Systems Architecture = Understanding the Architecture and Organization of Modern Computer Systems

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Co-sponsored by:

NWO Netherlands Organisation for Scientific Research

STW connecting innovators

@Alosup

Prof. dr. ir. Alexandru Iosup

Is This Your Computer?

CPU Type	2 x Xeon E5-2687W V2
CPU Speed	3.4 GHz
M/board chipset	Asus Z9PE-D8 WS
Memory	8 x Kingston 16GB DDR3-1866
Video card	2 x MSI Radeon R9 295X2 8GD
Max. Res.	3840 x 2160 (4K, UltraHD)
HDD	10TB SSD 850Pro + 12TB SATA
Interface USB/FW	6 x SATA 6GBps, 2 x USB 3.0
Network wired	2 x Ethernet 1Gbps
Power supply	Corsair AX1500i + UPS

Source: http://arstechnica.com/gadgets/2014/08/ars-technica-system-guide-august-2014/5/

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A Digital Computer

CPU Type	Intel Core i7-7820HQ, 4-core
CPU Speed	2.9 GHz / Turbo 3.9 GHz
M/board chipset	76 Wh Li-Poly
Memory	16 GB DDR3L
Video card	Radeon Pro 560
Max. Res.	2880x1800, 16:10, 15.4”
HDD	512GB SSD
Interface USB/FW	HDMI2/T’bolt3, 4xUSB-C
Network wired	802.11, B’tooth.4, no Ethernet
Power supply	…

Source: https://tweakers.net/pricewatch/785979/apple-macbook-pro-2017-15-komma-4-inch-i7-2-komma-9ghz-512gb-ssd-zilver-(azerty)/specificaties/

Source: https://ark.intel.com/products/97496/Intel-Core-i7-7820HQ-Processor-8M-Cache-up-to-3_90-GHz

