CMSC 411: Computer Architecture

Spring 2024
Jason Tang

About Your Friendly Instructor

- Jason Tang (just call me Jason!)
- UMBC adjunct faculty member since 2012
    - Taught CMSC 104, 202, 411, and 421
- Work full-time at a nearby mega-corporation as a software engineer

Contact Information

- Email me at jtang@umbc.edu
- Office in ITE 353
  - Tuesday / Thursday, 4:30 pm - 5:30 pm, right before class
- Teaching Assistant:
  - TBA

Am I in the Right Class?

- Prerequisites are:
  - CMSC 313, or
  - CMPE 212 + CMPE 310
- Must be able to read hexadecimal notation
- **Should already by familiar with C/C++ and some assembly code**
  - This does not mean Java, Python, or other scripting language

Required Programming Knowledge

- Able to (or research on Stack Overflow how to) do these things:
    - Read the very fantastic man pages
    - Call a function and pass values in and out
        - Difference between an *in parameter*, *out parameter*, and *in/out parameter*
        - Know what a C++ *reference* technically is
- Understand basic boolean logic

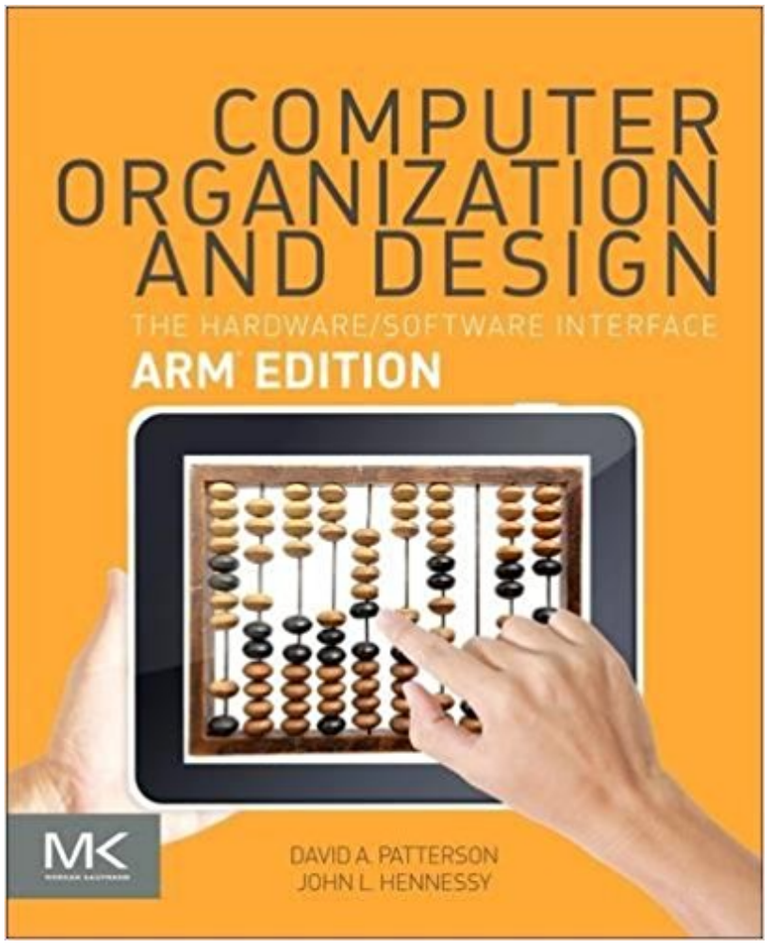
Topics Covered

- Instruction Sets
- Performance Measurements
- Machine Arithmetic
- Processor Design
- Memory Systems
- I/O and Peripherals
- Parallel Processing

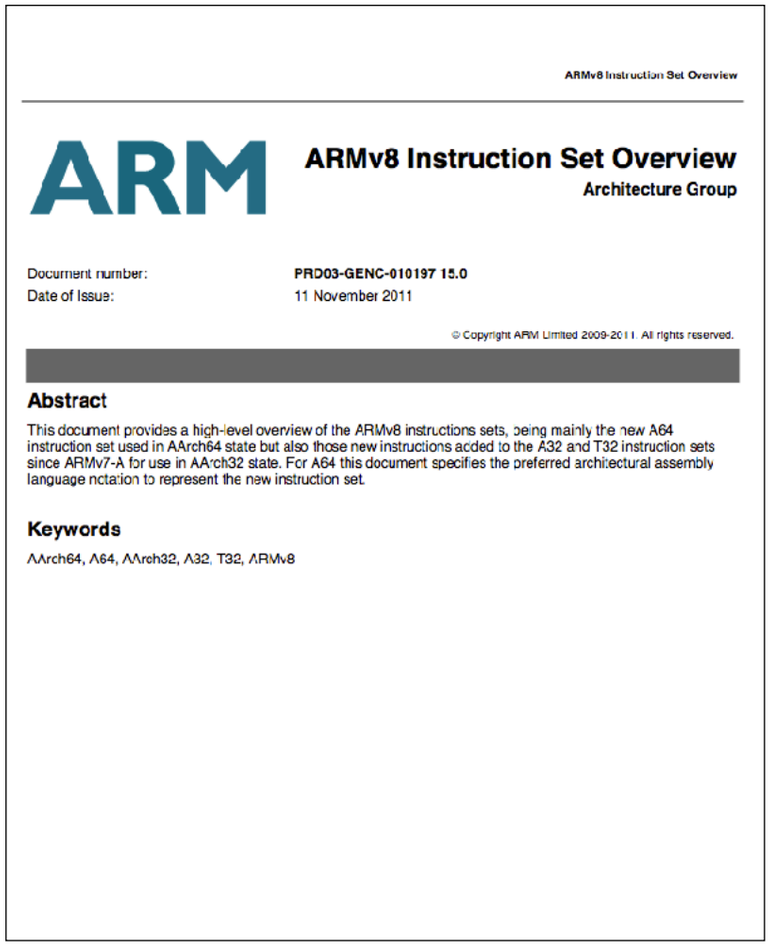
Course Information

- https://redirect.cs.umbc.edu/~jtang/cs411.s24/index.html
- Grades will be posted on Blackboard
- Discussion forums are also on Blackboard
- All assignments submitted via *submit* system at linux.gl.umbc.edu
  - Ensure you have a way to transfer files between your development machine and UMBC server (scp, PuTTy, ForkLift, or equivalent)
  - Using the clipboard to transfer data **will not work**

