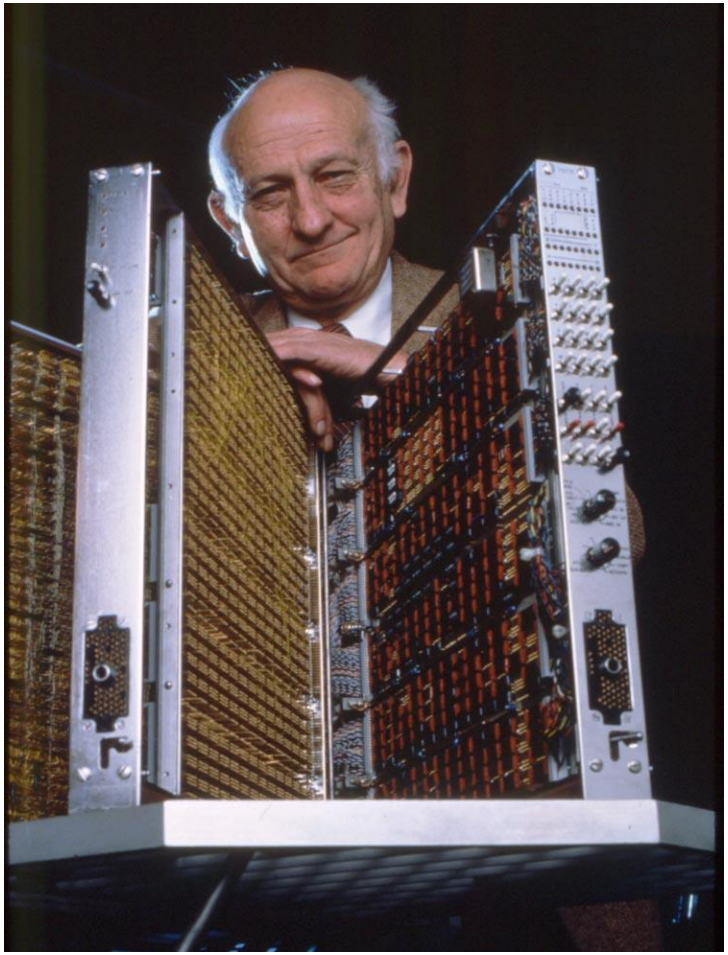
Computer Systems and Networks

ECPE 170 – Jeff Shafer – University of the Pacific

MIPS Assembly
(Arithmetic, Branches)

Person of the Day – John Cocke



- Computer architecture pioneer
  - "Father of RISC Architecture"
  - Developed IBM 801 processor, 1975-1980
- Winner, *ACM Turing Award*, 1987

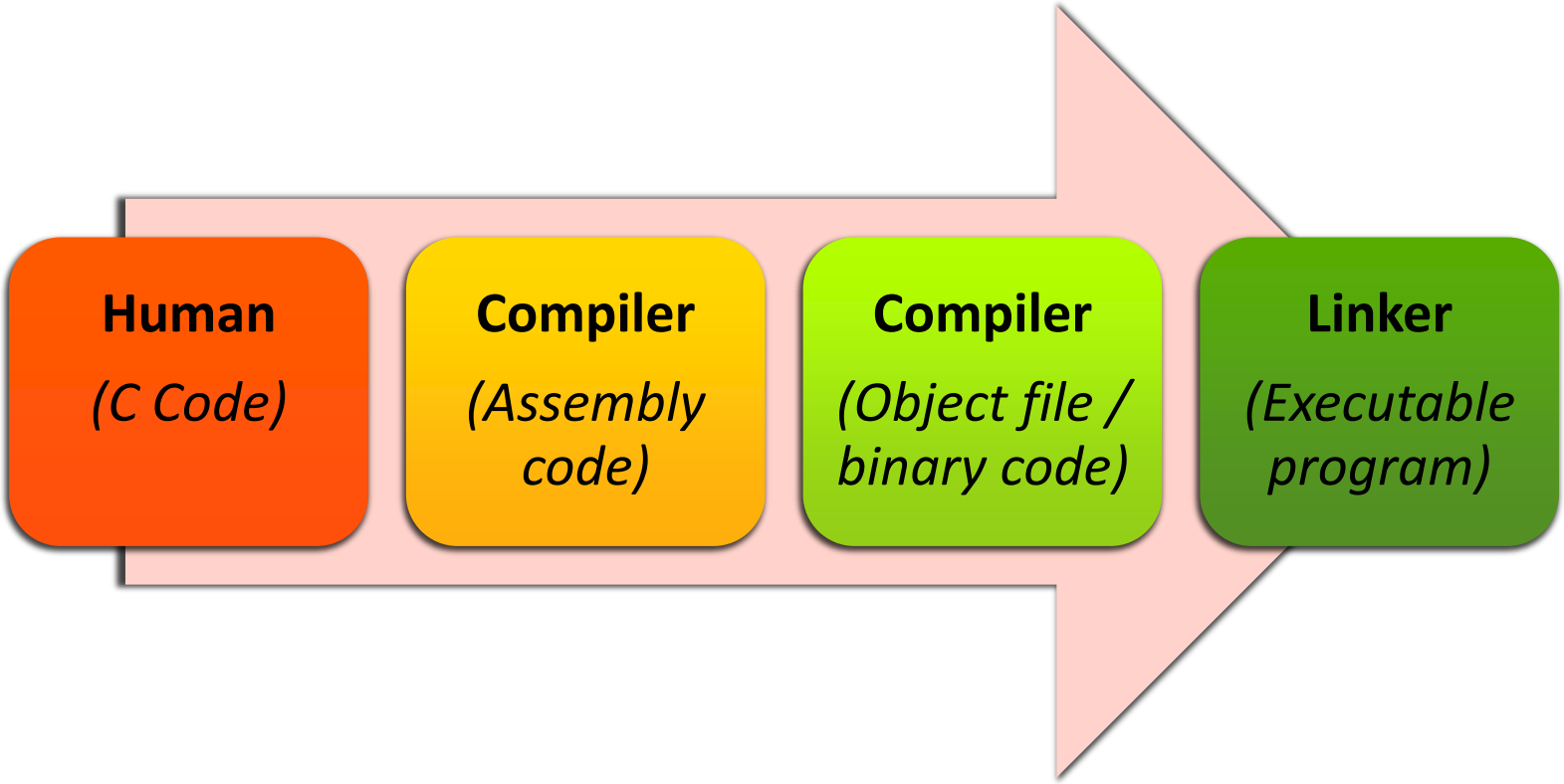
RISC = Reduced Instruction Set Computing

