School of Engineering
Ming Hsieh Department of Electrical and Computer Engineering

Introduction to ECE at USC

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The University of Southern California and the Viterbi School of Engineering

A regional view

- **California**
  - GDP $3.4 trillion (2021), and if a nation, it would be the fifth largest economy in the world behind Germany
  - GDP per capita $85,546 (2021) and population 39,237,836 (2021)
- **Southern California**
  - Defined as Los Angeles county, Orange county, San Diego county, Inland Empire, and Ventura county
  - Diverse economy with large engineering content including aerospace, IT, medical, specialty electronics manufacturing
  - If Southern California was a separate country, its economy would be the 13th largest in the world at $1.6 trillion in 2021 bigger than Brazil but smaller than Australia
  - Los Angeles county $815 billion, Orange County at $272 billion, San Diego County $256 billion, the Inland Empire — Riverside and San Bernardino counties — $211 billion, Ventura County $56 billion
  - Los Angeles County: GDP per capita $82,649 and population 9,861,224
- **USC facts 2022**
  - Total 49,500 students of which 21,000 are undergraduates and 28,500 are graduate and professional students
  - Endowment (as of June 30, 2021): $8.1 billion
  - University Budget (2020-21 fiscal year): $6.2 billion and near $1 billion in research expenditures
  - USC is the largest private employer in Los Angeles city (population near 4 million) and generates $8 billion annually in economic activity in the Los Angeles region and California

The Viterbi School of Engineering, ECE, CS, and ISI

- The USC Viterbi School of Engineering has 191 full-time tenure-track faculty members, 79 full-time teaching faculty, and 40 full-time research faculty. The School has 32 National Academy of Engineering members and annual research expenditures exceed $200M.
- The Ming Hsieh Department of Electrical and Computer Engineering **(ECE)** has 60 tenure/tenure-track faculty, 300 undergraduate students, more than 1000 master's students, and more than 300 Ph.D. students. In the 2021 school year, research expenditures exceeded $30M in direct costs. The department has received 4 Shannon Awards and has had more than 40 recipients of the NSF Early Career Award.
- The Computer Science Department **(CS)** has 40 tenure/tenure-track faculty, 1300 undergraduates, more than 2000 master's students and 360 Ph.D. students. The department Industry Affiliate Program (IAP), launched in fall 2018, provides engagement opportunities for students, faculty, and researchers with member companies that include Google, Lyft, and Microsoft.
- The Information Sciences Institute **(ISI)** supports basic and applied research in electrical engineering, computer science, mathematics, and applied physics. It has 400 faculty, staff, and students (June 2019) and expends about $110M per year on research for NSF, NIH, DHS, DoD, DOE technical offices, and industrial/commercial

Viterbi School of Engineering and USC in the Los Angeles region

- **ECE**: Electrical and Computer Engineering
- **CS**: Computer Science
- **ISI**: Information Science Institute
- Related University centers
  - ICT: Institute for Creative Technology – adjacent to ARL-West
  - HPCC: High Performance Computing Center

