Computer System Organization Recitation [Spring 2019]

CSCI-UA 0201-002

R2: Compiling and Debugging

Some slides based on Chien-Chin Huang's Spring 2018 CSO recitation

Recitation README.md

- Under each recitation folder, there is a README.md, which contains contents, exercise instructions and deadline for each recitation
  - r01/README.md
  - r02/README.md
  - …
- Always check the readme for each recitation
- Use GitHub to read README.md (and cheat sheet)
  - .md file is written in Markdown syntax
  - GitHub.com will render it properly

How to sign CSO_CHEAT_SHEET

- Open the file for modification
  - Open up a terminal and go to r01 folder
  - subl CSO_CHEAT_SHEET.md
  - Do **NOT** make any changes on GitHub
- submit your changes
  - git add CSO_CHEAT_SHEET.md
  - git commit -m “sign cheat sheet”
  - git push origin master

Work flow for our recitation and labs

Instructor's repository: iso-recitations

r01

r02

Your remote repository: recitations-XXX

r01

pull

clone

git remote add

push

Your local repository

r01

r02

GitHub

local machine (ubuntu16.04)

Track your instructor's repository

- For recitation repository:
  - cd cso-recitations
  - git remote add upstream https://github.com/nyu-cso-sp19/cso-recitations
- For lab repository:
  - cd cso-labs
  - git remote add upstream https://github.com/nyu-cso-sp19/cso-labs
- You only need to do this once

For each lab and recitation

- pull latest lab and recitation materials
  - git pull upstream master
- then make changes locally on you computer
- tell git to track changes
  - git add “file name”
- commit changes
  - git commit -m “commit messages”
- submit to your remote repository
  - git push origin master

Double check with “git status”

- git status tells you
  - what files are changed
  - what files are going to commit
  - what files are not tracked
  - whether your local repository and the remote repository is up-to-date

Double check with “git status”

- If you changed the cheat sheet and readme file, and you only “git add” the cheat sheet

```
➜  r01 git:(master) ✗ git status
On branch master
Your branch is ahead of 'origin/master' by 1 commit.
  (use "git push" to publish your local commits)

Changes to be committed:
  (use "git reset HEAD <file>..." to unstage)

        modified:   CSO_CHEAT_SHEET.md

Changes not staged for commit:
  (use "git add <file>..." to update what will be committed)
  (use "git checkout -- <file>..." to discard changes in working directory)

        modified:   README.md

Untracked files:
  (use "git add <file>..." to include in what will be committed)

        r01-backup.key
```

Triple check with GitHub

- Still not confident about whether assignment was submitted properly?

- Go to github.com, and navigate to your repo

- Manually check if every file contains your latest changes

Git is much more powerful than that

- Our git introduction only covers a small part of Git
- Git tutorial:
  - https://www.atlassian.com/git/tutorials/what-is-version-control
  - https://try.github.io/levels/1/challenges/1
- Please only test your skills elsewhere
  - Don’t try advanced skills in your lab or recitation repo

