The Design of C:
A Rational Reconstruction:
Part 2

Continued from previous lecture

Agenda

Data Types

Operators

Statements

I/O Facilities

Operators

Issue: 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

- `!0x00000010 => 0x00000000 (FALSE)`
- `~0x00000010 => 0xFFFFFFEF (TRUE)`

Logical AND vs. bitwise AND

- `0x00000010 && 0x00000001 => 0x00000001 (TRUE)`
- `0x00000010 &  0x00000001 => 0x00000000 (FALSE)`

Moral:

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

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 succinct to define an assignment **operator**
  - Performs assignment, and then evaluates to the assigned value
  - Allows assignment expression to appear within larger expressions

Assignment Operator

Decisions

- Provide assignment **operator**: **=**
    - Changes the value of a variable
    - Evaluates to the new value of the variable

Assignment Operator Examples

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). */
```

Special-Purpose Assignment Operators

Issue: Should C provide special-purpose assignment operators?

Thought process

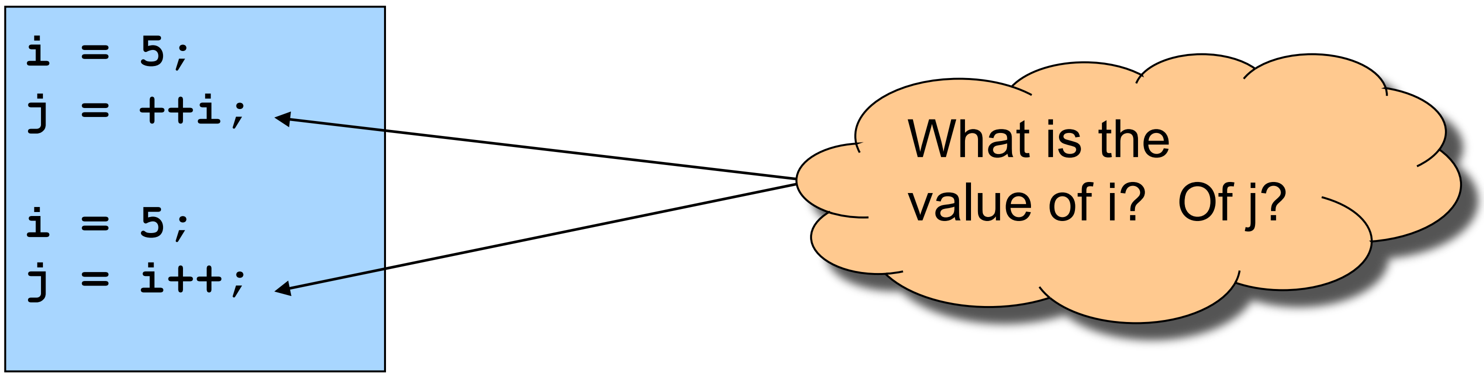
- The construct `i = i + 1` is common
- More generally, `i = i + n` and `i = i * n` are common
- Special-purpose assignment operators would make code more compact
- Such operators would complicate the language and compiler

Special-Purpose Assignment Operators

Decisions

- Provide increment and decrement operators: **`++ --`**
  - Prefix and postfix forms
- Provide special-purpose assignment operators:
  `+= -= *= /= ~= &= |= ^= <<= >>=`

Examples



```
i = 5;
j = ++i;

i = 5;
j = i++;
```

What is the value of i? Of j?

Sizeof Operator

Issue: How can programmers determine data sizes?

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

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 nobel using gcc217

- `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

Issue: 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

Agenda

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I/O Facilities

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, two-path decisions

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

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

0 => FALSE
non-0 => TRUE

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**?

Repetition Statements

Issue: 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

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

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
  - When used within `for`, still executes ***`incrementExpr`***
- `goto` statement
  - Jump to specified **label**

Declaring Variables

Issue: Should C require variable declarations?

Thought process:

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

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 */`

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

Computing with Expressions

Issue: How should C implement computing with expressions?

Decisions:

- Expression statement:

```
expression ;
```

Computing with Expressions

Examples

- `i = 5;`

  ```
  /* Side effect: set value of i to 5.
     Evaluate to 5. Discard the 5. */
  ```

- `j = i + 1;`

