Software Testing: Introduction

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License and Citation

- **The requested citation the overall tutorial is: David E. Bernholdt, Anshu Dubey, Rinku K. Gupta, and David M. Rogers, Software Productivity and Sustainability track, in Argonne Training Program on Extreme-Scale Computing (ATPESC), online, 2021. DOI: 10.6084/m9.figshare.15130590**
- 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

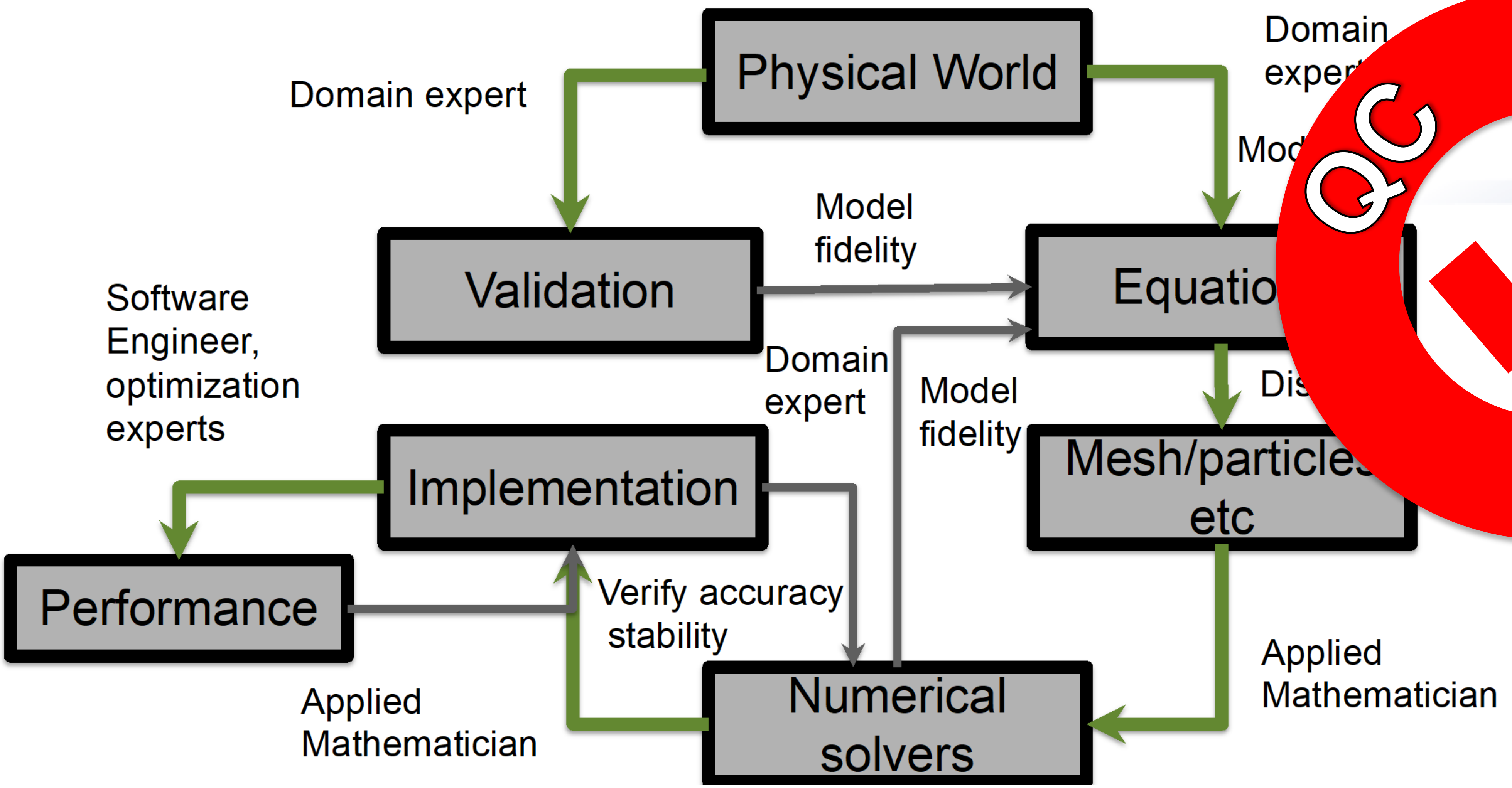
Testing Walkthrough

- 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



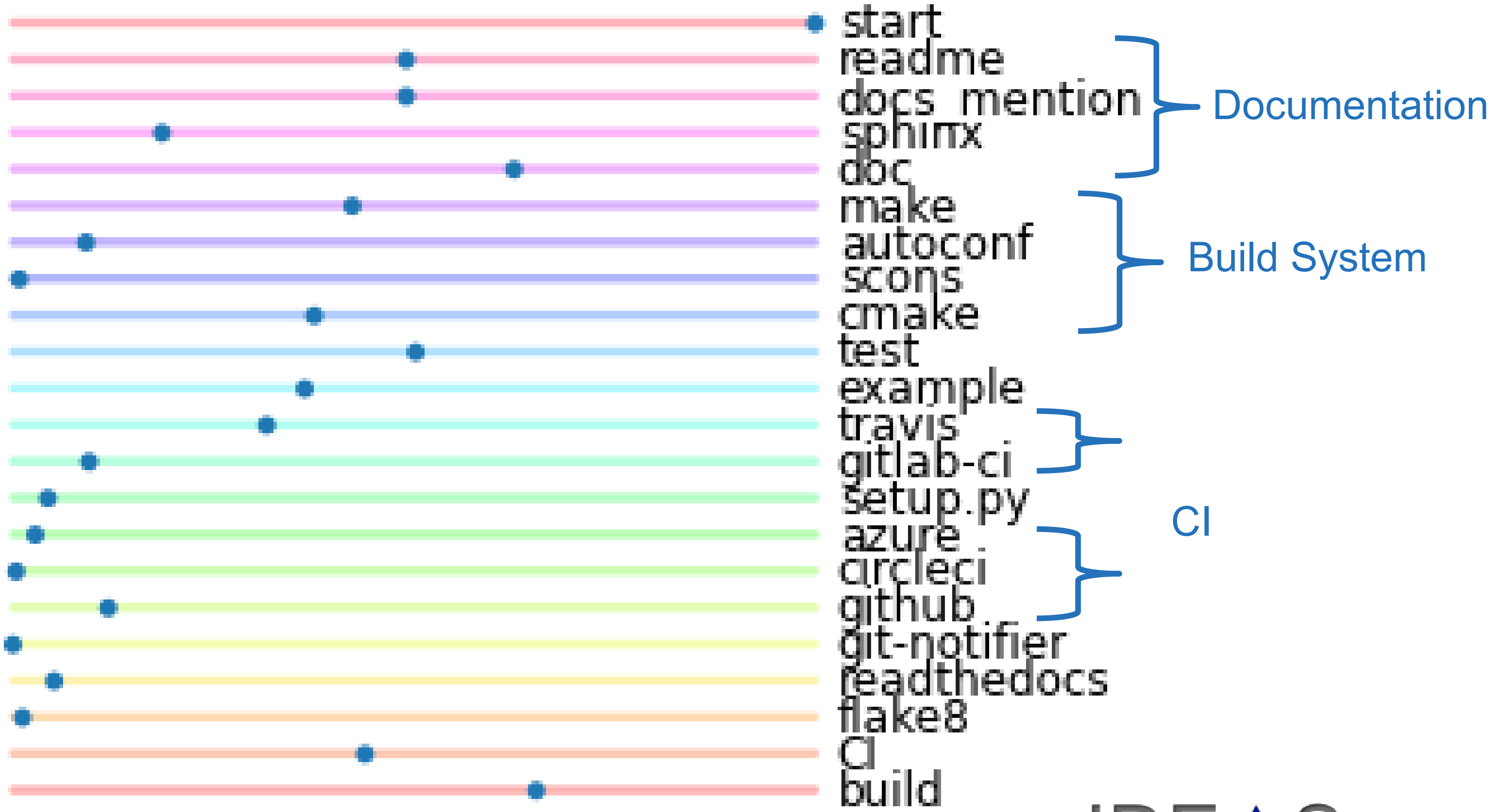
IDEAS productivity

ECP EXASCALE COMPUTING PROJECT

