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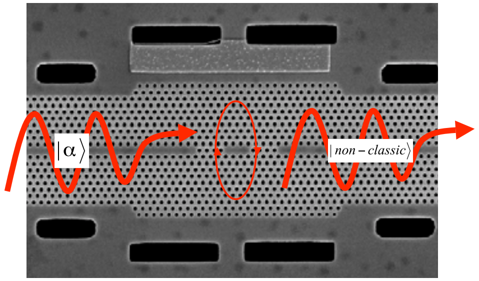
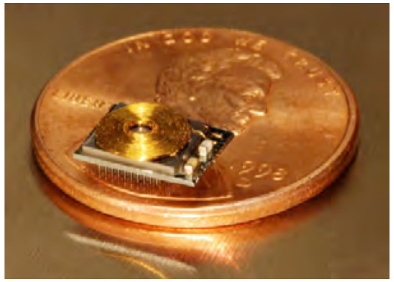
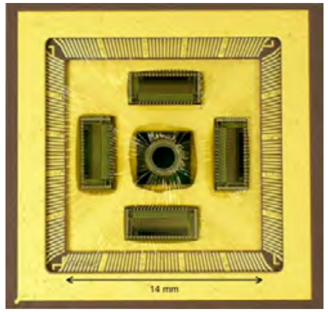
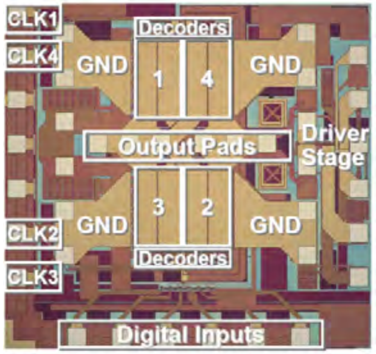




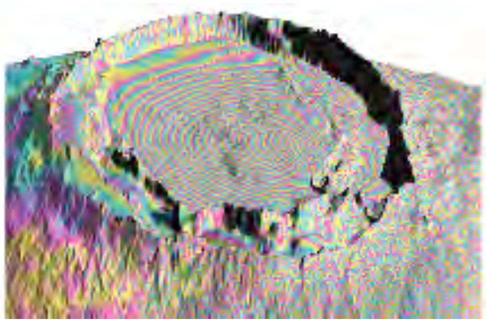


EE
Where the Virtual World Meets the Real World



1.3x1.4mm^2 in 0.18µm CMOS

Mark Horowitz, Stanford



Entrepreneurial History

- History of EE at Stanford:
  - Power Systems (think Hoover Dam)
  - Radar / Radio
  - Digital communication / Information Theory
  - Solid State
  - Integrated Circuits
  - Computer Systems

- Look beyond the traditional areas of activity
  - Find new “tools” to use and new problems to solve

Entrepreneurial History

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EE is a Successful Department

- Usually the largest department in Engineering School
  - Closely affiliated with CS
- Source of great job creation
  - And careers for students
- Rightly associated with high-technology
  - And the IT revolution
  - When people think of EE, they think IT

The Problems With Success

- We have won – everything has a chip in it
  - But fame is fleeting
    - People expect cards to talk
- But this is also part of the problem
  - Technology is sufficient complex, it is hard to engage
  - Have you taken apart any of your gadgets?
- Concern about the slowing of the IT engine
  - And thus concern about EE

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Silicon Technology Will Mature

- Silicon will not disappear
  - It will still be a huge business
    - Growth rate is slower, Eventually very slow scaling
- Silicon will become like concrete and steel
  - Basis of a huge industry
  - Critical to nearly everything
  - But fairly stable and predictable
- Will remain the dominate substrate for computing
  - And performance be limited by power dissipation

Changes are Exciting Times

- Technology scaling will slow down
  - The world will be different than people expect
  - That will create lots of dislocations, and stress
    - But that is not bad, creates opportunities
- Today is an exciting time for device researchers
  - Lots of creativity in different kinds of devices
  - Lots of More then Moore work
    - A single power device costs more than 1M transistors
- Remember Our History
  - EE is not about technology scaling
    - We are no more a tech scaling shop then a radio shop
    - Leverage our skills to new problem areas

What We Learned Riding Moore's Law

- The interface between physical and virtual
  - Convert anything into bits; use bits to control anything
    - Electronic, photonic, magnetic, and micro-mechanical
- The science & technology of information
  - Analyze and manipulate information
  - From basic abstractions to dynamic control & optimization
- Design and control of complex systems
  - From basic foundations to materials, circuits, & systems
  - Creating reliable & programmable systems
    - Which exponentially grew in complexity
- While keeping entrepreneurship and societal impact
  - Societal needs => innovative research => widely-used stuff

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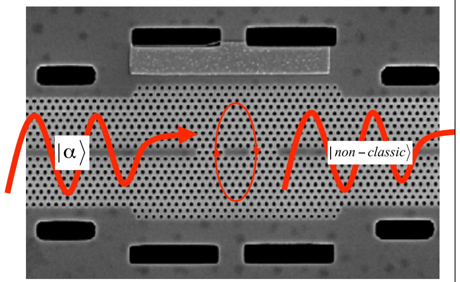
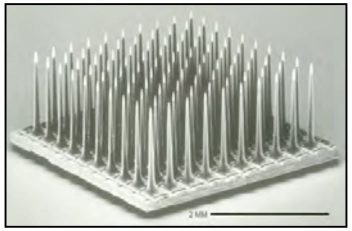
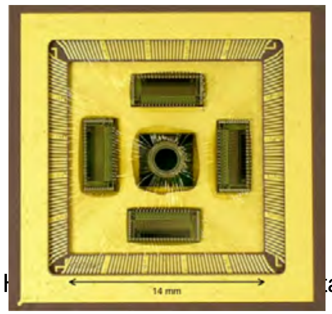
Moving These Skill to New Areas: Very Exciting Future

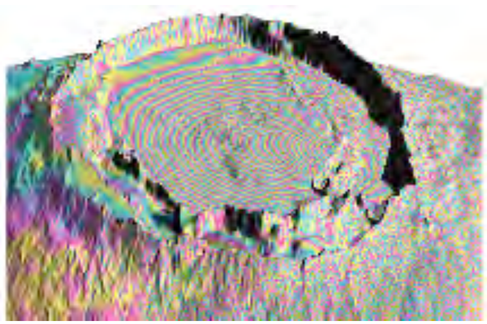
- Addition of bio / nano to math and physics
  - New systems measure / model
  - New underlying technology to build systems



