CSC 252: Computer Organization
Spring 2023: Lecture 5

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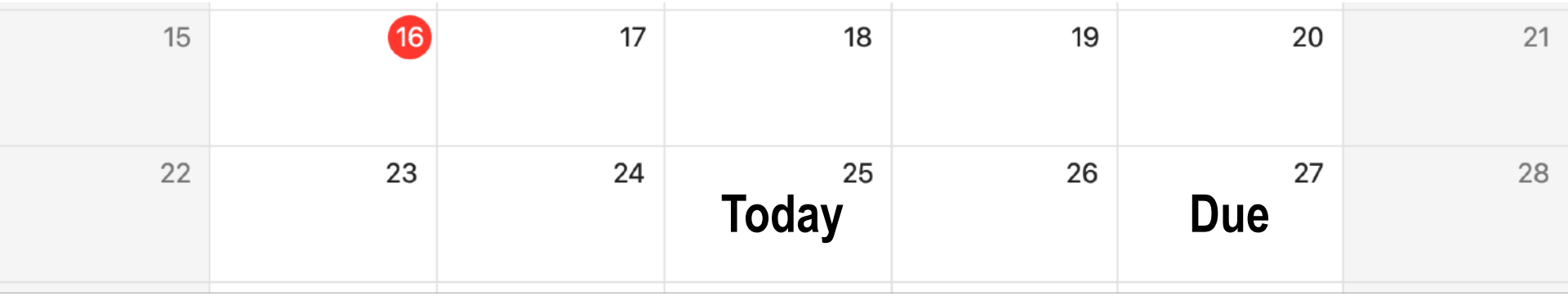
Announcement

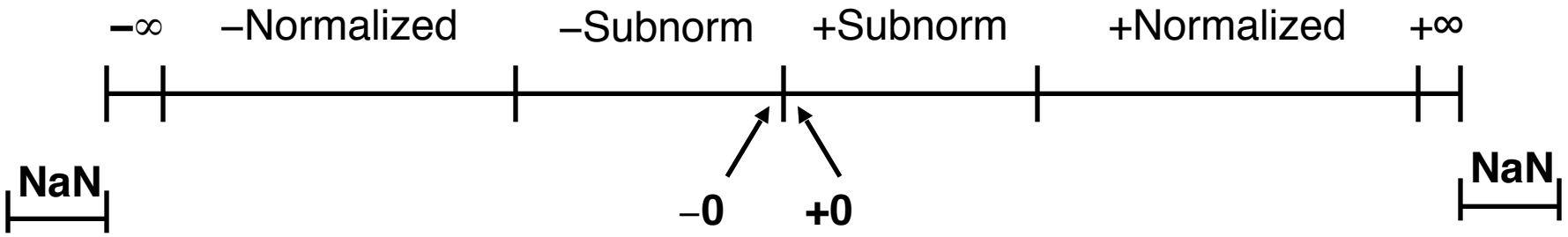
- Programming Assignment 1 is out
  - Details: https://www.cs.rochester.edu/courses/252/spring2023/labs/assignment1.html
  - Due on Jan. 27, 11:59 PM
  - You have 3 slip days



Announcement

- Programming assignment 1 is in C language. Seek help from TAs.
- TAs are best positioned to answer your questions about programming assignments!!!
- Programming assignments do NOT repeat the lecture materials. They ask you to synthesize what you have learned from the lectures and work out something new.

Visualization: Floating Point Encodings



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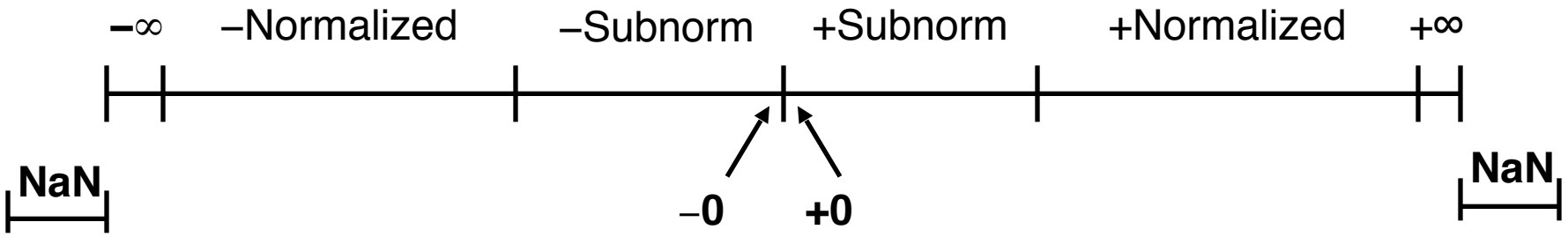

Infinite Amount of Real Numbers

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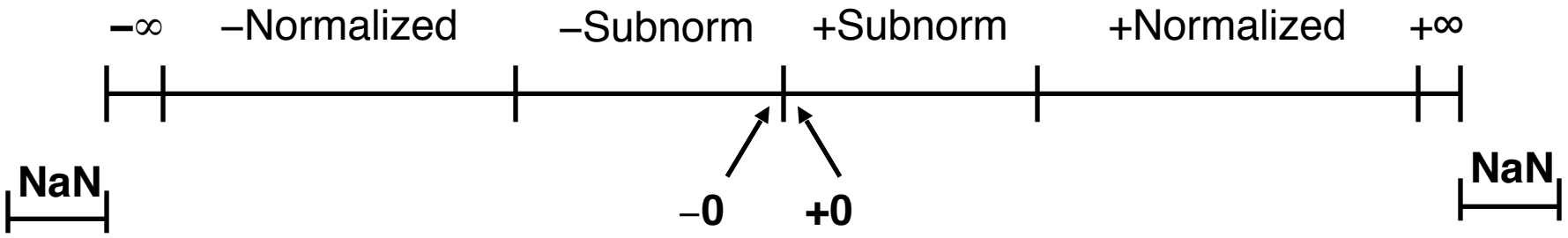

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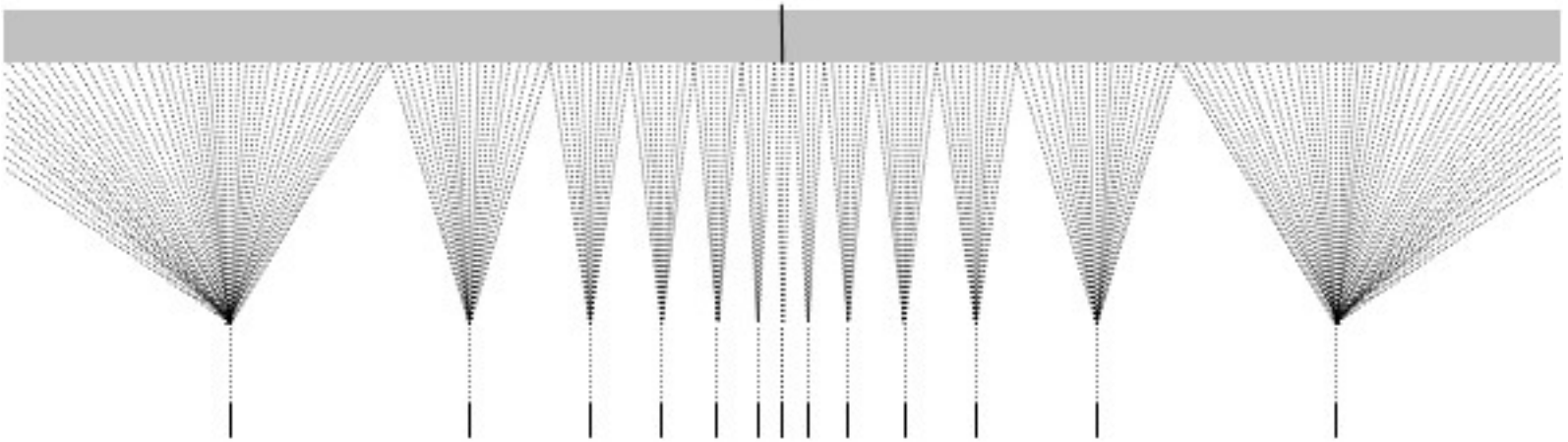

