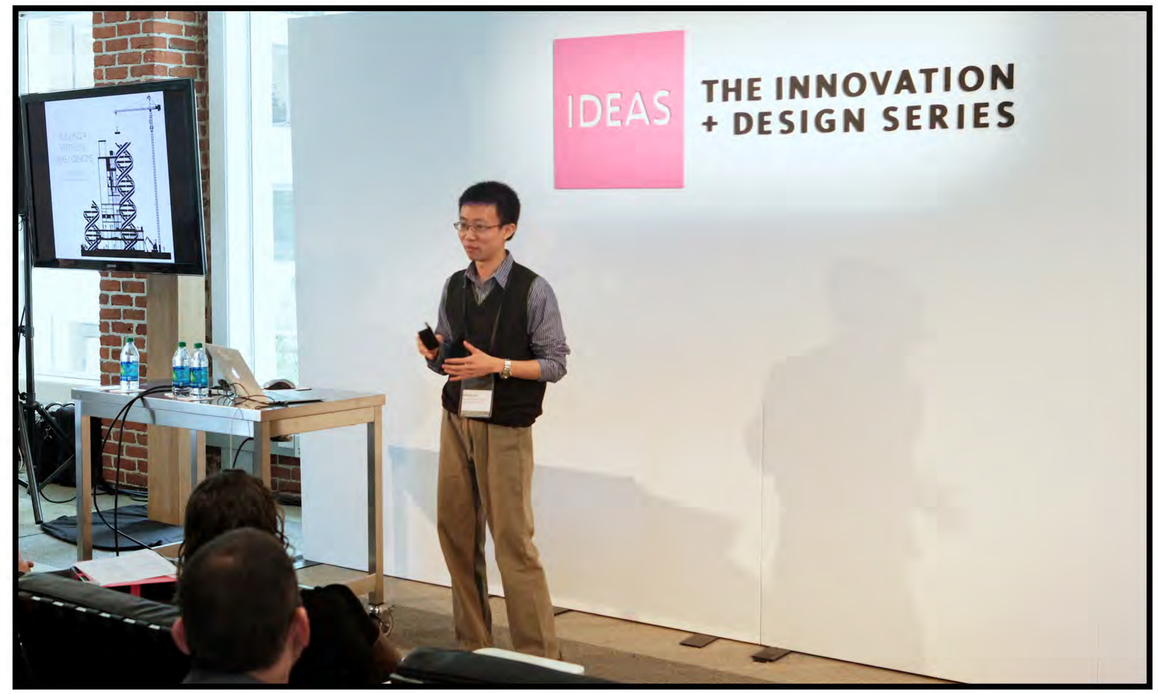
Joanna Chen
Lesia Bilitchenko
Adam Liu
Richard mar
Thien Nguyen
Nina Revko
Ann Van Devender
Matthew Johnson
Nade Sritanyaratana





Yizhi (Patrick) Cai
Autodesk Distinguished Scholar
Johns Hopkins University

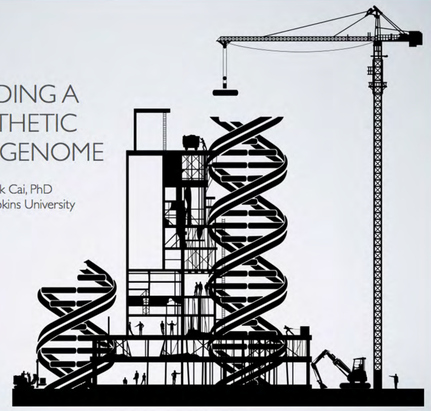
Patrick Cai received a bachelor of computer science in China, a master of bio--informatics from University of Edinburgh in the U.K., and a PhD in genetics, bioinformatics, and computational biology from Virginia Polytechnic Institute and State University (Viginia Tech) in the United States. Dr. Cai has a post--doctoral fellowship in the Johns Hopkins University School of Medicine. His scientific achievement has been well recognized by several international and national awards, including most recently, the DeLill Nasser Award for Professional Development from the Genetic Society of America.

Synthetic Yeast

Patrick demonstrated the technical practice of building a synthetic yeast genome. Following the design principles of do no harm, maintain genomic stability, and increase genetic flexibility, his team of undergraduates constucted chromosome 3 of synthetic yeast in 12 months, a period that will certainly become shorter with more knoweldge and better tools.

BUILDING A SYNTHETIC YEAST GENOME

Patrick Cai, PhD
Johns Hopkins University



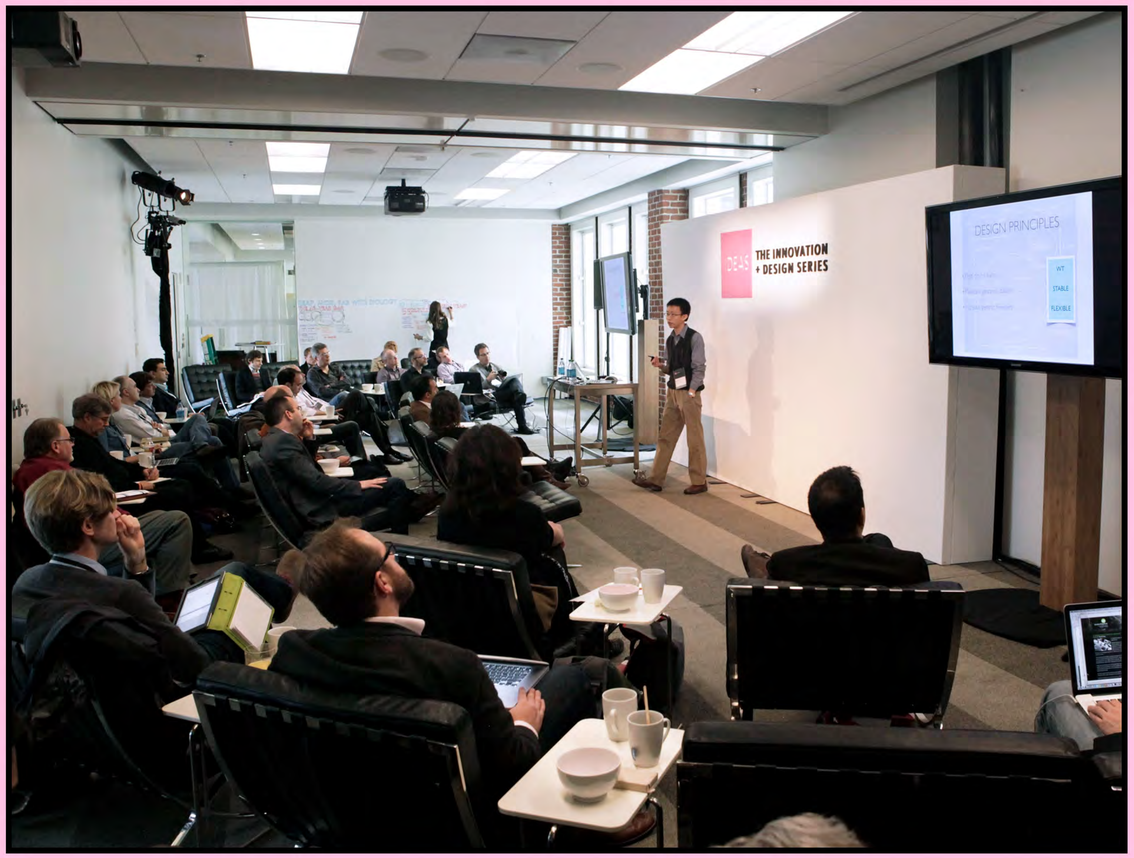
Saccharomyces cerevisiae 1.0

2.2 lbs = 1 kg yeast
6 trillion cells or
1000X the world human population

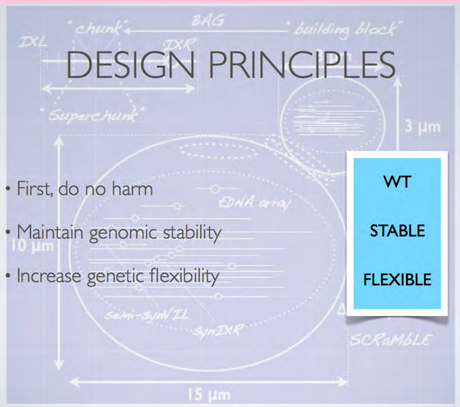
Yeast	Human
16 Chromosomes	46 Chromosomes
14M (million) bp DNA	6G (billion) bp DNA
~6,000 genes	~20,000 genes
1 yeast = 1 cell	1 human = 50 trillion cells
Haploid or Diploid	Diploid
MATa or Matα	Male or Female

What's in a name?
Saccharomyces = "sugar fungus"
cerevisiae = "found in beer"

"Beer is living proof that God loves us and wants us to be happy" - Benjamin Franklin



DESIGN PRINCIPLES



- First, do no harm
- Maintain genomic stability
- Increase genetic flexibility

WT
STABLE
FLEXIBLE

Saccharomyces cerevisiae 2.0

Design, construct, and integrate
an entirely synthetic version of the 12 Mb *S. cerevisiae* genome

Not just a milestone. Will allow examination of:

• Role/essentiality of: ◦ Repetitive elements/Transposons ◦ Introns/RNA Splicing	Remove by design
• Extent of genome plasticity ◦ genome structure/organization ◦ genome evolution ◦ speciation ◦ minimal genome sets	Built-in inducible "SCRaMbLE" system

Competing agendas: A sleek "designer" genome
Built in capacity for genome scrambling and expanding genetic code

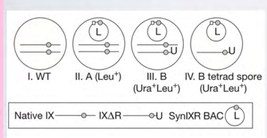
Sc2.0 genome SCRaMbLEing

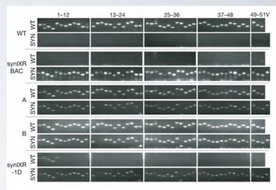
(Synthetic Chromosome Rearrangement and Modification by LoxP-mediated Evolution)

A LoxP site in every 3' UTR

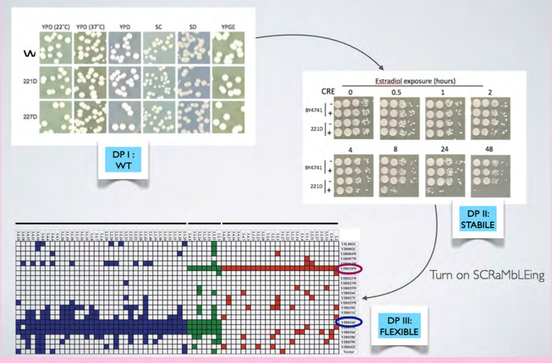
synIXR INCORPORATION

Chromosome synIXR:
- ~100 kb
- made by Codon Devices

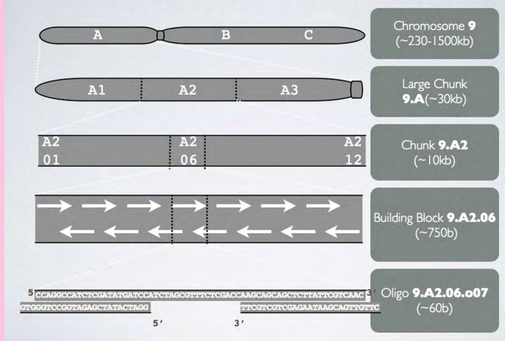




synIXR CHARACTERIZATION



Chromosome Breakdown



CONSTRUCTING SYNTHETIC YEAST

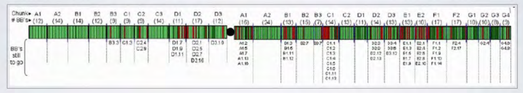
Chromosome synIXR:
- ~100 kb
- made by Codon Devices

But, commercial synthesis is costly…

Can we harness the awesome power of undergrads?

- Yes we can! Build-A-Genome (B-A-G) course
- Undergraduate course in synthetic biology/gene synthesis
- Now in 4th year, ~15 students/semester, dedicated lab space
- Course philosophy:
- students must pass personal interview
- freely available course materials, software
- 24/7 lab access after passing "Boot camp"
- Regular lab meetings; like grad school
- Must produce DNA; like Biotech

First pass of chromosome 3 completed in 12 months!



Pass
Pending

Jef Boeke
Joel Bader
Srinivasan Chandrasegaran
Jessica Dymond
Leslie Mitchell
Giovanni Stracquadanio
Héloïse Muller
Carlos Olguin

Build A Genome Faculties
JHU iGEM Teams

Beijing Genomics Institute
Tsinghua University
Tianjin University
Imperial College London
Loyola University

DARPA
NSF
Autodesk

Claes Gustafsson
Chief Commercial Officer
DNA2.0

As DNA2.0's co-funder and CCO, Dr. Claes Gustafsson is deeply involved in developing and implementing design criteria in the area of genes, proteins, and pathways for the purpose of building a marketplace for synthetic biology. Prior to co-founding DNA2.0 in 2003, Claes was a scientist at Maygen, developing protein engineering algorithms, and at Kosan Biosciences, pioneering synthesis of non-natural natural products. Claes grew up on the Swedish tundra and received his PhD from the University of Umea.

Navigating Biological Space using Machine Learning and Gene Synthesis

Claes discussed DNA 2.0, an organization that integrated machine learning with gene synthesis. The potential for this technology may vastly reduce the size of chemical manufacturing plants to a fraction of their current size as well as enable designers to design small and large organisms.

DNA 2.0 provides gene designer software, gene optimization and expression tools and protein engineering tools.

The long-term goal of DNA 2.0 is to to create a predicatable pathway.

DNA 2.0

Gene Synthesis + Machine Learning = BioDesign

IDEAS 20120328

Claes Gustafsson
DNA2.0, Inc

DNA 2.0

Picks and Shovels for Today's Gold Rush

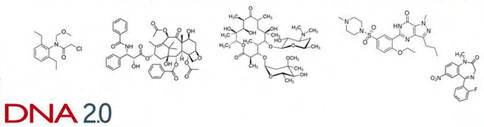
Integrating Gene Synthesis and Machine Learning
Private, profitable and no outside investors
Menlo Park, CA since 2003
Largest US Gene Synthesis Provider

DNA 2.0

1828 - Friedrich Wöhler Synthesize Urea

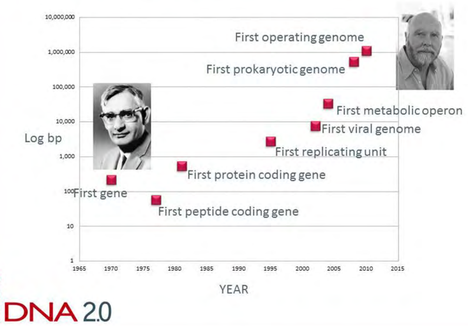
DNA 2.0

Organic Chemistry Today



DNA 2.0

Longer Synthetic Genes Faster



DNA 2.0

DNA is Information

1 and 0	Letters	Nucleotides
CD press	Printers	DNA2.0
Software makers *Oracle*	Publishers *Random House*	??
Applications *Bank of America*	Authors *Stieg Larsson*	Product Companies *Genentech*

DNA 2.0

Sequence Space is Vast

16 aa protein = $20^{16} \sim 10^{21}$

Grains of sand on planet earth: $\sim 10^{21}$

Genome is a lot more....

wt Genes

- Biased sampling
- Non-systematic variance
- Information poor
- Restricted to extant species

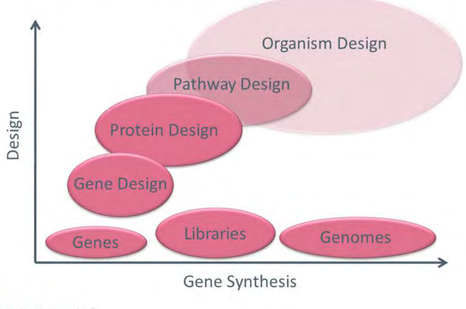
Library

- Biased sampling
- Gaussian variance (best case)
- Information poor
- Restricted by molbiol methods

Infologs

- Uniform sampling
- Systematic variance
- Information rich
- Unrestricted

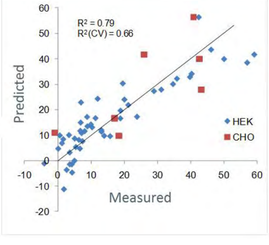
Core Technologies & Applications



DNA 2.0

Predictable Expression

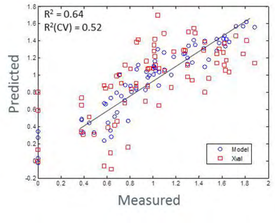
scFv Expression in HEK293 and CHO Cells



DNA 2.0

Predictable Activity

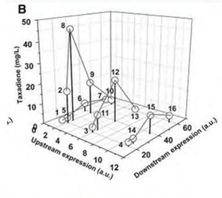
Biocatalysis of pharmaceutical intermediate



DNA 2.0

Predictable Pathway

(NOT DNA2.0 project)



Isoprenoid Pathway Optimization for Taxol Precursor Overproduction in *Escherichia coli*

Parayil Kumaran Ajikumar,[1,2] Wen-Hai Xiao,[1] Keith E. J. Tyo,[1] Yong Wang,[1] Fritz Simeon,[1] Effendi Leonard,[1] Oliver Mucha,[1] Too Heng Phon,[1] Blaine Pfeifer,[1*] Gregory Stephanopoulos[1,2*]

DNA 2.0

Omri Amirav-Drory
CEO
Genome Compiler Corp.

Omri Amirav-Drory, PhD, is the founder and CEO of Genome Compiler Corp., a synthetic biology venture. Prior to starting his company, Omri was a Fullbright postdoctoral research fellow at Stanford University School of Medicine and HHNI, performing neuroscience research using structural and synthetic biology methods. Omri received his PhD in biochemistry from Tel-Aviv University for biochemical and structural studies of membrane protein complexes involved in bio-energetics.

Democratizing the Tools of Design

Omri demonstrated an application called Genome Compiler, an easy to use tool that accesses public and private gene databases, visualize genes at a variety of focal settings or magnifications, illustrates their pathways, and allows for their modification and splicing by inserting properties of other organisims. Finally, one can print the gene.

The process is similary to the reading and writing of a human readable computer program into executable assembled machine code.

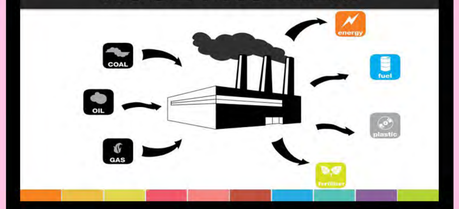
The promise is to apply breakthrough technologies to address huge problems to create radical solutions.

AUTODESK IDEAS

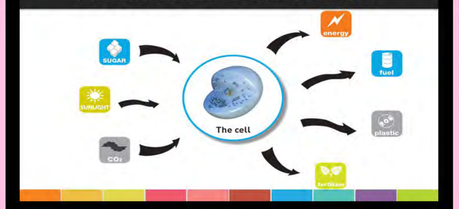
GENOME COMPILER
TOOLS FOR CREATION

Omri Amirav-Drory, Ph.D.
Founder & CEO

HUGE PROBLEM

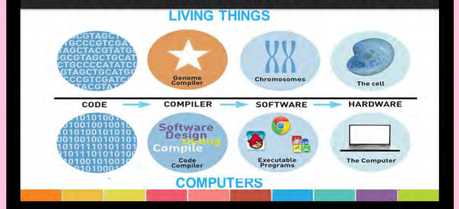


RADICAL SOLUTION



WHY LIVING THINGS?

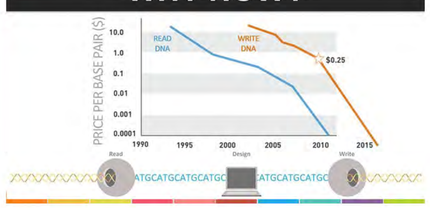
BIOLOGY IS INFORMATION TECHNOLOG



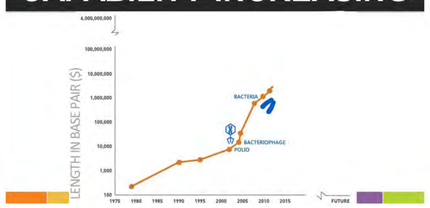
BREAKTHROUGH TECH

Tools that enable the design and creation of useful living things

WHY NOW?

