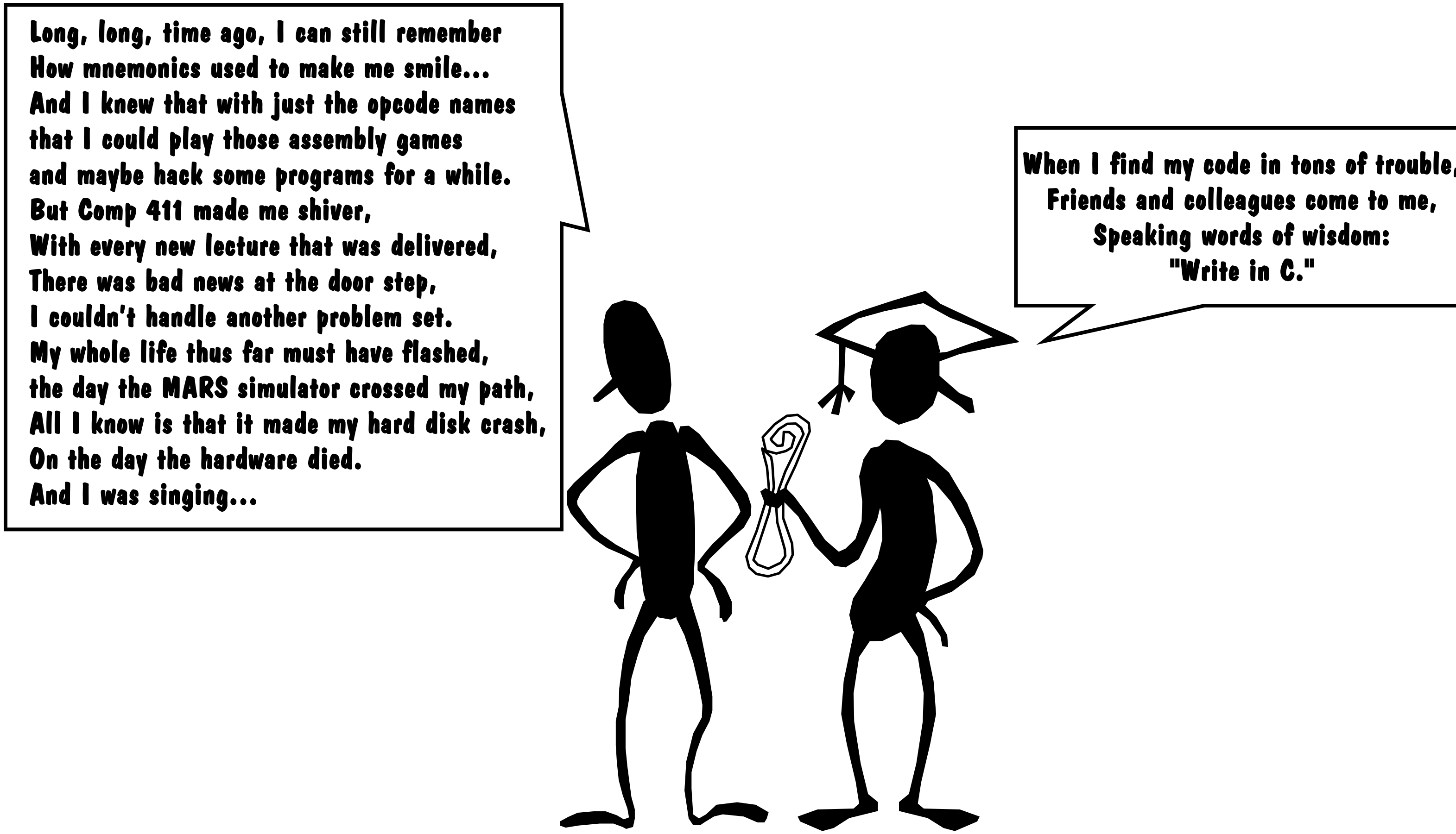