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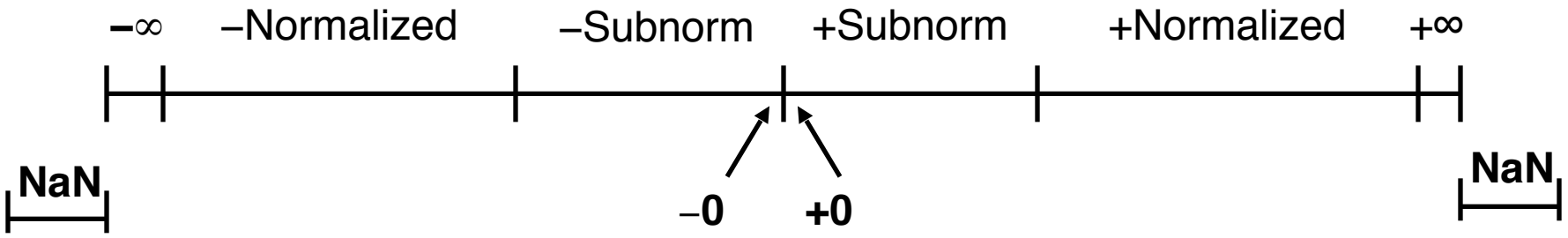

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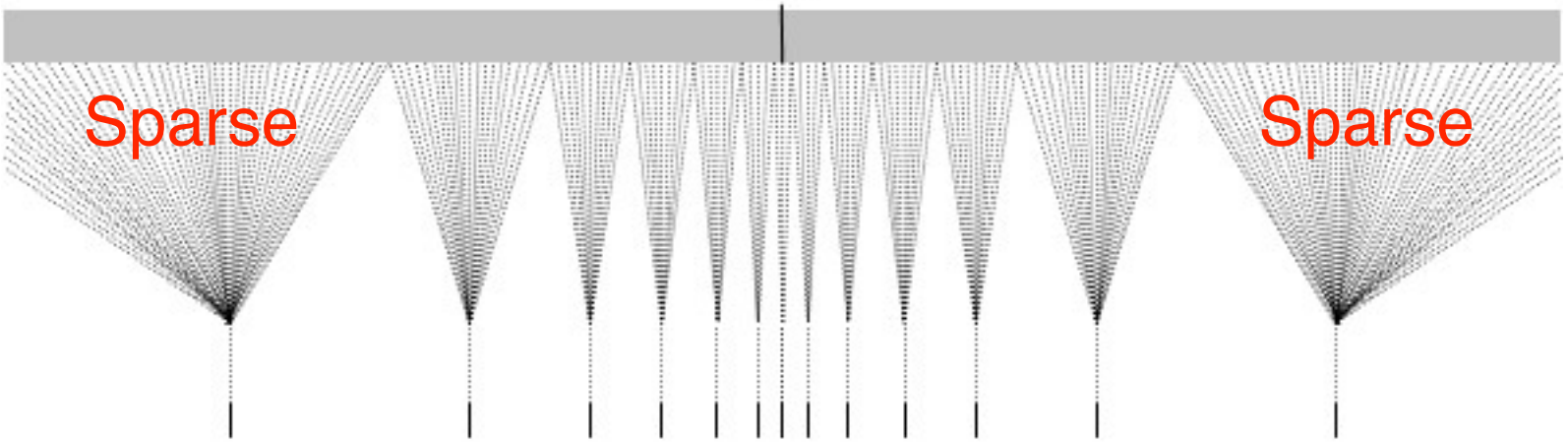

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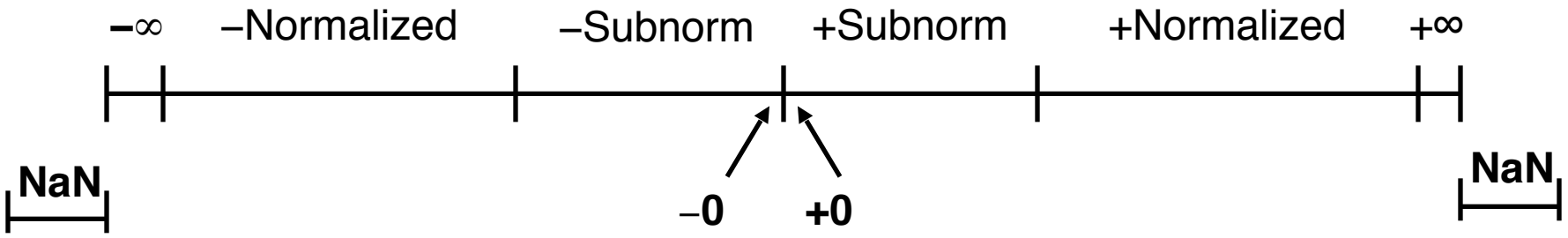

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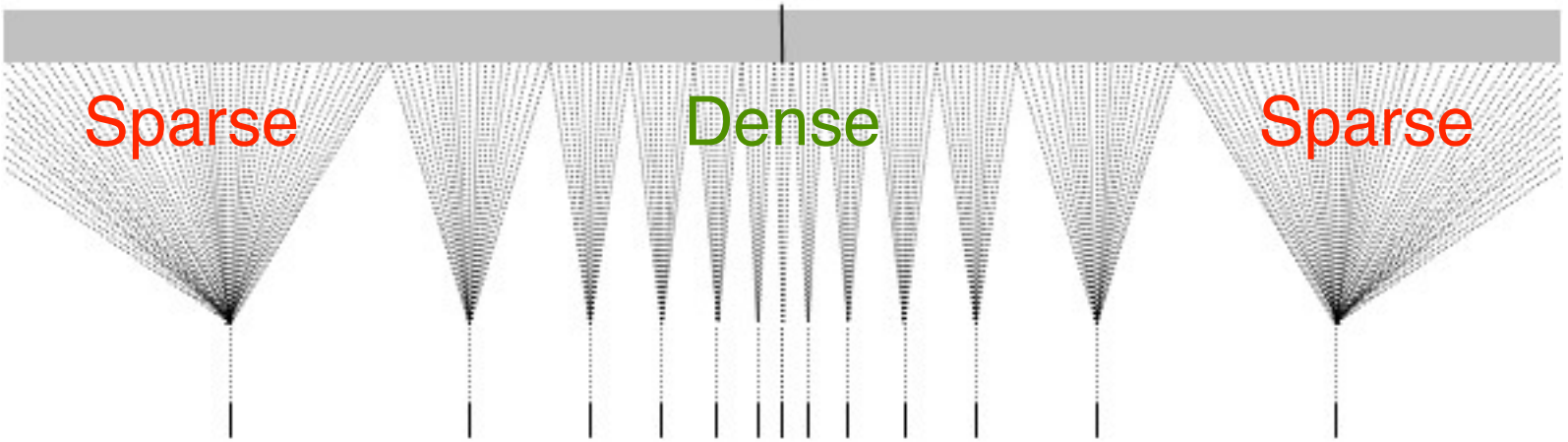