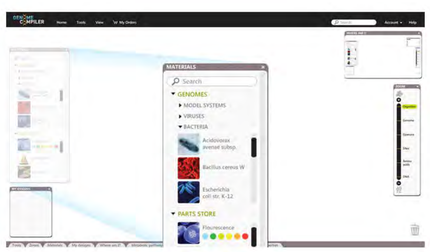


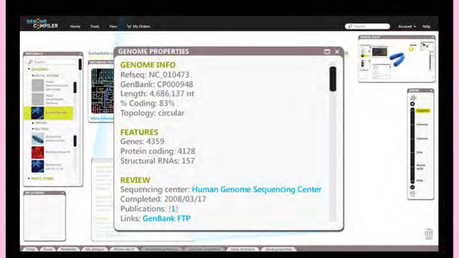
CAPABILITY INCREASING

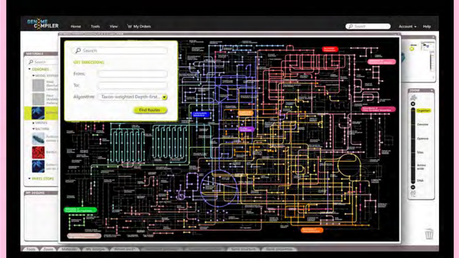


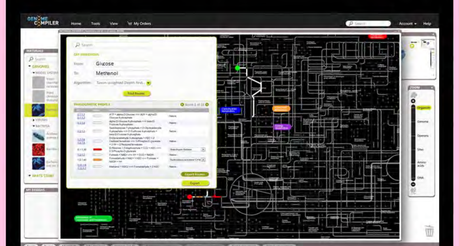
DESIGING LIVING THINGS

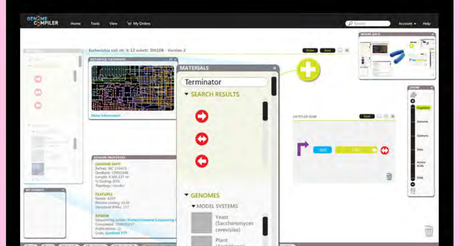
GENOME COMPILER
TOOLS FOR DESIGNING LIFE

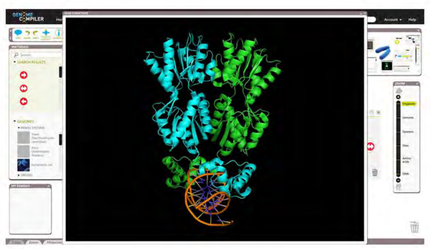


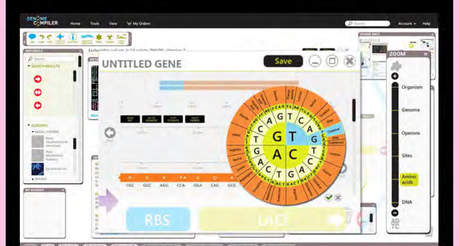




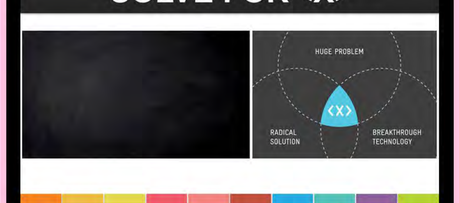








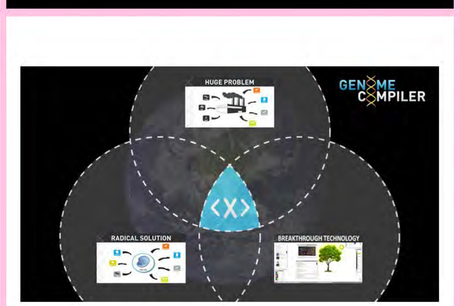
SOLVE FOR <X>



COMMENT

PUBLIC DATABASE OF LIFE

TECHNOLOGY FEAR



Jason Bobe
Executive Director
Personal Genome Project

Jason Bobe is the executive director of PersonalGenomes.org, a 501(c)(3) charity that aims to make genomes useful for humankind through research initiatives like the Personal Genome Project and the BioWeatherMap. He is also the co-founder of DIYbio.org, an organization that aims to help establish a vibrant, productive and safe community of do-it-yourself biologists worldwide. The focus of his work is making extraordinary biotechnologies ready for everyday use.

DIYbio: Extraordinary Technologies for Everyday Life

Jason described how the emerging technoogies demonstrated at IDEAS are already being used in the personal hacker culture with stories of how two students for their science fair project showed that a significant portion of fish in New York City was mislabeled - intentionally.

And with dropping costs of do it yourself tools, he is promoting the safe exploration of the public potential through DIYbio. Central is a code of ethics that stands for open access, transparency, education, safety, environment, peaceful purposes and tinkering - the essense of hacking.

Mar 28, 2012
Extraordinary Technologies
for Everyday Life

Autodesk IDEAS
San Francisco

Jason Bobe
@jasonbobe
jasonbobe@gmail.com

trickle down
innovation

cost of 1 human genome

$3,000,000,000	2002
$2,000,000	2007
$2,000	2012

cost of 1 human genome

$3,000,000,000	2002
$2,000,000	2007
$2,000	2012
-$20	2018?

Image: Life Technologies

Photo credit: Oxford Nanopore

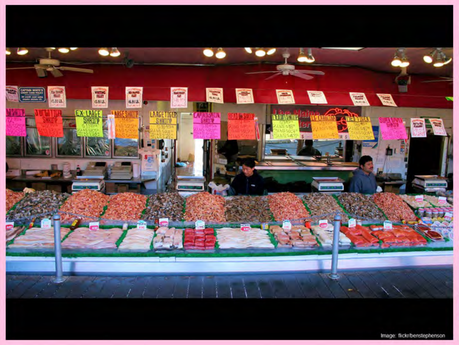


Image: flickr/bendaphenson

Kate Stoeckle

Louisa Strauss

The Boston Globe

State moves to take action against mislabeling of fish

Panel weighs DNA testing, bar coding

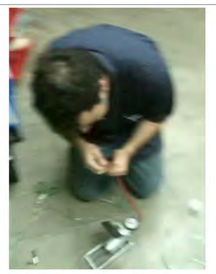
By Jenn Abelson | GLOBE STAFF JANUARY 12, 2012

ARTICLE PREVIEW VIDEO COMMENTS SUBSCRIBE

State officials are considering the use of DNA testing to combat fish mislabeling, weighing a ban on the sale of escolar, and launching a pilot program in partnership with Legal Sea Foods to trace fish through the supply chain. Leaders of various Massachusetts agencies disclosed these new efforts during a three-hour hearing on fish mislabeling held yesterday by the state Legislature's Joint Committee on Consumer Protection and Professional Licensure.

trickle up

Lo-Fi Technologies



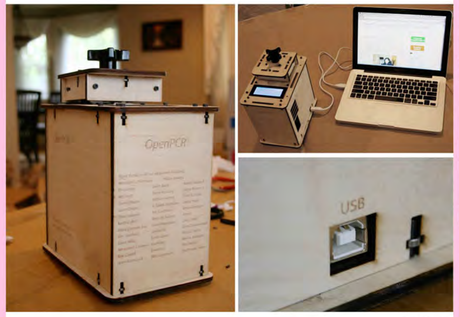


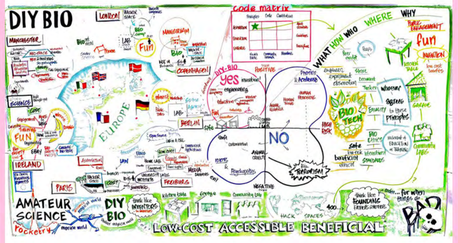
Image: Josh Perfetto

Image: flickr/bookfriend

Image: flickr/chachapoe

Photo Credit: Deirdre Brennan (Tech Review 2012)

OTC transformation



DIY BIO

Code of Ethics

OPEN ACCESS
Promote citizen science and decentralized access to biotechnology.

TRANSPARENCY
Emphasize transparency, the sharing of ideas, knowledge and data.

EDUCATION
Engage the public about biology, biotechnology and their possibilities.

SAFETY
Adopt safe practices.

ENVIRONMENT
Respect the environment.

PEACEFUL PURPOSES
Biotechnology should only be used for peaceful purposes.

TINKERING
Tinkering with biology leads to insight; insight leads to innovation.

DIY BIO

local projects blog

Ask a biosafety professional your question

Submitted questions are sent to a panel of professional biosafety experts and members of the American Biological Safety Association (ABSA.org).

Questions may be sent anonymously
How it works

Ask Now

☐ I have read the disclaimer

Keith Murphy
CEO
Organovo

Keith Murphy, chairman and CEO at Organovo, is a veteran of biotechnology startup Alkermes, Inc., where he played a central role on the development team for their first approved product, Nutropin(hGH) Depot. He moved to Amgen in 1997 and developed several other novel formulation and device products. He has 17 years of experience in biotechnology, including 10 years in product strategy and process development roles at Amgen, four of which he served as global operations leader for the largest development program in Amgen's history: Phase 3 osteoporosis/bone cancer drug denosumab. He holds a bachelor of chemical engineering from MIT, and is an alumnus of the University of California at Los Angeles Anderson School of Management.

Keith spoke about three broad approaches for commercializing bioprinting. The first is geometrically defined sheets, tubes and layered tubes to create living structures. The second is to transform these structures into functional physiology, primarily through angiogenises, the connection of a vascular system. And the third is to create complete living tissue.

Additive Biology

organovo™

Bioprinting for Medical Breakthroughs

Keith Murphy, CEO

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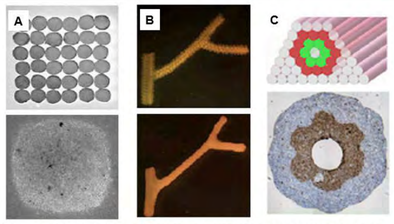
Geometrically-defined sheets, branched tubes, and layered tubes have been bioprinted



(A) Bio-ink composed of chick cardiac cell aggregates; (B) Bio-ink composed of CHO cells; (C) A bi-layered tube composed of fibroblasts and smooth muscle cells (brown = smooth muscle actin). *Adapted from Biofabrication 2:1, 2010, coauthored in part by K. Murphy and G. Forgacs, our CEO and Chief Scientific Officer.*

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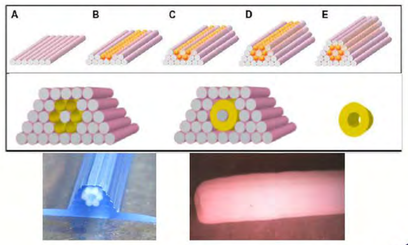
NovoGen™ Bioprinting of Vascular Tubes



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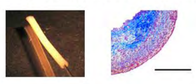
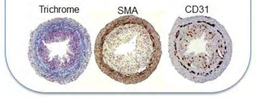
Models of Vessel Physiology/Pathobiology

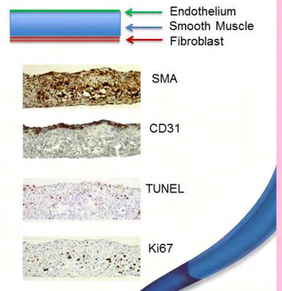
TUBULAR to UTILITARIAN

Purely cellular blood vessel wall



Purely cellular vascular constructs for physiology or pathogenesis





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Models of Angiogenesis/Vascularization

CURRENT PRACTICE

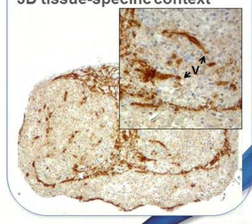
Endothelial tube formation

Chorioallantoic Membrane Assay

In Vivo, via histology

ORGANOVO ALTERNATIVE

Active vascularization within 3D tissue-specific context



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What Goes on in the Black Box?

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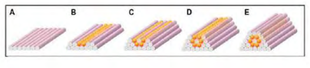
Beyond Fabrication Lies Maturation

Bioprinting



Maturation

Tissue

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Daisy Ginsberg
Design Fellow
Synthetic Aesthetics

Daisy Ginsberg is an artist, designer, and writer interrogating science, technology, and new roles for design in biotech future. As design fellow on Synthetic Aesthetics, an NSF/EPSRC-funded project at Stanford University and the University of Edinburgh, she is curating an international program researching synthetic biology, art, and design and investigating how we might "design nature." Daisy studied architecture at Cambridge University, design at Harvard University, and MA design interactions at the Royal College of Art. Her work has been exhibited at MoMA in New York, the Art Institute of Chicago, the Israel Museum, the Wellcome Trust, London's Design Museum, and the National Museum of China. Daisy publishes, teaches, and lectures internationally, with recent talks at TEDglobal, PopTech, MIT MediaLab, and Tsinghua University. Her work has been nominated for the Brit Insurance Designs of the Year 2011 and the Index Award 2011, and she is the recipient of the World Technology Award (Design) 2011.

Death and Life as the Stuff of Design

Daisy demonstrated a range of artistic expressions of biological manipulation. Examples included printing 'Hello World' with *E. coloroid*, a fictional bacteria, fictional plants, a biomimetic garden water gun, genetically engineering fruit and seeds, *E. Chromi* pigments and *E. Chromi* feces.

Through prototypes and demonstrations, her work explores the consequences of new technical discoveries on society and humanity.

THE CHANGING NATURE OF THINGS

Alexandra Daisy Ginsberg
Stanford University/University of Edinburgh

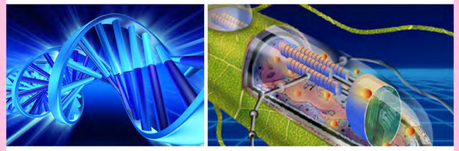
NATURE DESIGN CULTURE

DESIGN PRODUCTION DISTRIBUTION USE & MAINTENANCE

FUNCTIONAL LIFESPAN

E. coloroid
UCSF iGEM 2006

BIOLOGY BY DESIGN



DEATH + LIFE AS THE STUFF OF DESIGN

LIFE, DEATH, REPRODUCTION, COMBINATION, SYMBIOSIS DIVERSITY, NOISE, CONTEXT, COMPLEXITY, INTERACTION

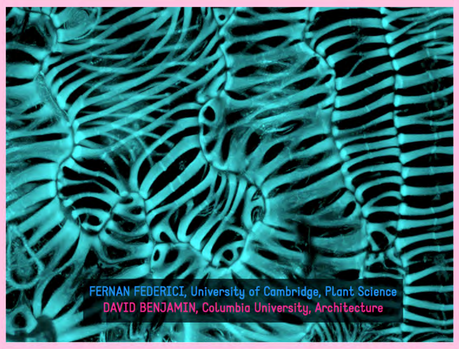
COMPLEXITY DESIRES AGENCY FORM LIFE FUNCTION DEATH COALESCENCE CONTEXT STYLE DIVERSITY UNIFORMITY ECOSYSTEM AESTHETICS

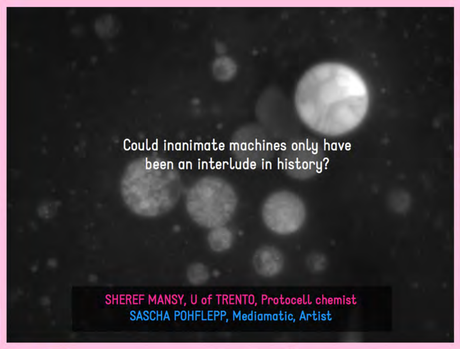
DISRUPTIVE WITHOUT DISRUPTING

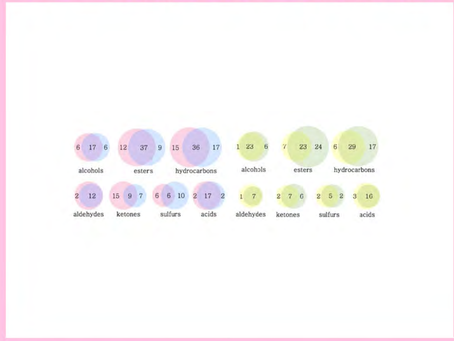
CAN YOU DESIGN NATURE?

HOW DO YOU DESIGN NATURE?

CAN YOU DESIGN NATURE WELL?







HOW DO WE DESIGN FOR A WORLD WE WANT WHEN THAT POSSIBLE WORLD DOESN'T YET EXIST?

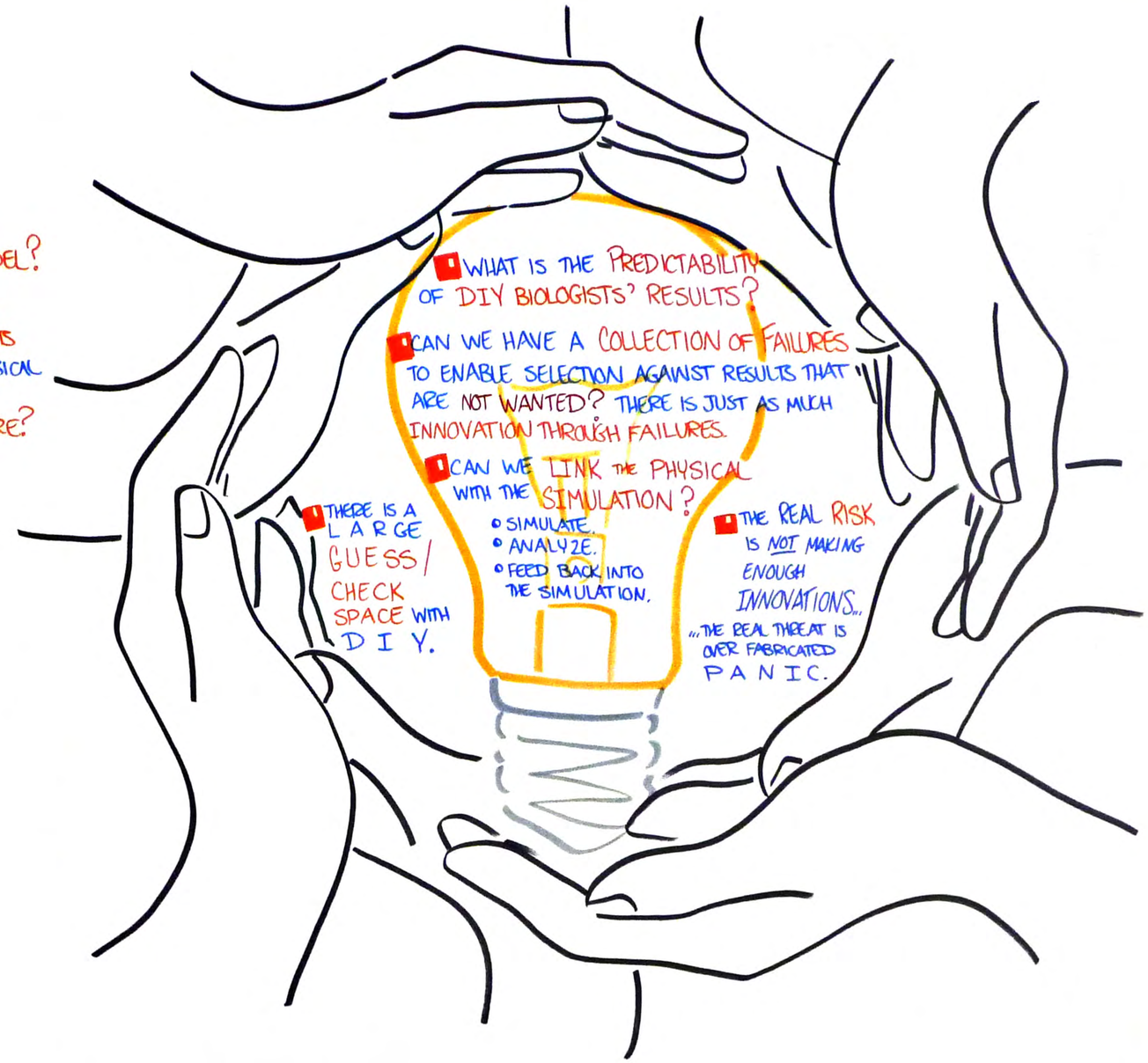
Thank you

daisyginsberg.com
syntheticaesthetics.org

@alexandradaisy
@synthaes

DISCUSSIONS

- CAN WE BUILD A LANDSCAPE MODEL?
- CAN WE DESIGN AROUND THE PARTS AND LET THE PHYSICAL DETERMINE THE OPTIMAL STRUCTURE?



EMERGING THEMES:

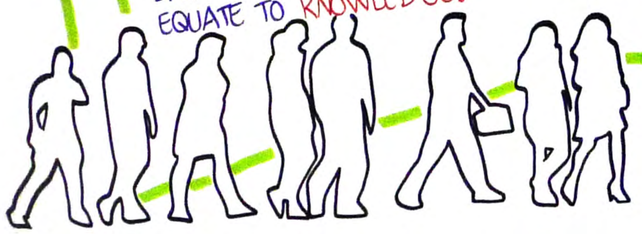
REGULATION/PROTECTION. VERSUS FREEDOM/CREATIVITY.