Achieve higher performance with simple instructions that execute faster

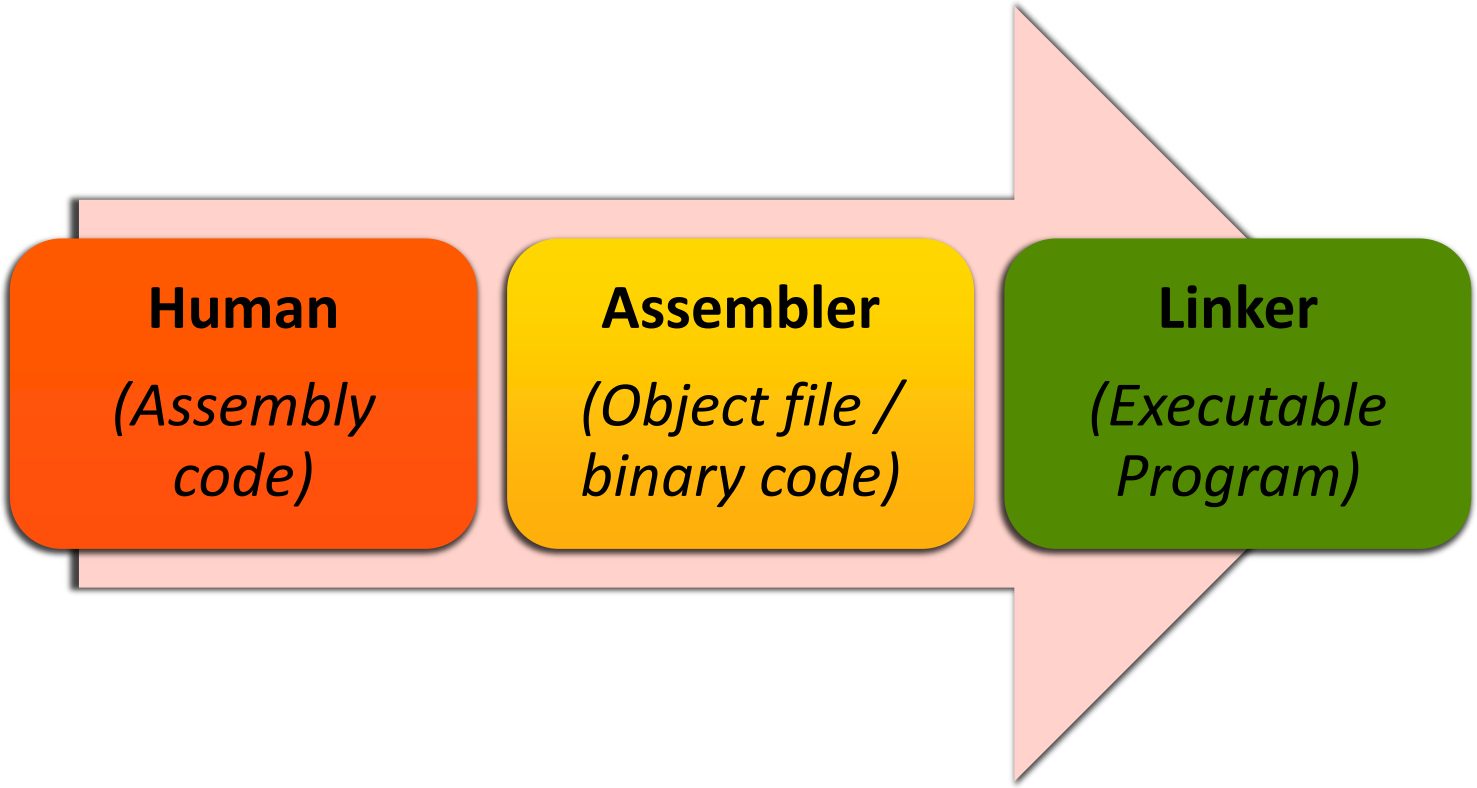
Person of the Day – John Hennessy

- Computer architecture pioneer
- Popularized RISC architecture in early 1980's
- Founder of MIPS Computer Systems in 1984
- Past president of Stanford University

Class to Date



Class Now


Human
(Assembly code)
Assembler
(Object file / binary code)
Linker
(Executable Program)

MIPS

MIPS Overview

- Family of computer processors first introduced in 1981
- **M**icroprocessor without **I**nterlocked **P**ipeline **S**tages
  - Original acronym
  - Now MIPS stands for nothing at all…