Finite Amount of Floating Point Numbers

Today: Floating Point

- Background: Fractional binary numbers and fixed-point
- Floating point representation
- IEEE 754 standard
- Rounding, addition, multiplication
- Floating point in C
- Summary

IEEE 754 Floating Point Standard

- Single precision: 32 bits

- Double precision: 64 bits

IEEE Floating Point

- IEEE Standard 754
  - Established in 1985 as uniform standard for floating point arithmetic
    - Before that, many idiosyncratic formats
  - Supported by all major CPUs (and even GPUs and other processors)

- Driven by numerical concerns
  - Nice standards for rounding, overflow, underflow
  - Hard to make fast in hardware
    - Numerical analysts predominated over hardware designers in defining standard

Single Precision (32-bit) Example

$v = (-1)^s M 2^E$

bias = $2^{(8-1)}-1 = 127$

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Floating Point Computations

- The problem: Computing on floating point numbers might produce a result that can't be precisely represented
- Basic idea
  - We perform the operation & produce the infinitely precise result
  - Make it fit into desired precision
    - Possibly overflow if exponent too large
    - Possibly round to fit into frac

Rounding Modes (Decimal)

- Common ones:
  - Towards zero (chop)
  - Round down (-∞)
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Rounding Mode	**1.40**	**1.60**	**1.50**	**2.50**	**-1.50**
Towards zero	1	1	1	2	-1
Round down (-∞)	1	1	1	2	-2
Round up (+∞)	2	2	2	3	-1
Nearest even (default)	1	2	2	2	-2

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- Assuming 3 bits for *frac*

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1.000011	1.000	1.000 is the nearest (down)
1.000110	1.001	1.001 is the nearest (up)
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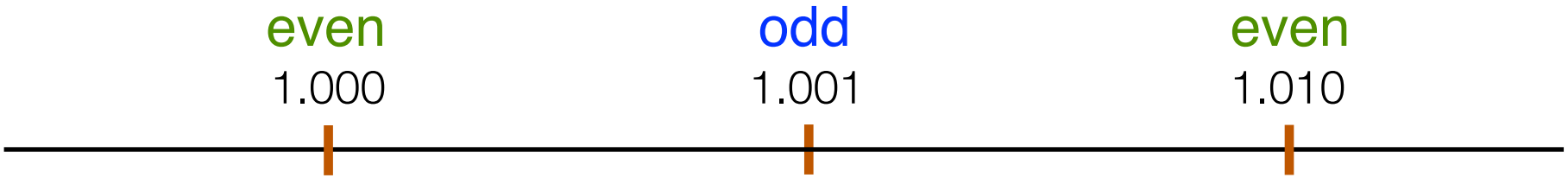

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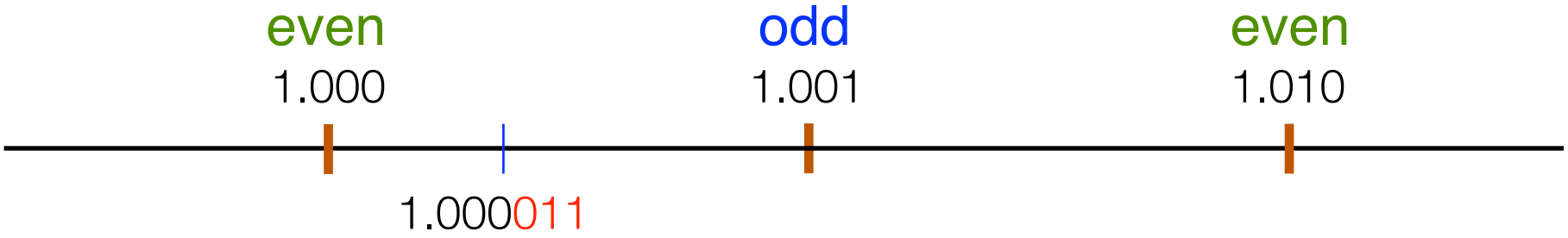

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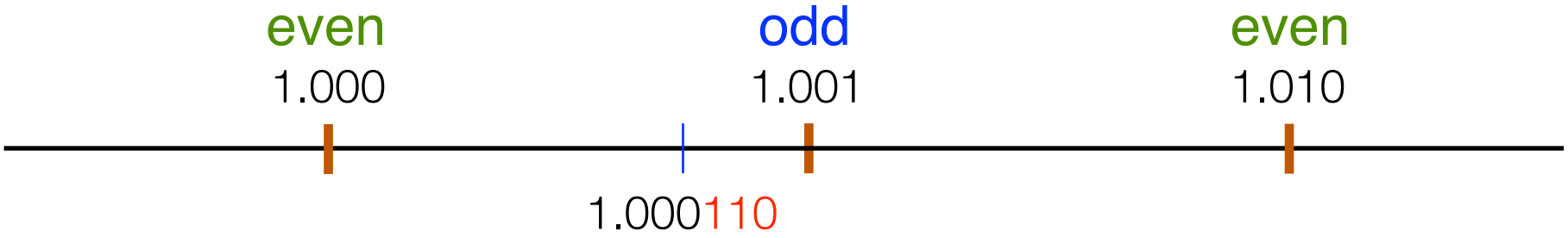

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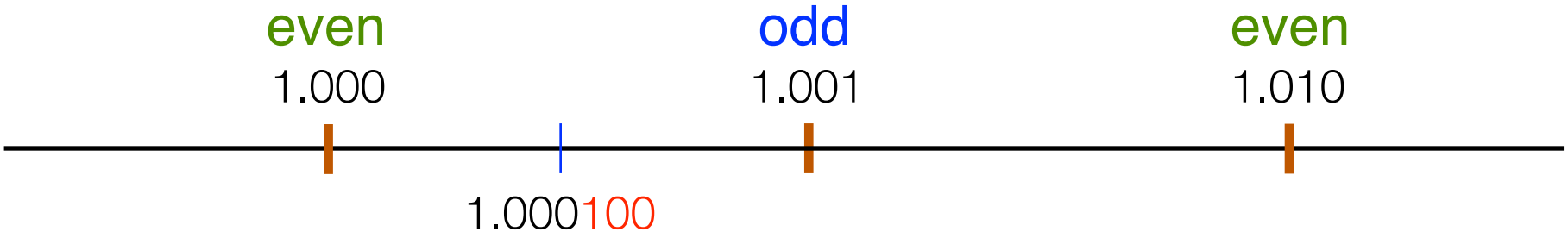

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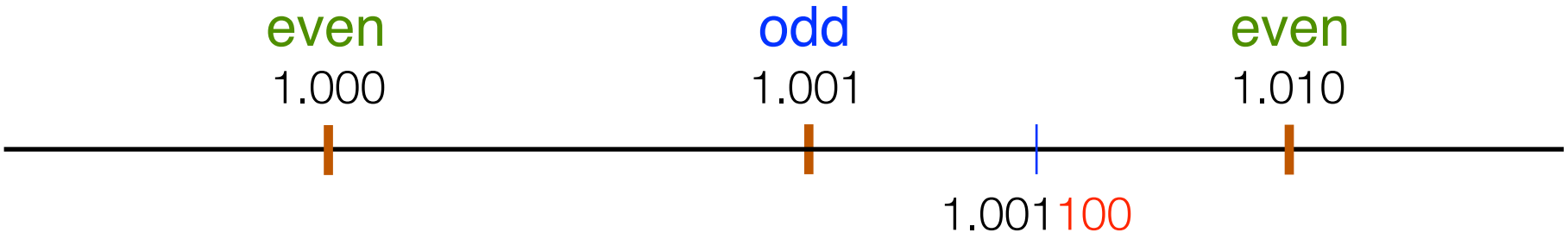

