

RISC, CISC, and Assemblers

Hakim Weatherspoon

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Computer Science

Cornell University

See P&H Appendix B.1-2, and Chapters 2.8 and 2.12

Announcements

PA1 due *this* Friday

Work in **pairs**

Use your resources

- FAQ, class notes, book, Sections, office hours, newsgroup, CSUGLab

Prelims1: next Thursday, March 10th **in class**

- Material covered
 - Appendix C (logic, gates, FSMs, memory, ALUs),
 - Chapter 4 (pipelined [and non-pipeline] MIPS processor with hazards),
 - Chapters 2 and Appendix B (RISC/CISC, MIPS, and calling conventions),
 - Chapter 1 (Performance).
 - HW1, HW2, PA1, PA2.
- Practice prelims are online in CMS
- Closed Book: cannot use electronic device or outside material
- **We will start at 1:25pm sharp, so come early**

Goals for Today

Instruction Set Architectures

- Arguments: stack-based, accumulator, 2-arg, 3-arg
- Operand types: load-store, memory, mixed, stacks, ...
- Complexity: CISC, RISC

Assemblers

- assembly instructions
- psuedo-instructions
- data and layout directives
- executable programs

Instruction Set Architecture

ISA defines the permissible instructions

- **MIPS**: load/store, arithmetic, control flow, ...
- ARM: similar to MIPS, but more shift, memory, & conditional ops
- VAX: arithmetic on memory or registers, strings, polynomial evaluation, stacks/queues, ...
- Cray: vector operations, ...
- x86: a little of everything

One Instruction Set Architecture

Toy example: subleq a, b, target

$\text{Mem}[b] = \text{Mem}[b] - \text{Mem}[a]$

then if ($\text{Mem}[b] \leq 0$) goto target

else continue with next instruction

clear a == subleq a, a, pc+4

jmp c == subleq Z, Z, c

add a, b == subleq a, Z, pc+4;

 subleq Z, b, pc+4;

 subleq Z, Z, pc+4

PDP-8

Not-a-toy example: PDP-8

One register: AC

Eight basic instructions:

AND a	# AC = AC & MEM[a]
TAD a	# AC = AC + MEM[a]
ISZ a	# if (!++MEM[a]) skip next
DCA a	# MEM[a] = AC; AC = 0
JMS a	# jump to subroutine (e.g. jump and link)
JMP a	# jump to MEM[a]
IOT x	# input/output transfer
OPR x	# misc operations on AC

Stack Based

Stack machine

- data *stack* in memory, *stack pointer* register
- Operands popped/pushed as needed
add

[Java Bytecode, PostScript, odd CPUs, some x86]

Tradeoffs:

Accumulator Based

Accumulator machine

- Results usually put in dedicated **accumulator** register
- add b
store b

[Some x86]

Tradeoffs:

Load-Store

Load/store (register-register) architecture

- computation only between registers

[MIPS, some x86]

Tradeoffs:

Axes

Axes:

- Arguments: stack-based, accumulator, 2-arg, 3-arg
- Operand types: load-store, memory, mixed, stacks, ...
- **Complexity**: CISC, RISC

Complex Instruction Set Computers

People programmed in assembly and machine code!

- Needed as many addressing modes as possible
- Memory was (and still is) slow

CPUs had relatively few registers

- Register's were more “expensive” than external mem
- Large number of registers requires many bits to index

Memories were small

- Encoraged highly encoded microcodes as instructions
- Variable length instructions, load/store, conditions, etc

Reduced Instruction Set Computer

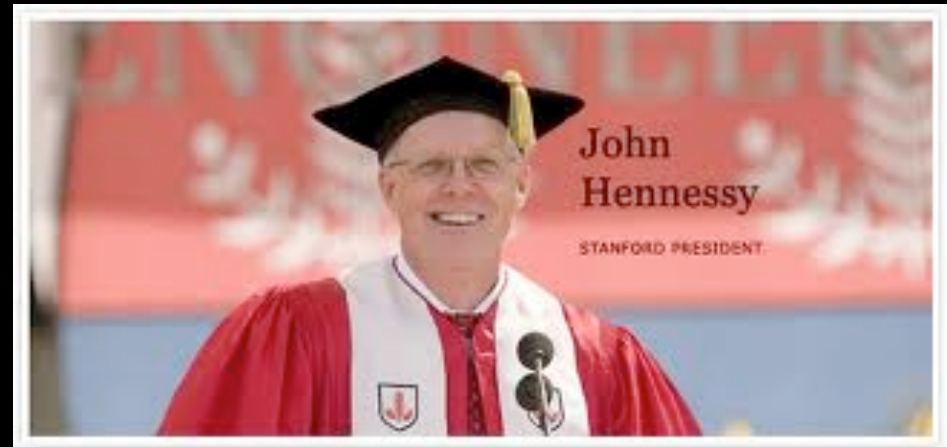
Dave Patterson

- RISC Project, 1982
- UC Berkeley
- RISC-I: $\frac{1}{2}$ transistors & 3x faster
- Influences: Sun SPARC, namesake of industry