Textbook / References



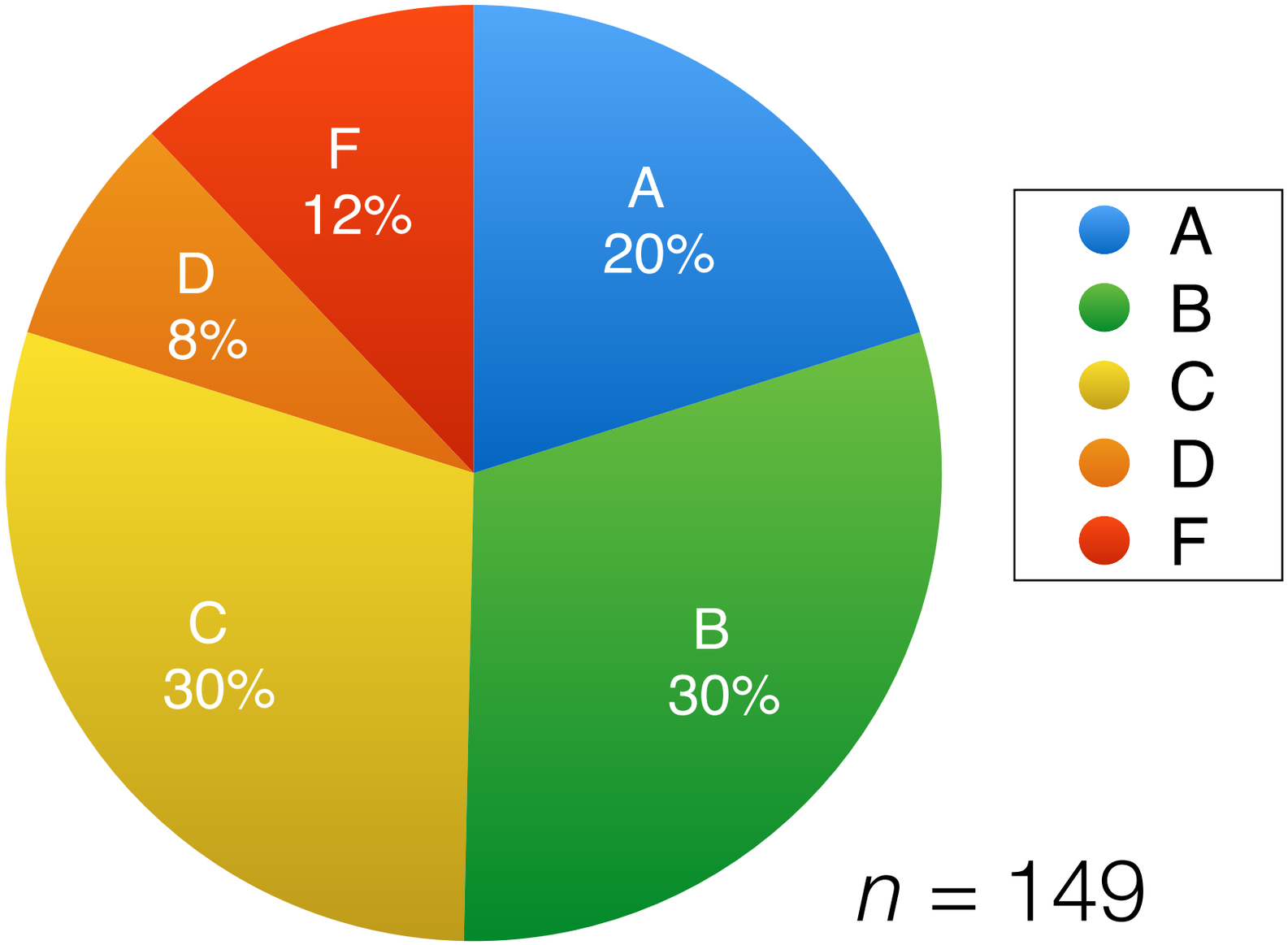
Highly Recommended:
Computer Organization and Design: ARM Edition



Reference:
ARMv8 Instruction Set Overview

Reference:
wiki.OSDev.org

Historical Grade Distributions



$n = 149$

Includes 5 academic misconducts

Grading Criteria

Homework	28% (4 each at 7%)
Project	22% (2 each at 11%)
Midterm	30% (2 each at 15%)
Final	20%

Homework and Project Assignments

- All assignments are *individual* efforts
- Due at 11:59:59 pm
  - **Assignment submission is disabled automatically at ten seconds past midnight**
  - **This is strictly enforced by the submit system**
- Neatness counts! Code must be properly indented, functions documented, good variable names chosen. All grading criteria include a “style” portion. You **will** lose points for sloppiness.

