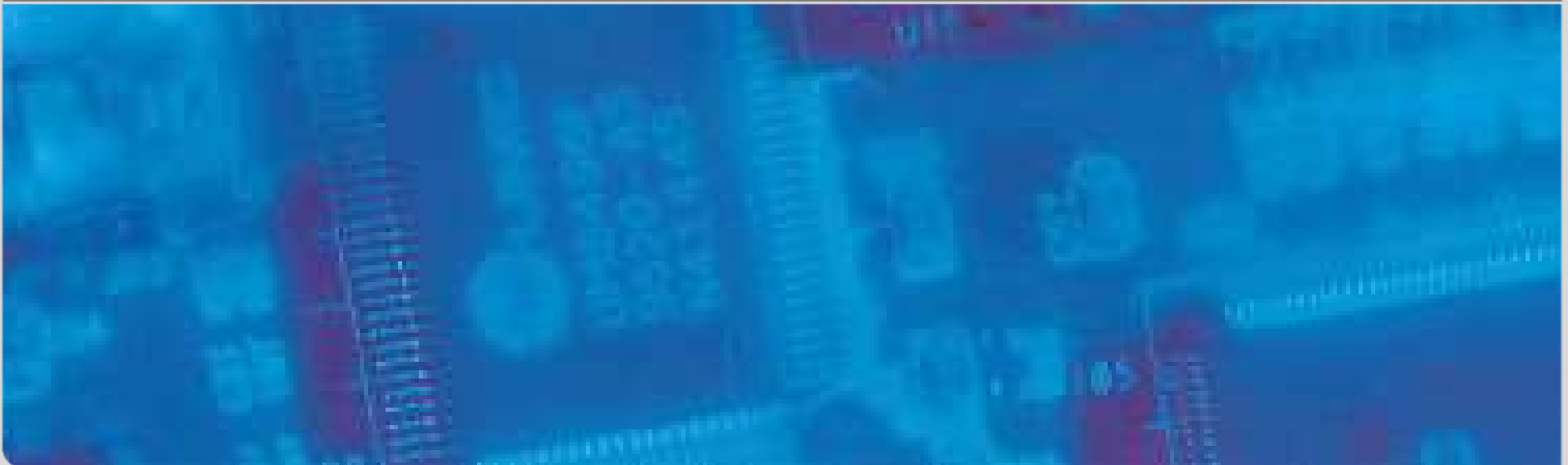


Lower Power Design

Lecture 0: Introduction

Anuj Pathania on behalf of Prof. Dr. Jörg Henkel
Summer Semester 2017

CES – Chair for Embedded Systems



Organizational Issues

- Slides available for download -
 - <http://cesweb.itec.kit.edu/teaching/LPD/s17/slides/>
 - Username: student
 - Password: CES-Student
- Homework
 - Read a relevant scientific paper.
 - Discussion next class.
- Oral Exam
 - Make appointment with KIT CES secretary 6-8 weeks in advance.
 - Exam will be in English (or German if told in advance).
 - More Information: <http://ces.itec.kit.edu/972.php>

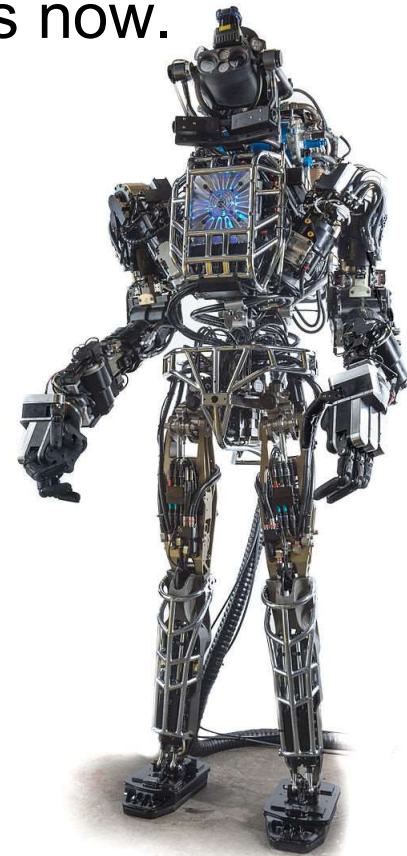
Lectures

- 27.04.2017 – Lecture 0: Introduction
- 04.05.2017 – Lecture 1: Energy Sources
- 11.05.2017 – TBA
- 18.05.2017 – TBA
- 25.05.2017 – Ascension Day (Holiday)
- 01.06.2017 – TBA
- 08.06.2017 – TBA
- 15.06.2017 – Corpus Christi (Holiday)
- 22.06.2017 – TBA
- 29.06.2017 – TBA
- 06.07.2017 – TBA
- 13.07.2017 – TBA
- 27.07.2017 – TBA

Expect Interesting Guest Lectures

Portable Embedded Systems

- Encompasses a truly diverse set of devices now.



Source: Wikipedia/Wikicommons

Why Save Power?



Battery Life



Cooling

Source: Wikipedia/Wikicommons

Jevons Paradox

- Proposed by William Staley Jevons.
- Efficiency of resource usage increases.
 - ~~Usage decreases.~~
 - Usage increases.

