ECE260: Fundamentals of Computer Engineering

Translation of High-Level Languages

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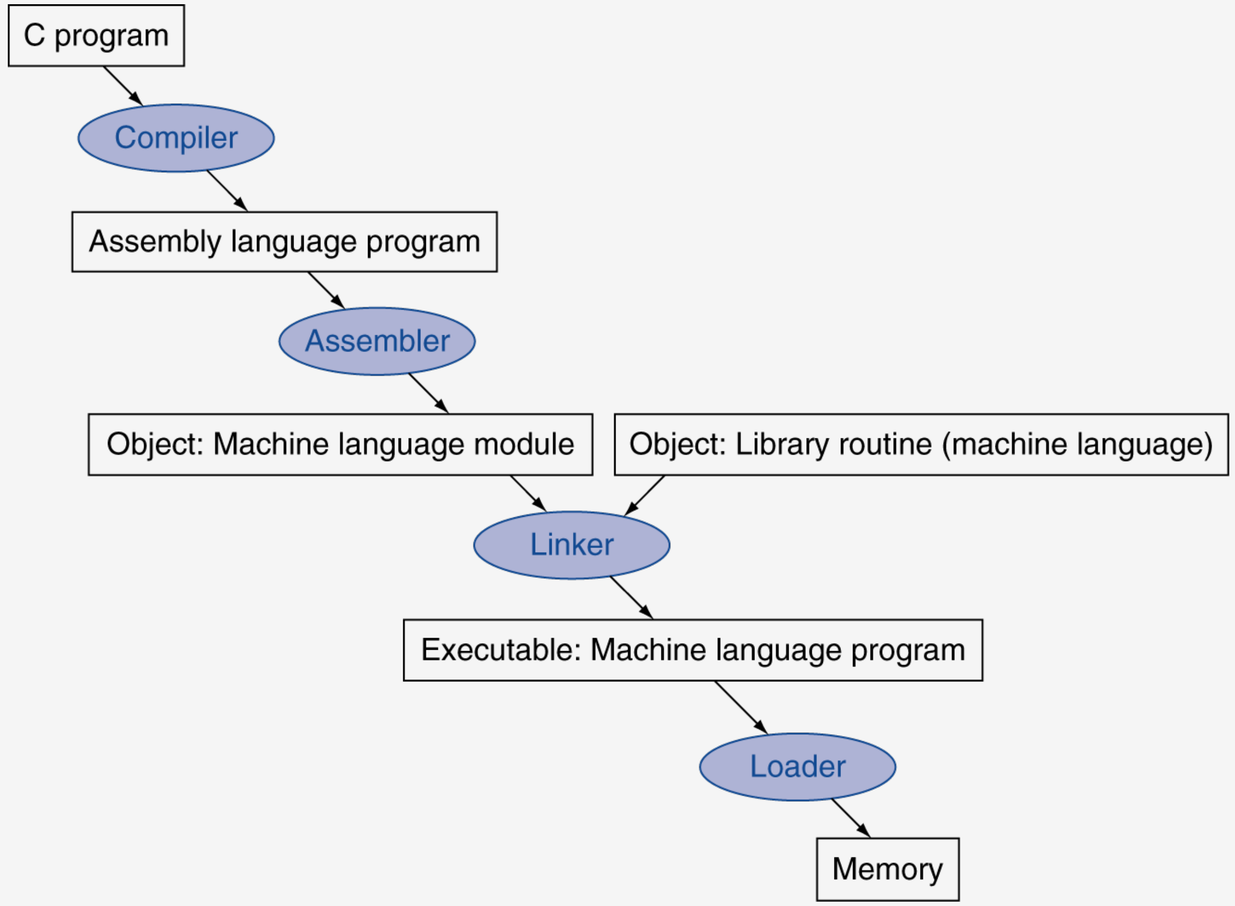
Translation of High-Level Languages

- **Writing code in assembly is time consuming and can be challenging**
  - A single line of C code may require many lines of assembly
    - Example: D[4 + i] = A[5 * j] + 6;
  - Must manage limited register set and stack
- **High-level languages exist to make programming computers easier**
  - Abstract away many of the complexities of the underlying hardware
  - Increase programmer productivity
- ***Compilers*** **exist to automate translation from a high-level language into assembly**
  - Typically integrated with an ***assembler*** and a ***linker*** to produce executable code

