Dynamic Software Model Checking

Patrice Godefroid

Microsoft Research

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- LASER'2011 summer school (Elba island, Italy)

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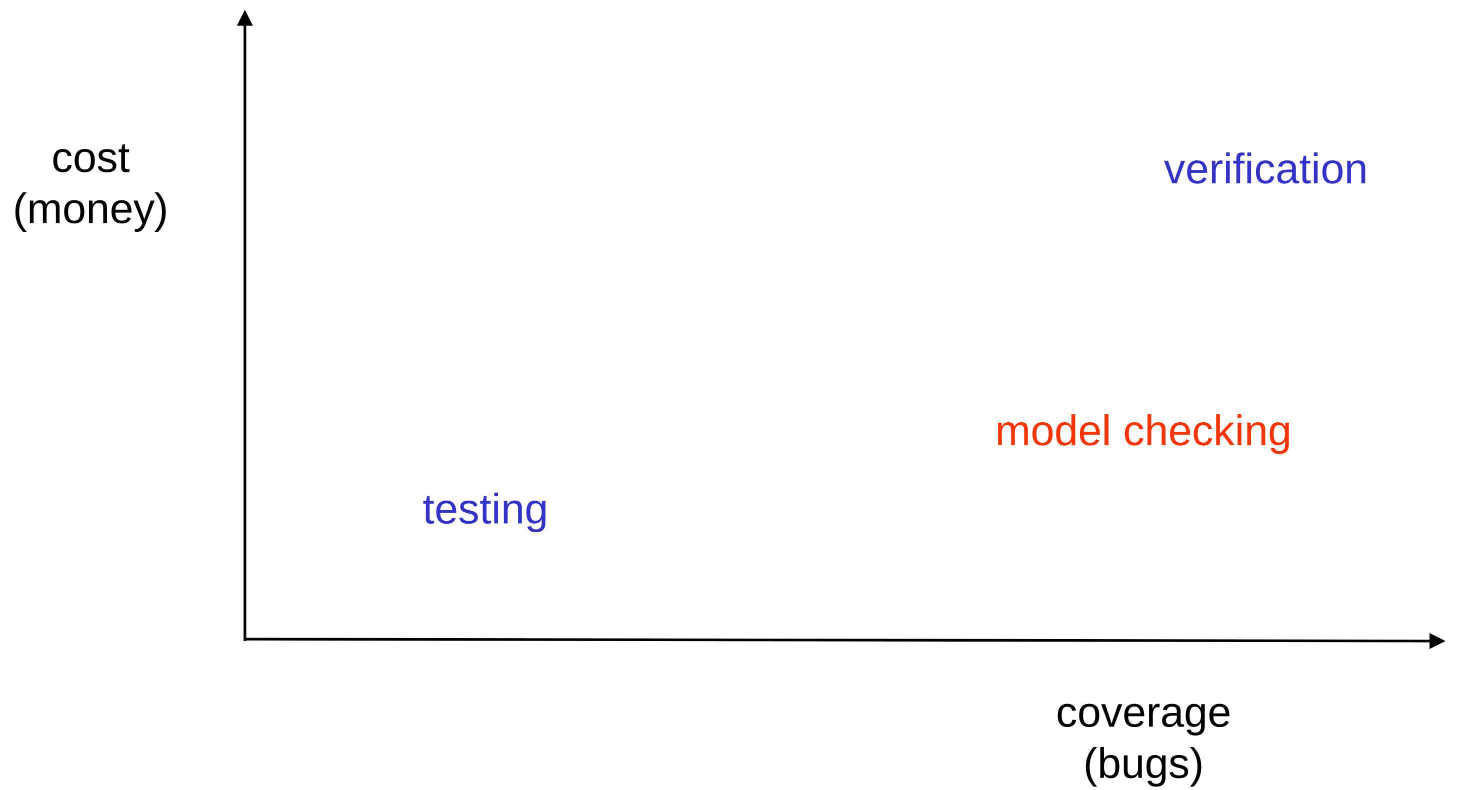
- LASER'2011 summer school (Elba island, Italy)
- Q from student: "career advice for young researcher?"
- Ed: "Pick an idea that excites you,
  then devote your life to it."

Insight: Model Checking is Super Testing

- Simple yet effective technique for finding bugs
- In the software-engineering universe:



Dynamic Software Model Checking

- How to apply model checking to analyze **software**?
  - "Real" programming languages (e.g., C, C++, Java),
  - "Real" size (e.g., 100,000's lines of code).

