

A group of approximately 15 people, including students and faculty, are posing for a group photo in a hallway. They are dressed in casual attire like hoodies and jackets. Some are making hand gestures, and one person in the center is holding a sign that says "SD". The background shows a typical university hallway with doors and a green exit sign.

Ming Hsieh Department of Electrical and Computer Engineering

Making Ideas Work in the Real World

Richard Leahy, ECE Chair - Systems
(leahy@usc.edu)

Tony Levi, ECE Chair - Electrophysics
(alevi@usc.edu)



USC University of Southern California

- Founded in 1880. The oldest private research university in California
- Second largest private university in USA with more than 47,000 students
- University budget (2017-2018) \$4.9B
- University endowment (2017) \$5.1B
- Sponsored research (2017) \$0.7B+
- Ranked 15th in USA by *Wall Street Journal* & *Times Higher Education*
- Distinguished faculty (more than 4,300 faculty)
 - 6 Nobel laureates and 1 Turing Award winner
 - 10 National Medal Winners
 - 14 National Academy of Sciences members
 - 32 National Academy of Engineering members
 - 17 Institute of Medicine members
 - 4 National Academy of Education members
- Notable alumni (375,000+ living)
 - Neil Armstrong, George Lucas, Frank Gehry, Andrew Viterbi, Shinzō Abe
 - Alumni founded companies include Qualcomm, Lucasfilm, Salesforce.com, Vizio, Intuit, Box, Tinder, Myspace, Riot Games, Oakley, Kinko's, CPK, ...
 - USC Olympians have taken 135 gold medals, 88 silver, and 65 bronze medals



Viterbi School of Engineering

- Ranked 10th in USA by *U.S. News and World Report*
- \$204M+ annual research expenditure
- ECE: Electrical and Computer Engineering
- CS: Computer Science
- ISI: Information Science Institute
- Related University centers
 - ICT: Institute for Creative Technology
 - HPCC: High Performance Computing Center



ISI

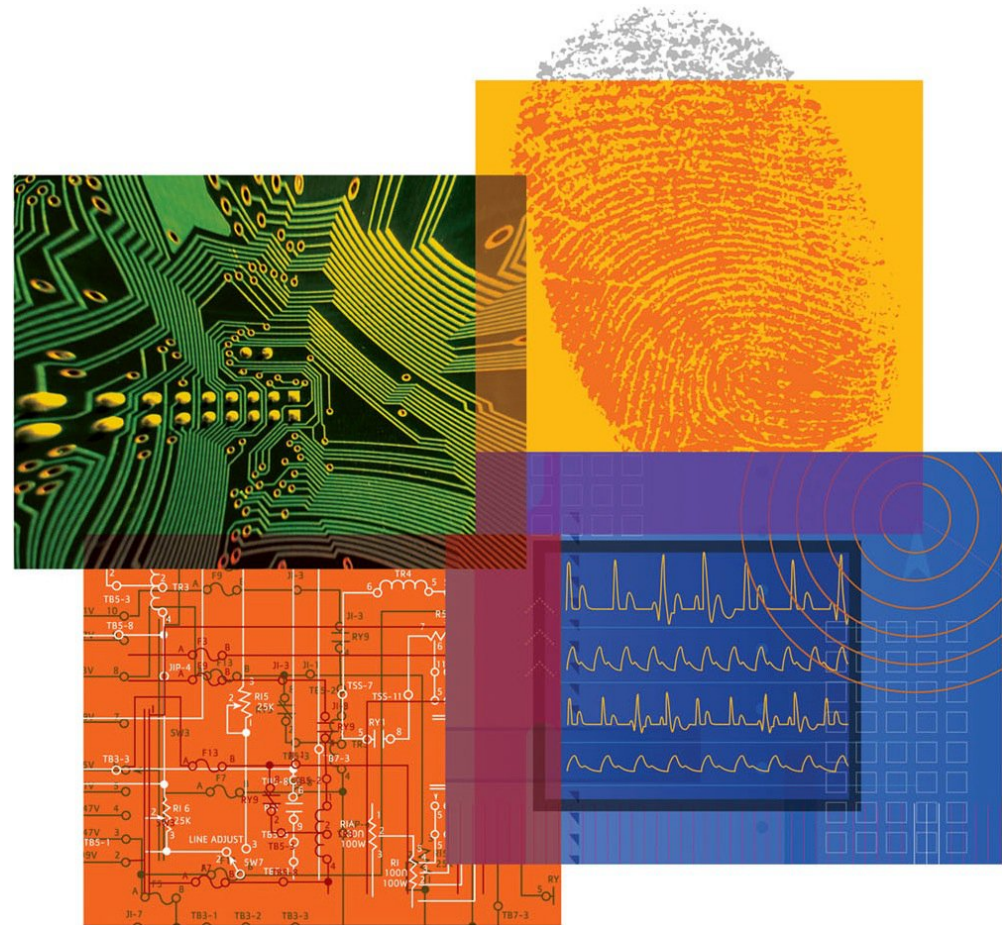
ICT

USC park campus



Ming Hsieh Department of Electrical and Computer Engineering

- Founded in 1905
- 300 undergraduate students, 1400+ M.S. students, 300 Ph.D. students
- Research volume (2017) \$35M+
- Ranked 13th in USA by *U.S. News and World Report*
- 66T/TT full-time faculty
- Notable alumni
 - Andrew Viterbi, Ph.D. in 1963, Co-founder of Qualcomm
 - Ming Hsieh, B.S. in 1983, M.S. in 1984, Founder & CEO of Cogent Systems Inc.
 - William Wang, B.S. in 1986, Founder & CEO of Vizio
 - Mike Markkula, B.S. and M.S., Angel Investor & second CEO of Apple
 - Kevin Jou, Ph.D., CTO of MediaTek
 - Xiaofan Simon Cao, M.S. & Ph.D., CEO of Materion Precision Optics (Shanghai)



Department organization and research areas

Electrophysics

Photonics and electromagnetics

Nanophotonics, lasers, silicon photonics integrated circuits, mid-infrared sensing, microphotonics, metamaterials, and imaging. Pulsed power and transient plasmas, radar and RF imaging

Nano- and micro-technologies

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

Analog and mixed-signal circuits

Radiofrequency 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, network control and optimization, asynchronous circuits, design for cyber physical systems and IoT, yield and testing



Electrophysics

Photonics and electromagnetics

Nanophotonics, lasers, silicon photonics integrated circuits, mid-infrared sensing, microphotonics, metamaterials, and imaging. Pulsed power and transient plasmas, radar and RF imaging

