Software Testing Walkthrough

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

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IDEAS productivity

ECP EXASCALE COMPUTING PROJECT

Hello Numerical World Example (heat equation)

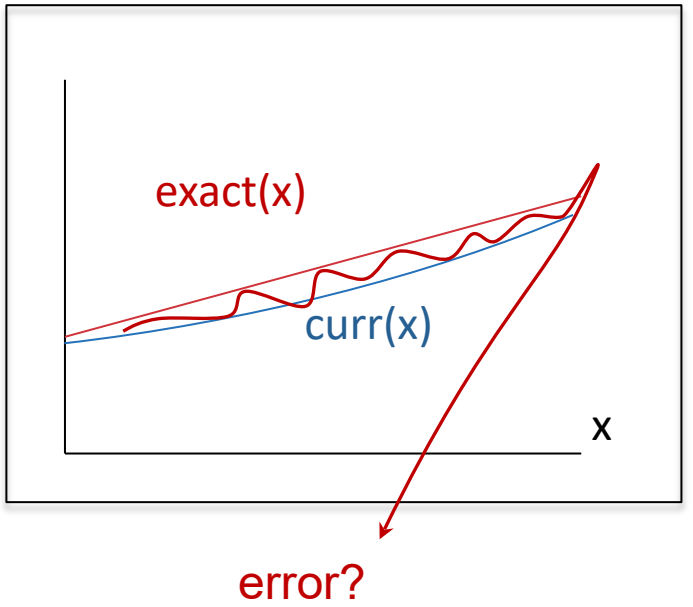
github.com/bssw-tutorials/hello-numerical-world

```
$ wc *.C
   125    494   4161 args.C     # parse arguments
   220    718   5667 heat.C     # main() – stores all vars
   151    498   3888 utils.C    # l2_norm, write, copy, init
    26    119    820 ftcs.C     # standard, centered stencil
    27    123    833 upwind15.C # alternate integration schemes
    94    344   2134 crankn.C
    43    190   1299 exact.C    # comparison solution
```

- Lots of setup code – prepares problem for kernel calls
- Isolated, swappable kernel calls
  - Imagine adding kernels to larger, multi-physics application.
- How can we support testing all these kernel configurations?

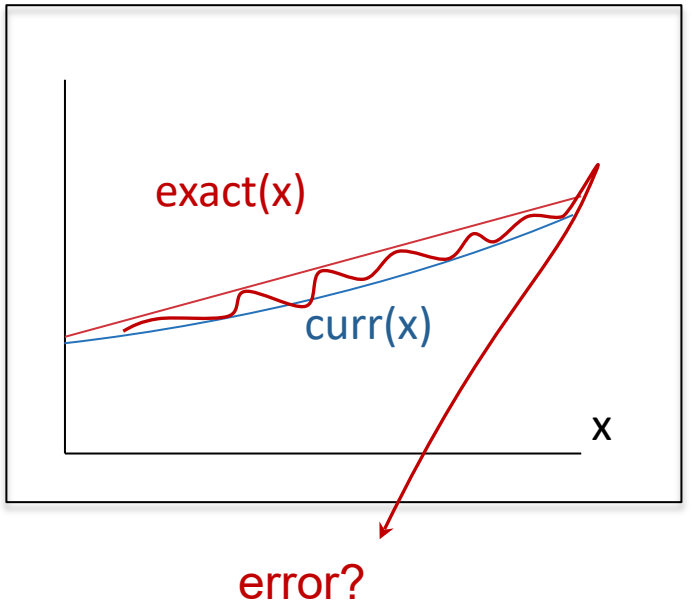
What to Test?

- Types of Tests:
  - code coverage – ensure options parse, bad cases detected, utilities fuction, etc.
  - steady-state (should be straight line)
    - external script can test file write() as well
  - solution time-dependence vs. reference
    - $(d/dx)^2 \sin(ax) = -a^2 \sin(ax)$
  - integration between codes?
  - test compile/run in multiple precisions?
    - combinatorial problems – listing tests in for() or matrix...



