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

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Goals of this 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
- Why?
  - Learning the design rationale of the C language provides a richer understanding of C itself
  - A power programmer knows both the programming language and its design rationale

Character Data Types

- 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

- Thought process
  - Could represent character constants as **`int`** constants, with truncation of high-order bytes
  - More readable to use single quote (**`'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

- 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

- 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

- 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 hats using gcc217
  - **`float`**: 4 bytes
  - **`double`**: 8 bytes
  - **`long double`**: 12 bytes

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`**

Why?

- Examples
  - **`double`**: **`123.456`**, **`1E-2`**, **`-1.23456E4`**
  - **`float`**: **`123.456F`**, **`1E-2F`**, **`-1.23456E4F`**
  - **`long double`**: **`123.456L`**, **`1E-2L`**, **`-1.23456E4L`**

Feature 2: Operators

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

Kinds of Operators

- 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

- 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

- 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

- 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

- 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 hats using gcc217
  - **`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

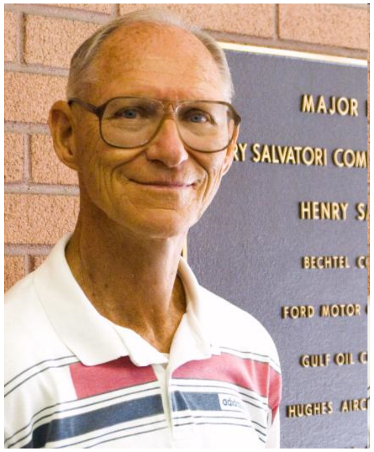
- Function call operator
  - Should mimic the familiar mathematical notation
  - **`function(param1, param2, …)`**
- Conditional operator: **`?:`**
  - The only ternary operator
  - See King book
- Sequence operator: **`,`**
  - See King book
- Pointer-related operators: **`& *`**
  - Described later 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

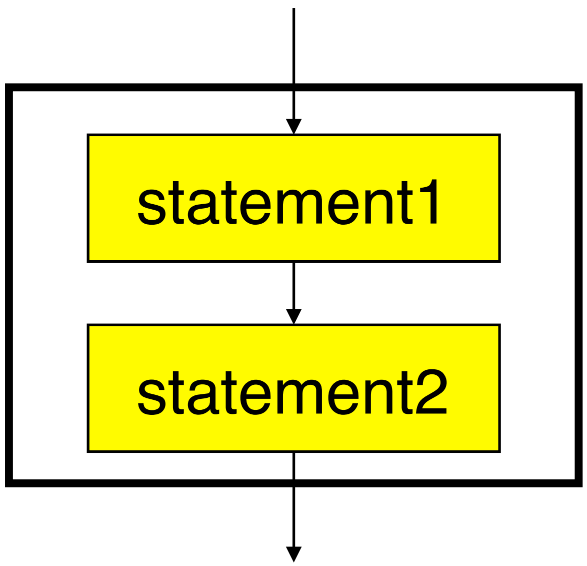
- Thought process
  - **Boehm** and **Jacopini** proved that any algorithm can be expressed as the nesting of only 3 control structures:



Barry Boehm

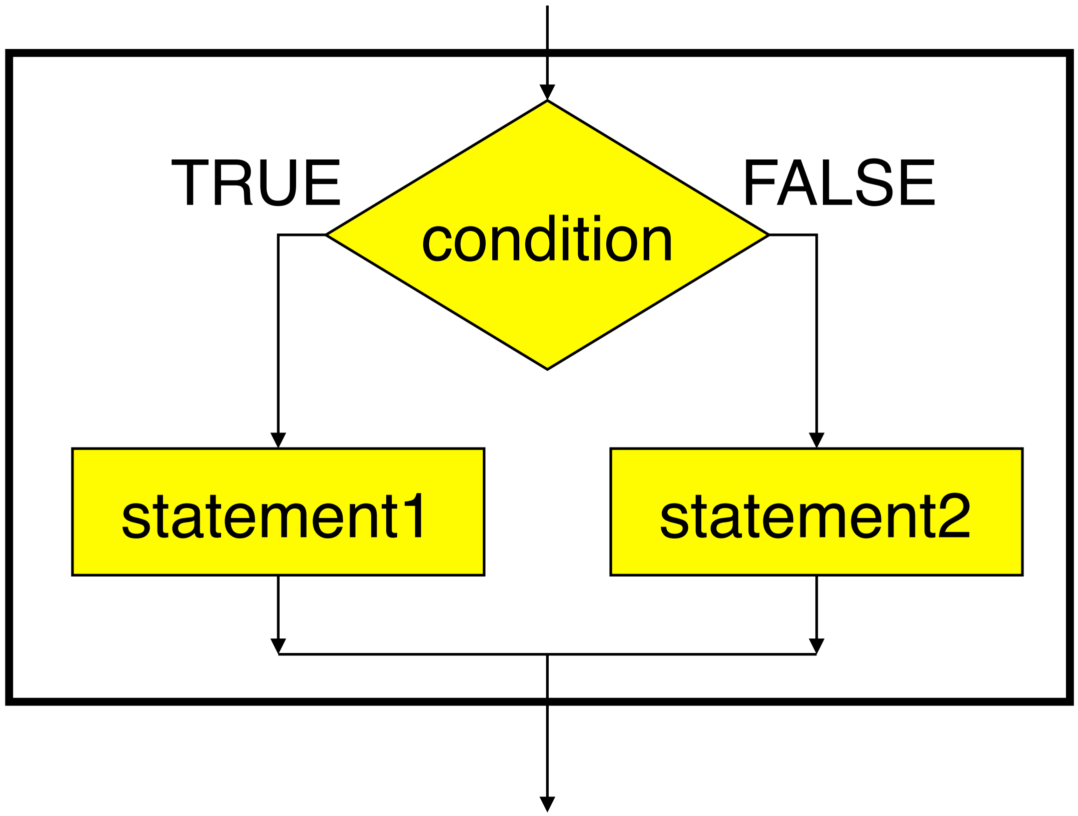
Control Statements (cont.)

(1) Sequence



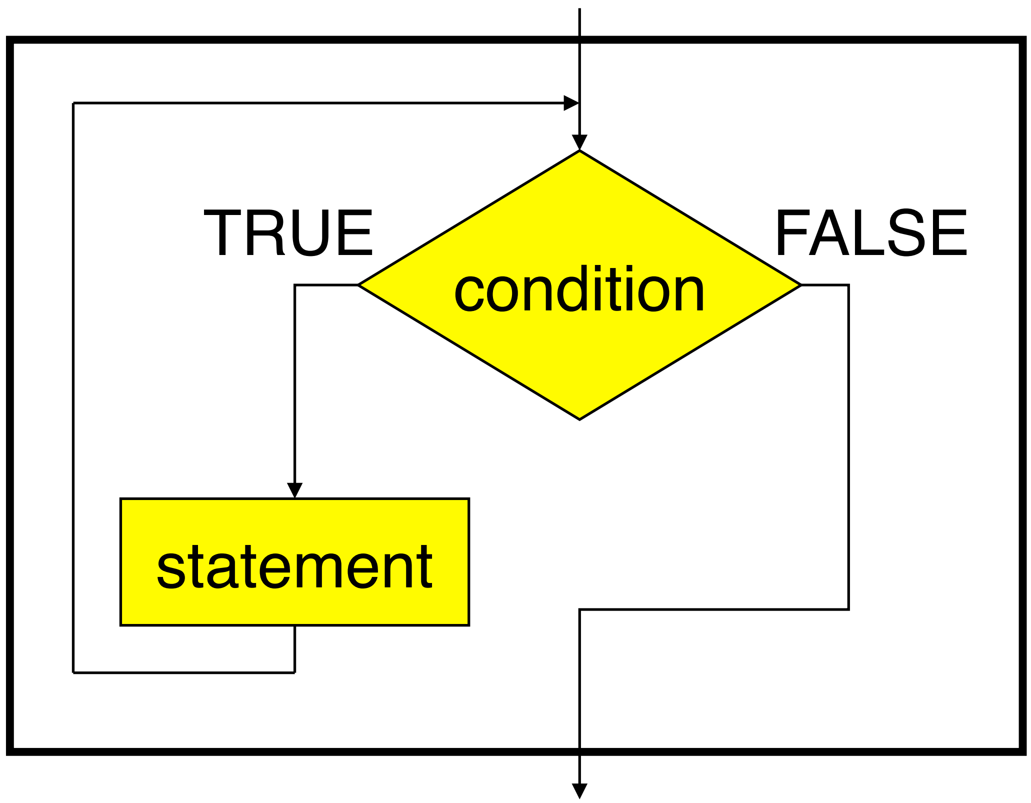
Control Statements (cont.)

(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

Edsgar Dijkstra

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

Sequence Statement

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

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

Selection Statements

- 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

- 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

- 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

- 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

- 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

- 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

- 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

- 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

- 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