Software Testing

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- Individual modules may be cited as *Speaker, Module Title*, in Better Scientific Software tutorial…

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Verification

- Code verification uses tests
  - It is much more than a collection of tests
- It is the holistic process through which you ensure that
  - Your implementation shows expected behavior,
  - Your implementation is consistent with your model,
  - Science you are trying to do with the code can be done.

How do verification and validation differ?

- Verification confirms that you have implemented what you meant to
  - Your method does what you wanted it to do
- Validation tells you were right in implementing what you meant to
  - What you wanted your method to do is valid
  - Your model correctly captures the phenomenon you are trying to understand

Stages and types of verification

- During initial code development
  - Accuracy and stability
  - Matching the algorithm to the model
  - Interoperability of algorithms
- In later stages
  - While adding new major capabilities or modifying existing capabilities
  - Ongoing maintenance
  - Preparing for production

Components of Verification

- Testing at various granularity
  - Individual components
  - Interoperability of components
  - Convergence, stability and accuracy
- Validation of individual components
  - Building diagnostics (e.g. ensure conservation of physical quantities)
- Testing practices
  - Error bars
    - Necessary for differentiating between drift and round-off
- Ensuring code and interoperability coverage

Why not always use the most stringent testing?

- Effort spent in devising running and maintaining test suite is a tax on team resources
- When the tax is too high…
  - Team cannot meet code-use objectives
- When is the tax is too low…
  - Necessary oversight not provided
  - Defects in code sneak through
- Evaluate project needs
  - Objectives: expected use of the code
  - Team: size and degree of heterogeneity
  - Lifecycle stage: new or production or refactoring
  - Lifetime: one off or ongoing production
  - Complexity: modules and their interactions

Balance is critical

Good Testing Practices

- Verify Code coverage
- Must have consistent policy on dealing with failed tests
  - Issue tracking
    - How quickly does it need to be fixed?
    - Who is responsible for fixing it?
- Someone should be watching the test suite
- When refactoring or adding new features, run a regression suite before check in
  - Add new regression tests or modify existing ones for the new features
- Code review before releasing test suite is useful
  - Another person may spot issues you didn’t
  - Incredibly cost-effective

How do we determine what other tests are needed?

Code coverage tools

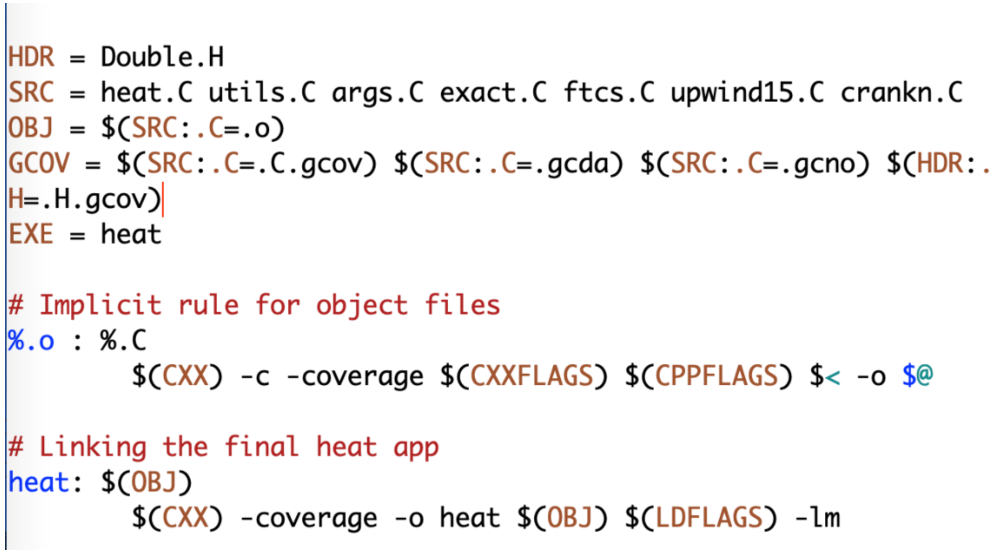
- Expose parts of the code that aren’t being tested
  - gcov - standard utility with the GNU compiler collection suite (we will use it in the next few slides)
  - Compile/link with –coverage & turn off optimization
  - counts the number of times each statement is executed
- gcov also works for C and Fortran
  - Other tools exist for other languages
  - JCov for Java
  - Coverage.py for python
  - Devel::Cover for perl
  - profile for MATLAB
- Lcov
  - a graphical front-end for gcov
  - available at http://ltp.sourceforge.net/coverage/lcov.php
  - Codecov.io in CI module
- Hosted servers (e.g. coveralls, codecov)
- graphical visualization of results
- push results to server through continuous integration server

