Complete System Testing

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CSE 218

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Today's Papers

1. **Automatic system testing of programs without test oracles**, Christian Murphy, Kuang Shen, and Gail Kaiser.
2. **Automating System Tests Using Declarative Virtual Machines**, van der Burg, S.; Dolstra, E.
3. **A formal analysis of requirements-based testing**, Charles Pecheur, Franco Raimondi, and Guillaume Brat.

Automatic System Testing of Programs without Test Oracles

Christian Murphy, Kuang Shen, Gail Kaiser
Columbia University

Problem Landscape

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Metamorphic Testing -

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  - What is its output??
  - A Simpler example..

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  - What is its output??
  - A Simpler example..Input to a program calculating PI
  - Output?????
- Generally, Scientific calculations, optimizations, machine learning etc fall in this category

Metamorphic Testing - How is it done?

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- Simple inputs and outputs to the system are identified
- System is first tested with them
- Modify existing test case input to produce new test case such that new output can be predicted from the existing output if x is the old input, $f(x)$ is old output, then create new input x' from x such that $f(x')$ can be predicted from $f(x)$

But..

- Very hard to manually enerate new inputs..

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- Very hard to manually enerate new inputs..
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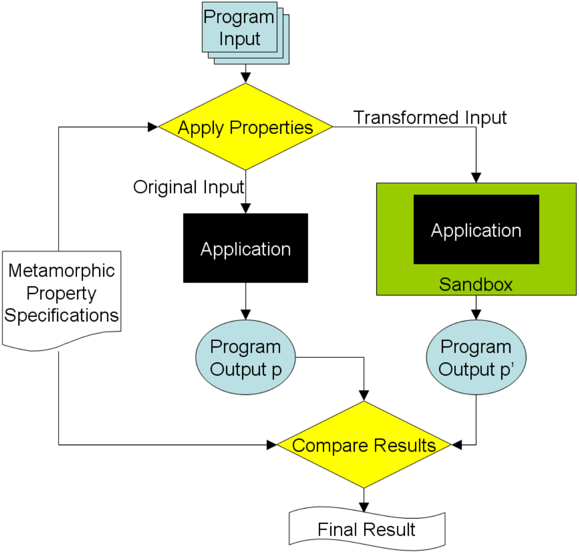
- They are even called "Non-Testable" programs
- Alternative??
  - * **Pseudo-Oracle**
    Make multiple implementations of same program with different algorithms and validate output..!!
  - * **Automated Metamorphic System Testing(Paper's proposal)**
    Automate the process of creating various inputs, running the test and validating the output

Automatic Metamorphic System Testing Framework



Framework Description

Input Transformations

- XML file specifies the transformation type

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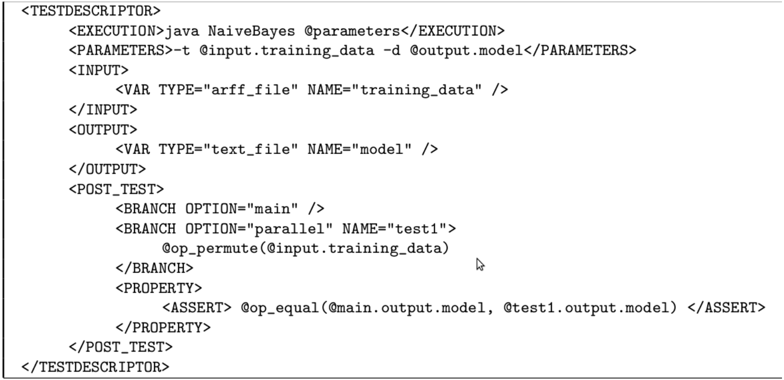
  6 transformations are implemented:

  1. Adding a constant to numerical values
  2. Multiplying numerical values by a constant
  3. Permuting the order of input data
  4. Reversing the order of input data
  5. Removing part of data
  6. Adding additional data