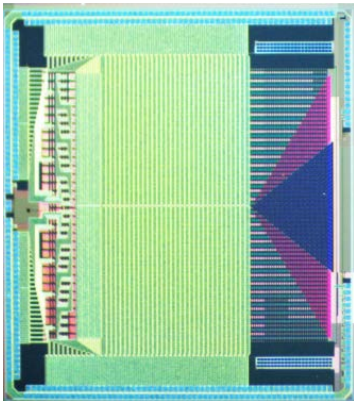
Nano- and micro-technologies

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

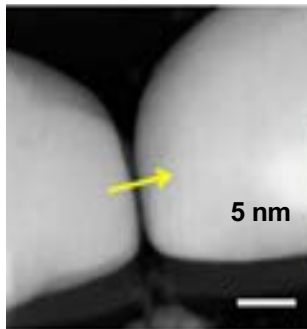
Analog and mixed-signal circuits

Radiofrequency 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

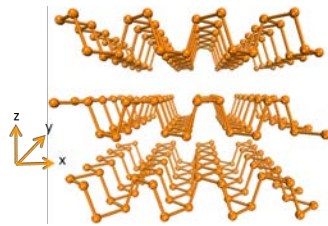
Photonics and electromagnetics



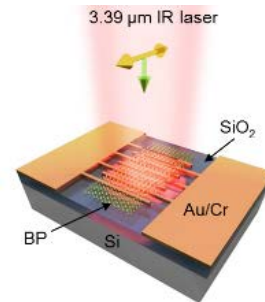
1024-Element CMOS SiPh Optical Phased Array



Controlled SERS at nm-scale



Black Phosphorus for Mid-IR Sensing

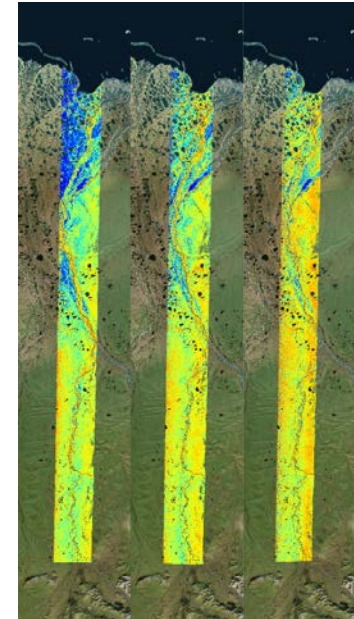


Prof. Martin Gundersen



Transient ("cold" plasma) by nanosecond pulses

Prof. Steve Cronin



2014 2015 2017
Deadhorse Alaska, moisture AirMOSS airborne radar data

Prof. Mahta Moghaddam

Prof. Hossein Hashemi

Prof. Wei Wu

Prof. Michelle Povinelli

Prof. Hahn Wang



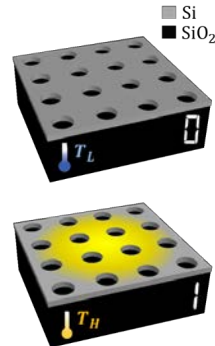
Photonics

- Nanophotonic thermal memories and logic
 - Nanophotonic resonant structures with laser read, write, erase and data stored in temperature
- Optomechanics and Nanophotonics
 - Fundamentals of light propagation in nanostructured materials for applications in optical communications, energy, and biology
 - Optical trapping, nano-particle manipulation, and size sorting
 - Arbitrary infrared emission spectra and radiation profiles using microstructure
- Tunable NIR FPA
 - Resonant optical structures integrated with 2D black phosphorous detection
- Silicon integrated photonics and CMOS
 - LIDAR beam-steering > +/- 22 deg

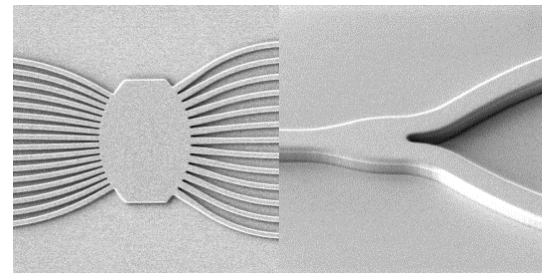
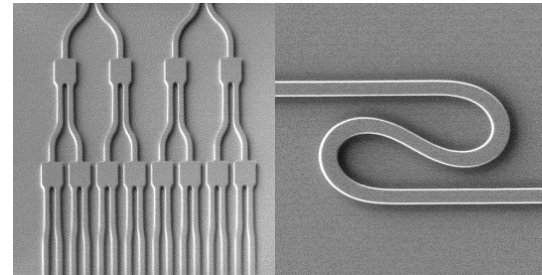
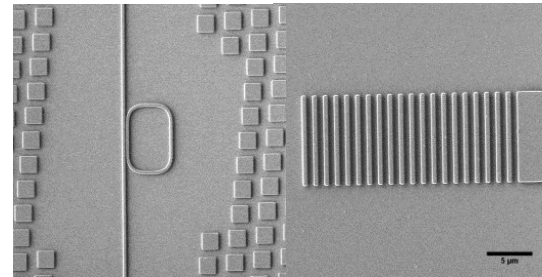
Han Wang



Michelle Povinelli



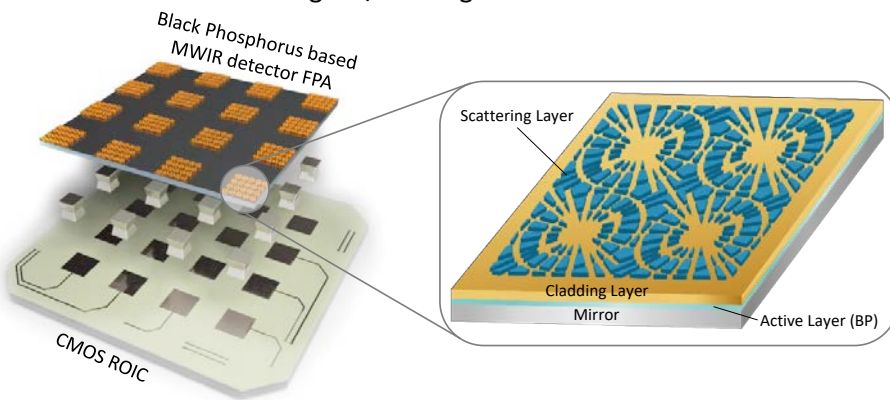
Thermal Memories and Thermal Logic



P. Dan Dapkus



Hossein Hashemi



Electromagnetics and plasma engineering

- Remote sensing with electromagnetic waves
 - Forward scattering models and the inverse problem
 - Polarimetric Synthetic Aperture Radar (SAR), P-band (420 – 440 MHz)
- Compact high-performance antennas
 - Ultra wideband array antennas
- Pulsed power
 - Ion propulsion, electron beams, x-ray sources
 - Cancer therapies with ultrashort intense pulsed electric fields
- Applied plasma devices and systems
 - Transient plasma ignition for improved combustion and fuel efficiency
 - Cold plasma for root canal disinfection

