Conditionals and Control Flow

CSE 220: Systems Programming

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Advice: Time Management

The Carnegie Rule: 2-3 hours of work outside class per credit

That's why 12 credits is full time!

Plan accordingly:

- Schedule ~1.5 hours per lecture in a block
  - Too long: hard to focus
  - Too short: lost time to overhead
- Work every day, not all at once
- Schedule the other 0.5–1.5 hours as needed

Advice: Time Management

Keep a TODO!

- Don’t lose time to “what do I do next?”
- Don’t miss deadlines

For every course:

- 10-15 minutes every week for TODO management
- Make a list of 5-7 items you can just do
- If the list gets short, curate it!

Example items:

- Good: Read Chapter 5 through 5.4
- Good: PA1: Check command line arguments for validity
- Bad: PA1

Administrivia

If you haven't completed the following, you are behind:

- Lab 01
- AI Quiz
- K&R up to and including 2.4

Impostor Syndrome is real!

If you already knew all of this, we wouldn't make you take it.

what is truth?

```
#include <stdio.h>
void printTruthValue(int);
int main() {
    for (int i=-2; i<=2; i++) {
        printTruthValue(i);
    }
    return 0;
}
void printTruthValue(int x) {
    printf("x has value %d, which is ",x);
    if (x) { printf("true\n"); }
    else   { printf("false\n"); }
}
```

stdbool

```c
#include <stdio.h>
#include <stdbool.h>
void printTruthValue(bool);
int main() {
    for (int i=-2; i<=2; i++) {
        printTruthValue(i);
    }
    return 0;
}
void printTruthValue(bool x) {
    printf("x has value %d, which is ",x);
    if (x) { printf("true\n"); }
    else   { printf("false\n"); }
}
```

operators yield bool

```
#include <stdio.h>
#include <stdbool.h>

int main() {
    int x = 2;
    printf("x has value %d, !x has value %d, !!x has
        value %d\n",x,!x,!!x);

    bool r = true;
    printf("r has value %d, !r has value %d, !!r has
        value %d\n",r,!r,!!r);
    return 0;
}
```

short circuiting

```c
#include <stdio.h>
#include <stdbool.h>
bool f(int x, int y) {
    printf("f(%d,%d) called\n",x,y);
    return x < y;
}
bool g(int z) {
    printf("g(%d) called\n",z);
    return z < 20;
}
int main() {
    if (f(2,3) && g(5)) { puts("main: true"); }
    else                { puts("main: false"); }
    return 0;
}
```

Conditionals in C

Truth in C is simple but possibly non-intuitive:

- Bit-wise `0` is false
- anything else is true

However, boolean expressions and `true` and `false` are less unpredictable:

- `true` and true results are exactly 1
- `false` and false results are exactly `0`

Control Flow

We have discussed only the for loop in C.

Required readings in K&R have covered other control flow.

We will look at `if` and its implementation.

There are other control flow statements (discussed in K&R), but they behave similarly.

Boolean Operators

C uses the following Boolean operators:

- `!`: Logical not; inverts the following expression
- `&&`: Logical and; true iff the LHS and RHS are both true
- `||`: Logical or; true if either the RHS or LHS is true

Do not confuse these with the similarly-named bitwise operators!
(We will discuss those later.)

Boolean Logic in C

C uses short circuit evaluation for Boolean logic.

This means that evaluation of a Boolean sentence stops as soon as its final truth value is known.

For example:

```
x && y
```

If x is false, then this sentence is false.

In that case, y will never be evaluated.

Short Circuit Consequences

The consequences of short-circuit evaluation can be surprising.

If terms in the sentence have side effects, those side effects may not run.

This can be very useful, but also surprising!

```
if (i < len && array[i] == SOMEVAL) {
    /* Useful!  If array[i] is past the end of the
          array, the illegal access never happens. */
}
```

Equality Operators

There are two equality operators:

- `==`: Compares value equality, returns true if equal
- `!=`: Compares value equality, returns false if equal

Note that these operators compare values, not logical truth!

