# CS 286
# Two Lecture Introduction

## Parallel Processing:

## A Hardware Solution
## &
## A Software Challenge

# We’re on the Road to Parallel Processing

# Outline

- Hardware Solution (Day 1)
- Software Challenge (Day 2)
- Opportunities

# Outline

- Hardware Solution
  - Technical
- Software Challenge
  - Technical
- Opportunities
  - Technical

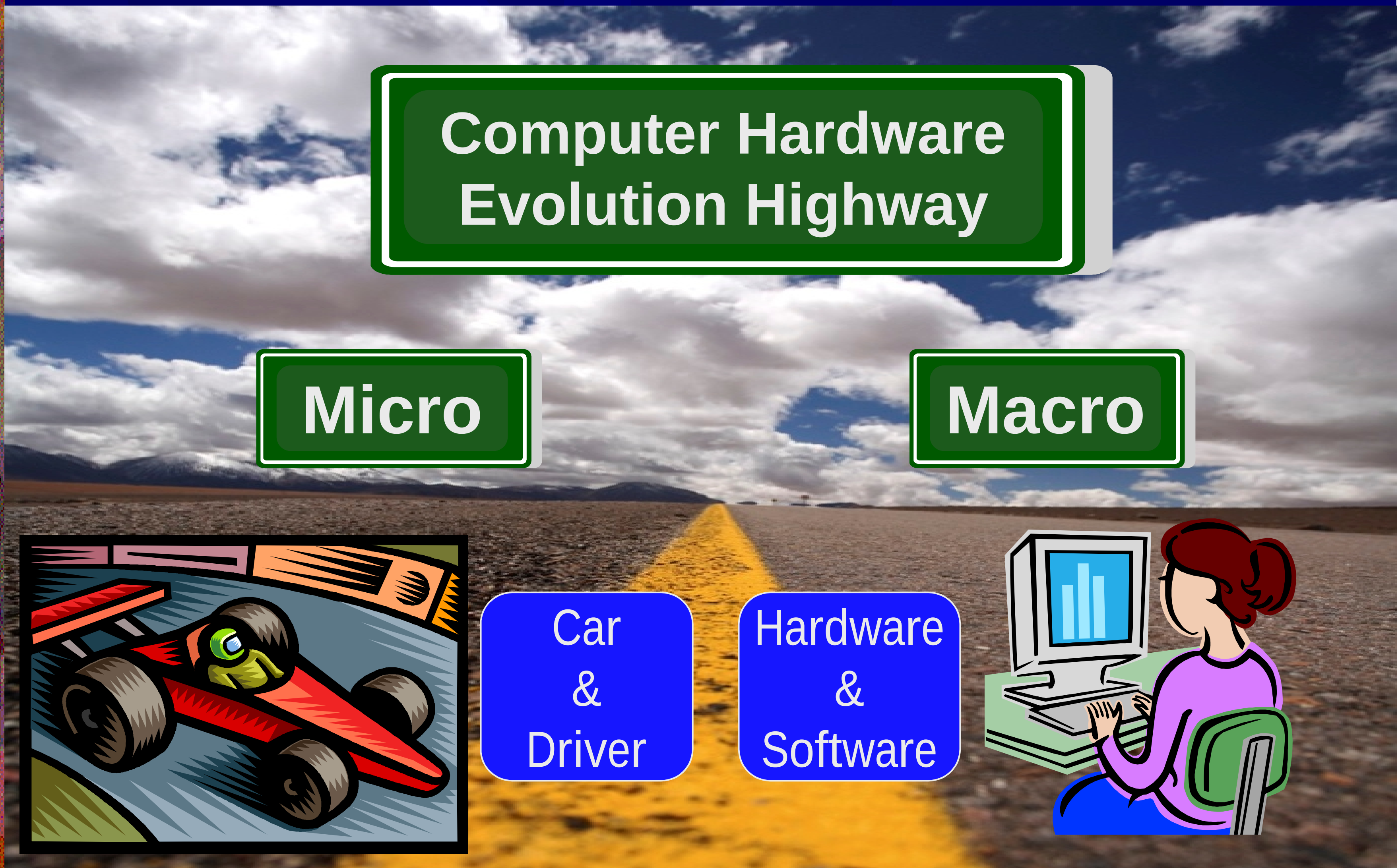
# Outline

- Hardware Solution
  - Technical
  - Business
- Software Challenge
  - Technical
  - Business
- Opportunities
  - Technical
  - Business

# Outline

- Hardware Solution
  - Technical
  - Business
- Software Challenge
- Opportunities

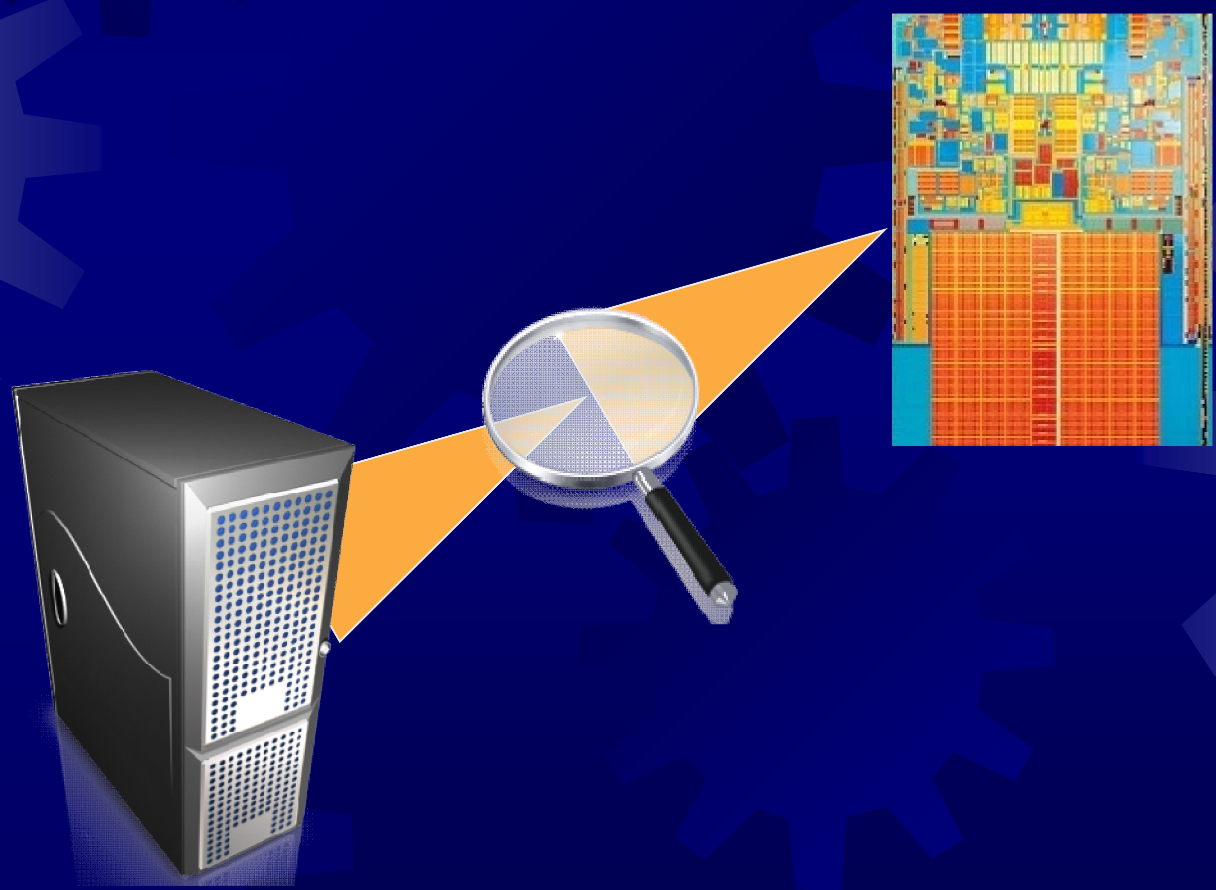
# Hardware Solution - Technical Evolution of Computer Architectures



