The Hardware/Software Interface

CSE351 Spring 2013

x86 Programming III

Today's Topics

- **Switch statements**

Switch Statement Example

```
long switch_eg (unsigned
   long x, long y, long z)
{
    long w = 1;
    switch(x) {
    case 1:
        w = y*z;
        break;
    case 2:
        w = y/z;
        /* Fall Through */
    case 3:
        w += z;
        break;
    case 5:
    case 6:
        w -= z;
        break;
    default:
        w = 2;
    }
    return w;
}
```

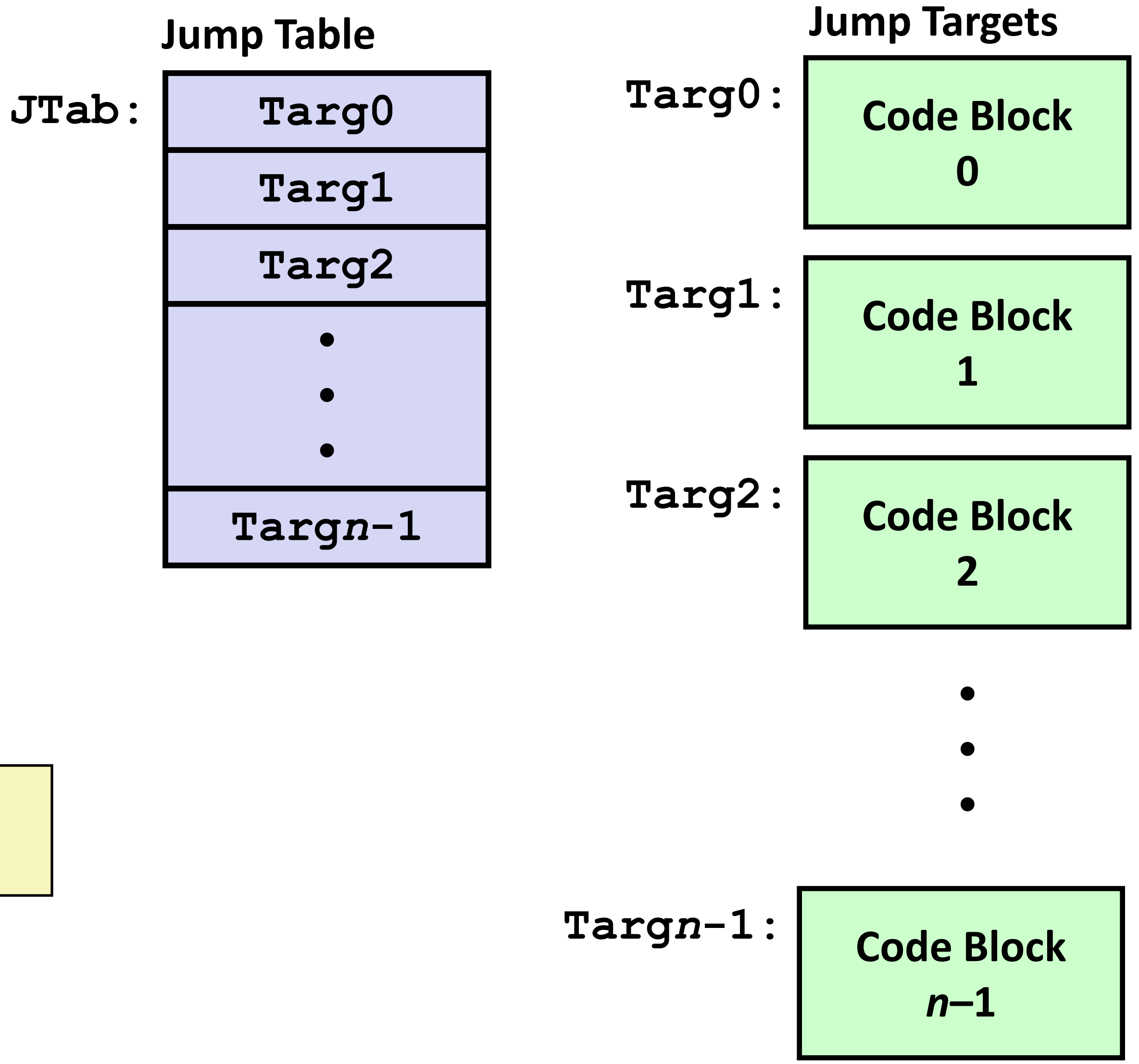
- **Multiple case labels**
  - Here: 5, 6
- **Fall through cases**
  - Here: 2
- **Missing cases**
  - Here: 4

