Spring 2022

ECE 568: Embedded Systems

Lecture #2: Introduction to Embedded Systems

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Reading List for Lecture #2

- Reading List
  - Wikipedia articles on Embedded Systems, Internet of Things, and Cyber Physical Systems
    - http://en.wikipedia.org/wiki/Embedded_system
    - https://en.wikipedia.org/wiki/Internet_of_Things
    - http://en.wikipedia.org/wiki/Cyber-physical_system
  - David Blaza, "Shifting Sands: Trends in Embedded Systems Design," available at http://www.embedded.com/design/embedded/4372666/Shifting-sands–Trends-in-embedded-systems-design

What are Embedded Systems?

- Computing systems that are embedded into a larger product that may or may not be an electronic system
  - The primary goal of the larger product is not general information processing, in contrast to personal computer systems (servers, desktops, laptops)

- Pretty much any device that has computing intelligence inside it, but is not a computer by itself

Embedded, Everywhere

https://www.nap.edu/read/10193/

[Prabal Dutta, U. Michigan]

A "Short" List of Embedded Sys.

- Anti-lock brakes
- Auto-focus cameras
- Automatic teller machines
- Automatic toll systems
- Automatic transmission
- Avionic systems
- Battery chargers
- Camcorders
- Cell phones
- Cell-phone base stations
- Cordless phones
- Cruise control
- Curbside check-in systems
- Digital cameras
- Disk drives
- Electronic card readers
- Electronic instruments
- Electronic toys/games
- Factory control
- Fax machines
- Fingerprint identifiers
- Home security systems
- Life-support systems
- Medical testing systems

- Modems
- MPEG decoders
- Network cards
- Network switches/routers
- On-board navigation
- Pagers
- Photocopiers
- Point-of-sale systems
- Portable video games
- Printers
- Satellite phones
- Scanners
- Smart ovens/dishwashers
- Speech recognizers
- Stereo systems
- Teleconferencing systems
- Televisions
- Temperature controllers
- Theft tracking systems
- TV set-top boxes
- VCR's, DVD players
- Video game consoles
- Video phones
- Washers and dryers

- and the list goes on and on...

[Vahid, UC Riverside]