Common mistakes about Git

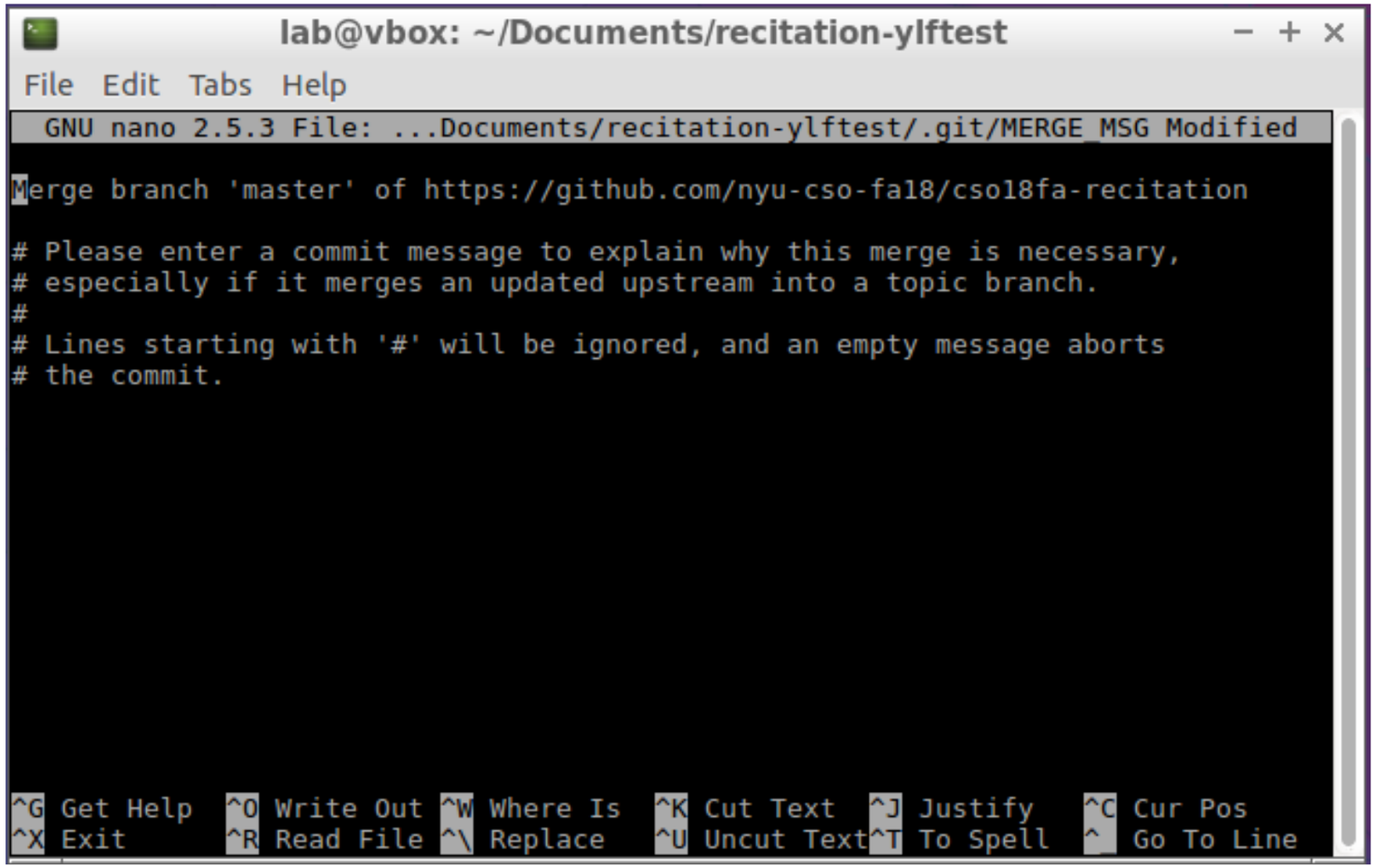
- Recitation and lab are two separate/independent repositories
  - Don’t clone lab repository inside recitation repository, vice versa.
  - Don’t try to merge them into one…
- You need to set up upstream correctly
  - check out instructions on CSO_CHEAT_SHEET.md
- Need help?
  - Come to office hour

For recitation 01

- Change every XXX with your Github Username (not your name)
- Recitation 01 due Feb 6th 11 pm
- Double check with git status and triple check with Github

Retrieve r02 from upstream

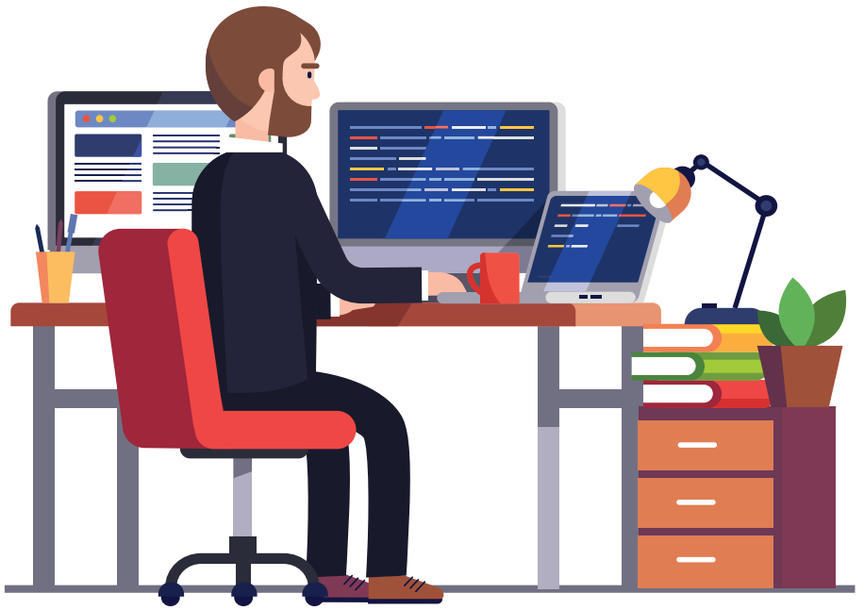
- git pull upstream master
- Get a merge message? Hit ctrl + x



