ECEN350 Computer Architecture Ref Sheet © Josh Wright 2015 Last Updated: November 9, 2016

Registers

n	10	hex	bin
`$0`	0	`0x00`	`00000`
`$at`	1	`0x01`	`00001`
`$v0`	2	`0x02`	`00010`
`$v1`	3	`0x03`	`00011`
`$a0`	4	`0x04`	`00100`
`$a1`	5	`0x05`	`00101`
`$a2`	6	`0x06`	`00110`
`$a3`	7	`0x07`	`00111`
`$t0`	8	`0x08`	`01000`
`$t1`	9	`0x09`	`01001`
`$t2`	10	`0x0a`	`01010`
`$t3`	11	`0x0b`	`01011`
`$t4`	12	`0x0c`	`01100`
`$t5`	13	`0x0d`	`01101`
`$t6`	14	`0x0e`	`01110`
`$t7`	15	`0x0f`	`01111`

`$s0`	16	`0x10`	`10000`
`$s1`	17	`0x11`	`10001`
`$s2`	18	`0x12`	`10010`
`$s3`	19	`0x13`	`10011`
`$s4`	20	`0x14`	`10100`
`$s5`	21	`0x15`	`10101`
`$s6`	22	`0x16`	`10110`
`$s7`	23	`0x17`	`10111`
`$t8`	24	`0x18`	`11000`
`$t9`	25	`0x19`	`11001`
`$k0`	26	`0x1a`	`11010`
`$k1`	27	`0x1b`	`11011`
`$gp`	28	`0x1c`	`11100`
`$sp`	29	`0x1d`	`11101`
`$fp`	30	`0x1e`	`11110`
`$ra`	31	`0x1f`	`11111`

- callee saved registers: `$s0-$s7, $sp, $gp, $fp`
  - ∗ save parent's value at beginning of function
- caller saved registers: basically all the others
  - ∗ save your value before calling subroutine
- general format is to list destination first, then operands

Clock Rate

period	rate
1 msec	1 MHz
100 nsec	10 MHz
10 nsec	100 MHz
5 nsec	200 MHz

2 nsec	500 MHz
1 nsec	1 GHz
500 psec	2 GHz
250 psec	4 GHz
200 psec	5 GHz

Metric Prefixes

peta	P	10^{15}	1 000 000 000 000 000
tera	T	10^{12}	1 000 000 000 000
giga	G	10^{9}	1 000 000 000
mega	M	10^{6}	1 000 000
kilo	k	10^{3}	1 000
hecto	h	10^{2}	100
deca	da	10^{1}	10
one		10^{0}	1
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	μ	10^{-6}	0.000 001
nano	n	10^{-9}	0.000 000 001
pico	p	10^{-12}	0.000 000 000 001
femto	f	10^{-15}	0.000 000 000 000 001

J format (absolute branching)

- cannot change the top 4 bits of PC. (`PC[31:28]`)
- range:
  - ∗ total of 2^{26} instructions or 2^{28} bytes
    - because range is $[0, 2^{26} - 1]$
  - ∗ farthest possible next instruction is 2^{26} away (if `PC+4` lies at the beginning of a 2^{28} byte boundary)
  - ∗ worst case is you can only jump 1 instruction ahead (if `PC+4` lies at the end of a 2^{28} byte boundary)
- conversion:
  - ∗ instruction stores 26 bits
  - ∗ right pad with two 0s to get 28
  - ∗ take the top four bits from current PC to get 32
- mask of top 4 bits: `0xF0000000`
- `target = (PC AND 0xF0000000) OR (addr << 2)`

Relative Branching

- range: $[PC - 2^{17}, PC + 2^{17} - 4]$
  - ∗ that's in bytes. It's a range of $2^{15} - 1$ words
  - ∗ you lose one from the exponent because it's 2's complement
- conversion
  - ∗ take 16 bit offset, zero pad by 2 (multiply by 4)
  - ∗ add to PC+4 (next PC)
- `target = (PC + 4) + (addr << 2)`
- due to the `PC+4` thing, if you want to jump back to the same instruction, the immediate value will be `-1`

Endianness

Value: `0xA0B0C0D0`

index	0	1	2	3
little	`0xD0`	`0xC0`	`0xB0`	`0xA0`
big	`0xA0`	`0xB0`	`0xC0`	`0xD0`

- ∗ Little Endian puts the least significant (littlest) stuff first
- x86 is little endian, MIPS is big endian
- networking is done in big endian

Two's Complement

- N bits can represent a range $[-2^N, +2^N - 1]$
- methods for converting negative values
- method 1:
  - ∗ start with absolute value
  - ∗ flip all bits (bitwise not)
  - ∗ add 1
- method 2:
  - ∗ use $N+1$ bits (2^N is $N+1$ bits)
  - ∗ start with absolute value x
  - ∗ find $2^N - x$
  - ∗ truncate

