# Introduction to Electrical and Computer Engineering

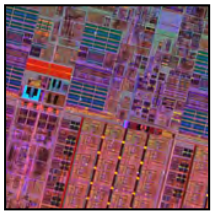
Christopher Batten

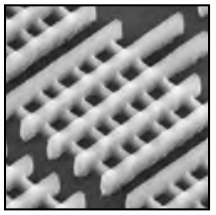
Computer Systems Laboratory
School of Electrical and Computer Engineering
Cornell University

ENGRG 1060 Explorations in Engineering Seminar
Summer 2013


Power Systems


Computer Engineering

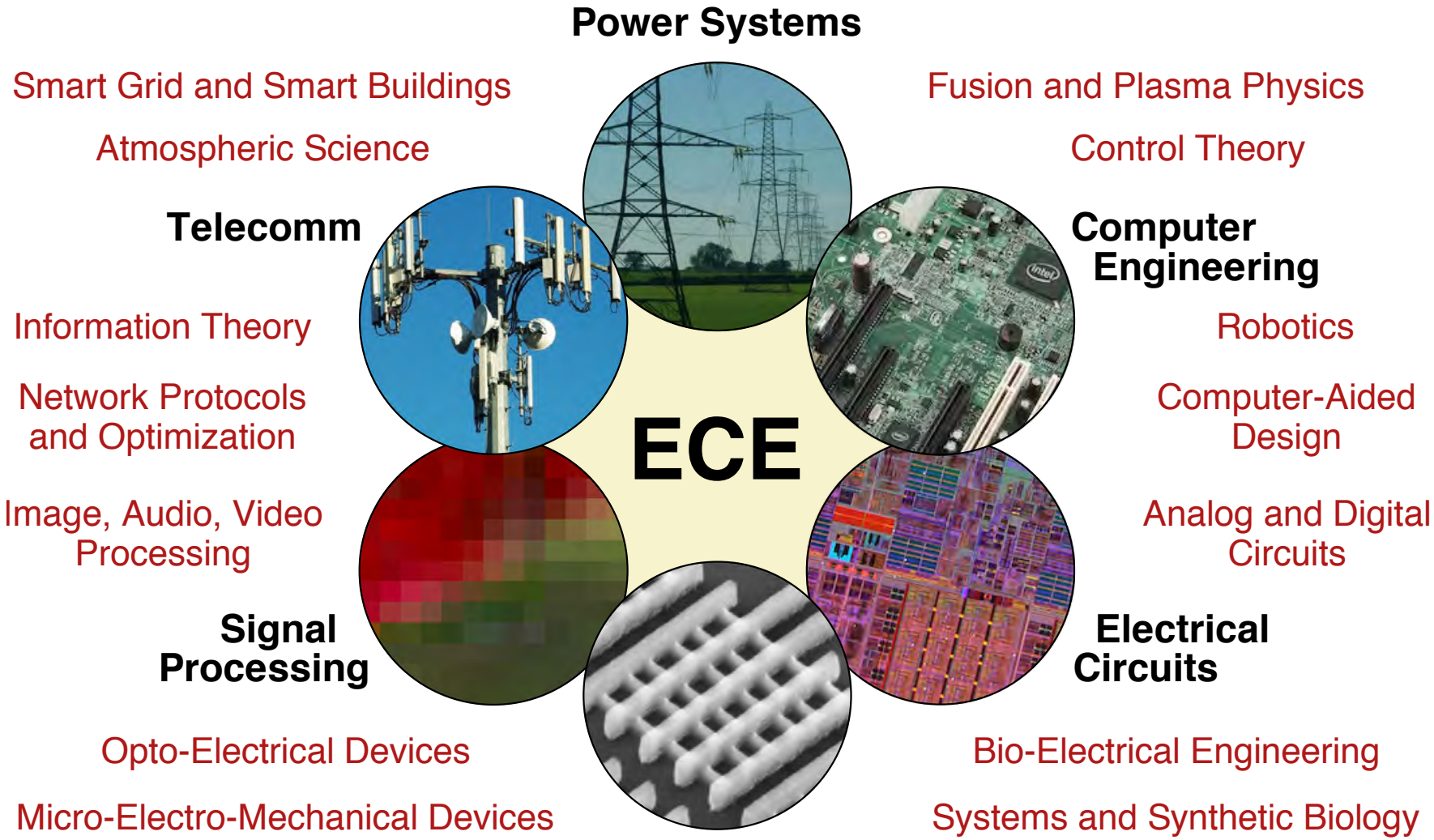

Electrical Circuits


Electrical Devices


Signal Processing


Telecomm

# ECE is the Study and Application of Electricity, Micro-Electronics, and Electro-Magnetism



# ECE is everywhere!

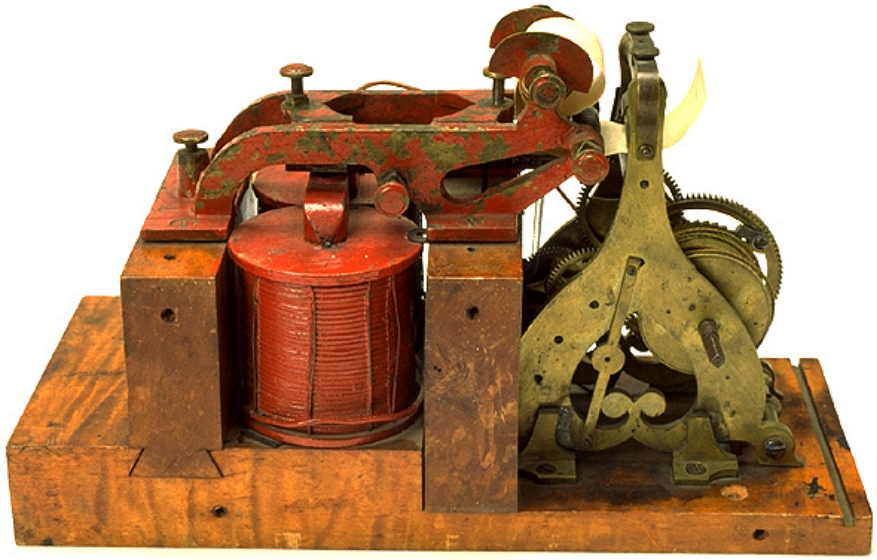
# What can one do with a background in ECE?

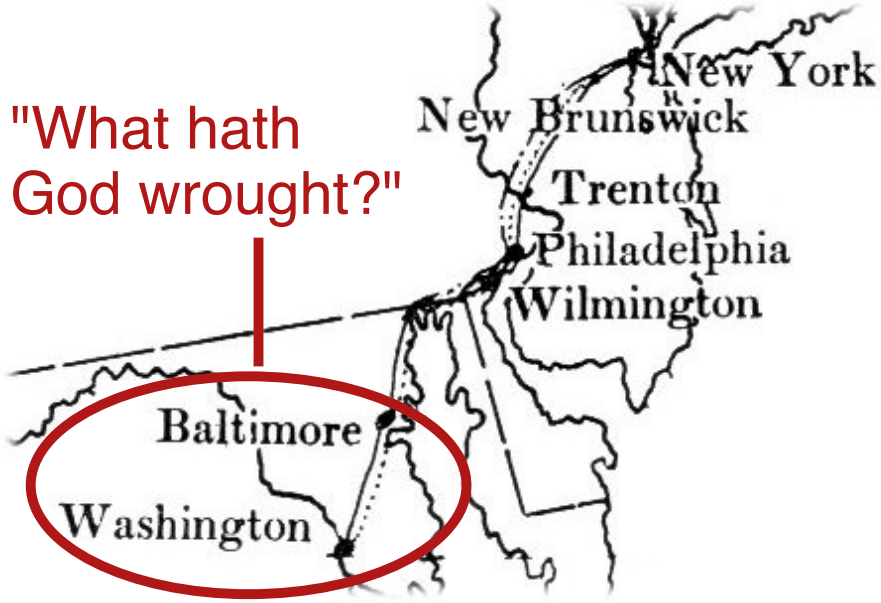
- **ECE Industry**: Intel, AMD, Analog Devices, NVIDIA, HP, Apple
- **General Engineering Industry**: GE, Lockheed Martin, Raytheon
- **Software Industry**: Microsoft, Amazon, Mathworks
- **Join a Startup**: Achronix, Hillcrest Labs
- **Research Lab**: Sandia National Labs, Draper Labs, NASA
- **Consulting**: McKinsey, Accenture, Deloitte, Booz Allen Hamilton
- **Finance**: Deutsche Bank, Capital One, UBS, Bloomberg
- **Graduate School**: Law School, Business School, Med School
- **Found a university!**

# Cornell was founded because of ECE!

**Samuel Morse** invented the telegraph (a digital communication device), but needed help building the network

**Ezra Cornell** built the first telegraph line (the beginning of telecommunications), and invested in the Western Union Telegraph Co

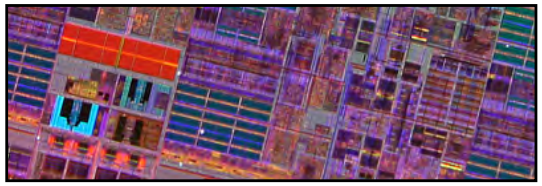
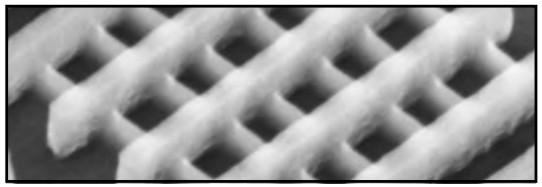
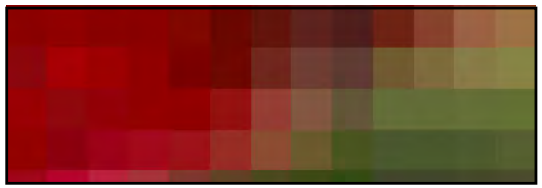





**Ezra Cornell's investments created the fortune that eventually enabled the founding of Cornell University**

# "Optional Homework"


- Visit the statue of Ezra Cornell on the Arts Quad
- Does something on the back of the statue relate to ECE?
- Take a picture with your cellphone and send it to your friend!
  - Power systems
  - Computer engineering
  - Electrical circuits
  - Electrical devices
  - Signal processing
  - Telecommunications


