CS 261
Fall 2021

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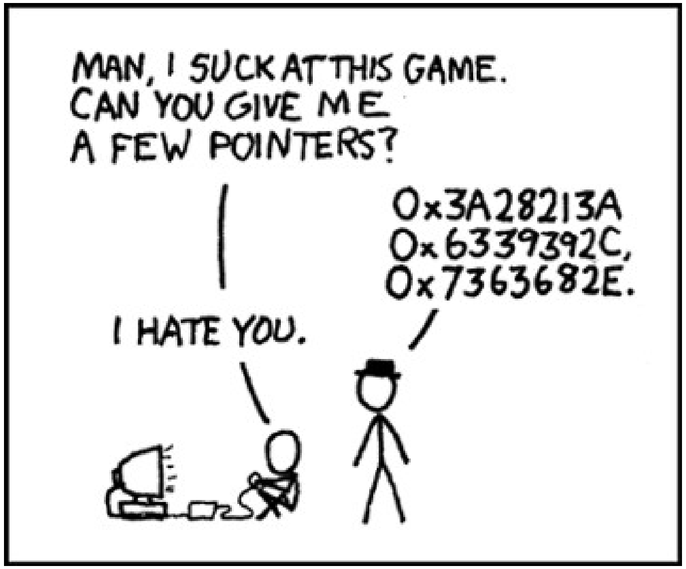


https://xkcd.com/138/

C Introduction

Comparison w/ Java, Memory Model, and Pointers

The C Language

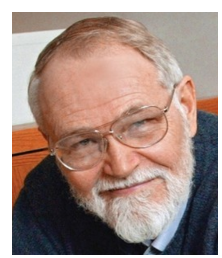
- Systems language originally developed for Unix
- Imperative, compiled language with static typing
- “High level” at the time; now considered low-level
- Allows “direct” access to memory (subject to architecture)
- Many compilers and standards: we’ll use GNU and C99

Ken Thompson

(inventor of B language and Unix)

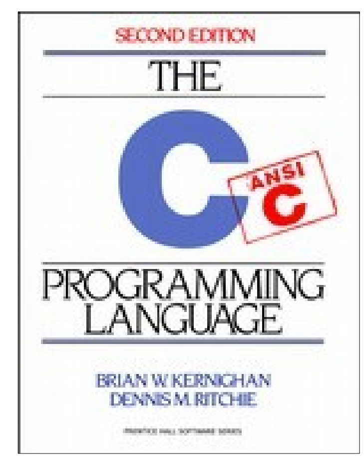
Dennis Ritchie

(inventor of C language and coauthor of C book)



Brian Kernighan

(coauthor of C book and contributor to Unix/C)