- Two main approaches to software model checking:

Modeling languages —state-space exploration→ Model checking

abstraction ↑ **(SLAM, Bandera, FeaVer, BLAST,…)**

adaptation ↓

Programming languages —state-space exploration→ Systematic testing

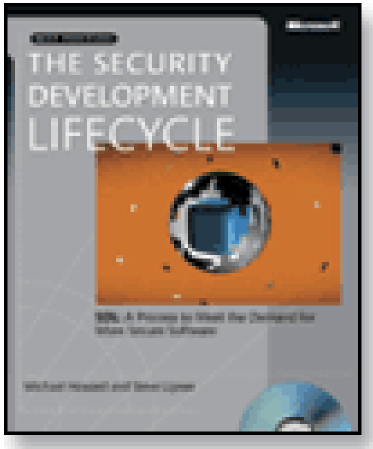
Dynamic

Concurrency: **VeriSoft, JPF, CMC, Bogor, CHESS,…**

Data inputs: **DART, EXE, SAGE,…**

Example: SAGE @ Microsoft

- Problem: How to systematically explore efficiently the state spaces of sequential programs to find bugs due to malformed inputs?



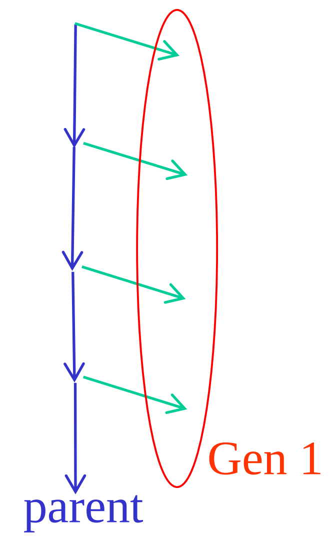
- Motivation: security testing at Microsoft
- Software security bugs can be very expensive:
  - Cost of each Microsoft Security Bulletin: $Millions
  - Cost due to worms (Slammer, CodeRed, Blaster, etc.): $Billions
- Many security exploits are initiated via files or packets
  - Ex: MS Windows includes parsers for hundreds of file formats
- Security testing: "hunting for million-dollar bugs"

A Solution: Whitebox Fuzzing [NDSS'08]

- Idea: mix fuzz testing with dynamic test generation
  - Dynamic symbolic execution to collect constraints on inputs
  - Negate those, solve new constraints to get new tests
  - Repeat → "systematic dynamic test generation" (= DART)

  (Why dynamic ? Because most precise ! [PLDI'05, PLDI'11])

- Combine with a generational search (not DFS)
  - Negate 1-by-1 each constraint in a path constraint
  - Generate many children for each parent run
  - Challenge all the layers of the application sooner
  - Leverage expensive symbolic execution