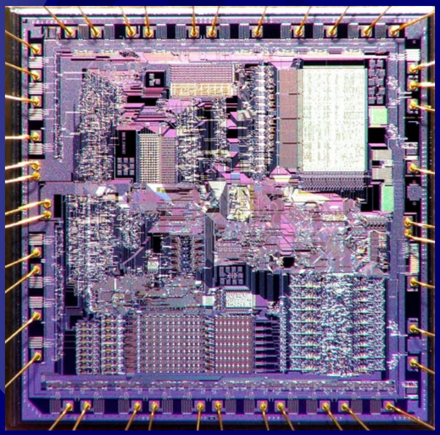
# Hardware Solution - Technical

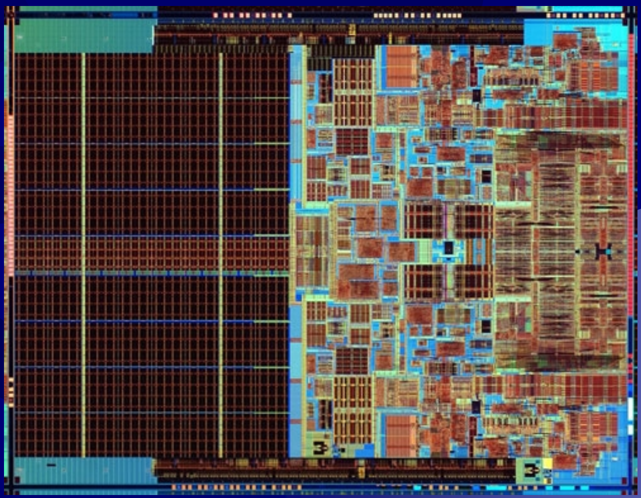
# Evolution of Computer Architectures

# Micro-Scopic View



# Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View



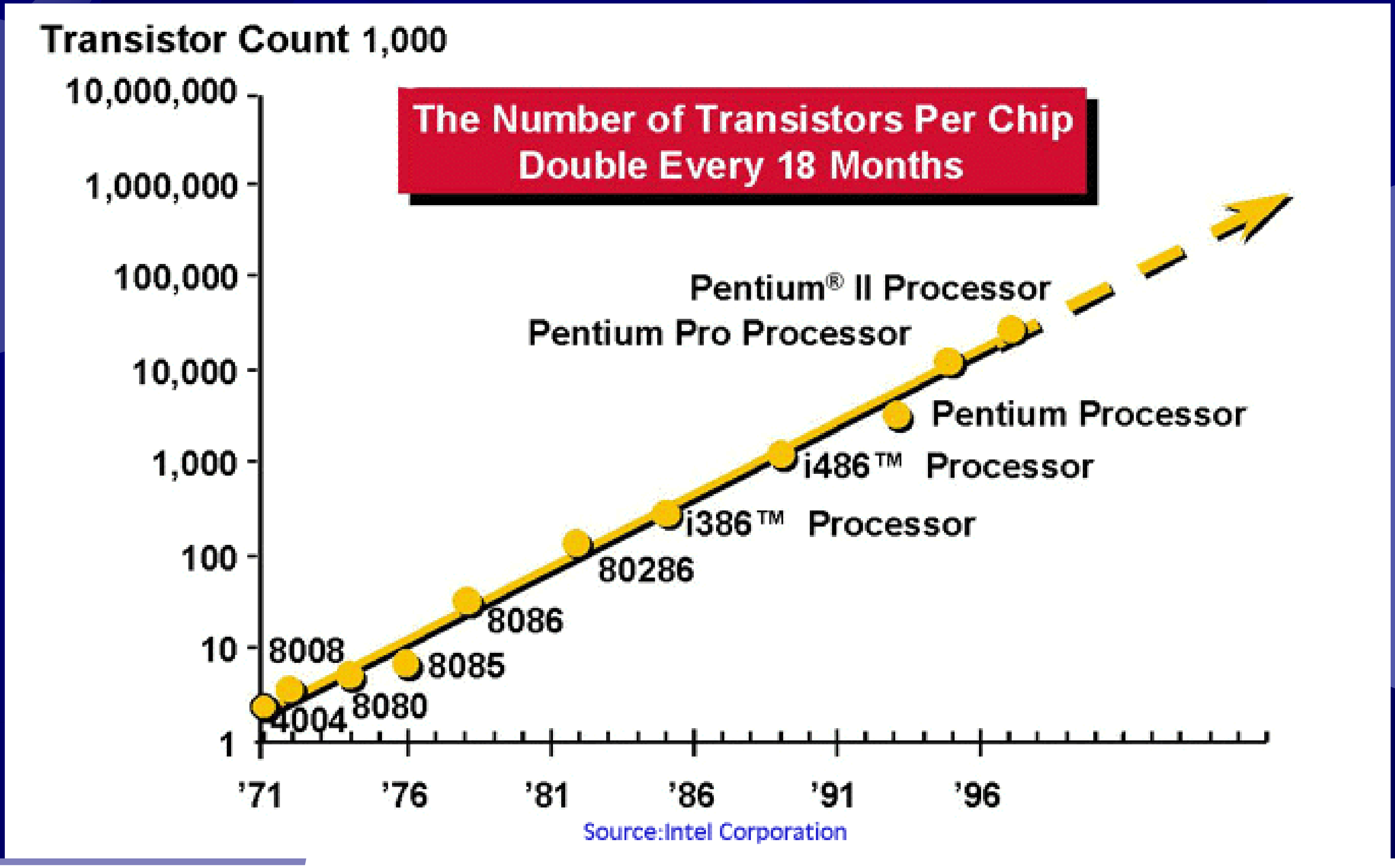


| Intel 8086 | | Intel Core 2 Duo |
|---|---|---|
| 1978 | Year | 2006 |
| 29,000 | Transistors | 291,000,000 |
| 5 MHz | Clock Frequency | 2.9 GHz |

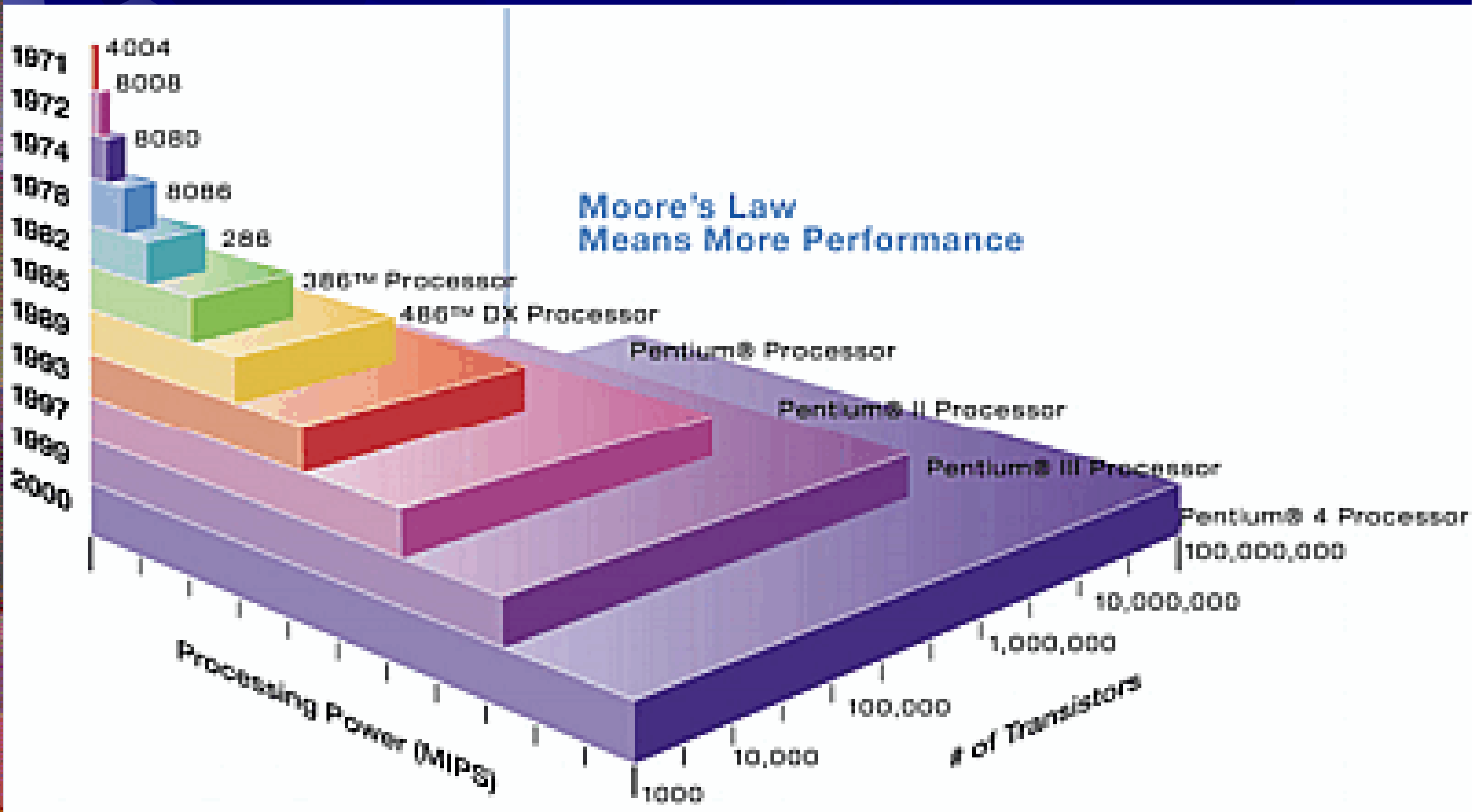
# Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View