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  - If $M < 1$, shift *M* left *k* positions, decrement *E* by *k*
  - Overflow if *E* out of range
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- Implementation
  - Biggest chore is multiplying significands

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- Single precision: 32 bits

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- In C language
  - `float` single precision
  - `double` double precision

Floating Point in C

32-bit Machine

Fixed point
(implicit binary point)

SP floating point

DP floating point

C Data Type	Bits	Max Value	Max Value (Decimal)
`char`	8	$2^7 - 1$	127
`short`	16	$2^{15} - 1$	32767
`int`	32	$2^{31} - 1$	2147483647
`long`	64	$2^{63} - 1$	$\sim 9.2 \times 10^{18}$
`float`	32	$(2 - 2^{-23}) \times 2^{127}$	$\sim 3.4 \times 10^{38}$
`double`	64	$(2 - 2^{-52}) \times 2^{1023}$	$\sim 1.8 \times 10^{308}$

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- To represent 2^{31} in fixed-point, you need at least 32 bits
  - Because fixed-point is a *weighted positional* representation
- In floating-point, we directly encode the exponent
  - Floating point is based on scientific notation
  - Encoding 31 only needs 7 bits in the *exp* field

Floating Point Conversions/Casting in C

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  - Can’t guarantee exact casting. Will round according to rounding mode

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- **`int → float`**
  - Can't guarantee exact casting. Will round according to rounding mode

- **`int → double`**

Floating Point Conversions/Casting in C

- **`double/float → int`**
  - Truncates fractional part
  - Like rounding toward zero
  - Not defined when out of range or NaN
- **`int → float`**
  - Can't guarantee exact casting. Will round according to rounding mode

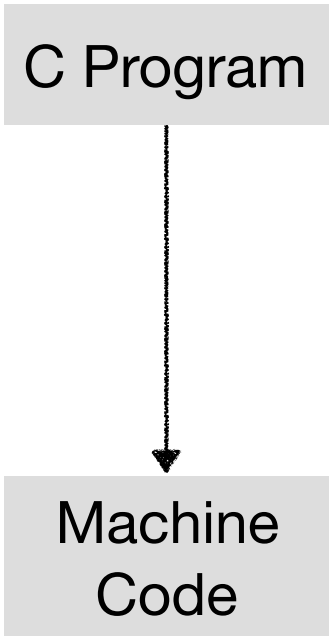
- **`int → double`**
  - Exact conversion

So far in 252…

C Program

```
int, float
if, else
+, -, >>
```

So far in 252…

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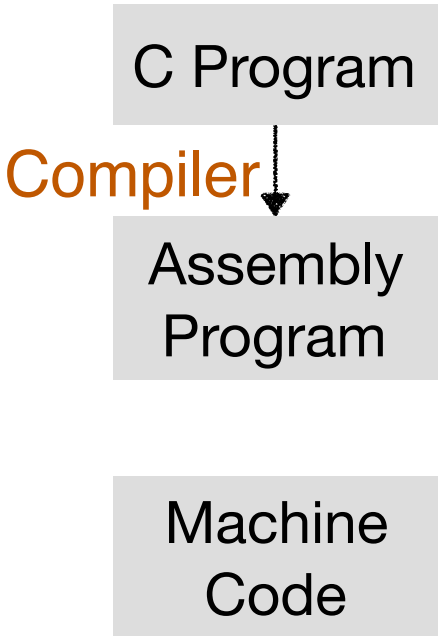
if, else
+, -, >>
```

