LING 408/508: Programming for Linguists

Lecture 2

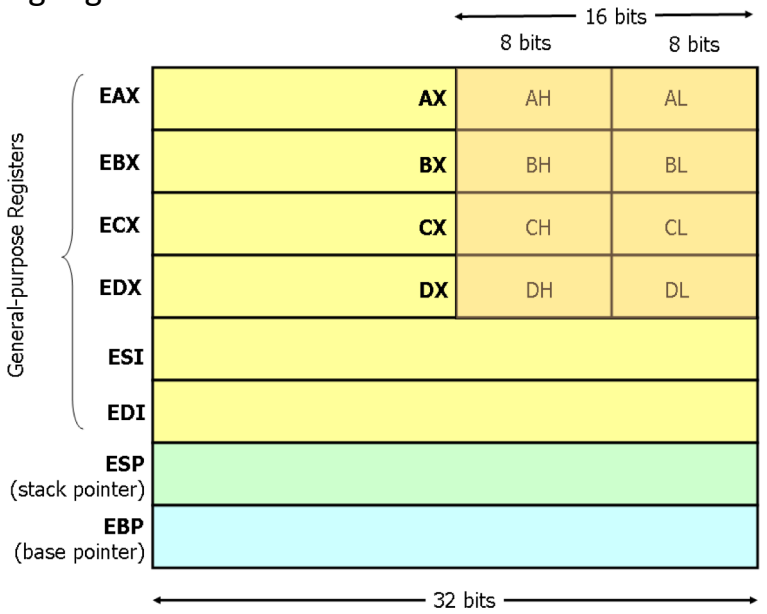
Today's Class

- Continue with the introduction
  - binary representation and arithmetic
  - ungraded homework exercise

Introduction

- Machine Language
  - A CPU understands only one language: machine language
    - **all other languages** must be translated into machine language
  - Primitive instructions include:
    - MOV
    - PUSH
    - POP
    - ADD / SUB
    - INC / DEC
    - IMUL / IDIV
    - AND / OR / XOR / NOT
    - NEG
    - SHL / SHR
    - JMP
    - CMP
    - JE / JNE / JZ / JG / JGE / JL / JLE
    - CALL / RET

Assembly Language: (this notation)
by definition, nothing built on it is more powerful



http://www.cs.virginia.edu/~evans/cs216/guides/x86.html

Introduction

- Not all machine instructions are conceptually necessary
  - many provided for speed/efficiency
- Theoretical Computer Science
  - All mechanical computation can be carried out using a TURING MACHINE (Turing, 1936)
  - Finite state table + (infinite) tape
  - Tape instructions:
    - at the tape head: Erase, Write, Move (Left/Right/NoMove)
  - Finite state table:
    - Current state x Tape symbol --> new state x New Tape symbol x Move