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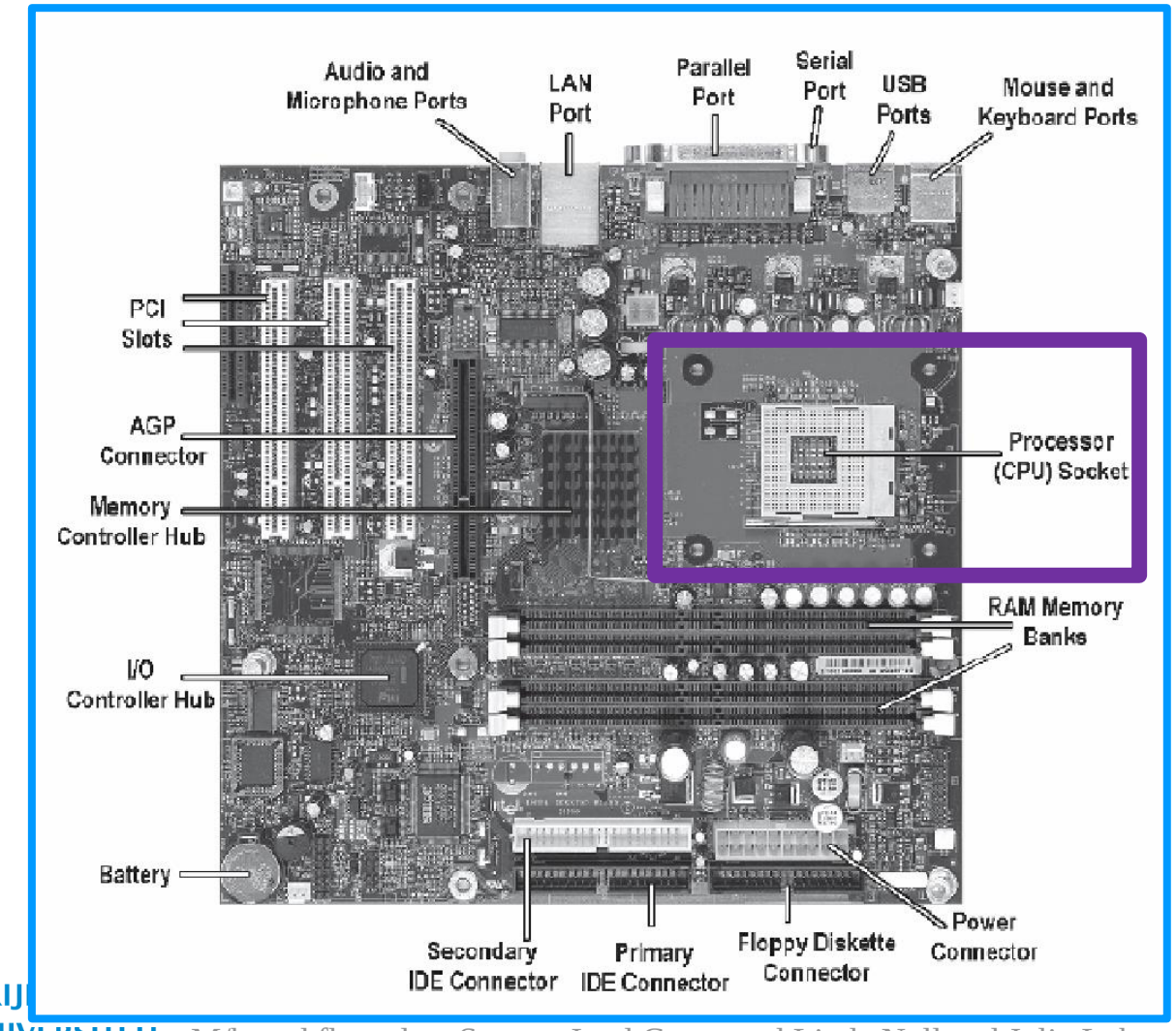
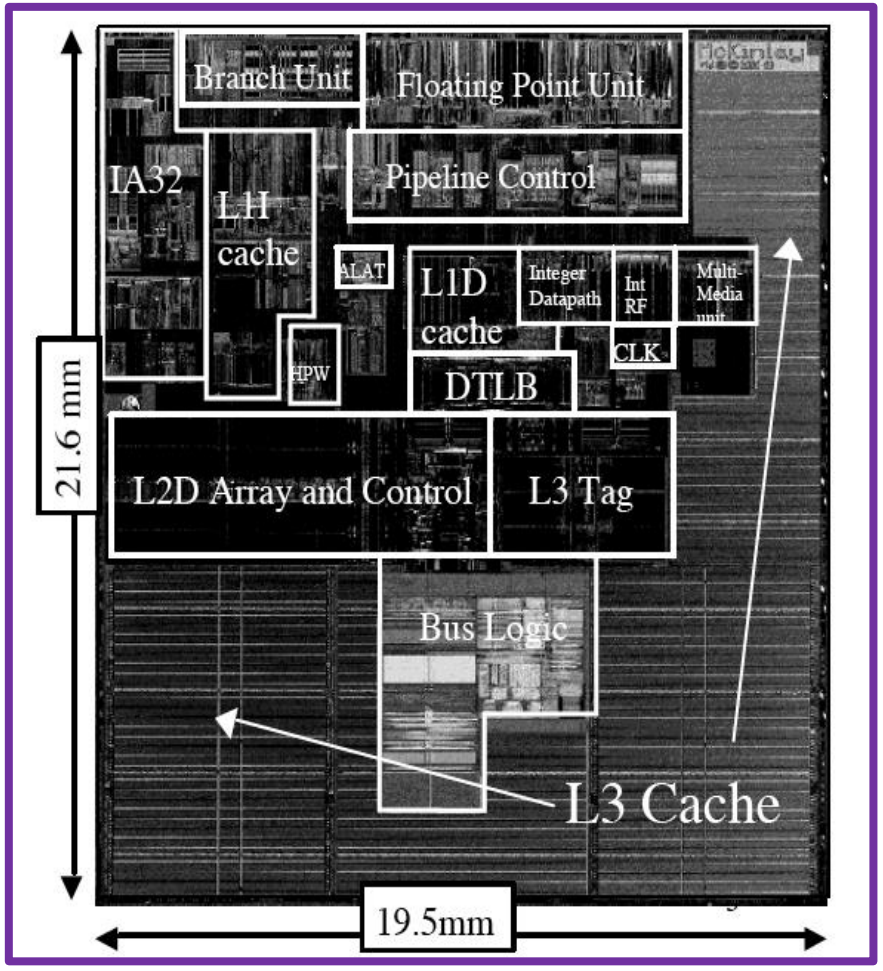
A Digital Computer

