COMP(2041|9044) 26T2 — Make

https://www.cse.unsw.edu.au/~cs2041/26T2/

Building Software Systems

- Even small software systems need to to use tools to control builds.
- Many, many tools available
- Tools popular with developers often changing, and specific to platform/language.
- We'll look at a classic tool **make** which is still widely used e.g. Linux kernel
- If you want current alternatives: cmake + ninja
- But you should know **make**

make

`make` allows you to

- document intra-module dependencies
- automatically track of changes for incremental compilation

`make` works from a file called `Makefile` (or `makefile`)

A `Makefile` contains a sequence of rules like:

```
target : source1 source2 ...
        commands to create target from sources
```

Beware: each command is preceded by a single **tab character**.

Take care using cut-and-paste with `Makefiles`

Dependencies

The `make` command is based on the notion of *dependencies*.

Each rule in a `Makefile` describes:

- dependencies between each target and its sources
- commands to build the target from its sources

`Make` decides that a target needs to be rebuilt if

- it is older than any of its sources (based on file modification times)

Building Multi-module C Program with incremental compilation

main.c

```
#include <stdio.h>
#include "world.h"
#include "graphics.h"

int main(void)
{
   ...
   drawPlayer(p);
   fade(...);
}
```

world.h

```
typedef ... Ob;
typedef ... Pl;

extern addObject(Ob);
extern remObject(Ob);
extern movePlayer(Pl);
```

world.c

```
#include <stdlib.h>

addObject(...)
{ ... }

remObject(...)
{ ... }

movePlayer(...)
{ ... }
```

graphics.h

```
extern drawObject(Ob);
extern drawPlayer(Pl);
extern spin(...);
```

graphics.c

```
#include <stdio.h>
#include "world.h"

drawObject(Ob o);
{ ... }

drawPlayer(Pl p)
{ ... }

fade(...)
{ ... }
```


Building Large C Program

For systems like Linux kernel with 50,000+ files building is either

- inefficient (recompile everything after any change)
- error-prone (recompile just what's changed + dependents)
  - module relationships easy to overlook
    (e.g. `graphics.c` depends on a `typedef` in `world.h`)
  - you may not know when a module changes
    (e.g. you work on `graphics.c`, others work on `world.c`)

Example Makefile #1

A **`Makefile`** for the earlier example program:

```
game : main.o graphics.o world.o
	gcc -Wall -o game main.o graphics.o world.o

main.o : main.c graphics.h world.h
	gcc -c main.c

graphics.o : graphics.c world.h
	gcc -c -g -Wall graphics.c

world.o : world.c
	gcc -c -g -Wall world.c
```


Using Make

```
$ make
gcc -c main.c
gcc -c graphics.c
gcc -c world.c
gcc -o game main.o graphics.o world.o
$ make
make: 'game' is up to date.
$ vi graphics.h # change graphics.h
$ make
gcc -c main.c
gcc -o game main.o graphics.o world.o
$ vi world.h # change world.h
$ make
make: 'game' is up to date.
$ make
gcc -c main.c
gcc -c graphics.c
gcc -c world.c
gcc -o game main.o graphics.o world.o
```


How make Works

The make command behaves as:

```
def make(target, dependencies, commands):
    # Stage 1
    for each D in dependencies:
        rebuild D if it needs rebuilding
    # Stage 2
    if target does not exist or any dependency is newer than target:
       # rebuild target
       run commands
```

Parsing a Makefile in Python

```
def parse_makefile(makefile_name):
    """return dict mapping makefile targets to (dependencies, build commands)
     ↪  tuple"""
    rules = collections.OrderedDict()
    with open(makefile_name, encoding="utf-8") as f:
        while line := f.readline():
            if not (m := re.match(r"^(\S+)\s*:\s*(.*)", line)):
                continue
            target = m.group(1)
            dependencies = m.group(2).split()
            build_commands = []
            while (line := f.readline()).startswith("\t"):
                build_commands.append(line.strip())
            rules[target] = (dependencies, build_commands)
    return rules
```