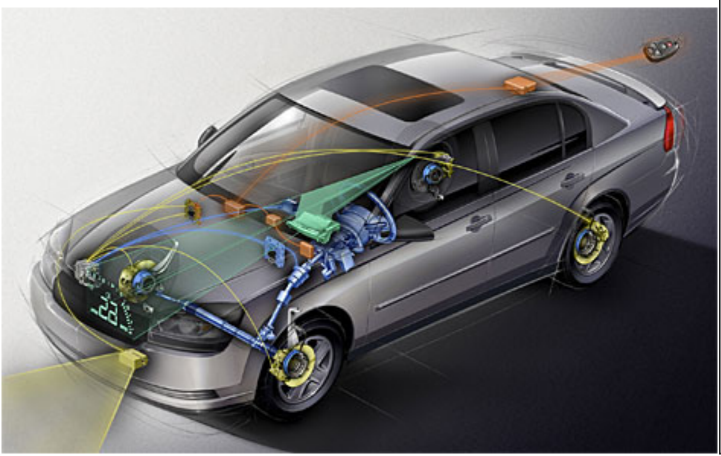
Example: Automotive Electronics

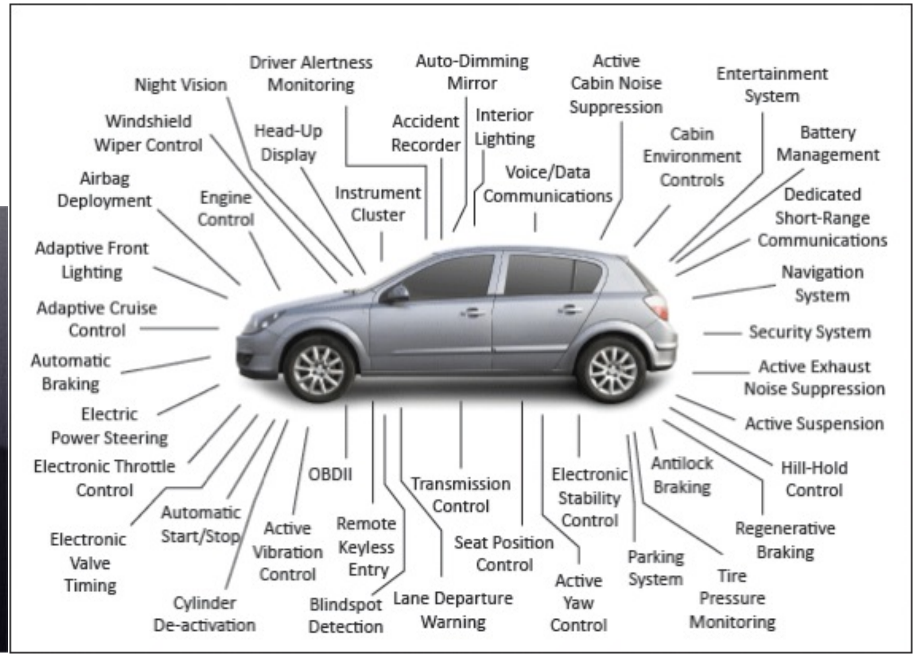
- Modern cars: Close to 100 micro-controllers running complex software
  - Engine and emissions control, stability and traction control, diagnostics, gear less automatic transmission, navigation, entertainment
  - http://www.howstuffworks.com/car-computer.htm

reliability of hardware & software within embedded system

- R. N. Charette, "This car runs on code", IEEE Spectrum, 2009
  - http://spectrum.ieee.org/green-tech/advanced-cars/this-car-runs-on-code

Tens of millions of lines of code!!!





What's driving this embedded, everywhere revolution?

1. Semiconductor Technology!

how did this affect the growth of embedded systems?

History of Semiconductor Tech.

- Computer History Museum
  - http://www.computerhistory.org/revolution/digital-logic/12/intro
  - Must see for every ECE/CS student

Great Videos

- We will look at two short videos to give us a glimpse into the world of semiconductor technology
  - [1] The Silicon Engine
  - http://www.computerhistory.org/revolution/digital-logic/12/272/2217
  - [2] From Sand to Silicon: Integrated Circuit Design and Manufacturing
  - http://www.computerhistory.org/revolution/digital-logic/12/288/2220
- Read the following overview article about Moore's Law:
  - http://arstechnica.com/gadgets/2008/09/moore/

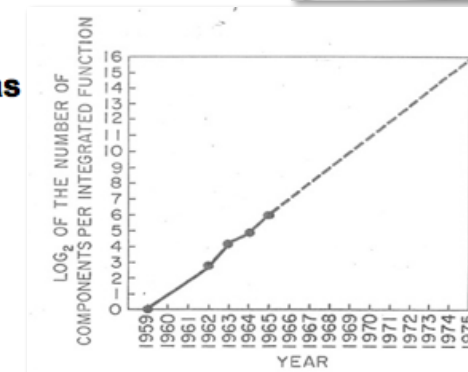
Video 2 Notes:

- Manufacturing of integrated circuits:
  - start off with a crystal seed
  - very, very slowly withdraw seed from a melt to create an even-sized ingot
  - ingot is sliced to be a pre-set, exactly measured thickness, and polished
  - polished wafer is placed in a furnace with highly-heated pure oxygen to form oxidizing layer "oxide" → impervious
  - a glass photomask with the pattern is created from the design
  - Dopants: change electrical properties of silicon

Moore's Prediction in 1965

Cramming more components onto integrated circuits

With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 65,000 components on a single silicon chip



By Gordon E. Moore

Director, Research and Development Laboratories, Fairchild Semiconductor division of Fairchild Camera and Instrument Corp.

The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas.