Interoperability coverage Example Later

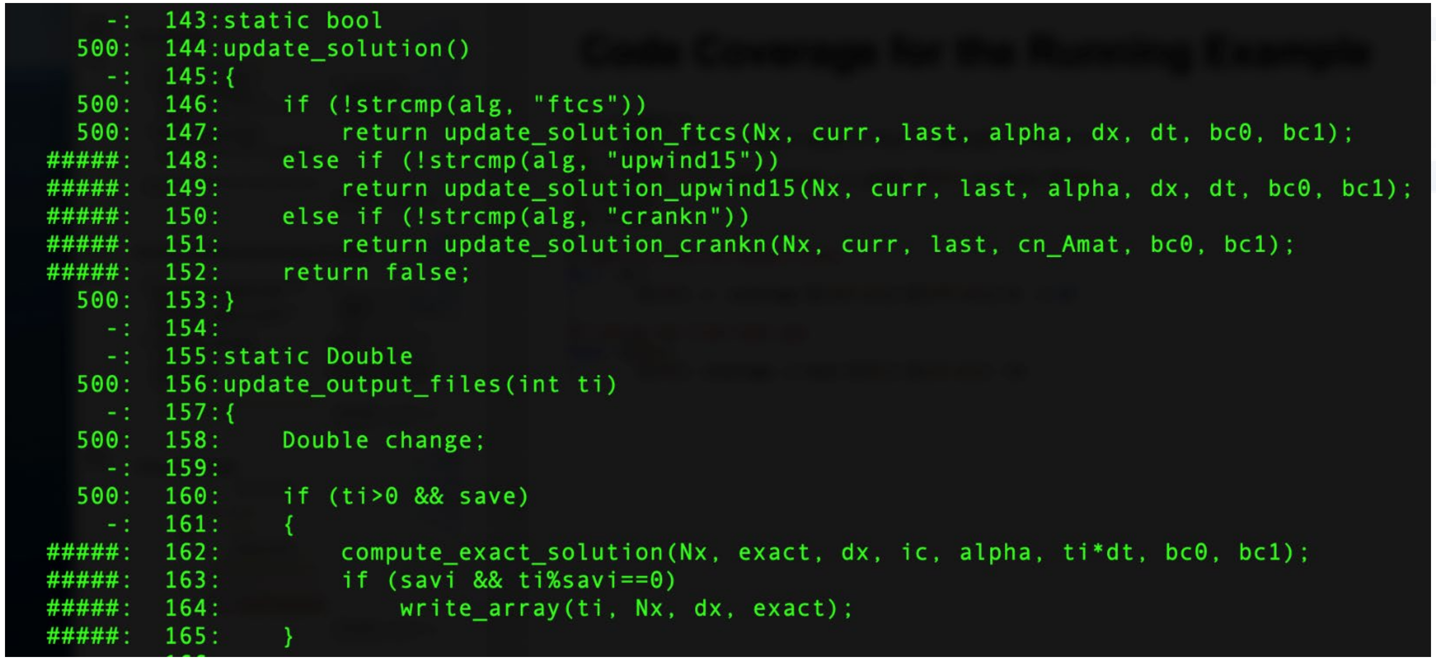
Checking coverage Example

- Example of heat equation
  - Add -coverage as shown below to Makefile
  - Run ./heat runame=“ftcs_results”
  - Run gcov heat.C
  - Examine heat.C.gcov

- A dash indicates non-executable line
- A number indicated the times the line was called
- ##### indicates line wasn’t exercised