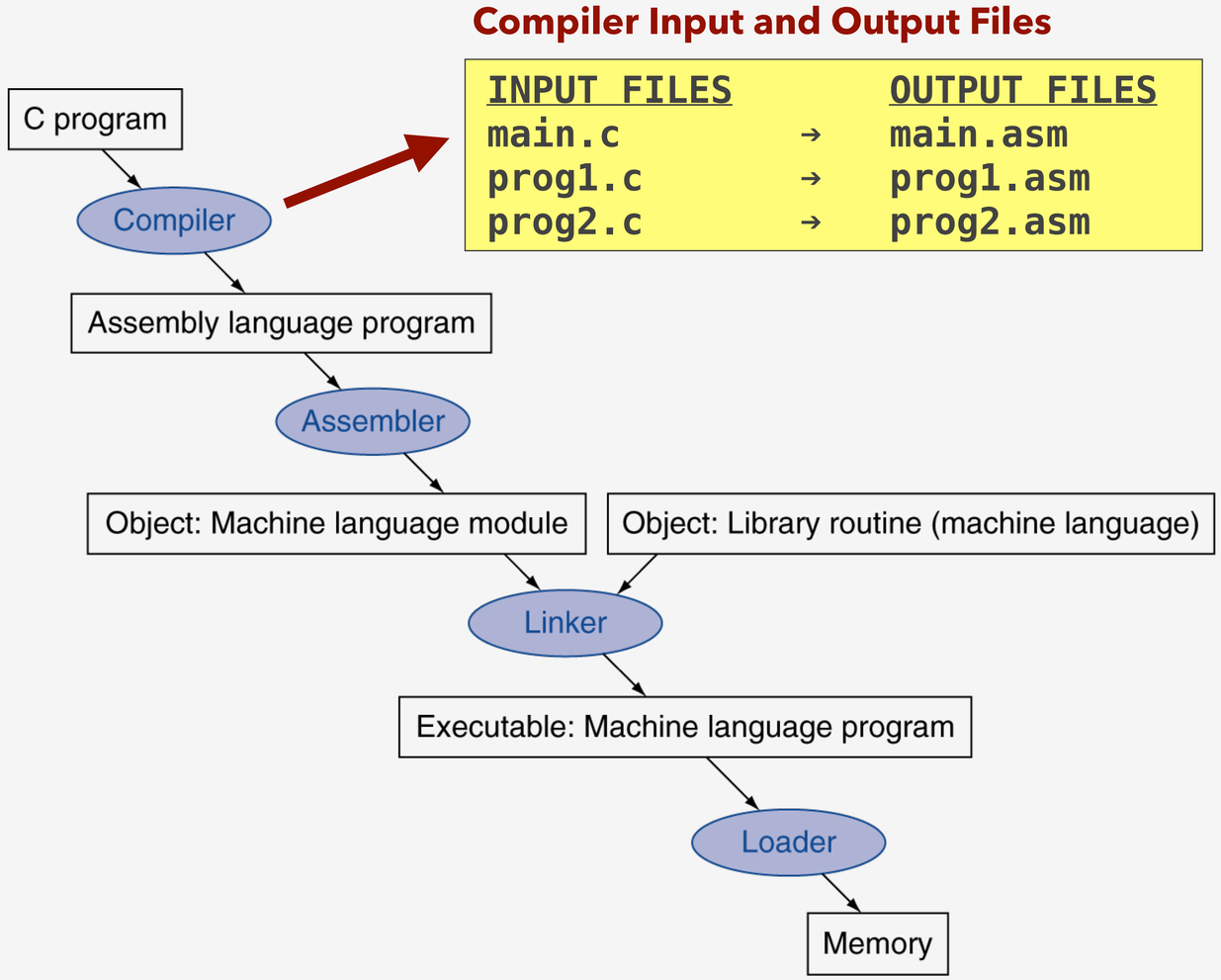
Translation and Startup of a Program

- Translation and startup of a program includes the following steps:
  - Programmer writes some code
  - Compiler translates code into assembly
  - Assembly is converted into an object file
  - Linker "stitches" together object files to produce an executable file
- At a later time, when the executable file is executed
  - A loader loads the executable instructions and data into memory



