The Design of C: A Rational Reconstruction: Part 2

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Continued from previous lecture

Agenda

Data Types

Operators

Statements

I/O Facilities

Operators

What kinds of operators should C have?

Thought process

- Should handle typical operations
- Should handle bit-level programming ("bit twiddling")
- Should provide a mechanism for converting from one type to another

Operators

Decisions

- Provide typical arithmetic operators: `+ - * / %`
- Provide typical relational operators: `== != < <= > >=`
  - Each evaluates to 0 => FALSE or 1 => TRUE
- Provide typical logical operators: `! && ||`
  - Each interprets 0 => FALSE, non-0 => TRUE
  - Each evaluates to 0 => FALSE or 1 =>TRUE
- Provide bitwise operators: `~ & | ^ >> <<`
- Provide a cast operator: `(type)`

Aside: Logical vs. Bitwise Ops

Logical NOT (!) vs. bitwise NOT (~)

- `! 1 (TRUE) => 0 (FALSE)`

Decimal	Binary
1	00000000 00000000 00000000 00000001
! 1	00000000 00000000 00000000 00000000

- `~ 1 (TRUE) => -2 (TRUE)`

Decimal	Binary
1	00000000 00000000 00000000 00000001
~ 1	11111111 11111111 11111111 11111110

Implication:

- Use **logical** NOT to control flow of logic
- Use **bitwise** NOT only when doing bit-level manipulation

Aside: Logical vs. Bitwise Ops

Logical AND (&&) vs. bitwise AND (&)

- `2 (TRUE) && 1 (TRUE) => 1 (TRUE)`

```
Decimal  Binary
      2  00000000 00000000 00000000 00000010
   && 1  00000000 00000000 00000000 00000001
   ----  -----------------------------------
      1  00000000 00000000 00000000 00000001
```

- `2 (TRUE)  & 1 (TRUE) => 0 (FALSE)`

```
Decimal  Binary
      2  00000000 00000000 00000000 00000010
    & 1  00000000 00000000 00000000 00000001
   ----  -----------------------------------
      0  00000000 00000000 00000000 00000000
```

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Aside: Logical vs. Bitwise Ops

Implication:

- Use **logical** AND to control flow of logic
- Use **bitwise** AND only when doing bit-level manipulation

Same for logical OR (||) and bitwise OR (|)

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Assignment Operator

What about assignment?

Thought process

- Must have a way to assign a value to a variable
- Many high-level languages provide an assignment **statement**
- Would be more succinct to define an assignment **operator**
  - Performs assignment, and then evaluates to the assigned value
  - Allows assignment expression to appear within larger expressions

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Assignment Operator

Decisions

- Provide assignment **operator**: `=`
  - Side effect: changes the value of a variable
  - Evaluates to the new value of the variable

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Assignment Operator Examples

Examples

```
i = 0;
   /* Side effect: assign 0 to i.
      Evaluate to 0.

j = i = 0; /* Assignment op has R to L associativity */
   /* Side effect: assign 0 to i.
      Evaluate to 0.
      Side effect: assign 0 to j.
      Evaluate to 0. */

while ((i = getchar()) != EOF) …
   /* Read a character.
      Side effect: assign that character to i.
      Evaluate to that character.
      Compare that character to EOF.
      Evaluate to 0 (FALSE) or 1 (TRUE). */
```

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Special-Purpose Assignment Operators

Should C provide special-purpose assignment operators?

Thought process

- The construct `i = i + 1` is common
- More generally, `i = i + n` and `i = i * n` are common
- Special-purpose assignment operators would make code more compact
- Such operators would complicate the language and compiler

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Special-Purpose Assignment Operators

Decisions

- Provide special-purpose assignment operators:
  `+= -= *= /= ~= &= |= ^= <<= >>=`

Examples

```
i += j  same as i = i + j

i /= j  same as i = i / j

i |= j  same as i = i | j

i >>= j same as i = i >> j
```


Special-Purpose Assignment Operators

Decisions (cont.)