Late Policy

- **Once per semester**, you may submit an assignment late by emailing the required files directly to the **instructor** (not the TA)
    - You will receive an automatic 20% late penalty deduction
    - This late submission must be received **within 8 hours** following the deadline
- **Subsequent late submissions** will be rejected by both the instructor and the TA

Exams

- **Midterm 1** is Wednesday, February 28, during normal lecture time
- **Midterm 2** is Monday, April 8, during normal lecture time
- **Final** is Monday, May 20, starting at 6:00 pm

- No laptops, mobile phones, tablets, phablets, smart watches, …
- You will be provided a reference sheet for each exam
    - This reference sheet also will be posted on Blackboard a few days before each exam
- **All exams are open book / open notes**
- Study guides, with sample exam questions, are on the class website

Academic Integrity

- You *may* get help from friends, family, neighbors, Blackboard discussions, Wikipedia, Google, ChatGPT, etc., as long as:
    - You (and only you) end up doing the typing
    - You **document** all outside help at the top of your submission
    - You **do not claim credit** for someone else's work
- You *may* consult with the instructor, TA, AI systems, and other humans about the assignments
    - You **document** others with whom or thing you consulted

Other Legal Disclosures

- Students with documented disabilities may receive reasonable accommodations, such as extended test time or other support through the Office of Student Disability Services:
    - website: sds.umbc.edu
    - email: disability@umbc.edu
    - phone number: 410-455-2459
- Contact me to discuss accommodations

Other Legal Disclosures

- If you are impacted by sexual harassment, sexual assault, domestic violence, dating violence, stalking, sexual exploitation, gender discrimination, pregnancy discrimination, gender-based harassment, or related retaliation, you may file a report with the University Title IX Coordinator
    - titleixcoordinator@umbc.edu
    - 410-455-1717
- As a faculty member, I am considered a Responsible Employee, and must therefore report possible Title IX Policy violations
    - I am also required by law to report suspicions of child abuse or neglect

Other Legal Disclosures

- UMBC expressly prohibits all forms of discrimination and harassment on the basis of sex, including pregnancy. Resources for pregnant, parenting, and breastfeeding students are available through the University's Office of Equity and Civil Rights

- UMBC Policy provides that students should not be penalized because of observances of their religious beliefs, and that students shall be given an opportunity, whenever feasible, to make up within a reasonable time any academic assignment that is missed due to individual participation in religious observances

Initial Survey

- On Blackboard, go to Course Documents and take survey
    - Survey is ungraded and anonymous
    - Allows me to get a better understanding of the class's skills and motivations
- Survey closes at 11:59:59 PM on Saturday, February 10

Homework 1

- HW1 has been posted to the course website, and is **due** on Monday, February 12

- Introduces cross-compilation process

- Write a small mixed C and assembly program

- Will take several hours (some of it unattended)

Lecture 1: Introduction

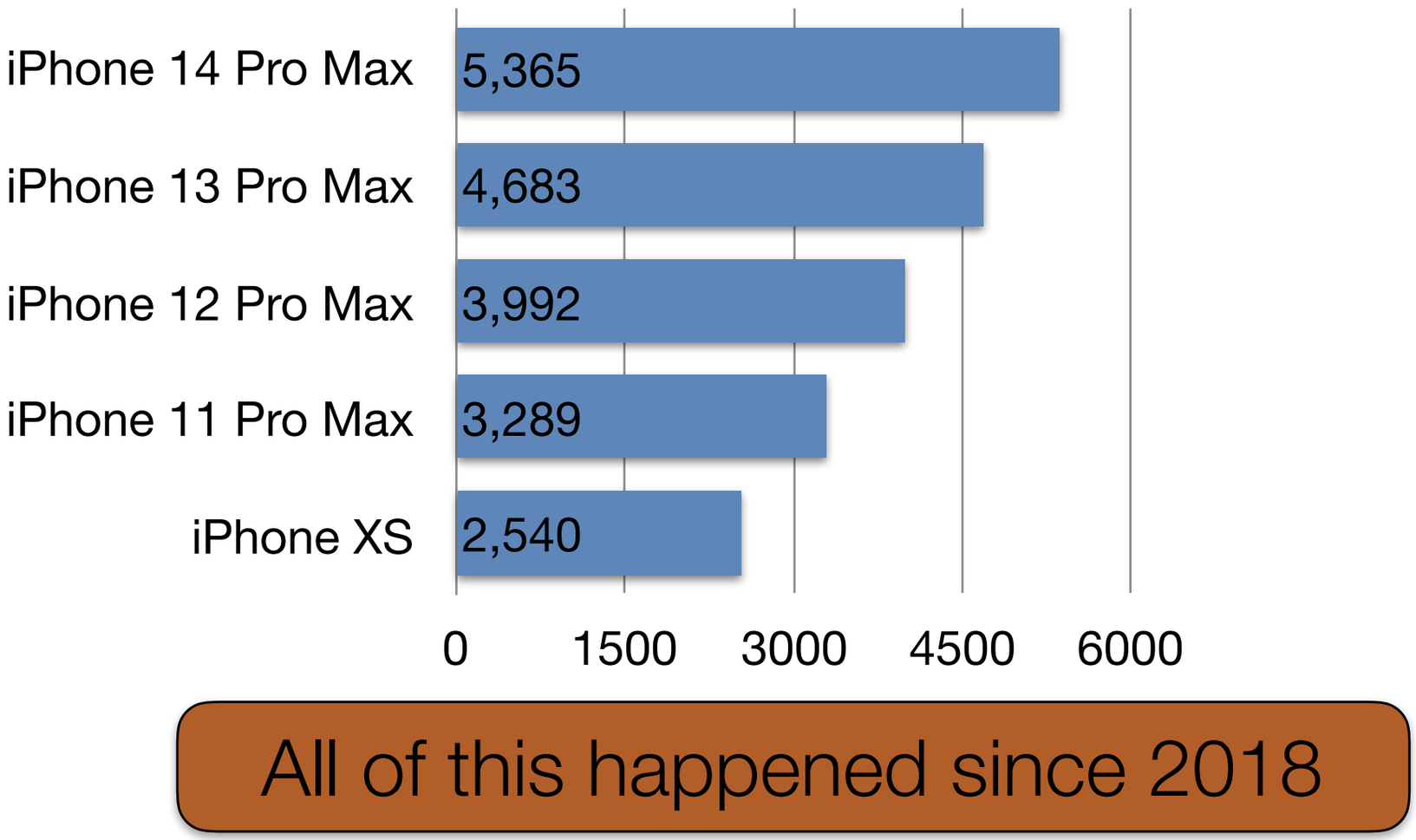
Spring 2024
Jason Tang

Topics

- What is computer architecture
    - Instruction set architecture
    - Machine organization
- Historical perspective

Why is Computer Architecture Important?

