Compiling and Linking C / C++ Programs

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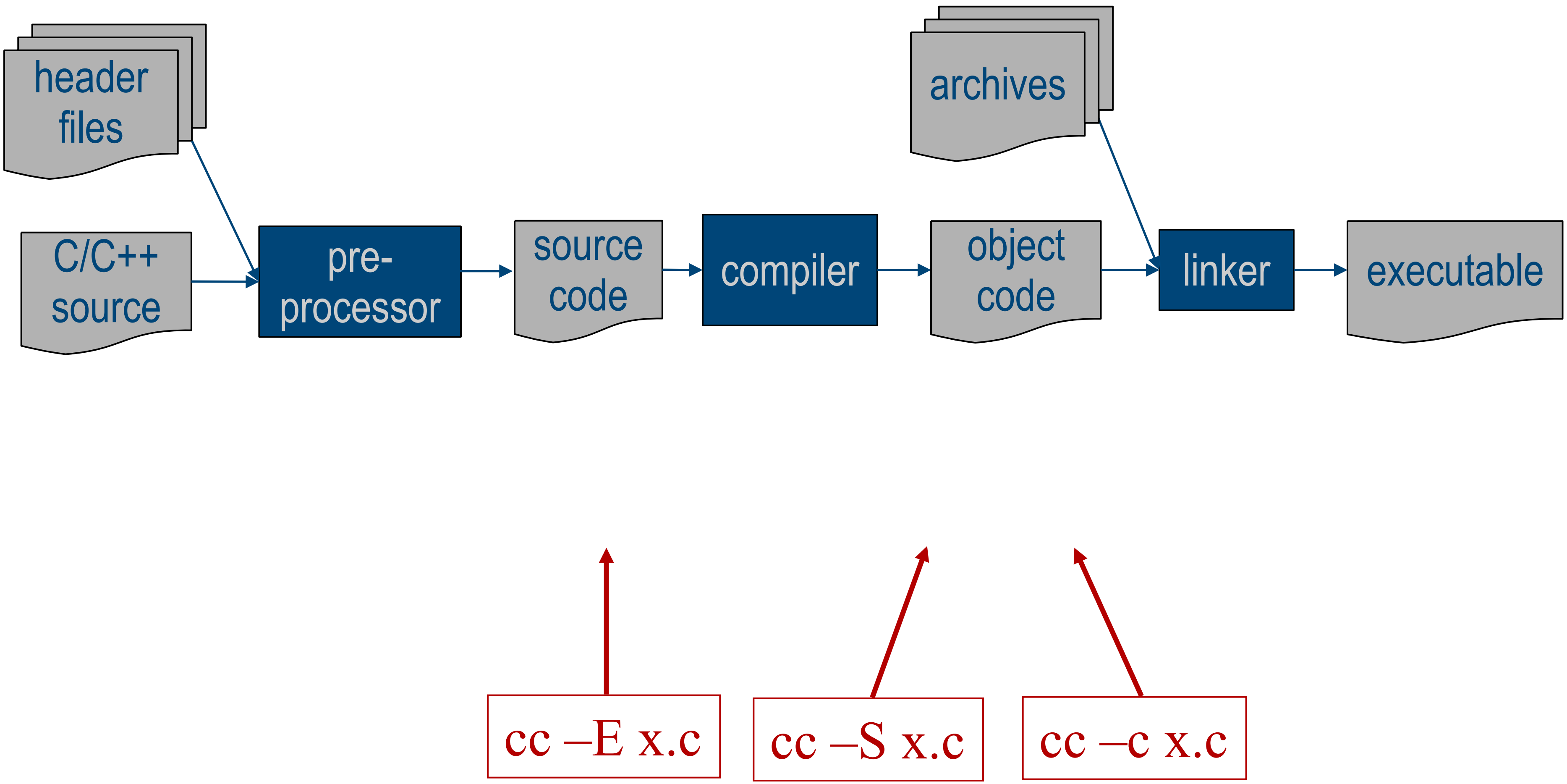
CPU @ Work

- ...watch your code like you never have seen it before!

