# System Software- Part 2

CIT 595
Spring 2007

## System Software: Programming Tools

- Programming tools carry out the mechanics of software creation within the confines of the operating system and hardware environment

- These include:
  - Assembler
  - Compiler
  - Linker
  - Loader



## Communicating with the Machine

- Computers understand only ones and zeros…
  - E.g. 00000001111100

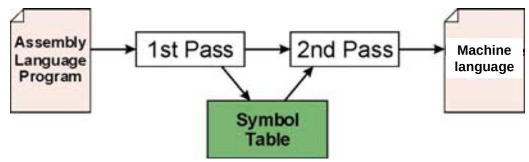
- Humans like readable form
  - E.g. A + B

- Assembler was the first step towards how people think and ,moving farther away from how the machine implements the solution



## Assembler

- Assemblers translate mnemonic instructions to machine code
- ISA specific
- One assembly instruction translates to one machine instruction
- Most assemblers carry out this translation in two passes over the source code



## Assembly Process Example: First Pass

```
                .ORIG   x3000
x3000           AND     R2,R2,#0
x3001           LD      R3,PTR
x3002           TRAP    x23
x3003           LDR     R1,R3,#0
x3004           ADD     R4,R1,#-4
x3005 TEST      BRz     OUTPUT
x3006           NOT     R1,R1
X3007           ADD     R1,R1,#1
x3008           ADD     R1,R1,R0
x3009           BRnp    GETCHAR
x300A           ADD     R2,R2,#1
x300B GETCHAR   ADD     R3,R3,#1
x300C           LDR     R1,R3,#0
x300D           BRnzp   TEST
x300E OUTPUT    LD      R0,ASCII
x300F           ADD     R0,R0,R2
x3010           TRAP    x21
x3011           TRAP    x25
x3012 ASCII     .FILL   x0030
x3013 PTR       .FILL   x4000
                .END
```

| Symbol | Address |
|---|---|
| TEST | x3005 |
| GETCHAR | x300B |
| OUTPUT | x300E |
| ASCII | x3012 |
| PTR | x3013 |



## Assembly Process Example: Second Pass

```
                .ORIG   x3000
x3000           AND     R2,R2,#0
x3001           LD      R3,PTR
x3002           TRAP    x23
x3003           LDR     R1,R3,#0
x3004           ADD     R4,R1,#-4
x3005 TEST      BRz     OUTPUT
x3006           NOT     R1,R1
x3007           ADD     R1,R1,#1
x3008           ADD     R1,R1,R0
x3009           BRnp    GETCHAR
x300A           ADD     R2,R2,#1
x300B GETCHAR   ADD     R3,R3,#1
x300C           LDR     R1,R3,#0
x300D           BRnzp   TEST
x300E OUTPUT    LD      R0,ASCII
x300F           ADD     R0,R0,R2
x3010           TRAP    x21
x3011           TRAP    x25
x3012 ASCII     .FILL   x0030
x3013 PTR       .FILL   x4000
                .END
```

```
0101 010 010 1 00000
0010 011 000010001
1111 0000 00100011
.
.
```

| Symbol | Address |
|---|---|
| TEST | x3005 |
| GETCHAR | x300B |
| OUTPUT | x300E |
| ASCII | x3012 |
| PTR | x3013 |



## Assembler

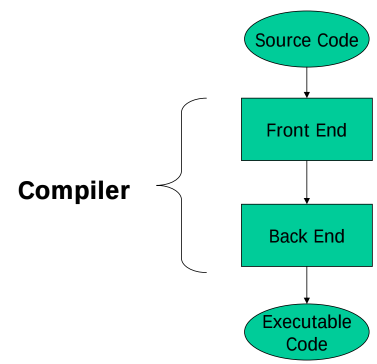
- However, assembler's job description must also include:
  - ➢ checking the illegal opcode
  - ➢ offset values
  - ➢ Register values

- Before assembler can create symbol table and output machine code it needs to
  - Extracting Keywords e.g. opcode, labels
  - Using extracted keywords to build instruction w/ its attributes
    - ➢ e.g. based on opcode, the instruction either has 0,1, 2 or 3 registers
  - Check whether attributes are within correct e.g. Register values are between 0 and 7 for LC3 ISA



## Compiler

- High-level Language to Machine Code – more complicated process



## Compiler – Front End

1. ***Lexical analysis***

• Input character stream is split into meaningful symbols a.k.a *tokens* defined by the high-level language

