Tools Seminar

Week 3 - C/C++ Toolchain

Hongzheng Chen

Nov 29, 2019

1. Computer System Overview

2. C/C++ Programming Language
   - C/C++ Introduction
   - Compiling and Running C/C++
   - Auto Building
   - Debugging
   - Testing
   - Profiling

3. Summary

1

Computer System Overview

Some Introductory Books & Courses You Need to Know

UC Berkeley CS Major Lower Division Degree Requirements (61 Series)

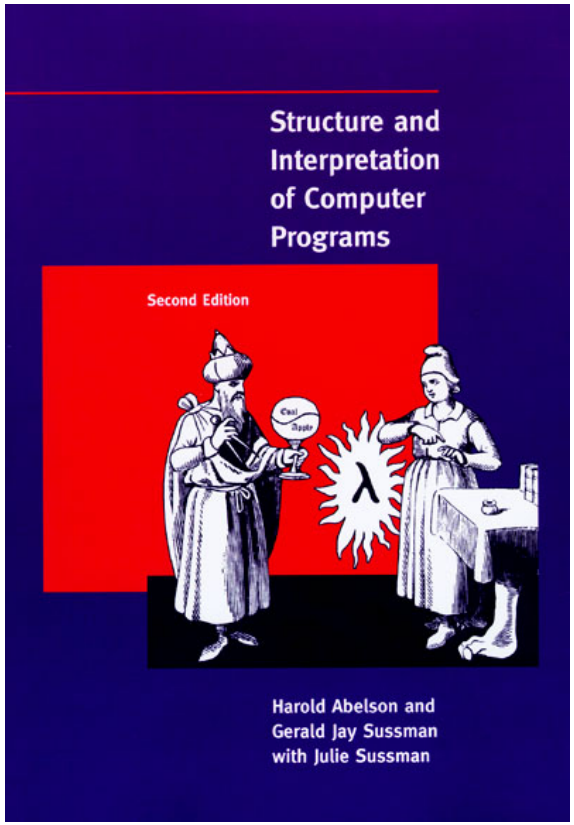
- 61A: Structure and Interpretation of Computer Programs
- 61B: Data Structures
- 61C: Great Ideas in Computer Architecture (Machine Structures)

MIT EECS General Institute Requirements

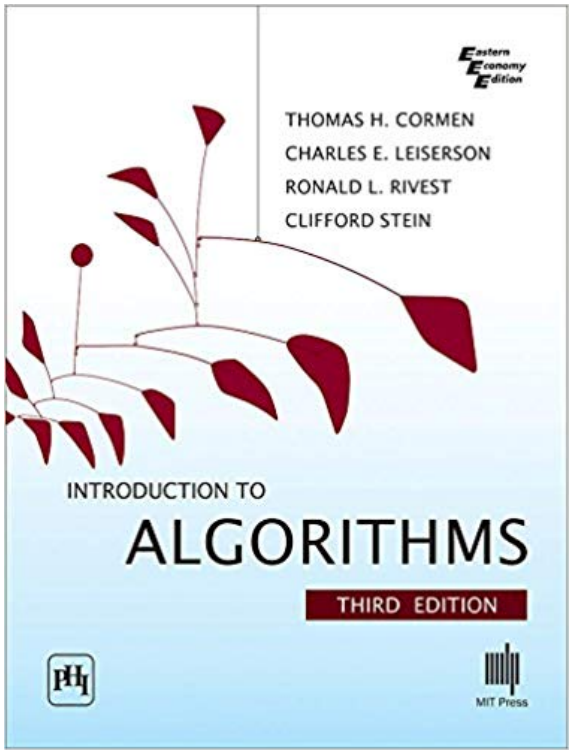
- 6.001: Structure and Interpretation of Computer Programs
  $\rightarrow$ 6.0001 Python
- 6.006: Introduction to Algorithms
- 6.004: Computation Structures