Review: Compilation

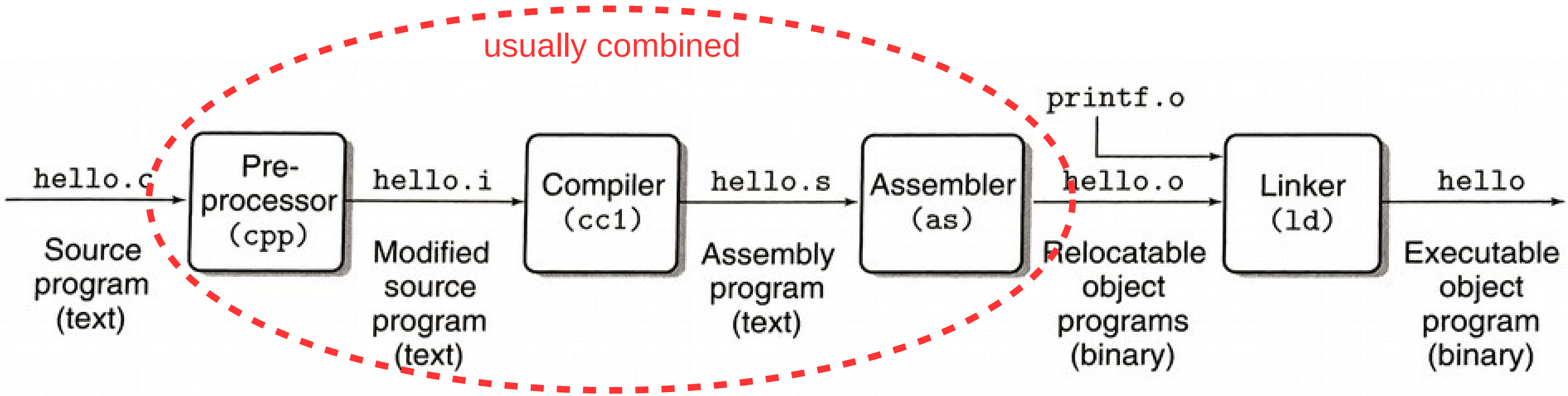


Figure 1.3 **The compilation system.**

```
linux> gcc -o hello hello.c
```

Review: Makefiles

- The compilation process is usually streamlined using a build system (we'll use Make)
- Provide a “Makefile” that contains targets, dependencies, and build commands
- Example Makefile:

target dependency

```
hello: hello.c
	gcc -g -O0 -o hello hello.c
```

build command

Hello, World

- How is this different from Java?

```
#include <stdio.h>

int main()
{
    printf("Hello, world!\n");
    return 0;
}
```

Similarities to Java

- Semicolons!
- Comments (both `//` and `/* */` styles)
- Basic types: `int`, `char`, `float`, `double`
  - Char is just a number
- Blocks w/ curly braces
- Loops: `do`, `while`, `for`
- Switch statements
  - Parameter must be integer
- Function definitions

Differences from Java

- Preprocessor macros (`#include`, `#define`)
- Functions must be declared before use
  - New distinction: declaration vs. definition
  - Interface (.h) vs implementation (.c)
- Fewer built-in types
  - Booleans are “`bool`” (not built-in; must include `stdbool.h`)
    - Actually integers: 0 is “false”, anything else is “true”
  - No built-in string type (C strings are just arrays of chars)
- No classes, packages, or built-in exceptions
- Different I/O functions: `printf`, `fgets`, `scanf` (in `stdio.h`)
  - For `printf`, embed variables in output using formatting codes
  - E.g., use "`%d`" to embed an integer (see documentation for more codes)

Variables in C

- Declared by type and name like in Java
  - Can be initialized when declared (this is recommended!)
  - E.g., `int file_counter = 0;`
  - If not initialized, contents are undefined until assigned
  - Can be declared '`const`'
    - Read-only, similar to '`final`' in Java—must be initialized!

- Multiple declarations per line are allowed
  - E.g., `int x, y;`
  - E.g., `int x = 0, y = 1;`
  - Mixed-initialization and multiple declarations is not recommended
    - E.g., `int x, y = 1;  // only initializes y!`

C data types

- Integer types: `char` and `int`
  - Can be signed (default) or `unsigned`
  - `short`, `long`, and `long long` modifiers for `int`
- Real types: `float` and `double`
  - Floating-point representation

Data type	Size on `stu` (bytes)
`char / bool`	1
`short int`	2
`int`	4
`long int / long long int`	8
`float`	4
`double`	8

1 byte = 8 bits

Explicit-width integer types

- C standard doesn't mandate integer widths
  - It only specifies a minimum
  - This causes problems when different architectures or compilers provide different actual sizes

- More portable alternative: `stdint.h` types
  - Basic format: ***X*int*Y*_t**
  - *X* can be empty (signed) or 'u' (unsigned)
  - *Y* can be 8, 16, 32, or 64 (bits)
  - Examples: `int8_t`, `uint8_t`, `int32_t`, `uint64_t`

Variable attributes (CS 430 preview)

- Name
- Value
- Type
- Address
- Scope
- Lifetime

Variable attributes (CS 430 preview)

- Name: **identifier** used to refer to the variable in code
- Value: current **contents** of a variable
- Type: **range of values** a variable can store
- Address: **location** of variable’s value
  - Most common locations: register, stack, heap, or static data
  - We’ll focus on the non-register locations for now
- Scope: **code range** where a variable is visible
  - Global: visible anywhere in file (code module)
  - Local: visible only inside a function or block
- Lifetime: **time period** when variable access is valid
  - Static: allocated when program starts; de-allocated on exit
  - Dynamic: allocated and de-allocated while program runs

