Course Overview

Computer Organization

Adapted from Ricardo Chaves

TÉCNICO LISBOA

The Computer Revolution

- Progress in computer technology
  - Reinforced by Moore's Law
- Makes novel applications feasible
  - Computers in automobiles
  - Cell phones
  - Human genome project
  - World Wide Web
  - Search Engines
- Computers are pervasive

Classes of Computers

- Desktop
  - single user, general purpose, with a typical set up of display, keyboard, and mouse

    Critical: cost, performance

Desktop Computer

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- Personal Mobile Device (PMD)
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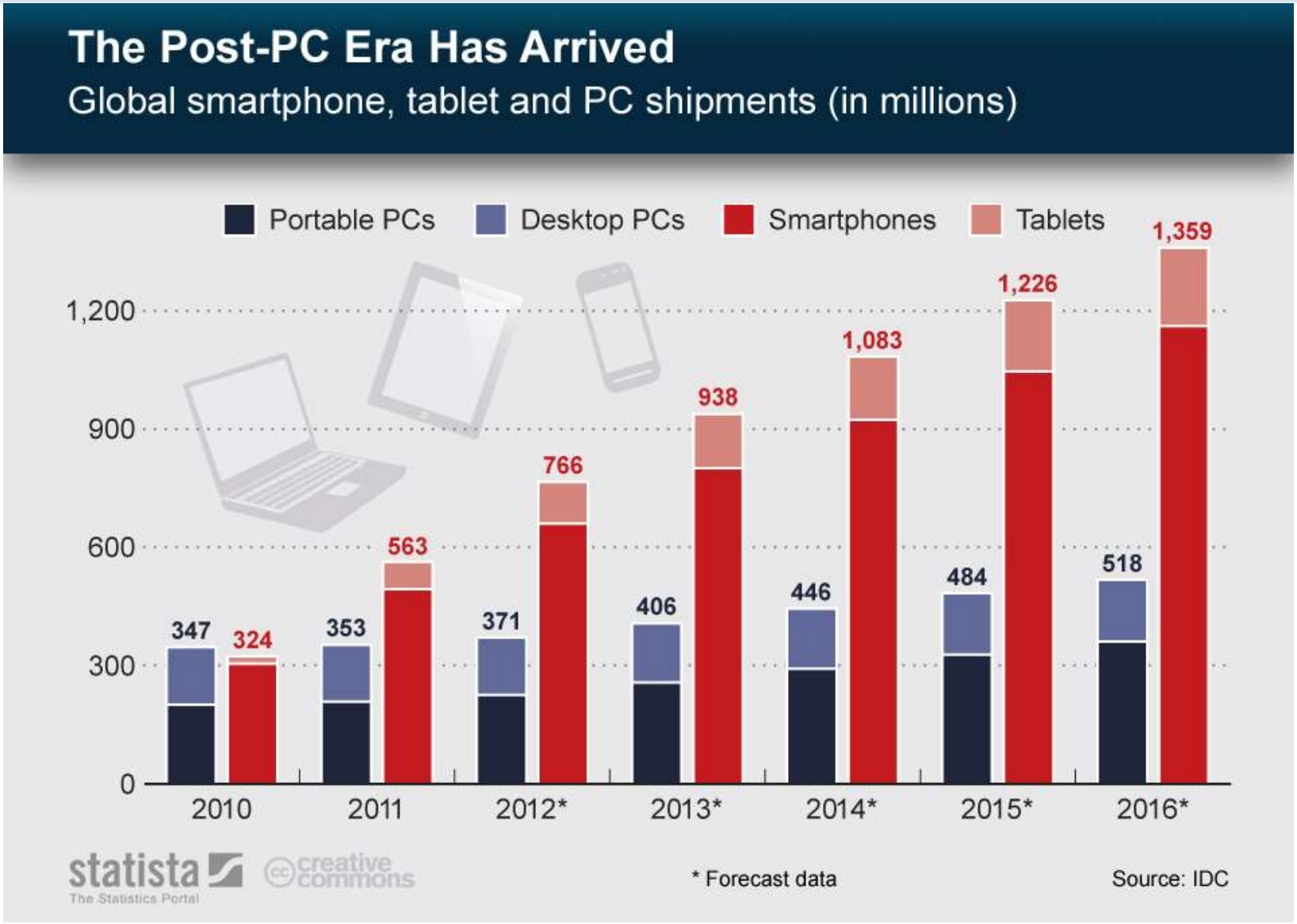
The Post-PC Era



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Server

Server

Rack

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Supercomputer

Summit, an IBM-built supercomputer
running at the Department of Energy's (DOE)

Currently the world most powerful supercomputer
(4,356 nodes each with 22-core Power9 and 6 NVIDIA Tesla V100 GPUs)
with a performance of **122.3 petaflops**

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- Embedded
  - hidden component of a system, running a predefined program
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Embedded Computers

Over 99% of processor sales are for embedded systems!