Mahta Moghaddam



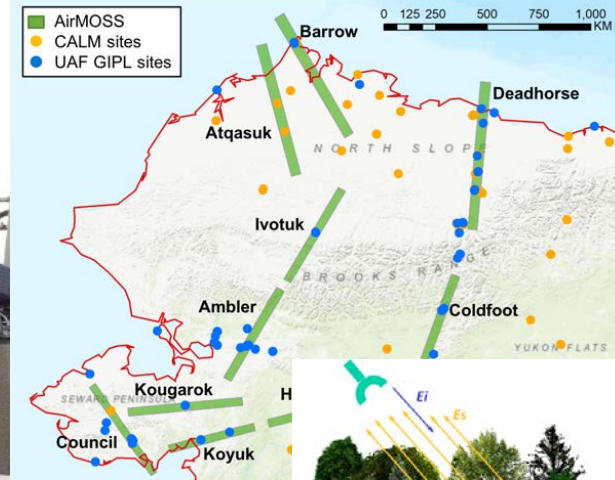
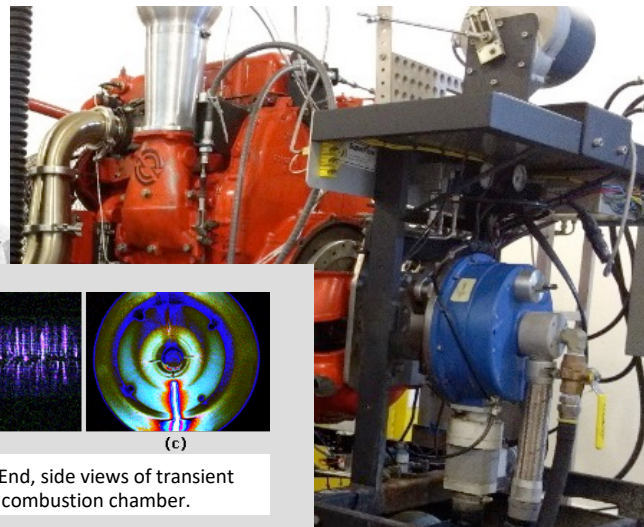
Aluizio Prata



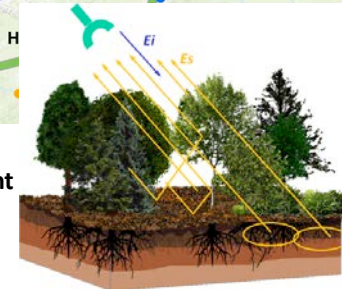
Steve Cronin



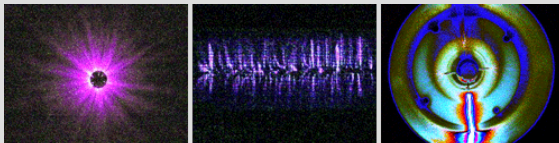
Martin Gundersen



NASA Arctic-Boreal Vulnerability Experiment (ABOVE)



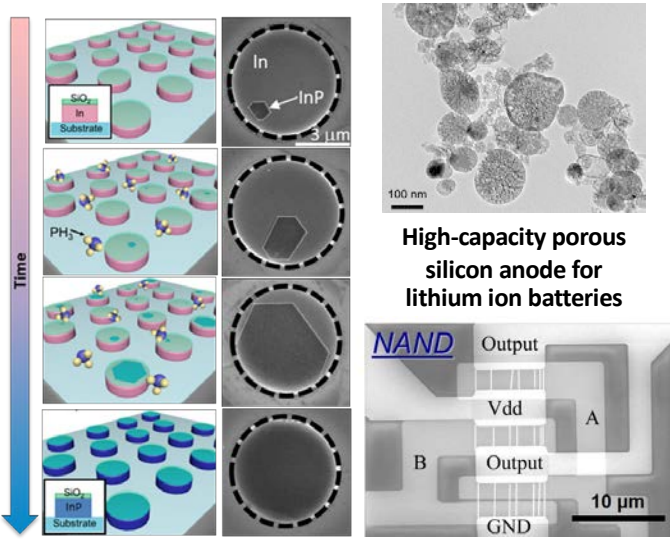
Transient Plasma Ignition



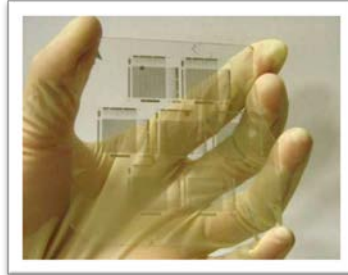
Transient Plasma Ignition: (a,b) End, side views of transient plasma. (c) streamer and arc in combustion chamber.

**3-D Computing Systems:
Materials and Devices**

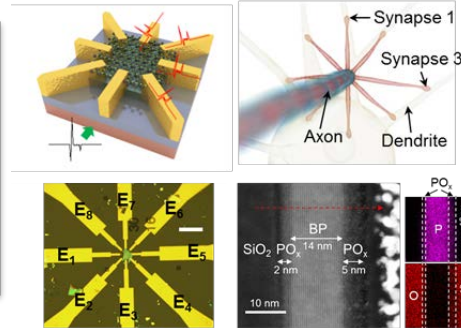
Nano- and micro-technologies



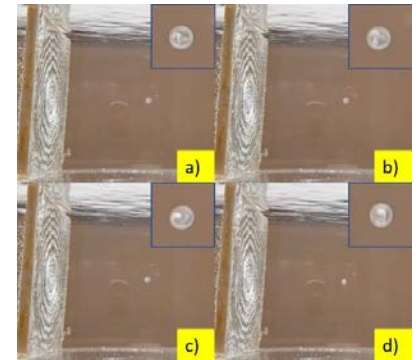
High-capacity porous silicon anode for lithium ion batteries



Active matrix OLED display with nanotube transistors: Technology transfer to Carbonics Inc.



Memristive devices for neuromorphic computing



Rotational manipulation of Zebrafish embryo (24 - 36 hours-post-fertilization) with acoustic tweezers

Prof. Rehan Kapadia

Prof. Chongwu Zhou

Prof. Wei Wu

Prof. Hahn Wang

Prof. Eun-Sok Kim

Prof. Tony Levi

Optimal device design



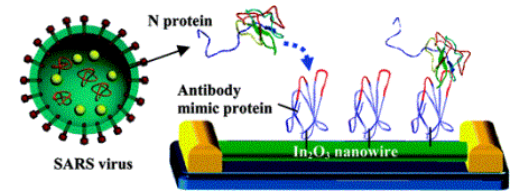
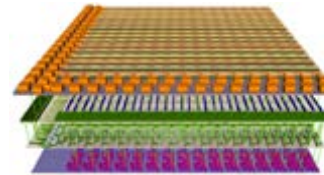
- Carbon nanotubes, graphene, nanowires
 - Synthesis, properties and applications
- Nanobiotechnology
 - Biosensors
- Nanochemistry – catalysis and spectroscopy
 - Hydrogen production, synthetic petroleum reducing CO emissions
- Energy nanotechnology
 - Super capacitors, lithium ion batteries
- Nano-electronics and nano-photonics
 - Optical negative index meta-material
- 2D material systems
 - Black phosphorus, graphene, hBN, metal dichalcogenides
 - 2D Material based plasmonics and metamaterials
- High-performance photonics and electronics on arbitrary substrates
 - Thin-film vapor-liquid-solid growth
- New format electronics
 - 3D integration and folding electronics
 - Bio-inspired/bio-integrated electronics
- III-V compounds on silicon
 - Growth of single crystal III-V's directly on Si
 - III-V photonics and electronics on Si

