


The Design of C: A Rational Reconstruction (cont.)

Goals of this Lecture

- Recall from last lecture...
- Help you learn about:
 - The decisions that were **available** to the designers of *C*
 - The decisions that were **made by** the designers of *C*
... and thereby...
 - *C*!
- Why?
 - Learning the design rationale of the *C* language provides a richer understanding of *C* itself
 - ... and might be more interesting than simply learning the language itself !!!
 - A power programmer knows both the programming language and its design rationale

Character Data Types

- Issue: What character data types should C have?
- Thought process
 - The most common character codes are (were!) ASCII and EBCDIC
 - ASCII is 7-bit
 - EBCDIC is 8-bit
- Decisions
 - Provide type `char`
 - Type `char` should be one byte



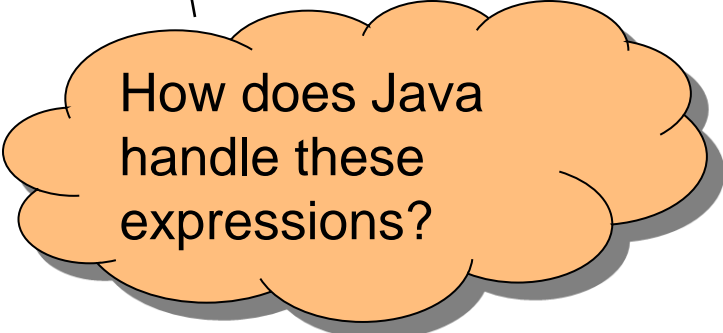
Was that a good decision?

Character Data Types (cont.)

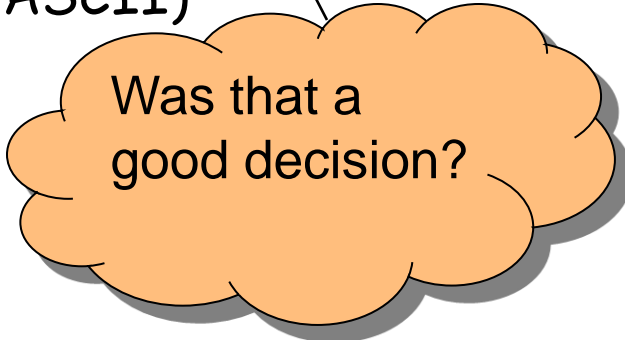
- **Tangential Decision**

- `char` should be an integer type

- Can use type `char` to store small integers
- Can do arithmetic with data of type `char`
- Can freely mix `char` and integer data
 - `('a' + 1)` is `'b'` (assuming ASCII)
 - `('0' + 5)` is `'5'` (assuming ASCII)



How does Java handle these expressions?



Was that a good decision?

Character Constants

- **Issue: How should C represent character constants?**
- **Thought process**
 - Could represent character constants as `int` constants, with truncation of high-order bytes
 - More readable to use single quote syntax (`'a'`, `'b'`, etc.); but then...
 - Need special way to represent the single quote character
 - Need special ways to represent non-printable characters (e.g. newline, tab, space, etc.)
- **Decisions**
 - Provide single quote syntax
 - Use backslash to express special characters

Character Constants (cont.)

- Examples

- 'a' **the a character**
- (char) 97 the a character
- (char) 0141 the a character
- '\o141' the a character, octal character form
- '\x61' the a character, hexadecimal character form
- '\0' **the null character**
- '\a' bell
- '\b' backspace
- '\f' formfeed
- '\n' **newline**
- '\r' carriage return
- '\t' **horizontal tab**
- '\v' vertical tab
- '\\' backslash
- '\'' single quote

Strings

- Issue: How should C represent strings?
- Thought process
 - String can be represented as a sequence of chars
 - How to know where char sequence ends?
 - Store length before char sequence?
 - Store special "sentinel" char after char sequence?
 - Strings are common in systems programming
 - C should be small/simple



Advantages/disadvantages?

Strings (cont.)