- Provide increment and decrement operators: `++ --`
  - Prefix and postfix forms

Examples

```
(1) i = 5;
    j = ++i;

(2) i = 5;
    j = i++;

(3) i = 5;
    j = ++i + ++i;

(4) i = 5;
    j = i++ + i++;
```

What is the value of i? Of j?

Sizeof Operator

How can programmers determine data sizes?

Thought process

- The sizes of most primitive types are unspecified
- Sometimes programmer must know sizes of primitive types
  - E.g. when allocating memory dynamically
- Hard code data sizes => program not portable
- C must provide a way to determine the size of a given data type programmatically

Sizeof Operator

Decisions

- Provide a **`sizeof`** operator
  - Applied at compile-time
  - Operand can be a **data type**
  - Operand can be an **expression**
    - Compiler infers a data type

Examples, on FC010

- `sizeof(int)` => 4

- When i is a variable of type int…
- `sizeof(i)` => 4
- `sizeof(i+1)`
- `sizeof(i++ * ++i – 5)`

What is the value?

Other Operators

What other operators should C have?

Decisions

- Function call operator
  - Should mimic the familiar mathematical notation
  - `function(arg1, arg2, …)`
- Conditional operator: `?:`
  - The only ternary operator
  - See King book
- Sequence operator: `,`
  - See King book
- Pointer-related operators: `& *`
  - Described later in the course
- Structure-related operators: `. ->`
  - Described later in the course

Operators Summary: C vs. Java

Java only

`>>>`	right shift with zero fill
`new`	create an object
`instanceof`	is left operand an object of class right operand?

C only

`->`	structure member select
`*`	dereference
`&`	address of
`,`	sequence
`sizeof`	compile-time size of

Operators Summary: C vs. Java

Related to type **boolean**:

- **Java**: Relational and logical operators evaluate to type `boolean`
- **C**: Relational and logical operators evaluate to type `int`
- **Java**: Logical operators take operands of type `boolean`
- **C**: Logical operators take operands of any primitive type or memory address

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Sequence Statement

How should C implement sequence?

Decision

- **Compound statement**, alias **block**

```
{
   statement1;
   statement2;
    …
}
```

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Selection Statements

How should C implement selection?

Decisions

- `if` statement, for one-path, two-path decisions

```
if (expr)
   statement1;
```

```
if (expr)
   statement1;
else
   statement2;
```

0 => FALSE
non-0 => TRUE

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Selection Statements

Decisions (cont.)

- `switch` and `break` statements, for multi-path decisions on a single *integerExpr*

```
switch (integerExpr)
{  case integerLiteral1:
      …
      break;
   case integerLiteral2:
      …
      break;
   …
   default:
      …
}
```

What happens if you forget `break`?

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Repetition Statements

How should C implement repetition?

Decisions

- `while` statement; test at leading edge

```
while (expr)
   statement;
```

- `for` statement; test at leading edge, increment at trailing edge

```
for (initialExpr; testExpr; incrementExpr)
   statement;
```

- `do…while` statement; test at trailing edge

```
do
   statement;
while (expr);
```

0 => FALSE
non-0 => TRUE

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Repetition Statements

Decisions (cont.)
- Cannot declare loop control variable in **for** statement

```
{
   …
   for (int i = 0; i < 10; i++)
      /* Do something */
   …
}
```

Illegal in C

```
{
   int i;
   …
   for (i = 0; i < 10; i++)
      /* Do something */
   …
}
```

Legal in C

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Other Control Statements

What other control statements should C provide?

Decisions
- **break** statement (revisited)
  - Breaks out of closest enclosing **switch** or repetition statement
- **continue** statement
  - Skips remainder of current loop iteration
  - Continues with next loop iteration
  - When used within **for**, still executes ***incrementExpr***
- **goto** statement
  - Jump to specified **label**

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Declaring Variables

Should C require variable declarations?