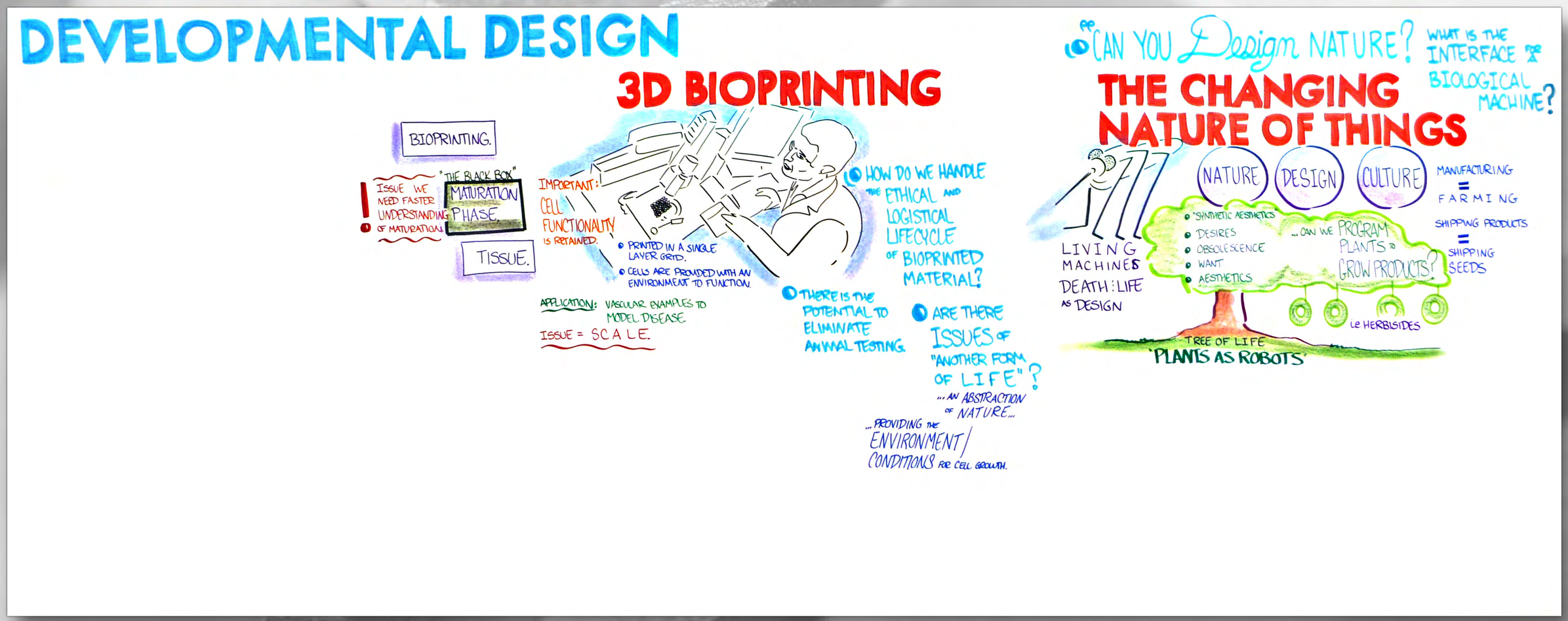
BIG PHARMA. VERSUS CROWD-SOURCING.

CENTRALIZED TOOLS. VERSUS DECENTRALIZED TOOLS.

DATA DOES NOT NECESSARILY EQUATE TO KNOWLEDGE.

HARVEST SOMETHING RARE AND REDISTRIBUTE.





Graphic Recording

Stephanie Crowley
Chrysalis Studios

Shawn Douglas
Fellow
Harvard University

Shawn Douglas received a bachelor of computer science from Yale in 2003 and a PhD in biophysics from Harvard in 2009. His research interest is in developing experimental methods and software to construct and manipulate self-assembling biomaterials on the nanometer scale. He worked as a graduate student in the laboratories of William Shih and George Church to generate custom three-dimensional shapes using the "DNA origami" method, including a novel alignment medium for NMR structure determination of membrane proteins. He has led the development of caDNAno, an open-source computer-aided design software that aids in the design of 3D shapes.

Nanoscale Construction using DNA

Shawn demonstrated how to use Maya to created nanostuctures with DNA for the purpose of scientific investigation as well as the creation of therapeutic devices.

Designing in a 2D cross-section, the CadNano application creates extruded shapes from DNA. These are bound by staple strands and embedded with functional elements to product a cancer attacking nanorobot.

Once designed digitally, the constituent DNA strands can be synthesized en masse cheaply and self-assembled into millions of nanorobots. The technology is now in clinical testing.

Nanoscale construction with DNA

Advisor: George Church

Shawn Douglas, Ph.D.
Wyss Institute for Biologically Inspired Engineering at Harvard University

Why build at the nanometer scale?

bio assemblies have nm dimensions

tools for studying bio assemblies don't have nm dimensions

Long-term goals:

scientific tools
therapeutic devices

Why build with DNA?

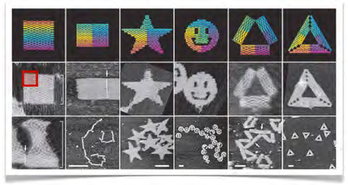
DNA is a simple material for making addressable shapes that self-assemble

DNA is a simple material for making addressable shapes that self-assemble

Pioneered by Ned Seeman
Seeman NC (1982) *J Theor Biol* **99**:237–47

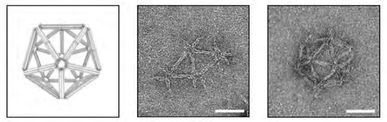
How do we get from 1D to 2D?

DNA origami



Rothemund PWK (2006) *Nature* **440**:297–302

Hierarchical assembly in 3D



Douglas SM, Dietz H, Liedl T, Högberg B, Graf F, Shih WM. (2009) *Nature* **459**:414–18

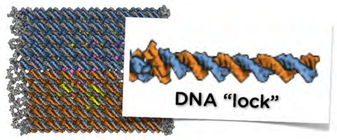
What are the applications?

Can we build a DNA nanostructure to mimic immune signaling in a targeted fashion?

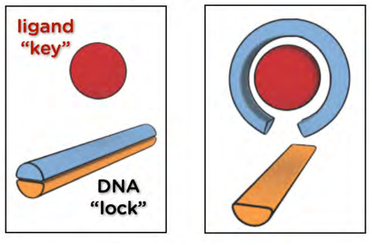
Result:

DNA nanorobot for cell targeting & allosteric payload delivery

Targeting mechanism

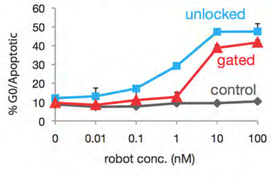


N. Hamaguchi, *et al.* (2001) Anal Biochem. **294**:126



Locked ⇌ Unlocked

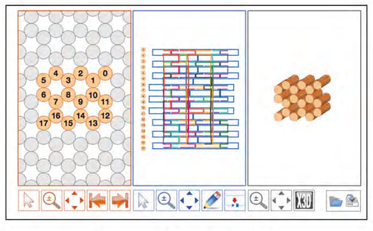
Selectively killing cancer cells



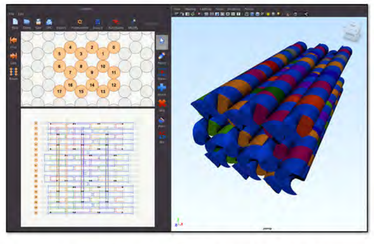
t = 72 hours after single dose

Computer-aided design

"How do I make my own nanorobot?"



Douglas SM, *et al.* (2009)
Nucleic Acids Res. **37**:5001–6



version 2: plugin for Autodesk Maya

Step 1: Route scaffold to approximate a shape

Step 2: Create staple strands

Step 3: Functional elements

Step 4: Sequence assignment

Step 5: Assembly

Babak Sanil
Postdoctorate
Lawrence Berkeley National Lab

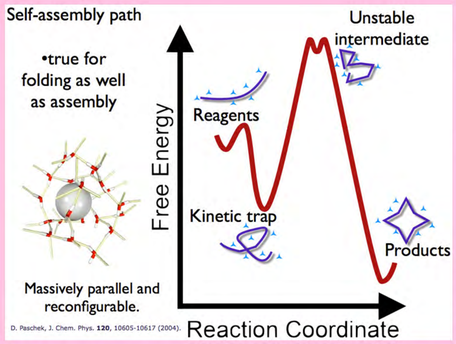
Babak Sanil is a scientist at Lawrence Berkeley Labs' Molecular Foundry, where he is designing bio-inspired molecules("peptoids") that self-assemble into new materials. Previously, he worked as an optical engineer at NASA and Pixar Animation Studios. Babak received his PhD in lipid self-assembly from the University of California at Davis, and holds a bachelor and master in engineering physics from Cornell University.

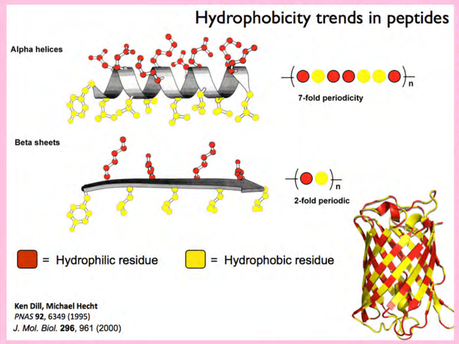
Directed Self-Assembled Peptoids

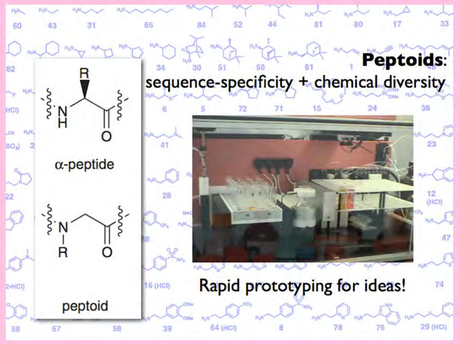
Babik demonstrated how to create peptoid nanosheets from a process of self-assembly. Through a series of trials, he illustrated that self-assembly of this form is a very delicate process. To pass through the kinetic trap, liquids in a test tube must be rotated gently, rather than shaken: the pathway for surface tension to work its process should fold successive layers rather than disrupt them by shaking or stirring.

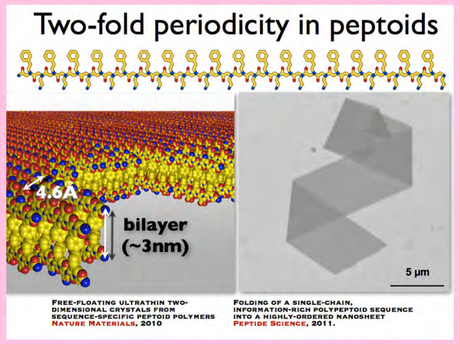
This process insight has implications for many kinds of self-assempled matter.

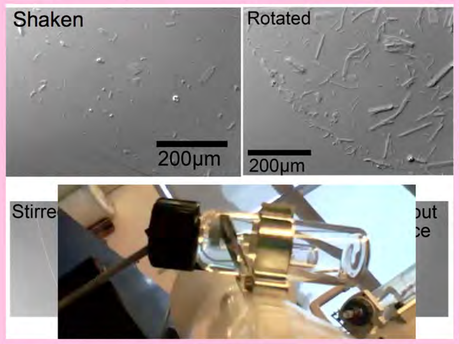
Self-assembly pathways and new materials
Babak Sanii
Lawrence Berkeley National Lab
3/28/12

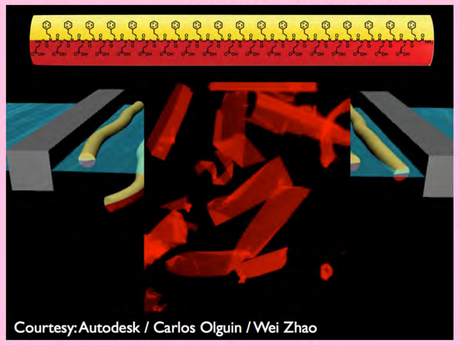

Self-assembly path
•true for folding as well as assembly
Massively parallel and reconfigurable.
Free Energy
Reagents
Kinetic trap
Unstable intermediate
Products
Reaction Coordinate
D. Paschek, J. Chem. Phys. 120, 10605-10617 (2004).

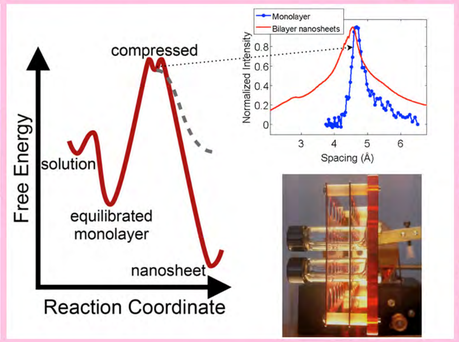

Hydrophobicity trends in peptides
Alpha helices
7-fold periodicity
Beta sheets
2-fold periodic
= Hydrophilic residue
= Hydrophobic residue
Ken Dill, Michael Hecht
PNAS 92, 6349 (1995)
J. Mol. Biol. 296, 961 (2000)

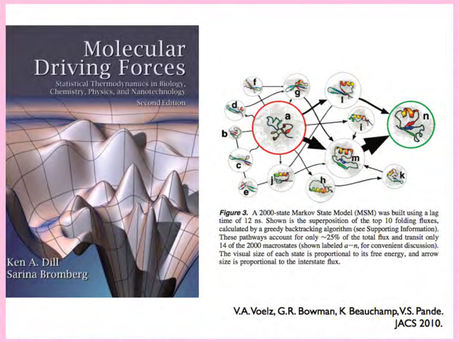

Peptoids:
sequence-specificity + chemical diversity
α-peptide
peptoid
Rapid prototyping for ideas!


Two-fold periodicity in peptoids
4.6A
bilayer (~3nm)
5 μm
Free-floating ultrathin two-dimensional crystals from sequence-specific peptoid polymers
Nature Materials, 2010
Folding of a single-chain, information-rich polypeptoid sequence into a highly-ordered nanosheet
Peptide Science, 2011.


Shaken
Rotated
200μm
200μm
Stirre

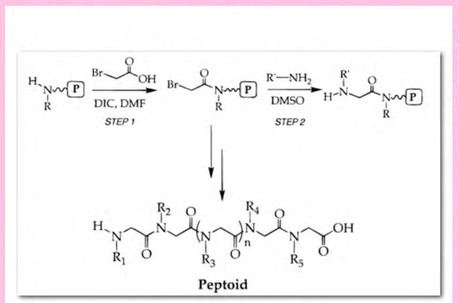

Courtesy:Autodesk / Carlos Olguin / Wei Zhao

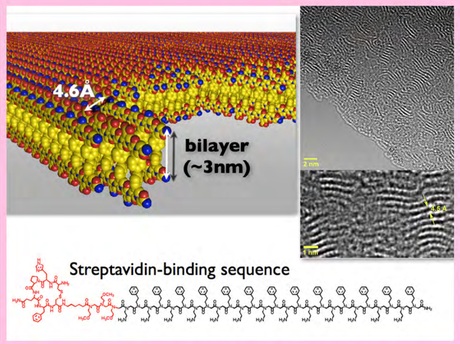

Free Energy
compressed
solution
equilibrated monolayer
nanosheet
Reaction Coordinate
Monolayer
Bilayer nanosheets
Normalized Intensity
Spacing (A)

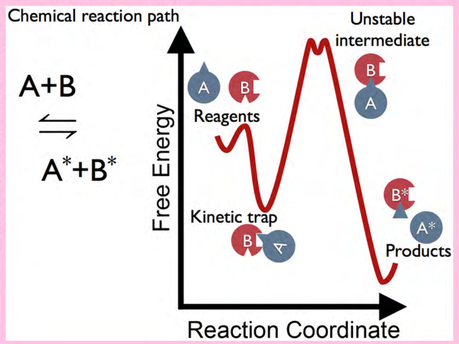

Molecular Driving Forces
Statistical Thermodynamics in Biology, Chemistry, Physics, and Nanotechnology
Second Edition
Ken A. Dill
Sarina Bromberg
V.A. Voelz, G.R. Bowman, K. Beauchamp, V.S. Pande. JACS 2010.

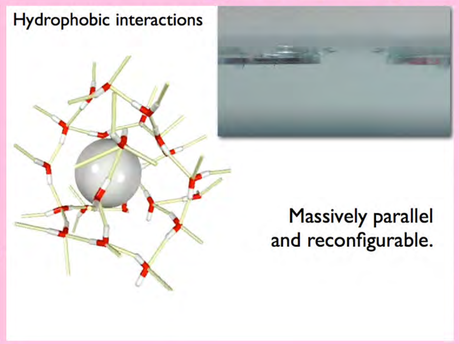
B. Sanii
R. Kudirka
A. Cho
N. Venkateswaran
G. Olivier
A.M. Olson
H. Tran
R.M. Harada
L. Tan &
R. N. Zuckermann*
Shaken, not stirred: Collapsing a peptoid monolayer to produce free-floating, stable nanosheets
JACS (cover), 2011.

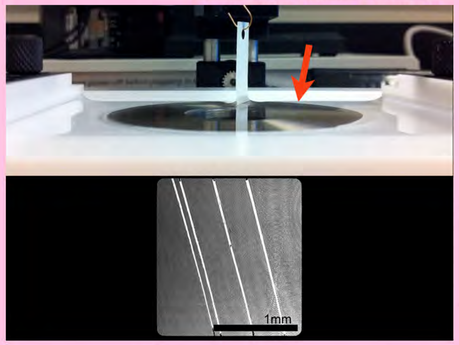
Molecular Foundry
The authors thank Stephen Whitelam, Behnaz Rad, Jeremy Schmit, Ki Tae Nam, Michael D. Connolly, Bastian Barton, Carlos Olguin/Autodesk and Promita Chakraborty for insightful discussions and valuable assistance. This work was carried out at the Molecular Foundry with support from the Advanced Light Source, at Lawrence Berkeley National Laboratory, both of which are supported by the Office of Science, Office of Basic Energy Sciences, of the US Department of Energy under Contract No. DE-AC02--05CH11231. The work was also funded by the Defense Threat Reduction Agency under Contract No: IACRO- B0845281. Preliminary data also gathered at the Advanced Photon Source at Argonne National Laboratory.
http://bsresearch.org
Babak Sanii
bsanii@lbl.gov


DIC, DMF
STEP 1
DMSO
STEP 2
Peptoid

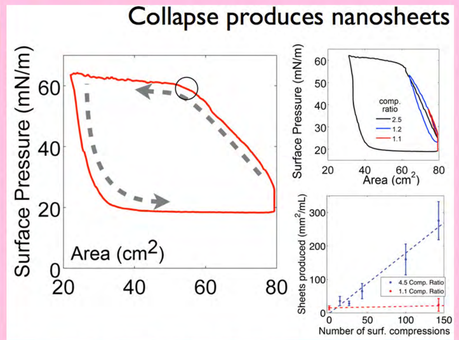

4.6A
bilayer (~3nm)
Streptavidin-binding sequence

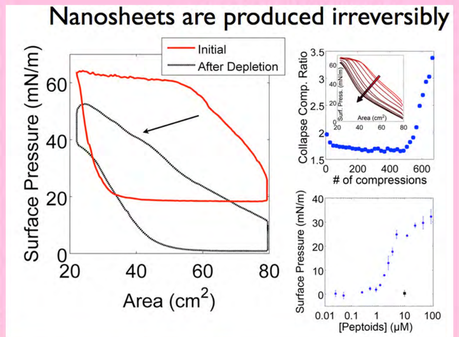

Chemical reaction path
A+B
A*+B*
Free Energy
Reagents
Kinetic trap
Unstable intermediate
Products
Reaction Coordinate

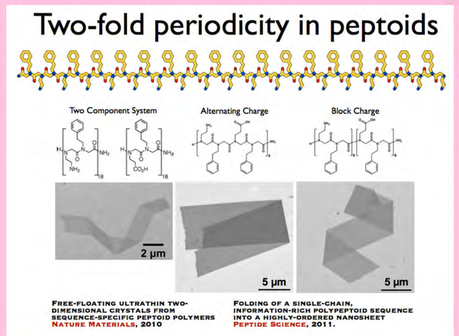

Hydrophobic interactions
Massively parallel and reconfigurable.

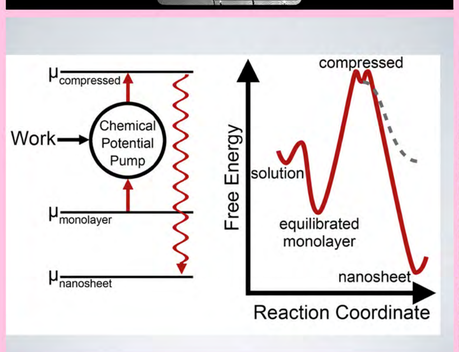

1mm

LBL
UC DAVIS
PIXAR
NASA

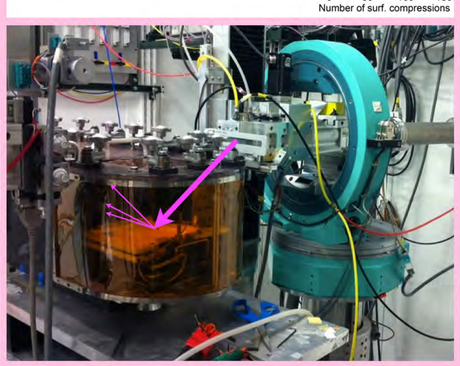

Collapse produces nanosheets
Surface Pressure (mN/m)
Area (cm²)
Surface Pressure (mN/m)
Area (cm²)
Sheets produced (mm²/mL)
Number of surf. compressions

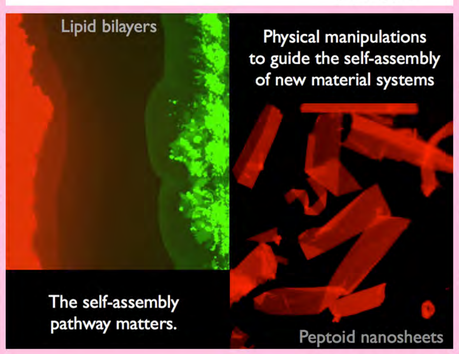

Nanosheets are produced irreversibly
Initial
After Depletion
Surface Pressure (mN/m)
Area (cm²)
Collapse Comp. Ratio
# of compressions
Surface Pressure (mN/m)
[Peptoids] (μM)

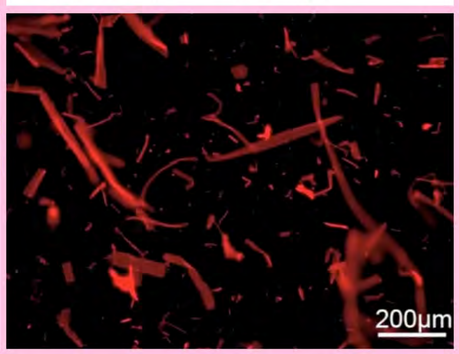

Two-fold periodicity in peptoids
Two Component System
Alternating Charge
Block Charge
2 μm
5 μm
5 μm
Free-floating ultrathin two-dimensional crystals from sequence-specific peptoid polymers
Nature Materials, 2010
Folding of a single-chain, information-rich polypeptoid sequence into a highly-ordered nanosheet
Peptide Science, 2011.