Running Tests via makefile

```
$ make check_all
      c++ -c  -Iinclude -DHEAT_VERSION_MAJOR=0 -
      DHEAT_VERSION_MINOR=5  args.C -o args.o
      c++ -o heat heat.o utils.o args.o exact.o ftcs.o upwind15.o
      crankn.o  -lm
      ./heat runame=check outi=0 maxt=-5e-8 ic="rand(0,0.2,2)"
          runame="check"
       ...
      Stopped after 001490 iterations for threshold 2.46636e-15
      cat check/check_soln_final.curve
      # Temperature
      ...
      ./check.sh check/check_soln_final.curve 0

 make completes: commands succeeded
```



steady-state test
(should be straight line)

TODO – try out new build tools and add tests to them

- Replace makefile with *CMakeLists.txt*
  - replaces rules with *targets* (tied to a list of source files)
  - targets have *attributes*
    - target_link_libraries (e.g. MPI::MPI_CXX)
    - target_include_directories (many already inferred from link libraries)
    - target_compile_features (e.g. cxx_std11)
  - provides *find_package* command
  - targets can be installed
- Replace "make check_all" with *ctest*
  - reduces glue code
  - different interface for adding tests
- End Result: contrast two methods of testing.

existing makefile

makefile

```
...

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

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

Standard makefile – user selects compile flags.
- but flags and features are compiler and system-specific
- enter automake and cmake -> generate makefiles

Conversion to cmake (entire file)

https://cmake.org/cmake/help/latest/guide/tutorial/index.html

CMakeLists.txt

```
cmake_minimum_required(VERSION 3.8)
project(heat VERSION 0.5 LANGUAGES CXX)
# can change boolean variable with "-DCMAKE_BUILD_TESTS=OFF"
option(BUILD_TESTS "Build the tests accompanying this program." ON)
# pass cmake options (e.g. version) into a header
configure_file(include/version.H.in include/version.H)
add_executable(heat args.C crankn.C ...) # list sources
# feature – lets cmake adjust flags for compiler --std=c++11 vs –c11
target_compile_features(heat cxx_std_11)
# include directories for all files in this target:
target_include_directories(heat ${PROJECT_BINARY_DIR}/include)
if(BUILD_TESTS) add_subdirectory(tests) endif() # subdir for tests
install(TARGETS heat DESTINATION bin) # "make install" target
```

existing tests

makefile include (tests.mk)

```
...
check_crankn/check_crankn_soln_final.curve:
        ./heat alg=crankn runame=check_crankn outi=0 maxt=-5e-8 ic="rand(0,0.2,2)"
check_crankn: heat check_crankn/check_crankn_soln_final.curve
        cat check_crankn/check_crankn_soln_final.curve
        ./check.sh check_crankn/check_crankn_soln_final.curve

check_upwind15/check_upwind15_soln_final.curve:
        ./heat alg=upwind15 ...
```

Create a test driver to:

1. run executable
2. check result
3. clean up outputs

Addition to CMakeLists.txt

cmake.org/cmake/help/latest/command/add_test.html

tests/CMakeLists.txt

```
enable_testing()

add_test(NAME heat_help
      COMMAND $<TARGET_FILE:heat> help)

add_test(NAME crankn
      COMMAND testDriver.sh $<TARGET_FILE:heat> crankn)

# functions/for/if/adding tests
```

Lots of potential for programmatically creating tests!

Try and keep it simple – complex cmake code is bad form.

Bonus: swap out test driver (perl -> awk)

tests/testDriver.sh

```
#!/bin/bash
set –e              # exit immediately on error
errbnd=1e-7
alg="$2"
$1 alg=$alg runame=check_$alg outi=0 maxt=-5e-8 ic="rand(0,0.2,2)"

# absolute error check (deviation from straight line)
err=$(awk 'function abs(x){return ((x < 0.0) ? -x : x)}; BEGIN {err=1e10;} ! /#/ {err1=abs($2-$1); if(err1
< err) err = err1;} END {print err;}' check_$alg/check_${alg}_soln_final.curve)

echo "Error = $err"
rm -fr check_$alg    # delete directory to test is re-runnable

awk "BEGIN {exit($err >= $errbnd);}"  # final return code
```

Running

```
cmake ..
make –j
cd tests && ctest
```

```
Test project hello-numerical-world/build/tests
    Start 1: ftcs
1/3 Test #1: ftcs ..........................   Passed    0.02 sec
    Start 2: crankn
2/3 Test #2: crankn ........................   Passed    0.02 sec
    Start 3: upwind15
3/3 Test #3: upwind15 ......................   Passed    0.03 sec