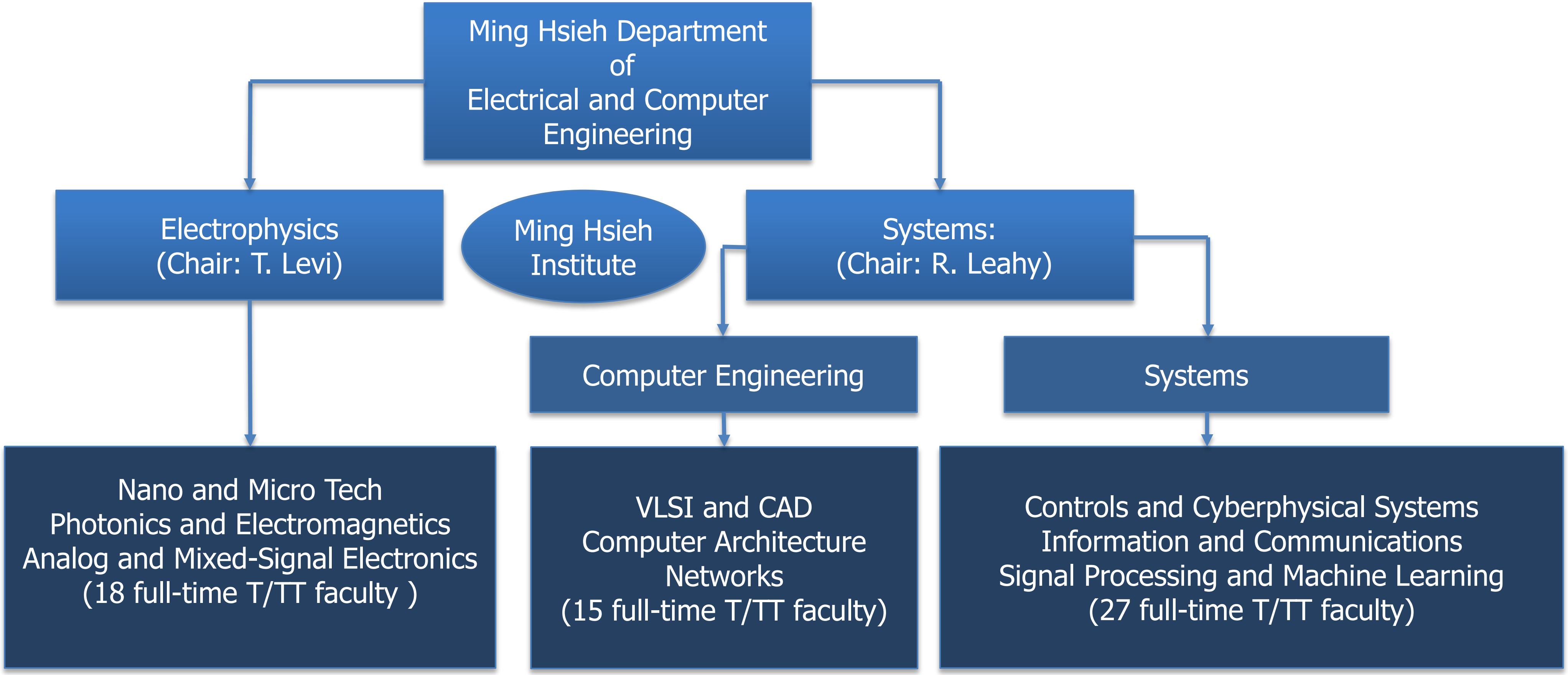
Keck School of Medicine

ISI

ICT

USC park campus

Ming Hsieh Department of Electrical and Computer Engineering organization



USC ECE organization and research areas

Electrophysics

Photonics and electromagnetics
Nanophotonics, lasers, silicon photonics integrated circuits, mid-infrared sensing, microphotonics, metamaterials, quantum. Remote RF imaging

Nano- and micro-technologies
Emerging nanomaterials for electronics and photonics, memory device technology and applications, carbon electronics, two-dimensional electronic materials, batteries, biosensors, non-equilibrium electrochemistry, photocatalysis, acoustic and ultra-sound MEMS

Analog and mixed-signal circuits
RF and millimeter-wave integrated circuits, data converters (ADC, DAC), clock generation (PLL), wireless/wireline communication circuits, low-power AI/ML computing circuitry, automated mixed-signal circuit design methodology. Low-power biomedical devices for personalized healthcare and neural interfaces

Systems

Signals and image processing
Human speech and audio signal processing, biomedical imaging and signal processing, theory and algorithms, machine learning, video, and graph applications

Communications and networks
Cognitive radio, wireless propagation channels, security, network optimization, protocols, modeling, network control, undersea systems, optical communication systems, information theory, coding, quantum information processing.

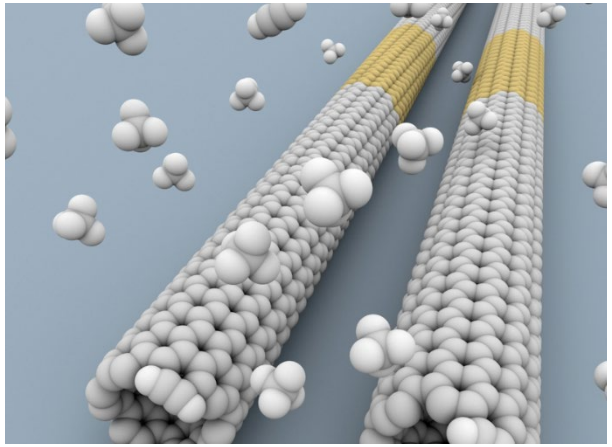
Control
Network and complex system control, quantum and cyber-physical control