```
00001111
01010101
11110000
```

So far in 252…



`int`, **`float`**
`if`, `else`
`+`, `-`, `>>`

`ret`, `call`
`fadd`, **`add`**
`jmp`, `jne`

00001111
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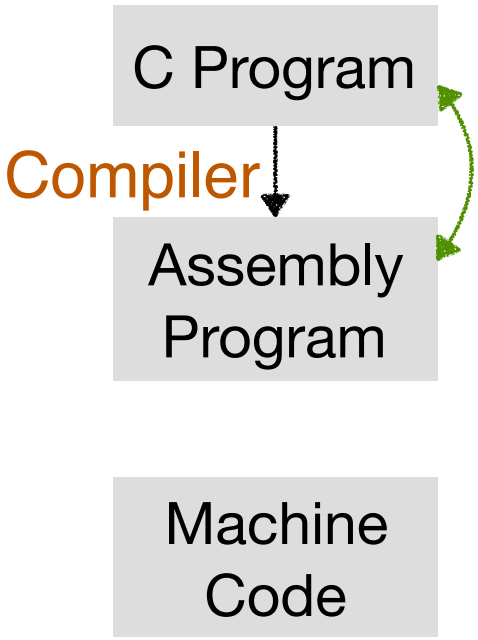
So far in 252…

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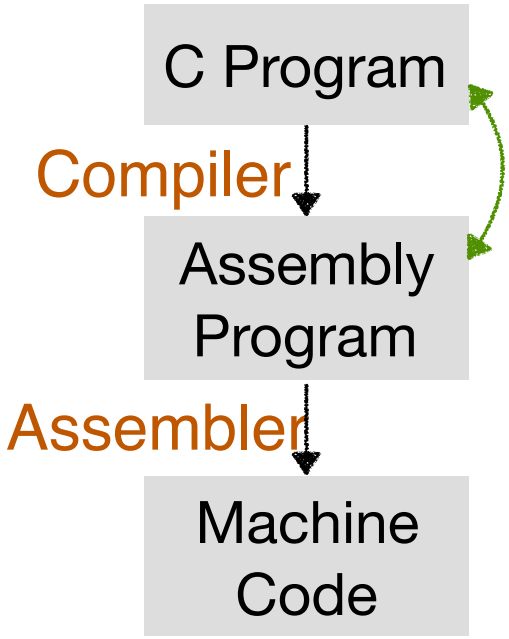


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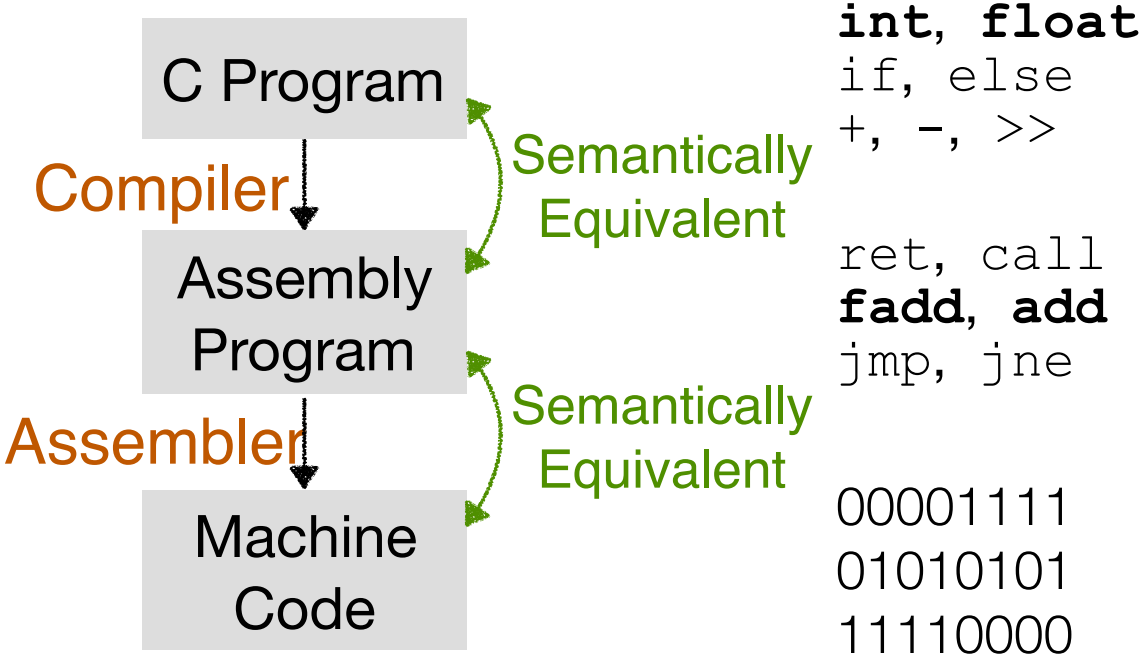
C Program
Compiler
Assembly Program
Assembler
Machine Code
Semantically Equivalent
Semantically Equivalent
int, float
if, else
+, -, >>
ret, call
fadd, add
jmp, jne
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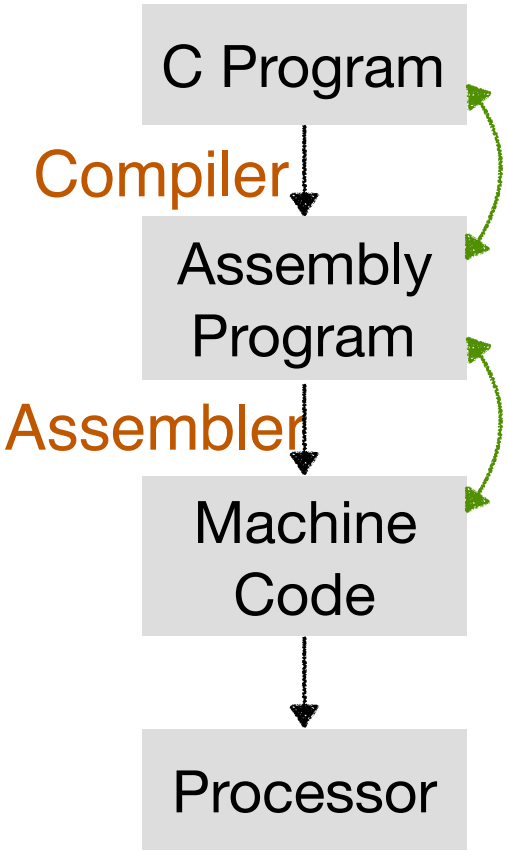
So far in 252…



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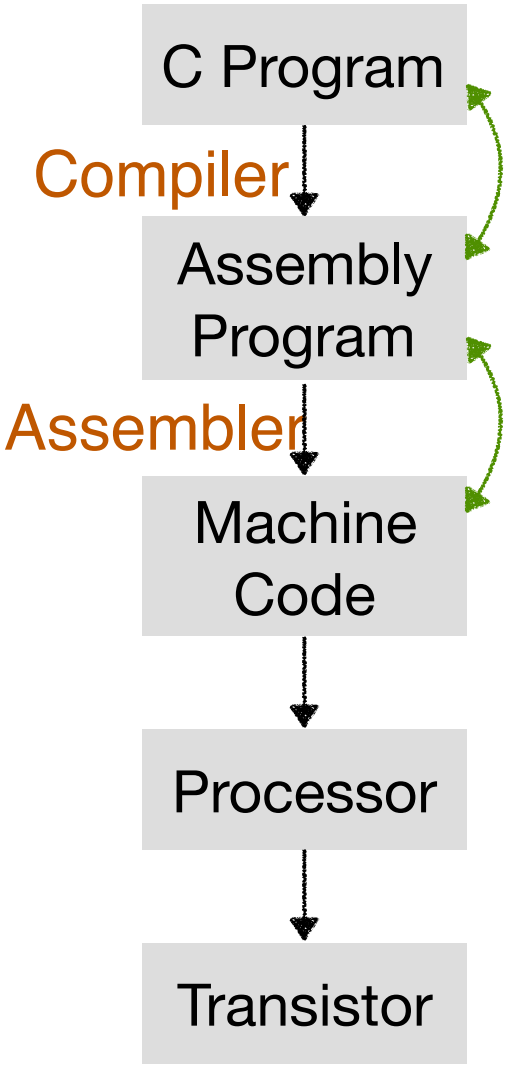
11110000

Fixed-point adder (e.g., ripple carry),
Floating-point adder

So far in 252…



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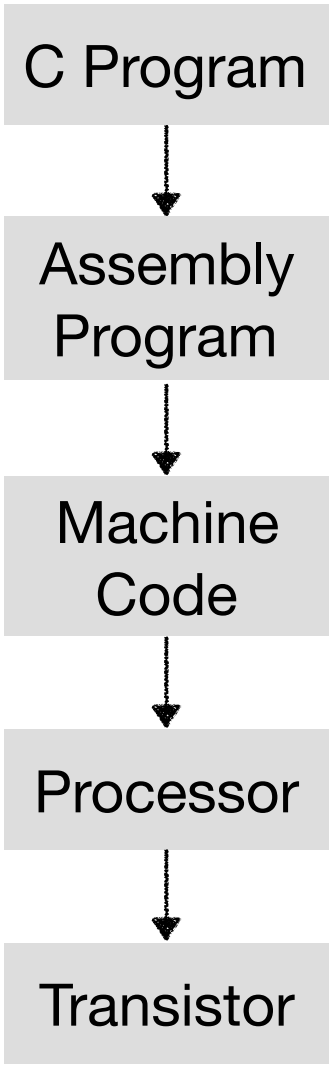
Fixed-point adder
(e.g., ripple carry),
Floating-point adder

NAND Gate
NOR Gate

So far in 252…

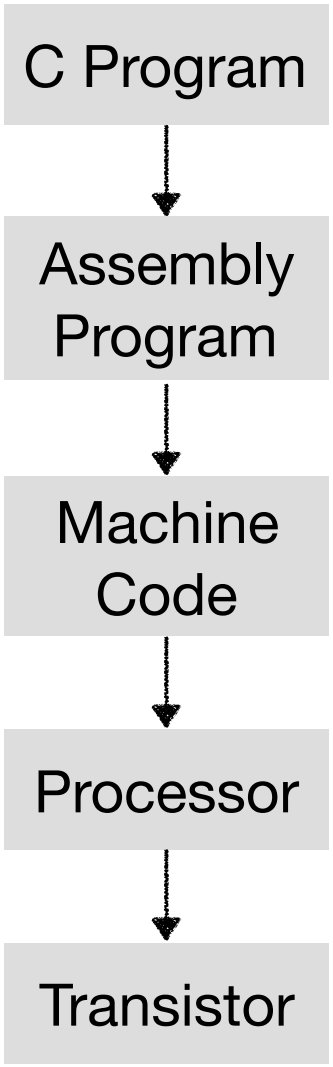
High-Level Language



So far in 252…

High-Level Language

Instruction Set Architecture (ISA)

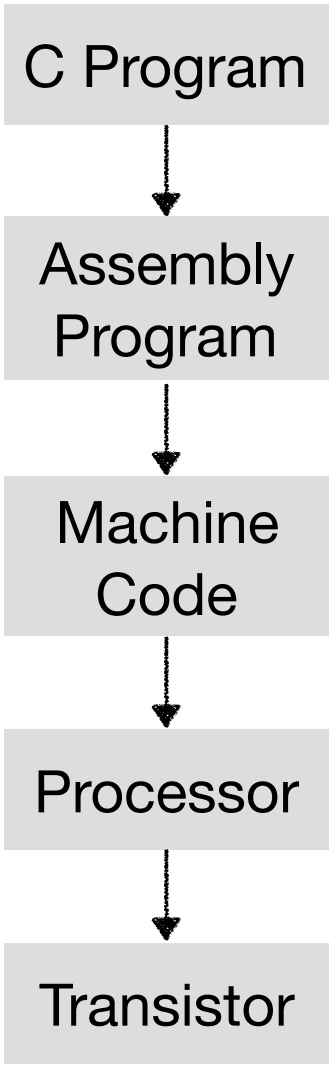


- ISA: Software programmers' view of a computer
  - Provide all info for someone wants to write assembly/machine code
  - "Contract" between assembly/ machine code and processor

So far in 252…

High-Level Language

Instruction Set Architecture (ISA)



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- Processors execute machine code (binary). Assembly program is merely a text representation of machine code

