Chapter 13
Control Structures

Control Structures

Conditional

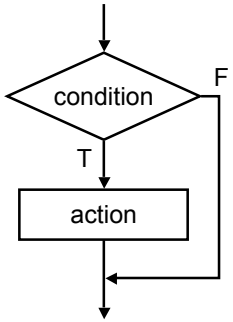
- **Making decision about which code to execute, based on evaluated expression**
- `if`
- `if-else`
- `switch`

Iteration

- **Executing code multiple times, ending based on evaluated expression**
- `while`
- `for`
- `do-while`

If

```
if (condition)
  action;
```



Condition is a C expression,
which evaluates to TRUE (non-zero) or FALSE (zero).
Action is a C statement,
which may be simple or compound (a block).

Example If Statements

```
if (x <= 10)
  y = x * x + 5;
```

Style: avoid singleton if statements (I **really** dislike them)

```
if (x <= 10) {
  y = x * x + 5;
  z = (2 * y) / 3;
}
```

compound statement; both executed if x <= 10

```
if (x <= 10)
  y = x * x + 5;
  z = (2 * y) / 3;
```

only first statement is conditional; second statement is ***always*** executed

More If Examples

```
if (0 <= age && age <= 11) {
  kids = kids + 1;
}
if (month == 4 || month == 6 ||
    month == 9 || month == 11) {
  printf("The month has 30 days.\n");
}
if (x = 2) {
  y = 5;
}
```

Common C error, assignment (=) Versus equality (==)

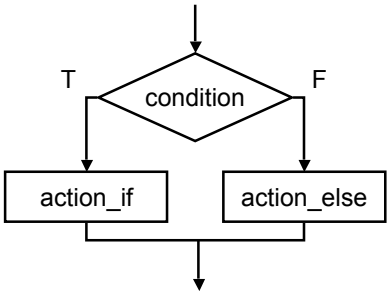
This is a common programming error (= instead of ==), not caught by compiler because it's syntactically correct.

Generating Code for If Statement

```
if (x == 2) {
  y = 5;
}
      LDR  R0, R6, #0   ; load x into R0
      ADD  R0, R0, #-2  ; subtract 2
      BRnp NOT_TRUE     ; if non-zero, x is not 2
      AND  R1, R1, #0   ; store 5 to y
      ADD  R1, R1, #5
      STR  R1, R6, #1
NOT_TRUE ...            ; next statement
```


If-else

```
if (condition)
  action_if;
else
  action_else;
```



Else allows choice between two mutually exclusive actions without re-testing condition.

Generating Code for If-Else

```
if (x) {
  y++;
  z--;
} else {
  y--;
  z++;
}
```

```
      LDR  R0, R6, #0
      BRz  ELSE
      ; x is not zero
      LDR  R1, R6, #1   ; incr y
      ADD  R1, R1, #1
      STR  R1, R6, #1
      LDR  R1, R6, #2   ; decr z
      ADD  R1, R1, #-1
      STR  R1, R6, #2
      JMP  DONE   ; skip else code
      ; x is zero
ELSE  LDR  R1, R6, #1   ; decr y
      ADD  R1, R1, #-1
      STR  R1, R6, #1
      LDR  R1, R6, #2   ; incr z
      ADD  R1, R1, #1
      STR  R1, R6, #2
DONE  ...  ; next statement
```

Matching Else with If

Else is always associated with *closest* unassociated if

```
if (x != 10)
  if (y > 3)
    z = z / 2;
  else
    z = z * 2;
```

is the same as...

```
if (x != 10) {
  if (y > 3)
    z = z / 2;
  else
    z = z * 2;
}
```

is NOT the same as...

```
if (x != 10) {
  if (y > 3)
    z = z / 2;
}
else
  z = z * 2;
```

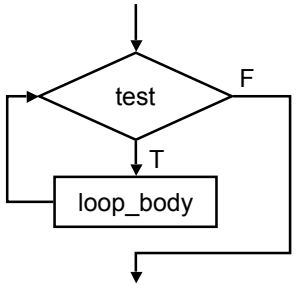
Solution: *always* use braces (avoids the problem entirely)

Chaining If's and Else's

```
if (month == 4 || month == 6 || month == 9 ||
    month == 11) {
  printf("Month has 30 days.\n");
} else if (month == 1 || month == 3 ||
           month == 5 || month == 7 ||
           month == 8 || month == 10 ||
           month == 12) {
  printf("Month has 31 days.\n");
} else if (month == 2) {
  printf("Month has 28 or 29 days.\n");
} else {
  printf("Don't know that month.\n");
}
```


While

```
while (test)
  loop_body;
```



Executes loop body as long as test evaluates to TRUE (non-zero)