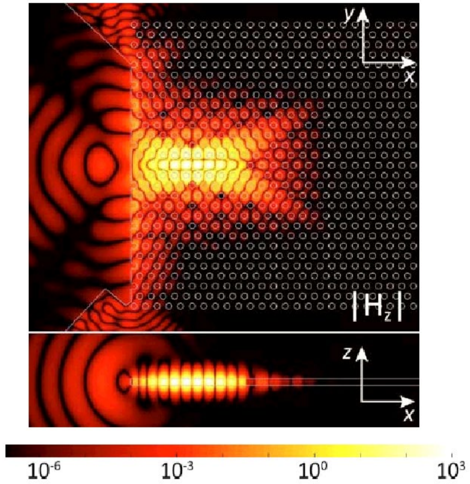
Computer engineering
VLSI/CAD methodology, data centers, cloud computing, big data, parallel and distributed processing, FPGAs, GPUs, resilience, computer architectures, superconducting electronics, network control and optimization, asynchronous circuits, design for cyber physical systems and IoT, yield and testing

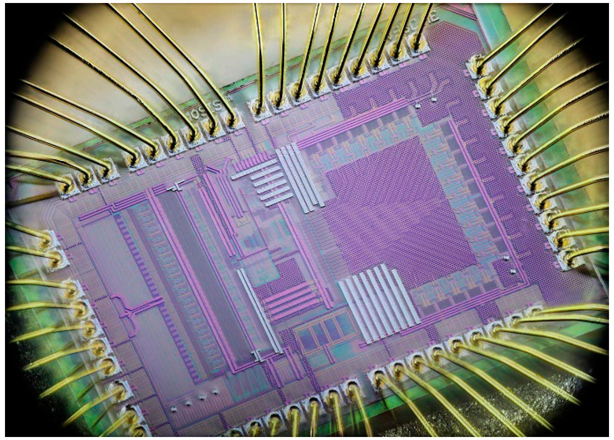
Electrical and Computer Engineering (**ECE**) at USC is defined by its faculty

https://minghsiehece.usc.edu/directory/faculty/

Research







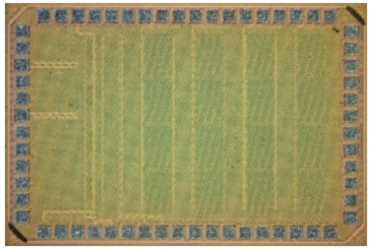
Ongoing electronics research into design, materials, and hardware accelerators

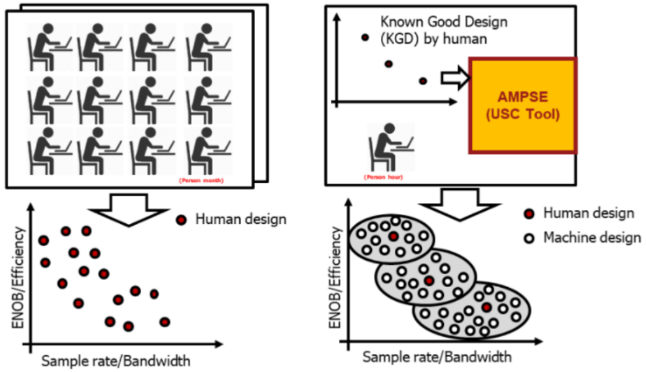
Efficient Design

Example: DARPA-ERI: **Automated AMS IP generator for CMOS technologies**. Led by USC (Tony Levi, Mike Chen, Sandeep Gupta)

The USC Analog Mixed-signal Parameter Search Engine (AMPSE)

