Tips for Writing Good Tests for Linux

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Outline

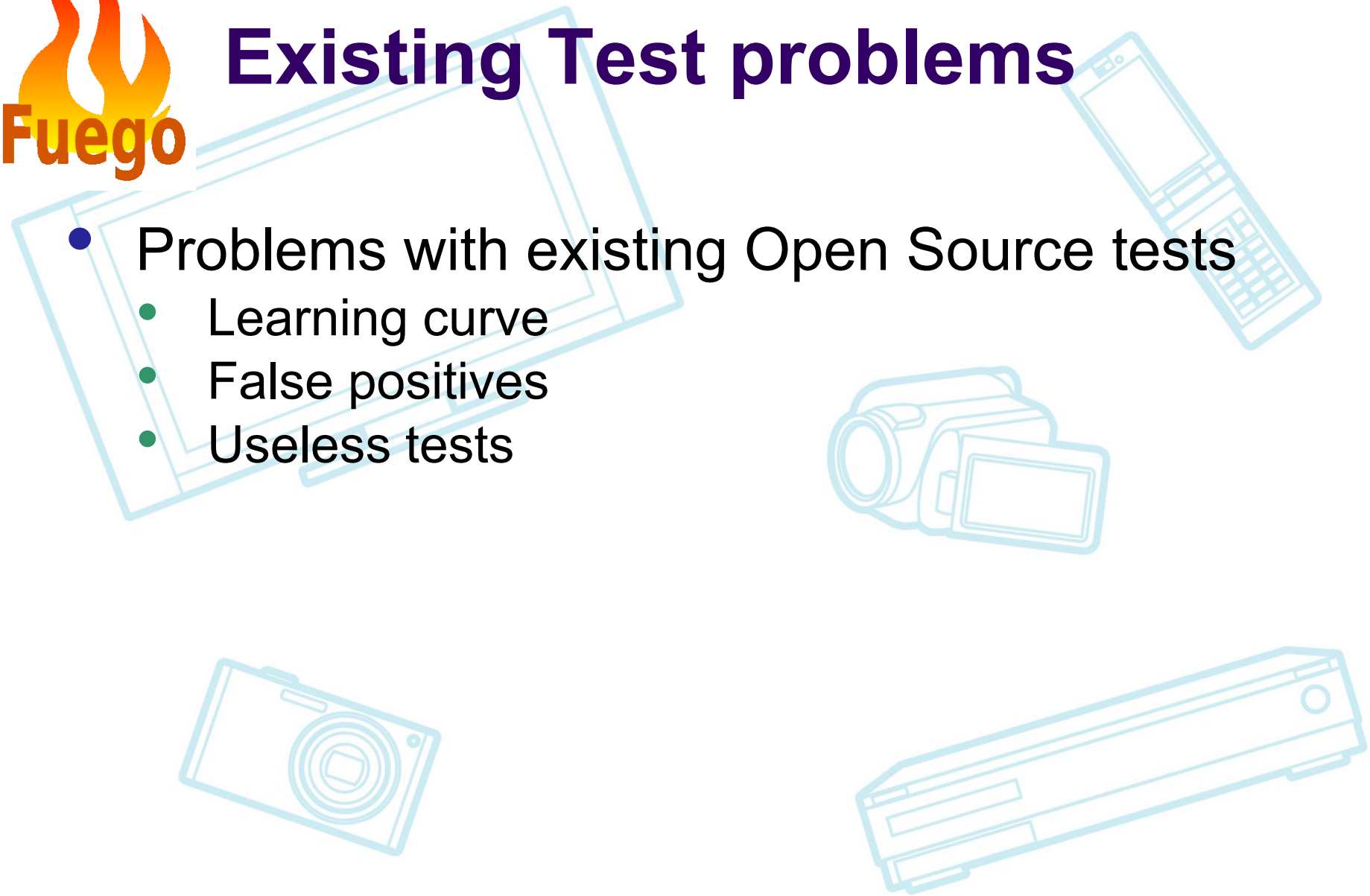
- Test ecosystem problems
- Test frameworks
  - LTP
  - kselftest
  - Fuego
- Attributes of a good test
- Tips
- Resources