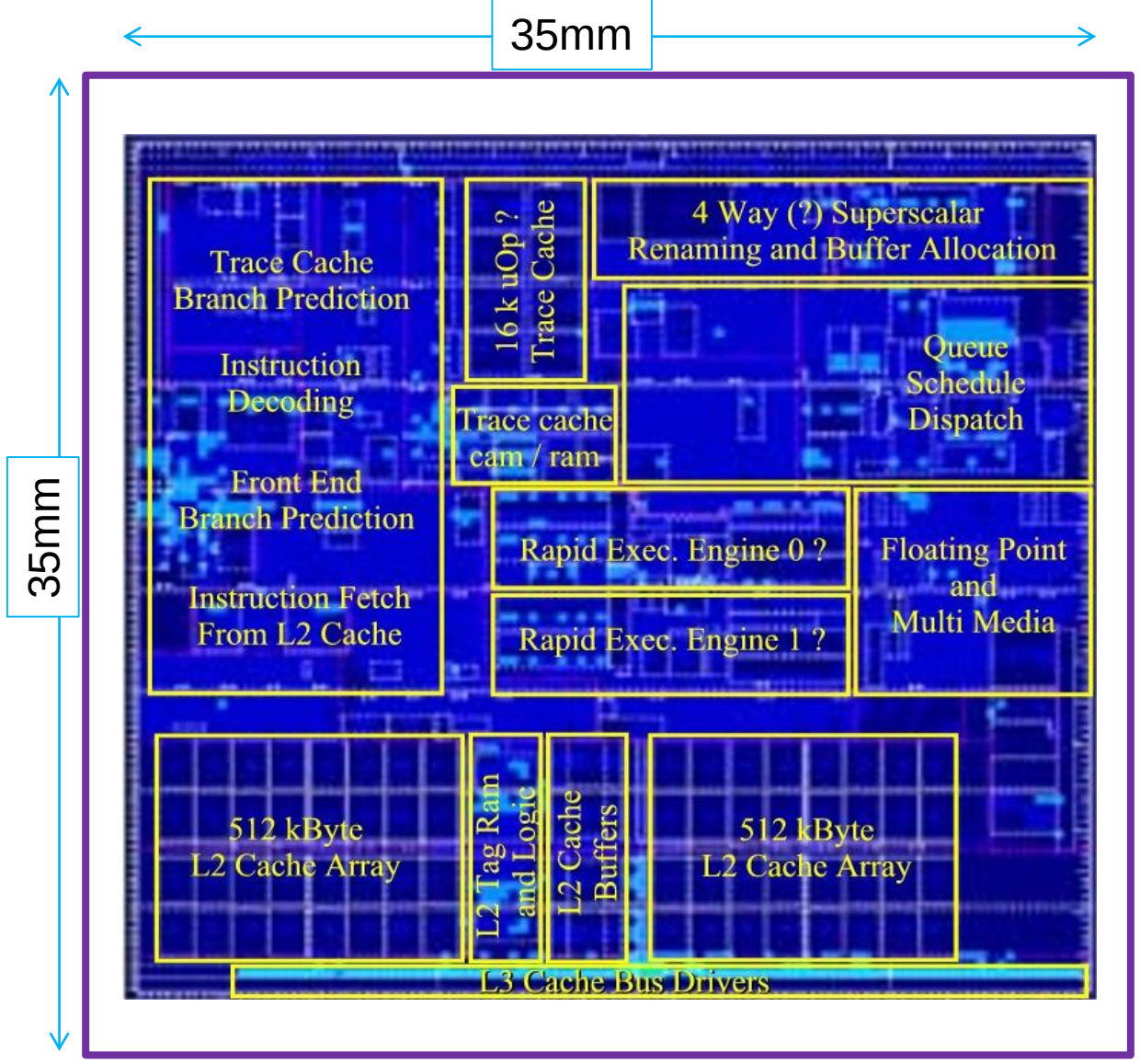


M/board floorplan. Source: Intel Corp., and Linda Null and Julia Lobur.

A CPU



IA-32 floorplan. Source: Intel Corp.



Intel P4 Prescott floorplan. Source: Intel Corp. and Hans de Vries for Chip Architect.

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Course Goals

"gain fundamental knowledge about the organization and architecture of computer systems"

- **Architecture** = the what? = all high-level design aspects
  - Lets programmers interact with the working system (instruction set)
  - Lets system designers explain what the system components should do
- **Organization** = the how? = all low-level design aspects
  - How to design and make the system components that implement an architecture
  - Circuits, memory types, signals, making things tick
  - From Instruction sets to opcodes, memory addressing, etc. ← lots of forward references