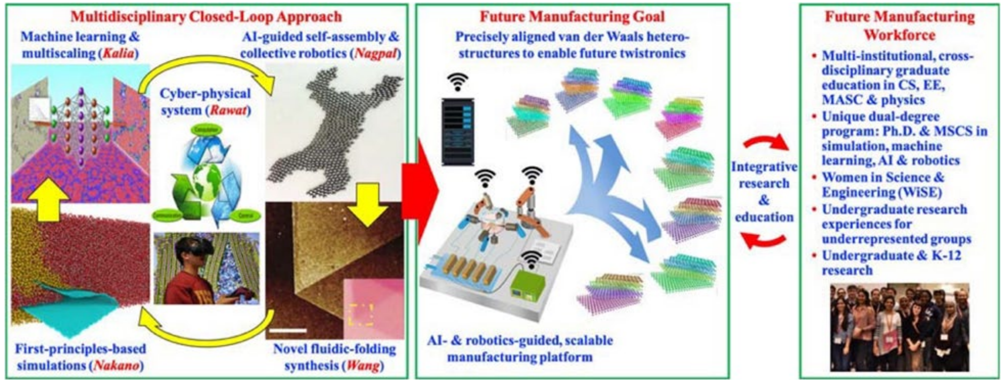
- Machine Learning (ML) used to solve the outstanding problem of automated Analog Mixed-Signal (AMS) circuit design
- ML-enables surrogate models used for accelerated exploration of optimal circuit designs that meet a wide range of user-defined specifications
- At least 600x faster than conventional approach
- Validation in GF12LP CMOS





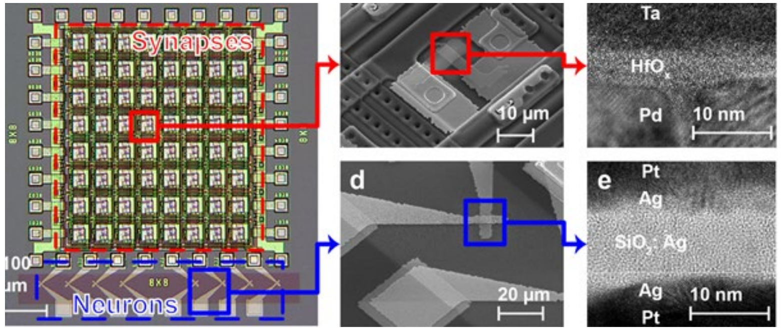
Quantum Engineering

Example: NSF-Future of Manufacturing: **AI-Driven Cybermanufacturing of Quantum Material Architectures**. Led by Harvard University with collaborating institutions USC (Han Wang, Rajiv Kalia, Aiichiro Nakano) and Howard University



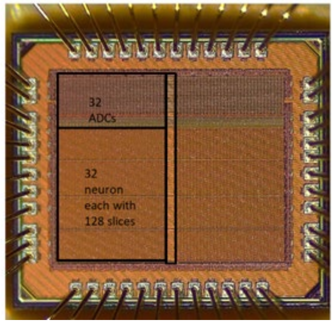
Hardware Accelerators

Example: MURI/AFOSR: **Brain-inspired networks for multifunctional intelligent systems in aerial vehicles**. Led by USC (Joshua Yang). First demonstration of fully memristive neural network for AI and ML neuromorphic computing using beyond-CMOS analog resistive switching devices. Also, NSF ASCENT: **3D memristor convolutional kernels with diffusive memristor based reservoir for real-time machine learning**.



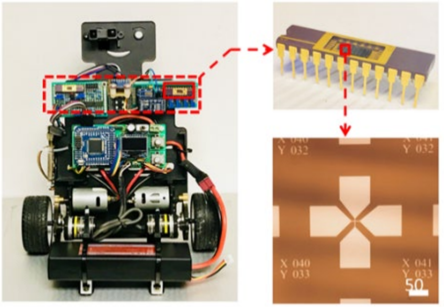
Example: **Deep Neural Network (DNN) mixed-signal accelerator in CMOS as energy-efficient solution compared to conventional CPU & GPU**. Mike Chen circuit group.

Results for 5b, 784-node input, 512-node hidden layer 1, 512-node hidden layer 2, 10-node output. The energy efficiency of this programable accelerator chip is world-beating.



Example: IARPA MicroE4AI: **Bio-inspired hybrid computing platform for micro-unmanned vehicles**. Led by USC (Wei Wu, Mike Chen, Quan Nguyen).

When speed is more important than precision, analog computing can have advantages over digital computing. In this case feedback control uses a simple, low feedback delay, memrister circuit. There is no ADC or DAC and no processor. The significantly reduced feedback delay results in improved mechanical response of robot motion – something that is not achieved using a conventional approach. This hardware innovation expands the control space for AI/ML applied to robotics.