Compiling Code

- Programmer may write code in multiple files
  - Program written in C may include many ".c" files
- For each file, a ***compiler*** parses and translates C code into assembly code
  - Basic blocks of code are converted into assembly
  - Conditions are translated into branch and jump instructions
  - Procedures are translated using conventions for saving/restoring registers and manipulating the stack
  - May perform variety of optimizations

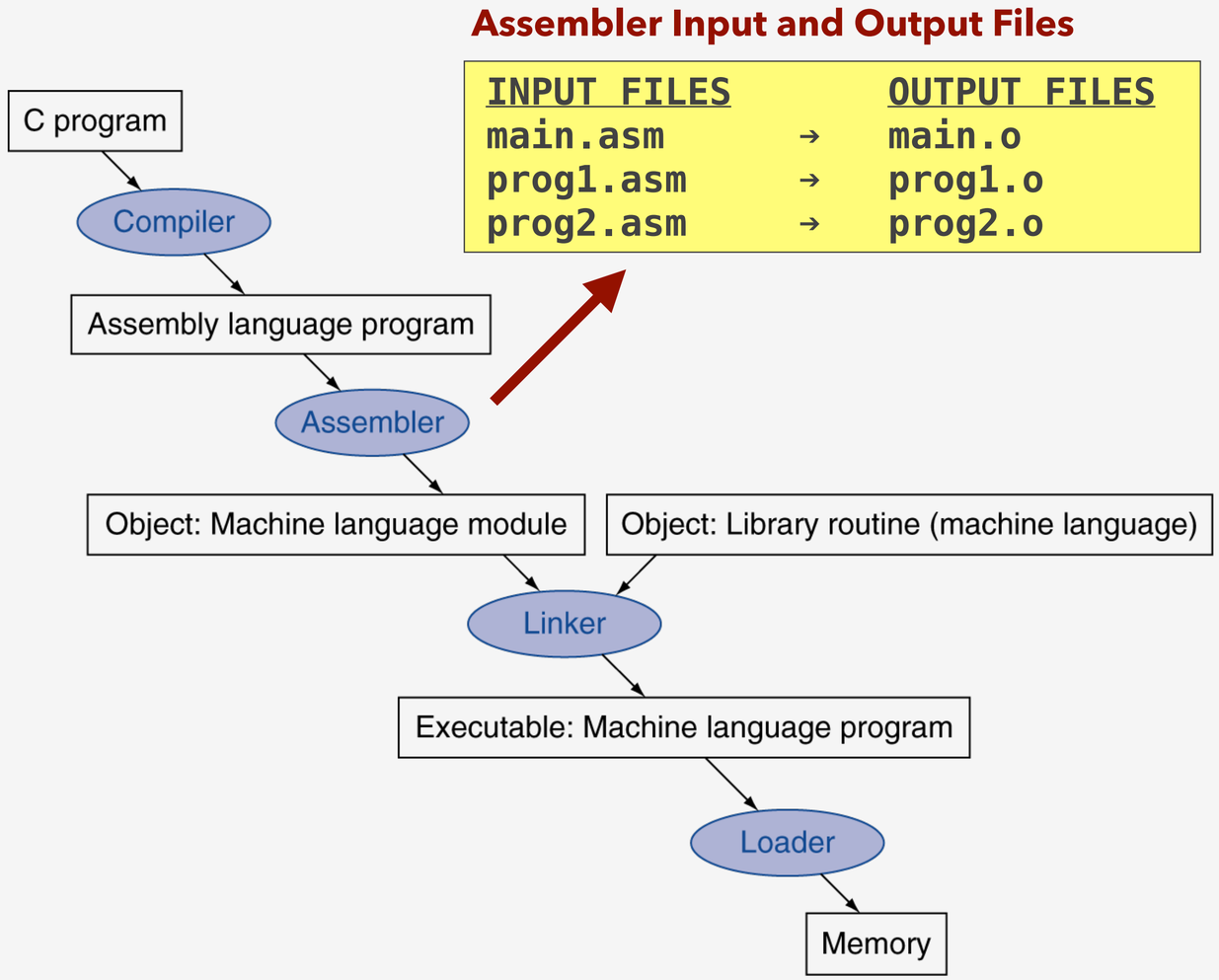


Assembling Into Object Files

- For each input file, an ***assembler*** converts assembly into object files (e.g. ".o" files)
  - Native instructions in the input .asm files are converted directly into machine code
  - Pseudoinstructions (e.g. move, bgt, ble, etc.) are converted into native instructions which are converted into machine code

```
move $t0, $t1  →  add $t0, $zero, $t1
```