Test ecosystem problems

- Not enough test sharing
  - Lots of test frameworks
  - Some tests are available
    - LTP and lots of individual and benchmarks exist
  - Many tests are not shared!
- Why aren't more aspects of QA cycle shared?
  - Many in-house tests use custom test rigs or specialized hardware
  - Interface between DUT, test system and test is not standardized

Existing Test problems

- Problems with existing Open Source tests
  - Learning curve
  - False positives
  - Useless tests



Learning curve

- For any particular test, the QA engineer must learn:
  - How to build, install and run the test
  - How to customize the test for the local environment
  - How to interpret results
- Developers need to:
  - Reproduce results
    - Have 3rd parties reproduce results
  - Report issues upstream

False positives

- Bad or missing dependencies
  - LTP tests often don't do a good job of checking dependencies
- Some tests are too sensitive to test environment conditions
  - Extra load on the machine will cause benchmarks to behave wildly
  - Bad network, bad flash, server unavailability cause false positives

Useless tests

- Tests an attribute so basic, the test never fails
- Tests conditions that are unrelated to required behavior
- Tests conditions that are already exercised just by booting the DUT and executing the test framework
  - ex: open syscall
- Tests something rare and unlikely
  - May cost more to execute than it's worth to find a bug

Solutions

- Need to have tests that are:
  - Well-documented
  - Easier to automate
    - Handle building and installation automatically
  - More robust
    - Handle dependencies, skip problematic tests
  - Sharable with others
    - Work in many scenarios
    - Work on many devices
    - Easily customized

Test Frameworks

- LTP
  - Linux Test Project
- kselftest
  - Kernel selftest (unit tests)
- Fuego
  - AGL/LTS test system
  - Like a test package system

LTP (Linux Test Project)

- Is a big “umbrella” project, with lots of tests
- Provides helper functions for setup, results reporting, cleanup

LTP introduction

- Mostly C and posix shell tests of kernel and core system functionality
  - No benchmarks
- Has lots of tests (>3000) in 3 broad categories
  - functional, posix conformance, realtime
  - Hard to assess coverage
    - New syscalls and behaviors show up every release
      - It's hard to keep up
- Heavy historical focus on testing error conditions

Included test harness

- Tests can be run individually, or in groups, or stress configurations
- ltp-pan – run a named collection of tests
  - Optionally with multiple simultaneous instances
  - Optionally repeatedly
    - for a count, or
    - for a period of time
  - Can customize command-line parameters
- ltprun – runs groups of tests
  - Many groups defined:
    - syscalls, input, fs, net, math, numa, etc.
    - Over 80 groups of tests

LTP output

- Individual test results schema:
  - TPASS – test passed (result was as expected or within tolerance)
  - TFAIL – test failed (result was unexpected or out-of-tolerance)
  - TBROK – test case broken (missing precondition, such as resource unavailable)
  - TCONF – test configuration not satisfied, such as machine type or kernel version.
  - TINFO – provides additional information about a test result
  - TWARN – provides additional information about a test condition (indicating undesirable situation), but that does not affect the test result
- Additional meta-data from harness
  - command line, duration, system times, exit code, etc.

