USC Viterbi
School of Engineering

THE PROMISE AND CHALLENGES OF CONVERGENT RESEARCH

Yannis C. Yortsos
USC Viterbi School of Engineering

Informed by:
Dean of Engineering- 2005-present
NRC CERC Report Contributor- 2015-2017
NRC SBE Report Contributor- 2017
NAE Grand Challenges Scholars Program 2009- present
NAE Council- 2017-present
ASEE Diversity Initiative- 20015-present
NSF I-Corps Node Los Angeles PI- 2015-present

ERC Planning Grant Workshop
October 1 , 2019 Alexandria, VA

USC Viterbi
School of Engineering

WHY ENGINEERING

Enabling Discipline of Our Times

1. Exponentially Growing
2. Convergent

Human Nature does not Change Exponentially Fast!

TECHNOLOGY AND ENGINEERING

LEVERAGING *PHENOMENA** FOR *USEFUL* PURPOSES**

- **PHYSICAL** (e.g. Photoelectric Effect)
- **CHEMICAL** (e.g. Catalysis)
- **GEOLOGICAL** (e.g. Groundwater)
- **BIOLOGICAL** (e.g. Bioengineering)
- ***SOCIAL-BEHAVIORAL***

Increasing complexity

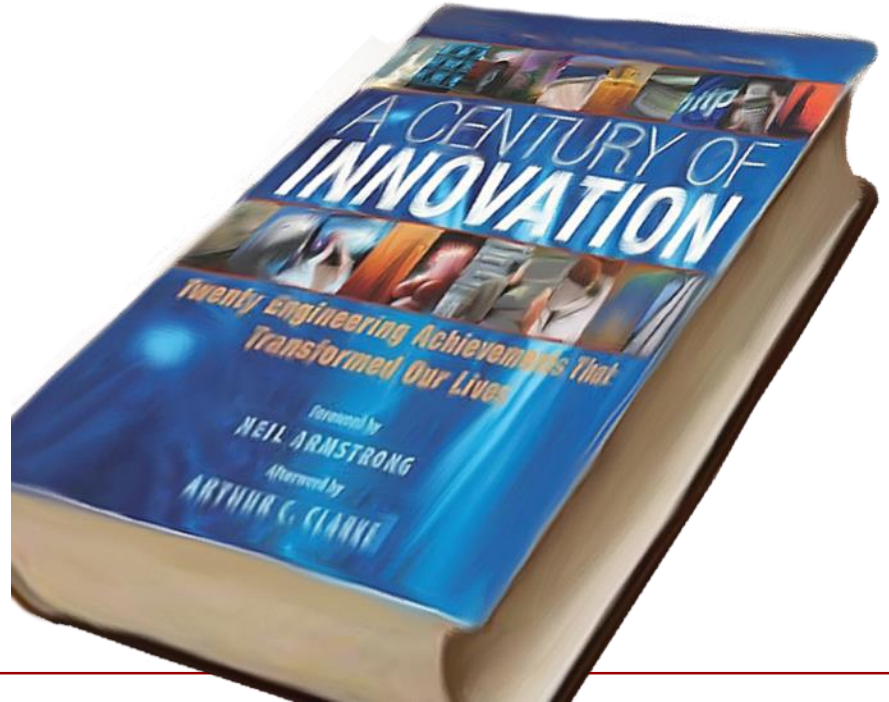
Paraphrased from Brian Arthur (2008)

**And systems, devices and tools- and combinations thereof*
Including the **discovering of new phenomena

USC Viterbi School of Engineering

A CENTURY OF INNOVATION, NAE

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronic
6. Radio and Television



7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. Petroleum and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials

Physical
Chemical
Biological

TECHNOLOGY AND ENGINEERING

LEVERAGING *PHENOMENA** FOR *USEFUL* PURPOSES**

- **PHYSICAL** (e.g. Photoelectric Effect)
- **CHEMICAL** (e.g. Catalysis)
- **GEOLOGICAL** (e.g. Groundwater)
- **BIOLOGICAL** (e.g. Bioengineering)
- ***SOCIAL-BEHAVIORAL***

Increasing complexity

Convergence

Paraphrased from Brian Arthur (2008)

**And systems, devices and tools- and combinations thereof*
Including the **discovering of new phenomena

USC Viterbi
School of Engineering

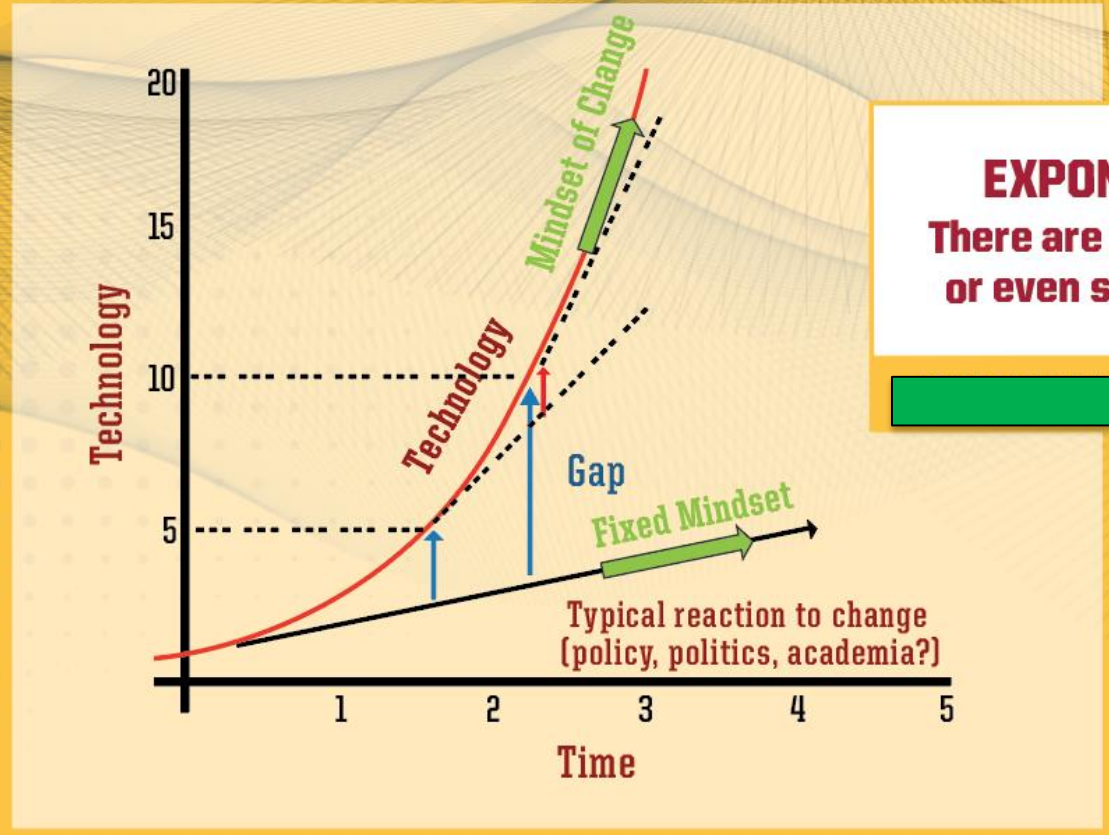
WHY CONVERGENCE?