MIPS Products

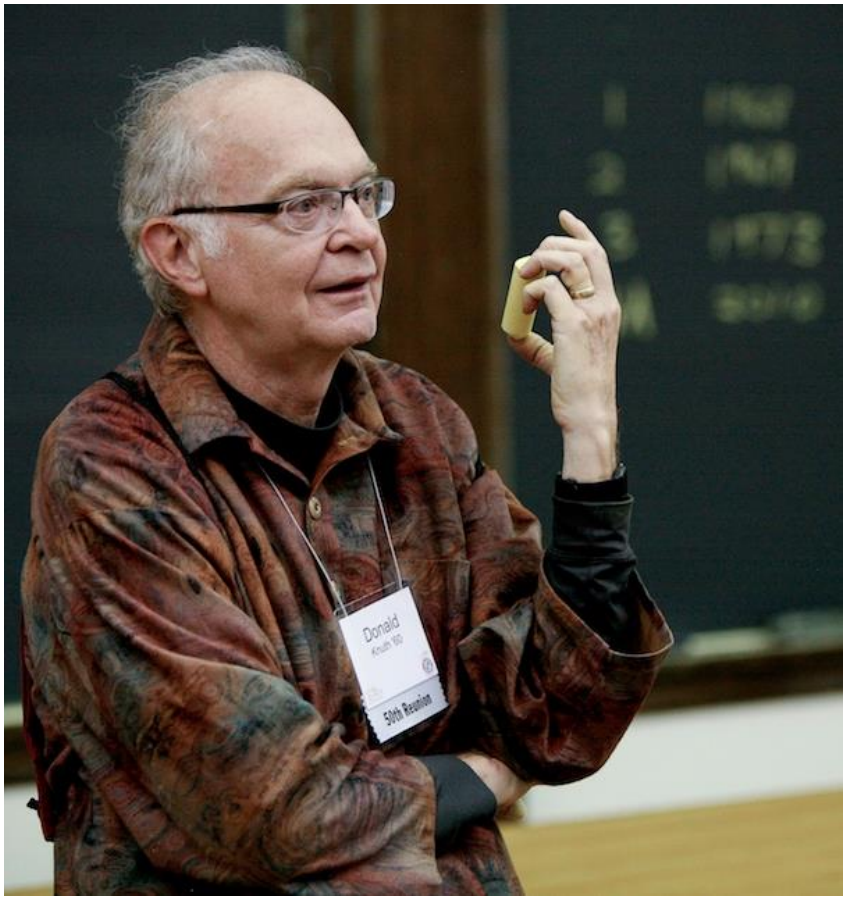
- **Embedded devices**
  - Cisco/Linksys routers
  - Cable boxes
  - MIPS processor is buried inside *System-on-a-Chip (SOC)*
- Gaming / entertainment
  - Nintendo 64
  - Playstation, Playstation 2, PSP
- Computers?
  - Not so much anymore…
  - SGI / DEC / NEC workstations back in 1990's

MIPS Design

- RISC – **What does this mean?**
  - **R**educed **I**nstruction **S**et **C**omputing
  - Simplified design for instructions
  - Use more instructions to accomplish same task
    - But each instruction runs much faster!
- 32 bits (originally) – **What does this mean?**
  - 1 “word”= 32 bits
  - Size of data processed by an integer add instruction
  - New(er) MIPS64 design is 64 bits, but we won’t focus on that

MIPS Assembly Programming

Quotes – Donald Knuth



"People who are more than casually interested in computers should have at least **some idea of what the underlying hardware is like**. Otherwise the programs they write will be pretty weird."
– Donald Knuth

This is your motivation in the assembly labs!

Why Learn Assembly Programming?

- **Computer Science** track
  - Understand capabilities (and limitations) of physical machine
  - Ability to optimize program performance (or functionality) at the assembly level *if necessary*
- **Computer Engineer** track
  - Future courses (e.g. ECPE 173) will focus on processor design
  - Start at the assembly programming level and move into hardware
    - *How* does the processor implement the `add` instruction?
    - *How* does the processor know what data to process?

Instruction Set Architecture

- **Instruction Set Architecture (ISA)** is the interface between hardware and software
  - Specifies the format of processor instructions
  - Specifies the format of memory addresses (and addressing modes)
  - Specifies the primitive operations the processor can perform

Instruction Set Architecture

- **ISA is the "contract" between the *hardware designer* and the assembly-level *programmer***
- Documented in a manual that can be hundreds or thousands of pages long
  - Example: Intel 64 and IA-32 Architectures Software Developers Manual
  - http://www.intel.com/content/www/us/en/processors/architectures-software-developer-manuals.html
  - No joke – the manual PDF (combined volumes) from Nov 2020 is **5066 pages long**!

Instruction Set Architecture

- Processor families share the same ISA
- Example ISAs:
  - Intel x86
  - Intel / AMD x86-64
  - Intel Itanium
  - ARM
  - IBM PowerPC
  - MIPS

All completely different, in the way that C++, Java, Perl, and PHP are all different…

… and yet learning one language makes learning the next one much easier

Why MIPS?

- Why choose MIPS?
  - The MIPS ISA manual (volume 1, at least) is a svelte **108 pages**!
  - Extremely common ISA in textbooks
  - Freely available simulator
  - Common embedded processor
  - Good building-block for other RISC-style processors
  - Aligns with ECPE 173 course

Arithmetic Instructions

- Addition

```
add <result>, <input1>, <input2>
```

- Subtraction

```
sub <result>, <input1>, <input2>
```

Operation / “Op code”

Operands

Task : Write Code

- **Write MIPS assembly for**

$$f = (g+h) - (i+j)$$

```
add temp0, g, h
add temp1, i, j
sub f, temp0, temp1
```

Congratulations!

