



CS 159

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

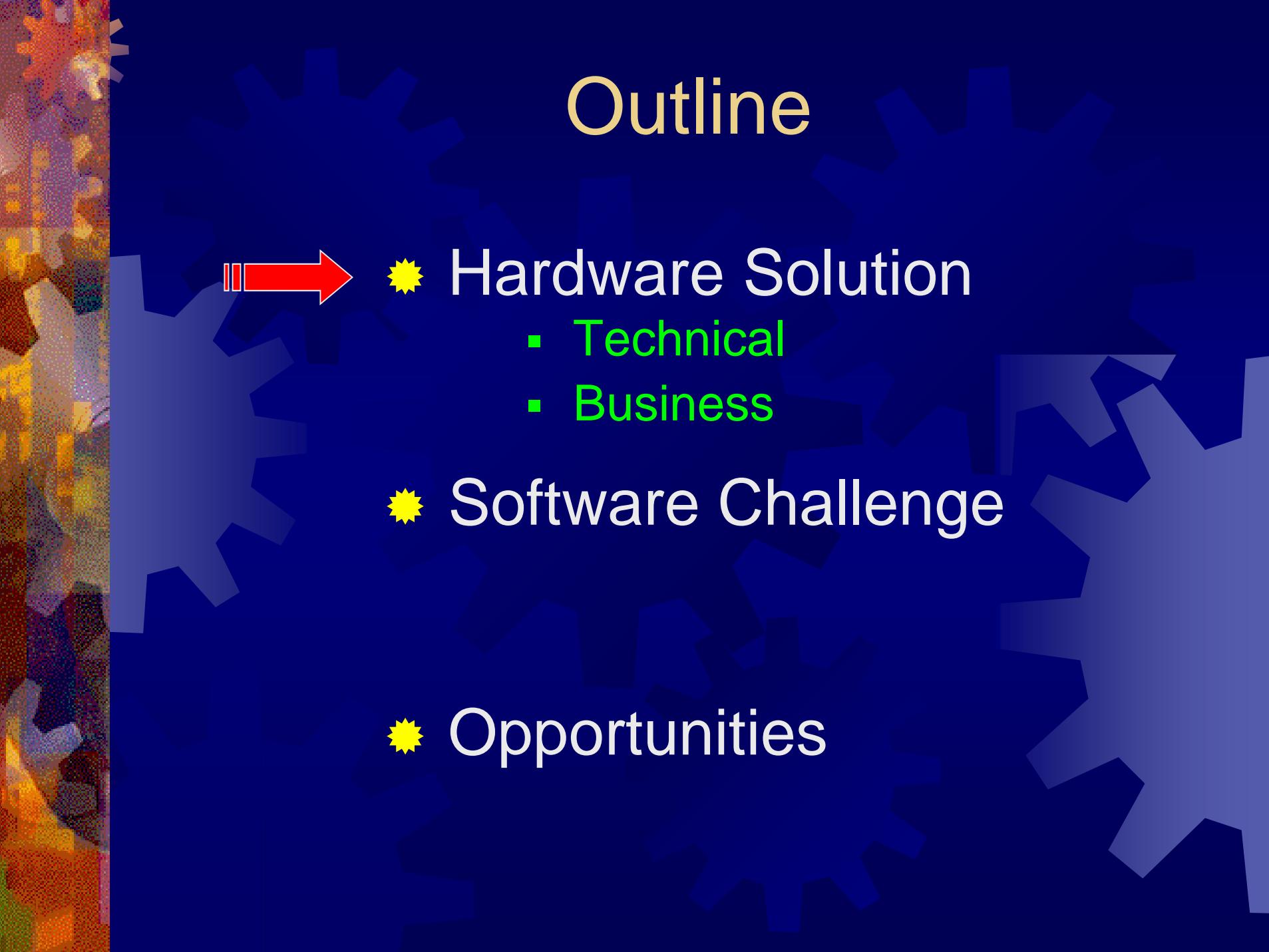
- Technical
- Business

- ★ Software Challenge

- Technical
- Business

- ★ Opportunities

- Technical
- Business



Outline

- ★ Hardware Solution

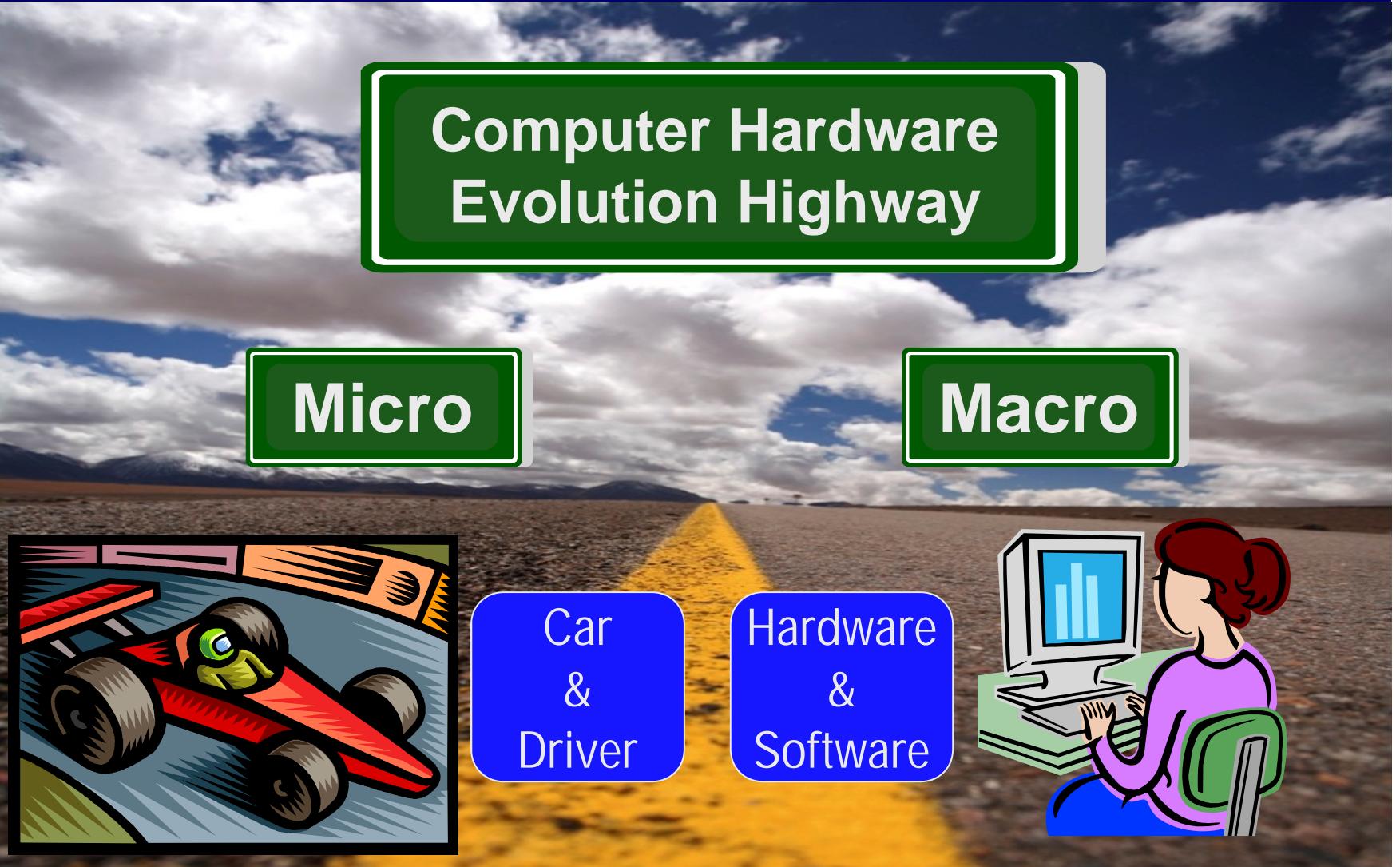
- Technical
- Business

- ★ Software Challenge

- ★ Opportunities



Hardware Solution - Technical Evolution of Computer Architectures



Computer Hardware
Evolution Highway

Micro

Macro



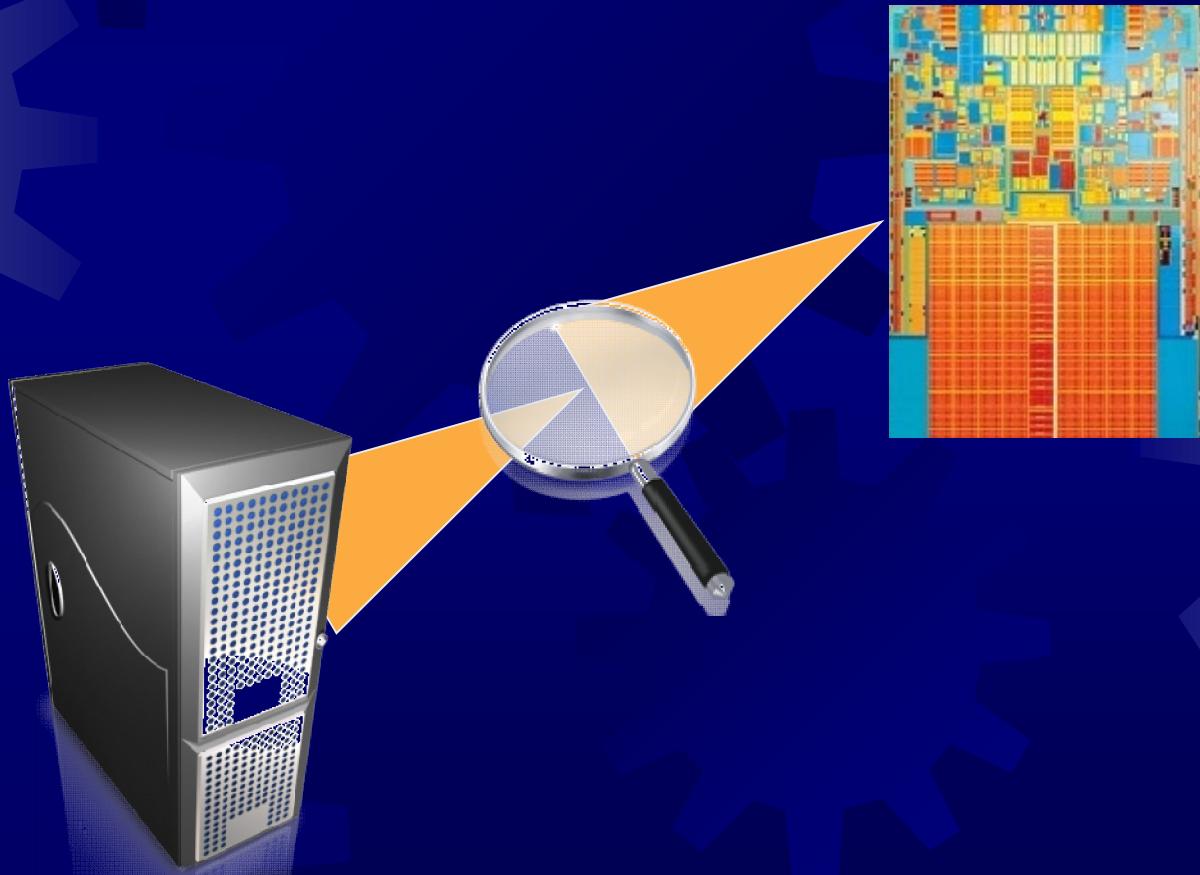
Car
