PURDUE
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CS 50011: Introduction to Systems II

Lecture 8: Compiling and Linking

Prof. Jeff Turkstra

Lecture 08

- Compiling a program
- Compiler structure
- Static vs. dynamic linking

- Some slides by Prof. Gustavo Rodriguez-Rivera

Program

- File in a particular format containing necessary information to load an application into memory and execute it
  - Often time part of this is split off into the "loader" and libraries
- Programs include:
  - Machine instructions
  - Initialized data
  - List of library dependencies
  - List of memory sections
  - List of values determined at load time

Executable file formats

- Number of formats
  - ELF – Executable Link File
    - Used on most *NIX systems
  - COFF – Common Object File Format
    - Windoze
  - a.out – Used in BSD (Berkeley Standard Distribution) and early UNIX
    - Not usually used anymore
- BSD UNIX and AT&T UNIX are predecessors to modern *NIXes

ELF

- File header
  - Magic number
  - Version
  - Target ABI
  - ISA
  - Entry point
  - Pointers to
    - Program header
    - Section header
  - etc

Program header

- How to create the process image
  - Segments
  - Types
  - Flags
  - File offset
  - Virtual address
  - Size in file
  - Size in memory

Section header

- Type (data, string, notes, etc
- Flags (writable, executable, etc
- Virtual address
- Offset in file image
- Size
- Alignment

- readelf –headers /bin/ls
- objdump -p, -h, -t

Building a program

- Start with source code
  - hello.c
- Prepocessor
- Compiler
- Assembler
- Linker

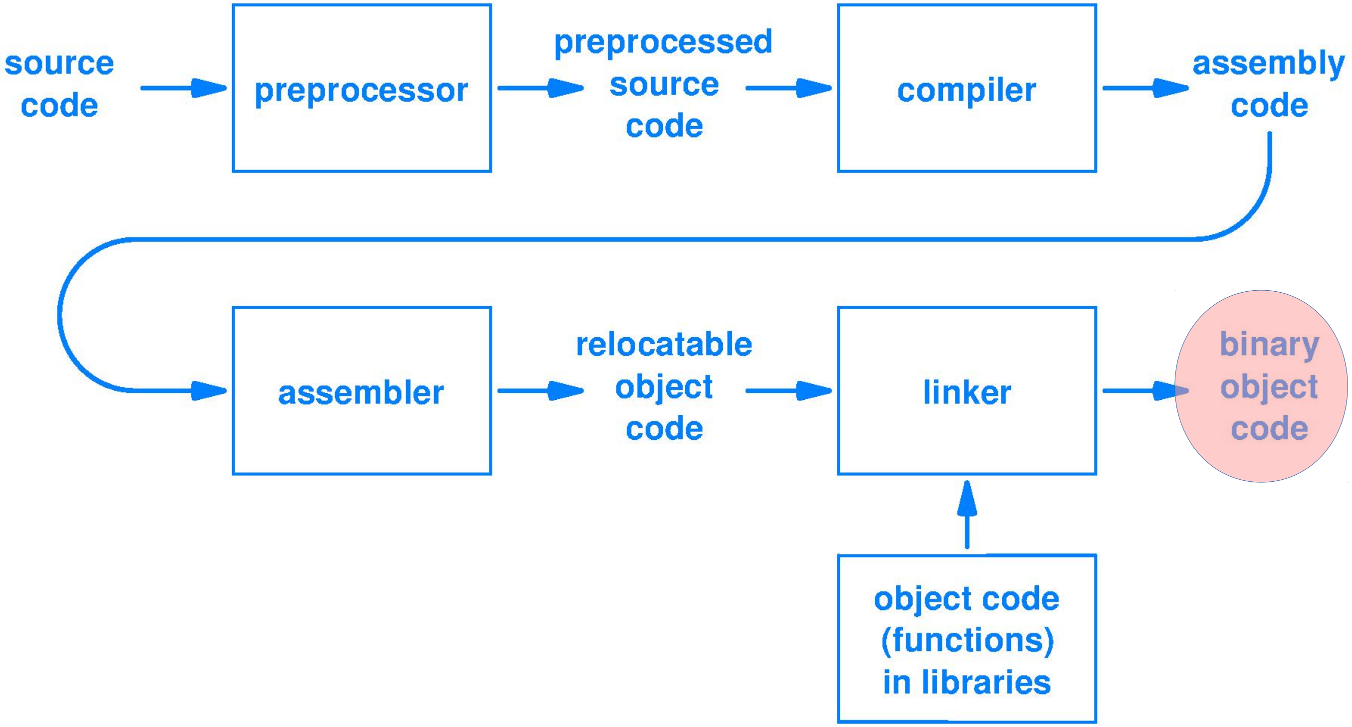


Figure 4.6 The steps used to translate a source program to the binary object code representation used by a processor.

