THE INTERNET OF SKILLS:
ONLINE VIRTUAL SIMULATORS FOR SKILLED TRADES

National Science Foundation
David Dornfeld Manufacturing Vision And Award
Blue Sky Competition
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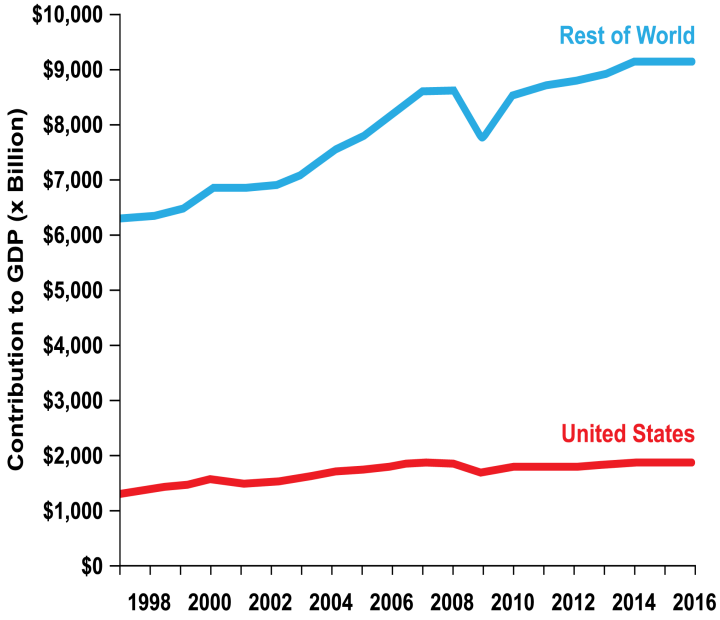
Future of Manufacturing: More

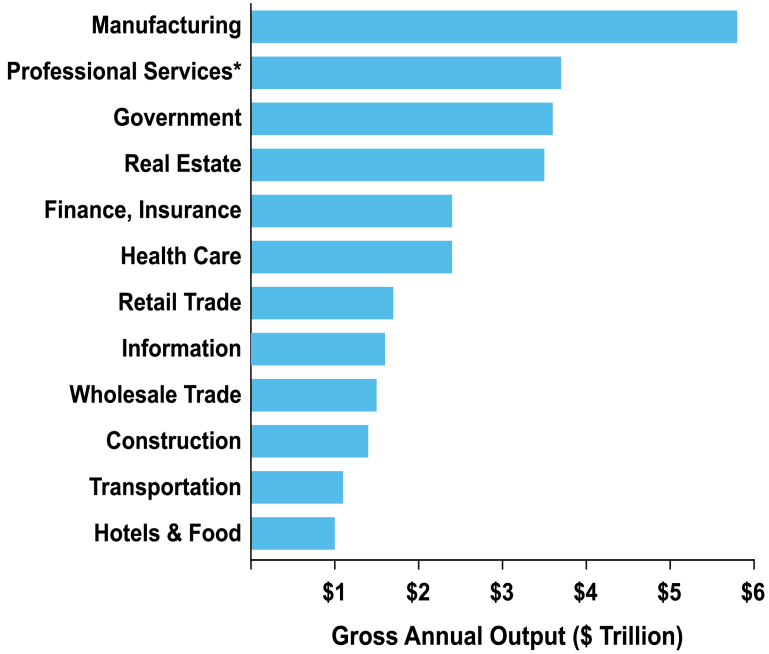
Global GDP Growth: Next two decades 2x the past 20 years

- More demand → more manufactured products
- More complexity per product
- Manufacturers are under-invested in automation