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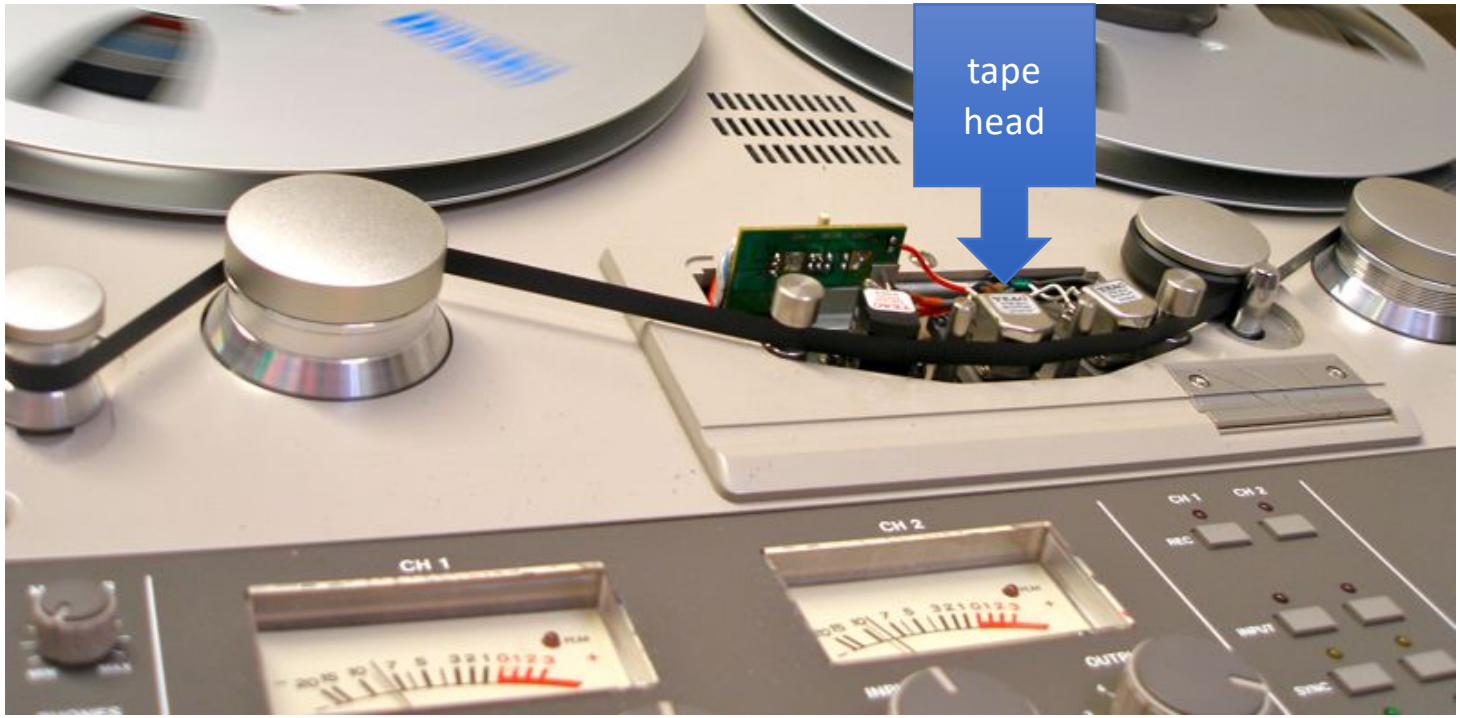
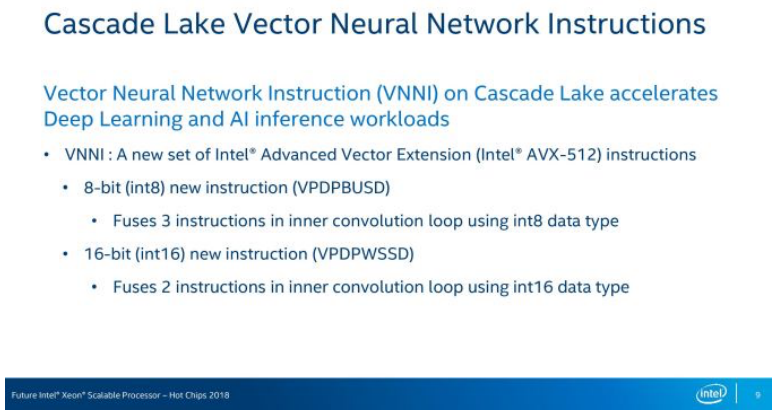
Introduction

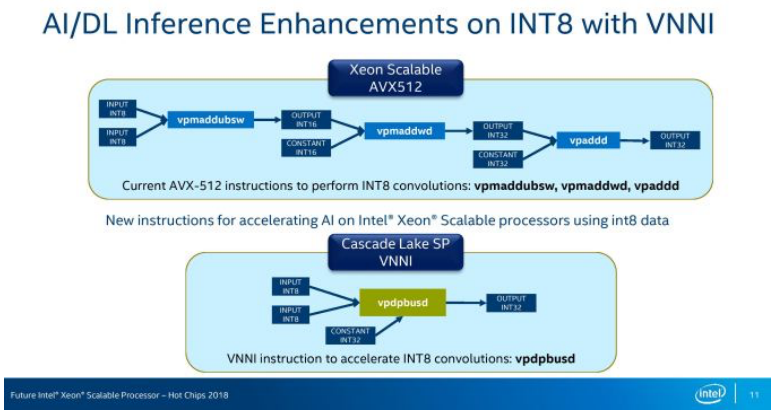


http://www.thegreatbear.net/audio-tape-transfer/quarter-inch-reel-to-reel-transfer/