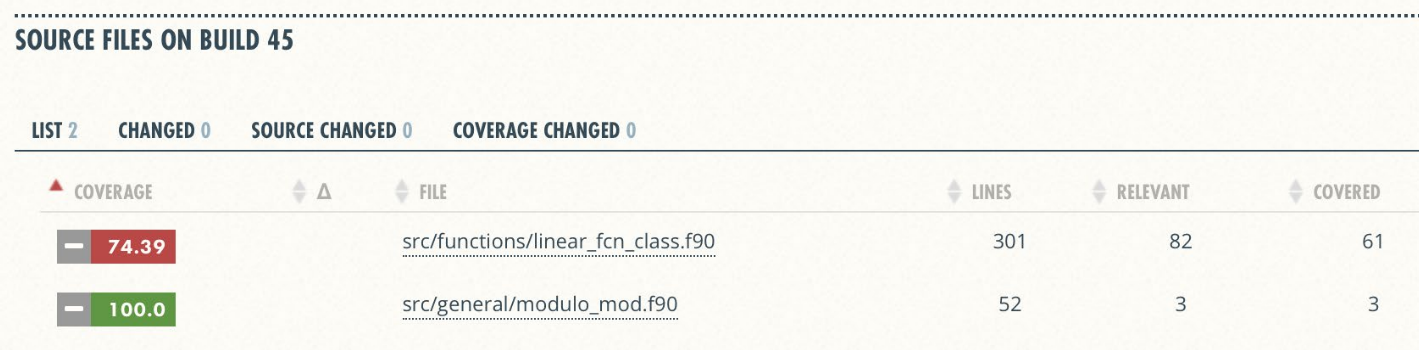
```
HDR = Double.H
SRC = heat.C utils.C args.C exact.C ftcs.C upwind15.C crankn.C
OBJ = $(SRC:.C=.o)
GCOV = $(SRC:.C=.C.gcov) $(SRC:.C=.gcda) $(SRC:.C=.gcno) $(HDR:.
H=.H.gcov)
EXE = heat

# Implicit rule for object files
%.o : %.C
	$(CXX) -c -coverage $(CXXFLAGS) $(CPPFLAGS) $< -o $@

# Linking the final heat app
heat: $(OBJ)
	$(CXX) -coverage -o heat $(OBJ) $(LDFLAGS) -lm
```



```
    -:  143:static bool
  500:  144:update_solution()
    -:  145:{
  500:  146:    if (!strcmp(alg, "ftcs"))
  500:  147:        return update_solution_ftcs(Nx, curr, last, alpha, dx, dt, bc0, bc1);
#####:  148:    else if (!strcmp(alg, "upwind15"))
#####:  149:        return update_solution_upwind15(Nx, curr, last, alpha, dx, dt, bc0, bc1);
#####:  150:    else if (!strcmp(alg, "crankn"))
#####:  151:        return update_solution_crankn(Nx, curr, last, cn_Amat, bc0, bc1);
#####:  152:    return false;
  500:  153:}
    -:  154:
    -:  155:static Double
  500:  156:update_output_files(int ti)
    -:  157:{
  500:  158:    Double change;
    -:  159:
  500:  160:    if (ti>0 && save)
    -:  161:    {
#####:  162:        compute_exact_solution(Nx, exact, dx, ic, alpha, ti*dt, bc0, bc1);
#####:  163:        if (savi && ti%savi==0)
#####:  164:            write_array(ti, Nx, dx, exact);
#####:  165:    }
```

Graphical View of Gcov Output and Tutorials for Code Coverage

Overall Analysis

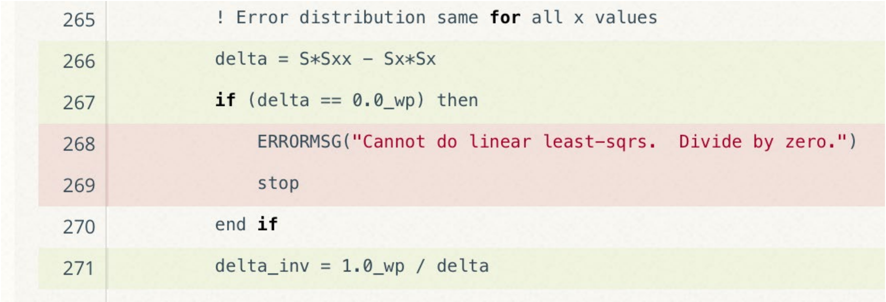


SOURCE FILES ON BUILD 45

LIST 2 CHANGED 0 SOURCE CHANGED 0 COVERAGE CHANGED 0

COVERAGE	Δ	FILE	LINES	RELEVANT	COVERED
− 74.39		src/functions/linear_fcn_class.f90	301	82	61
− 100.0		src/general/modulo_mod.f90	52	3	3

Detailed Analysis



```
! Error distribution same for all x values
delta = S*Sxx - Sx*Sx
if (delta == 0.0_wp) then
    ERRORMSG("Cannot do linear least-sqrs.  Divide by zero.")
    stop
end if
delta_inv = 1.0_wp / delta
```

Online tutorial - https://github.com/amklinv/morpheus

Other example - https://github.com/jrdoneal/infrastructure

How to build your test suite ?