# Talk Outline

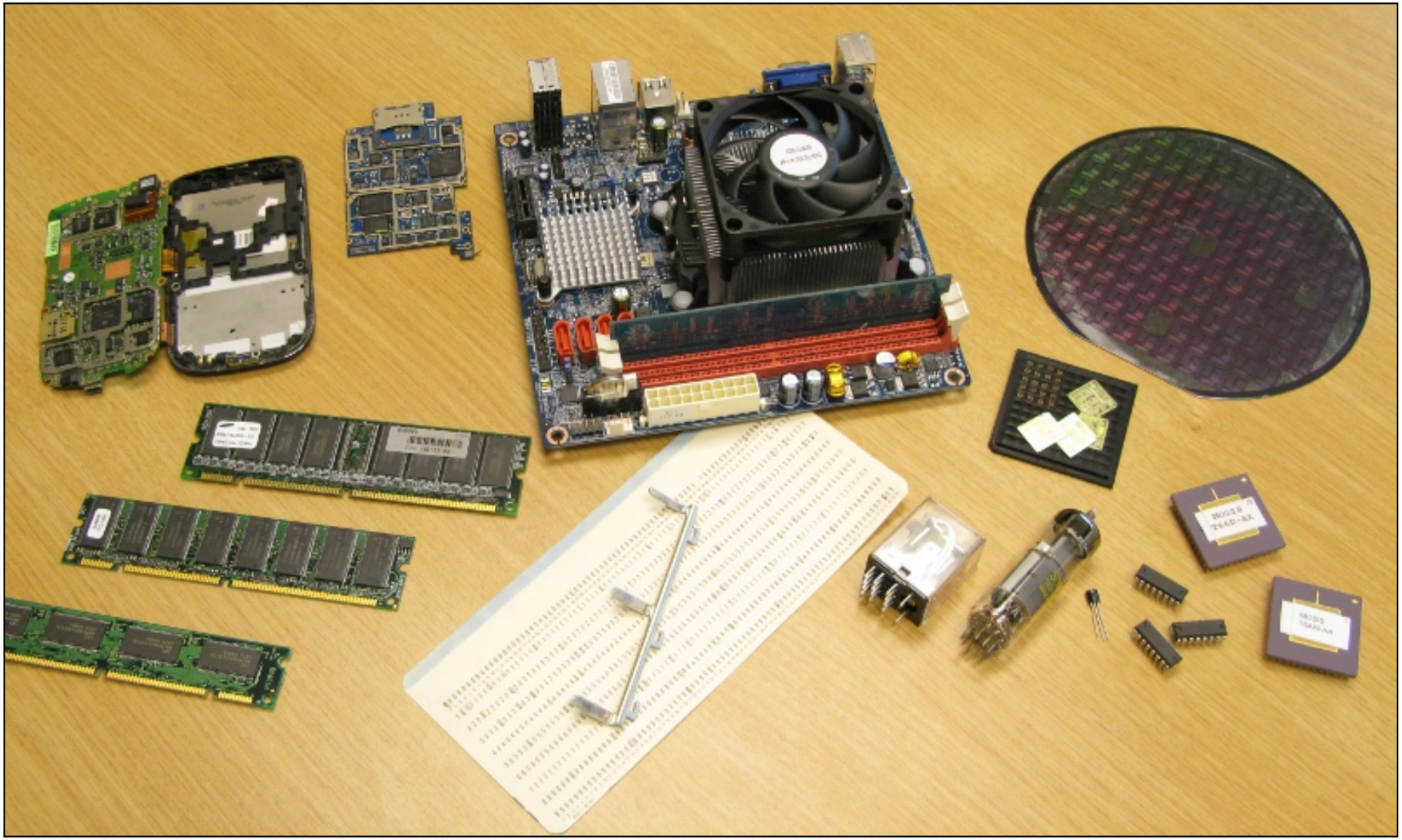
ECE Overview

What is Computer Engineering?

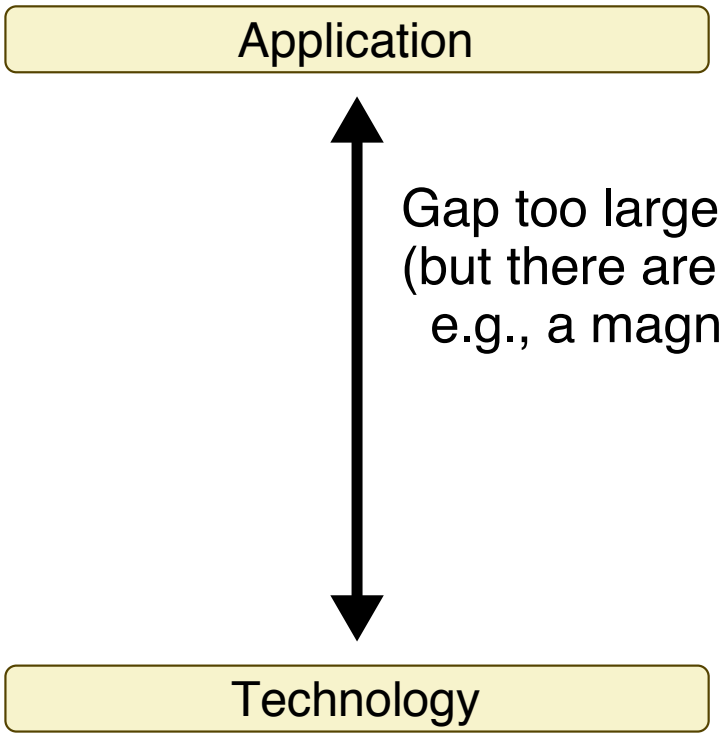
Trends in Computer Engineering

Computer Engineering Design

# Computer Engineering Artifacts



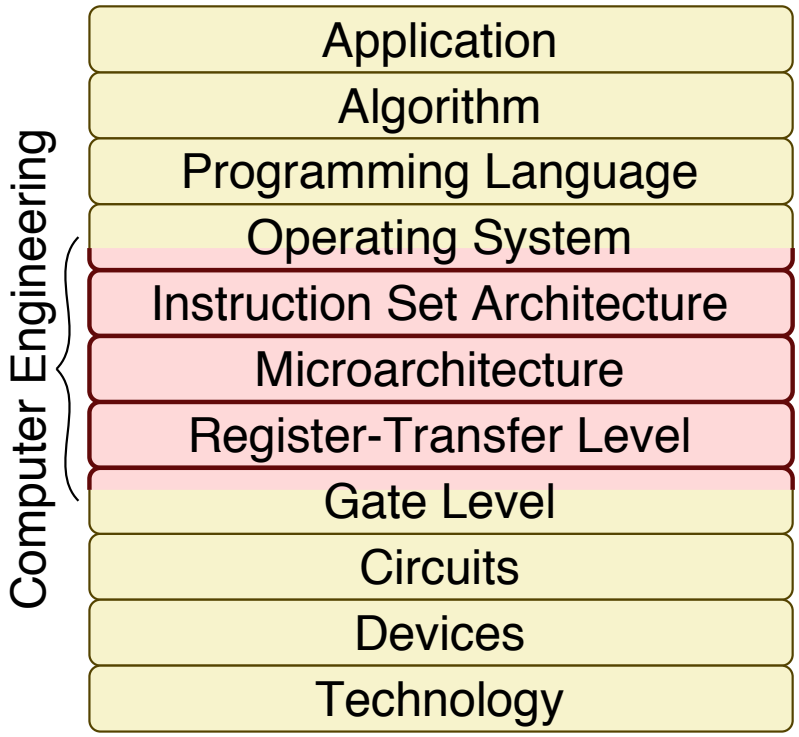
# The Computer Systems Stack




Gap too large to bridge in one step
(but there are exceptions,
e.g., a magnetic compass)


In its broadest definition, computer engineering is the development of the abstraction/implementation layers that allow us to execute information processing applications efficiently using available manufacturing technologies

# The Computer Systems Stack




**Sort an array of numbers**

2,6,3,8,4,5 -> 2,3,4,5,6,8

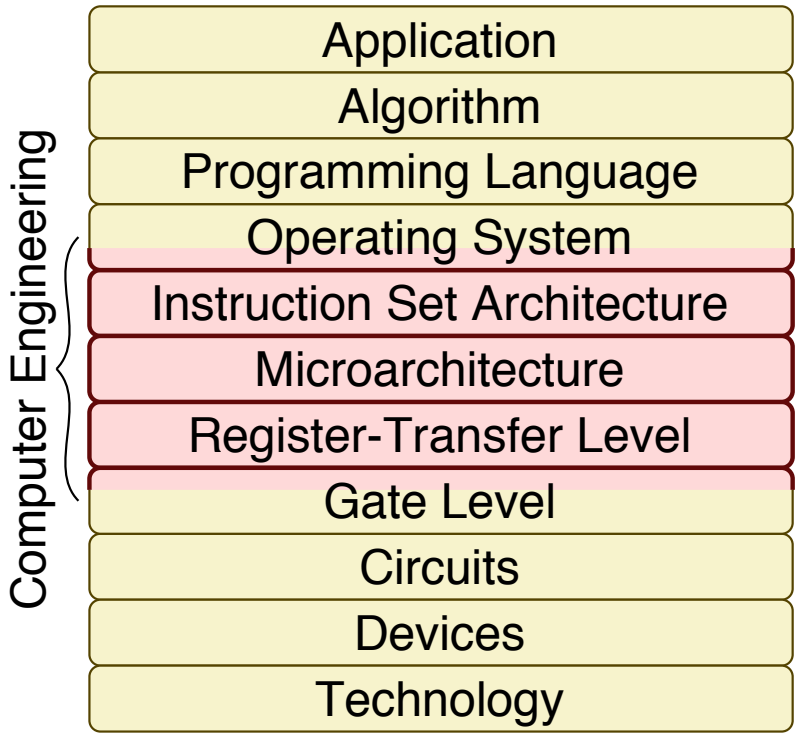
**Insertion sort algorithm**

1. Find minimum number in input array
2. Move minimum number into output array
3. Repeat steps 1 and 2 until finished

**C implementation of insertion sort**

```
void isort( int b[], int a[], int n ) {
  for ( int idx, k = 0; k < n; k++ ) {
    int min = 100;
    for ( int i = 0; i < n; i++ ) {
      if ( a[i] < min ) {
        min = a[i];
        idx = i;
      }
    }
    b[k]   = min;
    a[idx] = 100;
  }
}
```

