Software Development Practices in Project X

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April 8, 2005

Overview

- Project X (PX) research and software goals
- Introduction to extreme programming
- Continuous integration
- PX build tools
- PX testing tools
- Conclusions and future work

Project X Introduction

- Team Goal:
  - To improve the aerothermal design process for complex 3D configurations by significantly reducing the time from geometry to solution at engineering-required accuracy using high-order adaptive methods
- Students
  - Garrett Barter (shock capturing)
  - Tan Bui (unsteady aero/structures)
  - Shannon Cheng (plasma physics)
  - Krzysztof Fidkowski (hp adaptation)
  - James Lu (optimization and adaptation)
  - Todd Oliver (turbulence)
  - Mike Park (meshing/adaptation)
  - Peter Whitney (aeroacoustics)
- Advisors
  - David Darmofal
  - Robert Haimes
  - Jaime Peraire
  - Karen Wilcox

Goals for Software Development Practices

- Efficient code development
  - Accomplish research goals as fast as possible
- Flexible and lightweight — Little up front design required
  - Difficult to generate specific software design and long-term plan in research setting
- Readable code
  - Readable code serves as its own documentation
  - Easier to maintain
- Test as much code as possible as often as possible
  - Minimize debugging time
- Integrate as often as possible
  - Avoid code integration nightmares

Extreme Programming

- Extreme programming (XP) developed by Beck, Cunningham, and Jeffries in mid-1990s
  - Kent Beck, *Extreme Programming Explained: Embrace Change*, 2000
- Agile software development methodology based on four values:
  - Communication, simplicity, feedback, courage
- Consists of twelve core practices:
  - Sustainable pace, metaphor, coding standards
  - Collective ownership, continuous integration, small releases
  - Test-driven development, refactoring, simple design
  - Pair programming, on-site customer, planning game

XP in Scientific Computing

- Wood and Kleb applied XP to development of advection-diffusion solver in Ruby
  - Wood and Kleb, *Extreme Programming in a Research Environment*, 2002
- FAAST program at NASA Langley has incorporated XP methods into development approach
  - Kleb et al., *Collaborative Software Development in Support of Fast Adaptive AeroSpace Tools (FAAST)*, 2003
  - http://fun3d.larc.nasa.gov/