LTP example test

- umount02
- Sample output:

```
tst_device.c:213: INFO: Using test device LTP_DEV='/dev/loop0'
tst_test.c:792: INFO: Timeout per run is 0h 05m 00s
tst_mkfs.c:75: INFO: Formatting /dev/loop0 with ext2 opts='' extra opts=''
mke2fs 1.42.13 (17-May-2015)
umount02.c:72: PASS: umount() fails as expected: Already mounted/busy: EBUSY
umount02.c:72: PASS: umount() fails as expected: Invalid address: EFAULT
umount02.c:72: PASS: umount() fails as expected: Directory not found: ENOENT
umount02.c:72: PASS: umount() fails as expected: Invalid  device: EINVAL
umount02.c:72: PASS: umount() fails as expected: Pathname too long: ENAMETOOLONG

Summary:
passed   5
failed   0
skipped  0
warnings 0
```

Example setup & cleanup

```
static void setup(void)
{
        memset(long_path, 'a', PATH_MAX + 1);
        SAFE_MKFS(tst_device->dev, tst_device->fs_type, NULL, NULL);
        SAFE_MKDIR(MNTPOINT, 0775);
        SAFE_MOUNT(tst_device->dev, MNTPOINT, tst_device->fs_type, 0, NULL);
        mount_flag = 1;
        fd = SAFE_CREAT(MNTPOINT "/file", 0777);
}
static void cleanup(void)
{
        if (fd > 0 && close(fd))
                tst_res(TWARN | TERRNO, "Failed to close file");
        if (mount_flag)
                tst_umount(MNTPOINT);
}
```

Example setup & cleanup

```
static void setup(void)
{
        memset(long_path, 'a', PATH_MAX + 1);
        SAFE_MKFS(tst_device->dev, tst_device->fs_type, NULL, NULL);
        SAFE_MKDIR(MNTPOINT, 0775);
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        mount_flag = 1;
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}
static void cleanup(void)
{
        if (fd > 0 && close(fd))
                tst_res(TWARN | TERRNO, "Failed to close file");
        if (mount_flag)
                tst_umount(MNTPOINT);
}
```

setup and cleanup

- Use SAFE_ macros for automatic error handling
- Clean up in opposite order of resource allocation
- Use tst_* helper functions
  - There are many, to handle common operations

Example test

```
static struct tcase {
        const char *err_desc;
        const char *mntpoint;
        int exp_errno;
} tcases[] = {
        {"Already mounted/busy", MNTPOINT, EBUSY},
        {"Invalid address", NULL, EFAULT},
        {"Directory not found", "nonexistent", ENOENT},
        {"Invalid  device", "./", EINVAL},
        {"Pathname too long", long_path,
            ENAMETOOLONG}
};
```

```
static void verify_umount(unsigned int n)
{
        struct tcase *tc = &tcases[n];
        TEST(umount(tc->mntpoint));
        if (TEST_RETURN != -1) {
                tst_res(TFAIL,
                        "umount() succeeds unexpectedly");
                return;
        }
        if (tc->exp_errno != TEST_ERRNO) {
                tst_res(TFAIL | TTERRNO,
                        "umount() should fail with %s",
                         tst_strerrno(tc->exp_errno));
                return;
        }
        tst_res(TPASS | TTERRNO,
                "umount() fails as expected: %s",
                tc->err_desc);
}
```

test details

- verify_umount is the main ‘test’ routine
  - In this case, it is called with the sub-testcase number
- tst_res() is used to report results
  - Should be called once per sub-testcase (with actual result)
  - Can be called multiple times with INFO

Example struct tst_test

```
static struct tst_test test = {
        .tid = "umount02",
        .tcnt = ARRAY_SIZE(tcases),
        .needs_root = 1,
        .needs_tmpdir = 1,
        .needs_device = 1,
        .setup = setup,
        .cleanup = cleanup,
        .test = verify_umount,
};
```

struct tst_test

- Define a set of test attributes
  - Including function pointers for setup, cleanup and test
  - .tid defines the test identifier
- Can specify needed resources, which are automatically created and removed
- There is no “main” function
  - actual ‘main’ calls the routines specified in the tst_test struct.