# The Computer Systems Stack




**Mac OS X, Windows, Linux**

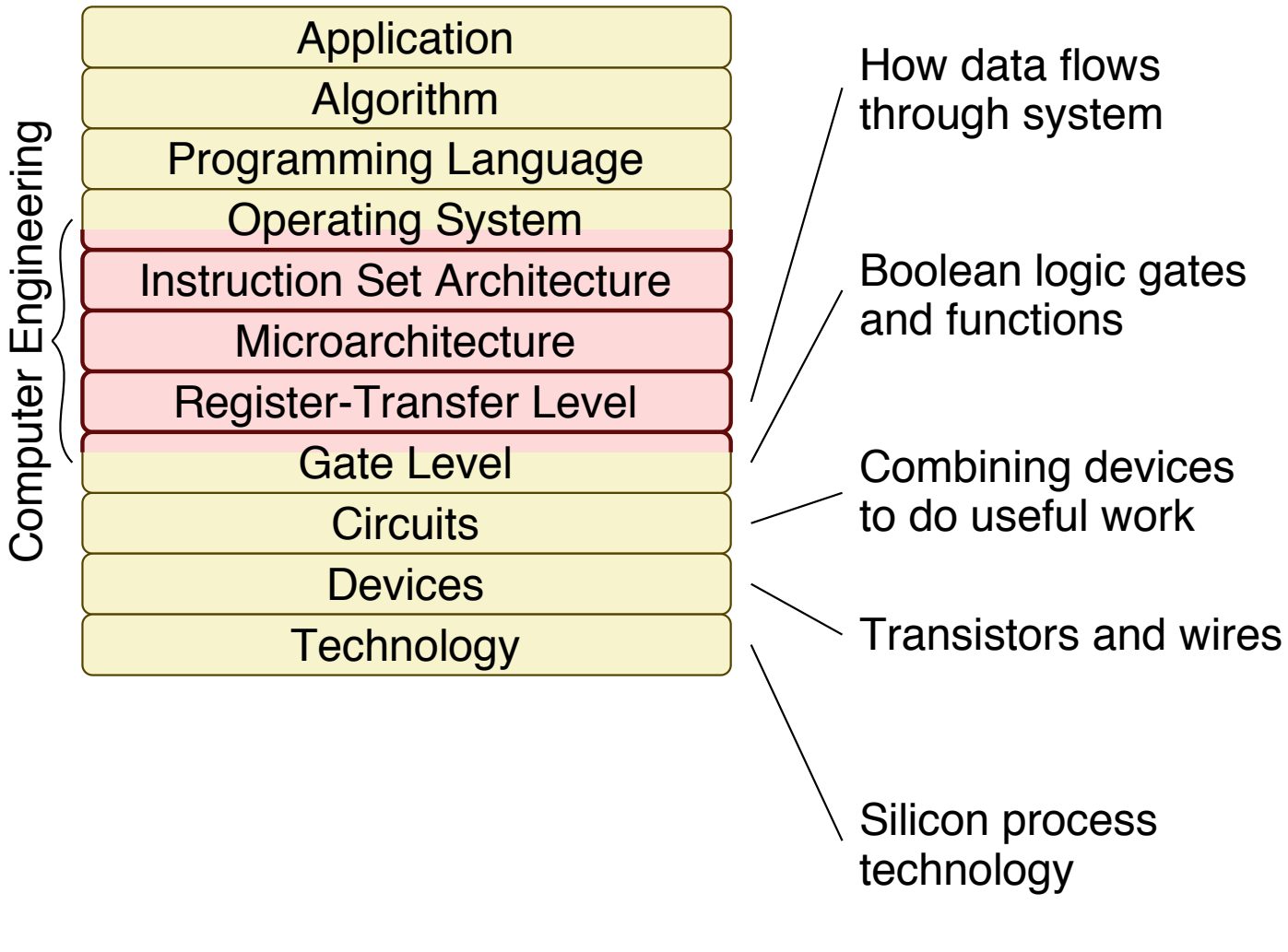
Handles low-level hardware management

**MIPS32 Instruction Set**

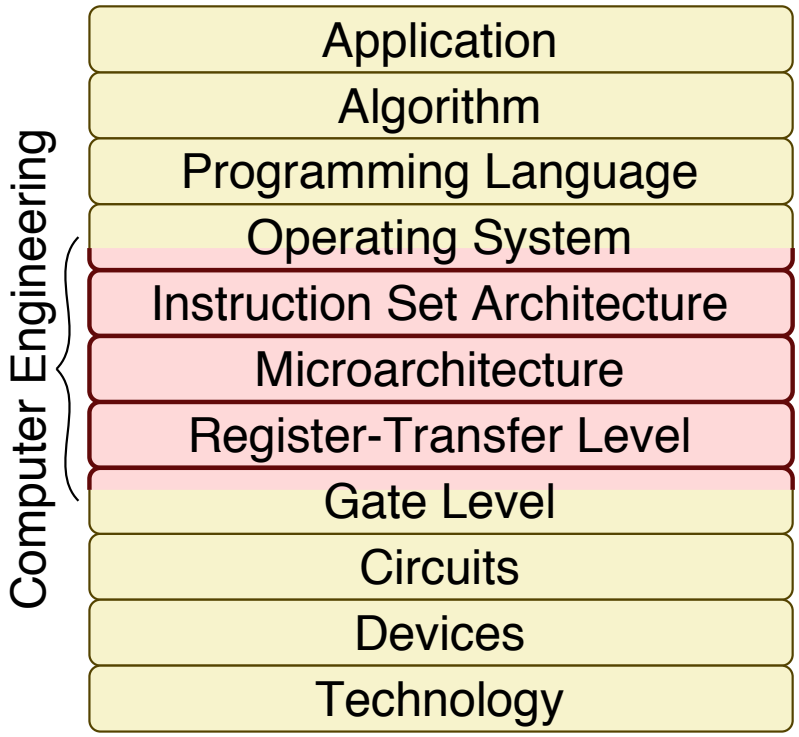
Instructions that machine executes

```
blez  $a2, done
move  $a7, $zero
li    $t4, 99
move  $a4, $a1
move  $v1, $zero
li    $a3, 99
lw    $a5, 0($a4)
addiu $a4, $a4, 4
slt   $a6, $a5, $a3
movn  $v0, $v1, $a6
addiu $v1, $v1, 1
movn  $a3, $a5, $a6
```