Preprocessor

- When a .c file is compiled, it is first scanned and modified by a preprocessor before being handed to the real compiler
- Finds lines beginning with #, hides them from the compiler, or takes some action
- #include, #define
- #ifdef, #else, #endif

- Can do math
    - #if (FLAG % 4 == 0) || (FLAG == 13)
- Macros
    - #define INC(x) x+1
    - No semi-colon
    - Have to be careful
        - #define ABS(x) x < 0 ? -x : x
        - ABS(B+C)

- Parentheses around substitution variables

```
#define ABS(x)  ( (x) < 0 ? -(x) : (x) )
```

Why macros?

- Run time efficiency
  - No function call overhead
- Passed arguments can be any type
  - #define MAX(x,y) ((x) > (y) ? (x) : (y))
  - Works with ints, floats, doubles, even chars

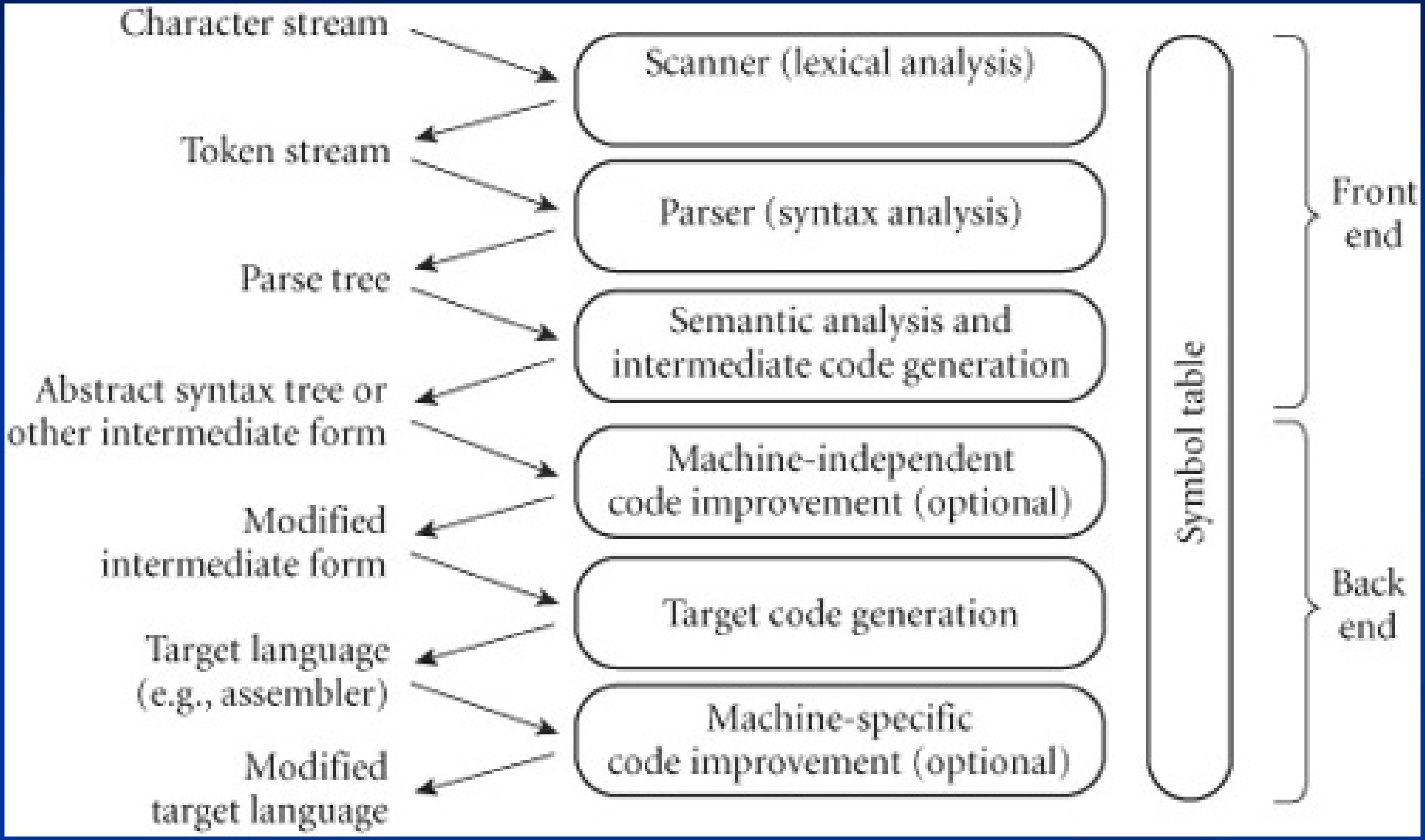
Lots of other tricks

```
printf(“The date is %s\n”, __DATE__);
```