You're now an assembly programming expert!

Data Sources

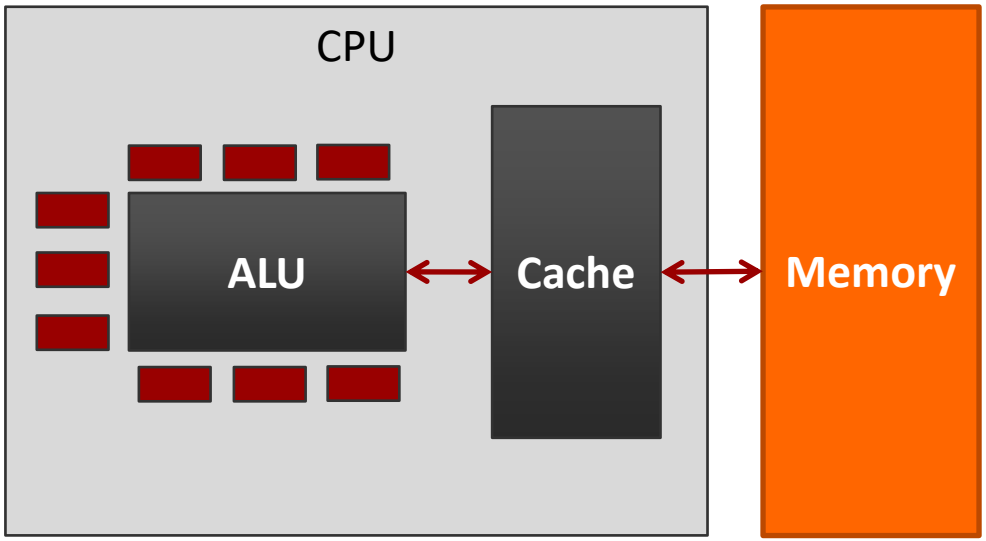
- Previous example was *(just a little bit)* fake…
  - We made up some variables: `temp0`, `temp1`, `f`, `g`, `h`, `i`, and `j`
  - This is what you do when programming in C++ (or any high level language)

Problem: You can't make up variables in assembly!

(as least, not in this fashion)

Data Sources

Where can we explicitly place data in assembly programming?



1. **Registers**
   - On the CPU itself
   - Very close to ALU
   - Tiny
   - Access time: 1 cycle
2. **Memory**
   - Off-chip
   - Large
   - Access time: 100+ cycles

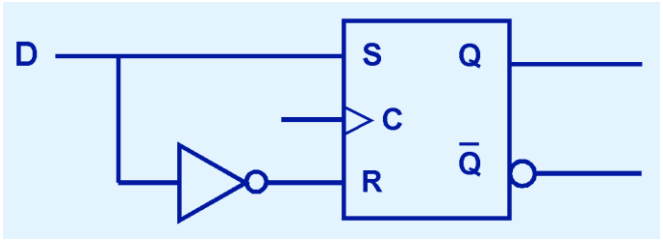
Aside – Cache

- **Review: Does the programmer explicitly manage the cache?**
- **Answer: No!**
  - The assembly programmer just reads/writes memory addresses
  - Cache is managed automatically in hardware
  - Result: Memory *appears* to be faster than it really is

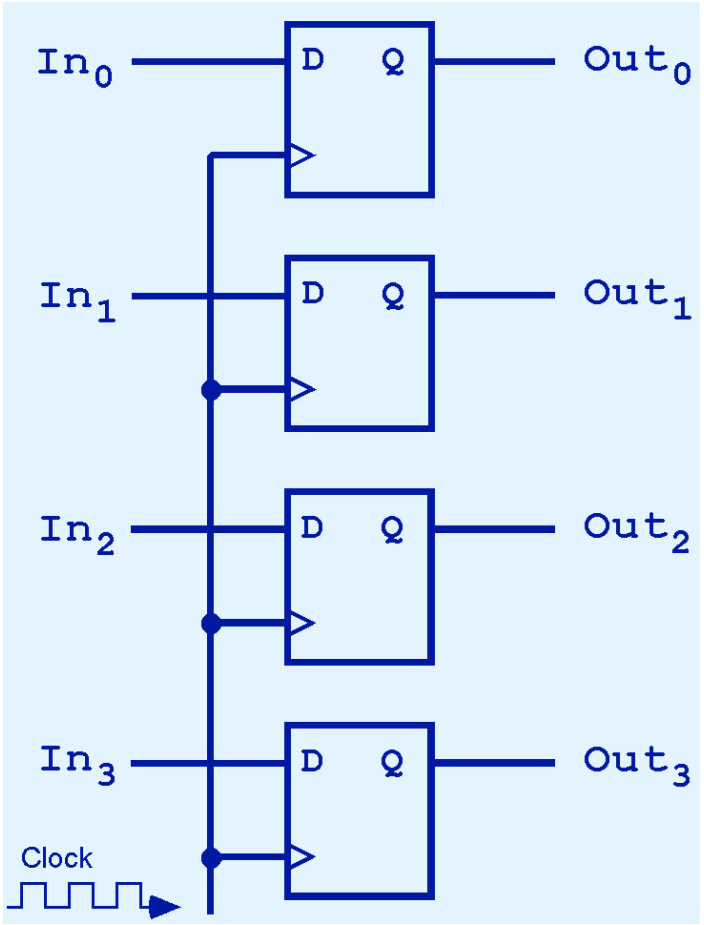
ECPE 71

- **From your knowledge of ECPE 71 (Digital Design), how would you construct a register?**