# The Computer Systems Stack



# Computer Systems: CS vs. EE vs. CE

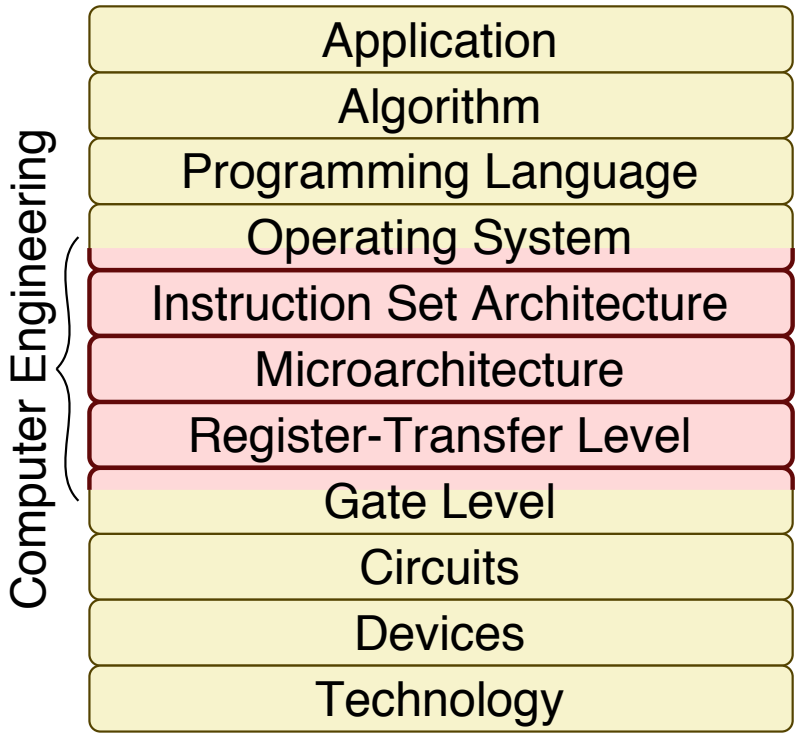


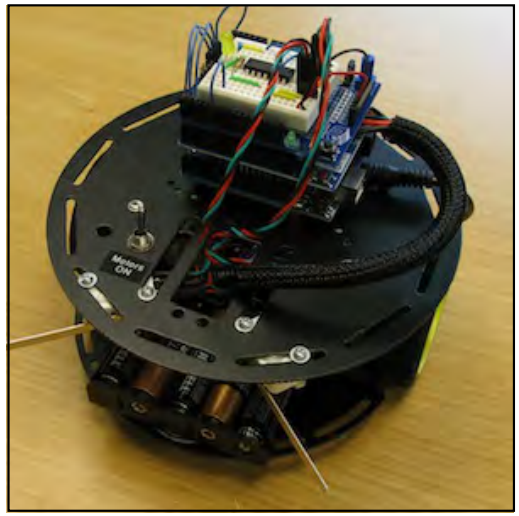

**Traditional Computer Science**

**Computer Engineering** is at the interface between hardware and software and considers the entire system

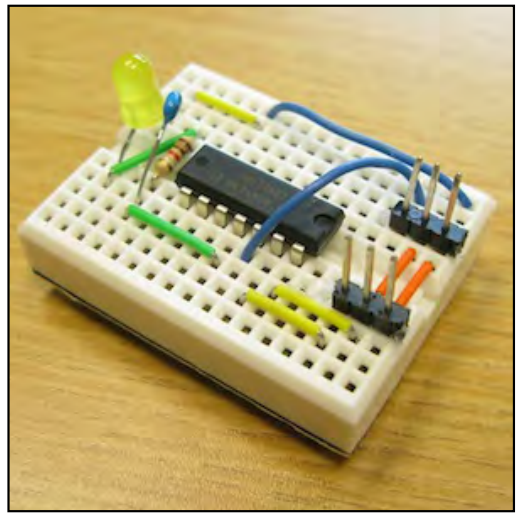
**Traditional Electrical Engineering**

# ENGRG 1060 Computer Systems Labs



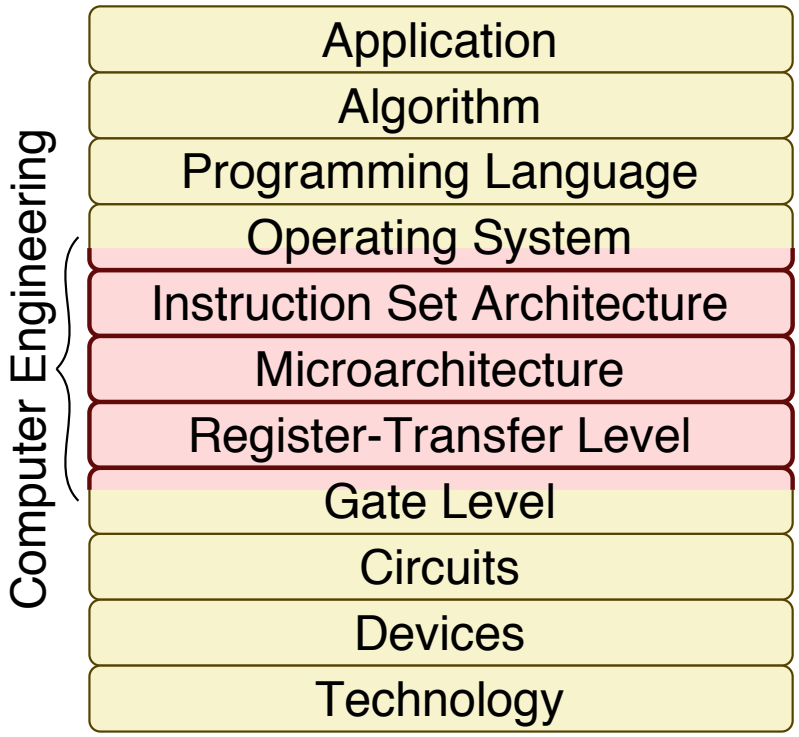



**Lab 4**
Software pushing towards hardware (CS,CE)



**Lab 2**
Hardware pushing towards software (EE,CE)

# Application Requirements vs. Technology Constraints



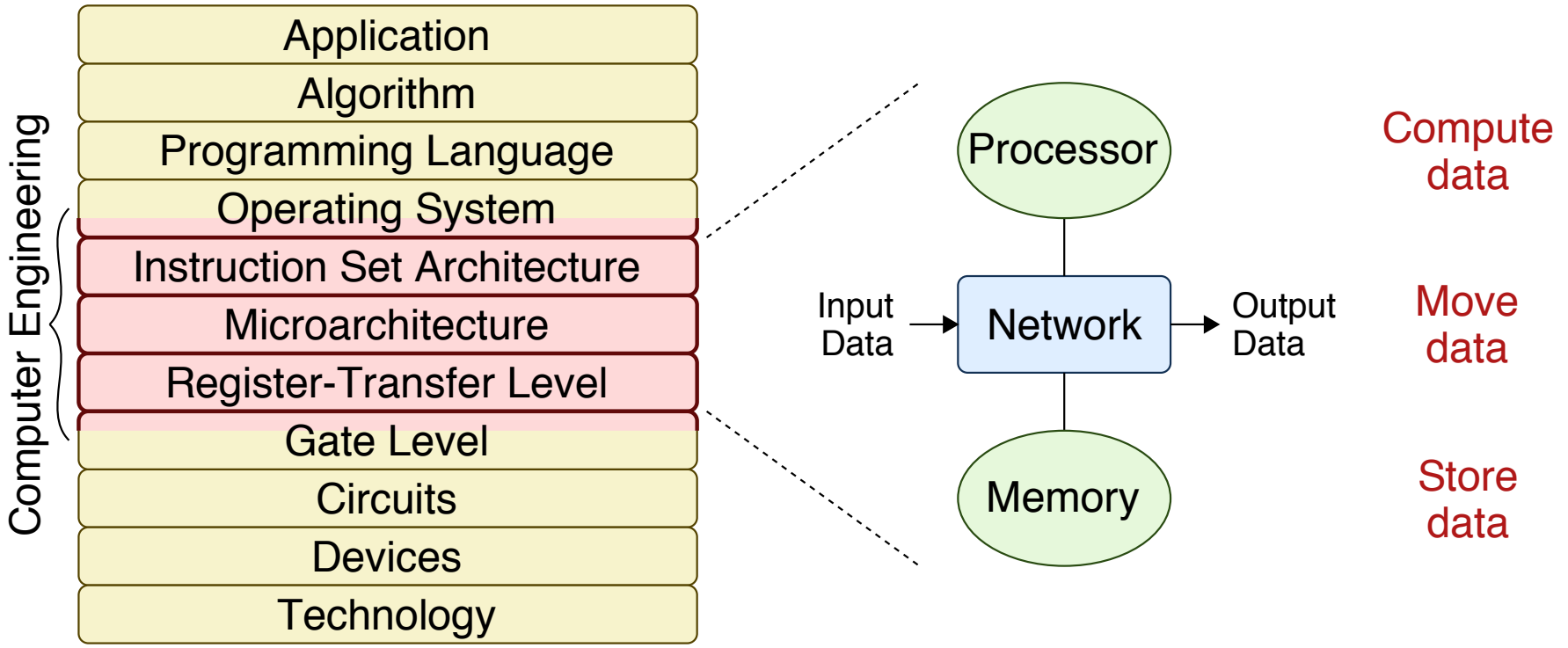

**Application Requirements**
- Suggest how to improve architecture
- Provide revenue to fund development

Computer architects provide feedback to guide application and technology research directions

**Technology Constraints**
- Restrict what can be done efficiently
- New technologies make new arch possible

In its broadest definition, computer engineering is the development of the abstraction/implementation layers that allow us to execute information processing applications efficiently using available manufacturing technologies

# Processors, Memories, and Networks

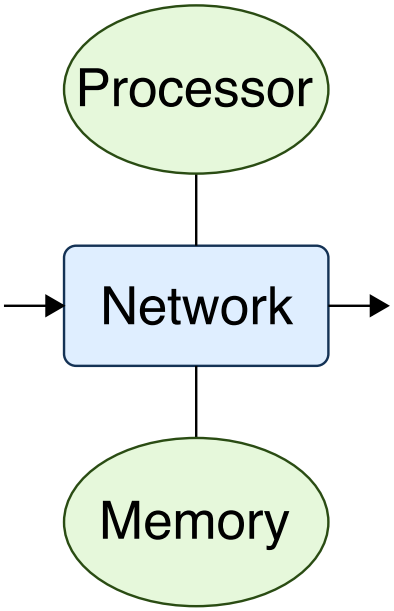


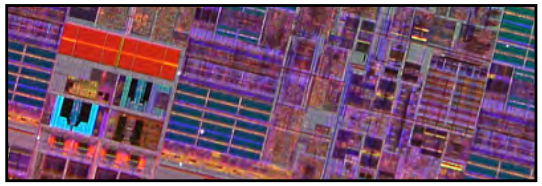
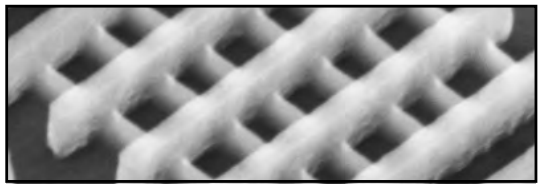
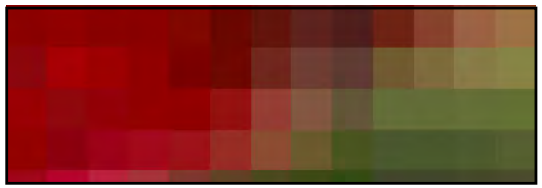

Computer engineering basic building blocks

- Processors for computation
- Memories for storage
- Networks for communication

# Activity #1: Sorting with a Sequential Processor

- **Application:** Sort 32 numbers
- **Simulated Sequential Computing System**
  - Processor: You!
  - Memory: Worksheet, read input data, write output data
  - Network: Passing/collecting the worksheets
- **Activity Steps**
  1. Discuss strategy with neighbors
  2. When instructor starts timer, flip over worksheet
  3. Sort 32 numbers as fast as possible
  4. Lookup when completed and write time on worksheet
  5. Raise hand
  6. When everyone is finished, then analyze data

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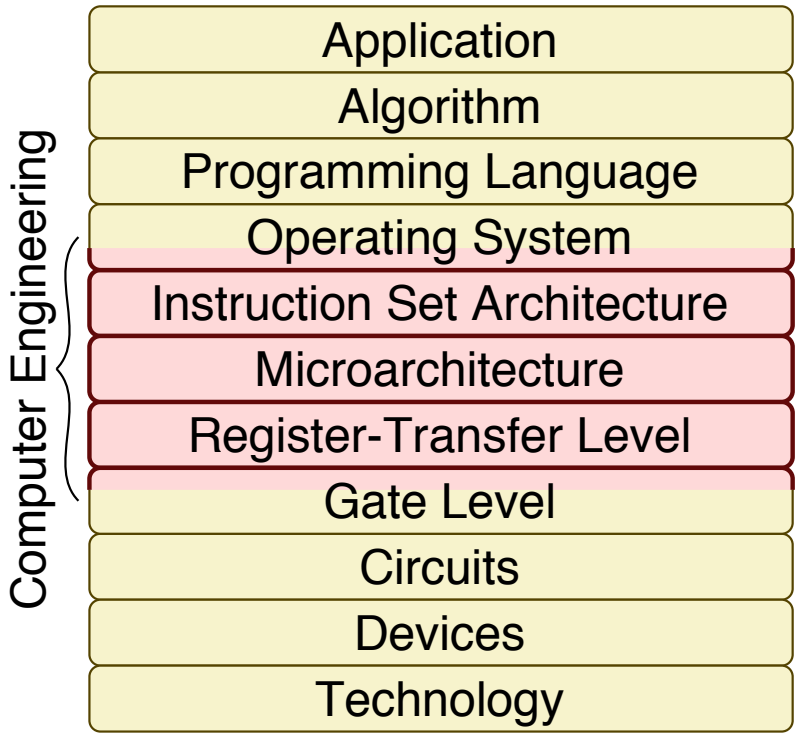
# Application Requirements vs. Technology Constraints



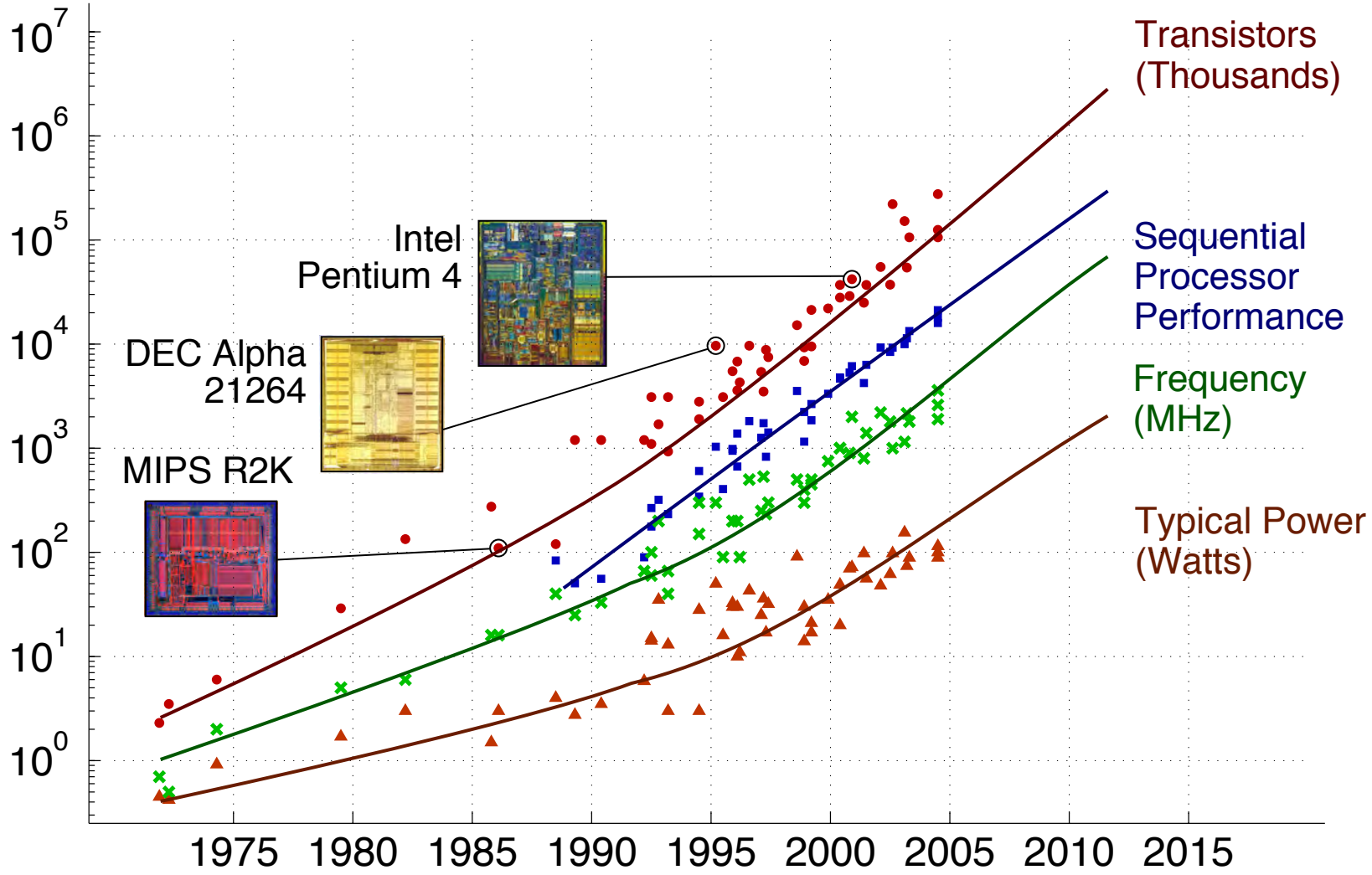

**Traditional Application Requirements**

- As much processor compute as possible
- As much memory capacity as possible
- As much network bandwidth as possible