Exponential Technology
*Era of Constant Accelerations**

**Friedman (2016)*

FAST GROWING TECHNOLOGY: ERA OF CONSTANT ACCELERATIONS (FRIEDMAN, 2016)

Materials, Energy, Knowledge: Only the latter has the property that the more it is consumed the more is created (not my remark)



EXPONENTIAL CHANGES

There are no longer steady states or even steady states in growth

Exponential, if the technology speed is proportional to it

$$\frac{\Delta A}{\Delta t} \approx \lambda A$$

Faster than exponential (*singularity*) if it is proportional to a higher power (n>1)

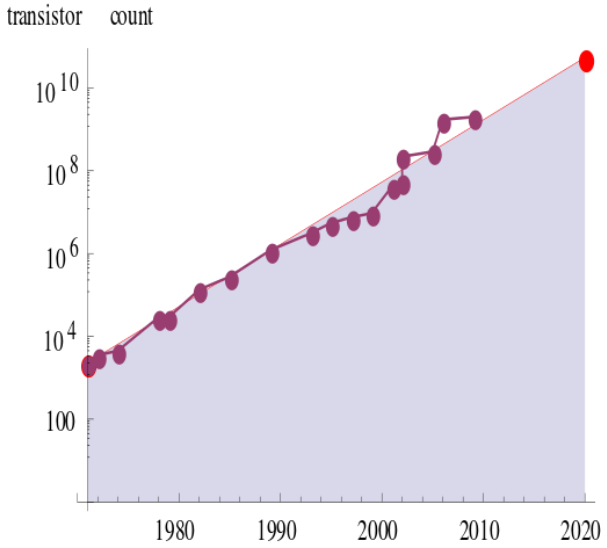
$$\frac{\Delta A}{\Delta t} \approx \lambda A^n$$

Chemical Kinetics for the Evolution of Technology?

LINEAR KINETICS: $A \rightarrow A$

$$\frac{\Delta A}{\Delta t} \approx \lambda A \quad \Rightarrow \quad A \approx A_0 \exp(\lambda t)$$

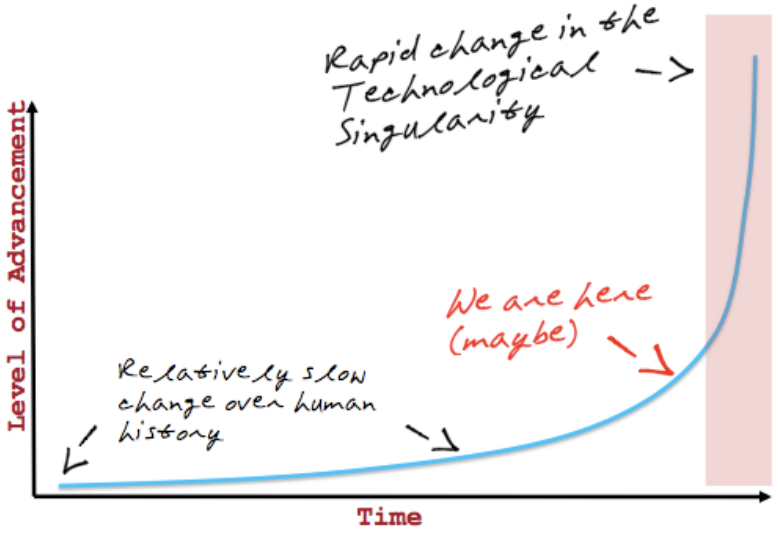
EXPONENTIAL INCREASE: ***MOORE'S LAW***!



QUADRATIC KINETICS: $A + A \rightarrow 2A$

$$\frac{\Delta A}{\Delta t} \approx \lambda A^2 \quad \Rightarrow \quad A \propto \frac{1}{(t^* - t)}$$

SINGULARITY AT t^*!
KURZWEIL'S CONJECTURE!



Convergence

ENGINEERING + X

Where X is anything!

E.g. Media, Medicine, Entertainment, Biology, Education,…

Three pathways:

E=>X (Engineering Empowers X)

X=>E (X empowers Engineering)

EUX (Engineering and X comingle)

E and X can be vectors

Convergence Paths

E=>X

ENGINEERING EMPOWERS X

E makes X "smarter"; more "efficient";
opens new dimensions, many disruptive.
The ubiquitous digitization of everything
(AI, ML, Analytics)
(Digital Technologies)

Convergence Paths

X=>E

X EMPOWERS E

X-mimetic

Biomimetic: Nature's optimization through evolution

Perhaps other

Convergence Paths

EUX

ENGINEERING AND X COMINGLE

E makes X "smarter", more "efficient"

X: new phenomena/provide context, which create new E.

A "double helix" of E and X

Nanotechnology, Biotechnology, Cognitive, etc.

(Exponential Technologies)

Likely the subject of a CERC

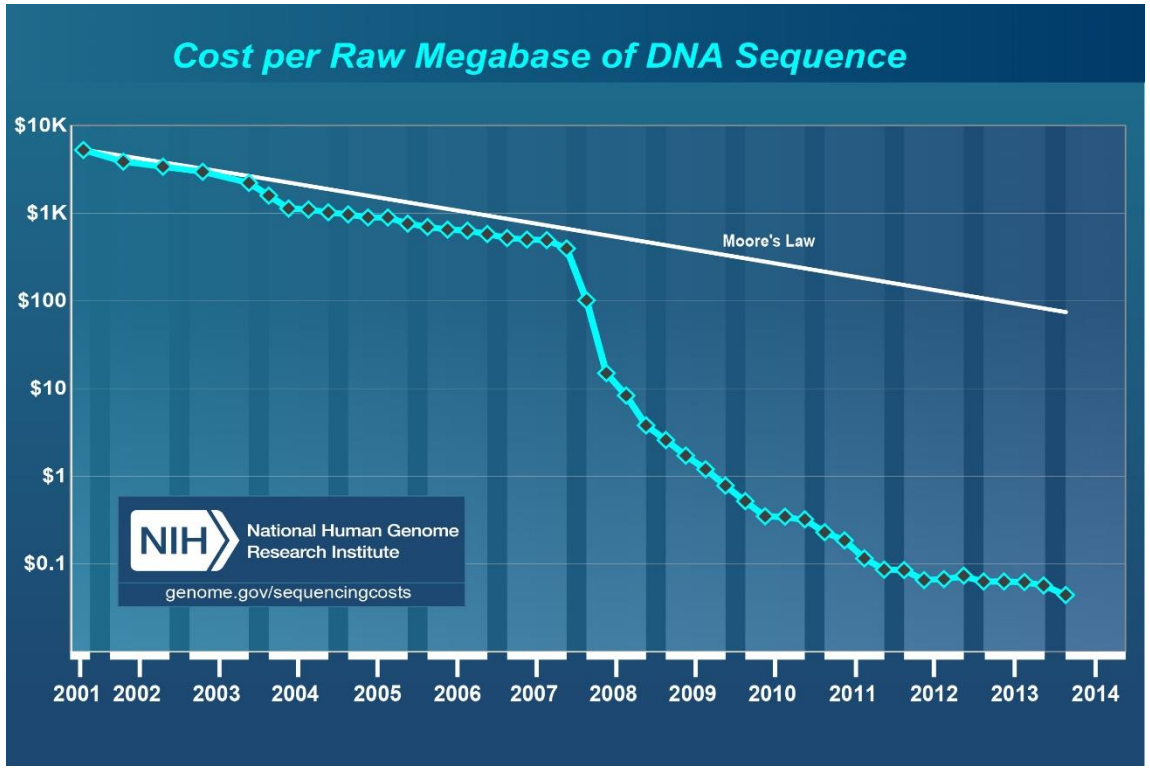
Example: The Evolution of Technology- Convergence

