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TESTING OF HPC SCIENTIFIC SOFTWARE

The IDEAS Team

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Introduction

Why is testing important ?

Granularity of tests

Types of tests

Benefits of testing

- Promotes high-quality software that delivers correct results and improves confidence
- Increases quality and speed of development, reducing development and maintenance costs
- Maintains portability to a variety of systems and compilers
- Helps in refactoring
  - Avoid introducing new errors when adding new features
  - Avoid reintroducing old errors

How common are bugs?

Programs do not acquire bugs as people acquire germs, by hanging around other buggy programs. Programmers must insert them.
- Harlan Mills

- Bugs per 1000 lines of code (KLOC)
- Industry average for delivered software
  - 1-25 errors
- Microsoft Applications Division
  - 10-20 defects during in-house testing
  - 0.5 in released product

Why testing is important:
the protein structures of Geoffrey Chang

- Some inherited code flipped two columns of data, inverting an electron-density map
- Resulted in an incorrect protein structure
- Resulted in 5 retracted publications
  - One was cited 364 times
- Many papers and grant applications conflicting with his results were rejected

A scientist's nightmare: Software problems lead to five retractions (Miller)

Why testing is important: the 40 second flight of the Ariane 5

- Ariane 5: a European orbital launch vehicle meant to lift 20 tons into low Earth orbit
- Initial rocket went off course, started to disintegrate, then self-destructed less than a minute after launch
- Seven variables were at risk of leading to an Operand Error (due to conversion of floating point to integer)
  - Four were protected
- Investigation concluded insufficient test coverage as one of the causes for this accident
- Resulted in a loss of $370,000,000.

ARIANE 5 Flight 501 Failure (report by the Inquiry Board)

Why testing is important: the Therac-25 accidents

- Therac-25: a computer-controlled radiation therapy machine
- Minimal software testing
- Race condition in the code went undetected
- Unlucky patients were struck with approximately 100 times the intended dose of radiation, ~ 15,000 rads
- Error code indicated that no dose of radiation was given, so operator instructed machine to proceed
  - Documentation gave no indication that the frequent malfunctions of the machine could place a patient at risk
  - See also: why documentation is important
- Recalled after six accidents resulting in death and serious injuries

An Investigation of the Therac-25 Accidents (Leveson & Turner)

Granularity of tests

- Unit tests
  - Test individual functions or classes
  - Build and run fast
  - Localize errors
  - Usually written before or during code development
    - Prevent faults from being introduced
  - Example: Can I correctly compute a dot-product?

If a unit test fails, you should know *exactly* what is broken.

Granularity of tests

- Integration tests
  - Test interaction of larger pieces of software
  - Do not build or run as fast as unit tests
  - Example: Does the preconditioner class work with the Krylov solver class?

Granularity of tests

- System-level tests
  - Test the full software system at the user interaction level
  - Example: Does my CFD code compute the correct solution?

Types of tests

- Verification tests
  - Does the code implement the intended algorithm correctly?
  - Check for specific mathematical properties
  - Example
    - Solving Ax=b where A has 5 distinct eigenvalues
    - Does my Krylov solver converge in 5 iterations?
  - Can be any granularity

Types of tests

- Acceptance tests
  - Assert acceptable functioning for a specific customer
    - Different from other types of tests, which don't involve customers
  - Generally at the system-level
  - Example: Does my linear solver achieve the correct convergence rate for a particular customer's linear system?

Types of tests

- Regression (no-change) tests
  - Compare current observable output to a gold standard
    - Gold standard frequently comes from previous version of software
  - Similar to verification tests
    - Must independently verify that the gold standard is correct
  - Example
    - My Krylov solver took 10 iterations last week; does it still take 10 iterations?
    - Does it achieve the same solution?
  - Bounded change tests are better for floating point computations

Types of tests

- Performance tests
  - Focus on the runtime and resource utilization
  - Nothing to do with correctness
    - Orthogonal to other types of tests
  - Example: It took my code 10s to solve this linear system last week; does it take longer now?

Types of tests

- Installation tests
  - Verify that the configure-make-install is working as expected
  - Example: Can I build and run a simple driver using my library after the library is installed?

Tpetra verification

- Distributed basic linear algebra subroutines
  - Sparse matrices
  - Dense matrices
- Check for correct linear algebra
- Check for correct errors
  - Does the program throw an exception if I try to multiply things with incompatible dimensions?

Belos verification

- Krylov solvers
- Use problems with known solutions
  - Given A and Y, generate B=AY
    - Ensures B is in the range of A
  - Solve AX=B
- Some tests use Belos matrix and vector classes
- Some tests use Epetra/Tpetra classes
- Test with and without preconditioning
  - Left and right

Anasazi verification

- Eigensolvers
- Use problems with known solutions
  - Generated using Matlab's sprand
  - Problems with analytic solutions
    - Discretization of the Laplace operator
- Measure the residual of the computed eigenvectors
  - $R = AX - BX\Lambda$
- Number of iterations are compared to a gold standard

Zoltan(2) verification

- Graph partitioning
  - Some Sandia-developed code
  - Some TPL wrappers
- Gold standard solutions
  - Labor intensive
  - Gold standard changes when algorithms change
  - Upgrades to a TPL such as ParMETIS require gold standard to be updated
- Uses metrics to determine whether the solution is correct
  - Edge cuts
  - Balance criteria

How did we motivate people to write 1500 tests?

- Tests protect YOU from other people from breaking your work
  - If someone else's changes break your code, they are responsible for fixing it
- Testing is cheaper and easier than debugging
- We already had some lying around anyway
  - Drivers for generating conference or paper results
  - User submitted bugs
  - Examples

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
    - counts the number of times each statement is executed
  - lcov
    - a graphical front-end for gcov
    - available at http://ltp.sourceforge.net/coverage/lcov.php

Similar tools exist for mac and windows

Continuous integration (CI): a master branch that always works

- Code changes trigger automated builds/tests on target platforms
- Builds/tests finish *in a reasonable amount of time*, providing useful feedback when it's most needed
- Immensely helpful!
- Requires some work, though:
  - A reasonably automated build system
  - An automated test system with significant test coverage
  - A set of systems on which tests will be run, and a controller

Continuous integration (CI): a master branch that always works

- Has existed for some time
- Adoption has been slow
  - Setting up and maintaining CI systems is difficult, labor-intensive (typically requires a dedicated staff member)
  - *You have to be doing a lot of things right to even consider CI*

Cloud-based CI is available as a service on GitHub

- Automated builds/tests can be triggered via pull requests
- Builds/tests can be run on cloud systems – no server in your closet. *Great use of the cloud!*
- Test results are reported on the pull request page (with links to detailed logs)
- Already being used successfully by scientific computing projects, with noticeable benefits to productivity
- Not perfect, but *far* better than not doing CI

Travis CI is a great choice for HPC

- Integrates easily with GitHub
- *Free* for Open Source projects
- Supports environments with C/C++/Fortran compilers (GNU, Clang, Intel[?])
- Linux, Mac platforms available
- *Relatively* simple, *reasonably* flexible configuration file
  - Documentation is sparse, but we now have working examples

Travis CI live demo

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

How to use lcov

- Compile and link your code with --coverage flag
  - It's a good idea to disable optimization
- Run your test suite
- Collect coverage data using lcov
- Generate html output using genhtml

Slide 27

KAM3 I will not be offended if someone recommends removing the gcov/lcov tutorial.
Klinvex, Alicia Marie, 8/18/2016

A simple example

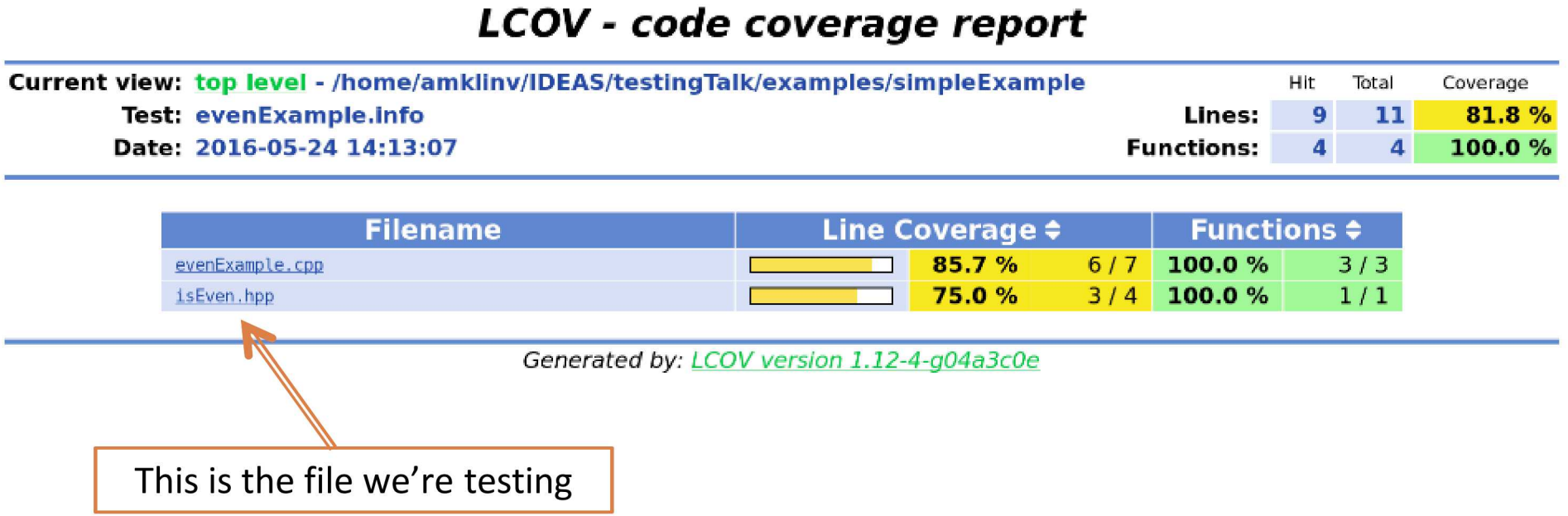
```
#include<iostream>
#include "isEven.hpp"

int main()
{
  int num = 8;

  if(isEven(num))
    std::cout << num << " is an even number.\nTEST PASSED";
  else
    std::cout << num << " is an odd number.\nTEST FAILED";

  return 0;
}
```

```
bool isEven(int x)
{
  if(x%2 == 0)
    return true;
  return false;
}
```

A simple example

- Compile and link with --coverage flag
  - `g++ --coverage evenExample.cpp -o evenExample`
  - This creates a file called evenExample.gcno
- Run the test
  - `./evenExample`
  - This creates a file called evenExample.gcda
- Collect coverage data using lcov
  - `lcov --capture --directory . --output-file evenExample.info`
  - This creates evenExample.info
- Generate html output using genhtml
  - `genhtml evenExample.info --output-directory evenHTML`
  - This generates html files in the directory evenHTML

A simple example



LCOV - code coverage report

Current view: top level - /home/amklinv/IDEAS/testingTalk/examples/simpleExample
Test: evenExample.info
Date: 2016-05-24 14:13:07

	Hit	Total	Coverage
Lines:	9	11	81.8 %
Functions:	4	4	100.0 %

Filename	Line Coverage		Functions	
evenExample.cpp	85.7 %	6 / 7	100.0 %	3 / 3
isEven.hpp	75.0 %	3 / 4	100.0 %	1 / 1

Generated by: LCOV version 1.12-4-g04a3c0e

This is the file we're testing

A simple example

LCOV - code coverage report

				Hit	Total	Coverage
Current view:	top level - home/amklinv/IDEAS/testingTalk/examples/simpleExample - isEven.hpp (source / functions)		**Lines:**	3	4	75.0 %
Test:	evenExample.info		**Functions:**	1	1	100.0 %
Date:	2016-05-24 14:13:07					

	Line data		Source code
1	1	:	bool isEven(int x)
2		:	{
3	1	:	if(x%2 == 0)
4	1	:	return true;
5		:	
6	0	:	return false;
7		:	}

We never tested this line of code
(which activates when x is odd)