Thought process:
- Declaring variables allows compiler to check spelling
- Declaring variables allows compiler to allocate memory more efficiently

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Declaring Variables

Decisions:
- Require variable declarations
- Provide **declaration statement**
- Programmer specifies type of variable (and other attributes too)

Examples
- `int i;`
- `int i, j;`
- `int i = 5;`
- `const int i = 5;   /* value of i cannot change */`
- `static int i;      /* covered later in course */`
- `extern int i;      /* covered later in course */`

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Declaring Variables

Decisions (cont.):
- Declaration statements must appear before any other kind of statement in compound statement

```
{
   int i;
   /* Non-declaration
      stmts that use i. */
   …
   int j;
   /* Non-declaration
      stmts that use j. */
   …
}
```

Illegal in C

```
{
   int i;
   int j;
   …
   /* Non-declaration
      stmts that use i. */
   …
   /* Non-declaration
      stmts that use j. */
   …
}
```

Legal in C

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Computing with Expressions

How should C implement computing with expressions?

Decisions:
- Provide **expression statement**
  - **expression ;**

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Computing with Expressions

Examples

```
i = 5;
   /* Side effect: assign 5 to i.
      Evaluate to 5. Discard the 5. */

j = i + 1;
   /* Side effect: assign 6 to j.
      Evaluate to 6. Discard the 6. */

printf("hello");
   /* Side effect: print hello.
      Evaluate to 5. Discard the 5. */

i + 1;
   /* Evaluate to 6. Discard the 6. */

5;
   /* Evaluate to 5. Discard the 5. */
```

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Statements Summary: C vs. Java

Declaration statement:
- **Java**: Compile-time error to use a local variable before specifying its value
- **C**: Run-time error to use a local variable before specifying its value

`final` and `const`
- **Java**: Has `final` variables
- **C**: Has `const` variables

Expression statement
- **Java**: Only expressions that have a side effect can be made into expression statements
- **C**: Any expression can be made into an expression statement

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Statements Summary: C vs. Java

Compound statement:
- **Java**: Declarations statements can be placed anywhere within compound statement
- **C**: Declaration statements must appear before any other type of statement within compound statement

`if` statement
- **Java**: Controlling *`expr`* must be of type `boolean`
- **C**: Controlling *`expr`* can be any primitive type or a memory address (0 => FALSE, non-0 => TRUE)

`while` statement
- **Java**: Controlling *`expr`* must be of type `boolean`
- **C**: Controlling *`expr`* can be any primitive type or a memory address (0 => FALSE, non-0 => TRUE)

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Statements Summary: C vs. Java

`do`…`while` statement
- **Java**: Controlling *`expr`* must be of type `boolean`
- **C**: Controlling *`expr`* can be of any primitive type or a memory address (0 => FALSE, non-0 => TRUE)

`for` statement
- **Java**: Controlling *`expr`* must be of type `boolean`
- **C**: Controlling *`expr`* can be of any primitive type or a memory address (0 => FALSE, non-0 => TRUE)

Loop control variable
- **Java**: Can declare loop control variable in *`initexpr`*
- **C**: Cannot declare loop control variable in *`initexpr`*

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Statements Summary: C vs. Java

`break` statement
- **Java**: Also has "labeled break" statement
- **C**: Does not have "labeled break" statement

`continue` statement
- **Java**: Also has "labeled continue" statement
- **C**: Does not have "labeled continue" statement

`goto` statement
- **Java**: Not provided
- **C**: Provided (but don't use it!)

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I/O Facilities

Should C provide I/O facilities?

Thought process
- Unix provides the **file** abstraction
  - A file is a sequence of characters with an indication of the current position
- Unix provides 3 standard files
  - Standard input, standard output, standard error
- C should be able to use those files, and others
- I/O facilities are complex
- C should be small/simple

I/O Facilities

Decisions
- Do not provide I/O facilities in the **language**
- Instead provide I/O facilities in **standard library**
  - **Constant**: `EOF`
  - **Data type**: `FILE` (described later in course)
  - **Variables**: `stdin`, `stdout`, and `stderr`
  - **Functions**: …

Reading Characters

What functions should C provide for reading characters?

Thought process
- Need function to read a single character from `stdin`
  - … And indicate failure

Reading Characters

Decisions
- Provide `getchar()` function
- Define `getchar()` to return `EOF` upon failure
  - `EOF` is a special non-character `int`
- Make return type of `getchar()` wider than `char`
  - Make it `int`; that's the natural word size

Reminder
- There is no such thing as "the EOF character"

Writing Characters

What functions should C provide for writing characters?