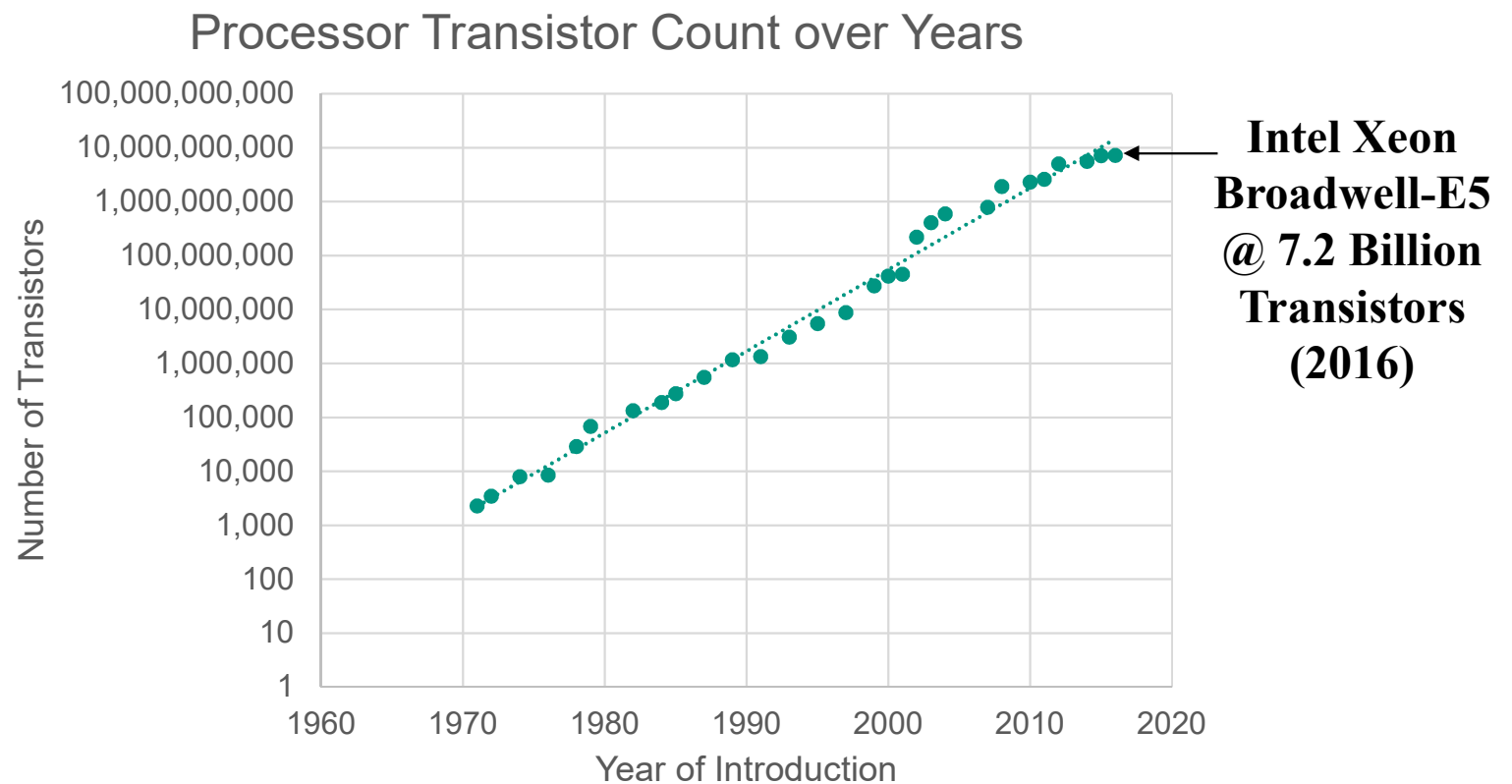


- More power we save on embedded devices; even more demanding power hungry applications emerge.

Source: Wikipedia

Moore's Law Success

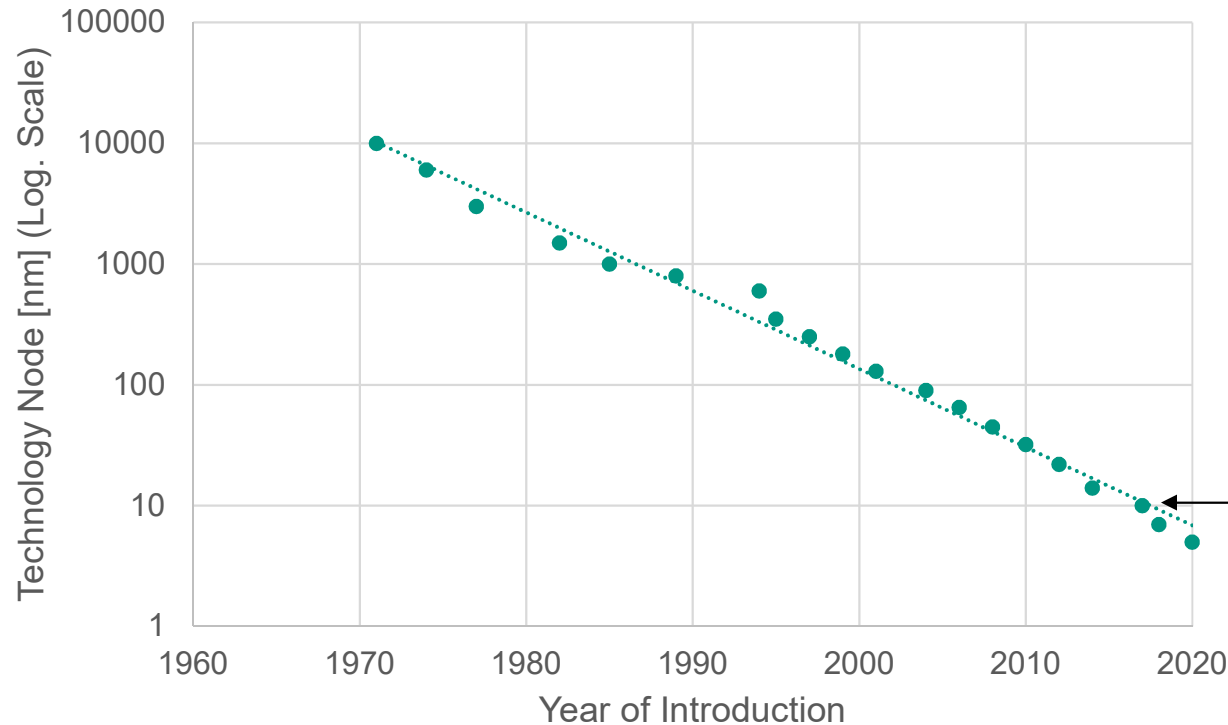
- Proposed by Gordon Moore in 1965.
- Number of transistors doubles in ICs every two years.