**Traditional Technology Constraints**

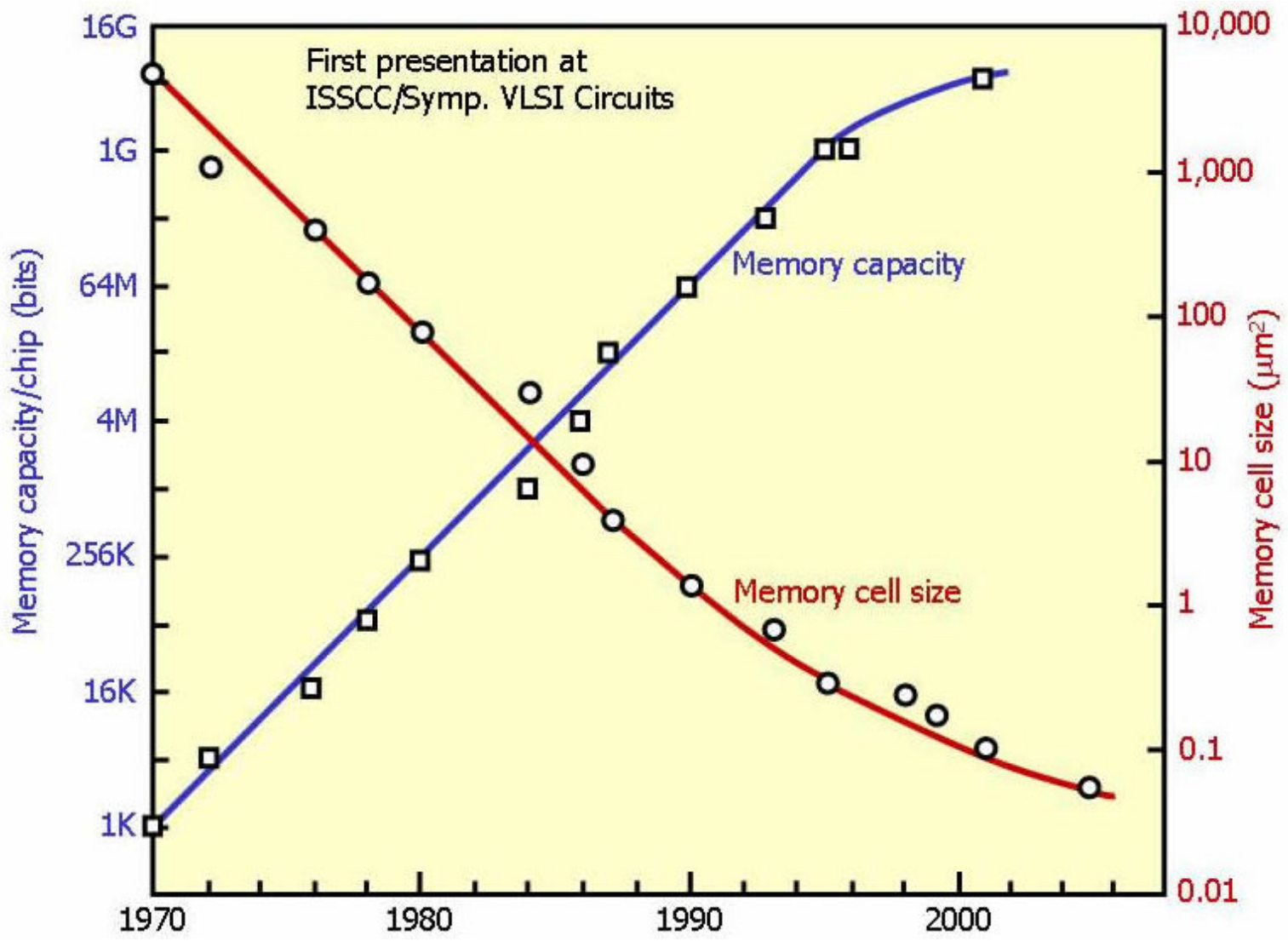
- Exponential scaling of resources

# Exponential Scaling for Processor Computation



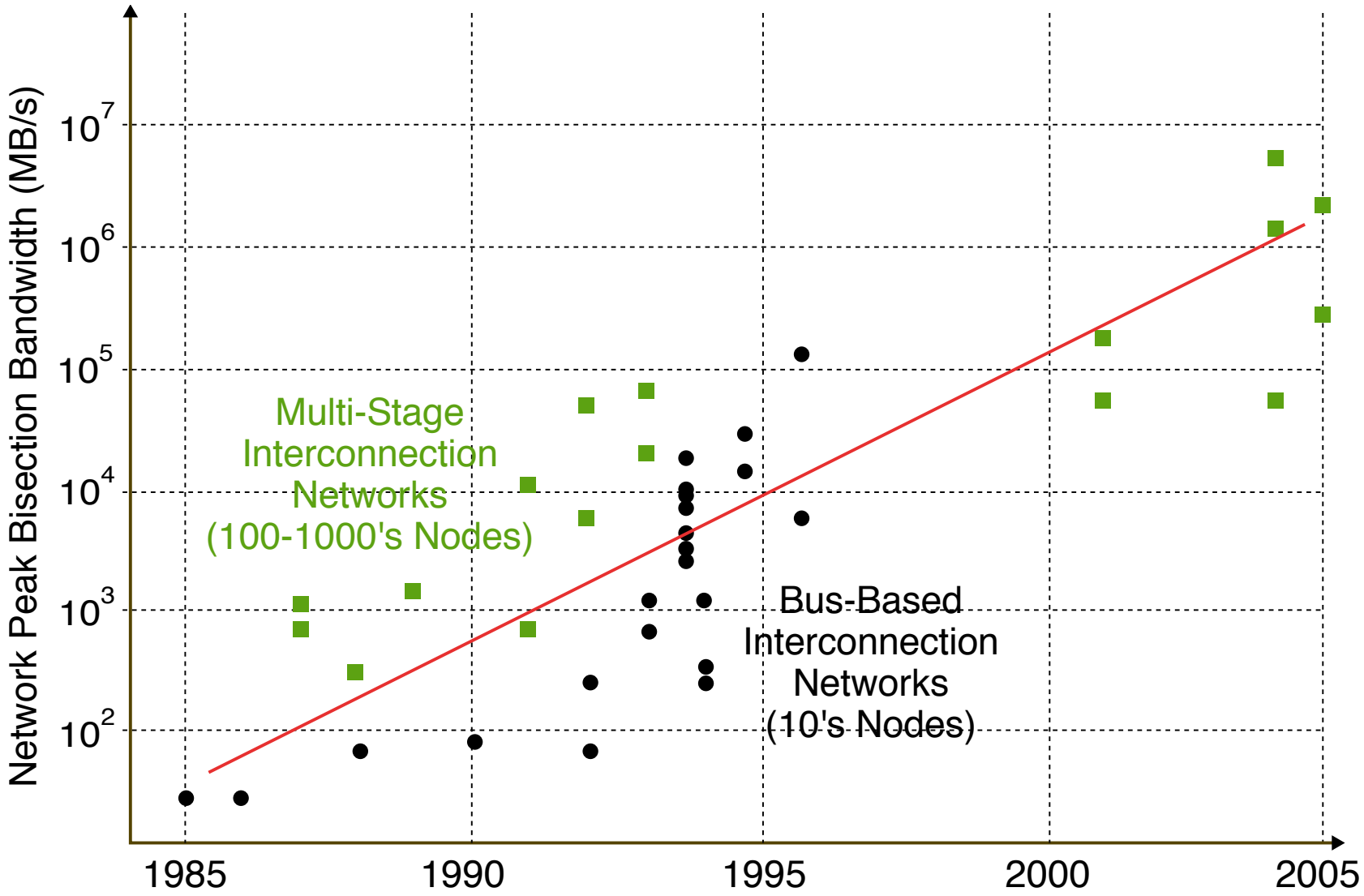

Data partially collected by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond

# Exponential Scaling for Memory Capacity




Adapted from [Itoh'07]

# Exponential Scaling for Network Bandwidth




Data from Hennessy & Patterson, Morgan Kaufmann, 2nd & 5th eds., 1996 & 2011; D.E. Culler et al., Morgan Kaufmann, 1999.

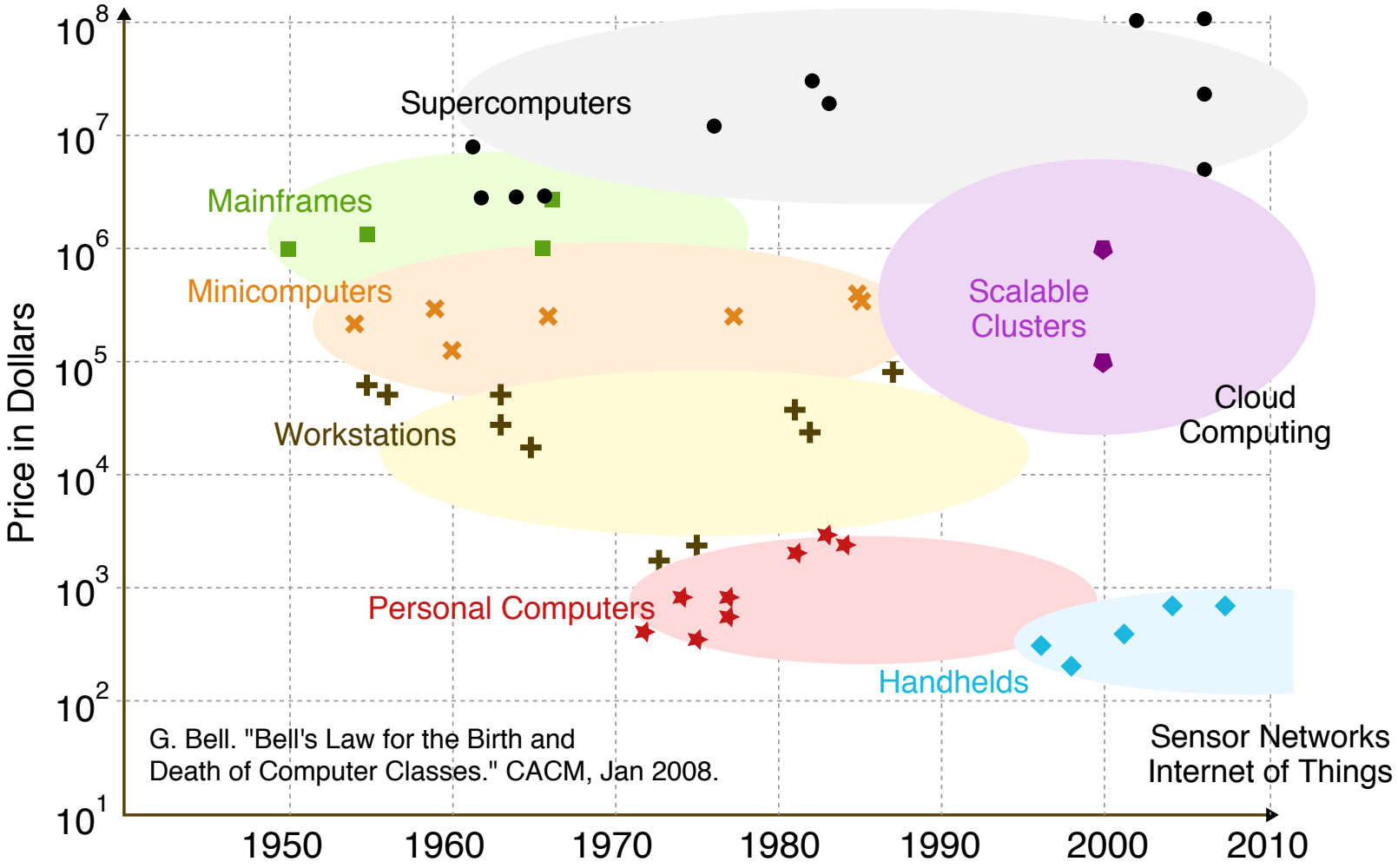
Key trends in the application requirements and technology constraints over the past decade have resulted in a radical rethinking of the processors, memories, and networks used in modern computing systems