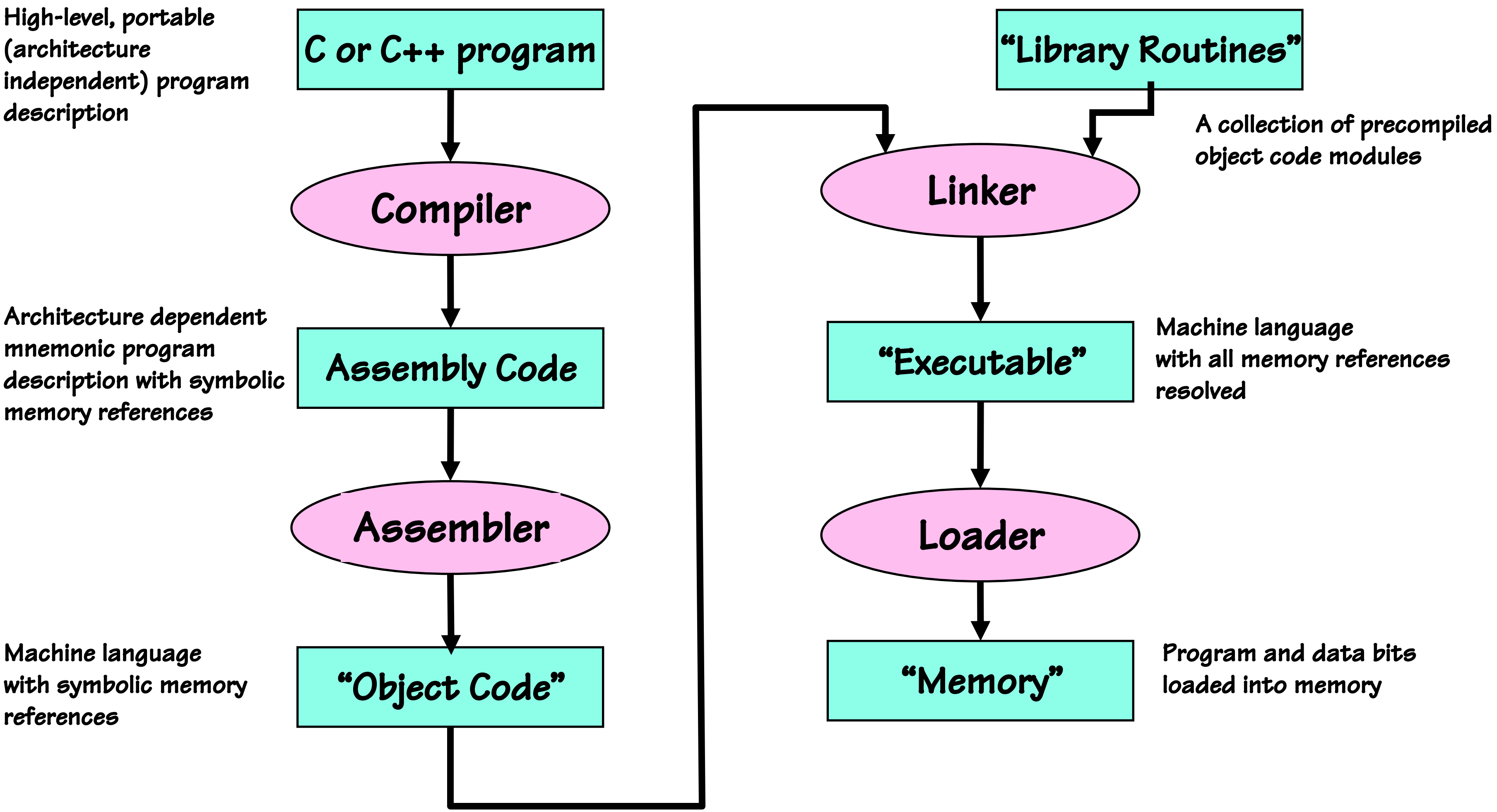
Assemblers and Compilers