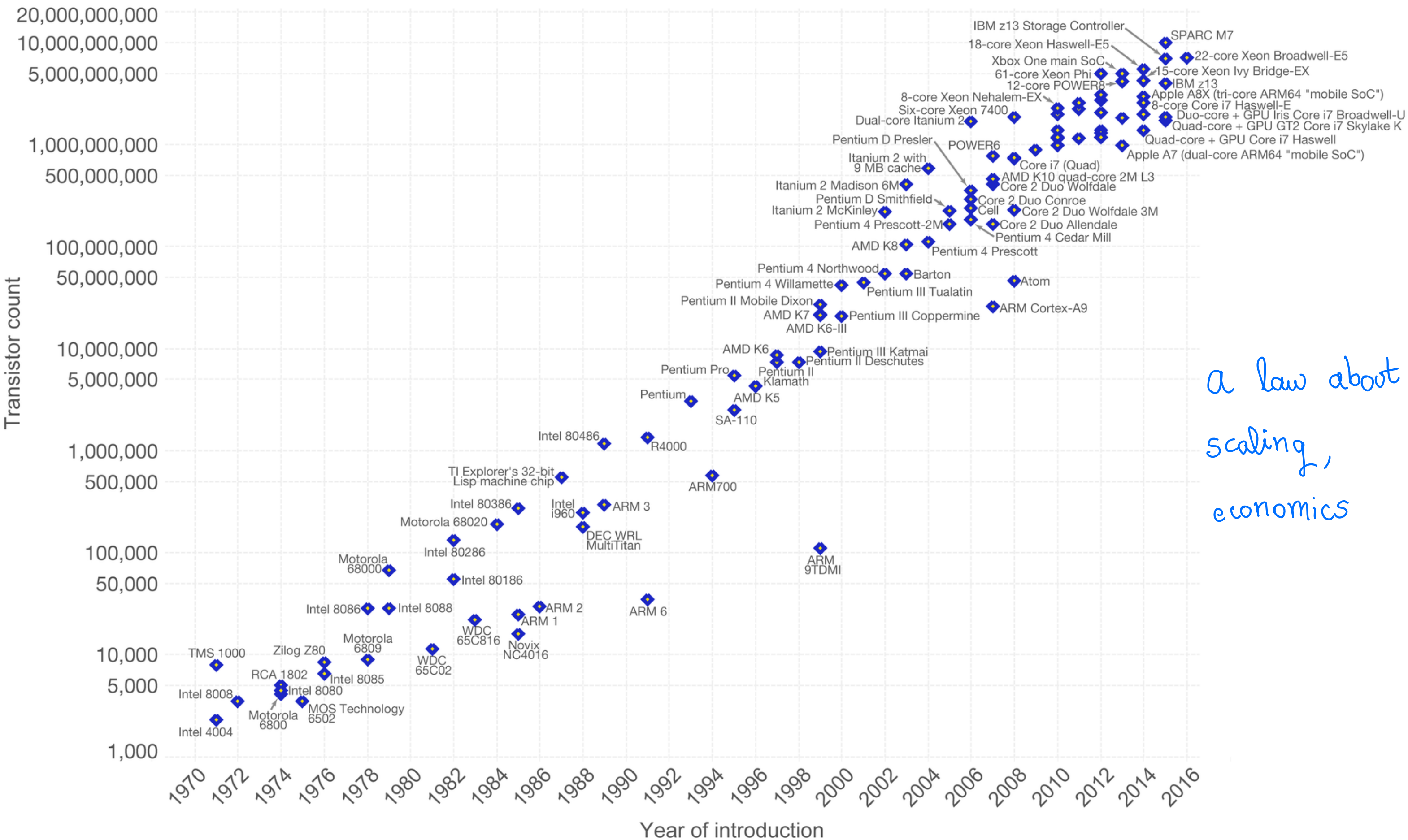
Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment. The electronic wrist-

machine instead of being concentrated in a central unit. In addition, the improved reliability made possible by integrated circuits will allow the construction of larger processing units. Machines similar to those in existence today will be built at lower costs and with faster turn-around.