  ```
  /* Side effect: set value of j to 6.
     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. */
  ```

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

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)

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`***

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!)

Agenda

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I/O Facilities

I/O Facilities

Issue: 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/Writing Characters

Issue: What functions should C provide for reading & writing characters?

Thought process

- Need function to read a single character from **`stdin`**
  - … And indicate failure
- Need function to write a single character to **`stdout`**

Reading/Writing Characters

Decisions

- Provide **`getchar()`** and **`putchar()`** functions
- 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
- Make **`putchar()`** take **`int`** for symmetry

Reminder

- There is no such thing as “the EOF character”

Writing Other Data Types

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

Thought process

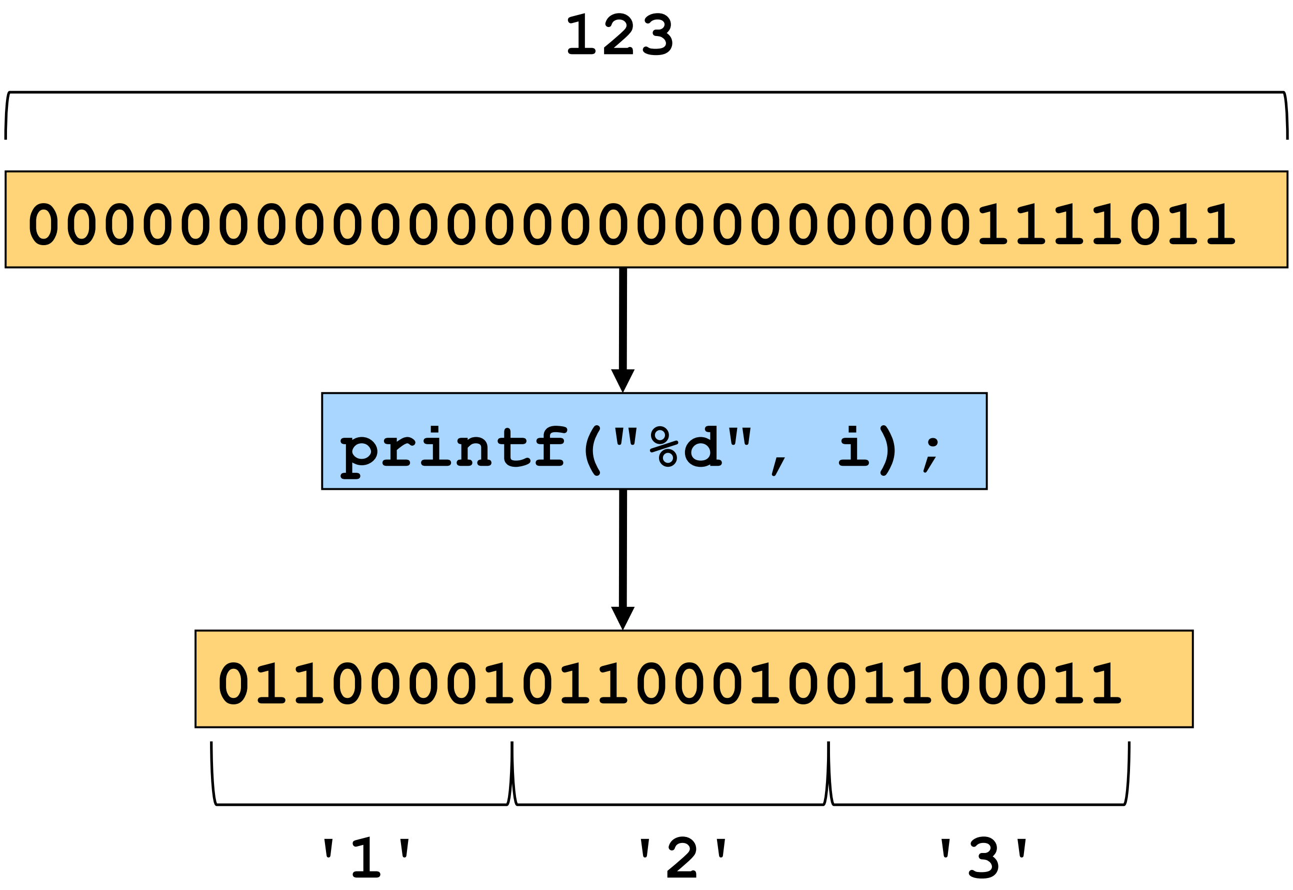
- Must convert internal form to external form (sequence of character codes)
- Could provide `putshort()`, `putint()`, `putfloat()`, etc.
- Could provide parameterized function to write any primitive type of data

Writing Other Data Types

Decisions

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

Writing Other Data Types



123

00000000000000000000000001111011

