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Introduction to make

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Why make at all?

- All large software projects are designed as modules.
- Compiling and linking all the modules gives the final product (an application or a library).
- There may be hundreds of modules each consisting of multiple files.
- A complete compilation of several millions of lines of code is time-consuming.
- Not all modules are dependent on one another.
- If one module changes, only that module and other affected modules need to be recompiled.
- This process is called software building.
- The GNU make utility automates this building process.

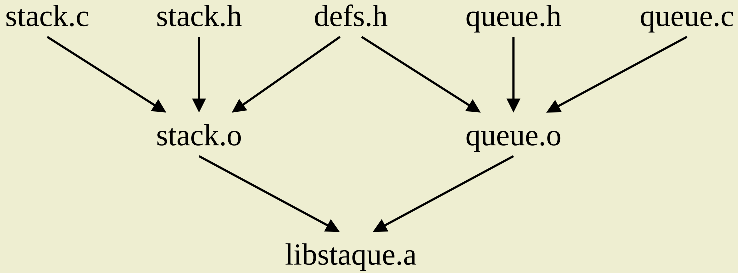
A simple example: Building the static library libstaque.a

- The following set of commands is used.

```
gcc -c -Wall stack.c
gcc -c -Wall queue.c
ar rcs libstaque.a stack.o queue.o
```

- These commands can be written in a shell script and executed to get the final product.
- For this small example, this is fine.
- If the source consists of thousands of files, compiling all of these is a slow process.
- Not all modules need recompilation for every change.
- If one makes (small/large) changes only in queue.c and/or queue.h, there is no need to recompile stack.c.
- Make helps you in the selective (re)compilation process.
- But you must instruct how to do it.

Example: The dependencies



- libstaque.a depends only on the object files stack.o and queue.o.
- stack.o can be generated by compiling stack.c with the –c option.
- This compilation additionally requires the header files defs.h and stack.h.
- queue.o can be generated by compiling queue.c with the –c option.
- This compilation additionally requires the header files defs.h and queue.h.

Makefile

- The dependency and compilation instructions are written in a file. The following names are searched in that order.
  - GNUmakefile
  - makefile
  - Makefile
- For using other makefiles, run make with the –f option.

  ```
  make -f mymakefile
  ```

- You run the utility as:

  ```
  make
  ```

  or

  ```
  make TargetName
  ```

Rules in makefiles

- A rule is of the form:

```
TargetName: List of dependencies
        Command 1
        Command 2
        Command 3
        ...
```

- Each line of command must start with a tab.
- A line (may be empty) **not** starting with a tab ends the rule.
- The target may be the name of a file or a symbolic name (phony).
- The dependency list may be empty (but make knows some default dependencies).
- Absence of commands in rules is allowed. Such rules mean:
    - Set the dependencies.
    - Use a predefined make rule to build the target.

How make works

- make checks timestamps to determine which parts of the project need to be recompiled.
- The commands are executed if one or more dependency file(s) is/are modified **after** the target was last built.
- Phony targets are always built.

Rule examples

```
library: stack.o queue.o
        ar rcs libstaque.a stack.o queue.o

stack.o: defs.h stack.h
queue.o: defs.h queue.h
```

- library is a phony target that depends on stack.o and queue.o. The build involves invoking the `ar` command.
- stack.o (a filename target) depends on the header files defs.h and stack.h.
- queue.o (another filename target) depends on the header files defs.h and queue.h.
- What make already knows is this:
  - stack.o also depends on stack.c, and queue.o also depends on queue.c. There is no need to specify these dependencies.
  - stack.o can be obtained from stack.c and queue.o from queue.c by invoking gcc –c. It is not needed to write the commands explicitly.
- What make does not know is what additional compilation flags you need with gcc –c.

Rule examples (continued)

- Suppose that you call:

  ```
  make library
  ```

- Since library is a phony target, it is always rebuilt.
- Before invoking **`ar`**, make checks whether any/both of the dependencies stack.o and queue.o need(s) to be rebuilt.
- If the timestamp of stack.o is more recent than all of the files defs.h, stack.h and stack.c, then stack.o is not rebuilt. If one or more of these dependencies is/are modified after the timestamp of stack.o, it is rebuilt using gcc –c.
- If the timestamp of queue.o is more recent than all of the files defs.h, queue.h and queue.c, then queue.o is not rebuilt. If one or more of these dependencies is/are modified after the timestamp of queue.o, it is rebuilt using gcc –c.

Which target to build?

- If you run make without any target name, the target of the **first rule** is built. For example, if library is the first rule in our example, it is built if make is called without an explicit target name.
- You can specify the target additionally like:

  ```
  make stack.o
  ```

  or

  ```
  make queue.o
  ```

Make variables

- Variables can be set using the assignment operator = (recursive) or := (evaluate only once).
- a variable VAR can be accessed as $(VAR) or ${VAR}.
- Default variables
  - SHELL specifies which shell to use for running the commands.
  - CC specifies the C compiler you want to use.
  - CFLAGS stands for the additional compilation flags that you use during gcc –c.

```
SHELL = /bin/sh
CC = gcc
CFLAGS = -O2 -g -I.
AR = ar
LIBNAME = libstaque.a
OBJFILES = stack.o queue.o

library: $(OBJFILES)
        $(AR) rcs $(LIBNAME) $(OBJFILES)

$(OBJFILES): defs.h
stack.o: stack.h
queue.o: queue.h
```