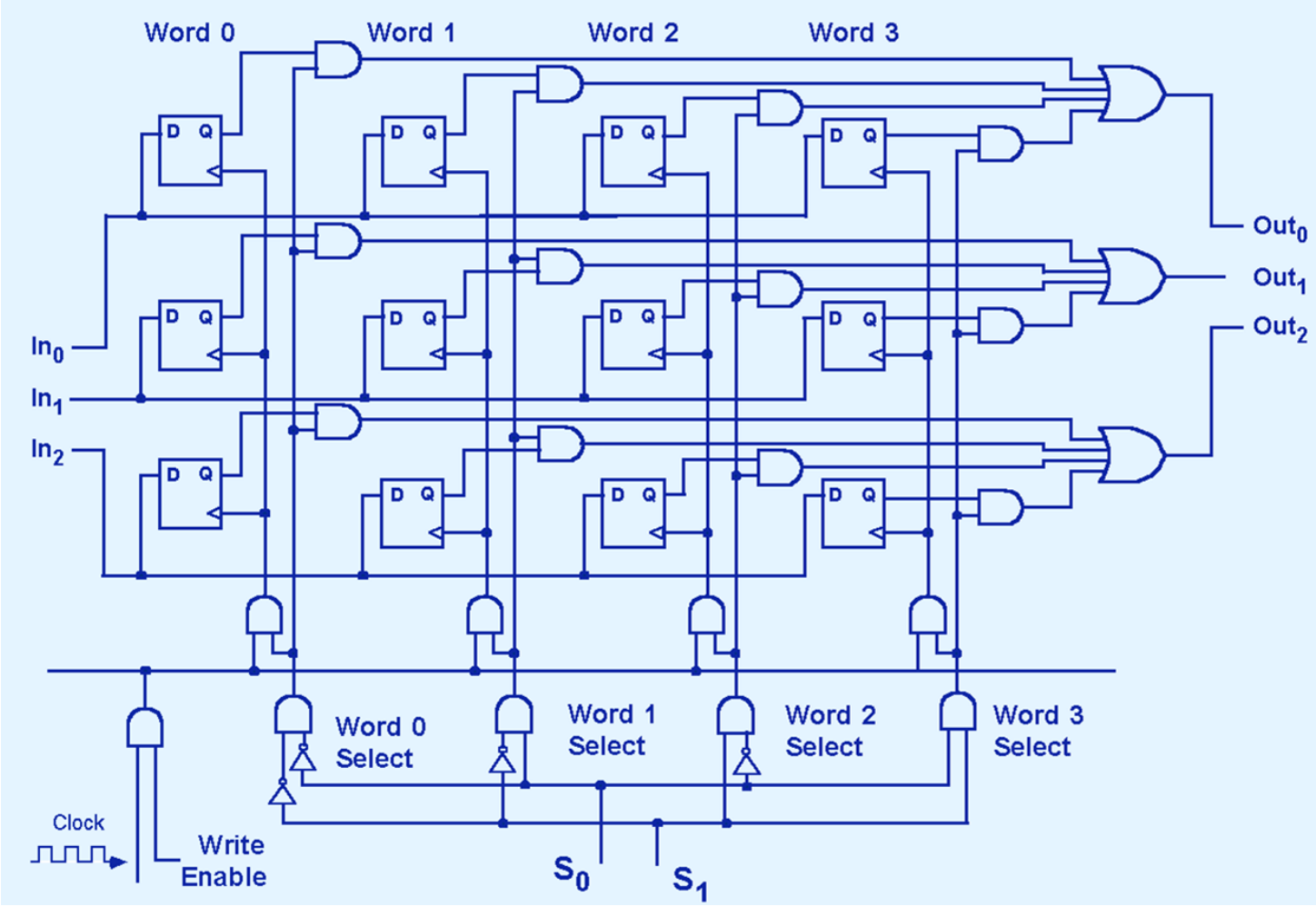
Flip Flops! *(D Flip Flop shown)*



D	Q(t+1)
0	0
1	1



ECPE 71 – Group of Registers



Registers

- MIPS design: **32 integer registers**, each holding **32 bits**
  - "Word size" = 32 bits

Name	Use
`$zero`	Constant value: ZERO
`$s0-$s7`	Local variables
`$t0-$t9`	Temporary results

- **This is only 19 – where are the rest of the 32?**
  - Reserved *by convention* for other uses
  - We'll learn a few more later…

Problem 1: Write Code

- **Write MIPS assembly using registers for:**

$$f = (g+h) - (i+j)$$

Map:

$s0 = g
$s1 = h
$s2 = i
$s3 = j
$s4 = f

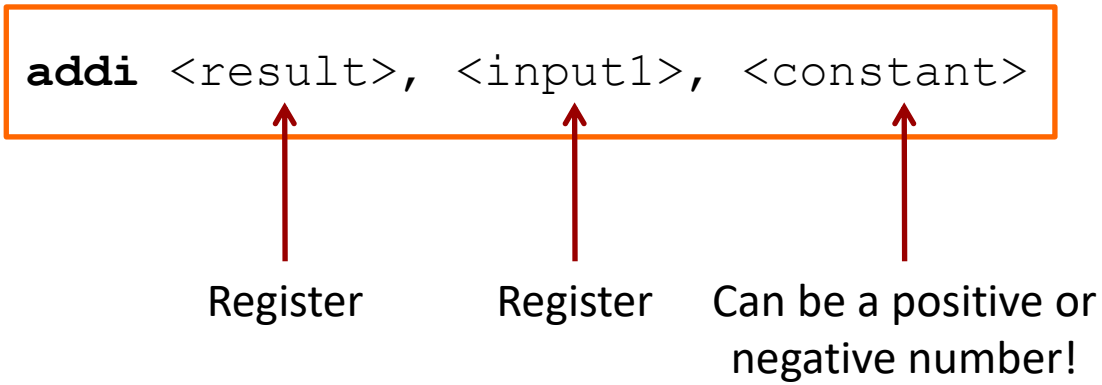
Code:

```
add $t0, $s0, $s1
add $t1, $s2, $s3
sub $s4, $t0, $t1
```