- The rise of sensing / imaging /communication
  - Most problems need more data
  - Leveraging new phenomena for measurement
  - Many interesting new ways of creating images
    - Both through capture and computation







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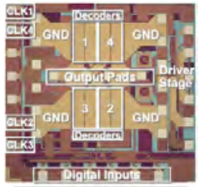
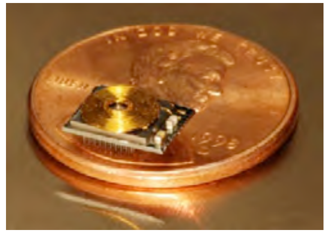
Exciting Future, cont'd

- Systems / Circuit Design
  - Embedded systems; large distributed systems
  - Complexity is crushing us but
    - Demand for customized systems will increase
  - Need to rethink how we design systems



1.3x1.4mm² in 0.18µm CMOS



- Extracting information from data / acting on it
  - Optimization, probabilistic methods, machine learning
  - Autonomous vehicles / control

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Visions of the Future

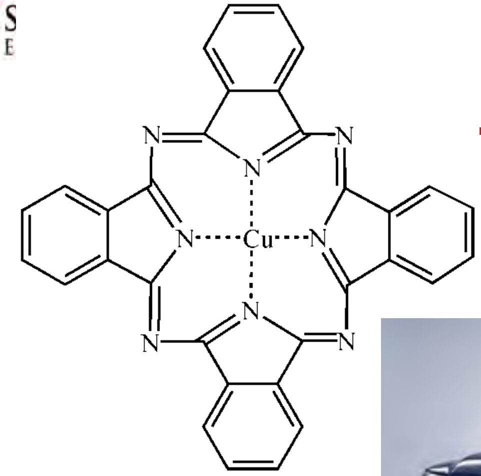
- Energy Efficiency and Environmental Sustainability
  - Efficient generation, transfer, and load control of energy
  - Continuous analysis of interactions with the environment
  - Dynamic influencing societal networks through incentives
  - New manufacturing technologies that are greener
- Human Healthcare
  - Continuous monitoring and analysis of human health
  - Intelligent devices to revolutionize treatment methods
- Scalable Information Technology
  - Reliable systems at nano and mega scales
  - Computation, networking, & storage available anywhere
    - At no cost

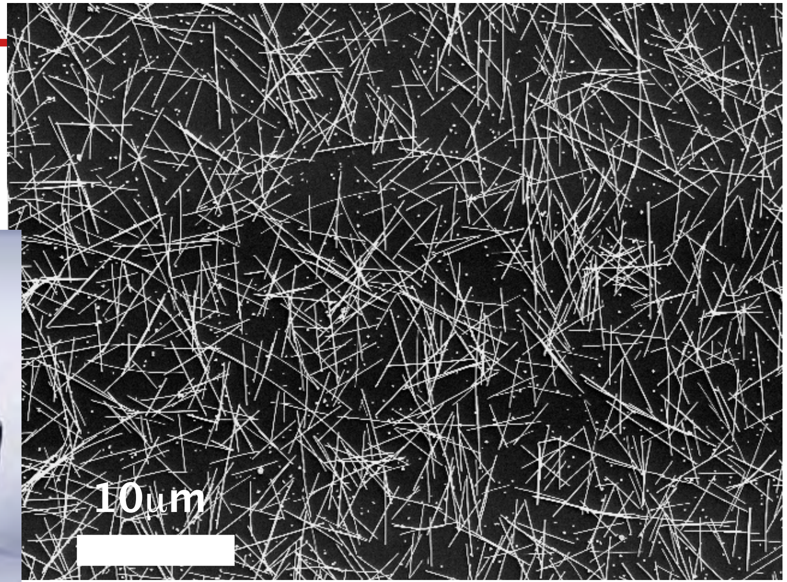
EE Skills are Key in All of These Areas

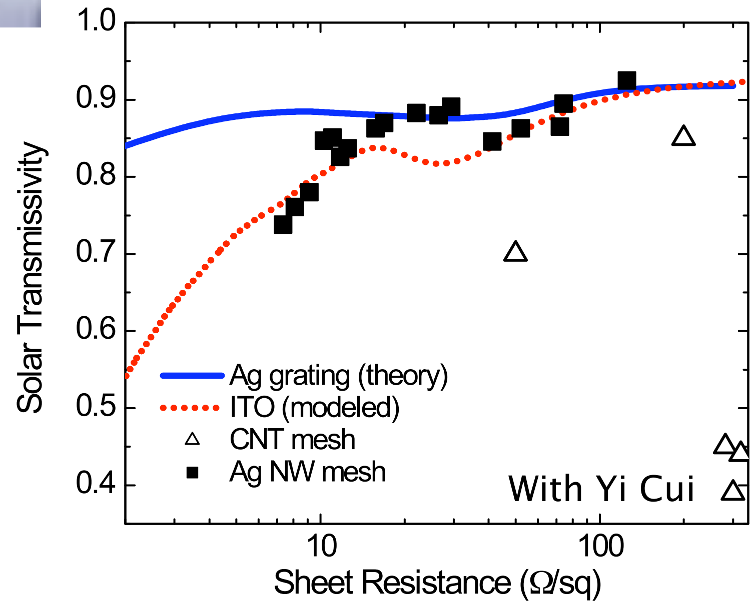
- All require coupling physical world to IT
  - Information processing is so cheap
  - Great way to analyze / communicate / process / control

- Most are complex systems
  - We have had large experience dealing with complexity
  - Our systems have been doubling for decades
    - Both in what we design and use

