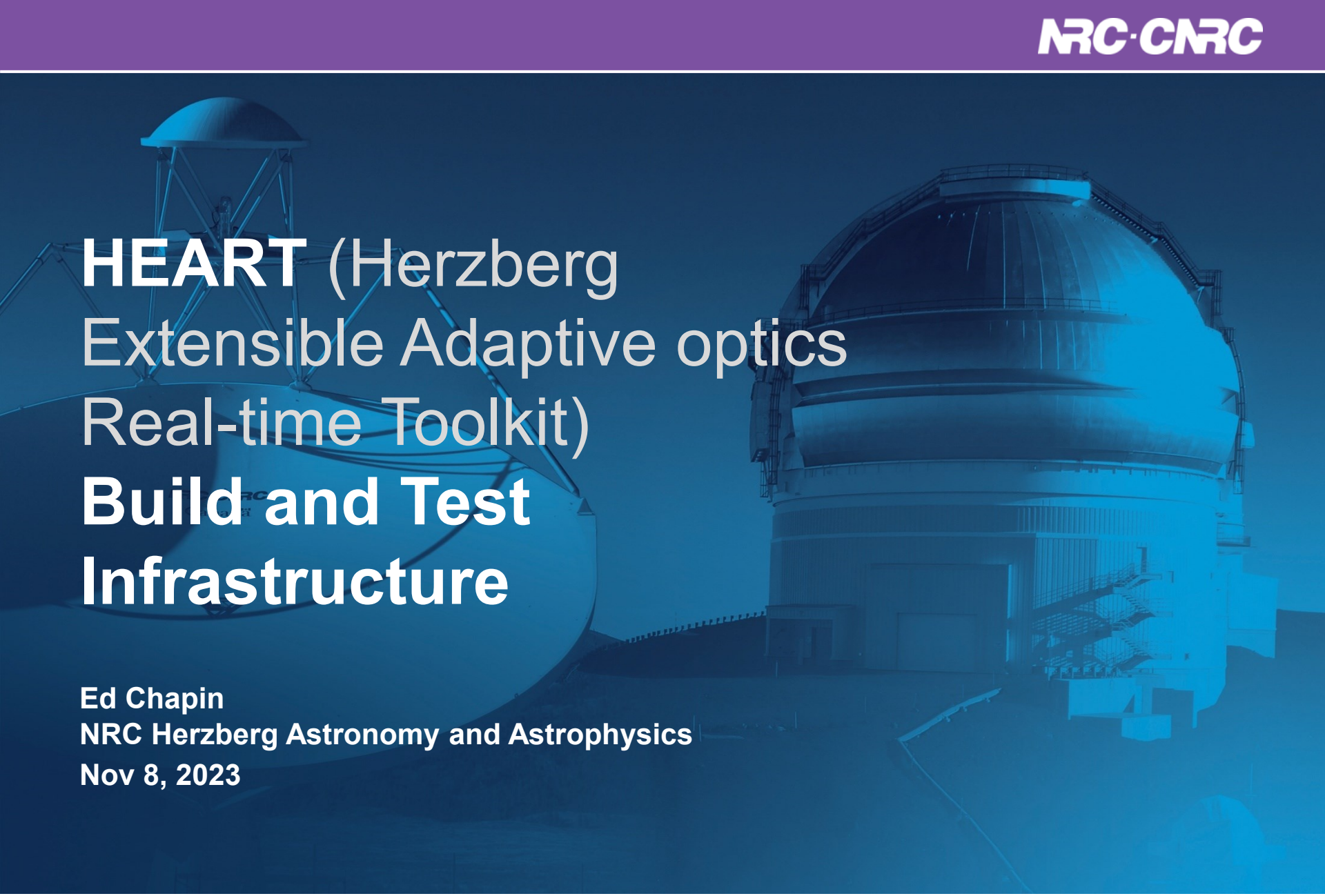

HEART (Herzberg Extensible Adaptive optics Real-time Toolkit) **Build and Test Infrastructure**

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NRC Herzberg Astronomy and Astrophysics
Nov 8, 2023

Introduction

We need you to use CentOS 7!

The Soft Realtime processes must run on the same server as the Hard Realtime!

A special PCIe card that only runs with Linux Kernel x.y.z must be installed in the RTC server!

We need you to use AlmaLinux 9!

The Soft Realtime processes must *NOT* run on the same server!

The complexity of the Hard Realtime processes requires multiple servers!

We need a release every month with test and coverage reports!

Continuous integration + extensive automated tests are essential for QA, and so we can refactor and extend our code “fearlessly”.