**Three Key Trends in Computer Engineering**

1. Growing diversity in application requirements motivate growing diversity in computing systems
2. Energy and power constraints motivate transition to multiple processors integrated onto a single chip
3. Technology scaling challenges motivate new emerging processor, memory, and network device technologies

# Trend 1: Bell's Law

Roughly every decade a new, lower priced computer class forms based on a new programming platform resulting in new usage and industries



# Trend 1: Growing Diversity in Apps & Systems

# Trend 2: Energy/Power Constrain All Modern Systems

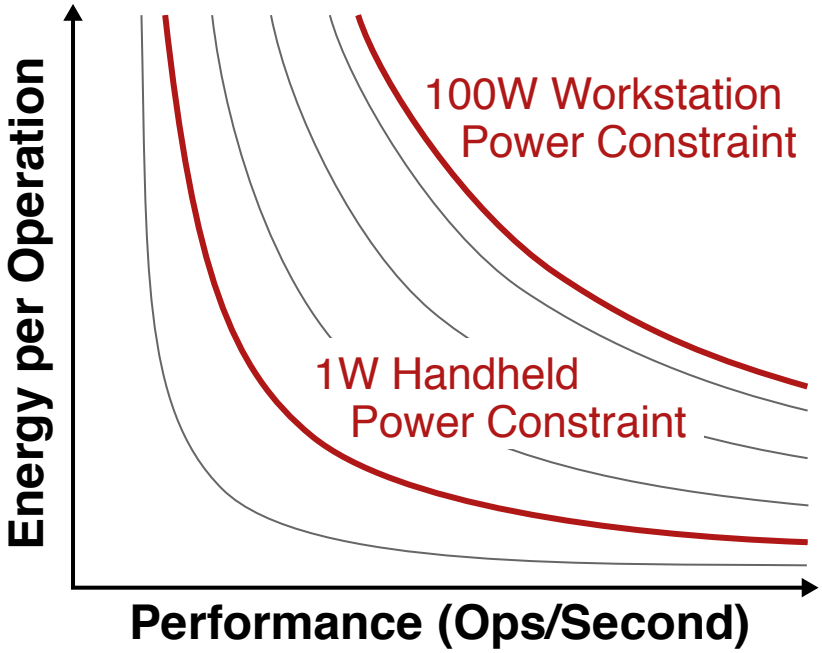
$$\text{Power} = \frac{\text{Energy}}{\text{Second}} = \frac{\text{Energy}}{\text{Op}} \times \frac{\text{Ops}}{\text{Second}}$$

**Power**

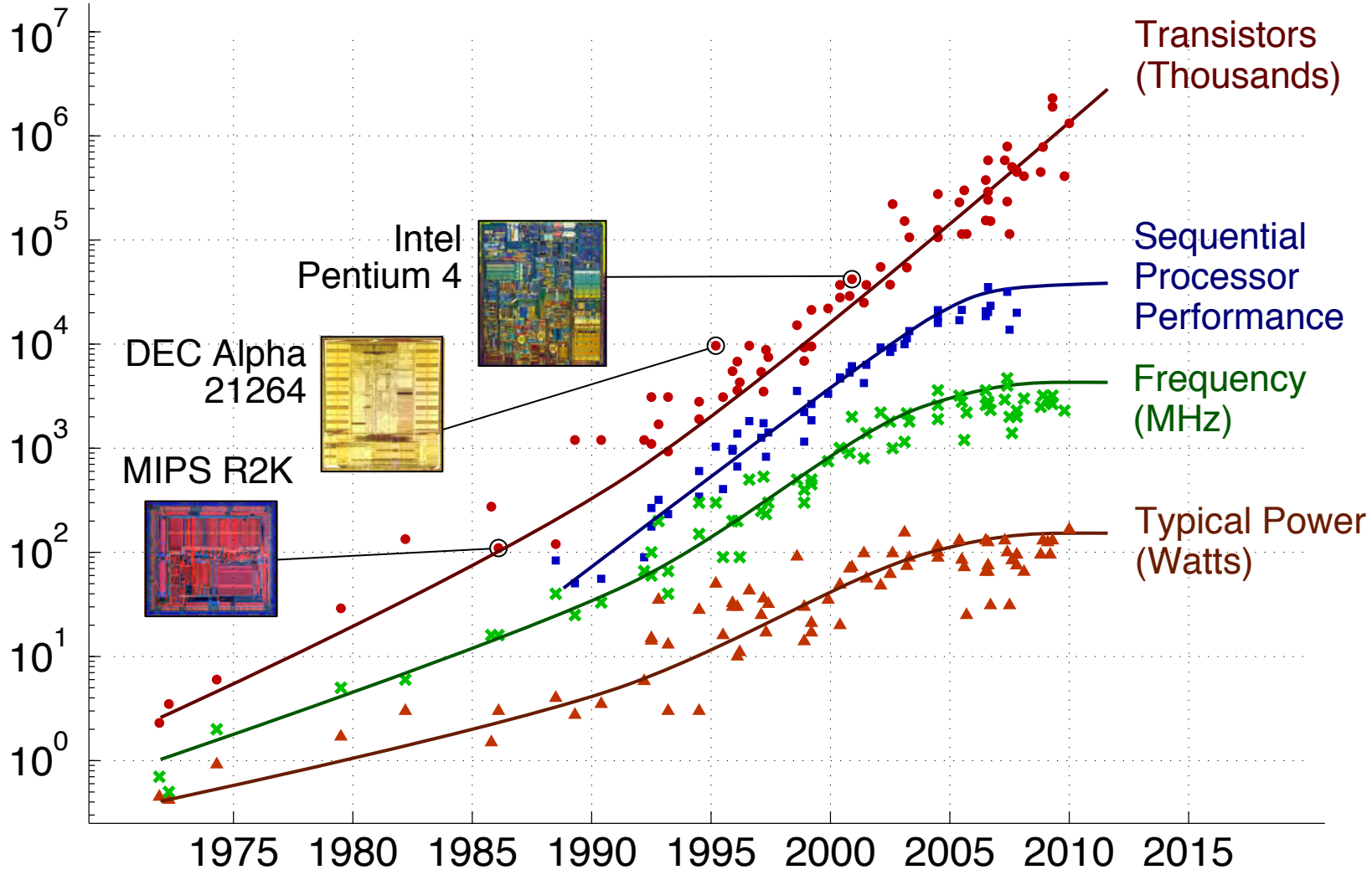
- Chip Packaging
- Chip Cooling
- System Noise
- Case Temperature
- Data-Center Air Conditioning

**Energy**

- Battery Life
- Electricity Bill
- Mobile Device Weight



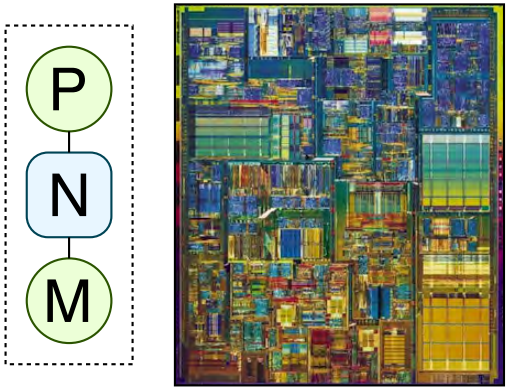
# Trend 2: Power Constrains Single-Processor Scaling



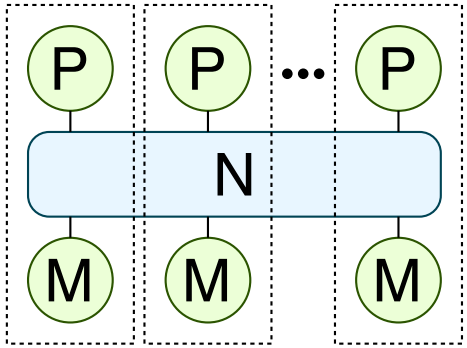

Data partially collected by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond

# Trend 2: Transition to Multicore Processors

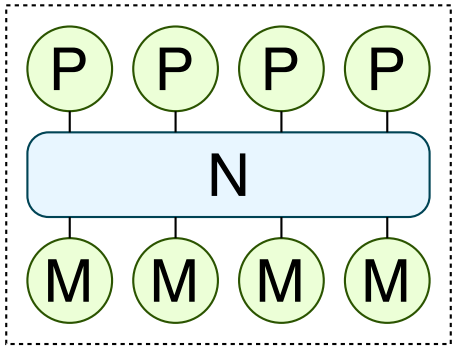
**Intel Pentium 4**
Single monolithic processor