Nano-science

Chongwu Zhou

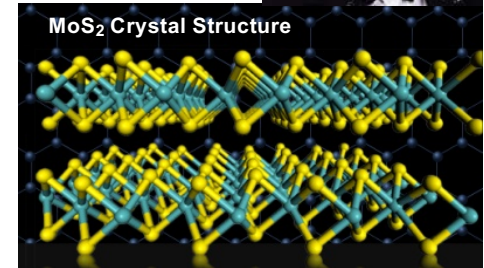
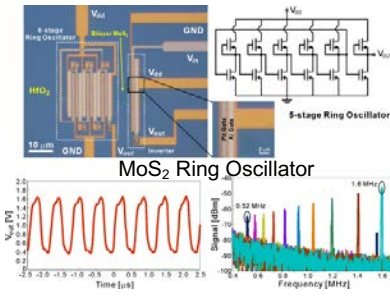


3D integration of unconventional materials on traditional silicon



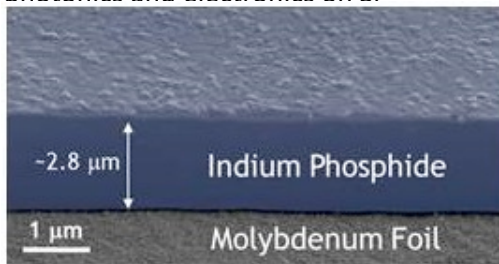
Biosensing InOx nanowire FET transistor functionalized with antibody selective to SARS virus

Han Wang

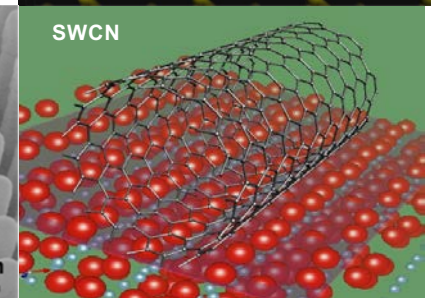
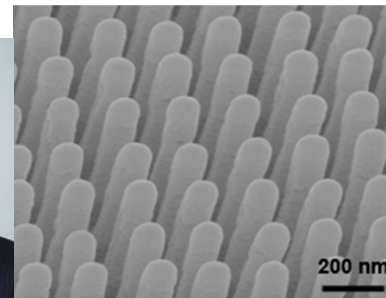


RRAM
CNFET-layer
CMOS

Rehan Kapadia



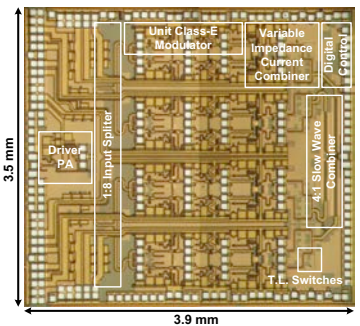
Wei Wu



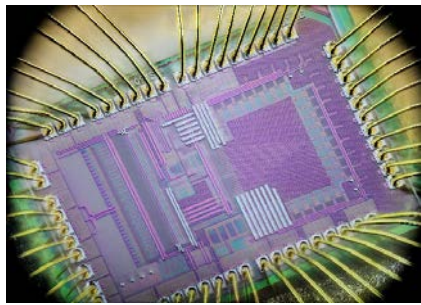


Software-defined radio receiver test-board

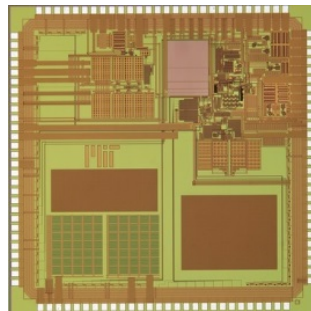
Analog and mixed-signal circuits



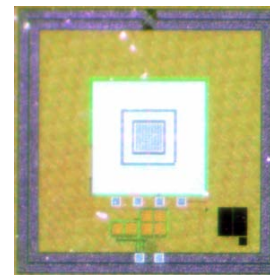
Digital Power Amplifier:
46 GHz, 29 dBm, 18%



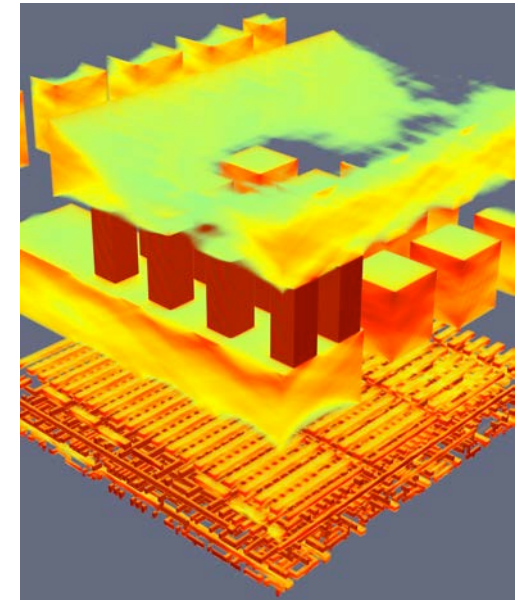
NUS ADC



Energy harvester



Fully Implantable Amperometric Biosensor



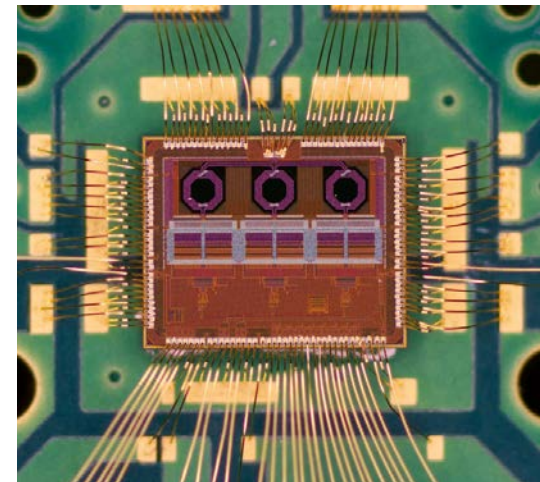
Machine learning for mixed-signal circuit design

Prof. Hossein Hashemi

Prof. Mike Chen

Prof. Dina El-Damak

Prof. Manuel Monge



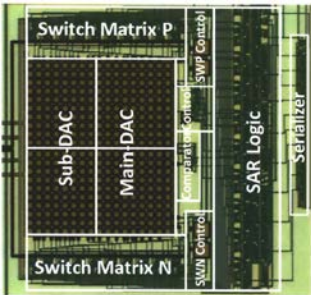
Biomedical interface engineering

Ultra-low power circuits and systems

Dina El-Damak



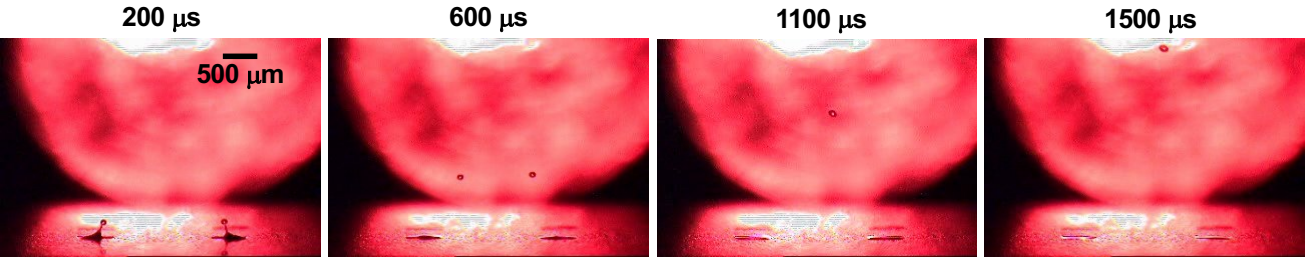
Low power SAR ADC for EEG SoC



- Circuit design with emerging technologies
- Power management, energy harvesting
- Biomedical devices for personalized healthcare