*Note: Test is evaluated **before** executing loop body*

Generating Code for While

```
x = 0;
while (x < 10) {
  printf("%d ", x);
  x = x + 1;
}
```

```
        AND  R0, R0, #0
        STR  R0, R6, #0 ; x = 0
        ; test
LOOP    LDR  R0, R6, #0 ; load x
        ADD  R0, R0, #-10
        BRzp DONE
        ; loop body
        LDR  R0, R6, #0 ; load x
        ...
        <printf>
        ...
        ADD  R0, R0, #1 ; incr x
        STR  R0, R6, #0
        JMP  LOOP    ; test again

DONE    ; next statement
```

Infinite Loops

The following loop will never terminate:

```
x = 0;
while (x < 10) {
  printf("%d ", x);
}
```

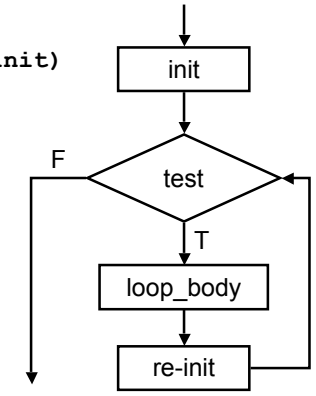
Loop body does not change condition...

- **...so test is never false**

Common programming error that can be difficult to find

For

```
for (init; end-test; re-init)
  statement
```



Executes loop body as long as test evaluates to TRUE (non-zero). Initialization and re-initialization code included in loop statement.

*Note: Test is evaluated **before** executing loop body*

Generating Code for For

```
for (i = 0; i < 10; i++) {
  printf("%d ", i);
}
```

This is the same as the while example!

```
        ; init
        AND  R0, R0, #0
        STR  R0, R6, #0  ; i = 0
        ; test
LOOP    LDR  R0, R6, #0  ; load i
        ADD  R0, R0, #-10
        BRzp DONE
        ; loop body
        LDR  R0, R6, #0  ; load i
        ...
        <printf>
        ...
        ; re-init
        ADD  R0, R0, #1  ; incr i
        STR  R0, R6, #0
        JMP  LOOP        ; test again

DONE    ; next statement
```


Example For Loops

```
/* -- what is the output of this loop? -- */
for (i = 0; i <= 10; i++) {
  printf("%d ", i);
}
/* -- what does this one output? -- */
letter = 'a';
for (c = 0; c < 26; c++) {
  printf("%c ", letter+c);
}
/* -- what does this loop do? -- */
numberOfOnes = 0;
for (bitNum = 0; bitNum < 16; bitNum++) {
  if (inputValue & (1 << bitNum)) {
    numberOfOnes++;
  }
}
```

Nested Loops

Loop body can (of course) be another loop

```
/* print a multiplication table */
for (mp1 = 0; mp1 < 10; mp1++) {
  for (mp2 = 0; mp2 < 10; mp2++) {
    printf("%d\t", mp1*mp2);
  }
  printf("\n");
}
```


Another Nested Loop

Here, test for the inner loop depends on counter variable of outer loop

```
for (outer = 1; outer <= input; outer++) {
  for (inner = 0; inner < outer; inner++) {
    sum += inner;
  }
}
```


For vs. While

In general:

For loop is preferred for counter-based loops

- Explicit counter variable
- Easy to see how counter is modified each loop

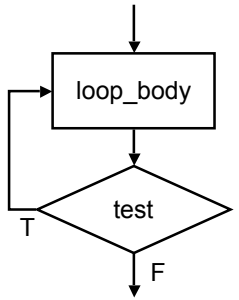
While loop is preferred for sentinel-based loops

- Test checks for sentinel value.

Either kind of loop can be expressed as other, so really a matter of style and readability

Do-While

```
do
  loop_body;
while (test);
```



Executes loop body as long as test evaluates to TRUE (non-zero).

*Note: Test is evaluated **after** executing loop body*

Break and Continue

`break;`

- used ***only*** in switch statement or iteration statement
- passes control out of the "smallest" (loop or switch) statement containing it to the statement immediately following
- usually used to exit a loop before terminating condition occurs (or to exit switch statement when case is done)

`continue;`

- used only in iteration statement
- terminates the execution of the loop body for this iteration
- loop expression is evaluated to see whether another iteration should be performed
- if `for` loop, also executes the re-initializer

Example

What does the following loop do?

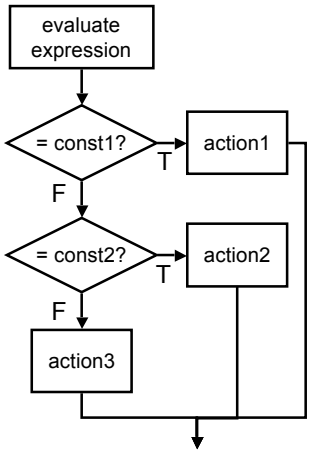
```
for (i = 0; i <= 20; i++) {
  if (i%2 == 0) {
    continue;
  }
  printf("%d ", i);
}
```

What would be an easier way to write this?