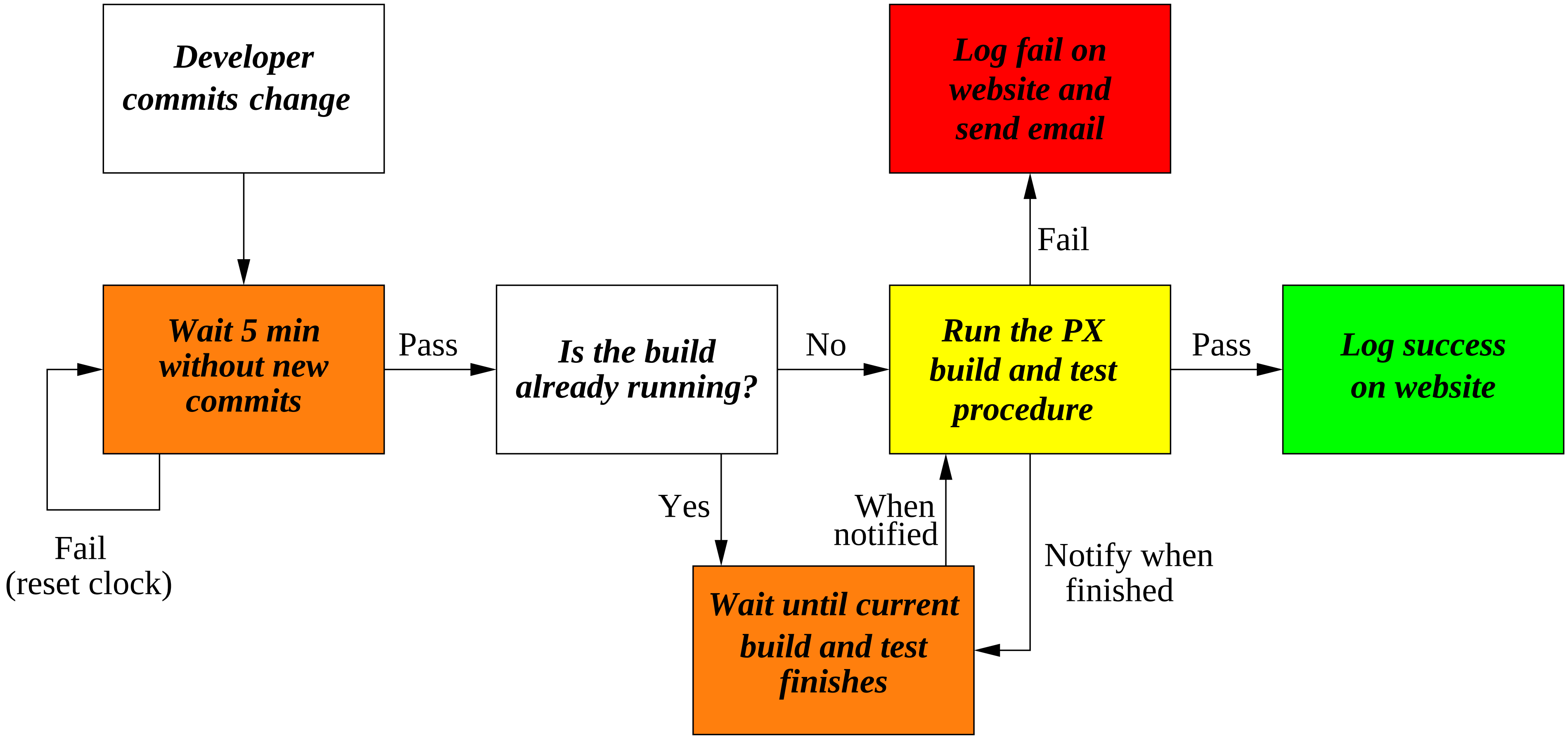
XP in PX

- Metaphor: High-order DGFEM, CFD jargon — p, q, ρ, ρu, etc.
- Coding standard: Virtually universal header comment conventions and some standard notations, but still lacking
- Collective ownership: No restrictions on who can modify what, but low truck number
- Test-driven development: Unit testing framework recently became available, but use not widespread yet
- Refactoring: Performed, but typically only to improve speed or when blatantly necessary
- Pair programming: Used infrequently
- Continuous Integration: All executables are built and entire test suite run after every CVS commit

Concurrent Versions System (CVS)

- Integration begins with software versioning system (in our case CVS)
- All source files stored on CVS repository
- All differences between versions of file also stored $\Rightarrow$ can always revert to old version if necessary
- Developers checkout the code from the repository and commit changes
- CVS merges changes into code
- Bottom line: CVS allows multiple developers to work on same code with very little chance of overwriting each other's changes or making conflicting changes.

Continuous Integration Overview



Build and Test

- What happens inside the build and test?
  - Executables built
  - Unit tests run
  - Acceptance tests run
- Tools required:
  - Build utilities (Autoconf and Automake)
  - Unit testing framework (CuTest and PXUnit)
  - Acceptance testing framework (runTests)

Autoconf

"Autoconf is a tool for producing shell scripts that automatically configure software source code packages to adapt to many kinds of UNIX-like systems."

– GNU Autoconf Manual

- Developer supplies `configure.ac` file
- `configure.ac` contains sequence of calls to Autoconf macros, for example,
  - `AC_PROG_CC` determines a C compiler to use
  - `AC_PATH_X` locates X header files and libraries
- Running `autoconf` produces `configure`
- Once created `configure` does not depend on Autoconf

Configure

- `configure` determines features of build environment, including
  - System type (linux, cygwin, etc)
  - Selects compilers (gcc, g77, mpicc, etc)
  - Probes for necessary system libraries (X11, mpich, etc)
  - Probes for necessary system headers (stdlib.h, string.h, etc)
- `configure` sets variables based on environment it finds
  - Allows creation of portable Makefiles
- Creates Makefile from Makefile.in
- Where does the Makefile.in come from?
  - You or . . .

Automake

"Automake is a tool for automatically generating Makefile.ins from files called Makefile.am. Each Makefile.am is basically a series of make variable definitions, with rules being thrown in occasionally."

– GNU Automake Manual

- Developer supplies `Makefile.am`s that are converted to `Makefile.in`s by running `automake` or `make dist`
- What is `make dist`?
  - Automake supplied target that creates tarball for distribution
  - Tarball contains configure and machine independent `Makefile.in`s
- Automake also supplies other "standard" targets
  - install, clean, check, . . .

Makefile.am Example

```
# -*- Makefile -*-

if HAVE_MPI
bin_PROGRAMS = PXRunSolver2d PXRunParallel2d
else
bin_PROGRAMS = PXRunSolver2d
endif

PXRunSolver2d_CFLAGS = -DDIM=2 -I$(top_srcdir)/include
PXRunSolver2d_SOURCES = PXRunSolver.c
PXRunSolver2d_LDADD = libPX2d.a libPX.a -lm @FLIBS@

if HAVE_MPI
PXRunParallel2d_CFLAGS = -DDIM=2 -DPAR=1 -I$(top_srcdir)/include
PXRunParallel2d_SOURCES = PXRunSolver.c
PXRunParallel2d_LDADD = libPXPar2d.a libPX.a -lm @FLIBS@
endif
```