LTP Resources

- https://github.com/Linux-test-project/ltp/wiki
  - https://github.com/linux-test-project/ltp/wiki/C-Test-Case-Tutorial
- Intro article by Cyril Hrubis (project maintainer) on LWN.net
  - https://lwn.net/Articles/625969/
- Lightning talk – Introduction and status at Fosdem 2018
  - https://fosdem.org/2018/schedule/event/linux_test_project/

LTP conclusion

- Has a lot of support for writing a good test
- LTP needs more tests, to keep it relevant
- Please add stuff to it, and fix anything you find that is broken
- Some project ideas:
  - Convert old tests to new API
  - Document specific test cases
    - Can do this in Fuego – more on this later
  - Clean up and add to developer docs
  - New tests (Linux commands)

kselftest Introduction

- Is the kernel unit test framework
  - Is in the kernel source tree
    - tools/testing/selftest
- Supports local execution, or remote installation
  - Can build tarfile for installation on external DUT
  - Can cross-compile (just like kernel)
- Can select individual test sets to build or run
  - make TARGETS="size timers" kselftest
- About 350 source files in 52 directories
- Where kernel devs put their own unit tests

kselftest

- Is super-convenient if you are a kernel developer
- Does not provide a harness or helpers for setup, cleanup, common operations
- Started as ad-hoc collection of kernel sub-system unit tests
  - It's still pretty ad-hoc...
- Is migrating to common output format

Example kselftest test

- Sorry....
- Each test is different
- There is no “typical” example, due to lack of API
- Each one written from scratch

Output format

- TAP is preferred output format
  - Test Anything Protocol (version 13)
  - See https://testanything.org/
  - Example:

```
1..4
ok 1 - Input file opened
not ok 2 - First line of the input valid
ok 3 - Read the rest of the file
not ok 4 - Summarized correctly # TODO Not written yet
```

- Use ksft_* output routines, to get TAP automatically (see kselftest.h)
  - ksft_test_result_pass, ksft_test_result_fail, etc.

kselftest resources

- https://www.kernel.org/doc/html/latest/dev-tools/ksefltest.html
  - from Documentation/dev-tools/kselftest.rst
- https://blogs.s-osg.org/introduction-testing-linux-kernel-kselftest/

kselftest tips

- Don’t assume you’re building or running on the latest kernel version
  - Don’t rely on features of current kernel version
  - Allow developers of earlier kernels to run latest kselftest
- Check for dependencies at runtime and notify user if they’re not fulfilled
  - Check for root user
  - Check kernel configuration