Present and future

By integrated electronics, I mean all the various tech-

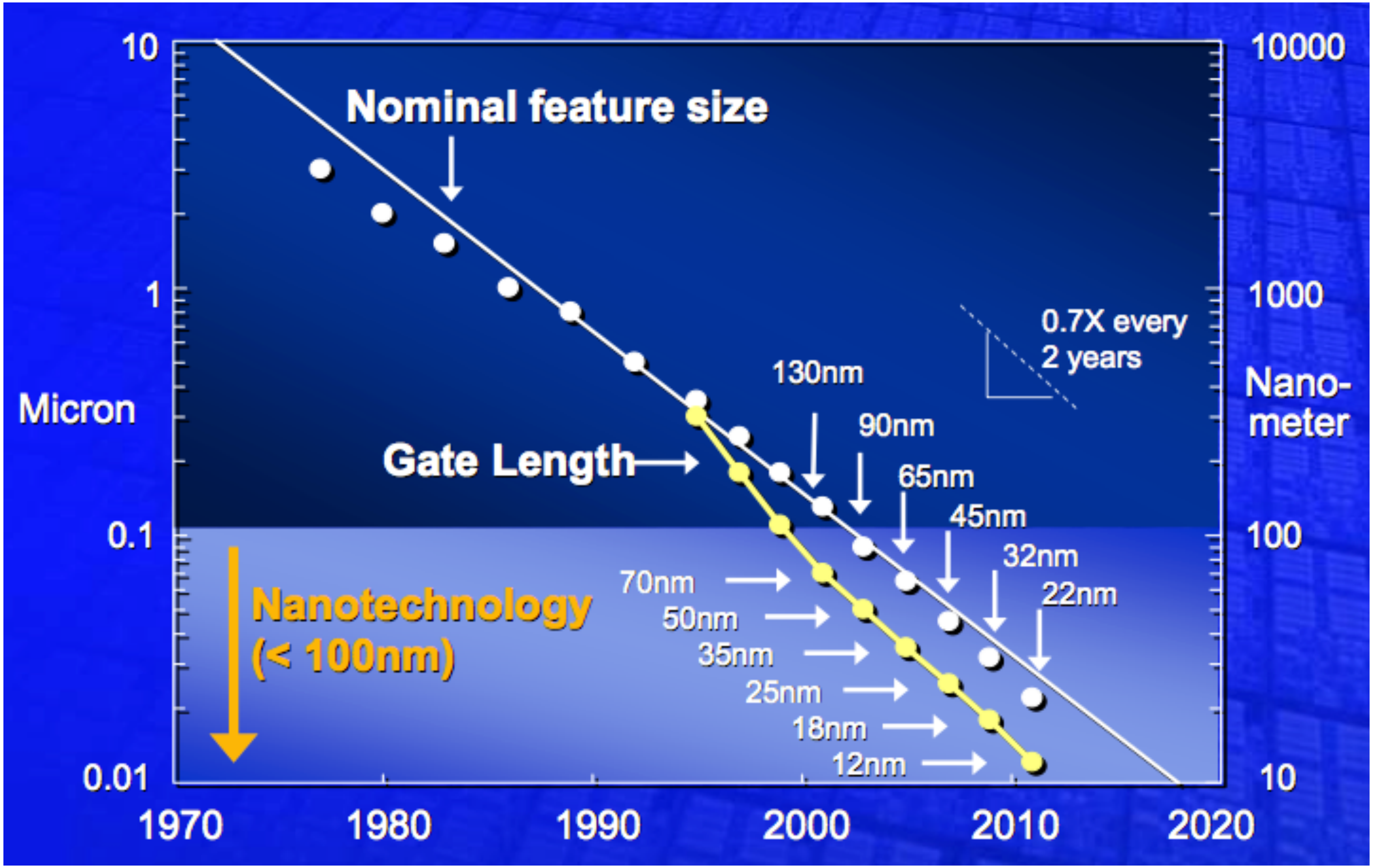
Moore's Law (1965 – now)



a law about scaling, economics

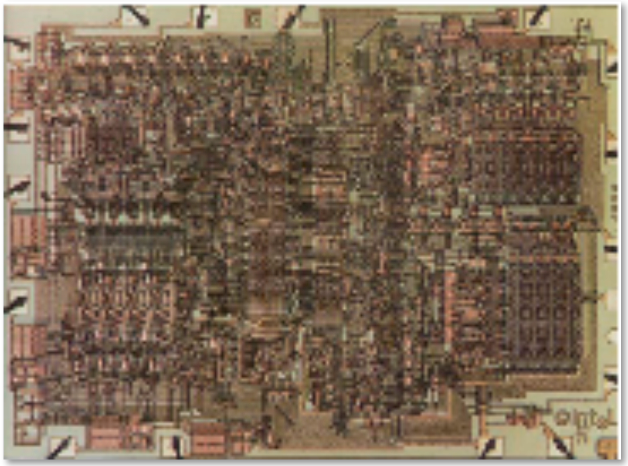
[Intel]

