Test Automation

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Is maintenance needed? (GUI change, internationalization)

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Does it delay finding bugs? (fewer resources to run tests)

Does it find enough bugs? Or are most found by manual testing?

Is it powerful enough? Or does it automate only "easy" tests?

Example: Capture-replay

1) Record user actions (*mouse/keyboard*) and resulting screen (bitmap) ⇒ most primitive level

– other checks: with tester effort (interrupt/insert)
– fragile: susceptible to any product change
– possible comparison errors in resulting image

2) script with *high-level actions* (select menu/button)

– more flexible, but does not check graphic layout (low level: font, text size/overwrite, etc.)

3) *scripting language* to automatically generate new tests

Example: Capture-replay

Disadvantage of capture-replay

Cannot continue from errors

$\Rightarrow$ errors are found manually in the recording process
$\Rightarrow$ only rerunning a "good" test is automated (regression)

Does not define tests *implicit* for human ("all the rest is OK")

(cannot detect unspecified errors, is inflexible – e.g. bitmap)

Example: Test monkeys

Automated tools that execute random tests
(without a testor's knowledge on product functionality)

Dumb monkeys: fully ignore purpose (know just mouse/keyboard)
but may have basic notions about windows/menus/buttons

Smart monkeys: have a *state model* of the application, explore transitions between these states

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++ can sometimes find 10-20% of errors [Nyman, Microsoft, 2000]
++ good preliminary coverage (e.g.: 65% in 15 min – text editor)
++ completely automated, no human effort for test capture
++ runs independently, unsupervised, minimal resources (cost)
−− "dumb": only bug known to monkeys is system crash
−− $\Rightarrow$ errors are hard to record and reproduce

What can we automate in testing?

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e.g. any unit testing framework

useful in regression testing

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= problem of *test oracle* : did the test pass ?
Nontrivial, often needs manual inspection.
Risks:

– undetected errors (imprecision)
– false warnings ⇒ cost of manual checking

Ex: compare continuous signals (in automotive industry)
image comparison (for screen/printer)

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Test generation

Relatively easy: generating test skeletons (declarations + calls)
More difficult: intelligent generation of relevant data (coverage)

Choosing a test architecture [Kaner]

1) *Data-driven* architecture
   separates data from test structure (like in programs)
   Example: table. row = test; columns = test parameters
   A script generates a test case for every table row
   Minimal reasonable coverage: every *pair* of parameter values
(for every *combination* of values, number is exponential)

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2) *Framework-based* architecture
   A library of functions separates testing from UI
   e.g. `open(`*`file`*`)`, independent of actions for opening
      (menu, button click, keyboard, etc.)
   ++ reuse for frequent actions
   ++ indirection ⇒ insulation from testing tool
   −− costly, amortized only in future releases

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Automatable (*keyword testing*) for spects in well-defined language

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Starting from documentation: tabular spec, e.g. [Pettichord]

Test ID	Operation	Table	Name	Type	Nulls
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More: automated test generation from specs in formal language
e.g. decision tables in RSML (Requirements State Machine Language) in TCAS-II aviation protocol
test generation from timing diagrams in embedded systems

Model-based testing

Models: finite automata, UML, Statecharts (hierarchical automata), Message Sequence Charts, timed automata, Petri nets, Markov chains...

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all states / transitions; combinations of k consecutive transitions (*k-switch cover*)

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Testing based on *model checking*
by *state space exploration*, starting from specifications:
1) question: can the model reach a given state ?
2) if so, a *model checker* will generate an example trace = test case

Implementation-based testing: symbolic execution

Goal: exercising program, satisfying a *coverage criterion*
$\Rightarrow$ needs: instrumentation to measure test coverage

How: set of *paths*: random choice + directed search
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Satisfiability of conditions is checked with specialized tools
(satisfiability checkers, constraint solvers)

$\Rightarrow$ generate input data that will exercise that path
or prove path is infeasible $\Rightarrow$ stops exploring that path