Thought process
- Need function to write a single character to `stdout`

Decisions
- Provide `putchar()` function
- Define `putchar()` to have `int` parameter
  - For symmetry with `getchar()`

Reading Other Data Types

What functions should C provide for reading data of other primitive types?

Thought process
- Must convert external form (sequence of character codes) to internal form
- Could provide `getshort()`, `getint()`, `getfloat()`, etc.
- Could provide parameterized function to read any primitive type of data

Reading Other Data Types

Decisions
- Provide `scanf()` function
  - Can read any primitive type of data
  - First parameter is a **format string** containing **conversion specifications**

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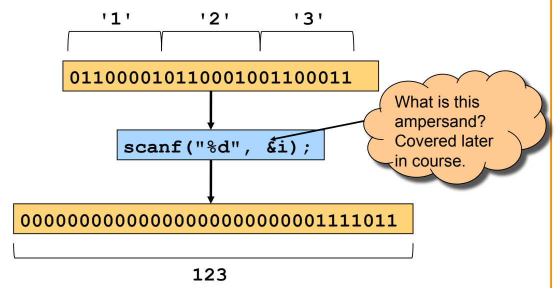
Reading Other Data Types



See King book for conversion specifications

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Writing Other Data Types

What functions should C provide for writing data of other primitive types?

Thought process
- Must convert internal form to external form (sequence of character codes)
- Could provide `putshort()`, `putint()`, `putfloat()`, etc.
- Could provide parameterized function to write any primitive type of data

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Writing Other Data Types

Decisions
- Provide `printf()` function
  - Can write any primitive type of data
  - First parameter is a **format string** containing **conversion specifications**

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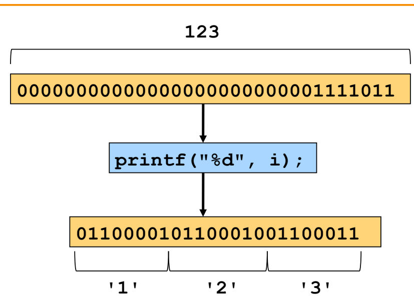
Writing Other Data Types



See King book for conversion specifications

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Other I/O Facilities

Issue: What other I/O functions should C provide?

Decisions
- `fopen()`: Open a stream
- `fclose()`: Close a stream
- `fgetc()`: Read a character from specified stream
- `fputc()`: Write a character to specified stream
- `fgets()`: Read a line/string from specified stream
- `fputs()`: Write a line/string to specified stream
- `fscanf()`: Read data from specified stream
- `fprintf()`: Write data to specified stream

Described in King book, and later in the course after covering files, arrays, and strings

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Summary

C design decisions and the goals that affected them

- Data types
- Operators
- Statements
- I/O facilities

Knowing the design goals and how they affected the design decisions can yield a rich understanding of C

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Appendix: The Cast Operator

Cast operator has multiple meanings:

(1) Cast between integer type and floating point type:

- Compiler generates code
- At run-time, code performs conversion

```
   f  11000001110110110000000000000000   -27.375

i = (int)f

   i  11111111111111111111111111100101   -27
```

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Appendix: The Cast Operator

(2) Cast between floating point types of different sizes:

- Compiler generates code
- At run-time, code performs conversion

```
   f  11000001110110110000000000000000   -27.375

d = (double)f

   d  11000000001110110110000000000000   -27.375
       00000000000000000000000000000000
```

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Appendix: The Cast Operator

(3) Cast between integer types of different sizes:

- Compiler generates code
- At run-time, code performs conversion

```
   i  00000000000000000000000000000010   2

c = (char)i

   c  00000010   2
```

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Appendix: The Cast Operator

(4) Cast between integer types of same size:

- Compiler generates no code
- Compiler views given bit-pattern in a different way

```
   i  11111111111111111111111111111110   -2

u = (unsigned int)i

   u  11111111111111111111111111111110   4294967294
```

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