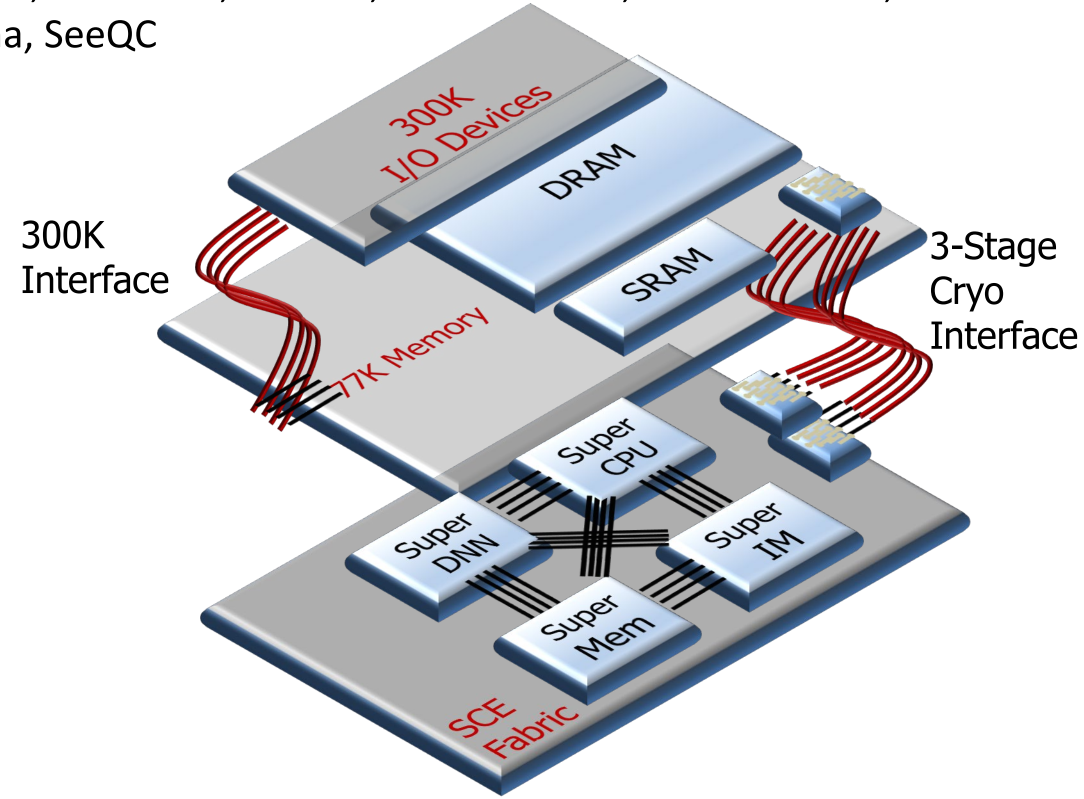
USC Institute for the Future of Computing

Massoud Pedram, Director
and
Joshua Yang, Co-Director

Address heterogeneous system integration and demonstration by coordinating across multiple research projects, including:

- Homomorphic computing (Massoud Pedram)
- Superconducting computing (Murali Annavaram)
- Custom computing (Keith Chugg)
- Quantum computing (Daniel Lidar)
- CMOS in-memory computing (Mike Chen)
- Nanoionic devices and systems (Joshua Yang)
- 1D materials and devices (Chongwu Zhou)
- 2D materials, devices, and systems (Han Wang)

Example: NSF/DARPA: **Superconducting computing**
Single flux quantum logic for beyond-Exascale computing using novel materials and devices to create new circuits and architectures. High density memory at 77K and superconductive memory.
Demonstration of superconductive system of cryogenic computing (SuperSoCC)
Goal: Performance-energy efficiency product gain of > 100x compared to end-of-Moore's Law CMOS
Team: USC, Rochester, Auburn, Northeastern, Northwestern, Yokohama, SeeQC



A Super-Custom Systems future: atoms-to-applications faster than software

Leverage 21st Century compute, design, and control technology

Co-design and optimization *before* fabrication

- Designer access and *control* of foundry processes enables modification, optimization and customization to the reticule level
- A massive new design parameter space

User Intent
Design specifications Designer knowledge Design priorities Design constraints