```
printf("%d", i);
```

011000010110001001100011

'1' '2' '3'

See King book for conversion specifications

Reading Other Data Types

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

Thought process

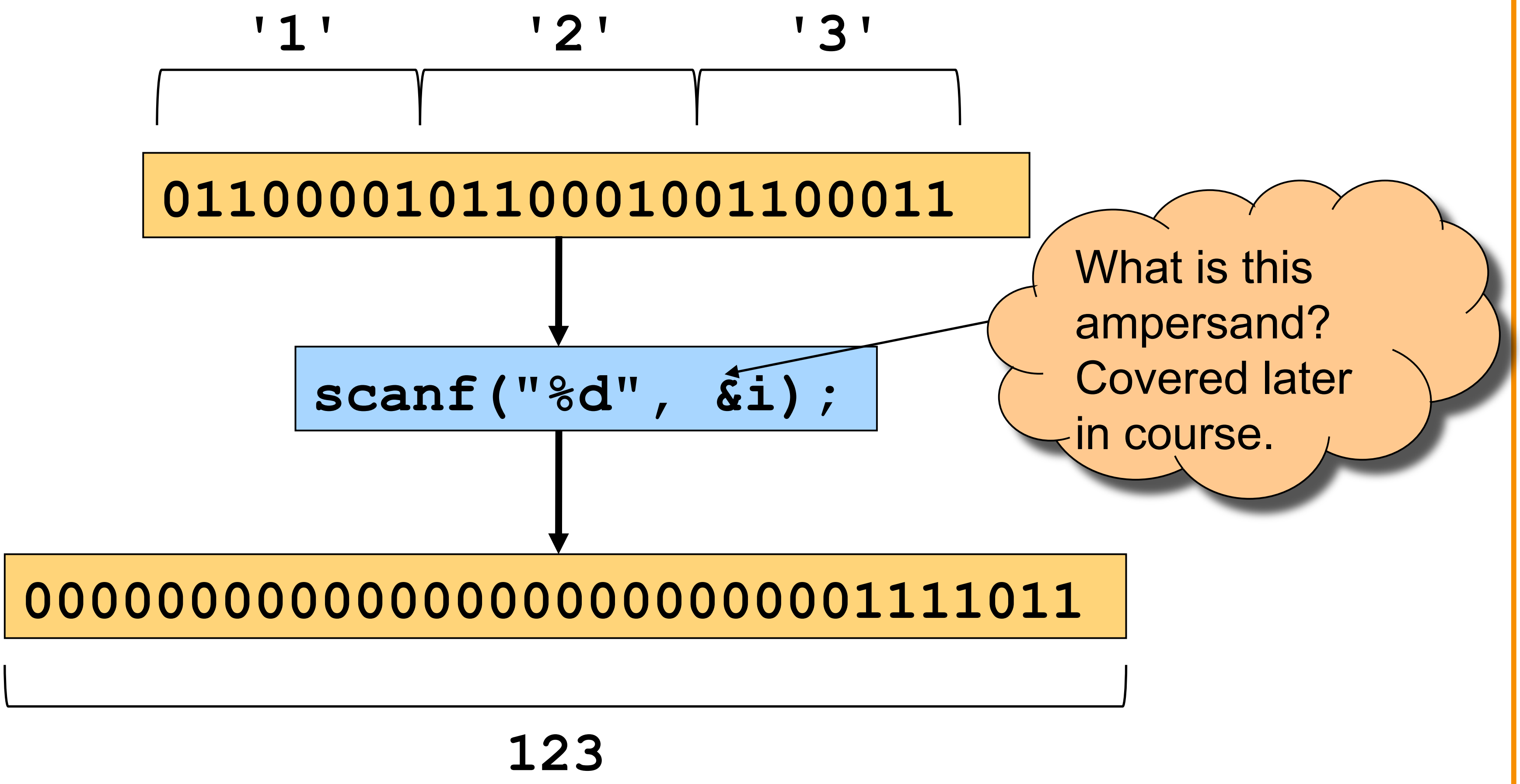
- Must convert external form (sequence of character codes) to internal form
- Could provide `getshort()`, `getint()`, `getfloat()`, etc.
- Could provide parameterized function to read any primitive type of data

Reading Other Data Types

Decisions

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

Reading Other Data Types



What is this ampersand? Covered later in course.

See King book for conversion specifications

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 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

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
```

Appendix: The Cast Operator

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

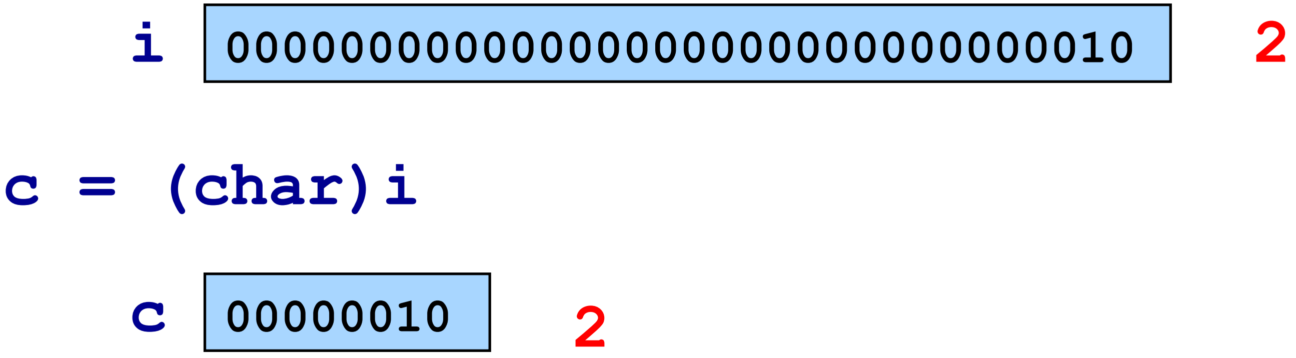
- Compiler generates code
- At run-time, code performs conversion

```
      f  11000001110110110000000000000000    -27.375

d = (double)f

      d  11000000001110110110000000000000    -27.375
          00000000000000000000000000000000
```

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

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
```