Organic Solar Cells

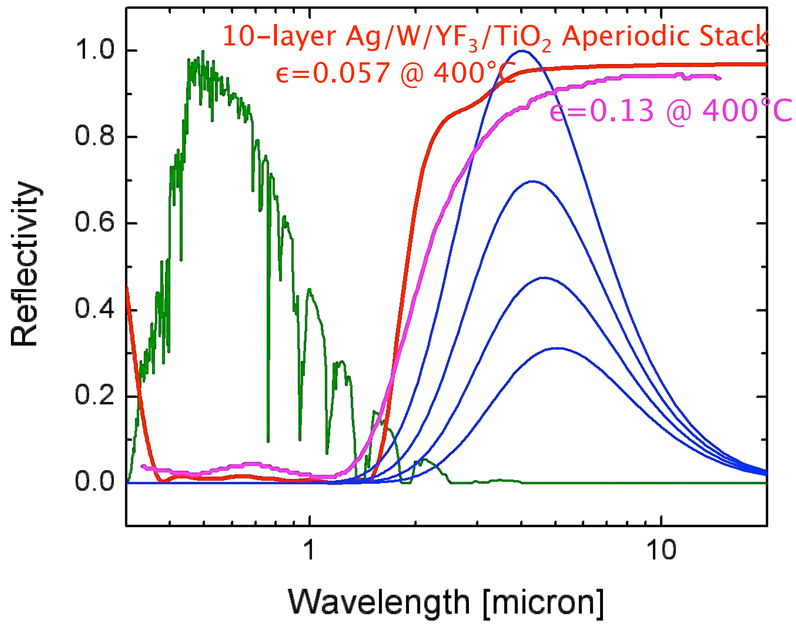


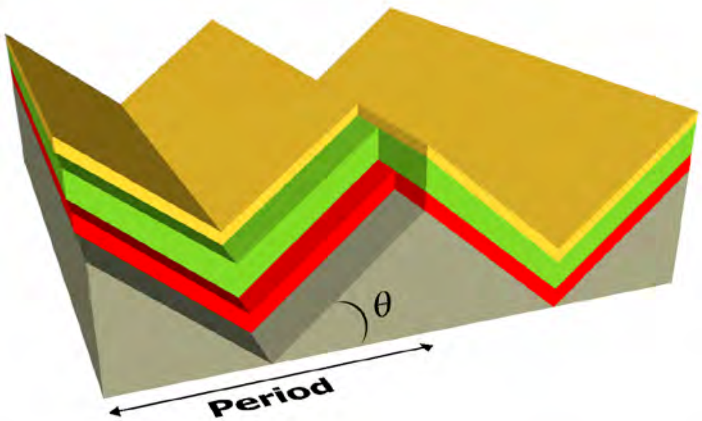




Photonic Crystal Solar Thermal Systems

SEGS @ Kramer Junction. Total 354MW capacity.





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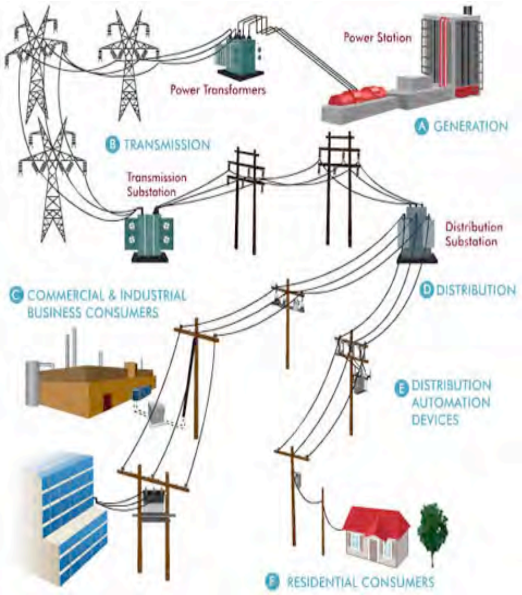
Active Energy Management



- Enable high % renewable energy on grid
- The nature of the challenge
  - Multi-scale: concepts applied at all levels, from individual devices to the overall grid
  - Multiple agents: optimize functionality & financial benefits for all parties (producers & consumers) and environmental impact
- Core research
  - Sophisticated real-time modeling and optimization techniques
  - Energy storage techniques
  - Low cost sensors and communication mechanisms
  - Hierarchical, secure network of all systems
  - Systems architectures for energy efficiency and automated management

Manage Societal Networks

- Societal network
  - Resources + Technology + Humans
- Goal:
  - Use continuous monitoring and on-line incentive mechanisms to align individual behavior with social good
- Examples
  - Road congestion & air pollution reduction
    - Through pricing incentives
  - Improving recycling efficiency

Instrumenting & Assisting our Bodies

- Revolution just starting in implantable medical systems
- Goal: Highly instrument our bodies, make decisions on these real-time streams, and directly assist our bodies
- Examples
  - Continuous monitoring of glucose levels => automatic, intelligent delivery of insulin
  - Continuous monitoring of brain waves => administering electric stimulation to prevent epileptic seizure onset
  - Continuous decoding of neural signals of paralyzed patients => control prosthetic limbs

Non-Invasive Diagnosis and Therapy

Future of Brain Surgery

Near Term (2010)

High-Intensity Focused Ultrasound (HiFU) with MR Guidance (Insightec)

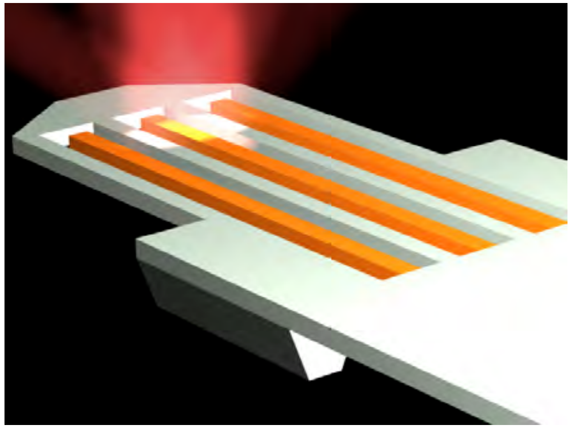
In Ten Years (2020)

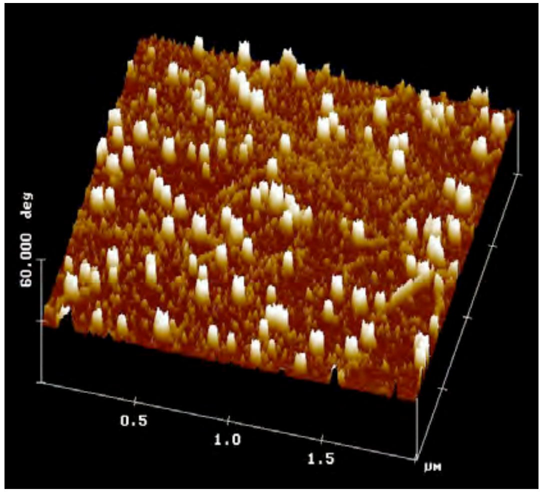
From: *Star Trek IV: The Voyage Home*

- Goal: targeted delivery and reception of energy deep within the body using ultrasound, RF, and light in order to perform disease specific imaging coupled with localized, precise, non-invasive treatment.
- Examples
  - Completely non-invasive surgery
  - Targeted drug activation and delivery with interactive image guidance.
  - Focused neuromodulation: activating specific brain areas noninvasively.