What happens if `break` instead of `continue`?

Switch

```
switch (expression) {
 case const1:
   action1;
   break;
 case const2:
   action2;
   break;
 default:
   action3;
 }
```



Alternative to long if-else chain.
If break is not used, then
case "falls through" to the next.

Switch Example

```
/* same as month example for if-else */
switch (month) {
 case 4:
 case 6:
 case 9:
 case 11:
   printf("Month has 30 days.\n");
   break;
 case 1:
 case 3:
 /* some cases omitted for brevity...*/
   printf("Month has 31 days.\n");
   break;
 case 2:
   printf("Month has 28 or 29 days.\n");
   break;
 default:
   printf("Don't know that month.\n");
}
```

More About Switch

Case expressions must be constant

```
case i:   /* illegal if i is a variable */
```

If no break, then next case is also executed

```
switch (a) {
  case 1:
    printf("A");
  case 2:
    printf("B");
  default:
    printf("C");
}
```

If a is 1, prints "ABC".
If a is 2, prints "BC".
Otherwise, prints "C".

Aside: Enumerations

Keyword `enum` declares a new type

- enum colors { RED, GREEN, BLUE, GREEN, YELLOW, MAUVE };
- RED is now 0, GREEN is 1, etc.
- Gives meaning to constants, groups constants

```
enum colors house_color;
house_color = get_color();
switch (house_color) {
  case RED:
    /* code here */
    break;
  /* more here… */
}
```

Enums are just ints, but can provide more type checking

- Warning on assignment (example: house_color = 85;)
- Warning on "partial" switch statement
- C++ adds even more checking support

Example: Searching for Substring

Have user type in a line of text (ending with linefeed) and print the number of occurrences of "the"

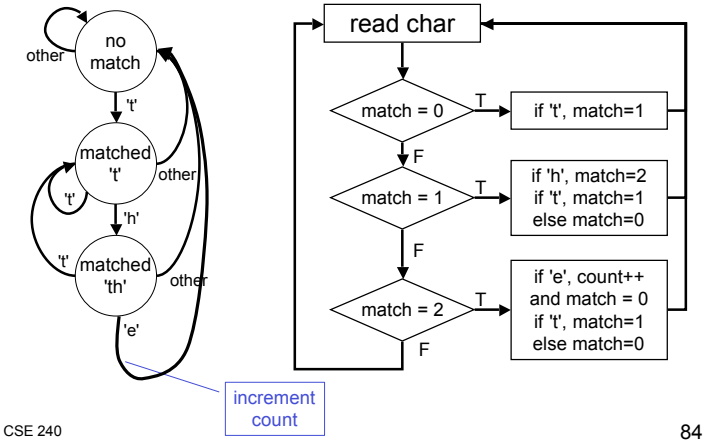
Reading characters one at a time

- Use the `getchar()` function -- returns a single character

Don't need to store input string; look for substring as characters are being typed

- Similar to state machine:
  based on characters seen, move toward success state
  or move back to start state
- Switch statement is a good match to state machine

Substring: State machine to flow chart



Substring: Code (Part 1)

```
#include <stdio.h>
enum state { NO_MATCH, ONE_MATCH, TWO_MATCHES };
main()
{
  char key;       /* input character from user */
  int match = NO_MATCH ; /* state of matching */
  int count = 0; /* number of substring matches */
  /* Read character until newline is typed */
  key = getchar();
  while (key != '\n') {
    /* Action depends on number of matches so far */
    switch (match) {
        See next two slides for
        contents of switch statement
    }
    key = getchar();
  }
  printf("Number of matches = %d\n", count);
}
```


Substring: Code (Part 2)

```
case NO_MATCH:  /* starting - no matches yet */
  if (key == 't') {
    match = ONE_MATCH;
  } else {
    match = NO_MATCH;
  }
  break;
case ONE_MATCH:  /* 't' has been matched */
  if (key == 'h') {
    match = TWO_MATCHES;
  } else if (key == 't') {
    match = ONE_MATCH;
  } else {
    match = NO_MATCH;
  }
  break;
```


Substring: Code (Part 3)

```
case TWO_MATCHES:  /* 'th' has been matched */
  if (key == 'e') {
    count++;   /* increment count */
    match = NO_MATCH; /* go to starting point */
  } else if (key == 't') {
    match = ONE_MATCH;
  } else {
    match = NO_MATCH;
  }
  break;
```