Issues in Embedded Systems

Specific issues when programming embedded systems:

- Real-time requirements
  - Often worst-case is more important than average-case
- Resource constraints
  - Power and memory
- Reliability
  - Safety critical systems
  - Difficult access
- Diversity
  - Heterogeneity of computing architectures
  - Diverse set of input/output devices

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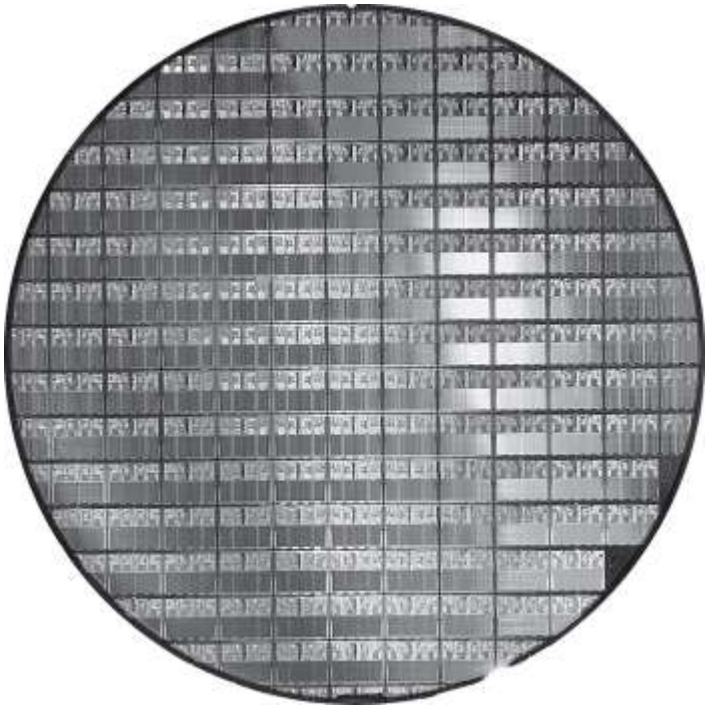
Technology Trends

- The transistor density increases about 35% per year.
- The circuits area increases about 10% to 20% per year.
- The number of transistors per circuit increases about 55% per year.