- E.g. of tokens include operators, literals, condition statements
- For instance, an *integer* token may contain any sequence of numerical digit characters
- "12*(3+4)" is split it into the tokens 12, *, (, 3, +, 4 and ). Each of which is a meaningful symbol in the context of an arithmetic expression

• Builds the symbol table for user-defined variables and methods and with their location (local, static, dynamic) and data types

• Checks lexical errors e.g. 1myvar is illegal variable



## Compiler: Front End

2. ***Syntax analysis*** (a.k.a Parsing)

• Checks that the tokens form an allowable expression i.e. checks whether expression or statement complies with language rules (or grammar)

- Creates parse or syntax tree of expressions which replaces the linear sequence of tokens with a tree structure
- Also checks illegal statement construction e.g. A = B + C = D
- User-defined variables that part of syntax tree are verified using looking up symbol table



## Compiler: Front End

3. ***Semantic Analyzer***

• Checks data types of variables using information from symbol table in order to apply operator on them

• If language rule supports, can make data type promotions such as changing from “int” to “float”

• Associates variable and function references with their definitions a.k.a object binding



## Compiler: Backend

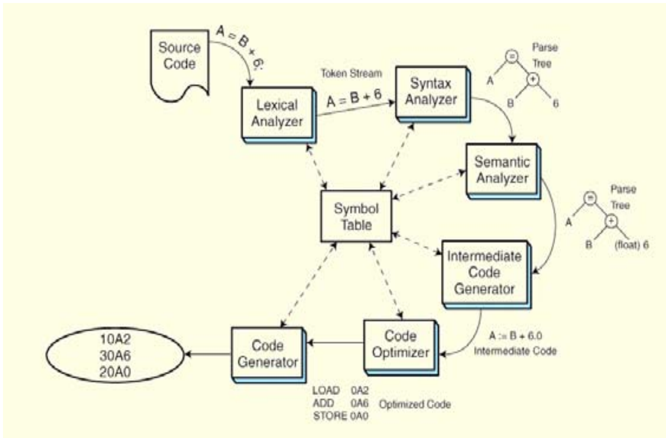
4. ***Intermediate code generation***
   - Creates *pseudo-assembly from the syntax tree*
   - Code produced is machine independent

5. ***Optimization***
   - Creates assembly code while taking into account architectural features that can make the code efficient
   - E.g. Register Allocation, accounts for hazards if pipeline architecture

6. ***Code generation***
   - Creates binary code from the optimized assembly code

**Note:** Through this modularity, compilers can be written for various platforms by rewriting only the last two phases

## Compilers






## Linker or Link Editor

- The machine code (a.k.a object code) produced by the compiler/assembler is outputted to a file
  - e.g. *.o* by C compiler and *.obj* by LC3 assembler
  - Each file or modules gets it own object code
    i.e. mylc3as.c ->mylc3as.o and parser.c ->parser.o
- These files still have some unresolved references
  - Inclusion of library routine
  - Programmer writes his/her own modules/files
- Linker's task is to match *external symbols* of a program with all symbols from other files and produce a *single binary file* with no unresolved external symbols

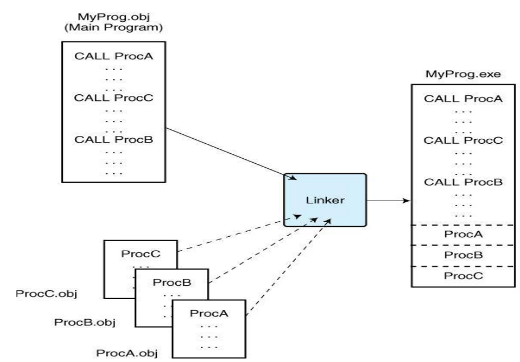


## Object File Formats

- operating systems embed a "magic number" in executable files to assure that only allowable file formats get executed
  - Solaris uses the Executable and Linking Format (ELF) file format identifiable by the "magic number" at its beginning:
    - hex 7f followed by ASCII chars E L F: **7F 45 4C 46**
- Format allows other programs Linkers and Loader (discussed shortly) to extract information
- File format contains header section that defines start of each section (code and data) and how long that section is noted in bytes
- Also contains symbol tables for variables and functions



## Linker (contd..)




- Object modules have machine code + information for the linker
- Single binary file is called as *executable*

## Absolute Code

- *Absolute* code requires that executable be loaded at particular location in memory
- All user programs in LC3 required program to loaded from address x3000
  - The loader program is notified by encoding this address in the .obj file
  - hex t1.obj: 0000 **30 00** 12 43
  - if you forget, explanation also provided in hw5 document!!
- Usually required for specific purpose e.g. involve control of attached devices e.g. driver software for disk