In particular, note that many values are "true", but `true` is 1!

This means that two logically true values may compare unequal.

Truthiness

```c
bool x = true;
int y = 2;

if (x)
    printf("x is true\n");
if (y)
    printf("y is true\n");
if (x == y)
    printf("x and y are equal\n");
```

Truthiness

```
bool x = true;
int y = 2;

if (x)
    printf("x is true\n");
if (y)
    printf("y is true\n");
if (x == y)
    printf("x and y are equal\n");
```

Output:

```
x is true
y is true
```

stdbool

The header `#include <stdbool.h>` defines some useful things.

- The type `bool`, which holds only 0 or 1
- The values `true` and `false`

Before C99, these things didn't exist in the standard, but were widely defined in programs.

Therefore they were standardized to require a header.

```
bool b = 2;
printf("%d\n", b);
```

Output:
1

Control Flow

Control flow is the path that execution takes through a program.

The C model is linear flow by default.

Control flow statements can change the order of execution.

This is how our programs make decisions.

We will examine how this flow is achieved.

The `if` Statement

The simplest control statement in C is `if`.

Its syntax is:

```
if (condition) {
    body;
}
```

If the expression `condition` evaluates to any true value, `body` runs.

Otherwise, `body` is skipped.

Implementing `if`

The `if` statement must be compiled to machine instructions.

Those machine instructions must encode the condition check and jump.

This is normally implemented as a conditional branch instruction.

You don't have to learn assembly for this course, but we will look at some machine instruction concepts.

A Simple Condition — C

```c
int main(int argc, char *argv[])
{
    if (argc == 2 && argv[1][0] == '-') {
        puts("negative");
    }
    return 0;
}
```

A Simple Condition — Assembly

```
        cmpl $2, %edi            ; compare argc to 2
        je   .L8                 ; jump to .L8 if ==
.L4:
        xorl %eax, %eax          ; set up return value
        ret                      ; return 0
.L8:
        movq 8(%rsi), %rax       ; load argv[2][0] to %rax
        cmpb $45, (%rax)         ; compare %rax to 45 ('-')
        jne  .L4                 ; jump to .L4 if !=
        leaq .LC0(%rip), %rdi; load "negative" to %rdi
        subq $8, %rsp            ; make room on stack
        call puts@PLT            ; call puts("negative")
                                 ; another return 0 goes
                                   here
```

Conditional Instruction Flow

Note that the structure of the program was lost.

One of the advantages of high-level languages is structure.

The computer can generally only:¶

- Make simple comparisons (sometimes only to zero!)
- Jump to a program location

Anything more complicated is a software construction.

The `else` Clause

The `else` clause is simply either:

- The next instruction after a jump
- The jump destination (with the `if` body being the next instruction)

Which layout the compiler uses depends on the code and architecture.

else Gotchas

I strongly advocate always using blocks.
Here is a place where it really matters:

```
if (modify_x)
    if (negate)
        x = x * -1;
else
    y = -x;
```

else Gotchas

I strongly advocate always using blocks.
What this actually means is:

```
if (modify_x)
    if (negate)
        x = x * -1;
    else
        y = -x;
```

else Gotchas

I strongly advocate always using blocks.
What you should use is:

```
if (modify_x) {
    if (negate) {
        x = x * -1;
    }
} else {
        y = -x;
}
```

Summary

- All nonzero values are true conditions in C.
- All Boolean expressions use 1 for true.
- The `bool` keyword holds only 0 or 1.
- C uses short-circuit evaluation of Boolean logic.
- Control flow is implemented with comparisons and jumps.
- Use blocks for if and else!

Next Time …

- POSIX memory model
- Pointer types
- Process layout

References I

Required Readings

[1] Brian W. Kernighan and Dennis M. Ritchie. *The C Programming Language*. Second Edition. Chapter 2: 2.6; Chapter 3: Intro, 3.1–3.7. Prentice Hall, 1988.

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