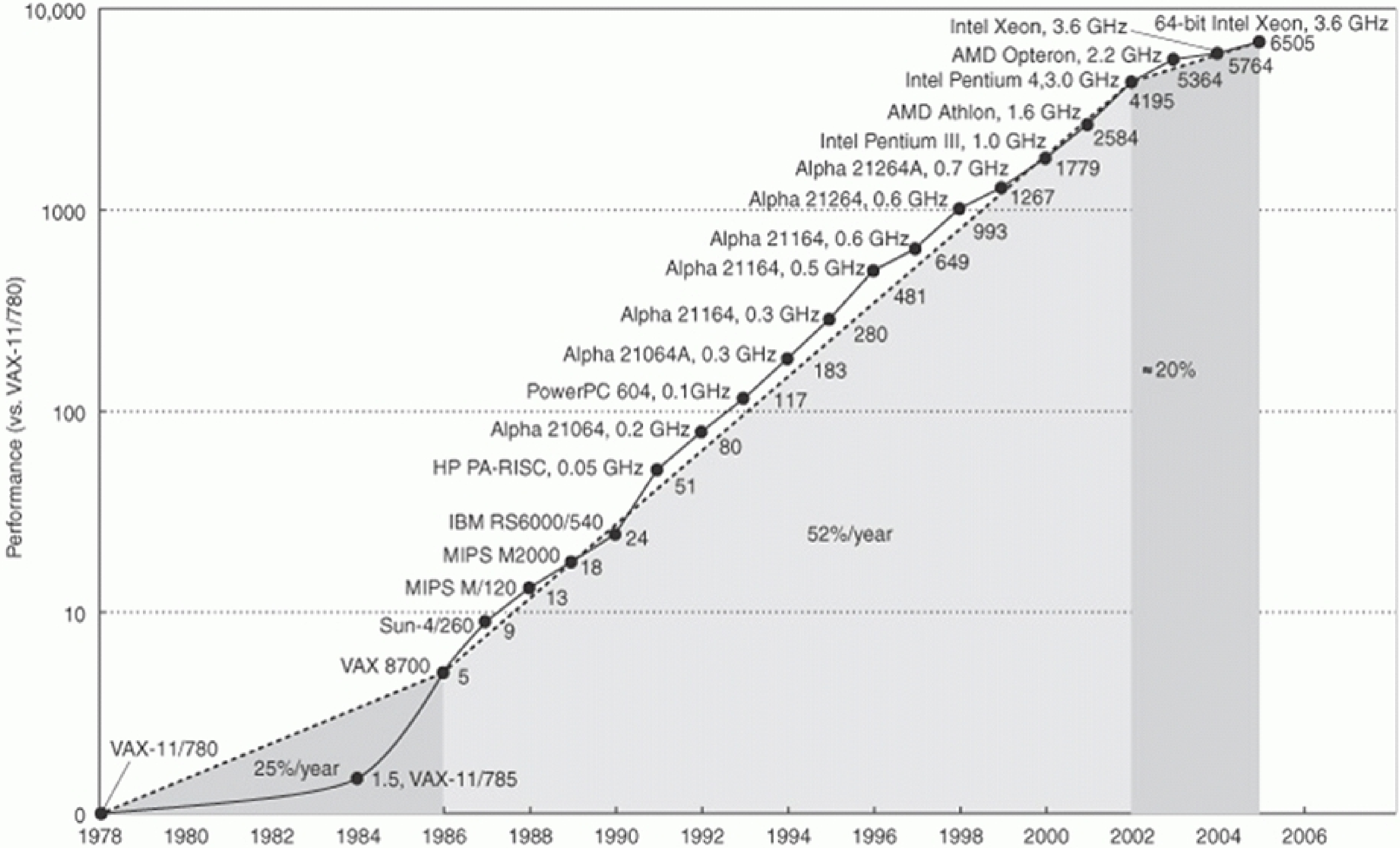
- In 28 Years from 1978 to 2006:
  - Number of Transistors Increased 10,034X
  - Clock Frequency Increased 586X
- Primary Driver / Facilitator was (and is) Moore's Law:
  - Number of Transistors Doubles every 18-24 Months
  - Stated by Gordon Moore, Intel Co-Founder in 1965
  - Prediction has been proven valid over a long term
    - "Prediction" has been the "Law" for over 40 years

# Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View



# Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View



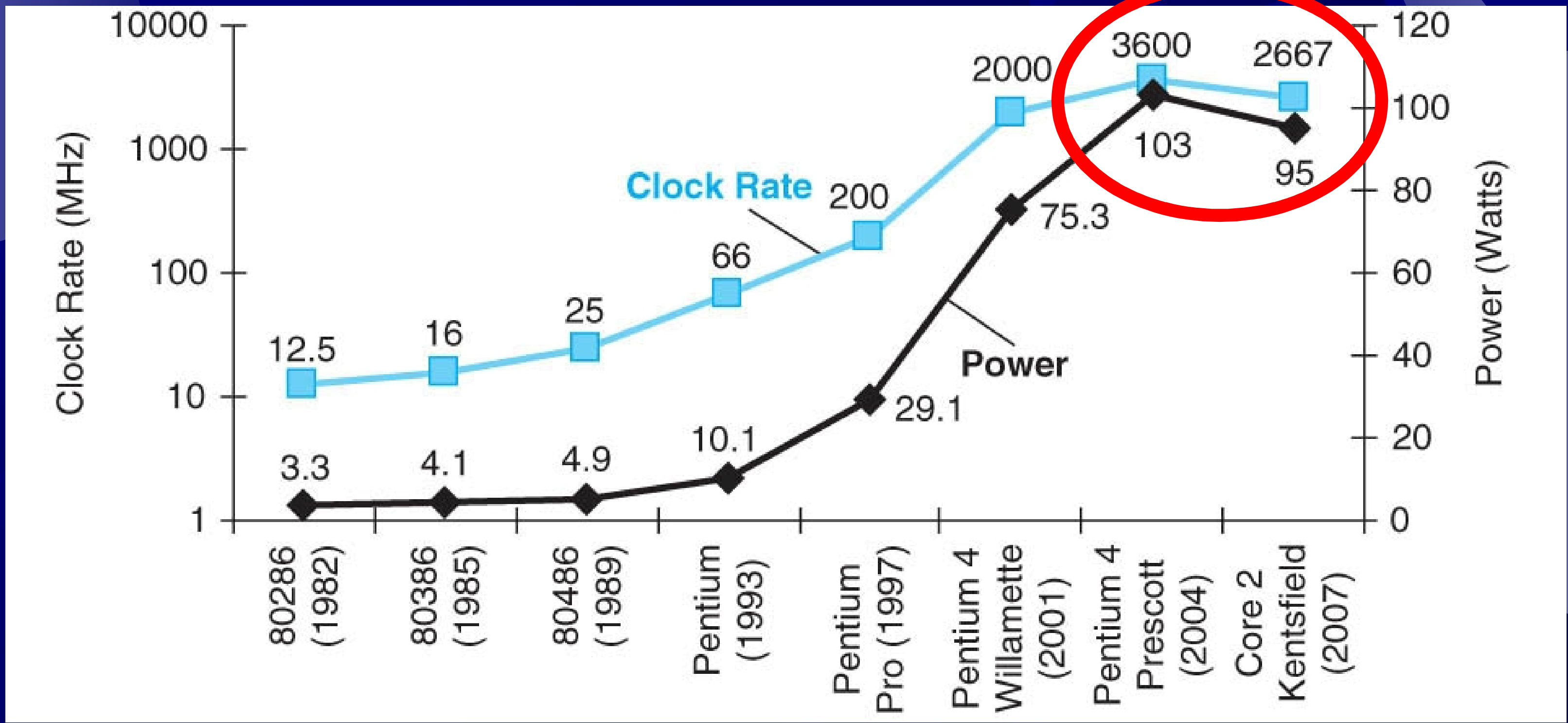



- Historically, Huge Performance Gains came from Huge Clock Frequency Increases

  Unfortunately ……….

# Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View

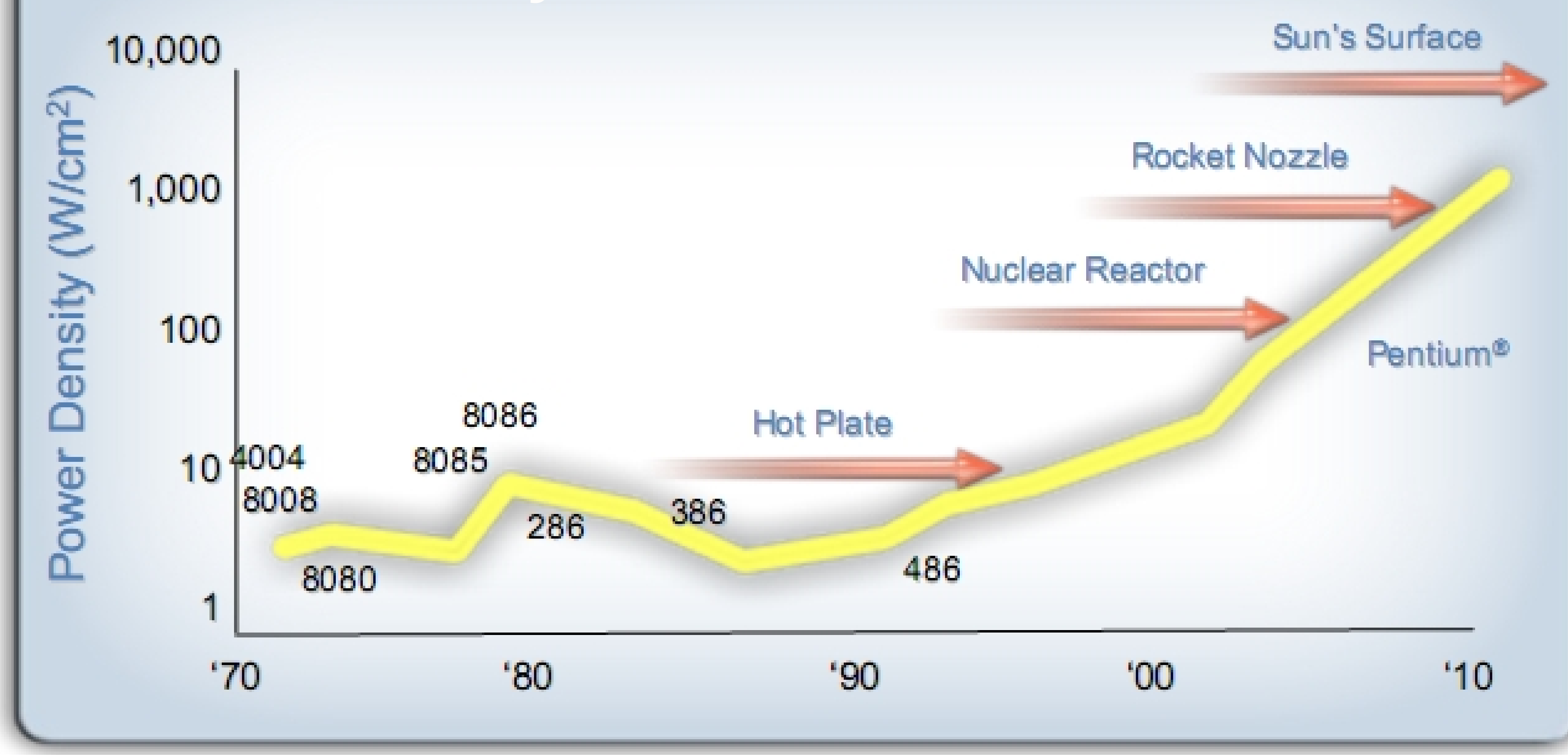
## Clock Rate Limits Have Been Reached




**Source: Patterson, *Computer Organization and Design***

# Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View

## Blocked by Heat and Power "Wall"




Intel Developer Forum, Spring 2004 - Pat Gelsinger

# Hardware Solution - Technical

## Evolution of Computer Architectures

## Micro-Scopic View

- Power (and Heat) Grows as Frequency$^3$

$$\text{Power} \propto \text{Voltage}^2 \times \text{Frequency}$$

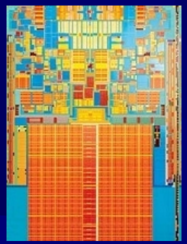
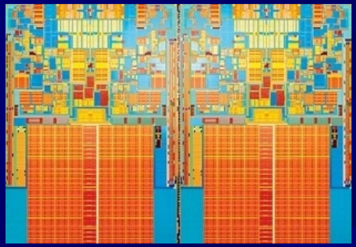
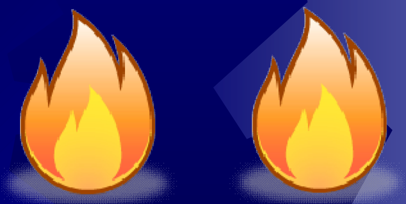
$$\text{Voltage} \propto \text{Frequency}$$

$$\text{Power} \propto \text{Frequency}^3$$

- How can HW Performance Continue to Increase?

Single Core → Multi-Core

# Single Core vs. Dual Core

| Single Core clocked at 2*f* | | Dual Core clocked at *f* |
|---|---|---|
|  | |  |
| $2f$ | **Throughput** | $f + f$ |
| $8f^{3}$ | **Heat** | $f^{3} + f^{3}$ |
|  | |  |

Sequential Processing → Parallel Processing

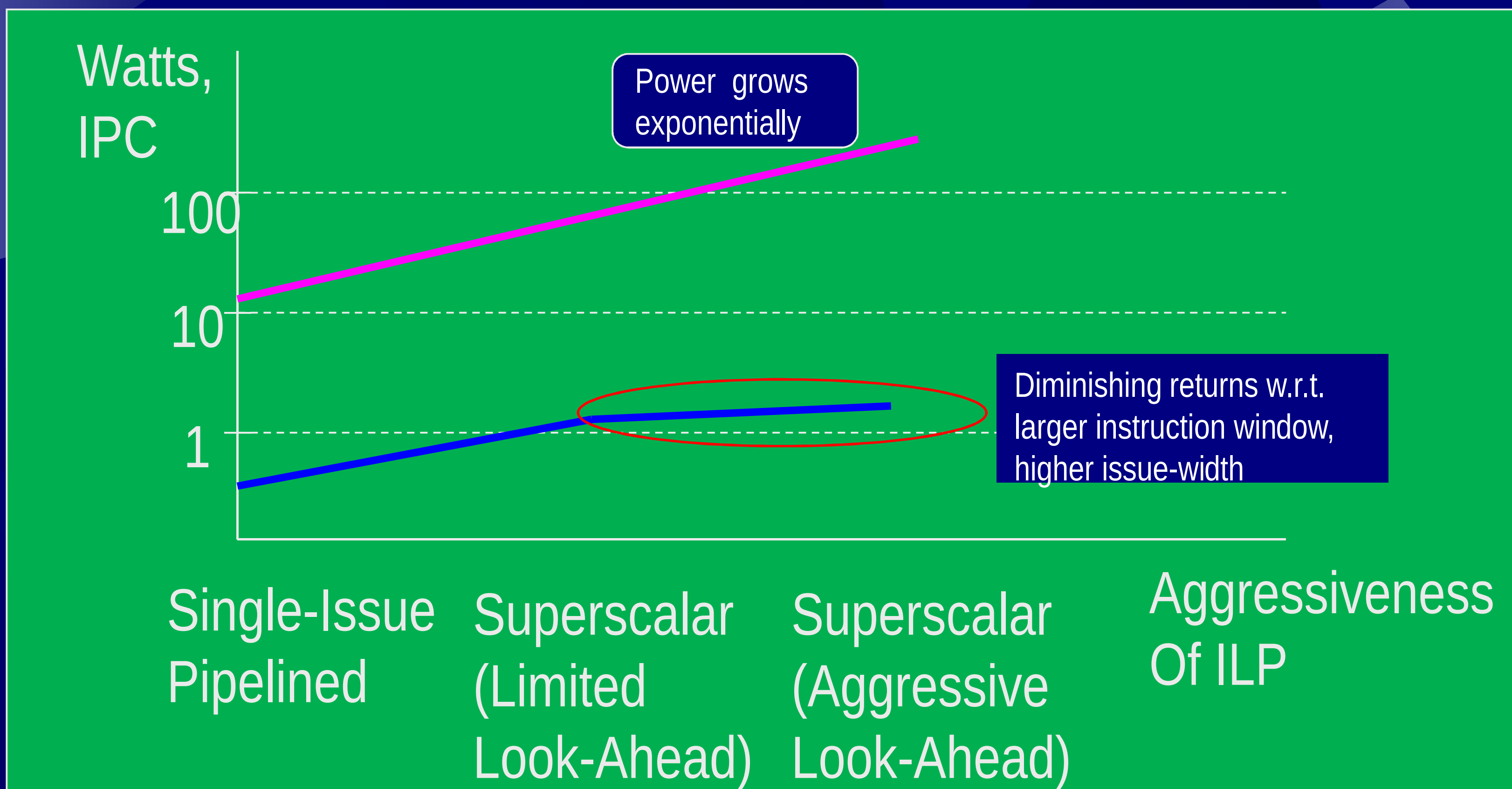
# Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View

- Instruction-Level Parallelism (ILP) was also Heavily Used
  - Implemented On-Chip via Hardware
  - Transparent to Software (No impact on Programmers)
- We will Study Two Types:
  - Pipelining (Intra-Instruction Parallelism)
  - Multi-Function Units (Inter-Instruction Parallelism)
- ILP has provided reasonable speedups in the past,

  Unfortunately…….

# Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View

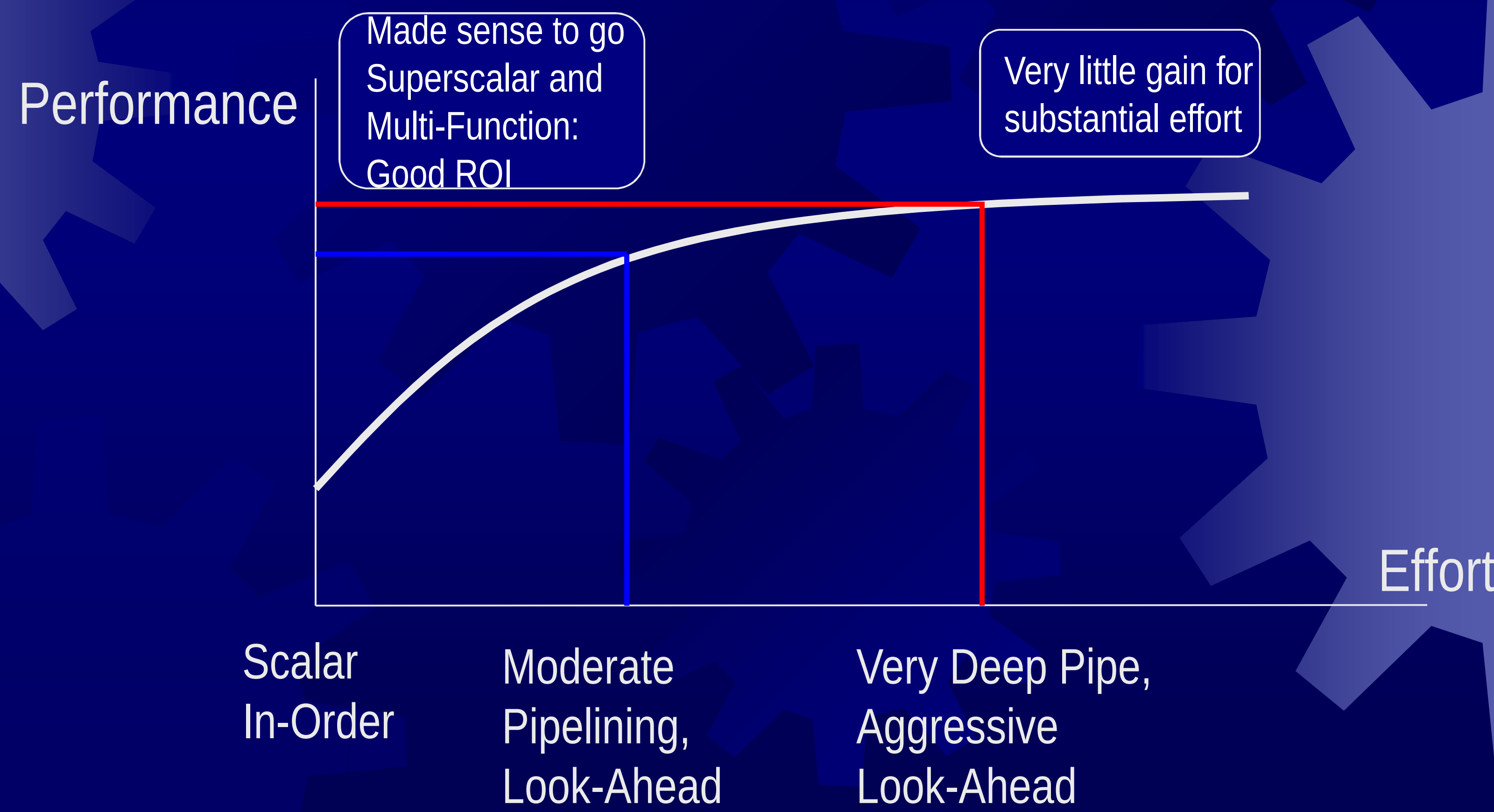
- Instruction-Level Parallelism Limits have been Reached too



