Boston Dynamics’ sprinting robot, Cheetah, has now broken the land-speed record for humans, clocking speeds of 29.3 miles per hour, meaning not even the 27.79mph Usain Bolt can escape. Fortunately for us, it's got a fatal flaw; a balance problem that means it can only remain upright with a boom keeping it steady. Unfortunately, that's not going to be a problem for long, since field-testing on an independently upright version begins early next year.

Open Questions

• Using dlc

  ./dlc -e bits.c
  comment explicitly on every problem

  [taylorm@jazz710:datalab-handout> ./dlc bits.c
  dlc:bits.c:142:bitNor: Illegal operator (/)
  dlc:bits.c:142:bitNor: Illegal operator (+)
  dlc:bits.c:142:bitNor: Illegal operator (<<)

• T*U = T or U? (integer mult)
  – Just conventions for talking about math
  – Really just bit patterns

• Other questions about the lab?
1. 3
2. 3
3. 5
4. 3
5. 4
6. 2
7. 1

21 min
Problems considered for Quiz

• 2.17 (p. 61)
• What is -5 in two’s compliment with 4 bits?
  – 5 bits?
  – 6 bits?
  – See the pattern?
• 2+5, 4 bit answer in two’s compliment
• 5+5, 4 bit answer in two’s compliment
• 2.31
• 3*3, 3 bit answer, in unsigned and two’s compliment
• 5*3, 3 bit answer, in unsigned and two’s compliment
• 2.40
• 2.44
Aside

- Precision in Python
### Fractional Binary Numbers

- **Representation**
  - Bits to right of “binary point” represent fractional powers of 2
  - Represents rational number:
    \[
    \sum_{k=-j}^{i} b_k \cdot 2^k
    \]
Floating Point Representation

- **Numerical Form:**
  \[ (-1)^s \ M \ 2^E \]
  - **Sign bit** \( s \) determines whether number is negative or positive
  - **Significand** \( M \) normally a fractional value in range \([1.0, 2.0)\).
  - **Exponent** \( E \) weights value by power of two

- **Encoding**
  - **MSB** \( s \) is sign bit \( s \)
  - **\( \text{exp} \)** field encodes \( E \) (but is not equal to \( E \))
  - **\( \text{frac} \)** field encodes \( M \) (but is not equal to \( M \))
Normalized Values

- Condition: \( \text{exp} \neq 000\ldots0 \) and \( \text{exp} \neq 111\ldots1 \)

- Exponent coded as biased value: \( E = \text{Exp} - \text{Bias} \)
  - \( \text{Exp} \): unsigned value \( \text{exp} \)
  - \( \text{Bias} = 2^{\text{e}-1} - 1 \), where \( \text{e} \) is number of exponent bits
    - Single precision: 127 (\( \text{Exp}: 1\ldots254, E: -126\ldots127 \))
    - Double precision: 1023 (\( \text{Exp}: 1\ldots2046, E: -1022\ldots1023 \))

- Significand coded with implied leading 1: \( M = 1.\text{xxx}...\text{x}_2 \)
  - \( \text{xxx}...\text{x} \): bits of \( \text{frac} \)
  - Minimum when 000...0 (\( M = 1.0 \))
  - Maximum when 111...1 (\( M = 2.0 - \varepsilon \))
  - Get extra leading bit for “free”
Normalized Encoding Example

- Value: Float $F = 15213.0$;
  - $15213_{10} = 11101101101101_2$
    - $= \text{[Diagram representation]}$

- Significand
  - $M = \text{[Diagram representation]}$
  - frac = \text{[Diagram representation]}

- Exponent
  - $E = \text{[Diagram representation]}$
    - Bias = \text{[Diagram representation]}
    - Exp = \text{[Diagram representation]}

- Result:
  - $s \text{ exp frac}$
Examples: 8 bit representation

- $k = 4$ (exponent)
- $n = 3$ (fraction bits)
- (bias = 7)

0 0001 000
0 0001 001
0 0111 000
0 1110 111