NON-LINEAR: $nA \rightarrow B$

$$\frac{\Delta B}{\Delta t} \approx \lambda A^n \Longrightarrow B \approx B_0 \exp(n\lambda t)$$

EXPONENTIAL INCREASE WITH A DIFFERENT EXPONENT

(A= INFORMATION TECHNOLOGY; B= BIOTECHNOLOGY?)



USC Viterbi
School of Engineering

WHY GRAND CHALLENGES?

Powerful, Fast Evolving, Convergent Technology Allows Us to Set Achievable Goals for all Humanity

Choosing Goals is an Ethical Question

(when the technology is increasingly powerful)

USC Viterbi School of Engineering

NAE GRAND CHALLENGES (2008)

Make solar energy economical

Provide energy from fusion

Develop carbon sequestration methods

Manage the nitrogen cycle

Provide access to clean water

Restore and improve urban infrastructure

Advance health informatics

Engineer better medicines

Reverse-engineer the brain

Prevent nuclear terror

Secure cyberspace

Enhance virtual reality

Advance personalized learning

Engineer the tools of scientific discovery

GRAND CHALLENGES FOR ENGINEERING

USC Viterbi School of Engineering

NAE Grand Challenges

SUSTAINABILITY

Make Solar Energy Economical, Provide Energy from Fusion, Develop Carbon Sequestration Methods, Manage the Nitrogen Cycle, Provide Access to Clean Water

SECURITY

Secure Cyberspace, Prevent Nuclear Terror, Restore and Improve Urban Infrastructure

HEALTH

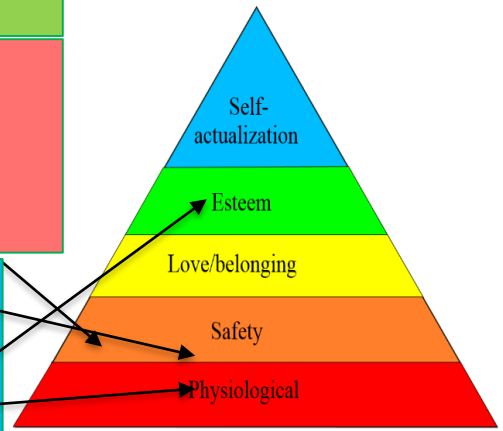
Engineer Better Medicines, Advance Health Informatics, Reverse Engineer the Brain

ENRICHING LIFE

Enhance Virtual Reality, Advance Personalized Learning, Engineer the Tools of Scientific Discovery

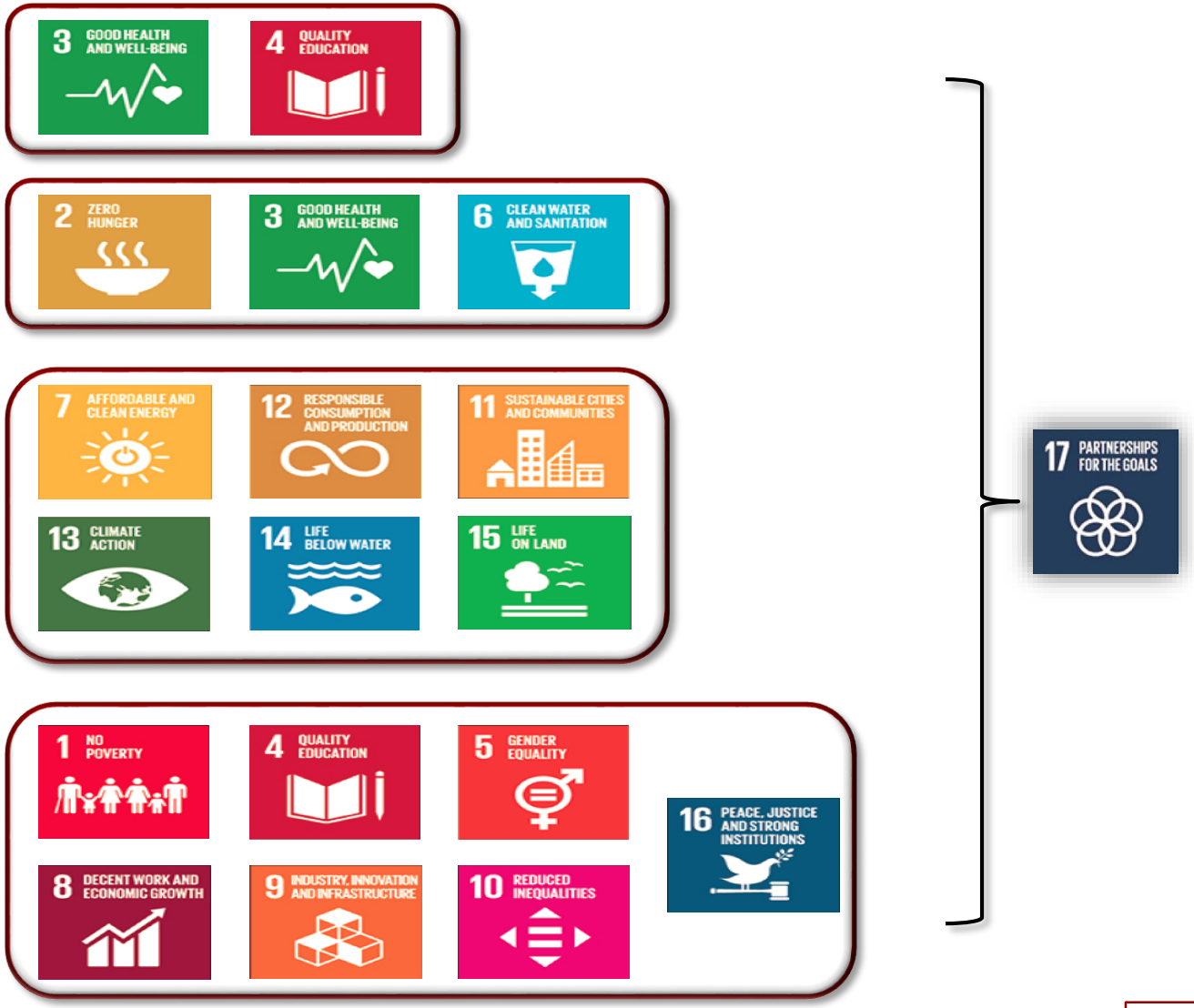
BEHAVIORAL AND SOCIETAL?