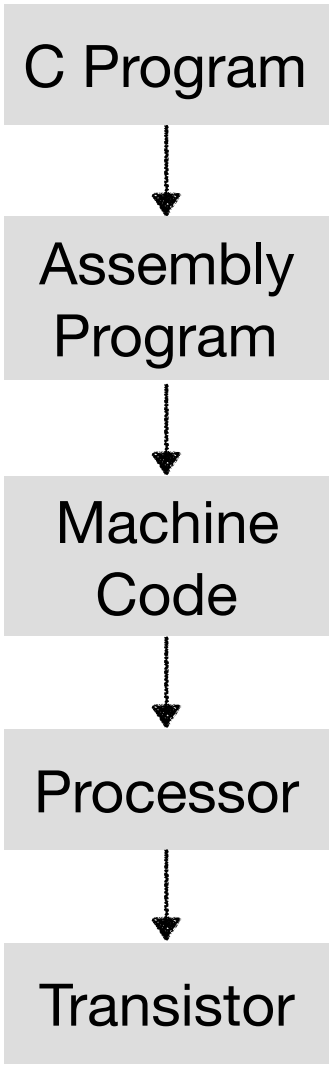
So far in 252…

High-Level Language

Instruction Set Architecture (ISA)

Microarchitecture

Circuit



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  - Provide all info for someone wants to write assembly/machine code
  - "Contract" between assembly/ machine code and processor
- Processors execute machine code (binary). Assembly program is merely a text representation of machine code
- Microarchitecture: Hardware implementation of the ISA (with the help of circuit technologies)

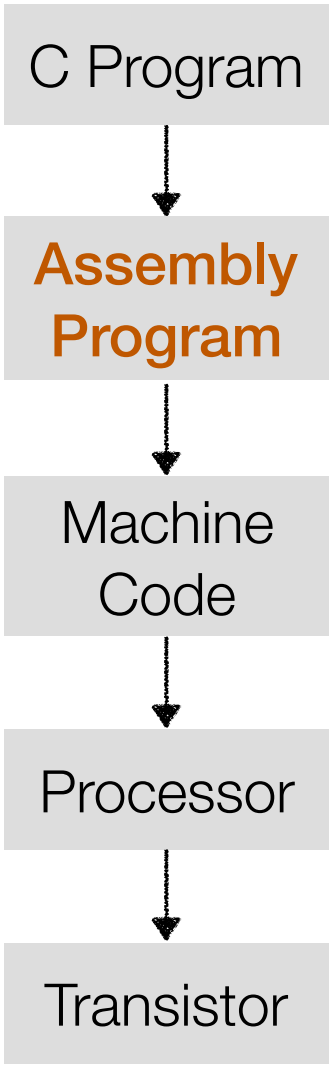
This Module (4 Lectures)

High-Level Language

Instruction Set Architecture (ISA)

Microarchitecture

Circuit



- Assembly Programming
  - Explain how various C constructs are implemented in assembly code
  - Effectively translating from C to assembly program manually
  - Helps us understand how compilers work
  - Helps us understand how assemblers work
- Microarchitecture is the topic of the next module

Today: Assembly Programming I: Basics

- Different ISAs and history behind them
- C, assembly, machine code
- Move operations (and addressing modes)

Instruction Set Architecture

Instruction Set Architecture

- There used to be many ISAs
  - x86, ARM, Power/PowerPC, Sparc, MIPS, IA64, z
  - Very consolidated today: ARM for mobile, x86 for others

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  - Intel and AMD have different microarchitectures for x86

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- There are even more microarchitectures