- **Lots to manage, we need a *jump table***

Jump Table Structure

Switch Form

```
switch(x) {
  case val_0:
    Block 0
  case val_1:
    Block 1
    • • •
  case val_n-1:
    Block n–1
}
```



Approximate Translation

```
target = JTab[x];
goto *target;
```

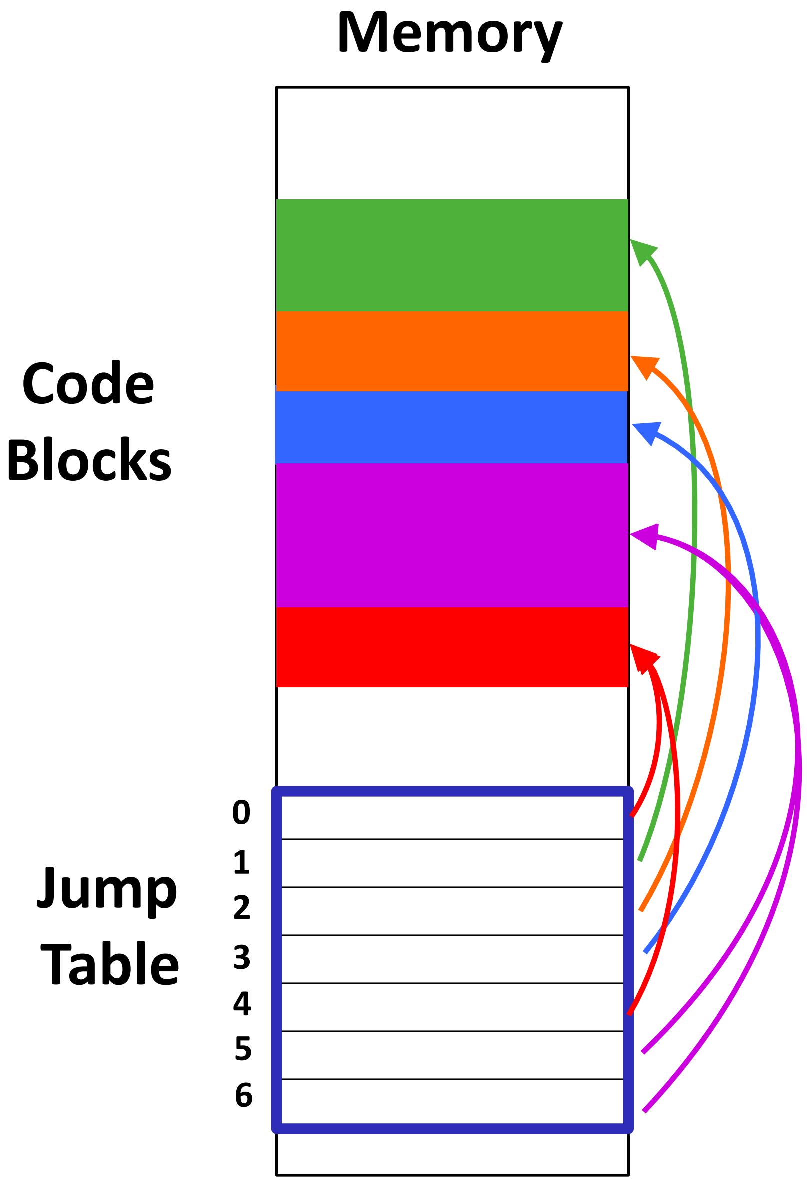
Jump Table Structure

C code:

```
switch(x)  {
   case 1: <some code>
           break;
   case 2: <some code>
   case 3: <some code>
           break;
   case 5:
   case 6: <some code>
           break;
   default: <some code>
}
```