IDEAS productivity

Let's add another test

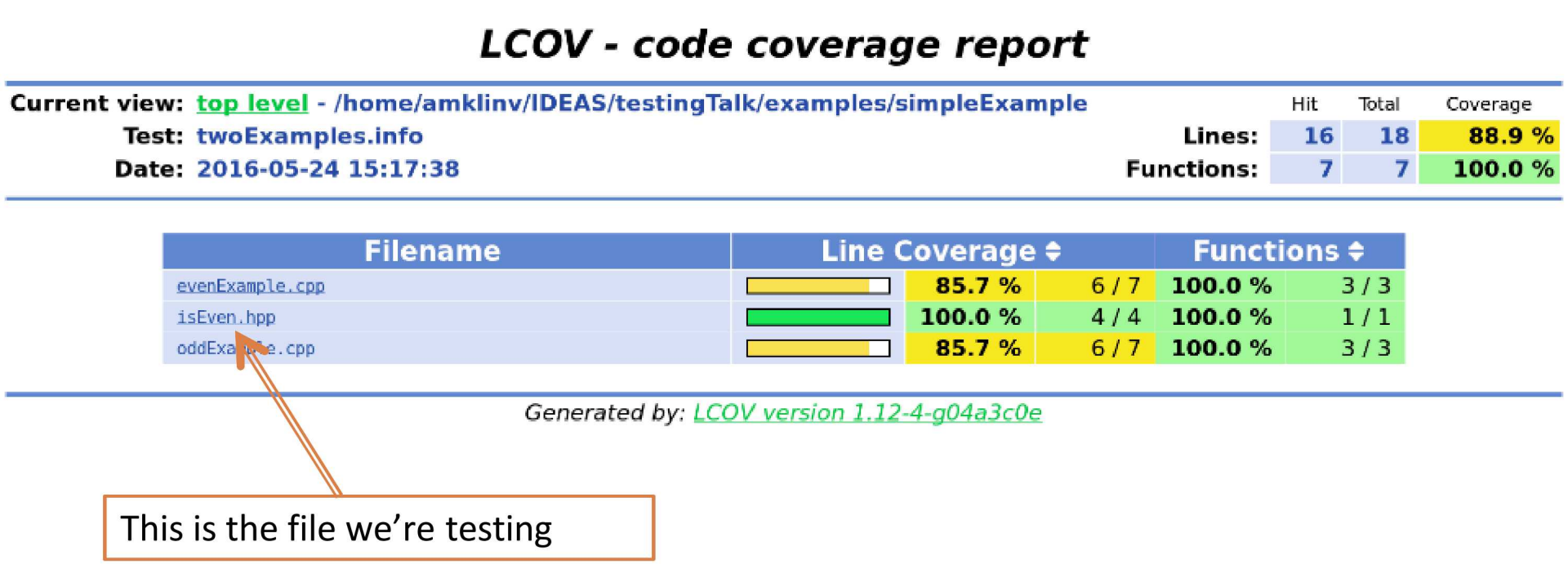
```
#include<iostream>
#include "isEven.hpp"

int main()
{
  int num = 7;

  if(isEven(num))
    std::cout << num << " is an even number.\nTEST FAILED";
  else
    std::cout << num << " is an odd number.\nTEST PASSED";

  return 0;
}
```

```
bool isEven(int x)
{
  if(x%2 == 0)
    return true;
  return false;
}
```

A simple example

- Compile and link with --coverage flag
  - `g++ --coverage oddExample.cpp -o oddExample`
  - This creates a file called oddExample.gcno
- Run the test
  - `./oddExample`
  - This creates a file called oddExample.gcda
- Collect coverage data for BOTH TESTS using lcov
  - `lcov --capture --directory . --output-file twoExamples.info`
  - This creates twoExamples.info
- Generate html output using genhtml
  - `genhtml twoExamples.info --output-directory totalHTML`
  - This generates html files in the directory totalHTML

A simple example



LCOV - code coverage report

		Hit	Total	Coverage
Current view:	top level - /home/amklinv/IDEAS/testingTalk/examples/simpleExample			
Test:	twoExamples.info	**Lines:**	16	18	**88.9 %**
Date:	2016-05-24 15:17:38	**Functions:**	7	7	**100.0 %**

Filename	Line Coverage		Functions	
evenExample.cpp	**85.7 %**	6 / 7	**100.0 %**	3 / 3
isEven.hpp	**100.0 %**	4 / 4	**100.0 %**	1 / 1
oddExample.cpp	**85.7 %**	6 / 7	**100.0 %**	3 / 3

Generated by: LCOV version 1.12-4-g04a3c0e

This is the file we're testing

A simple example

LCOV - code coverage report

Current view:	top level - home/amkInv/IDEAS/testingTalk/examples/simpleExample - IsEven.hpp (source / functions)		Hit	Total	Coverage
Test:	twoExamples.info	**Lines:**	4	4	100.0 %
Date:	2016-05-24 15:17:38	**Functions:**	1	1	100.0 %

Line data	Source code
1	2 : bool isEven(int x)
2	: {
3	2 : if(x%2 == 0)
4	1 : return true;
5	:
6	1 : return false;
7	: }

We tested every line of this function

IDEAS productivity

A real example - xSDKTrilinos

- Part of the Trilinos library, developed at SNL as part of the IDEAS project
- Contains the interfaces between Trilinos, PETSc, and hypre
- Available at https://github.com/trilinos/xSDKTrilinos
- Ten automated tests are run nightly
  - Six are actually examples that were converted into tests
- Did we leave anything out?

A real example - xSDKTrilinos

- Step 1: Modify our CMake configuration file to use

trilinos-build : vim

File Edit View Scrollback Bookmarks Settings Help

```
\
  -D TPL_ENABLE_PETSC:BOOL=ON \
  -D PETSC_LIBRARY_DIRS:FILEPATH="${PETSC_LIB_DIR}" \
  -D PETSC_INCLUDE_DIRS:FILEPATH="${PETSC_INCLUDE_DIR}" \
\
  -D TPL_ENABLE_ParMETIS:BOOL=ON \
  -D ParMETIS_LIBRARY_DIRS:FILEPATH="${SUPERLU_LIB_DIR}" \
  -D ParMETIS_INCLUDE_DIRS:FILEPATH="${SUPERLU_INCLUDE_DIR}" \
\
  -D TPL_ENABLE_HYPRE:BOOL=ON \
  -D HYPRE_LIBRARY_DIRS:FILEPATH="${HYPRE_LIB_DIR}" \
  -D HYPRE_INCLUDE_DIRS:FILEPATH="${HYPRE_INCLUDE_DIR}" \
\
  -D TPL_ENABLE_SuperLUDist:BOOL=ON \
  -D SuperLUDist_LIBRARY_DIRS:FILEPATH="${SUPERLU_LIB_DIR}" \
  -D SuperLUDist_INCLUDE_DIRS:FILEPATH="${SUPERLU_INCLUDE_DIR}" \
\
  -D Trilinos_ENABLE_Amesos2:BOOL=ON \
  -D Trilinos_ENABLE_xSDKTrilinos:BOOL=ON \
\
  -D CMAKE_CXX_FLAGS:STRING="--coverage" \
  -D CMAKE_C_FLAGS:STRING="--coverage" \
  -D CMAKE_EXE_LINKER_FLAGS:STRING="--coverage"\
  -D Trilinos_ENABLE_Fortran:BOOL=OFF \
\
  ${TRILINOS_HOME}
-- INSERT --                                                    59,48         Bot
```

trilinos-build : vim

A real example - xSDKTrilinos

- Build Trilinos (including xSDKTrilinos)
  - `./do-configure`
  - `make -j`
- This will create a whole bunch of .gcno files
- This will also build the xSDKTrilinos tests because the configure file included
  - `-D Trilinos_ENABLE_TESTS:BOOL=ON`
  - `-D Trilinos_ENABLE_EXAMPLES:BOOL=ON`
  - `-D Trilinos_ENABLE_ALL_OPTIONAL_PACKAGES=ON`

A real example - xSDKTrilinos

- Run the tests using ctest

trilinos-build : ctest

File Edit View Scrollback Bookmarks Settings Help

```
[amklinv@s995692 trilinos-build]$ ctest
Test project /home/amklinv/IDEAS/testingTalk/trilinos-build
      Start  1: Amesos2_KLU2_UnitTests_MPI_4
 1/18 Test  #1: Amesos2_KLU2_UnitTests_MPI_4 ........................   Passed    1.46 sec
      Start  2: Amesos2_SuperLU_DIST_Solver_Test_MPI_4
 2/18 Test  #2: Amesos2_SuperLU_DIST_Solver_Test_MPI_4 ..............   Passed    2.80 sec
      Start  3: Amesos2_SolverFactory_UnitTests_MPI_4
 3/18 Test  #3: Amesos2_SolverFactory_UnitTests_MPI_4 ...............   Passed    1.46 sec
      Start  4: Amesos2_Tpetra_MultiVector_Adapter_UnitTests_MPI_4
 4/18 Test  #4: Amesos2_Tpetra_MultiVector_Adapter_UnitTests_MPI_4 ...   Passed    1.36 sec
      Start  5: Amesos2_Tpetra_CrsMatrix_Adapter_UnitTests_MPI_4
 5/18 Test  #5: Amesos2_Tpetra_CrsMatrix_Adapter_UnitTests_MPI_4 .....   Passed    1.42 sec
      Start  6: Amesos2_Epetra_MultiVector_Adapter_UnitTests_MPI_4
 6/18 Test  #6: Amesos2_Epetra_MultiVector_Adapter_UnitTests_MPI_4 ...   Passed    1.35 sec
      Start  7: Amesos2_Epetra_RowMatrix_Adapter_UnitTests_MPI_4
 7/18 Test  #7: Amesos2_Epetra_RowMatrix_Adapter_UnitTests_MPI_4 .....   Passed    1.35 sec
      Start  8: Amesos2_CrsMatrix_Adapter_Consistency_Tests_MPI_4
 8/18 Test  #8: Amesos2_CrsMatrix_Adapter_Consistency_Tests_MPI_4 ....   Passed    1.47 sec
      Start  9: xSDKTrilinos_PETScAIJMatrix_MPI_4
 9/18 Test  #9: xSDKTrilinos_PETScAIJMatrix_MPI_4 ...................   Passed    1.42 sec
      Start 10: xSDKTrilinos_PETSc_Amesos2_example_MPI_4
10/18 Test #10: xSDKTrilinos_PETSc_Amesos2_example_MPI_4 ............   Passed    1.42 sec
      Start 11: xSDKTrilinos_PETSc_Anasazi_example_MPI_4
11/18 Test #11: xSDKTrilinos_PETSc_Anasazi_example_MPI_4 ............   Passed    2.71 sec
      Start 12: xSDKTrilinos_PETSc_Ifpack2_example_MPI_4
12/18 Test #12: xSDKTrilinos_PETSc_Ifpack2_example_MPI_4 ............   Passed    1.47 sec
      Start 13: xSDKTrilinos_PETSc_MueLu_example_MPI_4
```

...ilinos-build : ctest

A real example - xSDKTrilinos

- All tests passed. Yay!

trilinos-build : ctest

File Edit View Scrollback Bookmarks Settings Help

```
      Start 10: xSDKTrilinos_PETSc_Amesos2_example_MPI_4
10/18 Test #10: xSDKTrilinos_PETSc_Amesos2_example_MPI_4 .............   Passed    1.42 sec
      Start 11: xSDKTrilinos_PETSc_Anasazi_example_MPI_4
11/18 Test #11: xSDKTrilinos_PETSc_Anasazi_example_MPI_4 .............   Passed    2.71 sec
      Start 12: xSDKTrilinos_PETSc_Ifpack2_example_MPI_4
12/18 Test #12: xSDKTrilinos_PETSc_Ifpack2_example_MPI_4 .............   Passed    1.47 sec
      Start 13: xSDKTrilinos_PETSc_MueLu_example_MPI_4
13/18 Test #13: xSDKTrilinos_PETSc_MueLu_example_MPI_4 ...............   Passed    2.34 sec
      Start 14: xSDKTrilinos_example_TpetraKSP_MPI_4
14/18 Test #14: xSDKTrilinos_example_TpetraKSP_MPI_4 .................   Passed    1.50 sec
      Start 15: xSDKTrilinos_example_EpetraKSP_MPI_4
15/18 Test #15: xSDKTrilinos_example_EpetraKSP_MPI_4 .................   Passed    1.37 sec
      Start 16: xSDKTrilinos_HypreTest_MPI_4
16/18 Test #16: xSDKTrilinos_HypreTest_MPI_4 .........................   Passed    1.42 sec
      Start 17: xSDKTrilinos_Hypre_Belos_example_MPI_4
17/18 Test #17: xSDKTrilinos_Hypre_Belos_example_MPI_4 ...............   Passed    1.38 sec
      Start 18: xSDKTrilinos_Hypre_Solve_example_MPI_4
18/18 Test #18: xSDKTrilinos_Hypre_Solve_example_MPI_4 ...............   Passed    1.36 sec

100% tests passed, 0 tests failed out of 18

Label Time Summary:
Amesos2         =  12.67 sec (8 tests)
xSDKTrilinos    =  16.39 sec (10 tests)

Total Test time (real) =  29.11 sec
[amklinv@s995692 trilinos-build]$
```