Some Introductory Books & Courses You Need to Know

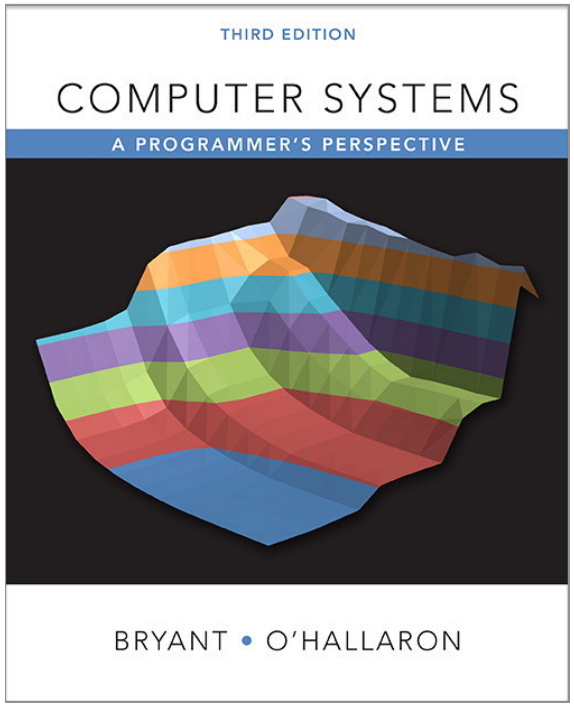
SICP



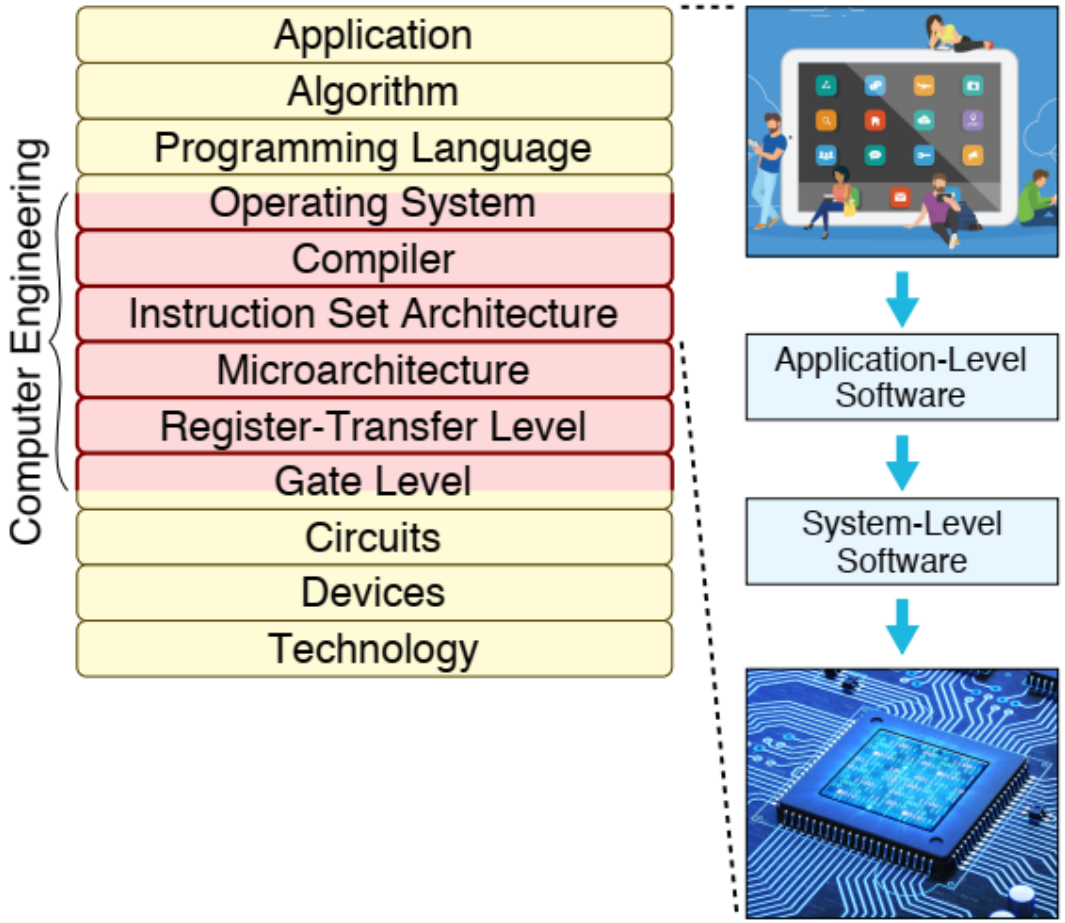
CLRS



⋆CS:APP



Computer Systems Programming is Diverse



- Python, MATLAB
- Ruby, Javascript
- SQL, LINQ
- NumPy
- GUI frameworks

- Interpreters
- Compilers
- Databases
- Numerical libraries
- Operating systems
- Embedded control

Source: Christopher Batten, *Cornell ECE 2400: Computer Systems Programming*, Fall 2019

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C/C++ Programming Language

2.1

C/C++ Introduction

TIOBE Ranking

Nov 2019 Ranking