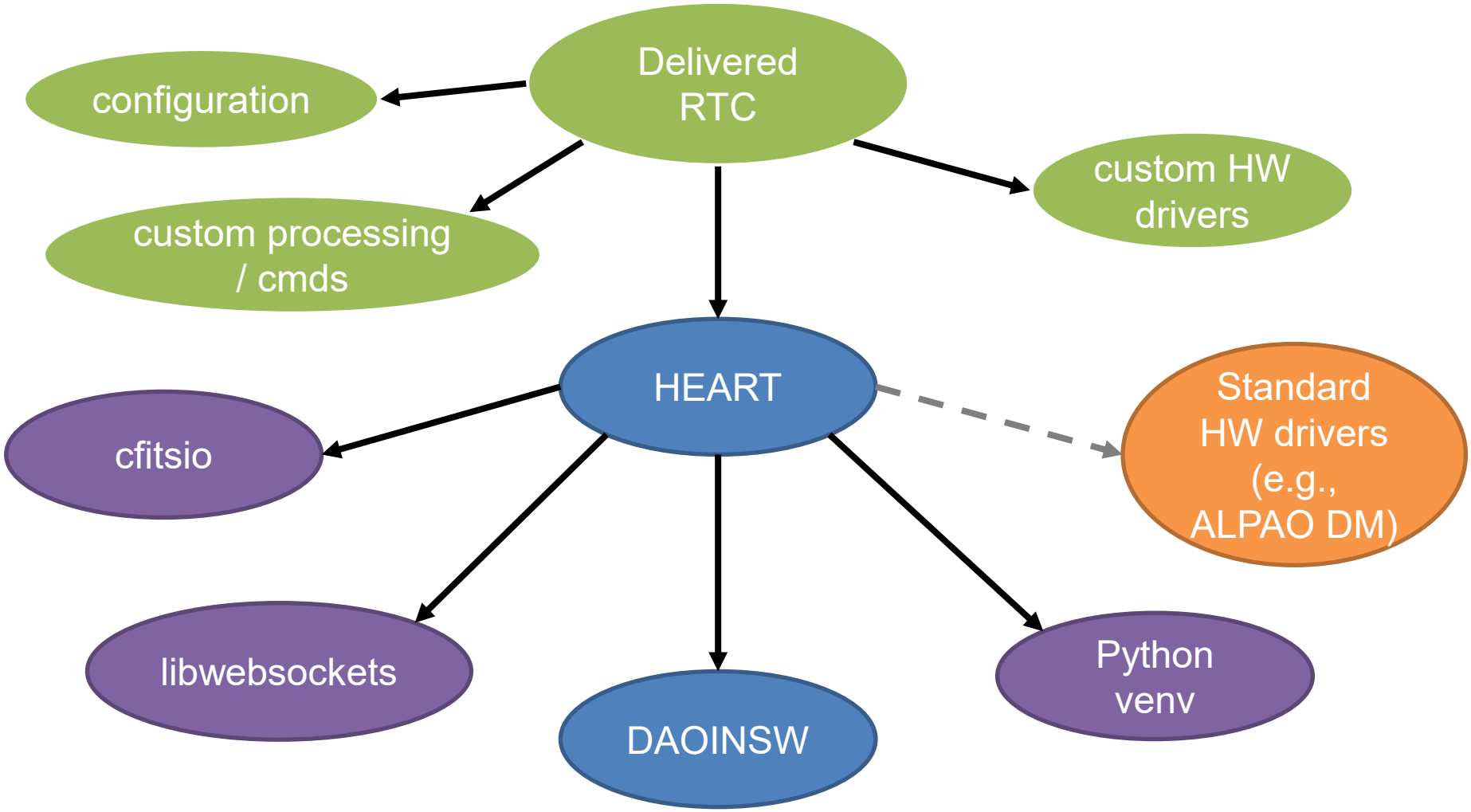
Overview

- **Managing dependencies and revision control** for multiple systems/clients
- **Languages** (C / Python) and **tooling**
- Types of automated testing:
  - Low-level unit tests
  - Application-level component tests
  - System tests
- (near) **future updates**:
  - Container-based test runners for different architectures
  - Automated Performance tests (currently manual)

Dependencies

- **Facility instrument requirements typically conservative** (need to run for many years), and vary by observatory (e.g., target OS)
- **Result**: HEART predominantly written in C and Python, *with minimal external dependencies*:
  - **Doxygen** for documentation
  - **GNU Make**
  - C: **cfitsio**, **libwebsockets, *CMocka, lcov***
  - Python: **numpy**, **astropy**, **matplotlib, *PyTest***
  - Optional: **support for different hardware based on availability of vendor SDKs** and build flags

Dependencies (cont'd)



Revision Control

```
+--gpi2.0-rtc   # root of the repo
  |--doc        # Top level documentation
  |--source     # GPI2.0 source code
  +--external   # Location of submodules
     |--cfitsio
     |--daoinsw
     |--heart
     |--heart-testdata
     +--libwebsockets
```

Submodules encode both the location of the external dependency and the particular version (commit) in its history

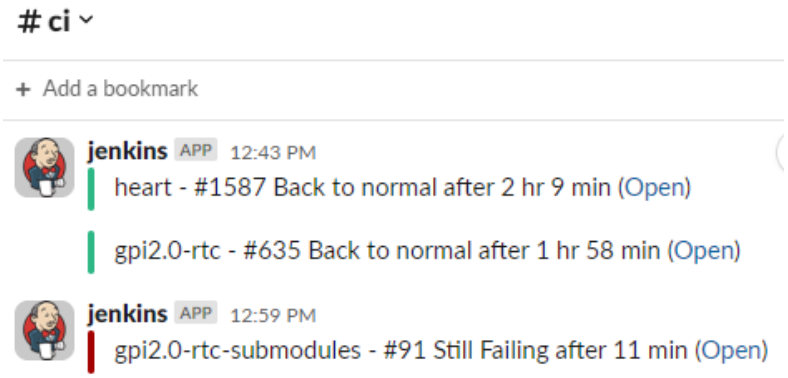
Tooling

- **Makefiles:** build all of the C source code (**gcc**), execute tests (C/Python), and produce documentation (Doxygen)
- **Python:** venv + requirements.txt
- **Git:** develop in branches labeled by Jira tickets
- **Jenkins:** merges trigger automated builds
- **Slack:** #ci sends annoying messages if someone caused a build to fail
- **Documentation:** built documentation includes test report