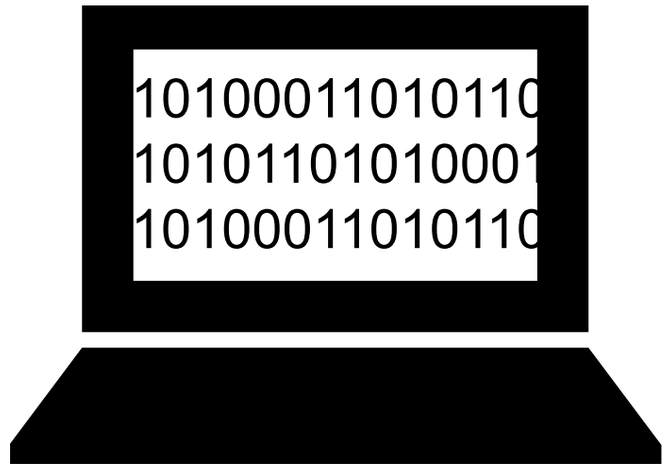
Today's topic

- Compilation with GCC
- Manage project compilation with make
- Debug code with GDB

Compile



Compile



You program in high level language

Machine only understands binary instructions

Images from https://www.freepik.com/

Terminology

- Compiler
  - A software that transforms computer code written in one programming language (the source language) into another language (the target language)
- Interpreter
  - A software that directly executes instructions written in a programming/scripting language without compiling them into a machine language program in advance

Terminology

- source file
  - the input of compiler, where you write the program in high level language like C

- target file
  - the output of compiler

- executable (file)
  - file that can be executed by machine directly

C, Python, and Java

- C language uses compiler to translate source file directly into machine code which is executable by your machine

- Python uses a interpreter to translate source code and execute line by line at runtime

- Java first compiles its source code to a more efficient immediate representation (called byte code) and uses a interpreter to run byte code

Compiling v.s. interpreting

- Compiling
  - No translation needed at runtime (fast)
  - More optimization opportunities (efficient)
  - Compiler is usually able to detect many problems during compilation
- Interpreting
  - Flexible and more interactive: you can decide which code to execute at runtime
  - Requires a runtime software, which can also be used to:
    - hide platform details (code is more portable)
    - keep runtime information and perform runtime checks (like boundary check, garbage collection)
  - The price you pay is speed

In CSO…

- We are going to use a language called C
  - It will be compiled directly into machine code
- We will use GCC as our C compiler

GCC: basic usage

- You wrote your first hello_world.c
- Compile it in terminal:
  - gcc hello_world.c
  - an executable file “a.out” will be generated
- Run your program
  - ./a.out
- Compile your source code into a different name
  - gcc hello_world.c -o hello_world

```
#include <stdio.h>
int main() {
   printf(“Hello World!”);
   return 0;
}
```

hello_world.c

Compile multiple source files into one executable

- Code are placed in multiple files
- To compile multiple files into one executable

```
gcc foo.c main.c -o main
```

```c
int foo() {
  int i = 0;
  i += 1;
  return i;
}
```

foo.c

```c
int main() {
  foo();
  return 0;
}
```

main.c

Compilation

```
int foo() {
   int i = 0;
   i += 1;
   return i;
}
```

foo.c

compile

```
foo:
...
movl 0, %eax
movl 1, %ebx
addl %ebx, %eax
...
```

foo.o

Temporary files, automatically removed after compiling

Keep the *.o for fast recompiling

Linker

main

```
int main() {
   foo();
}
```

main.c

compile

```
main:
...
move foo, %eax
call %eax
...
```

main.o

Compilation

```
int foo() {
   int i = 0;
   i += 1;
   return i;
}
```

foo.c

compile

```
foo:
...
movl 0, %eax
movl 1, %ebx
addl %ebx, %eax
...
```

foo.o

Linker

main

```
int main() {
   foo();
   Return 0;
}
```

main.c

recompile

```
main:
...
move foo, %eax
call %eax
...
```

main.o

To save intermediate files

- Compile without linking (-c option)

  gcc -c foo.c

  gcc -c main.c

- Run linker in a separate step

  gcc -o main foo.o main.o

Compile large projects

- If we have a very large project, containing 1 MILLION files
  - How can we manually run gcc to compile files one by one?
  - How can we know which file is changed and needs recompilation?
  - How can we give different compiling options when compile different files?
  - How can we compile files in parallel using multiple CPU cores and figure out dependency correctly?

You want one button to launch the rocket?