Nov 2019	Nov 2018	Change	Programming Language	Ratings	Change
1	1		Java	16.246%	-0.50%
2	2		C	16.037%	+1.64%
3	4	▲	Python	9.842%	+2.16%
4	3	▼	C++	5.605%	-2.68%
5	6	▲	C#	4.316%	+0.36%
6	5	▼	Visual Basic .NET	4.229%	-2.26%
7	7		JavaScript	1.929%	-0.73%
8	8		PHP	1.720%	-0.66%
9	9		SQL	1.690%	-0.15%
10	12	▲	Swift	1.653%	+0.20%

Source: https://www.tiobe.com/tiobe-index/

C Programming Language

Actually in 9102, most of the CS top schools in US use Python as their introductory language.

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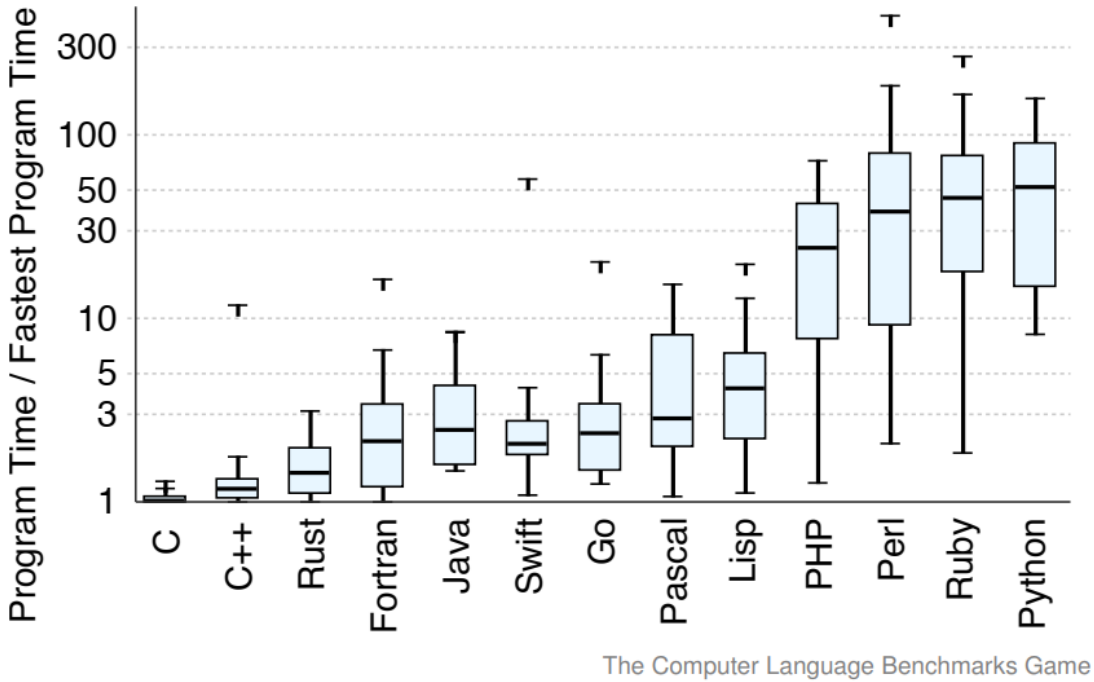
So why we still use C?