- Two purposes
  - Regression testing
    - May be long running
    - Provide comprehensive coverage
  - Continuous integration
    - Quick diagnosis of error
- A mix of different granularities works well
  - Unit tests for isolating component or sub-component level faults
  - Integration tests with simple to complex configuration and system level
  - Restart tests
- Rules of thumb
  - Simple
  - Enable quick pin-pointing

Useful resources https://ideas-productivity.org/resources/howtos/

Test Development For a New Code

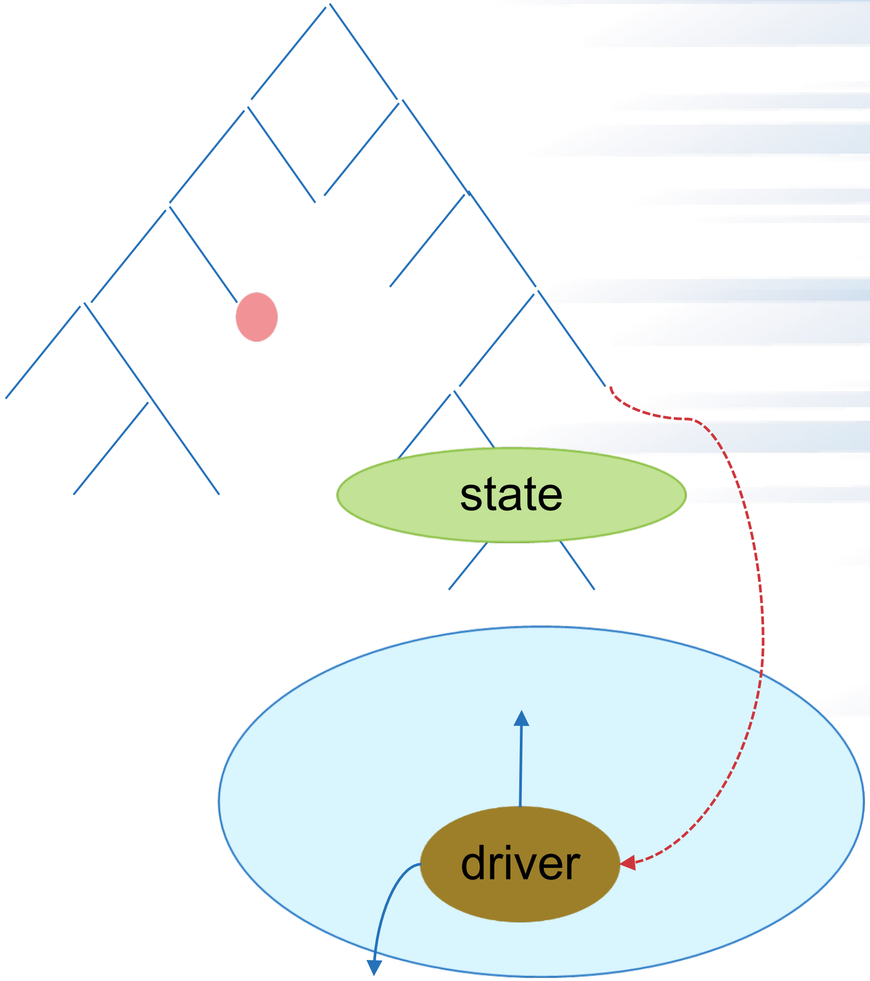
- Development of tests and diagnostics goes hand-in-hand with code development
  - Non-trivial to devise good tests, but extremely important
  - Compare against simpler analytical or semi-analytical solutions
  - Build granularity into testing
  - Use scaffolding ideas to build confidence
  - Always inject errors to verify that the test is working

Detailed example in the next presentation

Test Development For a Legacy Code

There may not be existing tests

- Isolate a small area of the code
- Dump a useful state snapshot
- Build a test driver
  - Start with only the files in the area
  - Link in dependencies
    - Copy if any customizations needed
- Read in the state snapshot
- Restart from the saved state
- Verify correctness
  - Always inject errors to verify that the test is working


state
driver