&
Driver

Hardware
&
Software

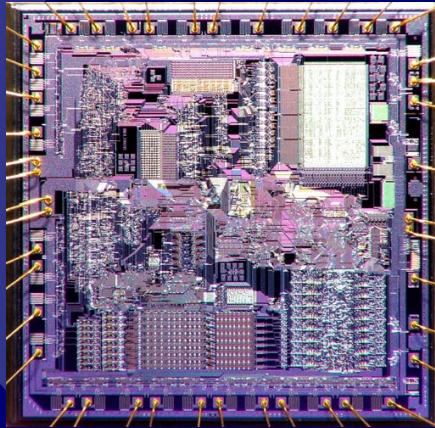




Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View



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

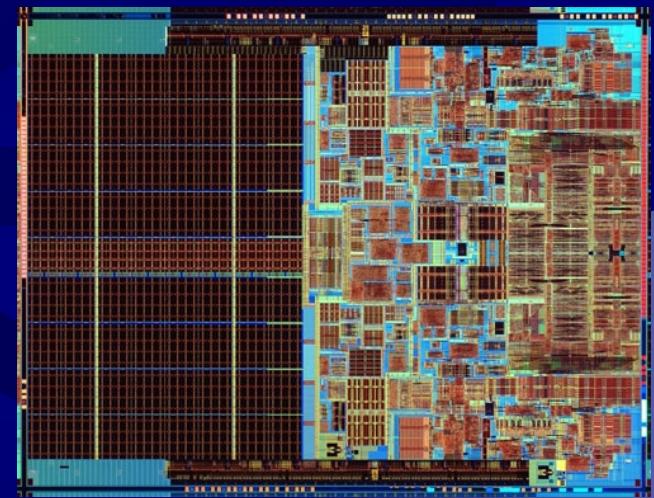
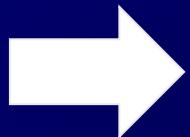


Intel 8086

1978

29,000

5 MHz



Intel Core 2 Duo

Year

Transistors

Clock Frequency

2006

291,000,000

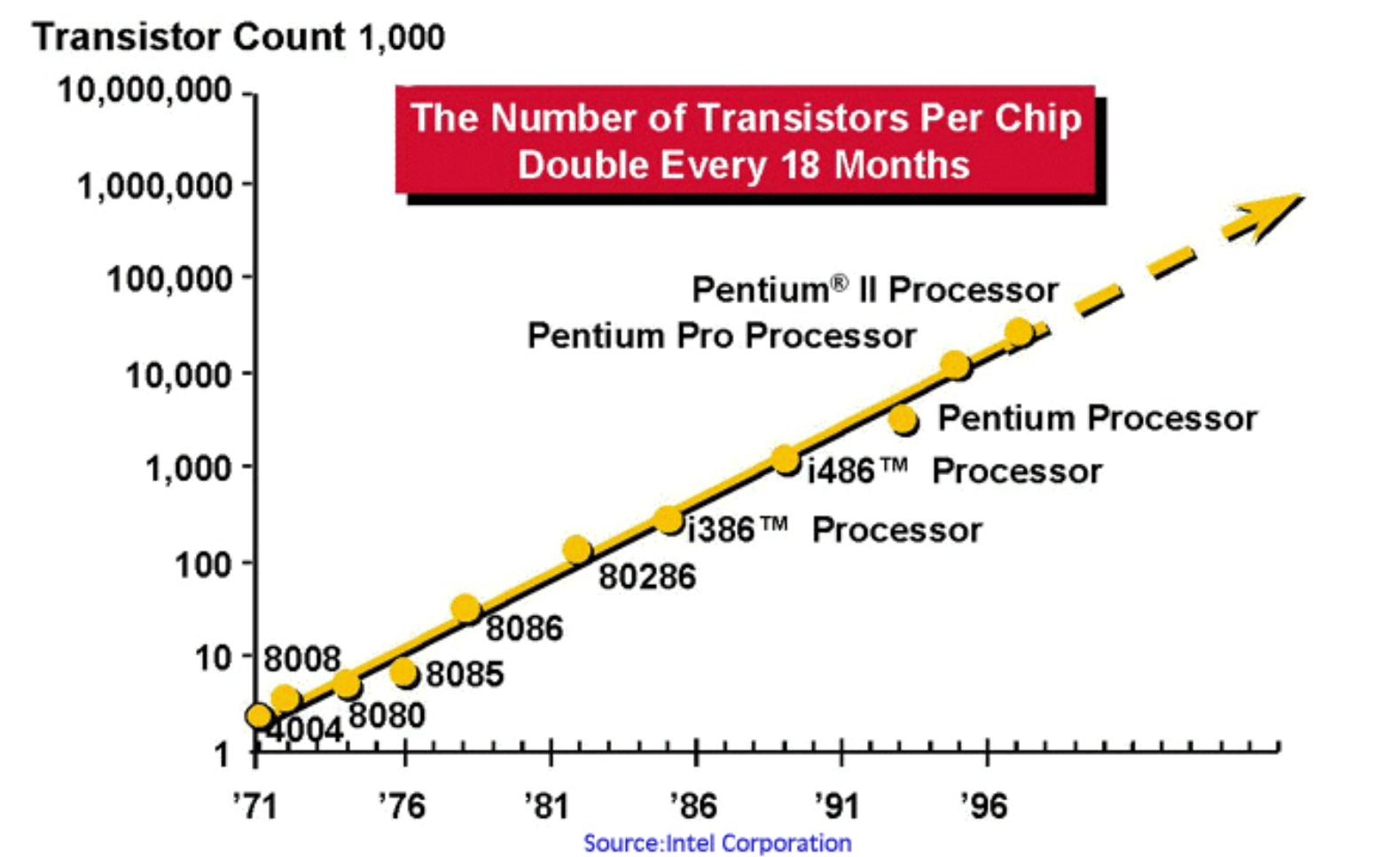
2.9 GHz



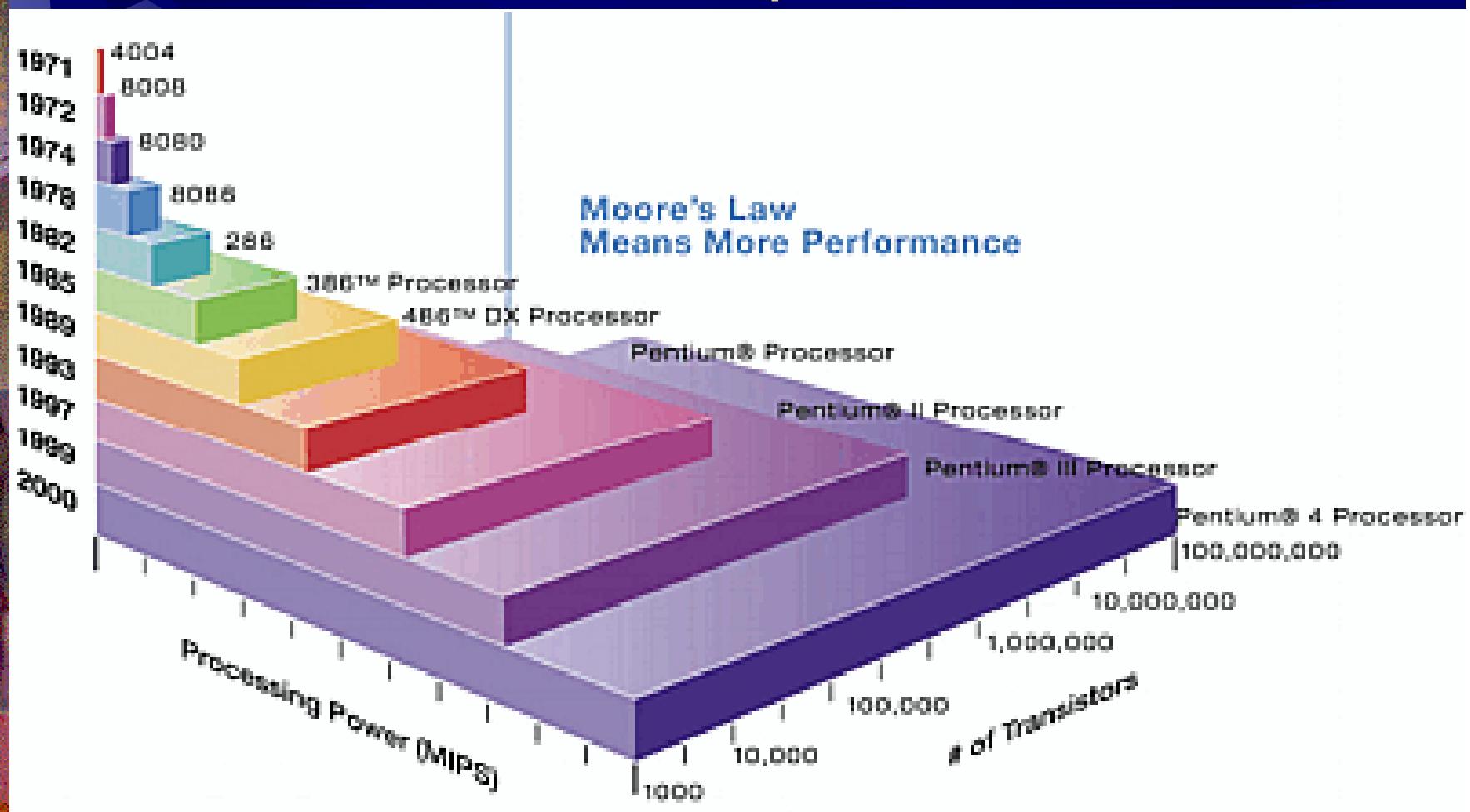
Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View