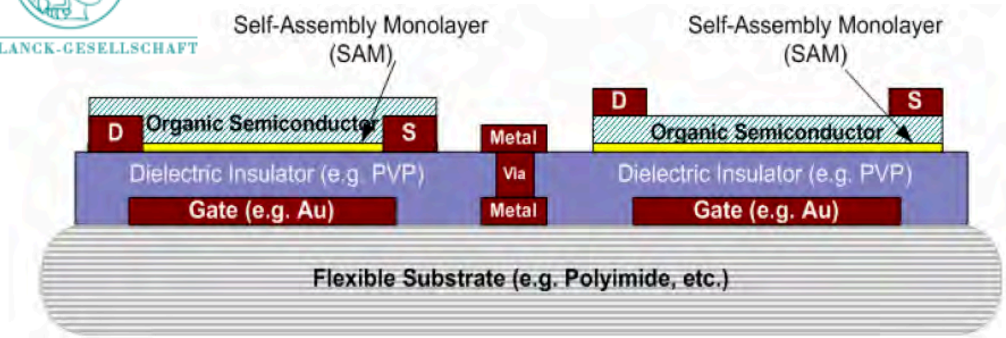
Time-Resolved Atomic Force Microscopy Using Differential Interferometric Sensors – Solgaard

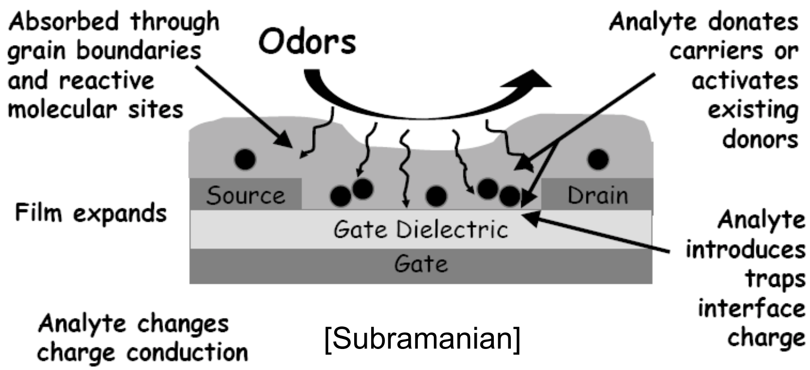
- AFM cantilevers with integrated, high-bandwidth, interferometric force sensors
  - Allows accurate measurements of the tip-sample interaction force with sub-microsecond temporal resolution
  - Enables quantitative characterization of material properties on the nanoscale
- Applications in imaging of samples with large variations in chemical and mechanical composition, e.g. bio-films on metal or dielectric surfaces





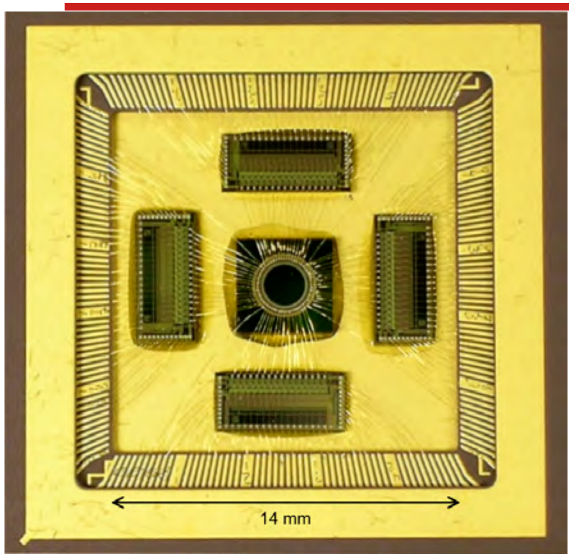
Sensor Circuits Using OFETS



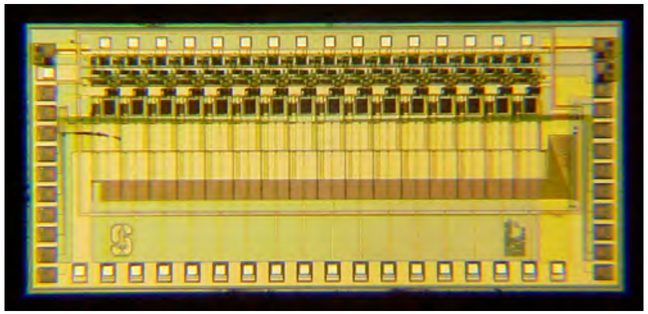


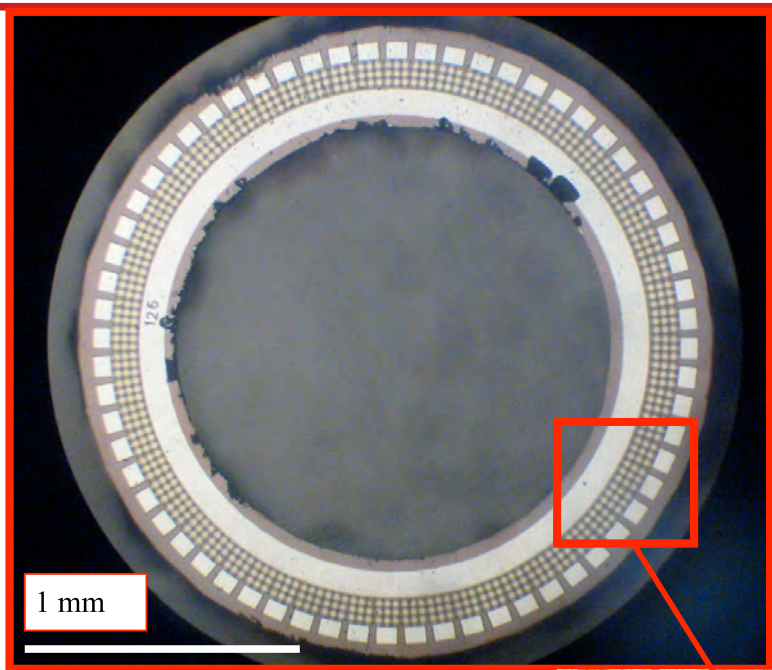
[Subramanian]