Framework Description

Metamorphic Property Specification XML



```
<TESTDESCRIPTOR>
      <EXECUTION>java NaiveBayes @parameters</EXECUTION>
      <PARAMETERS>-t @input.training_data -d @output.model</PARAMETERS>
      <INPUT>
            <VAR TYPE="arff_file" NAME="training_data" />
      </INPUT>
      <OUTPUT>
            <VAR TYPE="text_file" NAME="model" />
      </OUTPUT>
      <POST_TEST>
            <BRANCH OPTION="main" />
            <BRANCH OPTION="parallel" NAME="test1">
                  @op_permute(@input.training_data)
            </BRANCH>
            <PROPERTY>
                  <ASSERT> @op_equal(@main.output.model, @test1.output.model) </ASSERT>
            </PROPERTY>
      </POST_TEST>
</TESTDESCRIPTOR>
```

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  - Production Environment - Run by end-user after deployment
    - Invoke sanboxed application and “functional” app parallely

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  - Development Environment - Pre-release testing
    - Can disable parallel execution & Sandboxing
    - Trace dump enable

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    - Trace dump enable
- If test fails, Pop-up message or write to file

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- * Exact mismatch
- * Approximate Mismatch -
  Ex: Floating Point results
  Value of $sine(x)$ and $sine(x + 2\pi)$ should be same. But the precision depends on value of π used in the program.

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  Use *Heuristic Metamorphic Testing* - Upto 2% mismatch allowed

Empirical Sutdies

Evaluated on 3 machine learning applications from Weka 3.5.8 toolkit (Java)

- **Support Vector Machines** - Supervised classification
- **C4.5** - Decision tree builder
- **MartiRank** - Ranking algorithm
- **PAYL** - Network packets anomoly based intrusion detection system

Empirical Sutdies

Experiment Methodoly

- Insert random mutation in source code
- Determine if mutation can be detected by the testing suite

Three mutant types used:

- Flip comparison operators: $=$ becomes $\neq$
- Flip mathematical operators: $*$ become $\div$
- Off-by-one error: adjust loop variable, array indices etc by one

Results

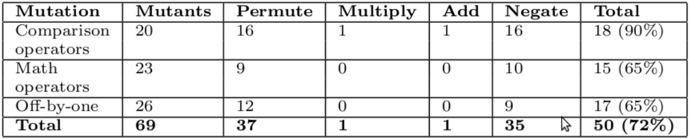
Mutation	Mutants	Permute	Multiply	Add	Negate	Total
Comparison operators	30	17	2	0	0	17 (57%)
Math operators	24	13	0	11	16	18 (75%)
Off-by-one	31	27	0	7	9	31 (100%)
Total	**85**	**57**	**2**	**18**	**25**	**66 (77%)**

Table 1: Results of Mutation Testing for SVM

Mutation	Mutants	Permute	Multiply	Add	Negate	Total
Comparison operators	8	8	0	1	7	8 (100%)
Math operators	15	2	3	1	13	14 (93%)
Off-by-one	5	2	0	0	5	5 (100%)
Total	**28**	**12**	**3**	**2**	**25**	**27 (96%)**

Table 2: Results of Mutation Testing for C4.5

Results



Mutation	Mutants	Permute	Multiply	Add	Negate	Total
Comparison operators	20	16	1	1	16	18 (90%)
Math operators	23	9	0	0	10	15 (65%)
Off-by-one	26	12	0	0	9	17 (65%)
Total	**69**	**37**	**1**	**1**	**35**	**50 (72%)**

Table 3: Results of Mutation Testing for MartiRank

For PAYL:

- Detected 2 of 40 mutants !!

- Reason: PAYL bothers about distribution of data. Input metamorphosis altered content and ordering only, not distribution.

Performance

Quad-core 3GHz CPU running Ubuntu
- 400ms lag in *application startup* for 10MB input file
- “Functional Application” and “Sanboxed Application” ran on different cores without measurable lag to user

Snake Oil

- Can't work with Databases and Network
- Can't work for applications requiring user response
- Fault Localization not possible
- Can't work for binary input/output
- No false +ve rate mentioned in paper

Automating System Tests Using Declarative Virtual Machines

Sander van der Burg, Eelco Dolstra
Delft University of Technology, The Netherlands

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  For example:
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  - **Transmission** requires a host behind NAT with UPnP-IGD protocol enabled router

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HOW TO AUTOMATICALLY RUN REGRESSION TEST?