- Decisions

- Adopt a convention

- String consists of a sequence of chars terminated with the null (' \0 ') character

- Use double-quote syntax (e.g. "abc", "hello") to represent a string constant

- Provide no other language features for handling strings

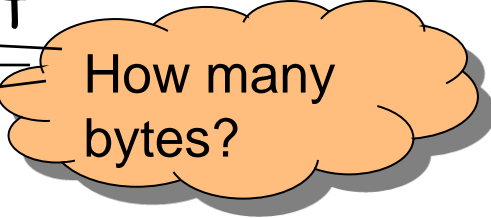
- Delegate string handling to standard library functions

- Examples

- "abc" is a string constant

- 'a' is a char constant

- "a" is a string constant



How many bytes?

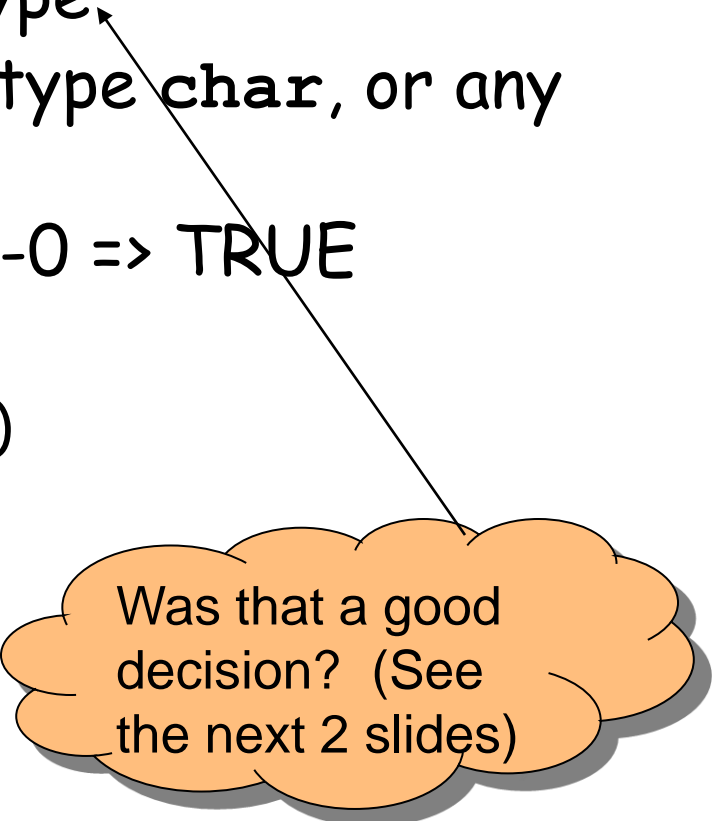
Logical Data Type

- Issue: How should C represent logical data?
- Thought process
 - Representing a logical value (TRUE or FALSE) requires only one **bit**
 - Smallest entity that can be addressed is one **byte**
 - Type `char` is one byte, so could be used to represent logical values
 - C should be small/simple

Logical Data Type (cont.)

- Decisions

- Don't define a logical data type
- Represent logical data using type `char`, or any integer type
- Convention: `0` => `FALSE`, `non-0` => `TRUE`
- Convention used by:
 - Relational operators (`<`, `>`, etc.)
 - Logical operators (`!`, `&&`, `||`)
 - Statements (`if`, `while`, etc.)



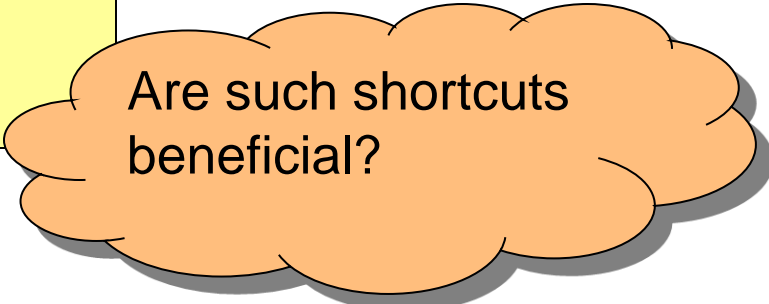
Was that a good decision? (See the next 2 slides)

Logical Data Type (cont.)

- **Note**

- Using integer data to represent logical data permits shortcuts

```
...  
int i;  
...  
if (i) /* same as (i != 0) */  
    statement1;  
else  
    statement2;  
...
```



Are such shortcuts beneficial?

Logical Data Type (cont.)