CMUT Ultrasound – Khuri-Yakub

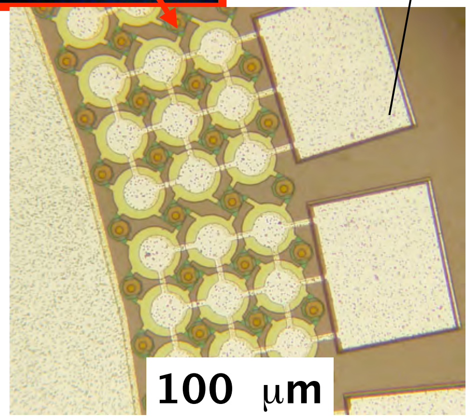


16-channel High-Voltage High Frequency
Frontend Integrated Circuits





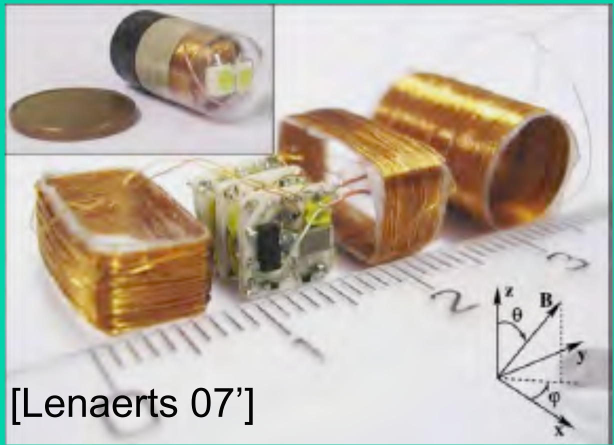
Individual
electrode
bond pad



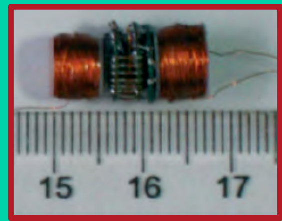
Forward-Looking CMUT
Annular Ring Array

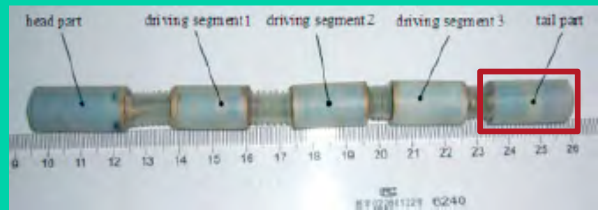
Collapse Operation at 20 MHz

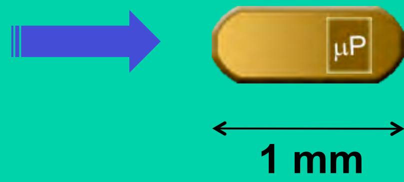
Active Electromagnetic Propulsion – Meng/Poon

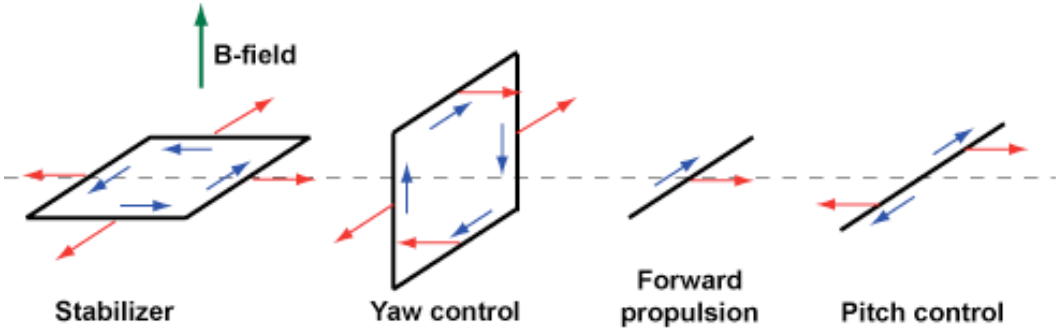


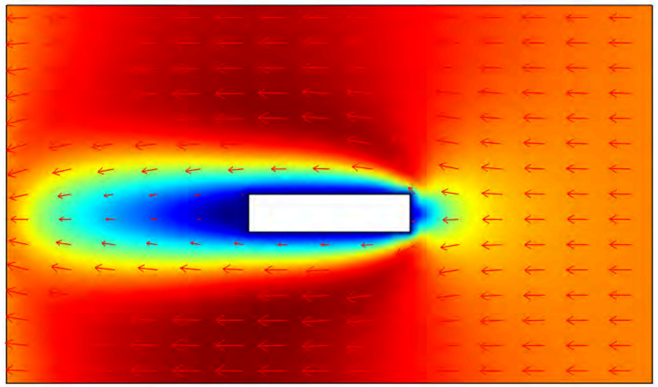
[Li 08']











- Force directly converted to thrust
- No mechanically moving part
- Highly controllable and scallable
- Low Reynolds number but fluid drag force α v^2

Power: less than 10 µW
Force: 500nN = .5µN (B = 0.5 T)
Device Size: 2mm x 2mm x .5 mm
Speed: approx. 3cm/s

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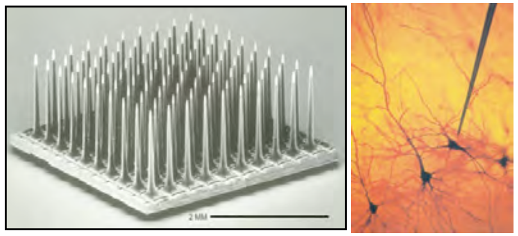
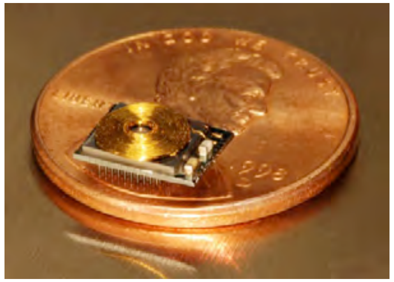
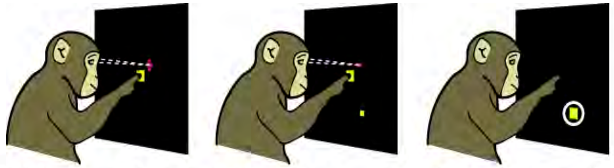
Neural Prosthetics Lab - Shenoy



