Assembling Programs

What is an assembler?

- Expands pseudo-operations into machine instructions
- Translates text assembly language to binary machine code
- Output: object file
  - "`.o`" files (Unix)
  - "`.obj`" files (Windows/DOS)

Assembling Programs

```
        .text                              # directive
        .ent main                          # directive
main:   la $4,$array                       # pseudo-op
        li $5,15                           # pseudo-op
        ...
        li $4,0                            # pseudo-op
        jal exit
        .end main                          # directive

        .data                              # directive
$array: .long 51,491,3991,4,6881,-41       # directive
        .globl exit .text                  # directive
```

Handling Forward References

- Two-pass assembly
  - 1: allocate instructions, thus determining addresses
  - 2: assemble instructions knowing all labels
- One-pass or backpatch assembly
  - 1: assemble instructions, put in zero for unknown offsets/addresses, keep track of unfinished instructions
  - Backpatch: when labels appear or at the end of pass 1, fill in the unfinished instructions.

Handling Forward References

Example:

```
     bne $1,$2,L     # branch forward
     sll $0,$0,0     # to label L
 L:  addiu $2,$3,$2
```

The assembler will change this to:

```
   bne $1,$2,+1    # branch forward 1 word
   sll $0,$0,0     # relative to the sll
   addiu $2,$3,$2
```

Final machine code:

```
   0x14220001  # bne
   0x00000000  # sll
   0x24620002  # addiu
```

Assembling Programs

Start at address zero (arbitrary).

- Keep track of where the jumps are
- Keep track of references to labels in data
- Keep track of unresolved labels (like "`exit`")

All this information is saved in the object file.

Try using `mips-sgi-irix5-objdump` on the `.o` files generated for your project.

Object File

- Header
- Code segment (text segment in Unix)
- Data segment
- Relocation information
- Symbol table
- Debugging information

Try using `mips-sgi-irix5-nm` on the `.o` files generated for your project to see the symbol table.

Code Reuse

Standard functions saved in libraries.

- On Unix: `lib`*name*`.a`, `lib`*name*`.so` files
- On Windows: *name*`.lib`, *name*`.dll` files
- Consist of a collection of object files

The linker takes a collection of object files and libraries and generates an executable program.

- On Unix: `ld`
- On Windows: `link`

Linkers

- Static
  - Combine object files and libraries into one executable
  - All symbols are resolved
- Dynamic
  - Generate "partial" executable
  - Add library code at runtime
  - Reduces executable size
  - Libraries can be changed without recompilation
  - One copy of shared library in memory
  - Performance hit

Linkers And Loaders

- Linker
  - resolves all symbols
  - creates final executable
  - stores entry point in executable
- Loader
  - reads executable
  - loads code and data into memory
  - initializes registers, stacks, arguments
  - jumps to start-up routine
  - part of the operating system

ISA Alternatives

- Internal storage: registers, stacks, none
  - registers: choice since 1984
  - stacks: 1960s–70s
  - only memory: not used successfully in 25 years
- Typical operations
  - heavily used ones, little changed since 1970
  - fancy instructions, underused and eliminated
- Operands
  - register-register: all since 1980
  - register-memory: x86, Motorola 680x0, 360
  - memory-memory: VAX

Operations Supported

- Most machines have a base set like the MIPS ISA
- Recently, instructions added for multimedia and graphics applications (Intel MMX, Sun VIS, HP MAX-2)

Some Elaborate Operations:

- arithmetic/logical operations on bytes and halfwords
- string operations: copy, compare
- subroutine call/return
- bit field operations
- data structure support (lists, queues)

Control Flow

- Condition Codes

  Special bits set as a side-effect of arithmetic operations.

  ```
  add r1,r2,r3
  bz label
  ```

- Condition Register

  Evaluate into a register and test its value.

  ```
  cmp r1,r2,r3
  bgt r1, label
  ```

- Compare and Branch

  ```
  bgt r1,r2, label
  ```

Accessing And Addressing Operands

- Recent architectures are load-store architectures
- Registers are general-purpose
- Substantial differences in different architectures
- Example: VAX
  - any operand can be in a register or memory
  - memory locations can be addressed with many modes