- Image from https://www.canstockphoto.com/businessman-pushing-the-start-button-51114320.html

Manage compiling with Make

- What is Make?
  - A build automation tool that automatically builds executable programs and libraries from source code.
- How?
  - Describe compilation rules in Makefile to specify dependencies, and Make will do everything for you.
- The button to launch rocket
  - just type `make`

How to write Makefile

- Makefile consists of a bunch of rules

  target: dependencies

  commands

- The rule means if any file in dependencies changed, generate target using commands

  For example:

  main: main.c foo.c

  gcc -o main main.c foo.c

Simplest but terrible way to write Makefile

Makefile

```
main:
  gcc -o main main.c foo.c
```

File format

- No white space before “all”
- one tab before commands

- Type `make` and the command will be executed
- It’s terrible because
  - you still handle compiling manually
  - Recompile everything if you type make again

A good Makefile

Makefile

```
main: foo.o main.o
  gcc -o main main.o foo.o

foo.o: foo.c
  gcc -c foo.c

main.o: main.c
  gcc -c main.c

clean:
  rm -f main main.o foo.o
```

- Make knows file dependency and can automatically figure out which files needs recompilation
  - By checking file timestamp
- Problem:
  - What if I have 1M source files?

Pattern matching and automatic variables

- Use pattern matching to define dependency
  - %.o: %.c
  - % is matches the stem of file name
  - any target ends with .o depends on the file start with the same filename stem and ends with .c

- Use automatic variables to refer to target and dependency in commands
  - $@ (target name)
  - $^ (name of all prerequisites, i.e. dependencies)
  - $< (name of the first prerequisite)

Here is a better one

Makefile

```
main: foo.o main.o
  gcc -o $@ $^

%.o: %.c
  gcc -o $@ -c $<

clean:
  rm -f main main.o foo.o
```

- Succinct enough
- Can automatically compile source file into object file
- Not general enough
  - If we have more files to compile, we have to change the first and last rules manually

Let's make it even better

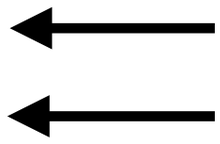
Makefile

```
SRC:=$(wildcard *.c)
OBJ:=$(SRC:.c=.o)

main: $(OBJ)
  gcc -o $@ $^

%.o: %.c
  gcc -o $@ -c $<

clean:
  rm -f main $(OBJ)
```



Find all files ending with .c

Replace .c with .o

The target “clean”

- If you type “make clean”, executable and immediate files will be deleted
- If you change the Makefile:
  - make clean
  - make
- Otherwise, make things everything is up-to-date because Makefile itself is not included in the dependency list

Run the executable

- Now that you can compile your code, run it by type

  ./main

- And you will see the program hangs there…

- Hit Ctrl+C to interrupt and kill the program

- Actually, most of the time, you will find yourself mostly writing bugs when you first start to program in C

Debug

- How to debug your code?
  - The best way to debug is to write assertions, print logs (program states), observe and then debug
  - Use a debugger to help you
    - gdb
- What does a debugger do?
  - It executes program step by step in an interactive fashion
  - It allows you to examine program state whenever you want
- To use gdb
  - First ask gcc to add debug information when compiling the source files.

Add debugging flag to Makefile

Makefile

```
SRC:=$(wildcard *.c)
OBJ:=$(SRC:.c=.o)

main: $(OBJ)
  gcc -o $@ $^

%.o: %.c
  gcc -o $@ -c $<  -g

clean:
  rm -f main $(OBJ)
```

How to use gdb

- a list of commands you will frequently use
  - b (set break point)
  - r (run the program)
  - n (execute one statement, treat one function call as a step)
  - s (execute one statement, will go into function)
  - p (examine and print value of an expression)
  - l (print lines from the relevant source file)
  - c (continue execution)
  - q (quit debugging)

To learn more about GDB

- Learning C with gdb
  - https://www.recurse.com/blog/5-learning-c-with-gdb
- A Youtube video on gdb
  - https://www.youtube.com/watch?v=xQ0ONbt-qPs

What to submit

- Modified Makefile
  - use pattern matching and automatic variable
  - with debugging enabled
- Fixed foo.c
- Due Feb 6th 11 pm
- Don’t forget to submit recitation 01 as well

A few more words…

- We have talked about VM, bash, git, gcc, make, gdb
- If you feel you still understand nothing…
  - Don’t panic too early
- You don’t need to be a master these tools to pass CSO
  - They help you do coursework more smoothly
  - You will be using them for your entire life, so learn them early!
- learn them from online resources (especially those we provide to you)

If you want to get a good grade for CSO

- I hope Professor has convinced you that CSO is pretty hard if you don't work hard

- Expect to devote at least 15 hours to CSO after class every week
  - Or you might easily get a D…

- If you think you are lagging behind, speak to the Professor for advice.

- Come to office hour

- Never wait until last second to ask for help or to submit your assignments