Manufacturing Contribution to GDP

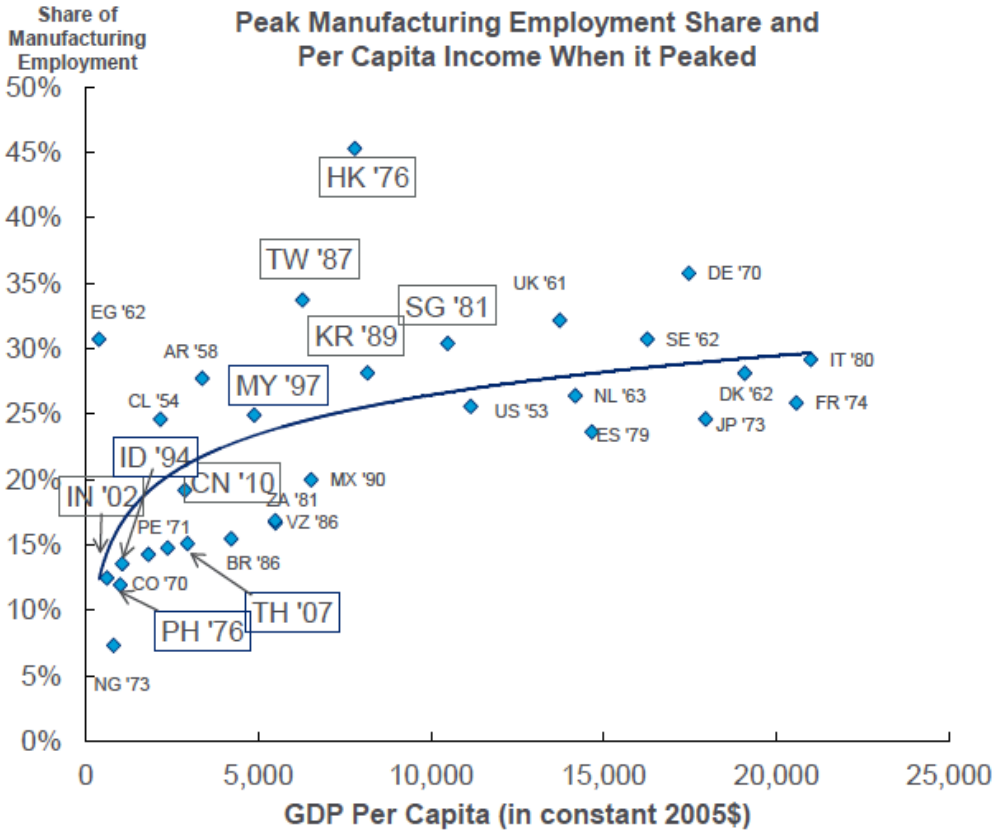


Top 12 U.S. Economic Sectors



Manufacturing Employment: More Demand for Skills

- Skilled trades shortage #1 issue past 7 years
- 88% manufacturers report trouble finding skilled workers
- 500k vocational jobs unfilled 2016 & will get worse
  - Silver Tsunami: employees in skilled trades older than average
- Workforce training #1 impediment to automation (2016 MAPI survey)



Future of Training: Virtual Skills Simulator

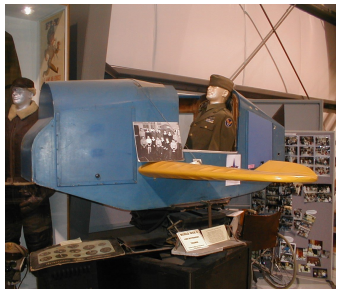
Can't close skills gap with incentives, K-12 voc-tech, etc. → Breakthrough needed

Skills Training Revolution 1.0

- **1927, Edwin Link, first Flight Simulator**
- **Enormous progress underlying electromechanical, display, computing systems**

Skills Training Revolution 2.0

- **2027 (?) name TBD, first Virtual Skills Simulator achieves True Virtual Reality**
- **Revolutionary for healthcare, gaming … everything … Interactive Internet**



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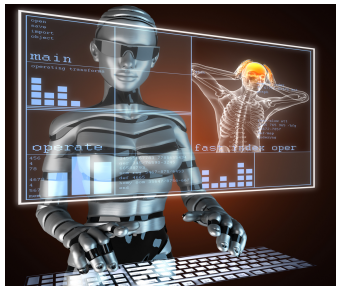


Virtual Skills Simulator: Enabling Technologies

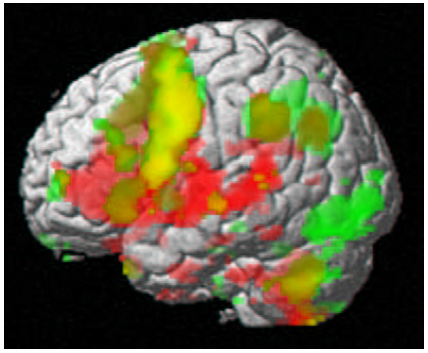
Sensors
- **Sight, sound, touch (smell, taste)**