P1

More Arithmetic Instructions

- Add Immediate



Code Example

- **Write MIPS assembly using registers for:**

f = g+20

Map:
$s0 = f
$s1 = g

Code:

```
addi $s0, $s1, 20
```

MIPS Branches / Loops

Branches

- Branch on Equal (if $1 == $2, goto dest)

```
beq <reg1>, <reg2>, <destination>
```

- Branch on Not Equal (if $1 != $2, goto dest)

```
bne <reg1>, <reg2>, <destination>
```

- Branch on Greater Than (if $1 > $2, goto dest)

```
bgt <reg1>, <reg2>, <destination>
```

Branches

- Branch on Greater Than or Equal (if $1 >= $2, goto dest)

```
bge <reg1>, <reg2>, <destination>
```

- Branch on Less Than (if $1 < $2, goto dest)

```
blt <reg1>, <reg2>, <destination>
```

- Branch on Less Than or Equal (if $1 <= $2, goto dest)

```
ble <reg1>, <reg2>, <destination>
```

Tests, Jump

- Set on Less Than (if $2 < $3, set $1 = 1, otherwise 0)

```
slt <reg1>, <reg2>, <reg3>
```

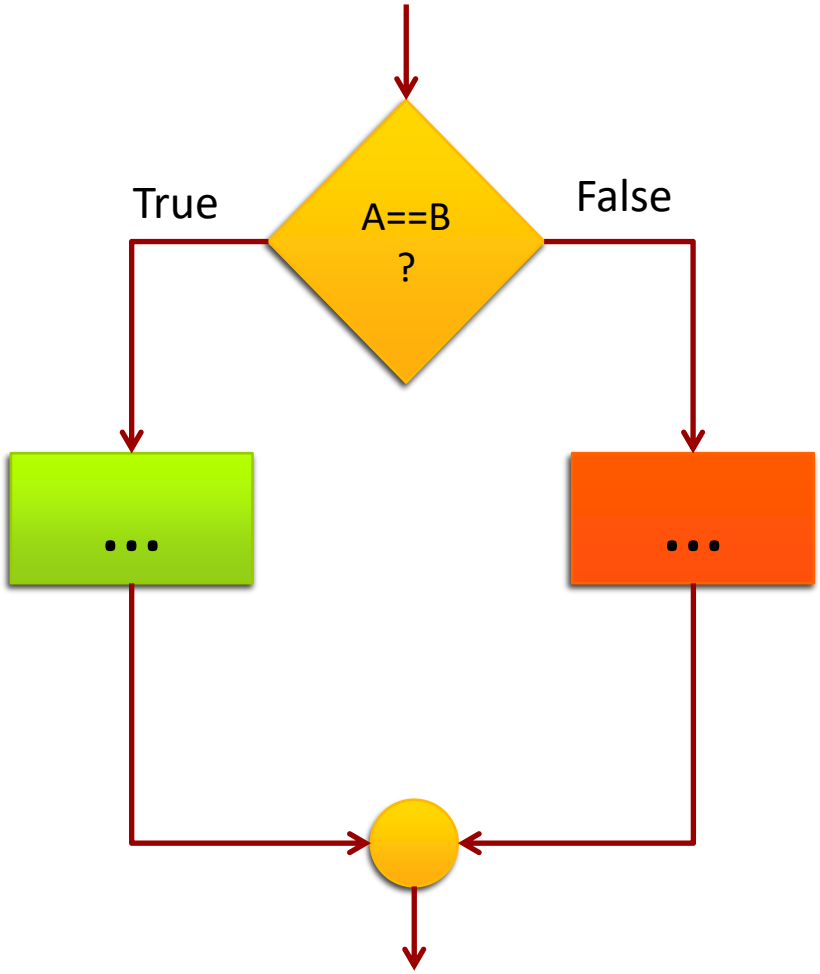
- Jump (goto dest)

```
j <destination>
```

Code Example

- **Write MIPS assembly for:**

```
if (A == B)
{
    <equal-code>
}
else
{
    <not-equal-code>
}
<after-if-code>
```



Code Example

- **Write MIPS assembly:**

Map:
$s0 = A
$s1 = B

Code:

```
        beq $s0,$s1,equal
        <not-equal-code>
        j done
equal:  <equal-code>
        j done
done:   <after-if-code>
```

Problem 2: Write Code

- **Write MIPS assembly for:**

Map:
$s0 = C
$s1 = A
$s2 = B

```
if( (A>=B) || A>6 )
    C=A;
else
    C=B-A;
```