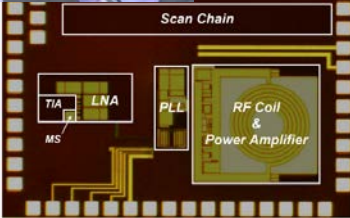
Piezo-electric nozzle-less droplet ejector

Eun Sok Kim

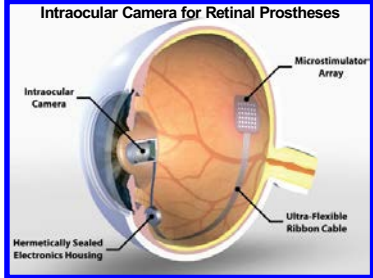


High-precision electronic medicine

Manuel Monge



Addressable Transmitters Operated as Magnetic Spins (ATOMS) with power, communication, location, integrated bio-sensing and actuation technologies



Armand R. Tanguay, Jr.



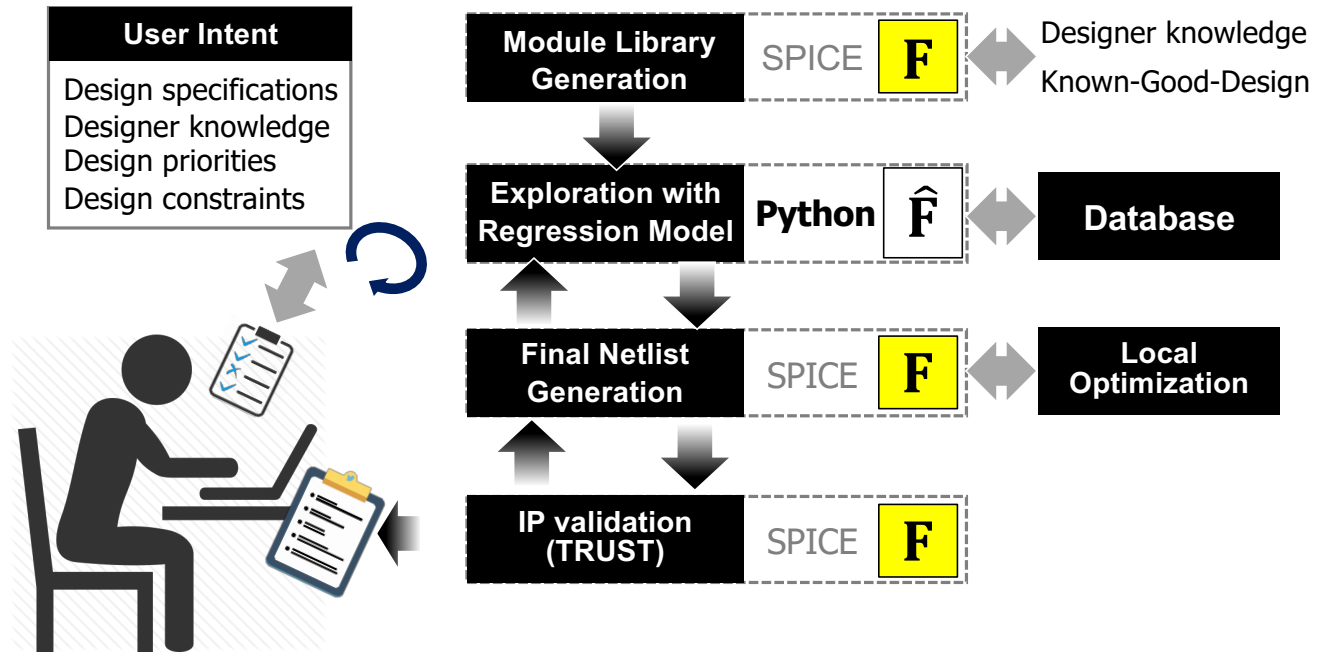
Gianluca Lazzi



Director ITEMS Neuro-interface engineering

Example research project: Automated Analog Mixed Signal (AMS) netlist generation ecosystem

- *Open-source automated AMS IP schematic generation*
- Leverage USC circuit designs in 180nm, 65nm and 14nm FinFET
- Architectures for advanced technology IP blocks that meet or exceed metrics:
 - PLL range: 10 MHz – 10 GHz
 - DLL range: 10 MHz – 10 GHz
 - ADC range: 1 – 10,000 MS/s
 - DAC range: 1 – 10,000 MS/s
- Machine learning (e.g., ANN) and optimization (e.g., convex) around known-good design (KGD) points



Mike Chen Tony Levi Sandeep Gupta



<https://github.com/USCPOSH/usc-posh>



Systems

Signals and Image Processing

Human speech and audio signal processing, biomedical imaging and signal processing, brain-computer interfaces, theory and algorithms, machine learning, video, computer vision 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

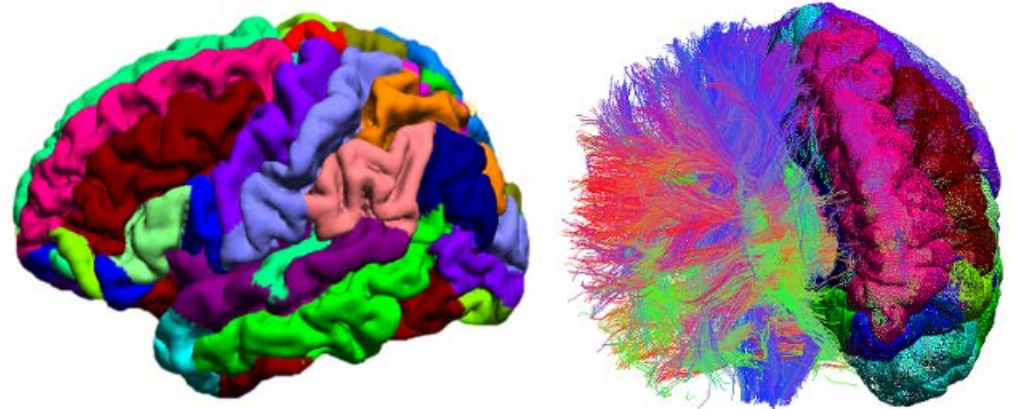
Network and complex system control, robust control, quantum and cyber-physical control, power distribution and financial networks, AI for autonomous vehicles.