# Hardware Solution - Technical

# Evolution of Computer Architectures

- Gain - to - Effort Ratio of ILP beyond “Knee” of Curve
  - Diminishing Returns due to
    Increased Cost and Complexity of Extracting ILP



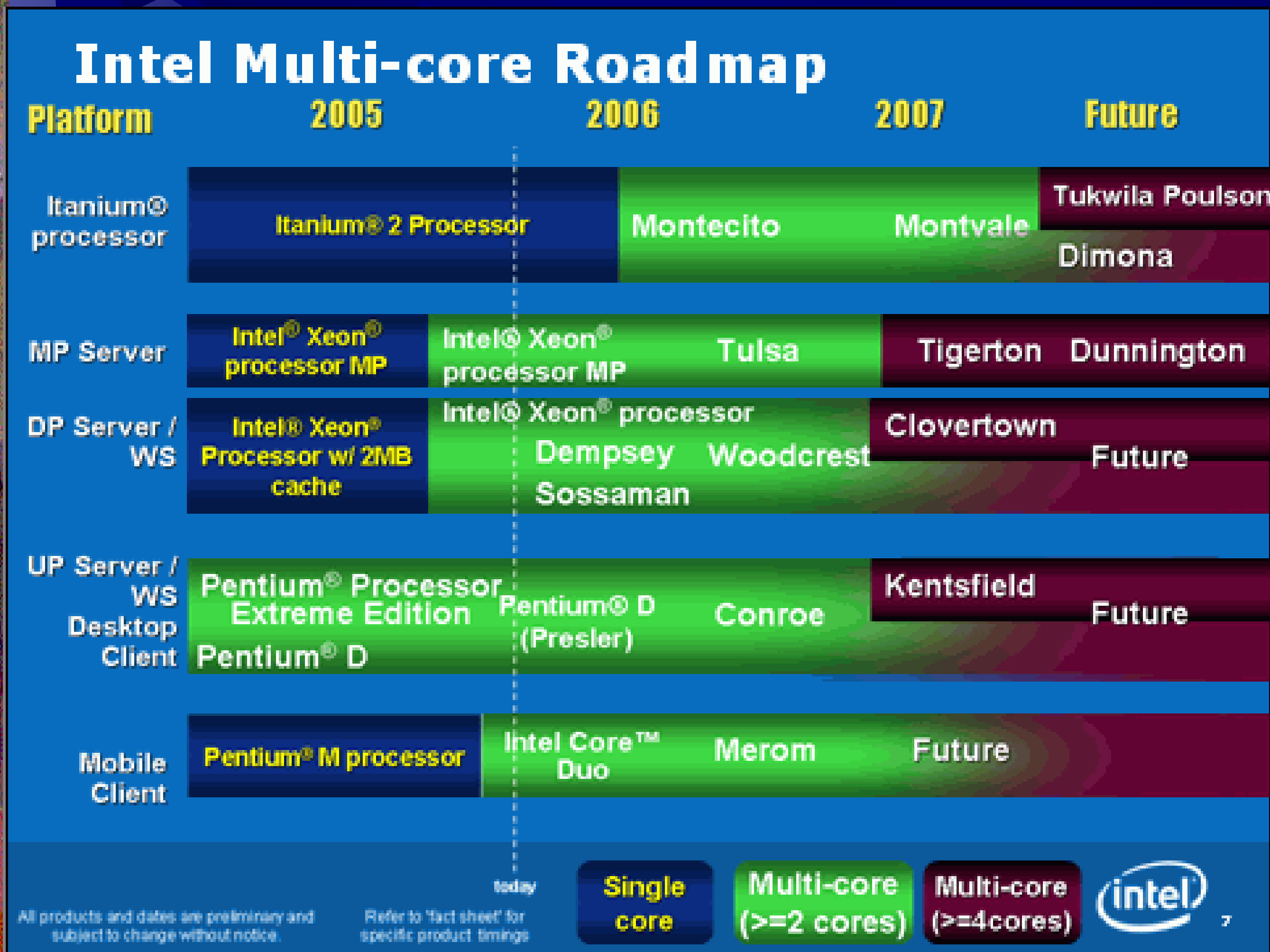
# Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View Summary

- Clock Frequency Scaling Limits have been Reached
- Instruction Level Parallelism Limits have been Reached
- Era of Single Core Performance Increases has Ended
- No More "Free Lunch" for Software Programmers
  - Multiple Cores Will Directly Expose Parallelism to SW
- All Future Micro-Processor Designs will be Multi-Core
  - Evident in Chip Manufacturer's RoadMaps