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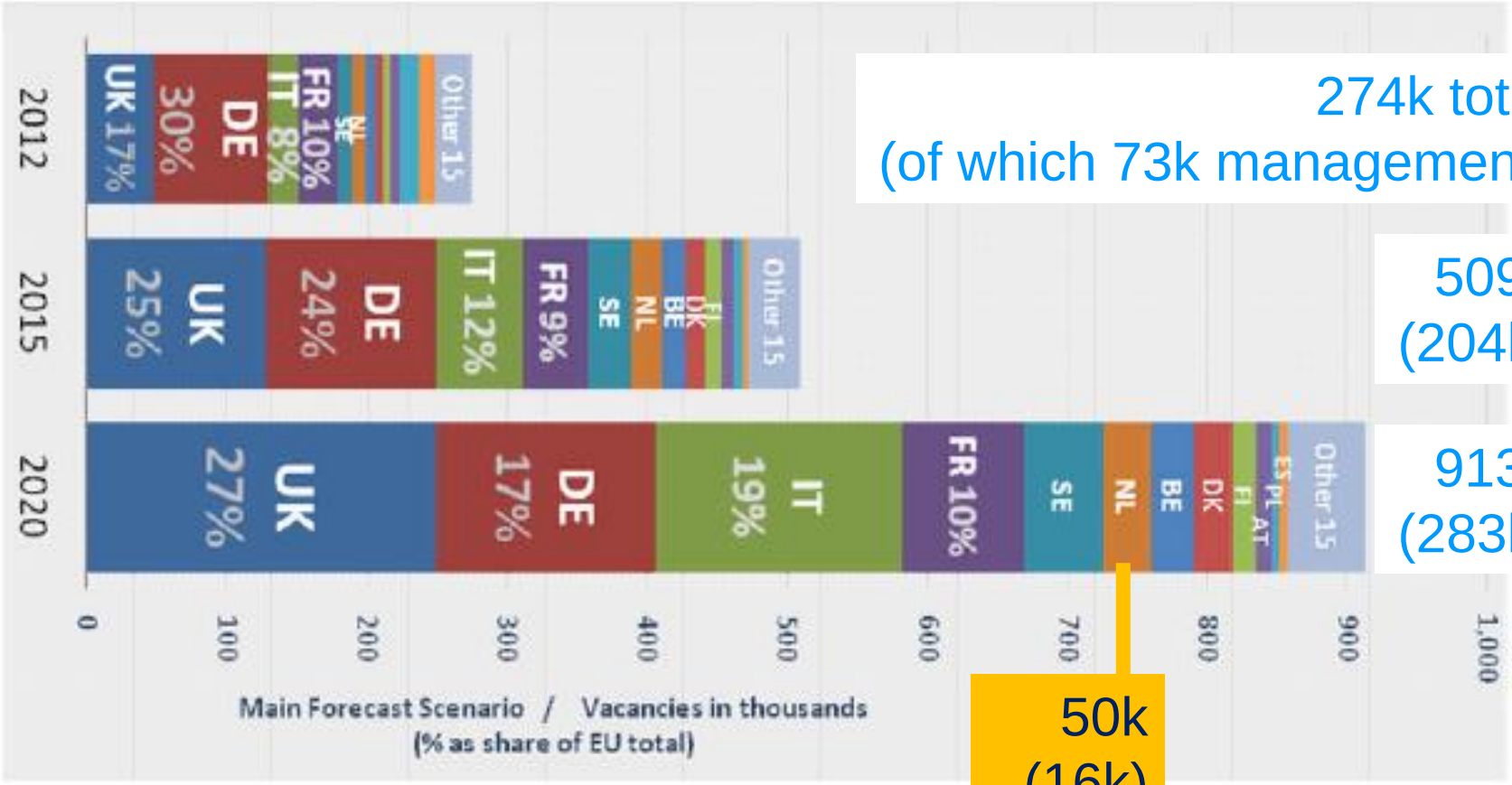
Why is Computer Organization Useful to You?

The Human Resource Gap



Source: e-Skills for Jobs in Europe – Measuring Progress and Moving Ahead (2014)
http://eskills-monitor2013.eu/fileadmin/monitor2013/documents/MONITOR_Final_Report.pdf

Why is Computer Organization Useful to You?

Know Thy Platform

- **Programming hot functions**
- **Programming optimized functions**
  - Linear algebra (BLAS)
  - Video, sound, and security codecs
  - Vertex and pixel shaders on GPUs
- **Building low-power devices (embed: $1Tn/2011)**
- **Real-time platforms**
  - Games, Simulations, Navigation systems, Medical equipment
- **Matching algorithm and platform:**
  - Improve performance up to a factor of 100
  - The art of assembly (Michael Abrash: Doom, Quake, …)

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Why is Computer Organization Useful to You?

Tuning the ATARI VCS (1977)

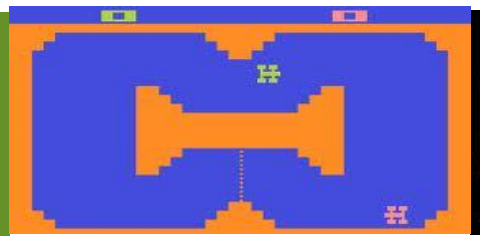
Home entertainment system

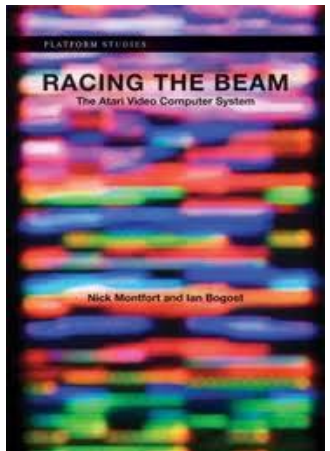
- Video, Sound, Games
- Pluggables: joystick, dance mat, …
- Today we use Wiis and Xbox and PS Pros

Ultra-low-cost platform

- **CPU**: MOS 6502 at **1MHz**
  low cost, low mem
- GFX, sound: **4 KB ROM** (max 8K)
- State, score: **128 bytes RAM**
  (Apple II had 4 *kilo*-bytes)
- RAM/Input/Output/Timer controller

"Any mistake in timing produced visual artifacts, a problem programmers called racing the beam."





Why is Computer Organization Useful to You?