Solution

NixOS

Build and instantiate Virtual Machine and run application inside it

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- Supports multiple builds simultaneously with different configurations
- Runs NixOS on QEMU/KVM Hardware Emulator

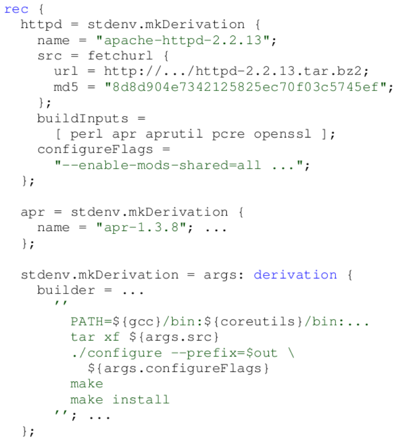
Nix Expression Script

```
derivation {
  name = "foo";
  builder = "${bash}/bin/sh";
  args = [ "-c" "echo Hello $who > $out" ];
  who = "world";
}
```

Output: “Hello world” will be written into /nix/store/lw1e3or1p45n2-foo

Nix Expression Script

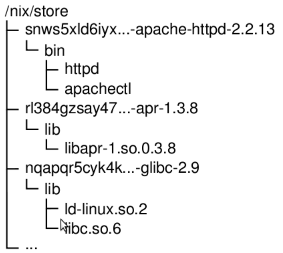
To build Apache: `nix-build pkgs.nix -A httpd`



```
rec {
  httpd = stdenv.mkDerivation {
    name = "apache-httpd-2.2.13";
    src = fetchurl {
      url = http://.../httpd-2.2.13.tar.bz2;
      md5 = "8d8d904e7342125825ec70f03c5745ef";
    };
    buildInputs =
      [ perl apr aprutil pcre openssl ];
    configureFlags =
      "--enable-mods-shared=all ...";
  };

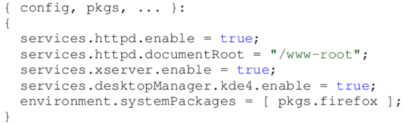
  apr = stdenv.mkDerivation {
    name = "apr-1.3.8"; ...
  };

  stdenv.mkDerivation = args: derivation {
    builder = ...
      ''
        PATH=${gcc}/bin:${coreutils}/bin:...
        tar xf ${args.src}
        ./configure --prefix=$out \
          ${args.configureFlags}
        make
        make install
      ''; ...
  };
```



```
/nix/store
├ snws5xld6iyx...-apache-httpd-2.2.13
│ └ bin
│   ├ httpd
│   └ apachectl
├ rl384gzsay47...-apr-1.3.8
│ └ lib
│   └ libapr-1.so.0.3.8
├ nqapqr5cyk4k...-glibc-2.9
│ └ lib
│   ├ ld-linux.so.2
│   └ libc.so.6
└ ...
```

Figure 2. Partial closure of Apache in the Nix store



```
{ config, pkgs, ... }:
{
  services.httpd.enable = true;
  services.httpd.documentRoot = "/www-root";
  services.xserver.enable = true;
  services.desktopManager.kde4.enable = true;
  environment.systemPackages = [ pkgs.firefox ];
}
```

Building NixOS from scratch

```
nix-build /etc/nixos/nixos -A config.build.system.toplevel
```

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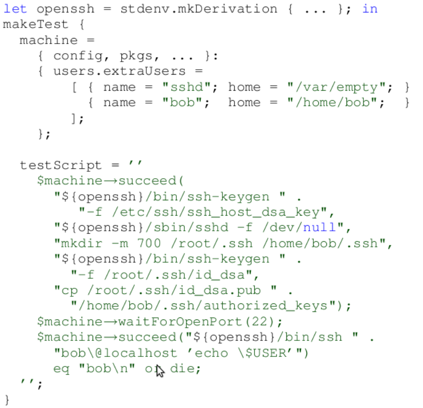
```

Testing OpenSSH