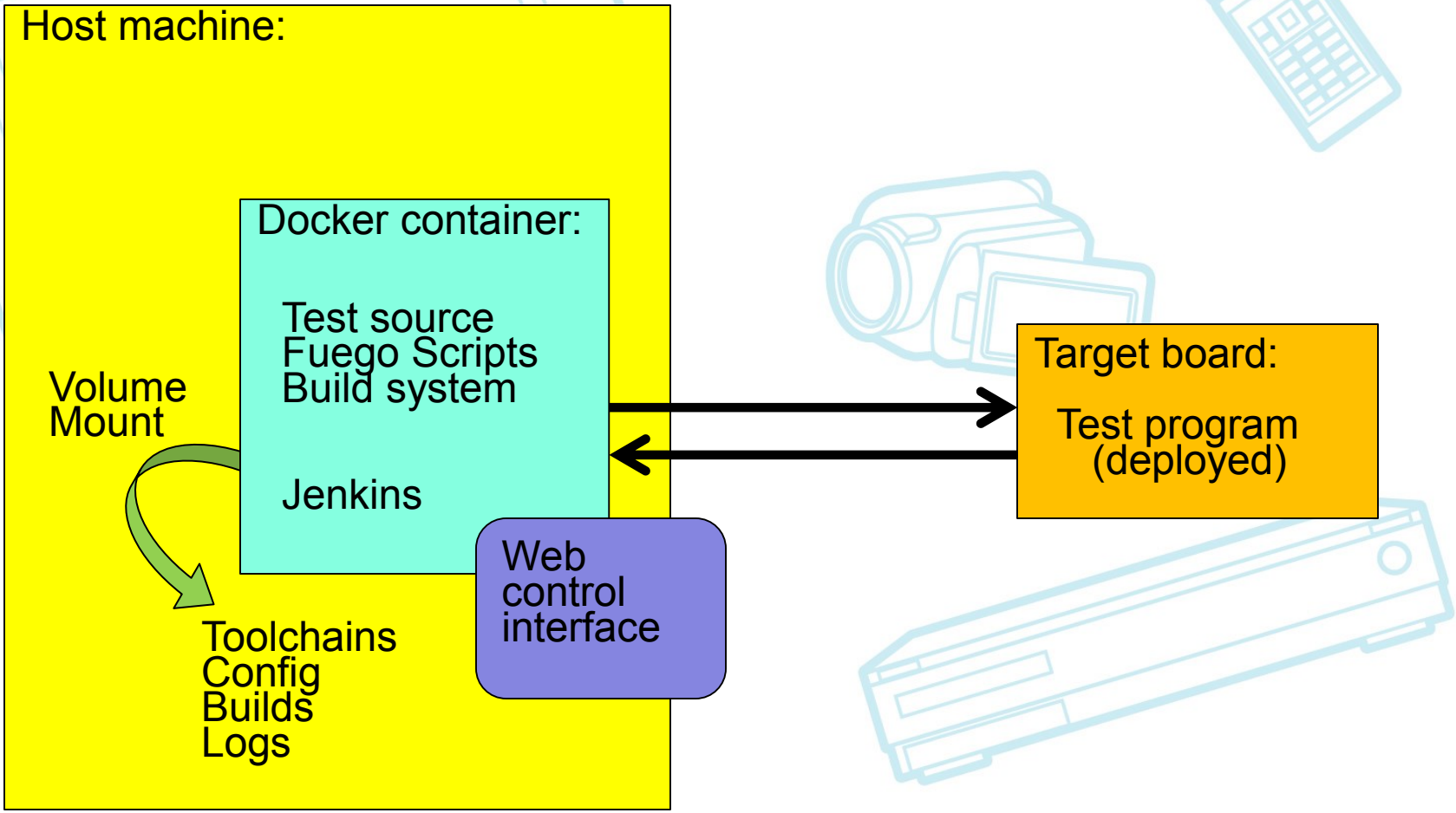
Fuego Introduction

- Fuego =
  - host test distribution +
  - a bunch of tests + test wrappers +
  - Jenkins interface
  - ALL inside a docker container
- Is intrinsically host/target
- Fuego is like the Debian of QA software
  - A distribution of tests, each one of which can be used individually (and is maintained individually)
- About 150 test suites and benchmarks so far

Fuego test

- Is more like a packaging system than an individual test
- fuego_test.sh is a wrapper for:
  - build (cross-compile)
  - deploy (put on target)
  - run
  - collect results
- Can also provide a parser to:
  - Collect individual test case data
  - Create standardized output (run.json file)
  - Apply pass criteria

Fuego Architecture



Fuego Test

- A Fuego test is usually a wrapper around an existing test:
  - Example existing tests: iozone, LTP, bonnie, iperf, Dhrystone, cyclictest
- Can also write a new individual test
  - For simple tests
  - Shell commands inside a Fuego test_run routine, or simple standalone script
- Consists of: fuego_test.sh and parser.py
- Also: spec.json, criteria.json, and other files

Fuego test example

```
tarball=hello-test-1.1.tgz

function test_pre_check {
        assert_define FUNCTIONAL_HELLO_WORLD_ARG
}

function test_build {
         make
}

function test_deploy {
         put hello  $BOARD_TESTDIR/fuego.$TESTDIR/
}

function test_run {
        report "cd $BOARD_TESTDIR/fuego.$TESTDIR; \
                ./hello $FUNCTIONAL_HELLO_WORLD_ARG"
}

function test_processing {
        log_compare "$TESTDIR" "1" "SUCCESS" "p"
}
```

