



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

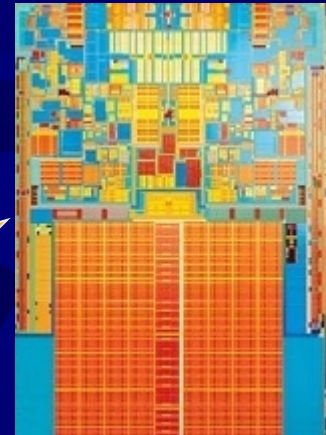


Car
&
Driver

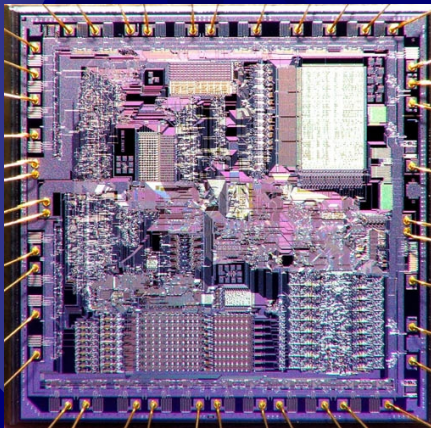
Hardware
&
Software



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



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

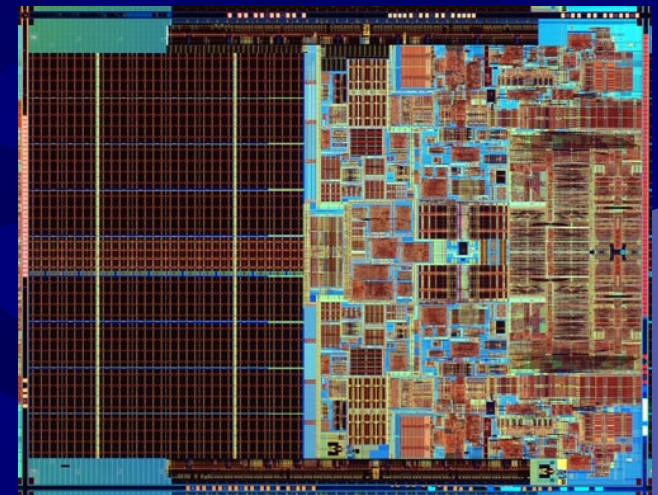
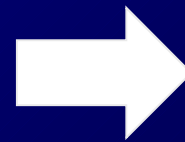


Intel 8086

1978

29,000

5 MHz



Intel Core 2 Duo

2006

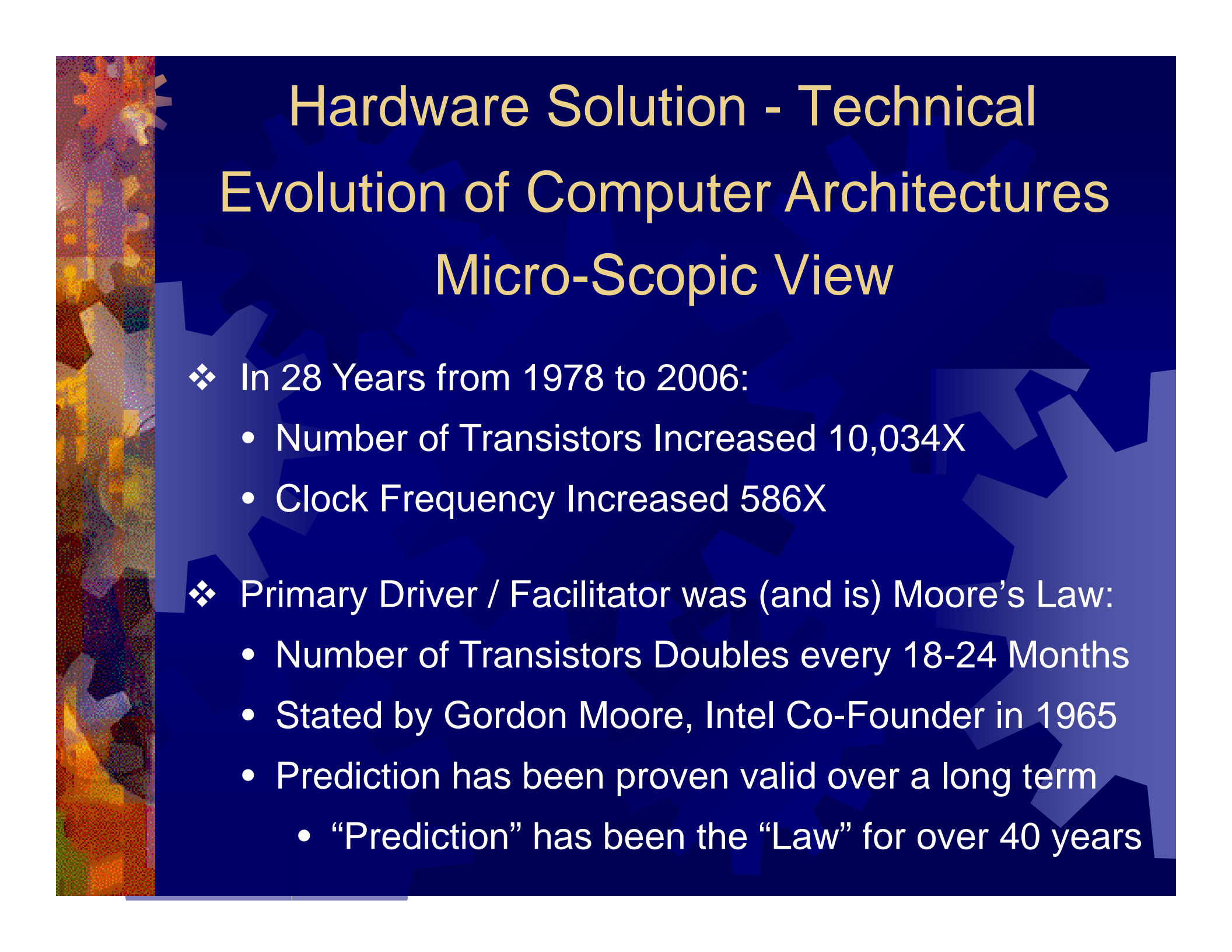
291,000,000

2.9 GHz

Year

Transistors

Clock Frequency



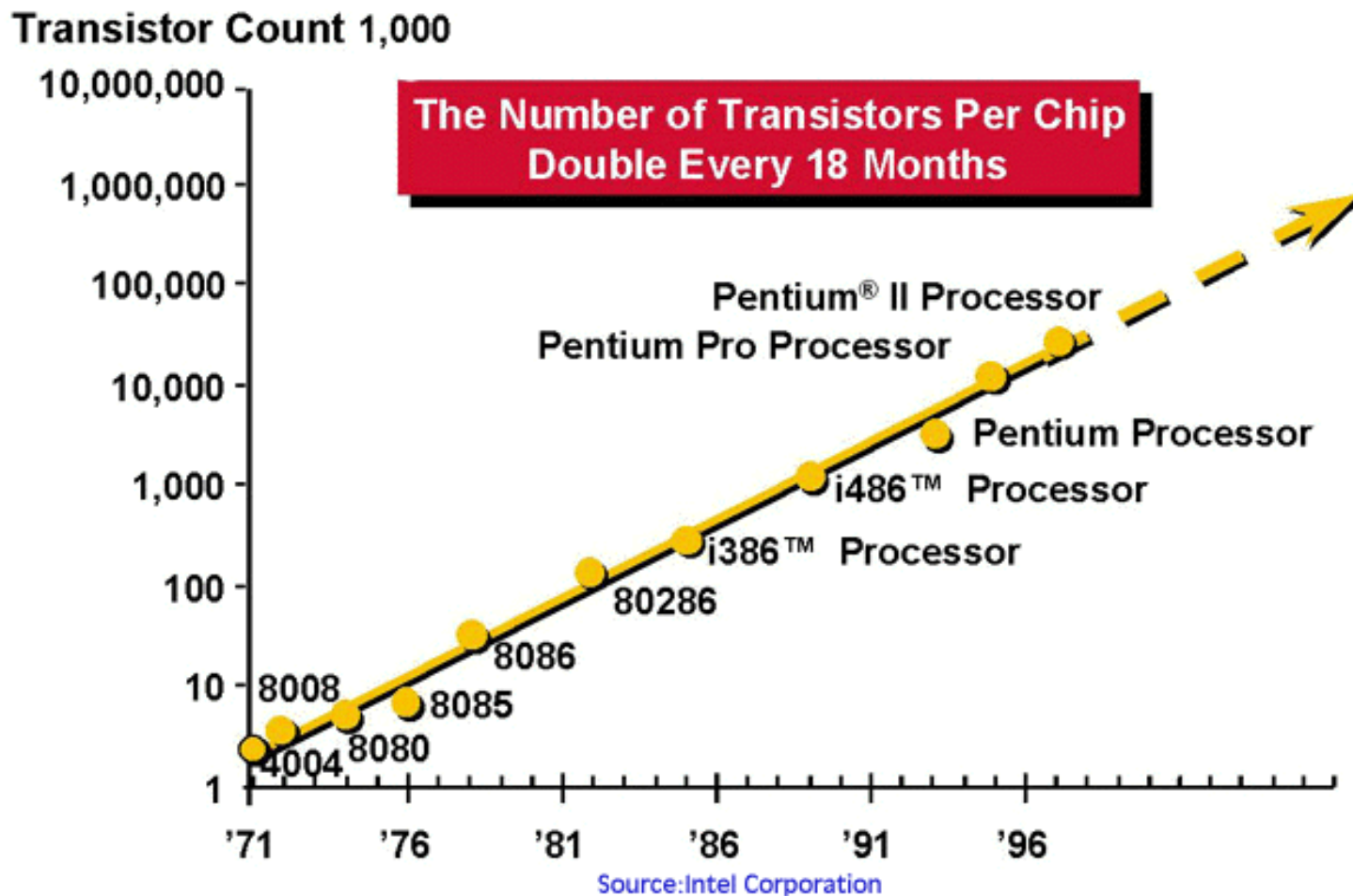
Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View