- Note

- The lack of logical data type cripples compiler's ability to detect some errors

```
...  
int i;  
...  
i = 0;  
...  
if (i = 5)  
    statement1;  
else  
    statement2;  
...
```

What is the problem with this code?

What is the effect of this code?

How does Java handle this code?

Floating-Point Data Types

- **Issue:** What floating-point data types should C have?
- **Thought process**
 - Systems programs use floating-point data infrequently
 - But some application domains (e.g. scientific) use floating-point data often
- **Decisions**
 - Provide three floating-point data types: `float`, `double`, and `long double`
 - bytes in `float` <= bytes in `double` <= bytes in `long double`
- **Incidentally, on lab machines using gcc209**
 - `float`: 4 bytes
 - `double`: 8 bytes
 - `long double`: 12 bytes

Floating-Point Constants

- **Issue:** How should C represent floating-point constants?
- **Thought process**
 - Convenient to allow both fixed-point and scientific notation
 - Decimal is sufficient; no need for octal or hexadecimal
- **Decisions**
 - Any constant that contains decimal point or "E" is floating-point
 - The default floating-point type is **double**
 - Append "F" to indicate **float**
 - Append "L" to indicate **long double**
- **Examples**
 - **double:** 123.456, 1E-2, -1.23456E4
 - **float:** 123.456F, 1E-2F, -1.23456E4F
 - **long double:** 123.456L, 1E-2L, -1.23456E4L



Why?

Feature 2: Operators

- A high-level programming language should have **operators**
- Operators combine with constants and variables to form expressions

Kinds of Operators

- Issue: What kinds of operators should C have?
- Thought process
 - Should handle typical operations
 - Should handle bit-level programming ("bit fiddling")
- 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)

Assignment Operator

- Issue: 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 expressive to define an assignment **operator**
 - Performs assignment, and then evaluates to the assigned value
 - Allows expressions that involve assignment to appear within larger expressions
- Decisions
 - Provide assignment operator: =
 - Define assignment operator so it changes the value of a variable, and also evaluates to that value

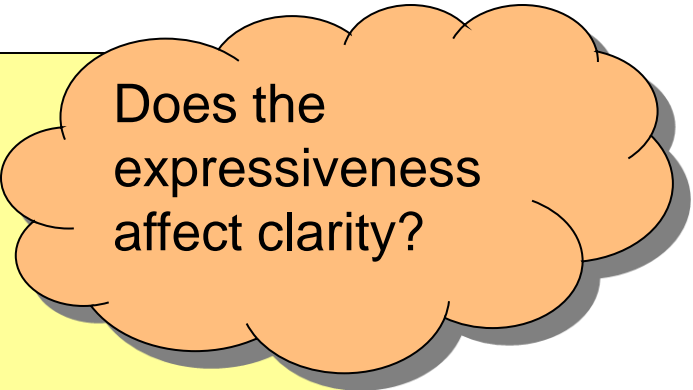
Assignment Operator (cont.)

- Examples

```
i = 0;
/* Assign 0 to i. Evaluate to 0.
   Discard the 0. */

i = j = 0;
/* Assign 0 to j. Evaluate to 0.
   Assign 0 to i. Evaluate to 0.
   Discard the 0. */

while ((i = getchar()) != EOF) ...
/* Read a character. Assign it to i.
   Evaluate to that character.
   Compare that character to EOF.
   Evaluate to 0 (FALSE) or 1 (TRUE). */
```



Does the expressiveness affect clarity?

Increment and Decrement Operators

- Issue: Should C provide increment and decrement operators?
- Thought process
 - The construct `i = i + 1` is common
 - Special purpose increment and decrement operators would make code more expressive
 - Such operators would complicate the language and compiler
- Decisions
 - The convenience outweighs the complication
 - Provide increment and decrement operators: `++` `--`

Was that a good decision?

Special-Purpose Assignment Operators

- Issue: Should C provide special-purpose assignment operators?
- Thought process
 - Constructs such as `i = i + n` and `i = i * n` are common.
 - Special-purpose assignment operators would make code more expressive
 - Such operators would complicate the language and compiler
- Decisions
 - The convenience outweighs the complication
 - Provide special-purpose assignment operators: `+=` `--=` `*=`
`/=` `~=` `&=` `|=` `^=` `<<=` `>>=`

Was that a good decision?

