CS 4120
Introduction to Compilers

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Lecture 32: Shared libraries and dynamic loading

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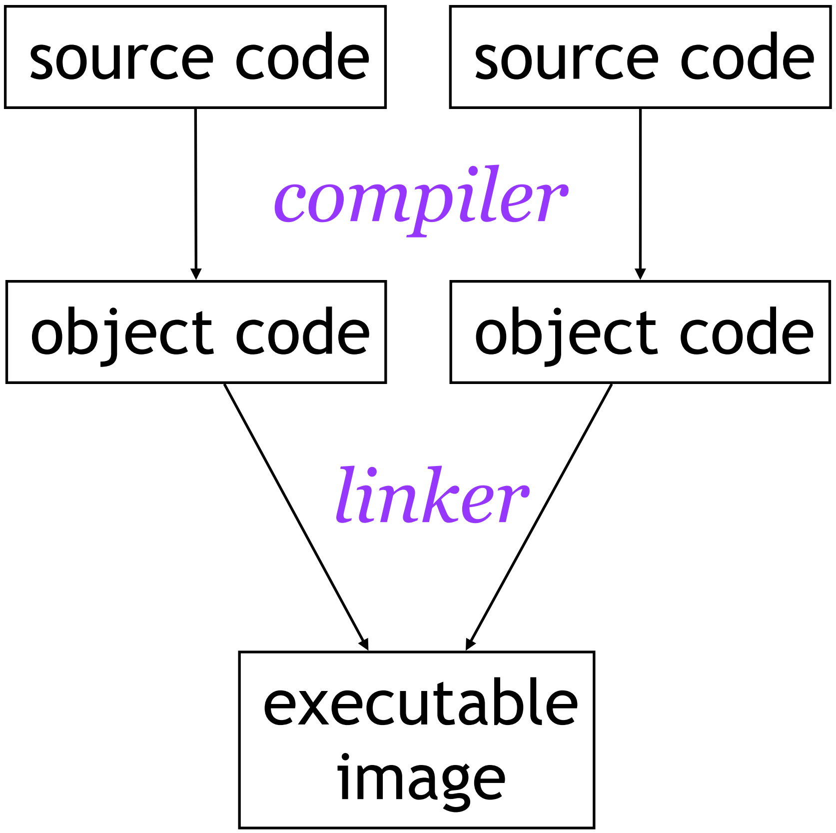
Object files

- Output of assembler is an ***object file***
  - not executable
  - may refer to external symbols (variables, functions, etc.) whose definition is not known.
- Linker joins together object files, resolves external references