- ❖ 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

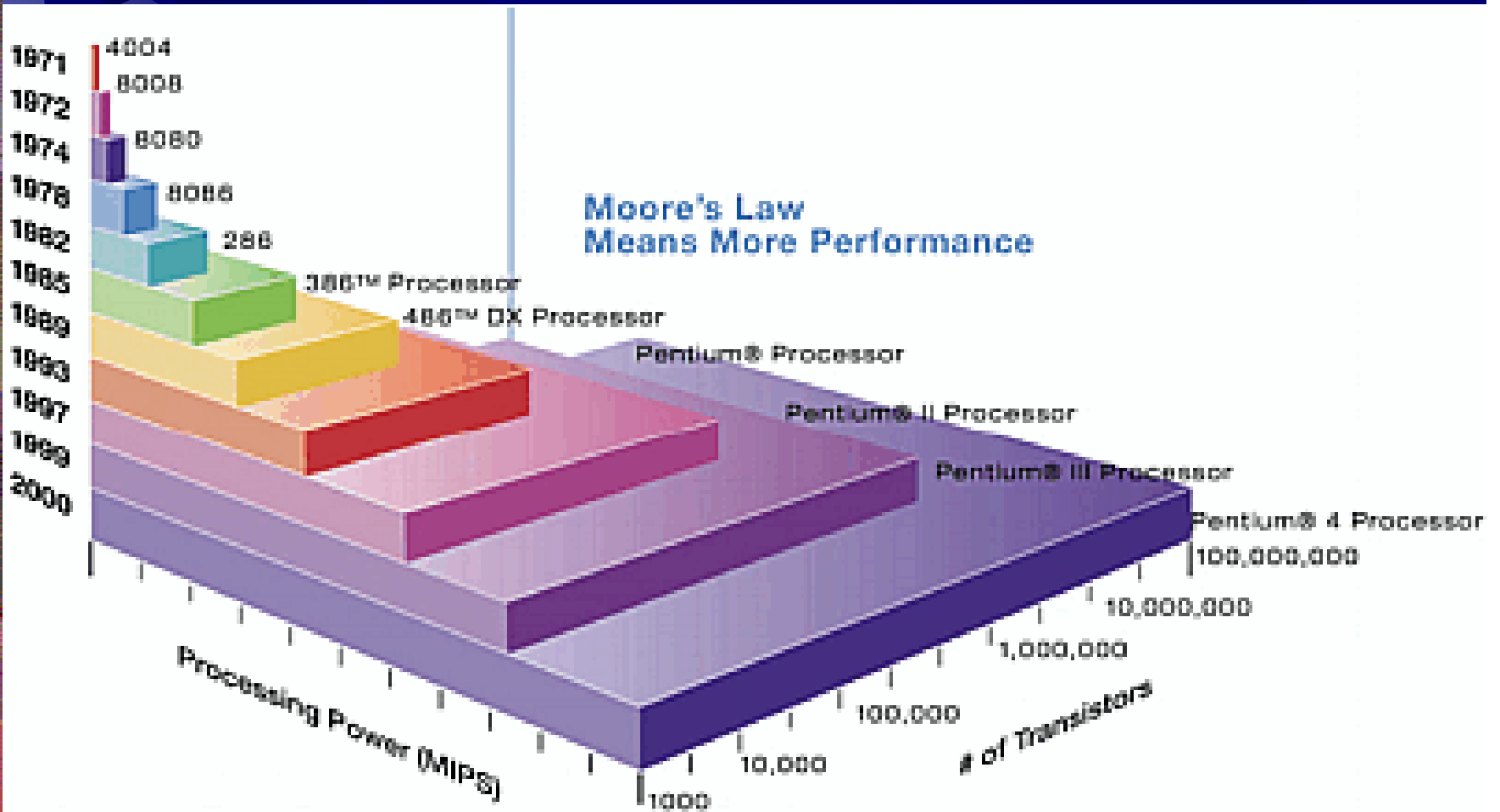
Micro-Scopic View

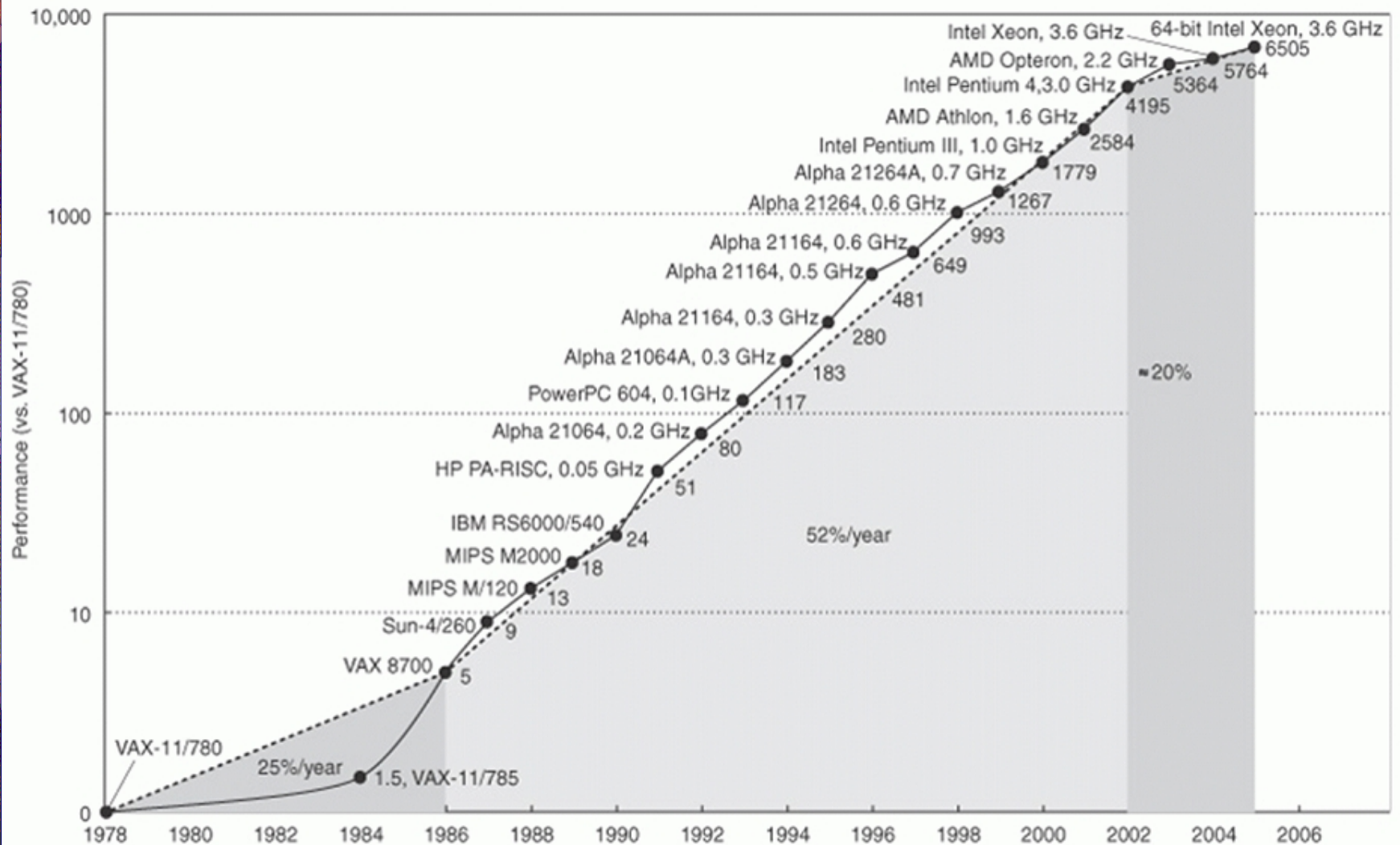


Hardware Solution - Technical

Evolution of Computer Architectures

Micro-Scopic View





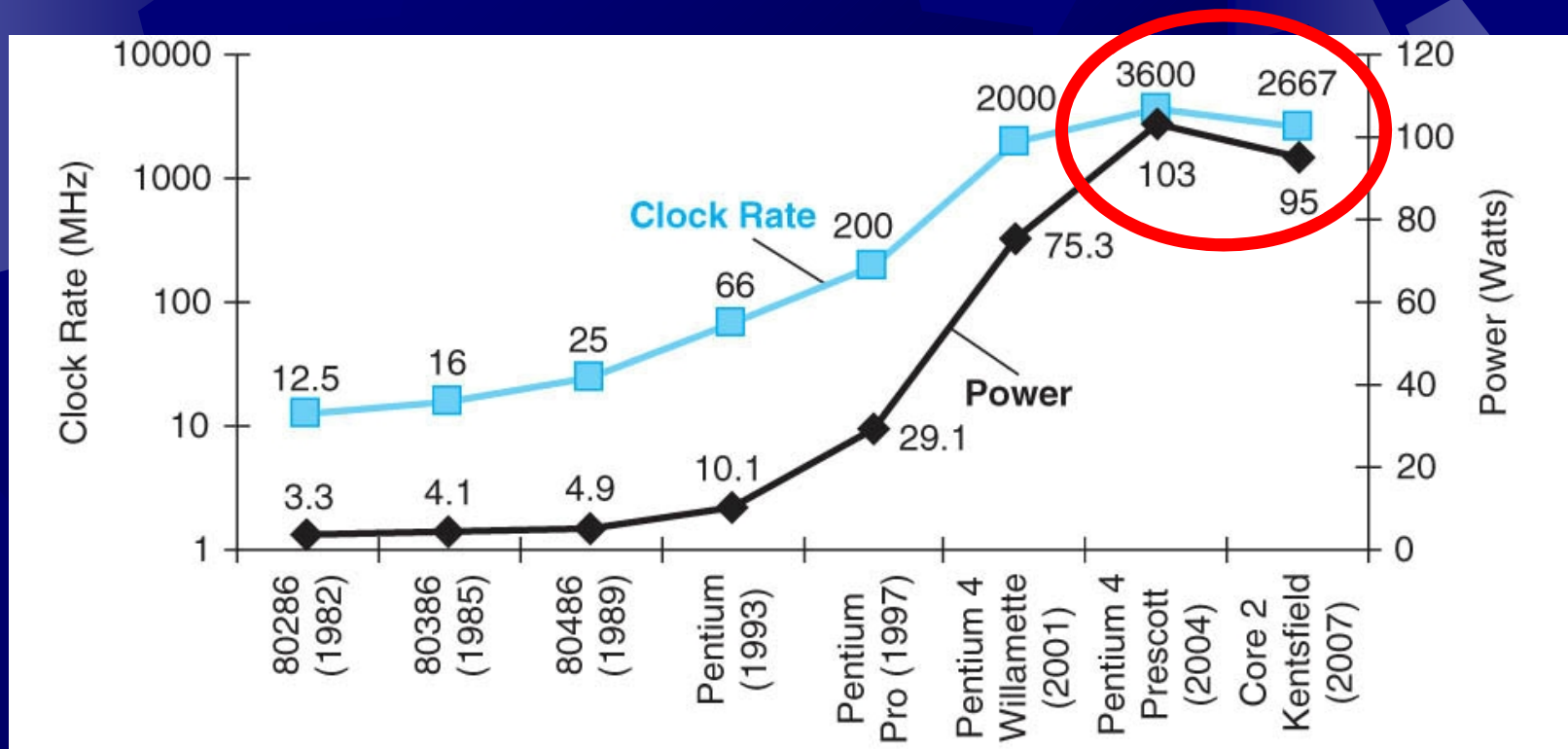
❖ Historically, Huge Performance Gains came from Huge Clock Frequency Increases
 Unfortunately

Hardware Solution - Technical