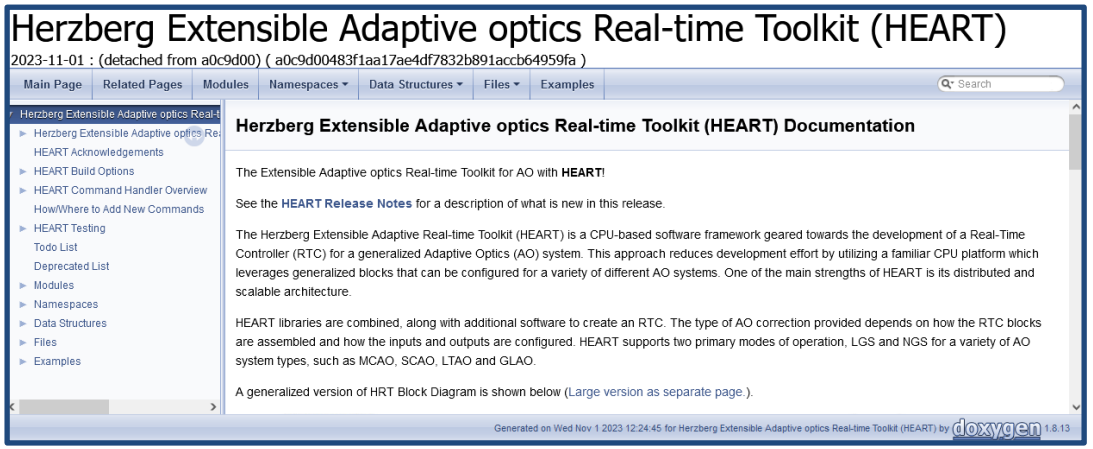
Automated Builds

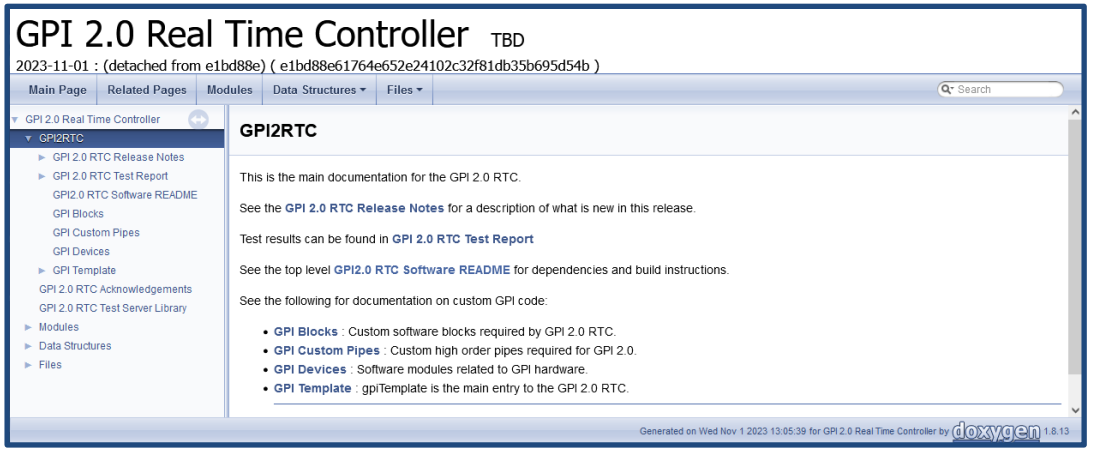
Merge of branch to master triggers builds (with dependencies)

Result sent to slack



Built Documentation





Unit Tests

- CMocka (https://cmocka.org/):
  - lightweight / capable framework for C + XML test report
  - Used for a mixture of “true” unit tests (single functions), but also some more complex (including multi-threaded) tests.
  - Use linker option “--wrap” to incorporate mocked functions when needed
  - **lcov** to measure code coverage
- PyTest
  - unit tests of our Python code
  - Measure code coverage + XML test reports

Unit Tests: CMocka

We use CMocka for both low-level tests (individual) functions), and higher-level tests that may involve complex interactions between multiple threads.

Since everything is running in the same process, our test code is able to **make assertions about internal variables, as well as inputs and outputs.**

Each test suite is a stand-alone executable with XML output that can be included in a test report.

