Instruction Set Comparisons
CS 347

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Topics

- **Code Examples**
  - Procedure Linkage
  - Sparse Matrix Code
- **Instruction Sets**
  - MIPS
  - PowerPC
  - VAX

Procedure Examples

Procedure linkage

- Passing of control and data
- stack management

Control

- Register tests
- Condition codes
- loop counters

Code Example

```
int rfact(int n)
{
  if (n <= 1)
    return 1;
  return n*rfact(n-1);
}

int ifact(int n)
{
  int i;
  int result = 1;
  for (i = 2; i <= n; i++)
    result *= i;
  return result;
}
```

MIPS rfact

Registers

- **$4 Argument n**
- **$16 Saved n**
  - Callee save

Stack Frame

- **24 bytes**
- **return PC**
- **$16**

```
rfact:
        subu    $sp,$sp,24      # Allocate stack frame
        sw      $31,20($sp)     # Store return PC
        sw      $16,16($sp)     # Store $16
        move    $16,$4          # $16 <- n
        slt     $2,$16,2        # $2 <- n < 2
        BNE     $2,$0,$L3       # if < goto $L3
        li      $2,0x00000001   # with return value 1
        JAL     rfact           # Call recursively
        subu    $4,$16,1        # with argument n-1
        mult    $16,$2
        mflo    $2              # compute return value
$L3:
        lw      $31,20($sp)     # Restore return PC
        lw      $16,16($sp)     # Restore $16
        addu    $sp,$sp,24      # Remove stack frame
        j       $31             # return
        .end    rfact
```

MIPS ifact

Registers

- **$3 i**
- **$4 n**
- **$5 result**

Stack Frame

- **none**

```
ifact:
#       $3      i
#       $4      n
#       $5      result
        li      $5,0x00000001   # result <- 1
        slt     $2,$4,2         # $2 <- n < 2
        BNE     $2,$0,$L6       # if < goto $L6
        li      $3,0x00000002   # with i <- 2
        mult    $5,$3
$L9:
        mflo    $5              # result *= i
        addu    $3,$3,1         # i++
        slt     $2,$4,$3        # $2 <- n < i
        BEQ     $2,$0,$L9       # if !< goto $L9
        mult    $5,$3           # starting mult
$L6:
        J       $31             # return
        move    $2,$5           # with result
```

Power / PowerPC

History

- **IBM develops Power architecture**
  - Basis of RS6000
  - Somewhere between RISC & CISC
- **IBM / Motorola / Apple combine to develop PowerPC architecture**
  - Derivative of Power
  - Used in Power Macintosh

CISC-like features

- **Registers with control information**
  - Set of condition registers (CR0–7) holding outcome of comparisons
  - link register (LR) to hold return PC
  - count register (CTR) to hold loop count
- **Updating load / stores**
  - Update base register with effective address

PPC rfact

Registers

- **r3**
  - –argument n
  - –return val
- **r31 saved arg**
- **CR0 comparison**

Instructions

`mfspr` move from special purp. reg.

