

- jump instructions are unconditional
- branch instructions are conditional and can implement if and while
 - ▶ except **b** label which has same effect as **j** label
 - ▶ you can use either
- branch instruction encode a 16-bit relative offset
 - ▶ target (label) must be within -32768..32767 instructions
 - ▶ not a problem in CP1521 - we write small programs
- jump instruction encode a 28-bit value
 - ▶ allows jumps to be used for targets (labels) further away

MIPS Programming

Writing correct assembler directly is hard.

Recommended strategy:

- develop a solution in C
- map down to “simplified” C
- translate simplified C statements to MIPS instructions

Simplified C

- does *not* have while, compound if, complex expressions
- does have simple if, goto, one-operator expressions

Simplified C makes extensive use of

- *labels* ... symbolic name for C statement
- *goto* ... transfer control to labelled statement

Mapping C into MIPS

Things to do:

- allocate variables to registers/memory
- place literals in data segment
- transform C program to:
 - ▶ break expression evaluation into steps
 - ▶ replace most control structures by goto

goto in C

The **goto** statement allows transfer of control to any labelled point with a function. For example, this code:

```
for (int i = 1; i <= 10; i++) {  
    printf("%d\n", i);  
}
```

can be written as:

```
int i = 1;  
loop:  
    if (i > 10) goto end;  
    printf("%d", i);  
    printf("\n");  
    i = i + 1;  
    goto loop;  
end:
```

goto in C

- **goto** statements can result in very difficult to read programs.
- **goto** statements can also result in slower programs.
- In general, use of **goto** is considered **bad** programming style.
- Do not use **goto** without very good reason.
- kernel & embedded programmers sometimes use goto.

Conditionals — if from C to Simplified C

Standard C

```
if (n < 0) {  
    n = n - i;  
}  
else {  
    n = n + i;  
}
```

Simplified C

```
if (n >= 0) goto else1;  
n = n - i;  
goto end1;  
else1:  
n = n + i;  
end1:
```

note: else is not a valid label name in C

Conditionals — if from Simplified C to MIPS

Simplified C

```
    if (n >= 0) goto else1;
    n = n - i;
    goto end1;
else1:
    n = n + i;
end1:
```

MIPS

```
# assuming i in $t0,
# assuming n in $t1...

bge $t1, 0, else1
sub $t1, $t1, $t0
b end1
else1:
    add $t1, $t1, $t0
end1:
```

Odd or Even: C to simplified C

C

```
int main(void) {
    int x;
    printf("Enter a number: ");
    scanf("%d", &x);
    if (x % 2 == 0) {
        printf("Even\n");
    } else {
        printf("Odd\n");
    }
    return 0;
}
```

source code for odd_even.c

Simplified C

```
int main(void) {
    int x, v0;
    printf("Enter a number: ");
    scanf("%d", &x);
    v0 = x % 2;
    if (v0 != 0) goto odd;
    printf("Even\n");
    goto end;
odd:
    printf("Odd\n");
end:
    return 0;
}
```

source code for odd_even.simple.c

Odd or Even: MIPS

```
# read a number and print whether its odd or even
main:
    la  $a0, string0    # printf("Enter a number: ");
    li  $v0, 4
    syscall
    li  $v0, 5          # scanf("%d", x);
    syscall
    rem $t0, $v0, 2     # if (x % 2 == 0) {
    bne $t0, $zero, odd
    la  $a0, string1    # printf("Even\n");
    li  $v0, 4
    syscall
    b   end
```

source code for odd_even.s

Odd or Even: MIPS

```
odd:                # else
    la  $a0, string2 # printf("Odd\n");
    li  $v0, 4
    syscall
end:
    li  $v0, 0        # return 0
    jr  $ra
.data
string0:
    .asciiz "Enter a number: "
string1:
    .asciiz "Even\n"
string2:
    .asciiz "Odd\n"
```

source code for odd_even.s

Exercise: if-else if-else

Map the following into simplified C then into MIPS

```
int temperature;
scanf("%d",&temperature);
if(temperature >= 40){
    printf("Too hot\n");
} else if (temperature < 10){
    printf("Too cold\n");
} else {
    printf("Just right\n");
}
```

Loops — while from C to Simplified C

Standard C

```
i = 0;
n = 0;
while (i < 5) {
    n = n + i;
    i++;
}
```

Simplified C

```
i = 0;
n = 0;
loop:
    if (i >= 5) goto end;
    n = n + i;
    i++;
    goto loop;
end:
```

Loops – while from Simplified C to MIPS

Simplified C

```
i = 0;
n = 0;
loop:
  if (i >= 5) goto end;
  n = n + i;
  i++;
  goto loop;
end:
```

MIPS

```
li $t0, 0 # i in $t0
li $t1, 0 # n in $t1
loop:
  bge $t0, 5, end
  add $t1, $t1, $t0
  addi $t0, $t0, 1
  j loop
end:
```