Social Phenomena (Through cyberphysical and data science)



Maslowe's Hierarchy

UN Sustainable Development Goals



USC Viterbi School of Engineering

The Grand Challenges for Social Work

Individual and family well-being

- Ensure healthy development for all youth
- Close the health gap
- Stop family violence
- Advance long and productive lives

Stronger social fabric

- Eradicate social isolation
- End homelessness
- Create social responses to a changing environment
- Harness technology for social good

Just society

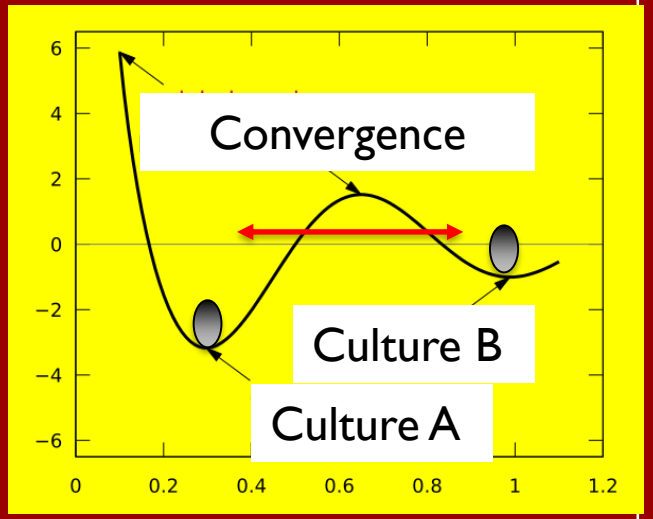
- Promote smart decarceration
- Build financial capability for all
- Reduce extreme economic inequality
- Achieve equal opportunity and justice

USC Viterbi
School of Engineering

CONVERGENCE CHALLENGES

"Culture wants to be enduring and prevailing"

from Antonio Damasio's "The strange world of things" (2018)



USC Viterbi School of Engineering

CONVERGENCE CHALLENGES: ALL PARTS OF ACADEMY

1. Talent: students, faculty, staff- and environment to flourish

PEOPLE

2. Value: Continuously adding value to curriculum, programs

PROGRAMS

3. Thought Leadership: Research and discovery

PAPERS

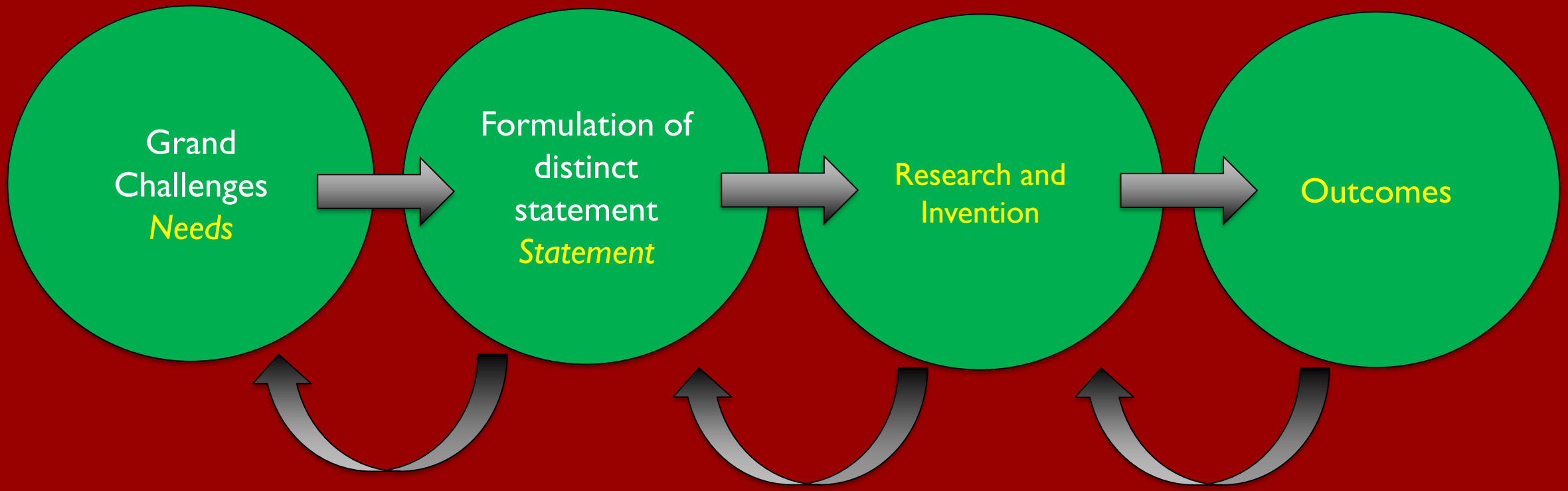
4. Impact: Impact on society and the economy (Innovation and Entrepreneurship)

PRACTICES-PATENTS

USC Viterbi School of Engineering

WHY INNOVATION?