  - Apple/Samsung/Qualcomm have their own microarchitecture (implementation) of the ARM ISA
  - Intel and AMD have different microarchitectures for x86
- ISA is lucrative business: ARM's Business Model
  - Patent the ISA, and then license the ISA
  - Every implementer pays a royalty to ARM
  - Apple/Samsung pays ARM whenever they sell a smartphone

The ARM Diaries, Part 1: How ARM's Business Model Works: https://www.anandtech.com/show/7112/the-arm-diaries-part-1-how-arms-business-model-works

Intel x86 ISA

- Dominate laptop/desktop/cloud market

Intel x86 ISA

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Intel x86 ISA

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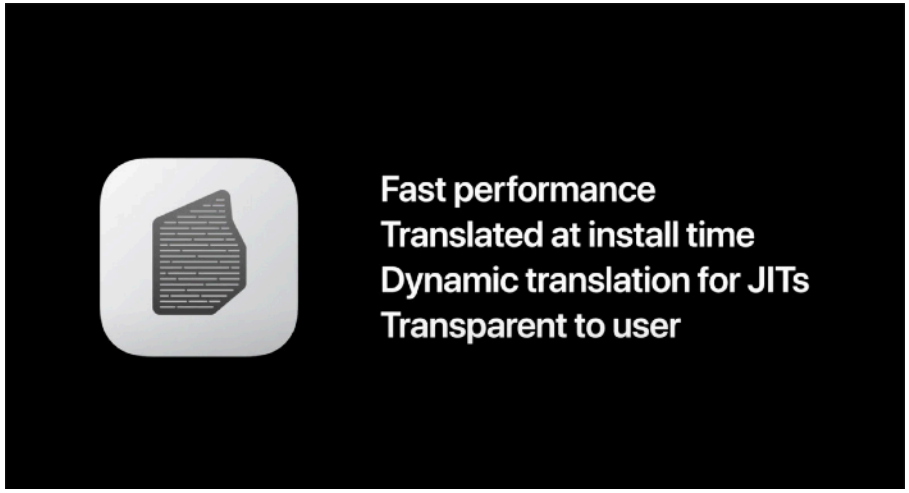
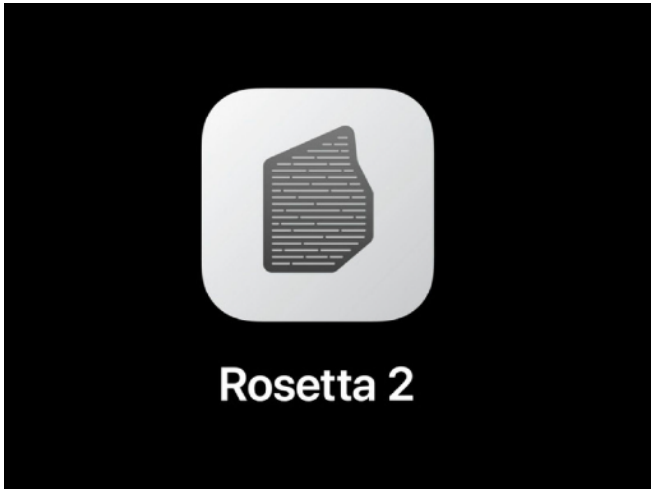
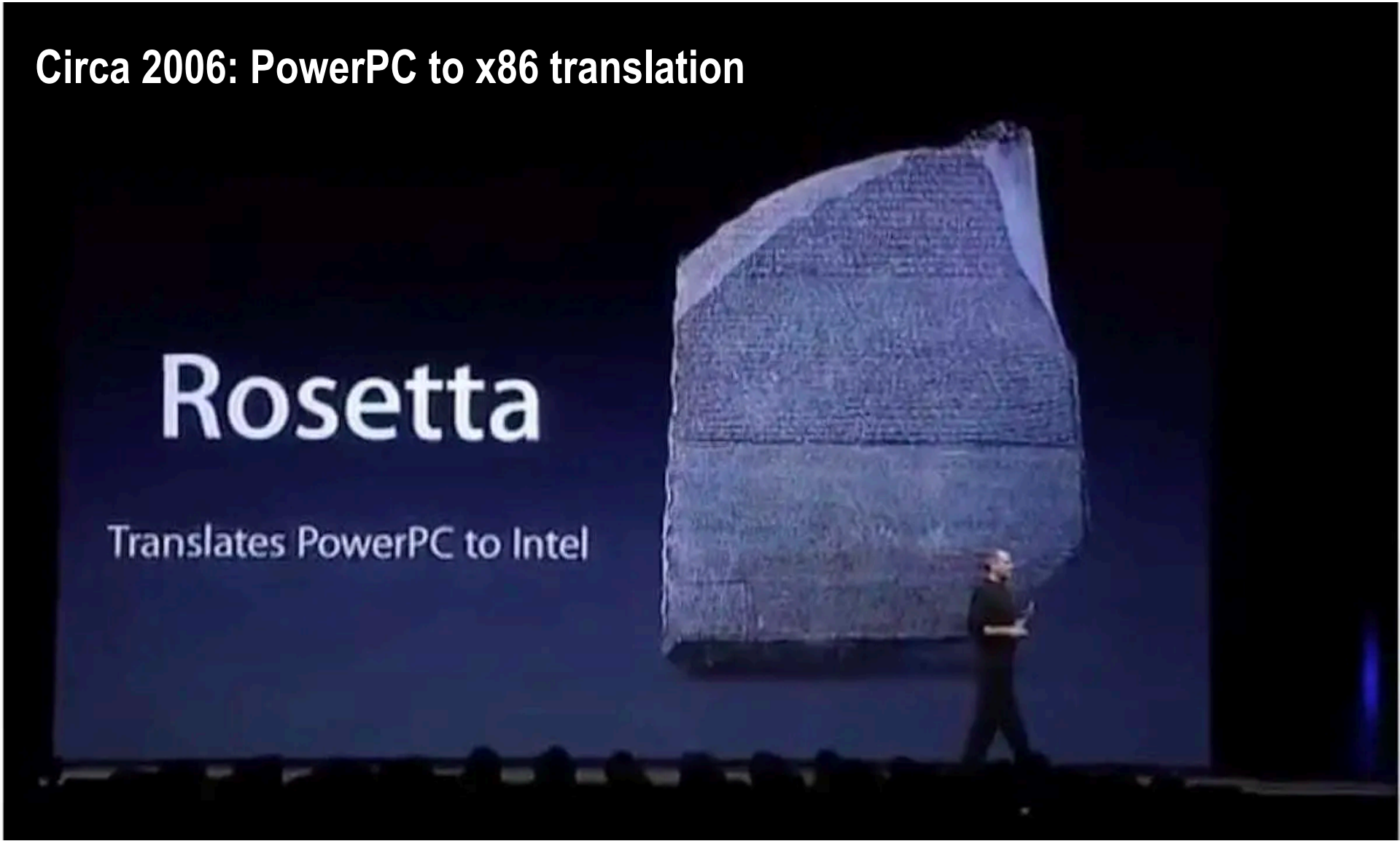
Aside: Dynamic Binary Translation

- Apple M1 is based on the Arm ISA. A program compiled to x86 ISA is dynamically translated to Arm ISA by Rosetta.
- Not the first time Apple plays this trick.





Aside: Dynamic Binary Translation



Intel x86 ISA Evolution (Milestones)

- Evolutionary design: Added more features as time goes on

Intel x86 ISA Evolution (Milestones)

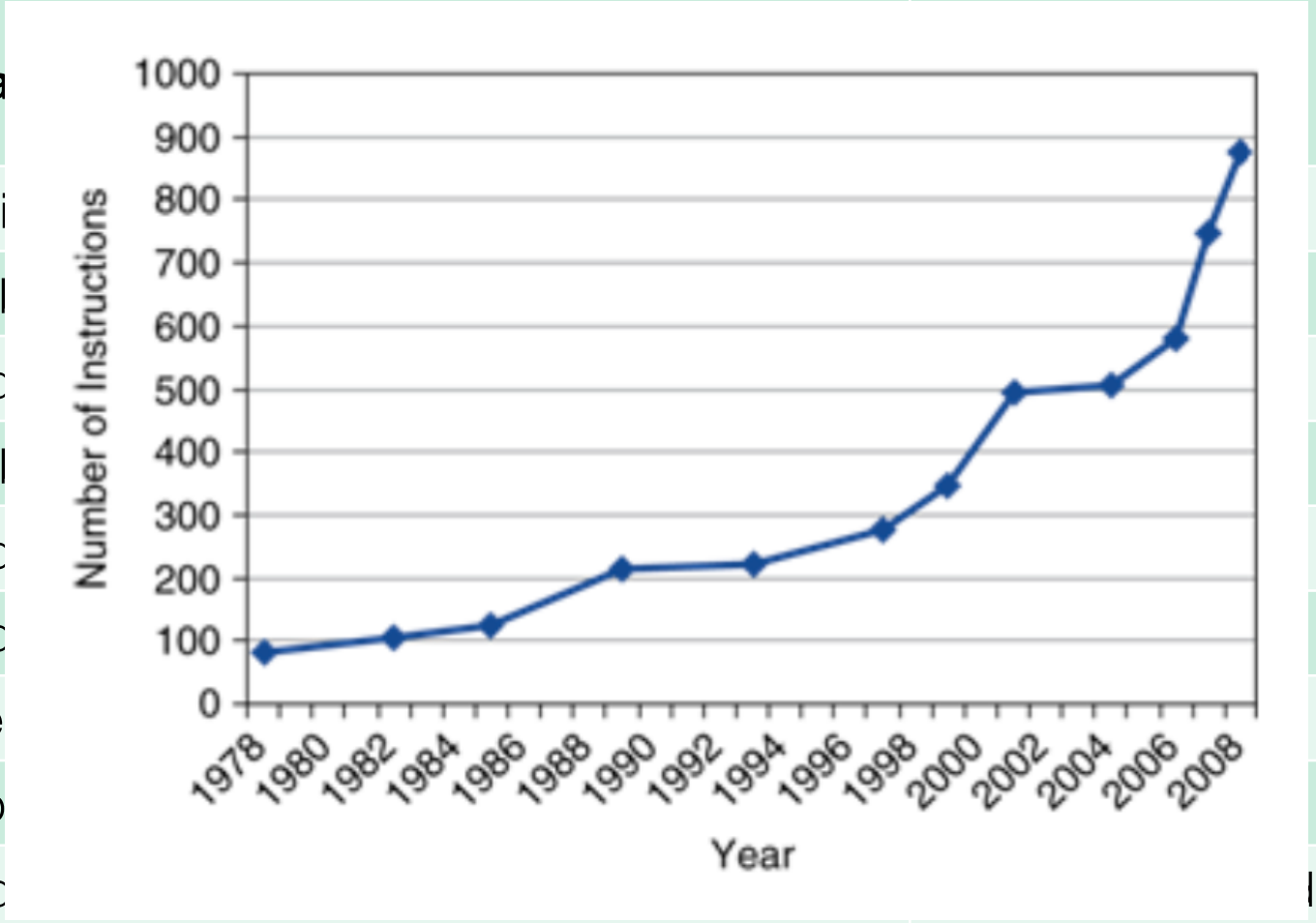
- Evolutionary design: Added more features as time goes on

Date	Feature	Notable Implementation
1974	8-bit ISA	8080
1978	16-bit ISA (Basis for IBM PC & DOS)	8086
1980	Add Floating Point instructions	8087
1985	32-bit ISA (Refer to as IA32)	386
1997	Add Multi-Media eXtension (MMX)	Pentium/MMX
1999	Add Streaming SIMD Extension (SSE)	Pentium III
2001	Intel's first attempt at 64-bit ISA (IA64, failed)	Itanium