Evolution of Computer Architectures

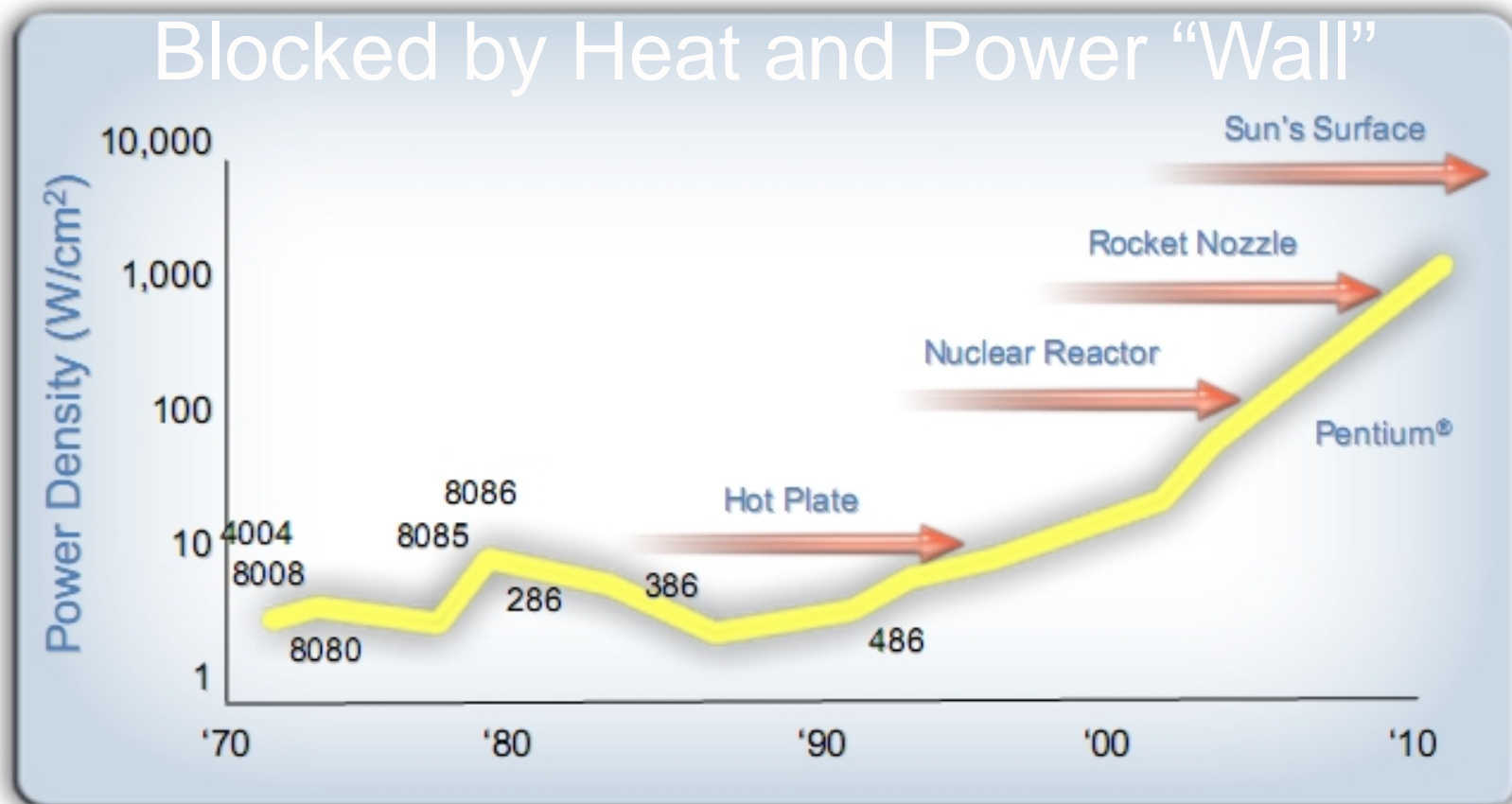
Micro-Scopic View

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

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

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

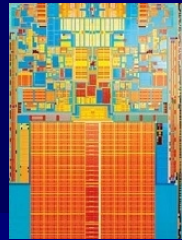
$$\text{Power} \propto \text{Frequency}^3$$

- How can HW Performance Continue to Increase?