Symbolic execution for program testing

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Test generation purpose:

attaining high coverage

sometimes, reaching a specific branch

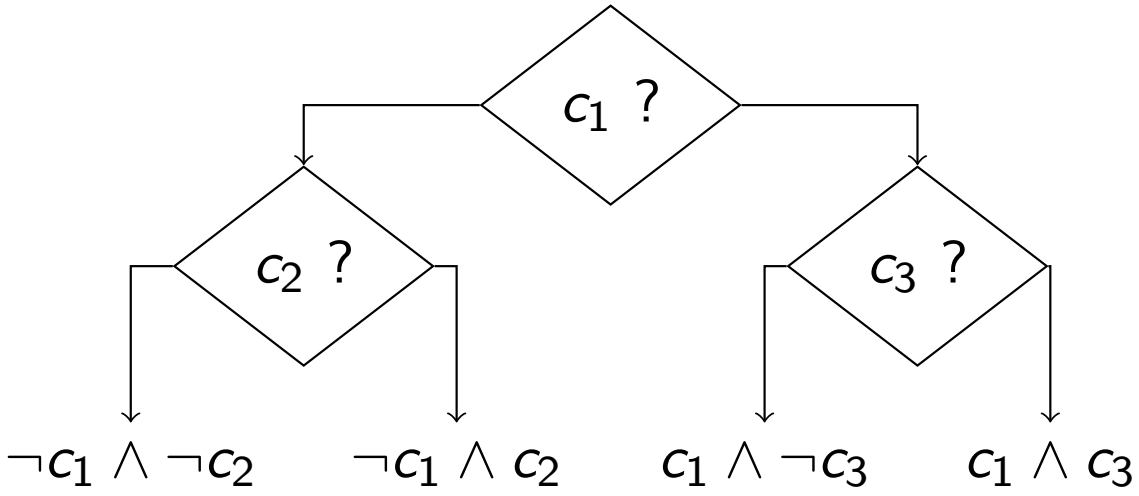
Successful mature technique, hundreds of papers, many tools:
Java Pathfinder, (j)CUTE, CREST, KLEE, Pex, SAGE, ...

for C/C++, C#, Java, more recently JavaScript

Variants of symbolic execution

Classic *completely symbolic execution*

explores each execution path independently



Problem: must express all program/language semantics as formula
solving arbitrary formulas impossible (limited to simple arithmetic)

reality: complex math, library function, environment

solution: *model* libraries & environment

e.g. KLEE tool has models for some 40 syscalls (2.5 kloc)

Dynamic (concolic) symbolic execution

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When symbolic execution is infeasible, perform a *concrete* execution step

e.g. nonlinear arithmetic, library/system functions

function explore($pathcond = [c_1, c_2, \ldots, c_n]$)
for $k = n$ downto 1 **do**
  inputs = solve $pathcond = c_1 \wedge \ldots \wedge c_{k-1} \wedge \neg c_k$ (flip c_k)
  rerun with new inputs; capture new pathcond'
  explore(pathcond')

Problem: by using concrete values, might not reach desired path

Concretization as potential obstacle

```
y = hash(x); //unknown hash formula => y concrete
if (x + y > 0)
  // path 1
else
  // path 2
```

Assume: x = 20; y = hash(20) = 13 ⇒ *path 1*

To reach *path 2*, negate $x + y > 0$, with *concrete* y (constant 13)

Solver might return, e.g., x = -15
but we might have hash(-15) = 27 (can't predict)
and then $x + y > 0$
⇒ execution still follows path 1

⇒ *retry*; worst-case: degrades to *random testing*

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Fuzz testing: generate large quantities of random / possibly hostile input, to detect input validation errors or security vulnerabilities

e.g. RANDOOP [Microsoft]: 4 M tests in 150 CPU hours / 15 person-hr
30 bugs in code tested for 200 person-years, vs. 20 errors/year manually
see also `http://research.microsoft.com/en-us/projects/Pex/`

Basic workings of a fuzzer

e.g. American Fuzzy Lop `http://lcamtuf.coredump.cx/afl/`

- maintains queue of test inputs
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highly successful, found many security vulnerabilities

mutating inputs can synthesize interesting formats (e.g. images)

can identify format fields with various meaning
(length, checksum, payload, control opcode, etc.)

Automated debugging

After automating detection $\Rightarrow$ help in *fault localization*

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binary search, finds (file) input half that caused error

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Delta debugging [Zeller]: partial automation of these techniques

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Technique used in most automated debugging approaches, inspired from the mental actions of people during debugging [Weiser '79]

based on transitive tracking of dependencies:
– *data dependencies* (value of `y` depends on `x`)
– *control dependencies* (value of `y` depends on a condition on `x`)

Program slicing

Slicing types:

- *static* (conservative, on the source code)
  dynamic (precise, on a certain execution trace)
- *forward* (what shall/could be affected by the current state?)
  or *backwards* (what lead to the current state?)
- on the *precision level* of potential considered dependencies
- *executable* (simplified standalone program) or not, etc.