`inst.eecs.berkeley.edu/~cs61c`

UCB CS61C : Machine Structures

Lecture 9
MIPS Instruction Representation II

Guest Lecturer
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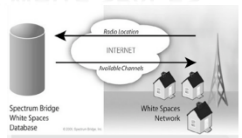
FCC BEGINS OPENING "WHITE SPACES"

The FCC is about to implement a database of white spaces – unused spectrum between television channels. New devices can contact the database to see if they're allowed to broadcast. New opportunities for wireless comms!



`http://thehill.com/blogs/hillicon-valley/technology/181571-fcc-will-begin-testing-white-spaces-database`

Review

- Simplifying MIPS: Define instructions to be same size as data word (one word) so that they can use the same memory (compiler can use `lw` and `sw`).
- Computer actually stores programs as a series of these 32-bit numbers.
- MIPS Machine Language Instruction: 32 bits representing a single instruction

R	opcode	rs	rt	rd	shamt	funct
I	opcode	rs	rt	immediate		

I-Format Problems (0/3)

- Problem 0: Unsigned # sign-extended?
  - `addiu`, `sltiu`, sign-extends immediates to 32 bits. Thus, # is a "signed" integer.
- Rationale
  - `addiu` so that can add w/out overflow
    - See K&R pp. 230, 305
  - `sltiu` suffers so that we can have easy HW
    - Does this mean we'll get wrong answers?
    - Nope, it means assembler has to handle any unsigned immediate $2^{15} \le n < 2^{16}$ (I.e., with a `1` in the 15th bit and `0`s in the upper 2 bytes) as it does for numbers that are too large. ⇒

I-Format Problem (1/3)

- Problem:
  - Chances are that `addi`, `lw`, `sw` and `slti` will use immediates small enough to fit in the immediate field.
  - …but what if it's too big?
  - We need a way to deal with a 32-bit immediate in any I-format instruction.

I-Format Problem (2/3)

- Solution to Problem:
  - Handle it in software + new instruction
  - Don't change the current instructions: instead, add a new instruction to help out
- New instruction:

```
lui   register, immediate
```

  - stands for Load Upper Immediate
  - takes 16-bit immediate and puts these bits in the upper half (high order half) of the register
  - sets lower half to `0`s

I-Format Problems (3/3)

- Solution to Problem (continued):
  - So how does `lui` help us?
  - Example:

```
addiu $t0,$t0, 0xABABCDCD
```

…becomes

```
lui $at 0xABAB
ori $at, $at, 0xCDCD
addu $t0,$t0,$at
```

  - Now each I-format instruction has only a 16-bit immediate.
  - Wouldn't it be nice if the assembler would this for us automatically? (later)

Branches: PC-Relative Addressing (1/5)

- Use I-Format

opcode	rs	rt	immediate

- `opcode` specifies `beq` versus `bne`
- `rs` and `rt` specify registers to compare
- What can immediate specify?
  - `immediate` is only 16 bits
  - PC (Program Counter) has byte address of current instruction being executed; 32-bit pointer to memory
  - So `immediate` cannot specify entire address to branch to.

Branches: PC-Relative Addressing (2/5)

- How do we typically use branches?
  - Answer: `if-else`, `while`, `for`
  - Loops are generally small: usually up to 50 instructions
  - Function calls and unconditional jumps are done using jump instructions (`j` and `jal`), not the branches.
- Conclusion: may want to branch to anywhere in memory, but a branch often changes PC by a small amount

Branches: PC-Relative Addressing (3/5)

- Solution to branches in a 32-bit instruction: PC-Relative Addressing
- Let the 16-bit immediate field be a signed two's complement integer to be *added* to the PC if we take the branch.
- Now we can branch ± 2^{15} bytes from the PC, which should be enough to cover almost any loop.
- Any ideas to further optimize this?

Branches: PC-Relative Addressing (4/5)

- Note: Instructions are words, so they're word aligned (byte address is always a multiple of 4, which means it ends with `00` in binary).
  - So the number of bytes to add to the PC will always be a multiple of 4.
  - So specify the `immediate` in words.
- Now, we can branch ± 2^{15} words from the PC (or ± 2^{17} bytes), so we can handle loops 4 times as large.