Unresolved references

source code

```
extern long
abs( int x );
…
y = y + abs(x);
```

assembly code

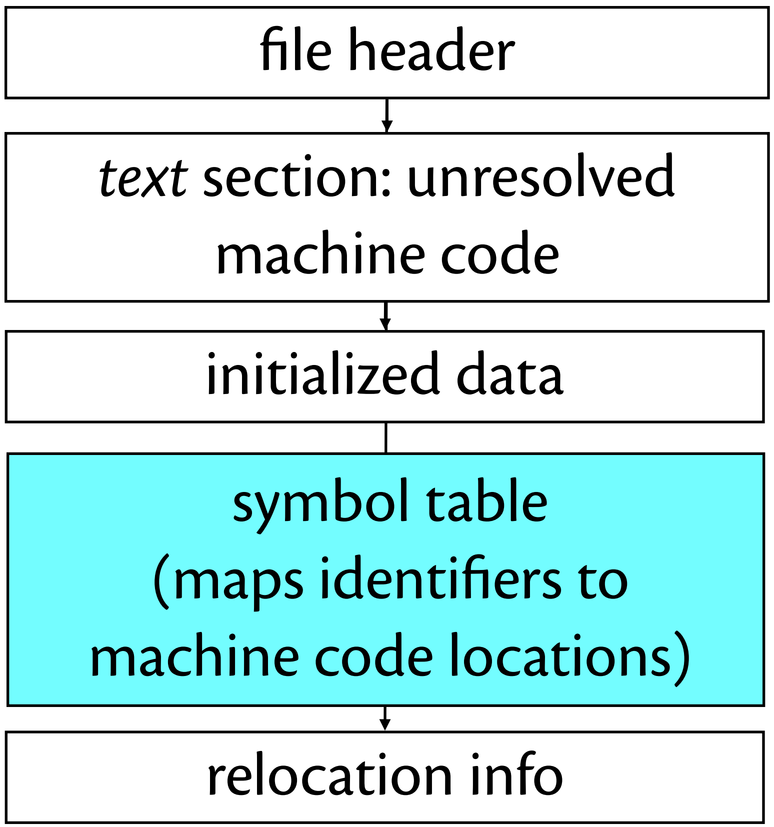
```
push rcx
call _abs
add rdx, rax
```

object code

```
51
E8 00 00 00 00
01 C2
```

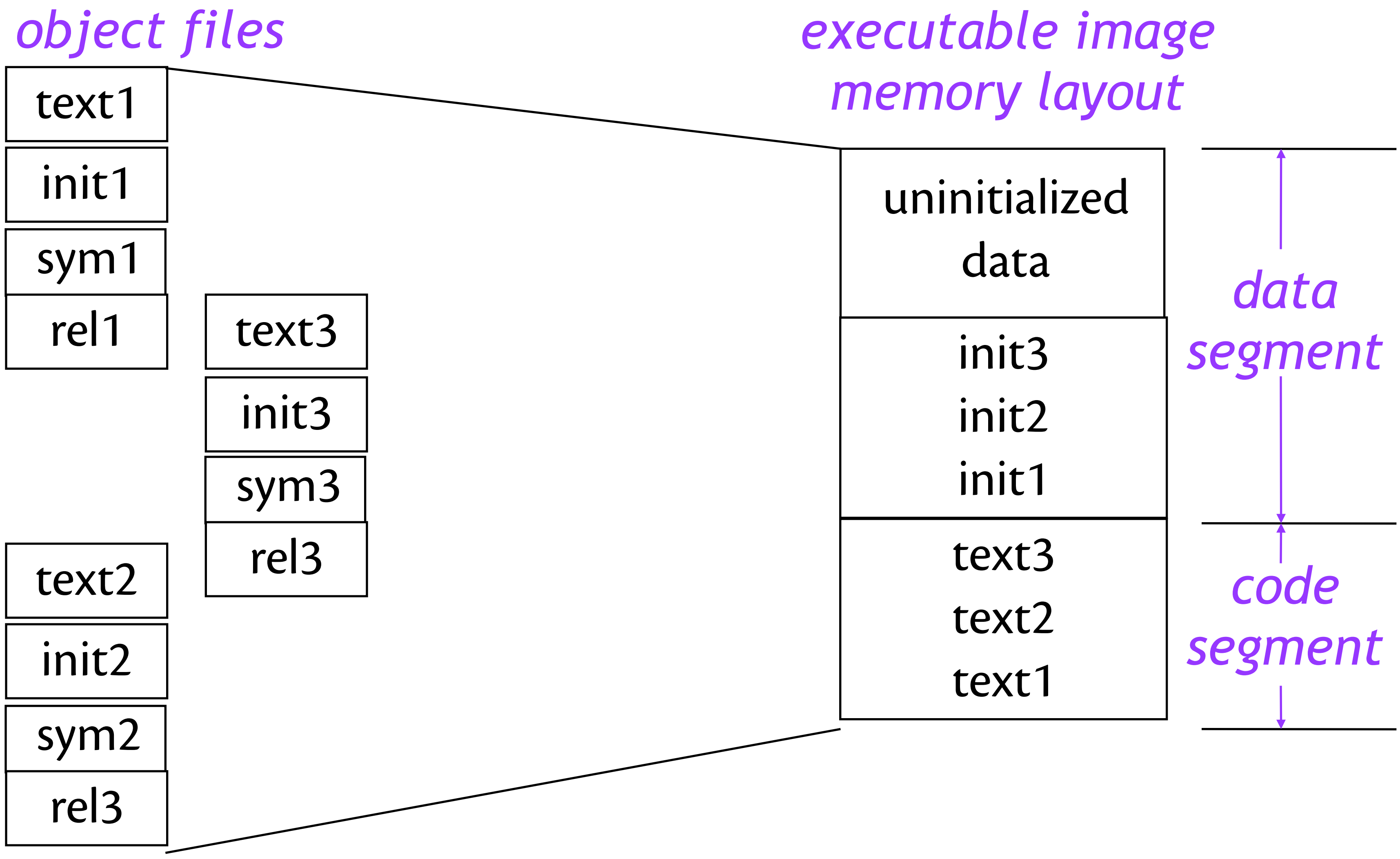
} filled in by linker

Object file structure