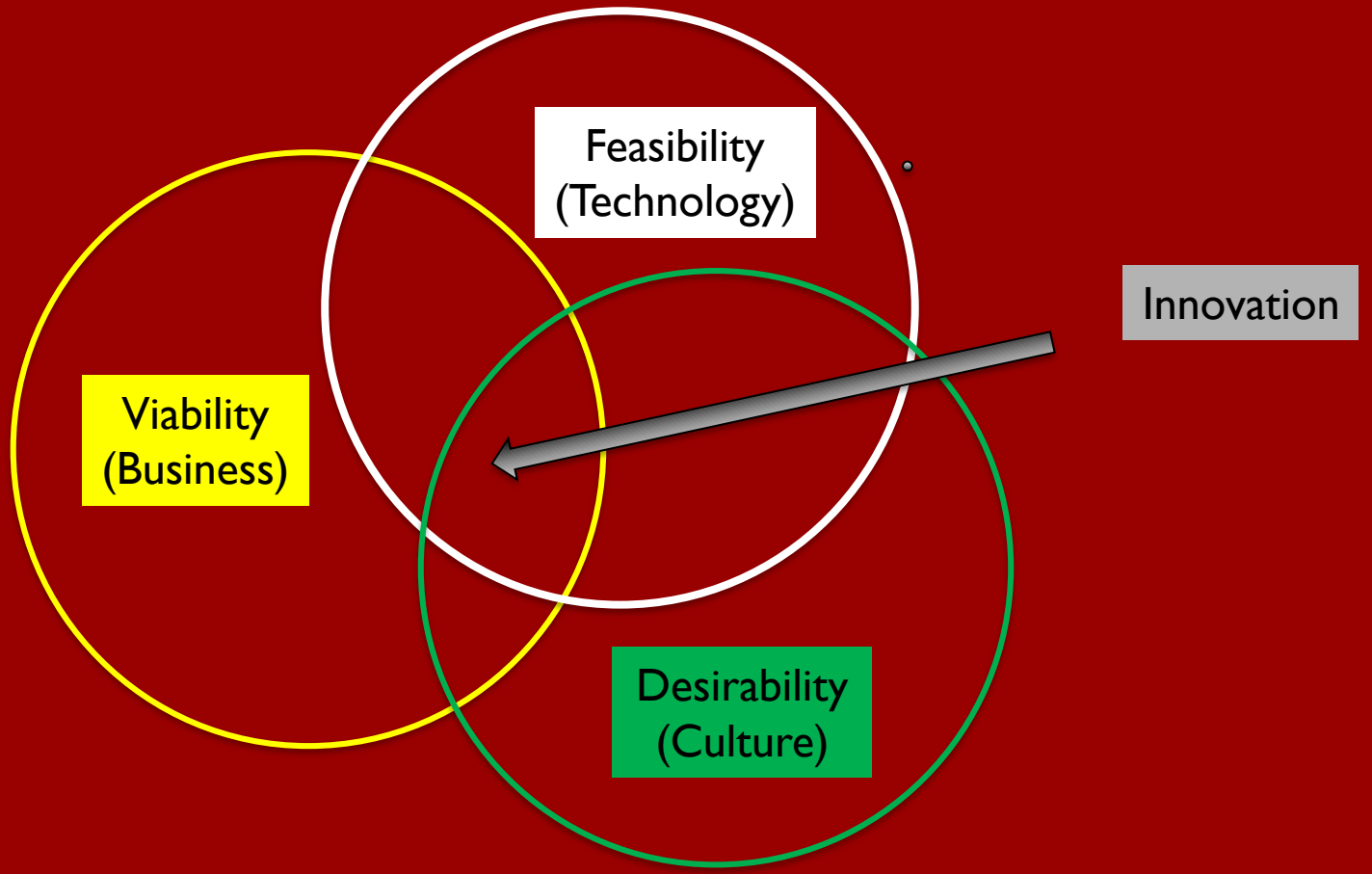
Addressing the solution of Grand Challenge-like problems requires innovation and innovation methodologies



Adapted from Stanford's Biodesign

USC Viterbi School of Engineering

After all Innovation is Intrinsically Convergence



USC Viterbi
School of Engineering

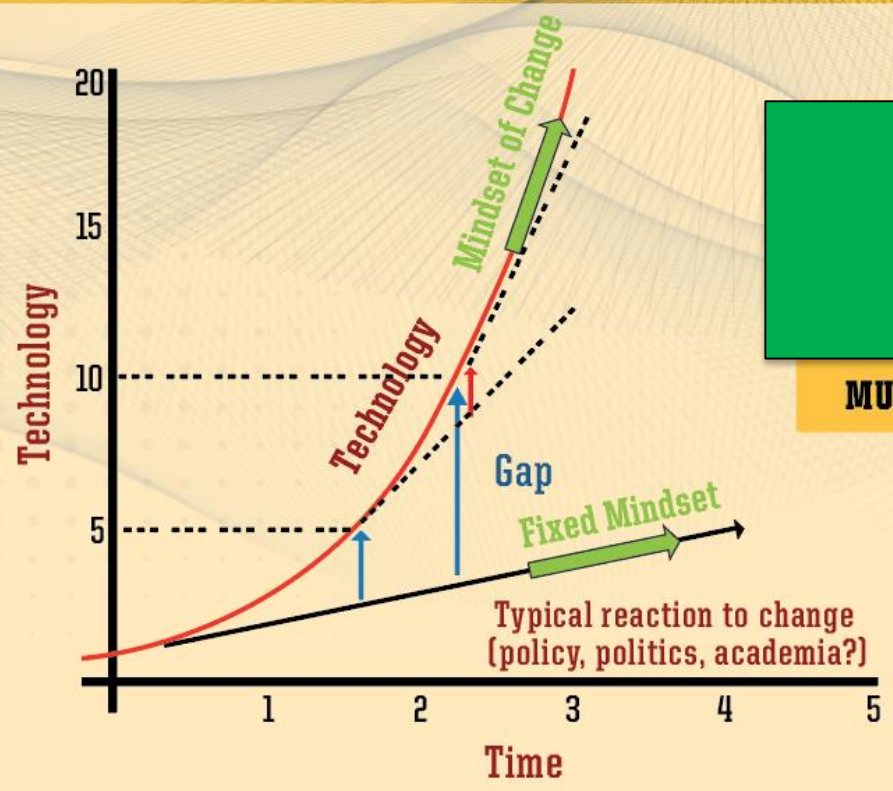
CHANGING THE CONVERSATION ABOUT ENGINEERING

IN OUR EXPONENTIALLY CHANGING WORLD

What we do: Convergence
Who we are: Attributes
What we look like: Diversity, Equity, Inclusion