The Shrinking Transistor



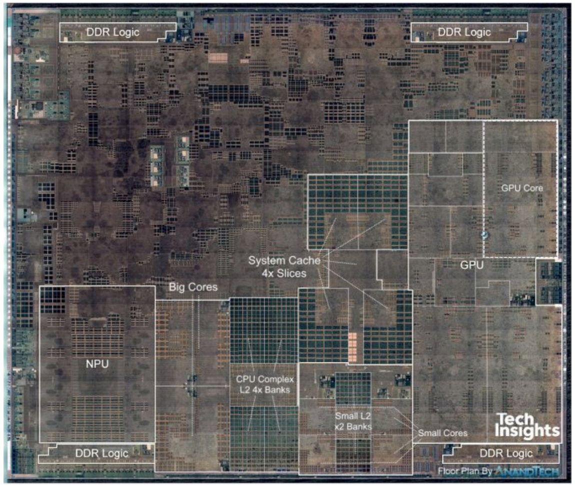
[Intel]

Chip of 1971 vs. Chip of 2018



Intel 4004 (first microprocessor)

- 2300 transistors
- 10 μm feature size
- 12 mm² die area



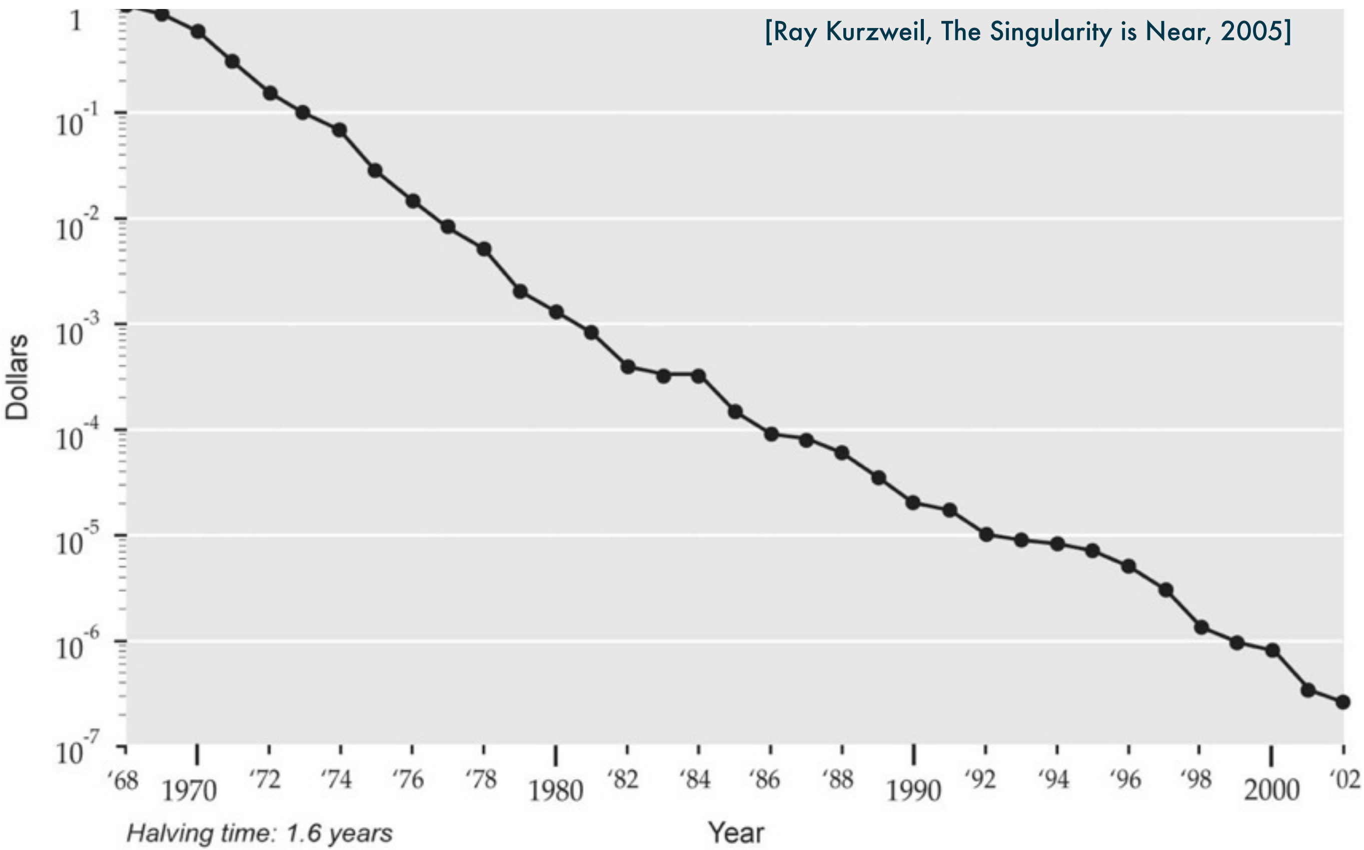
Apple A12X Bionic

- 10 billion transistors