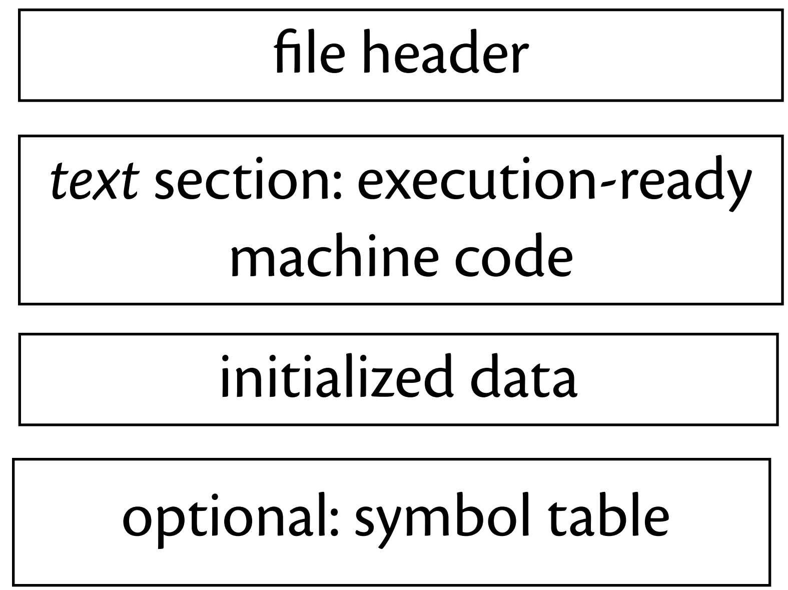
- Object file contains various **sections**
- **text** section contains the compiled code with some patching needed
- For uninitialized data, only need to know total *size* of data segment
- Describes structure of text and data sections
- Points to places in text and data section that need fix-up