EXPONENTIAL TECHNOLOGY BRINGS DISRUPTION REQUIRES AGILITY AND ADAPTABILITY – AND *NEW MINDSETS*

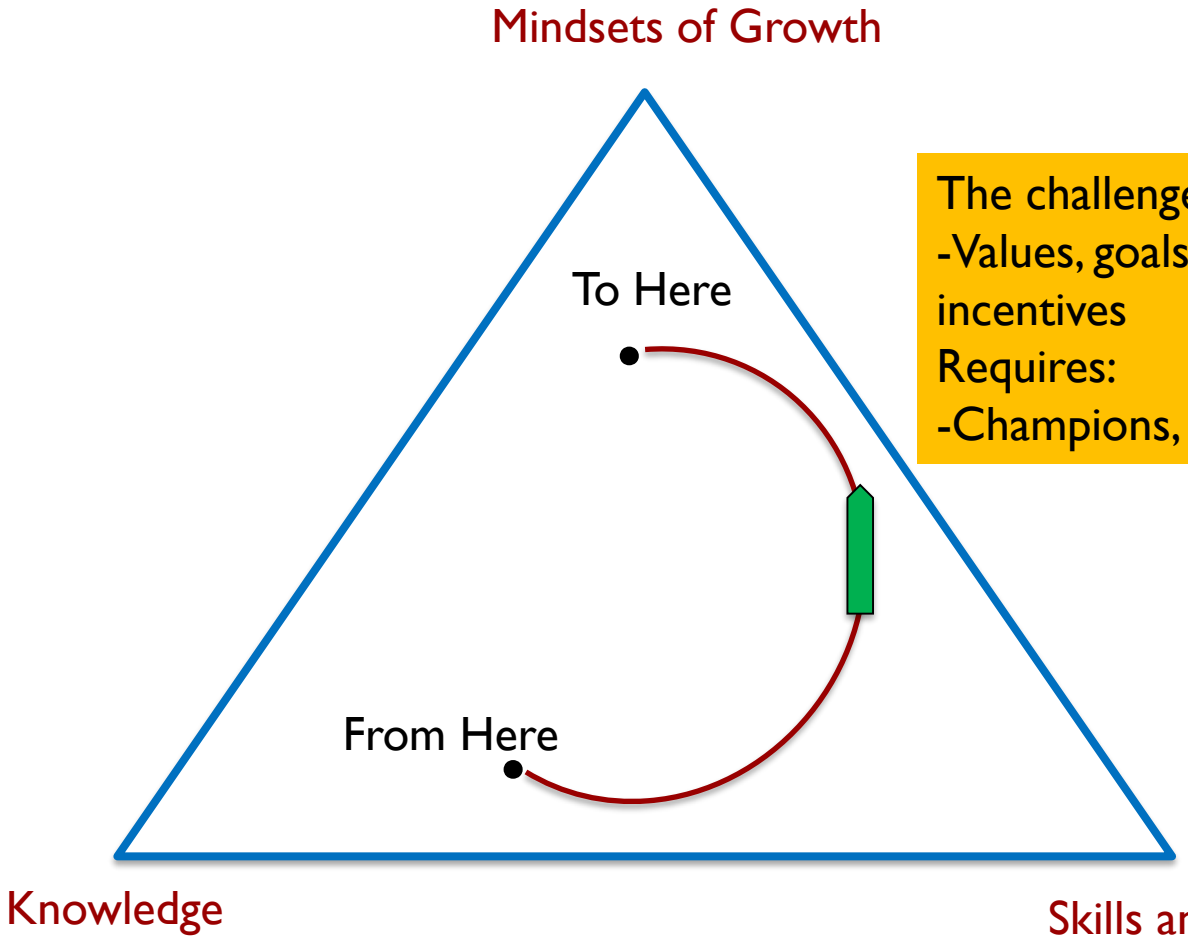
THE EXPONENTIAL PACE OF TECHNOLOGY BRINGS CONSTANT DISRUPTION. THIS REQUIRES AGILITY AND ADAPTABILITY - AND *NEW MINDSETS*



Keep closing the gap by
"*Hugging the Exponential*"!

MUST REINVENT OURSELVES EVERY YEAR

Adding Mindsets to Skills and Knowledge



The challenge to changing culture:
-Values, goals, behavior, attitude, rewards and incentives
Requires:
-Champions, leadership, mindsets of growth

From Ortiz et al.

USC Viterbi School of Engineering

EXPONENTIAL TECHNOLOGY BRINGS DISRUPTION REQUIRES AGILITY AND ADAPTABILITY – AND *NEW MINDSETS*

THE FIVE MINDSETS OF CHANGE TO THRIVE IN TODAY'S WORLD

1. **HUG THE EXPONENTIAL**
   Superb Technical Skills and Knowledge to Lead the Exponentially Changing Technology
2. **ENGINEERING +: CHANGE THE CONVERSATION ABOUT ENGINEERING**
   Engineering + X where X is anything (particularly, human-centric)
   Who we are, what we do and what we look like.
3. **INNOVATION IN THE BROADEST SENSE**
   Innovation and Entrepreneurship, to help create the new markets, the new jobs and to design the new self.
4. **THE CULTURAL MIND**
   Cultural Awareness (with culture broadly interpreted), to help thrive in today's fast changing world.
5. **HEROIC ENGINEERING**
   Awareness of the Impact of Engineering to Society (and the importance of technology ethics).

Competence

Character

Competence and Character

TRUST: FOUR CORES OF CREDIBILITY*

1. *Capabilities (talent, attitude, skills, knowledge, mindset)*
2. *Results (performance- past, current, anticipated)*
3. *Integrity (humility, courage, congruence)*
4. *Intent (motive, agenda, behavior)*

} Competence

} Character

Trustworthiness: an increasingly demanded attribute of engineers and technologists

*From Covey, "The Speed of Trust"

USC Viterbi School of Engineering

NAE GRAND CHALLENGES SCHOLARS PROGRAM

Conceived in 2009 (USC, Duke, Olin):
Adopted by > 80 schools nationwide: Now an NAE signature program

Consistent with WEF report on added skills for the 21st century:
Creativity, Leadership, Perseverance
Consistent with the *Engineer of 2020*

CULTIVATES FIVE MINDSETS
(and Trustworthiness)