- This also created a bunch of .gcda files

A real example - xSDKTrilinos

- Collect coverage data for the tests using lcov
  - `lcov --capture --directory . --output-file xSDKTrilinos.info`
  - This creates xSDKTrilinos.info
  - lcov processes 634 gcda files in this step, so this does take a few minutes

A real example - xSDKTrilinos

- Generate html output using genhtml
  - `genhtml xSDKTrilinos.info --output-directory xSDKTrilinos`
  - This generates html files in the directory xSDKTrilinos
  - This step takes a few minutes too

A real example - xSDKTrilinos

LCOV - code coverage report

		Hit	Total	Coverage
Current view:	**top level - xSDKTrilinos/petsc/src**			
Test:	**xSDKTrilinos.info**	**Lines:**	**342**	**420**	**81.4 %**
Date:	**2016-06-02 15:36:10**	**Functions:**	**77**	**117**	**65.8 %**

Filename	Line Coverage		Functions	
BelosPETScSolMgr.hpp	**84.7 %**	166 / 196	**68.2 %**	30 / 44
Tpetra_PETScAIJGraph.hpp	**75.3 %**	67 / 89	**62.5 %**	20 / 32
Tpetra_PETScAIJMatrix.hpp	**80.7 %**	109 / 135	**65.9 %**	27 / 41

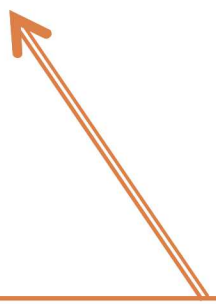
Generated by: LCOV version 1.12-4-g04a3c0e

Let's take a look at the solver interface.

```
766           : //=============================================================================
767           : template<class ScalarType, class MV, class OP>
768       192 : PetscErrorCode PETScSolMgr<ScalarType,MV,OP>::applyPrec(PC M, Vec x, Vec Mx)
769           : {
770           :   using Teuchos::RCP;
771           :   typedef PETScSolMgrHelper<ScalarType,MV,OP> Helper;
772           :
773           :   PetscErrorCode ierr;
774           :   const PetscScalar * xData;
775           :   PetscScalar * MxData;
776           :   void * ptr;
777           :
778           :   // Get the problem out of the context
779       192 :   ierr = PCShellGetContext(M,&ptr); CHKERRQ(ierr);
780       192 :   LinearProblem<ScalarType,MV,OP> * problem = (LinearProblem<ScalarType,MV,OP>*)ptr;
781           :
782           :   // Rip the raw data out of the PETSc vectors
783       192 :   ierr = VecGetArrayRead(x, &xData); CHKERRQ(ierr);
784       192 :   ierr = VecGetArray(Mx, &MxData); CHKERRQ(ierr);
785           :
786           :   // Wrap the PETSc data in a Trilinos Vector
787       192 :   RCP<MV> trilinosX, trilinosMX;
788       192 :   Helper::wrapVector(const_cast<PetscScalar*>(xData), *problem->getLHS(), trilinosX);
789       192 :   Helper::wrapVector(MxData, *problem->getLHS(), trilinosMX);
790           :
791           :   // Perform the multiplication
792       192 :   if(problem->isLeftPrec()) {
793       192 :     problem->applyLeftPrec(*trilinosX, *trilinosMX);
794           :   }
795           :   else {
796         0 :     problem->applyRightPrec(*trilinosX, *trilinosMX);
797           :   }
798           :
799           :   // Unwrap the vectors; this is necessary if we copied data in the wrap step
800       192 :   Helper::unwrapVector(MxData, trilinosMX);
801           :
802           :   // Restore the PETSc vectors
803       192 :   ierr = VecRestoreArrayRead(x,&xData); CHKERRQ(ierr);
804       192 :   ierr = VecRestoreArray(Mx,&MxData); CHKERRQ(ierr);
805           :
806       192 :   return 0;
807           : }
808           :
```

A real example - xSDKTrilinos


```
791              :   // Perform the multiplication
792          192 :   if(problem->isLeftPrec()) {
793          192 :     problem->applyLeftPrec(*trilinosX, *trilinosMX);
794              :   }
795              :   else {
796            0 :     problem->applyRightPrec(*trilinosX, *trilinosMX);
797              :   }
```



Oops. I never tested the RIGHT preconditioning branch.

A hands-on gcov tutorial

- https://amklinv.github.io/morpheus/index.html

Coverity scan

- A free cloud-based static analysis product for open source code
  - Also available for non open source code, but not free
- Analyzes over 4000 open source projects
- Used to analyze
  - Sudden unintended acceleration of Toyota vehicles
  - Large Hadron Collider software
  - Mars Curiosity rover flight software
  - Libre Office

Coverity scan

- Automatically looks at all the different paths
- Finds
  - Resource leaks
  - Dereferences of null pointers
  - Use of uninitialized data
  - Memory corruptions
  - Control flow issues
  - Use of resources that have been freed
  - And more!

How to use coverity scan

- Create a project
- Tell it about your open source license
- Options for performing the scan:
  - Upload a tarball
  - Point it to a URL
  - Use TravisCI (https://scan.coverity.com/travis_ci)

Coverity analysis of Trilinos

- https://scan.coverity.com/projects/1680

Methodology

Evaluating project needs

Devising testing regime

Examples from Alquimia, Amanzi and Trilinos

Evaluating Project Needs

Why not use the most stringent testing always ?

- Effort spent in devising tests and testing regime are a tax on team resources
- When does the tax become too high
  - The team is not able to meet its code use objectives
- When is the tax paid too low
  - Necessary oversight not provided
  - Defects in code sneak through

Evaluating Project Needs

- Objectives
  - Proof of concept
  - Limited research use
  - Library
  - Production – simulations and analysis
- Team
  - Number of developers
  - Background of developers
  - Geographical spread
- Lifecycle stages
- Lifetime
  - New code versus some legacy components
- Complexity

Commonalities

- Unit testing is always good
  - It is unlikely to be sufficient
- Verification of expected behavior
- Understanding the range of validity and applicability is always important
  - Especially for individual solvers

Customizing for Project Needs : Objectives

- Proof of concept
  - Nothing more than the common testing of previous slide
- Limited use
  - Manually run test-suite before each use may suffice
    - Coverage is still important
- Library
  - Depends on team and complexity
- Regular simulation and analysis
  - Depends on team and complexity
  - Testing coverage needs system level integrated coverage

Customizing for Project Needs : Team

- One to two developers – periodic manual testing and verification
- Mid size to large team – automated test suite running regularly
- Subgroups within the team – automated test-suite with tests of different granularity
  - May also need multiple suites run on their own schedules

Other Factors

- Frequency of testing depends upon lifecycle stage
  - Midsize to large team working on the same code component doing rapid development – ideally continuous integration
  - Stable mature code - regular automated testing
  - Refactoring – needs its own strategy
- Complexity and Lifetime
  - Affect the testing regime being devised
  - Testing needs and strategy differ when code incorporates legacy components

Devising the Testing Regime

- Ignoring the easy cases
- Considering complexity and long lifetime
  - What runs in the regular test-suite?
  - If there are subgroups, what goes into the separate test-suites?
  - How often should each test-suite run?
  - How do you ensure interoperability coverage?
- The question to answer is how to balance the tax amount for maximum productivity.

Examples

- From Alquimia, amanzi and Trilinos
- Focus on different team sizes and objectives
- Different lifetime spans

How is real DOE code tested?

	How many developers?	How much code?	How frequent are changes?
Alquimia	< 1 FTE	O(1,000) lines of code	Every few months
Amanzi	About a dozen	O(100,000) lines of code	A few commits every day
Trilinos	A few dozen	O(1,000,000) lines of code	About 12 per day

Slide 60

KAM8 This is the beginning of the examples section (30 min)

Klinvex, Alicia Marie, 8/18/2016

What is Alquimia?

- Biogeochemistry API and wrapper library
- Provides a unified interface to existing geochemistry engines
  - CrunchFlow
  - PFLOTRAN
- Allows subsurface flow and transport simulators to access a range of functionality
- NOT an implementation of a biogeochemistry reaction library
- Does NOT perform geochemical calculations

How is Alquimia tested?

- Continuous integration testing using Travis CI

What is Amanzi/ATS?

- Amanzi
  - A parallel flow and reactive transport simulator
  - Used to analyze multiple DOE waste disposal sites
  - Example application: modeling hydrological and biogeochemical cycling in the Colorodo River System
    - Carbon cycling is especially important because of its role in regulating atmospheric CO_2
- ATS
  - Advanced Terrestrial Simulator
  - Built on Amanzi
  - Adds physics capability to solve equations for ecosystem hydrology

Amanzi/ATS testing practices

- 156 tests that can be run via “ctest”
  - No continuous integration, but developers are expected to run the test suite before committing
  - Medium and fine-grained tests
- New physics contributions are required to come with new system-level tests
- Various granularity tests

Slide 64

KAM6 David/Ethan: is there any automated testing for Amanzi/ATS?

Klinvex, Alicia Marie, 8/18/2016

Amanzi/ATS testing granularity

- Unit tests
  - Code is highly componentized
- Medium-grained component tests
  - Discretizations
  - Solvers
- Coarse-grained system-level tests
  - Test full capability
  - Serve as example for new users

What is Trilinos?

- A collection of libraries intended to be used as building blocks for the development of scientific applications
- Organized into 66 packages
  - Linear solvers
  - Nonlinear solvers
  - Eigensolvers
  - And more!
- 10,000+ commits
- 135 contributors (according to github)
- Millions of lines of code

How is Trilinos tested?

- Trilinos has 1500 tests between its 66 packages
- Developers are strongly advised to run a checkin test script when committing
- Automated testing on a variety of different platforms

