

# CS 4120 Introduction to Compilers

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Lecture 35: Linking and Loading

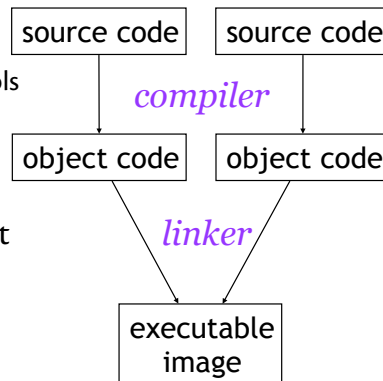
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## Outline

- Static linking
  - Object files
  - Libraries
  - Shared libraries
  - Relocatable code
- Dynamic linking
  - explicit vs. implicit linking
  - dynamically linked libraries/dynamic shared objects

## Object files

- Output of compiler 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 int abs( int x );
...
y = y + abs(x);
```

assembly code

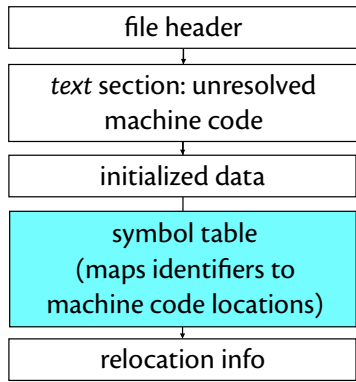
```
push %ecx
call _abs
add %eax, %edx
```

object code

51				
E8	00	00	00	00
01	C2			

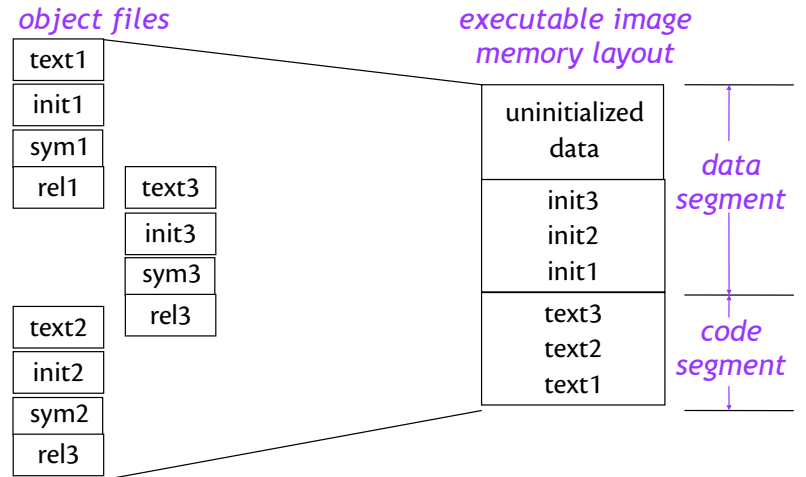
} to be filled in by linker

# Object file structure



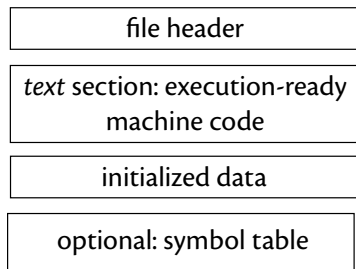
- Object file contains various **sections**
- **text** section contains the compiled code with some patching needed
- For uninitialized data, only need to know total size of data segment
- Describes structure of text and data sections
- Points to places in text and data section that need fix-up

# Linker output



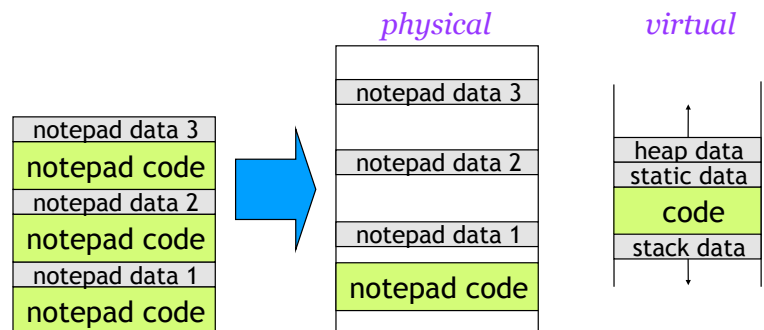
# Executable file structure

- 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

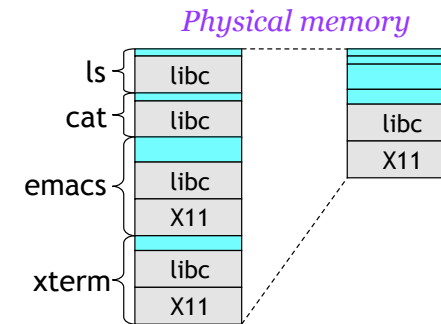


## Libraries

- *Library*: collection of object files
- Linker adds all object files necessary to resolve undefined references in explicitly named files
- Object files, libraries searched in user-specified order for external references
  - **Unix**: `ld main.o foo.o /usr/lib/X11.a /usr/lib/libc.a`
  - **NT**: `link main.obj foo.obj kernel32.lib user32.lib ...`
- Library contains 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)



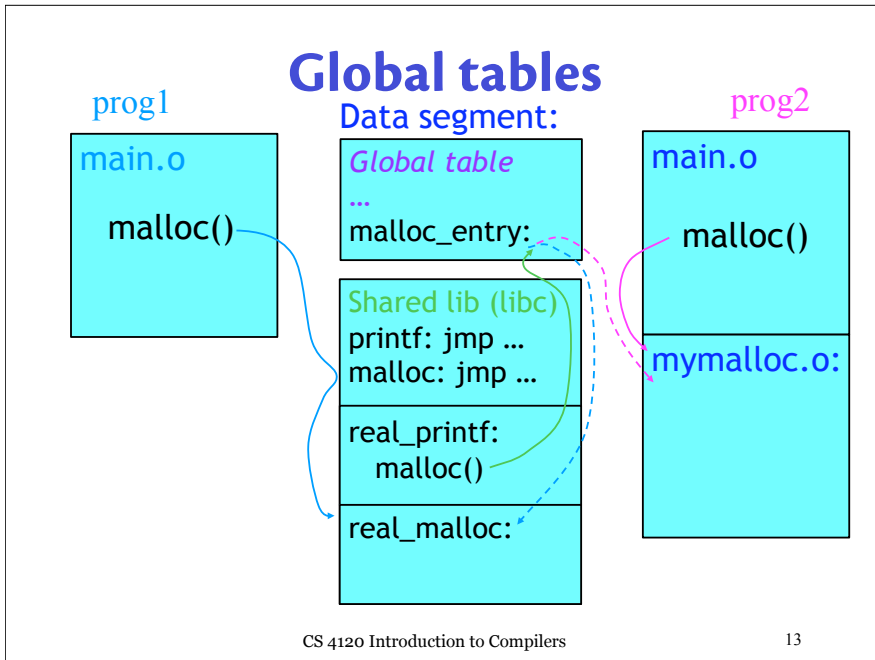
## Step 1: Jump tables

- 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.

