



Software Testing

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- **The requested citation the overall tutorial is: David E. Bernholdt, Anshu Dubey, Mark C. Miller, Katherine M. Riley, and James M. Willenbring, Software Productivity Track, in Argonne Training Program for Extreme Scale Computing (ATPESC), online. DOI: [10.6084/m9.figshare.12719834](https://doi.org/10.6084/m9.figshare.12719834)**
- Individual modules may be cited as *Speaker, Module Title*, in Software Productivity Track...

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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 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	▲	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

```
265      ! Error distribution same for all x values
266      delta = S*Sxx - Sx*Sx
267      if (delta == 0.0_wp) then
268          ERRORMSG("Cannot do linear least-sqrs. Divide by zero.")
269          stop
270      end if
271      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