Unit Tests: CMocka (cont'd)

```
int main( DAO_ERR_COMP_UNUSED int argc, DAO_ERR_COMP_UNUSED char *argv[] )
{
    const struct CMUnitTest hrtMvmTests[] = {

        cmocka_unit_test( test_hrtMvm_subMvm_invalid ),
        cmocka_unit_test( test_hrtMvm_subMvm_column_matrix ),
        cmocka_unit_test( test_hrtMvm_subMvm_full_matrix ),
        cmocka_unit_test( test_hrtMvm_subMvm_row_matrix ),
        cmocka_unit_test( test_hrtMvm_mvm_invalid ),
        cmocka_unit_test( test_hrtMvm_mvm_full_matrix ),
        cmocka_unit_test( test_hrtMvm_partitioned_mvm ),
        cmocka_unit_test( test_hrtMvm_parallel_mvm_row_partitions ),
        cmocka_unit_test( test_hrtMvm_parallel_mvm_col_partitions ),
        cmocka_unit_test( test_hrtMvm_parallel_mvm_4x8_partitions ),
        cmocka_unit_test( test_hrtMvm_scratch_memory ),
        cmocka_unit_test( test_hrtMvm_parallel_invalid ),
    };

    cmocka_set_message_output( CM_OUTPUT_XML );
    return cmocka_run_group_tests( hrtMvmTests, NULL, NULL );
}
```

Test suite "cmocka_hrtMvm.c" for low-level MVM module

Unit Tests: CMocka (cont'd)

```
/*!
 * \test \ref test_hrtMvm_subMvm_column_matrix <br>
 *
 * \brief Test hrtMvm_subMvm function when matrix is a small column vector.
 *
 * The matrix M is set to a known column vector and X is set to a
 * known scalar. The vector length iterates through lengths 1 ... 32.
 */
static void test_hrtMvm_subMvm_column_matrix( DAO_ERR_COMP_UNUSED void **state )
{
    // ... Setup omitted ...
    for ( vLen = 1; vLen <= maxLen; ++vLen )
    {
        rv = hrtMvm_subMvm( V, &mat.full, X );
        assert_int_equal( rv.status, DAO_ERR_NONE );

        // Compute error vector as V - expected.
        rv = hrtVec_acc_ax_by( vLen, error, 1.0f, V, -1.0f, expected );
        assert_int_equal( rv.status, DAO_ERR_NONE );

        rv = hrtVec_norm( vLen, error, hrtVec_norm_L1, &errNorm, 0 );
        assert_int_equal( rv.status, DAO_ERR_NONE );

        assert_float_equal( errNorm, 0.0, 0.0 );
    // ... etc ...
```

Doxygen-friendly comments for test report

Failed assertions will appear in test report with line number

Unit Tests: CMocka (cont'd)

More complex tests using setup & teardown functions. Example for wavefront input sensor block:

```
cmocka_unit_test_setup_teardown( test_hrtWfsInputBlock_normal, setup, teardown )
```

setup:

- Configure and start the block (multi-threaded) with simulator for feeding pixels

teardown:

- Shutdown block, free resources

test code:

- Triggers reading of pixels (command), checks results

CMocka test reports

Our test reports appear in the doxygen-generated pages as a hierarchy, ranging from an overview, to modules (like “HEART math” in this example), and individual test functions

HEART math

Summary of Results

test suite	# of tests	failures	errors	skipped	time
cmocka_hrtFft	8	0	0	0	0.007
cmocka_hrtFilterIIR	16	0	0	0	0.000
cmocka_hrtMatrix	20	0	0	0	0.015
cmocka_hrtMvm	12	0	0	0	0.409
cmocka_hrtPixelCalibration	4	0	0	0	0.032
cmocka_hrtSparse	21	0	0	0	0.249
cmocka_hrtVec_acc_aacc_bx	1	0	0	0	0.006
cmocka_hrtVec_acc_ax_by	1	0	0	0	0.009
cmocka_hrtVec_alloc_free	3	0	0	0	0.000
cmocka_hrtVec_dot	4	0	0	0	0.002
cmocka_hrtVec_eProd	1	0	0	0	0.001
cmocka_hrtVec_mvm	6	0	0	0	0.426
cmocka_hrtVec_norm	4	0	0	0	0.689
cmocka_hrtVec_sum	1	0	0	0	0.001
cmocka_hrtVector	10	0	0	0	0.008
subtotal	**112**	0	0	0	**1.854**

result	test name	test description	time
passed	test_hrtMvm_subMvm_invalid	Test hrtMvm_subMvm function with NULL parameters and 1x1 matrix.	0.000
passed	test_hrtMvm_subMvm_column_matrix	Test hrtMvm_subMvm function when matrix is a small column vector.	0.000

CMocka code coverage (lcov)