C Programming Language

- Speed: Very close to hardware, extremely fast
  $\rightarrow$ *High performance computing (HPC)
  - Parallel computing: OpenMP, MPI
  - Specific accelerator: cuda, Verilog

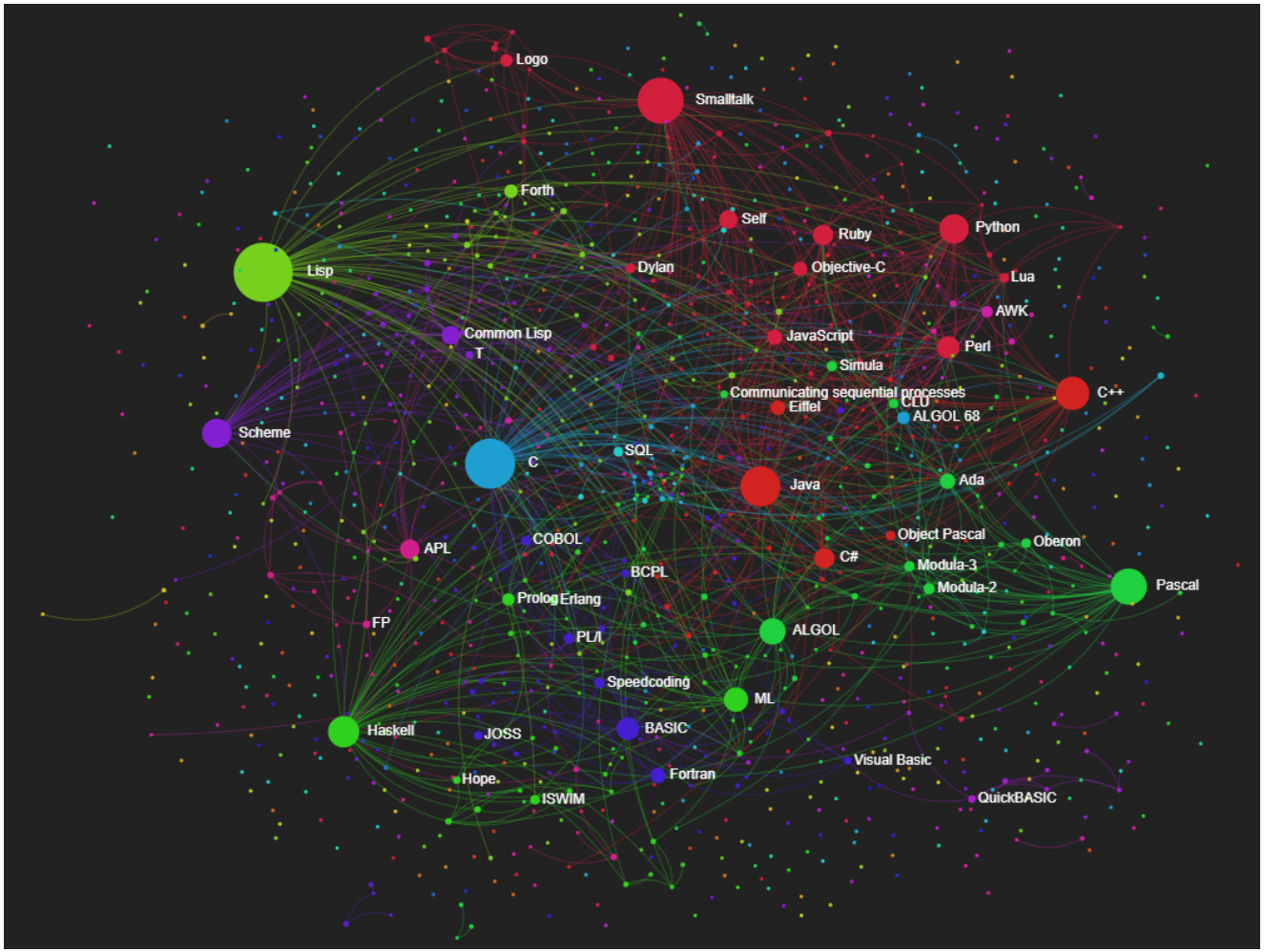


C Programming Language

- Portability:
  - OS
  - Networking
  - Embedded systems
- Stability: Static type & rigorous spec
  - Compiler / Interpreter

C Programming Language

C influences lots of PLs which all has C-like grammar (Java, C#)



Source: Programming Languages Influence Network

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- Superset of C, but not only C

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  - Enable to distribute works in a large project