Networks
- **Cyber-physical & Haptic latency ~ 1-10ms → 100-1000km**

Software
- **Exascale at the center & HPC at the edge**

Neuropsychology & neurophysiology
- **Active MRI + exascale → Perception of reality**

Actuators
- **Immersive reality emulation → conformal human-friendly**

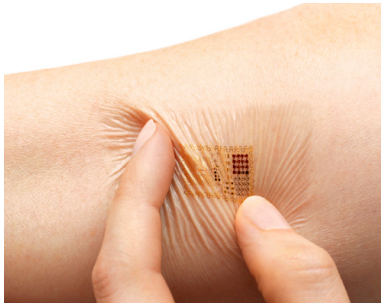


Virtual Skills Simulator: The Hard Problems

Sensors & Actuators for cyber-physical systems

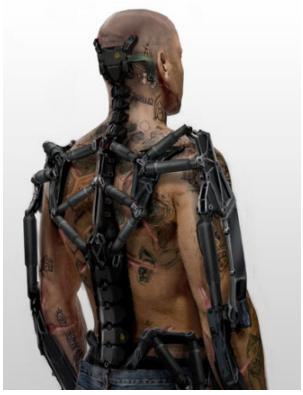
Sensors: Detect & transmit reality

- **Force, location, roughness, softness/hardness, warm/cold, friction**
- **Accuracy, resolution, speed and no power**
- **Solutions: Moore's Law + new conformal bio-compatible materials**



Actuators & Haptics: Transition from cyber to physical world

- **Creating force – physical realism – move atoms not bytes**
- ***No Moore's Law***



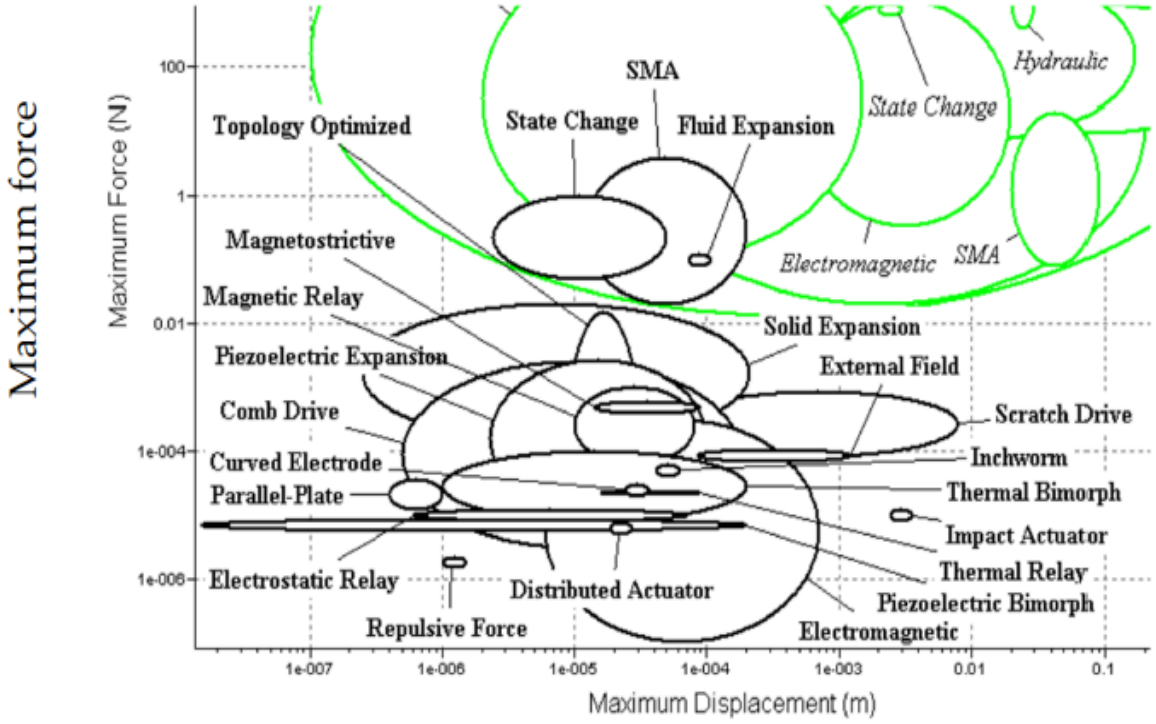
Actuators: Gatekeeper Tech for Cyber-Physical Systems