source code for make.v1.py

Building everything whether needed or not - Implementation in Python

```
def build(target, rules, dryrun=False):
    """recursively check dependencies and, if needed, run commands  to build
     ↪  target"""
    (dependencies, build_commands) = rules.get(target, ([], []))
    for d in dependencies:
        build(d, rules, dryrun)
    if not build_commands and not os.path.exists(target):
        sys.exit(f"*** No rule to make target {target}")
    for command in build_commands:
        print(command)
        if not dryrun:
            subprocess.run(command, shell=True)
```

source code for make.v0.py

How make builds what is needed - Implementation in Python

```
def build(target, rules, dryrun=False):
    """recursively check dependencies and, if needed, run commands  to build
     ↪  target"""
    (dependencies, build_commands) = rules.get(target, ([], []))
    build_needed = not os.path.exists(target)
    for d in dependencies:
        build(d, rules, dryrun)
        build_needed = build_needed or os.path.getmtime(d) >
 ↪  os.path.getmtime(target)
    if not build_needed:
        return
    if not build_commands and not os.path.exists(target):
        sys.exit(f"*** No rule to make target {target}")
    for command in build_commands:
        print(command)
        if not dryrun:
            subprocess.run(command, shell=True)
```

source code for make.v1.py

Make command-line Arguments

If **make** arguments are targets, build just those targets:

```
$ make world.o
$ make clean
```

If no args, build first target in the **Makefile**.

The **-n** option instructs **make**

- to print what it would do to create targets
- but don't execute any of the commands

A different makefile name can be optionally specified with **-f**

- to print what it would do to create targets
- but don't execute any of the commands

Command-line Arguments - Implementation in Python

```
def main():
    """determine targets to build and build them"""
    parser = argparse.ArgumentParser()
    parser.add_argument("-f", "--makefile", default="Makefile")
    parser.add_argument("-n", "--dryrun", action="store_true")
    parser.add_argument("build_targets", nargs="*")
    args = parser.parse_args()
    rules = parse_makefile(args.makefile)
    # if not target is specified use first target in Makefile (if any)
    build_targets = args.build_targets or list(rules.keys())[:1]
    for target in build_targets:
        build(target, rules, args.dryrun)
```

source code for make.v1.py

Makefile - variables & comments

```
# string-valued variables/macros
CC = gcc
CFLAGS = -g
LDFLAGS = -lm
BINS = main.o graphics.o world.o

# implicit commands, determined by suffix
main.o     : main.c graphics.h world.h
graphics.o : graphics.c world.h
world.o    : world.c

# pseduo-targets
clean :
        rm -f game main.o graphics.o world.o
            # or ... rm -f game $(BINS)
```

Parsing Variables and comments in Python

```
variables = {}
with open(makefile_name, encoding="utf-8") as f:
    while line := f.readline():
        # remove any comment
        line = re.sub(r"#.*", "", line)
        # check for variable definition
        if m := re.match(r"^\s*(\S+)\s*=\s*(.*)", line):
            variables[m.group(1)] = m.group(2)
            continue
        line = replace_variables(line, variables)
```

source code for make.v2.py

```
def replace_variables(line, variables):
    """return line with occurances of $(variable) replaced by variable's
     ↪  value"""
    return re.sub(r"\$\((.*?)\)", lambda m: variables.get(m.group(1), ""),
     ↪  line)
```

source code for make.v2.py

Building the Latest Python from Sources with make

```
$ curl -sO https://www.python.org/ftp/python/3.15.0/Python-3.15.0a8.tar.xz
$ tar xf Python-3.15.0a8.tar.xz
$ cd Python-3.15.0a8
$ find . -type f|wc -l
4929
$ find . -type f|sed 's/.*\.//'|sort|uniq -c|sort
...
$ ./configure
...
creating Makefile
$ make
gcc ...
...
$ ./python
Python 3.15.0a8 (main, Apr 14 2026, 10:42:12) [GCC 14.2.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>>
```


make in parallel

The **-jN** option instructs **make** to build dependencies in parallel using up to N parallel processes