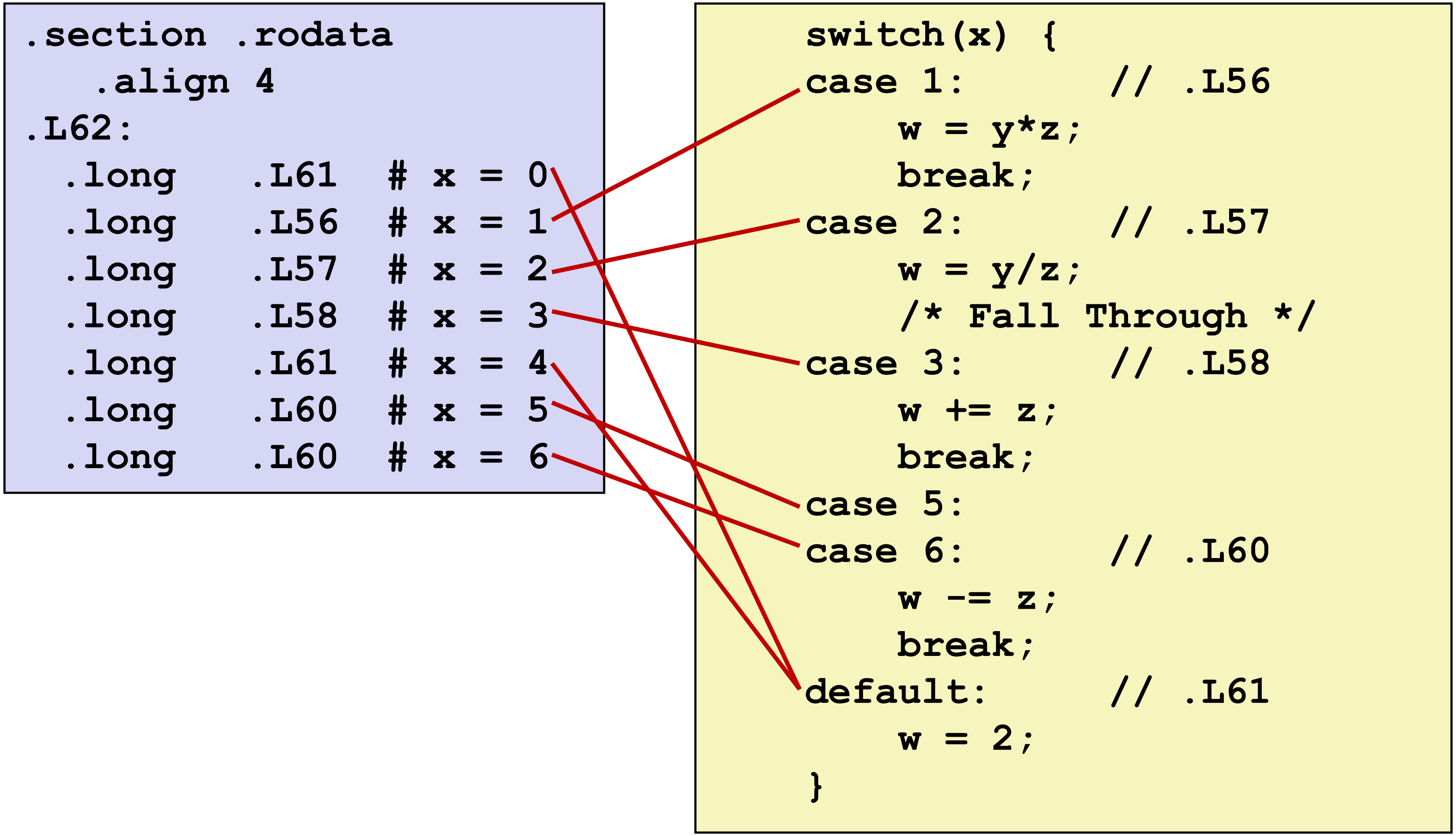
We can use the jump table when x <= 6:

```
if (x <= 6)
   target = JTab[x];
   goto *target;
else
   goto default;
```