Sizeof Operator

- Issue: How can programmers determine the sizes of data?
- Thought process
 - The sizes of most primitive types are unspecified
 - C must provide a way to determine the size of a given data type programmatically
- Decisions
 - Provide a `sizeof` operator
 - Applied at compile-time
 - Operand can be a **data type**
 - Operand can be an **expression**, from which the compiler infers a data type
- Examples, on lab machines using gcc209
 - `sizeof(int)` evaluates to 4
 - `sizeof(i)` evaluates to 4 (where `i` is a variable of type `int`)
 - `sizeof(i+1)` evaluates to 4 (where `i` is a variable of type `int`)

Other Operators

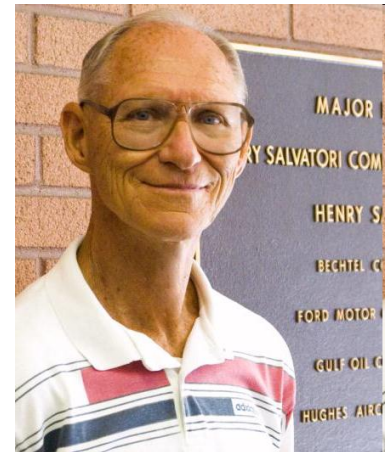
- Issue: What other operators should C have?
- Decisions
 - Function call operator
 - Should mimic the familiar mathematical notation
 - `function(param1, param2, ...)`
 - Conditional operator: `?:`
 - The only ternary operator
 - See King book
 - Sequence operator: `,`
 - See King book
 - Pointer-related operators: `&` `*`
 - Described later in the course
 - Structure-related operators (`.` `->`)
 - Described later in the course

Feature 3: Control Statements

- A programming language must provide **statements**
- Some statements must affect flow of control

Control Statements

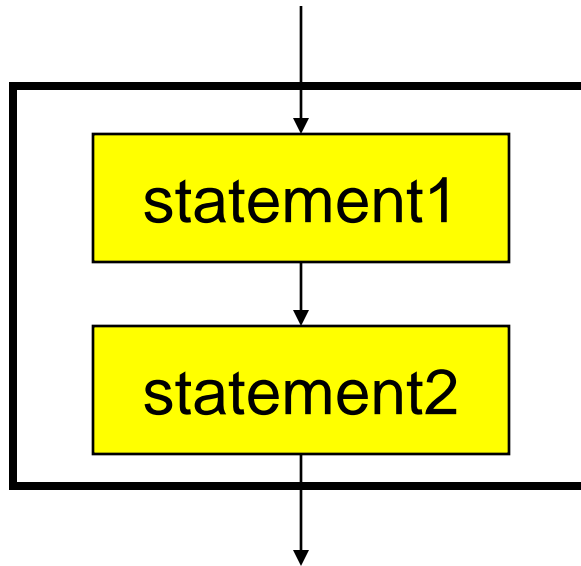
- Issue: What control statements should C provide?
- Thought process
 - Boehm and Jacopini proved that any algorithm can be expressed as the nesting of only 3 control structures:



Barry Boehm

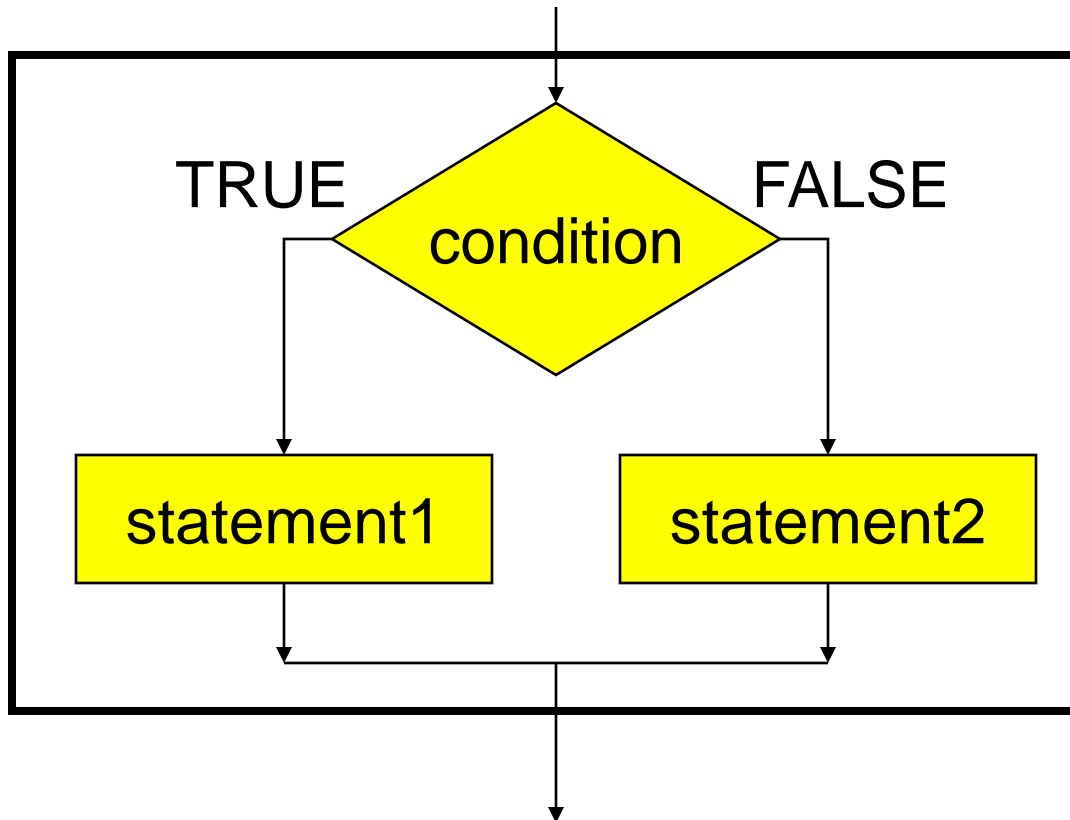
Control Statements (cont.)

(1) Sequence



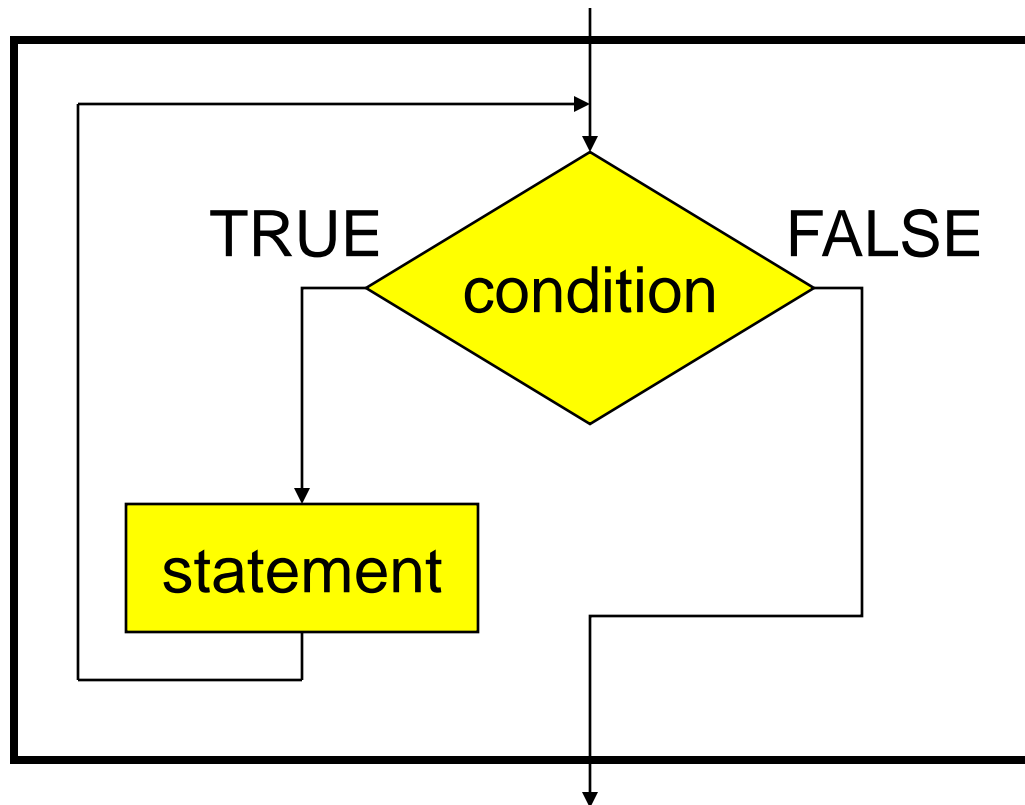
Control Statements (cont.)