Study sections 2.10,12,13

Path from Programs to Bits

- Traditional Compilation



How an Assembler Works

Three major components of assembly

1) Allocating and initialing data storage
2) Conversion of mnemonics to binary instructions
3) Resolving addresses

```
.data
array:   .space 40
total:   .word 0

.text
.globl main
main:    la      $t1,array
         move    $t2,$0
         move    $t3,$0
         beq     $0,$0,test
loop:    sll     $t0,$t3,2
         add     $t0,$t1,$t0
         sw      $t3,($t0)
         add     $t2,$t2,$t3
         addi    $t3,$t3,1
test:    slti    $t0,$t3,10
         bne     $t0,$0,loop
         sw      $t2,total
         j       $ra
```

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→

```
lui   $9, arrayhi
ori   $9,$9,arraylo
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0x3529????
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Resolving Addresses- 1st Pass

- "Old-style" 2-pass assembler approach

Pass 1

Segment offset	Code	Instruction
0 4	0x3c090000 0x35290000	la $t1,array
8 12	0x00005021 0x00005821	move $t2,$ move $t3,$0
16	0x10000000	beq $0,$0,test
20	0x000b4080	loop: sll $t0,$t3,2

24
28
32
36
	0x01284020
	0xad0b0000
	0x014b5020
	0x216b0001
		add $t0,$t1,$t0
		sw $t0,($t0)
		add $t0,$t1,$t0
		addi $t3,$t3,1

40	0x2968000a	test: slti $t0,$t3,10
44	0x15000000	bne $t0,$0,loop
48 52	0x3c010000 0xac2a0000	sw $t2,total
56	0x03e00008	j $ra

- In the first pass, data and instructions are encoded and assigned offsets within their segment, while the symbol table is constructed.
- Unresolved address references are set to 0

Symbol table after Pass 1

Symbol	Segment	Location pointer offset
array	data	0
total	data	40
main	text	0
loop	text	20
test	text	40

Resolving Addresses – 2nd Pass

- "Old-style" 2-pass assembler approach

Pass 2

Segment offset	Code	Instruction
0 4	0x3c091001 0x35290000	la $t1,array
8 12	0x00005021 0x00005821	move $t2,$ move $t3,$0
16	0x10000005	beq $0,$0,test
20	0x000b4080	loop: sll $t0,$t3,2

24
28
32
36
	0x01284020
	0xad0b0000
	0x014b5020
	0x216b0001
		add $t0,$t1,$t0
		sw $t0,($t0)
		add $t0,$t1,$t0
		addi $t3,$t3,1

40	0x2968000a	test: slti $t0,$t3,10
44	0x1500fff9	bne $t0,$0,loop
48 52	0x3c011001 0xac2a0028	sw $t2,total
56	0x03e00008	j $ra

– In the second pass, the appropriate fields of those instructions that reference memory are filled in with the correct values if possible.

Symbol table after Pass 1

Symbol	Segment	Location pointer offset
array	data	0
total	data	40
main	text	0
loop	text	20
test	text	40

Modern Way – 1-Pass Assemblers

Modern assemblers keep more information in their symbol table which allows them to resolve addresses in a single pass.

- **Known addresses (backward references) are immediately resolved.**
- **Unknown addresses (forward references) are "back-filled" once they are resolved.**

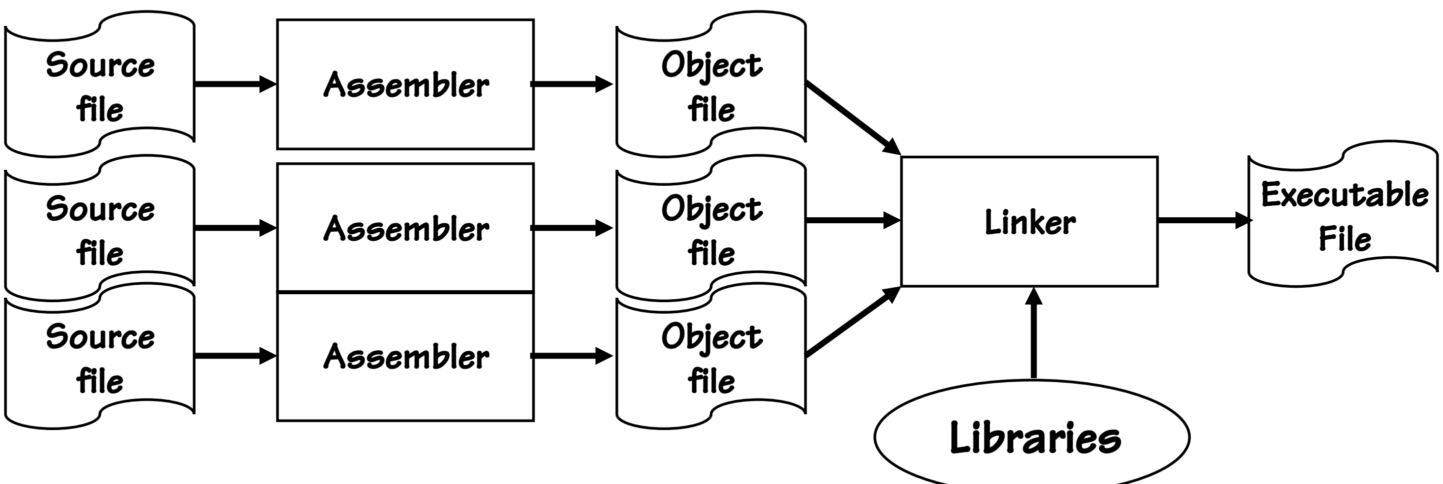
SYMBOL	SEGMENT	Location pointer offset	Resolved ?	Reference list
array	data	0	y	null
total	data	40	y	null
main	text	0	y	null
loop	text	16	y	null
test	text	?	n	16

The Role of a Linker

Some aspects of address resolution cannot be handled by the assembler alone.

1) References to data or routines in other object modules
2) The layout of all segments in memory
3) Support for REUSABLE code modules
4) Support for RELOCATABLE code modules

This final step of resolution is the job of a LINKER



Static and Dynamic Libraries

- LIBRARIES are commonly used routines stored as a concatenation of "Object files". A global symbol table is maintained for the entire library with entry points for each routine.
- When routines in LIBRARIES are referenced by assembly modules, the routine's entry points are resolved by the LINKER, and the appropriate code is added to the executable. This sort of linking is called STATIC linking.
- Many programs use common libraries. It is wasteful of both memory and disk space to include the same code in multiple executables. The modern alternative to STATIC linking is to allow the LOADER and THE PROGRAM ITSELF to resolve the addresses of libraries routines. This form of lining is called DYNAMIC linking (e.x. .dll).

Dynamically Linked Libraries

- **C call to library function:**