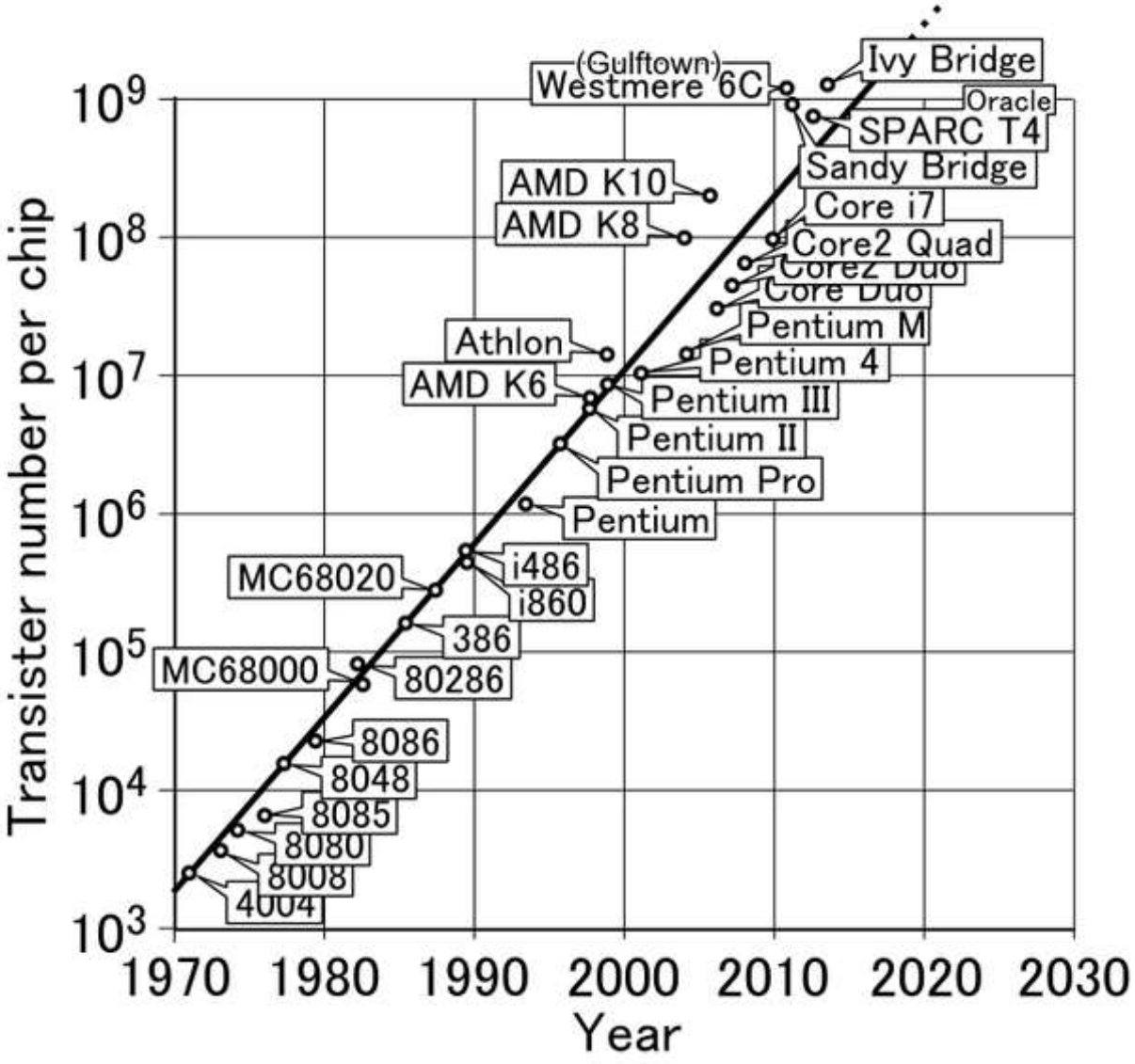


Moore's Law (1965):

"The number of transistors per square-centimeter of integrated circuit doubles every 18 months."

- In practice, the density increased about 1,000,000x in the last 45 years!

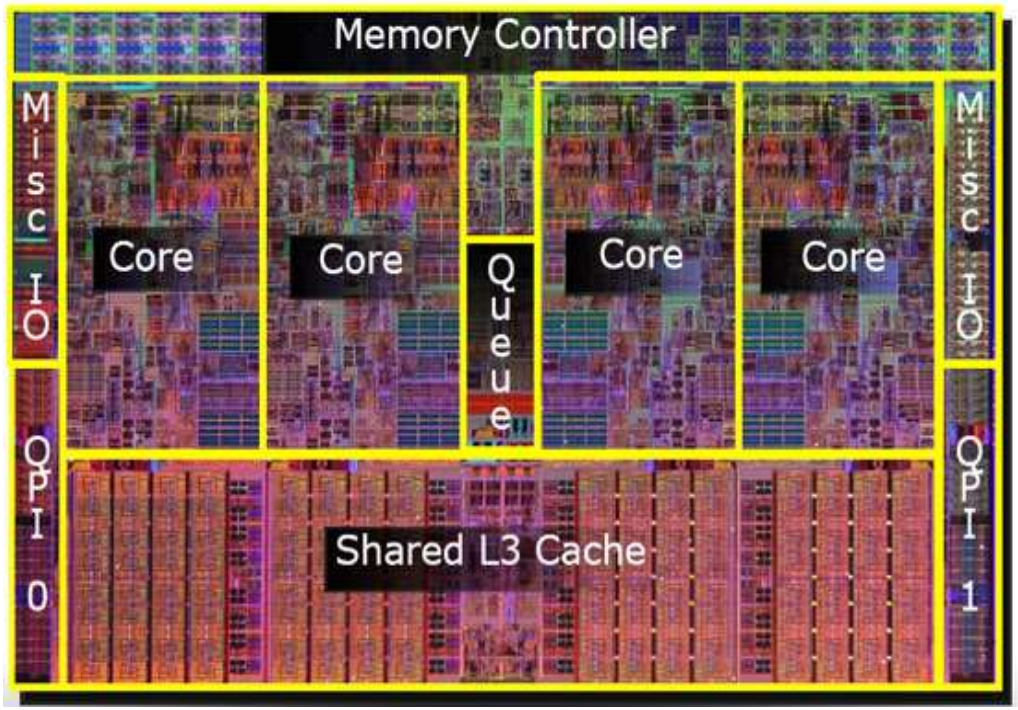
Moore's Law in Practice



Inside the Processor

Intel Core i7:

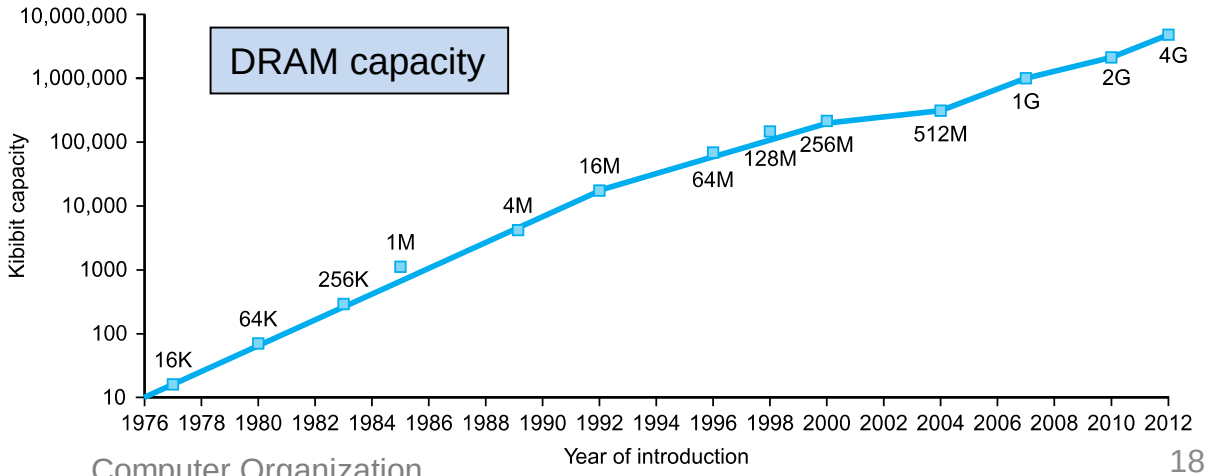
4 processor cores, 1.3×10^9 transistors



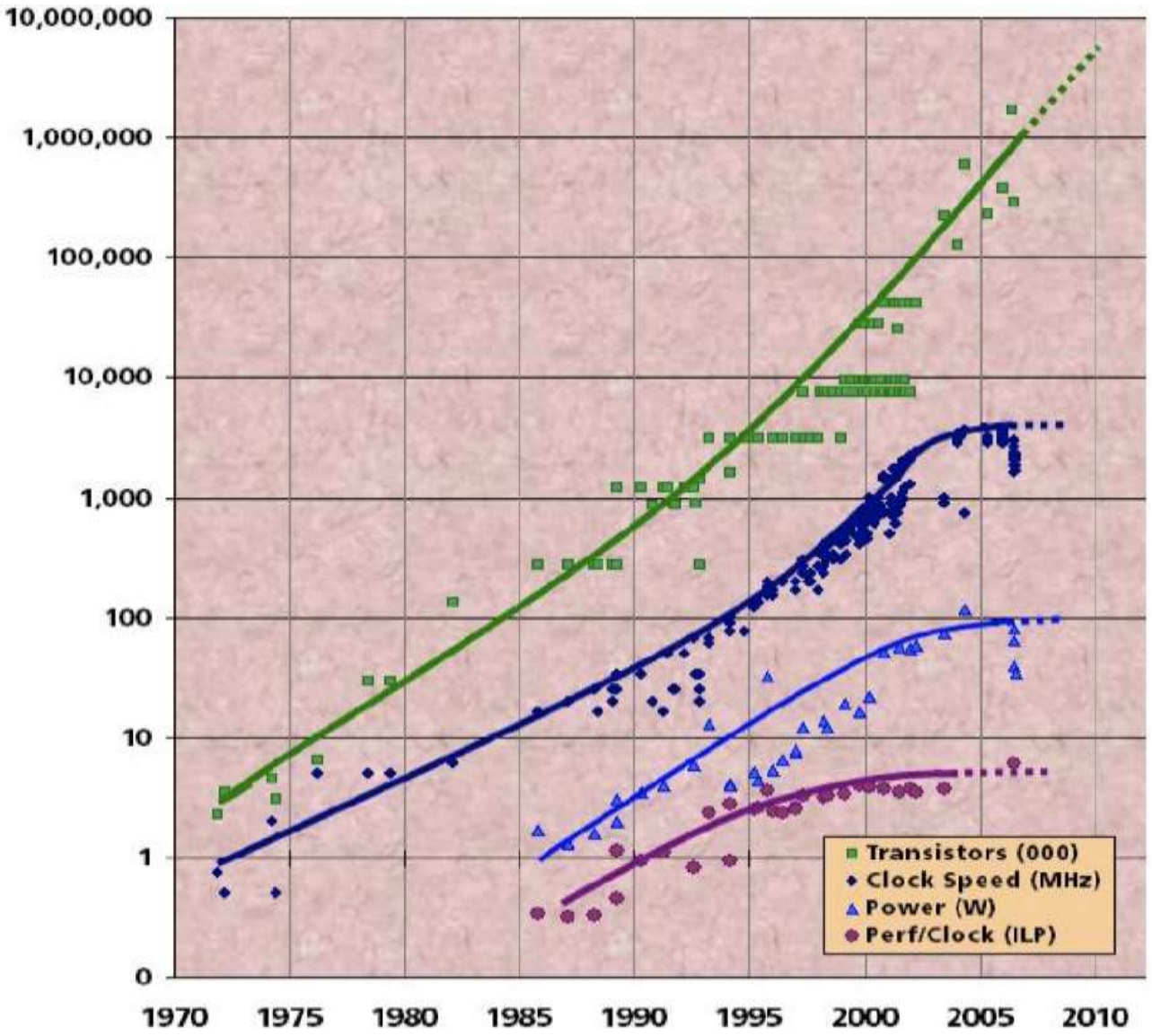
Technology Trends

Year	Technology	Relative performance/cost
1951	Vacuum tube	1
1965	Transistor	35
1975	Integrated circuit (IC)	900
1995	Very large scale IC (VLSI)	2,400,000
2013	Ultra large scale IC	250,000,000,000