- Modern language features
  - Templates and Generic Programming: Polymorphism
  - C++11 standard
- Also lightweight, fast, and high-performance

2.2

Compiling and Running C/C++

Some Compilers for C/C++

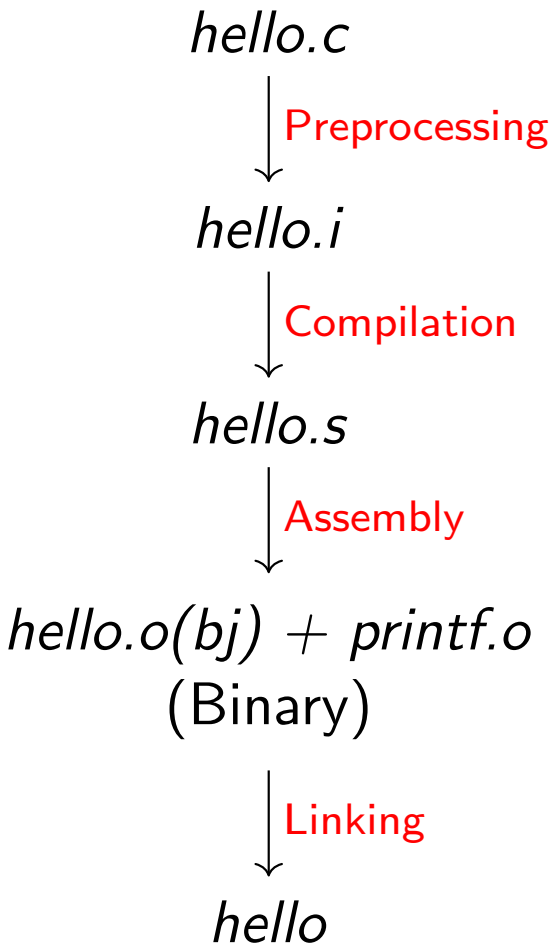
- gcc/g++: GNU Compiler Collection
  - MinGW (Minimalist GNU for Windows)
- clang/clang++
  - Low Level Virtual Machine (LLVM) [UIUC, CGO'04]
  - $\rightarrow$ commonly used for building your own compiler for DSL
- Visual Studio C++
  - Mainly for Windows applications development
- icc/icpc: Intel C/C++ Compiler
  - Extremely high-performance when compiling to Intel CPU architecture
  - Need a student account

