



Software Testing: Introduction



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- **The requested citation the overall tutorial is: David E. Bernholdt, Anshu Dubey, Patricia A. Grubel, Rinku K. Gupta, and David M. Rogers, Better Scientific Software tutorial, in ISC High Performance, online, 2021. DOI: [10.6084/m9.figshare.14642520](https://doi.org/10.6084/m9.figshare.14642520)**
- Individual modules may be cited as *Speaker, Module Title*, in Better Scientific Software tutorial...



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Software Testing - Outline

Testing Introduction

- Development context for testing
- Challenges
- Toy Example

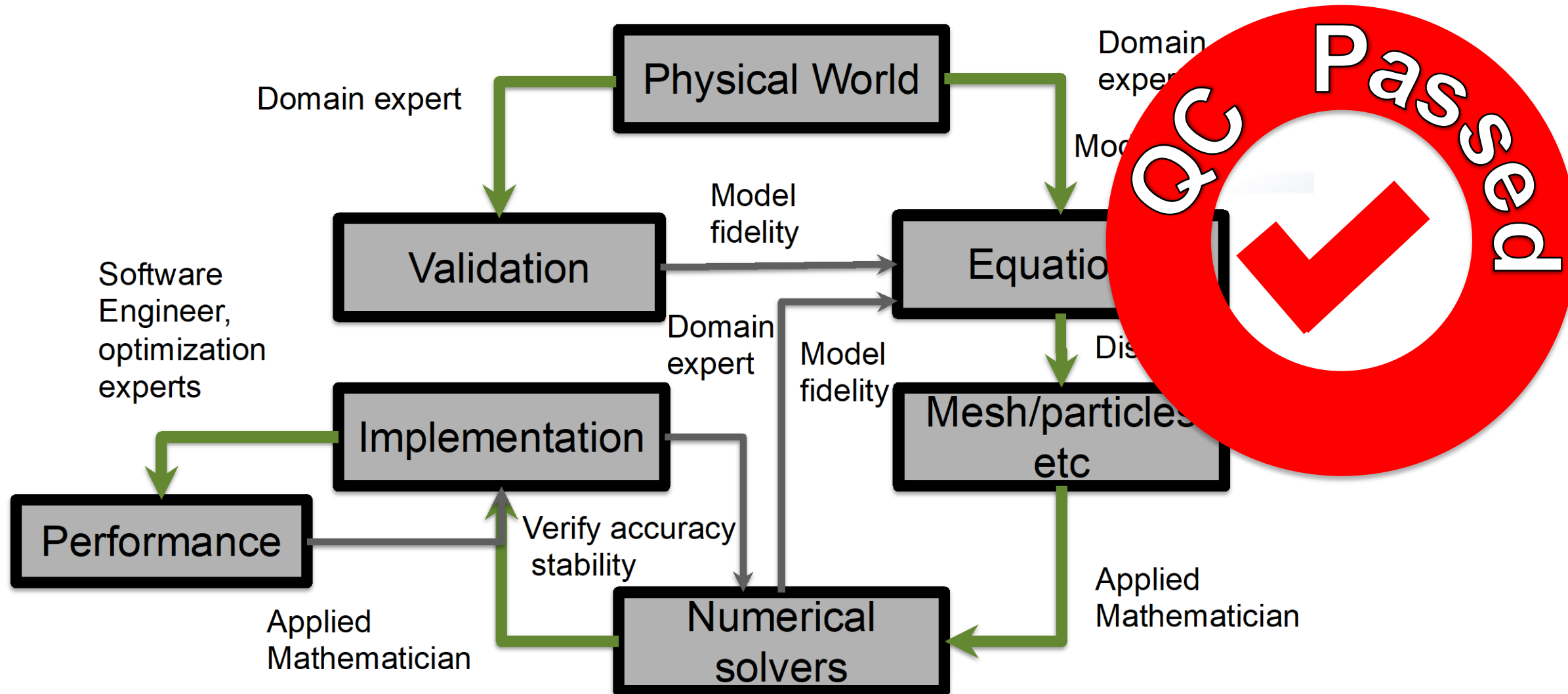
Testing Walkthrough

- Walk Through Testing Example

Advanced Testing

- Guidelines for developing a testing & validation plan
- Production Examples
 - Testing a legacy Fortran code
 - Designing tests alongside code development
- Conclusions: Testing within a team context