Shrinking of Technology Node

- Moore's law is enabled by shrinking of technology nodes.
 - Transistors have become smaller and smaller.

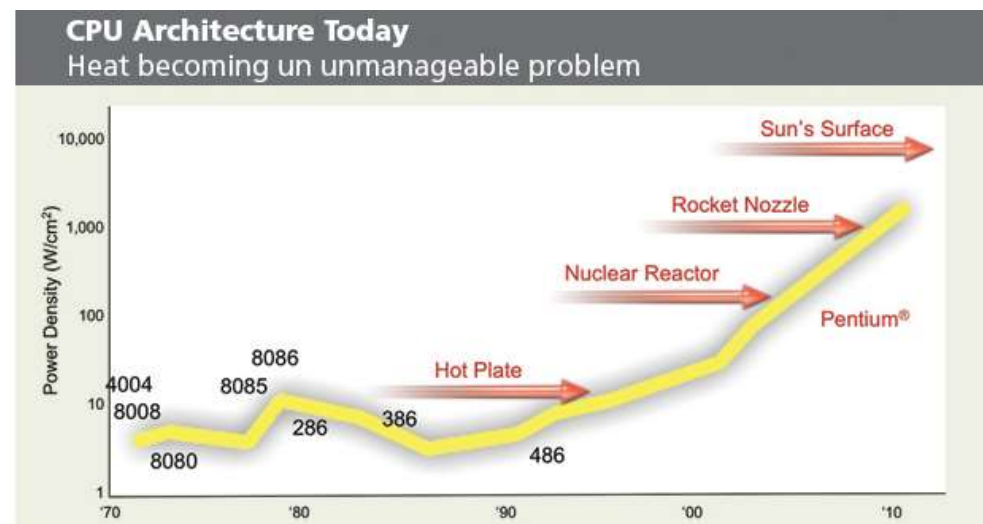
Introduction of Different Technology Nodes



**Qualcomm
Snapdragon835
@ 10nm
(2017)**

Dennard Scaling Failure

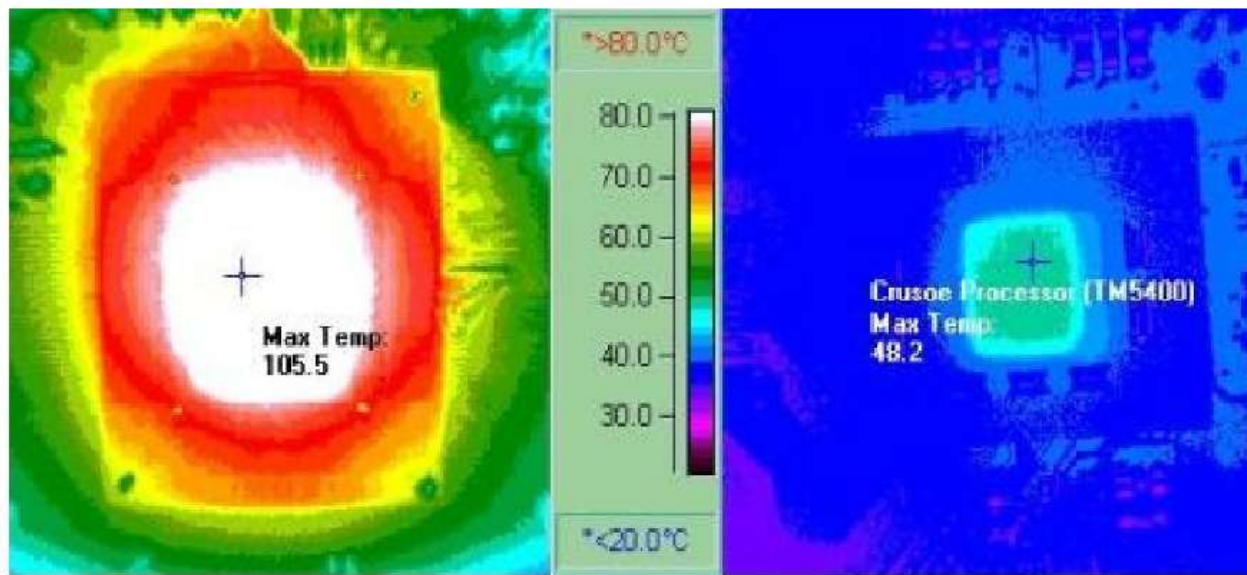
- Proposed by Robert Dennard in 1974.
- Power density will remain constant as tech. node shrinks.
 - Failed around 2006 due to multiple factors.



Source: Intel

Frequency and Chip Temperature

- Processors operating temperature increase significantly with frequency.
 - Active Power = $C.V^2.F$
 - Sustaining higher freq. require higher volt.; result cubic relationship.