Checkin test script

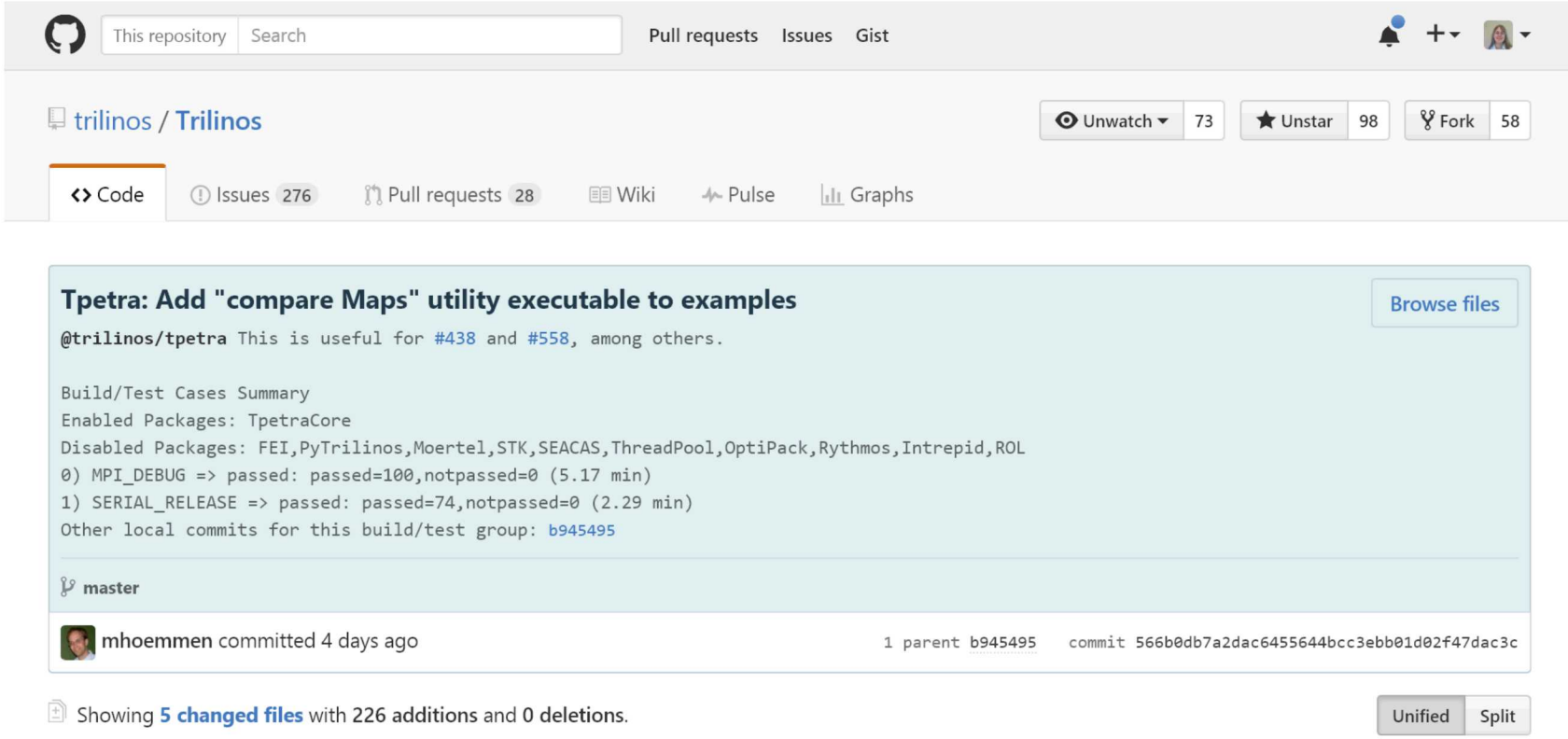
- Detects which packages were modified by your commits
- Determines which packages you potentially broke
- Configures, builds, and tests those packages
  - On success, pushes to repo
  - On failure, reports why it failed
- Useful for ensuring your changes don't break another package
- May take a while, but many people run it overnight

Why do we do automated testing if everyone uses the checkin script?

- May test a different set of packages
- May test different environments
  - Do your changes work with Intel compilers as well as GNU?
  - Do your changes work on a mac?
  - Do your changes work with CUDA?
- Identifies a small set of commits that could have broken a build or test
  - Average 12 commits per day
  - Identifies the person who knows how to un-break it
- Bugs are easier to fix if caught early

What if “bad people” don’t use the checkin script?

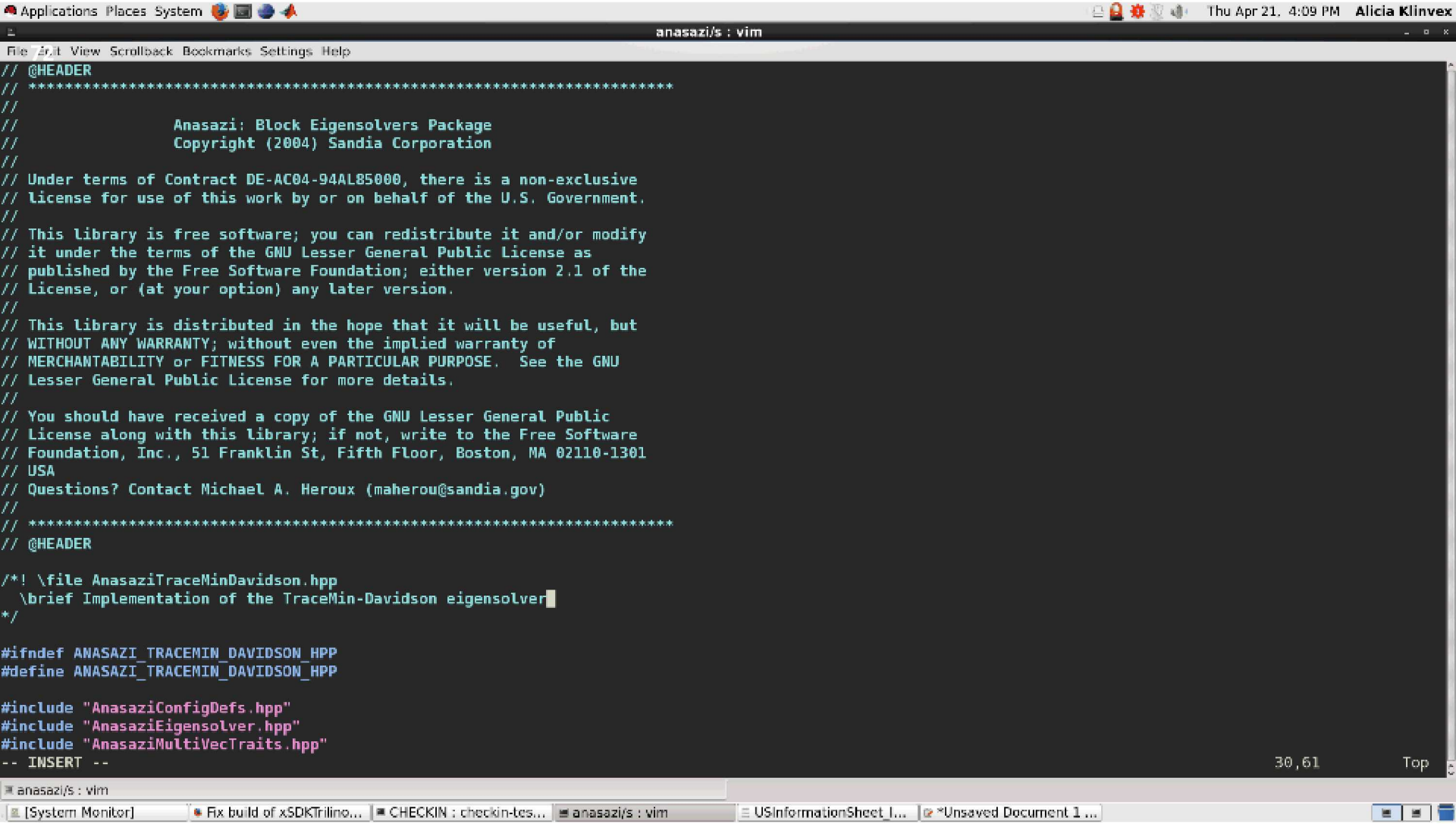
- Their commit doesn’t include the checkin script information



Checkin test script examples

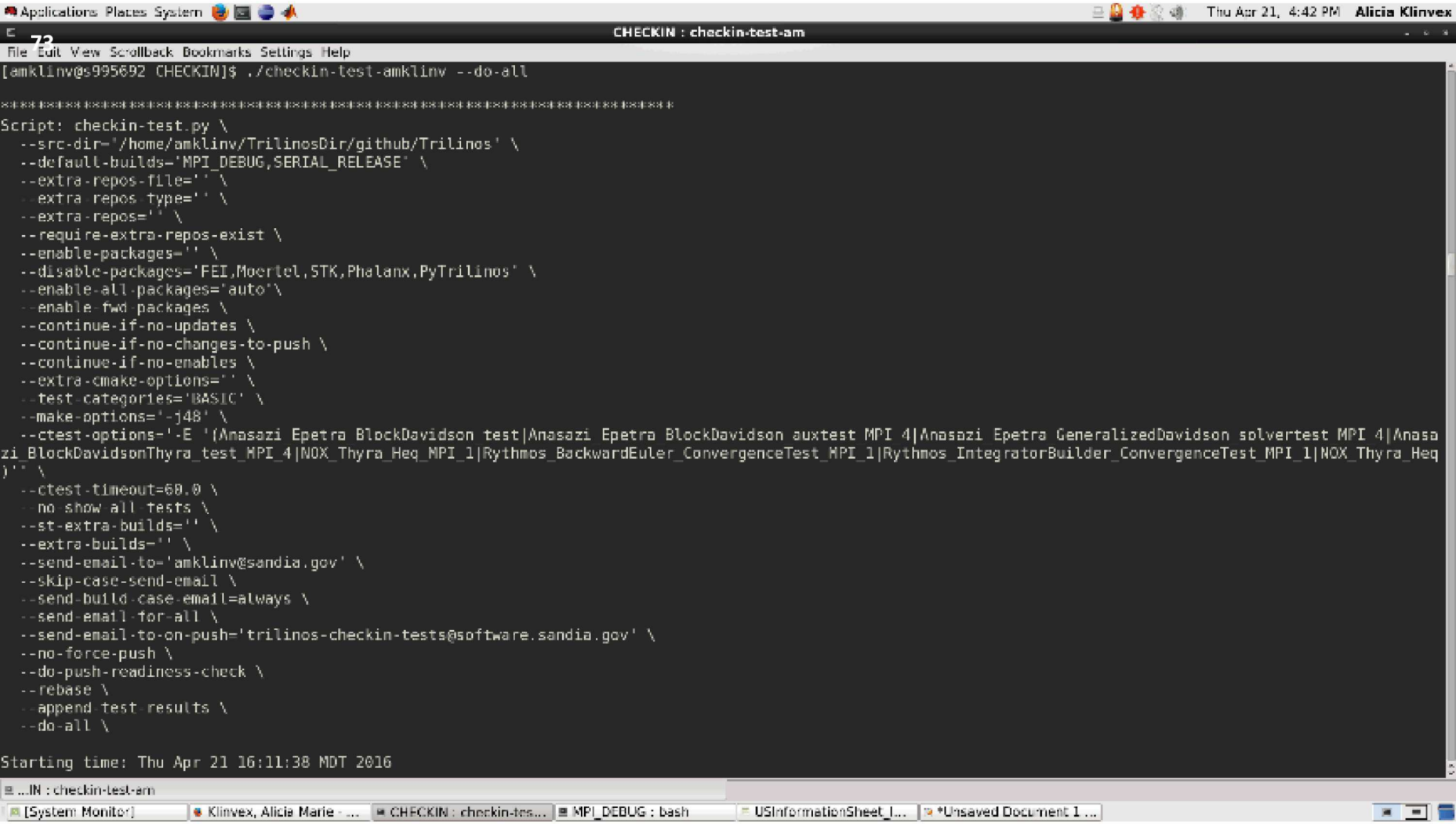
- Example 1: a harmless change to a comment
- Example 2: breaking the build
- Example 3: breaking some tests