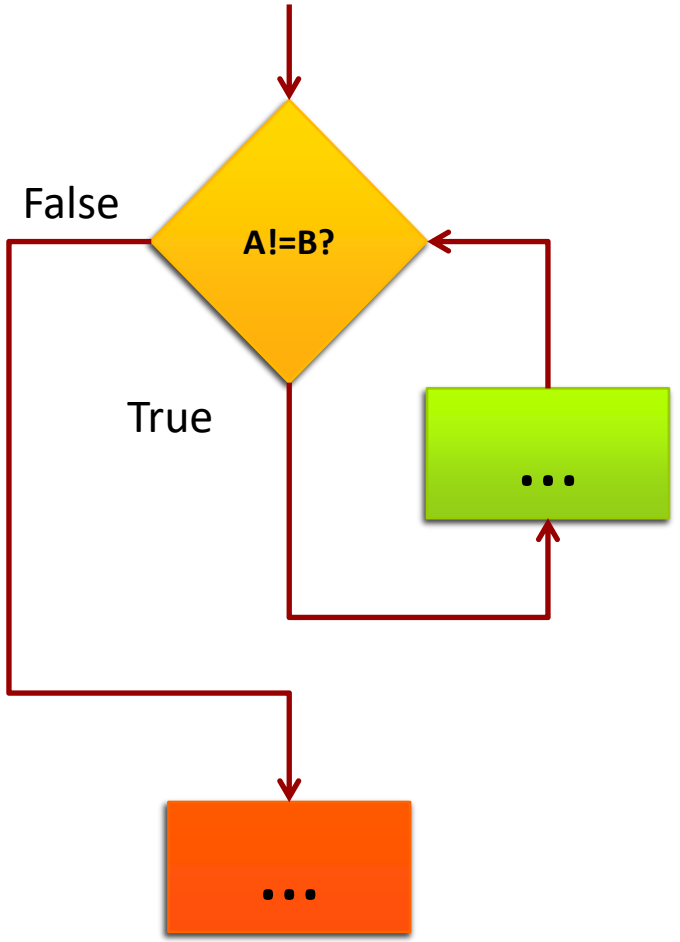
P2

Code Example

- **Write MIPS assembly for:**

```
while (A != B)
{
      <loop-body>
}

<post-loop-code>
```



Code Example

- **Write MIPS assembly:**

Map:
$s0 = A
$s1 = B

Code:

```
start:   beq $s0,$s1,done
         <loop-body>
         j start
done:    <post-loop-code>
```

Problem 3: Write Code

- **Write MIPS assembly for:**

Map:
$s0 = sum
$t0 = i

```
sum=0;
for(i=0; i<10; i++)
{
   sum+=i;
}
```

P3

Problem 4: Write Code

- **Write MIPS assembly for:**

Map:
$s0 = sum
$s1 = i
$s2 = j

```
sum=0;
for(i=0;i<10;i++)
{
   j=i;
   while(j<2*i)
   {
      sum=sum+j;
      j++;
   }
}
```

P4

Problem 5: Write Code

- **Write MIPS assembly for:**

Map:
$s0 = sum
$s1 = i

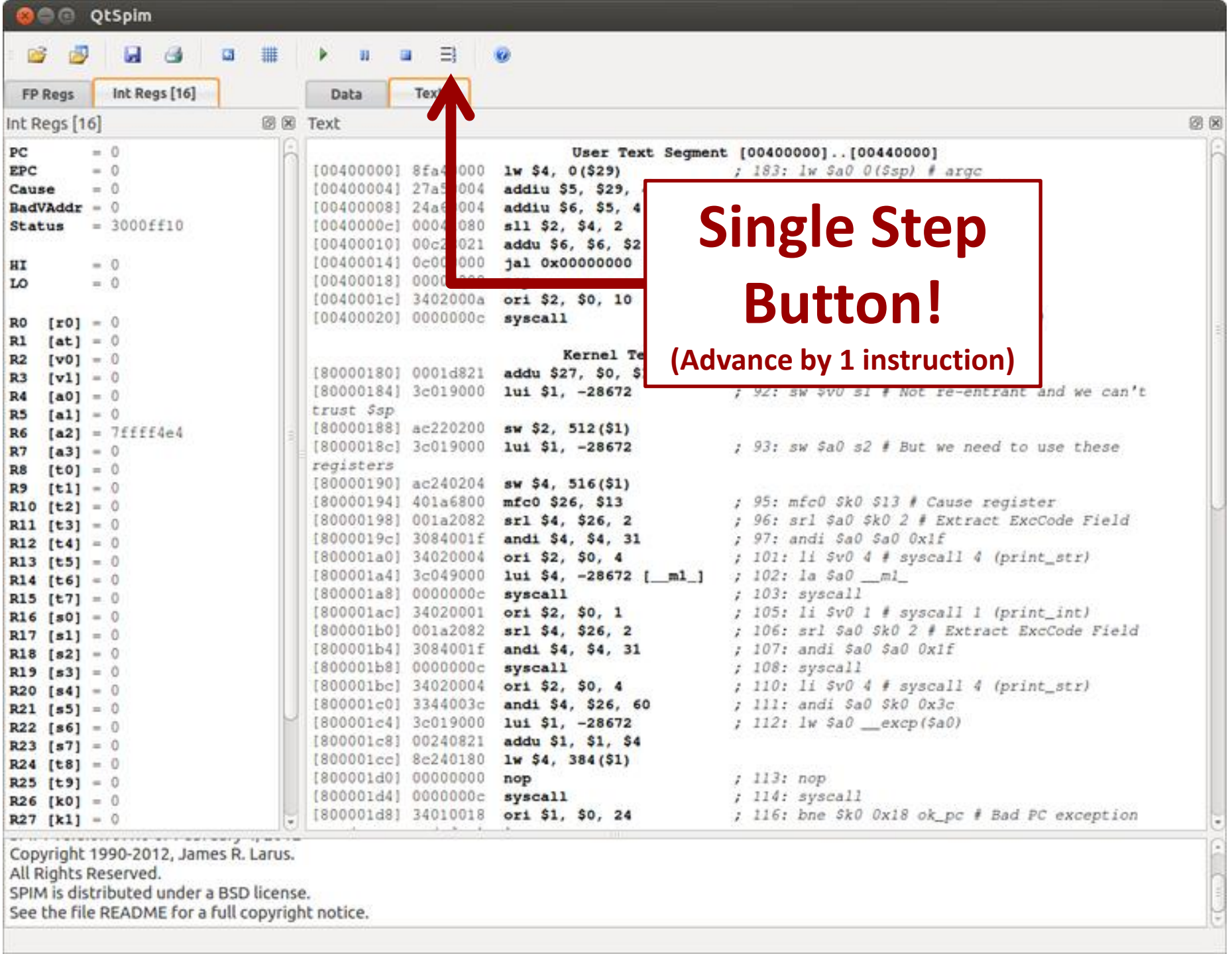
```
while(1)
{
   sum=sum+i;
   i--;
   if(i<=0)
      break;
   else
      continue;
}
```