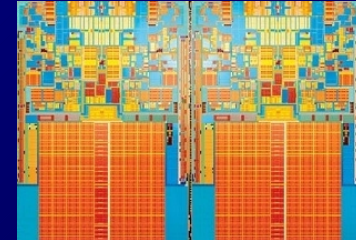
Single Core  Multi-Core

Single Core vs. Dual Core

Single Core clocked at $2f$



Dual Core clocked at f



$$2f$$

Throughput

$$f + f$$

$$8f^3$$

Heat

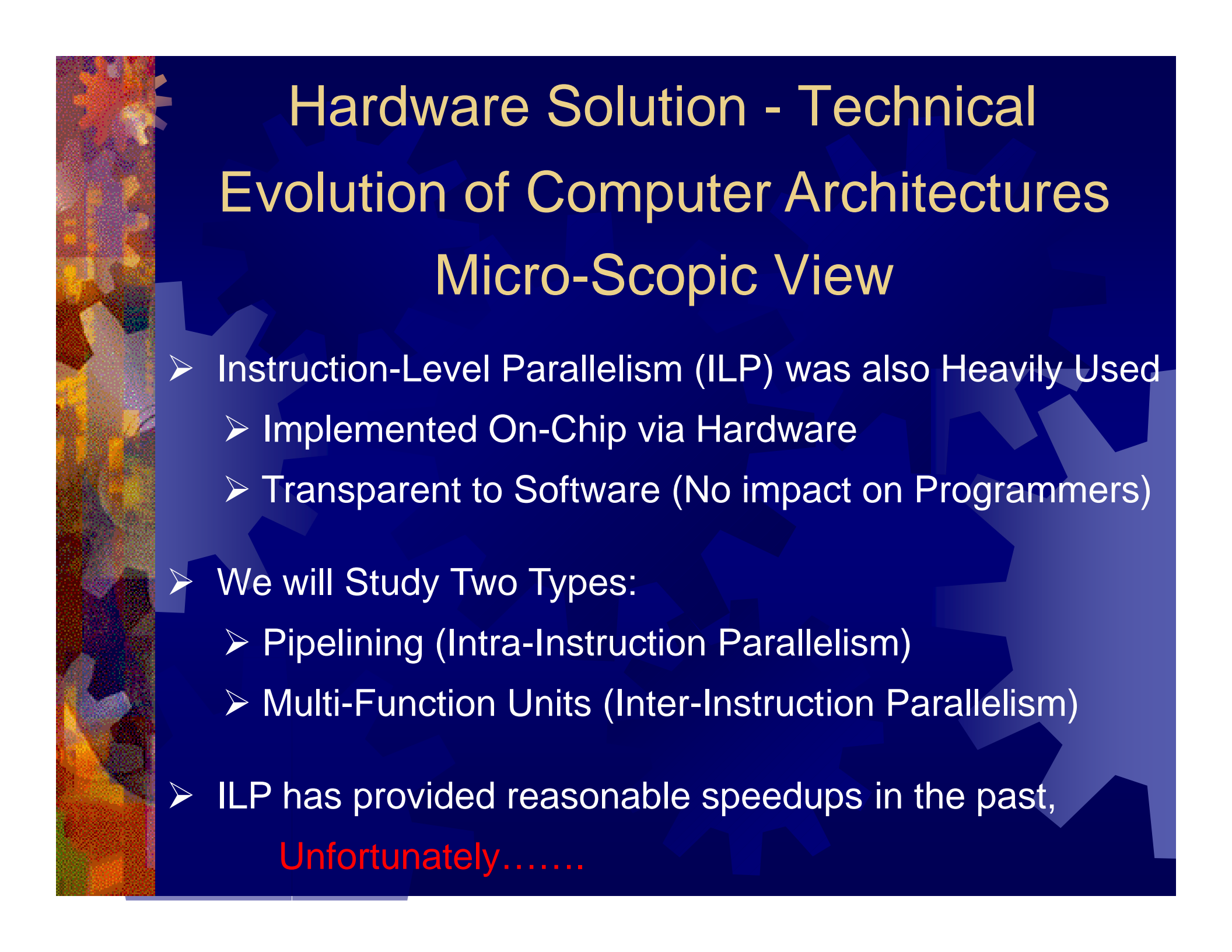
$$f^3 + f^3$$



Sequential Processing



Parallel Processing



Hardware Solution - Technical

Evolution of Computer Architectures

Micro-Scopic View

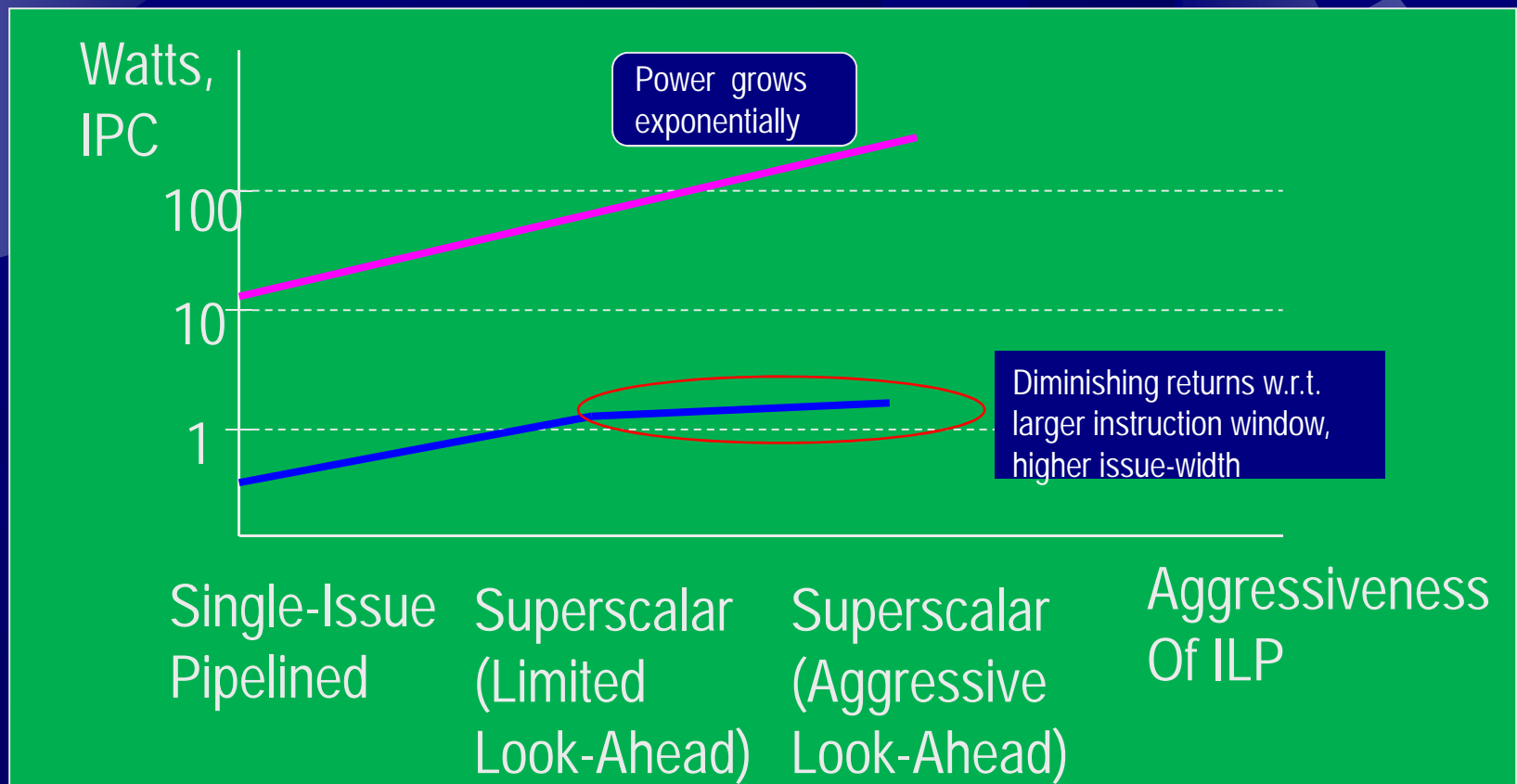
- Instruction-Level Parallelism (ILP) was also Heavily Used
 - Implemented On-Chip via Hardware
 - Transparent to Software (No impact on Programmers)
- We will Study Two Types:
 - Pipelining (Intra-Instruction Parallelism)
 - Multi-Function Units (Inter-Instruction Parallelism)
- ILP has provided reasonable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

Hardware Solution - Technical

Evolution of Computer Architectures

Micro-Scopic View

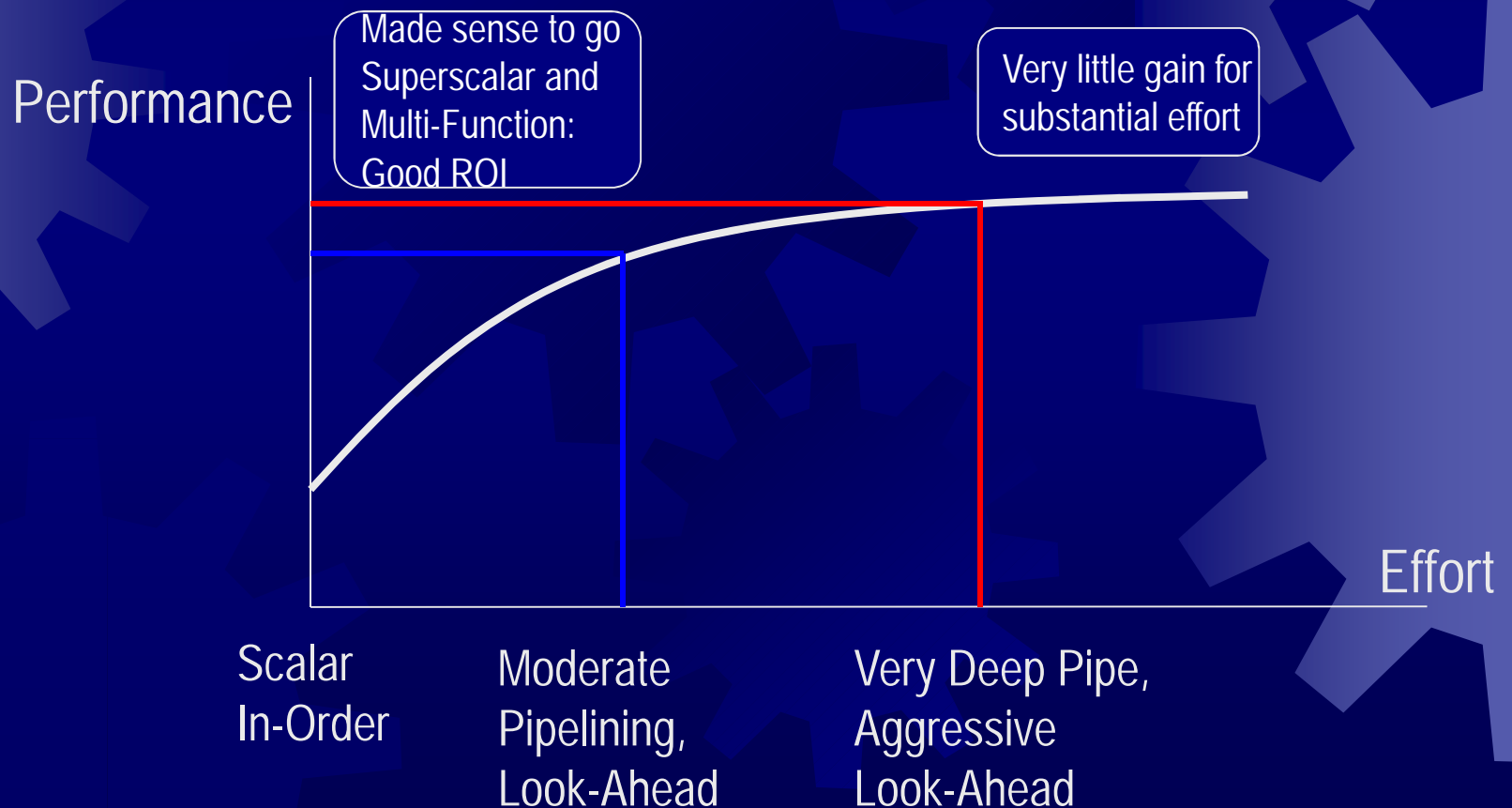
➤ Instruction-Level Parallelism Limits have been Reached too