Jump Table

Jump table



```
.section .rodata
   .align 4
.L62:
  .long    .L61  # x = 0
  .long    .L56  # x = 1
  .long    .L57  # x = 2
  .long    .L58  # x = 3
  .long    .L61  # x = 4
  .long    .L60  # x = 5
  .long    .L60  # x = 6
```

```
switch(x) {
case 1:       // .L56
    w = y*z;
    break;
case 2:       // .L57
    w = y/z;
    /* Fall Through */
case 3:       // .L58
    w += z;
    break;
case 5:
case 6:       // .L60
    w -= z;
    break;
default:      // .L61
    w = 2;
}
```

Switch Statement Example (IA32)

```
long switch_eg(unsigned long x, long y,
   long z)
{
    long w = 1;
    switch(x) {
      . . .
    }
    return w;
}
```

Setup:

```
switch_eg:
    pushl  %ebp              # Setup
    movl   %esp, %ebp        # Setup
    pushl  %ebx              # Setup
    movl   $1, %ebx          # w = 1
    movl   8(%ebp), %edx     # edx = x
    movl   16(%ebp), %ecx    # ecx = z
    cmpl   $6, %edx
    ja     .L61
    jmp    *.L62(,%edx,4)
```

Jump table

```
.section .rodata
   .align 4
.L62:
   .long    .L61   # x = 0
   .long    .L56   # x = 1
   .long    .L57   # x = 2
   .long    .L58   # x = 3
   .long    .L61   # x = 4
   .long    .L60   # x = 5
   .long    .L60   # x = 6
```

Translation?

Switch Statement Example (IA32)

```
long switch_eg(unsigned long x, long y,
   long z)
{
    long w = 1;
    switch(x) {
      . . .
    }
    return w;
}
```

Setup:

```
switch_eg:
   pushl  %ebp              # Setup
   movl   %esp, %ebp        # Setup
   pushl  %ebx              # Setup
   movl   $1, %ebx          # w = 1
   movl   8(%ebp), %edx     # edx = x
   movl   16(%ebp), %ecx    # ecx = z
   cmpl   $6, %edx          # x:6
   ja     .L61              # if > goto default
   jmp    *.L62(,%edx,4)    # goto JTab[x]
```

Indirect jump →

Jump table

```
.section  .rodata
   .align 4
.L62:
  .long    .L61  # x = 0
  .long    .L56  # x = 1
  .long    .L57  # x = 2
  .long    .L58  # x = 3
  .long    .L61  # x = 4
  .long    .L60  # x = 5
  .long    .L60  # x = 6
```

Assembly Setup Explanation

- **Table Structure**
  - Each target requires 4 bytes
  - Base address at `.L62`

- **Jumping: different address modes for target**

Direct: `jmp .L61`

  - Jump target is denoted by label `.L61`

Indirect: `jmp *.L62(,%edx,4)`

  - Start of jump table: `.L62`
  - Must scale by factor of 4 (labels are 32-bits = 4 bytes on IA32)
  - Fetch target from effective address `.L62 + edx*4`
    - `target = JTab[x]; goto *target;` (only for $0 \leq \mathbf{x} \leq 6$)

Jump table

```
.section .rodata
    .align 4
.L62:
  .long    .L61   # x = 0
  .long    .L56   # x = 1
  .long    .L57   # x = 2
  .long    .L58   # x = 3
  .long    .L61   # x = 4
  .long    .L60   # x = 5
  .long    .L60   # x = 6
```

Code Blocks (Partial)

```
  switch(x) {
    . . .
  case 2:        // .L57
      w = y/z;
      /* Fall Through */
  case 3:        // .L58
      w += z;
      break;
    . . .
  default:       // .L61
      w = 2;
  }
```

```
.L61:  // Default case
   movl  $2, %ebx    # w = 2
   movl  %ebx, %eax  # Return w
   popl  %ebx
   leave
   ret
.L57:  // Case 2:
   movl  12(%ebp), %eax  # y
   cltd                 # Div prep
   idivl %ecx           # y/z
   movl  %eax, %ebx # w = y/z
# Fall through
.L58:  // Case 3:
   addl  %ecx, %ebx # w+= z
   movl  %ebx, %eax # Return w
   popl  %ebx
   leave
   ret
```