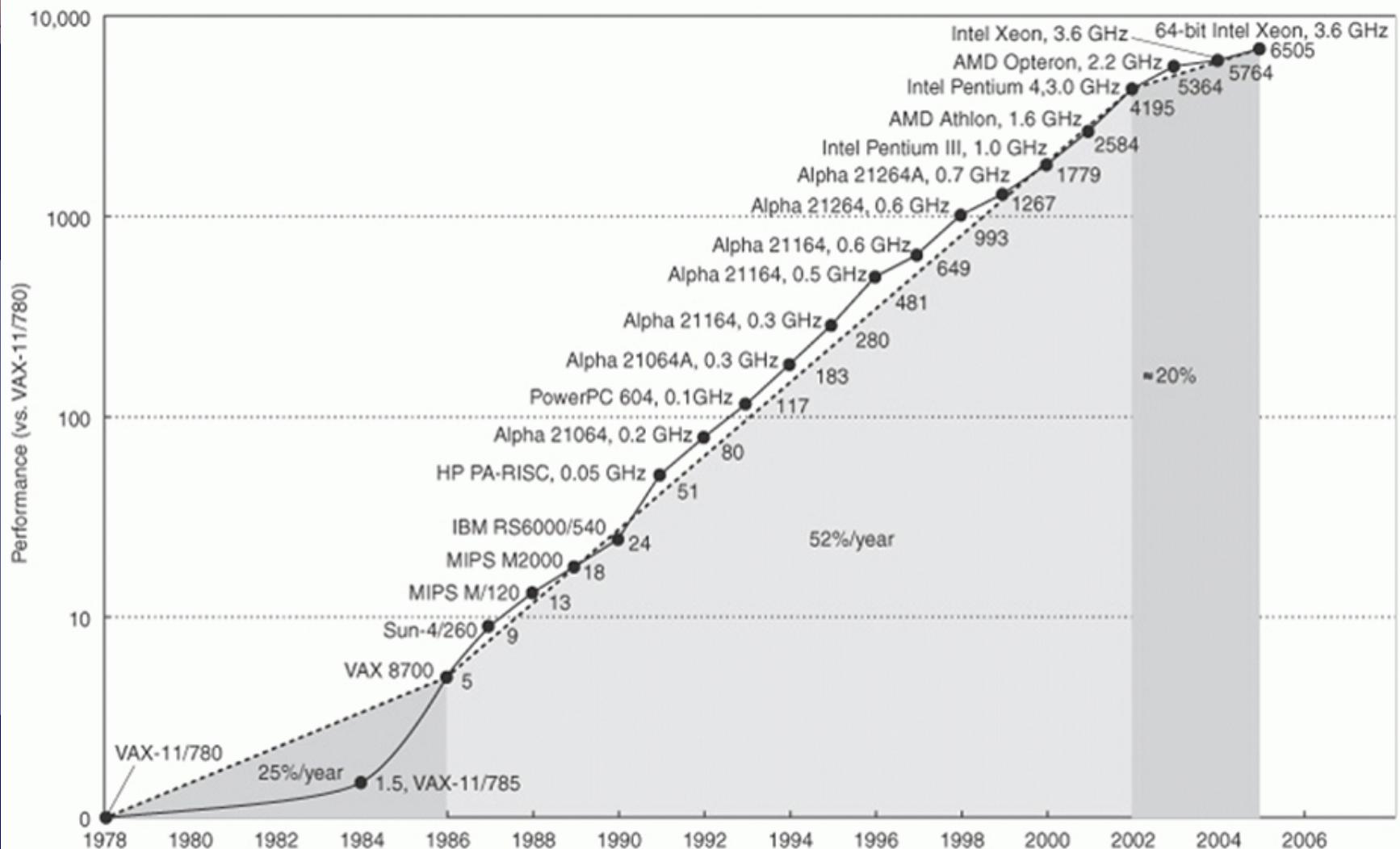
- ❖ In 28 Years from 1978 to 2006:
 - Number of Transistors Increased 10,034X
 - Clock Frequency Increased 586X
- ❖ Primary Driver / Facilitator was (and is) Moore's Law:
 - Number of Transistors Doubles every 18-24 Months
 - Stated by Gordon Moore, Intel Co-Founder in 1965
 - Prediction has been proven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

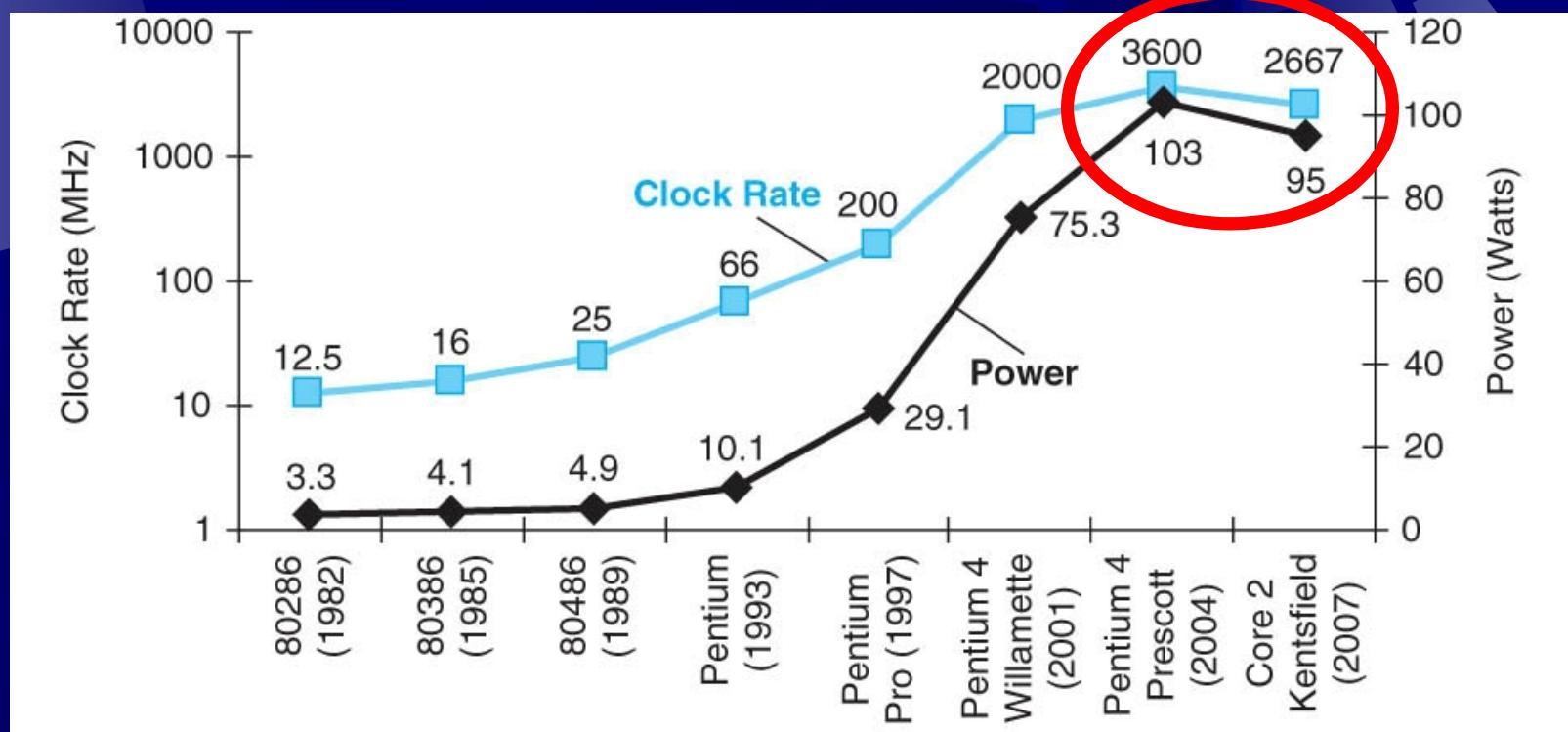




- ❖ Historically, Huge Performance Gains came from Huge Clock Frequency Increases Unfortunately

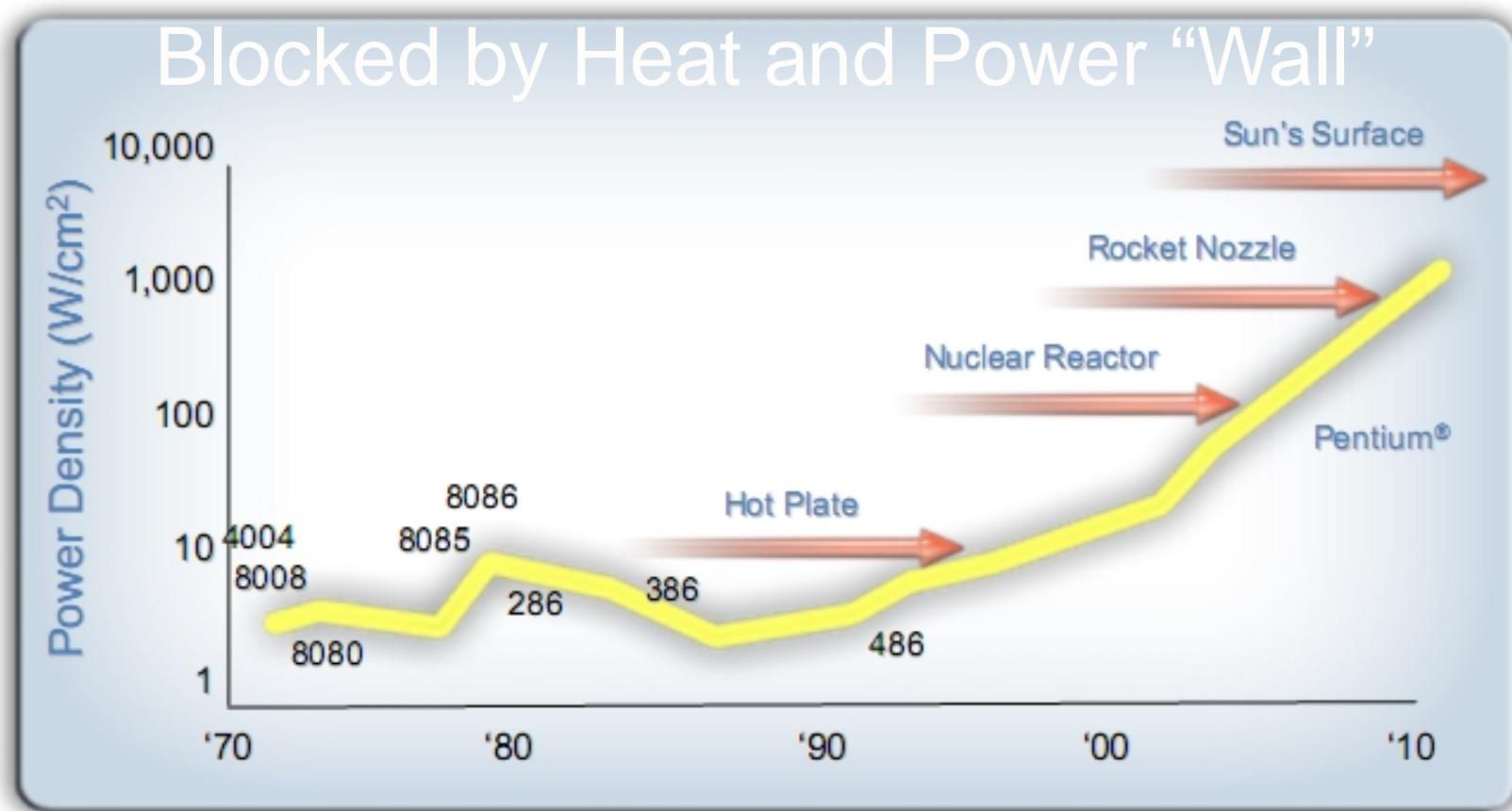
Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View

Clock Rate Limits Have Been Reached



Source: Patterson, *Computer Organization and Design*

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





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

- Power (and Heat) Grows as Frequency³

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

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

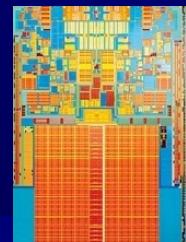
$$\text{Power} \propto \text{Frequency}^3$$

- How can HW Performance Continue to Increase?