Computer engineering

New computing paradigms (hardware and software), VLSI/CAD methodology, data centers, cloud computing, big data, parallel and distributed processing, FPGAs, GPUs, resilience, computer architectures, network control and optimization, asynchronous circuits, design for cyber physical systems and IoT, yield and testing

Signals and image processing

- Signals
 - Traditional (speech, audio, images, video)
 - New datasets (MoCap, MRI, event traces, data in the wild)
 - Big data (social media, genomic, brain images)
- Theory and Algorithms
 - Signals and system: compressed sensing, wavelets, non-Gaussian modeling, stochastic resonance, close-looped control
 - Inference: fuzzy logic, machine learning
- Broad applications
 - Biomedical
 - Communications
 - Cybersecurity
 - Speech and audio
 - Human behavior



BrainSuite image analysis tools to process magnetic resonance images (MRI) of the human head

Graphs, neural networks, optimization and big data – video, vision and other applications

Speech, audio and human-centered signal processing

Biomedical imaging and signal processing

Prof. Jay Kuo

Prof. Mahdi Soltanolkotabi

Prof. Antonio Ortega

Prof. Bart Kosko

Prof. Shri Naryanan

Prof. Panos Georgiou

Prof. Justin Haldar

Prof. Krishna Nayak

Prof. Maryam Shanechi

Prof. Richard Leahy



Example research project: TILES tracking Individual performance with sensors study

- Researchers at the University of Southern California (USC), University of Washington, INRS-EMT/University of Quebec, and Evidation Health have partnered with The Intelligence Advanced Research Projects Activity (IARPA)
- The purpose of this study is to understand how individual differences, mental states, and well-being affect job performance
- Data collected from 250 Keck Medicine of USC nurses
- Project led by Professor Shri Narayanan



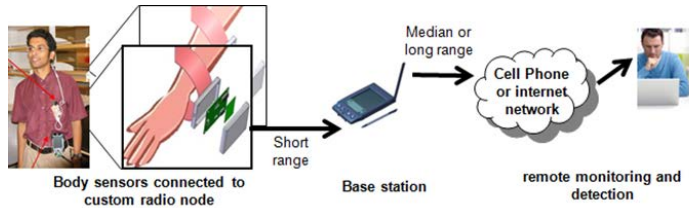
Prof. Shri Narayanan



- Multisensor tracking:
 - Personal: Fitbit Charge 2 (wrist), Omsignal (chest), Android Jelly (audio)
 - Environmental: ReelyActive Owl-in-one (temp, humidity, motion, etc), Minew Beacons (environmental factors)
 - Analysis using signal processing, graph analysis, machine learning to understand relationship between individual physiological and environmental factors in stressful work situations.

Communications and networks

Wireless and sensor networks



High-speed networks

Prof. Alan Willner Prof. John Silvester



- Wireless and sensor networks (Krishnamachari, Psounis, Raghavendra)
- Algorithms and protocols for wireless networks (Krishnamachari)
- Network control, optimization and games (Jain)
- High performance computing networks (Silvester)
- Optical communications and networks (Willner)
- Information theory (Avestimehr, Mitra)
- Routing and Scheduling (Neely, Avestimehr, Molisch)
- Body area networks (Mitra, Molisch)
- MM-wave directional links (Willner, Molisch)
- Video networks (Molisch, Neely)
- MIMO systems, propagation channels, cognitive radio (Molisch, Mitra)
- Modulation and Coding (Chugg)
- Underwater systems (Mitra)
- Quantum Information Processing (Brun, Lidar, Reichardt)

Information theory

Prof. Salman Avestimehr Prof. Urbashi Mitra



Networks, wireless communications, and coding

Prof. Rahul Jain Prof. Michael Neely Prof. Andreas Molisch



Prof.

Konstantinos Psounis Prof. Bhaskar Krishnamachari

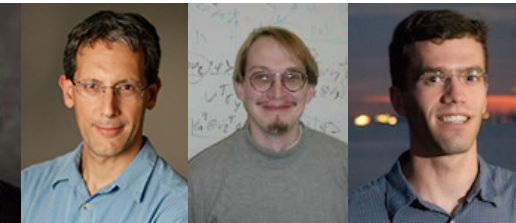


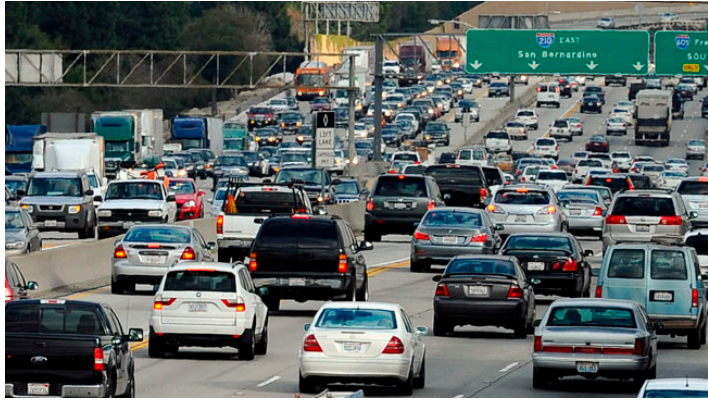
Prof. Keith Chugg



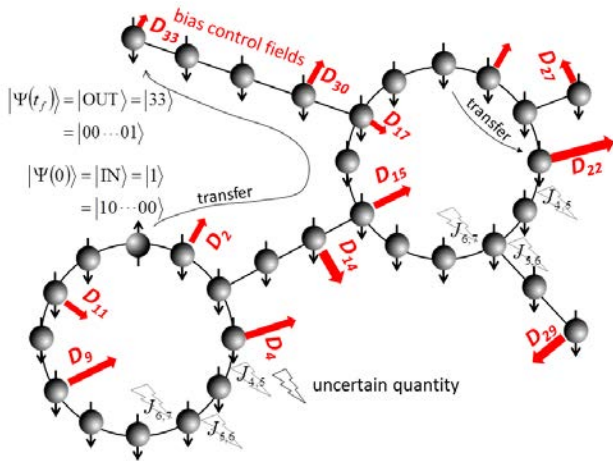
Quantum information processing

Prof. Daniel Lidar Prof. Todd Brun Prof. Ben Reichardt





Transportation networks (Ioannou)



Quantum adiabatic computations to solve network optimization subject to noise constraints (Jonckheere)

Control



Power grid, network of dynamical distributed systems (Jonckheere, Ioannou, Jain, Jovanovic)

- Robust, multivariable, nonlinear, big data driven adaptive control (Ioannou, Jonckheere, Jovanovic)
- Network control
 - Transportation networks (Ioannou)
 - Power grid (Jonckheere, Jain)
 - Stochastic networks and network economics (Jain)
 - Congestion control (Jonckheere, Krishnamachari)
- Quantum and cyber-physical control (Jonckheere, Lidar, Bogdan)
- Dynamics and control of distributed systems (Jovanovic)
- Stochastic control and communications (Nayyar)
- Network market design and power system economics (Jain)