Foundry fabrication

Co-design optimization *during* fabrication

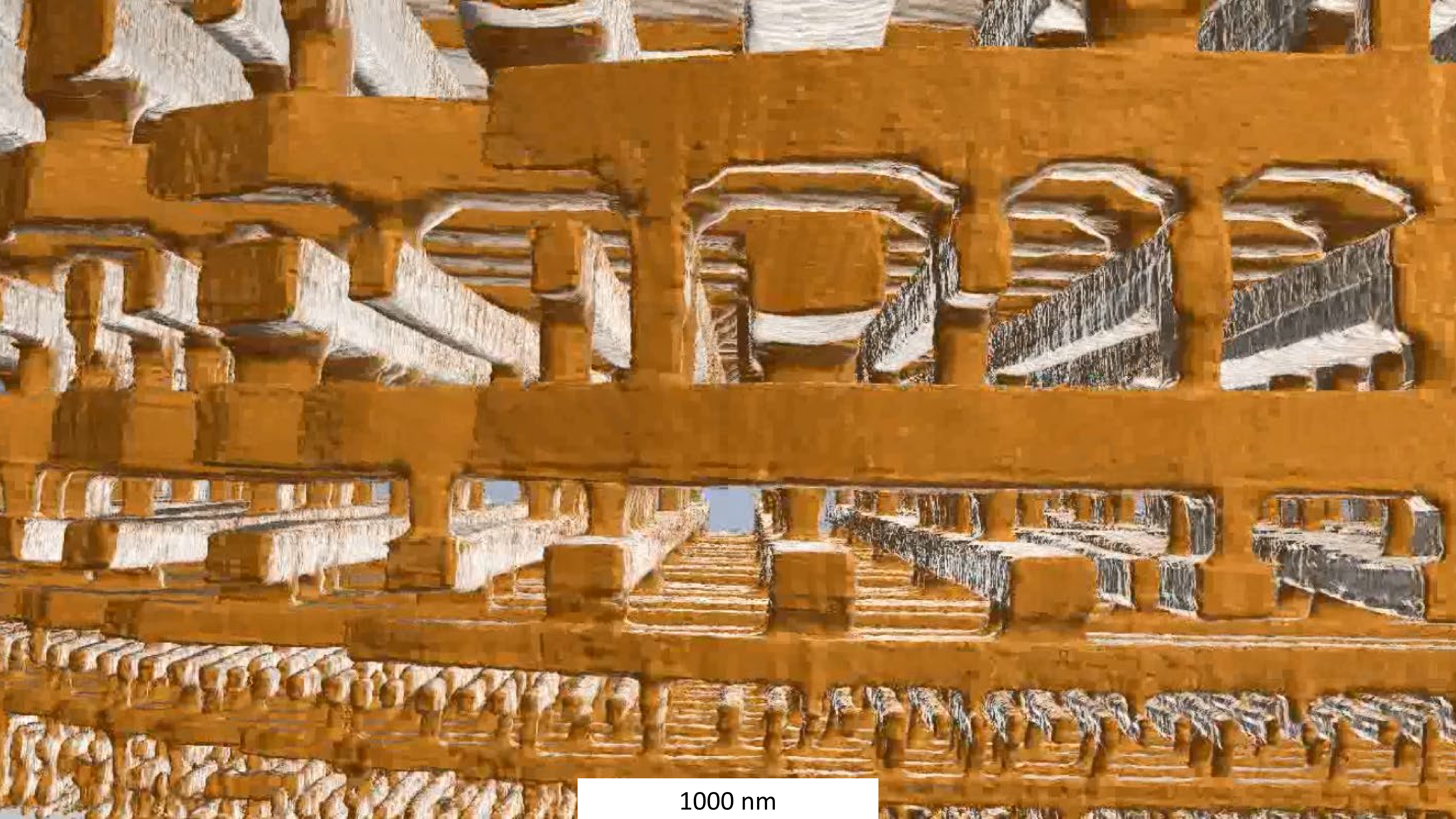
Continuous optimization *after* fabrication

- Customized components and *post-manufacture hardware evolution*
- Real-time non-Markovian adaptation and modification of hardware in the wild
- Post-manufacture continuous optimization in both hardware and software in response to tasks
  - Getting better performance from hardware by learning and physically adapting to tasks
- Feedback to factory and designers

Challenge **manufacturing to be *faster* than software redesign (currently 6 weeks for Facebook)**

A hardware ecosystem enabling concept, co-design, to physical product in less than 2 weeks

However, ….


1000 nm

Regional cooperation to bridge the gap between research ideas and adoption?

Is there mutual benefit in working to create a regional pilot manufacturing capability for heterogeneous electronic system manufacturing and integration?

End