# Hardware Solution - Technical

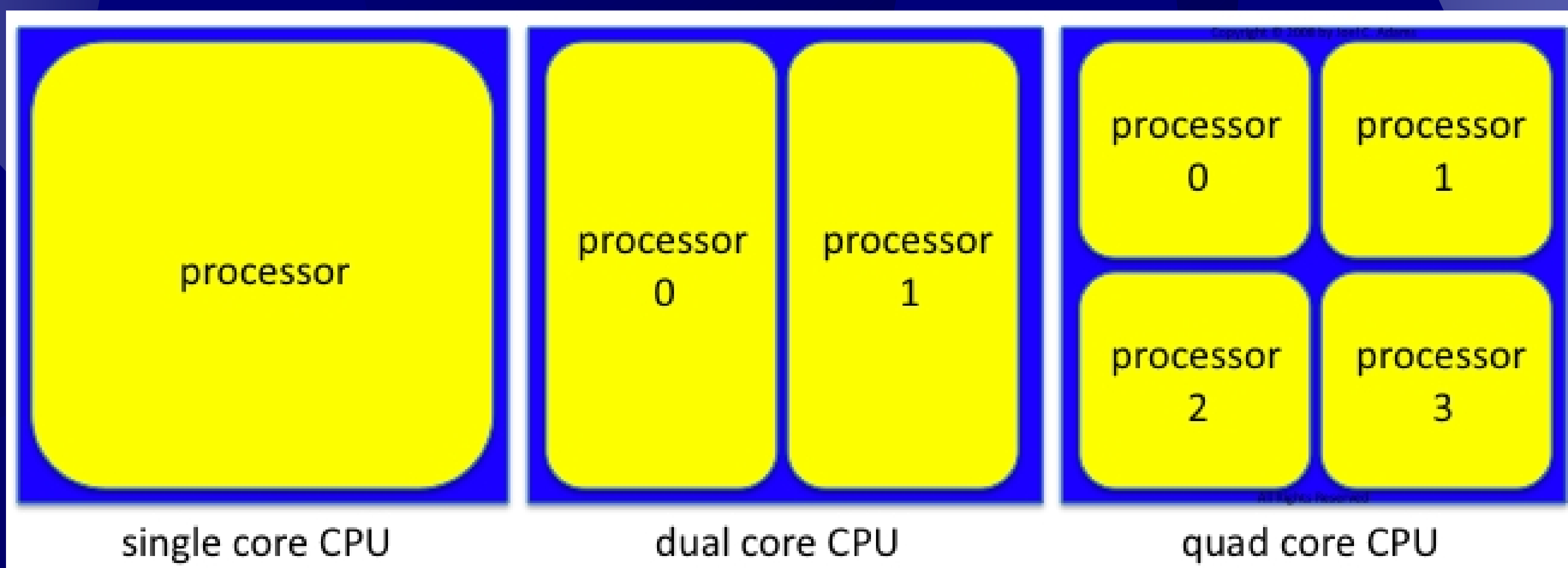
# Evolution of Computer Architectures

# Micro-Scopic View Summary

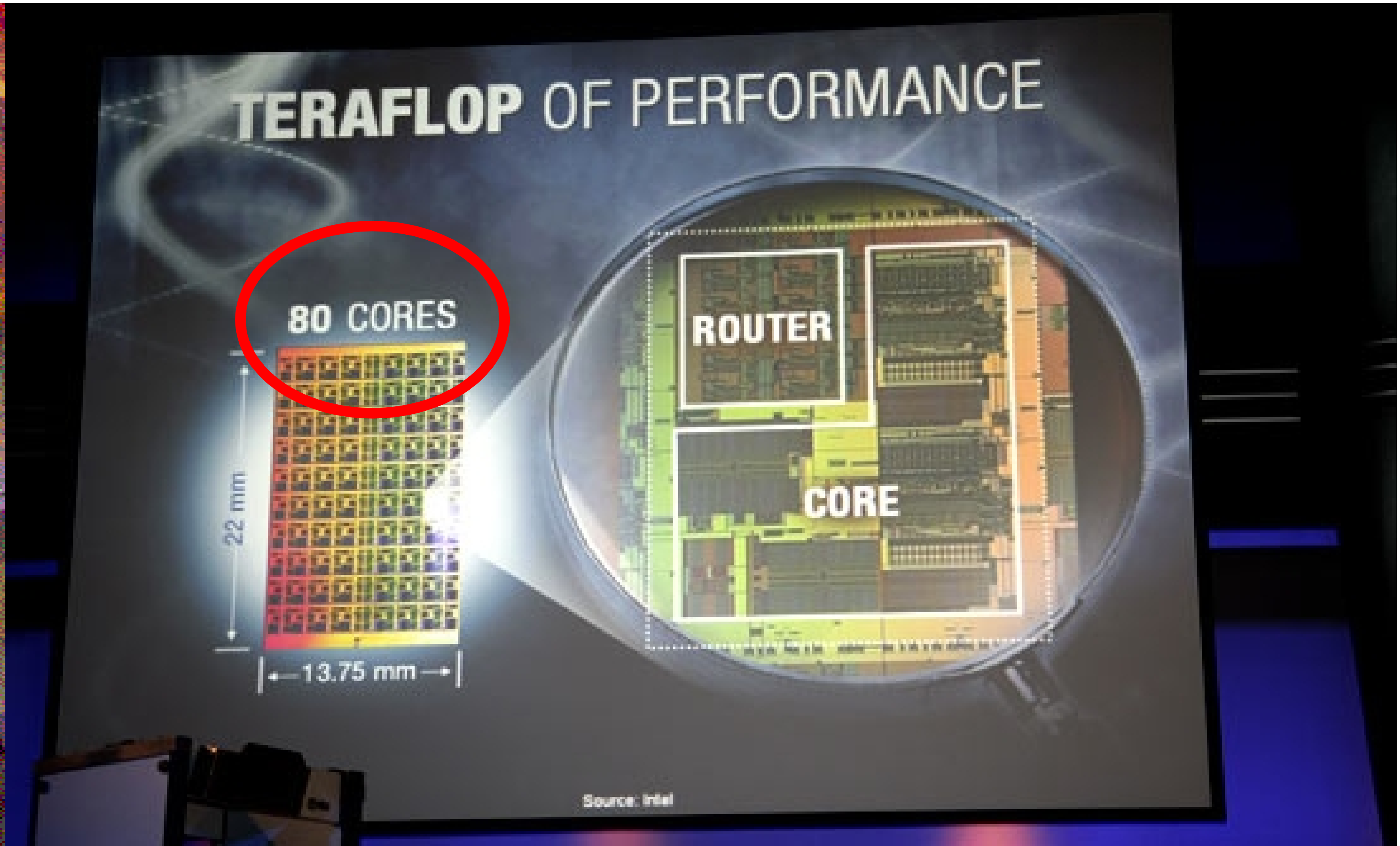


# Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View Summary

- Moore's Law Continues to 2x Transistors / 24 mos, but It will be used to Increase Number of Cores Instead




1 2 4 ……




Single Core → Multi-Core

Sequential Processing → Parallel Processing

# Hardware Solution - Technical Evolution of Computer Architectures

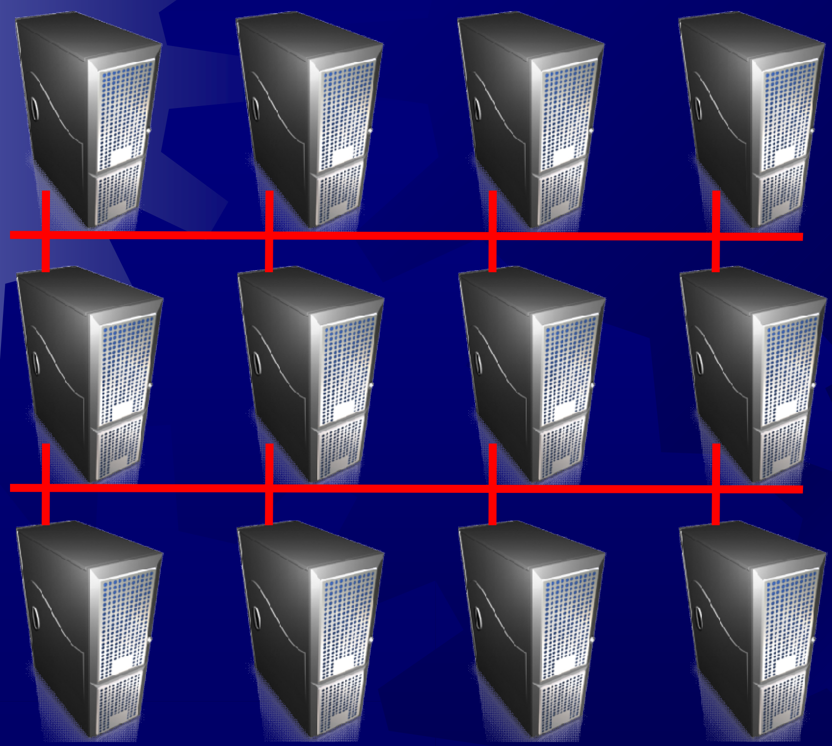
# Hardware Solution - Technical Evolution of Computer Architectures Macro-Scopic View