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



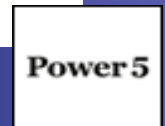
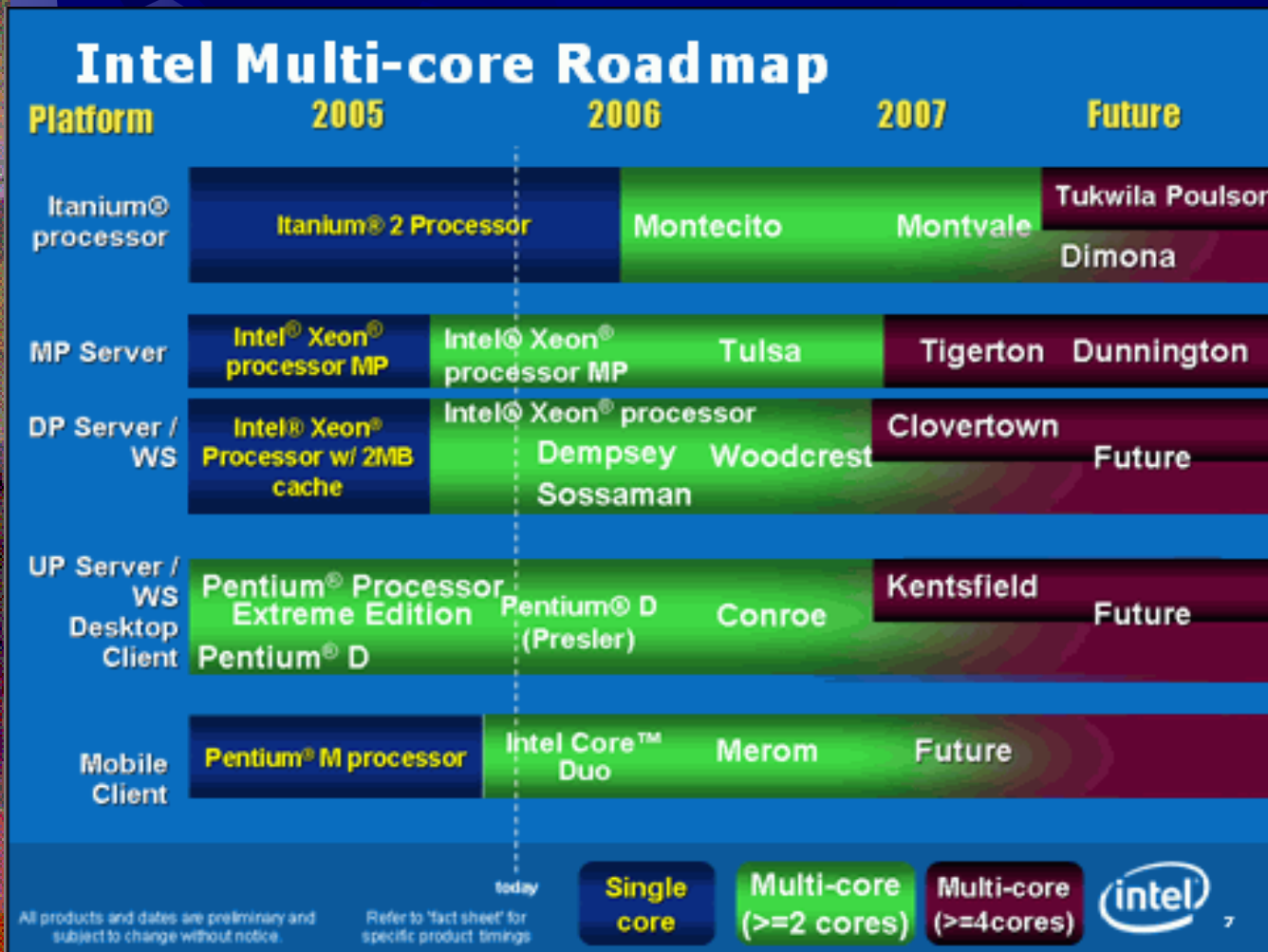


Hardware Solution - Technical Evolution of Computer Architectures Micro-Scopic View Summary

- 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

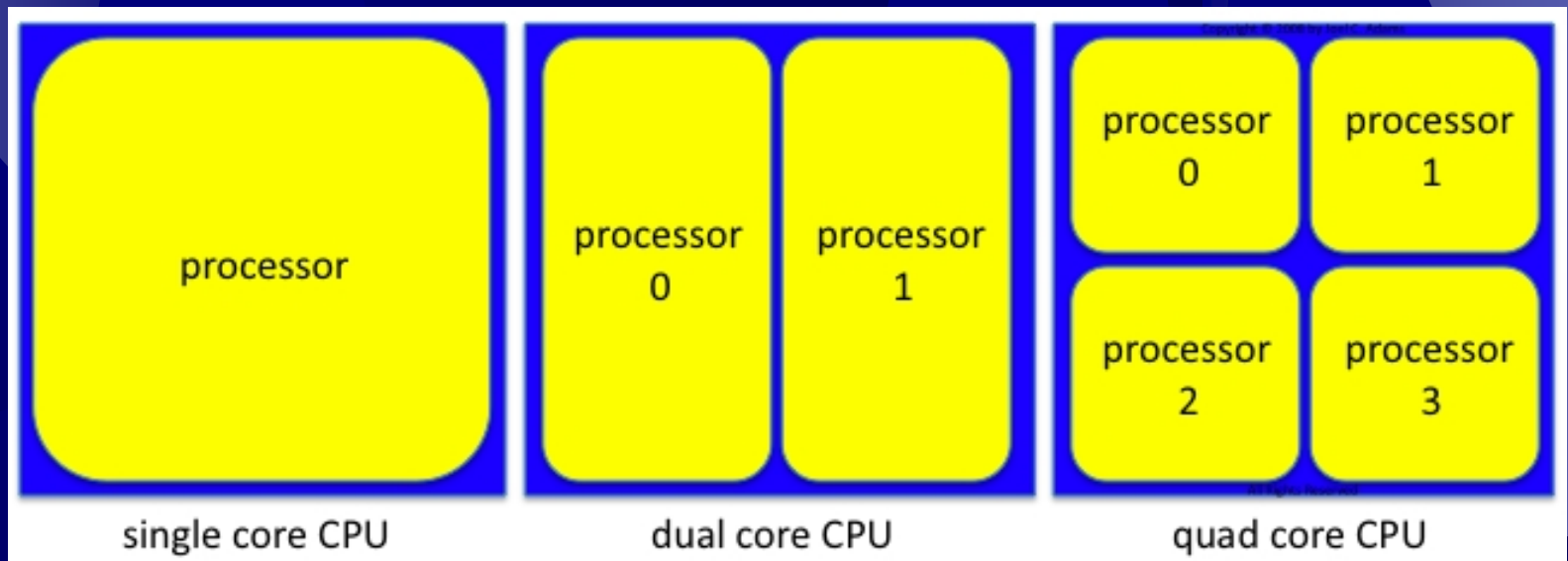
Hardware Solution - Technical Evolution of Computer Architectures

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



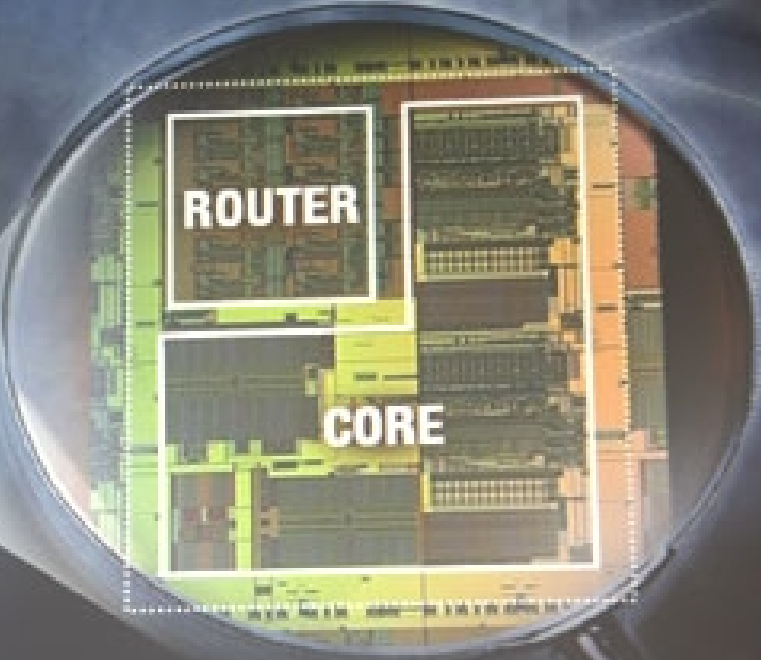
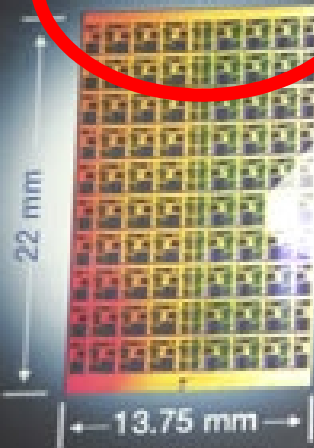
1