`cmpi` compare immediate

`cal` add immediate

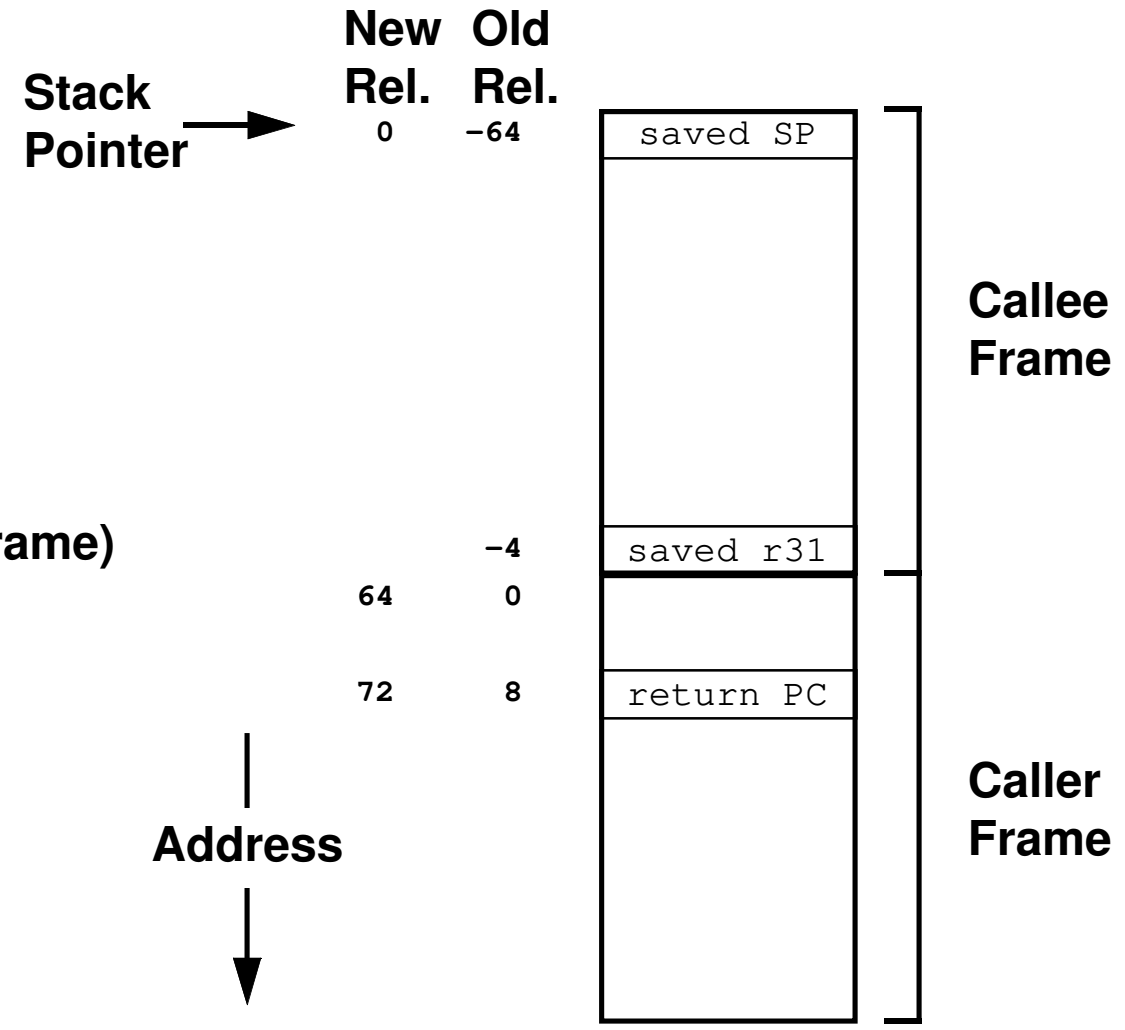
`stu` store with update

```
.rfact:
        st      r31,-4(SP)       # save R31
        mfspr   r0,LR            # r0 <- return PC
        cmpi    0,r3,1           # compare n to 1
        st      r0,8(SP)         # save return PC
        cal     r31,0(r3)        # r31 <- n
        stu     SP,-64(SP)      # save & update SP
        ai      r3,r3,-1         # r3 <- n-1
        # if comparison result is >, goto __Le8
        bc      BO_IF,CR0_GT,__Le8
        l       r31,60(SP)       # restore r31
        cal     r3,1(r0)         # return val <- 1
        ai      SP,SP,64         # restore SP
        bcr     BO_ALWAYS,CR0_LT   # return
__Le8:
        bl      .rfact           # call rfact
        muls    r3,r3,r31        # compute result
        l       r12,72(SP)       # r12 <- return PC
        ai      SP,SP,64         # restore SP
        mtspr   LR,r12           # set return PC
        l       r31,-4(SP)       # restore R31
        bcr     BO_ALWAYS,CR0_LT   # return
```

PPC rfact Stack Frame

Frame

- 64 bytes
- old SP
- return PC (in caller's frame)
- R31



PPC ifact

Registers

- **r3**
  - argument n
  - result
- **r4 i**
- **CR0 comparison**
- **CTR counter**