Single Core → Multi-Core

Single Core vs. Dual Core

Single Core clocked at $2f$



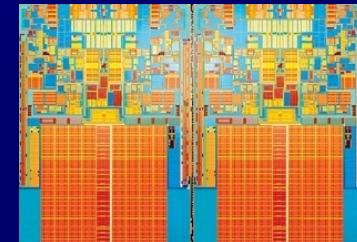
$2f$

$8f^3$



Sequential Processing

Dual Core clocked at f



$f + f$
 $f^3 + f^3$



Parallel Processing

Throughput
Heat

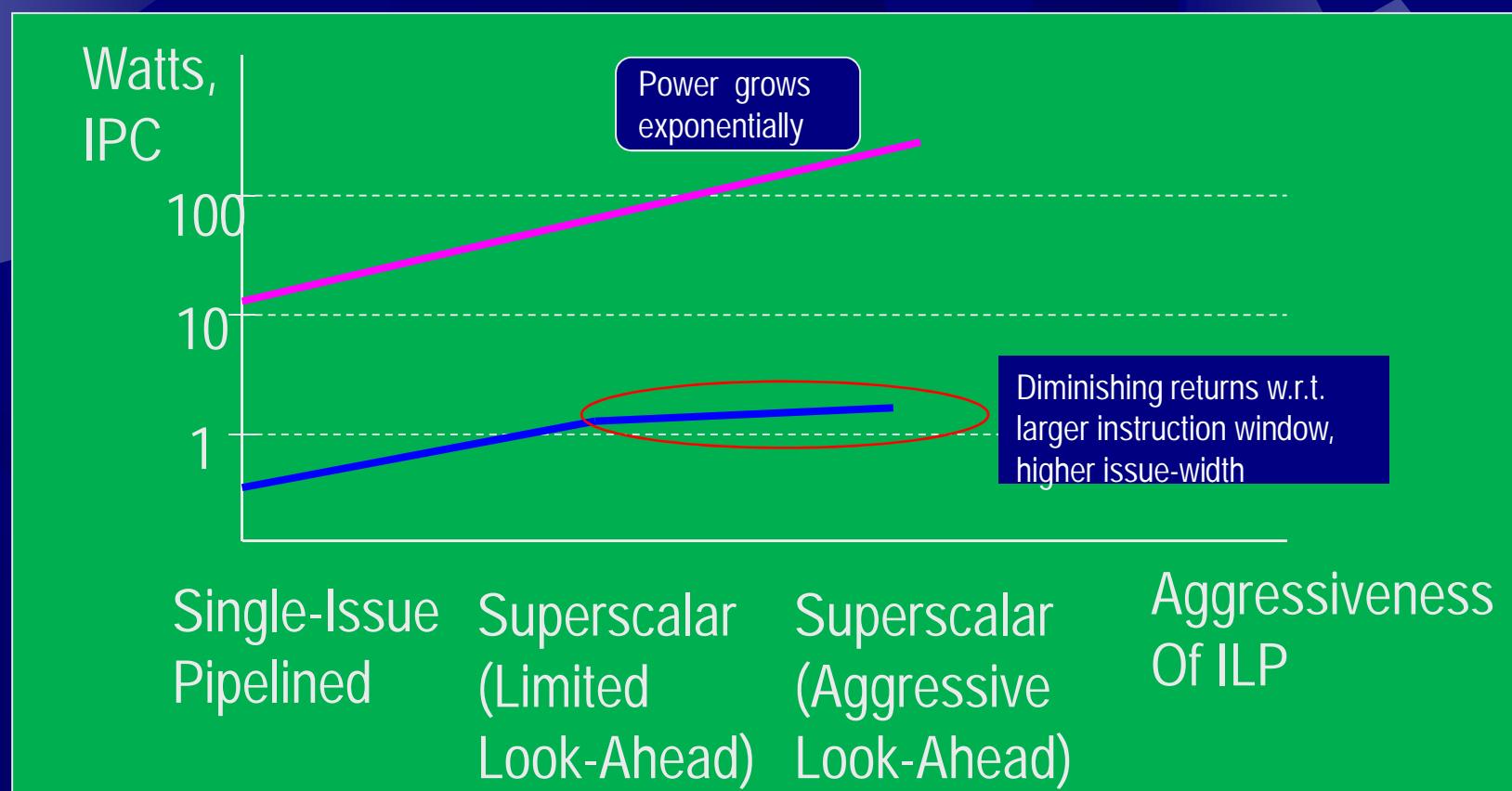


Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View

- 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.....

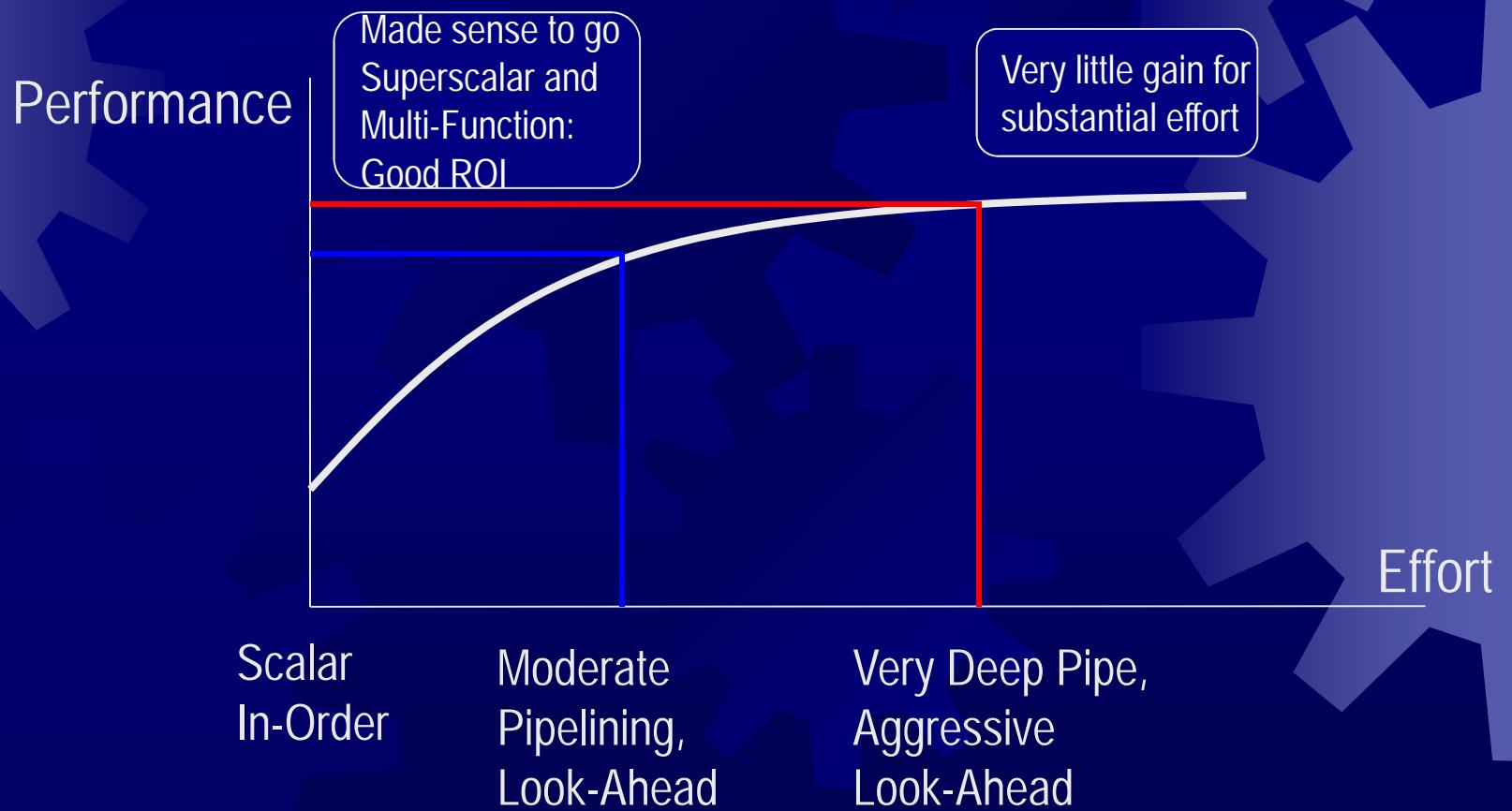
Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View

➤ 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



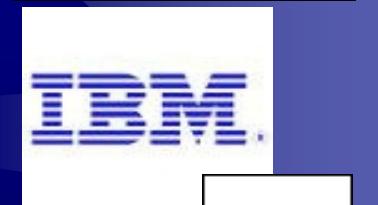
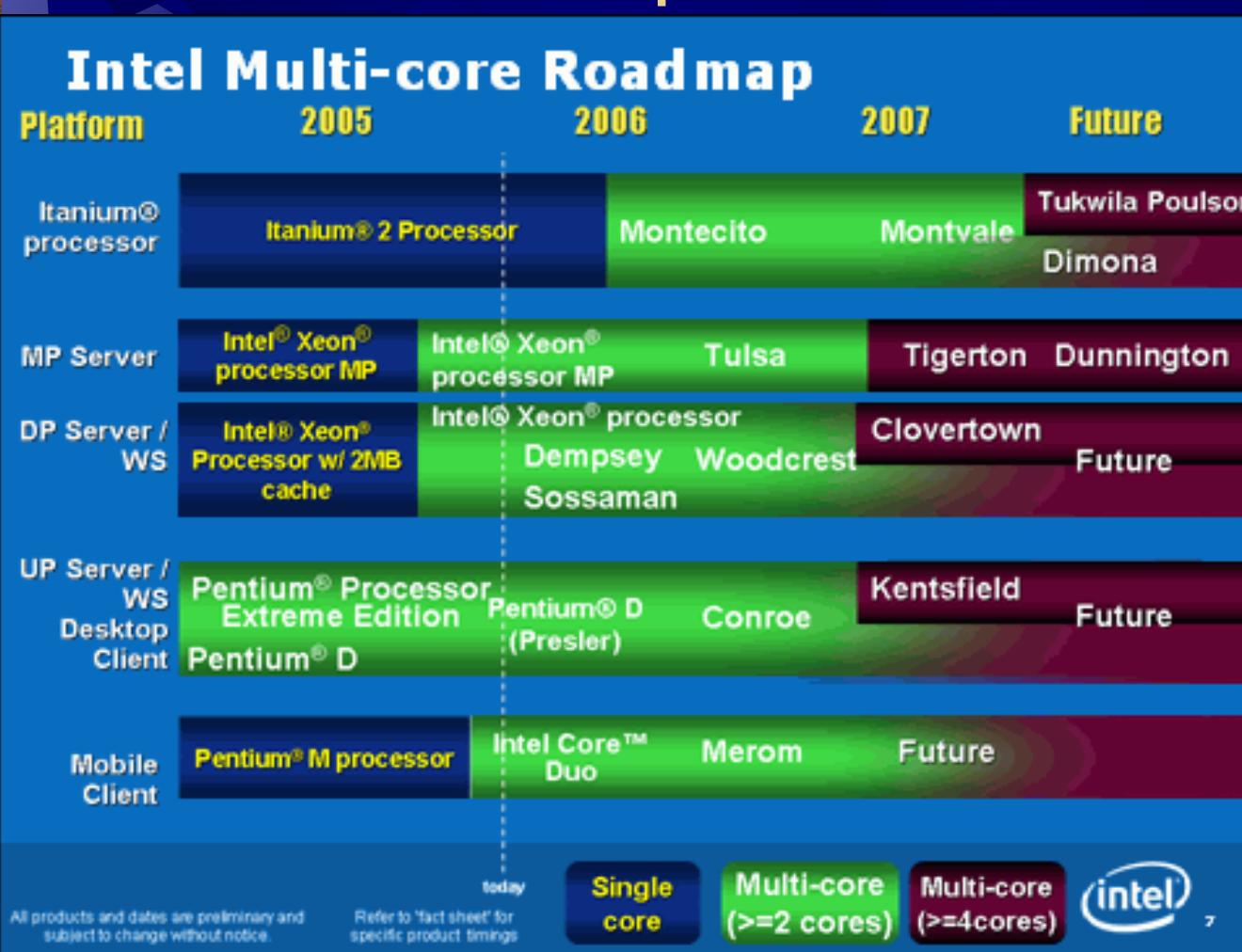


Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View Summary

- 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

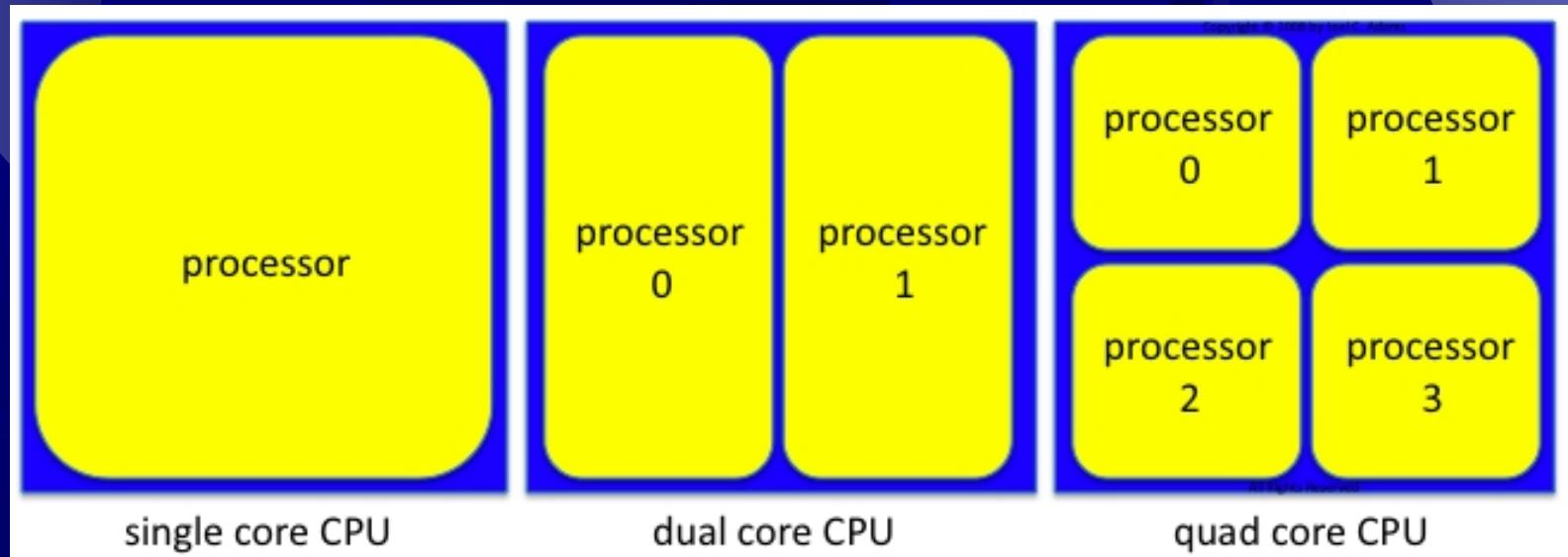
Micro-Scopic View Summary





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

TERAFLOP OF PERFORMANCE

80 CORES

22 mm

| - 13.75 mm - |

ROUTER

CORE

Source: Intel

Single Core

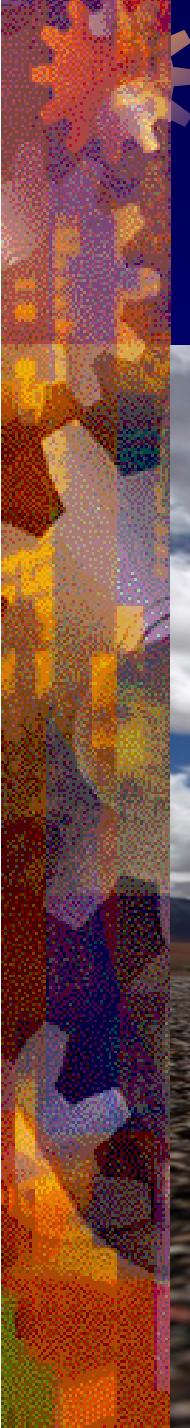


Multi-Core

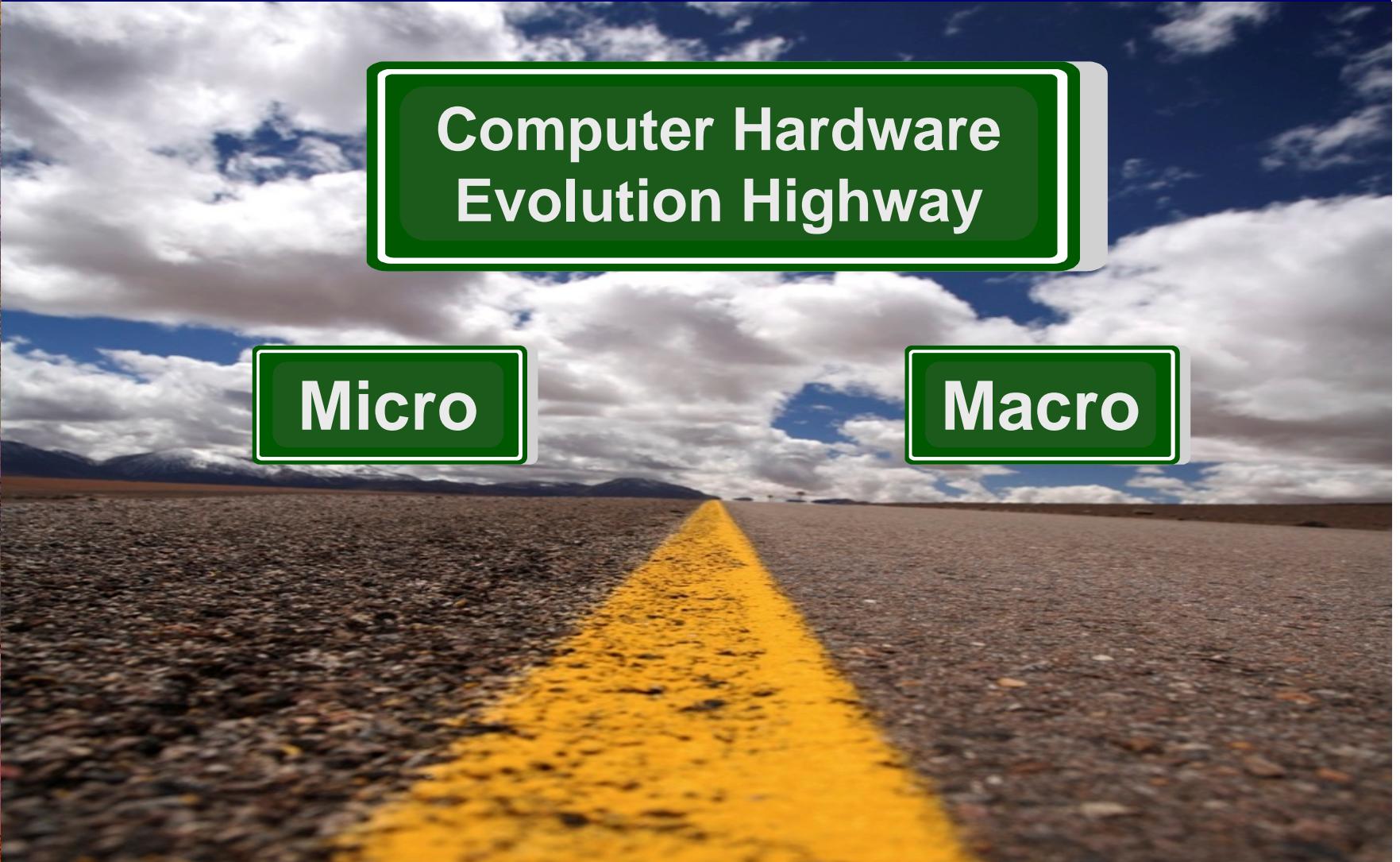
Sequential Processing



Parallel Processing



Hardware Solution - Technical Evolution of Computer Architectures



Computer Hardware
Evolution Highway

Micro

Macro



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

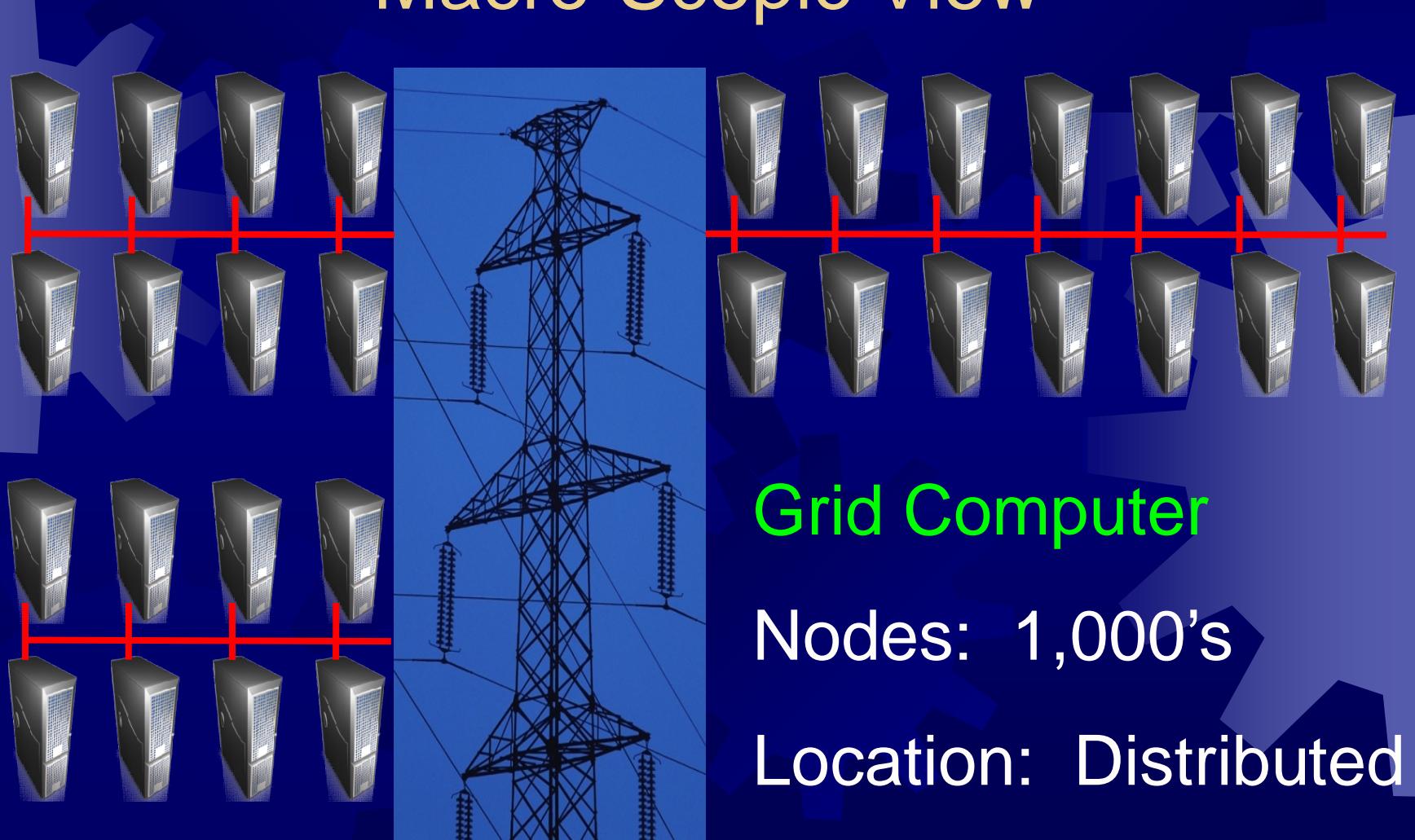
Hardware Solution - Technical Evolution of Computer Architectures Macro-Scopic View