a) Silicon BioMEMs electrode arrays

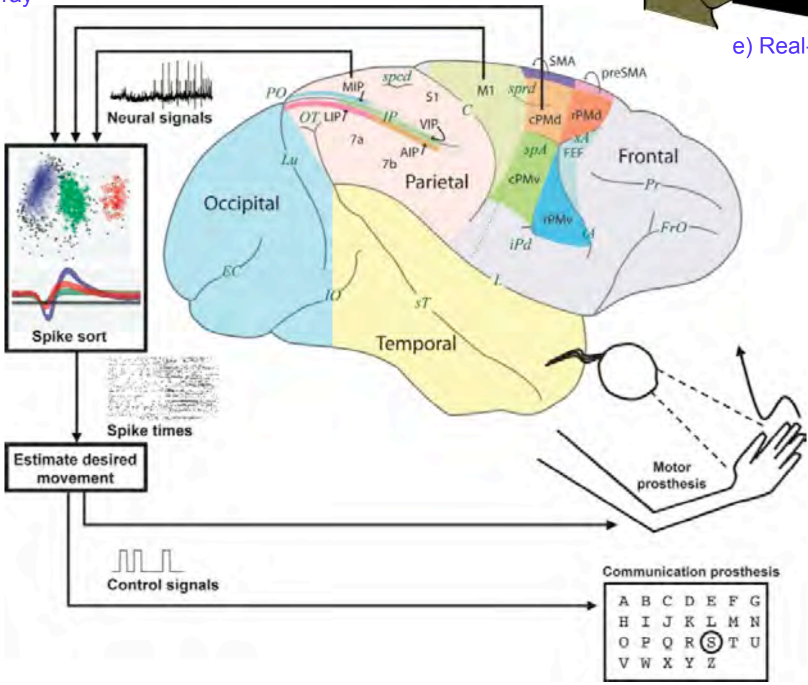


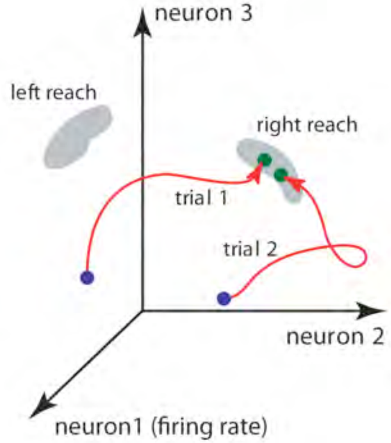
b) Integrated electronics & telemetry on array



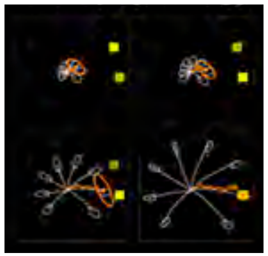
e) Real-time prosthetic system tests with monkeys

c) Mobile recording systems





f) Basic systems neuroscience



d) Real-time decode algorithms
(estimation & signal processing)

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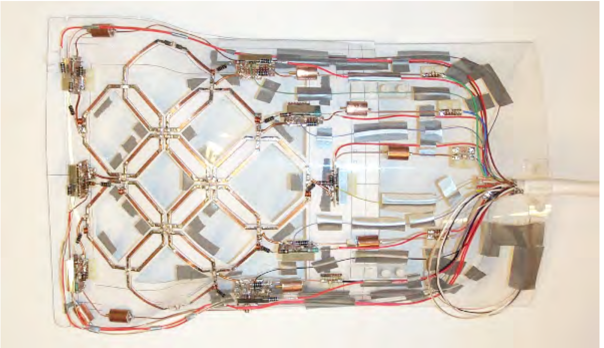
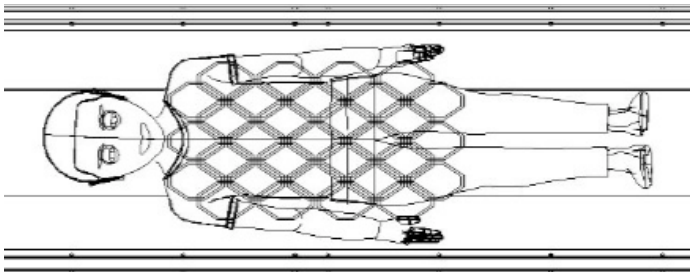
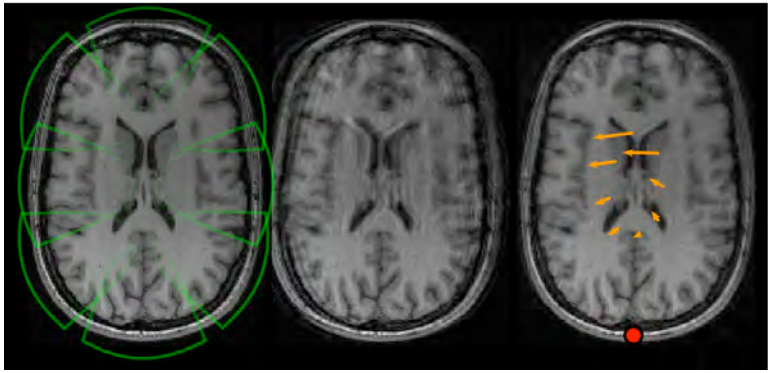
Pediatric Imaging - Pauly

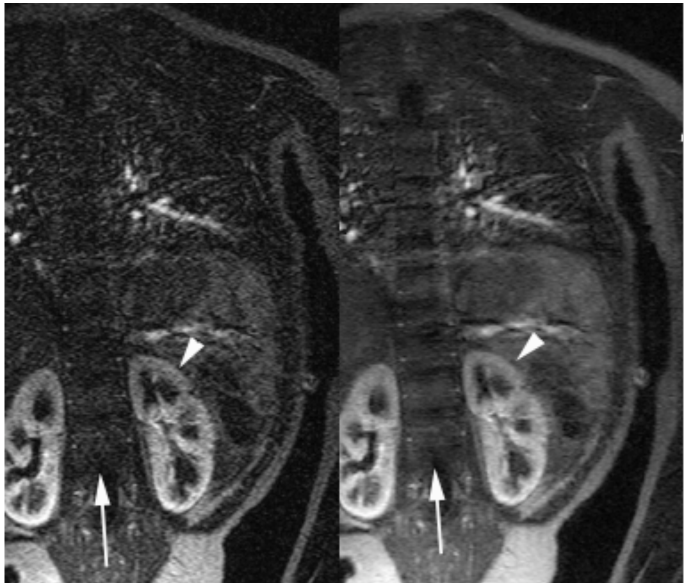




Highly Parallel Receive Arrays



Motion Correction



Compressed Sensing

Collaborators: Shreyas Vasanawala, Michael Lustig, Marcus Alley, Thomas Grafendofer
Students: Tao Zhang