- Advances in computer hardware have made modern computing possible:



All of this happened since 2018

Chart based upon https://browser.geekbench.com/ios-benchmarks/#multi-core

What is Computer Architecture?

- Instruction Set Architecture: Functional behavior of a computer system as viewed by a programmer
  - Interfaces
  - Compiler/System View
  - “How many bits are in an `int`?”
- Machine Organization: Structural relationships of components within
  - Layout of components and buses
  - Logic Designer’s View
  - “What’s the penalty for a pipeline stall?”

Instruction Set Architecture

- Distinguishes semantics of the architecture from its detailed hardware implementation
- Organization of programmable storage (registers, RAM, I/O)
- Data types and structure, encoding
- Instruction set
- Address modes
- Exception handling

Examples of ISAs

Architecture	Year Introduced	Data Size (in bits)	Endianness
x86	1978	16/32/64	Little
MIPS	1981	32/64	Big/Bi
ARM	1983	32 (mostly)	Little/Bi
PowerPC	1991	32/64	Big/Bi
RISC-V	2010	32/64	Little
ARMv8-A	2011	64 (mostly)	Little/Bi

- Abstraction that hides details and complexity of the hardware

- Allows for binary compatibility of software within a computing family

ARMv8-A ISA Register Summary

- Architecture name is “ARMv8-A”, its ISA is named “AArch64”
- 31 general purpose registers (GPRs):
  - 32-bit form: `w0–w30`, 64-bit form: `x0–x30`
- 32nd register is special “zero” register (`wzr` / `xzr`) or stack pointer (`wsp` / `sp`)
- Separate register file for floating point registers
- Program counter cannot be directly set, but is read by **`adr`** instruction and updated via branch instructions

Programmer’s Guide for ARMv8-A, §4.1

Machine Organization

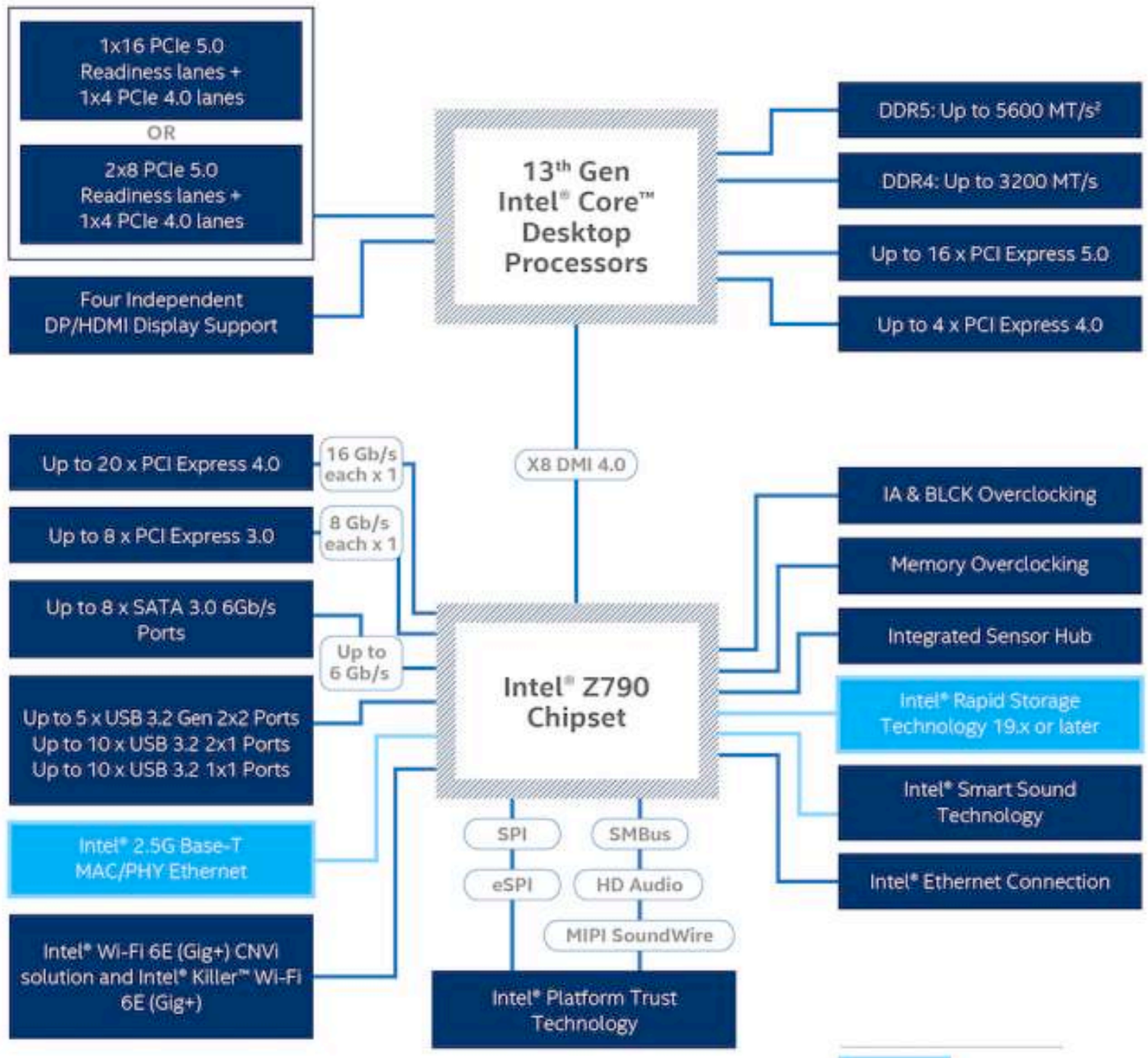
- Capabilities and performance characteristics of principal functional units (registers, ALU, shifters, logic units, etc.)