Example 1: a harmless change



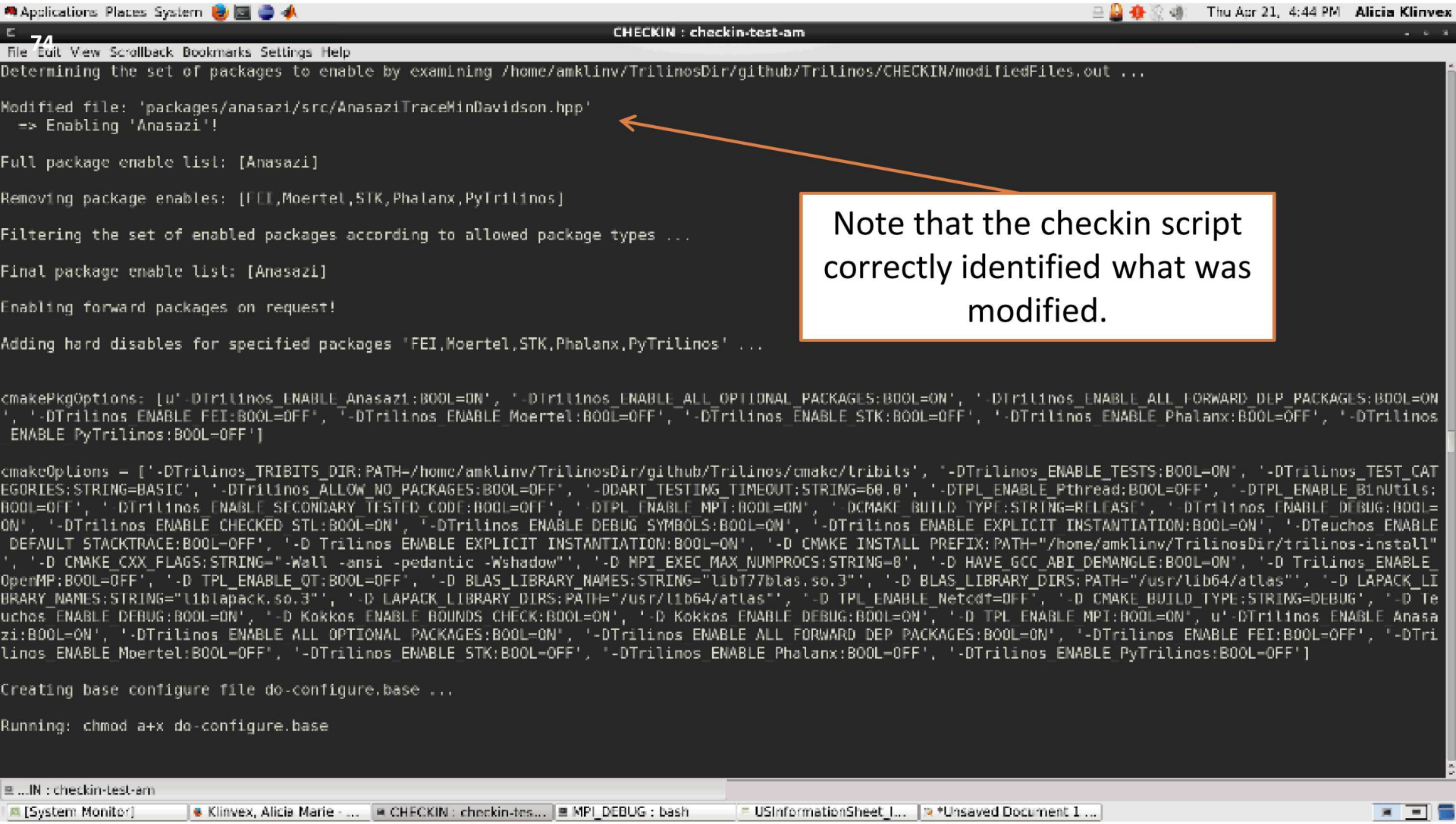
IDEAS productivity

Example 1: a harmless change



IDEAS productivity

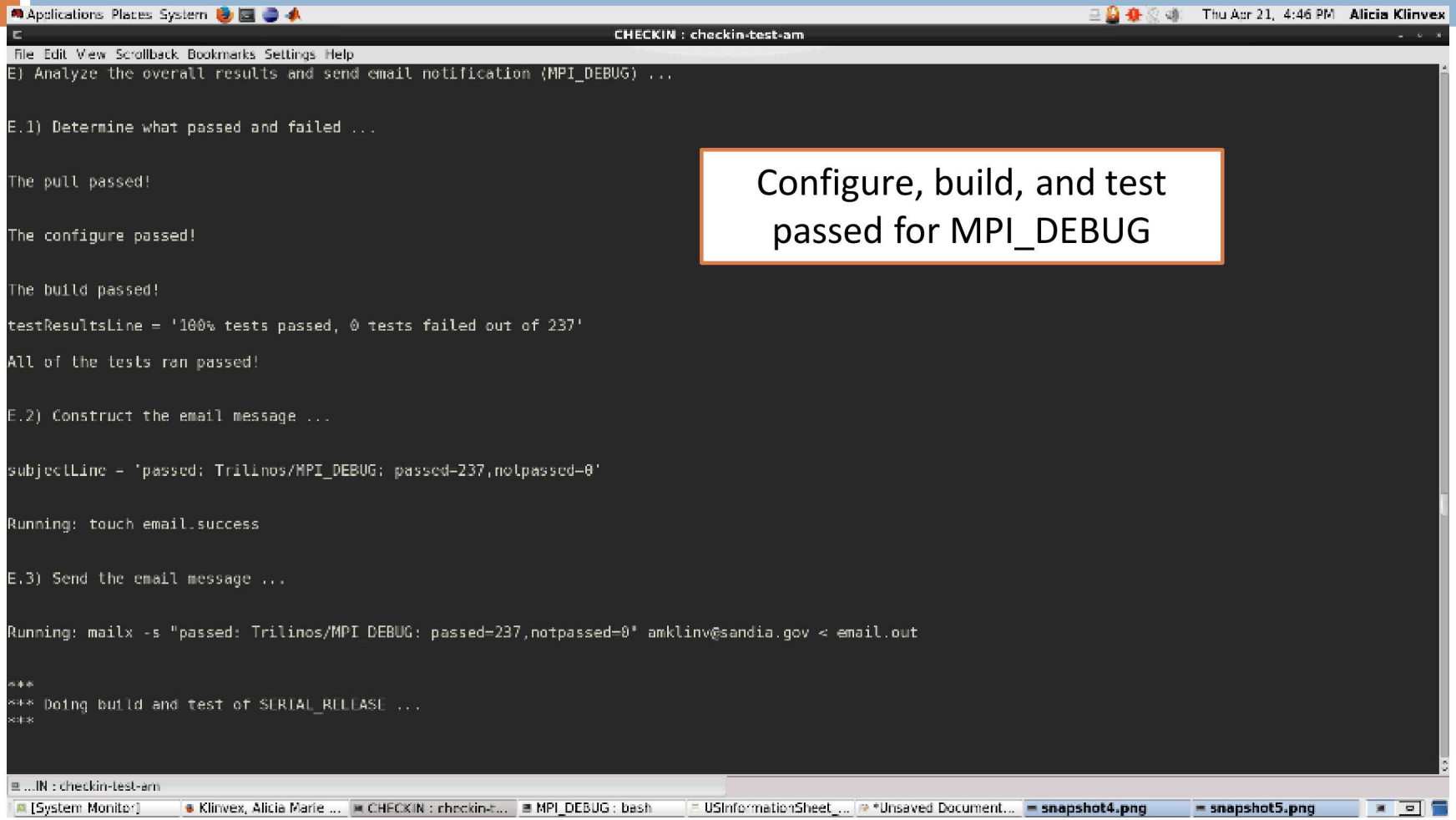
Example 1: a harmless change



Note that the checkin script correctly identified what was modified.

IDEAS productivity

Example 1: a harmless change



Configure, build, and test passed for MPI_DEBUG

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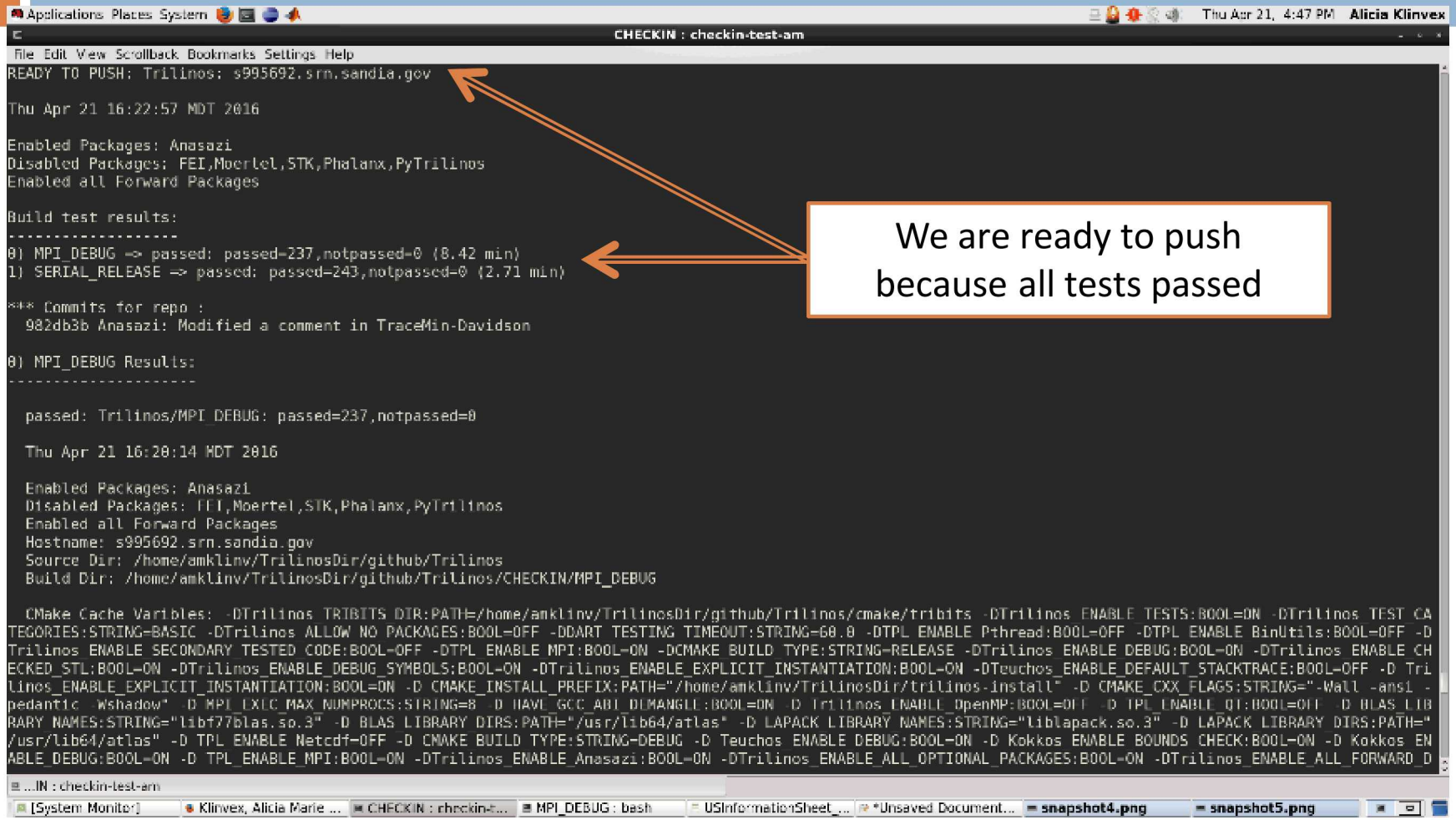
Example 1: a harmless change



We are ready to push because all tests passed

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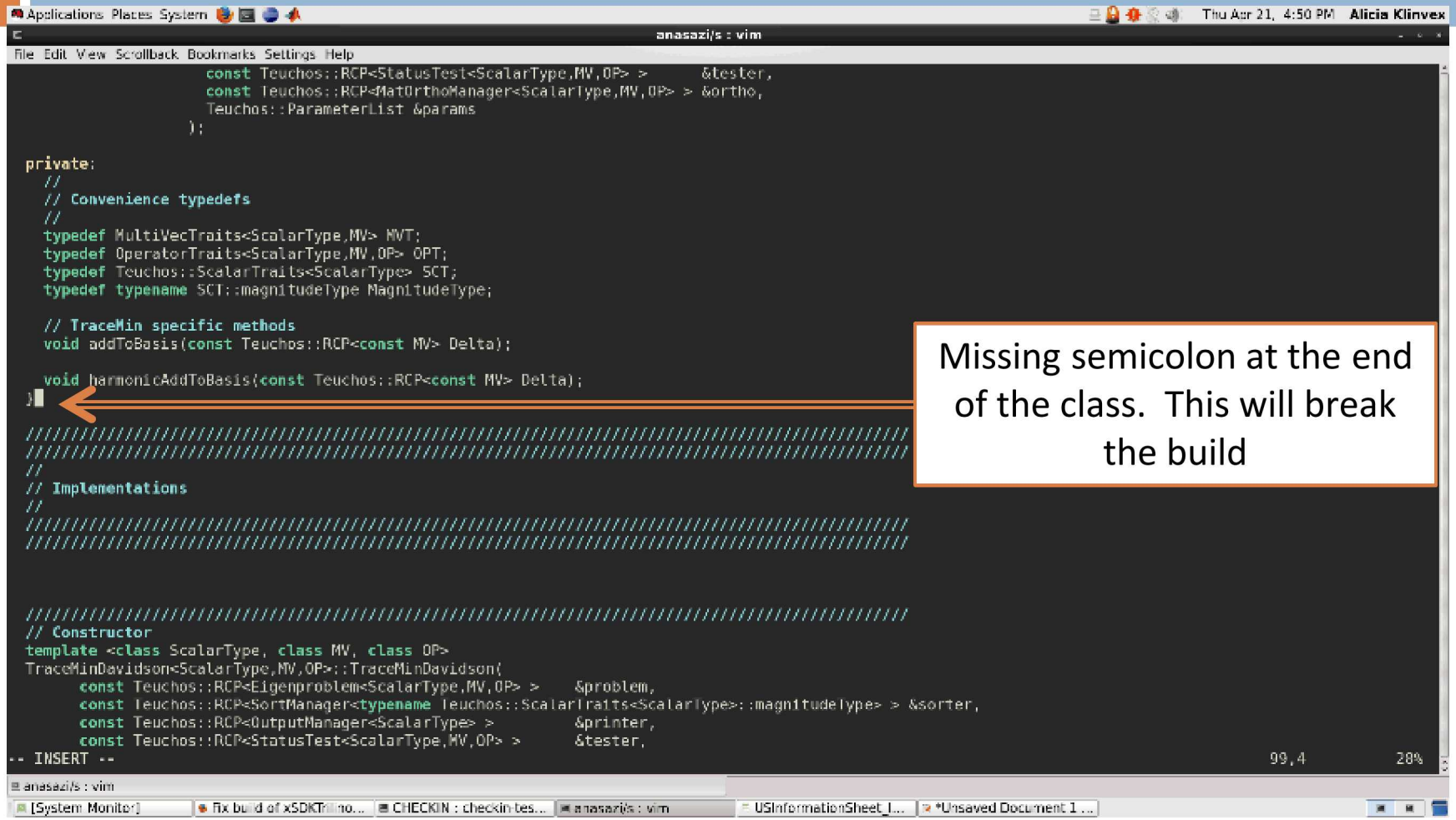
Example 2: broken build