Linker output



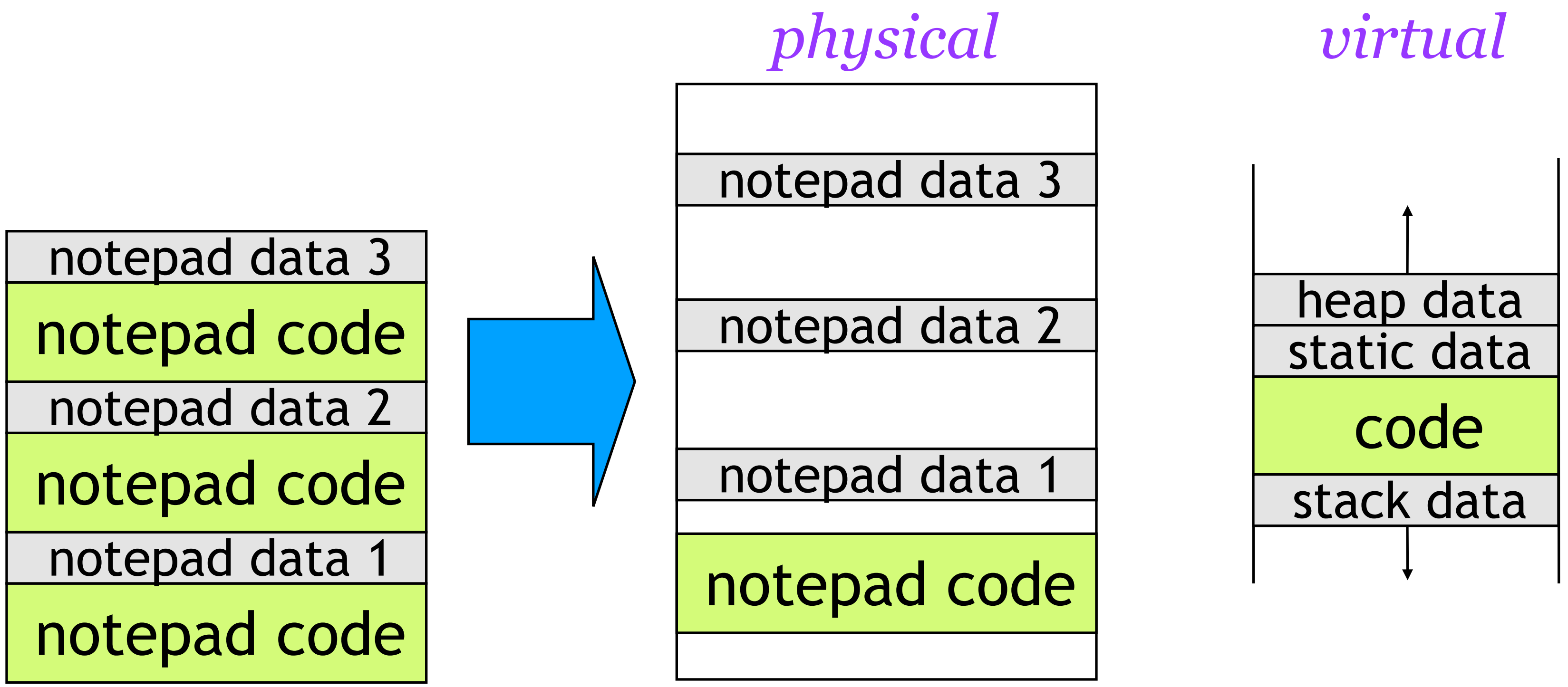
Executable file structure

- Same as object file, but ready to be executed as-is
- Pages of code and data brought in lazily from text and data section as needed: rapid start-up
- Text section shared across processes
- Symbols for debugging (global, stack frame layouts, line numbers, etc.)



Executing programs

- Multiple copies of program share code (text), have own data
- Data appears at same virtual address in every process



Libraries

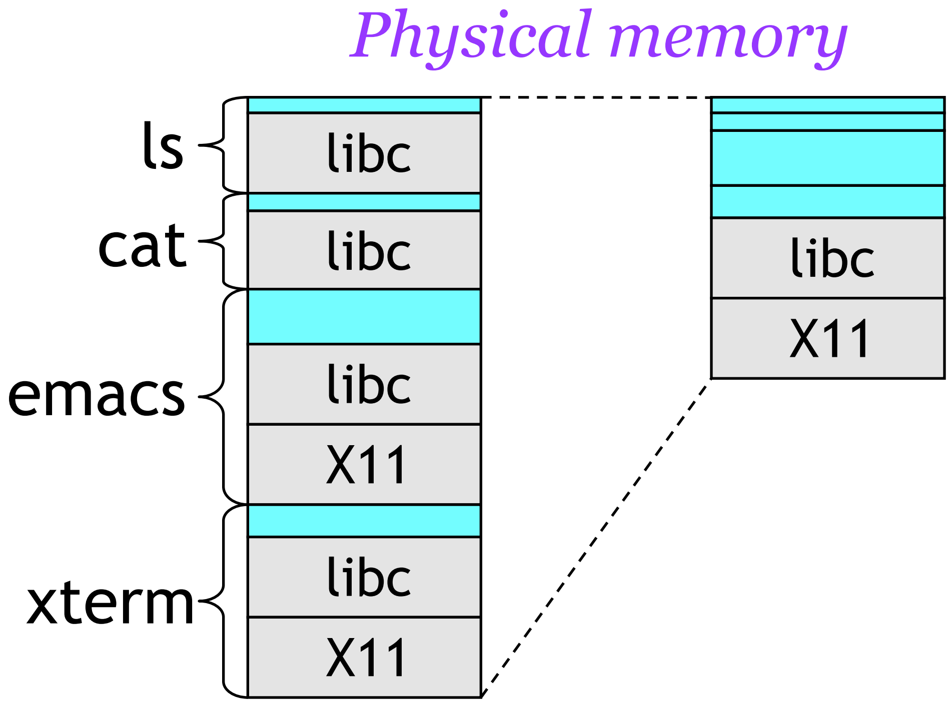
- *Library* : collection of object files
- Linker (Unix: ld) adds all object files necessary to resolve undefined references in explicitly named files
- Object files, libraries searched in user-specified order for external references

```
ld main.o foo.o /usr/lib/X11.a /usr/lib/libc.a
```