- Interconnects between components

- Information flow between components

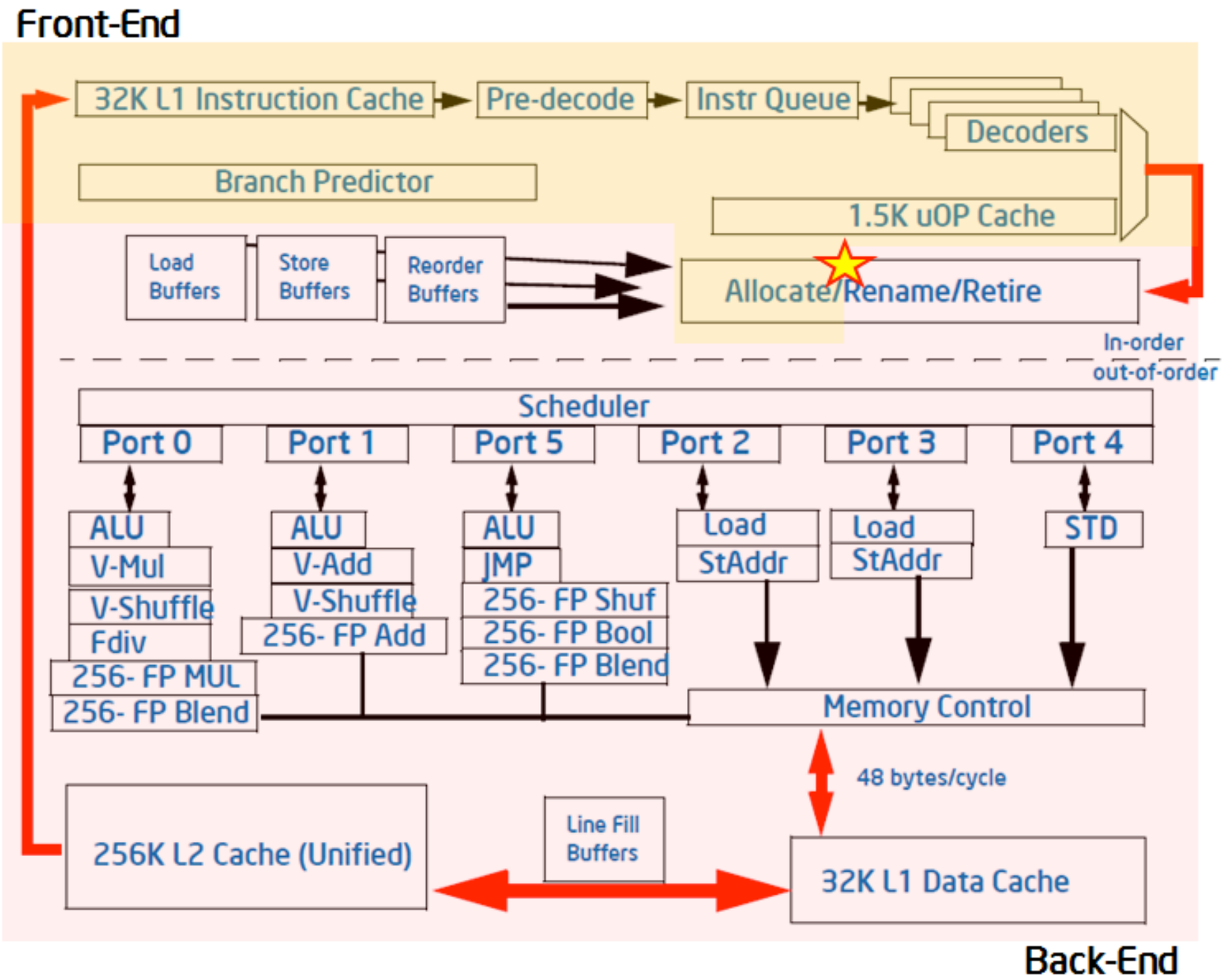
- Register transfer level description

Modern Intel Organization



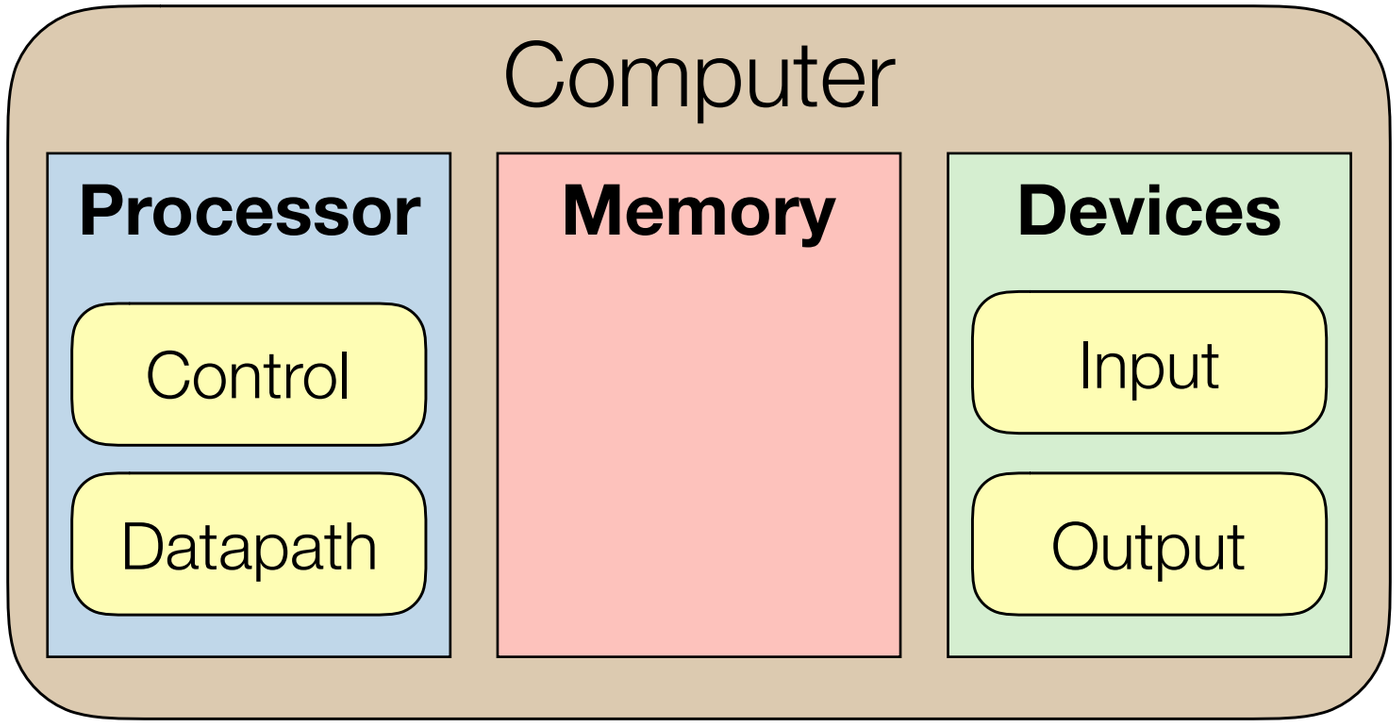
https://www.intel.com/content/www/us/en/products/docs/chipsets/desktop-chipsets/z790-chipset-brief.html

Modern CPU Pipeline