μcompressed
Work
Chemical Potential Pump
μmonolayer
μnanosheet
Free Energy
compressed
solution
equilibrated monolayer
nanosheet
Reaction Coordinate

OUR SECTOR (9ID-C)




Lipid bilayers
Physical manipulations to guide the self-assembly of new material systems
The self-assembly pathway matters.
Peptoid nanosheets


200μm

Skylar Tibbits
Founder and Principal, SJET & Lecturer MIT
SJET, MIT

Skylar Tibbits is a trained architect, designer, and computer scientist whose research currently focuses on developing self-assembly technologies for large scale structures in our physical environment. Skylar graduated from Philadelphia University with a five-year bachelor of architecture and a minor in experimental computation. Continuing his education at MIT, he received a master of design and computation and a masters of computer science. Skylar is currently a lecturer in MIT's Department of Architecture, teaching graduate and undergraduate design studios and co-teaching How to Make (Almost) Anything a seminar at MIT's Media Lab. Skylar was recently awarded a TED 2012 senior fellowship and a TED 2011 fellowship, and has been named a "Revolutionary Mind" in SEED Magazine's 2008 design issue. His previous work experience includes Zaha Hadid Architects, Asymptote Architecture, SKIII Space Variations, and Point b Design.

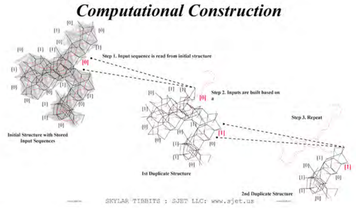
Self-Assembly and Computational Construction

Skylar demonstrated how the principles of self-assembly that occur at the molecular and nanoscale can also operate at the macro scale. What's required are interlocking and fitting parts, an attractive force, such as magnetism, an environment that contains the parts and energy to cause them to move and connect.

The results are a variety of structures from the hand-sized to the room sized objects that create their own shapes.

Future scenarios include the application to extreme environments, extreme lengths, deformable materials and material computation.

Self-Assembly & Computational Construction



SKYLAR TIBBITS : AJET LLC: www.ajet.us

User as Information

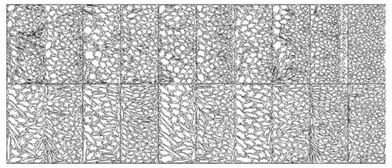
Dramatic & Robots

Figure 11. (i) Dramatic Robot. IFTTTpitch

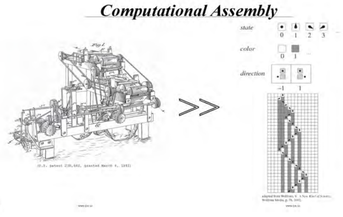
Environment as Information

Courtesy of iRobot

Custom Parts as Information

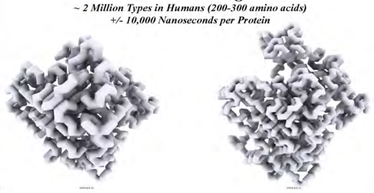


Computational Assembly



Protein Folding:

~ 2 Million Types in Humans (200-300 amino acids)
+/- 10,000 Nanoseconds per Protein

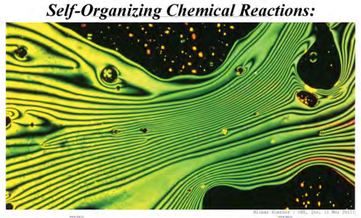


DNA Replication:

~ 3 Billion Base Pairs
+/- 50 Nucleotides per/sec - Hours per Human Genome

www.3dmedicine.com

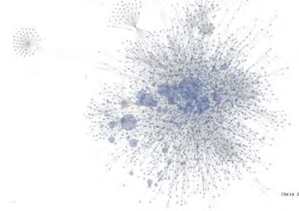
Self-Organizing Chemical Reactions:



Belousov-Zhabotinsky reaction

www.3dmedicine.com

Web-Based Networks:



Chris Davis at en.wikipedia

Macrobot & Decibot

MACROBOT | MIT | 2000

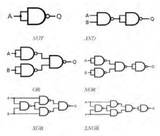
SHIGNOT | MIT | 2010

MIGRED CHAINS | MIT | 2010

Logic Matter

LOGIC MATTER | MIT | 2010

Digital Information:



~ Reliable Systems from unreliable parts

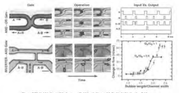
~ Redundancy stops error propagation

Figure 10. NAND Gate diagram

LOGIC MATTER | MIT | 2010

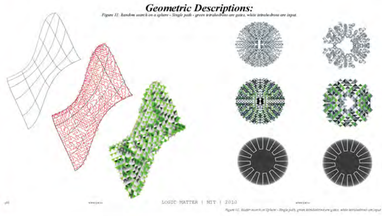
Billiard Logic:

Bubble Logic:



LOGIC MATTER | MIT | 2010

Geometric Descriptions:



LOGIC MATTER | MIT | 2010

LOGIC MATTER | MIT | 2010

LOGIC MATTER | MIT | 2010

Self-Assembly Line

Skylar Tibbits & Arthur Olson, The Scripps Institute

Self-Assembly Line

SELF-ASSEMBLY LINE | AJET | 2012

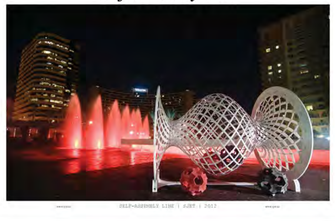
Self-Assembly Line

SELF-ASSEMBLY LINE | AJET | 2012

Self-Assembly Line

SELF-ASSEMBLY LINE | AJET | 2012

Self-Assembly Line



SELF-ASSEMBLY LINE | AJET | 2012

Future Scenarios:

+ *Extreme Environments*
+ *Extreme Scale-Lengths*
+ *Precision/Energy Constraints*
+ *Material Computing*
+ *Self-Adaptive Structures*
+ *Quickly Deployable Structures*

SKYLAR TIBBITS | WWW.3.DET.US | 2011

Our Challenge:

Can we design material parts with enough information and decision-making that they can assemble themselves, non-deterministically for automated universal construction?

SKYLAR TIBBITS | WWW.3.DET.US | 2011

Rachel Armstrong
Senior Lecturer
University of Greenwich

Rachel Armstrong is co-director of AVATAR(Advanced Virtual and Technological Architectural Research) in architecture and synthetic biology at the School of Architecture and Construction, University of Greenwich, London. She is also senior TED fellow and visiting research assistant at the Center for Fundamental Living Technology, Department of Physics and Chemistry, University of Southern Denmark. Rachel is a sustainability innovator who investigates a new approach to building materials called “living architecture,” which suggests it is possible for our buildings to share some of the properties of living systems. She collaboratively works across disciplines to build and develop prototypes that embody her approach.

Towards Big Bio Bricks

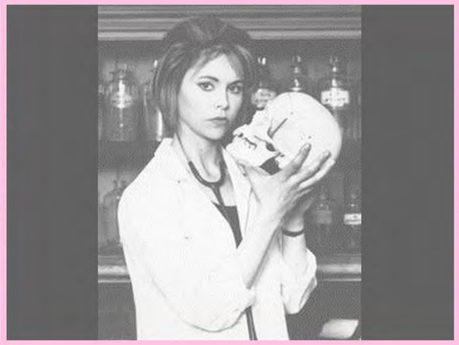
Sarah described her work in bringing together synthetic biology - specifically, artificial cells - to the domains of performance art, installation art, architecture and renewable battery technology.

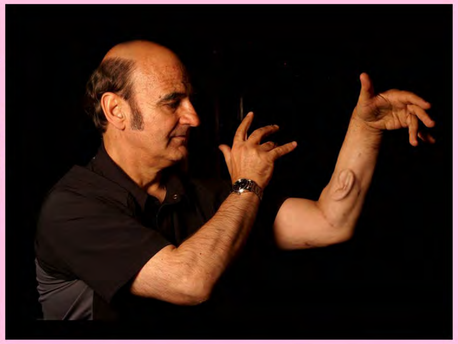
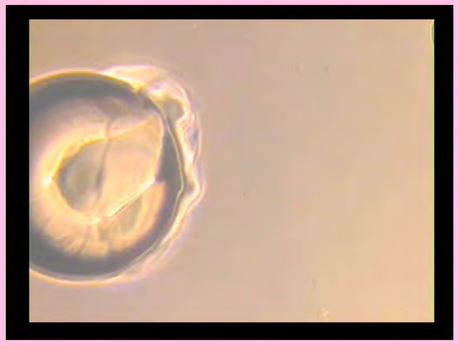
An aspirational initiative is to use synthetic biology to stop the sinking of venice with environmentally friendly bio-engineered ballasts.

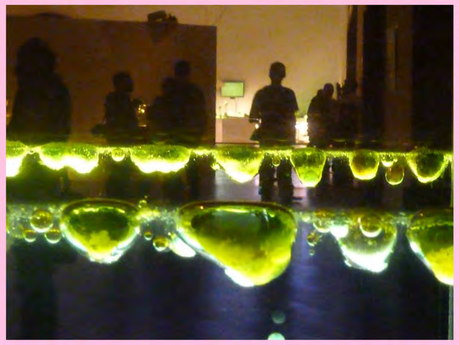
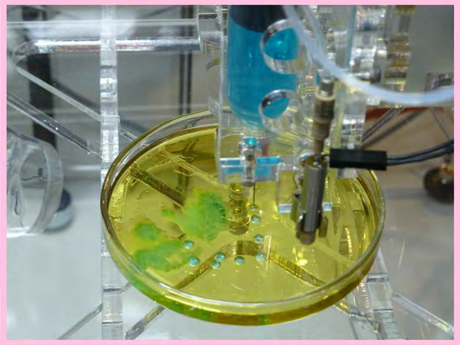
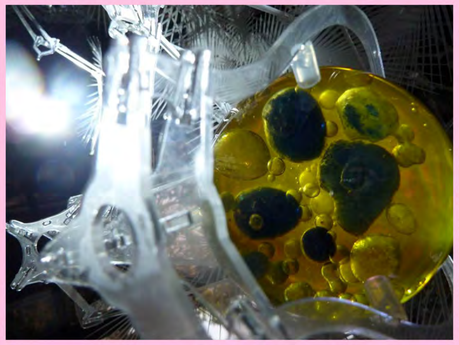
Towards BIG BIO BRICKS

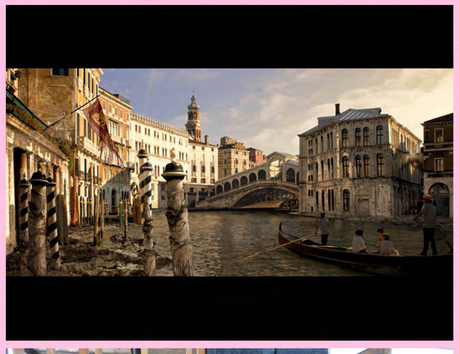
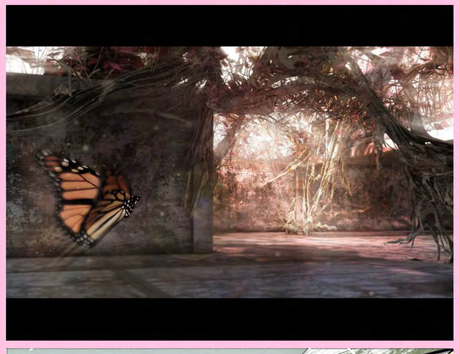
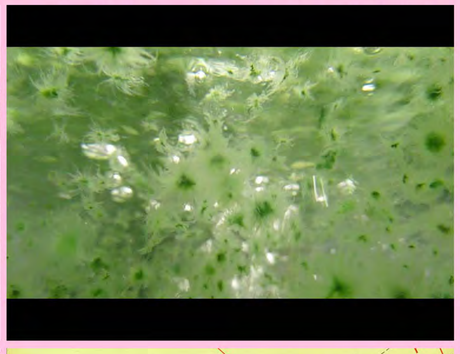
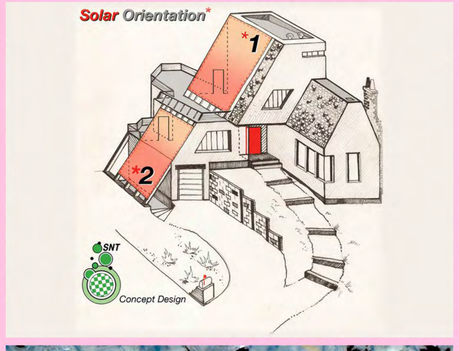
a design-led engagement with 'life'
& its supporting infrastructures

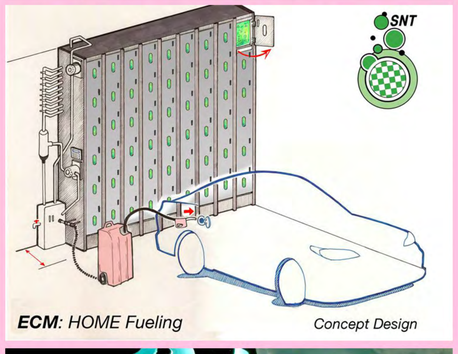
Rachel Armstrong, Senior TED Fellow
School of Architecture & Construction, University of Greenwich

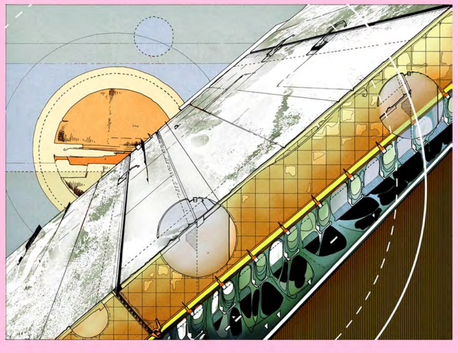
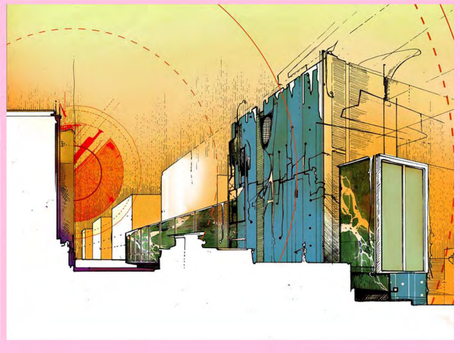


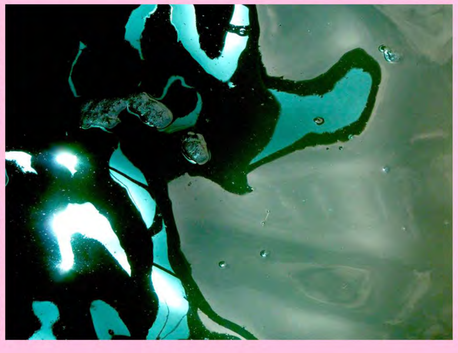







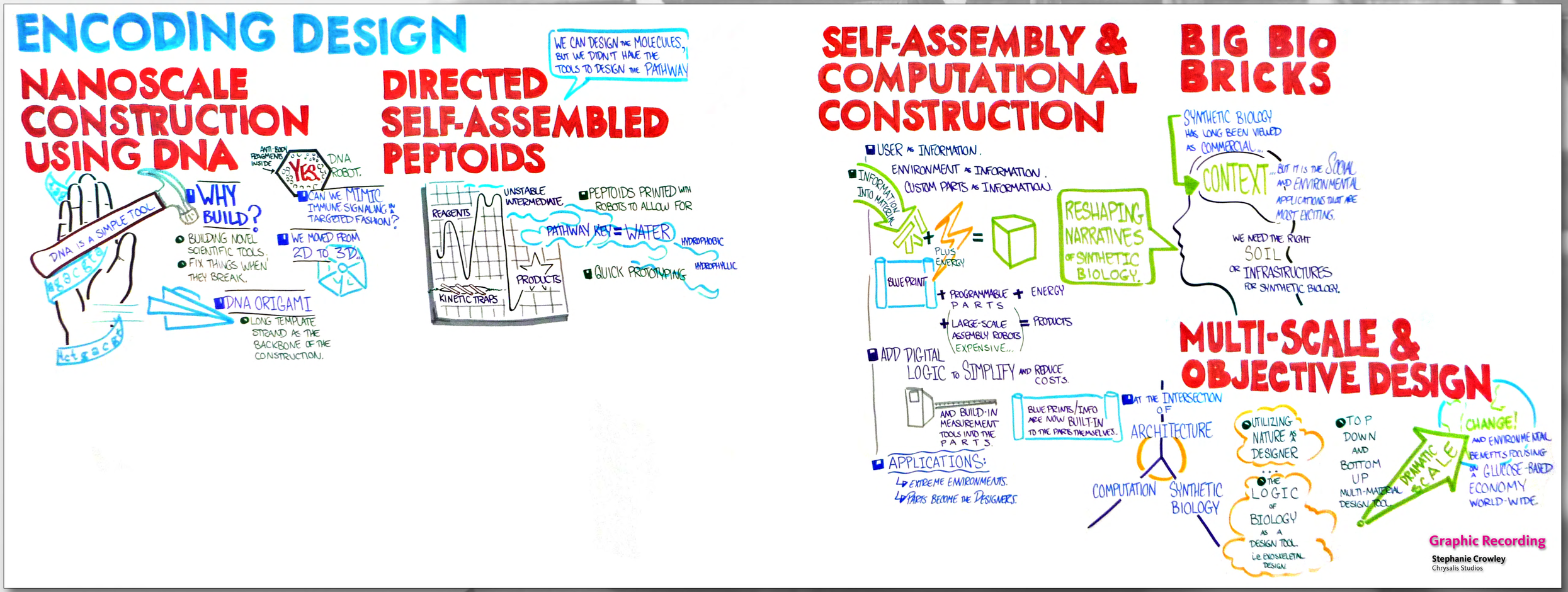
David Benjamin
Director
The Living

David Benjamin is principal of architecture firm The Living and director of the Living Architecture Lab at Columbia University's Graduate School of Architecture, Planning and Preservation. The practice and the lab involve open source research and design. Recent projects include Living City (a platform for buildings to talk to one another), Amphibious Architecture (a cloud of light above New York's East River that glows and blinks according to water quality and public interest in the environment), Proof (a series of design studios that explore methods of testing and evolutionary computation), and Architecture Biosynthesis (a hands-on-research initiative about synthetic biology, computation, and innovation in buildings).

Multi-Scale and Multi-Objective Design

As the principal of the Living, a NYC architectural firm, David illustrated approaches for designing and manufacturing bio materials, substances that embody some specific properties of living systems, such as leaf patterns or cell packing. Using 3D printing technology, he showed a biopolymer webbing that is a composite new substance resembling biological skins.

With large or programmatic robot 3D printers, the potential to create bigger structures is becoming increasingly viable. Examples include interiors, buildings as well as airplaine frames.