```
$ nix-build openssh.nix -A vm
$ ./result/bin/run-vm
```



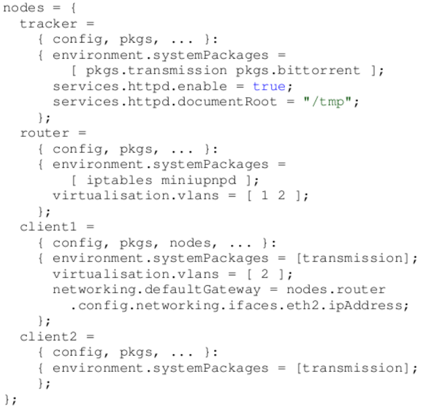
```
let openssh = stdenv.mkDerivation { ... }; in
makeTest {
  machine =
    { config, pkgs, ... }:
    { users.extraUsers =
        [ { name = "sshd"; home = "/var/empty"; }
          { name = "bob";  home = "/home/bob";  }
        ];
    };

  testScript = ''
    $machine→succeed(
      "${openssh}/bin/ssh-keygen " .
         "-f /etc/ssh/ssh_host_dsa_key",
      "${openssh}/sbin/sshd -f /dev/null",
      "mkdir -m 700 /root/.ssh /home/bob/.ssh",
      "${openssh}/bin/ssh-keygen " .
        "-f /root/.ssh/id_dsa",
      "cp /root/.ssh/id_dsa.pub " .
        "/home/bob/.ssh/authorized_keys");
    $machine→waitForOpenPort(22);
    $machine→succeed("${openssh}/bin/ssh " .
      "bob\@localhost 'echo \$USER'")
      eq "bob\n" or die;
  '';
}
```

Figure 4. openssh.nix: Specification of an OpenSSH regression test

Distributed Tests - For Transmission

Network Specification

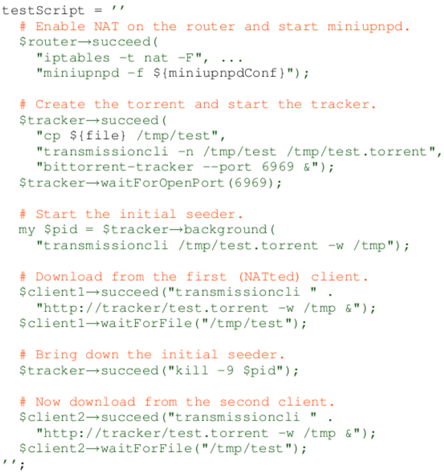


```
nodes = {
  tracker =
    { config, pkgs, ... }:
    { environment.systemPackages =
        [ pkgs.transmission pkgs.bittorrent ];
      services.httpd.enable = true;
      services.httpd.documentRoot = "/tmp";
    };
  router =
    { config, pkgs, ... }:
    { environment.systemPackages =
        [ iptables miniupnpd ];
      virtualisation.vlans = [ 1 2 ];
    };
  client1 =
    { config, pkgs, nodes, ... }:
    { environment.systemPackages = [transmission];
      virtualisation.vlans = [ 2 ];
      networking.defaultGateway = nodes.router
        .config.networking.ifaces.eth2.ipAddress;
    };
  client2 =
    { config, pkgs, ... }:
    { environment.systemPackages = [transmission];
    };
};
```

Figure 6. Network specification for the Transmission regression test

Distributed Tests - For Transmission

Test Script



```
testScript = ''
  # Enable NAT on the router and start miniupnpd.
  $router→succeed(
    "iptables -t nat -F", ...
    "miniupnpd -f ${miniupnpdConf}");

  # Create the torrent and start the tracker.
  $tracker→succeed(
    "cp ${file} /tmp/test",
    "transmissioncli -n /tmp/test /tmp/test.torrent",
    "bittorrent-tracker --port 6969 &");
  $tracker→waitForOpenPort(6969);

  # Start the initial seeder.
  my $pid = $tracker→background(
    "transmissioncli /tmp/test.torrent -w /tmp");

  # Download from the first (NATted) client.
  $client1→succeed("transmissioncli " .
    "http://tracker/test.torrent -w /tmp &");
  $client1→waitForFile("/tmp/test");