2004	Implement AMD's 64-bit ISA (x86-64, AMD64)	Pentium 4E
2008	Add Advanced Vector Extension (AVE)	Core i7 Sandy Bridge

Intel x86 ISA Evolution (Milestones)

- Evolutionary design: Added more features as time goes on

Date	Fea
1974	8-bi
1978	16-I
1980	Adc
1985	32-I
1997	Adc
1999	Adc
2001	Inte
2004	Imp
2008	Adc



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Backward Compatibility

- Binary executable generated for an older processor can execute on a newer processor
- Allows legacy code to be executed on newer machines
  - Buy new machines without changing the software
- x86 is backward compatible up until 8086 (16-bit ISA)
  - i.e., an 8086 binary executable can be executed on any of today's x86 machines
- Great for users, nasty for processor implementers
  - Every instruction you put into the ISA, you are stuck with it *FOREVER*

x86 Clones: Advanced Micro Devices (AMD)

- Historically
  - AMD build processors for x86 ISA
  - A little bit slower, a lot cheaper
- Then
  - Recruited top circuit designers from Digital Equipment Corp. and other downward trending companies
  - Developed x86-64, their own 64-bit x86 extension to IA32
  - Built first 1 GHz CPU
- Intel felt hard to admit mistake or that AMD was better
- 2004: Intel Announces EM64T extension to IA32
  - Almost identical to x86-64!
  - Today's 64-bit x86 ISA is basically AMD's original proposal

x86 Clones: Advanced Micro Devices (AMD)

- Today: Holding up not too badly

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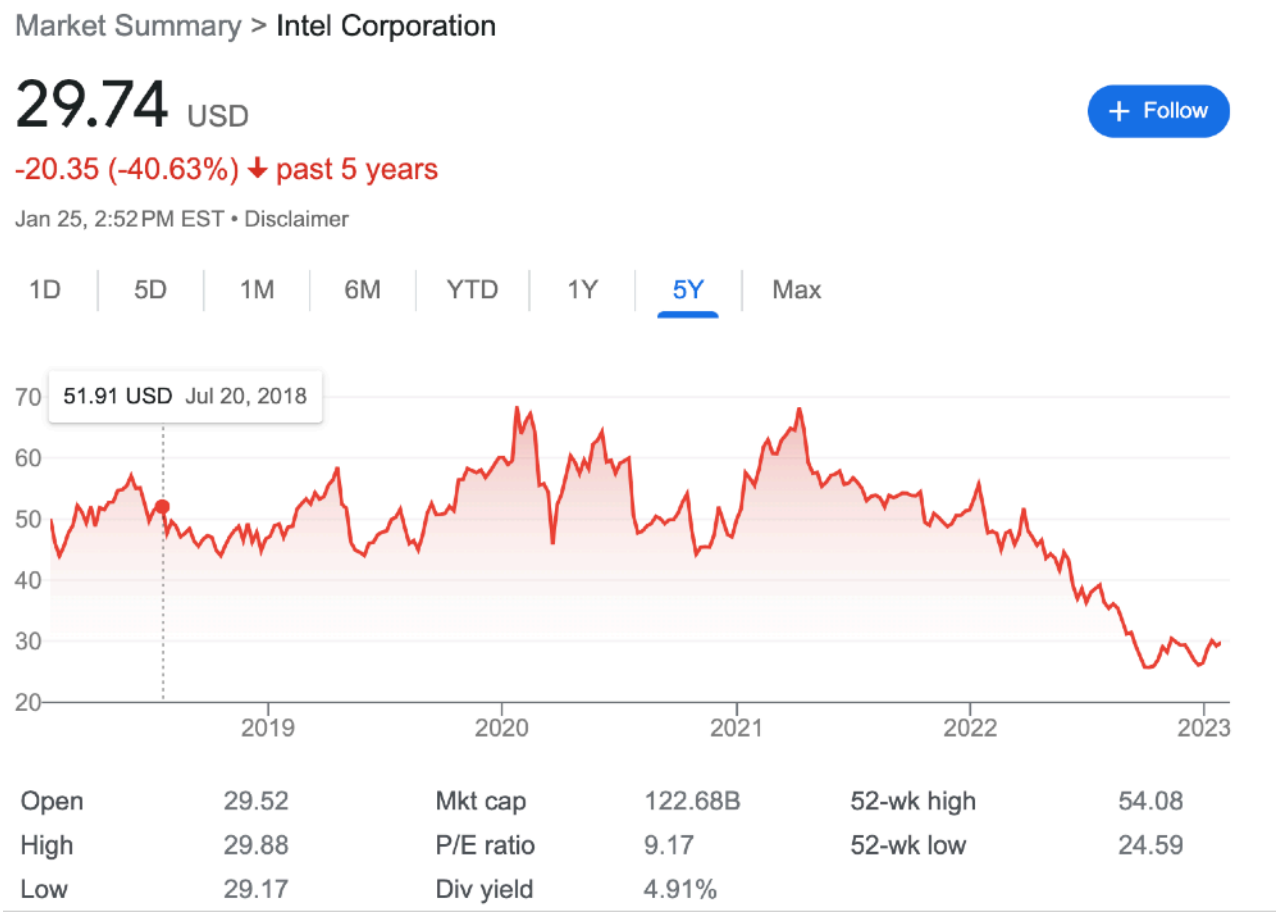

x86 Clones: Advanced Micro Devices (AMD)

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