## Relocatable Object Code

- In real systems the executable can be loaded anywhere in user-space section in memory to allow multiprogramming
- The generated executable code then contains relative addressing for offsets with address starting at location 0
  - The code then produced is known as ***relocatable code***
- A *Loader* program now chooses which location in memory executable will be loaded
  - Depending on activity in the system i.e. which chunks of memory are free and how much memory does the executable require

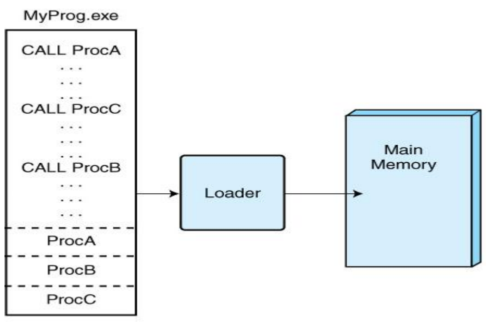


## Loader

- *Loading* is the process of copying an executable image into memory i.e. at the actual physical location
- How does the Loader distinguish between relocatable and absolute code?
  - Depends from system to system
  - Example 1: Pretending binary executable code with prefix or preamble – uncommon in real systems
  - Example 2: MS-DOS operating system uses different file formats
    - .COM extension for absolute (nonrelocatable) code
    - .EXE extension for relocatable code



## Loader (contd..)



## Loader (cont..)

- Regardless of relocatable or absolute code
  - Program's instruction and data are bound to physical address
  - This known as address *binding* a process
- Binding can be done at:
  - *Compile-Time*: executable already indicates where exactly it should be loaded i.e. absolute code
  - Load-Time
    - Adds starting address to each reference in the binary module
    - The loaded executable a.k.a *process image* cannot be moved during execution as starting address must remain same (code now is absolute)
    - The loader tells OS the value of PC (program counter) to start executing program (OS puts this info in PCB)



## Loader (contd..)

- Run-time or execution time Binding
  - Delays binding till the time process is actually running
  - User program generates logical address or virtual address
  - Need to map this address to physical address
  - Possible due to Virtual Memory



## Dynamic Linking

***Dynamic Linking*** defers much of the linking process till either load or runtime

- At load time program and it's unlinked modules are loaded by the loader
  - Causes start up delays
- The unlinked module can be linked upon invocation of that module while the program that requires it is running
  - Dynamically linked functions are populated with "stubs"
  - A stub is code to call the dynamic linker a.k.a *linking loader* at runtime



## Advantage of Dynamic Linking

- Many programs can *share* the same object module (library code), hence only one copy of the module needs to be present in memory
  - Shared object modules are called *Dynamic Linked Libraries* (DLL)
  - With prior linking (static linking) there will be n copies of same routine as n programs might require it
- Dynamically linked shared libraries are easier to *update* than static linked shared libraries
  - Change is visible to all programs that use it
  - Static libraries would have to be relinked
- Can you think of a disadvantage ?

## Example: GCC program

- At *compile time*, *gcc* directs the *building* of executable files in 4 phases

1. compiler invokes the C preprocessor (*cpp*)
   - #includes and #defines cause string substitutions
2. compiler translates C to assembler (*gcc*)
   - input = preprocessed C, output = assembler (.s file)
3. compiler invokes the assembler (*gas*)
   - input = .s file, output = object file (.o file)
     - *partial* machine instructions are present in the .o file
     - addresses are *offsets* in the TEXT or DATA segments at this point



## GCC compile time (contd..)

4. compiler invokes the static linker (*ld*)
   - input = .o file, output = executable file (no extension)
   - **static** library functions are combined into the executable at this time
   - *gcc* tells *ld* which versions of which libraries to link
   - all intermediate files (.o) are deleted unless otherwise specified



## GCC programs at Run-time

1. loader (*ldd*)
   - input is an executable file
   - output is a process image on disk
   - result is a PCB (process control block) placed in the "ready to run" queue of the operating system's scheduler
   - *ldd* is also called the "dynamic linker" or the "linking loader"
2. scheduler (part of OS)
   - all populated parts of the process image exist (either in main memory or on disk)
   - PCB is either 1) running, 2) in "ready to run" queue, 3) in "blocked" queue
3. dynamic linker (accessed via "stub" functions)
   - maps dynamic library functions into process image as needed