Requirements

- **Sensitivity, speed, linearity, repeatability, stability, strength, compliance, etc. etc.**
- **Force, displacement, scaling, efficiency**

Options

- **Mechanical (ultrasonic, MEMS), thermal, chemical, optical, shape memory alloy (SMA), electro phenomena (piezo, motors), electroreactive polymers**



Maximum displacement

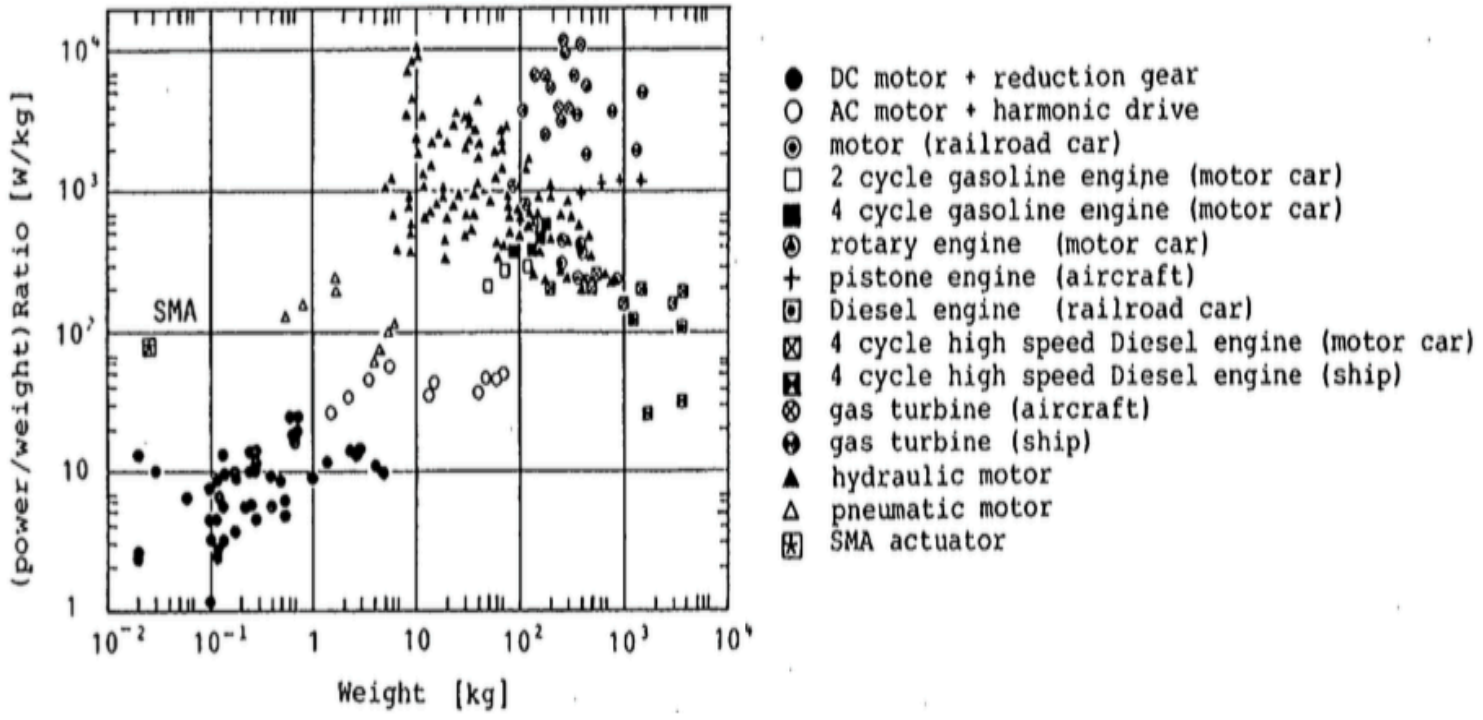
Actuators: Tyranny of Power in Cyber-Physical Systems