Branches: PC-Relative Addressing (5/5)

- Branch Calculation:
  - If we don't take the branch:
    PC = PC + 4 = byte address of next instruction
  - If we do take the branch:
    PC = (PC + 4) + (`immediate` * 4)
  - Observations
    - `Immediate` field specifies the number of words to jump, which is simply the number of instructions to jump.
    - `Immediate` field can be positive or negative.
    - Due to hardware, add `immediate` to (PC+4), not to PC; will be clearer why later in course

Branch Example (1/3)

- MIPS Code:

```
Loop:beq   $9,$0,End
      addu  $8,$8,$10
      addiu $9,$9,-1
      j     Loop
End:
```

- `beq` branch is I-Format:

  `opcode` = 4 (look up in table)

  `rs` = 9 (first operand)

  `rt` = 0 (second operand)

  `immediate` = ???

Branch Example (2/3)

- MIPS Code:

```
Loop: beq   $9,$0,End
      addu  $8,$8,$10
      addiu $9,$9,-1
      j     Loop
End:
```

- `immediate` Field:
  - Number of instructions to add to (or subtract from) the PC, starting at the instruction *following* the branch.
  - In `beq` case, `immediate` = 3

Branch Example (3/3)

- MIPS Code:

```
Loop: beq   $9,$0,End
      addu  $8,$8,$10
      addiu $9,$9,-1
      j     Loop
End:
```

decimal representation:

4	9	0	3

binary representation:

000100	01001	00000	0000000000000011

Questions on PC-addressing

- Does the value in branch field change if we move the code?
- What do we do if destination is > 2^{15} instructions away from branch?
- Why do we need different addressing modes (different ways of forming a memory address)? Why not just one?

Administrivia

- Project 1, Part 1 due Sunday, 11:59 PM
  - Worth ~15% of total project grade
  - (Warning! Part 2 is way more time-consuming, so prepare accordingly.)
- HW1 grades now posted; HW2 should be up Monday
  - Find your reader on the course website

J-Format Instructions (1/5)

- For branches, we assumed that we won't want to branch too far, so we can specify *change* in PC.
- For general jumps (`j` and `jal`), we may jump to *anywhere* in memory.
- Ideally, we could specify a 32-bit memory address to jump to.
- Unfortunately, we can't fit both a 6-bit opcode and a 32-bit address into a single 32-bit word, so we compromise.

J-Format Instructions (2/5)

- Define two "fields" of these bit widths:

6 bits	26 bits

- As usual, each field has a name:

opcode	target address

- Key Concepts
  - Keep `opcode` field identical to R-format and I-format for consistency.
  - Collapse all other fields to make room for large target address.

J-Format Instructions (3/5)

- For now, we can specify 26 bits of the 32-bit bit address.
- Optimization:
  - Note that, just like with branches, jumps will only jump to word aligned addresses, so last two bits are always `00` (in binary).
  - So let's just take this for granted and not even specify them.

J-Format Instructions (4/5)

- Now specify 28 bits of a 32-bit address
- Where do we get the other 4 bits?
  - By definition, take the 4 highest order bits from the PC.
  - Technically, this means that we cannot jump to *anywhere* in memory, but it's adequate 99.9999…% of the time, since programs aren't that long
    - only if straddle a 256 MB boundary
  - If we absolutely need to specify a 32-bit address, we can always put it in a register and use the `jr` instruction.

J-Format Instructions (5/5)

- Summary:
  - New PC = { PC[31..28], target address, 00 }
- Understand where each part came from!
- Note: { , , } means concatenation
  { 4 bits , 26 bits , 2 bits } = 32 bit address
  - { 1010, 11111111111111111111111111, 00 } = 10101111111111111111111111111100
  - Note: Book uses ||

Peer Instruction Question

(for A,B) When combining two C files into one executable, recall we can compile them independently & then merge them together.

1) **Jump** insts don't require any changes.
2) **Branch** insts don't require any changes.

	12
a)	FF
b)	FT
c)	TF
d)	TT
e)	dunno

In conclusion

- MIPS Machine Language Instruction: 32 bits representing a single instruction

R	opcode	rs	rt	rd	shamt	funct
I	opcode	rs	rt	immediate		
J	opcode	target address				

- Branches use PC-relative addressing, Jumps use absolute addressing.
- Disassembly is simple and starts by decoding `opcode` field. (more in a week)