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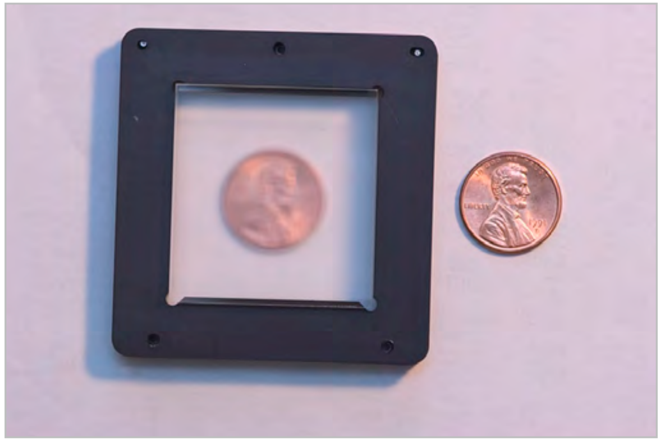
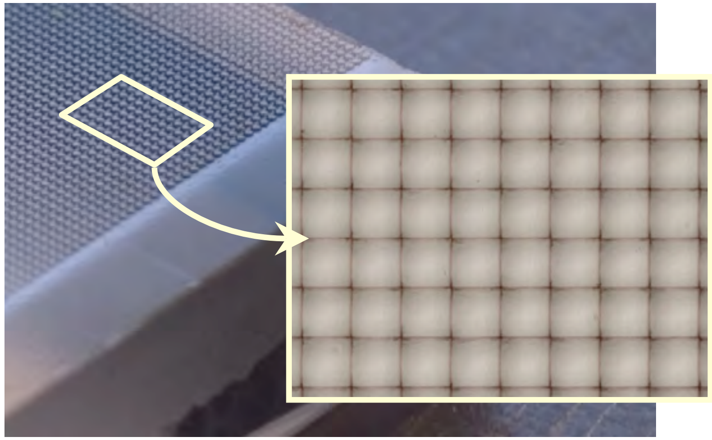
Light-Field Camera

Contax medium format camera

Kodak 16-megapixel sensor



Adaptive Optics microlens array



0.125 mm, square lenslets

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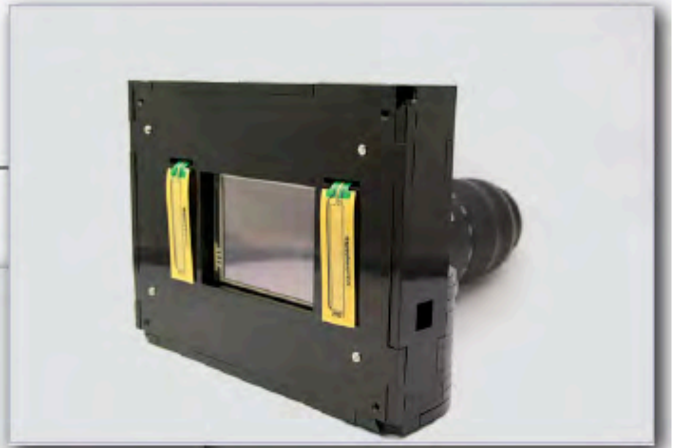
High-Speed Action

The Frankencamera

version 1

version 2



- for research we can't currently do on cell phones
- for students in computational photography courses worldwide
- testbed for the software architecture of computational cameras
- proving ground for plugins and apps for future cameras

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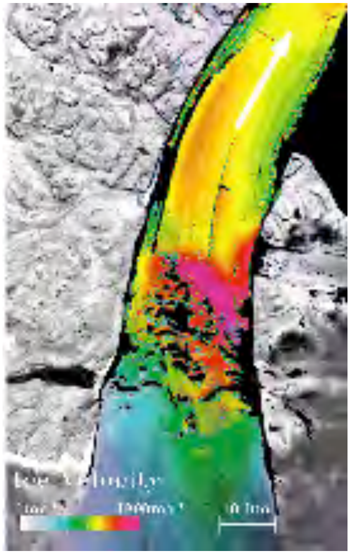
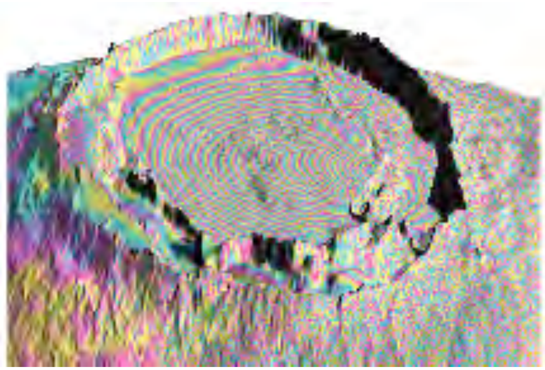
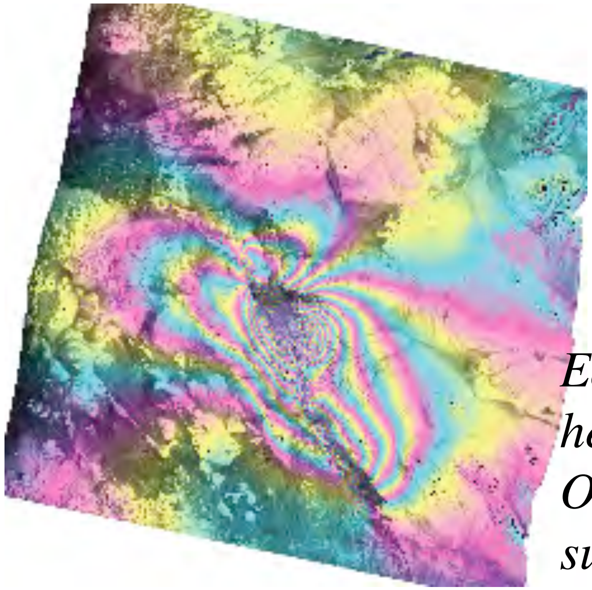
Radar Remote Sensing - Zebker

Glacier velocities, such as on this outflow glacier in Greenland, help determine the world's climate