Introduction

- Not all machine instructions are conceptually necessary
  - many provided for speed/efficiency
- **Example (Hot Chips 2018):**





Introduction

- Storage:
  - based on digital logic
  - binary (base 2) – everything is a power of 2
  - Byte: 8 bits
    - 01011011
    - = $2^6+2^4+2^3+2^1+2^0$
    - = 64 + 16 + 8 + 2 + 1
    - = 91 (in decimal)
  - Hexadecimal (base 16)
    - 0-9,A,B,C,D,E,F (need 4 bits)
    - 5B (= 1 byte)
    - = $5*16^1 + 11$
    - = 80 + 11
    - = 91

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
0	1	0	1	1	0	1	1

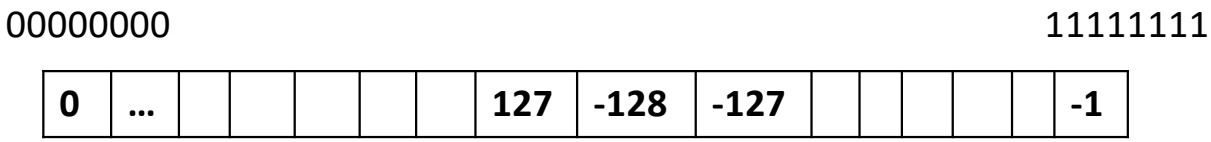
2^3	2^2	2^1	2^0	2^3	2^2	2^1	2^0
0	1	0	1	1	0	1	1

5 B

16^1	16^0
5	B

Introduction: data types

- Integers
  - In one byte (= 8 bits), what's the largest and smallest number, we can represent?
  - 00000000 = 0
  - 01111111 = 127
  - 10000000 = -128
  - 11111111 = -1



2's complement representation

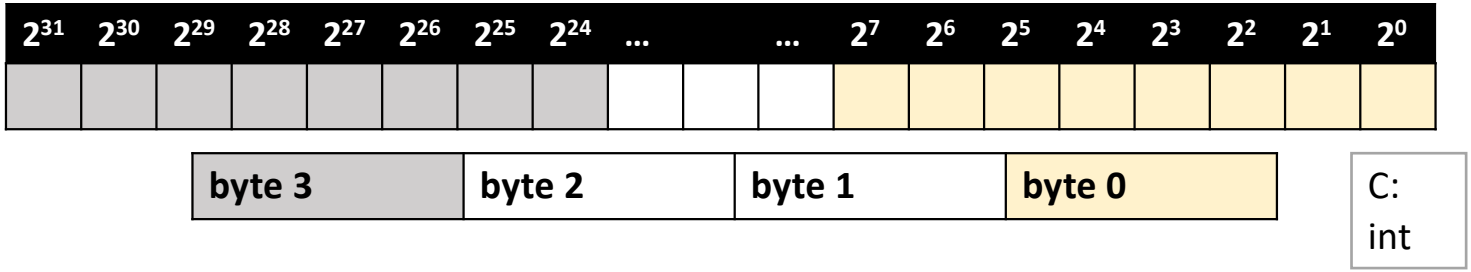
Introduction: data types

- Integers
  - In one byte, what's the largest and smallest number, we can represent?
  - **Answer**: -128 .. 0 .. 127 using the **2's complement representation**
  - Why? super-convenient for arithmetic operations
  - "to convert a positive integer X to its negative counterpart, flip all the bits, and add 1"
  - **Example**:
  - 00001010 = $2^3 + 2^1 = 10$ (decimal)
  - 11110101 + 1 = 11110110 = -10 (decimal)
  - 11110110 flip + 1 = 00001001 + 1 = 00001010