```
printf("sqr[%d] = %d\n", x, y);
```

- **Assembly code**

```
addi   $a0,$0,1
la     $a1,ctrlstring
lw     $a2,x
lw     $a3,y
call   fprintf
```

- **Maps to:**

```
addi   $a0,$0,1
lui    $a1,ctrlstringHi
ori    $a1,ctrlstringLo
lui    $at,xhi
lw     $a2,xlo($at)
lw     $a3,ylo($at)
lui    $at,fprintfHi
ori    $at,fprintfLo
jalr   $at
```

How does dynamic linking work?

Dynamically Linked Libraries

- C call to library function:

```
printf("sqr[%d] = %d\n", x, y);
```

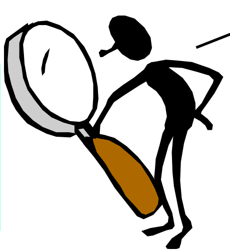
- Assembly code

```
addi    $a0,$0,1
la      $a1,ctrlstring
lw      $a2,x
lw      $a3,y
call    fprintf
```

- Maps to:

```
addi    $a0,$0,1
lui     $a1,ctrlstringHi
ori     $a1,ctrlstringLo
lui     $at,xhi
lw      $a2,xlo($at)
lw      $a3,ylo($at)
lui     $at,fprintfHi
