Instruction Sets

Why Not Make My Own?

Paul Gentemann
10/21/2014

Objectives

- Learn about Instruction Sets (IS).
- Design something new - a special-purpose IS that handles probabilities.
- Explore alternatives to standard floating point numbers.

Types of Instructions

- Data Handling/Memory
  - Load memory or a value into a register.
- Arithmetic/Logic
  - Add, subtract, multiply, divide, bitwise operations, compare values.
- Control Flow
  - Branch, make a call, conditional branch.

Types of Instruction Sets

- CISC - Complex Instruction Set Circuit
- RISC - Reduced Instruction Set Circuit
- MISC - Minimal Instruction Set Circuit
- OISC - One Instruction Set Circuit
- ZISC - Zero Instruction Set Circuit
- Still waiting for negative numbers...

CISC - Complex

- Think x86 architecture.
- Named because instructions are capable of executing several low-level operations.
  - LEA EAX, [ECX + EBX + 1234567]
- Designed to support high-level programming concepts.
- Too general-purpose for our needs.

RISC - Reduced

- For example, ARM.
- The name is meant to contrast CISC, though the gulf has narrowed over the years.
- Designed to use an optimized set of instructions.
  - Do one thing well philosophy.
  - Memory ops are generally separate from math ops.

MISC - Minimal

- ENIAC, or most ancient digital computers.
- Simpler design and implementation:
    - generally a stack-based machine
    - >1 instruction, <33 instructions
    - Not support general inputs
    - No hardware memory protections
    - Only Load/Store memory ops are supported
    - 64KB to 4GB memory, usually <1MB
    - No pipelines, branches, superscalar, register renaming

OISC - One

- Most "famous" is probably subleq:
  - Sample instruction: A B C
  - Means: B = B - A, jump to C if B<=0
- Cool, but not exactly the point of this project.

http://da.vidr.cc/projects/subleq/

ZISC - Zero

- Check out the CM1K.
- Massively hardwired, parallel processed, neural network stuff.
- “Zero” because no traditional instructions.
- Also not in scope, but still cool.

ZISC - Zero

- 15 registers
- 1024 neurons
- 4 “operations”
    - broadcast vector
    - recognize/learn vector
    - save knowledge
    - load knowledge

Register	Description	Addr	
COMP	Component	0x01	RW
LCOMP	Last Component	0x02	RW
DIST	Distance	0x03	R
CAT	Category	0x04	RW
AIF	Active Influence Field	0x05	R
NCR	Neuron Context Register	0x00	RW
NID	Neuron Identifier	0x06	R
NSR	Network Status Register	0x0D	RW
GCR	Global Context Register	0x00	RW
MINIF	Minimum Influence Field	0x06	RW
MAXIF	Maximum Influence Field	0x07	RW
FORGET	Clear the neurons	0x0F	W
NCOUNT	Committed neurons	0x0F	R
RESETCHAIN	Reset the neuron chain	0x0C	W

http://general-vision.com/documentation/TB_CM1K_simplest_API.pdf

Instruction Set Decision

- Either a simplified RISC, or a slightly extended MISC.
- Reasons for MISC:
  - Everything except the stack-focus.
- Reasons for RISC:
  - Uniform instruction format
  - Identical Registers
  - Simple addressing modes

Data Types

- Most integers and floats are <-1, or >1.
- Probability lies entirely in the range of [0,1]; except for quantum physicists, where [-1,1] is perfectly acceptable and useful.
- Feynman illustrating how negative probabilities might be interpreted: http://cds.cern.ch/record/154856/files/pre-27827.pdf

Data Types - Denormal?

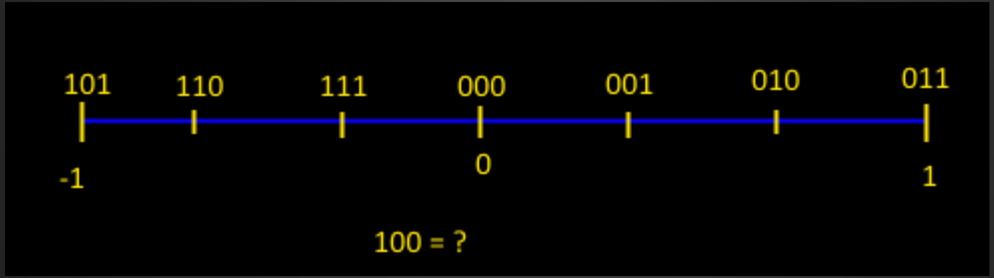
- Use only denormalized numbers?
  - Multiplication will always shrink, so accuracy will eventually reach 0.
  - In 32-bit, denormalized numbers exist in the range of +/- 2^{126}, or about +/- 1.18e-38… so no such thing as .5, let alone 1.

Data Types - Fixed Precision?

- Fixed-precision floats?
  - Essentially, split up the number line into equally-spaced pieces, determined by number of bits.
  - Can add flag bits to assist with divide-by-zero, +/-inf, NaN, out-of-range [-1, 1].
  - -1, 0, and 1 are in the set, and thus accurately represented.
  - Epsilon circuit, which checks whether an operation has underflowed our precision.

Data Types - Fixed Precision?

- Ex: 3-bits splits number line into 7 values: -1, $-\frac{2}{3}$, $-\frac{1}{3}$, 0, $\frac{1}{3}$, $\frac{2}{3}$, 1.



- $2^n - 1$ unique values, one excluded, balanced around zero.

Data Types - Fixed Precision?

- Denominator is (#values-1) / 2.
- Multiplication will often require more bits for accuracy.
  - No more than 2 bits, and that is squaring the smallest nonzero value.

Bit Value	Denominator	Squared
101	-3	1001
1001	-7	110001
10001	-15	11100001
100001	-31	1111000001

Data Types - Analog-Digital

- Use analog circuits, where voltage on a given bit represents the probability that the bit is a 1.
- Fast, simple, power efficient.
- Just recently learned of this type, so requires more research.

https://www.cs.uaf.edu/2011/spring/cs641/proj1/rarutter/

Operations - Algebraic Analogues

- Algebraic operations’ probability analogues:
    - Addition - sum of probabilities of mutually exclusive events. Also known as OR.
    - Subtraction - sum of probabilities excluding other events (usually All events not including event A).
    - Multiplication - independ joint probability of events. Also known as AND.
    - Division - used in conditional probabilities.

Operations - Unique to Probability

- Conditional Probability -

  P(A given B) = P(A AND B)/P(B)
  = P(B given A) * P(A) / P(B)
- Mutually dependent events -

  P(A OR B) = P(A) + P(B) - P(A AND B)
- Negation - P(~A) = 1 - P(A)

Operations

- Probability and CS haven’t communicated much. Here are the instructions I propose (let “val” be a number or register.
  - add val, val
  - sub val, val
  - mul val, val
  - div val, val
  - con val, val, val, val
  - mde val, val, val
  - not val

Operations

- It might be valuable to make not special, so you can say “add not val, val”, but that may be too complicated for the circuit I intend to design.
- There are also considerations from Lawlor’s comments on my draft that need to be addressed.

Thanks!

- You may applaud.