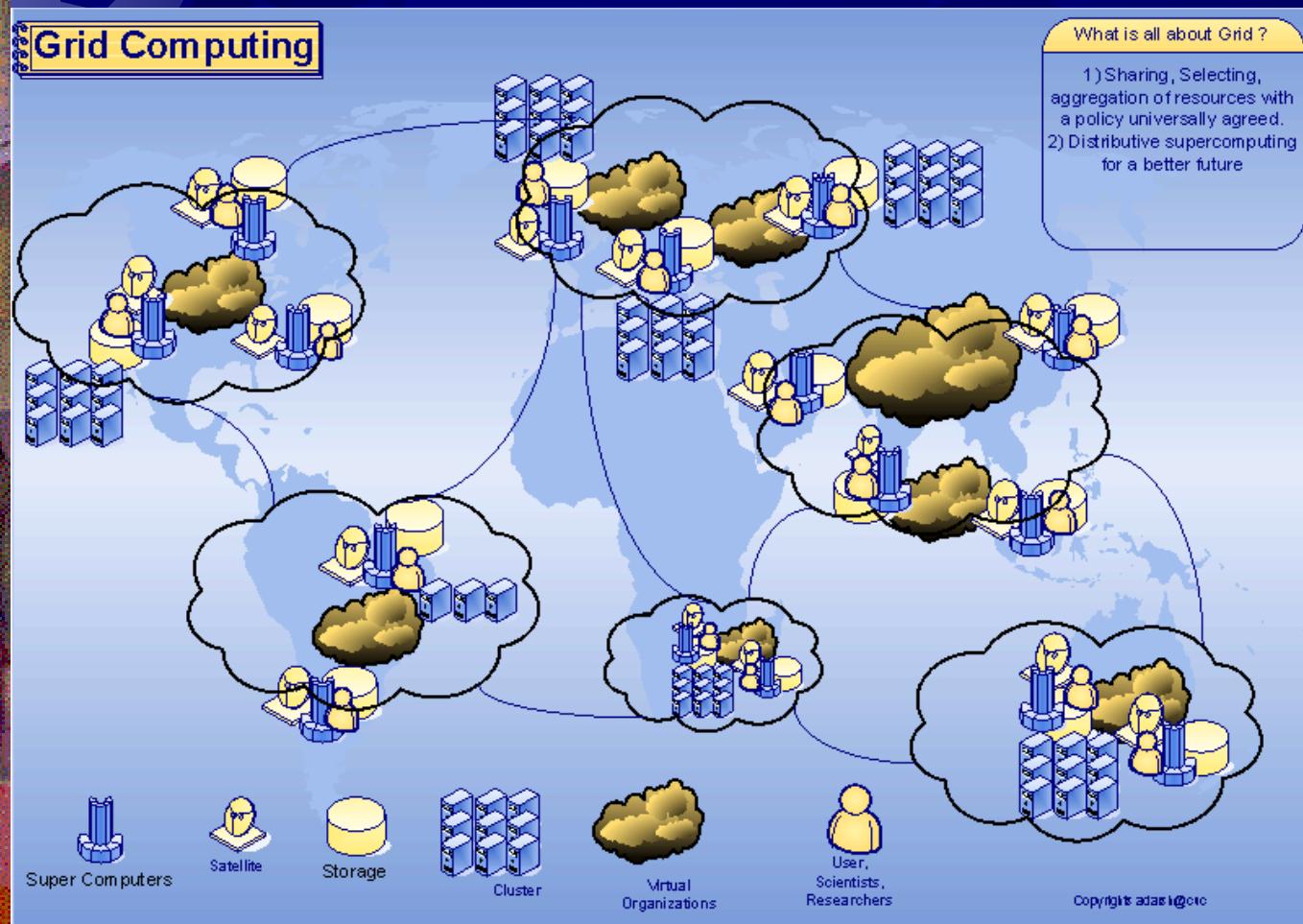
Example
Cluster
Computer



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



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

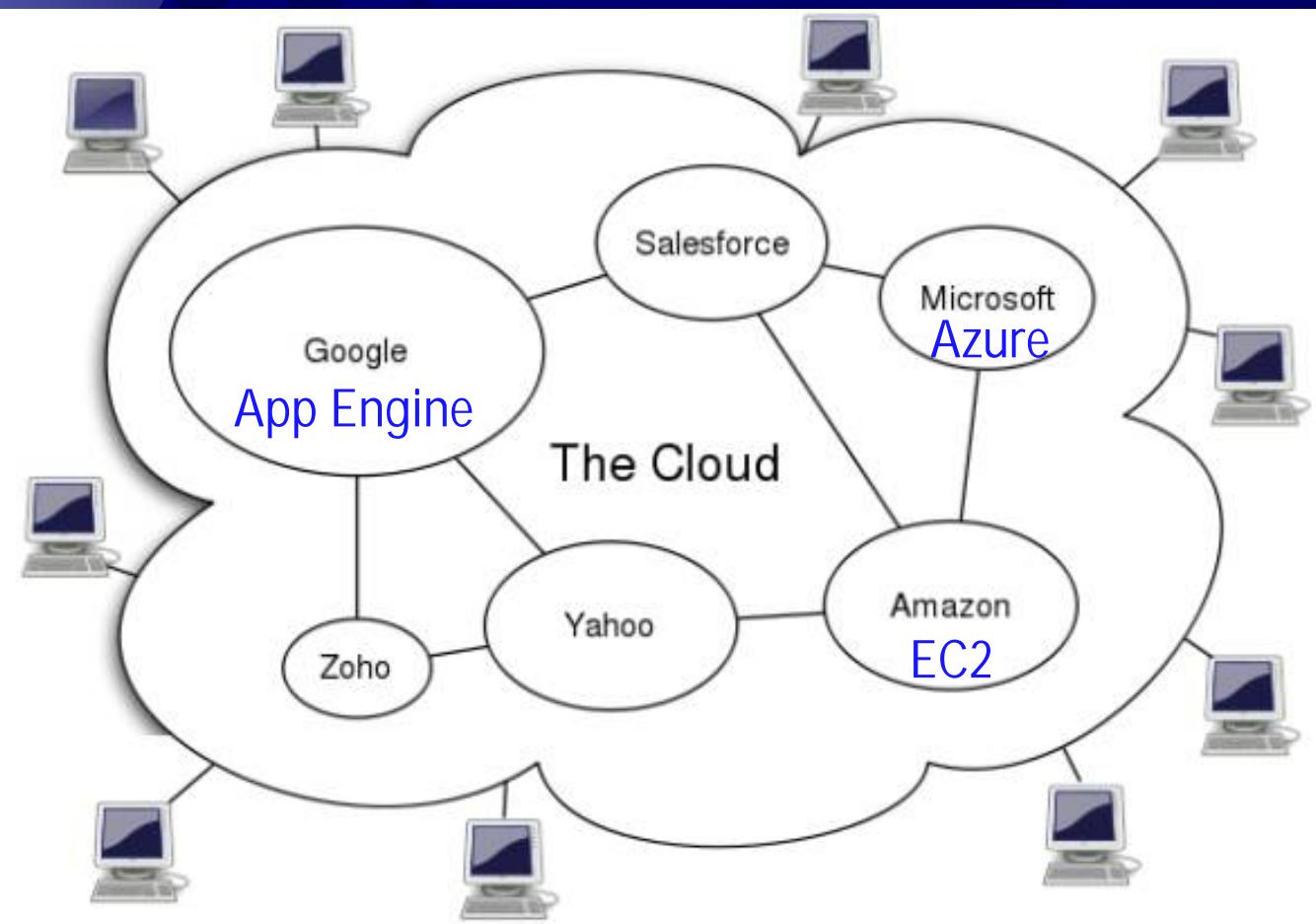


Hardware Solution - Technical Evolution of Computer Architectures Macro-Scopic View



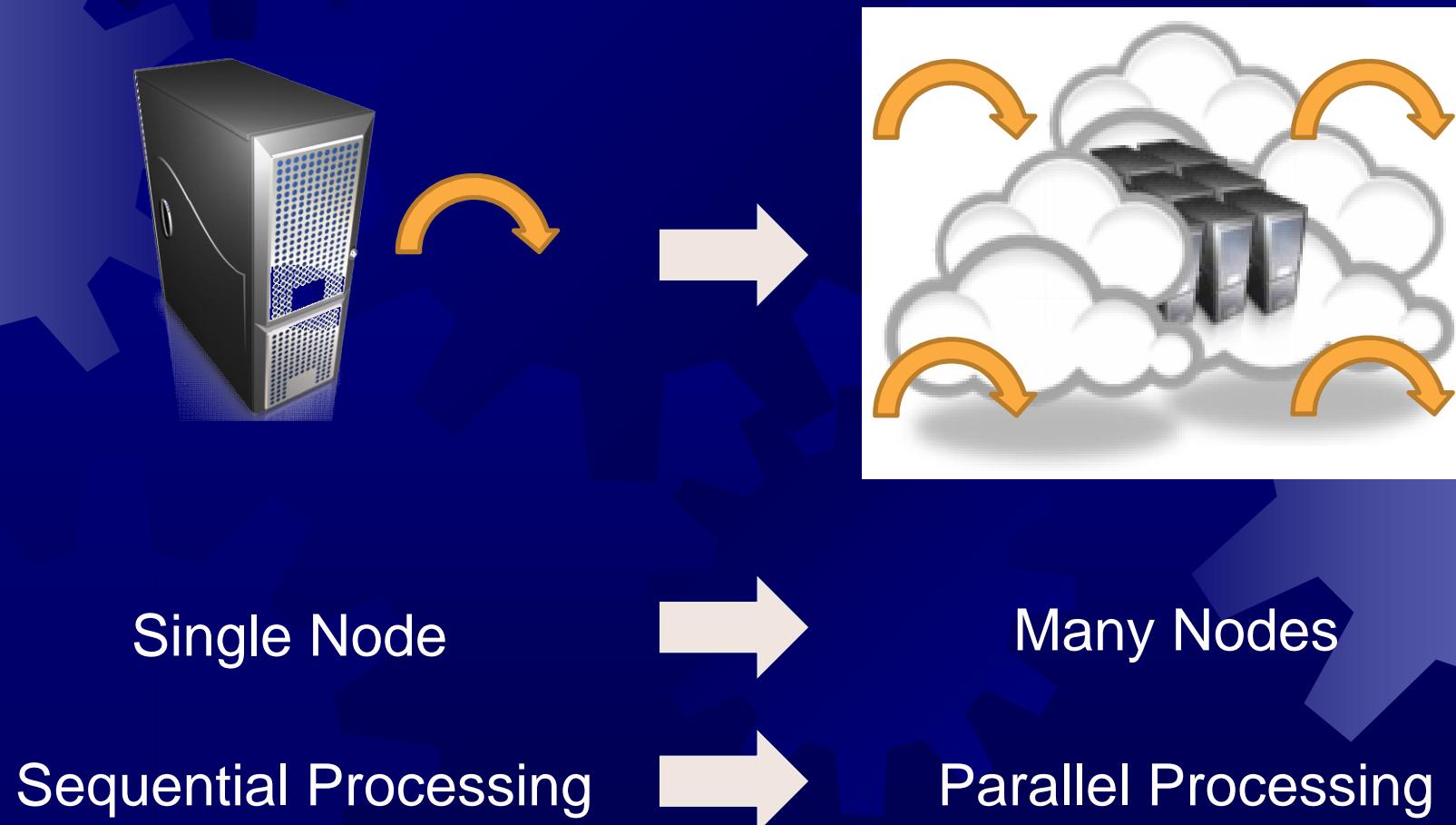
Cloud Computer
Nodes: 10,000's
Location: Highly
Distributed