Fuego output

- Every test produces run.json file
  - test meta-data, logs, results in JSON format
- Results schema:
  - PASS
  - FAIL
  - ERROR
  - SKIP

Fuego advocacy

- Don’t write your DUT-based test in Fuego
  - I don’t care if you don’t write a Fuego test
    - I’d rather you didn’t
  - Write something for LTP or kselftest, and the whole industry benefits
- If writing a multi-node test, consider Fuego
  - Fuego supports host-client operations
    - serial, network
  - We need standard interfaces for other hardware control
  - Probably Board Control summit at Plumbers

Fuego Resources

- Fuego web server:
  - http://fuegotest.org/
  - wiki: http://fuegotest.org/wiki
- Mailing list:
  - https://lists.linuxfoundation.org/mailman/listinfo/fuego
- Repositories:
  - https://bitbucket.org/tbird20d/fuego
  - https://bitbucket.org/tbird20d/fuego-core

Tim's scorecard

Attribute	LTP	kselftest	Fuego
Well-documented	APIs - some tests - no	no	APIs - yes tests - in-progress
Handles builds and installs	yes	yes	yes+
Test scheduling	no	no	yes (via jenkins)
Helper routines (setup, cleanup, etc.)	lots	few	some
Handles dependencies	some	no	lots
Customizable	some	no	yes
Consistent output	yes* (in different groups)	no* (TAP started)	yes
Test ids	numbers only	numbers only	some strings
Visualization	no	no	yes

Choosing a framework

- For white-box testing of the Linux kernel, use kselftest
- For black-box testing, use LTP
  - Especially for kernel behavior testing
- For benchmarks, extend or customize one of the current tools
  - xfstests, mmtests, iperf, etc.
- For dual-machine tests, use Fuego
  - Intrinsically supports host/target test operation
  - Needs more support for API for hardware connections (e.g. bus control, audio, video)

Tips for good tests

- Produce good output
- Make tests universal
- Avoid false positives
- Test something useful

Test output

- 6 elements of good test output:
  - Testcase identifier (tguid)
  - Description
  - Result (pass/fail)
  - Behavior
    - Expected behavior
    - Seen behavior
  - Interpretation
- Distinguish results from errors
  - Errors are problems that interfere with the test

Tips for test output

- Make results machine parsable, but human readable
  - Use unique strings for results output (e.g. TPASS)
  - Use common results schema:
    - Use the same strings to indicate:
      - pass, fail, error, skip
  - Use unique and persistent test case identifiers
  - Use line-based output
    - Output should be greppable.
  - Results exposition should follow the results or preced the results, but NOT BOTH
    - This makes the parser much easier.

Test case identifiers

- Don’t just use numbers
- TGUID = test globally unique identifier
  - LTP.syscall.umount02.03
  - LTP.syscall.umount02.try_nonexistent_dir
- Make the identifier persistent
  - That is, id should be the same run-to-run
  - BAD: list of connections is read from dynamic source, and numbers are used to indicate the network test to each one:
    - ‘net_test 1’ *(= test to google.com)*
    - ‘net_test 2’ *(= test to amazon.com)*
  - Better:
    - ‘net_test connect to google’
    - ‘net_test connect to amazon’

Make tests universal

- Limit the languages used:
  - Native program or POSIX shell
- Don’t assume DUT capabilities
  - Check for dependencies
- Use minimal resources

Limited Languages

- Compiled language
  - Usually C (most common denominator)
  - Provide source, not binaries
  - Make source cross-compilable
    - Don't assume architecture of DUT
  - Statically link, if possible
    - Avoid library dependencies
- POSIX shell
  - POSIX features only (no, not bash)
  - Use "checkbashisms" tool to find things that are unsupported by POSIX shell standard
    - Then get rid of them
- If another interpreted language, provide virtual machine with test