ENCODING DESIGN
NANOSCALE CONSTRUCTION USING DNA
DNA IS A SIMPLE TOOL
WHY BUILD?
BUILDING NOVEL SCIENTIFIC TOOLS.
FIX THINGS WHEN THEY BREAK.
ANTI-BODY FRAGMENTS INSIDE
YES
DNA ROBOT.
CAN WE MIMIC IMMUNE SIGNALING IN A TARGETED FASHION?
WE MOVED FROM 2D TO 3D...
DNA ORIGAMI
LONG TEMPLATE STRAND AS THE BACKBONE OF THE CONSTRUCTION.
DIRECTED SELF-ASSEMBLED PEPTOIDS
WE CAN DESIGN THE MOLECULES, BUT WE DIDN'T HAVE THE TOOLS TO DESIGN THE PATHWAY
REAGENTS
UNSTABLE INTERMEDIATE
KINETIC TRAPS
PRODUCTS
PEPTOIDS PRINTED WITH ROBOTS TO ALLOW FOR
PATHWAY KEY = WATER
HYDROPHOBIC
HYDROPHYLLIC
QUICK PROTOTYPING
SELF-ASSEMBLY & COMPUTATIONAL CONSTRUCTION
USER AS INFORMATION.
ENVIRONMENT AS INFORMATION.
CUSTOM PARTS AS INFORMATION.
INFORMATION INTO MATERIAL
PLUS ENERGY
BLUE PRINT
+ PROGRAMMABLE PARTS + ENERGY
+ LARGE-SCALE ASSEMBLY ROBOTS EXPENSIVE... = PRODUCTS
ADD DIGITAL LOGIC TO SIMPLIFY AND REDUCE COSTS.
AND BUILD-IN MEASUREMENT TOOLS INTO THE PARTS.
BLUE PRINTS/INFO ARE NOW BUILT-IN TO THE PARTS THEMSELVES.
APPLICATIONS:
EXTREME ENVIRONMENTS.
PARTS BECOME THE DESIGNERS.
RESHAPING NARRATIVES OF SYNTHETIC BIOLOGY.
BIG BIO BRICKS
SYNTHETIC BIOLOGY HAS LONG BEEN VIEWED AS COMMERCIAL...
CONTEXT ...BUT IT IS THE SOCIAL AND ENVIRONMENTAL APPLICATIONS THAT ARE MOST EXCITING.
WE NEED THE RIGHT SOIL OR INFRASTRUCTURES FOR SYNTHETIC BIOLOGY.
MULTI-SCALE & OBJECTIVE DESIGN
AT THE INTERSECTION OF ARCHITECTURE
COMPUTATION
SYNTHETIC BIOLOGY
UTILIZING NATURE AS A DESIGNER
THE LOGIC OF BIOLOGY AS A DESIGN TOOL. i.e. EXOSKELETAL DESIGN
TOP DOWN AND BOTTOM UP MULTI-MATERIAL DESIGN TOOL
DRAMATIC SCALE
CHANGE! AND ENVIRONMENTAL BENEFITS FOCUSING ON A GLUCOSE-BASED ECONOMY WORLD-WIDE.
Graphic Recording
Stephanie Crowley
Chrysalis Studios

Steve Jurvetson
Managing Director
Draper Fisher Jurvetson

Steve Jurvetson is a managing director of Draper Fisher Jurvetson, a leading venture capital firm with affiliate offices around the world. He was the founding venture capital investor in Hotmail (MSFT), Interwoven (IWOV), Kana (KANA), and NeoPhotonics (NPTN). He also led the firm's investments in other companies which were then acquired for $12 billion in aggregate. Current board positions include SpaceX, Synthetic Genomics, and Tesla Motors (TSLA). Previously, Steve was an R&D engineer at Hewlett-Packard, where seven of his communications chip designs were fabricated. His prior technical experience also includes programming, materials science research (TEM atomic imaging of GaAs), and computer design as HP's PC Division, the Center for Materials Research, and Mostek. He has also worked in product marketing at Apple and NeXT Software. As a consultant with Bain & Company, Steve developed executive marketing sales, engineering, and business strategies for a wide range of companies in the software, networking, and semiconductor industries.

Whether to Design or Evolve

Steve introduced approaches to managing innovation through building complex systems. These approaches include a cut and paste metaphor, iterative algorithms, and evolutionary based systems landing on the idea that the growth of technology becomes the evolution of evolution itself.

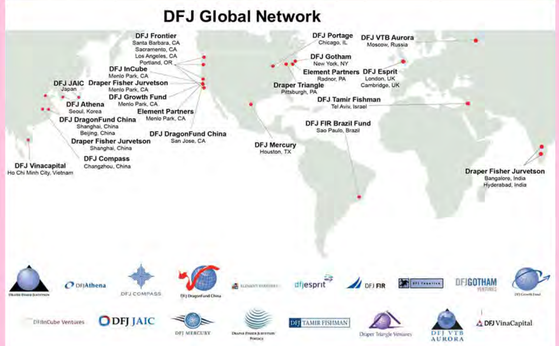
Steve contrasted two fundamental design paradigms: top down is slow and steady; while bottom up is grown, evolved and iterated, inspired by biology.

His innovation management principles: cognitive diversity is more important than ability, disagreement is more vital than consensus, voting policy trumps coherence.

Draper Fisher Jurvetson

Autodesk IDEAS
Evolution of Design
March 2012

Who are we?



Building Complex Systems

- Nanotech
- Synthetic Biology
- Computer Science
- Innovative Organizations

…whether to design or evolve?

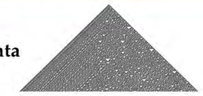
Cut & Paste Metaphor

"It should be possible to share components of learning the way we share components of software.

An intelligent machine could be reprogrammed as if I could download a new set of connections into your brain and instantly change you from an English speaker to a French speaker, or from a political science professor to a musicologist."

Iterative Algorithms & Evolved Systems

- Consider:
  - Cellular automata



  - Genetic programming
    - Analog Circuits & Antennae
    - Danny Hillis: Sort Algorithms

  - Neural networks, QC

  - Wisdom of Crowds

The Problem with Evolution

- Subsystem Inscrutability
  - Black box defined by its interfaces
  - No "reverse evolution"
  - Tweak the process not the product
- No simple shortcuts across the iterations
  - Simulation ~ Reality
  - Beauty from irreducibility

Dichotomy

Design	Evolution
• Simple Problems	• Complex (>MSFT) - Transcendence proof
• Control	• Out of Control
• Brittle	• Robust, Resilient, Adaptive - Co-evolutionary islands
• Subsystem Clarity - Portable, Modular	• Inscrutable subsystems
• Top Down - Inheritance of Scale	• Bottom Up - Hierarchical subsumption - Layers of abstraction - Path dependence

Implications

- Cut & Paste Portability?
- Locus of learning: *Process*, not *Product*
  - Would we bother to reverse engineer?
- Co-evolutionary islands
  - accustomed environment (differential immunity)
- Path dependence
  - algorithm survival
  - AI = Alien Intelligence defined by sensory I/O

Grand Engineering Challenge

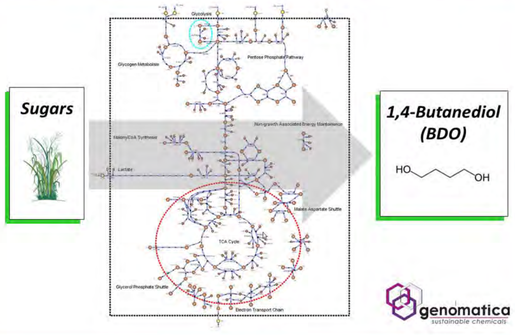
Danny Hillis, *The Pattern on the Stone*:
"The greatest achievement of our technology may well be the creation of tools that allow us to go *beyond* engineering – that allow us to create more than we can understand."

Ray Kurzweil:
"Each epoch continues the evolution of information through a paradigm shift to a further level of indirection."

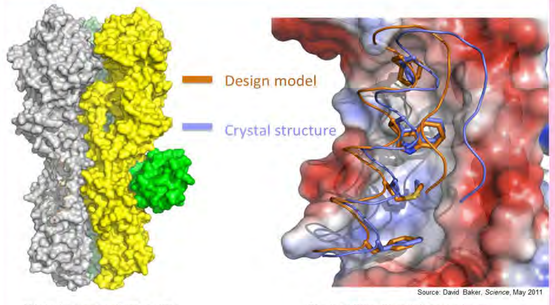
Geoffrey West, SFI:
"Evolution did not change the building blocks, only the size of the networks."

Kevin Kelly:
"Technology is the evolution of evolution itself"

Design, engineer, evolve



Computational Design Gaps



H1N1 hemagglutinin protein — Binding Site: Simulator vs. X-ray

Innovation Management

- Cognitive Diversity > Ability
- Disagreement > Consensus
- Voting Policy > Coherence or Comprehensibility
- Communication Tuning > Leadership

Why does technology accelerate?

"All technologies are combinations of technologies that already exist." —

- Combinatorial Explosion
- Creates Economy

— "Science quickly became the greatest tool for making new things the world has ever seen. Science was in fact a superior method for a culture to learn."

"Throughout history, the engine of human progress has been the meeting and mating of ideas to make new ideas. It is our habit of trade, idea-sharing and specialization that has created the collective enterprise which set human living standards on a rising trend. The human race will prosper mightily in the years ahead, because ideas are having sex with each other as never before."

—

- Urbanization
- Interdisciplinary Disruption
- Globalization

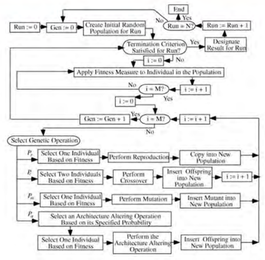
Summary

Accelerating Technological Change

- Interdisciplinary Renaissance
- IT innervates $T markets
- More Black Swans
- Perpetual driver of disruption
  - ⇒ Virtuous cycle for entrepreneurs
  - ⇒ a great time to build new companies

Genetic-Programming.org (2007)

- Breeding programs
- 23 patented inventions
  - Analog circuits
  - Antennae



"Genetic programming now routinely delivers human-competitive machine intelligence."

Nanotech Thinking

- Top-Down
  - Design
  - Inheritance of Scale and modularity
  - Slow & Steady

- Bottom-Up
  - Grown, Evolved, Iterated
  - Bio-inspired
  - Powerful & Out of Control (Systems Theory)
  - Transcendence Existence Proof

Andrew Hessel
Co-Chair Bioinformatics
Singularity University

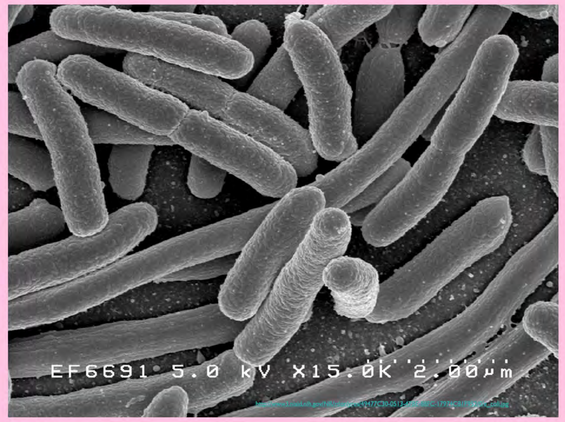
Andrew Hessel co-chairs the bioinformatics and biotechnology track at Singularity University, an institution founded by futurist Ray Kurzwell and X Prize Foundation CEO Peter Diamandis, with sponsorship from world-leading organizations that include Google, Autodesk, and NASA. He is also the founder of Pink Army Cooperative, a venture aiming to become the linux of personalized cancer therapies. His work has been featured in the *New York Times*, *Futurist Magazine*, *H+*, and *Wired News*.

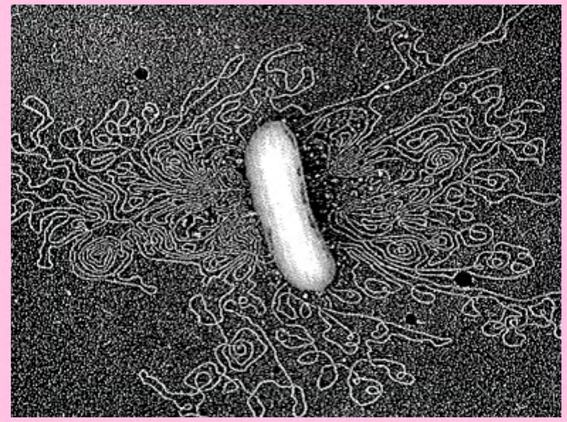
The Promise of Synthetic Biology

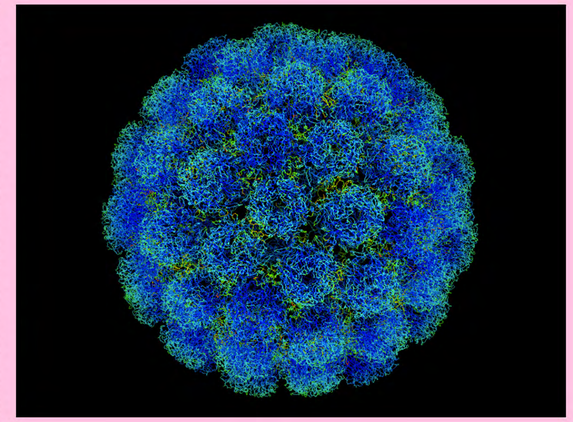
Andrew spoke about Clouds and Crowds, that innovation will be driven by networked groups of talented and motivated people using the resources of inexpensive, virtually infinite computation.

Current application include the creation of apps to address specific problems, from tackling rare genetic diseases, creating personal drugs, pet modification, special de-extinction, precious resource creation amond many others.

Crowds and Clouds
AUTODESK IDEAS
March 28, 2012
ANDREW HESSEL, CO-CHAIR BIOINFORMATICS
SINGULARITY UNIVERSITY
Preparing Humanity For Accelerating Technological Change


EF6691 5.0 kV X15.0K 2.00μm





Tap
Tap
Revenge

RareGenomics
Empowering Communities. Accelerating Research
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The Process
OUR PATIENTS
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FOR RESEARCHERS
Help Advance Science
NEWS & EVENTS
Updates & Press
Did You Know...
An estimated 250 million people worldwide are suffering from a rare disease. For most, there is no cure because of the low prevalence of their disease, which is often genetic in nature. We were founded to offer these patients a new hope for a cure -- through a new channel of crowdfunding.
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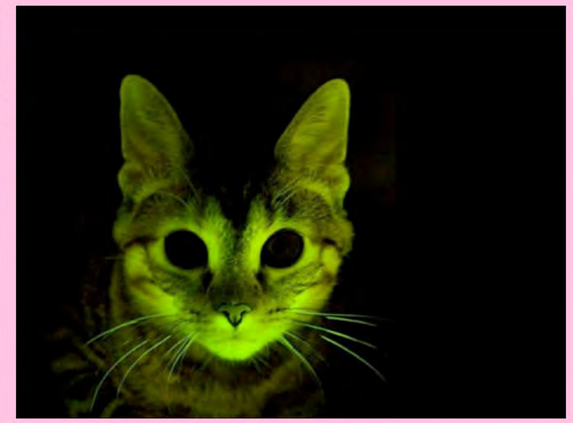
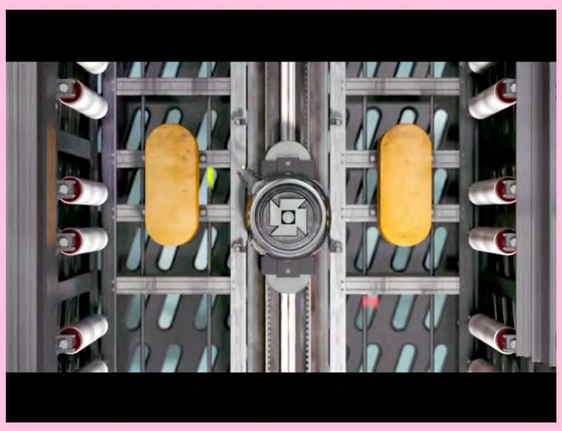
02.29.2012
is World Rare Disease Day.
Rare but Strong Together.
Let's Show the World We Care >
<< 1 2 3 4 5 >>



Human
Genome
Project
2.0
CHEMISTRY
BIOLOGY
PHYSICS
ETHICS
ENGINEERING
INFORMATICS
RESOURCES FOR THE BIOLOGY SECTION



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10+ Overview | SU Companies | Global Impact Competitions | Team Projects | Scholarships
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Faster, Cheaper, Better...

Marc Goodman
Founder
Future Crimes Institute

Marc Goodman is a global thinker, writer, and consultant focused on the profound change technology is having on security, business, and international affairs. Over the past 20 years, he has built his expertise in cyber crime and terrorism working with organizations such as INTERPOL, the United Nations Counterterrorism Task Force, NATO, and the U.S. Government. Marc frequently consults with global policy makers, security executives, and industry leaders on transnational cyber risk and intelligence and has operated in more than 70 countries around the world. Additionally, he serves as the global security advisor at Singularity University. he founded the Future Crimes Institute to inspire and educate others on the security implications of disruptive technologies such as artificial intelligence, the social data revolution, synthetic biology, virtual worlds, robotics, ubiquitous computing, and location-based services. He has been published in the *Harvard Business Review*, *Forbes*, the *Economist*, and *Jane's Intelligence Review*. He is a graduate of Harvard University and the London School of Economics.

Biosecurity

Mark introduced the dark side of emerging technologies and bio-security. With a $2 trillion global market in organized crime, criminals are transforming their business, applying the digital and biological tools, to deliver crime as a service, hack the internet of things, 3D print of guns and credit card skimmers and produce evil robots.

The democritization of nanobots will introduce new issues in bio-security. The solutions are unclear and complex but will mean the rethinking of 21st century institutions and most certainly involve crowdsourcing.

IDEAS THE INNOVATION + DESIGN SERIES

SMALL THINGS, BIG DANGERS

(and opportunities)

Marc Goodman
@futurecrimes

THE BUSINESS OF ORGANIZED CRIME

- $2 trillion dollar business in 2010
- 15% of Global GDP

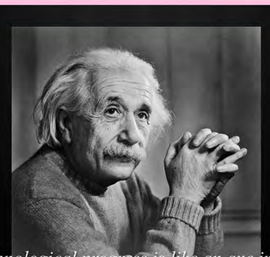
2011 STATE OF THE FUTURE

A PARADIGM SHIFT IN CRIME

CRIME AS A SERVICE (CaaS)

DEMOCRATIZATION OF TECHNOLOGY DIY/MAKER MOVEMENT

- No Longer "Just Us Guys"
  - Cyber
  - Robotics
  - Bio
  - Medicine
  - Nano



"Technological progress is like an axe in the hands of a pathological criminal"

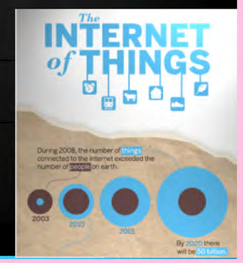
Albert Einstein

GROWTH OF THE NETWORK

- IPv4 versus IPv6
- 2^{32} versus 2^{128} Internet

INTERNET OF THINGS

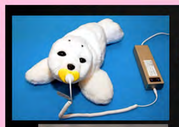
- Cars
- Refrigerators
- Pacemakers
- Elevators
- Smoke detectors
- Video cameras
- Soldiers
- Televisions
- Pets
- Prisoners



ALL THINGS HACKABLE

hacker inside

RISE OF ROBOTICS



MICRO AND NANO-BOTS

Technology

Print me a Stradivarius

How a new manufacturing technology will change the world

Feb 10th 2011 | from the print edition

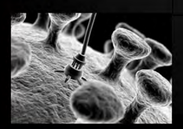
Tweet 562 Like 9K

3D PRINTING

HUMAN BODY VULNERABLE TO CYBER ATTACKS

NANO: PROMISES & THREATS

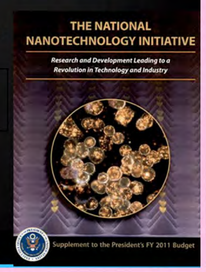
Molecular manufacturing will bring a revolution in military affairs greater than the transition from hand-made spears to mass-produced guns. It is unwise to be on the wrong side of such a technology gap"



- Eric Drexler, 2004

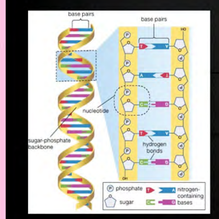
DEMOCRATIZATION OF NANO

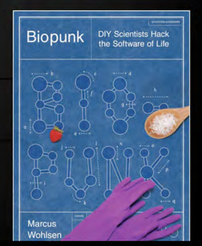
- 1,600 Nano Companies in U.S. Alone
- More in China



ISSUES IN BIO-SECURITY

THE HUMAN GENOME

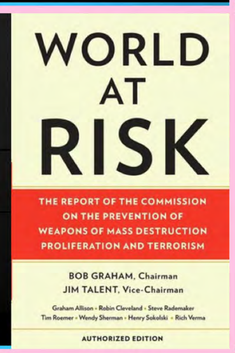




TERRORISTS & BIOLOGY

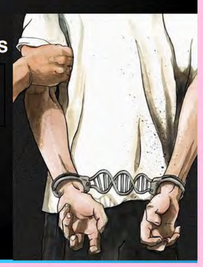
- Aum Shinrikyo in 1990 & 1995
- $10M/10 Year Bio Weapons Program
- Jihadi Chat Rooms

Bio Attack Likely by 2013



Bio Hacks & Bio Crime

- Bio Zero Day Exploits
- DDOS
- Phishing & Spear Phishing
- Bio Stuxnet



DNA AS A TARGET

IDEAS

NANOSCALE TECHNOLOGIES HUMAN SCALE PROBLEMS

RESPONSE

- 21st Century Institutions
- Crowdsourcing the Solution

Carlos Olguin
Senior Principal Research Scientist
Autodesk, Inc.

Carlos Olguin is an interdisciplinary designer with more than 13 years of combined experience in domains such as design tools for 2D and 3D modeling, social learning, GIS, risk management, network service brokerage, web search experience, online emergent social phenomena, and, more recently, systems biology. He joined Autodesk in 2006 as a senior product designer. In his current role in research, he leads a new initiative to understand and exploit the intersection of (bio)nanotechnology with 3D visualization, simulation, and design. He obtained a master of science in information networking from Carnegie Mellon in 2001. He holds a bachelor of science in electronics and communications from Instituto Tecnologico y de Estudios Superiores de Monterrey (Mexico). He has also studied telecommunications at the Institute National des Telecommunications in Evry, France. In 2005, he began studying systems biology part-time, first at Chalmers University in Sweden, and then, starting in 2008, at Columbia University.