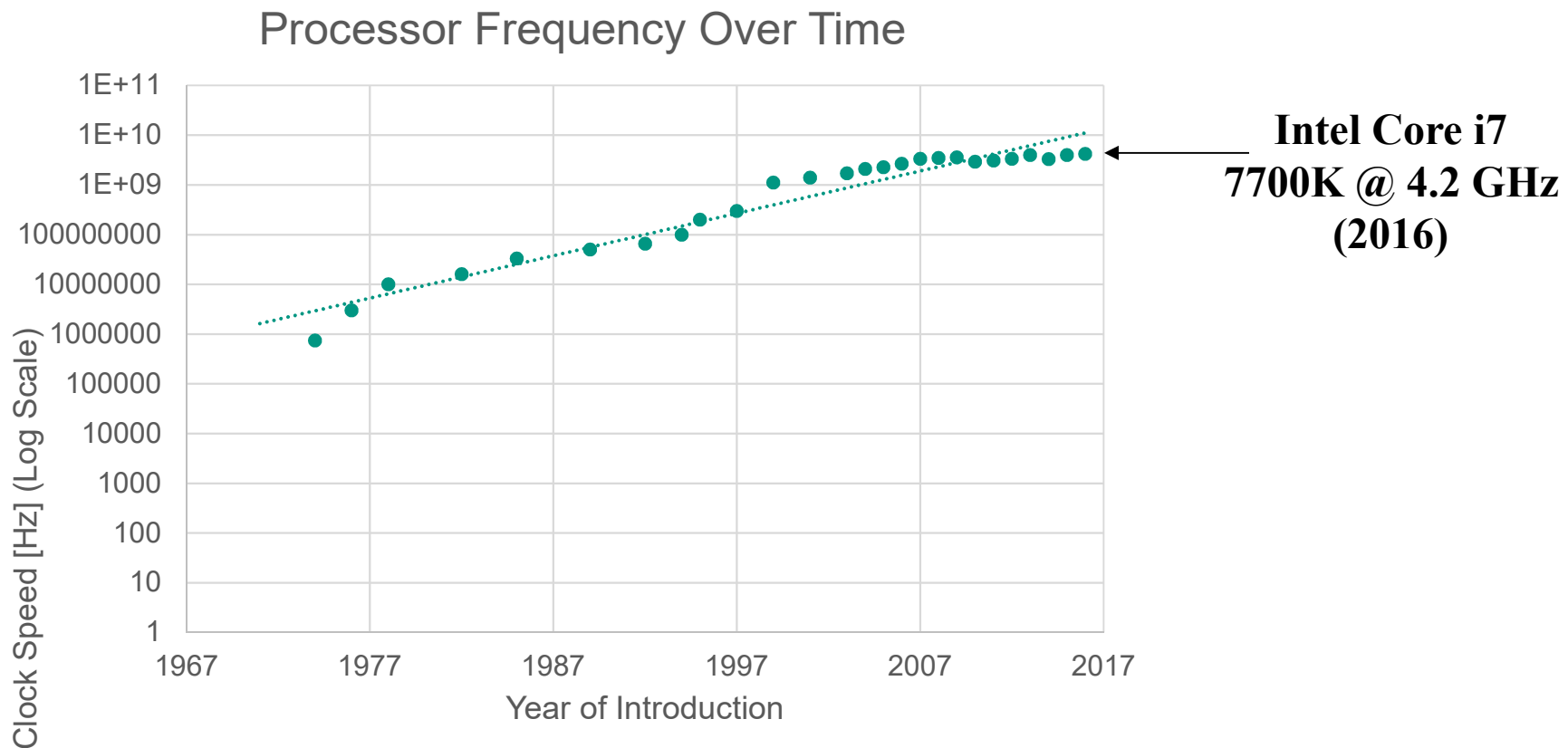
Pentium 4 @ 3.46 GHz

Crusoe @ 0.8 GHz

Source: transmeta.com

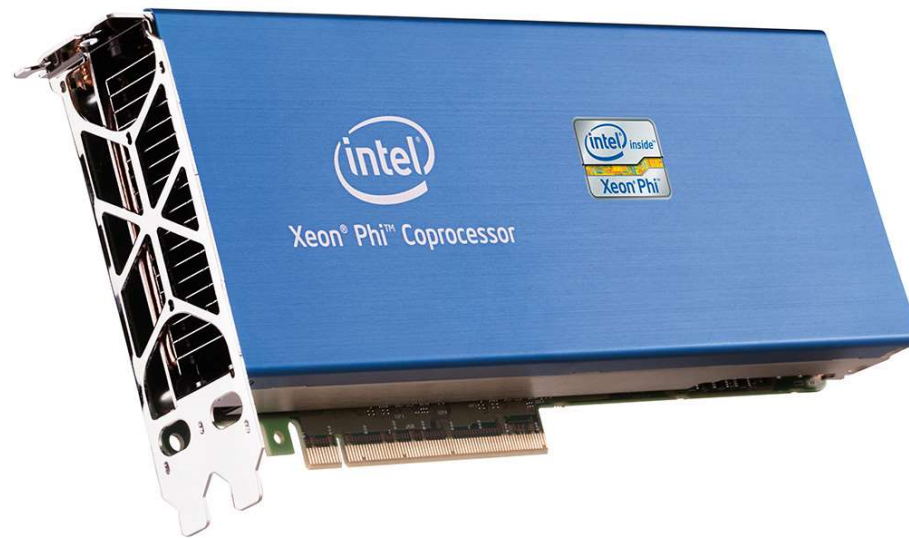
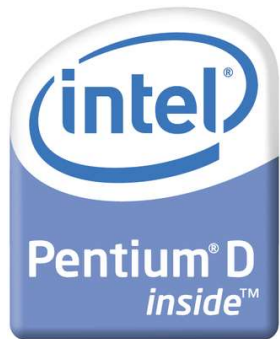
CPU Frequency Stagnation

- CPU frequency could not be raised further.