2

4

TERAFLOP OF PERFORMANCE

80 CORES



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

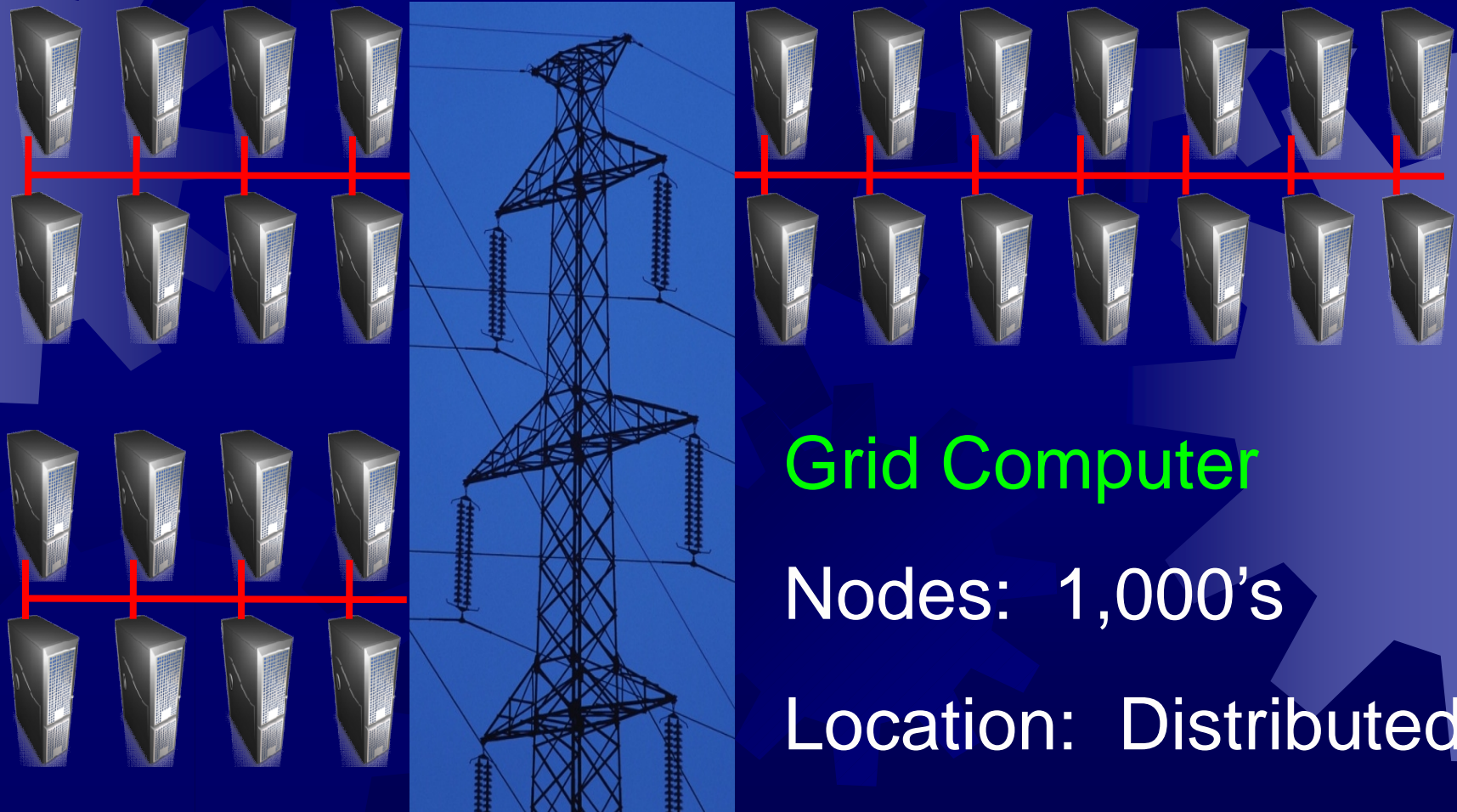


Example
Cluster
Computer

Hardware Solution - Technical

Evolution of Computer Architectures

Macro-Scopic View



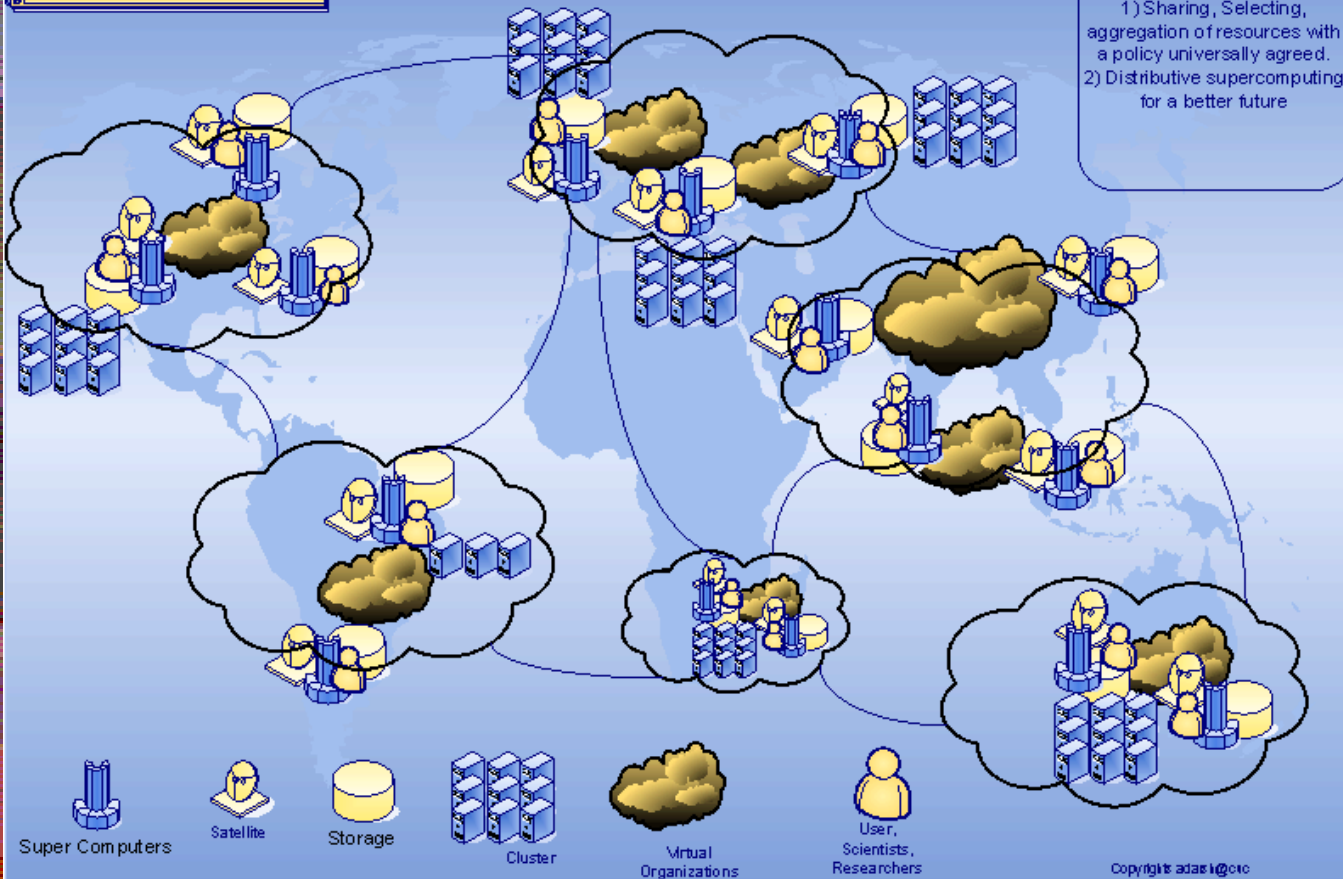
Grid Computer

Nodes: 1,000's

Location: Distributed

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

Grid Computing



Example
Grid
Computer

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



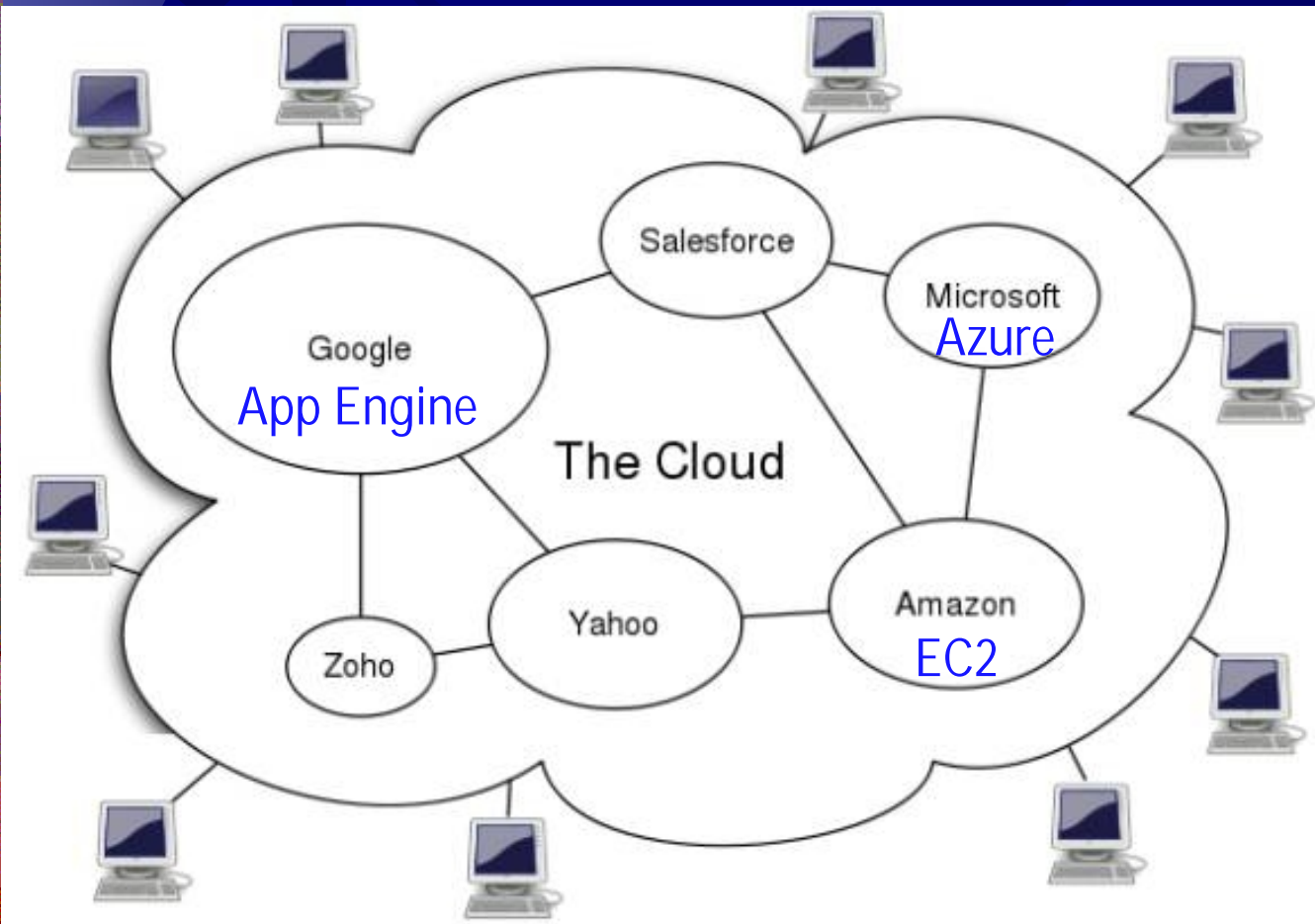
Cloud Computer

Nodes: 10,000's

Location: Highly

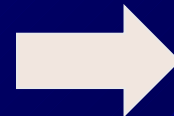
Distributed

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

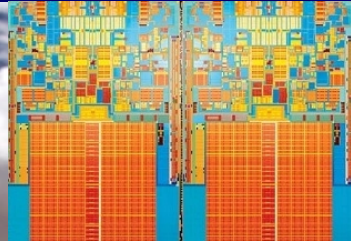
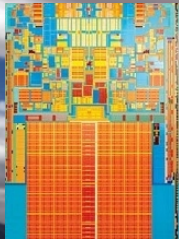
Parallel Processing



Hardware Solution - Business

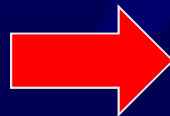
Evolution of Computer Architectures

Micro



Macro

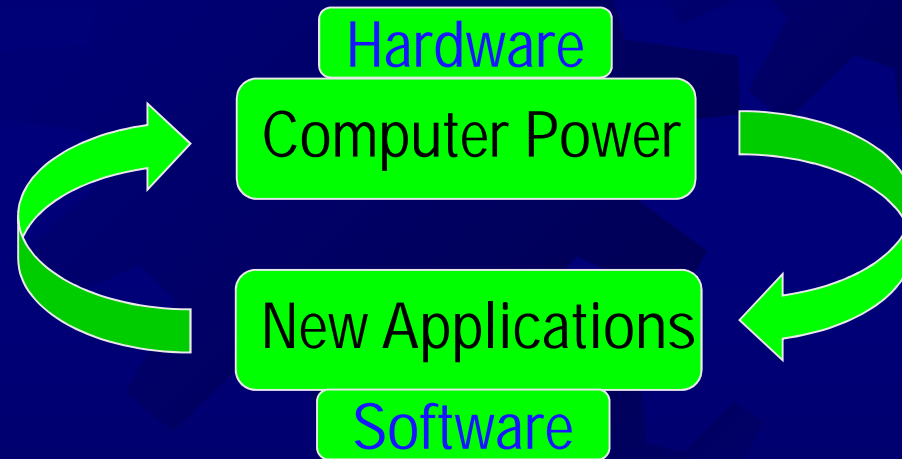
Sequential Processing



Parallel Processing

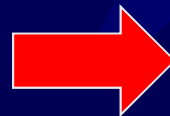
Hardware Solution - Business

- ❖ 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”