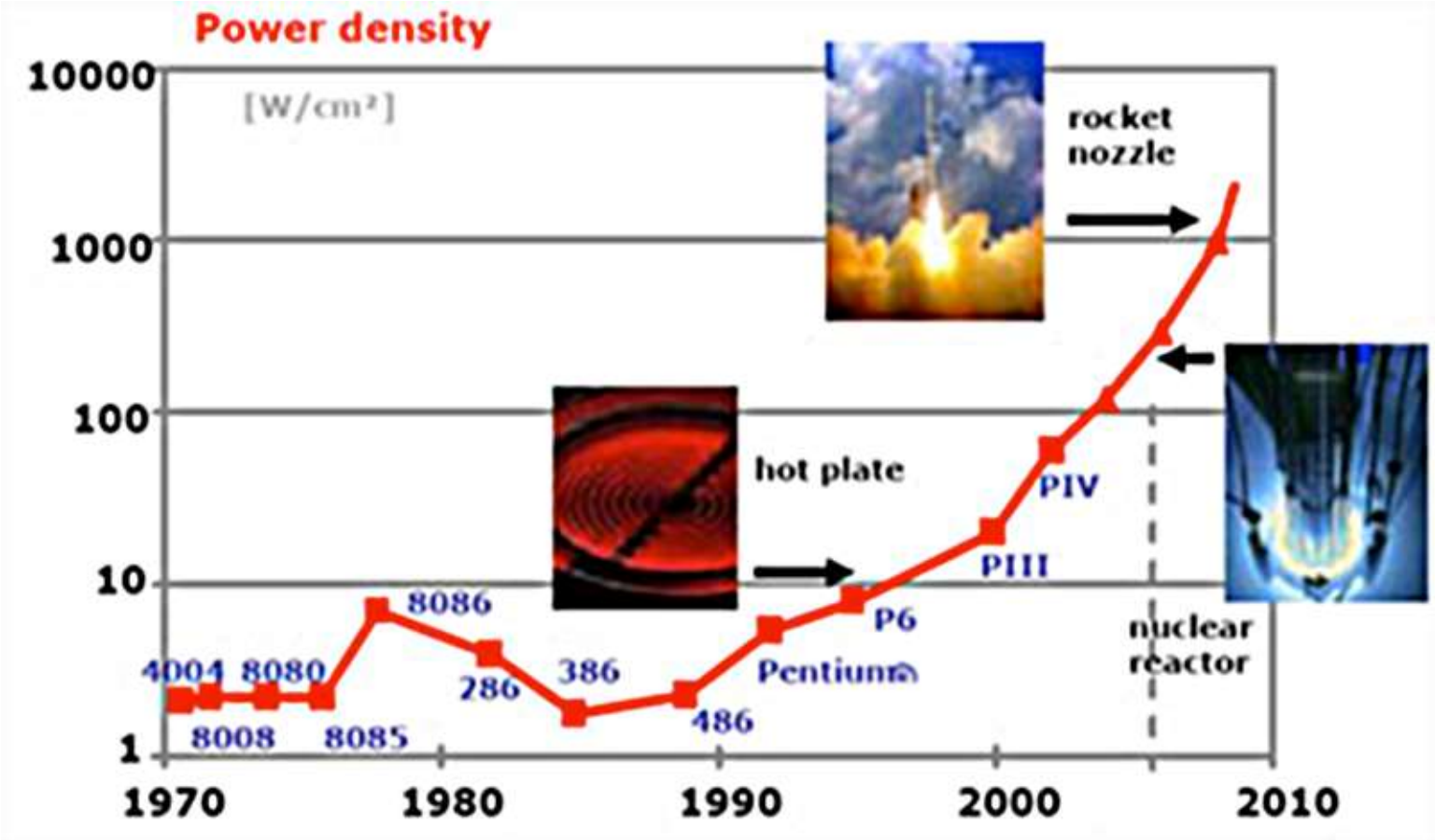
- Electronics technology continues to evolve
  - Increased capacity and performance
  - Reduced cost