Transition to Multi-Core

- Keep using transistors: Constant Frequency + More Cores

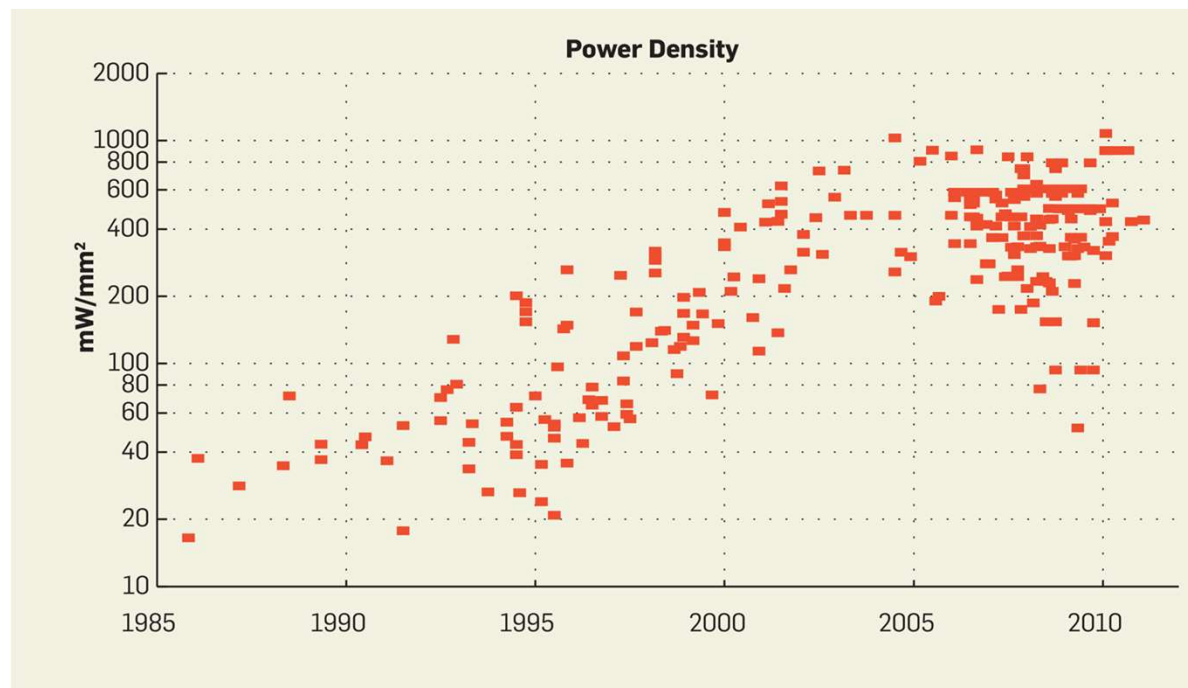


Xeon Phi 7290F @ 72 Cores (2016)

Source: Wikipedia & SiliconAngle

Power Density is Under Control

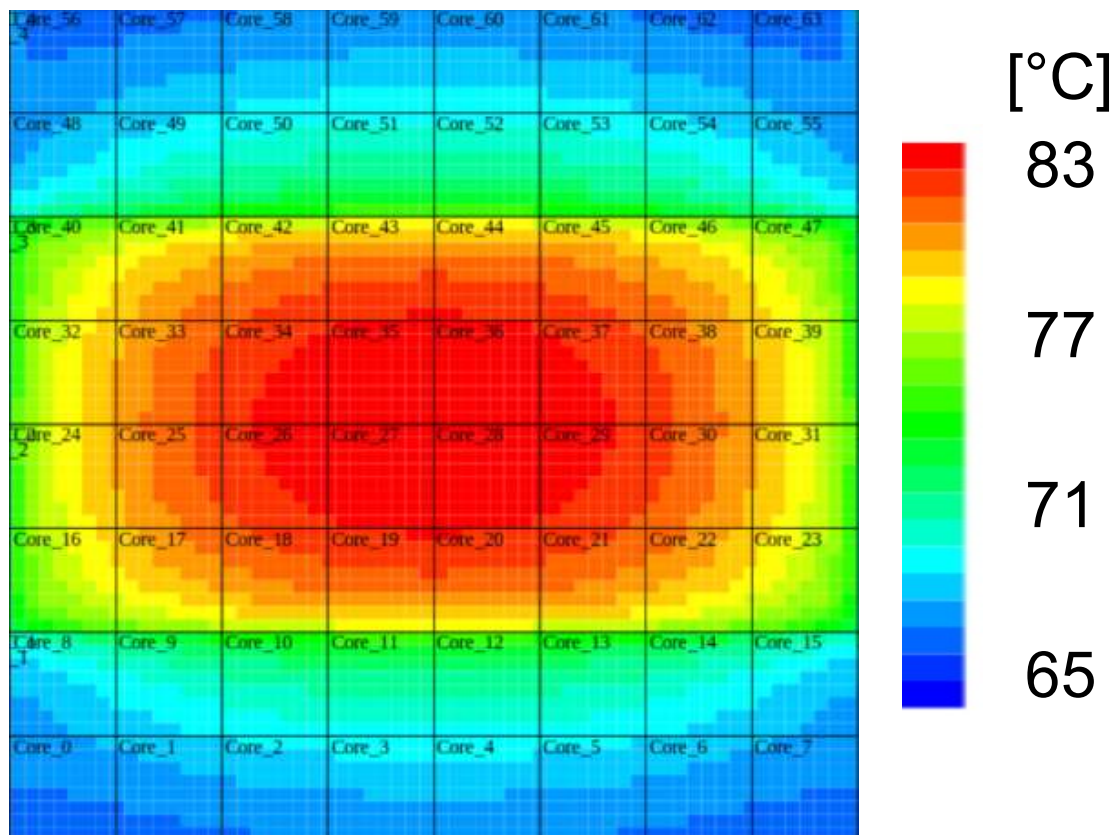
- Power density seems to be under control for now.



Source: Danowitz [2012]

Dark Silicon: Multi-Core Party is Over?

- Active cores transfer heat to each other.
- So many cores, all cannot be turned on together.



Source: Henkel [2015]

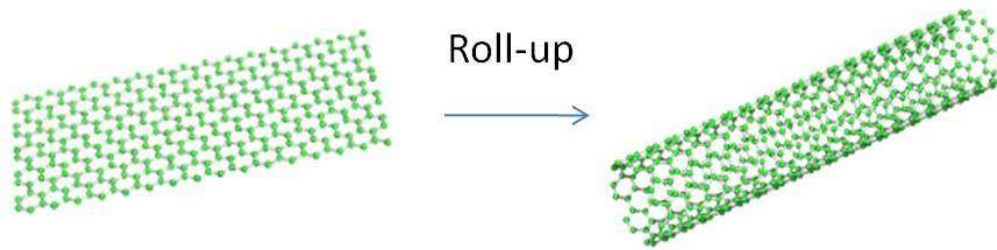
Saving Power, Saves \$\$\$

- Facebook is making data centers in Sweden.
 - Average temperature of 2°C allows for cheaper cooling.
 - Computers can also run faster at higher frequency when required.