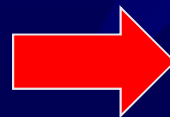
Thomas Watson, 1943

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

Cost
Performance

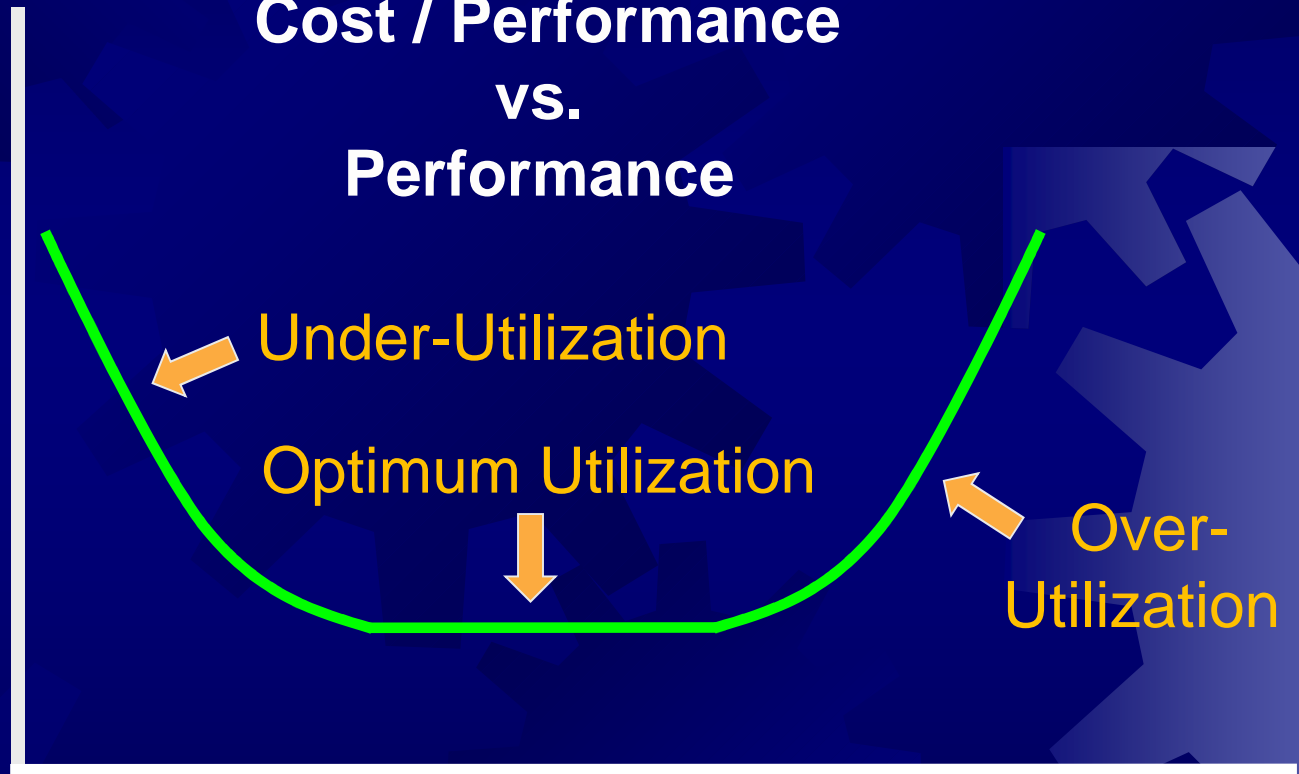
Cost / Performance
vs.
Performance

Under-Utilization

Optimum Utilization

Over-Utilization

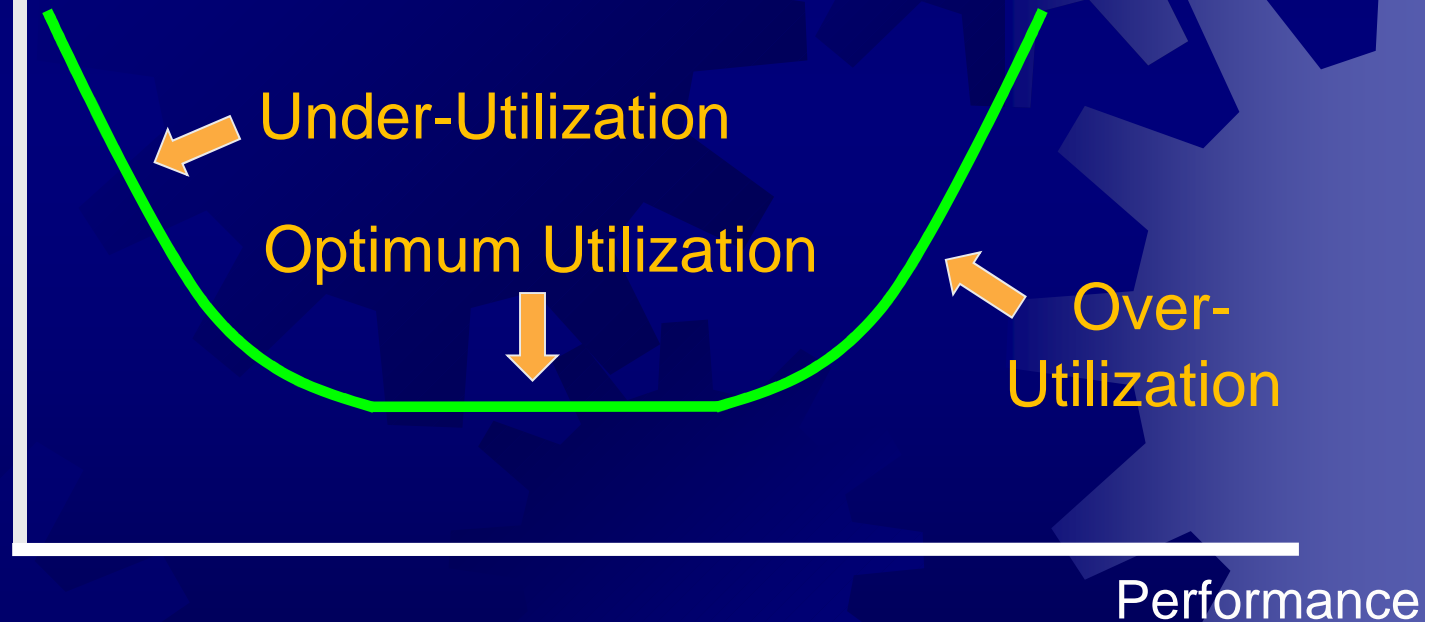
Performance



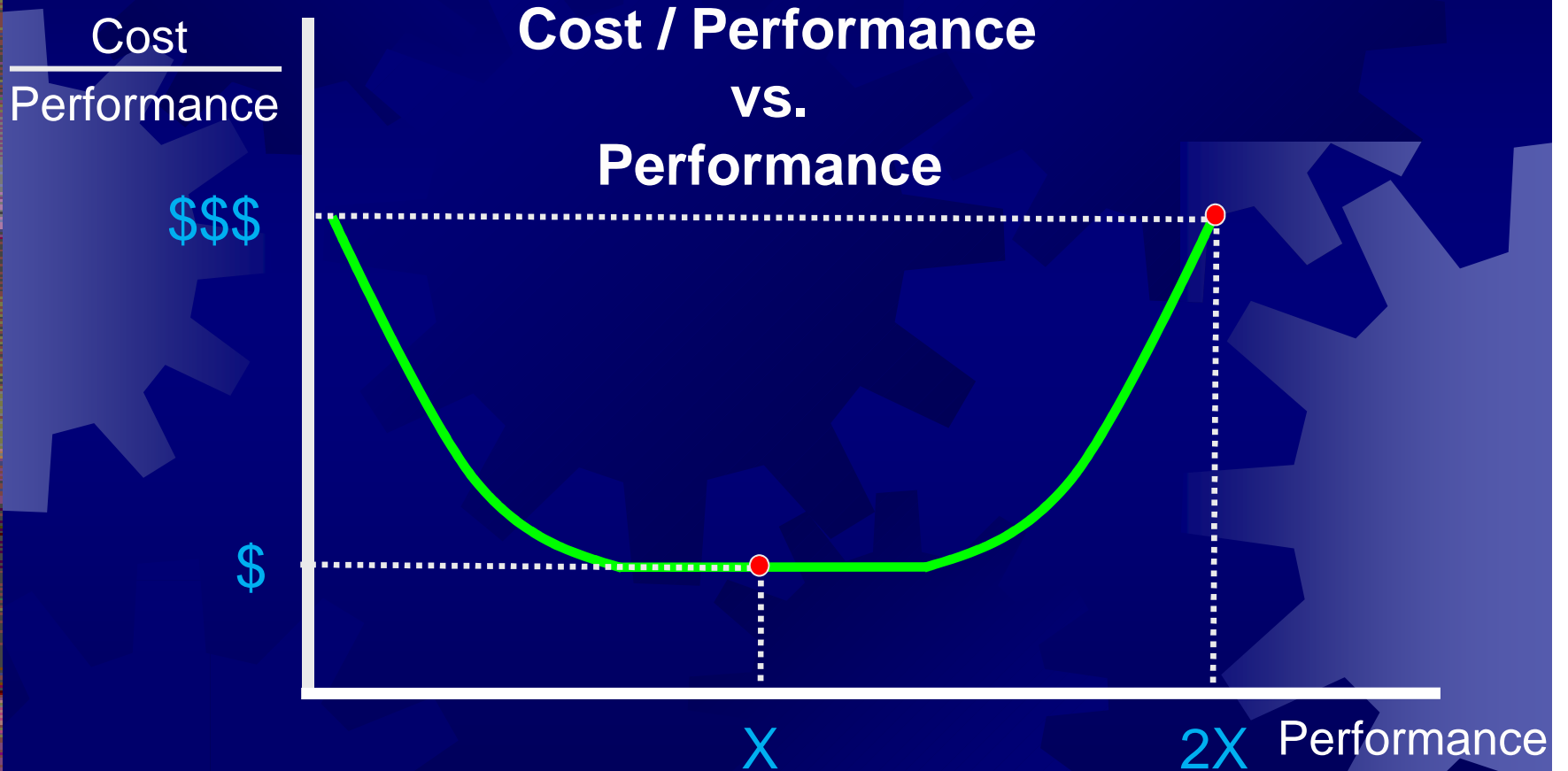
Hardware Solution - Business Technology Curve

Cost
Performance

Cost / Performance
vs.
Performance