https://www.intel.com/content/www/us/en/docs/vtune-profiler/cookbook/2023-0/top-down-microarchitecture-analysis-method.html

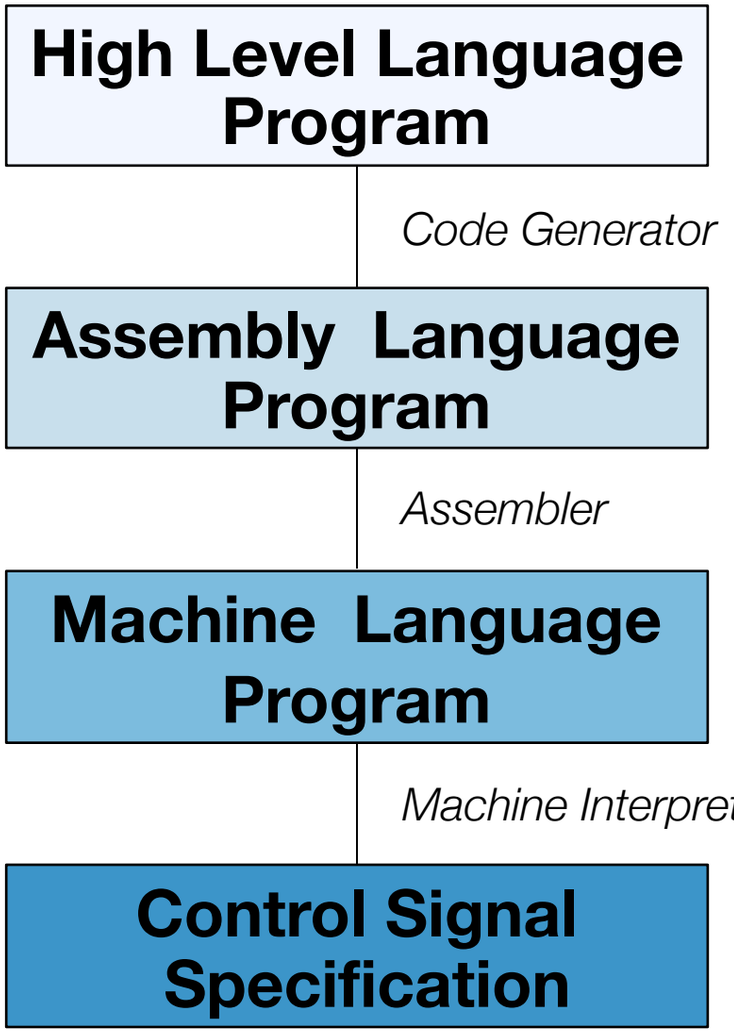
General Computer Organization



- Every part of a computer can be categorized as one of the above

- Design approach based upon necessary capabilities / cost / physical constraints (SWaP)