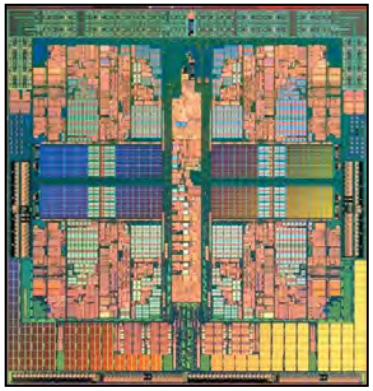


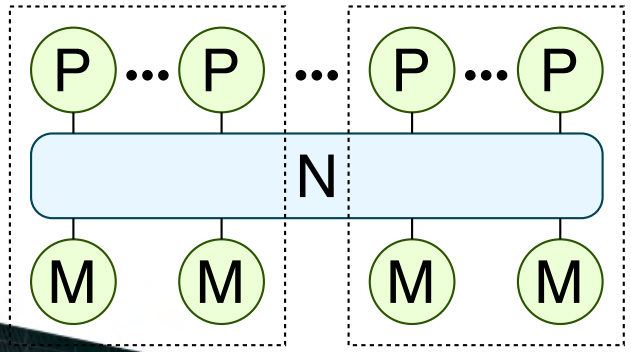

**Cray XT3 Supercomputer**
1024 single-core processors




**AMD Quad-Core Opteron**
Four cores on the same die

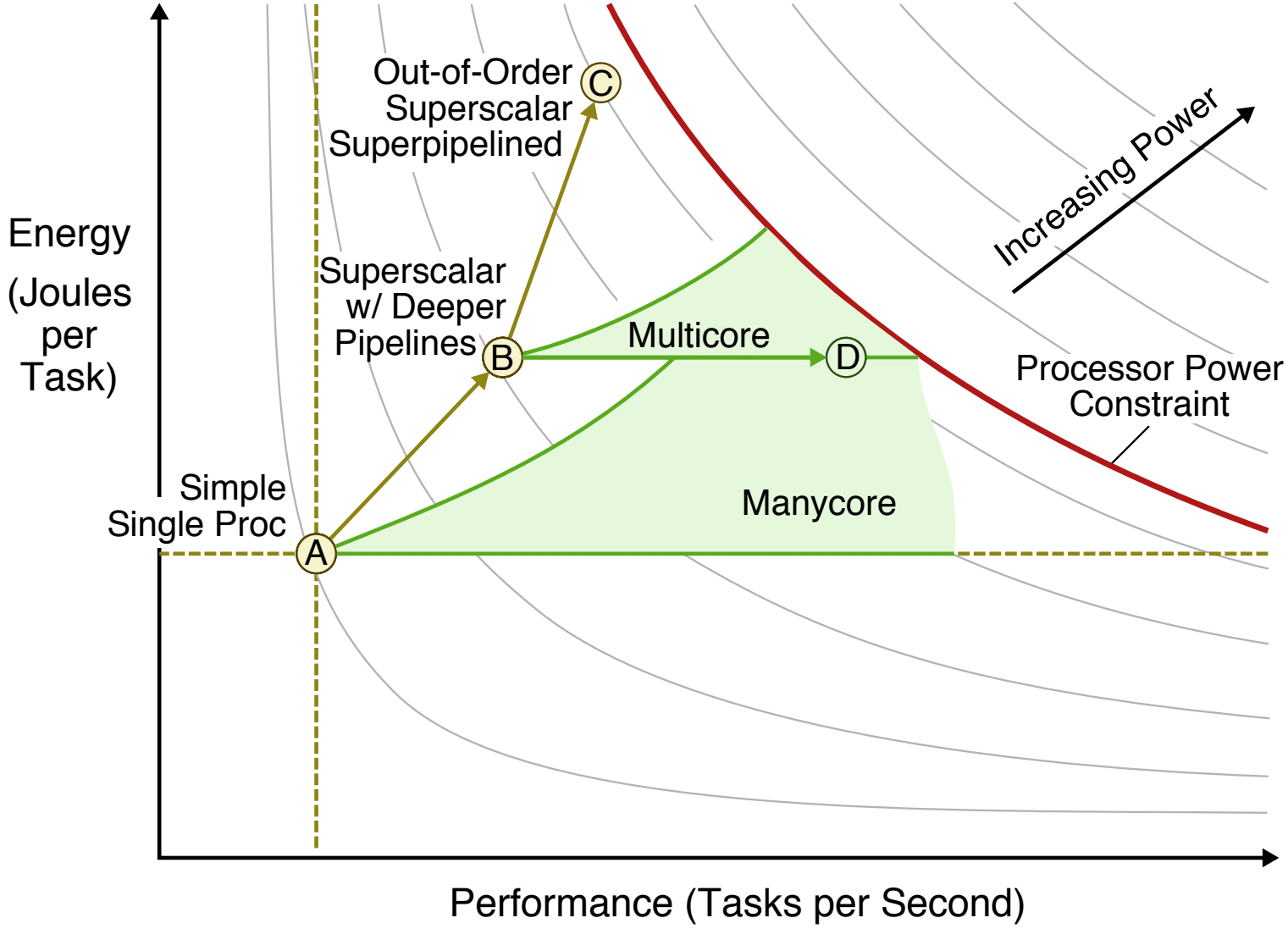


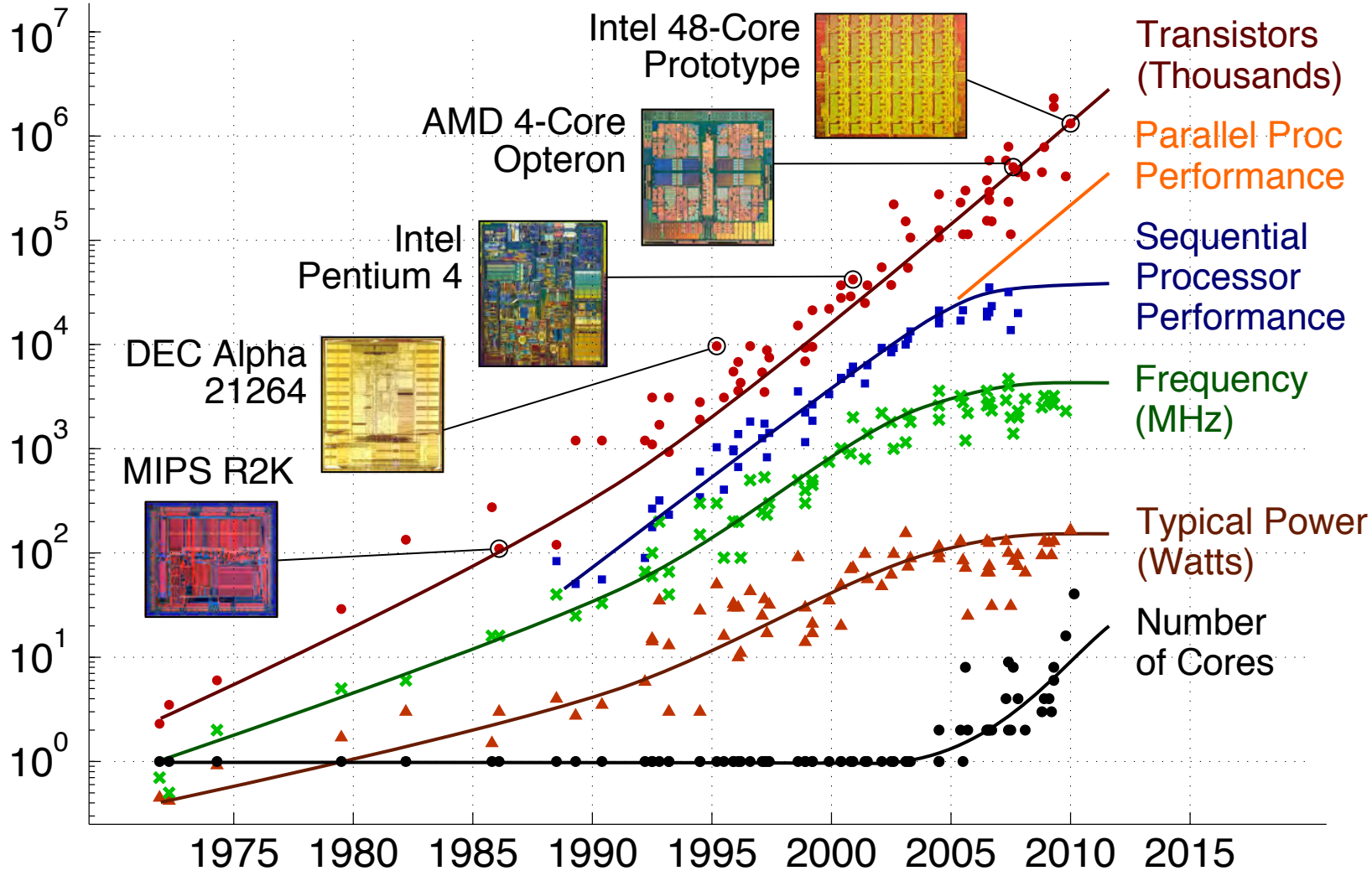



**IBM Blue Gene Q Supercomputer**
Thousands of
18-core processors

# Trend 2: Energy and Performance of Multicores

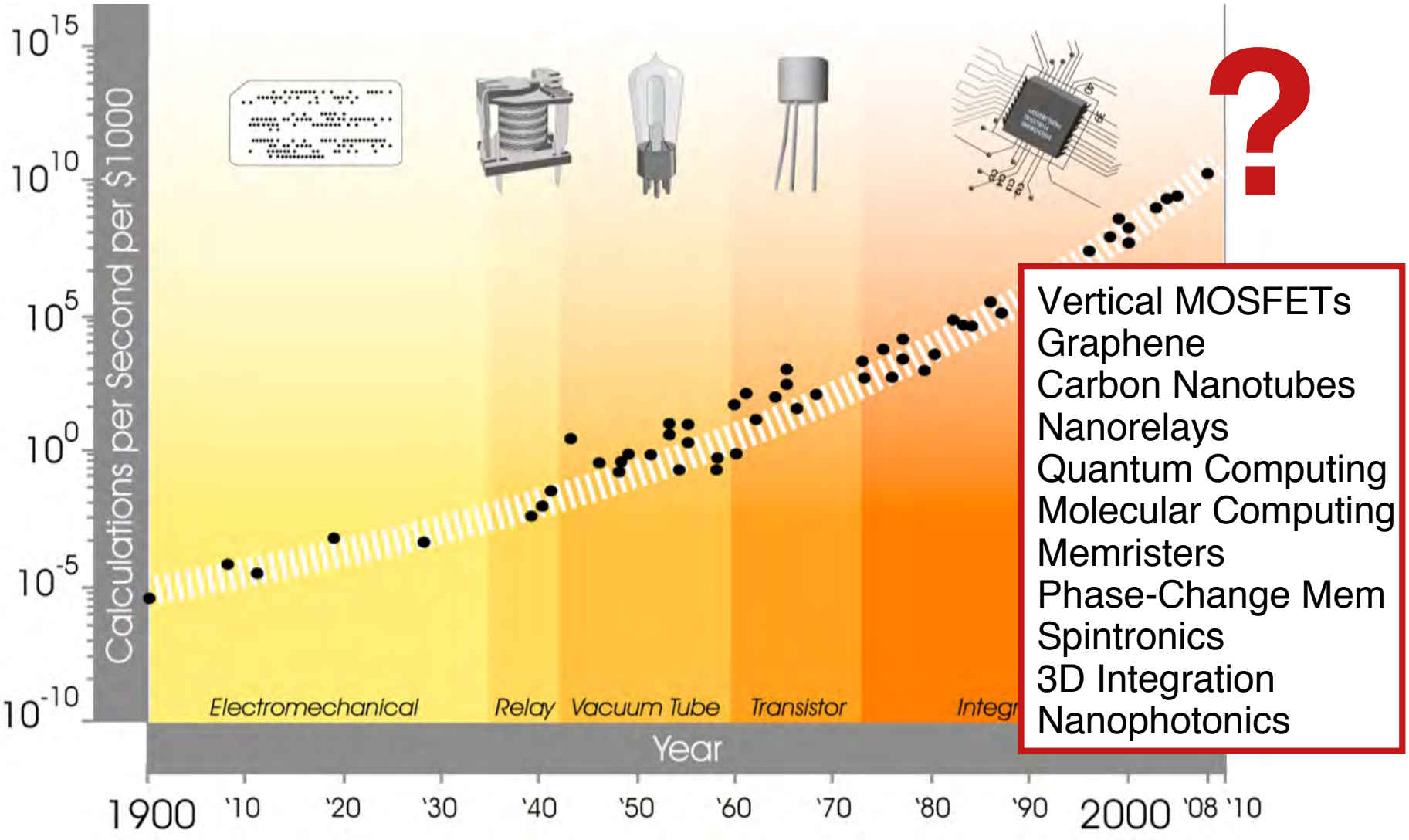


# Trend 2: Multicore Performance Scaling




Data partially collected by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond

# Trend 3: Emerging Device Technologies




Adapted from R. Kurzweil. "The Singularity is Near." Penguin Books, 2006.