  - A ***symbol table*** is created in object file
    - Label name/memory address mapping
    - Memory addresses are relative to beginning of each object file (this will change later)

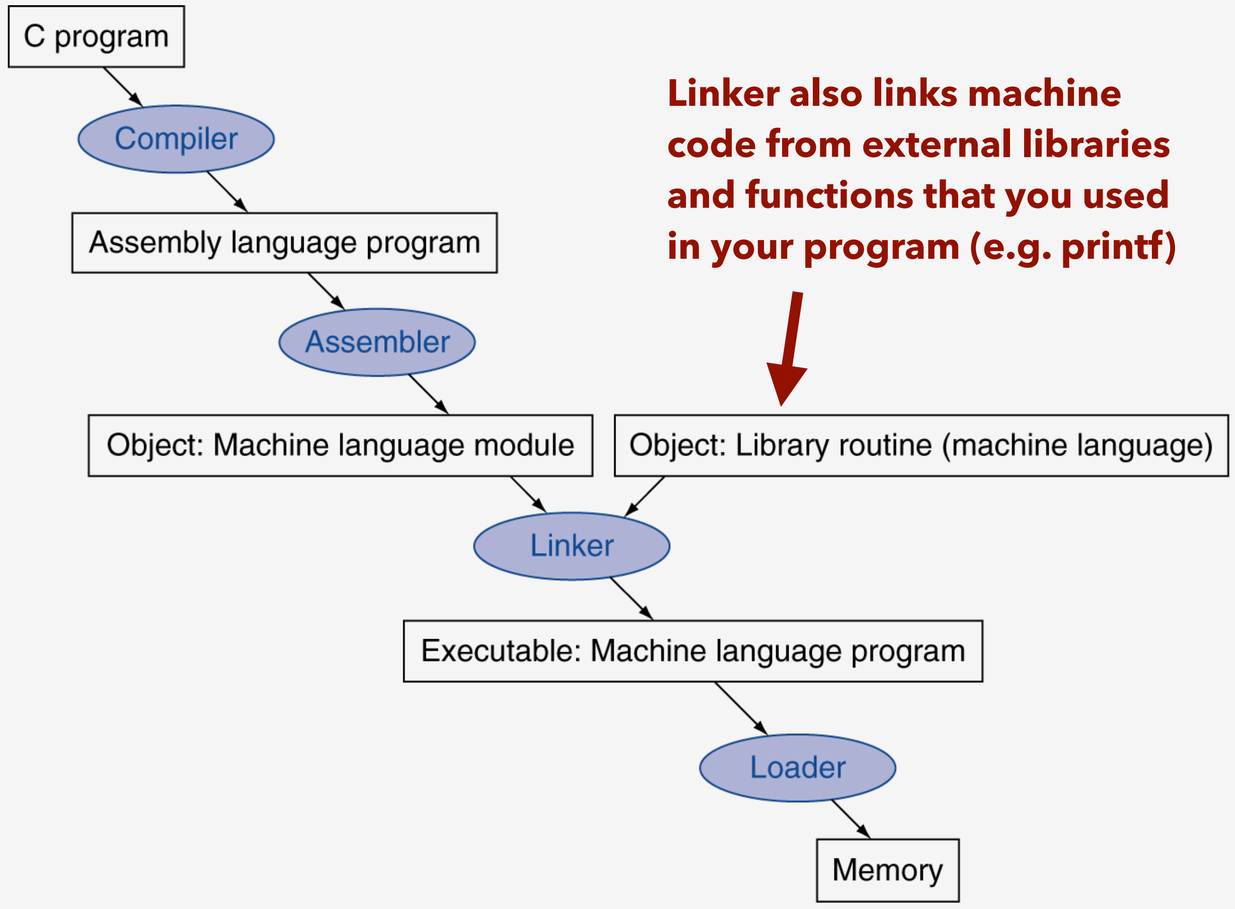


Anatomy of an Object File

- Object file provides information for building a complete program from the multiple input files
  - ***Object File Header*** – describes the size and position of the other pieces of the object file
  - ***Text Segment*** – contains the translated assembly instructions as machine code
  - ***Static Data Segment*** – contains global and static data that is allocated for the life of the program
  - ***Relocation Info*** – contains location of instructions and data words that may need modification when multiple object files are linked together
  - ***Symbol Table*** – contains list of labels that are not defined in the input file (i.e. external references)