Missing semicolon at the end of the class. This will break the build

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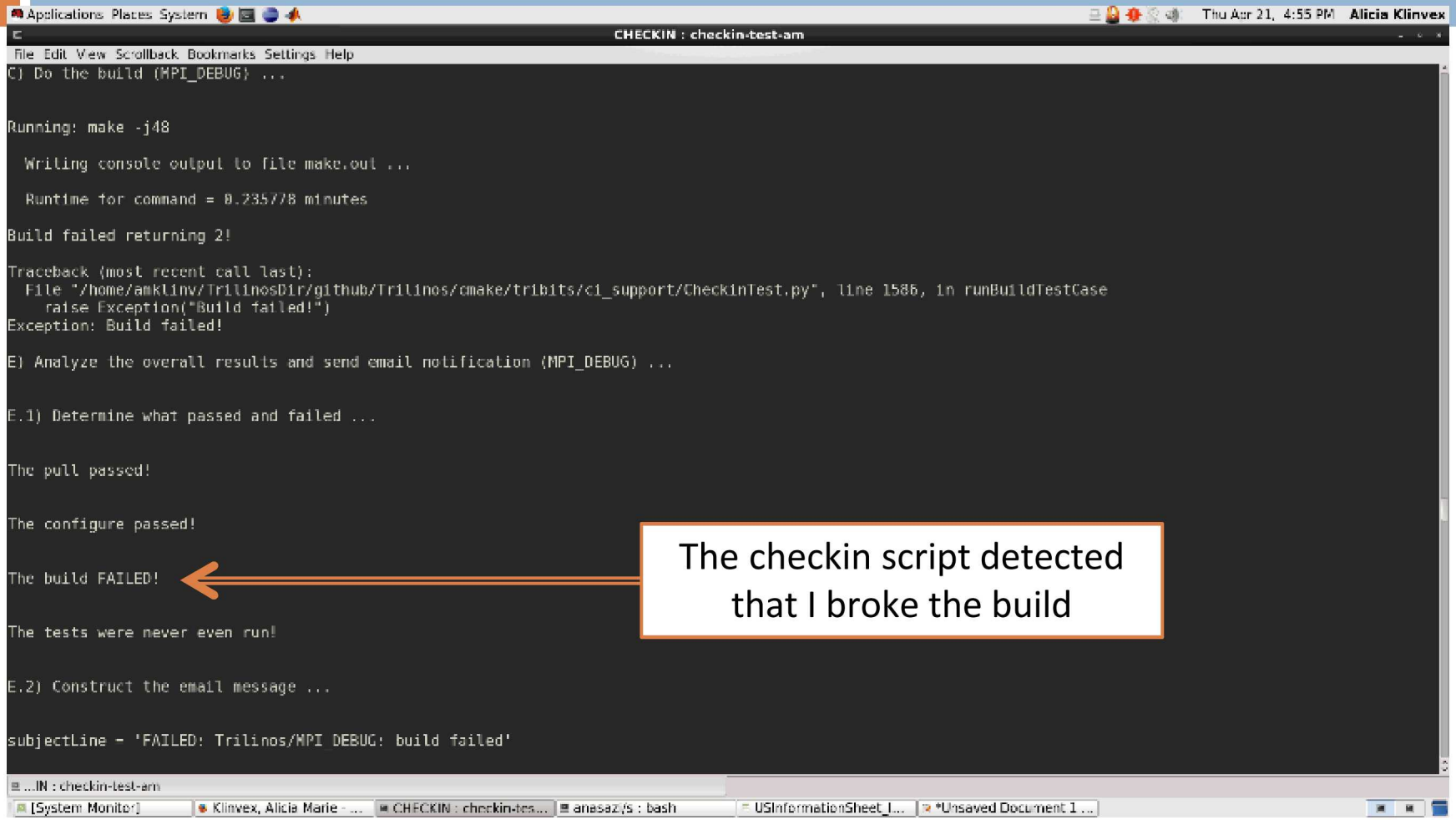
Example 2: broken build



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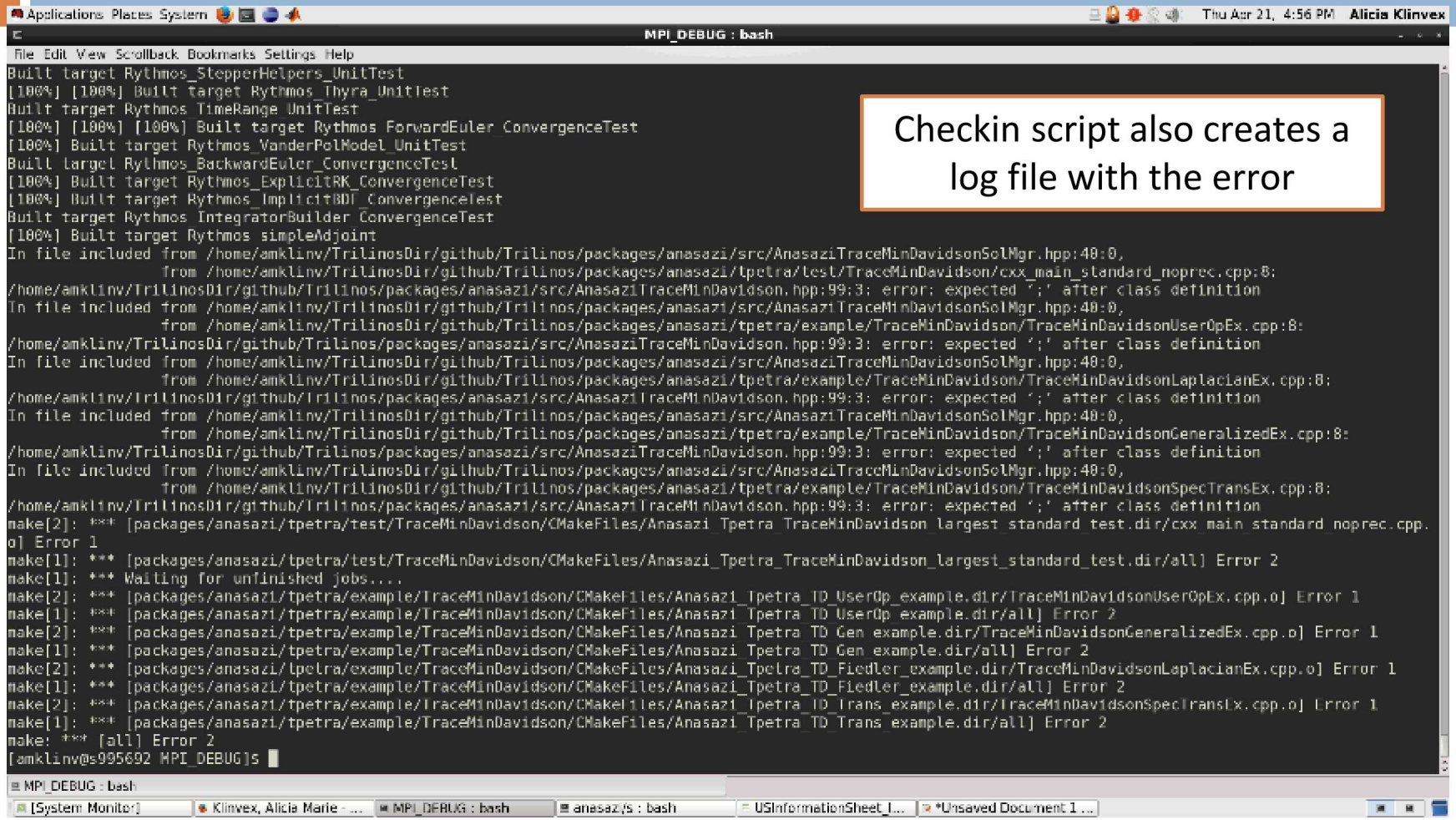
Example 2: broken build



Checkin script also creates a log file with the error

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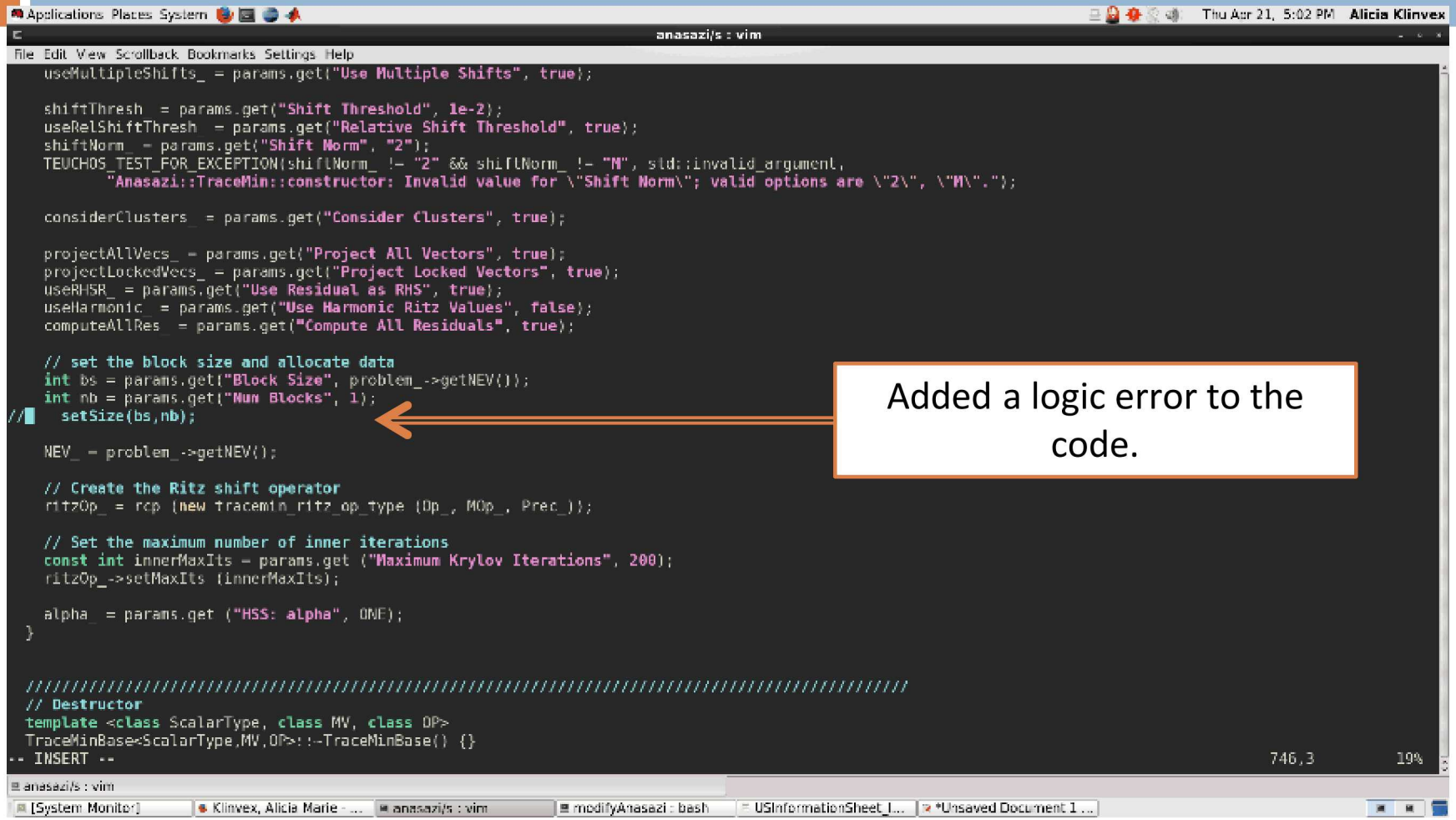
Example 3: broken tests



Added a logic error to the code.