- 7 nm feature size
- 122 mm² die area

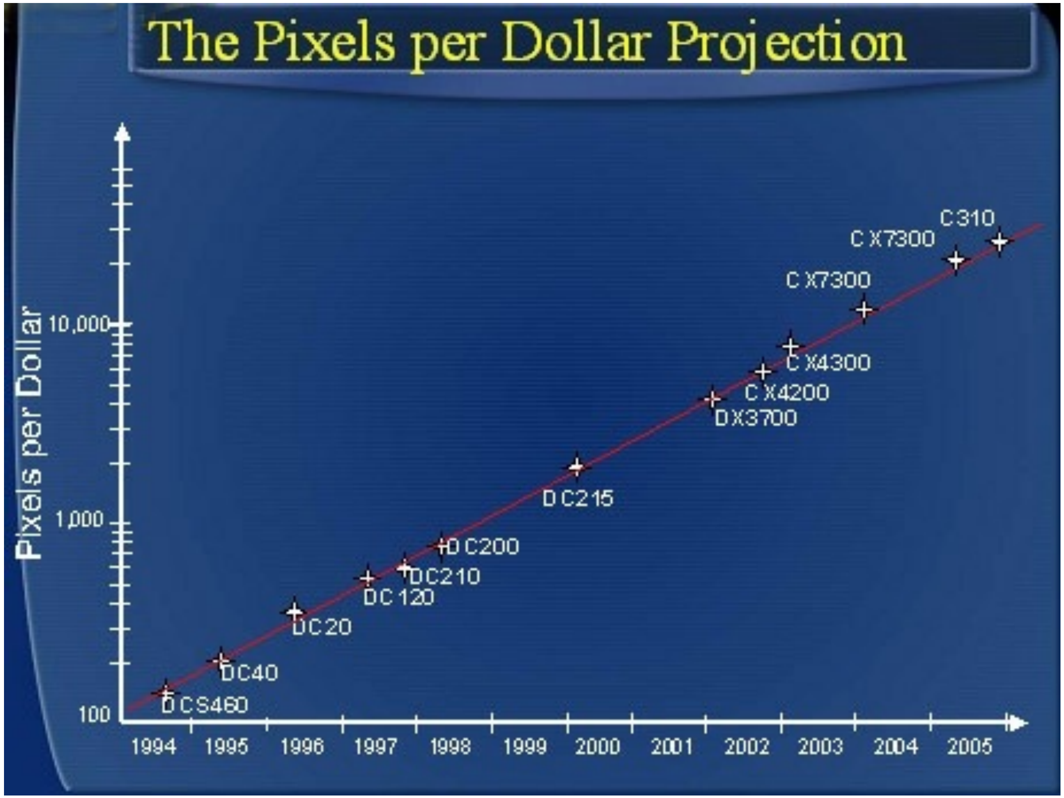
[Intel, Apple]

Decreasing Cost per Transistor

- Average cost of a transistor halves every 1.6 years
  - Keep in mind that the transistor also gets faster, so you can do more with it