1. Research/creative

2. Multidisciplinary

3. Entrepreneurial

4. Cultural

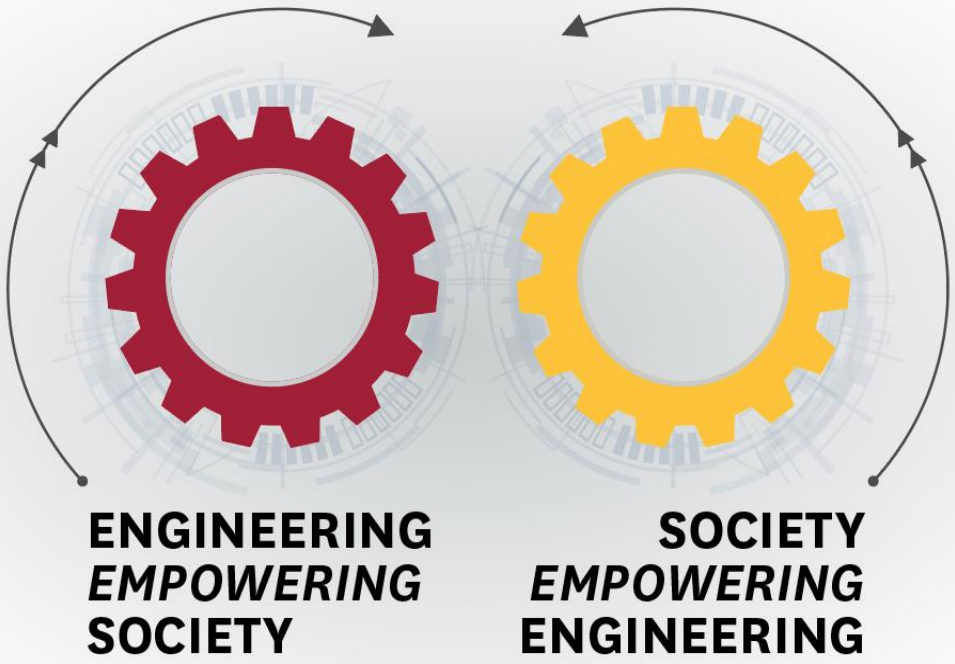
5. Society conscious

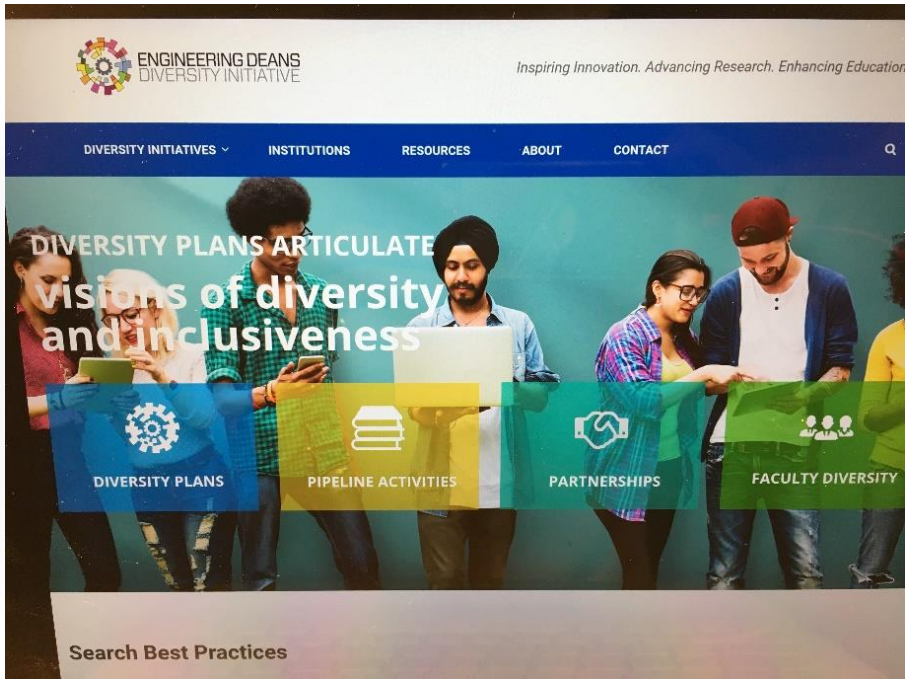
USC Viterbi
School of Engineering

USC NAE GRAND CHALLENGES SCHOLARS CLASS OF 2018
BRILLIANT AND DIVERSE

USC Viterbi School of Engineering

EMPOWERING CERCS (ENGINEERING, SOCIETY)





NATIONAL (ASEE) DIVERSITY AND INCLUSION INITIATIVE (NOW SIGNED BY 230+ SCHOOLS NATIONALLY)

"FROM STEAM ENGINE TO STEAM ENGINE*": THE NEED FOR DEI

WALPORT (GGCS, LONDON 2019)

USEFUL PURPOSES

USEFUL LINKS PHENOMENA WITH LEVERAGING

- ETHICAL-LEGAL
- UNINTENDED CONSEQUENCES
- COMPLEXITY
- POLICY- LEGISLATION- REGULATION

WHY ETHICS

LEVERAGING PHENOMENA
FOR *USEFUL PURPOSES (GOALS)*

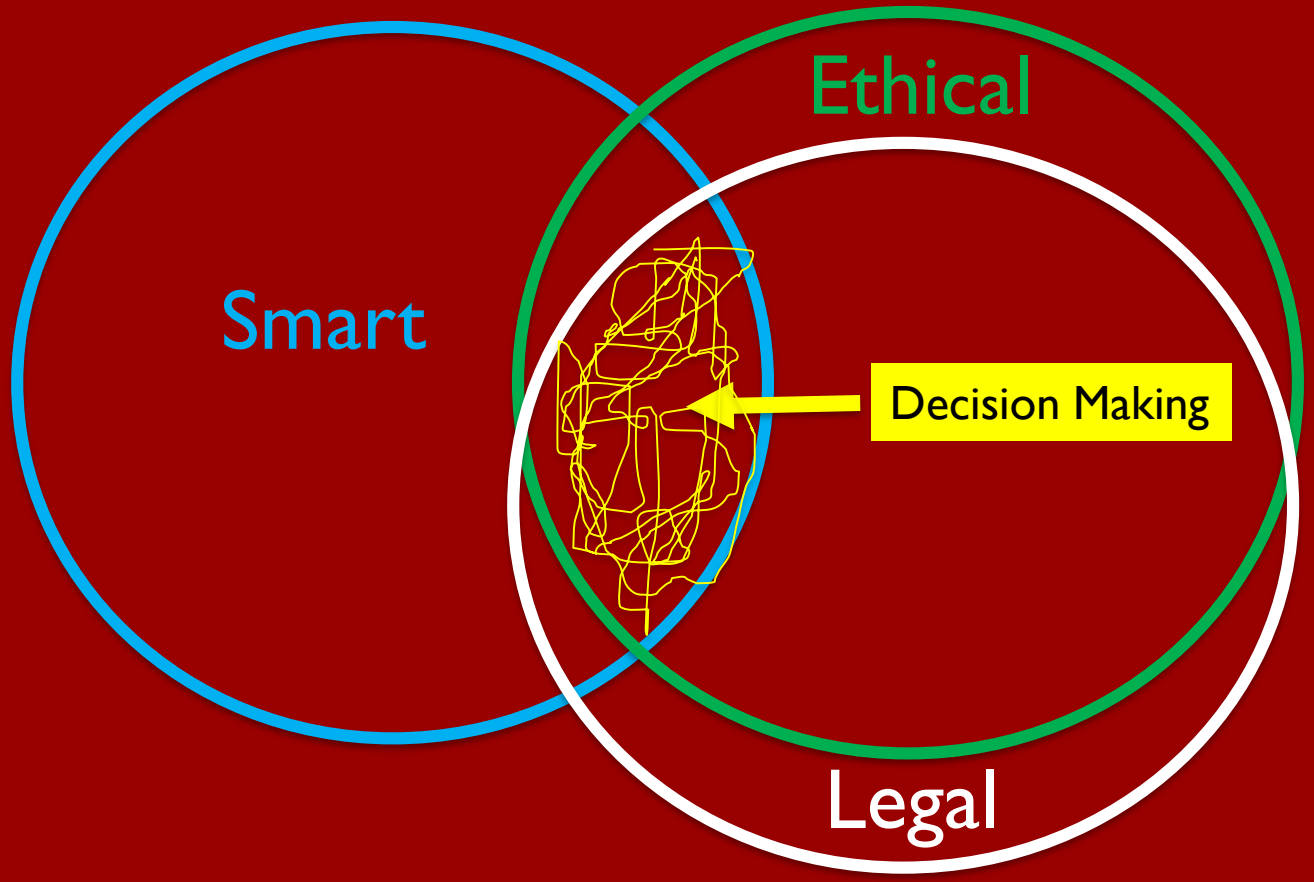
Goals Driven by Values

But, Unintended Consequences (increasingly powerful)