Technology Trends



Power Density

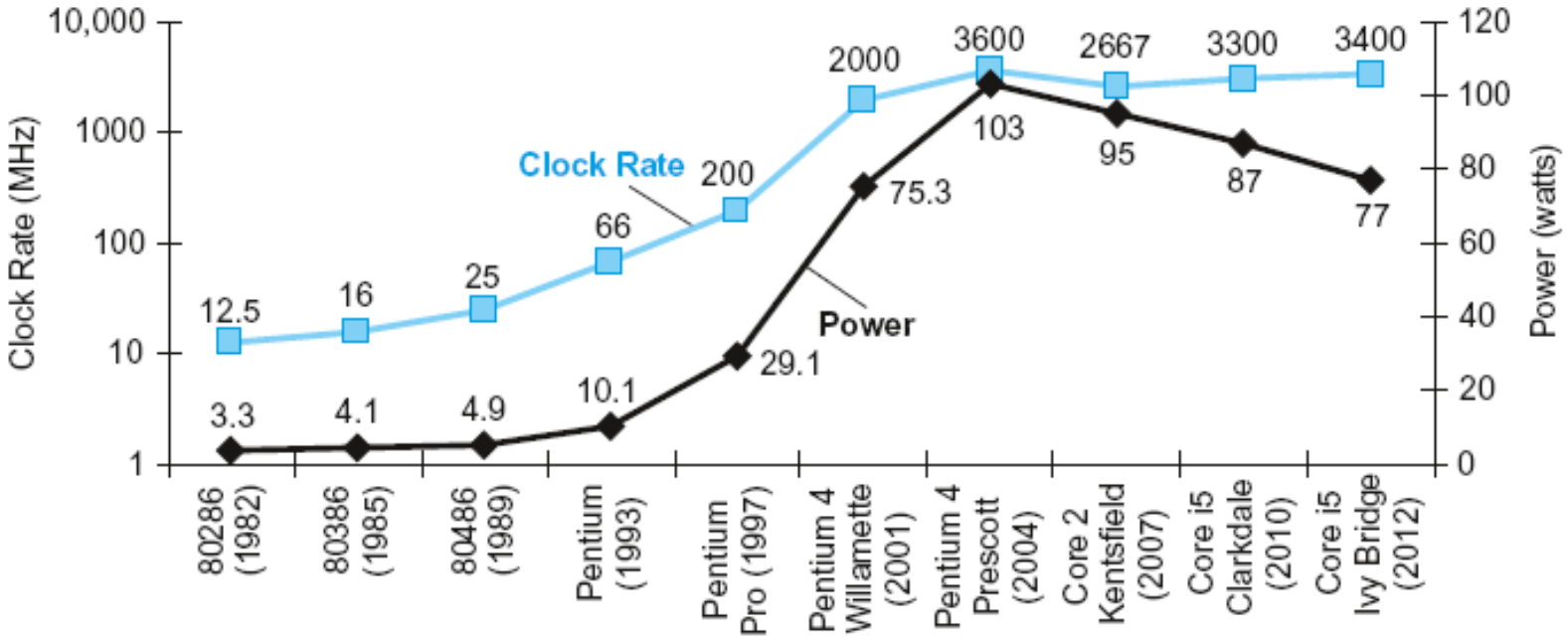


Power Trends

In CMOS IC technology

$$\text{Power} = \text{Capacitive load} \times \text{Voltage}^2 \times \text{Frequency}$$

×30 | 5V → 1V | ×1000



The power wall!

Multiprocessors

The power wall:

- can't reduce voltage further
- can't remove more heat

How else can we improve performance?