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



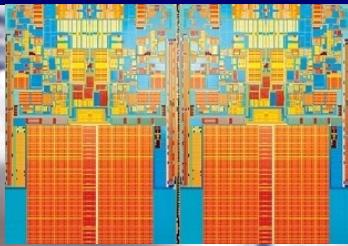
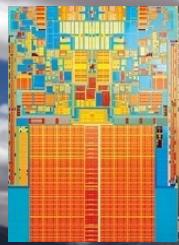
Example
Cloud
Computer

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



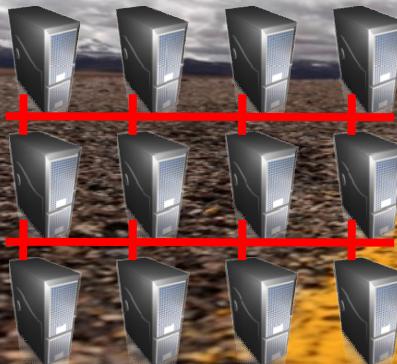
Hardware Solution - Business Evolution of Computer Architectures

Micro

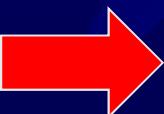


Macro

Macro



Sequential Processing



Parallel Processing



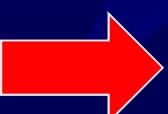
Hardware Solution - Business

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



- ❖ 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”

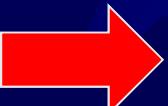
Thomas Watson, 1943

Even Visionaries Sometime Forget

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

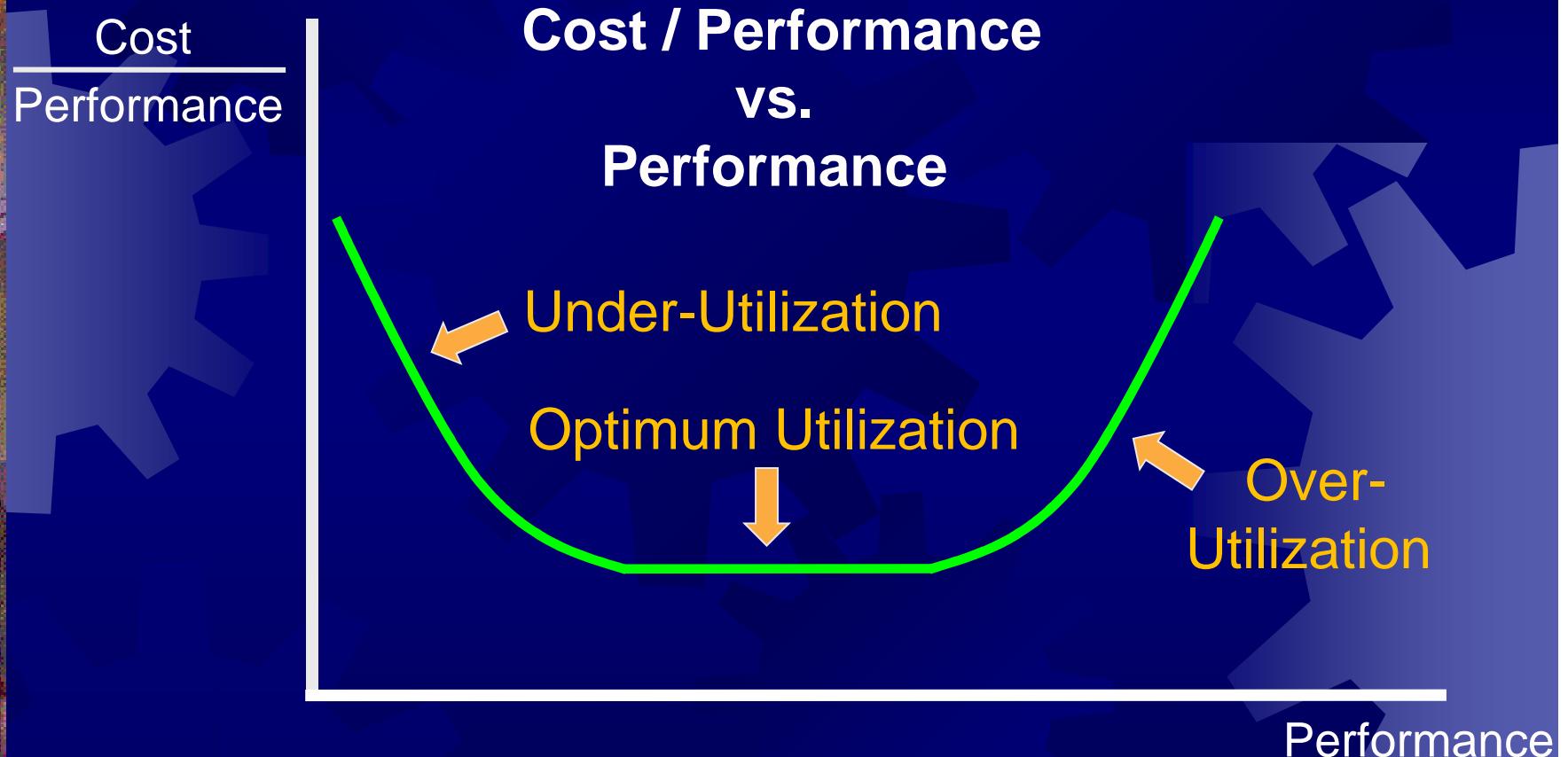
- ❖ Goal of Computer Hardware and Software Designers
 - Continually Increase Performance and Lower Cost
 - Operate at Optimum Point on Technology Curve