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**Three Key Trends in Computer Engineering**

1. Growing diversity in application requirements motivate growing diversity in computing systems
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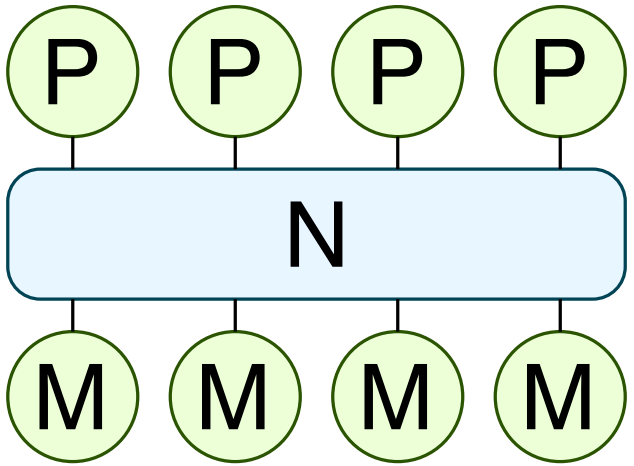
3. Technology scaling challenges motivate new emerging processor, memory, and network device technologies

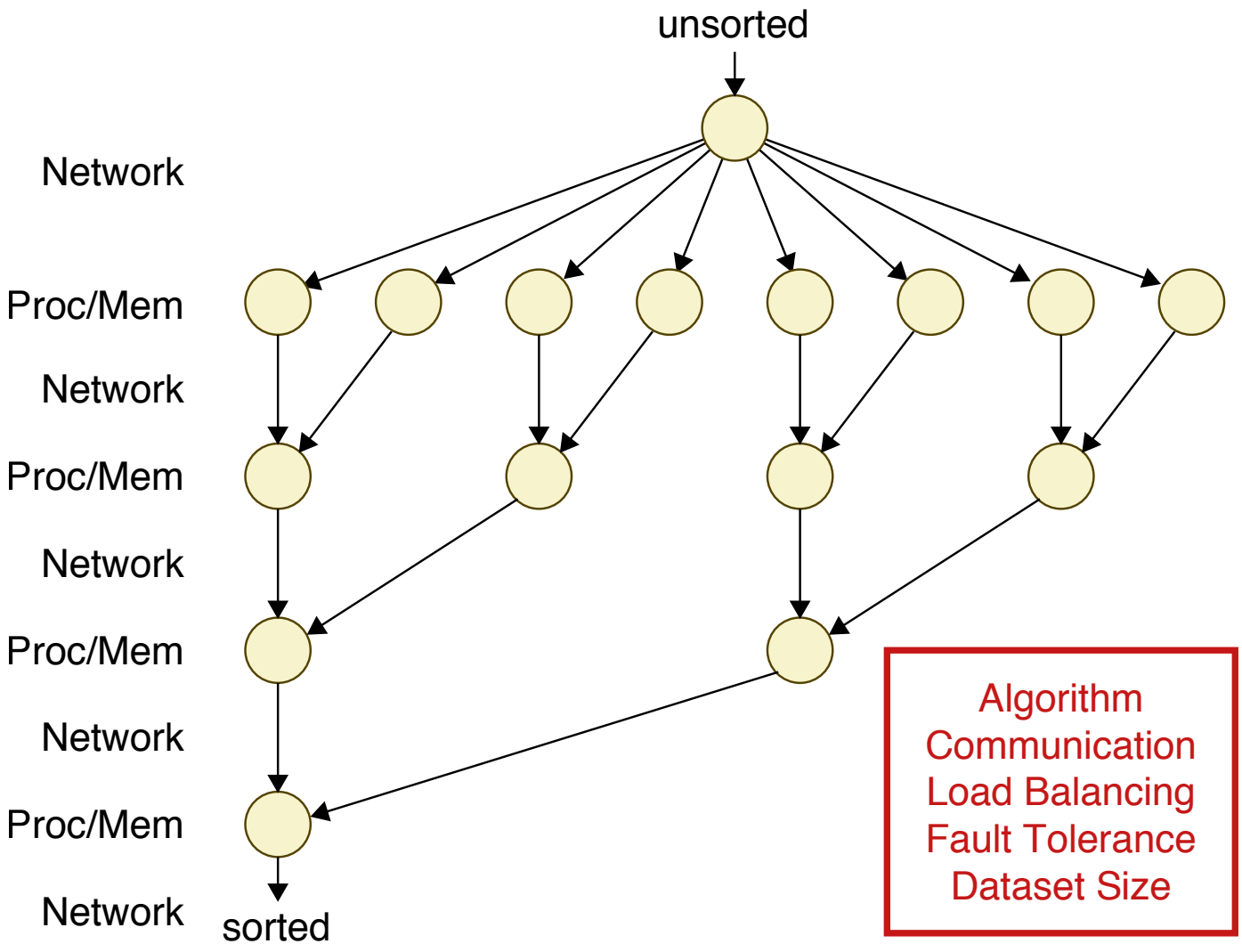
# Activity #2: Sorting with a Parallel Processor

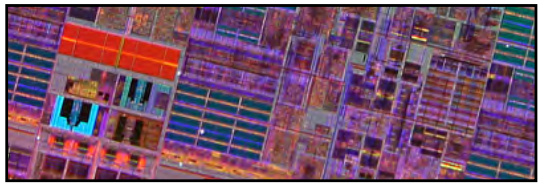
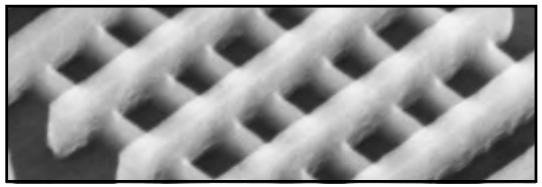
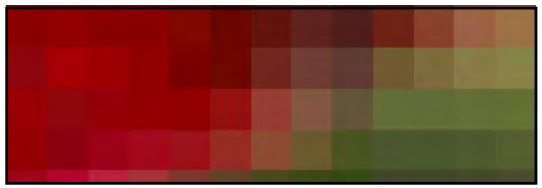
- **Application:** Sort 32 numbers
- **Simulated Parallel Computing System**
  - Processor: Group of 2–8 students
  - Memory: Worksheet, scratch paper
  - Network: Communicating between students




- **Activity Steps**
  1. Discuss strategy with group
  2. When instructor starts timer, master processor flips over worksheet
  3. Sort 32 numbers as fast as possible
  4. Lookup when completed and write time on worksheet
  5. *Master processor only* raises hand
  6. When everyone is finished, then analyze data

# Activity #2: Discussion




# Talk Outline

ECE Overview

What is Computer Engineering?

Trends in Computer Engineering

Computer Engineering Design

# What do computer engineers actually do?

## General Science

Discover truths about nature

Ask question about nature

↓

Construct hypothesis

↓

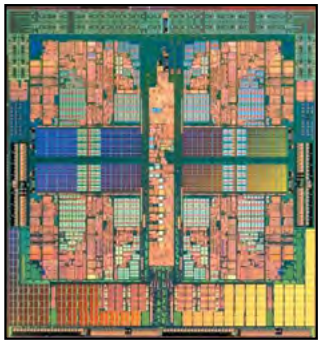
Test with experiment

↓

Analyze results and draw conclusions

## Computer Engineering

Explore design space for a given system



Design and build initial system

↓

Ask question about system

↓

Modify system or build/design alternative

↓

Test with experiment to compare alternatives

↓

Analyze results and draw conclusions

# How do we design something so incredibly complex?

**Computer Engineering**

Explore design space for a given system

Design and build initial system

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Ask question about system

↓

Modify system or build/design alternative

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Test with experiment to compare alternatives

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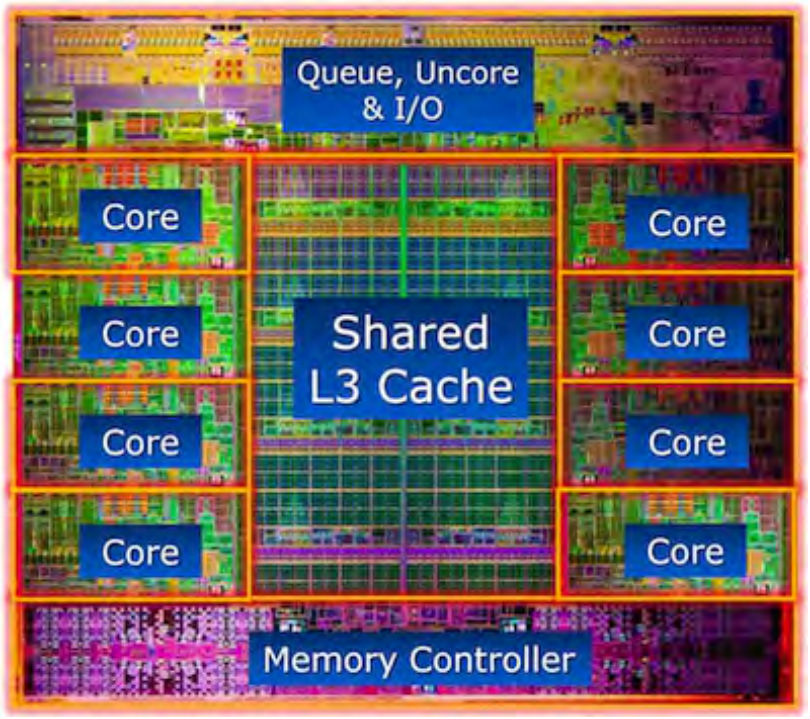
Analyze results and draw conclusions




**Fighter Airplane:** ~100,000 parts

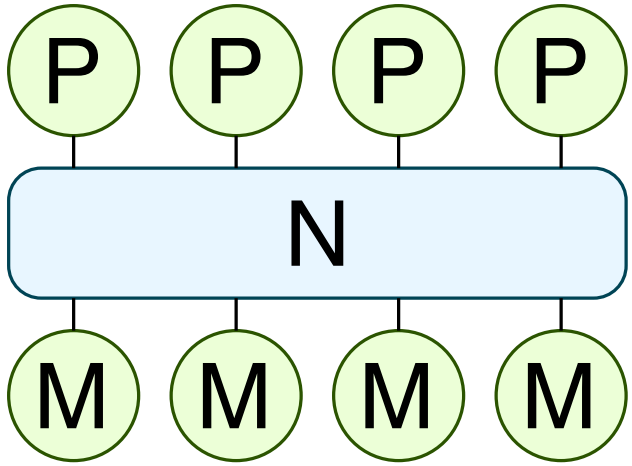
**Intel Sandy Bridge E:** 2.27 Billion transistors

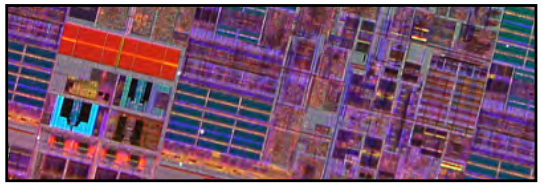
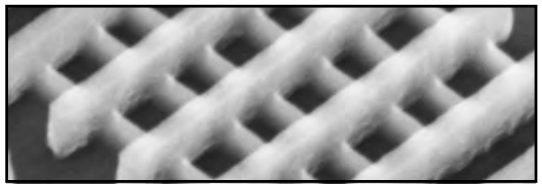
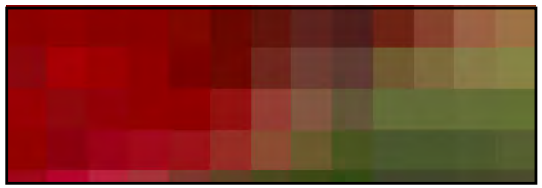
## Design Principles

- Abstraction – Hide low-level details to create higher-level models
- Hierarchy – Structurally decompose design; e.g., net → router → queues
- Regularity – Structural and physical regularity; e.g., uniform tiles
- Modularity – Well-defined interfaces; e.g., latency insensitive net interface
- Encapsulation – Hide implementation details; e.g., processor microarch
- Extensibility – Design for future extensions; e.g., new network topo

## Design Methodologies

- Incremental development
- Test-driven development
- Agile development




# Take-Away Points

- ECE is a broad field focused on the study and application of electricity, micro-electronics, and electro-magnetism
- Computer engineering is the process of designing abstraction and implementation layers to meet application requirements within physical technology constraints
- We are entering an exciting new era of computer engineering with emerging applications and systems, a remarkable shift towards mainstream parallel processing, and significant technology challenges