➥ Multicore microprocessors

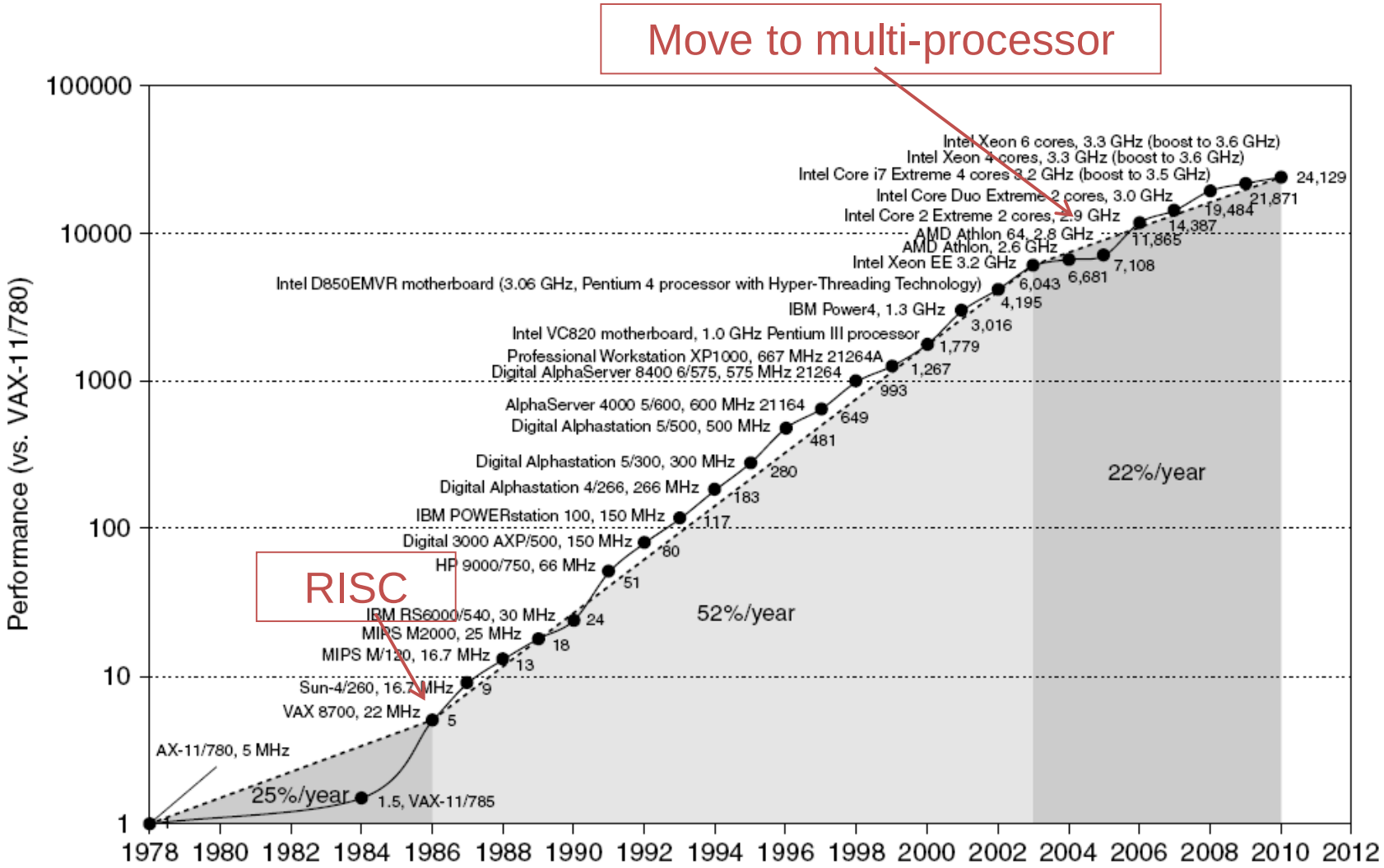
- More than one processor per chip

New paradigm!

Requires explicitly parallel programming:

- Compare with instruction level parallelism
  - Hardware executes multiple instructions at once
  - Hidden from the programmer
- Hard to do
  - Programming for performance
  - Load balancing
  - Optimizing communication and synchronization

Processor Performance



Trends in Technology

- Integrated circuit technology
  - Transistor density: 35%/year
  - Die size: 10-20%/year
  - Integration overall: 40-55%/year
- DRAM capacity: 25-40%/year (slowing)
- Flash capacity: 50-60%/year
  - 15-20X cheaper/bit than DRAM
- Magnetic disk technology: 40%/year
  - 15-25X cheaper/bit then Flash
  - 300-500X cheaper/bit than DRAM

Bandwidth and Latency

- Bandwidth or throughput
  - Total work done in a given time
  - 10,000-25,000X improvement for processors
  - 300-1200X improvement for memory and disks

- Latency or response time
  - Time between start and completion of an event
  - 30-80X improvement for processors
  - 6-8X improvement for memory and disks

What You Will Learn

- Architecture of current processors
  - Performance metrics
- Integrated view of the computer system
  - Memory hierarchy
  - Input/Output system
- How to improve program performance
- Features related to embedded systems
- What is parallel processing
- Future trends

Teaching Staff

Theoretical lectures:

Alberto Cunha

alberto.cunha@tecnico.ulisboa.pt Sub:[OC] …

Practice/Lab classes:

David Martins

Course email:

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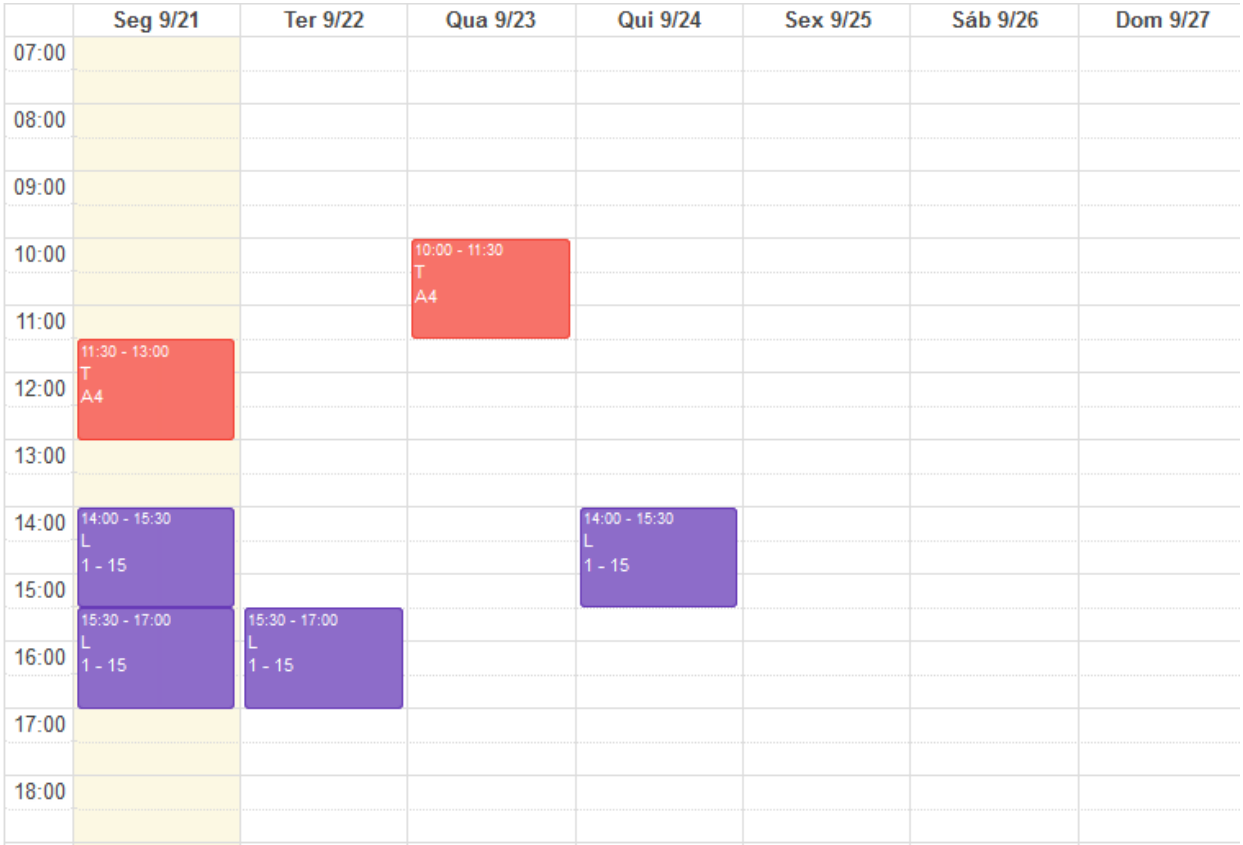
Class Schedule