John L. Hennessy

- MIPS, 1981
- Stanford
- Simple pipelining, keep full
- Influences: MIPS computer system, PlayStation, Nintendo



Complexity

MIPS = Reduced Instruction Set Computer (RISC)

- \approx 200 instructions, 32 bits each, 3 formats
- all operands in registers
 - almost all are 32 bits each
- \approx 1 addressing mode: Mem[reg + imm]

x86 = Complex Instruction Set Computer (CISC)

- $>$ 1000 instructions, 1 to 15 bytes each
- operands in dedicated registers, general purpose registers, memory, on stack, ...
 - can be 1, 2, 4, 8 bytes, signed or unsigned
- 10s of addressing modes
 - e.g. Mem[segment + reg + reg*scale + offset]

RISC vs CISC

RISC Philosophy

Regularity & simplicity

Leaner means faster

Optimize the
common case

CISC Rebuttal

Compilers can be smart

Transistors are plentiful

Legacy is important

Code size counts

Micro-code!

Goals for Today

Instruction Set Architectures

- Arguments: stack-based, accumulator, 2-arg, 3-arg
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- Complexity: CISC, RISC

Assemblers

- assembly instructions
- psuedo-instructions
- data and layout directives
- executable programs

Examples

```
...
T: ADDI r4, r0, -1
   BEQ r3, r0, B
   ADDI r4, r4, 1
   LW r3, 0(r3)
   J T
   NOP
B: ...
```

```
...
JAL L
nop
nop
L: LW r5, 0(r31)
   ADDI r5, r5, 1
   SW r5, 0(r31)
   ...
```


cs3410 Recap/Quiz

C

compiler

```
int x = 10;  
x = 2 * x + 15;
```

MIPS

assembly

assembler

```
addi r5, r0, 10  
muli r5, r5, 2  
addi r5, r5, 15
```

machine
code

```
00100000000010100000000000001010  
00000000000000101001010000100000  
001000001010010100000000000001111
```

CPU

Circuits

Gates

Transistors

Silicon

Example 1

```

...
T: ADDI r4, r0, -1
   BEQ r3, r0, B
   ADDI r4, r4, 1
   LW r3, 0(r3)
   J T
   NOP
B: ...

```

...
001000
000100
001000
100011
000010
00
...

References

Q: How to resolve labels into offsets and addresses?

A: Two-pass assembly

- 1st pass: lay out instructions and data, and build a *symbol table* (mapping labels to addresses) as you go
- 2nd pass: encode instructions and data in binary, using symbol table to resolve references

Example 2

```
...  
JAL L  
nop  
nop  
L: LW r5, 0(r31)  
ADDI r5,r5,1  
SW r5, 0(r31)  
...
```

...
00100000000100000000000000000100
00000000000000000000000000000000
00000000000000000000000000000000
10001111110010100000000000000000
00100000101001010000000000000001
00000000000000000000000000000000
...

Example 2 (better)

```
.text 0x00400000 # code segment
```

```
...
```

```
ORI r4, r0, counter
```

```
LW r5, 0(r4)
```

```
ADDI r5, r5, 1
```

```
SW r5, 0(r4)
```

```
...
```

```
.data 0x10000000 # data segment
```

```
counter:
```

```
.word 0
```

Lessons

Lessons:

- Mixed data and instructions (von Neumann)
- ... but best kept in separate *segments*
- Specify layout and data using *assembler directives*
- Use *pseudo-instructions*

Pseudo-Instructions

Pseudo-Instructions

NOP # do nothing

MOVE reg, reg # copy between regs

LI reg, imm # load immediate (up to 32 bits)

LA reg, label # load address (32 bits)

B label # unconditional branch

BLT reg, reg, label # branch less than

Assembler

Assembler:

psuedo-instructions

+ data and layout directives

= executable program

Slightly higher level than plain assembly

e.g: takes care of delay slots

(will reorder instructions or insert nops)