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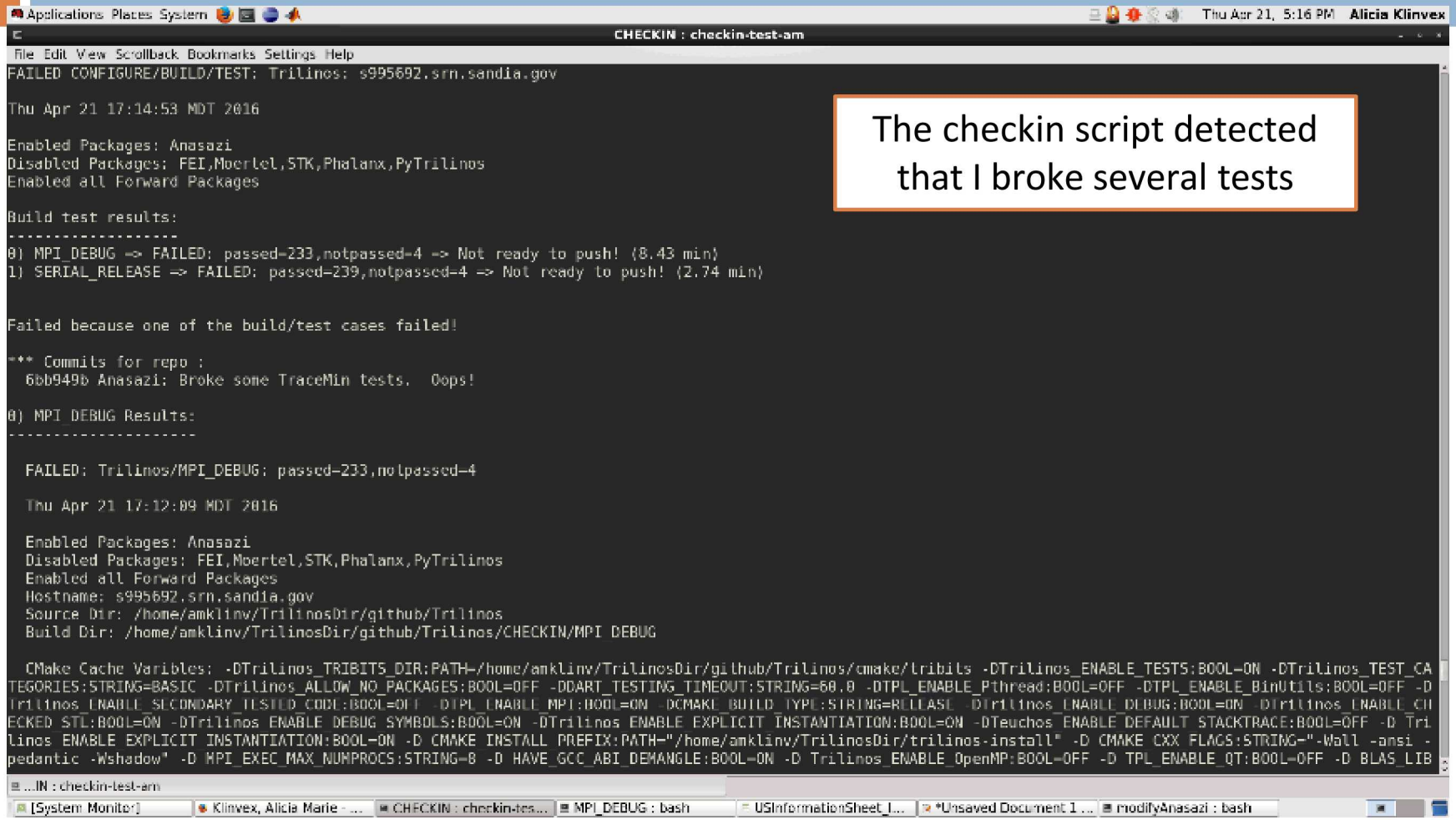
Example 3: broken tests



The checkin script detected that I broke several tests

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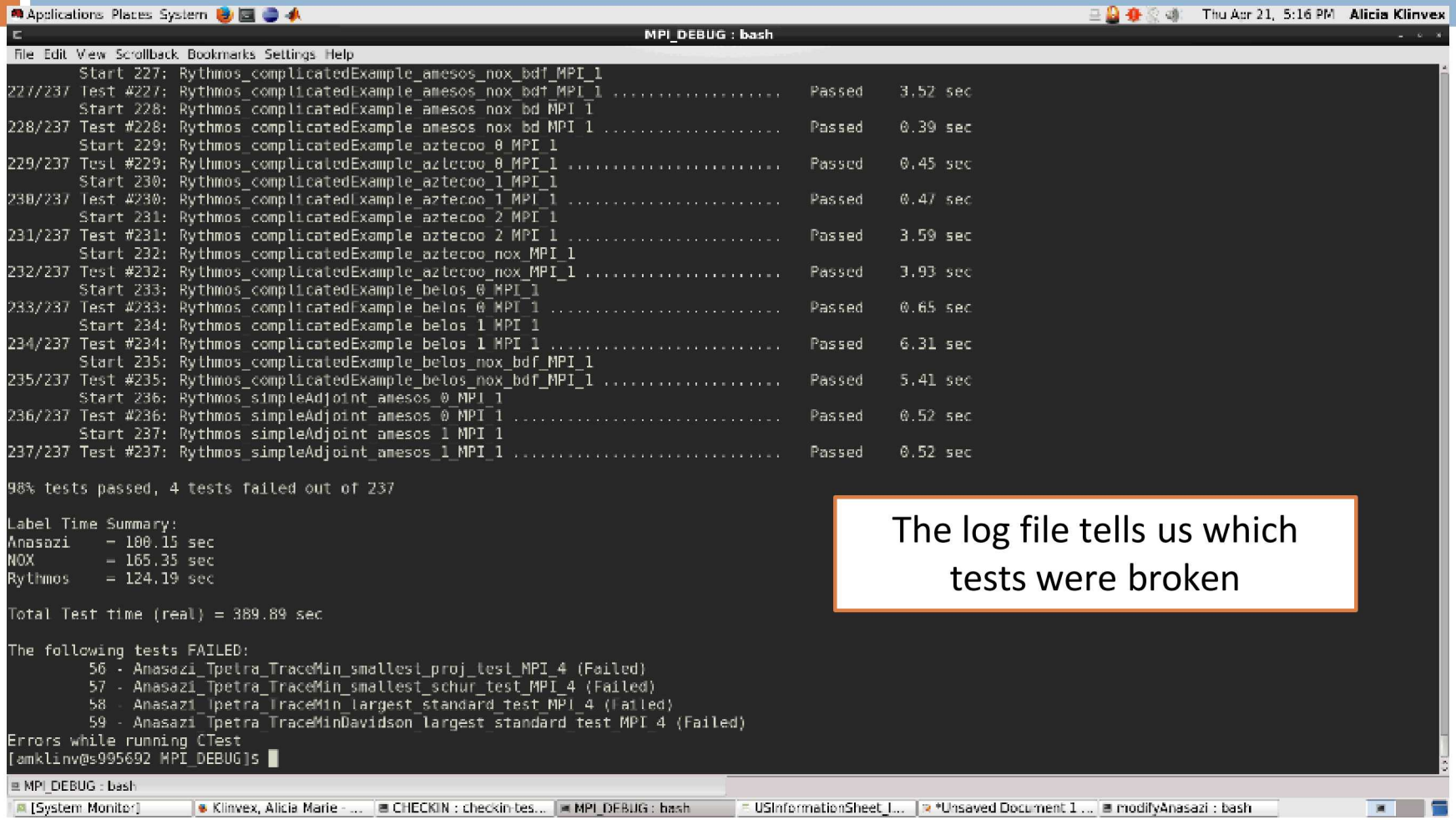
Example 3: broken tests



The log file tells us which tests were broken

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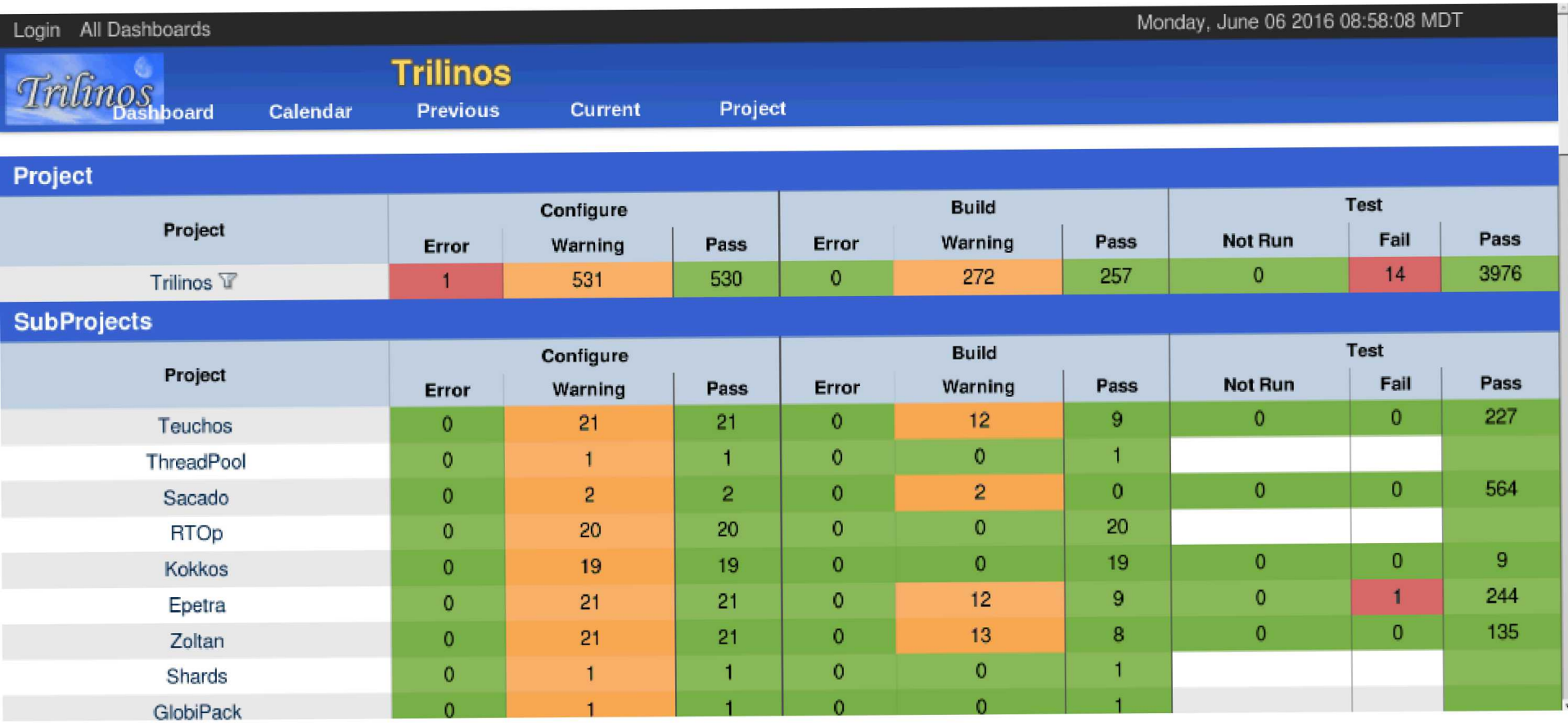
Trilinos automated testing