- Library has index over all object files for rapid searching

Shared libraries

- Problem: libraries take up a lot of memory when linked into many running applications
- Solution: *shared libraries (e.g. DLLs)*



Step 1: Jump tables

- Executable file does not contain library code; library code loaded dynamically.
- Library code found in separate shared library file (similar to DLL); linking done against **import library** that does not contain code.
- Library compiled at fixed address, starts with **jump table** to allow new versions; application code jumps to jump table (indirection).
  – library can evolve since jump table doesn't move.

program:	*library*:
	`scanf: jmp real_scanf`
`call printf`	`printf: jmp real_printf`
	`putc: jmp real_putc`

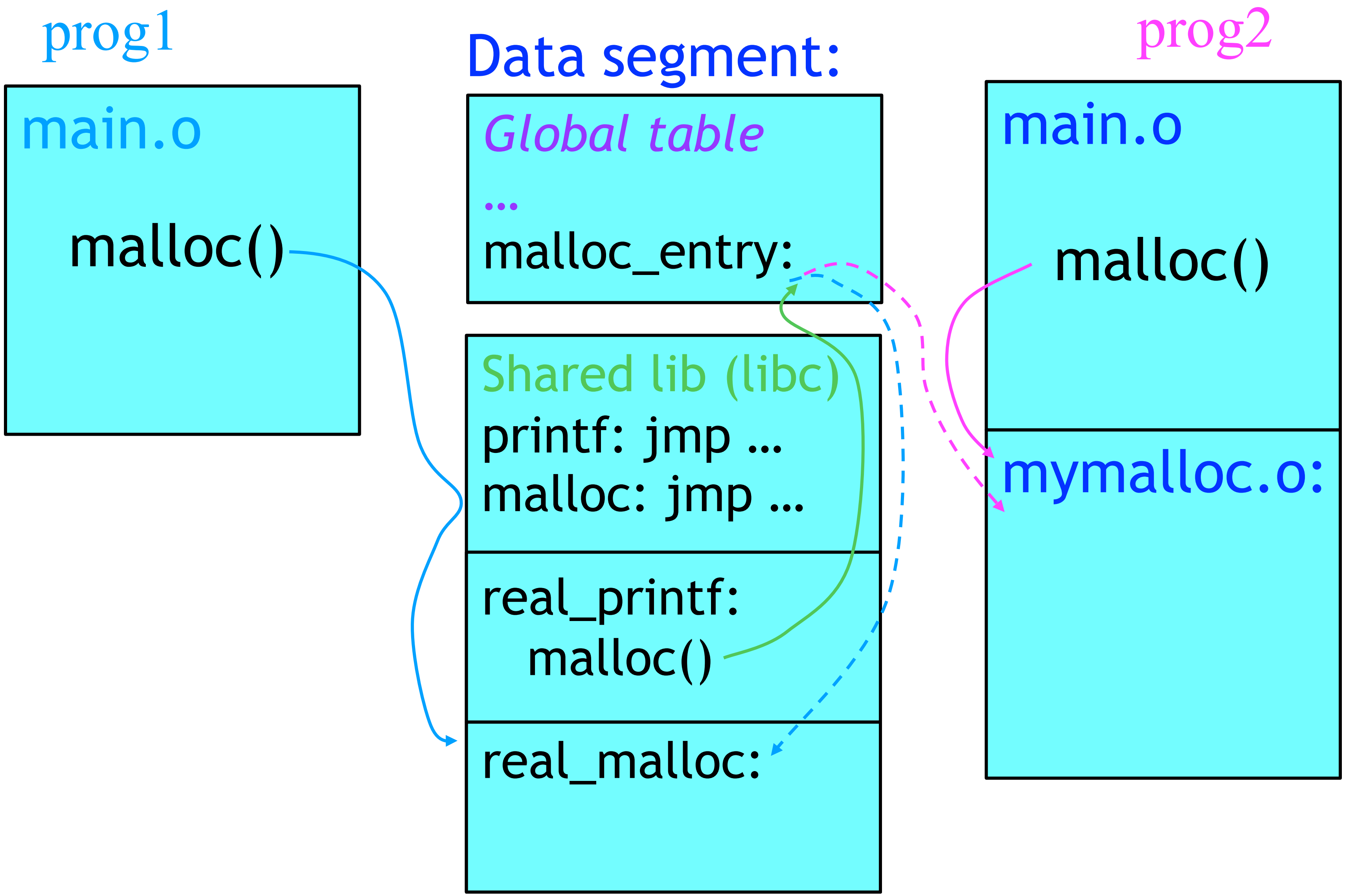
Global tables

- Problem: shared libraries may depend on external symbols (even symbols within the shared library); different applications may have different *linkage*:

```
gcc -o prog1 main.o /usr/lib/libc.a
gcc -o prog2 main.o mymalloc.o /usr/lib/libc.a
```