Doom (1993)

"while I do take a lot of pride in shipping a great product, **the achievements along the way are more memorable**. I don't remember any of our older product releases, but I remember the important insights all the way back to using CRTC wraparound for infinite smooth scrolling in Keen (actually, all the way back to understanding the virtues of structures over parallel arrays in apple II assembly language…) **Knowledge builds on knowledge.**"
– John Carmack, .plan, Feb 1998

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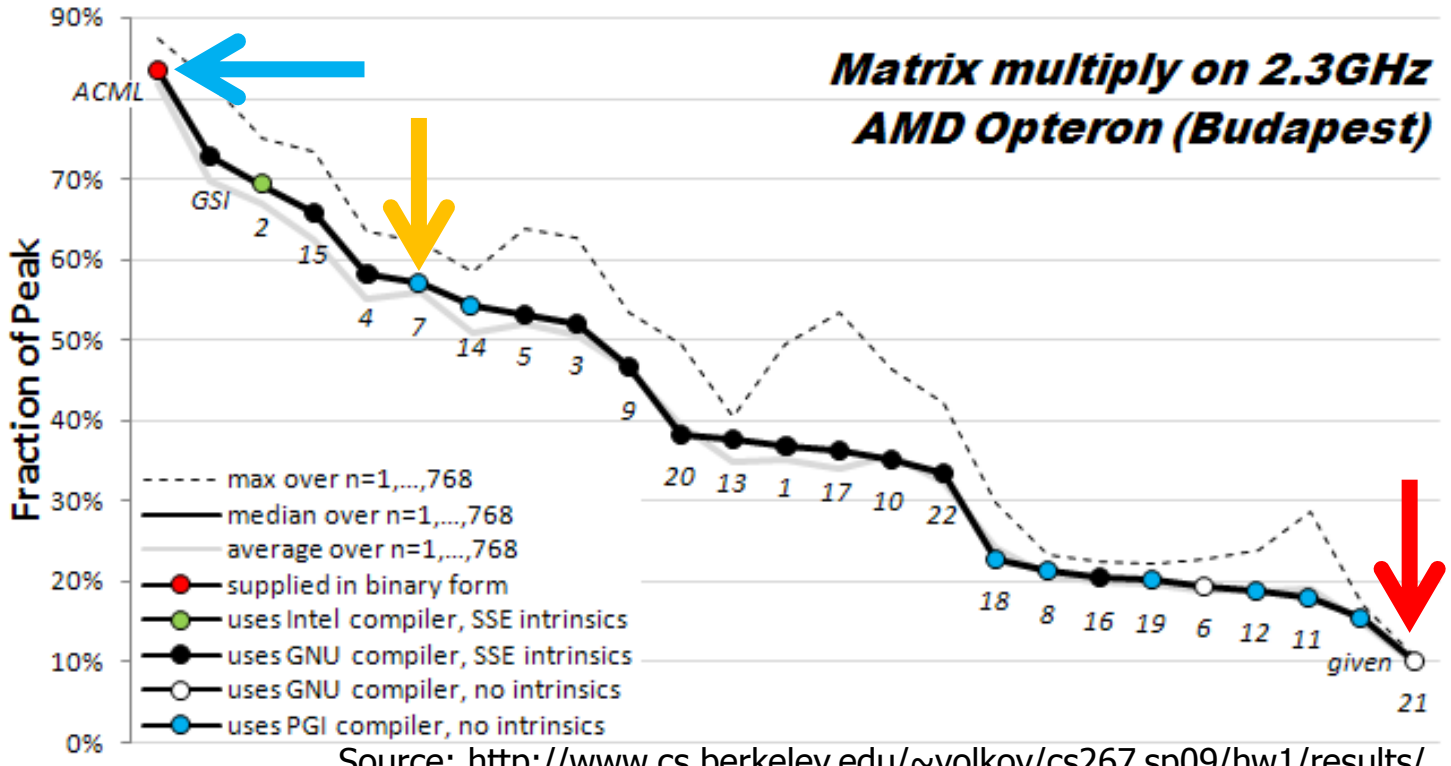
Why is Computer Organization Useful to You?

Optimization: Peak vs Real Performance

"One EC2 Compute Unit (ECU) provides the equivalent CPU capacity of a 1.0-1.2 GHz 2007 Opteron or 2007 Xeon processor." Amazon EC2