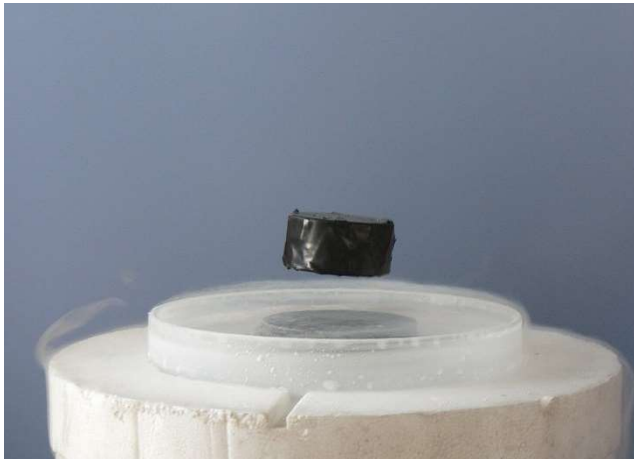


Source: cnet.com

Exotic Solutions to Heat Problem



Carbon Nanotube Transistors

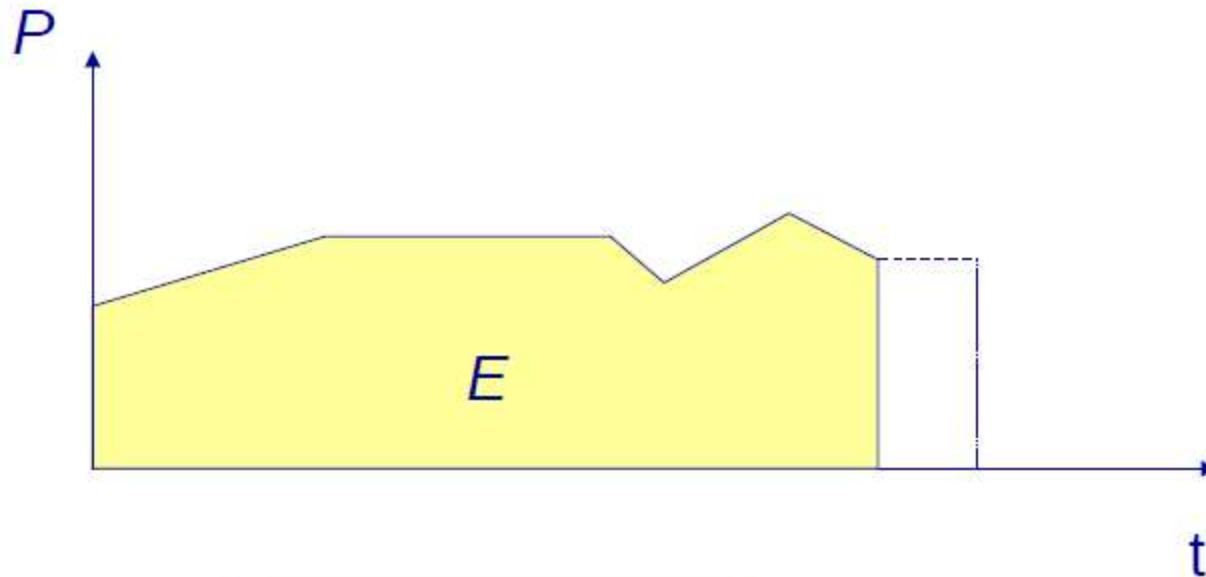


Superconducting Transistors

Source: Wikipedia

Relationship Between Power and Energy

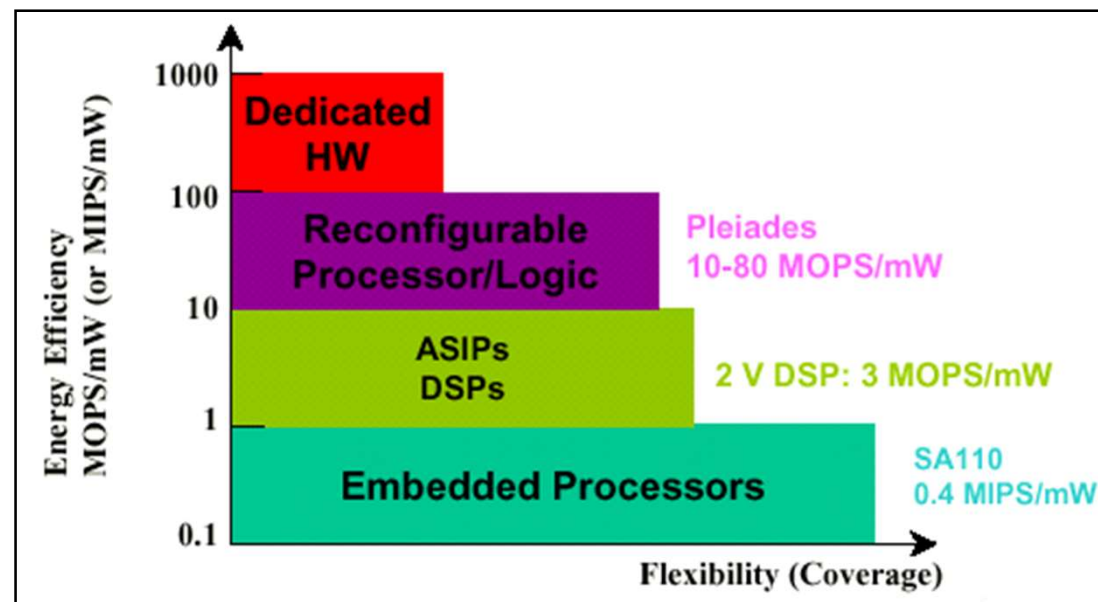
- Power efficient system may not be energy efficient.



$$E = \int P dt$$

Energy vs Programmability

- Large gap (100x – 1000x) in energy efficiency between full programmable and full custom implementation.
- Ample scope of tradeoff.