    - These will be resolved later when multiple object files are linked together
  - ***Debug Info*** – contains info for associating machine code with original high-level language code
    - Enables your IDE to step through code!

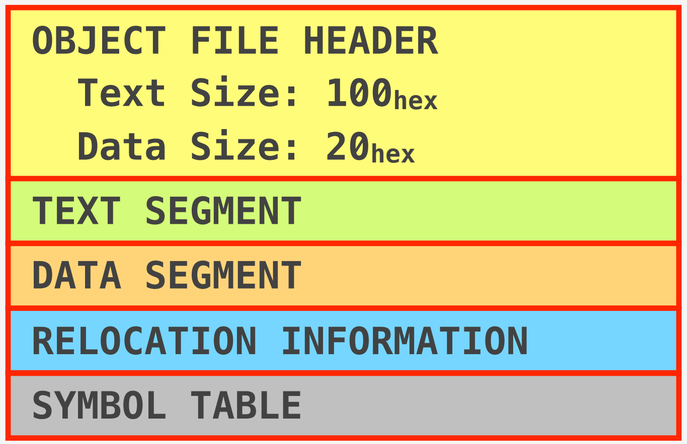
Linking Object Files

- A ***linker*** combines all of the object files that constitute a program into a single ***executable file***
  - Merges .text and .data segments from multiple object files into single .text and .data segments
  - Determines addresses of data and instruction labels in newly combined file
  - Patches memory addresses that were relative to individual object files – now relative to combined object file
- This approach reduces compile time since only high-level language files that have changed need to be recompiled

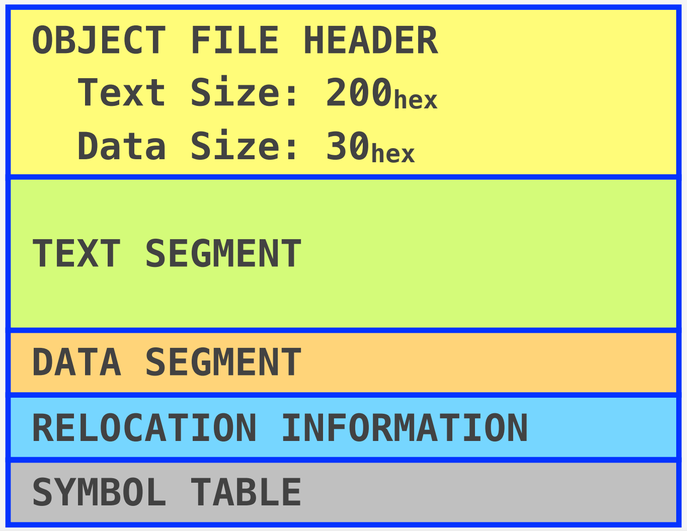


Linking Object Files (continued)