  # Bring down the initial seeder.
  $tracker→succeed("kill -9 $pid");

  # Now download from the second client.
  $client2→succeed("transmissioncli " .
    "http://tracker/test.torrent -w /tmp &");
  $client2→waitForFile("/tmp/test");
'';
```

Figure 7. Test script for the Transmission regression test

Evaluation

Coverage:-

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Apache + SVN + Linux Kernel was instrumented:

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Apache + SVN + Linux Kernel was instrumented:
Run client on one VM, server on another VM; Evaluate coverage together for both!!

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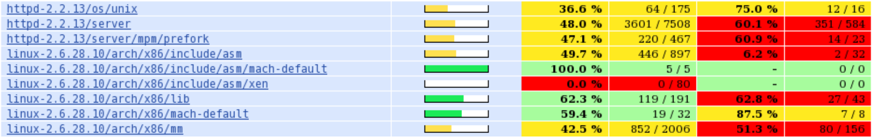
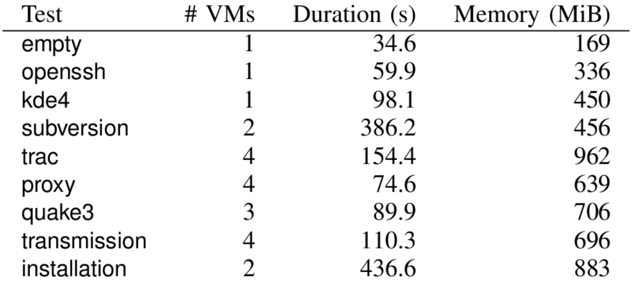


httpd-2.2.13/os/unix		36.6 %	64 / 175	75.0 %	12 / 16
httpd-2.2.13/server		48.0 %	3601 / 7508	60.1 %	351 / 584
httpd-2.2.13/server/mpm/prefork		47.1 %	220 / 467	60.9 %	14 / 23
linux-2.6.28.10/arch/x86/include/asm		49.7 %	446 / 897	6.2 %	2 / 32
linux-2.6.28.10/arch/x86/include/asm/mach-default		100.0 %	5 / 5	-	0 / 0
linux-2.6.28.10/arch/x86/include/asm/xen		0.0 %	0 / 80	-	0 / 0
linux-2.6.28.10/arch/x86/lib		62.3 %	119 / 191	62.8 %	27 / 43
linux-2.6.28.10/arch/x86/mach-default		59.4 %	19 / 32	87.5 %	7 / 8
linux-2.6.28.10/arch/x86/mm		42.5 %	852 / 2006	51.3 %	80 / 156

Evaluation

Resource Consumption on 4-core Intel Core i5 with 6GiB RAM



Test	# VMs	Duration (s)	Memory (MiB)
empty	1	34.6	169
openssh	1	59.9	336
kde4	1	98.1	450
subversion	2	386.2	456
trac	4	154.4	962
proxy	4	74.6	639
quake3	3	89.9	706
transmission	4	110.3	696
installation	2	436.6	883

Table I
TEST RESOURCE CONSUMPTION

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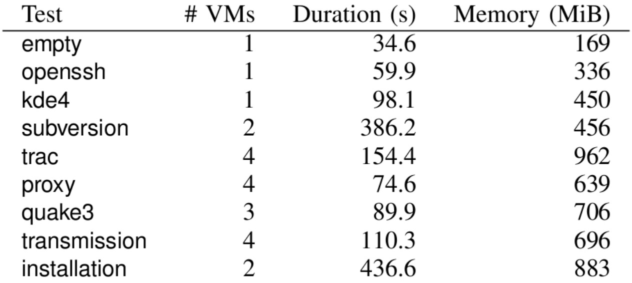

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>>> Fast enough to do **continuous builds** <<<

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- Only for Linux applications
- Not for scalability testing - Can't spawn 1000 VMs..!!

A Formal Analysis of Requirements-Based Testing

Charles Pecheur,, Franco Raimondi, Guillaume Brat

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- Difficult because requirements are in natural language
- Very critical for avionics - Ex: MARS Rovers
- Model checkers are slow - Massive state space

Problem Landscape

- Requirements-based Testing - generate test cases from requirements
- Difficult because requirements are in natural language
- Very critical for avionics - Ex: MARS Rovers
- Model checkers are slow - Massive state space
- Requirements are temporal - Ex: if the rover is moving, then all instruments are stored

Solution

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- Express requirements in Linear Temporal Logic

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- FLIP - A formalism prove that an execution path π is an adequate test case for a formula ϕ and an atom *a* appearing in the formula.

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a	b	a ∨ b
T	F	T
F	T	T
F	F	F

- Can't work when conditions are coupled - Ex: $(a \wedge b) \vee (\neg a \wedge c))$

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- Verified with NuSMV and Maude module
- Restricted to *linear formulae* for requirements

References

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Thank you !!