Levels of Behavior Representation



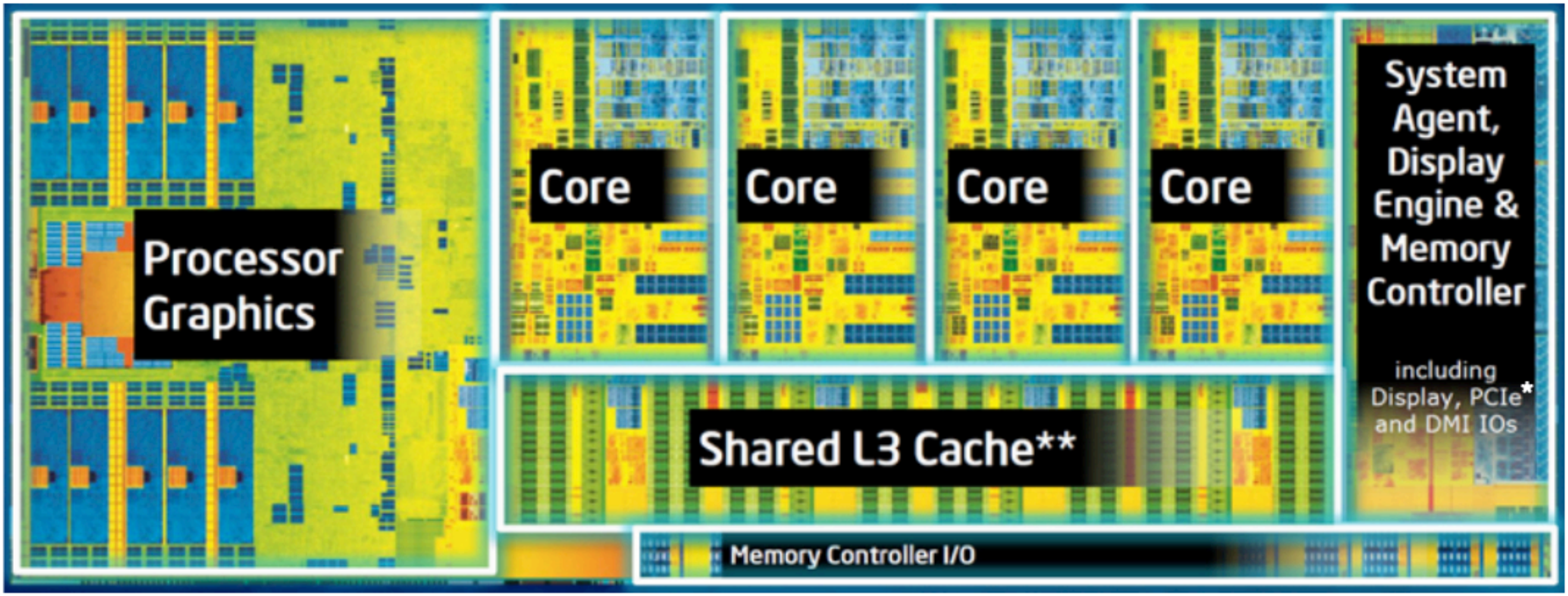

```
temp = v[k];
v[k] = v[k+1];
v[k+1] = temp;
```

```
lw  %15, 0(%2)
lw  %16, 4(%2)
sw  %16, 0(%2)
sw  %15, 4(%2)
```

```
0000 1001 1100 0110 1010 1111 0101 1000
1010 1111 0101 1000 0000 1001 1100 0110
1100 0110 1010 1111 0101 1000 0000 1001
0101 1000 0000 1001 1100 0110 1010 1111
```

ALUOP[0:3] <= InstReg[9:11] & MASK

Intel Core i7 Internal Die



https://www.intel.com/content/dam/www/public/us/en/documents/white-papers/ia-introduction-basics-paper.pdf

Changes in Computing Technology

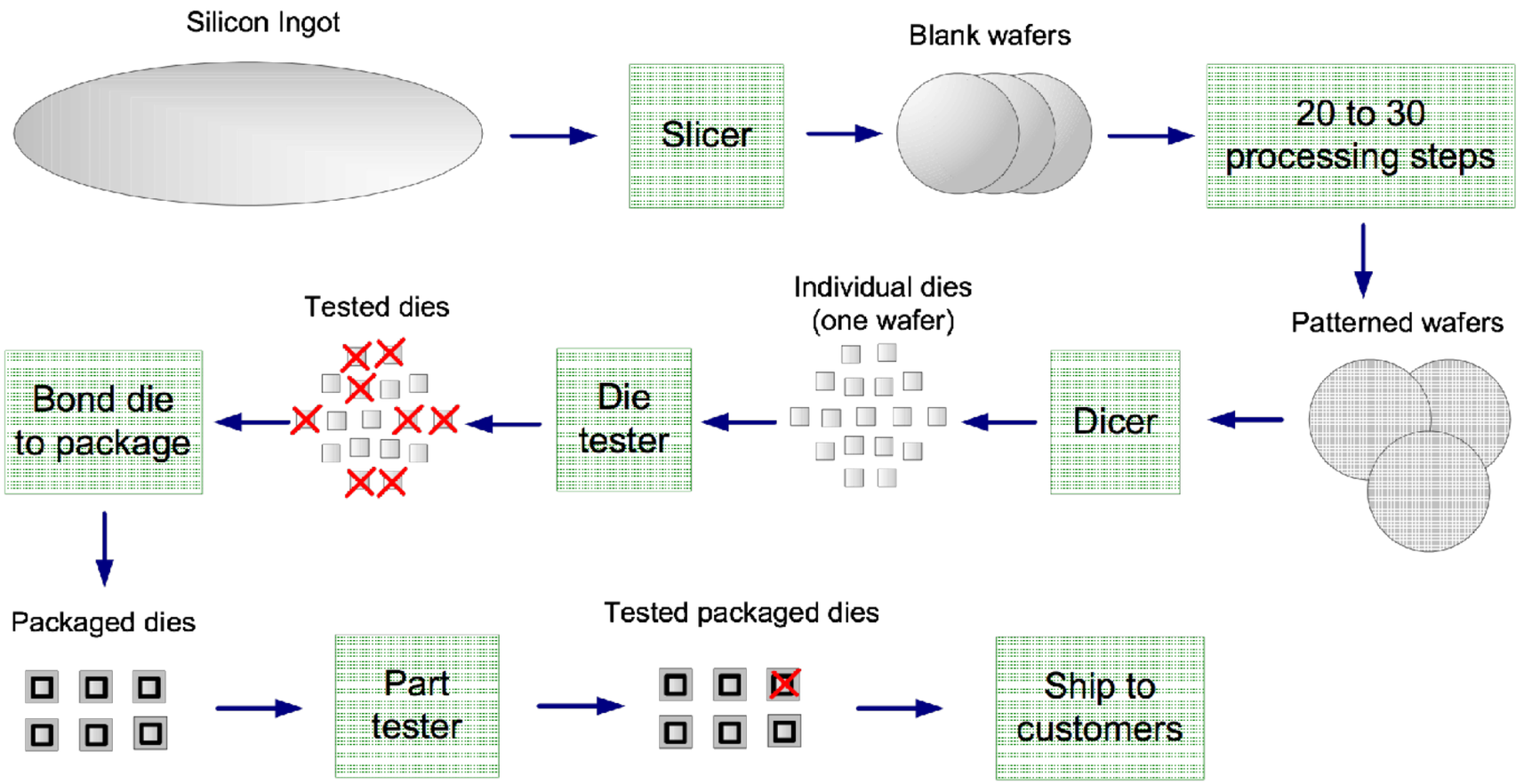
- Processor: Improved pipelining and caching
  - Logic capacity: +30% per year
  - Clock rate: +20% per year
- Memory: Programs no longer size limited
  - DRAM: +60% per year
  - Memory access: +10% per year
- Storage: Lighter and more power efficient
  - Capacity: +60% increase per year