- Original code
  ~10% Peak
- w/o SIMD
  <60%
- ACML
  ~90%



Source: http://www.cs.berkeley.edu/~volkov/cs267.sp09/hw1/results/

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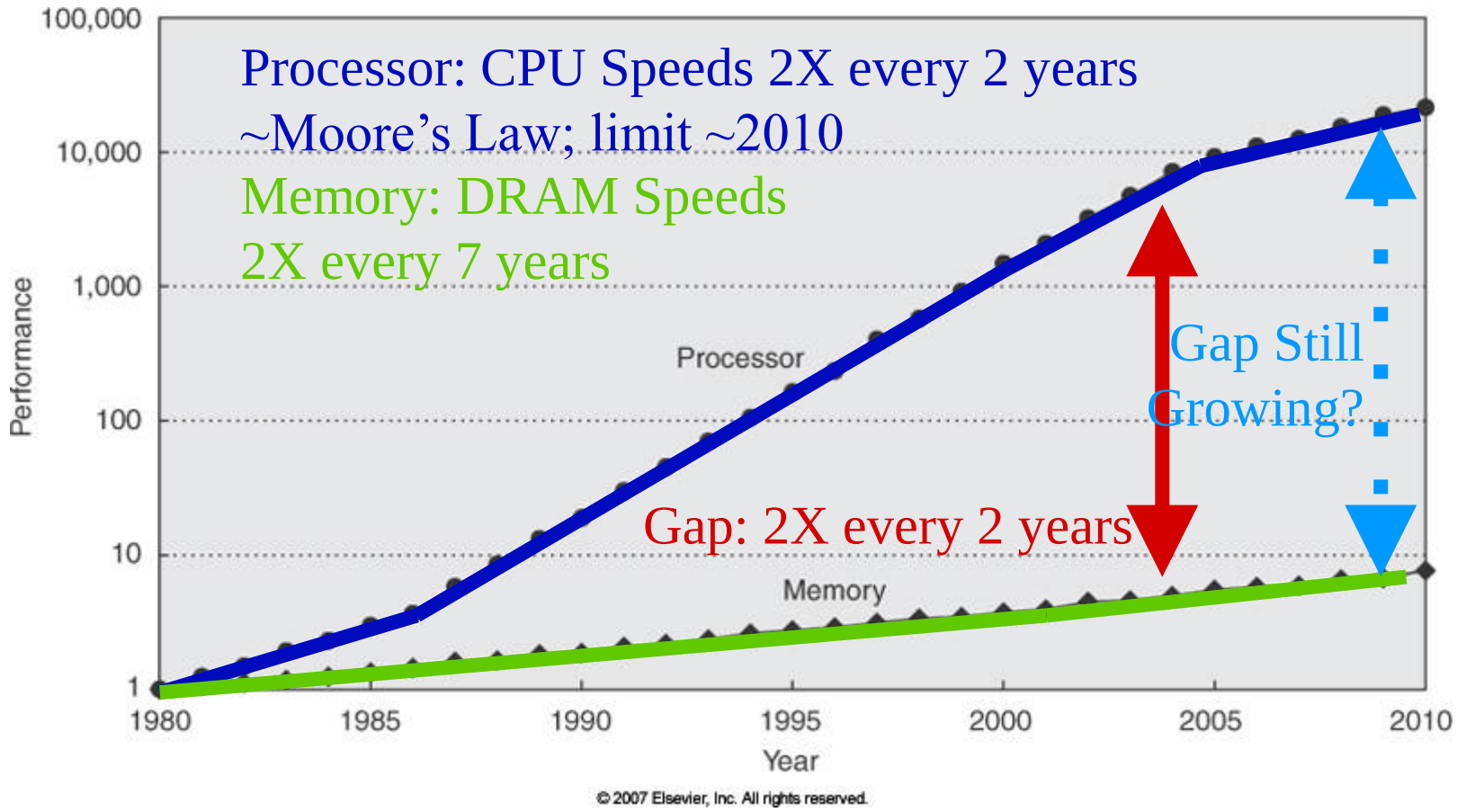
Why is Computer Organization Useful to You?

The Performance Gap Processor-Memory



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Energy Ceiling

Nov 2015: Over 500 YouTube videos have at least 100,000,000 viewers each.

Jun 2017: How many are there?

If you want to help kill the planet:
https://www.youtube.com/playlist?list=PLirAqAtl_h2r5g8xGajEwdXd3x1sZh8hC

PSY Gangnam consumed ~500GWh

= more than entire countries* in a year (*41 countries),
= over 50MW of 24/7/365 diesel, 135M liters of oil,
= 100,000 cars running for a year, ...

Source: Ian Bitterlin and Jon Summers, UoL, UK, Jul 2013.
Note: Psy has >3 billion views (Nov 2015).

Why is Computer Organization Useful to You?