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



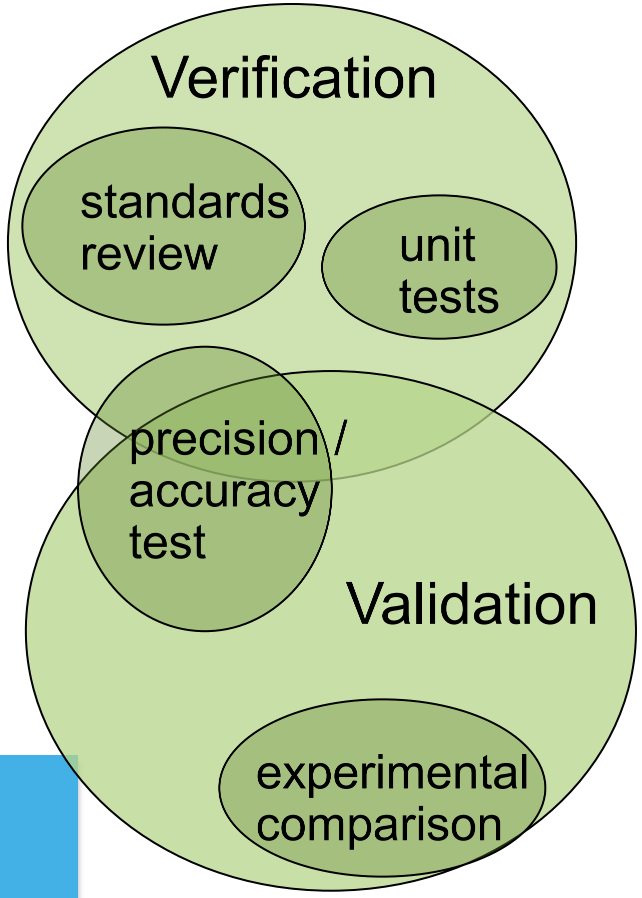
SIAM CSE21, "Querying the ECP" - figshare

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

- Software verification addresses design:
  - Does the operational standard make logical sense?
  - Is the implementation consistent with model?
- Model validation checks operation:
  - Is the code capable of handling your target science cases?
  - Is its answer consistent with use expectations?

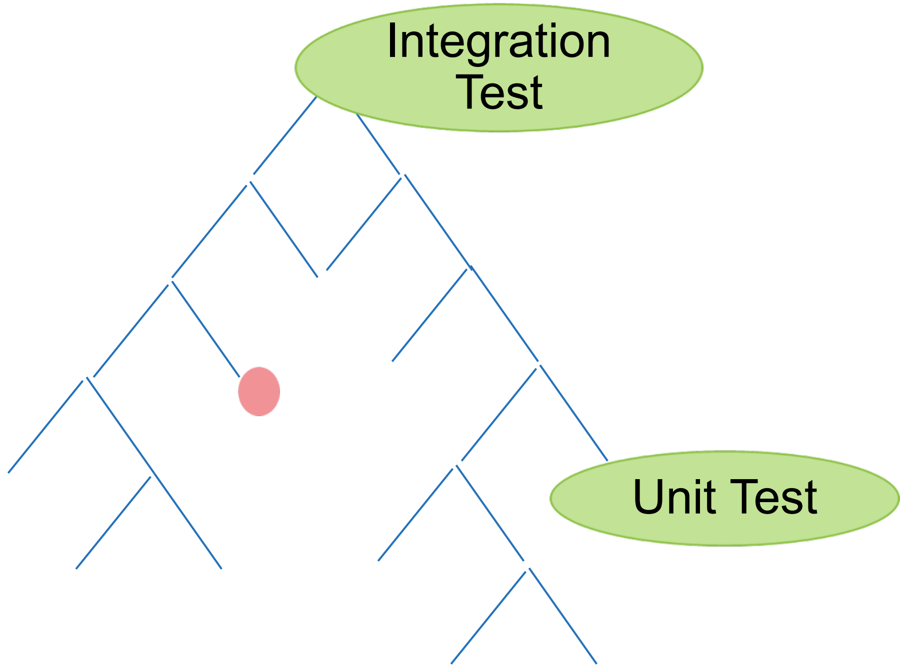


How do verification and validation differ?

- 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)

https://www.energy.gov/nnsa/articles/face-uncertainties-nnsa-seeks-verification-and-validation

Components of Verification



- Testing at various granularity levels
  - Individual components
  - Interoperability of components
  - Convergence, stability and accuracy
  - Includes testing "upstream dependencies"
- 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

pyscaffold.org

EXASCALE COMPUTING PROJECT

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	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

Line-by-line details

```
        ! 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

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.