Four stages of Compilation

```c
// hello.c
#include <stdio.h>

int main(void) {
    printf("Hello world!\n");
    return 0;
}
```

```asm
; hello.s
.LC0:
    .string "Hello world!"
main:
    ; protect state
    push    rbp
    mov     rbp, rsp
    ; call function
    mov     edi, OFFSET FLAT:.LC0
    call    puts
    ; restore state & return
    mov     eax, 0
    pop     rbp
    ret
```



Preprocessing

Try this:

```
// student.c
#include "name.txt"
#include "number.txt"
```

Use C preprocessor (cpp) to generate output

```
$ cpp student.c -o student.out
$ cat student.out
```

Preprocessing

You can include several times

```
#include "name.txt"
#include "name.txt"
#include "name.txt"
#include "number.txt"
#include "number.txt"
#include "number.txt"
```

But it's very dangerous due to dependency $\rightarrow$ function redefinition

Preprocessing

Make sure the file is only included once:

```
#ifndef NAME_TXT
#define NAME_TXT
Alice
Bob
Carlo
#endif // NAME_TXT
```

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```
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#define NAME_TXT
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```

* Preprocessor macros are very ugly! C++20 proposes Modules (`import`)

Compilation & Assembly

```
$ gcc avg.c -c -o avg.o
$ objdump -dC avg.o
```

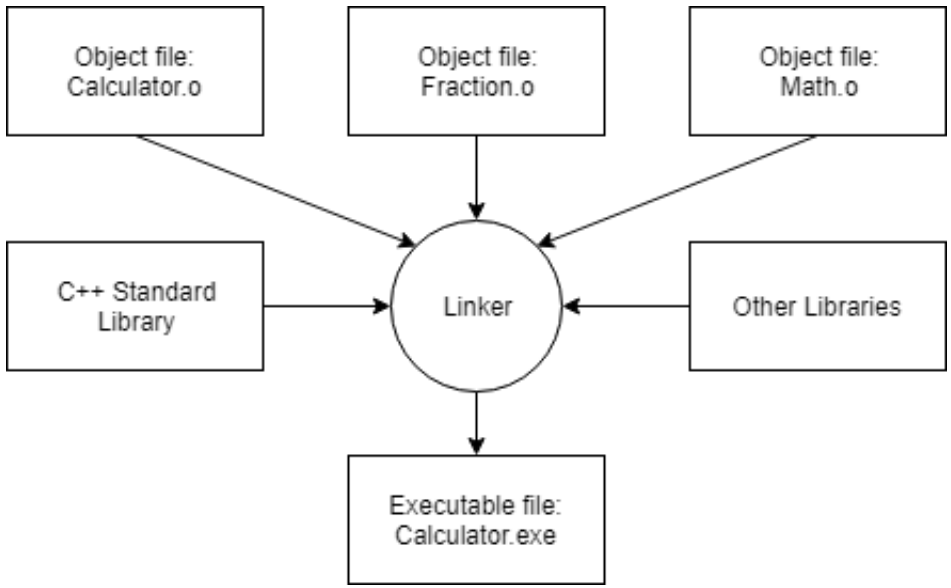
- Online editor and compiler: Repl.it
- Online assembly code generation: GodBolt

Ref: ECE 2400

Linking

```
$ gcc avg.o -o avg
```

- Static library: `.a` (Linux), `.lib` (Windows)
- Dynamic library: `.so` (Linux), `.dll` (Windows)



Source: LearnCpp

Compilation Flags

When you configure C environment in VS Code, you need to add them

- `-o`: output to file
- `-O`: `-O0`, `-O1`, `-O2`, `-O3` (See gcc optimization options)
- `-Wall`: with all warnings
- `-Werror`: all warnings to errors
- `-D[FLAG]` or `-D[FLAG]=VALUE`: pass preprocessor flag `#if FLAG ...`
- `-std=c++11`: standard
- `-I`: [/path/to/header-files] (`.h`, `.hpp`)
- `-L`: [/path/to/shared-libraries]
- `-l`: Links to shared library or shared object (`.so`, `.dll`)

Ref: https://caiorss.github.io/C-Cpp-Notes/compiler-flags-options.html

2.3

Auto Building

Existing Problems

- Programs with hard dependency, say projects with 100k LoC
- Intractable to enter a bunch of commands
- Some unmodified files will be regenerated

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- Programs with hard dependency, say projects with 100k LoC
- Intractable to enter a bunch of commands
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We need **auto compilation** tools!