Filename	Line Coverage			Functions		Branches	
hrtFft.c		89.8 %	273 / 304	100.0 %	14 / 14	76.3 %	145 / 190
hrtFilterIIR.c		67.6 %	200 / 296	85.7 %	6 / 7	66.7 %	108 / 162
hrtMath.c		0.0 %	0 / 5	0.0 %	0 / 1	0.0 %	0 / 2
hrtMatrix.c		97.1 %	435 / 448	100.0 %	15 / 15	94.6 %	176 / 186
hrtMvm.c		92.1 %	152 / 165	100.0 %	6 / 6	87.1 %	61 / 70
hrtPixelCalibration.c		90.6 %	58 / 64	100.0 %	2 / 2	85.0 %	34 / 40
hrtSparse.c		93.8 %	347 / 370				
hrtVec_acc_aacc_b...		100.0 %	14 / 14				
hrtVec_acc_ax.c		100.0 %	14 / 14				
hrtVec_acc_ax_by.c		100.0 %	18 / 18				
hrtVec_copySlice.c		100.0 %	17 / 17				
hrtVec_dot.c		100.0 %	40 / 40				
hrtVec_eProd.c		100.0 %	18 / 18				
hrtVec_mvm.c		93.5 %	58 / 62				
hrtVec_norm.c		100.0 %	38 / 38				
hrtVec_sum.c		100.0 %	19 / 19				
hrtVec_v_ax.c		100.0 %	14 / 14				
hrtVec_v_ax_b.c		100.0 %	22 / 22				
hrtVec_zero.c		100.0 %	5 / 5				
hrtVector.c		91.0 %	7... / 78				

```
629        [ +  + ]:         16 :     if ( M->mvmScratch == NULL )
630                 :            :     {
631                 :          2 :         rv = daoErr( HRT_MAT_ERR_MVM_SCRATCH,
632                 :            :                      "No MVM scratch memory available." );
633                 :          2 :         DAO_DEBUG( DAO_DEBUG_ERROR, "%s", rv.errMsg );
634                 :          2 :         return rv;
635                 :            :     }
636                 :            :
637                 :            :     /*
638                 :            :      * The upper bound should be based on current limits.
639                 :            :      */
640                 :         14 :     lastCore = firstCore + coreStride * ( numThreads - 1 );
641                 :            :
642        [ +  + ]:         14 :     if ( lastCore >= daoCpuSet_maxCores )
643                 :            :     {
644                 :          2 :         rv = daoErr_format( HRT_MAT_ERR_MVM_CORE,
645                 :            :                             "# threads (%d) != # partition (%u * %u).",
646                 :            :                             numThreads, M->numRowPartitions, M->numColPartitions );
647                 :            :
648                 :          2 :         DAO_DEBUG( DAO_DEBUG_ERROR, "%s", rv.errMsg );
649                 :          2 :         return rv;
650                 :            :     }
651                 :            :
652                 :            :     /*
653                 :            :      * Check requested priority and adjust if necessary.
654                 :            :      * This check may generate a warning but will not prevent the
655                 :            :      * MVM from being performed.
656                 :            :      */
657                 :            :
658                 :         12 :     mvmPriority = daoRT_getAllowedPriority( reqPriority );
659                 :            :
660        [ -  + ]:         12 :     if ( mvmPriority < reqPriority )
661                 :            :     {
662                 :          0 :         rv = daoErr_format( HRT_MAT_WARN_MVM_PRIORITY,
663                 :            :                             "Requested MVM thread priority (%d) clipped at %d.",
664                 :            :                             reqPriority, mvmPriority );
665                 :            :
666                 :          0 :         DAO_DEBUG( DAO_DEBUG_ERROR, "%s", rv.errMsg );
667                 :            :     }
```

PyTest: native code

- Python used in HEART for:
  - a number of **soft real-time tasks**, e.g., generating reconstructor matrices using statistics provided by hard real-time (C) code
  - **data analysis and plotting**
  - **general utilities**
- PyTest used to test native Python code. Test reports and coverage incorporated into documentation similar to CMocka

PyTest: native code (cont'd)

```
def test_telemetryStream_basic():
    """
    \test \ref test_telemetryStream_basic

    \addtogroup hrtTelemetryUnitTests
    @{
    \copybrief test_telemetryStream_basic
    @}

    \brief Basic test of streaming from a sender to a receiver
    - sender is started and not yet connected
    - receiver is started and after brief pause both report connected
    - verify that receive queue is initially empty
    - bucket is sent from sender to receiver
    - verify that receive queue has the (single) bucket
    """

    debug = True

    with TelemetryStream(TEST_ADDRESS, TEST_PORT, specs=TEST_SPECS, debug=debug) as sender:
        assert sender._streamThreadState == TelemetryStream.ThreadState.CONNECTING

    # ... etc ...
```

doxypypy allows us to include Doxygen commands in Python docstrings

PyTest: native code (cont'd)

test_telstream

Unit tests for **daoinsw.util.telstream**.

test suite	# of tests	failures	errors	skipped	time
pytest	**5**	0	0	0	4.513

result	test name	test description	time
passed	daoinsw.util.tests.test_telstream.test_telemetryStream_fails		0.009
passed	daoinsw.util.tests.test_telstream.test_telemetryStream_basic		1.158
passed	daoinsw.util.tests.test_telstream.test_telemetryStream_reconnect		0.478
passed	daoinsw.util.tests.test_telstream.test_telemetryStream_largeBucket		1.138
passed	daoinsw.util.tests.test_telstream.test_telemetryStream_customBucket		1.148

PyTest: native code (cont'd)