100% tests passed, 0 tests failed out of 3


Total Test time (real) =   0.08 sec
```

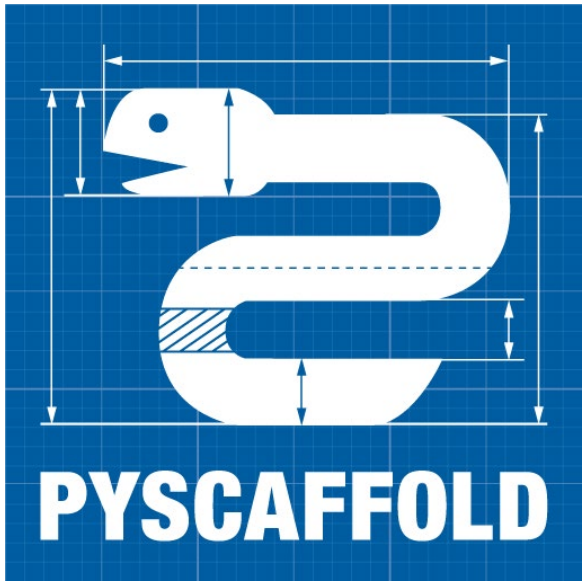
Conclusion – C, kernels, makefiles, CMakeLists, coverage, etc.

- Start your projects small, stay organized
  - makefiles provide fast development path
  - add tests before complexity grows!
  - simple to do with a "make check" target
- cmake (like autoconf) helps make portable builds
  - find_package
  - programmatic build options
  - set target properties -> cmake looks up compiler flags for you
- good testing strategies exist for both
  - directly run the executable with all options
  - create shell-script "test driver"
  - build stand-alone executables loading a library

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

Adding BLT

```
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
```

```
...
[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
```

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 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

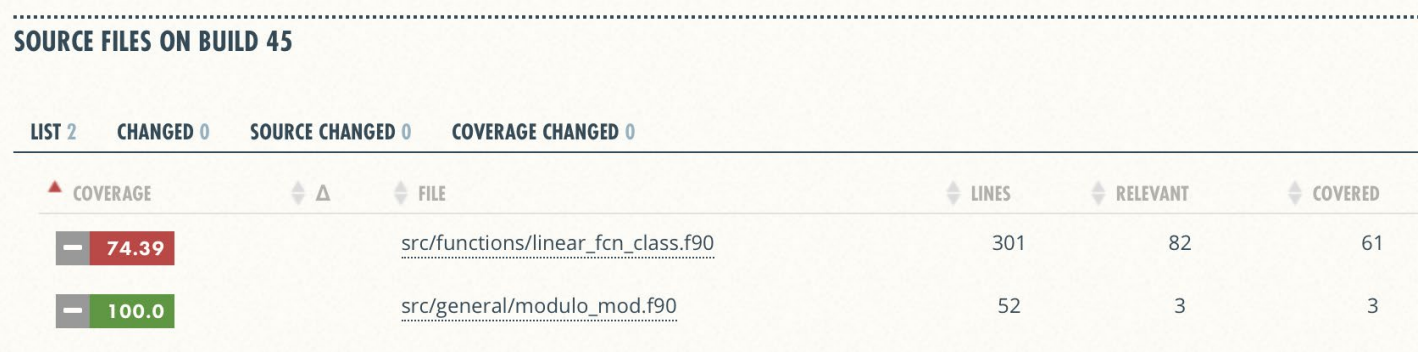
```
HDR = Double.H
SRC = heat.C utils.C args.C exact.C ftcs.C upwind15.C crankn.C
OBJ = $(SRC:.C=.o)
GCOV = $(SRC:.C=.C.gcov) $(SRC:.C=.gcda) $(SRC:.C=.gcno) $(HDR:.
H=.H.gcov)
EXE = heat

# 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
```

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

```
    -:  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

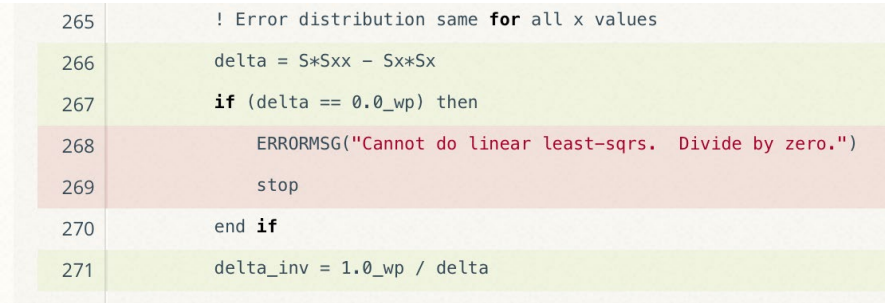


SOURCE FILES ON BUILD 45

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



```
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