Source: Rabaey [2000]

Famous Real-World Example

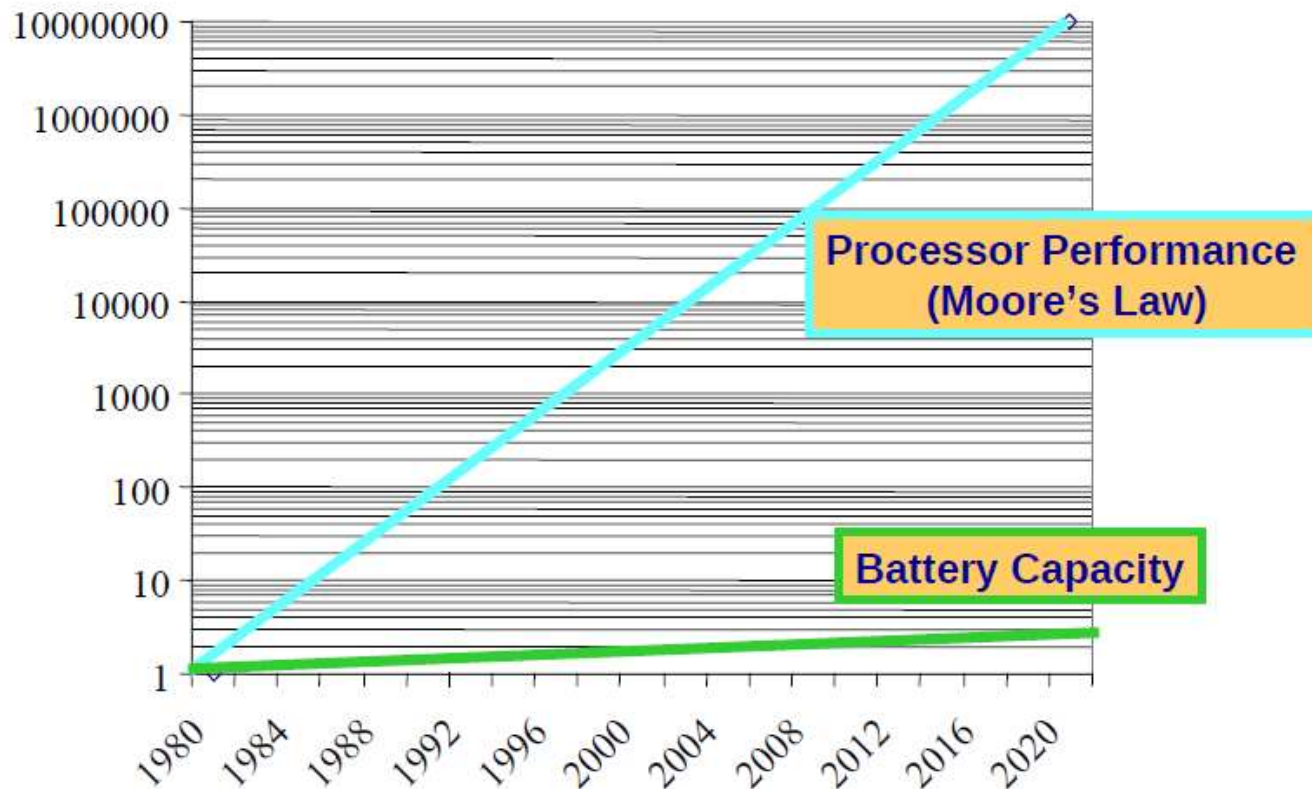
- GPUs are real-world omnipresent dedicated hardware.
 - Can run games but cannot run operating systems.
 - Can also do scientific computing.



Source: Wikipedia

Battery Technology is Stuck!!!

- No Moore's law in batteries.



Source: Cuomo [2004]

Lithium-Ion Batteries

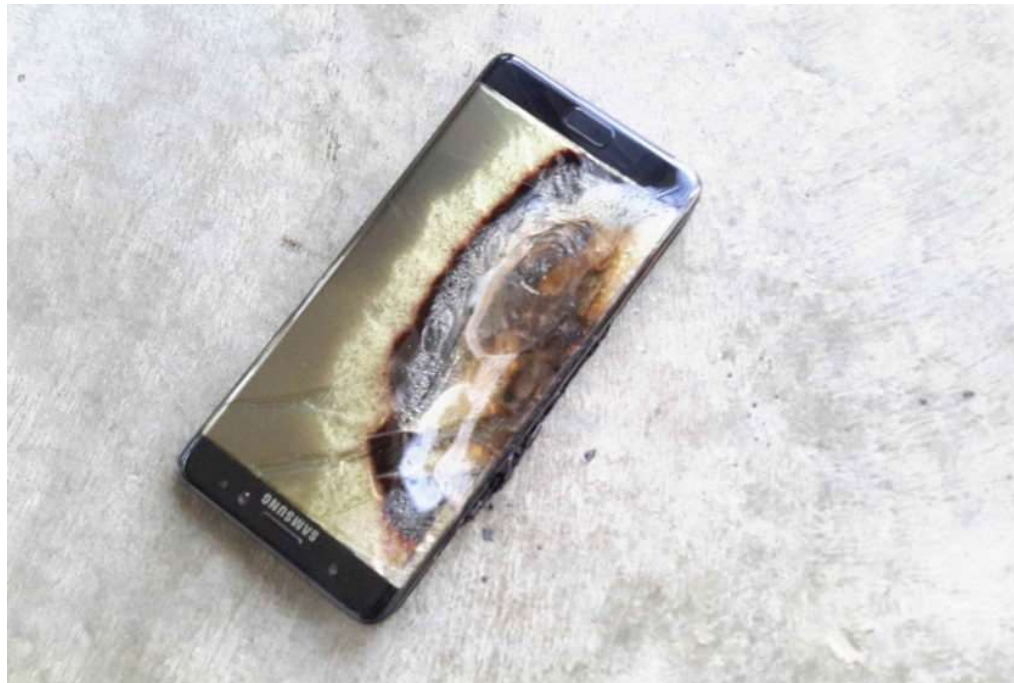
- Lithium-Ion Batteries are current state-of-the-art.
- Plans for massive mass production.
 - Elon Musk's Giga Factory.