Personal Computer

Nodes: 1

Location: Desktop

# Hardware Solution - Technical Evolution of Computer Architectures Macro-Scopic View



Cluster Computer

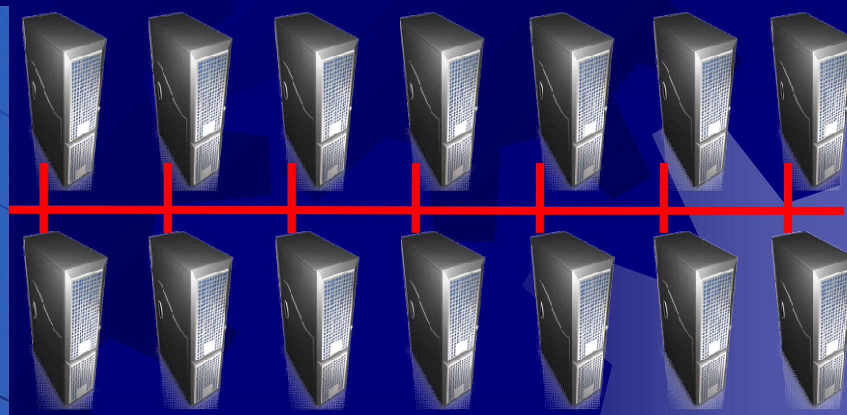
Nodes: 10's – 100's

Location: Local

# Hardware Solution - Technical Evolution of Computer Architectures Macro-Scopic View

Example Cluster Computer

# Hardware Solution - Technical Evolution of Computer Architectures Macro-Scopic View

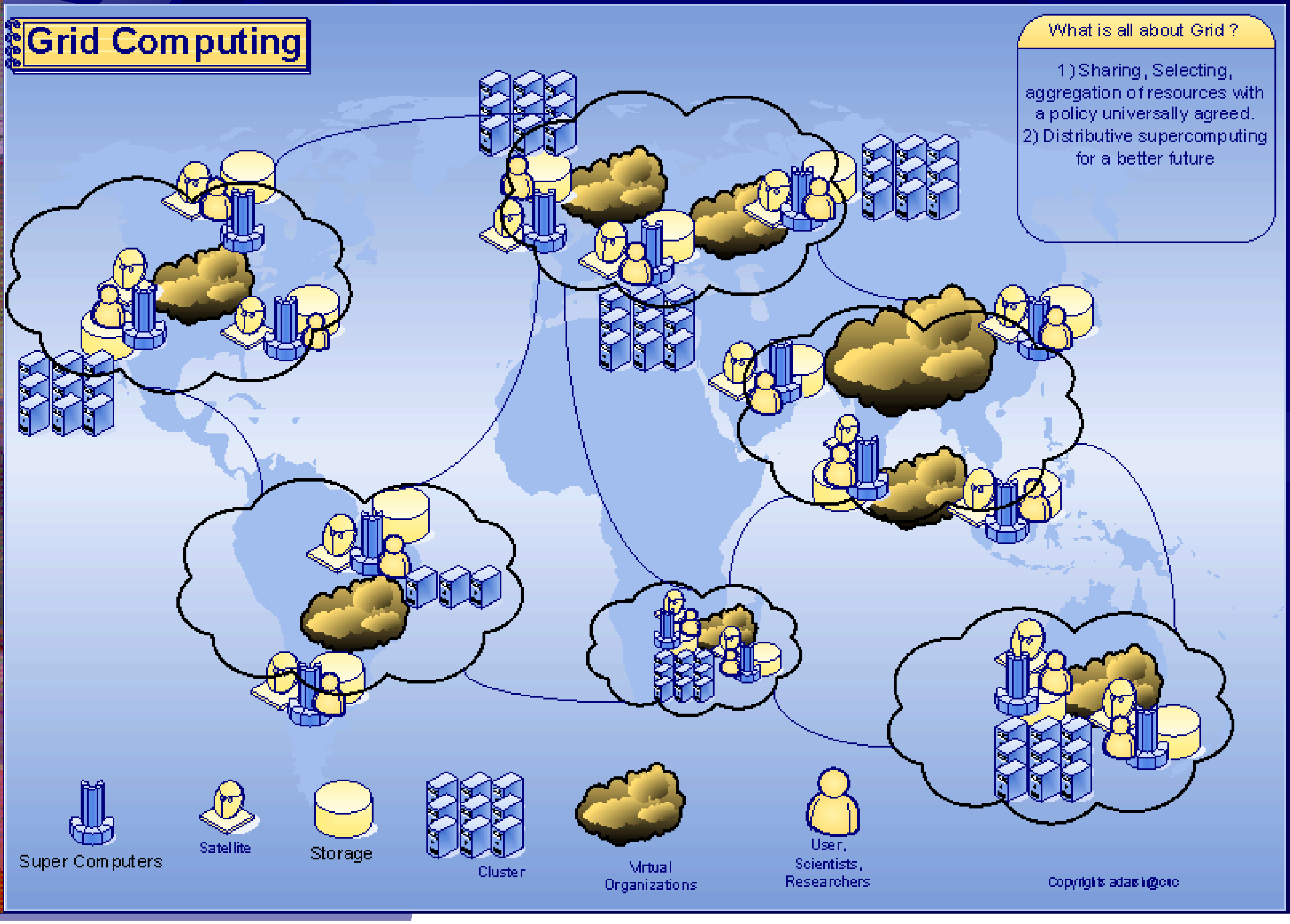


Grid Computer

Nodes: 1,000's

Location: Distributed

# Hardware Solution - Technical Evolution of Computer Architectures Macro-Scopic View




Example Grid Computer

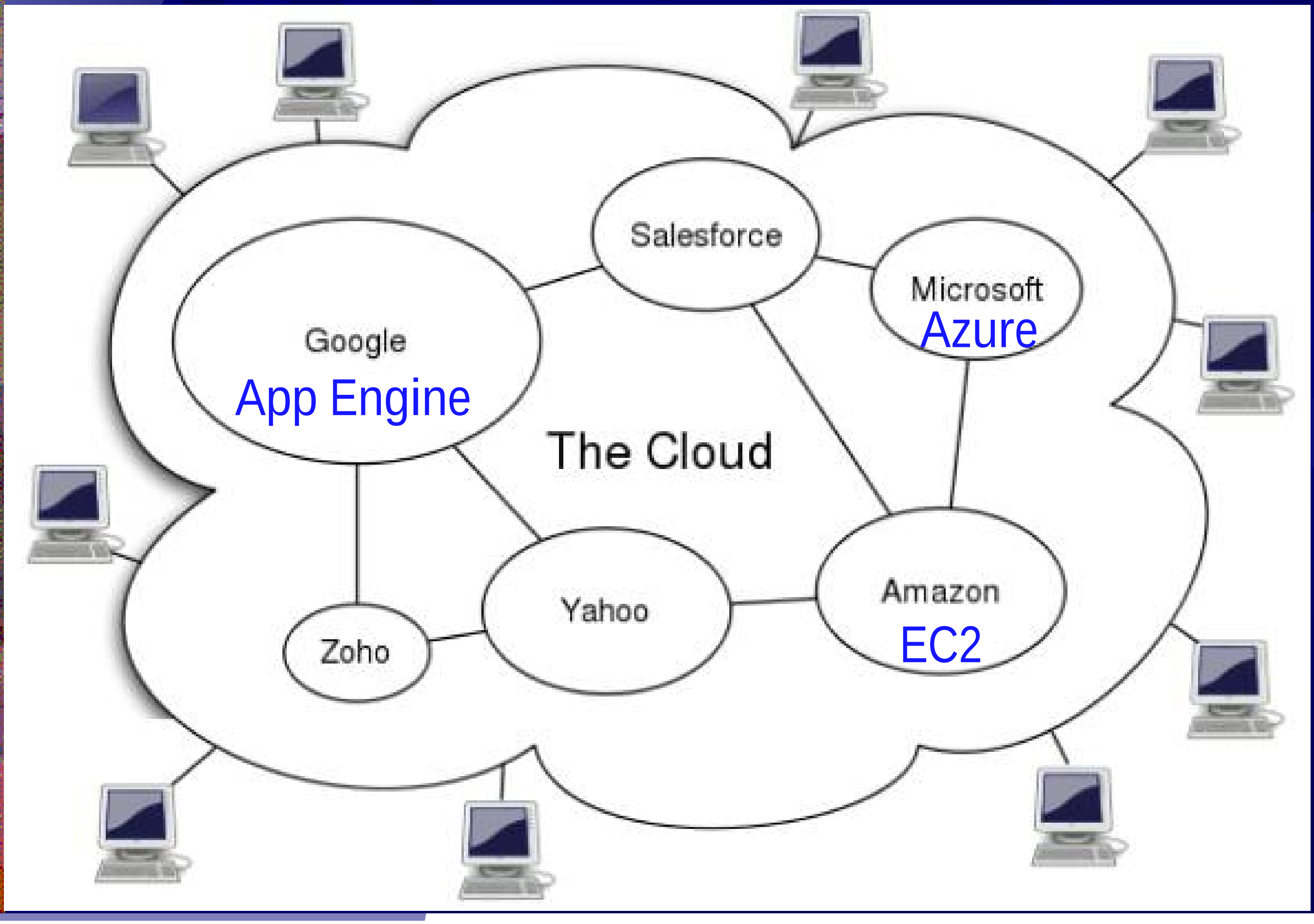
# Hardware Solution - Technical Evolution of Computer Architectures Macro-Scopic View

Cloud Computer

Nodes: 10,000's

Location: Highly Distributed

# Hardware Solution - Technical Evolution of Computer Architectures Macro-Scopic View



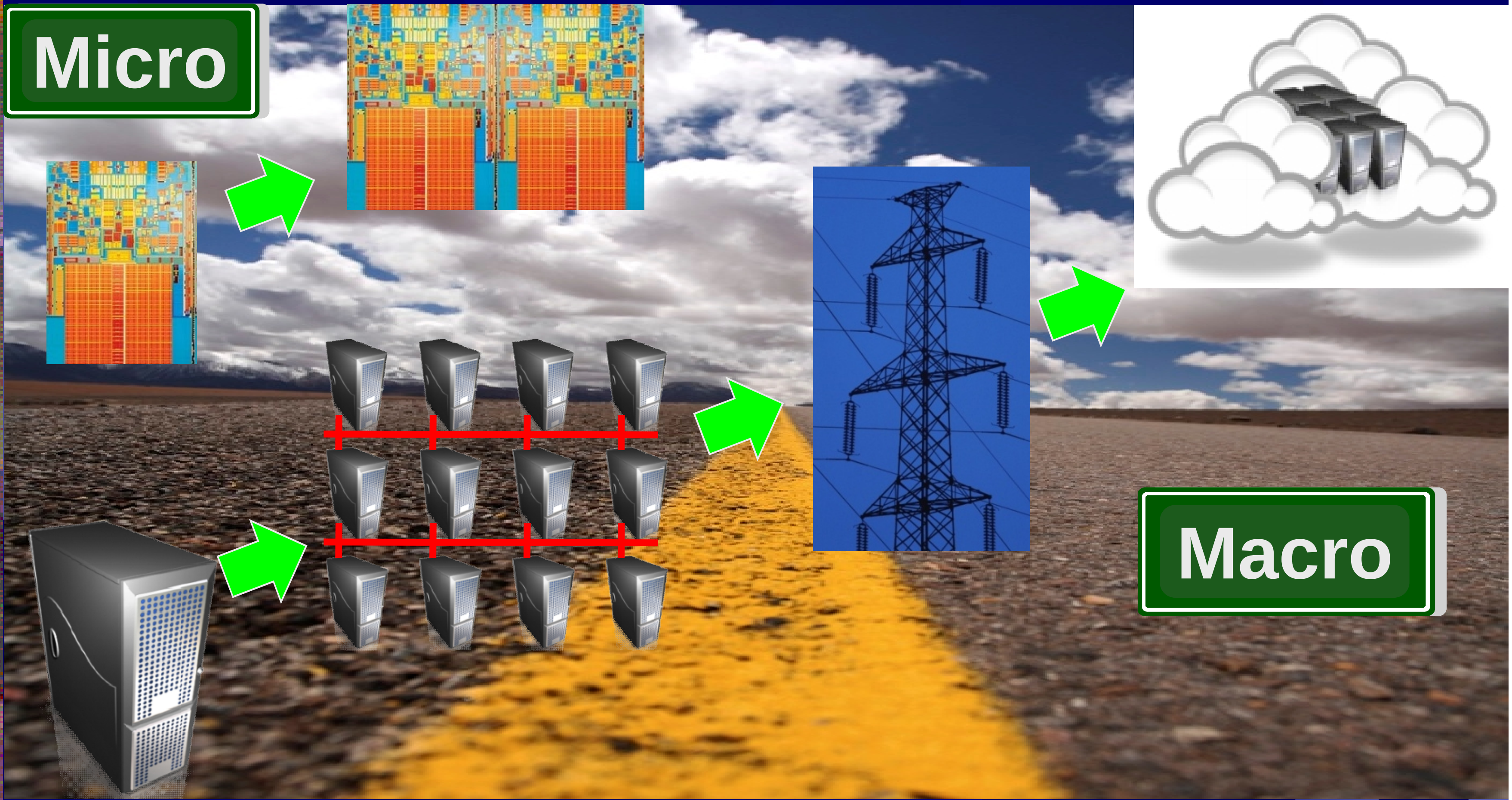

Example Cloud Computer

# Hardware Solution - Technical Evolution of Computer Architectures Macro-Scopic View Summary

Single Node → Many Nodes

Sequential Processing → Parallel Processing

# Hardware Solution - Business
# Evolution of Computer Architectures




**Sequential Processing → Parallel Processing**

# Hardware Solution - Business

- Computer Processing Power:
  - Has a Highly Elastic Supply and Demand Curve
  - Increased Supply Generates Increased Demand

