This lecture:

- Multi-file Fortran codes
- Makefiles

Reading:

Software Carpentry lectures on Make

Dependency checking

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Also used for checking dependencies in other build systems,

e.g. creating figures, running latex, bibtex, etc. to construct a manuscript.

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More modern build systems are available, e.g. SCons, which allows expressing dependencies and build commands in Python.

But make (or gmake) are still widely used.

Fortran code with 3 units

```fortran
! $UWHPSC/codes/fortran/multifile1/fullcode.f90

program demo
    print *, "In main program"
    call sub1()
    call sub2()
end program demo

subroutine sub1()
    print *, "In sub1"
end subroutine sub1

subroutine sub2()
    print *, "In sub2"
end subroutine sub2
```

Split code into 3 separate files...

```fortran
! $UWHPSC/codes/fortran/multifile1/main.f90

program demo
    print *, "In main program"
    call sub1()
    call sub2()
end program demo
```

```fortran
! $UWHPSC/codes/fortran/multifile1/sub1.f90

subroutine sub1()
    print *, "In sub1"
end subroutine sub1
```

```fortran
! $UWHPSC/codes/fortran/multifile1/sub2.f90

subroutine sub2()
    print *, "In sub2"
end subroutine sub2
```

Splitting Fortran codes into files

Compile all three and link together into single executable:

```
$ gfortran main.f90 sub1.f90 sub2.f90 \
    -o main.exe
```

Run the executable:

```
$ ./main.exe
 In main program
 In sub1
 In sub2
```

Splitting Fortran codes into files

Can split into separate compile....

```
$ gfortran -c main.f90 sub1.f90 sub2.f90

$ ls *.o
main.o  sub1.o  sub2.o
```

... and link steps:

```
$ gfortran main.o sub1.o sub2.o -o main.exe

$ ./main.exe > output.txt
```

Note: Redirected output to a text file.

Splitting Fortran codes into files

Advantage: If we modify sub2.f90 to print "Now in sub2" we only need to recompile this piece:

```
$ gfortran -c sub2.f90

$ gfortran main.o sub1.o sub2.o -o main.exe

$ ./main.exe
 In main program
 In sub1
 Now in sub2
```

When working on a big code (e.g. 100,000 lines split between 200 subroutines) this can make a big difference!

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$ ./main.exe
 In main program
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Use of Makefiles greatly simplifies this.

Makefiles

A common way of automating software builds and other complex tasks with dependencies.

A Makefile is itself a program in a special language.

```
1   # $UWHPSC/codes/fortran/multifile1/Makefile
2
3   output.txt: main.exe
4           ./main.exe > output.txt
5
6   main.exe: main.o sub1.o sub2.o
7           gfortran main.o sub1.o sub2.o -o main.exe
8
9   main.o: main.f90
10          gfortran -c main.f90
11  sub1.o: sub1.f90
12          gfortran -c sub1.f90
13  sub2.o: sub2.f90
14          gfortran -c sub2.f90
```

Makefiles

```
$ cd $UWHPSC/codes/fortran/multifile1
$ rm -f *.o *.exe   # remove old versions

$ make main.exe
gfortran -c main.f90
gfortran -c sub1.f90
gfortran -c sub2.f90
gfortran main.o sub1.o sub2.o -o main.exe
```

Uses commands for making `main.exe`.

note: First had to make all the `.o` files.
Then executed the rule to make `main.exe`

Structure of a Makefile

Typical element in the simple Makefile:

```
target:   dependencies
<TAB>   command(s) to make target
```

Important to use tab character, not spaces!!
Warning: Some editors replace tabs with spaces!

Typing "make target" means:

1. Make sure all the dependencies are up to date (those that are also targets)
2. If target is older than any dependency, recreate it using the specified commands.

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1. Make sure all the dependencies are up to date (those that are also targets)
2. If target is older than any dependency, recreate it using the specified commands.

These rules are applied recursively!

Make examples

```
$ rm -f *.o *.exe

$ make sub1.o
gfortran -c sub1.f90

$ make main.o
gfortran -c main.f90

$ make main.exe
gfortran -c sub2.f90
gfortran main.o sub1.o sub2.o -o main.exe
```

Note: Last make required compiling `sub2.f90`
   but not `sub1.f90` or `main.f90`.

Age of dependencies

The last modification time of the file is used.

```
$ ls -l sub1.*
-rw-r--r--  1 rjl  staff  111 Apr 18 16:05 sub1.f90
-rw-r--r--  1 rjl  staff  936 Apr 18 16:56 sub1.o

$ make sub1.o
make: 'sub1.o' is up to date.

$ touch sub1.f90;   ls -l sub1.f90
-rw-r--r--  1 rjl  staff  111 Apr 18 17:10 sub1.f90

$ make main.exe
gfortran -c sub1.f90
gfortran main.o sub1.o sub2.o -o main.exe
```

Makefiles

First version of Makefile has 3 rules that are very similar

```
1   # $UWHPSC/codes/fortran/multifile1/Makefile
2
3   output.txt: main.exe
4           ./main.exe > output.txt
5
6   main.exe: main.o sub1.o sub2.o
7           gfortran main.o sub1.o sub2.o -o main.exe
8
9   main.o: main.f90
10          gfortran -c main.f90
11  sub1.o: sub1.f90
12          gfortran -c sub1.f90
13  sub2.o: sub2.f90
14          gfortran -c sub2.f90
```

Replace these with a pattern rule...