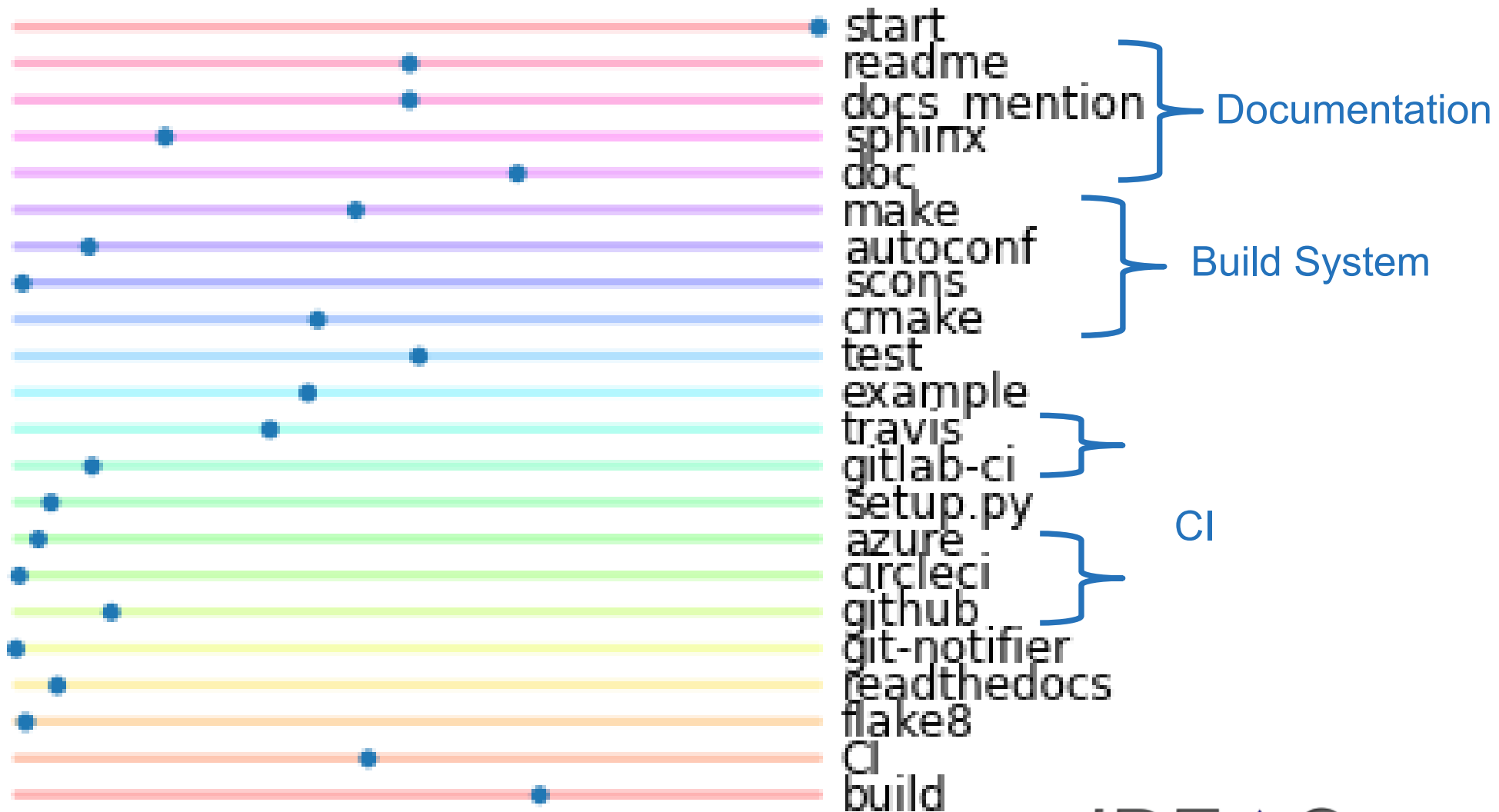
Testing within the software development lifecycle