Printing First 10 Integers: C to simplified C

C

```
int main(void) {
  for (int i = 1; i <= 10; i++) {
    printf("%d\n", i);
  }
  return 0;
}
source code for print10.c
```

Simplified C

```
int main(void) {
  int i;
  i = 1;
loop:
  if (i > 10) goto end;
  printf("%d", i);
  printf("\n");
  i = i + 1;
  goto loop;
end:
  return 0;
}
source code for print10.simple.c
```

Printing First 10 Integers: MIPS

```
# print integers 1..10 one per line
main:                                # int main(void) {
                                     # int i; // in register $t0
    li $t0, 1                         # i = 1;
loop:                                 # loop:
    bgt $t0, 10, end                 # if (i > 10) goto end;
    move $a0, $t0                    # printf("%d" i);
    li $v0, 1
    syscall
    li $a0, '\n'                     # printf("%c", '\n');
    li $v0, 11
    syscall
    addi $t0, $t0, 1                 # i++;
    b loop                            # goto loop;
end:
    li $v0, 0                         # return 0
    jr $ra
```

source code for print10.s

Sum 100 Squares: C to simplified C

C

```
int main(void) {
    int sum = 0;
    for (int i = 0; i <= 100; i++) {
        sum += i * i;
    }
    printf("%d\n", sum);
    return 0;
}
```

source code for sum_100_squares.c

Simplified C

```
int main(void) {
    int i, sum, square;
    sum = 0;
    i = 0;
loop:
    if (i > 100) goto end;
    square = i * i;
    sum = sum + square;
    i = i + 1;
    goto loop;
end:
    printf("%d", sum);
    printf("\n");
    return 0;
}
```

source code for sum_100_squares.simple.c

Sum 100 Squares: MIPS

```
# calculate 1*1 + 2*2 + ... + 99 * 99 + 100 * 100
# sum in $t0, i in $t1, square in $t2
main:
    li    $t0, 0           # sum = 0;
    li    $t1, 0           # i = 0
loop:
    bgt   $t1, 100, end    # if (i > 100) goto end;
    mul   $t2, $t1, $t1    # square = i * i;
    add   $t0, $t0, $t2    # sum = sum + square;
    addi  $t1, $t1, 1      # i = i + 1;
    b     loop
end:
```

source code for sum_100_squares.s

Sum 100 Squares: MIPS

```
end:
    move  $a0, $t0         # printf("%d", sum);
    li    $v0, 1
    syscall
    li    $a0, '\n'       # printf("%c", '\n');
    li    $v0, 11
    syscall
    li    $v0, 0          # return 0
    jr    $ra
```

source code for sum_100_squares.s

Conditionals — i f and &&: from C to Simplified C

Standard C

```
if (i < 0 && n >= 42) {  
    n = n - i;  
} else {  
    n = n + i;  
}
```

Simplified C

```
if (i >= 0) goto else1;  
if (n < 42) goto else1;  
n = n - i;  
goto end1;  
else1:  
    n = n + i;  
end1:
```

Conditionals — i f and &&: from Simplified C to MIPS

Simplified C

```
if (i >= 0) goto else1;  
if (n < 42) goto else1;  
n = n - i;  
goto end1;  
else1:  
    n = n + i;  
end1:
```

MIPS

```
# assume i in $t0  
# assume n in $t1  
  
bge $t0, 0, else1  
blt $t1, 42, else1  
sub $t1, $t1, $t0  
j end1  
else1:  
    add $t1, $t1, $t0  
end1:
```

Conditionals — i f and | |: from C to Simplified C

Standard C

```
if (i < 0 || n >= 42) {  
    n = n - i;  
} else {  
    n = n + i;  
}
```

Simplified C

```
if (i < 0) goto then1;  
if (n >= 42) goto then1;  
goto else1;  
then1:  
    n = n - i;  
    goto end1;  
else1:  
    n = n + i;  
end1:
```

Simplified C

```

if (i < 0) goto then1;
if (n >= 42) goto then1;
goto else1;
then1:
  n = n - i;
  goto end1;
else1:
  n = n + i;
end1:

```

MIPS

```

# assume i in $t0
# assume n in $t1

blt $t0, 0, then1
bge $t1, 42, then1
j else1
then1:
  sub $t1, $t1, $t0
  j end1
else1:
  add $t1, $t1, $t0
end1:

```

Example Translation of Branch Pseudo-instructions

Pseudo-Instructions

```

bge $t1, $t2, label

blt $t1, 42, label

beqz $t3, label

bnez $t4, label

b label

```

Real Instructions

```

slt $at, $t1, $t2
beq $at, $0, label

addi $at, $zero, 42
slt $at, $t1, $at
bne $at, $0, label

beq $t3, $0, label

bne $t4, $0, label

beq $0, $0, label

```