Addition:
-10 + 10
= 11110110
+ 00001010 = 0 (ignore overflow)

Introduction: data types

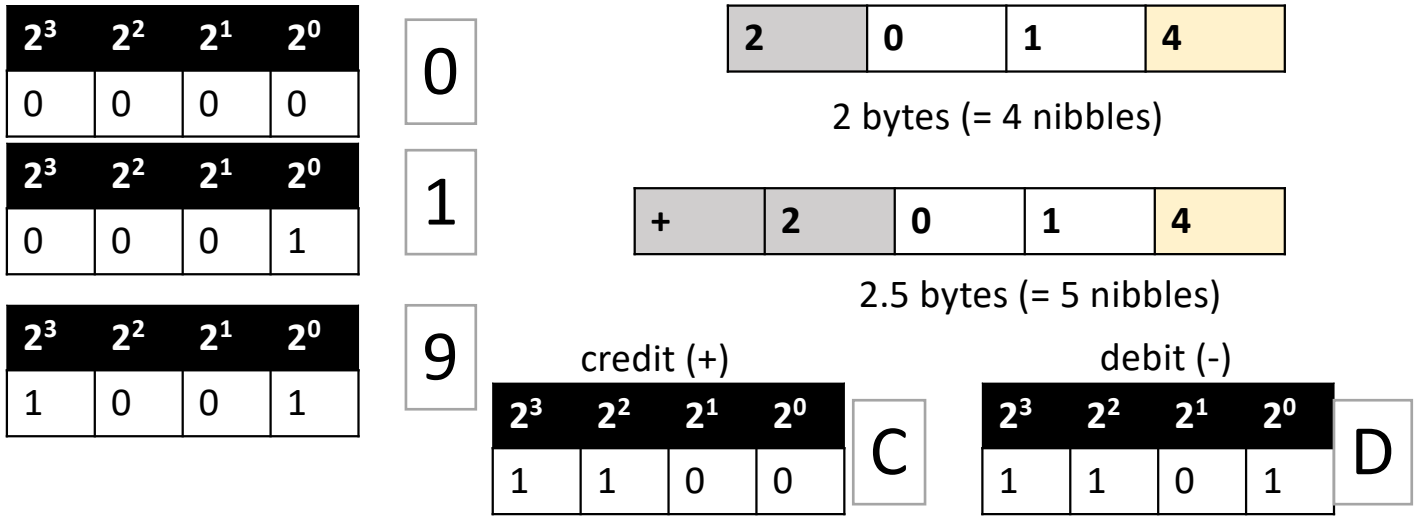
- Typically 32 bits (4 bytes) are used to store an integer
  - range: -2,147,483,648 ($2^{(31-1)}$ -1) to 2,147,483,647 ($2^{(32-1)}$ -1)



- what if you want to store even larger numbers?
  - Binary Coded Decimal (BCD)
  - code each decimal digit separately, use a string (sequence) of decimal digits …

Introduction: data types

- what if you want to store even larger numbers?
  - Binary Coded Decimal (BCD)
  - 1 byte can code two digits (0-9 requires 4 bits)
  - 1 nibble (4 bits) codes the sign (+/-), e.g. hex C/D