Compile/Link Steps Overview



File Extension Conventions

▪ C source code	.c
▪ C include file	.h
▪ C++ source file	.cc , .C, .cxx, .c++, .cp, .cpp
▪ C++ header file	.hh, .hpp
▪ Object file (relocatable)	.o
▪ Executable	no extension (Windows: .com, .exe)
▪ Library	
• static	.a
• dynamic	.so

The C Preprocessor

- Purpose:
  - Define commonly used constants, code fragments, etc.
  - Conditional compilation (code activation depending on external settings)
- Main mechanism: replace by textual substitution
  - No idea about semantics (parentheses, semicolons, ...) !!
  - Does not follow C syntax
- Preprocessor directives
  - `#include`
  - `#define`
  - `#if / #ifdef`
  - …plus more

```
#define X 1
```

```
const int x = 1;
```

Using Preprocessor Directives

```
#ifndef _MYSTDIO_H_
#define EOF (-1)
#define NULL 0L
#define _MYSTDIO_H_
#endif _MYSTDIO_H_
```

- Conditional compilation
  - Include guard in header files, eg in **`mystdio.h`**:
- Include files
  - **`#include <stdio.h>`** – taken from predefined location
  - **`#include "myclass.h"`** – taken from local directories
- Where to find include files?
  - Standard locations: **`/usr/include`**, **`/usr/local/include`**, ...
  - Specified locations **`cc -I/home/project/include`**
- Can also pass definitions
  - **`cc -DCOMPILE_DATE=\"`date`\" -DDEBUG`**

Common Preprocessor Pitfall

- Use parentheses!!!
  - bad:

```
#define mult(a,b) a*b
main()
{
printf( "(2+3)*4=%d\n", mult(2+3,4) );
}
```

```
printf( "(2+3)*4=%d\n", 2+3*4 );
```

  - good:

```
#define mult(a,b) ((a)*(b))
main()
{
printf( "(2+3)*4=%d\n", mult(2+3,4) );
}
```

```
printf( "(2+3)*4=%d\n", ((2+3)*(4)) );
```

The C(++) Compiler

- Task: Generate (relocatable) machine („object“) code from source code
- Relocation: code can sit at different places in address space
- Address space classified into „segments“
  - Code, text, data, ...
- Note: OS (with HW support) uses this to implement user address space
  - Actual main memory address = base address + relative address
  - Base address kept in segment register, added dynamically by CPU
  - Security: program cannot access base register ("priviledged mode"), hence cannot address beyond its segment limits

Object Files

- Contain code for a program fragment (module)
  - Machine code, constants, size of static data segments, ...
- ```
  $ nm rasserver_main.o
  0000000c D clientTimeOut
           U __cxa_allocate_exception
           U __cxa_begin_catch
           U __cxa_end_catch
           U __cxa_free_exception
           U __cxa_throw
  00000004 B debugOutput
           U free
           U getenv
  00000120 B globalHTTPort
  00000000 T main
           U memset
  ```

or **objdump**
  ```

External Functions & Variables

- Module **`server`**:
  Variable **`sema`** allocated in data segment
- Module **`client`**:
  functions obtain sema address by
  - Module **`server`** offset
    + local address **`sema`**
- Cross-module addressing rules:
  - (no modifier) = locally allocated, globally accessible
  - static = locally allocated, locally accessible
  - extern = allocated in other compilation unit
- Why is this wrong?
  - **`extern int sema = 1;`**

```
int sema = 0;

int serverBlock()
{
if (sema==0)
        sema = 1;
return sema;
}
```

```
extern int sema;

int clientBlock()
{
if (sema==0)
        sema = 1;
return sema;
}
```

Name Mangling

- Problem: classes convey complex naming, not foreseen in classic linkage
  - Classes, overloading, name spaces, ...
    - *Ex:* `MyClass1::myFunc()`
      `MyClass2::myFunc()`
  - But only named objects in files, flat namespace
- Solution: name mangling
  - Compiler modifies names to make them unique (prefix/suffix)
  - Ex: **`Transaction::begin()`**
    ➔ **`_ZN13r_Transaction5beginENS_8r_TAModeE`**
- Every compiler has its individual mangling algorithm!
  - Code compiled with different compilers is incompatible

Name Mangling (contd)

- Q: My linker cannot find function **`flatFunc()`**, although I link against library **`libff.a`** which definitely contains **`flatFunc()`**.
  - Proof: **`nm libff.a | grep flatFunc`**
- A: You‘re probably linking with C code.
  Tell the C++ compiler that it‘s C, not C++, to avoid name mangling:

```
extern "C"
{
   void flatFunc();
}
```

The Linker/Loader

- Task: generate *one* executable file from *several* object and library files
  - Read object files
  - Resolve addresses from (relocatable) code
  - Link runtime code (start/exit handling!)
  - Add all code needed from libraries
  - If required: establish stubs to dynamic libraries
  - Write executable code into file, set magic number, etc.

John R. Levine:
Linkers and Loaders.
Morgan Kaufmann, 1999

- cc, g++, etc. have complex logics inside
  - can silently *invoke* linker, don't link themselves!
  - Common shorthand: `cc –o x x.c`
- Ex: `ld –o x /lib/crt0.o x.o -lc`

What It Really Looks Like

```
cc -v x.c
```

```
cc1 ... x.c ... -o /tmp/ccWs4dqa.s
as ... -o /tmp/cckBDoD2.o /tmp/ccWs4dqa.s
collect2 ... -o x /lib/ld-linux.so.2 \\
       crt1.o crti.o crtbegin.o /tmp/cckBDoD2.o
       -lgcc -lgcc_eh -lc -lgcc -lgcc_eh
       crtend.o crtn.o
```

Strip

- By default, executable contains symbol tables
  - Function names, addresses, parametrization
  - Static variables
  - ...some more stuff
- Disadvantages:
  - Allows reverse engineering (gdb!)
  - Substantially larger code files
- Before shipping: strip executables
  - **`file rasserver`**
    ```
    rasserver: ELF 32-bit LSB executable, Intel 80386, version
    1 (SYSV), for GNU/Linux 2.2.5, dynamically linked (uses
    shared libs), not stripped
    ```
  - **`strip rasserver`**

Libraries (Archive Files)

- Library = archive file containing a collection of object files
  - Code fragments (classes, modules, ...)
  - `ar rv libxxx.a file1.o file2.o ...`
- Object files vs. Libraries
  - Object file linked in completely, from library only what is actually needed
- Static vs. Dynamic
  - Static library: code is added to the executable, just like object file; not needed after linkage
  - Dynamic library: only stub linked in, runtime system loads; needed at runtime (version!)
- Naming conventions (Linux)
  - Static libraries: `libxxx.a`
  - Dynamic libraries: `libxxx.so`
  - link with: `ld ... -lxxx`

Dynamic Libraries

- How to find my dynamic libraries?
  - **`LD_LIBRARY_PATH`** variable, similar to **`PATH`**: set before program start
- How to know about use of dynamic libraries?
  - ```
    $ ldd rasserver
        linux-gate.so.1 =>  (0xffffe000)
        libstdc++.so.5 => /usr/lib/libstdc++.so.5 (0x40028000)
        libm.so.6 => /lib/tls/libm.so.6 (0x400e5000)
        libgcc_s.so.1 => /lib/libgcc_s.so.1 (0x40128000)
        libc.so.6 => /lib/tls/libc.so.6 (0x40130000)
        libresolv.so.2 => /lib/libresolv.so.2 (0x4029c000)
    ```
    ```

Schematic Program Run

- OS:
  - Open file
  - Look at first page:
    magic number, segment sizes, etc.
  - Allocate segments
    (code, runtime stack, heap, ...)
  - Read code file into code segment
  - Set up process descriptor
    (external resources, limits, ...)
  - Pass control to this process
  - Handle system calls
  - Terminate program,
    free process slot and resources

- Application program:
  - Set up runtime environment
    (**`argv/argc`**, ...)
  - Call **`main()`**
  - On system calls, interrupts, etc.:
    pass control to OS
  - Upon **`exit()`**,
    or **`main()`**'s **`return`**,
    or a forced abort:
    clean up (close file descriptors, sockets, ...),
    pass back to OS

Summary

- To create executable program, you must perform:
  - Preprocess – textually expands definitions, condition-guarded code pieces
  - Compile – translates source code into relocatable machine code („object code“)
  - Link – bind object files and archives into executable program

```
cc –o x x.c
```

=

```
cpp x.c x.cpp
cc –o x.o –c x.cpp
ld –o x /lib/crt0.o x.o -lc
```

Summary (contd.)

- A word about code quality
  - Set compiler to max rigidity: `cc -W -Wall ...`
  - Eliminate *all* warnings
- Finally, the formatting war:

ANSI C:

```
void foo()
{
   myAction();
}
```

Kernighan/Ritchie:

```
void foo() {
   myAction();
}
```

- The answer: whatever style, use one coherently
  - Use automatic beautifier (see my SE course page for some)