Shifts

- shift left always fills with 0s
- **Logical** left shift fills with 0s
- **Arithmetic** left shift sign-extends
  - ∗ extends based on far left bit (most significant)

Assembler

- Spilling: when a compiler puts a variable in main memory because it's run out of registers
  - ∗ the variable has spilled to RAM
  - ∗ inverse is filling
- Object file sections: header; text; data; relocation information; symbol table; debugging information
  - ∗ Object file is assembled assuming that instructions start at `0x00`. (this is corrected later by the linker)
- Global label can be referenced in any file
  - ∗ you must declare it global in the file where it is defined, and declare it global again where it's used
  - ∗ `main` must be global so the linker can find it

* `printf` is global so you can use it (but you must still declare it as global in that file where you use it)
- local label can be referenced in only the current file
  * labels are local by default
- **Symbol Table:** contains all external references
  * also lists unresolved references (e.g. printf)
  * as far as assembler is concerned, symbol table contains both local and global labels, resolved and unresolved.
  * The final assembled object file only contains global labels
- **Relocation Table:** contains references to all things that depend on absolute addresses
  * e.g. all absolute jumps, load address
  * these must be changed after loading into memory
  * does not contain addresses of labels

Verilog

- always block: synthesize to combinational logic iff:
  * everything written to is always written exactly once for every case of inputs
  * the outputs of the always block depend only on inputs that are in the sensitivity list
  * stuff assigned to inside an always block must be declard `reg`
    - will be optimized out if it's combinational
- bitwise not is $\sim$
- ternary operator: `cond ? if_true : if_false`
- assignments: `=` is blocking, `<=` is non-blocking
  * `=`: happens in order
  * `<=`: happens all at once
- case statement: can use `?` to specify 'don't care' for some bits
- `` `timescale unit/precision ``:
  * `unit`: 1, 10, or 100, unit either s, ms, us, ps, fs
  * `precision`: must be shorter than `unit`

State Machine

- Mealy Machine: outputs determined by current state and current inputs
- Moore Machine: outputs determined by current state only

Performance

- execution time = (# of clock cycles) × (clock cycle time) = (# of clock cycles)/(clock rate)
- CPI: Cycles Per Instruction
  * effective CPI is just a weighted average (varies by instruction mix)
- instructions per time = CPI / clock rate = CPI * clock period
- compare two systems:
  * use instruction latencies and instruction mix to calculate CPI for each setup
  * then calculate instructions per time, and do comparison there

IEEE Floating-Point

- 1 bit sign; 8 bit exponent; 23 bit mantissa
  * $x = (-1)^s \cdot (1 :: m) \cdot 2^{e-127}$
- sign: 0 for positive, 1 for negative
- exponent: bias is -127
- mantissa: the fractional part; denominator 2^{23}
  * implicit leftmost bit is not stored, only fractional
- conversion: decimal to float:
  * start with x
  * use $\lfloor \log_2 \rfloor$ to express x as $a \cdot 2^b$ where $1 \leq a < 2$
  * exponent $= 127 + b$
  * mantissa $= (a-1) \cdot 2^{23}$
    - round to nearest integer
- conversion: float to decimal:
  * real exponent $a = exp - 127$
  * take exponent as integer $\rightarrow a$
  * decimal $= (1 + \frac{a}{2^{23}}) \cdot 2^a$
- calculate mantissa directly: $\frac{x}{2^{\lfloor \log_2(x) \rfloor}} \cdot 2^{23}$
- mantissa the long way:
  take right-of-decimal part and repeatedly multiply by 2. On each iteration, the 1's place is that bit in the mantissa. (starting from leftmost bit)
- quantity of numbers on range $[2^n, 2^{n+1}] = 2^{23} + 1$
  quantity of numbers on range $[2^n, 2^{n+1}) = 2^{23}$
  * the 2^{n+1} bumps it up because the exponent changes
- next largest float: add 2^{-23} to mantissa (assuming exponent doesn't change, i.e. number isn't evenly 2^n)
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exponent	mantissa	meaning
0	0	±zero
0	$\neq 0$	denormalized
1-254	any	normal
255	0	$\pm\infty$
255	$\neq 0$	NaN

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	float	double
sign	1 bit	1 bit
exponent	8 bits	11
exp bias	127	1023
exp min	-126	-1022
exp max	+127	+1023
mantissa	23 bits	52 bits

- minimum integer that can't be exactly represented: $2^{24} + 1 = 16\ 777\ 217$