Run make

```
$ make
gcc -O2 -g -I.   -c -o stack.o stack.c
gcc -O2 -g -I.   -c -o queue.o queue.c
ar rcs libstaque.a stack.o queue.o
$ make
ar rcs libstaque.a stack.o queue.o
$ touch defs.h
$ make
gcc -O2 -g -I.   -c -o stack.o stack.c
gcc -O2 -g -I.   -c -o queue.o queue.c
ar rcs libstaque.a stack.o queue.o
$ touch queue.c
$ make
gcc -O2 -g -I.   -c -o queue.o queue.c
ar rcs libstaque.a stack.o queue.o
$
```

Rules to install

- Often the final products (like libstaque.a and the header files) need to be installed in the system area.
- Run make in the superuser mode as:

  `sudo make install`

```
LIBDIR = /usr/local/lib
INCLUDEDIR = /usr/include
INCLUDESUBDIR = $(INCLUDEDIR)/staque

install: library
        cp $(LIBNAME) $(LIBDIR)
        -mkdir $(INCLUDESUBDIR)
        cp defs.h stack.h queue.h $(INCLUDESUBDIR)
        cp staque.h $(INCLUDEDIR)
```

- A dash before a command directs make to ignore errors. Here, if the directory /usr/include/staque already exists, mkdir fails. But make moves forward ignoring the error.

Run make install

```
$ sudo make install
[sudo] password for abhij:
ar rcs libstaque.a stack.o queue.o
cp libstaque.a /usr/local/lib
mkdir /usr/include/staque
mkdir: cannot create directory ‘/usr/include/staque’: File exists
make: [Makefile:30: install] Error 1 (ignored)
cp defs.h stack.h queue.h /usr/include/staque
cp staque.h /usr/include
$
```

Cleaning previous builds

```
RM = rm -f

clean:
        -$(RM) $(OBJFILES)

distclean:
        -$(RM) $(OBJFILES) $(LIBNAME)
```

Difference between = and :=

- = is the *recursive* assignment operator.
- := is the *evaluate once* assignment operator.
- If the recursive evaluation of a variable VAR eventually (in one or more steps) depends upon \$(VAR), then further expansion of \$(VAR) will again involve \$(VAR), and the process continues ad infinitum.

```
VAR1 = $(VAR2)
VAR2 = Hi $(VAR1)
```

- Here, `$(VAR1)` expands to `$(VAR2)` which in turn expands to `Hi $(VAR1)`.
- Replacing one (or both) = to := stops the infinite recursive substitution.

An example for the difference between = and :=

makefile

```
SHELL = /bin/bash

AA := Atpug
AA = $(AA) Adnibora

ST = Sad
ST := $(ST) Tijihba

aa:
        @echo Hi $(AA)

st:
        @echo Hi $(ST)
```

Running make

```
$ make aa
makefile:4: *** Recursive variable ’AA’ references itself (eventually).
Stop.
$ make st
Hi Sad Tijihba
```

Writing makefile in pieces

Syntax

```
include file1 file2 file3 ...
```

Example

```
STARTMKF = defs.mk primitives.mk
include preamble.mk $(STARTMKF) util*.mk
```

- Suppose that there are four matches `util1.mk`, `util2.mk`, `util3.mk`, `utilfinal.mk`.
- The following seven files are included:
    - `preamble.mk`
    - `defs.mk`
    - `primitives.mk`
    - `util1.mk`
    - `util2.mk`
    - `util3.mk`
    - `utilfinal.mk`

Recursive make

- Useful when several subdirectories possess independent makefiles.
- cd to each subdirectory, and call make.
- Each line of command opens a new shell, so both cd and make must be in the same line.

```
SHELL = /bin/sh

all:
        cd static; make
        cd shared; make

install:
        cd static; make install
        cd shared; make install

clean:
        cd static; make clean
        cd shared; make clean
```

Run recursive make

```
$ make
cd static; make
make[1]: Entering directory ’/home/abhij/IITKGP/course/lab/SPL/Spring22/prog/libstaque/static’
gcc -O2 -g -I.   -c -o stack.o stack.c
gcc -O2 -g -I.   -c -o queue.o queue.c
ar rcs libstaque.a stack.o queue.o
make[1]: Leaving directory ’/home/abhij/IITKGP/course/lab/SPL/Spring22/prog/libstaque/static’
cd shared; make
make[1]: Entering directory ’/home/abhij/IITKGP/course/lab/SPL/Spring22/prog/libstaque/shared’
gcc -O2 -g -fPIC -I.   -c -o stack.o stack.c
gcc -O2 -g -fPIC -I.   -c -o queue.o queue.c
gcc -shared -o libstaque.so stack.o queue.o
make[1]: Leaving directory ’/home/abhij/IITKGP/course/lab/SPL/Spring22/prog/libstaque/shared’
$ make clean
cd static; make clean
make[1]: Entering directory ’/home/abhij/IITKGP/course/lab/SPL/Spring22/prog/libstaque/static’
rm -f stack.o queue.o
make[1]: Leaving directory ’/home/abhij/IITKGP/course/lab/SPL/Spring22/prog/libstaque/static’
cd shared; make clean
make[1]: Entering directory ’/home/abhij/IITKGP/course/lab/SPL/Spring22/prog/libstaque/shared’
rm -f stack.o queue.o
make[1]: Leaving directory ’/home/abhij/IITKGP/course/lab/SPL/Spring22/prog/libstaque/shared’
$
```