Implicit rules

General rule to make the `.o` file from `.f90` file:

```
1   # $UWHPSC/codes/fortran/multifile1/Makefile2
2
3   output.txt: main.exe
4           ./main.exe > output.txt
5
6   main.exe: main.o sub1.o sub2.o
7           gfortran main.o sub1.o sub2.o -o main.exe
8
9   %.o : %.f90
10          gfortran -c $<
```

Making `main.exe` requires `main.o sub1.o sub2.o` to be up to date.

Rather than a rule to make each one separately, the implicit rule (lines 9-10) is used for all three.

Specifying a different makefile

To use a makefile with a different name than `Makefile`:

```
$ make sub1.o -f Makefile2
gfortran -c sub1.f90
```

The rules in `Makefile2` will be used.

The directory `$UWHPSC/codes/fortran/multifile1` contains several sample makefiles.

See class notes: Makefiles for a summary.

Implicit rules

We have to repeat the list of `.o` files twice:

```
1   # $UWHPSC/codes/fortran/multifile1/Makefile2
2
3   output.txt: main.exe
4           ./main.exe > output.txt
5
6   main.exe: main.o sub1.o sub2.o
7           gfortran main.o sub1.o sub2.o -o main.exe
8
9   %.o : %.f90
10          gfortran -c $<
```

Simplify and reduce errors by defining a macro.

Makefile variables or macros

```
1    # $UWHPSC/codes/fortran/multifile1/Makefile3
2
3    OBJECTS = main.o sub1.o sub2.o
4
5    output.txt: main.exe
6            ./main.exe > output.txt
7
8    main.exe: $(OBJECTS)
9            gfortran $(OBJECTS) -o main.exe
10
11   %.o : %.f90
12           gfortran -c $<
```

By convention, all-caps names are used for Makefile macros.

Note that to use `OBJECTS` we must write `$(OBJECTS)`.

Makefile variables

```
1   # $UWHPSC/codes/fortran/multifile1/Makefile4
2
3   FC = gfortran
4   FFLAGS = -O3
5   LFLAGS =
6   OBJECTS = main.o sub1.o sub2.o
7
8   output.txt: main.exe
9           ./main.exe > output.txt
10
11  main.exe: $(OBJECTS)
12          $(FC) $(LFLAGS) $(OBJECTS) -o main.exe
13
14  %.o : %.f90
15          $(FC) $(FFLAGS) -c $<
```

Here we have added for the name of the Fortran command and for compile flags and linking flags.

Makefile variables

```
$ rm -f *.o *.exe
$ make -f Makefile4

gfortran  -O3 -c main.f90
gfortran  -O3 -c sub1.f90
gfortran  -O3 -c sub2.f90
gfortran  -O3 main.o sub1.o sub2.o -o main.exe
./main.exe > output.txt
```

Can specify variables on command line:

```
$ rm -f *.o *.exe
$ make main.exe FFLAGS=-g  -f Makefile4

gfortran  -g -c main.f90
gfortran  -g -c sub1.f90
gfortran  -g -c sub2.f90
gfortran  -g main.o sub1.o sub2.o -o main.exe
```

Phony targets — don't create files

```
1    # $UWHPSC/codes/fortran/multifile1/Makefile5
2
3    OBJECTS = main.o sub1.o sub2.o
4    .PHONY: clean
5
6    output.txt: main.exe
7            ./main.exe > output.txt
8
9    main.exe: $(OBJECTS)
10           gfortran $(OBJECTS) -o main.exe
11
12   %.o : %.f90
13           gfortran -c $<
14
15   clean:
16           rm -f $(OBJECTS) main.exe
```

Note: No dependencies, so always do commands

```
$ make clean -f Makefile5
rm -f main.o sub1.o sub2.o main.exe
```

Common Makefile error

Using spaces instead of tab...

If we did this in the `clean` commands, we'd get:

```
$ make clean -f Makefile5



Makefile5:14: *** missing separator.  Stop.
```

make help

```
1    # $UWHPSC/codes/fortran/multifile1/Makefile6
2
3    OBJECTS = main.o sub1.o sub2.o
4    .PHONY: clean help
5
6    output.txt: main.exe
7            ./main.exe > output.txt
8
9    main.exe: $(OBJECTS)
10           gfortran $(OBJECTS) -o main.exe
11
12   %.o : %.f90
13           gfortran -c $<
14
15   clean:
16           rm -f $(OBJECTS) main.exe
17
18   help:
19           @echo "Valid targets:"
20           @echo "  main.exe"
21           @echo "  main.o"
22           @echo "  sub1.o"
23           @echo "  sub2.o"
24           @echo "  clean:  removes .o and .exe files"
```

echo means print out the string.
@echo means print out the string but don't print the command.

Fancier things are possible...

```
# $UWHPSC/codes/fortran/multifile1/Makefile7

SOURCES = $(wildcard *.f90)
OBJECTS = $(subst .f90,.o,$(SOURCES))

.PHONY: test

test:
        @echo "Sources are: " $(SOURCES)
        @echo "Objects are: " $(OBJECTS)
```

This gives:

```
$ make test -f Makefile6
Sources are:  fullcode.f90 main.f90 sub1.f90 sub2.f
Objects are:  fullcode.o main.o sub1.o sub2.o
```

Note this found `fullcode.f90` too!