New "Jevons Effect": More Efficient, Less Capable

The "Data Deluge"

Data Deluge =

data generated by humans and devices (IoT)

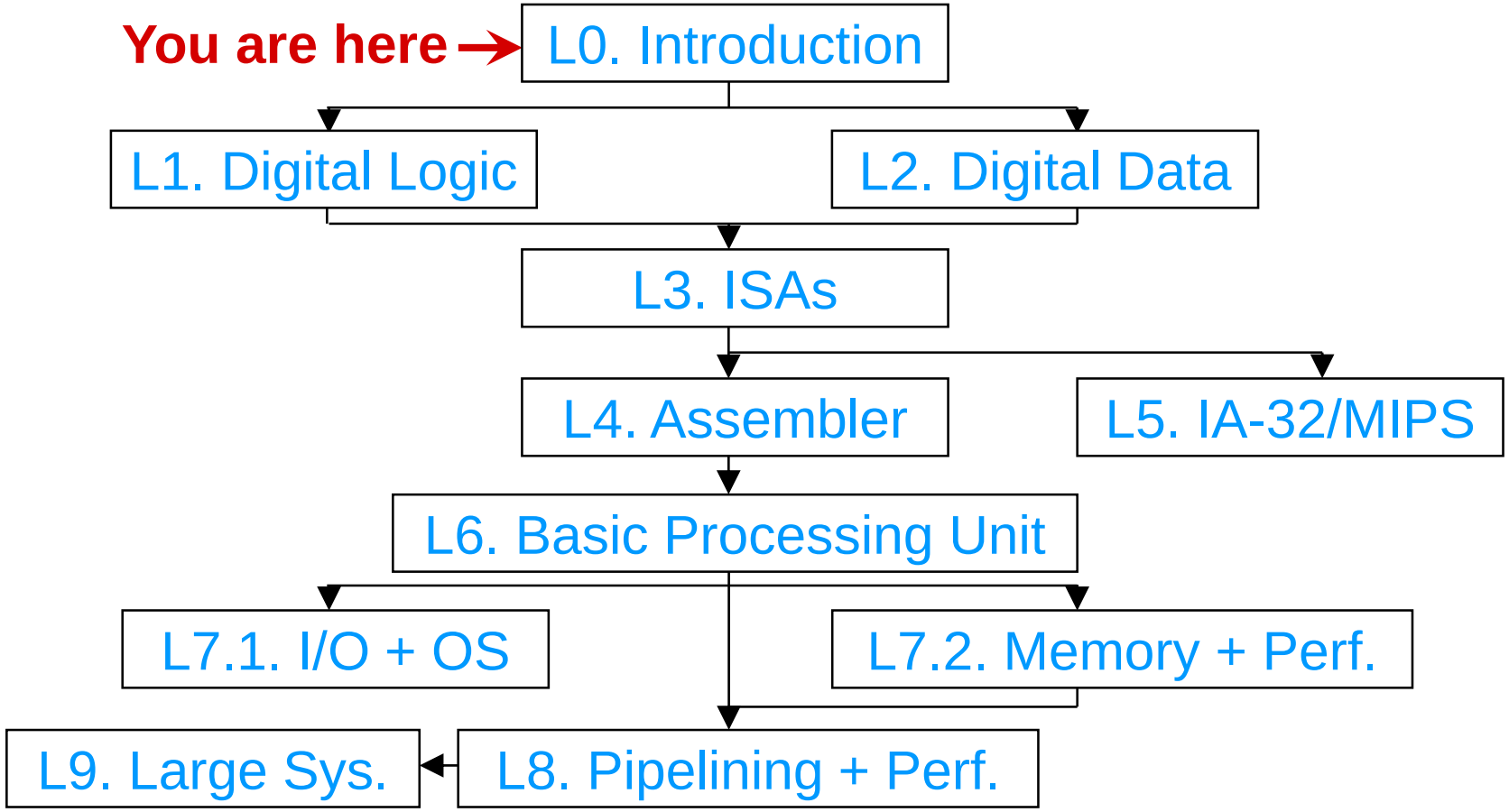
- Interacting
- Understanding
- Deciding
- Creating

To be capable of processing Big Data, need to address Volume, Velocity, Variety of Big Data*

* Other Vs possible: ours is "vicissitude"

Sources: IDC, EMC.

Conceptual Map of the Course



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Course Mapping to CS Curricula of ACM/IEEE and VU

- **Body of Knowledge: Architecture and Organization**

L1,L2	AR1. Digital Logic and Data Representation [core]	Week 44, 45, 46
L3-5	AR2. Computer Architecture and Organization [core]	Week 47, 48
L7.1	AR3. Interfacing and I/O Strategies [core]	Week 48
L7.2	AR4. Memory Architecture [core]	Week 49
L6	AR5. Functional Organization [core]	All but 49
L9	AR6. Multiprocessing [core]	Week 50
L8, all	AR7. Performance Enhancements [elective]	Week 49
L0, all	AR8. Directions in Computing [elective]	Week 44

- **VU: Programming Fundamentals, Operating Systems, Distributed Algorithms, Distributed Systems, Cloud Comp., ...**

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Course Material

- Textbooks
  - Check Canvas!

- Lectures, Tutorials
- Lab exercises
- Exemplary exams (when due)
  - Plenty of material not in the book!
  - All available on Canvas, after the session

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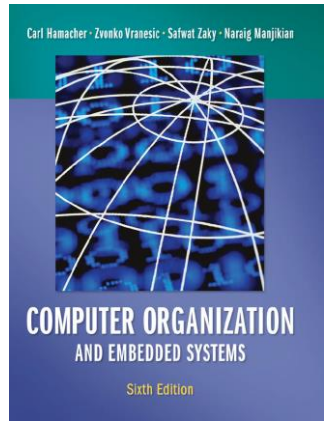
Material To Study+

V.C. Hamacher, Z.G. Vranesic, S.G. Zaky, Computer Organization, McGraw-Hill, 6th Ed., 2012.