- Most preprocessor features are used for large/advanced software development practices

- gcc -E

Compiler?


Character stream
Scanner (lexical analysis)
Token stream
Parser (syntax analysis)
Parse tree
Semantic analysis and intermediate code generation
Abstract syntax tree or other intermediate form
Machine-independent code improvement (optional)
Modified intermediate form
Target code generation
Target language (e.g., assembler)
Machine-specific code improvement (optional)
Modified target language
Symbol table
Front end
Back end

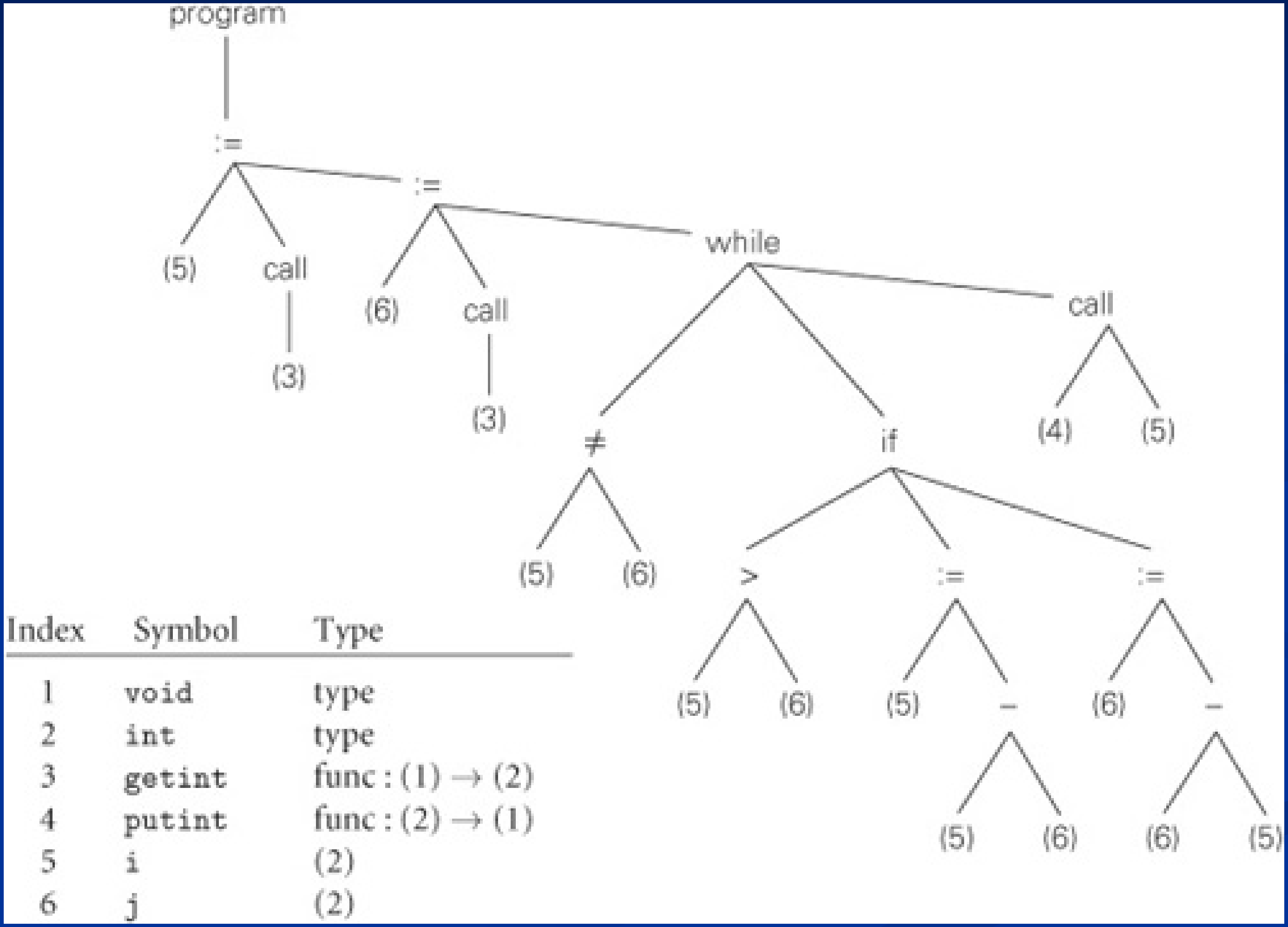
* http://www.cs.montana.edu/~david.watson5/

```
int main() {
    int i = getint(), j = getint();
    while (i != j) {
        if (i > j) i = i - j;
        else j = j - i;
    }
    putint(i);
}
```