Prof. Rahul Jain

Prof. Mihailo Jovanovic

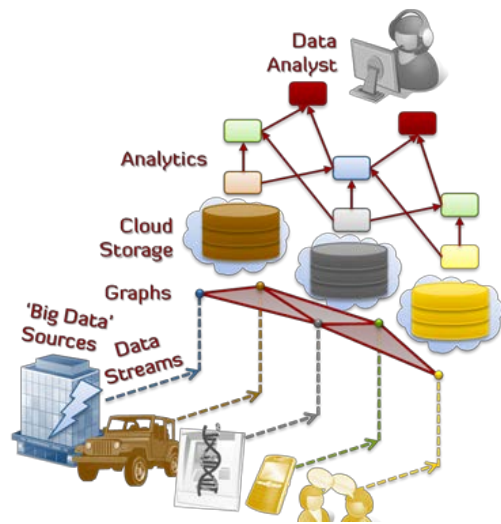
Prof. Edmond Jonckheere

Prof. Paul Bogdan

Prof. Petros Ioannou

Prof. Ashutosh Nayyar





Data Centers, Cloud Computing, Big Data

Computer engineering

- Data centers, cloud computing, big data (Annavaram, Hwang, Prasanna)
- Tools and techniques for hardware resilience (Annavaram, Dubois)
- GPUs and GPGPUs (Annavaram)
- Parallel and distributed processing, FPGAs, GPUs, Accelerators (Prasanna)
- Cross-stack graph processing acceleration (Qian)
- Accelerating applications using emerging memory technology (Qian)
- CMP protocols and micro-architectures (Dubois)
- Cyber Physical Systems (CPS) (Bogdan)
- Methodologies and tools for the design of CPS and the Internet-of-Things (Nuzzo)
- BioRC biomimetic real-time cortex (Parker)
- Asynchronous circuits (Beerel)
- Energy-efficient information systems and CAD (Pedram)
- Yield and testing (Gupta)

Prof. Murali
Annavaram

Prof. Peter
Beerel

Prof. Paul
Bogdan

Prof. Sandeep
Gupta

Prof. Pierluigi
Nuzzo

Prof. Massoud
Pedram

Prof. Alice
Parker

Prof. Victor
Prasanna



Example research project: The AutoDRIVE Lab

- Average human driving records ~200 crashes/100 injuries/1 fatality per 100M vehicle miles travelled (150x greater deaths vs. commercial airline miles flown)
- Current autonomous driving technology no match! Achieves ~1 disengagement per 2-5k miles
- Need new/different methods
- Formal Reinforcement Learning to learn from safe human driving demonstrations and yet satisfy formal safety specifications to match human driving performance
- autoDX: An Experimental testbed for a signalized traffic intersection with scaled vehicular models equipped with cameras, radar, ultrasonic sensors, GPS, etc. and a high-fidelity driving simulator



Prof. Pierluigi
Nuzzo

Prof. Rahul
Jain



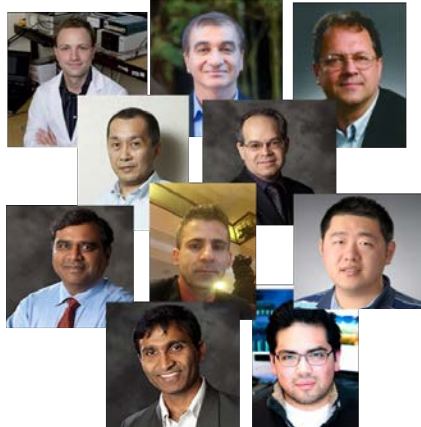
Artificial Intelligence (AI) for Safe Autonomy



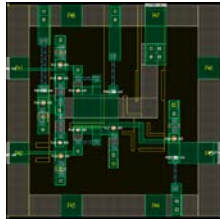
ColdFlux: CAD methodologies and tools for single-flux quantum-based superconductive electronics

- The ColdFlux project develops design flows, tools, and capabilities to empower VLSI design of Superconductive Electronics (SCE) as a step toward the realization and widespread deployment of ultra energy-efficient and high-performance superconductive computing fabrics
- The ColdFlux team is conducting research and developing Single Flux Quantum (SFQ) cell libraries with a comprehensive set of open-source EDA tools to enable compact modeling and simulation of devices and gates and VLSI design and verification of SFQ circuits at least from the RTL description down to mask layout

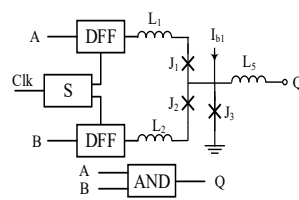
University of Southern California
 University of Florida
 Northeastern University
 Stellenbosch University
 Université Savoie Mont Blanc
 Yokohama National University



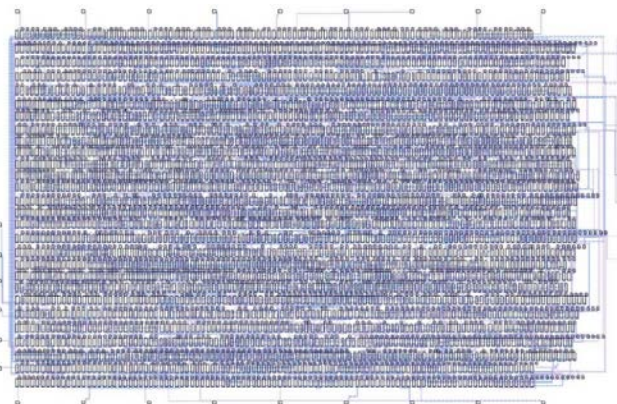
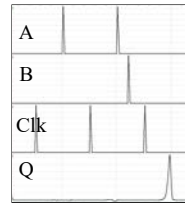
ColdFlux team members



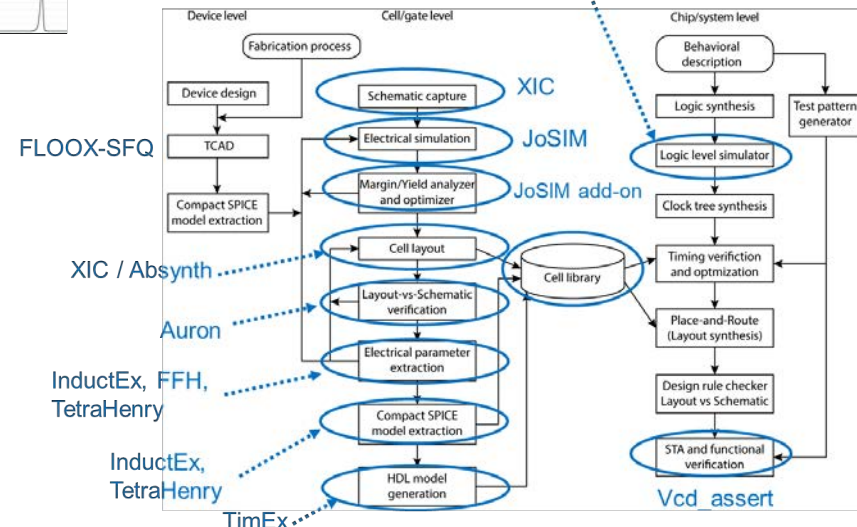
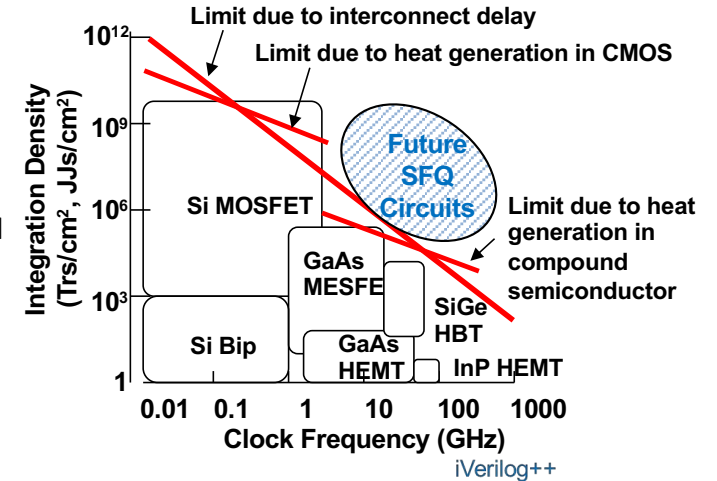
AND2 gate done in MIT LL
 100 μA/μm² SFQ5ee process