Code Blocks (Rest)

```
switch(x) {
case 1:         // .L56
    w = y*z;
    break;
  . . .
case 5:
case 6:         // .L60
    w -= z;
    break;
  . . .
}
```

```
.L60: // Cases 5&6:
   subl   %ecx, %ebx   # w -= z
   movl   %ebx, %eax   # Return w
   popl   %ebx
   leave
   ret
.L56: // Case 1:
   movl   12(%ebp), %ebx # w = y
   imull  %ecx, %ebx      # w*= z
   movl   %ebx, %eax   # Return w
   popl   %ebx
   leave
   ret
```

IA32 Object Code

- **Setup**
  - Label **`.L61`** becomes address **`0x08048630`**
  - Label **`.L62`** becomes address **`0x080488dc`**

Assembly Code

```
switch_eg:
  . . .
  ja     .L61             # if > goto default
  jmp    *.L62(,%edx,4)   # goto JTab[x]
```

Disassembled Object Code

```
08048610 <switch_eg>:
 . . .
08048622:  77 0c                  ja     8048630
08048624:  ff 24 95 dc 88 04 08   jmp    *0x80488dc(,%edx,4)
```

IA32 Object Code (cont.)

- **Jump Table**
  - Doesn’t show up in disassembled code
  - Can inspect using GDB

```
 gdb asm-cntl
(gdb) x/7xw 0x080488dc
```

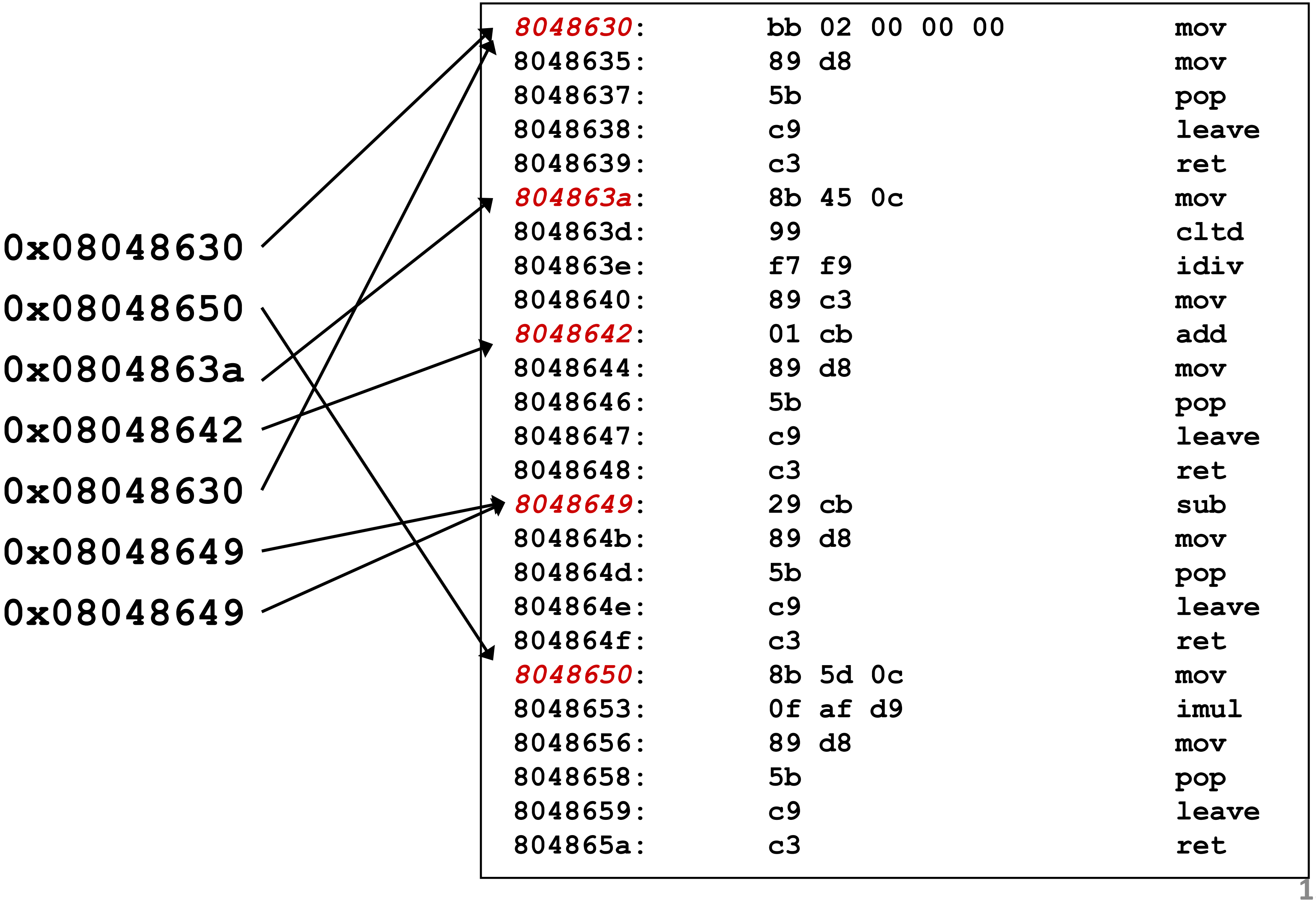
    - Examine 7 hexadecimal format “words” (4-bytes each)
    - Use command “**`help x`**” to get format documentation

```
0x080488dc:
   0x08048630
   0x08048650
   0x0804863a
   0x08048642
   0x08048630
   0x08048649
   0x08048649
```