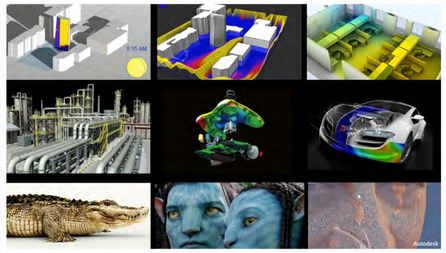
Future Design Paradigms

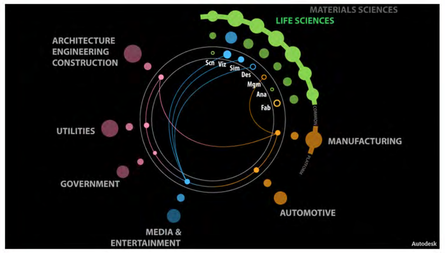
Carlos summarized the day's discussion with an exploration of future design paradigms. The fundamental metaphor presented - scan, modify, print - means a genetic sequence is initially captured, then visualized and analyzed, and finally synthesized and realized. The technologies and approaches illustrated throughout the IDEAS summit show variations of these basic themes.

Carlos introduced a domain agnostic computational framework that spans in-vivo, in-vitro and in-silico processing tools.

Future Design Paradigms

Carlos Olguin | Autodesk





Scan Modify Print

Autodesk

Scan
Sequence
Capture
Modify
Print

Autodesk

Scan
Sequence
Capture

Modify
Simulate
Analyze
Visualize

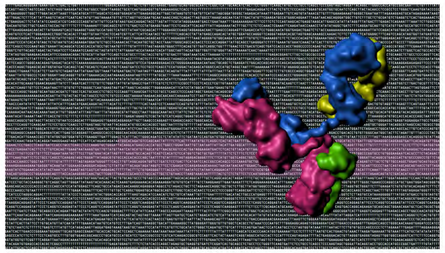
Print
Synthesize
Create

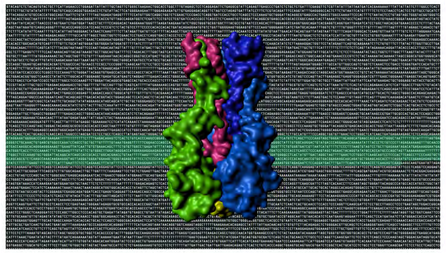
Manage
Automate
Optimize

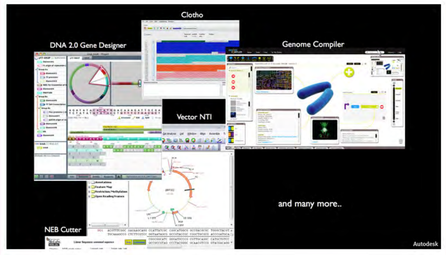
Autodesk

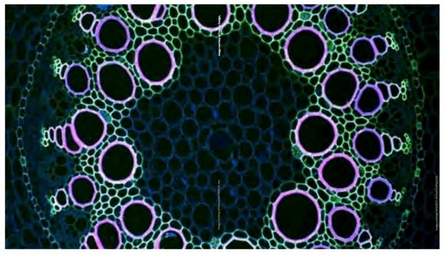
1. Design Substrates
2. Design Paradigms
3. Applications

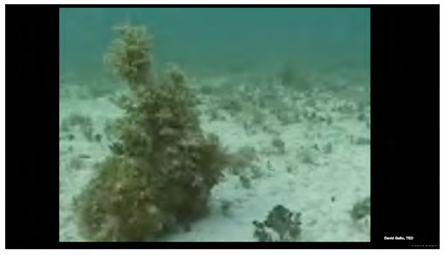
Autodesk

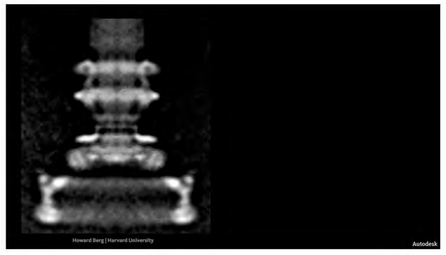


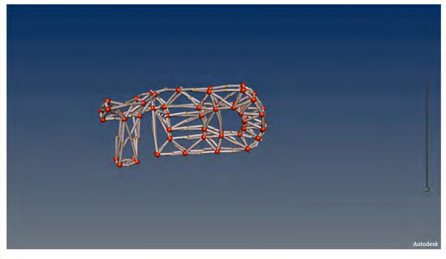


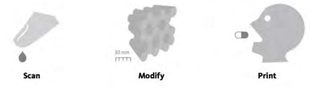












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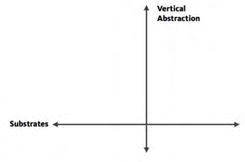
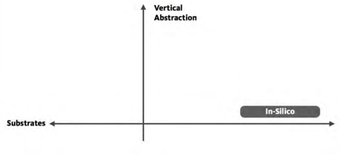




Domain Agnostic Computational Framework

In-Vivo In-Vitro In-Silico

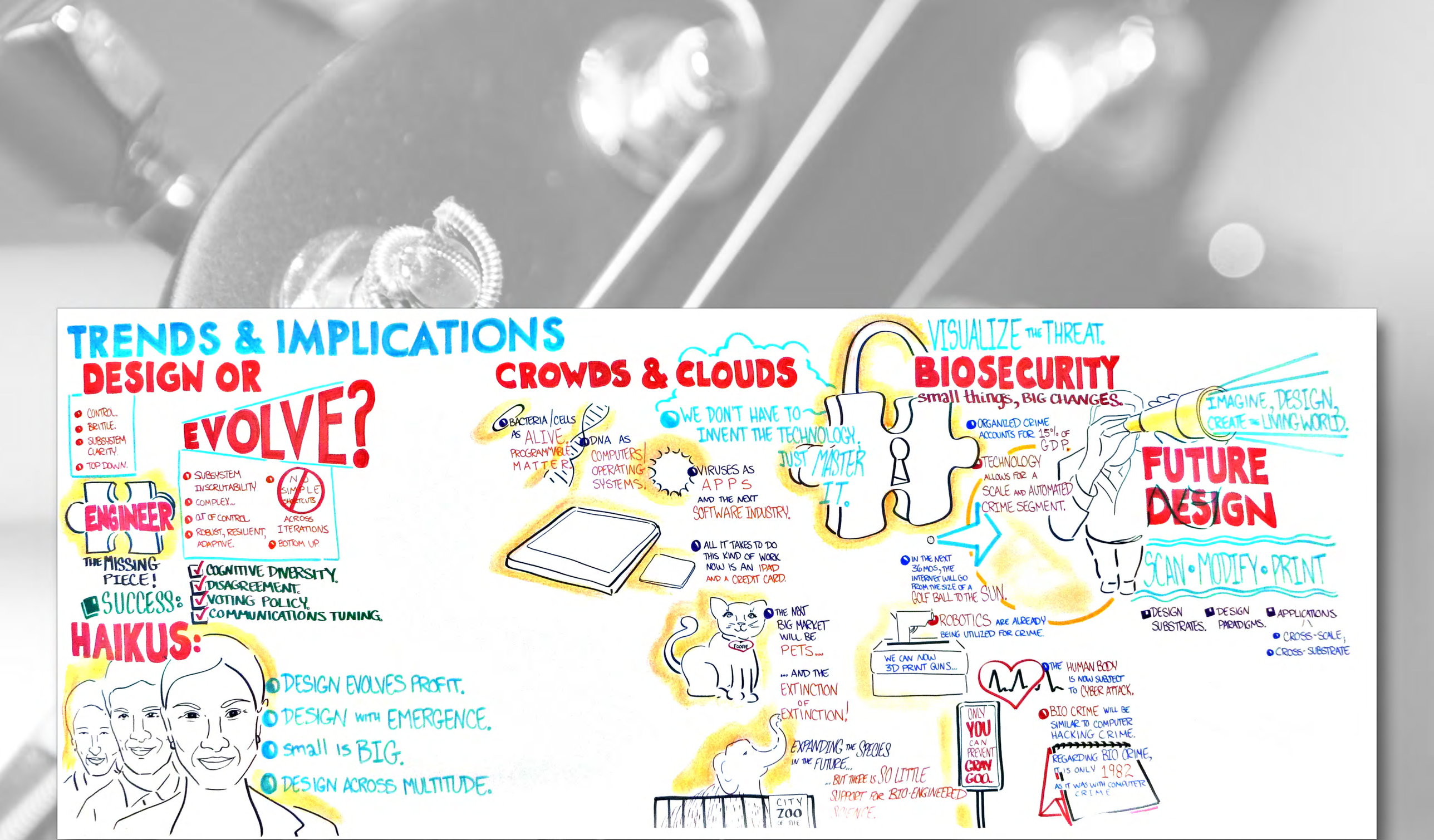
Domain Agnostic Computational Framework

In-Quantum

In-Vivo In-Vitro In-Silico

Autodesk

Autodesk



Graphic Recording

Stephanie Crowley
Chrysalis Studios

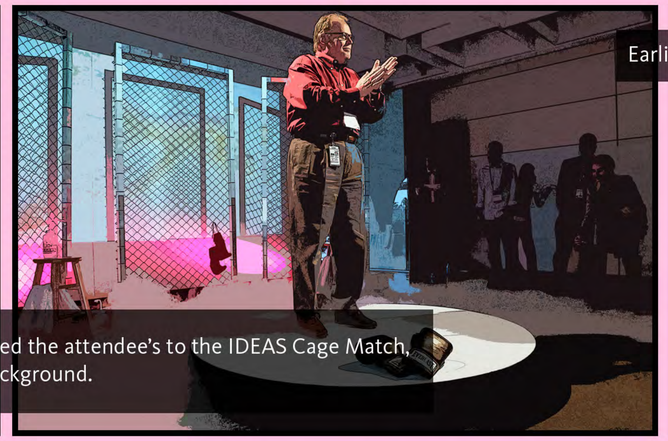
...part Oxford-style debate,
part *Lucha Libre* Mexican-style wrestling...

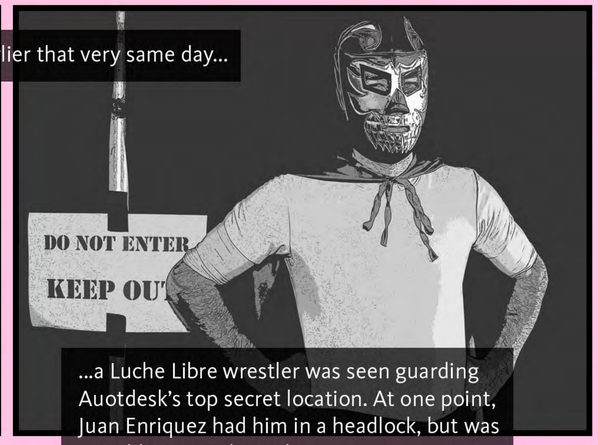
IDEAS

THE INNOVATION
+ DESIGN SERIES

IDEAS Cage Match

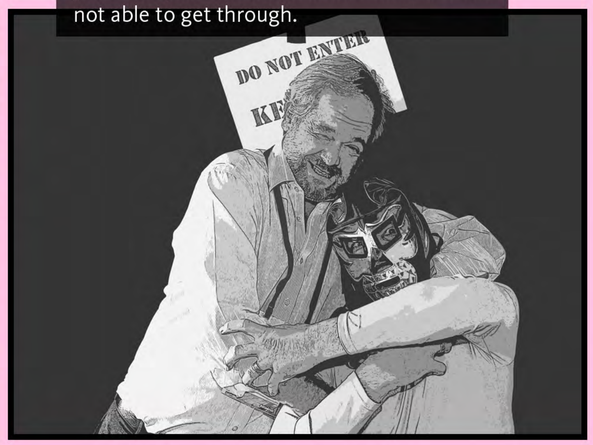
Wednesday, March 28th, 2012

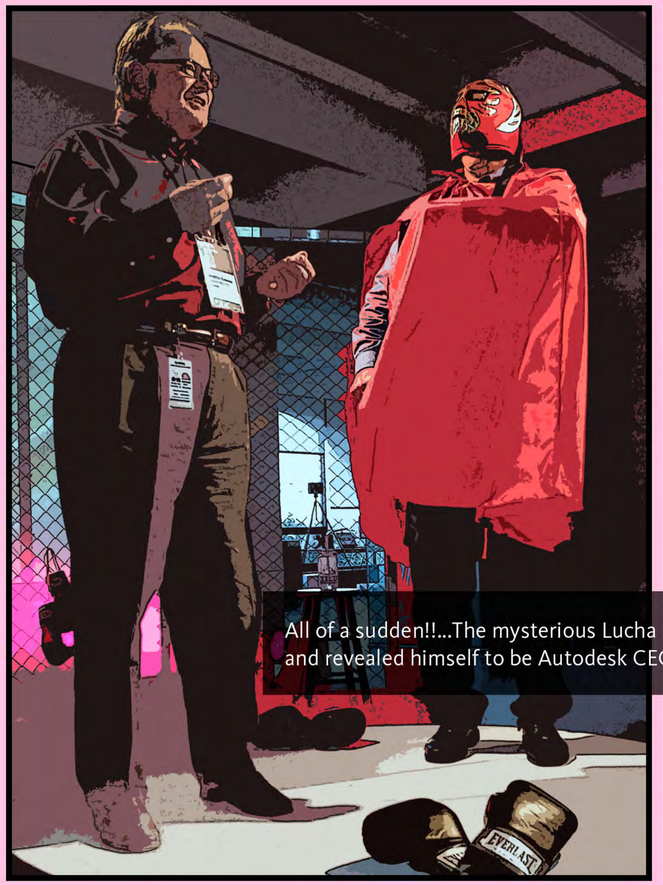

IDEAS Impresario Jonathan Knowles welcomed the attendee's to the IDEAS Cage Match, while Referree Tom Wujec stood by in the background.



...a Luche Libre wrestler was seen guarding Auotdesk's top secret location. At one point, Juan Enriquez had him in a headlock, but was not able to get through.

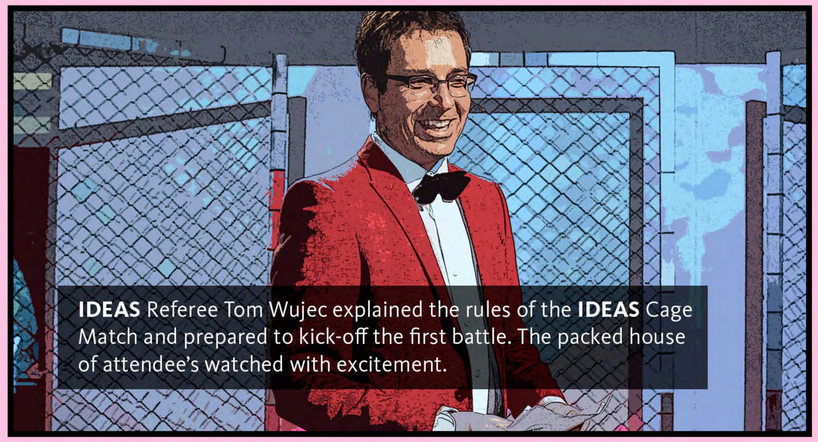
Jonathan promised to reveal who the masked man was, as Daisy Ginsberg looked on in anticipation.

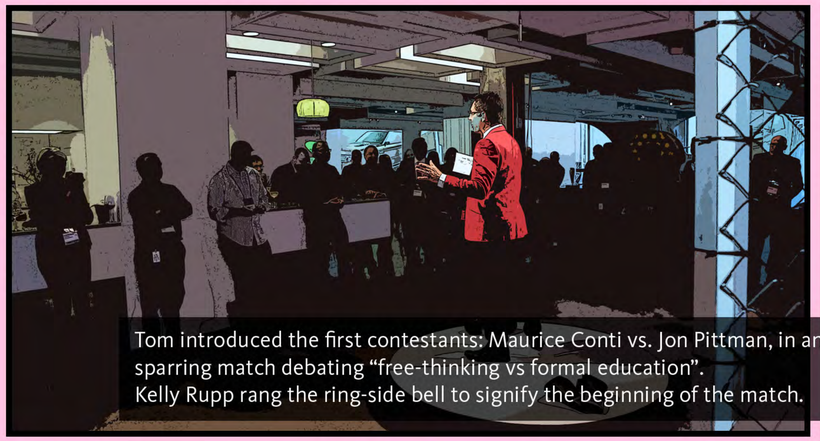




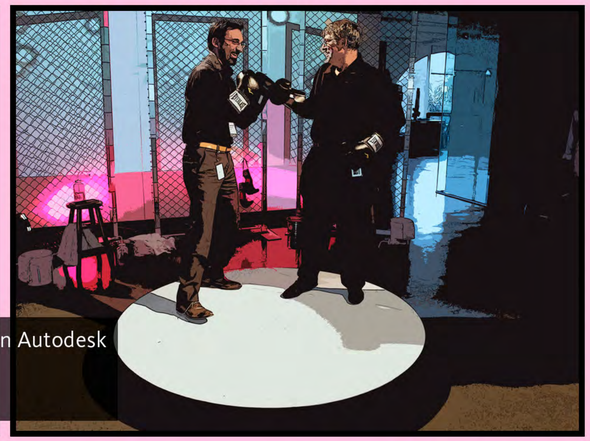
All of a sudden!!...The mysterious Lucha Libre appeared in the cage, and revealed himself to be Autodesk CEO Carl Bass.

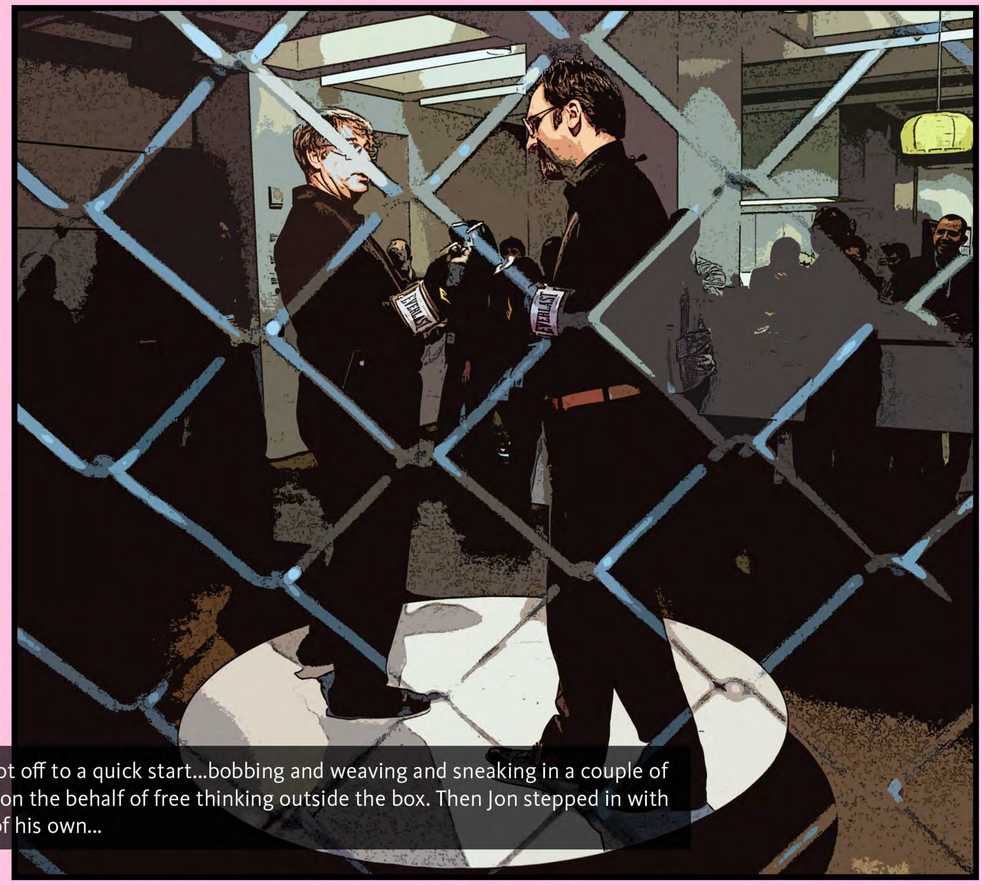
You would think he has better things to do, but it just shows how important IDEAS is.


IDEAS Referee Tom Wujec explained the rules of the **IDEAS** Cage Match and prepared to kick-off the first battle. The packed house of attendee's watched with excitement.