Memory management

- The fundamental difference between C and Java is how they handle memory
  - Java is a managed language, where the compiler and runtime handle memory management for the programmer and direct access to memory is difficult or impossible
  - C is **not** a managed language, meaning we can directly access and manipulate memory using arbitrary addresses
  - This makes it possible to do the kind of low-level experimentation we want to do in CS 261, and it also enables optimizations that are not possible using Java
  - However, it is also far more dangerous!

"With great power comes great responsibility."

Pointers

- **A pointer is a variable that contains a memory address**
- Type modifier: “*” indicates one level of pointer
  - `int *p;`
  - `int **p;    // yes, this works`
- Often initialized using the “&” operator (“address of”)
  - `int x;`
  - `p = &x;`
- Dereferenced with “*” operator (“follow the pointer”)
  - `*p = 7;`
- Set a pointer to `NULL` to mark them as invalid
- C does NOT check pointers before dereferencing them!
  - `int *p = NULL; *p = 123;   // this will segfault!`

Types

- Pointers are variables, so they have a type
  - The type describes what kind of data it points to
  - An int has type `int`
  - A *pointer to an int* has type `int*`
  - A pointer to a pointer to an int has type `int**`

- Expressions also have a type
  - If `x` has type `int`, then `x+4` also has type `int`
  - If `x` has type `int`, then `&x` has type `int*`
  - If `p` has type `int*`, then `*p` has type `int`
  - If `p` has type `int*`, then `&p` has type `int**`

What will this C code print?

```
int a = 42;
int b = 7;
int c = 999;
int *t = &a;
int *u = NULL;
printf("%d %d\n", a, *t);

c = b;
u = t;
printf("%d %d\n", c, *u);

a = 8;
b = 9;
printf("%d %d %d %d\n", b, c, *t, *u);

*t = 123;
printf("%d %d %d %d %d\n", a, b, c, *t, *u);
```

Question

- What does the following C code do?

```
int* c, d;
```

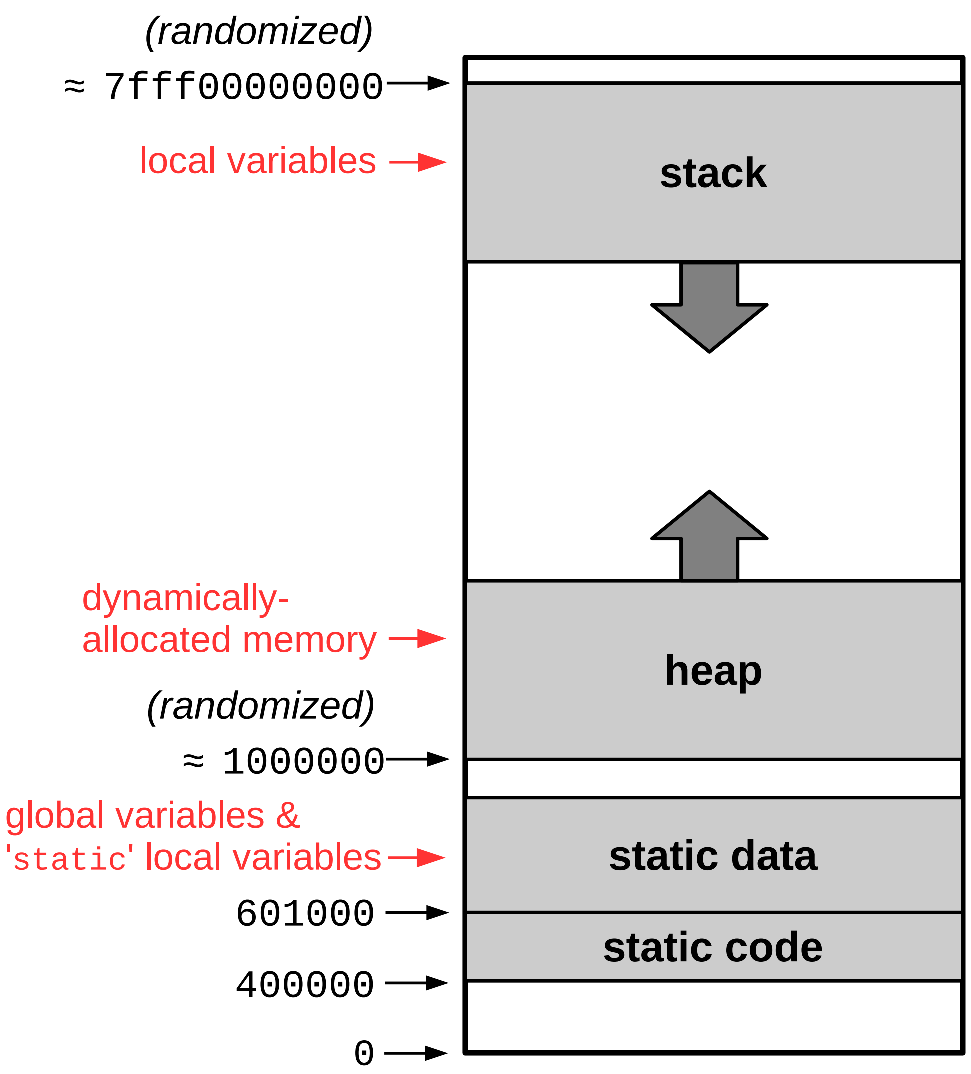
  - A) Declares two integers “c” and “d”
  - B) Declares two integer pointers “c” and “d”
  - C) Declares one integer pointer “c” and one integer “d”
  - D) Declares one integer “c” and one integer pointer “d”
  - E) The behavior is undefined