Sequential Processing

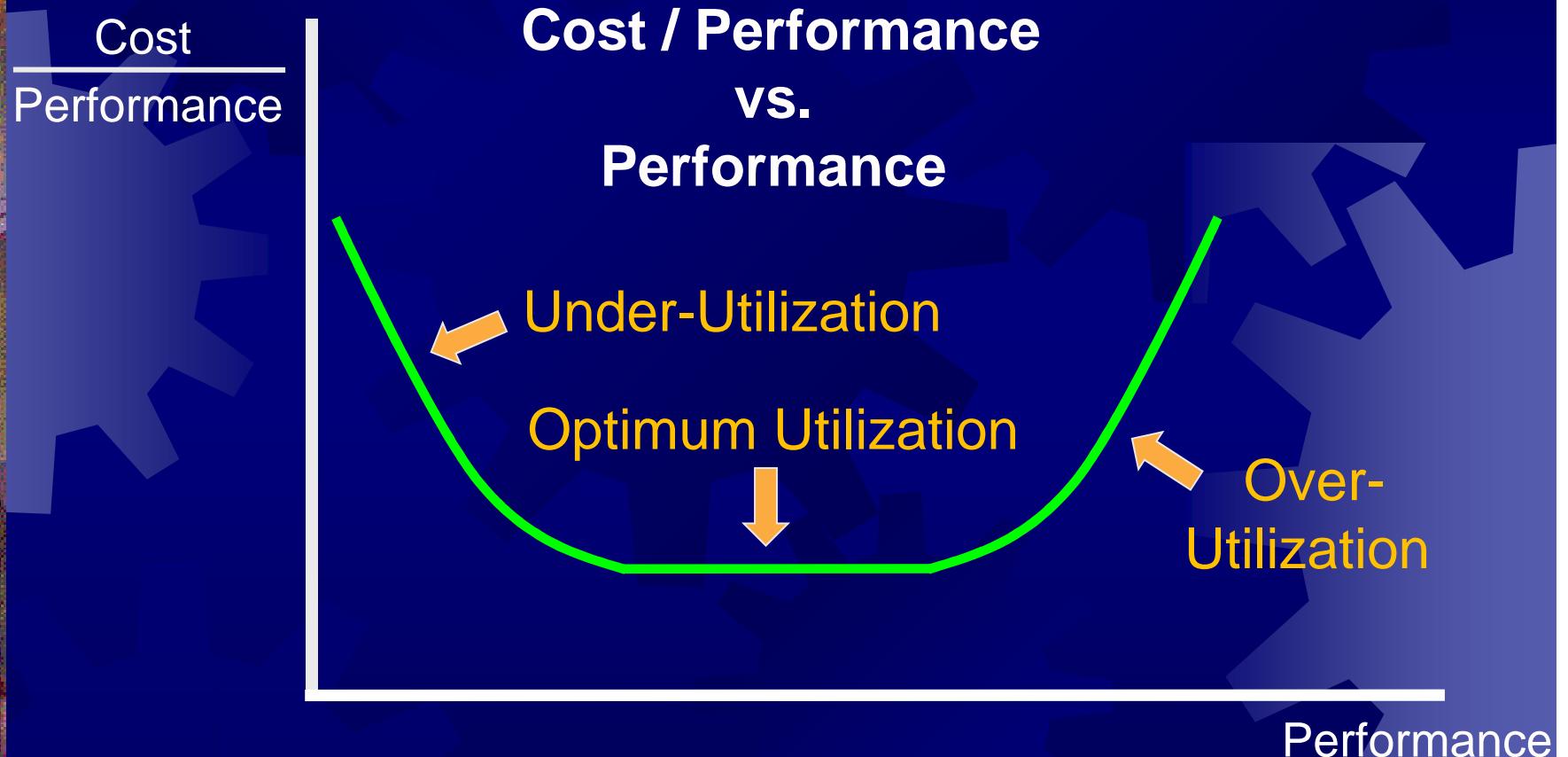


Parallel Processing

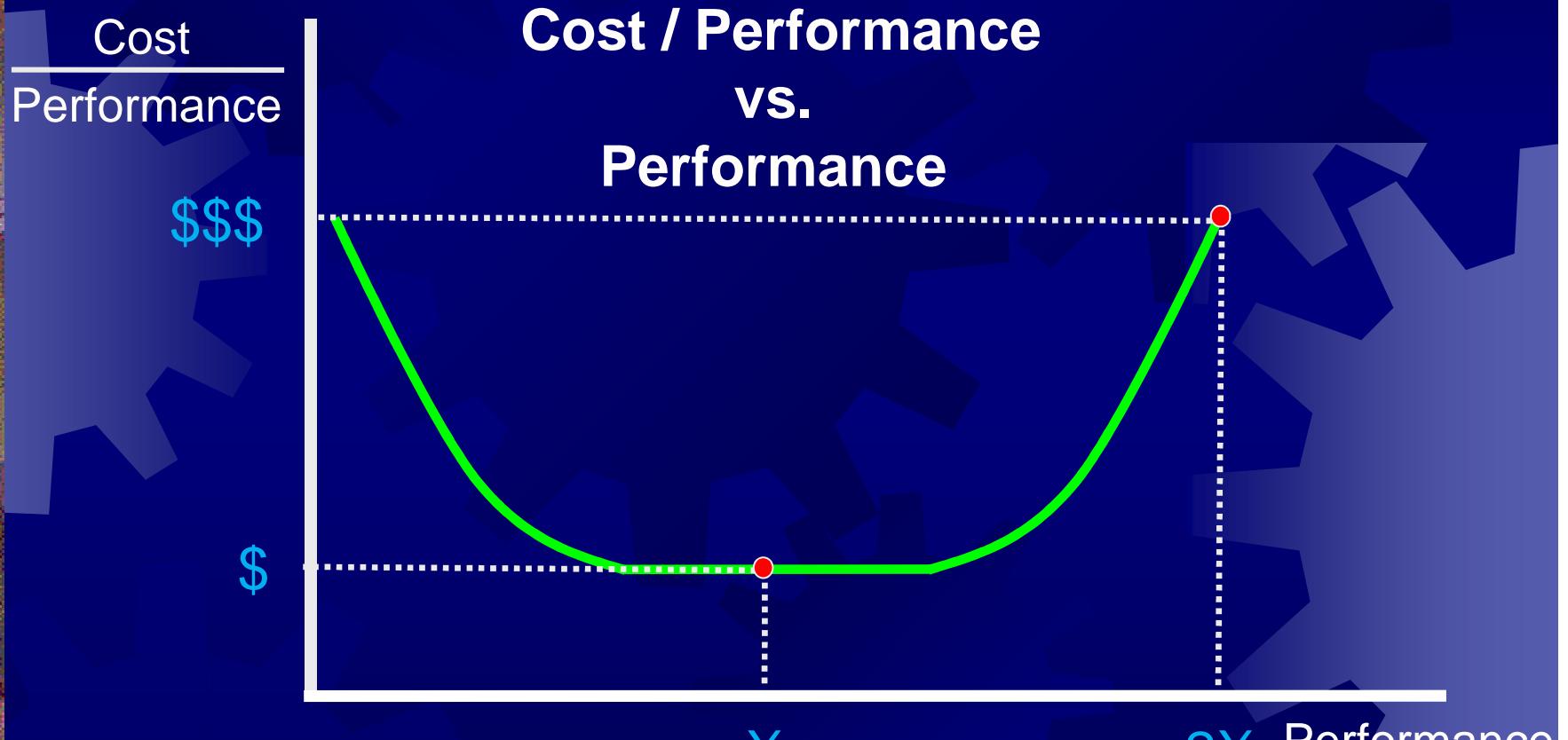
Hardware Solution - Business Technology Curve



Hardware Solution - Business Technology Curve

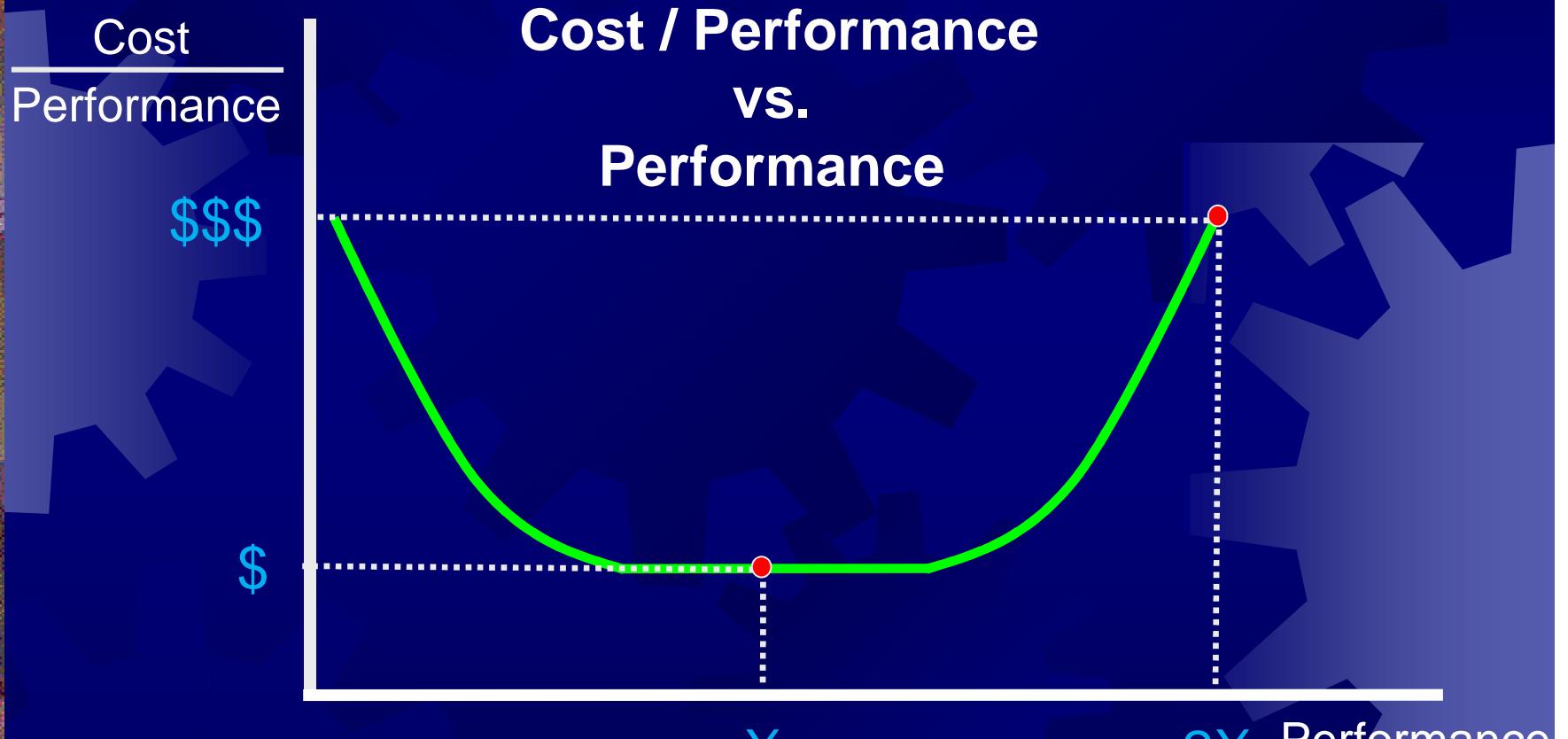


Hardware Solution - Business Technology Curve



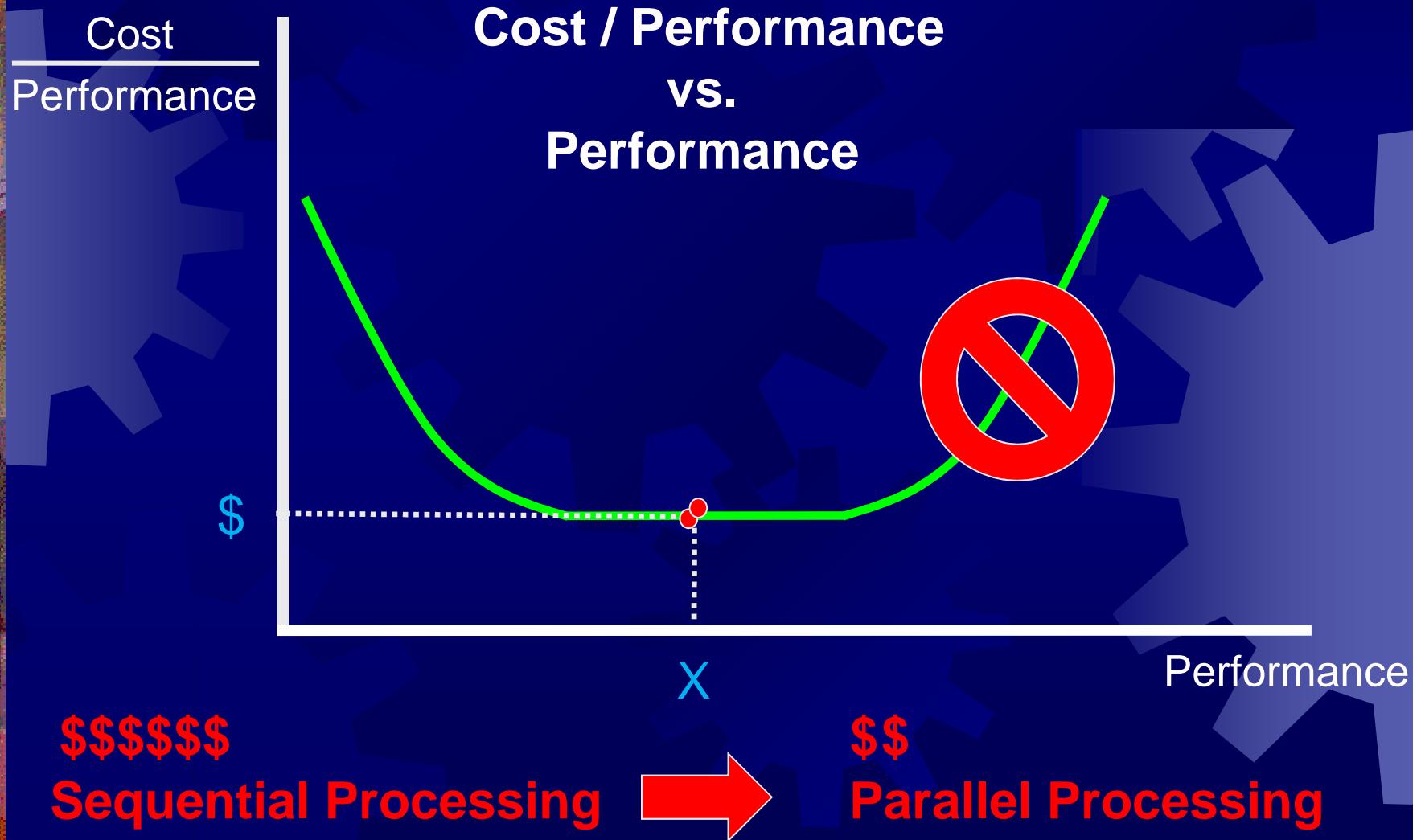
\$\$\$\$\$\$
Sequential Processing

Hardware Solution - Business Technology Curve



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Sequential Processing

Hardware Solution - Business Technology Curve





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