Stack Frame

- **none**

```
.ifact:
#       r3      argument n & result
#       r4      i
        cmpi    0,r3,2  # compare n to 2
        ai      r0,r3,-1        # r0 <- n-1
        cal     r3,1(r0)        # result <- 1
        cal     r4,2(r0)        # i <- 2
        bcr     BO_IF,CR0_LT    # return if n < 2
        mtspr   CTR,r0      # Count Reg <- n-1
__L8c:
        muls    r3,r4,r3        # result *= i
        ai      r4,r4,1         # i++
        # decrement & loop if nonzero
        bc      BO_dCTR_NZERO,CR0_LT,__L8c
        bcr     BO_ALWAYS,CR0_LT # return
```

VAX

Pinnacle of CISC

- **Maximize instruction density**
- **Provide instructions closely matched to typical program operations**

Instruction format

- **OP, arg1, arg2, …**
  - Each argument has arbitrary specifier
  - Accessing operands may have side effects

Condition Codes

- **Set by arithmetic and comparison instructions**
- **Basis for successive branches**

Procedure Linkage

- **Direct implementation of stack discipline**

VAX Operand Specifiers

Examples

Notation	Value	Side Eff	Use
Ri	**ri**		**General purpose register**
$v	**v**		**Immediate data**
(Ri)	**M[ri]**		**Memory reference**
v(Ri)	**M[ri+v]**		**Mem. ref. with displacement**
A[Ri]	**M[a+ri*d]**		**Array indexing**
– A is specifier denoting address a			
– d is size of datum			
(Ri)+	**M[ri]**	**Ri += d**	**Stepping pointer forward**
-(Ri)	**M[ri-d]**	**Ri -= d**	**Stepping pointer back**
@(Ri)+	**M[M[ri]]**	**Ri += 4**	**Step through pointer table**

VAX Registers

- **R0–R11 General purpose**
  - R2–R7 Callee save in example code
  - Use pair to hold double
- **R12 AP Argument pointer**
  - Stack region holding procedure arguments
- **R13 FP Frame pointer**
  - Base of current stack frame
- **R14 SP Stack pointer**
  - Top of stack
- **R15 PC Program counter**
  - Used to access data in code

VAX Procedure Linkage

Caller

- **Push Arguments**
  - Relative to SP
- **Execute CALLS n, proc**
  - n denotes number of arguments
  - proc starts with mask denoting registers to be saved on stack

CALLS Instruction

- **Creates stack frame**
  - Saved registers, PC, FP, AP, mask, PSW
- **Sets AP, FP, SP**

Callee

- **Compute return value in R0**
- **Execute ret**
  - Undoes effect of CALLS

VAX rfact

Registers

- r6 saved n
- r0 return value

Stack Frame

- save r6

Note

- Desination argument last

```
_rfact:
        .word 0x40      # Save register r6
        movl 4(ap),r6   # r6 <- n
        cmpl r6,$1      # if n > 1
        jgtr L1         # then goto L1
        movl $1,r0      # r0 <- 1
        ret             # return
L1:
        pushab -1(r6)   # push n-1
        calls $1,_rfact # call recursively
        mull2 r6,r0     # return result * n
        ret
```

VAX ifact

Registers

- **r0 result**
- **r1 i**
- **r2 n**

Stack Frame

- **No saved regs.**

```
_ifact:
        .word 0x0         # no saved regs.
        movl 4(ap),r2     # r2 <- n
        movl $1,r0        # result <- 1
        movl $2,r1        # i <- 2
        cmpl r1,r2        # if i > n
        jgtr L3           # then goto L3
L5:
        mull2 r1,r0       # result *= i
        incl r1           # i++
        cmpl r1,r2        # if i > n
        jleq L5           # then goto L5
L3:
        ret               # return
```

Sparse Matrix Code

Task

- **Multiply sparse matrix times dense vector**
  - Matrix has many zero entries
  - Save space and time by keeping only nonzero entries
  - Common application

Compressed Sparse Row Representation

$$\begin{bmatrix} 3.5 & 0.9 & & 2.2 & \\ & 4.1 & & 1.9 & \\ 4.6 & & 0.7 & 2.7 & 3.0 \\ & & & 2.9 & \\ & & 1.2 & & 2.8 \\ & & & & 3.4 \end{bmatrix}$$

```
[(0,3.5) (1,0.9) (3,2.2)]
[(1,4.1) (3,1.9)]
[(0,4.6) (2,0.7) (3,2.7) (5,3.0)]
[(2,2.9)]
[(2,1.2) (4,2.8)]
[(5,3.4)]
```