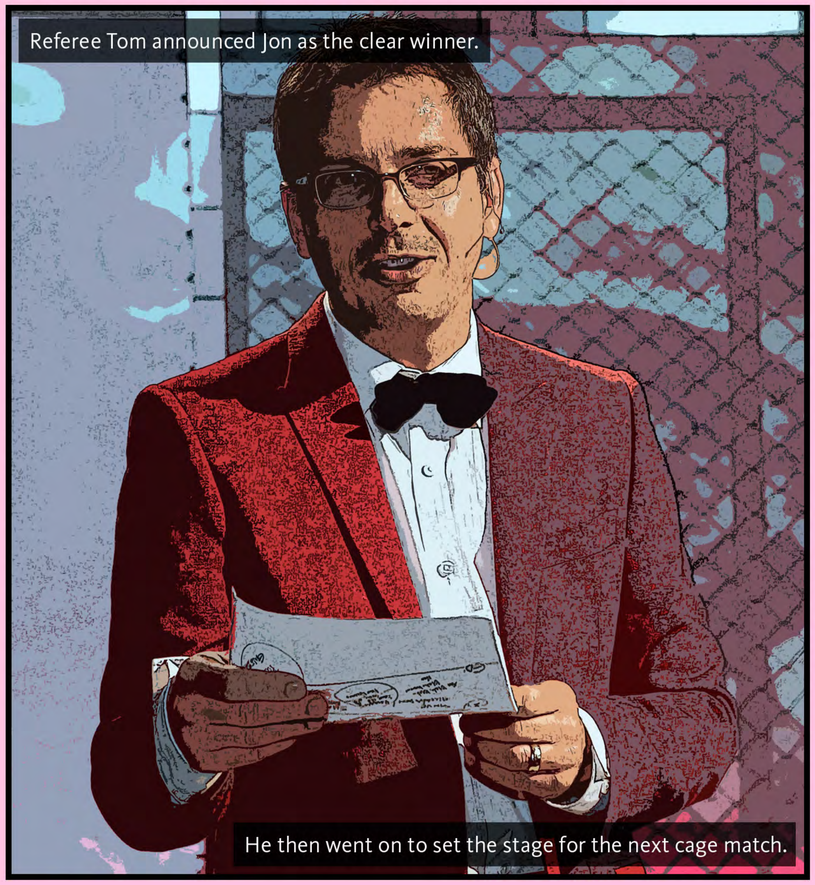
Tom introduced the first contestants: Maurice Conti vs. Jon Pittman, in an Autodesk sparring match debating “free-thinking vs formal education”.
Kelly Rupp rang the ring-side bell to signify the beginning of the match.





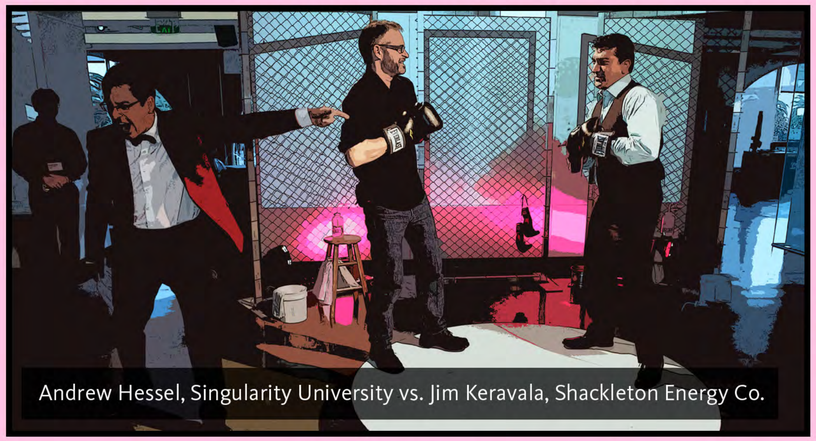
Maurice got off to a quick start...bobbing and weaving and sneaking in a couple of quick jabs on the behalf of free thinking outside the box. Then Jon stepped in with a rebutle of his own...

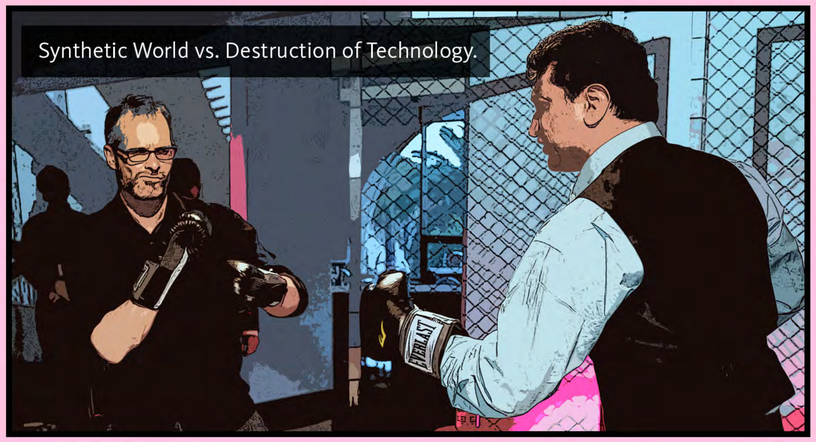
...and when he pulled out a concealed weapon, in the form of a text book on behalf of the formal education side, everybody knew it was all over. Autodesk’s Bill O’Connell stepped in before it got too ugly. He consoled Maurice’s tears...sort of.

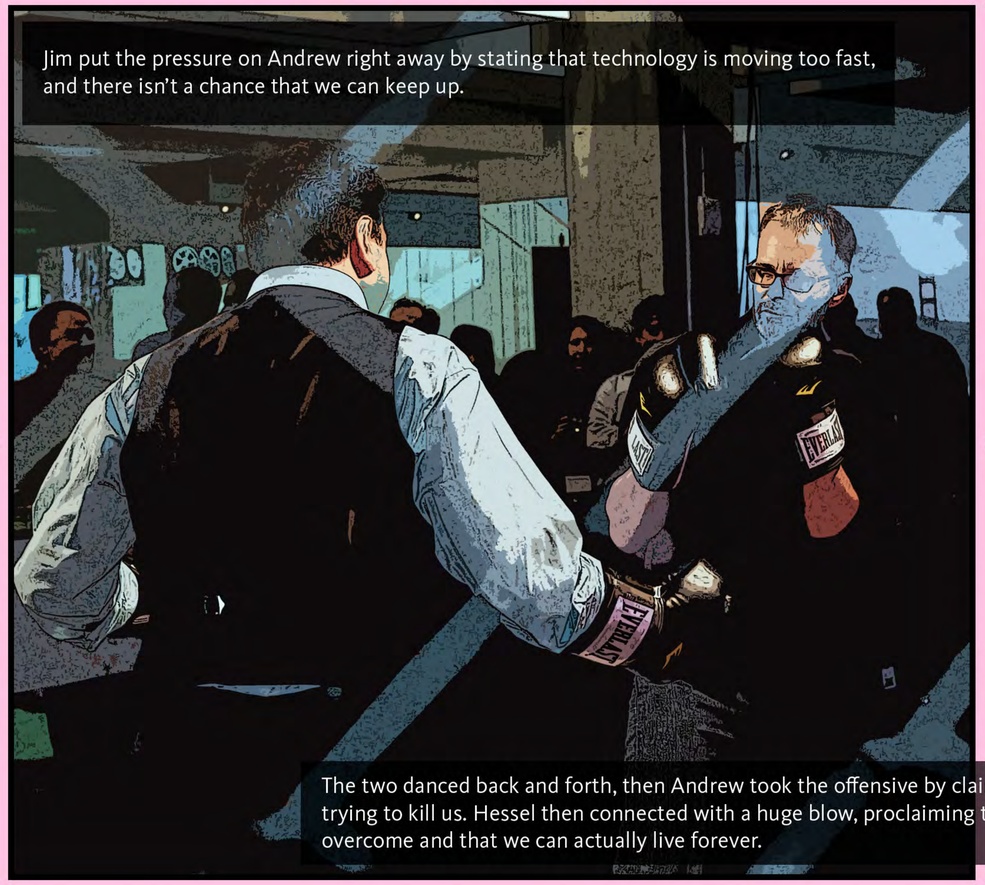


Referee Tom announced Jon as the clear winner.

He then went on to set the stage for the next cage match.

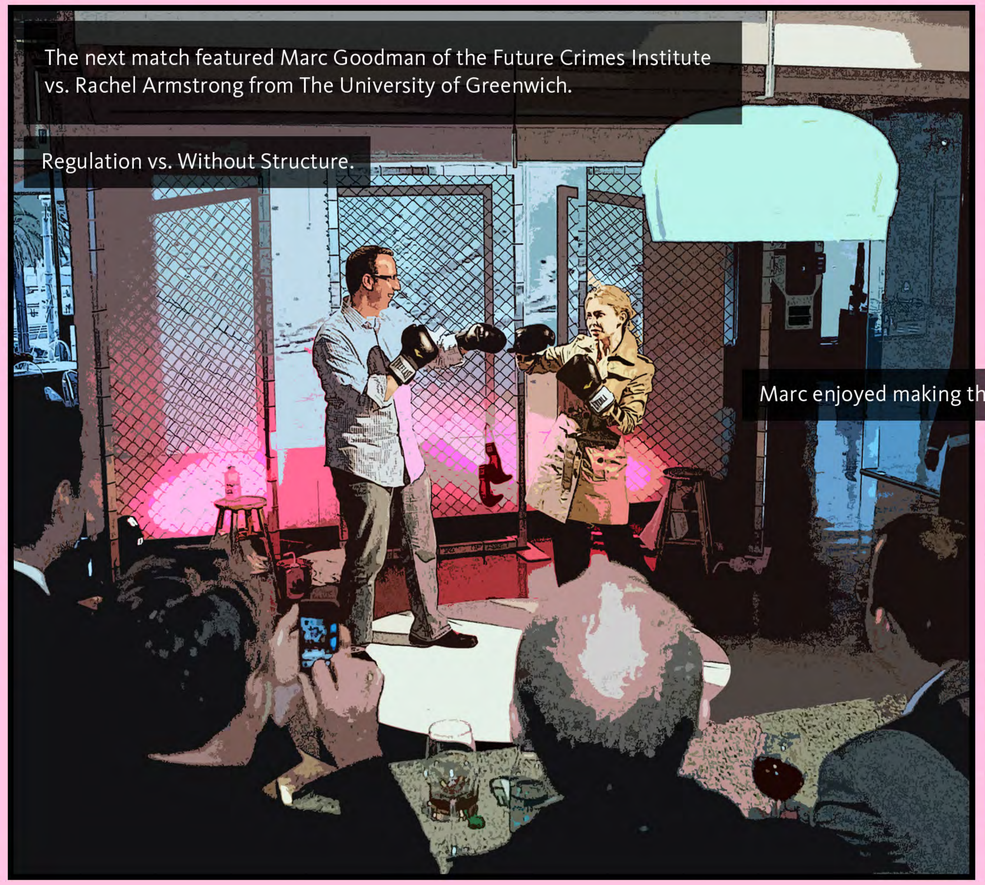

Andrew Hessel, Singularity University vs. Jim Keravala, Shackleton Energy Co.

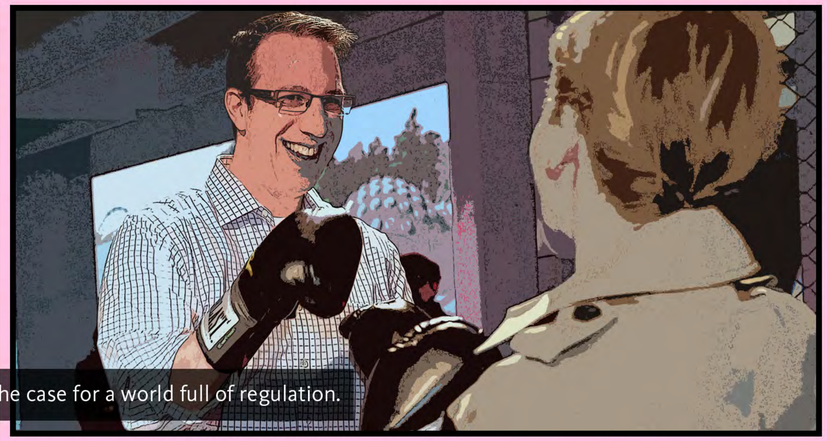

Synthetic World vs. Destruction of Technology.

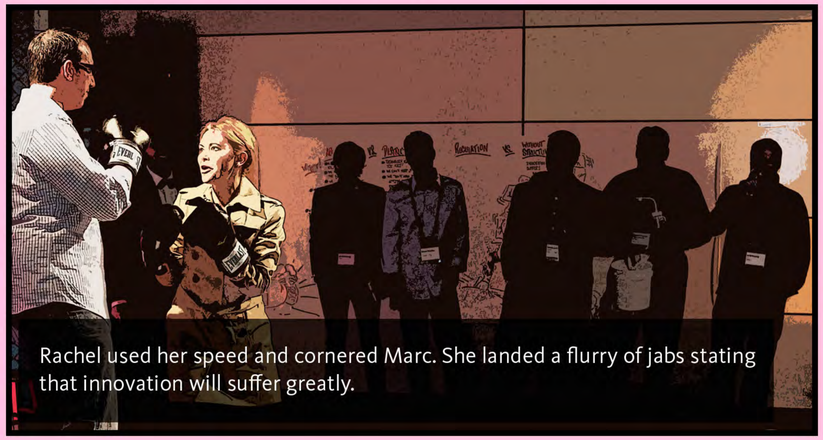

Jim put the pressure on Andrew right away by stating that technology is moving too fast, and there isn't a chance that we can keep up.
The two danced back and forth, then Andrew took the offensive by claiming that nature is actually trying to kill us. Hessel then connected with a huge blow, proclaiming that the synthetic world will overcome and that we can actually live forever.

Keravala was stunned. His cornerman had to quickly step in with the white towel.

The Ref. raised Andrew's glove as the outright winner.


The next match featured Marc Goodman of the Future Crimes Institute vs. Rachel Armstrong from The University of Greenwich.
Regulation vs. Without Structure.

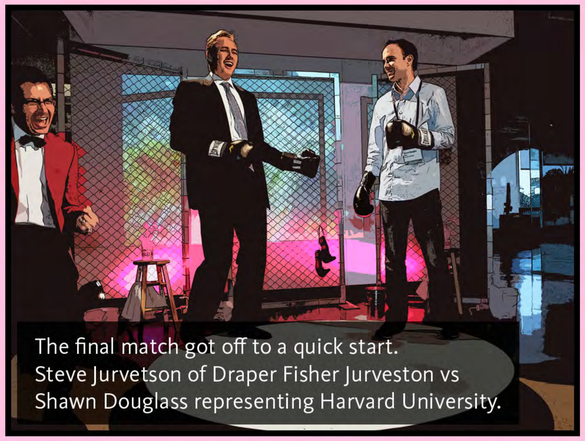

Marc enjoyed making the case for a world full of regulation.


Rachel used her speed and cornered Marc. She landed a flurry of jabs stating that innovation will suffer greatly.

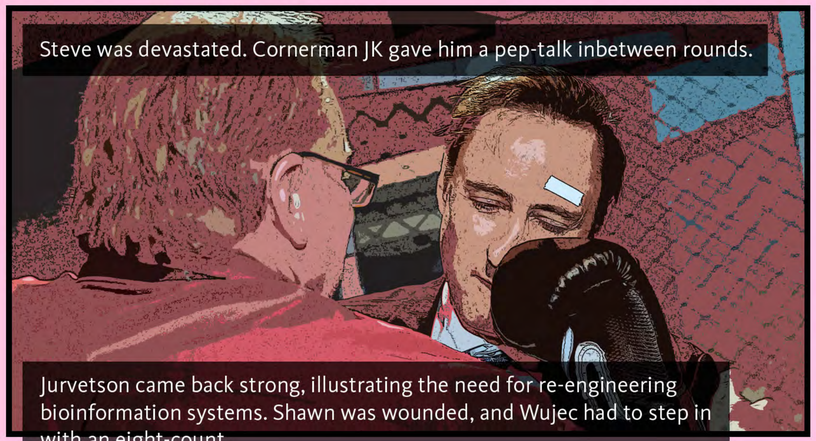
Rachel screamed out that over regulation is an old paradigm.

Marc suggested that we can now crowd-source regulation.

Eventhough it was an extremely close match, the crowd chose Rachel in a very popular unanimous decision.


The final match got off to a quick start.
Steve Jurvetson of Draper Fisher Jurveston vs
Shawn Douglass representing Harvard University.

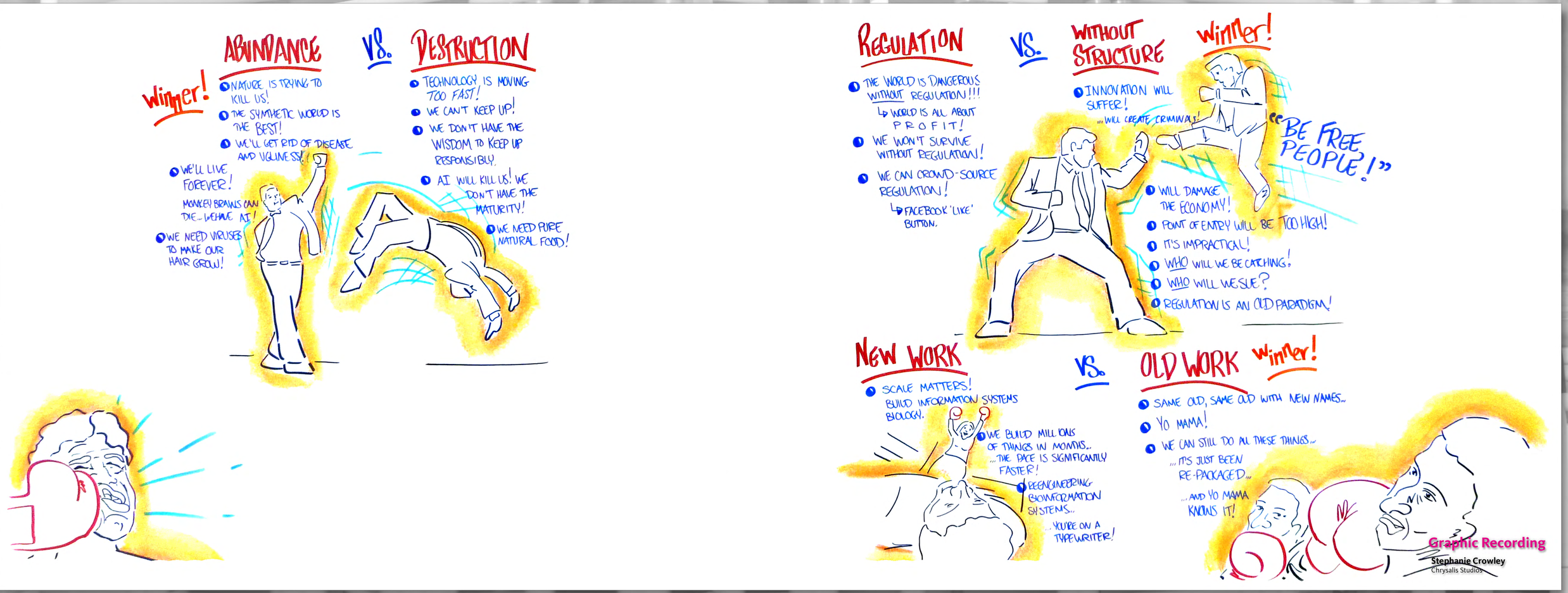
Old Work vs. New Work.
Shawn struck a quick low-blow by enforcing that things simply just need to be repackaged, while also bringing Steve's mom into the conversation.


Steve was devastated. Cornerman JK gave him a pep-talk inbetween rounds.
Jurvetson came back strong, illustrating the need for re-engineering bioinformation systems. Shawn was wounded, and Wujec had to step in with an eight-count.

The medic was called in to tend to Shawn.

Referee Tom gauged the crowds favor.

It was a close battle and a split decision, but in the end, the crowd favored Shawn Douglass in support of 'old work'.


ABUNDANCE
VS.
DESTRUCTION
Winner!
NATURE IS TRYING TO KILL US!
THE SYNTHETIC WORLD IS THE BEST!
WE'LL GET RID OF DISEASE AND UGLINESS!
WE'LL LIVE FOREVER!
MONKEY BRAINS CAN DIE... WE HAVE AI!
WE NEED VIRUSES TO MAKE OUR HAIR GROW!
TECHNOLOGY IS MOVING TOO FAST!
WE CAN'T KEEP UP!
WE DON'T HAVE THE WISDOM TO KEEP UP RESPONSIBLY.
AI WILL KILL US! WE DON'T HAVE THE MATURITY!
WE NEED PURE NATURAL FOOD!
REGULATION
VS.
WITHOUT STRUCTURE
Winner!
THE WORLD IS DANGEROUS WITHOUT REGULATION!!!
WORLD IS ALL ABOUT PROFIT!
WE WON'T SURVIVE WITHOUT REGULATION!
WE CAN CROWD-SOURCE REGULATION!
FACEBOOK 'LIKE' BUTTON.
INNOVATION WILL SUFFER!
...WILL CREATE CRIMINALS!
"BE FREE PEOPLE!"
WILL DAMAGE THE ECONOMY!
POINT OF ENTRY WILL BE TOO HIGH!
IT'S IMPRACTICAL!
WHO WILL WE BE CATCHING!
WHO WILL WE SUE?
REGULATION IS AN OLD PARADIGM!
NEW WORK
VS.
OLD WORK
Winner!
SCALE MATTERS!
BUILD INFORMATION SYSTEMS BIOLOGY.
WE BUILD MILLIONS OF THINGS IN MONTHS...
...THE PACE IS SIGNIFICANTLY FASTER!
REENGINEERING BIOINFORMATION SYSTEMS...
...YOU'RE ON A TYPEWRITER!
SAME OLD, SAME OLD WITH NEW NAMES...
YO MAMA!
WE CAN STILL DO ALL THESE THINGS...
...IT'S JUST BEEN RE-PACKAGED...
...AND YO MAMA KNOWS IT!
Graphic Recording
Stephanie Crowley
Chrysalis Studios

IDEAS THE INNOVATION + DESIGN SERIES

Dinner

Wednesday, March 28th, 2012

IDEAS

IDEAS THE INNOVATION + DESIGN SERIES

Discussion + Group Work

Thursday, March 29th, 2012

I Wish to Know...