Login All Dashboards — Monday, June 06 2016 08:58:08 MDT

Trilinos

Dashboard Calendar Previous Current Project

Project

Project	Configure			Build			Test		
	Error	Warning	Pass	Error	Warning	Pass	Not Run	Fail	Pass
Trilinos	1	531	530	0	272	257	0	14	3976

SubProjects

Project	Configure			Build			Test		
	Error	Warning	Pass	Error	Warning	Pass	Not Run	Fail	Pass
Teuchos	0	21	21	0	12	9	0	0	227
ThreadPool	0	1	1	0	0	1			
Sacado	0	2	2	0	2	0	0	0	564
RTOp	0	20	20	0	0	20			
Kokkos	0	19	19	0	0	19	0	0	9
Epetra	0	21	21	0	12	9	0	1	244
Zoltan	0	21	21	0	13	8	0	0	135
Shards	0	1	1	0	0	1			
GlobiPack	0	1	1	0	0	1			

testing.sandia.gov/cdash/viewSubProjects.php?project=Trilinos

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Trilinos automated testing

Nightly

Site	Build Name	Update	Configure		Build		Test				
		Files	Error	Warn	Error	Warn	Not Run	Fail	Pass	Build Time	Labels
artemis.srn.sandia.gov	Linux-intel-15.0.2-MPI_RELEASE_DEV_DownStream_ETI_SERIAL-OFF_OPENMP-ON_PTHREAD-OFF_CUDA-OFF_COMPLEX-OFF	68	1	140	0	216	0	3	1256	6 hours ago	(44 labels)
lightsaber.srn.sandia.gov	Linux-GCC-4.7.2-RELEASE_DEV_MueLu_Matlab	69	0	111	0	51	0	0	431	10 hours ago	(25 labels)
enigma.sandia.gov	Linux-GCC-4.8.3-OPENMPI_1.6.4_DEBUG_DEV_MueLu_Basker	69	0	227	0	117	0	0	96	9 hours ago	(25 labels)
hansel.sandia.gov	Linux-GCC-4.4.7-MPI_OPT_DEV_XYCE	121	0	70	0	28	0	0	553	9 hours ago	(13 labels)
enigma.sandia.gov	Linux-GCC-4.8.3-OPENMPI_1.6.4_DEBUG_DEV_MueLu_KLU2	69	0	225	0	91	0	0	73	8 hours ago	(25 labels)
enigma.sandia.gov	Linux-GCC-4.8.3-OPENMPI_1.6.4_DEBUG_DEV_MueLu_ExtraTypes_EI	69	0	227	0	117	0	0	97	8 hours ago	(25 labels)
enigma.sandia.gov	Linux-GCC-4.8.3-SERIAL_DEBUG_DEV_MueLu_ExtraTypes	69	0	227	0	117	0	3	94	7 hours ago	(25 labels)
enigma.sandia.gov	Linux-GCC-4.8.3-SERIAL_RELEASE_DEV_MueLu_Experimental	69	0	227	0	113	0	4	107	6 hours ago	(25 labels)

IDEAS productivity

Trilinos automated testing

- Several Amesos2 (direct solver) tests are broken.

SubProject Dependencies

Project	Configure			Build			Test			Last submission
	Error	Warning	Pass	Error	Warning	Pass	Not Run	Fail	Pass	
Teuchos	0	22	22	0	13	9	0	0	227	2016-06-06 09:01:20
Epetra	0	22	22	0	13	9	0	1	244	2016-06-06 09:02:05
Triutils	0	22	22	0	0	21	0	0	2	2016-06-06 09:02:16
Tpetra	0	20	20	0	18	2	0	0	285	2016-06-06 08:10:13
EpetraExt	0	21	21	0	3	18	0	0	26	2016-06-06 08:11:16
ThreadPool	0	1	1	0	0	1				2016-06-06 02:51:44
Amesos	0	21	21	0	1	20	0	0	41	2016-06-06 08:16:59

- Are any of its dependencies broken?
  - Yes, there is a broken Epetra (basic linear algebra) test
  - Maybe this broke Amesos2

Trilinos automated testing

- Which tests were broken in Amesos2?

Testing started on 2016-06-06 07:42:35

Site Name: enigma.sandia.gov
Build Name: Linux-GCC-4.8.3-SERIAL_DEBUG_DEV_MueLu_ExtraTypes
Total time: 16s 840ms
OS Name: Linux
OS Platform: x86_64
OS Release: 3.10.0-229.4.2.el7.x86_64
OS Version: #1 SMP Fri Apr 24 15:26:38 EDT 2015
Compiler Version: unknown

3 tests failed.

Name	Status	Time	Details	Labels	Summary
Amesos2_Epetra_RowMatrix_Adapter_UnitTests_MPI_4	Failed	1s 860ms	Completed (Failed)	Amesos2	Broken
Amesos2_Epetra_MultiVector_Adapter_UnitTests_MPI_4	Failed	1s 980ms	Completed (Failed)	Amesos2	Broken
Amesos2_Tpetra_CrsMatrix_Adapter_UnitTests_MPI_4	Failed	1s 900ms	Completed (Failed)	Amesos2	Broken

Trilinos automated testing

- If you may have broken something, you will get an

CDash <trilinos-regression@sandia.gov> 4:05 AM (5 hours ago)

to anasazi-regres.

A submission to CDash for the project Trilinos has failing tests.
You have been identified as one of the authors who have checked in changes that are part of this submission or you are listed in the default contact list.

Details on the submission can be found at http://testing.sandia.gov/cdash/buildSummary.php?buildid=2469557

Project: Trilinos
SubProject: Anasazi
Site: artemis.srn.sandia.gov
Build Name: Linux-intel-15.0.2-MPI_RELEASE_DEV_DownStream_ETI_SERIAL-OFF_OPENMP-ON_PTHREAD-OFF_CUDA-OFF_COMPLEX-OFF
Build Time: 2016-06-06T03:59:42 MDT
Type: Nightly
Tests failing: 1

Tests failing
Anasazi_Epetra_MVOPTester_MPI_4 (http://testing.sandia.gov/cdash/testDetails.php?test=33891492&build=2469557)

New master/develop workflow

- Want master branch to remain stable
- All developer changes are now pushed to develop branch
- If changes are “okay”, merge develop to master
  - Currently a manual process for Trilinos framework team
  - If no new tests are failing on the dashboard, merge
  - Will eventually be automated

An important consideration: commits are so frequent, and the test suite is so large, it is not possible to run the test suite after each commit.

Good testing practices

- Test-driven development – acceptance tests are written before the software
  - Gain clarity on code
  - Guarantees tests will exist
  - Useful when testing is viewed as unsustainable tax on resources
- Provide users a regression test suite
- Test software regularly, preferably daily

Building a test suite for CSE codes

Ideal time is *during development*

- When software is mature, must ensure new code does not break old features
  - Without regular testing, adding new code is error-prone
  - Structural changes are tedious without a way to verify ongoing correctness
  - Regular automated testing can provide a huge savings

New software vs legacy code

- Legacy code often has insufficient tests
  - First step in doing new, nontrivial development: add more tests
  - The issue: legacy code is not organized for unit tests

The key to working with legacy code is getting it to a place where it is possible to know that you are making changes *one at a time*.
- Michael Feathers, Working Effectively with Legacy Code

New software vs legacy code

- Test coverings
  - Set of tests used to introduce an invariant
  - Cover a small area of the system
    - Unit tests might not be possible, given legacy code organization
  - Correct behavior is defined by what the code did yesterday, not an external standard of correctness
    - If the original legacy code was incorrect, that's a separate issue
  - Build the invariant, then refactor to make the code clear

Michael Feathers, Working Effectively with Legacy Code

Development phase

- Necessary to devise tests that give confidence the software is behaving correctly
  - Analyze mathematical properties of numerical algorithm
    - Stability
    - Accuracy
  - Apply algorithm to physical situation, ensuring physical laws are not broken
  - Possible statistical or other analysis to evaluate solution quality

Formulating a continuous testing regime

- Identify verification needs within software
  - Defines code-coverage requirements
  - Pick features of the code necessary for correct behavior
    - Individual units
    - Interaction between units
  - Know the purpose of testing each feature
    - Reduces wasted effort and computing resources
    - Helps identify the most appropriate type of test
- Identify behaviors of code with detectable response to changes

Maintenance of a test suite

- Testing regime is only useful if it is
  - Maintained
  - Monitored regularly
  - Has rapid response to failure
- Maintenance includes
  - Updating tests and benchmarks
  - Adjustments to software stack
  - Archiving and retrieval of test suite output
    - Helpful in tracing change in code behavior

Maintenance of a test suite

- Monitoring individual tests manually is unreasonable and should be automated
  - Manual inspection should be limited to failing tests
  - For repository code, failure can be correlated to check-ins within a particular time-frame
    - Only certain developers need to be involved

Maintenance of a test suite

- Tests should pass most of the time
  - Easy when code changes are infrequent
  - Harder when code is large and rapidly changing
    - Difficult to determine cause of failure
    - Pre-commit test suites are a good idea
- Periodically review collection of tests
  - Look for gaps and redundancies
  - Pruning is important to conserve testing resources
  - Deprecated features can be removed
  - New tests may be necessary when new features are added

Example: SuperLU test suite

- SuperLU – sparse Gaussian elimination code
- Test suite
  - Many unit and integration level tests
  - Entire suite can be run in a few minutes
  - Demonstrates validation and acceptance testing, also no-change or bounded-change testing
  - Demonstrates how to deal with floating point issues

Example: SuperLU test suite

- Suite has two main goals
  - Tests query functions to floating-point parameters
    - Machine epsilon, underflow and overflow thresholds, etc
  - Provide coverage of all routines
    - Tests all functions of the user-callable routines

Example: SuperLU test suite

- Many input matrices are generated
  - Different numerical and structural properties
- Uses several numerical metrics to assert accuracy of solution
  - Stable LU factorization
  - Small forward and backward errors

Example: SuperLU test suite

- Performs exhaustive testing of a large number of input parameters

```
For each I1 ∈ set of valid values {
  For each I2 ∈ set of valid values {
    ...
    For each Iq ∈ set of valid values {
      For each matrix type {
        Generate the input matrix A and rhs b;
        Call a user-callable routine with input values {I1, I2,…, Iq};
        Compute the test metrics;
        Check whether each metric is smaller than a prescribed
threshold;
      }
    }
    ...
  }
}
```

- Runs over 10,000 tests in a few minutes

Use of test harnesses

- Essential for large code
  - Set up and run tests
  - Evaluate test results
- Easy to execute a logical subset of tests
  - Pre-push
  - Nightly
- Automation of test harness is critical for
  - Long-running test suites
  - Projects that support many platforms

Automated test harnesses

- crontab
  - Time-based scheduler for Linux
  - Execute specific command at specific time
- Newer tools…
  - Allow centralized servers to execute tests on multiple platforms
  - Assist in load balancing and scheduling on available test resources
  - Test execution can be triggered by
    - Time
    - An event (such as repository modification)
    - Manual request by developer

Reporting test results

- Output results to screen
  - Appropriate for pre-push testing
- Send email to a mail list
  - Can be generated by dashboard
- Test results dashboard
  - Can display results from a range of dates
  - Can detect changes in pass/fail conditions
  - Allows results to be sorted and searched
  - Enhances visibility of failing builds and tests

Example: hypre

- Multigrid preconditioner package
- Uses a system of scripts
  - Send emails to hypre developers indicating issues
  - Emails point to directories where issues occurred

Policies on testing practices

- 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?
  - Add regression test afterwards (to avoid reintroducing issue later)
- Someone needs to be in charge of watching the test suite

Policies on testing practices

- When refactoring or adding new features, run a regression suite before checkin
  - Be sure to add new regression tests for the new features
- Make sure at least two people are familiar with every portion of code
- Require a code review before releasing test suite
  - Another person may spot issues you didn't
  - Incredibly cost-effective

Policies on testing practices

- Avoid regression suites consisting of system-level no-change tests
  - Tests often need to be re-baselined
    - Often done without verification of new gold-standard
  - Hard to maintain across multiple platforms
  - Loose tolerances can allow subtle defects to appear