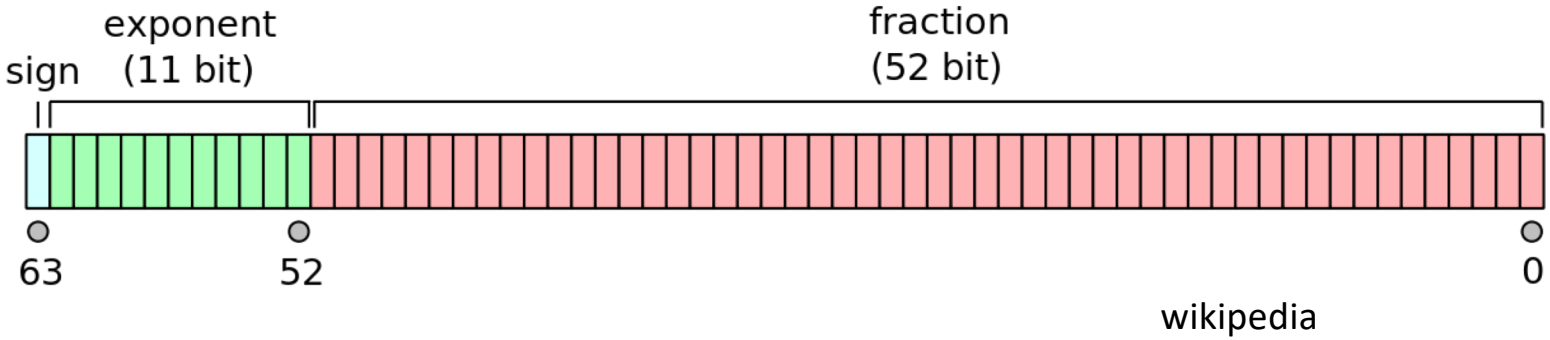
Introduction: data types

e.g. probabilities

- Typically, 64 bits (8 bytes) are used to represent floating point numbers (double precision)
  - c = 2.99792458 x 10^8 (m/s)
  - coefficient: 52 bits (**implied 1**, therefore treat as 53)
  - exponent: 11 bits (usually not 2's complement, unsigned with bias $2^{(10-1)}-1$ = 511)
  - sign: 1 bit (+/-)

C:
float
double

x86 CPUs have a built-in floating point coprocessor (x87)
80 bit long registers



wikipedia

Example 1

- The speed of light:
  - $c = 2.99792458 \times 10^8$ (m/s)

1. Can a 4 byte integer be used to represent *c* exactly?
   - 4 bytes = 32 bits
   - 32 bits in 2's complement format
   - Largest positive number is
   - $2^{31}-1 = 2,147,483,647$
   - $c = 299,792,458$

Example 2

- Recall the speed of light:
  - $c = 2.99792458 \times 10^8$ (m/s)

2. How much memory would you need to encode *c* using BCD notation?
   - 9 digits
   - each digit requires 4 bits (a nibble)
   - BCD notation includes a sign nibble
   - total is 5 bytes

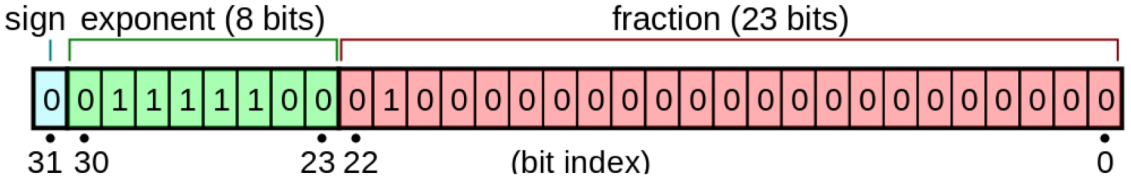
Example 3

- Recall the speed of light:
  - $c = 2.99792458 \times 10^8$ (m/s)

3. Can the 64 bit floating point representation (`double`) encode *c* without loss of precision?
   - Recall significand precision: 53 bits (52 explicitly stored)
   - $2^{53}-1 = 9{,}007{,}199{,}254{,}740{,}991$
   - almost 16 digits
   - (we only need 9 digits of precision)

Example 4

- Recall the speed of light:
  - c = 2.99792458 x 10^8 (m/s)
- The 32 bit floating point representation (`float`) – sometimes called single precision - is composed of 1 bit sign, 8 bits exponent (unsigned with bias $2^{(8-1)}$-1), and 23 bits coefficient (24 bits effective).



- Can it represent c without loss of precision?
  - 2^{24}-1 = 16,777,215
  - Nope (7 digits of precision)

Ungraded Homework Exercise

- What would the integer representation of the speed of light (in m/s) look like in binary representation as a 32 bit number?