- L shifts are currently almost full.
- We are waiting for indications from the Taguspark management (more capacity and, possibly, other rooms → check OC page).

Grade assessment

Final grade = 50% x Exam + 24% x Labs + 26% x Exercises

- Exam = max(Ex_1, Ex_2) , Min. grade = 7
- Labs = (L1 + L2 + L3) / 3 , Min. grade = 9
- Exercises = (∑ 5 best P_i) / 5 , Min. grade = 9

Exam (50%):

- 1st Exam: January 11, 9h30
- 2nd Exam: February 3, 15h00
- minimum grade in the exam ≥ 7
- recovery exam can be used to improve grade (best grade used).

Grade assessment: Labs

Labs (25%)

- 3 lab works, 8% each
- groups of 3 elements (odd or even)
- lab grade defined individually at the oral discussions
- minimum grade of 9
- can be reused from the last 2 years (2018/2019 and 2019/2020)

- Important dates (weeks):
  - Publication Lab1 & 2 : 12 Oct
  - Delivery of Lab 1 : 19 Oct
  - Publication Lab3 : 2 Nov
  - Delivery of Lab 2 : 9 Nov
  - Defense of Labs 1 & 2 : 16 Nov
  - Delivery of Lab 3 : 30 Nov
  - Defense of Lab 3 : 7 Dec

Grade assessment: Exercises

Exercises (25%)

- 6 exercises, counting the best 5
  - Starting from the 3rd practical class
  - Handwritten, 2 submissions by each student in the group
- groups of 3 elements (odd or even)
  - Does not have to be the same group as the one for the labs (but highly recommended)
    - Can be separate groups. especially for those that already have the grade for the labs (from the previous 2 years)
- the grade is defined individually at the oral discussions
  - 3 during the semester (each discussion will consider 2 exercises)
  - Zoom authenticated via IST, and with camera ON
  - Can be in-person, rather than remote
- minimum grade of 9
- All students must do it. (NEW. Exercises are not TPCs of 2019/20.)

Lectures

Theoretical lectures:

- Remote lectures via Zoom
  - Do use your cameras…
  - Lectures are interactive
- First 3 weeks
  - 1h30 lecture
- Following weeks
  - 1h00 lecture
  - 30 min exercise solving

Teaching logistics

Theoretical lectures

- Remote via zoom
  - With camera on, please!!
    - We need some visual feedback

Practice/Lab lectures

- Hybrid (in-person + zoom + discord)

David Martins

Bibliography

Main book:

Computer Organization and Design: The Hardware/Software Interface
D. Patterson, J. Hennessy
Morgan Kaufmann, 5th Edition, 2014, ISBN: 978-0-12-407726-3

Secondary Bibliography:

- *Structured Computer Organization*
  A. Tanenbaum, T. Austin
  Prentice-Hall, 6th Edition, 2013, ISBN: 978-0273769248

- *Embedded Computing: A VLIW Approach to Architecture, Compilers and Tools*
  J. Fisher, P. Faraboschi, C. Young
  Morgan Kaufmann, 4th Edition, 2005, ISBN: 978-1558607668

- *Computer Architecture: A Quantitative Approach*
  J. Hennessy, D. Patterson
  Morgan Kaufmann, 5th Edition, 2011, ISBN: 978-0123838728

Next Class

- Review of basic concepts on computer architecture
- Performance metrics

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