Coverage report: 91%

coverage.py v7.2.1, created at 2023-10-16 16:45 -0700

Module	*statements*	*missing*	*excluded*	*coverage*
daoinsw/__init__.py	0	0	0	100%
daoinsw/util/__init__.py	2	0	0	100%
daoinsw/util/circbuf.py	153	11	0	93%
daoinsw/util/cstruct.py	85	13	0	85%
daoinsw/util/hist.py	159	44	0	72%
daoinsw/util/stringHelpers.py	21	0	0	100%
daoinsw/util/telstream.py	223	21	0	91%

```
227     def waitForConnection(self, timeout=None):
228         """Blocking method that returns when a connection has been made
229 
230         Args:
231             timeout: optionally specify a timeout in seconds
232         """
233 
234         if self._streamThreadState == TelemetryStream.ThreadState.CONNECTING:
235             self._connectedEvent.wait(timeout=timeout)
236 
237         if self._streamThreadState == TelemetryStream.ThreadState.STOPPED:
238             raise Exception("The stream thread has stopped.")
```

Component & System Tests

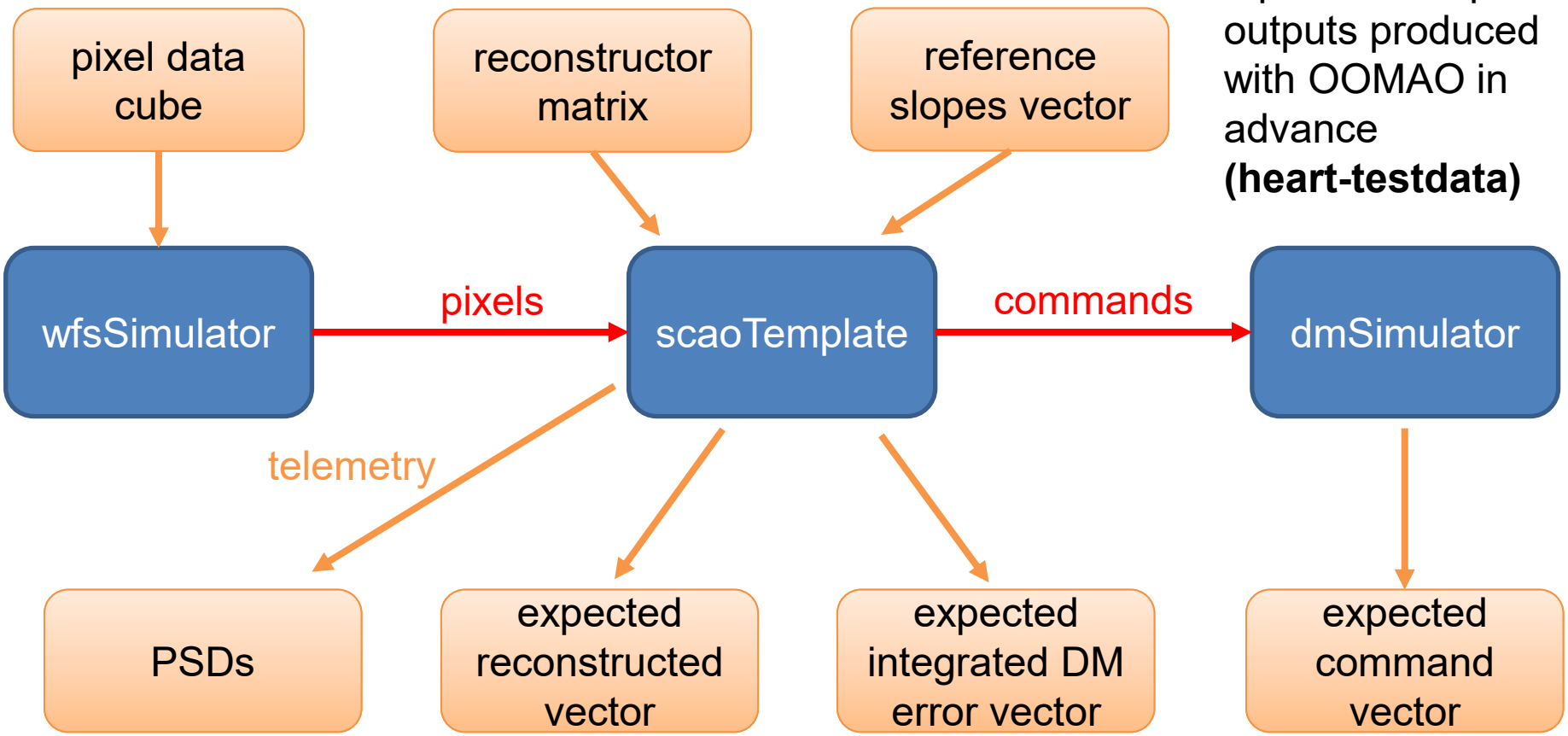
- Component and System tests are “black box”.
  - **Component test**: single application
  - **System test**: multiple (interacting) applications
  - Use external interfaces to provide inputs, and observe outputs (results)
- Many goals for these tests:
  - **Verify external interfaces** (commands, files, telemetry)
  - **Correctness** (RTC produces expected DM commands from WFS data?)
  - **Performance** (e.g., timing requirements)

Component & System Tests (cont'd)

Also use PyTest to orchestrate these tests:

- Makes sense to **re-use existing tool**
- Execute applications using **subprocess** module
- Elegant way to start and monitor multiple applications using **fixtures** (setup/teardown with dependencies)
- **Provide inputs** (commands, telemetry, input files)
- Perform **assertions on outputs**
- Create **test reports**

Example: SCAO RTC Validation



Example: SCAO RTC Validation

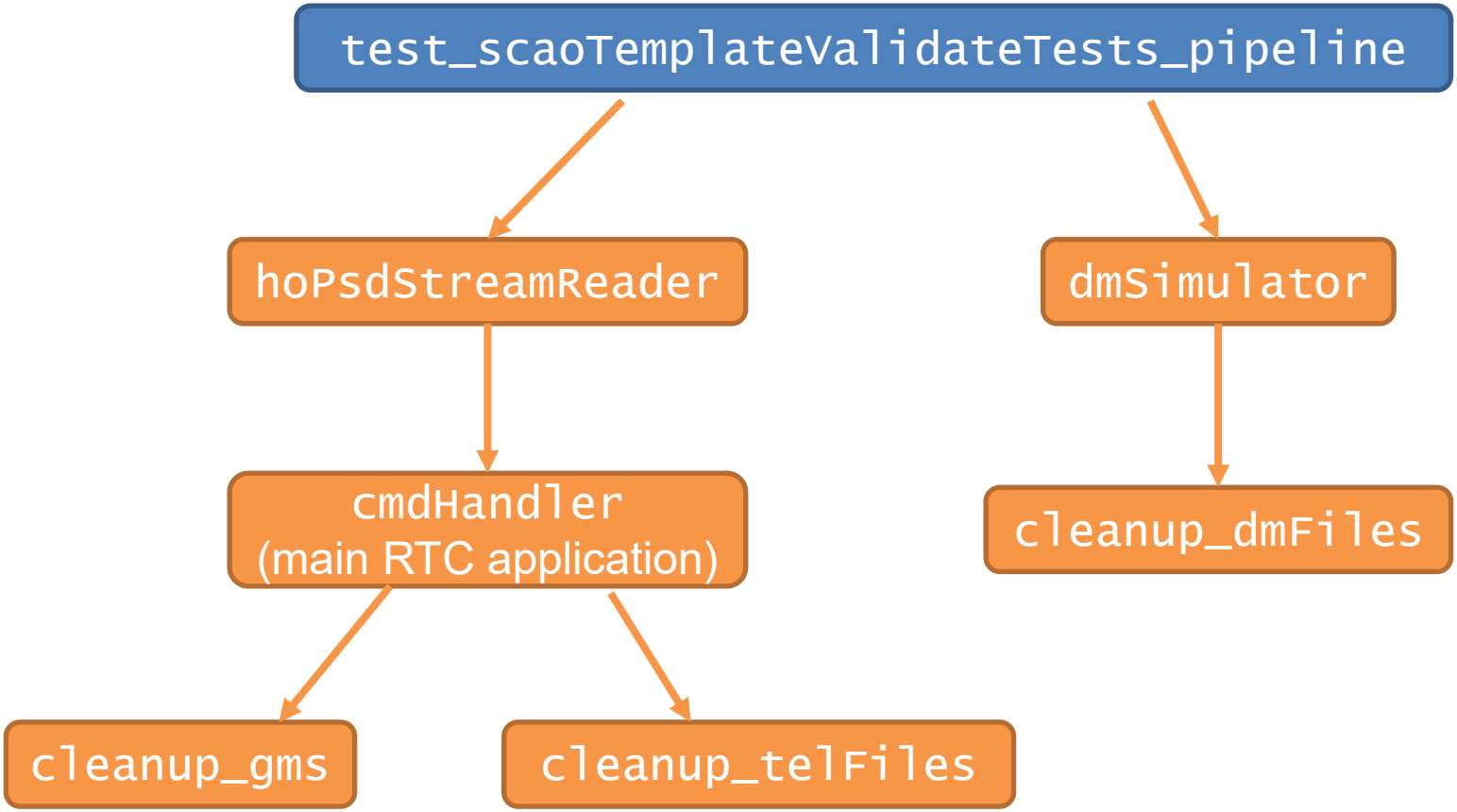
The main test depends on **fixtures,** which may themselves depend on other fixtures. Used to start up applications/processes in a particular order.

```
def test_scaoTemplateValidateTests_pipeline(hoPsdStreamReader, dmSimulator):
    """
    \test \ref test_scaoTemplateValidateTests_pipeline

    \addtogroup scaoTemplateValidateTests
    @{
    \copybrief test_scaoTemplateValidateTests_pipeline
    @}

    \brief Feed pipeline known WFS inputs and check correctness of results
    """
```

Example: SCAO RTC Validation



Example: SCAO RTC Validation

```
@pytest.fixture
def cmdHandler(cleanup_gms, cleanup_telFiles, dmSimulator):
    """
    Startup and shutdown of \ref scaoTemplate
    """

    # === Setup ===

    proc = None
    configPathFile = DEFAULT_CONFIG_PATH + "/" + DEFAULT_CONFIG_FILE_NAME
    cmdLine = [compPrg, "-config", configPathFile,
               "-host", "compTestScaoTemplate"] #, "-d", "4"]
    proc = ServiceProc(cmdLine, expect_str="About to create listening address")

    # === Teardown ===

    yield cmdHandler

    if proc is not None:
        print("Shutting down cmdHandler")
        proc.stopProc()
```

This fixture starts the main RTC process and returns once it is ready to accept commands.