CSR Encoding

Parameters

- **type** [Allows different formats]
- **nrow** Number of rows (and columns)
- **nentries** Number of nonzero matrix entries

```
typedef struct {
  matrix_t type;
  int nrow;
  int nentries;
  double *val;
  int *cindex;
  int *rstart;
} csr_rec, *csr_ptr;
```

Val

- **List of nonzero values** (nentries)

Cindex

- **List of column indices** (nentries)

Rstart

- **List of starting positions for each row** (nrow+1)

CSR Example

Parameters

- **nrow = 6**
- **nentries = 13**

Val

```
[3.5, 0.9, 2.2, 4.1, 1.9, 4.6, 0.7, 2.7, 3.0, 2.9, 1.2, 2.8, 3.4]
```

Cindex

```
[0,   1,   3,   1,   3,   0,   2,   3,   5,   2,   2,   4,   5]
```

Rstart

```
[0, 3, 5, 9, 10, 12, 13]
```

```
[(0,3.5) (1,0.9) (3,2.2)]
[(1,4.1) (3,1.9)]
[(0,4.6) (2,0.7) (3,2.7) (5,3.0)]
[(2,2.9)]
[(2,1.2) (4,2.8)]
[(5,3.4)]
```

CSR Multiply: Clean Version

```
void csr_mult_smpl(csr_ptr M, double *x, double *z)
{
  int r, ci;
  for (r = 0; r < M->nrow; r++) {
    z[r] = 0.0;
    for (ci = M->rstart[r]; ci < M->rstart[r+1]; ci++)
      z[r] += M->val[ci] * x[M->cindex[ci]];
  }
}
```

CSR Multiply: Fast Version

```
void csr_mult_opt(csr_ptr M, double *x, double *z)
{

                    Left as exercise!


}
```

Inner Loop Pointers

`cip` steps through cindex

`valp` steps through Val

```
    while (...)
      temp += *(valp++) * x[*cip++];
```

Performance

- Approx 2X faster
- Avoids repeated memory references

PPC Inner Loop

Registers

- **r3 *cip**
- **r4 x**
- **r10 valp-8**
- **r11 cip**
- **fp3 temp**

```
    while (...)
      temp += *(valp++) * x[*cip++];
```

```
__L208:
        rlinm   r3,r3,3,0,28    # *cip * 8
        lfdx    fp0,r4,r3      # fp0 <- x[*cip]
        lfdu    fp1,8(r10)      # fp1 <- *(++valp)
        lu      r3,4(r11)       # r3  <- *++cip
        fma     fp3,fp1,fp0,fp3 # fp3 += fp1*fp0
        # Decrement & loop
        bc      BO_dCTR_NZERO,CR0_LT,__L208
```

VAX Inner Loop

Registers

- **r4 cip**
- **r2,r3 temp**
- **r5 valp**
- **r6 cip_end**
- **r10 x**

```
    while (...)
      temp += *(valp++) * x[*cip++];
```

```
L36:
        movl (r4)+,r0    # r0 <- *cip++
        muld3 (r5)+,(r10)[r0],r0 # r0,r1 <- *valp++ * x[r0]
        addd2 r0,r2      # temp += r0,r1
        cmpl r4,r6       # if cip < cip_end
        jlssu L36        # then goto L36
```

Performance Comparison

Experiment

- 10 X 10 matrices
- 100% density
- 100 multiply accumulates

Machine	MHz	μsecs	Cycles/Ele
MIPS	25	365	18
PPC 601	62	63	8
PPC 603	75	125	19
VAX	25?	2448	122?

Summary

MIPS

- **Simple register state**
- **Every operation has single effect**
  - Load, store, operate, branch

VAX

- **Hidden control state**
- **Operations vary from simple to complex**
- **Side effects possible**

Power PC

- **Complex control state**
- **Operations simple to medium**
- **Side effects possible**
- **Hard target for code generator**