(2) Selection



Control Statements (cont.)

(3) Repetition



Control Statements (cont.)

- **Thought Process** (cont.)
 - Dijkstra argued that any algorithm should be expressed using only those three control structures (*GOTO Statement Considered Harmful* paper)
 - The ALGOL programming language implemented control statements accordingly



Edsger Dijkstra

- **Decisions**
 - Provide statements to implement those 3 control structures
 - For convenience, provide a few extras

Sequence Statement

- Issue: How should C implement sequence?
- Decision
 - Compound statement, alias **block**

```
{  
    statement1;  
    statement2;  
    ...  
}
```

Selection Statements

- Issue: How should C implement selection?

- Decisions

- **if** statement, for one-path or two-path decisions

```
if (integerExpr)  
    statement1;
```

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

Selection Statements (cont.)

- Decisions (cont.)

- **switch** and **break** statements, for multi-path decisions

```
switch (integerExpr) {  
  case integerConstant1:  
    ...  
    break;  
  case integerConstant2:  
    ...  
    break;  
  ...  
  default:  
    ...  
}
```

What if these **break** statements are omitted?

Was that use of **break** a good design decision?

Repetition Statements

- Issue: How should C implement repetition?
- Decisions
 - **while** statement, for general repetition

```
while (integerExpr)  
    statement;
```

- **for** statement, for counting loops

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

- **do...while** statement, for loops with test at trailing edge

```
do  
    statement;  
while (integerExpr);
```


Other Control Statements

- Issue: 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
 - Can be difficult to understand; generally should avoid
 - **goto** statement and labels
 - Avoid!!! (as per Dijkstra)

Feature 4: Input/Output

- A programming language must provide facilities for reading and writing data
- Alternative: A programming **environment** must provide such facilities

Input/Output Facilities

- Issue: Should C provide I/O facilities?
- Thought process
 - Unix provides the stream abstraction
 - A stream is a sequence of characters
 - Unix provides 3 standard streams
 - Standard input, standard output, standard error
 - C should be able to use those streams, and others
 - I/O facilities are complex
 - C should be small/simple
- Decisions
 - Do not provide I/O facilities in C
 - Instead provide a **standard library** containing I/O facilities
 - Constants: `EOF`
 - Data types: `FILE` (described later in course)
 - Variables: `stdin`, `stdout`, and `stderr`
 - Functions: ...

Reading Characters

- Issue: What functions should C provide for reading characters from standard input?
- Thought process
 - Need function to read a single character from `stdin`
 - Function must have a way to indicate failure, that is, to indicate that no characters remain
- Decisions
 - Provide `getchar()` function
 - Make return type of `getchar()` wider than `char`
 - Make it `int`; that's the natural word size
 - Define `getchar()` to return `EOF` (a special non-character `int`) to indicate failure
- Note
 - There is no such thing as "the `EOF` character"

Writing Characters

- Issue: What functions should C provide for writing a character to standard output?
- Thought process
 - Need function to write a single character to `stdout`
- Decisions
 - Provide a `putchar()` function
 - Define `putchar()` to accept one parameter
 - For symmetry with `getchar()`, parameter should be an `int`

Reading Other Data Types

- Issue: 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 one parameterized function to read any primitive type of data
- Decisions
 - Provide `scanf()` function
 - Can read any primitive type of data
 - First parameter is a **format string** containing **conversion specifications**
- See King book for details

Writing Other Data Types

- Issue: 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 one parameterized function to write any primitive type of data
- Decisions
 - Provide `printf()` function
 - Can write any primitive type of data
 - First parameter is a **format string** containing **conversion specifications**
- See King book for details

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

Summary

- *C*'s design goals affected decisions concerning language features:
 - Data types
 - Operators
 - Control statements
 - I/O facilities
- Knowing the design goals and how they affected the design decisions can yield a rich understanding of *C*