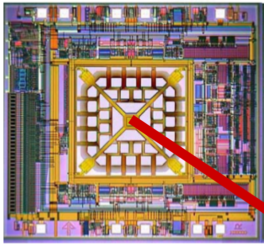
Hendy's Law: Pixels per $ trend



- Cell phone cameras – From 0.35 Megapixels in 2000 (Samsung SCH-V200) to 48 Megapixels (Sony's IMX586 imager) in 2018

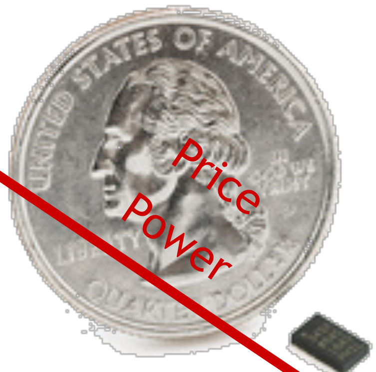
Credit: Barry Hendy/Wikipedia

MEMS Accelerometer Price Trend



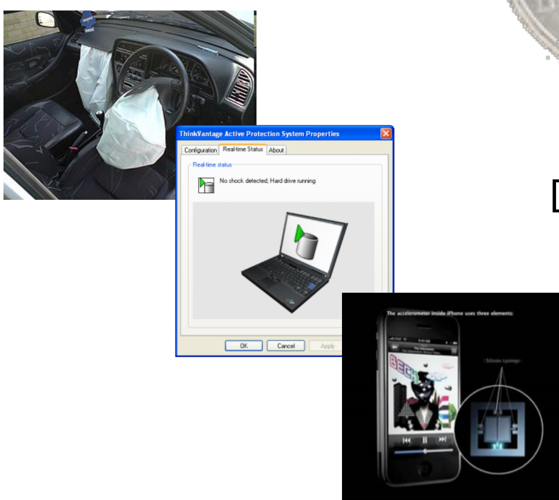
O(mA)

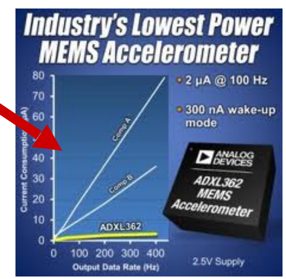
Price
Power



25 μA @ 25 Hz

ADXL345
[Analog Devices]





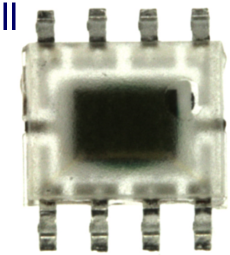
1.8 μA @ 100 Hz @ 2V

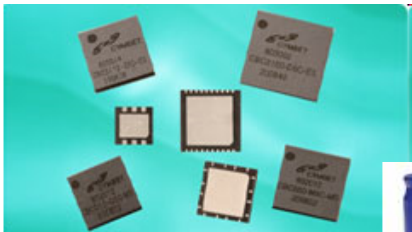
ADXL362, Analog Devices

Micro-Scale Energy Harvesting

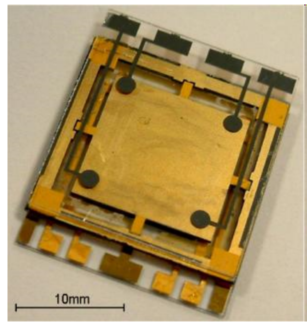
RF [Intel]

Clare Solar Cell

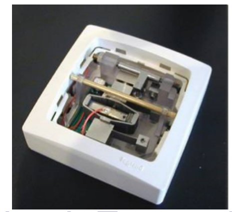




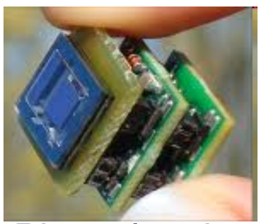
Thin-film batteries



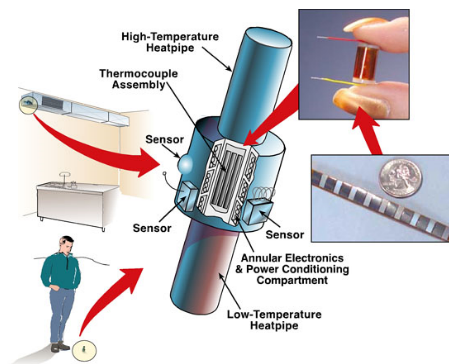
Electrostatic Energy Harvester [ICL]