Makefile

Put previous commands together

```
avg: avg.o
        gcc avg.o -o avg

avg.o: avg.c
        gcc avg.c -c -o avg.o
```

Just type `make`!

Makefile - Grammar

```
target : prerequisite0 prerequisite1 prerequisite2
<TAB>command
```

- First finish `prerequisite`
  - If pre does not change, skip it
  - If pre changes, re-generate it
- When all the pre are finished, do `command`
  - Can be ANY Linux command!

Makefile - Variables

```
CC = gcc

avg: avg.o
	$(CC) avg.o -o avg

avg.o: avg.c
	$(CC) avg.c $(FLAGS) -c -o avg.o
```

Makefile - Auto Variables

- $@: Target file
- $^: all prerequisite
- $<: The first prerequisite
- %: wildcard

```
CC = gcc
FLAGS = -O3

% : %.c
	$(CC) $(FLAGS) $< -o $@
```

Compared with

```
avg: avg.c
	$(CC) avg.c $(FLAGS) -o avg.o
```

Makefile - .PHONY

```
.PHONY : clean
clean :
        -rm edit $(objects)
```

- .PHONY: not associated with physical files; target is always out-of-date
- Put it at the back of Makefile

* For complete usage of Makefile,

please refer to https://chhzh123.github.io/2019-02-24-makefile/

CMake

```
cmake_minimum_required(VERSION 2.8)
enable_language(C)
add_executable( avg avg.c )
```

Need to install CMake first (`apt-get install`)

```
$ cmake .
$ make target
```

2.4

Debugging

Debugging

The GNU Debugger (GDB)[1]

- `gcc -g`: Add debug flag
- `gdb program`: Debug `program` (from the shell)
- `run -v`: Run the loaded program with the parameters
- `bt`: Backtrace (in case the program crashed)
- `info registers`: Dump all registers
- `break 10`: Breakpoint at line 10

[1] source: Wiki

Debugging

Demo by *Yucheng Chen*

- DFS
- BFS

2.5

Testing

CTest

```c
#include <stdio.h>
#include "avg.h"
#include "utst.h"

int main()
{
  UTST_ASSERT_INT_EQ( avg( 10, 20 ), 15 );
  return 0;
}
```

CTest

```
cmake_minimum_required(VERSION 2.8)
enable_language(C)
enable_testing()

add_executable( avg avg.c )
add_executable( avg-test avg-test.c )
add_test( avg-test avg-test )
```

Type

```
$ make avg-test
$ make test
```

Change the number and regenerate it

Other Tools

- Google Unit Test: Google Test
- Code Coverage: gcov
- Continuous Integration: Travis-CI, Codecov.io

2.6

Profiling

Profiling

Timing:

- <time.h>

```
void timing()
{
    time_t start,stop;
    start = time(NULL);
    foo(); // do something
    stop = time(NULL);
    printf("Time:%ld\n",(stop-start));
}
```

- time <command>
  - **Real**: Wall clock time - time from start to finish of the call
  - User: Amount of CPU time spent in user-mode code (outside the kernel)
  - Sys: Amount of CPU time spent in the kernel

Profiling

- perf (Linux): CPU, cache, memory etc.
- pcm (Intel): CPU, cache, memory etc.
- valgrind [PLDI'07]: memory management

3

Summary

Week 2 - C/C++ Toolchain

- Compiling: gcc, clang
- Auto building: Makefile, CMake
- Debugging: gdb
- Testing: CTest
- Profiling: time, perf, valgrind