Testing within the software development lifecycle

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

Testing as a development practice



[SIAM CSE21, "Querying the ECP" - figshare](#)

Audiences for this presentation

- New to testing / beginning development on a new project
 - Helpful starting points and ways to “start small.”
- Working with a legacy project that needs testing
 - Code isolation for incrementally adding testing
- Improving testing practices on an existing project
 - Ideas and guidelines for a holistic verification strategy

Definitions: Verification vs. Testing vs. Validation

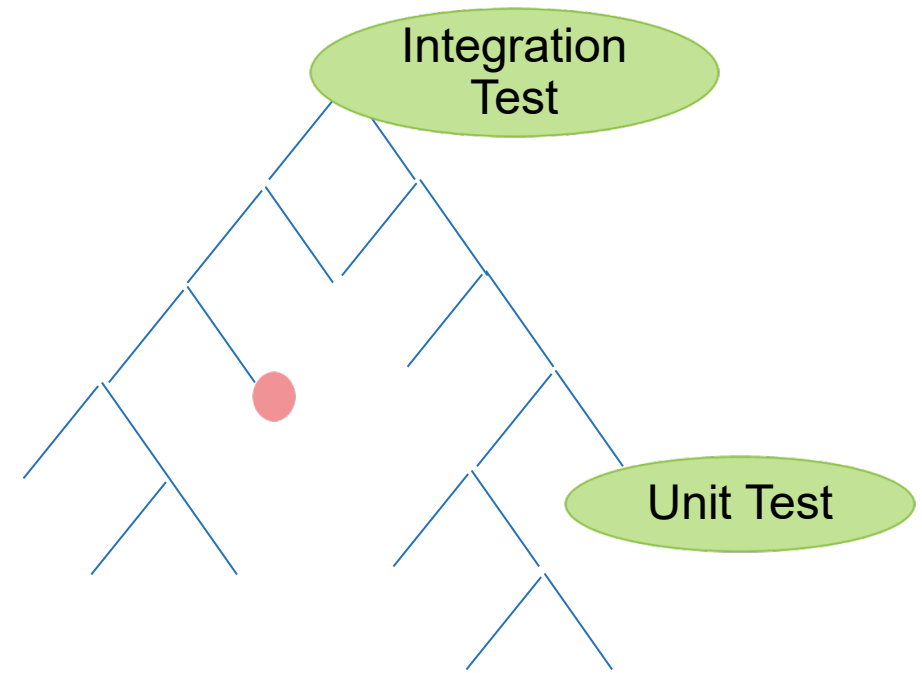
- Code verification uses tests
 - It is much more than a collection of tests
- It is the holistic process through which you ensure that
 - Your implementation shows expected behavior,
 - Your implementation is consistent with your model,
 - Your code is capable of handling your target science cases

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 says whether your science goals are met by your implementation
 - What you wanted your method to do is scientifically valid
 - Your model correctly captures the phenomenon you are trying to understand (outward-looking, not fully captured by tests)

Components of Verification

- Testing at various granularity levels
 - 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



Challenges

- Exploratory Software
 - Implies one does not know the outcome
 - Still determining where model is valid
 - A: Validation from domain experts feeds back into design
- Legacy Codes
 - Original verification has been lost in the mists of time.
 - Assumptions, conditions, interactions unknown: “Bad code or necessary evil?”
- Releasing Codes
 - Code review to check scope of problem, solution, and documentation.
 - Verification before product release is a cost-effective way to prevent defects from getting through.