- If routine in `libc.a` calls `malloc()`, `prog1` should get standard version; for `prog2`, version in `mymalloc.o`
- Solution: Calls to external symbols made through **global offset tables** unique to each program, generated at dynamic load time.

Global tables



Using global tables

- Global table contains entries for all external references

```
malloc(n) ⇒ mov rdi, n
            mov rax, [malloc_entry]
            call rax                    ; indirect jump
```

- Non-shared application code unaffected
- Same-object references can still be used directly
- Global table entries (`malloc_entry`) placed in non-shared memory locations so each program has different linkage
- Initialized by dynamic loader when program begins: reads symbol tables, relocation info.
- Code above may be dynamically generated as trampoline at load time.

Relocation

- Before widespread support for virtual memory, code had to be **position-independent** (could not contain fixed memory addresses)
- With virtual memory, all programs could start at same address, *could* contain fixed addresses
- Problem with shared libraries (*e.g.*, DLLs): if allocated at fixed addresses, can collide in virtual memory (code, data, global tables, ...)
  - Collision ⇒ code copied and explicitly relocated
- Back to position-independent code!

Dynamic shared objects

- Unix (Linux) systems: code typically compiled as a **dynamic shared object** (DSO): fully relocatable
- Shared libraries can be mapped to any address in virtual memory—no copying!
- *Questions:*
  - how to make code completely relocatable?
  - what is the performance impact?

Relocation difficulties

- No **absolute addresses** (directly named memory locations) anywhere:
  - Not in calls to external functions
  - Not for global variables in data segment
  - Not even for global table entries

```
mov rdi, n
mov rax, [malloc_entry]     ;   Oops!
call rax
```

- Not a problem: branch instructions, local calls: **relative addressing (offset from rip)**

Global offset tables

- Put address of all globals into global table
- But…can't put global table itself at a fixed address: not relocatable!

- Three solutions:
  1. (Usual approach) Use address arithmetic on current program counter (`rip` register) to find global table. Link-time constant offset between `rip` and global table.
  2. Pass global table address as an extra argument: affects first-class functions (callee global table address stored in current GT)
  3. Stick global table entries into the current object's dispatch table : DT *is* the global table (ideal, but only works for OO code)

Cost of DSOs

- Call to external function f:

```
call f_stub
...
f_stub:  jmp [rip + f_offset]
```

- Global variable accesses:

```
lea rax, [rip + v_offset]
mov rbx, [rax]
```

- Calling global functions ≈ calling single-inheritance methods
- Global variables: *more* expensive than local variables
- Most benchmarks run w/o DSOs!

Prelinking/prebinding

- Idea: precompute relocation of dynamic libraries to virtual addresses to speed up load times
- Conflicting libraries assigned disjoint virtual memory regions

⇒ whole-system optimization, usually done every few weeks

Dynamic linking

- Shared libraries (DLLs) and DSOs can be linked dynamically into a running program
- Normal case: implicit linking. When setting up global tables, shared libraries are automatically loaded if necessary (even *lazily*), symbols looked up & global tables created.
- Explicit dynamic linking: application can choose how to extend its own functionality
  - *Unix*: `h = dlopen(filename)` loads an object file into some free memory (if necessary), allows query of globals: `p = dlsym(h, name)`
  - *Windows*: `h = LoadLibrary(filename)`, `p = GetProcAddress(h, name)`

Conclusions

- Shared libraries and DSOs allow efficient memory use on a machine running many different programs that share code.
- Usually improves cache, TLB performance overall.
- But: hurts individual program performance: indirections through global tables, code bloat
- Globals are more expensive than they look!
- Important new functionality: dynamic extension of program.