What are the emerging technologies and needs of the synthetic biology community?

What will be the first application of synthetic biology to wake up the world?

How can software tools inform the design of experiments in self-assembly?
Can self-assembly experiments solve computational problems?

What design tools for modeling, analysis, simulation, and visualization will accelerate life sciences?
Where is biology computable?

How will existing design strategies, such as obsolescence, be modified for a biotech future?
Can synthetic biology be truly sustainable?

Does E. coli have a Buddha nature?

What are the best ways to simultaneously design at vastly different scales-from the scale of DNA, to the scale of buildings, to the scale of Earth?

What will be the first domains of synthetic biology where we will have sufficient understanding to build predictive computational models and simulations?

How can we design, build, and test molecular logic and I/O for immune and nervous systems?

How can we make it easier for students to learn to use sophisticated design software?

Can design software aid in teaching nonintuitive concepts, such as how the world behaves at length scales where viscous forces dominate inertial forces?

Should I be scared?

Why?

How do we better categorize better quantity of scale?
Has the power of microscale technologies been underestimated?

How can we scale very small things up to the human level? How can we design and engineer with emergence?

Can we redesign life?

What is the future of synthetic biology?
How can we all work together to achieve a most excellent future?

IDEAS

Which of the emerging technologies is projected to create the largest cultural shift, from both a business perspective and a social perspective?

How will the emergence of new rapid manufacturing technologies that allow broad access to bespoke goods and services affect future business models and where innovation takes place?

Top Secret.

How best integrate machine learning algorithms and cloud computing to evaluate biological functional space, and what are the killer-apps that will drive this industrial transformation?

What are the shared and contrasting design principles and approaches for nano and macroscale? What are the tools needed to do or "program" great design at the nanoscale?

Is biological actually complicated or is it just really tiny and invisible?

What nanoscale artifacts will my 4 year old daughters be making at school in 10 years time?
How will the nanoscale change the macroscale of the built environment?

How do we accelerate development and adoption of these technologies and bring them to our lives?

How can nanoscale technologies drive human innovation and solve our global grand challenges?

How eill organized criminals, terrorists, and emerging non-state actors exploit these new forms of innovation for ill?

What design paradigms will be used to create objects, structures, and entities with the emerging technologies of programmable matter and synthetic biology?

How are systems of software trying to incorporate properties of material programmability and self-assembly? What type of physical translations and large-scale scenarios can be explored through programmable matter and accompanying software tools?

We have built our world mostly from macro manufacturing processes. What are the likely pathways and tools for manufacturing up from the nano and moleculare domains, and what possibilities will they bring for the new extraordinary materials that we could make?

Terminology: Would a virus by any other name scare us less? What do effective safeguards look like for bio-nano technologies?

What enabling factors are necessary to safely intoduce biotech R&D to audiences beyond traditional professional boundaries? Which of those factors are inadequate or missing from the current landscape, and how do we remedy the situation?

What will be the breakout application of engineered biology?

What data about yourself are you missing?

How will nanoscale technologies and designing with biological materials and methods change the way we imagine, design, and create a better world?

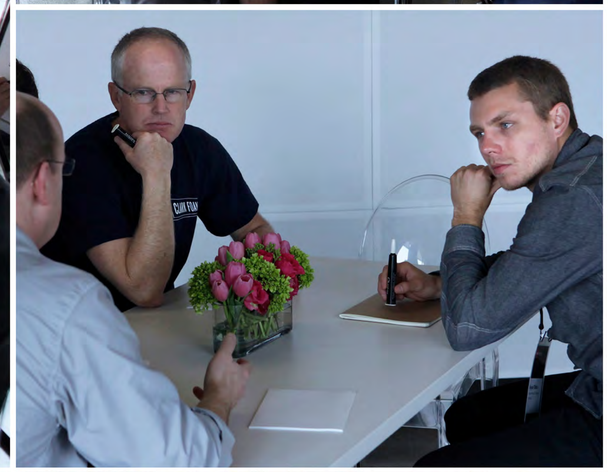
IDEAS

Jonathan Knowles, Autodesk, Inc.
Jonathan Knowles is a senior advisor to the CEO and CTO at Autodesk, providing thought leadership and insight on the intersection of emerging technology and social trends, the impact of discontinuous innovation, and beyond-the-horizon technologies. Prior to joining Autodesk, he held senior strategy, marketing, and product management positions at Adobe and Apple. He is regularly invited to deliver advisory briefings to Fortune Global 500 senior executives, government leaders, and tier-one academics around the world concerning the future of technoogy and its societal implications.

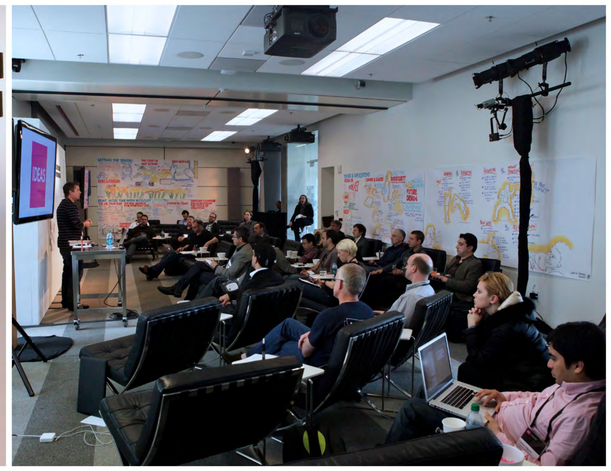
Jon Pittman, Autodesk, Inc.
Jon Pittman is vice president of corporate strategy for Autodesk, where he is responsible for enhancing Autodesk's business with strategic programs to drive profitable growth. He works closely with the Autodesk Worldwide Education team to ensure that Autodesk is supporting educators in preparing the next generation of design professionals. Jon is also presently a lecturer at the Haas School of Business at the University of California at Berkeley.

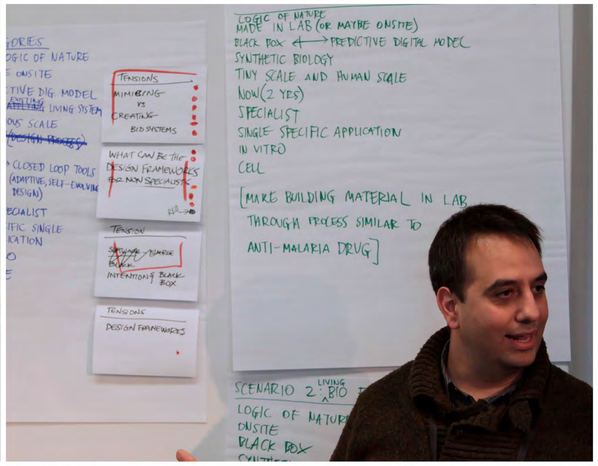
Tom Wujec, Autodesk, Inc.
Tom Wujec is a fellow at Autodesk, where he has worked on Autodesk SketchBook Pro, PortfolioWall, and Autodesk Maya, which won an Academy Award for its contribution to the film industry. In his position at Autodesk, he helps companies work in the emerging field of business visualization-the art of using images, sketches, and infographics to help teams solve complex problems as a group.

Participants summarizing
key questions



Participants discussing implications

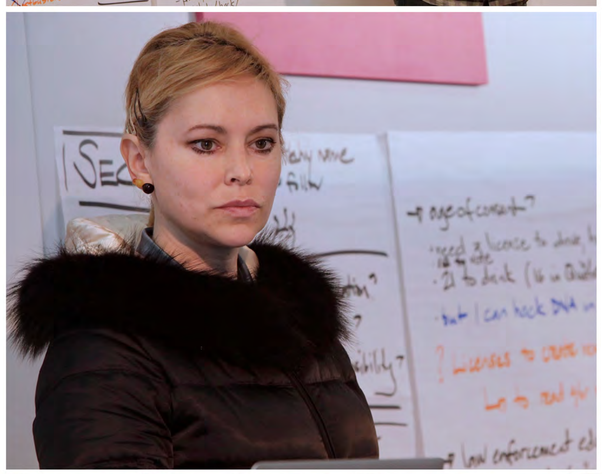


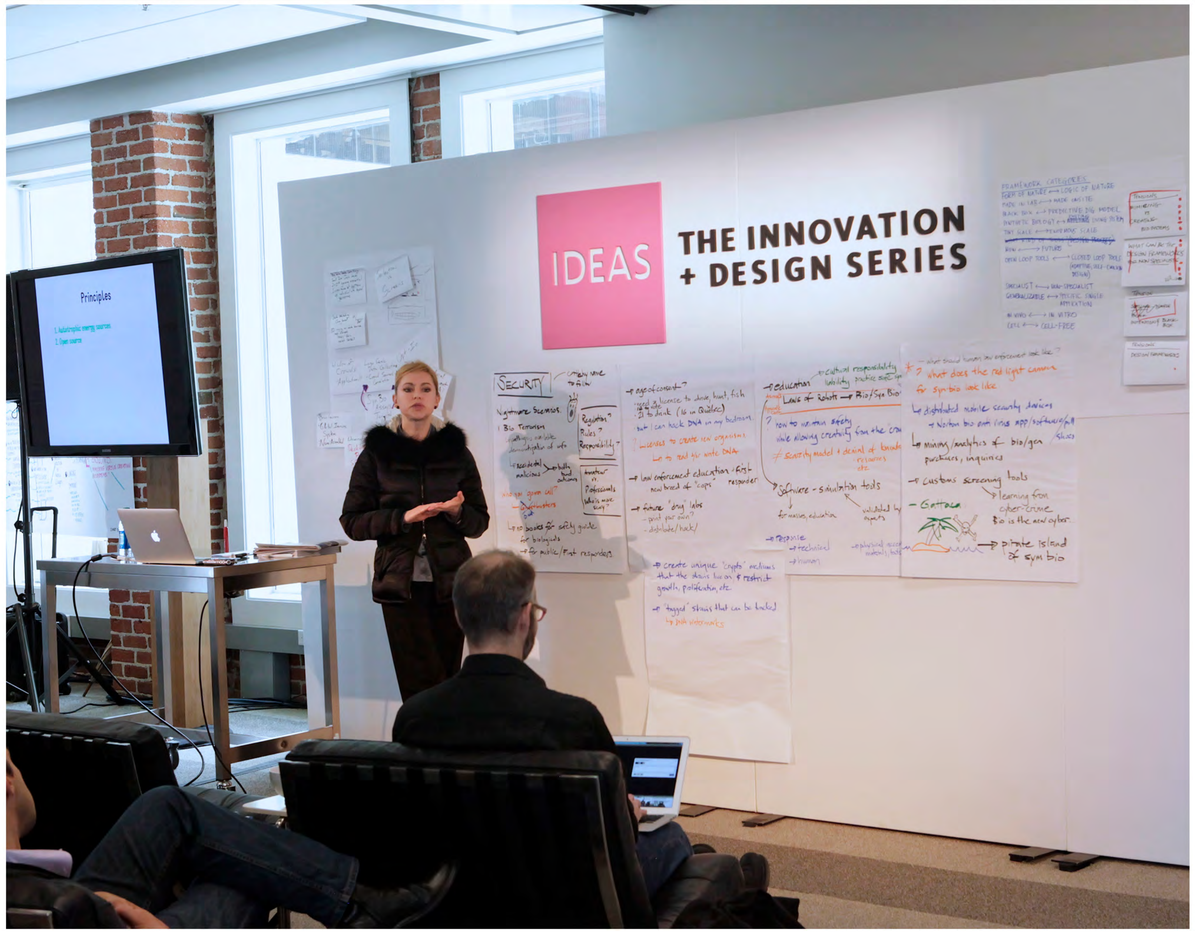


Participants presenting implications of ideas.

IDEAS
THE INNOVATION
+ DESIGN SERIE

IDEAS
IDEAS
THE INNOVATION
+ DESIGN SERIES
IDEAS



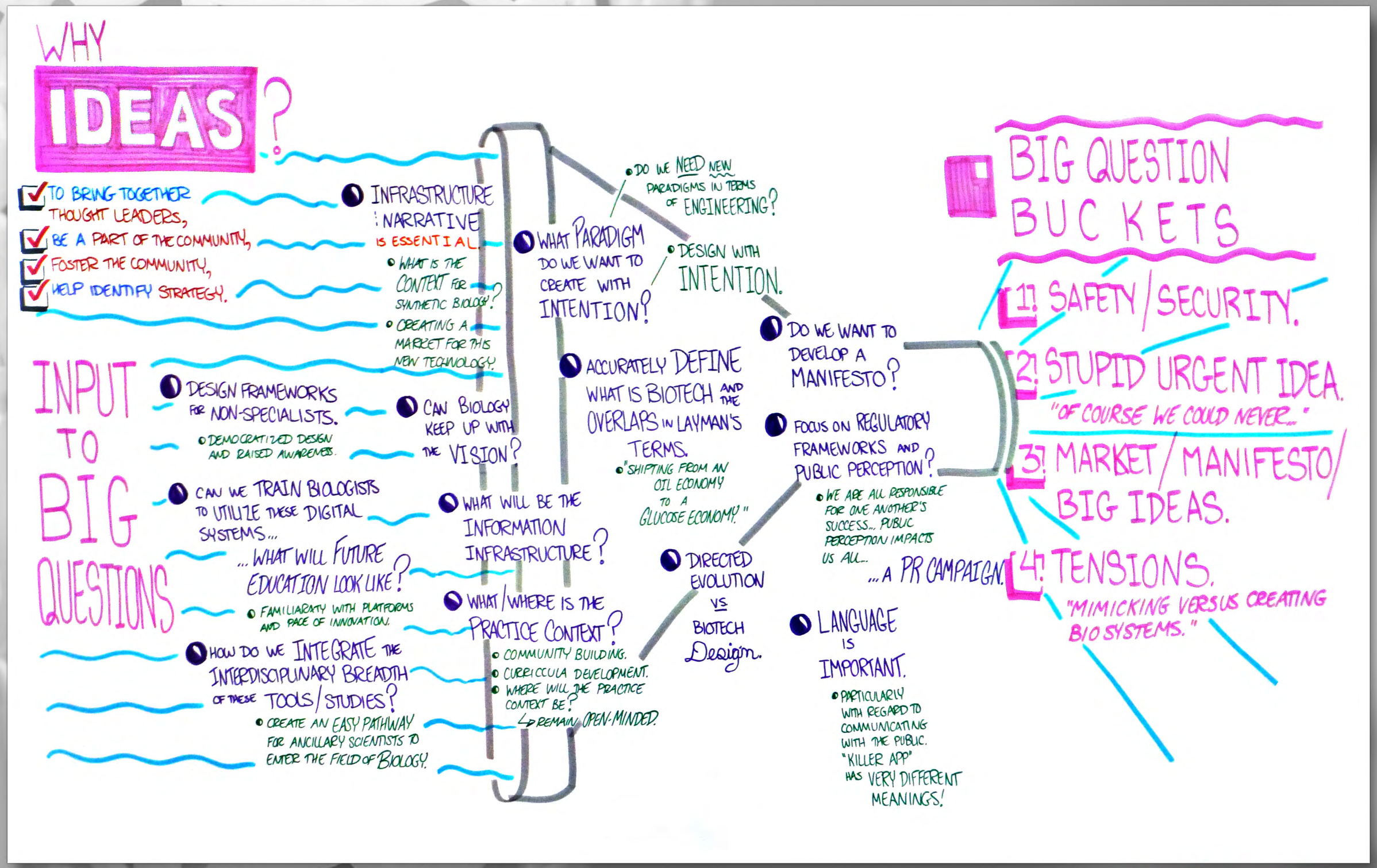

IDEAS
THE INNOVATION
+ DESIGN SERIES
Principles
SECURITY

Nanoscale, Humanscale and Beyond.

What is the relation to the human scale?

What are the factors that will help democratize design and the applications of the future?

What is the balance between physical and digital?



Graphic Recording

Stephanie Crowley
Chrysalis Studios

OUR actg...

a. BIG URGENT IDEA

- COMPUTATION IS FREE AND STORAGE IS NEGLIGABLE.

GENOMIC DATA IS INCOMPLETE.

- CROWD-SOURCE THE DATASET.
- opt-in.
- AND PUT THE DATA ONLINE TO AID IN FINDING CORRELATIONS.

NOTE: There will be PRIVACY ISSUES.

SUBSCRIBE

GLOBAL IMMUNE SYSTEM.

- CAN WE UTILIZE SYNBIO TOOLS TO CREATE A...

THE GLOBAL IMMUNE SYSTEM!

c. FRAMEWORKS

- USING BIODESIGN IN UNIQUE APPLICATIONS.
- DESIGNABLE BY BOTH SPECIALISTS OR NON-SPECIALISTS.
- OPEN- & -CLOSE LOOPS
- ...NOT JUST CELLS, BUT ENTIRE ORGANS.
- UTILIZE THE LOGIC OF NATURE, VS NATURE ITSELF.
- BLACK BOX VS PREDICTIVE MODEL.
- ...AND SOME ASPECTS COULD ALSO TAKE ON THE FORM OF NATURE. i.e. 'LEAVES' ON BUILDINGS.

...FRAMEWORKS THAT NATURALLY FALL INTO THE QUESTIONS WE ASK... WHO, WHAT, WHEN, WHY.

t. SECURITY

- PARALLELS TO CYBERCRIME.
- WHO YOU GONNA CALL?

DNA BUSTERS!

- NEED A GENERAL SAFETY GUIDE FOR THE PUBLIC AND FIRST RESPONDERS.
- AGE OF CONSENT IS NEEDED...

...A "LICENSE" TO CREATE NEW ORGANISMS?

...NET-NANNY FOR BIO.

- DESKTOP PUBLISHING FOR DRUGS.
- THERE NEEDS TO BE A EDUCATION/CULTURAL SHIFT OF BIO. (symmetric)
- WHAT IS THE HYPPOCRATIC OATH IN RELATION TO SYNTHETIC BIO?
- BETTER SIMULATIONS MEANS LESS DANGER... THE LESS WE HAVE TO DO IN THE REAL WORLD
- WHAT SHOULD HUMAN LAW ENFORCEMENT LOOK LIKE?

...AND WHAT DOES THE RED LIGHT DISTRICT OF SYNTHETIC BIO LOOK LIKE?

- HOW DO WE MINE ANALYTICS WITH REGARD TO PURCHASES?
- PROVIDE CUSTOMS TRAINING TOOLS.
- HOW WILL WE SCREEN DNA ON A REGULAR BASIS IN THE FUTURE?

g. A MANIFESTO

- INDUSTRIAL MODEL HAS CREATED ITS OWN OBSCELESENCE
- WHAT DOES A BIO ECONOMY REQUIRE?

PRINCIPLES

- ☑ SOLAR POWER.
- ☑ OPEN-SOURCE, DISTRIBUTED INFORMATION.
- ☑ SELF-CONTAINED PRODUCTION.
- ☑ THINK IN TERMS OF LIFE CYCLES
- ☑ BUILT-IN OBSCELESENCE.
- ☑ SYSTEM IS SELF-OPTIMIZING

BENEFITTING HUMANKIND... WE LIVE IN A BACTERIAL WORLD... NEEDS TO BENEFIT THE ECOLOGICAL WORLD

- ☑ DIRECT VALUE REPRESENTATION w/ COMMUNITIES
- ☑ TOOLS ACROSS CULTURES: ACCESSIBLE.
- ☑ TOOLS FOR DIFFERENT AUDIENCES
- ☑ BOTH ETHICAL; ECOLOGICALLY INCLUSIVE
- ☑ CONVERGENT: SYMBIOTIC
- ☑ COMMUNICATE WITH EXISTING PLATFORMS
- ☑ EMBRACE SOLUTIONS FOR ECOSYSTEMS.
- ☑ INCLUSIVE DESIGNS

- A NEW SOCIAL SCIENCES PHILOSOPHY:

A PHILOSOPHY, PROCESS AND INFRASTRUCTURES FOR CHANGE

Graphic Recording

Stephanie Crowley

Chrysalis Studios

Participants

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J. Christopher Anderson, UC Berkeley
Rachel Armstrong, The University of Greenwich
Carl Bass, Autodesk, Inc.
David Benjamin, The Living
Jason Bobe, PersonalGenomes.org
Yizhi Patrick Cai, Johns Hopkins University
George Church, Harvard Medical School
Maurice Conti, Autodesk, Inc.
Shawn Douglas, Harvard University
Drew Endy, Stanford University & BioBricks Foundation
Juan Enriquez, Excel Venture Management
Michel Fero, TeselaGen Bio
Eri Gentry, Scanadu & BioCurious
Daisy Ginsberg, Synthetic Aesthetics
Marc Goodman, Future Crimes Institute
Claes Gustafsson, DNA2.0
Jim Hasselhoff, University of Cambridge
Andrew Hessel, Singularity University
Steve Jurvetson, Draper Fisher Jurvetson
Jim Karkanias, Microsoft
Jim Keravala, Shackleton Energy Company
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Matthew Nurse, Nike, Inc.
Carlos Olguin, Autodesk, Inc.
Rachel Pike, Draper Fisher Jurvetson
Jon H. Pittman, Autodesk, Inc.
Babak Sanil, Lawrence Berkeley National Lab
Skylar Tibbits, S/JET & MIT
Duncan Wilson, Arup
Gary Wolf, Quantified Self
Tom Wujec, Autodesk, Inc.

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