Department of Electrical and Computer Engineering
Rutgers, The State University of New Jersey

Computer Architecture and Assembly Lab (14:332:333)
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Lab 1 *Introduction*

1.Number Representation

In order to write down a large number, we typically use the IEC or SI prefixing system:
IEC: Ki = 2^{10}, Mi = 2^{20}, Gi = 2^{30}, Ti = 2^{40}, Pi = 2^{50}, Ei = 2^{60}, Zi = 2^{70}, Yi = 2^{80};
SI: K = 10^3, M = 10^6, G = 10^9, T = 10^{12}, P = 10^{15}, E = 10^{18}, Z = 10^{21}, Y = 10^{24}.
I guess no one uses the SI system in the computer world except the harddisk vendors.

1.1 (12 pts) When programming in the C language, variable types such as char, short, int are often used. They can hold one byte, two bytes, and four bytes, respectively.
Convert the following numbers from decimal to binary and hexadecimal:
255, 65535, 4294967295

1.2 (12 pts) On x86 architecture, with the flat or the segmented memory model, linear address space is mapped into the processors' physical memory space either directly or through paging. When using the paging mode, the linear address space (often referred to as virtual memory) is composed of pages. For simplicity, we only consider 4KB pages. The pages are backed with physical pages through the Memory Management Unit (MMU). The MMU provides each process a 4GB virtual memory space.
Write the following using IEC prefixes: 2^{10}, 2^{12}, 2^{20}, 2^{31}, 2^{32}

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2. Two's complement

Unsigned binary numbers work for natural numbers, but many calculations use negative numbers as well. To deal with this, a number of different methods have been used to represent signed numbers, but we will focus on two's complement, as it is the standard solution for representing signed integers.

The two's complement of an N-bit number is defined as its complement with respect to 2^N. **The two's complement is calculated by inverting the bits and adding one.** For instance, for the three-bit number 101, the two's complement is 011, because 101 + 011 = 8 which is equal to 2^3.

2.1 (12 pts) What is the largest signed integer that can be represented with 8 bits? What is the largest unsigned integer that can be represented with 8 bits?

2.2 (12 pts) What is the range of decimals that 16-bit two's complement can represent?

2.3 (12 pts) Convert the following decimal numbers to binary numbers using two's complement: 5, -5 (assume the numbers are 8 bits)?

2.4 (16 pts) An adder is a digital circuit that performs the addition of numbers. In processors, adders are used in the arithmetic logic unit (ALU).
Finish the following equations in two's complement format. (If there is an overflow, only keep the last 8 bits).

5 + 5 = ?
5 + (-3) = ?
5 + (-5) = ?
3 + (-5) = ?
126 + 5 = ?

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3. Counting

Bit strings can be used to represent more than just numbers. In fact, we use bit strings to represent everything inside a computer. And, because we don't want to be wasteful with bits it is important to remember that **n** bits can be used to represent $\mathbf{2^n}$ distinct numbers. For each of the following questions, answer with the minimum number of bits possible:

3.1 (12 pts) On Intel x86 architecture, the processor has four protection rings: ring 0, ring 1, ring 2, and ring3. On the Windows system, ring 0 is the most privileged level and interacts directly with the physical hardware, while ring3 is the least privileged level where it runs user applications. How many bits do we need to represent the four rings in the processor hardware?

3.2 (12 pts) In the base RV32I ISA (RISC-V 32-bit Integer Instruction Set Architecture), there are six instruction formats based on the handling of immediate: R-type, I-type, S-type, B-type, U-type, and J-type. How many bits are needed to represent them when decoding instructions?