Unit Testing

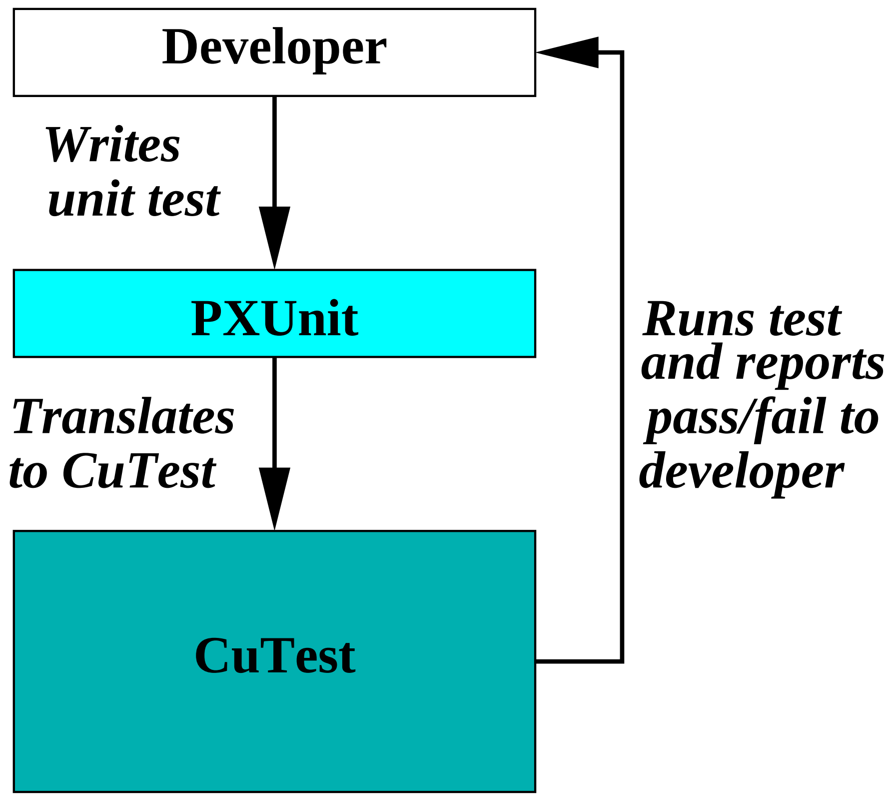
- Unit tests excercise small pieces of code in isolation from each other and the application as a whole
- Most easily applied to low level functions
  - Flux calculation, viscosity calculation
- Useful for medium level functions if low level functions adequately tested
  - Calculation of inviscid Galerkin residual
- Not applicable to highest level functions
  - Line solver
- To make unit testing practical, need a unit testing framework
- For list of unit testing frameworks see http://c2.com/cgi/wiki?TestingFramework

CuTest

- CuTest is a C unit testing framework written by Asim Jalis
- CuTest provides
  - Assert functions (e.g. CuAssertDblEquals, CuAssertStrEquals)
  - Functions for aggregating tests into suites and running test suites
  - Functions for recording and reporting test failures
  - Simplicity—only 2 files: CuTest.c and CuTest.h
- For PX purposes, CuTest drawbacks include
  - Tests are not added to suites automatically
  - CuTest defines structures that are required in testing code

PXUnit

- Set of C macros and 1 shell script
- Eliminates CuTest drawbacks for PX developers
  - Automates process of adding tests to suites and producing a main program
  - Eliminates need for PX developers to interact with CuTest data structures
- No knowledge of CuTest required to write unit tests in PX