Source: teslamotors.com

Lithium-Ion Batteries Problem

- Do not hold much juice.
- They explode !!!



Source: androidauthority.com

Solution on Horizon.

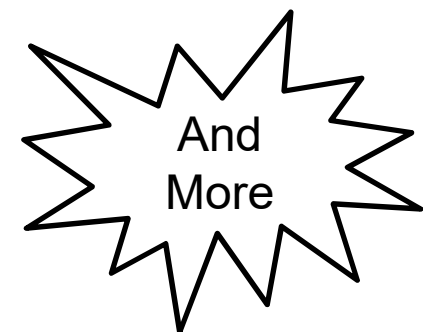
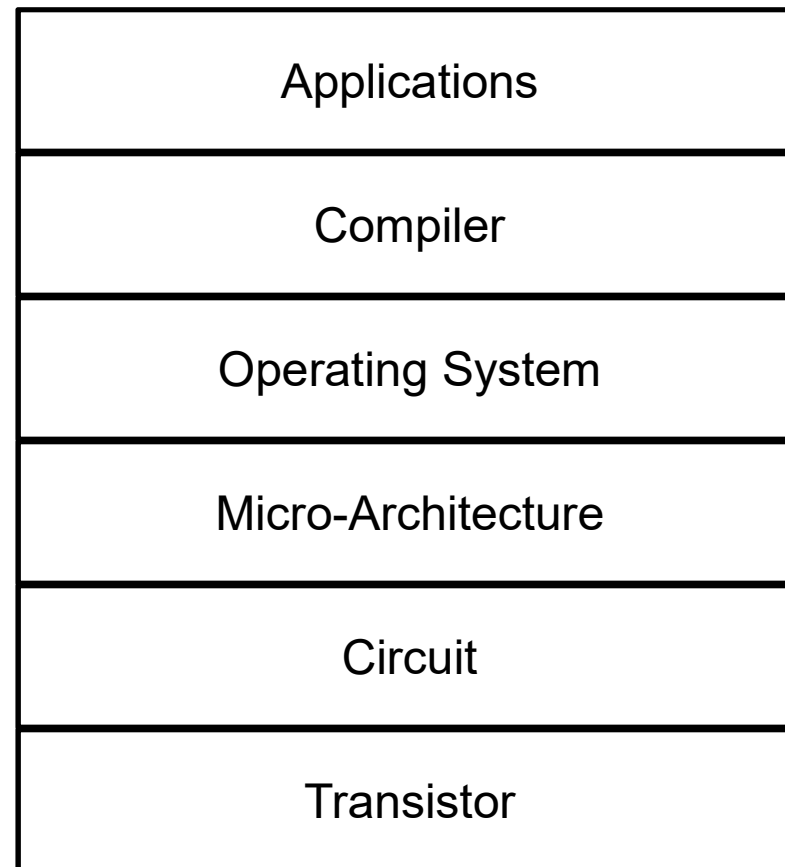
- Aluminum-Ion Batteries.
 - Three times Lithium-Ion battery capacity.
 - Flexible.
 - Safer.



Source: sciencedaily.com

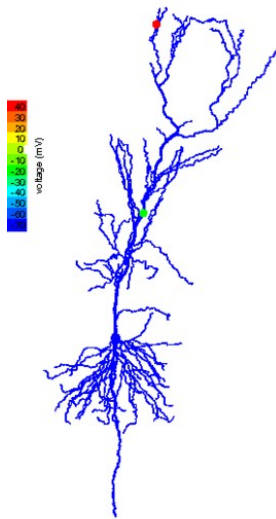
Less Exotic Solution

- Apocalypse delayed from solutions at every abstraction.

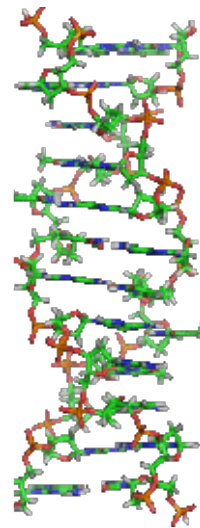


Theoretical Limits of Low Power Design

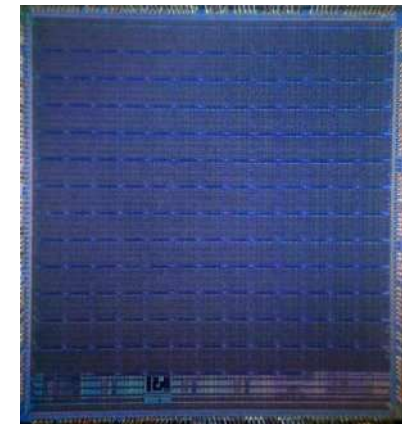
- **Landauer principle.**
 - Gives theoretical limit of energy consumption of computation.
 - One bit operation must consume at least **.69 kT** of energy.
 - Equals to 0.0172eV at room temperature 20°C.



Neurons: 10^{11} kT



DNA: 100 kT



Processors: 10^7 kT

Source: Wikicommons + Bennet [1982]

Source

- Danowitz, Andrew, et al. "CPU DB: recording microprocessor history." *Communications of the ACM* 55.4 (2012): 55-63.
- **Homework >>** Henkel, Jörg, et al. "New trends in dark silicon." *Proceedings of the 52nd Annual Design Automation Conference*. ACM, 2015.
- Andrea Coumo, Advanced System Technology, *STMicroelectronics*, Keynote at CODE+ISSS 2004, Stockholm, Sweden, 2004.
- Rabaey, Jan M., et al. "PicoRadio supports ad hoc ultra-low power wireless networking." *Computer* 33.7 (2000): 42-48.
- Bennett, Charles H. "The thermodynamics of computation—a review." *International Journal of Theoretical Physics* 21.12 (1982): 905-940.