Chapter 1	Complete
Chapter 2	Complete
Chapter 3	All but "An Example of …"
Chapter 4	No
Chapter 5	Complete
Chapter 6	All but 6.10
Chapter 7	7.1-3
Chapter 8	8.1-2, 8.4-7
Chapter 9	All but 9.2,9.5,9.6, *.*.*
Chapter 10	No
Chapter 11	No
Chapter 12	Complete

Mid-term
Final part
Not



Appendix A	All but A.5,A.11-12
Appendix B	No
Appendix C	No
Appendix D	No
Appendix E	No (Covered Lab)

+ Indicative, but not final. In-class slides also material.

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Recommended Time Allocation

	Lecture	Tutorial	Lab	Self-Study
1. Digital Logic	4h	1/2h	-	>10h
2. Data Repr./Processing	4h	1/2h	-	>10h
3. ISAs/Assembler	<6h	2h	8+16h	←
4. Basic Processing Unit	<4h	2h	-	>10h
5. I/O + OS Principles	2h	1h	-	>5h
6. Mem. + Performance	2h	1h	-	>5h
7. Pipelining + Perf.	2h	2h	-	>10h
8. Progr. Principles	<2h	-	4+8h	←
9. Parallelism/Distribution	2h	1h	-	>16h
History, Evolution	<1h	-	-	>10h
Total (6EC ~ 168h)	**<28h**	**14h**	**12+24h**	**>80h**

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Recommended Time Allocation

- Lectures

Week 44	45	46	47	48	49	50

  - From Week 44, 4 hours per week in-class, Tue + Thu
- Tutorial

Week 45	46	47	48	49	50

  - From Week 45, 2 hours/week, Wed
- Self-Study

Week 47	48	49	50

  - From Week 46, >6 hours/week, own mgmt. Find team in Week 44!
- Lab sessions

Week 48	49	50

  - From Week 47, 4 hours, Mon and Wed

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The Grading System
This Course Is Gamified

1. Course Points	2. Access Tokens	3. Brownie Points
10,000 for straight 10	Start with 1	
+1,000 **team** self-study		
+1,000 max lab. bonus/ex.	Bonus Lab assignments	Our team will bake brownies for *you*! (but not force you to eat them)
Lab and Self-Study, various		
+300 correct exam Q	Advanced topics (GPUs, clouds)	
+50 activity in Slide Error/ Lecture/Tutorial activity		
+50 correct end-lecture quiz	Discuss w Lecturer	
Up to 500 entry quiz	Rec. letter	

http://www.elanaspantry.com/brownies/

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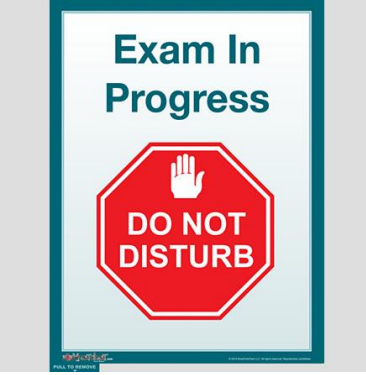
Mid-Term and Final Exams: Perfect 10 for Perfect Exam!



- **Week 47, Wed, Nov 22, 2017: mid-term exam, 10 Qs**
  - You can take the exam, but you do not have to
  - 3,000 points up for grabs
  - You can only win by taking the quiz!

- **Week 51, Fri, Dec 22, 2017: Final exam, 25 Qs**
  - 10 Qs overlap with mid-term exam, we use your best score
  - 15 Qs about new material
  - **Twice per academic year**
  - Old examinations will be found in due time on Blackboard (also, via material shared on other channels)

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Our Team

Laurens Versluis

Alexandru Uță

Alexandru Iosup

- Course coordinator
  - Prof. dr. ir. Alexandru Iosup
- Co-teachers
  - Prof. dr. ir. Alexandru Iosup
  - Dr. Alexandru Uță
- Teaching Assistants
  - Ir. Laurens Versluis, Ahmed Musaafir, et al.

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Entry Quiz

(closes after class)

- You choose if you want to do this quiz
  - Not mandatory
  - 500p at stake

The images used in this lecture courtesy of the Computer History Museum, Mountain View, California, USA, http://www.computerhistory.org/ ; the German Museum of Technology (Deutsches Technikmuseum Berlin, Germany, http://www.sdtb.de/Englisch.55.0.html ; the Science Museum, London, UK, http://www.sciencemuseum.org.uk/; and many anonymous contributors via Google Images. Many thanks!