Challenges at small & human scales

- **Deliver enough power, efficiently**
  - (Most data ignores energy source & power electronics overhead)
- **Conformal & impedance matched**

@ Ant-size

- **Actuator ~ 100 mW vs insect < 100 µW → 1,000 x less efficient**
- **Engine (10 mm) < 1µW → 100,000 x less efficient**



Muscles: Magic of Biological Actuators

Muscles conquer the blend of key metrics:

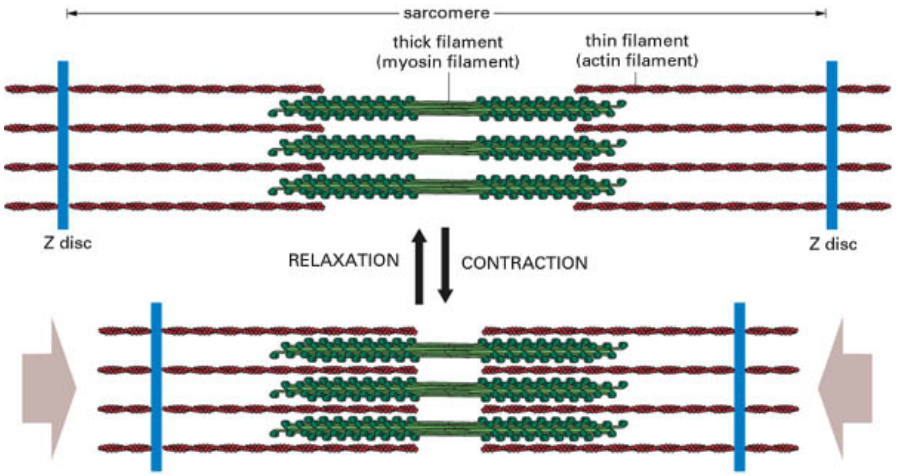
- **Strain, stress, deformation, displacement, power**
- **Conformal, coupling efficiency**
- **Power efficiency (>50% v ~5%)**

Material revolution needed to mimic nature

Promising progress but miles from *Nirvana*

- **Beijing Institute of Physics carbon nanotube bimorph EAP (200 W/kg)**
- **UCLA elastomer sandwich**
- **Harvard self-healing stretchy electropolymer**
- **LBNL vanadium dioxide torsional muscle/motor (40 kW/kg)**
- **UT fishing-line coil w 50% displacement (5 kW/kg)**
- **LSU bio-inspired shape-memory polymer**

300 W/kg (10x cockroach)



Enabling Virtual Simulators – Biomimetic Muscle Actuator

Time to follow Feynman's "Room at the Bottom" → but for atoms, not bytes

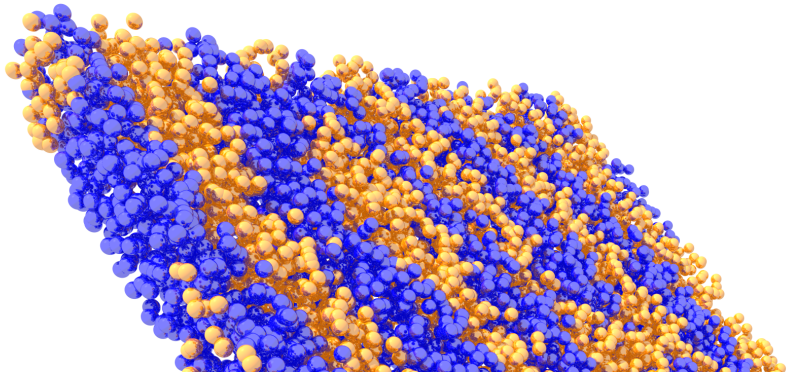
Need actuation tech equivalent to the vacuum-tube-to-transistor for information

New science & transformational tools unlock that possibility:

- **Computational materials & materials genome (Exascale coming)**
- **Molecular machines -- 2016 Nobel Prize in chemistry**
- **Analytical instruments see molecular processes in real-time**
  - Cryo-electron microscopy & super-resolved fluorescence microscopy
- **3D printing biomaterials @ microscale**