Compiler?

- Scanning or lexical analysis
  - Groups program into tokens
    - Token = smallest meaningful unit of a program
- Parsing or syntax analysis
  - Create a parse tree
  - Shows how tokens “fit together”
  - Context-free grammar

- Semantic analysis
  - Determines/discovers meaning
  - Builds symbol table
  - Builds syntax tree



Index	Symbol	Type
1	`void`	type
2	`int`	type
3	`getint`	func : (1) → (2)
4	`putint`	func : (2) → (1)
5	`i`	(2)
6	`j`	(2)

- Code generation
  - Traverse symbol table and syntax tree
  - Generate loads, stores, arithmetic ops, tests, branches, etc

- gcc -c
  nm -v

Assembler

- Discussed in architecture lecture
- gcc -S

Libraries

- Libraries are just collections of object files
  - Internal symbols are indexed for fast lookup by the linker
- Searched for symbols that aren’t defined in the program
  - Symbol found, pull it into executable (static)
  - Otherwise include a pointer to the file, loaded by loader

Statically linked

- Faster, to a degree
- Portable
- Larger binaries
- Fixed version, no updates

Dynamically linked

- More complexity
- Easy to upgrade libraries
  - Vulnerabilities
- Have to manage versions
- Loader re-links every time program is executed

```
readelf --dynamic /bin/ls
ldd /bin/ls
```

Interpreter

```
readelf --headers /bin/ls
```

Lazy binding

- Binding a function call to a library can be expensive
  - Have to go through code and replace the symbol with its address
- Delay until the call actually takes place
  - Calls stub PLT function
  - Invokes dynamic linker to load the function into memory and obtain real address
    - Rewrites address that the sub code references
    - Only happens once
- Procedure Lookup Table (PLT)

- gcc -o nm

Makefile

- Simple way to help organize code compilation

  ```
  gcc -o hello hello.c somefunc.c -I.
  ```

```
hello: hello.c hellofunc.c
    gcc -o hello hello.c hellofunc.c -I.
```

Or...

```
CC=gcc
CFLAGS=-I.

hello: hello.o hellofunc.o
    $(CC) -o hello hello.o hellofunc.o -I.
```

```
CC=gcc
CFLAGS=-I.
DEPS = hello.h

%.o: %.c $(DEPS)
$(CC) -c -o $@ $< $(CFLAGS)

hello: hello.o hellofunc.o
    gcc -o hello hellomake.o hellofunc.o -I.
```

```
CC=gcc
CFLAGS=-I.
DEPS = hellomake.h
OBJ = hellomake.o hellofunc.o


%.o: %.c $(DEPS)
	$(CC) -c -o $@ $< $(CFLAGS)


hellomake: $(OBJ)
	gcc -o $@ $^ $(CFLAGS)
```

```
IDIR =../include
CC=gcc
CFLAGS=-I$(IDIR)

ODIR=obj
LDIR =../lib

LIBS=-lm

_DEPS = hellomake.h
DEPS = $(patsubst %,$(IDIR)/%,$(_DEPS))

_OBJ = hellomake.o hellofunc.o
OBJ = $(patsubst %,$(ODIR)/%,$(_OBJ))


$(ODIR)/%.o: %.c $(DEPS)
$(CC) -c -o $@ $< $(CFLAGS)

hellomake: $(OBJ)
gcc -o $@ $^ $(CFLAGS) $(LIBS)
```

```
.PHONY: clean

clean:
    rm -f $(ODIR)/*.o *~ core $(INCDIR)/*~
```

Questions?