ori     $at,fprintfLo
jalr    $at
```

How does dynamic linking work?



Why are we loading the function's address into a register first, and then calling it?

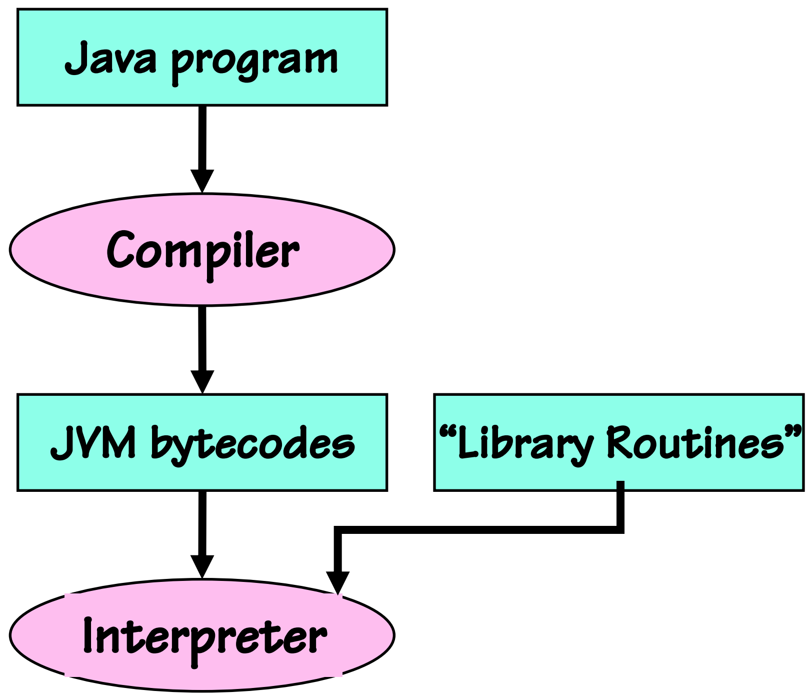
Modern Languages

- Intermediate "object code language"

High-level, portable (architecture independent) program description

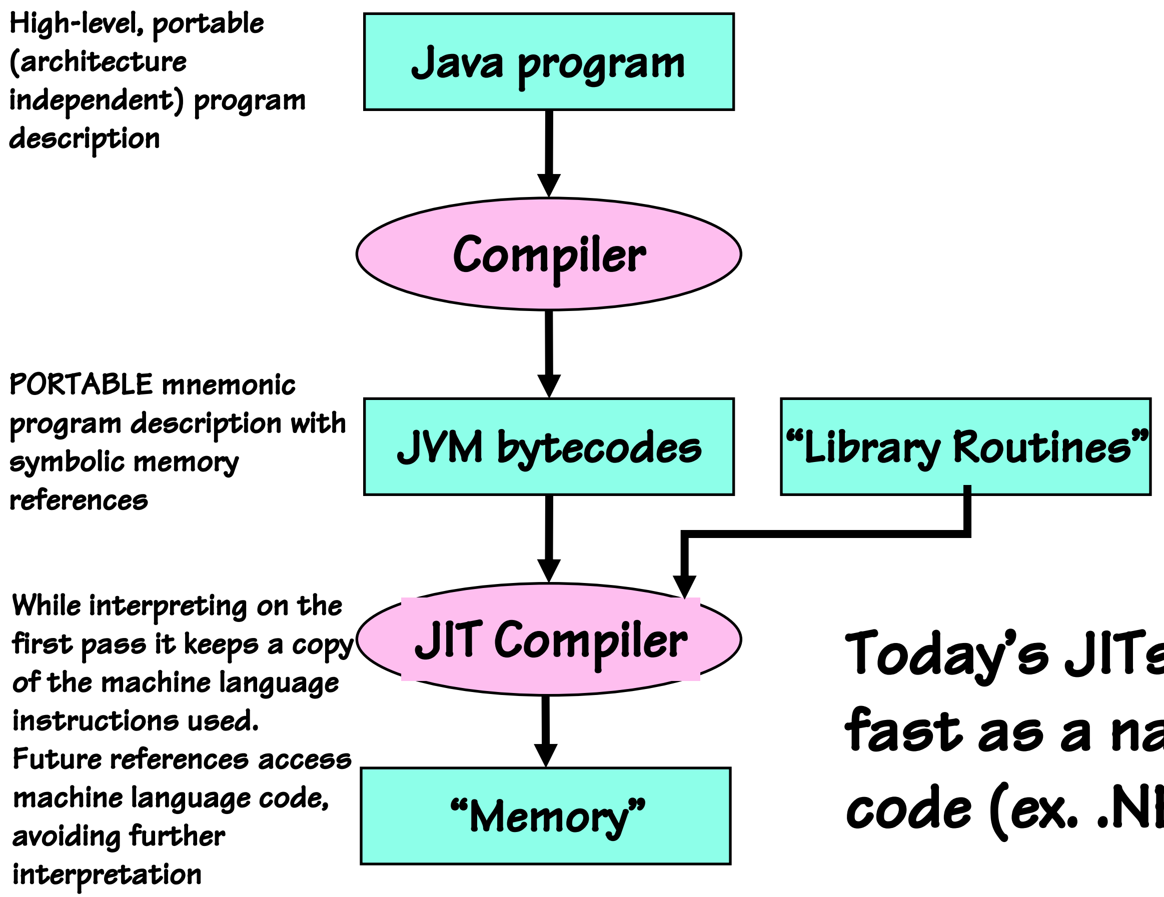
PORTABLE mnemonic program description with symbolic memory references

An application that EMULATES a virtual machine. Can be written for any Instruction Set Architecture. In the end, machine language instructions must be executed for each JVM bytecode



Modern Languages

- Intermediate "object code language"



Today's JITs are nearly as fast as a native compiled code (ex. .NET).

Compiler Optimizations

- **Example "C" Code:**