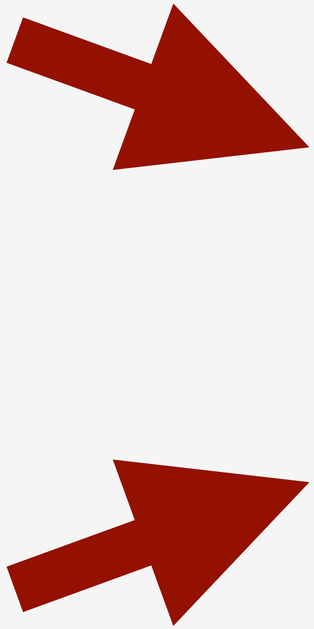
Object File #1



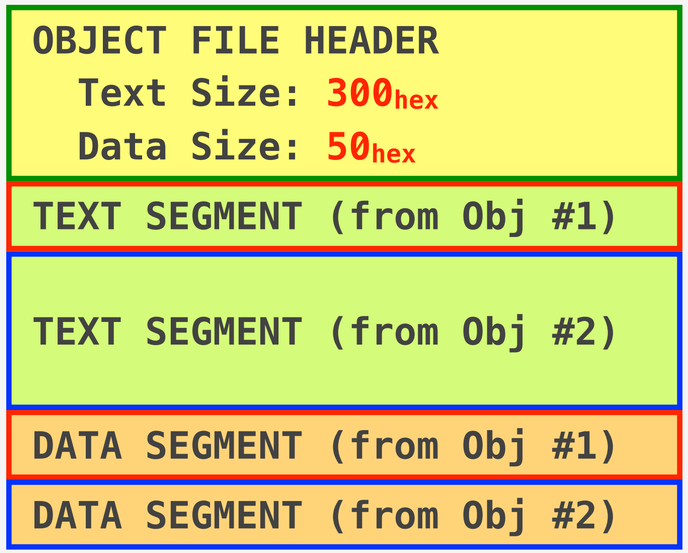
Object File #2



Object files are merged into a single executable file



Executable File



Linking Object Files – Example

Object file header			
	Name	Procedure A	
	Text size	100_{hex}	
	Data size	20_{hex}	
Text segment	Address	Instruction	
	0	`lw $a0, 0($gp)`	
	4	`jal 0`	
	...	...	
Data segment	0	(X)	
	...	...	
Relocation information	Address	Instruction type	Dependency
	0	`lw`	X
	4	`jal`	B
Symbol table	Label	Address	
	X	–	
	B	–	

Object File #1

Object file header			
	Name	Procedure B	
	Text size	200_{hex}	
	Data size	30_{hex}	
Text segment	Address	Instruction	
	0	`sw $a1, 0($gp)`	
	4	`jal 0`	
	...	...	
Data segment	0	(Y)	
	...	...	
Relocation information	Address	Instruction type	Dependency
	0	`sw`	Y
	4	`jal`	A
Symbol table	Label	Address	
	Y	–	
	A	–	

Object File #2

Linked Object Files (i.e. executable file)

Executable file header		
	Text size	300_{hex}
	Data size	50_{hex}
Text segment	Address	Instruction
	$0040\ 0000_{hex}$	`lw $a0,` 8000_{hex}`($gp)`
	$0040\ 0004_{hex}$	`jal 40 0100`$_{hex}$
	...	...
	$0040\ 0100_{hex}$	`sw $a1,` 8020_{hex}`($gp)`
	$0040\ 0104_{hex}$	`jal 40 0000`$_{hex}$
	...	...
Data segment	Address	
	$1001\ 0000_{hex}$	(X)
	...	...
	$1001\ 0020_{hex}$	(Y)
	...	...

Assume:

- **.text segment starts at $0040\ 0000_{hex}$**
- **.data segment starts at $1000\ 0000_{hex}$**
- **$gp is initialized to $1000\ 8000_{hex}$**

Loading a Program

- ***Loader*** loads executable file from disk into memory
  - Reads header to determine size of text and data segments
  - Creates an address space large enough for the text and data
  - Copies the instruction and data from the executable file into memory
  - Copies parameters (if any) to the main program onto the stack (e.g. command line arguments)
  - Initializes machine registers (including $sp, $fp, $gp)
  - Jumps to a startup routine that copies parameters into argument registers (i.e. $aX) and calls “main”
  - When “main” returns, the startup routine terminates the program

Static vs. Dynamic Linking

- ***Static linking*** occurs during the linking phase of the compilation process
  - Objects that are statically linked are combined into the executable output file
  - All libraries that are used compile directly into executable
    - Increases executable file size
    - Library updates require generation of a new executable file :-(
- ***Dynamic linking*** occurs at runtime and only links/loads code when it is called
  - Often used when linking with operating system libraries (e.g. Windows .DLL files)
  - Avoids executable file bloat
  - Automatically links with updated libraries next time program is run
    - NOT ALWAYS A GOOD THING