Addressing Modes

Mode	Example	Meaning
register	add r4,r3	r4:=r4+r3
immediate	add r4,3	r4:=r4+3
displacement	add r4,100(r1)	r4:=r4+mem[100+r1]
register indirect	add r4,(r1)	r4:=r4+mem[r1]
indexed/base	add r4,(r1+r2)	r4:=r4+mem[r1+r2]
direct/absolute	add r4,(100)	r4:=r4+mem[100]
memory indirect	add r4,@(r3)	r4:=r4+mem[mem[r3]]
auto-increment	add r4,(r3)+	r4:=r4+mem[r3]; r3:=r3+d
auto-decrement	add r4,-(r3)	r3:=r3-d; r4:=r4+mem[r3]

Instruction Encoding

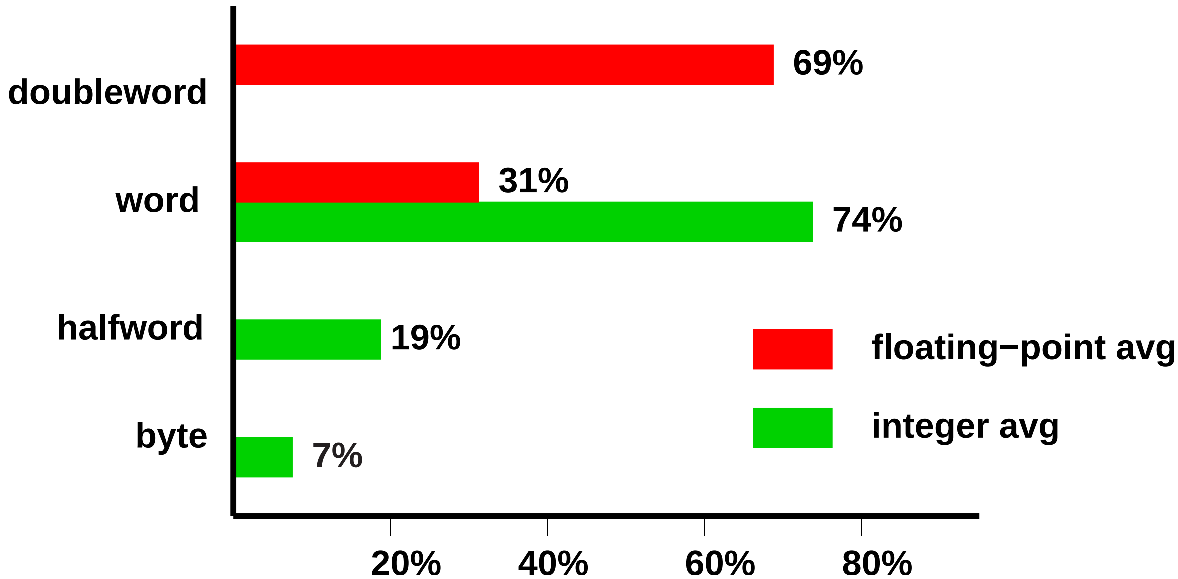
- Fixed
  - Each instruction uses fixed number of bits
  - Example: MIPS, 1 word per instruction
  - Know where next instruction begins without looking at current instruction $\Rightarrow$ hardware is simpler
- Variable
  - Number of bits used per instruction varies
  - Example: x86 uses 1, 2, 3, ... > 10 bytes
  - Compact code (x86: avg 3 bytes)
  - Hardware more complex

ISA Rationale

- Metrics
  - design cost: HW and SW
  - performance, power, code size
- Influenced by
  - program usage: which instructions are frequently used?
  - efficient HW implementation strategies
  - compiler technology
- Code efficiency and compilation
  - orthogonality: avoid special cases
  - complex operations are hard to compile to

Operand Usage

Operand sizes:



⇒ support 8-bit, 16-bit, 32-bit integer, and 32-bit and 64-bit floating-point.

Constant Usage

- Immediate sizes:
  - 50% to 60% fit within 8 bits
  - 75% to 80% fit within 16 bits with sign extension
- Address displacements:
  - 1% of addresses need >16 bits
  - 12-16 bits sufficient
- Conditional branch distance:
  - 35% of integer branches are within -4..+3 ins
  - Virtually none beyond 512 instructions
  - Equality test: most frequent branch case