Unit Test Example

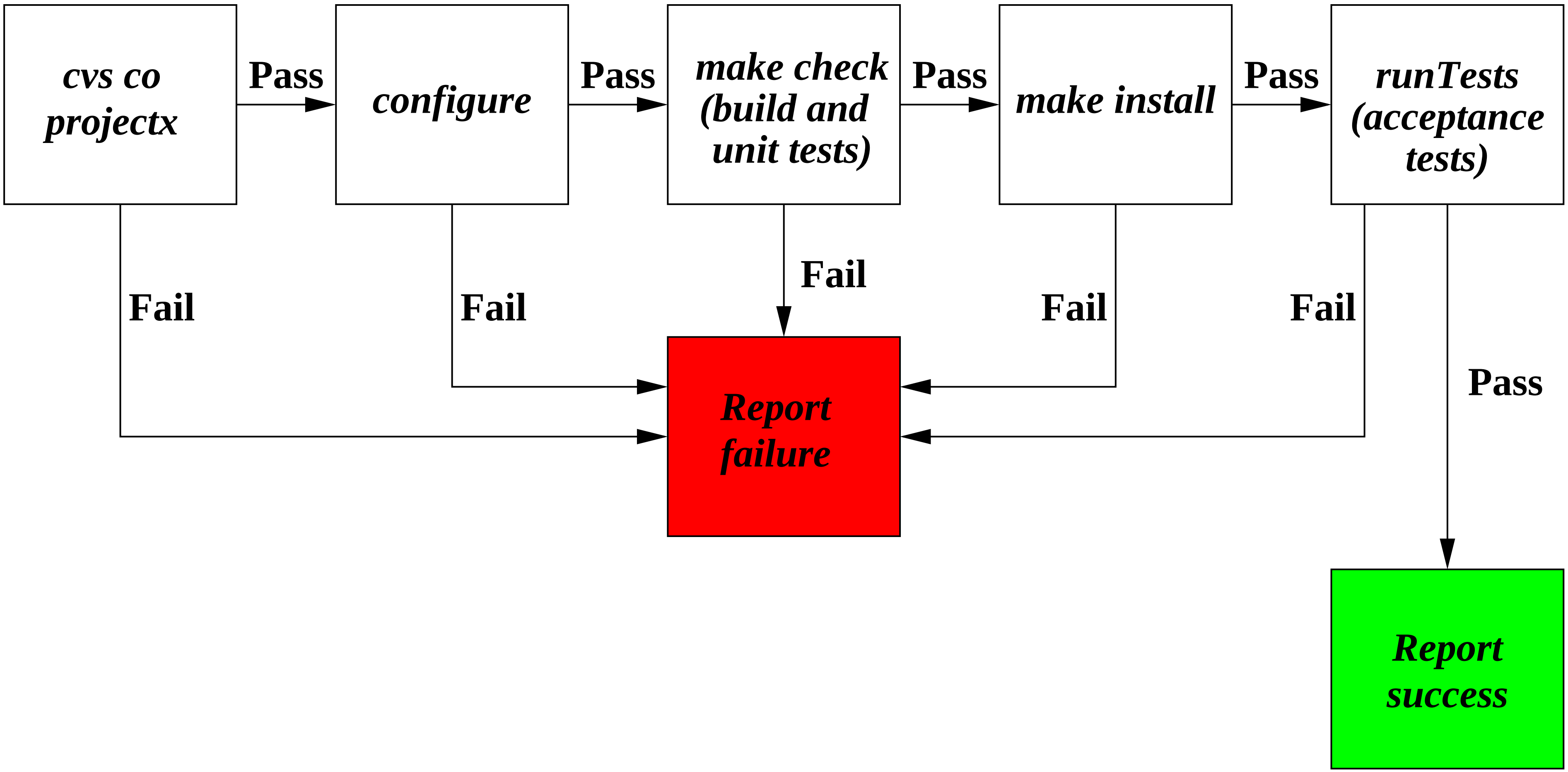
```
PX_TEST( TestStaticTemperatureTrivial ){
  int ierr;
  PX_REAL params[6] = {1.4, 1.0, 1.0, 1.0, 1.0, 1.0};
  PX_REAL T;
#if( SA_TURB == 1 )
  PX_REAL U[5], T_U[5];
#else
  PX_REAL U[4], T_U[4];
#endif
  U[0] = 1.0;  U[1] = 0.0;  U[2] = 0.0;  U[3] = 2.5;
#if( SA_TURB == 1 )
  U[4] = 1.0;
#endif

  ierr = PXError( PXStaticTemperature(U, params, &T, T_U) );
  PXAssertIntEquals( PX_NO_ERROR, ierr );
  PXAssertDblEquals( 1.0, T);
}
```

Acceptance Testing

- Regression tests: Ensure code produces same answer as yesterday
- Verification tests: Ensure code produces expected order of accuracy
- Validation tests: Ensure code results match experimental data or analytic exact solution
- Only automated acceptance tests currently in PX are regression tests
- Regression tests controlled by two shell scripts
  - jobTest.csh: Runs single test and reports pass/fail
  - runTests.csh: Runs all tests and reports total number or errors
- Change in any output quantity (e.g. residual, force, adjoint residual, etc) of greater than 1e-13 causes failure

Build and Test



Conclusions

- Shown that agile software development philosophy applicable in scientific computing environment
- Developed continuous integration procedure for use in Project X
- Developed build and test procedure to check code after every modification
- Features of the build and test procedure include:
  - Build of all executables and libraries in Project X
  - 214 unit tests
  - 17 acceptance (regression) tests

Possible Improvements

- Enforce more rigorous coding standard
- Expand unit test coverage and use of test-driven development
- Extend build and test to run automatically on multiple architectures

Acknowledgments

- Prof. David Darmofal
- Garrett Barter
- Chris Fidkowski
- Mike Park
- PX Team