Hardware

Computer Power

New Applications

Software

- Software is Like a Gas
  - It Expands to Fill any size Hardware Container

**Sequential Processing** → **Parallel Processing**

# Hardware Solution - Business

*"640K should be enough for anybody"*
Bill Gates, 1981

*"There is a world market for maybe five computers"*
Thomas Watson, 1943

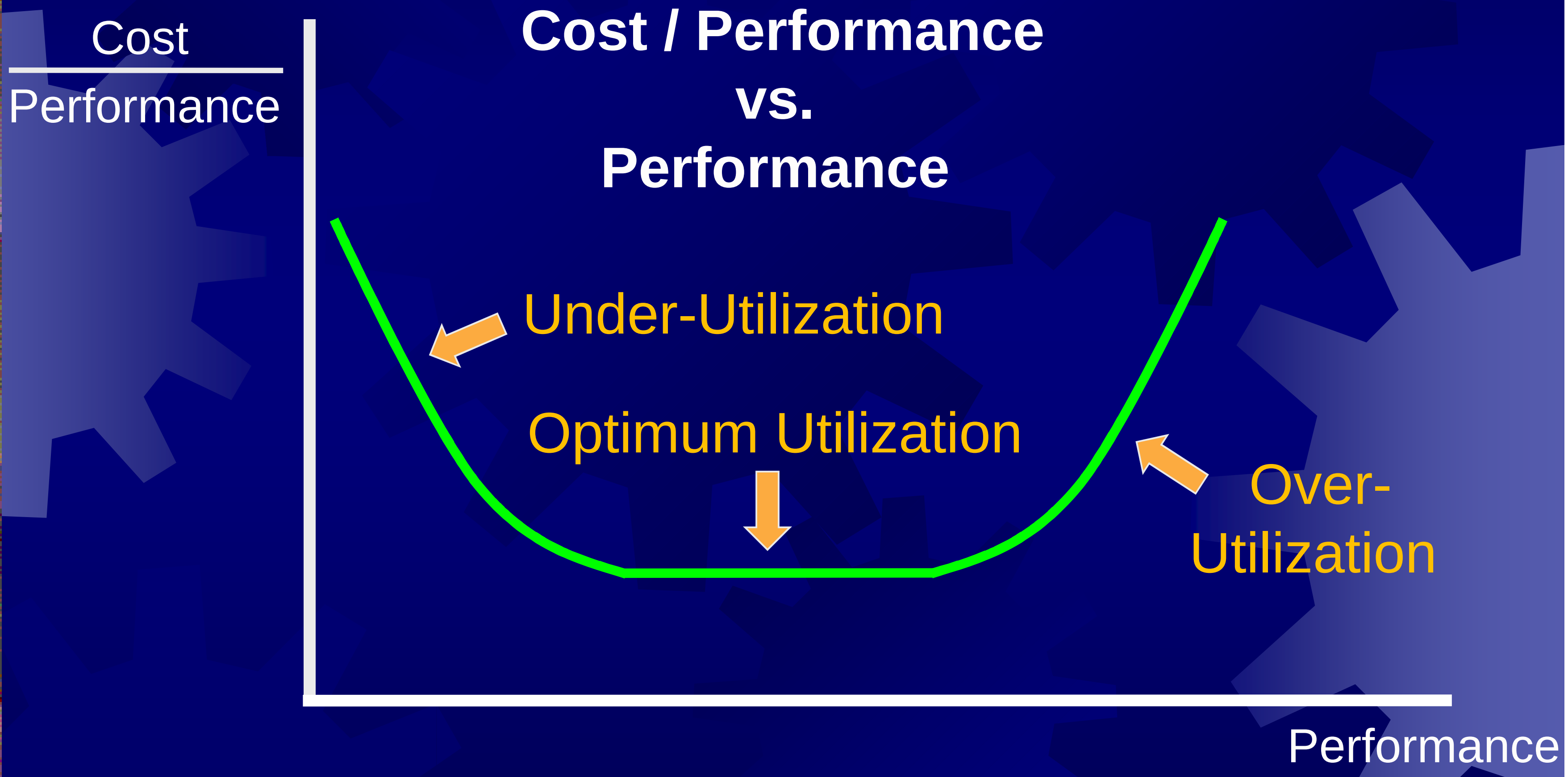
Even Visionaries Sometime Forget

No Matter How Much Computer Power People Have,
They Always Want More

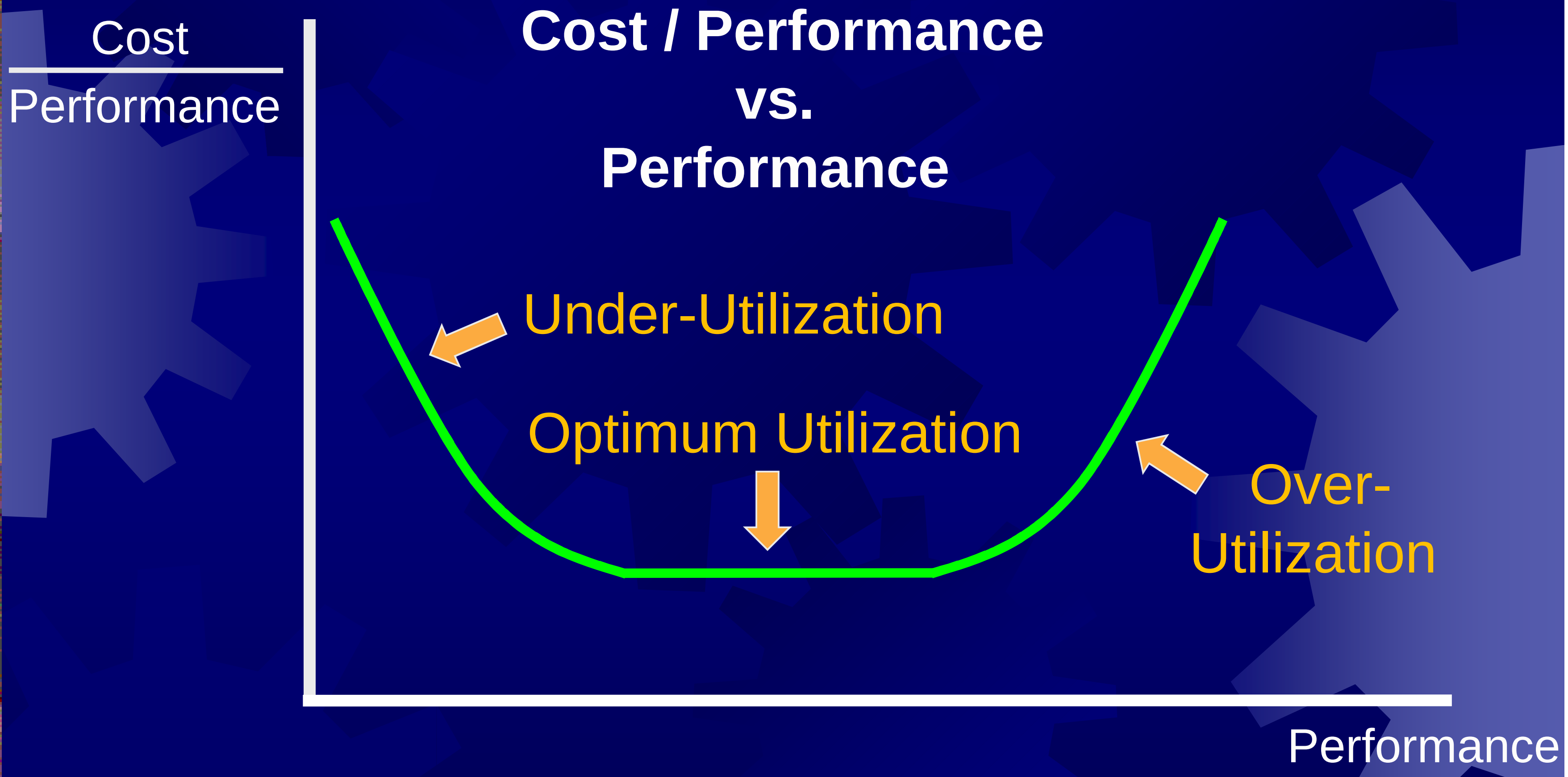
- Goal of Computer Hardware and Software Designers
  - Continually Increase Performance and Lower Cost
  - Operate at Optimum Point on Technology Curve

**Sequential Processing** → **Parallel Processing**

# Hardware Solution - Business Technology Curve



# Hardware Solution - Business Technology Curve



# Hardware Solution - Business Technology Curve


**$$$$$$**

**Sequential Processing**

# Hardware Solution - Business Technology Curve


**$$$$$$**

**Sequential Processing**

# Hardware Solution - Business Technology Curve


**$$$$$$**
**Sequential Processing** → **$$**
**Parallel Processing**

# Key Points

## Hardware Solution

- Parallel Processing is really an Evolution in
  - Micro- and Macro-Architecture Hardware
    - That provides a Solution to:
      - The Heat and Power Wall
      - The Limitations of ILP
      - Cost-Effective Higher Performance
- Parallel Processing is also a Software Challenge