Building Software Systems

- Even small software systems need 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
- **make** automatically tracks changes

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

A **Makefile** contains a sequence of rules like:

```plaintext
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

```c
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);
```

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

```
world.c
#include <stdlib.h>

addObject(...) {
  ...
}
remObject(...) {
  ...
}
movePlayer(...) {
  ...
}
```

```
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)
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
```

### Parsing a Makefile in Python

```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
How make Works

The make command behaves as:

```python
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
```

Building everything whether needed or not - Implementation in Python

```python
def build(target, rules, dryrun=False):
    """recursively check dependencies and run commands to build target""
    (dependencies, build_commands) = rules.get(target, ([], []))
    if not build_commands and not os.path.exists(target):
        print("*** No rule to make target", target)
        sys.exit(1)
    for command in build_commands:
        print(command)
        if not dryrun:
            subprocess.run(command, shell=True)
```

How make builds what is needed - Implementation in Python

```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):
        print("*** No rule to make target", target)
        sys.exit(1)
    for command in build_commands:
        print(command)
        if not dryrun:
            subprocess.run(command, shell=True)
```
Make command-line Arguments

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

```bash
$ 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

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Command-line Arguments - Implementation in Python

```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

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

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

Compiling Python from Sources with make

$ tar xf Python-3.12.4.tar.xz
$ cd Python-3.12.4
$ find . -type f | wc -l
  4498
$ find . -type f | sed 's/.*\./\//' | sort | uniq -c | sort ...
$ ./configure ...
creating Makefile
$ make
$ gcc ...
$ ./python
Python 3.12.2 (main, Apr  9 2024, 09:28:45) [GCC 13.2.0] 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  0m19.566s
user  1m15.477s
sys  0m4.032s
Useful other Makefiles functionalities

# multiple targets with same sources
stats1 stats2 : data1 data2 data3
  perl analyse1.pl data1 data2 data3 > stats1
  perl analyse2.pl data1 data2 data3 > stats2

# creating subsystems via make
parser:
  cd parser && $(MAKE)
  # assumes parser directory has own Makefile