```
int a[10];
int total;

int main( ) {
    int i;

    total = 0;
    for (i = 0; i < 10; i++) {
        a[i] = i;
        total = total + i;
    }
}
```

Unoptimized Assembly Output

- **With debug flags set:**

```
.globl main
.text
main:
     addu $sp,$sp,-8          # allocates space for ra and i
     sw $0,total              # total = 0
     sw $0,0($sp)             # i = 0
     lw $8,0($sp)             # copy i to $t0
     b  L.3                   # goto test
L.2:                          # for(...) {
     sll $24,$8,2             #  make i a word offset
     sw $8,array($24)         #  array[i] = i
     lw $24,total             #  total = total + i
     addu $24,$24,$8
     sw $24,total
     addi $8,$8,1             #  i = i + 1
L.3:
     sw $8,0($sp)             #  update i in memory
     la $24,10                #  loads const 10
     blt $8,$24,L.2           #} loops while i < 10
     addu $sp,$sp,8
     j $31
```

Register Allocation

- Assign local variables to registers

```
.globl main
.text
main:
     addu $sp,$sp,-4           #allocates space for ra
     sw $0,total               #total = 0
     move $8,$0                #i = 0
     b  L.3                    #goto test
L.2:                           #for(...) {
     sll $24,$8,2              #  make i a word offset
     sw $8,array($24)          #  array[i] = i
     lw $24,total              #  total = total + i
     addu $24,$24,$8
     sw $24,total
     addi $8,$8,1              #  i = i + 1
L.3:
     la $24,10                 #  loads const 10
     blt $8,$24,L.2            #} loops while i < 10
     addu $sp,$sp,4
     j $31
```

Loop-Invariant Code Motion

- **Assign globals to temp registers and moves assignments outside of loop**

```
.globl main
.text
main:
     addu $sp,$sp,-4          #allocates space for ra
     sw $0,total              #total = 0
     move $9,$0               #temp for total
     move $8,$0               #i = 0
     b  L.3                   #goto test
L.2:                          #for(...) {
     sll $24,$8,2             #  make i a word offset
     sw $8,array($24)         #  array[i] = i
     addu $9,$9,$8
     sw $9,total
     addi $8,$8,1             #  i = i + 1
L.3:
     la $24,10                #  loads const 10
     blt $8,$24,L.2           #} loops while i < 10
     addu $sp,$sp,4
     j $31
```

Remove Unnecessary Tests

- Since "i" is initially set to "0", we already know it is less than "10", so why test it the first time through?

```
.globl main
.text
main:
     addu $sp,$sp,-4          #allocates space for ra
     sw $0,total              #total = 0
     move $9,$0               #temp for total
     move $8,$0               #i = 0
L.2:                          #for(...) {
     sll $24,$8,2             #  make i a word offset
     sw $8,array($24)         #  array[i] = i
     addu $9,$9,$8
     addi $8,$8,1             #  i = i + 1
     slti $24,$8,10           #  loads const 10
     bne $24,$0,L.2           #} loops while i < 10
     sw  $9,total
     addu $sp,$sp,4
     j $31
```

Remove Unnecessary Stores

- All we care about it the value of total after the loop, and simplify loop

```
.globl main
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main:
     addu $sp,$sp,-4          #allocates space for ra and i
     sw $0,total              #total = 0
     move $9,$0               #temp for total
     move $8,$0               #i = 0
L.2:
     sll $24,$8,2             #for(...) {
     sw $8,array($24)         #  array[i] = i
     addu $9,$9,$8
     addi $8,$8,1             #  i = i + 1
     slti $24,$8,10           #  loads const 10
     bne $24,$0,L.2           #} loops while i < 10
     sw  $9,total
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```

Unrolling Loop

- Two copies of the inner loop reduce the branching overhead

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L.2:
     sll $24,$8,2              #for(...) {
     sw $8,array($24)          #  array[i] = i
     addu $9,$9,$8
     addi $8,$8,1              #  i = i + 1
     sll $24,$8,2              #
     sw $8,array($24)          #  array[i] = i
     addu $9,$9,$8
     addi $8,$8,1              #  i = i + 1
     slti $24,$8,10            #  loads const 10
     bne $24,$0,L.2            #} loops while i < 10
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