Pointer declaration caveat

- The following code doesn't do what you think it does:
  - `int* c, d;`
- Recommendation: put asterisk next to variable names in declarations
  - `int *c, *d;`
  - Or declare only one variable per line!
- Exception: function declarations (since there can only be one return value)
  - `int* myfunc();`

C/Linux memory model

- Every process has its own virtual private memory called an address space.
- The address space is divided into regions. Some regions are static and do not change size while the process runs, while others are dynamic, changing size if necessary.
- The stack region expands when a function is called and shrinks when a function returns. The heap region expands when `malloc()` is called.
- Some regions begin at a randomized location (different on every run) for security reasons.



Dynamic memory allocation

- If you do not know how much memory you need until after the program is running, you must allocate memory on the heap
- Allocate with `malloc()` function (or `calloc`)
  - Pass it the number of bytes you need
  - Often calculated using the `sizeof` operator
  - Returns a pointer to the beginning of the allocated region
- De-allocate with `free()` when you are done
  - Pass it a pointer to the beginning of the region you want to free
  - Good code practice: set pointer to `NULL` afterwards
  - Neglecting to free memory will result in a memory leak when the reference is no longer valid (e.g., the pointer goes out of scope)

Variable summary

- Global variables
  - **Static data** address, **global** scope, **static** lifetime
- Local variables (regular)
  - **Stack** address, **local** scope, **dynamic** lifetime
  - Valid while the function executes
- Local variables declared ‘static’
  - **Static data** address, **local** scope, **static** lifetime
  - Similar to global variable but with local scope
- Dynamically-allocated memory
  - **Heap** address, **local** scope (via pointer), **dynamic** lifetime
  - Valid from malloc until free
  - Pointer(s) themselves are usually local variables (see above)

Memory model example

```
int global_var;

void foo()
{
    static int foo_st_var;
    int foo_var;
}

int main()
{
    int main_var;
    int *malloc_var = (int*)malloc(sizeof(int));
    foo();
    return 0;
}
```

For each of the following variables, classify their address as static, stack, or heap:

- `global_var`
- `foo_st_var`
- `foo_var`
- `main_var`
- `malloc_var`
- `*malloc_var`

Does this program leak memory? If so, where, and how would you fix it?