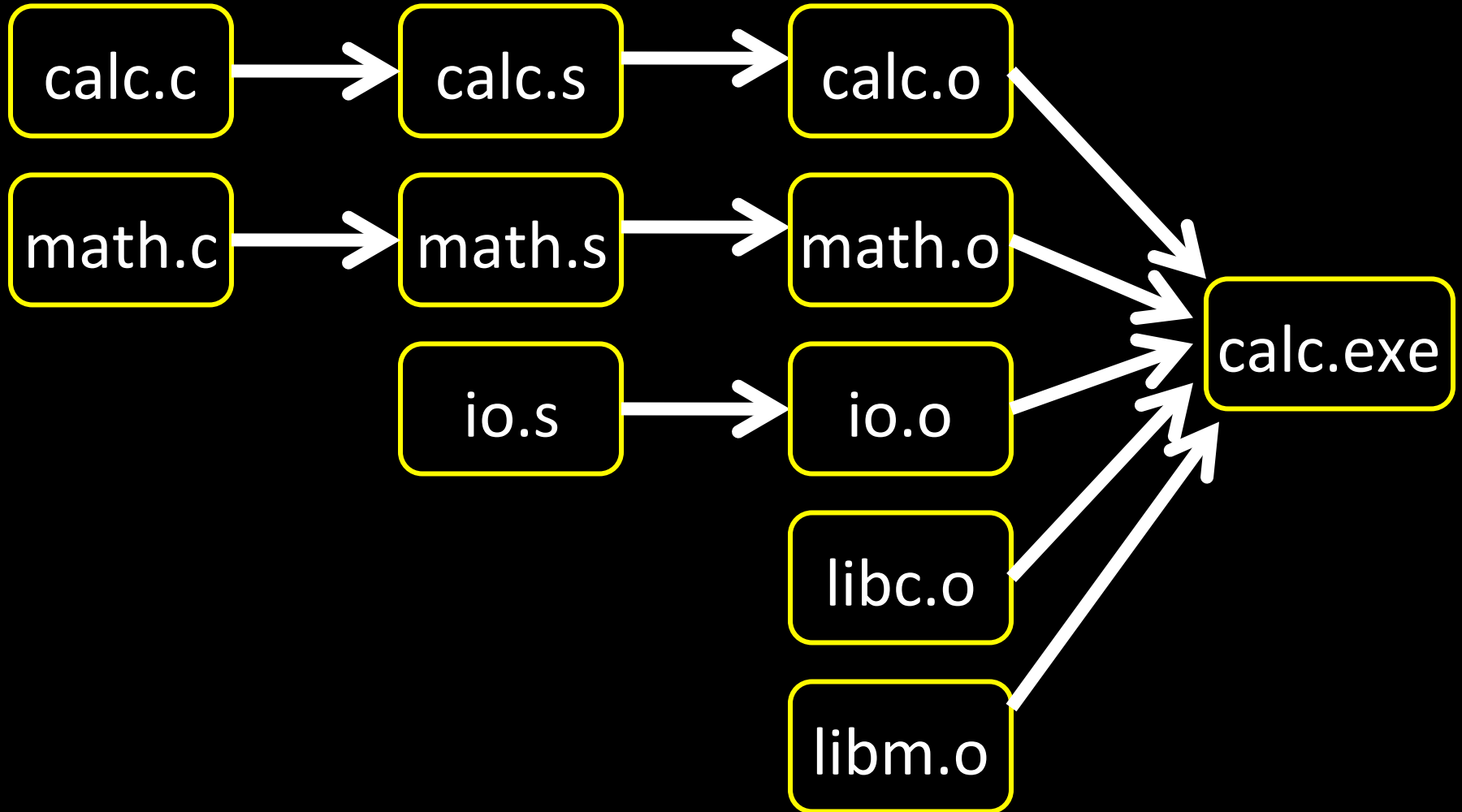
Motivation

Q: Will I program in assembly?

A: I do...

- For kernel hacking, device drivers, GPU, etc.
- For performance (but compilers are getting better)
- For highly time critical sections
- For hardware without high level languages
- For new & advanced instructions: rdtsc, debug registers, performance counters, synchronization, ...

Stages



Anatomy of an executing program

0xfffffffffc

top

0x80000000

0x7fffffff

0x10000000

0x00400000

0x00000000

bottom

Example program

calc.c

```
vector v = malloc(8);  
v->x = prompt("enter x");  
v->y = prompt("enter y");  
int c = pi + tnorm(v);  
print("result", c);
```

math.c

```
int tnorm(vector v) {  
    return abs(v->x)+abs(v->y);  
}
```

lib3410.o

```
global variable: pi  
entry point: prompt  
entry point: print  
entry point: malloc
```

math.s

math.c

```
int abs(x) {  
    return x < 0 ? -x : x;  
}  
int tnorm(vector v) {  
    return abs(v->x)+abs(v->y);  
}
```

tnorm:

arg in r4, return address in r31

leaves result in r4

abs:

arg in r3, return address in r31

leaves result in r3

calc.s

calc.c

```
vector v = malloc(8);
v->x = prompt("enter x");
v->y = prompt("enter y");
int c = pi + tnorm(v);
print("result", c);
```

.data

str1: .asciiz "enter x"

str2: .asciiz "enter y"

str3: .asciiz "result"

.text

.extern prompt

.extern print

.extern malloc

.extern tnorm

.global dostuff

dostuff:

no args, no return value, return addr in r31

MOVE r30, r31

LI r3, 8 # call malloc: arg in r3, ret in r3

JAL malloc

MOVE r6, r3 # r6 holds v

LA r3, str1 # call prompt: arg in r3, ret in r3

JAL prompt

SW r3, 0(r6)

LA r3, str2 # call prompt: arg in r3, ret in r3

JAL prompt

SW r3, 4(r6)

MOVE r4, r6 # call tnorm: arg in r4, ret in r4

JAL tnorm

LA r5, pi

LW r5, 0(r5)

ADD r5, r4, r5

LA r3, str3 # call print: args in r3 and r4

MOVE r4, r5

JAL print

IR r30

Next time

Calling Conventions!

PA1 due Friday

Prelim1 Next Thursday, in class