Use minimal resources

- Avoid dependencies, where possible
- C programs:
  - Limit usage of library calls: POSIX subset
    - Depends on the test, of course
    - OSkit defines a good minimal C library subset
    - http://www.cs.utah.edu/flux/oskit/html/oskit-wwwch14.html
      - Ignore the weird parts of memory allocation (14.5)
  - Assume minimal OS features (reduced syscall set)
- Shell scripts:
  - Limit usage of external commands
    - Recommended minimum list:
      - cat, df, find, grep, free, head, mkdir, mount, ps, reboot, rm, rmdir, route, sync, tee, test, touch, true, umount, uname, uptime, xargs
  - Limit use of /proc and /sys

Detect dependencies

- When you have dependencies (and you will)...
- Detect dependencies before test
  - Use dependency system
  - Probe system and abort early, with message
- Missing dependency = skip, not fail
  - Let user specify if a testcase should be run
    - ie Support skiplists, or auto-handle skips

Don’t assume DUT capabilities

- Don’t assume capacity or speed of DUT
  - Don’t hardcode loops or sizes
  - Automatically detect loops or sizes, if needed
    - Probe for capabilities (disk size, mem size, CPU speed)
    - Consider using a pre-test run (ie calibration run), to adjust loops or sizes
  - As a last resort, use test parameters to adjust loops or sizes
    - NOTE: test parameters are a royal pain to maintain. Please document not just their presence, but when and why they would be used

Make tests reusable

- Make tests usable in a wide variety of circumstances
  - Parameterize tests
  - Allow results criteria external to test
    - Required for benchmarks, to avoid dependency on the speed, latency, etc. of particular machine
    - Most benchmarks just produce results, but don't evaluate them
    - Fuego allows specifying pass criteria for Benchmarks (criteria.json file)

Parameterize tests

- Parameters allow for adapting your test to circumstances
  - Should not be used as a way of avoiding writing parts of test that are difficult
  - Allows a single test to be used in different circumstances
- Parameters must be well-documented
  - This is often a big deficiency
- Use command line arguments for parameters
  - Don’t use shell environment variables

Documenting Tests

- What does it test?
- How does it test it?
- What are the expected results?
- What to do if bad results are seen?
  - What config items can be changed?
  - What /proc or /sys knobs can be adjusted?
  - What hardware can be changed? (e.g. mmc, antenna, etc.)
  - Where to report failures?
- What do parameters adjust?

Test automation

- Things that make a test automatable:
  - Uses standard build tropes (configure, make)
  - Is self-contained
  - Creates needed resources, cleans up after self
  - Has easily parsed output for results determination
    - Has consistent output patterns
  - Is deterministic
  - Does not require human setup or input

Test usability

- Things that make a test usable:
  - Indicates what it is testing
  - Gives additional information when test fails

Test robustness

- Check for dependencies
- Create needed resources at test time
  - But this can require time
- Tune for DUT capabilities
  - Capacity, speed, RT latencies
- Handle errors gracefully
- Clean up after test

Test something useful

- Test behavior that your program relies on
  - Stuff that would break your app if it changed
- Don't just test everything in the spec
- Don't test existing behavior if your code doesn't rely on it
  - This just codifies that behavior
- Read *your* code, not the specs or the system code, to produce a test
- Make tests for things that broke and were fixed
  - Create regression tests
  - If it broke before, it can break again

Miscellaneous

- Use clitest for shell test automation
  - Provide a script with command and expected output
  - clitest executes command and compares results
  - See https://github.com/aureliojargas/clitest

My advice and preference

- Write new functional tests in LTP
  - Has a good test library, build system is free
  - Has consistent output schema
    - Many harnesses already parse LTP output
- For existing test, publish it and add Fuego test for your test
  - Fuego can automate it, document it, make the results sharable, and provide visualization for it
- Would like to see kselftest use the LTP test library
- Need board automation standards!

Go forth and test...

Share your tests!


Fuego