Disassembled Targets

```
8048630:     bb 02 00 00 00          mov    $0x2,%ebx
8048635:     89 d8                   mov    %ebx,%eax
8048637:     5b                      pop    %ebx
8048638:     c9                      leave
8048639:     c3                      ret
804863a:     8b 45 0c                mov    0xc(%ebp),%eax
804863d:     99                      cltd
804863e:     f7 f9                   idiv   %ecx
8048640:     89 c3                   mov    %eax,%ebx
8048642:     01 cb                   add    %ecx,%ebx
8048644:     89 d8                   mov    %ebx,%eax
8048646:     5b                      pop    %ebx
8048647:     c9                      leave
8048648:     c3                      ret
8048649:     29 cb                   sub    %ecx,%ebx
804864b:     89 d8                   mov    %ebx,%eax
804864d:     5b                      pop    %ebx
804864e:     c9                      leave
804864f:     c3                      ret
8048650:     8b 5d 0c                mov    0xc(%ebp),%ebx
8048653:     0f af d9                imul   %ecx,%ebx
8048656:     89 d8                   mov    %ebx,%eax
8048658:     5b                      pop    %ebx
8048659:     c9                      leave
804865a:     c3                      ret
```

Matching Disassembled Targets



```
0x08048630
0x08048650
0x0804863a
0x08048642
0x08048630
0x08048649
0x08048649
```

```
8048630:        bb 02 00 00 00          mov
8048635:        89 d8                   mov
8048637:        5b                      pop
8048638:        c9                      leave
8048639:        c3                      ret
804863a:        8b 45 0c                mov
804863d:        99                      cltd
804863e:        f7 f9                   idiv
8048640:        89 c3                   mov
8048642:        01 cb                   add
8048644:        89 d8                   mov
8048646:        5b                      pop
8048647:        c9                      leave
8048648:        c3                      ret
8048649:        29 cb                   sub
804864b:        89 d8                   mov
804864d:        5b                      pop
804864e:        c9                      leave
804864f:        c3                      ret
8048650:        8b 5d 0c                mov
8048653:        0f af d9                imul
8048656:        89 d8                   mov
8048658:        5b                      pop
8048659:        c9                      leave
804865a:        c3                      ret
```

Question

- **Would you implement this with a jump table?**

```
switch(x) {
  case 0:     <some code>
              break;
  case 10:    <some code>
              break;
  case 52000: <some code>
              break;
  default:    <some code>
              break;
}
```

- **Probably not:**
  - Don’t want a jump table with 52001 entries (too big)