SFQ And2 logic gate with
 simulation result



Design and layout of an 8-bit integer divider (> 50,000 JJ's , 50 mm² area)



Example research projects: New computing paradigms: Coded and Neuromorphic Computing

Shannon's Coding Theory

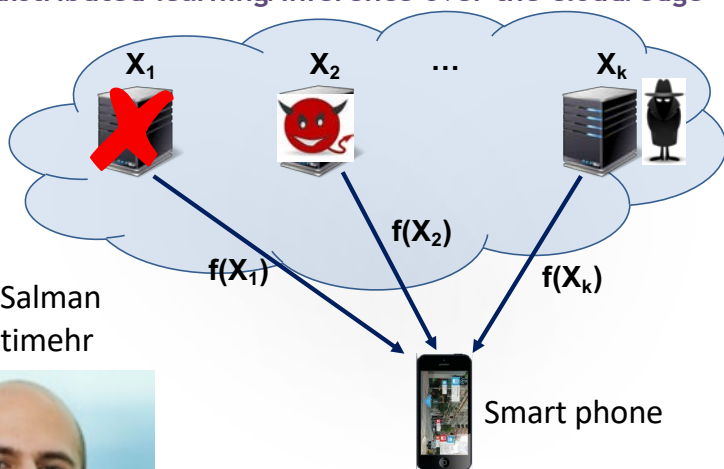


von Neumann's Computing Theory



Coded Computing

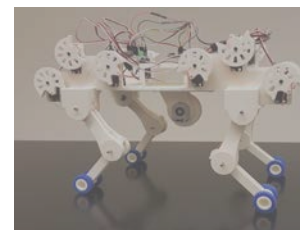
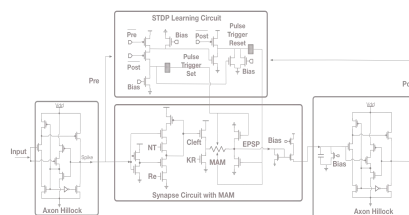
is distributed learning/inference over the cloud/edge



Prof. Salman Avestimehr



- What if some nodes straggle/fail?
- What if some nodes are malicious?
- What if we want to keep data private?



NeuRoBot: quadruped robot with neuromorphic spinal cord

- The *NeuRoBot* with a nervous system is learning new tasks continuously, overlaid on existing analog electronic neurons modeling the cortex
- The *NeuRoBot* features neuromorphic implementations of biological systems
- Learning mechanisms have a biological basis, include synaptic, dendritic and structural connectivity and plasticity
- *NeuRoBots* are learning to perform locomotor tasks by exploiting plasticity and reward mechanisms (electronic dopamine) at the neural level
- We are imbuing a biomimetic quadruped robot with a neuromorphic spinal cord that implements reflexes and drives simulated muscles

Coded computing provides a framework for **Resilient, Secure, and Privacy-Preserving** distributed machine learning

Prof. Francisco Valero-Cuevas (BME)



Prof. Alice Parker



The Center for Intelligent Biosensing, Imaging, Analysis and Control (CIBIAC)

- Example of group activity that may migrate to the Michelson Center for Convergent Bioscience (MCCB)
 - **5 key ECE faculty:** Maryam Shanechi, Justin Haldar, Krishna Nayak, Shri Naryanan and Richard Leahy
 - Active funding in which one of the 5 CIBIAC faculty is **PI** exceeds \$40M (~\$10M/yr)
 - Currently, 56 PhD students, 6 postdocs, and 2 research faculty
 - With recruitment of two new junior faculty, anticipate expansion to total of approximately 85 individuals
 - Unique **experimental facility** enabled by \$2.4M NSF instrumentation grant to develop a new whole-body high-performance low-field (0.5T) MRI scanner optimized for use in dynamic speech, sleep, cardiac, and musculoskeletal imaging studies, likely to be located in the basement of MCCB



Maryam Shanechi Justin Haldar Krishna Nayak Shri Naryanan Richard Leahy





Welcome to the
Ming Hsieh Department of
Electrical and Computer Engineering
Making Ideas Work in the Real World

Additional background material

Information Sciences Institute

- Founded in 1972 and headquartered in Marina Del Rey
- \$100M+ annual budget
- Pioneering contributions to some important technologies
 - Foundational contributions to the Internet
 - Fundamental contributions to electronics and several areas of AI
 - Home of USC/Lockheed Martin Quantum Computing Center
- Broad research portfolio combines basic and applied research
 - AI/ML, Networking, Cybersecurity, Electronics, Quantum Computing, Medical Informatics, Scientific Workflows, Space technologies
 - History of open source software: Karma – information integration tool (top 1% of GitHub downloads worldwide), Domain Insight Graphs



Computer Science

- 1200 undergraduate students, 2000+ M.S. students, 300 Ph.D. students
- Ranked 11th in USA by *U.S. News and World Report* (2017)
- 45 T/TT full-time faculty
- Research areas:
 - Artificial Intelligence, Agents, Natural Language, Vision (total faculty: 25)
 - Computational Linguistics, Statistical Machine Learning Lab, Data Science Lab
 - Databases and Information Management (total faculty: 6)
 - Database Lab, Machine Learning and Data Mining Lab, Semantic Information Research
 - Graphics, Games & Multimedia (total faculty: 9)
 - Computer Graphics and Immersive Technologies, USC Gamepipe Laboratory
 - Parallel and Distributed Computation (total faculty: 4)
 - Collaboratory for Advanced Computing and Simulations (CACs), FPGA/Parallel Computing Group
 - Privacy & Security (total faculty: 3)
 - Center for Computer Systems Security, Privacy Research Lab, STEEL Security Research Lab
 - Robotics, Brain Theory, and Computational Neuroscience (total faculty: 10)
 - USC Brain Project, Interaction Lab, Polymorphic Robotics Lab, Computational Social Science Lab
 - Software Systems and Engineering (total faculty: 3)
 - US Center for Systems and Software Engineering (CSSE)
 - Systems, Distributed Systems, Communication Networks (total faculty: 7)
 - Quantitative Evaluation & Design Lab (QED), Autonomous Networks Research Group, Networked Systems Lab
 - Theory and Computational Sciences (total faculty: 10)
 - Collaboratory for Advanced Computing and Simulations (CACs), CS Theory Group