Volcanoes distort the surface before eruptions, and deformations as observed here in the Galapagos Islands can predict future activity



Earthquakes in California - here is the Hector Mine (M7.1) Oct, 1999 event - displace the surface and allow us to estimate slip at depth along the fault

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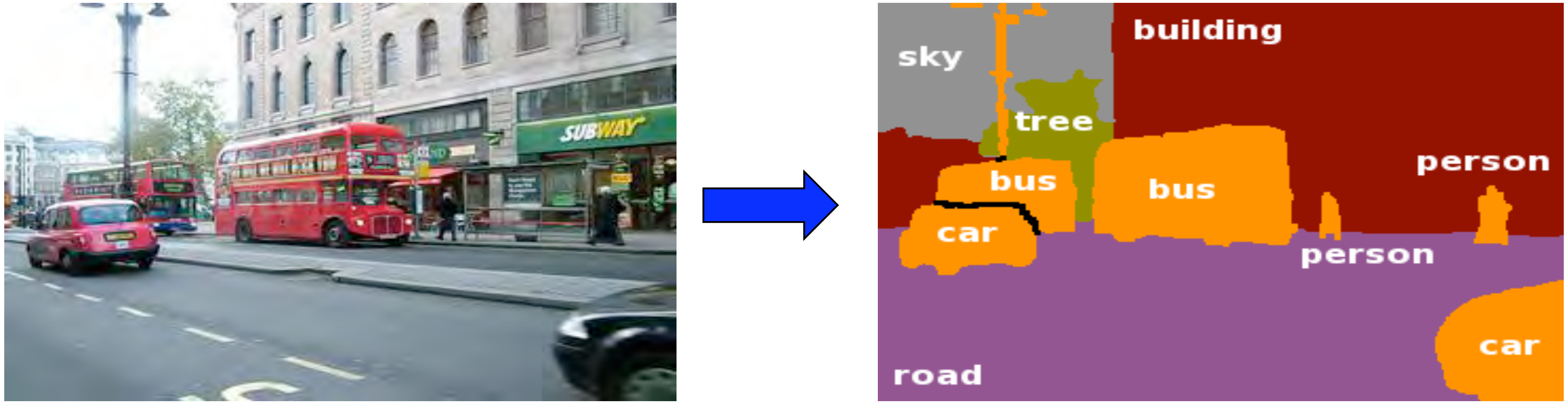
Goal: Holistic Understanding



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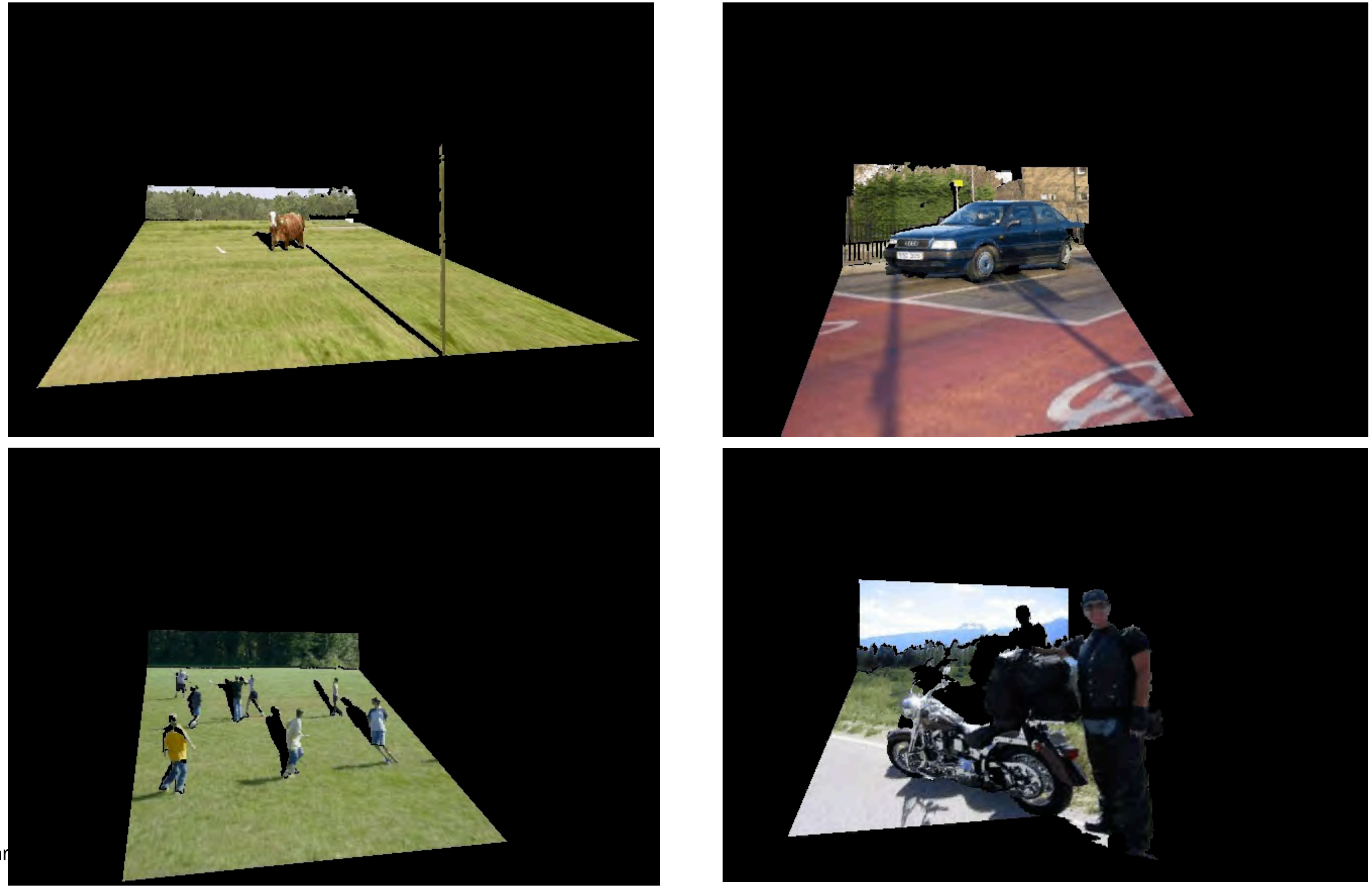
Example 3D Reconstructions



Stanley, the robotic car

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Junior Slide

The Stanford Autonomous Helicopter

How to fly it?

There is a lot going on in EE