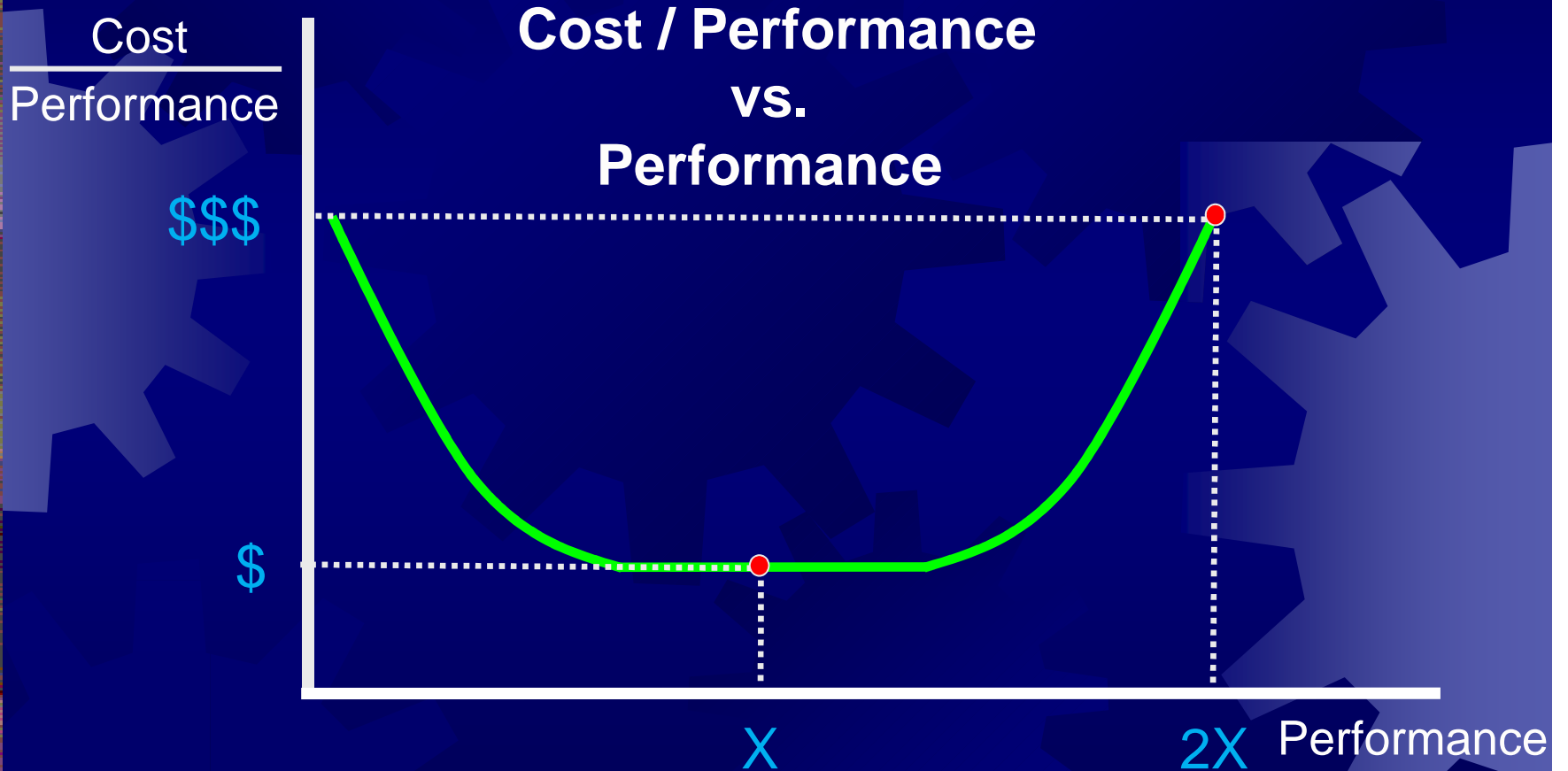
Hardware Solution - Business Technology Curve



\$\$\$\$\$\$

Sequential Processing

Hardware Solution - Business Technology Curve



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Sequential Processing

Hardware Solution - Business Technology Curve

Cost
Performance

Cost / Performance
vs.
Performance

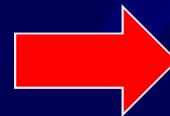
\$

X

Performance

\$\$\$\$\$\$

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