KEY GOAL EQUIVALENT TO LSI: Biomimetic Muscle Actuator (BMA)

- **Enormous potential beyond Internet of Skills**
- **Age of Responsive Media, Interactive Internet, Tactile Internet**



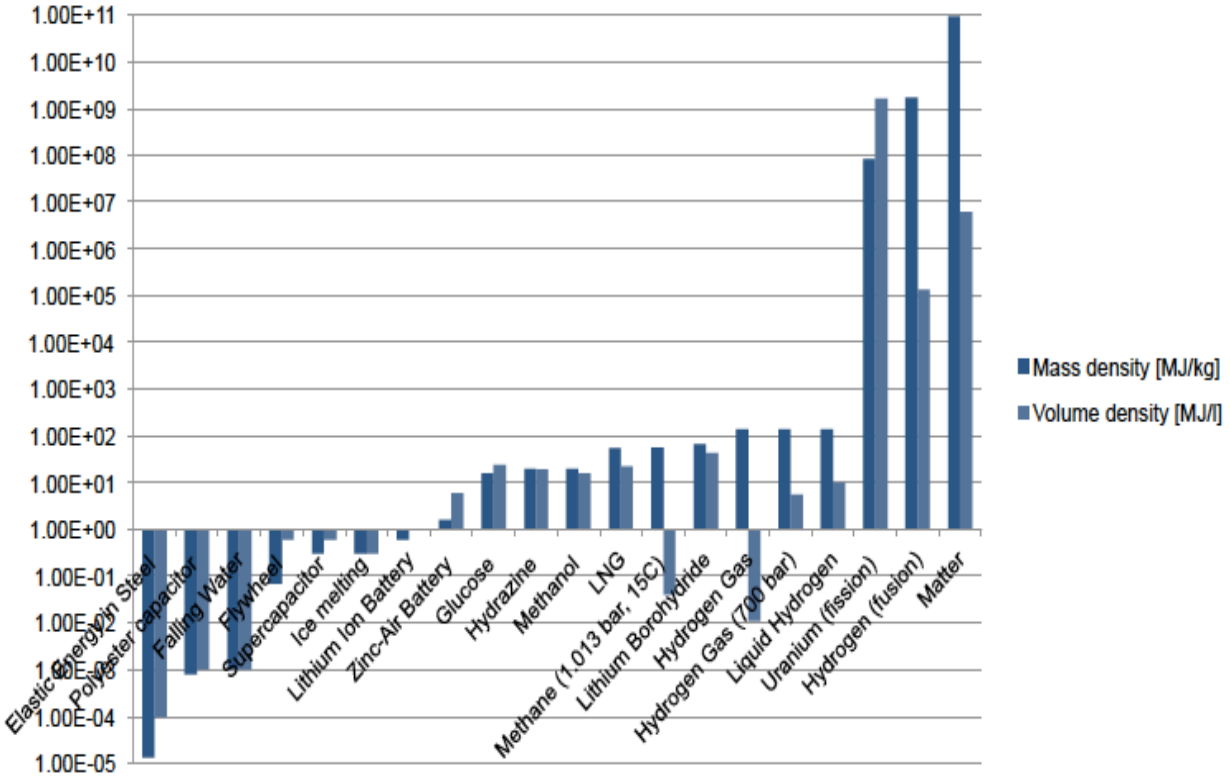
When BMAs Scale Like LSI

Cyber-physical equivalent of mainframe→PC?

- **Conformal bio-compatible force-sense force-delivering glove**

Cyber-physical equivalent of mainframe→smartphone?

- **Multi-layer molecular-dimensioned smart-powered exoskin**
- **@ bio-efficiency delivering kW-class power w kg of fuel**



Time for a Grand Challenge:
Jaynes Prize for Biomimetic Muscle Actuator

"The Muscle as an Engine," E.T. Jaynes, 1984

- **"We are speculating about the possibility of advancing the technology of energy convertors by taking hints from how Nature has managed it in biology."**

- **"Having seen this [muscle] biological system…It is easy to believe that … macromolecules could be 'designed' to do similar things, perhaps more easily."**

- **"In time the design of useful anti-Carnot molecular engines (artificial muscles) might become as systematic and well understood as the design of dyes, drugs, and antibiotics is now."**