Toy Example

```
pip3 install pyscaffold
pip3 install tox
putup autoQCT
cd autoQCT # tests in tests/ subdir.
tox
```

```
default run-test: commands[0] | pytest
===== test session starts =====
platform darwin -- Python 3.9.0, pytest-6.2.2, py-1.10.0, pluggy-0.13.1 -- plugins:
cov-2.11.1
collected 2 items
```

```
tests/test_skeleton.py::test_fib PASSED [ 50%]
tests/test_skeleton.py::test_main PASSED [100%]
```

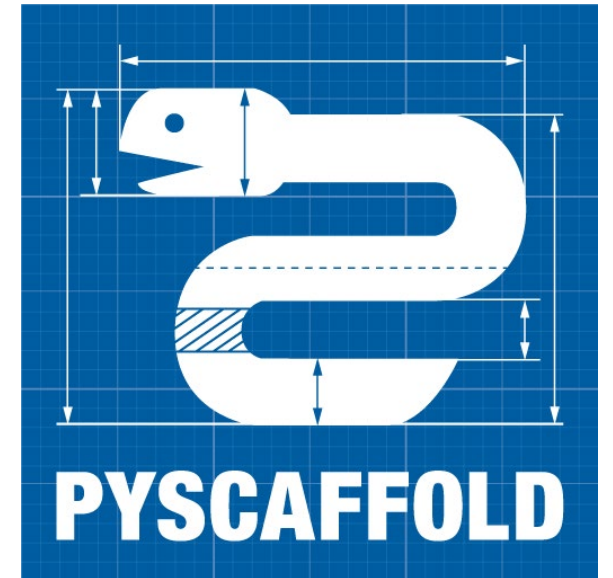
```
----- coverage: platform darwin, python 3.9.0-final-0 -----
Name                Stmts  Miss Branch BrPart  Cover  Missing
```

```
src/autoqct/__init__.py    6     0     0     0  100%
src/autoqct/skeleton.py   32     1     2     0   97%  135
```

```
-----
TOTAL                   38     1     2     0   98%
```

```
===== 2 passed in 0.07s =====
```

```
default: commands succeeded
congratulations :)
```



pyscaffold.org

Toy Example

```
cat >CMakeLists.txt <<.
cmake_minimum_required(VERSION 3.8)
project( blank )
set(CMAKE_CXX_STANDARD 11)
set(CMAKE_CXX_STANDARD_REQUIRED ON)
include(blt/SetupBLT.cmake)
.
git clone https://github.com/LLNL/blt/
mkdir build && cd build
make -j && make test
```



llnl-blt.readthedocs.io

```
...
[100%] Linking CXX executable .././tests/blt_gtest_smoke
[100%] Built target blt_gtest_smoke
mac0103234:build 99r$ make test
Running tests...
Test project /Users/99r/work/autoQCT/blank_project/build
  Start 1: blt_gtest_smoke
1/1 Test #1: blt_gtest_smoke ..... Passed    0.46 sec

100% tests passed, 0 tests failed out of 1

Total Test time (real) =  0.46 sec
```

Going Further

- C, C++, Fortran
 - Running and Reporting Tests: ctest / cdash
 - Code Coverage: gcov / lcov (C, C++, Fortran)
 - Static Analysis: clang-tidy (only C, C++)
- Python
 - Running and Reporting Tests: pytest / unittest / nose
 - Code Coverage: pytest-cov
 - Static Source Code Analysis: pylint / flake8

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

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

Coverage Summary

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

Line-by-line details

```
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>

Summary

- A productive software team is always checking their work.
 - Take time to recognize these checks and harden them into “real,” repeatable tests.
- Test layout should mirror the logical structure of your code.
 - Test each module, being aware of module to module dependencies.
- Different challenges are associated with exploratory, legacy, and release codes.
 - Adapt your strategy to fit your situation.
 - Eventually you will want to be able to verify all components in a code release.
- Don't get distracted by all the technologies out there – focus on exercising your code.
 - Scaffolding projects can help with mechanics.