Integrated Circuits

- Manufacturing a chip (currently) begins with silicon
- Silicon does not conduct electricity well:
    - Can chemically transform it to be a conductor or to be an insulator
- Transistor is an on/off switch that controls electricity

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
2005	Ultra large scale IC	6,200,000,000

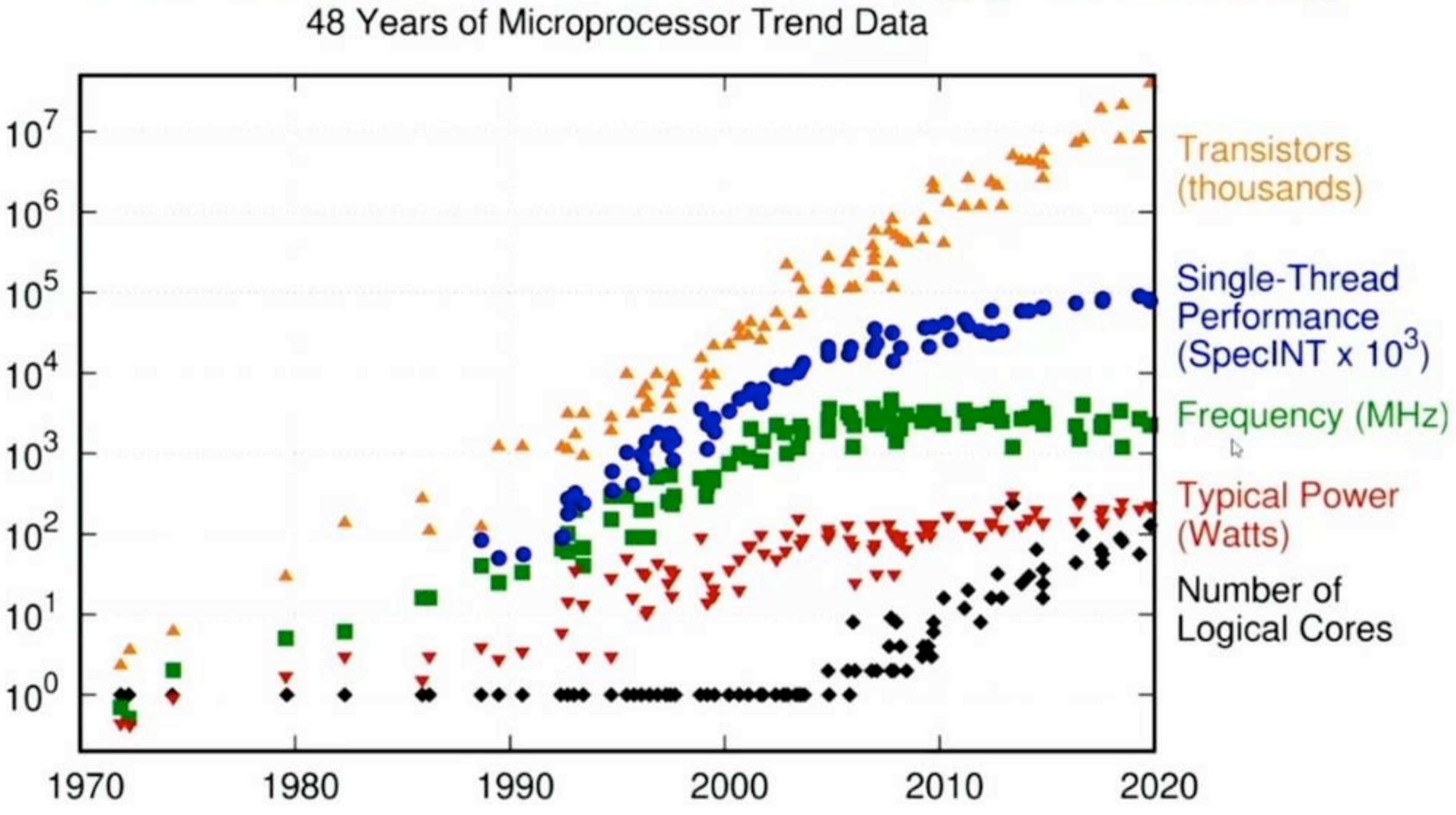
Microelectronics Process



- Silicon ingot are 6-12 inches diameter, 12-24 inches long

- Impurities in wafer lead to defective devices and reduces yield

Moore's Law



https://www.datacenterknowledge.com/supercomputers/after-moore-s-law-how-will-we-know-how-much-faster-computers-can-go