Policy- Legislation- Politics

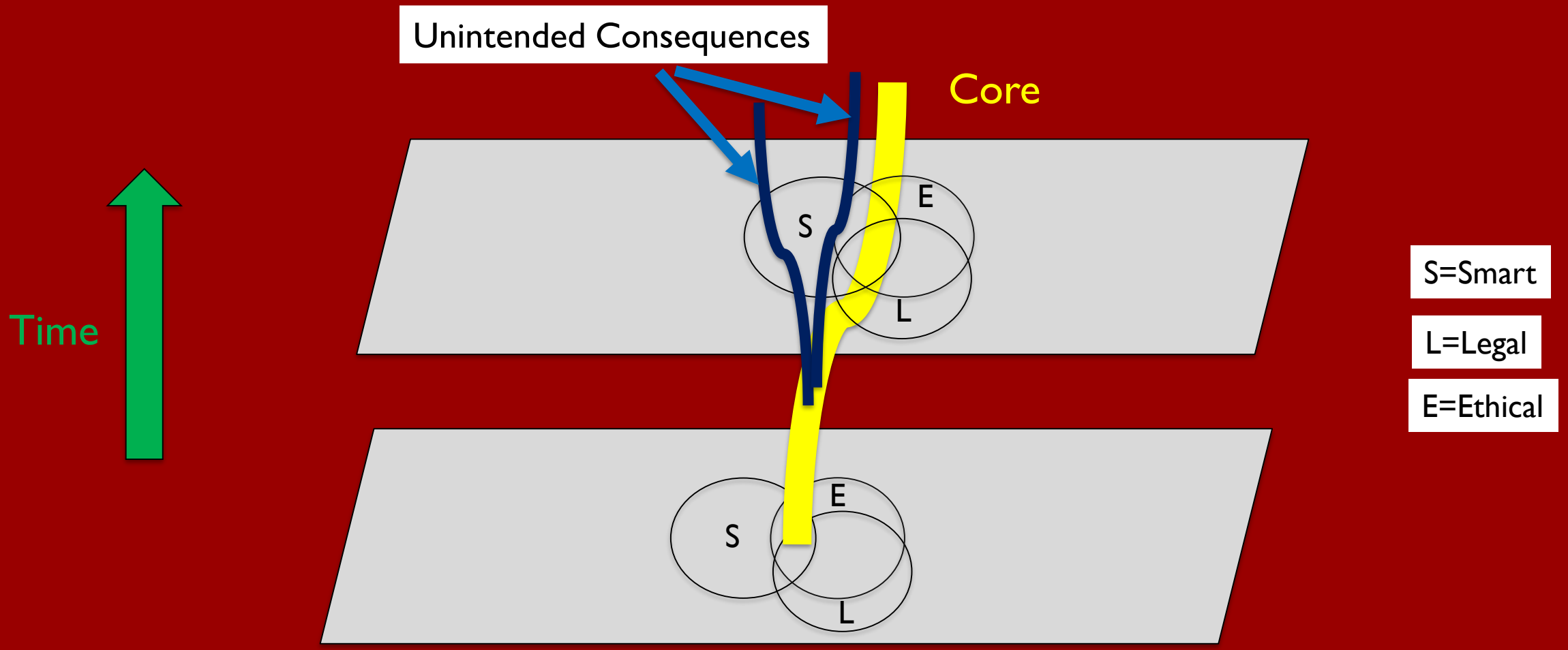
USC Viterbi School of Engineering

TECHNOLOGY ETHICS



USC Viterbi School of Engineering

EVOLUTION OF TECHNOLOGY



Unintended consequences will always be there because of our complex, non-linear world.

USC Viterbi School of Engineering

TECHNOLOGY ETHICS

- Synergy of humans with technology, e.g. Human Machine Interaction (HMI), Building Machine Interaction (BMI), Socially Assistive Robotics (SAR).
- Autonomy and symbiosis of machines with humans
- Automation impact on human labor; employment and income inequality issues
- Personalized customization (from medicine to preferences and human desires) and the risk of the loss of privacy
- Machine Learning and AI to model and leverage human and societal behavior, and to inform future action, inherently includes biases
- Reverse engineering the brain probes truly fundamental aspects of what it means to be human- and so does the field of Synthetic Biology
- These bring fundamental questions in what we value as society- from the individual to the collective- and how we educate our students

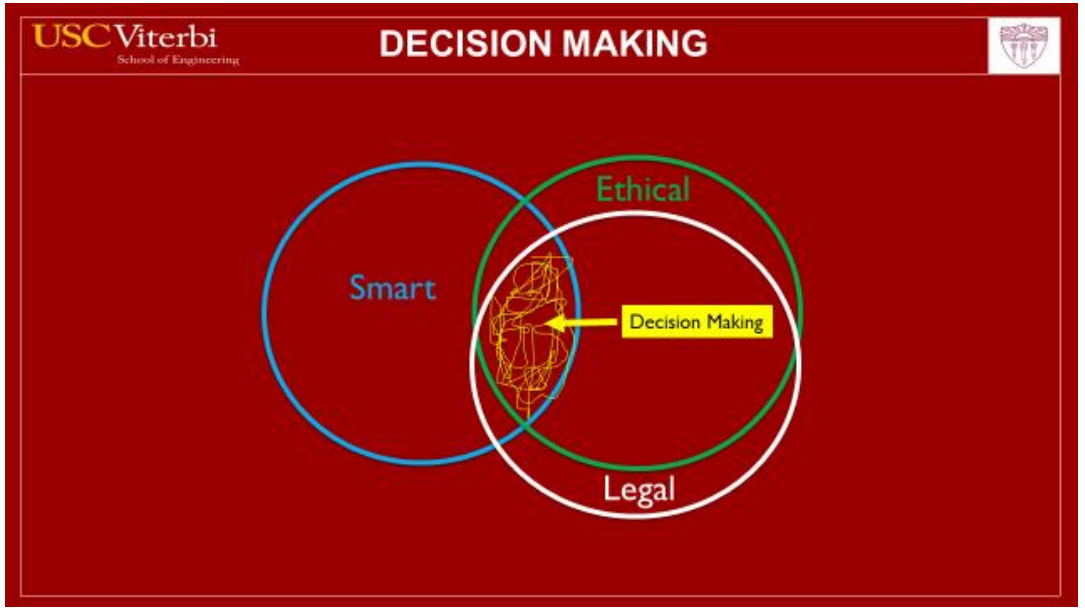
Competence and Character

TRUST: FOUR CORES OF CREDIBILITY*

1. *Capabilities (talent, attitude, skills, knowledge, mindset)*
2. *Results (performance- past, current, anticipated)*
3. *Integrity (humility, courage, congruence*
4. *Intent (motive, agenda, behavior)*

} Competence

} Character



*From Covey, "The Speed of Trust"

SOME MNEMONIC RULES

1. Hug the Exponential
2. Engineering +
3. Innovation in the Broadest sense
4. The Cultural Mind
5. Heroic Engineering

USC Viterbi School of Engineering

SUMMARIZING….

Powerful and Convergent Technology Helps:

Setting and Solving Humanity's Goals- and Changing the Conversation about Engineering

- Problems are inevitable
- All Problems are solvable

(From David Deutsch's book "The beginning of infinity")