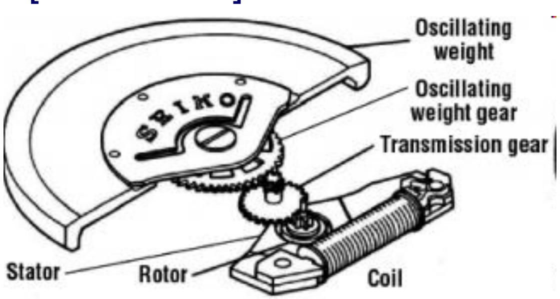
Shock Energy Harvesting CEDRAT Technologies

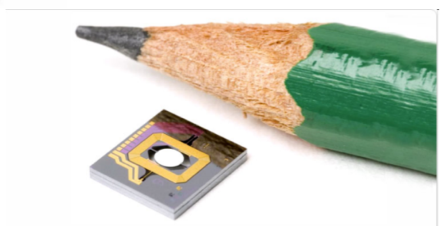


Piezoelectric [Holst/IMEC]

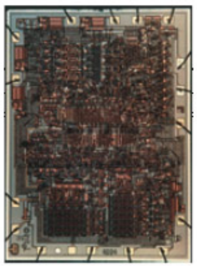


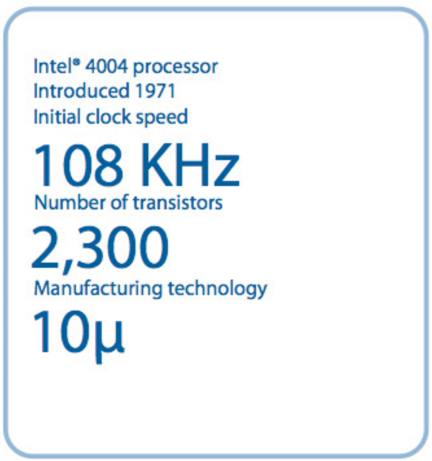
Thermoelectric Ambient Energy Harvester [PNNL]





Riding the Cost Curve





- **Cost: ~$26 in today's dollars**

- Intel Haswell Core i7-4558U
- Dual core, 2.8GHz, 22nm
- **Cost: ~$540**

- TI Tiva-C MCU
- ARM Cortex M4, 80MHz
- **Cost: ~$6**

Embedded Systems Market

- The global embedded systems market was valued at $140 billion in 2013 and is expected to be an estimated $214 billion by the end of 2021, a compound annual growth rate (CAGR) of 6.3%
  - Embedded hardware was worth $131 billion in 2013 and is expected to grow at a CAGR of 6.2% to reach $199 billion in 2020
  - Embedded software generated $8.6 billion in 2013. This should increase to $14.4 billion in 2020, for a CAGR of 8.2%
  - https://www.radiantinsights.com/press-release/global-embedded-system-market (published Nov. 2018)

- Of all microprocessors sold, 99% go into "non-computers"

- More than 21 billion ARM-based chips sold in 2017 alone (Intel has sold less than 10 billion processors during its entire history!)

One Possible Taxonomy

- Small systems
  - E.g., Cellular phones, pagers, home appliances, toys, smart cards, MP3 players, PDAs, digital cameras and camcorders, sensors, smart badges
  - Key challenge: Deal with stringent resource constraints
- Signal processing systems (input is a signal; decoded/transformed/classified, output is a signal)
  - E.g., Radar, sonar, real-time video, set-top boxes, DVD players, medical equipment, residential gateways
  - Key challenge: Need for high computational power
- Mission critical systems (need for extreme reliability)
  - E.g., Avionics, space-craft control, nuclear plant control
  - Key challenge: Need for extreme reliability

TMR: Triple modular redundancy

- Distributed control (communication network)
  - E.g., Smart grid, mass transit systems, elevators in buildings
  - Key challenge: Need to deal with distributed nature of systems