P5

Demos and Resources

Demos

1. **QtSPIM** is a MIPS simulator
    1. Review installation tutorial
    2. Walkthrough of simulator with `example1.asm`


QtSpim
FP Regs
Int Regs [16]
Data
Text
Int Regs [16]
PC = 0
EPC = 0
Cause = 0
BadVAddr = 0
Status = 3000ff10
HI = 0
LO = 0
R0 [r0] = 0
R1 [at] = 0
R2 [v0] = 0
R3 [v1] = 0
R4 [a0] = 0
R5 [a1] = 0
R6 [a2] = 7fffff4e4
R7 [a3] = 0
R8 [t0] = 0
R9 [t1] = 0
R10 [t2] = 0
R11 [t3] = 0
R12 [t4] = 0
R13 [t5] = 0
R14 [t6] = 0
R15 [t7] = 0
R16 [s0] = 0
R17 [s1] = 0
R18 [s2] = 0
R19 [s3] = 0
R20 [s4] = 0
R21 [s5] = 0
R22 [s6] = 0
R23 [s7] = 0
R24 [t8] = 0
R25 [t9] = 0
R26 [k0] = 0
R27 [k1] = 0
Text
User Text Segment [00400000]..[00440000]
[00400000] 8fa4 000 lw $4, 0($29) ; 183: lw $a0 0($sp) # argc
[00400004] 27a5 004 addiu $5, $29,
[00400008] 24a6 004 addiu $6, $5, 4
[0040000c] 0004 080 sll $2, $4, 2
[00400010] 00c2 021 addu $6, $6, $2
[00400014] 0c00 000 jal 0x00000000
[00400018] 0000
[0040001c] 3402000a ori $2, $0, 10
[00400020] 0000000c syscall
Kernel Te
[80000180] 0001d821 addu $27, $0, $
[80000184] 3c019000 lui $1, -28672 ; 92: sw $v0 s1 # Not re-entrant and we can't trust $sp
[80000188] ac220200 sw $2, 512($1)
[8000018c] 3c019000 lui $1, -28672 ; 93: sw $a0 s2 # But we need to use these registers
[80000190] ac240204 sw $4, 516($1)
[80000194] 401a6800 mfc0 $26, $13 ; 95: mfc0 $k0 $13 # Cause register
[80000198] 001a2082 srl $4, $26, 2 ; 96: srl $a0 $k0 2 # Extract ExcCode Field
[8000019c] 3084001f andi $4, $4, 31 ; 97: andi $a0 $a0 0x1f
[800001a0] 34020004 ori $2, $0, 4 ; 101: li $v0 4 # syscall 4 (print_str)
[800001a4] 3c049000 lui $4, -28672 [__m1_] ; 102: la $a0 __m1_
[800001a8] 0000000c syscall ; 103: syscall
[800001ac] 34020001 ori $2, $0, 1 ; 105: li $v0 1 # syscall 1 (print_int)
[800001b0] 001a2082 srl $4, $26, 2 ; 106: srl $a0 $k0 2 # Extract ExcCode Field
[800001b4] 3084001f andi $4, $4, 31 ; 107: andi $a0 $a0 0x1f
[800001b8] 0000000c syscall ; 108: syscall
[800001bc] 34020004 ori $2, $0, 4 ; 110: li $v0 4 # syscall 4 (print_str)
[800001c0] 3344003c andi $4, $26, 60 ; 111: andi $a0 $k0 0x3c
[800001c4] 3c019000 lui $1, -28672 ; 112: lw $a0 __excp($a0)
[800001c8] 00240821 addu $1, $1, $4
[800001cc] 8c240180 lw $4, 384($1)
[800001d0] 00000000 nop ; 113: nop
[800001d4] 0000000c syscall ; 114: syscall
[800001d8] 34010018 ori $1, $0, 24 ; 116: bne $k0 0x18 ok_pc # Bad PC exception
Single Step Button!
(Advance by 1 instruction)
Copyright 1990-2012, James R. Larus.
All Rights Reserved.
SPIM is distributed under a BSD license.
See the file README for a full copyright notice.

Resources

- Many resources available on ECS website

1. The ***MIPS Example Programs*** page
   (basic arithmetic, looping, I/O, and function calls)
   1. The **`example1.asm`** program – Good example of empty "stub program" template to use

2. The ***MIPS Instruction Set*** page
   1. Partial guide

Resources

- Files available in Canvas site (under ECPE 170)
  - **HP_AppA.pdf**
    - Appendix A from famous Hennessy & Patterson *Computer Organization* textbook
    - Assemblers, Linkers, and the SPIM simulator
    - Starting on page 51 is an overview of the MIPS assembly commands!
  - **MIPS_Green_Sheet.pdf**
    - "Cheat sheet" for expert programmers
    - MIPS commands, registers, memory conventions, …