```
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(), for 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.



## Using global tables

- Global table contains entries for all external references

```

malloc(n) ⇒ push [%ebp + n]
             mov %eax, [malloc_entry]
             call *%eax                ; 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

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## 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!

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## Dynamic shared objects

- Unix systems: code typically compiled as a **dynamic shared object (DSO)**: relocatable shared library
  - gcc: `-shared` option
- 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?

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## 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

```
push [ebp + n]
mov eax, [malloc_entry] ; Oops!
call eax
```

- Not a problem: branch instructions, local calls. Use **relative addressing**

## Global offset tables

- Can put address of all globals into global table
- But...can't put the global table at a fixed address: not relocatable!

- **Three solutions:**

1. Pass global table address as an extra argument (possibly in a register): affects first-class functions (next global table address stored in current GT)
2. Use address arithmetic on current program counter (eip register) to find global table. Use link-time constant offset between eip and global table. (extract eip w/ dummy call)
3. Stick global table entries into the current object's dispatch table: DT is the global table (only works for OO code, but otherwise the best)

## Cost of DSOs

- Assume esi contains global table pointer (setup code at beginning of function)

- Call to function f:

```
call [esi + f_offset]
```


- Global variable accesses:

```
mov eax, [esi + v_offset]
```

```
mov ebx, [eax]
```

- Calling global functions  $\approx$  calling methods
- Accessing global variables is *more* expensive than accessing local variables
- Most benchmarks run w/o DSOs!

## Link-time optimization

- When linking object files, linker provides flags to allow peephole optimization of inter-module references
  - Unix: `-static` link option means application to get its own copy of library code
    - calls and global variables performed directly (peephole opt.)
- ```
call [esi + malloc_addr]  call malloc
```
- Allows performance/functionality trade-off

## 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
- Improves cache, TLB performance overall
- Hurts individual program performance by adding indirections through global tables, bloating code with extra instructions.
- Important new functionality: dynamic extension of program.
- Peephole linker optimization can restore performance, but with loss of functionality.