What is computer architecture?
Why study computer architecture?
Common principles
What is Computer Architecture?
What is Computer Architecture?

Instruction set architecture (ISA)
- Interface between hardware and software
- Instructions visible to programmer
  - e.g., Intel IA32 vs. Intel 64 (x86-64); ARM v7 vs. ARM v8 vs. v9; RISC-V

Organization or Microarchitecture
- High-level aspects of the system design
  - e.g., functional units, pipeline organization, cache/memory hierarchy, cores, accelerators, interconnect, chiplets, …
  - e.g., AMD Ryzen ThreadRipper PRO vs. Intel Core i9;
    ARM Cortex-A710 vs. Cortex-A715

Implementation or hardware
- Logic design, packaging, …
  - e.g., AMD Ryzen 9 5980HX vs. 5980HS (3 vs. 3.3 GHz base clock)
Previously, Computer Architecture ~ ISA

Instruction set architectures
Most ISAs today are general-purpose register based
Operands may be registers or memory locations
Register-memory vs. load-store
Addressing modes
Register, immediate, displacement, …
Operand sizes
8 bits, 16 bits, 32 bits, 64 bits, SP and DP FP
Operations: Arithmetic, memory, control flow, floating point
Encoding: fixed vs. variable length
Evolution of ISAs
Pre-1980s: lots of action $\rightarrow$ CISC vs. RISC wars $\rightarrow$ 2 to 3 decades of (almost) stability $\rightarrow$ new questions again
Our main focus: organization
Goals of the Computer Architect
Goals of the Computer Architect

Depends on type of computer
  Internet of things (IoT) / embedded / wearables / AR/VR
  Personal mobile device
  Desktop
  Server
  Cluster/warehouse-scale
  Supercomputer
**Goals of the Computer Architect**

Functional goals
- Meet application area demands
- Compatibility with previous systems
- Standards (e.g., IEEE floating point)
- Last through trends

Performance: Latency, throughput, real-time constraints, scalability, quality of experience

Cost
- Power, Energy, Temperature, …

Dependability

Security

Maintainability, Verifiability, …’ity…

Need to be familiar with design alternatives and criteria for selecting among them
Why Study Computer Architecture? - Historical Trends

- **25% per year**
  - AX-11/780, 5 MHz

- **52% per year**
  - Digital Alphastation 4/266, 266 MHz

- **23% per year**
  - IBM RS/6000/540, 30 MHz

- **12% per year**
  - MIPS M2000, 25 MHz

- **3.5% per year**
  - Sun-4/260, 16.7 MHz

- **1978** to **2018**

Performance (vs. VAX-11/780)
Why Study Computer Architecture? - Historical Trends

- Historical Trends
  - Dennard scaling ends
  - Amdahl’s law limits
  - Moore’s law ends

Performance (vs. VAX-11/780)

- Intel Core i7 4 cores 4.2 GHz (Boost to 4.5 GHz)
- Intel Core i7 4 cores 4.0 GHz (Boost to 4.2 GHz)
- Intel Core i7 4 cores 4.0 GHz (Boost to 4.2 GHz)
- Intel Xeon 4 cores 3.6 GHz (Boost to 4.0 GHz)
- Intel Core 7 4 cores 3.4 GHz (Boost to 3.8 GHz)
- Intel Core 2 Extreme 2 cores, 3.0 GHz
- Intel Core 2 Extreme 2 cores, 3.0 GHz
- Intel Xeon 4 cores, 3.3 GHz (Boost to 3.6 GHz)
- Intel Xeon 4 cores, 3.3 GHz (Boost to 3.6 GHz)
- Intel Xeon 4 cores, 3.3 GHz (Boost to 3.6 GHz)
- Intel Core i7 Extreme 4 cores 3.2 GHz (boost to 3.5 GHz)
- Intel Core i7 4 cores 3.4 GHz (boost to 3.8 GHz)
- Intel Xeon 6 cores, 3.3 GHz (boost to 3.6 GHz)
- Intel Xeon 6 cores, 3.3 GHz (boost to 3.6 GHz)
- Intel Xeon 4 cores, 3.0 GHz (boost to 3.6 GHz)
- Intel Core i7 4 cores 4.0 GHz (Boost to 4.2 GHz)
- Intel Core i7 4 cores 4.0 GHz (Boost to 4.2 GHz)
- Intel Xeon 4 cores 3.6 GHz (Boost to 4.0 GHz)
- Intel Xeon 4 cores 3.6 GHz (Boost to 4.0 GHz)
- Intel Core i7 4 cores 3.4 GHz (boost to 3.8 GHz)

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Figure 1.1 Growth in processor performance over 40 years. This chart plots program performance relative to the VAX 11/780 as measured by the SPEC integer benchmarks (see Section 1.8). Prior to the mid-1980s, growth in processor performance was largely technology-driven and averaged about 22% per year, or doubling performance every 3.5 years. The increase in growth to about 52% starting in 1986, or doubling every 2 years, is attributable to more advanced architectural and organizational ideas typified in RISC architectures. By 2003 this growth led to a difference in performance of an approximate factor of 25 versus the performance that would have occurred if it had continued at the 22% rate. In 2003 the limits of power due to the end of Dennard scaling and the available instruction-level parallelism slowed uniprocessor performance to 23% per year until 2011, or doubling every 3.5 years. (The fastest SPECintbase performance since 2007 has had automatic parallelization turned on, so uniprocessor speed is harder to gauge. These results are limited to single-chip systems with usually four cores per chip.) From 2011 to 2015, the annual improvement was less than 12%, or doubling every 8 years in part due to the limits of parallelism of Amdahl’s Law. Since 2015, with the end of Moore’s Law, improvement has been just 3.5% per year, or doubling every 20 years! Performance for floating-point-oriented calculations follows the same trends, but typically has 1% to 2% higher annual growth in each shaded region. Figure 1.11 on page 27 shows the improvement in clock rates for these same eras. Because SPEC has changed over the years, performance of newer machines is estimated by a scaling factor that relates the performance for different versions of SPEC: SPEC89, SPEC92, SPEC95, SPEC2000, and SPEC2006. There are too few results for SPEC2017 to plot yet.
Why Study Computer Architecture?
Why Study Computer Architecture Today?

Golden Age of Computer Architecture!


Full video here: https://www.acm.org/hennessy-patterson-turing-lecture

QnA: Why software community needs to learn about hardware now? https://youtu.be/3LVeEjsn8Ts?t=4268
Relationship to Prerequisites

Prerequisite
  How to design a computer?

This course
  How to design a computer WELL?
    Emphasis on Quantitative vs. Qualitative

Be sure to check the course information slides for details on the prerequisites