It also shuts it down after the test.

Example: SCAO RTC Validation

```
# ... Further down in the main test function ...

# Send simulated pixels to RTC and return when done
wfsDataPath = TEST_DATA_PATH+"/"+TIPTILT_DATA_PATH+WFS_DATA_FILE
wfsProc = run_WfsSimulator(wfsDataPath)
assert wfsProc.returncode == 0

# ... Command RTC to dump circular buffers to disk and also
#     load in expected values from OOMAO, then compare ...

for frame in range(nTestFrames):
    np.testing.assert_allclose(dmCmds[frame, :, 0],
                               dmExpected[frame, :],
                               atol=dmtol,
                               err_msg='DM commands from '+dmFile)
```

NumPy has some great testing routines for comparing arrays with tolerances

Component & System Test Reports

HEART Test Report

- HEART Test Coverage
- HEART cmocka Unit Test Results
- HEART Component Test Results
- heart Python Package Unit Test Results
- heart Python Package Unit Test Coverage
- HEART Test Li

This test report was pr duced using the following tool versions:

```
Computer   : ncc  24 of 24 cores available )
CPU        : Intel R) Xeon(R) CPU E5-2697 v2 @ 2.70GHz
Compiler   : gcc ( CC) 4.8.5 20150623 (Red Hat 4.8.5-36)
Doxygen    : 1.8.1
Python3    : Python 3.9.13
pytest     : pytest 7.1.2
pytest-cov : pytest cov-4.0.0

Linux version 3.10.0 957.1.3.el7.x86_64 (mockbuild@kbuilder.bsys.centos.org)
(gcc version 4.8.5 2 150623 (Red Hat 4.8.5-36) (GCC) ) #1 SMP Thu Nov 29 14:49:4 UTC 2018
```

See HEART Testing for mo information on testing HEART.

HEART Component Test Results

library test suite	# of tests	failures	errors	skipped	time
HEART cmdHandler	8	0	0	0	14.644
HEART gui	2	0	0	1	12.387
HEART perfMon	16	0	0	0	11.531
HEART template	8	0	0	0	88.546
HEART testServer	12	0	0	0	18.945
HEART util	1	0	0	0	1.735
total	48	0	0	1	147.788

HEART template

Summary of Results

test suite	# of tests	failures	errors	skipped	time
comptest_scao2Wfs	1	0	0	0	36.833
comptest_scaoTemplate	3	0	0	0	5.821
comptest_scaoTemplateExtra	1	0	0	0	4.386
comptest_scaoTemplateValidate	1	0	0	0	10.594
comptest_scaoTemplateValidate_pyrPix_modal	1	0	0	0	17.287
comptest_scaoTemplateValidate_wooferTweeter	1	0	0	0	13.321
ubtotal	8	0	0	0	88.242

comptest_scaoTemplateValidate

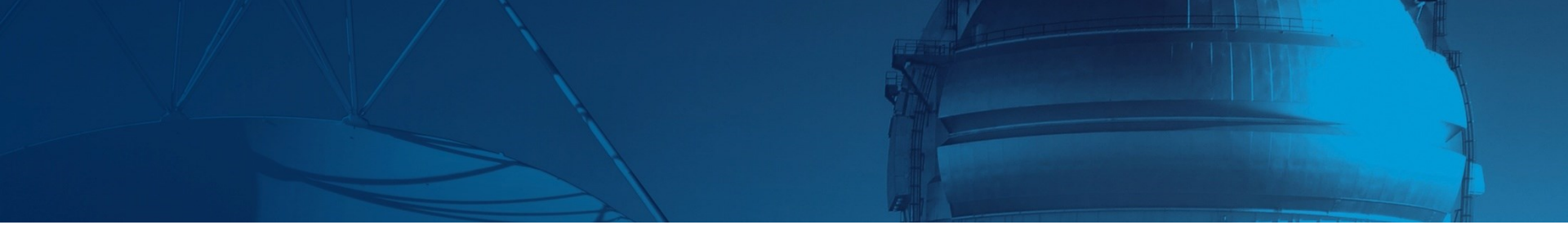
Validation testing for for scaoTemplate.

test suite	# of tests	failures	errors	skipped	time
pytest	1	0	0	0	10.594

result	test name	test description	time
passed	comptest_scaoTemplateValidate.test_scaoTemplateValidateTests_pipeline		10.303

The Future

- Currently updating test servers infrastructure:
  - **Install range of operating systems** to get more experience with tuning (e.g., Ubuntu vs. RedHat-style systems), identify toolchain issues
  - Use **docker containers** to test different operating systems *within* different host operating systems
- Performance tests currently manual. Want **standard set of automated performance** tests to check for regressions (**mean latency**, **tail**, **dropped frames**)
- Migrate from **Jenkins -> GitLab** (locally hosted) to manage test execution



QUESTIONS?

Thank you

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