For example an approximately 7x real-time speedup building Python:

```
$ make clean
$ time make -j16
...
real    0m13.556s
user    1m55.979s
sys 0m7.663s
$ make clean
$ time make
real    1m19.566s
user    1m15.477s
sys 0m4.032s
```

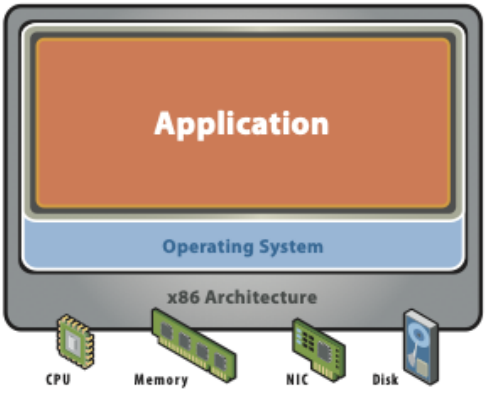
Virtualisation

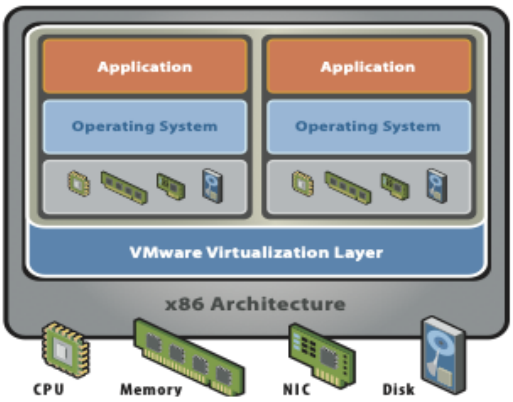
- allows multiple virtual computers, called virtual machines (VMs), to run on a single physical computer.
- each virtual machine behaves as if it has its own:
  - CPU
  - memory
  - storage
  - network interface
  - operating system

even though all of these resources are actually shared with other virtual machines.

Virtualisation

- separation of resource from the underlying hardware
- an abstraction layer on top of the hardware





- Single OS per machine
- Software and hardware tightly coupled
- Underutilized resources
- Inflexible and costly infrastructure

- Hardware independent of OS and applications
- Virtual machines to any system
- OS and application as a single unit into virtual machines

What is a hypervisor

- A hypervisor is software (or firmware) that creates and manages virtual machines.
- Its responsibilities include:
  - allocating CPU time
  - allocating memory
  - virtualising devices
  - isolating virtual machines *scheduling execution
- It makes one physical computer appear as many virtual computers.
- Examples include Hyper-V, VMware ESXi, Xen, and VirtualBox (hosted hypervisor)

What use virtualisation

Virtualization is one of the key technologies behind cloud computing.

- Better hardware utilisation
  - multiple VMs share the same hardware
  - hundreds of VMs on one physical server in clouds
- Isolation
  - each VM is isolated. If one VM crashes, the others continue run nomrally
  - malware inside one VM usually cannot affect the others
- Flexibility
  - different operating systems can run simultaneously

Containter

- A container is a lightweight, isolated environment that packages an application together with everything it needs to run.
- Why are containers lightweight?
  - Unlike a virtual machine, a container does not contain its own operating system.
  - All containers runing on the same machine share the the same operating system kernel
  - A container often starts in less than a second, but a virtual machine may take tens of seconds or even minutes to boot.

Docker

- Docker is a platform that creates and manages containers
- Create a Debian Linux container

```
$ docker run --privileged  --name linux -it debian:latest bash
```

- `--privileged`: gives the container almost all the privileges of the host
- `--name`: assigns the container a name
- `-it`: gives an interactive shell.
- `debian:latest`: the Docker image to use
- `bash`: starts the Bash shell
- After running this command, it automatically log into the container and the prompt changed to something similar to

```
root@d359e0042f2a:/#
```

Other useful Docker commands

```
# list current running containers
docker ps

# show all containers incuding those not running
docker ps -a

#pause/unpause the container
docker pause <container_name_or_id>
docker unpause <container_name_or_id>

#start/stop a container
docker start/stop <container_name_or_id>

#log into a running container
docker exec -it <container_name_or_id> bash
```