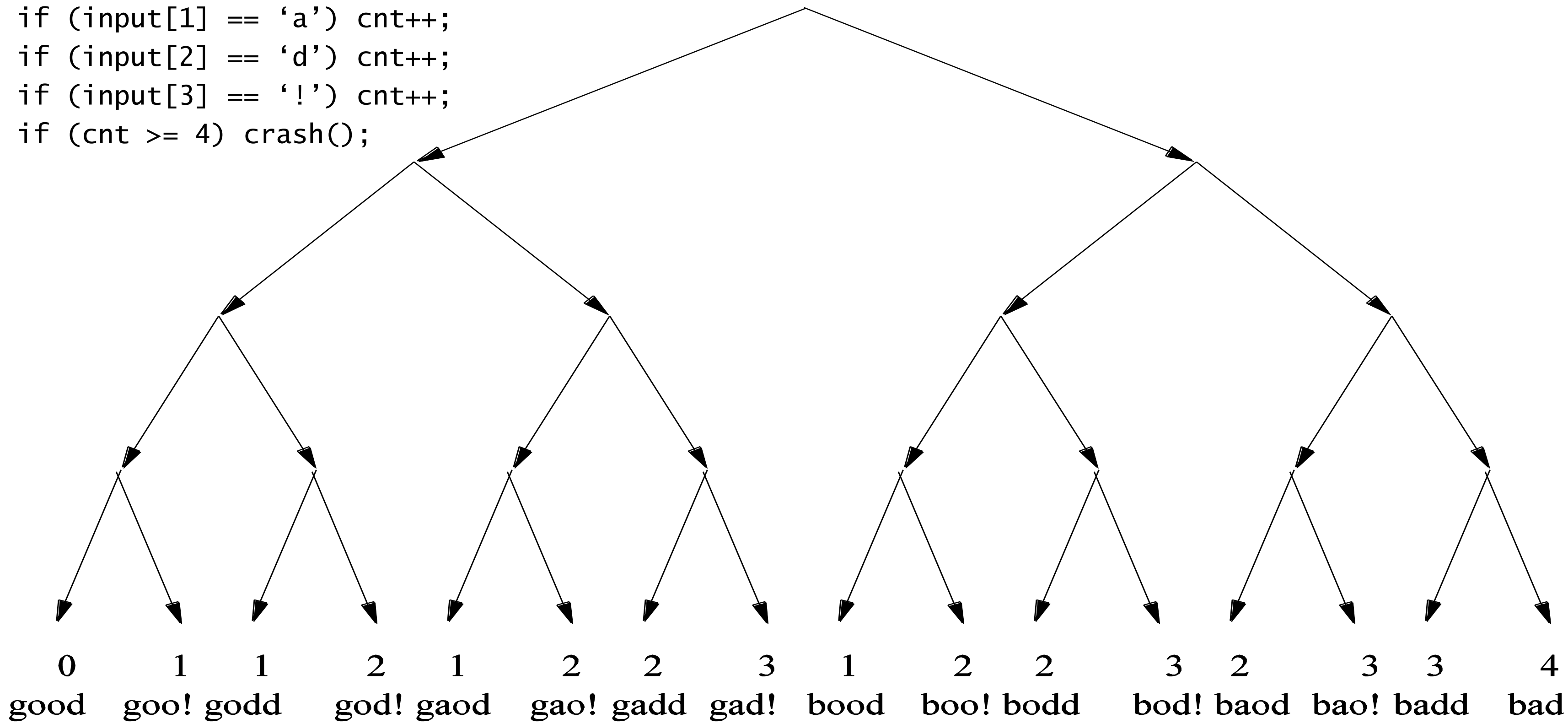


- Implemented in the tool SAGE
  - Optimized for large x86 trace analysis, file fuzzing

The Search Space

```
void top(char input[4])
{
   int cnt = 0;
   if (input[0] == 'b') cnt++;
   if (input[1] == 'a') cnt++;
   if (input[2] == 'd') cnt++;
   if (input[3] == '!') cnt++;
   if (cnt >= 4) crash();
}
```

If symbolic execution is perfect and search space is small, this is verification !

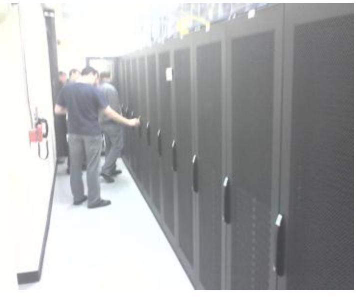


SAGE Results

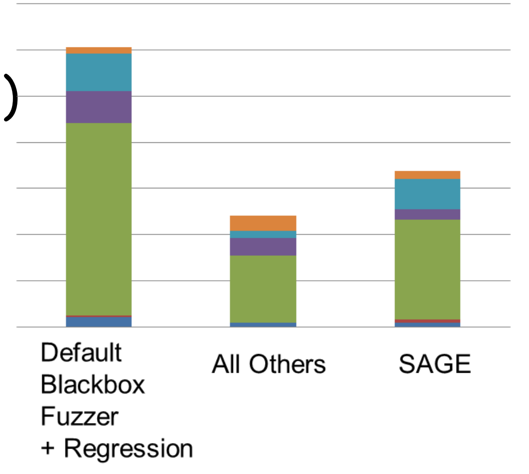
Since 2007: many new security bugs found

(missed by blackbox fuzzers, static analysis)

- Apps: image decoders, media players, document processors,…
- Bugs: Write A/Vs, Read A/Vs, Crashes,…
- Many triaged as "security critical, severity 1, priority 1" (would trigger Microsoft security bulletin if known outside MS)
- Example: WEX Security team for Win7
  - Dedicated fuzzing lab with 100s machines
  - 100s apps (deployed on 1 billion+ computers)
  - ~1/3 of all fuzzing bugs found by SAGE !



How fuzzing bugs found (2006-2009) :



Impact of SAGE (in Numbers)

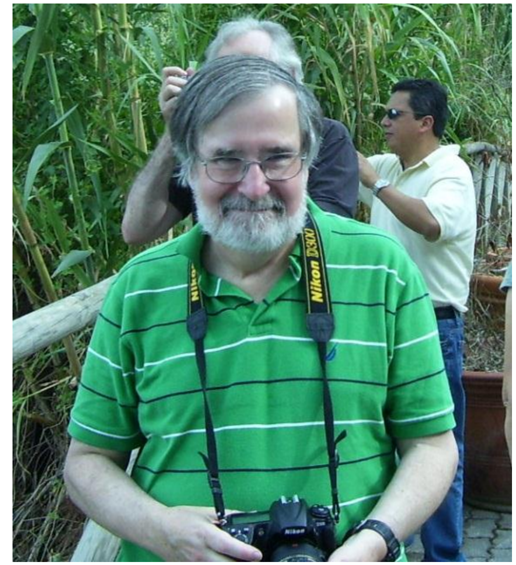
- 500+ machine-years
  - Runs in the largest dedicated fuzzing lab in the world
  - Largest computational usage ever for any SMT solver
- 100s of apps, 100s of bugs (missed by everything else)
  - Bug fixes shipped quietly (no MSRCs) to 1 Billion+ PCs
  - Millions of dollars saved (for Microsoft and the world)
- "Practical Verification":
  - Eradicate all buffer overflows in all Windows parsers
    - <5 security bulletins in all SAGE-cleaned Win7 parsers, 0 since 2011
    - If nobody can find bugs in P, P is observationally equiv to "verified"!
    - Reduce costs & risks for Microsoft, increase those for Black Hats

2000 2005 2010 2015

Blackbox Fuzzing | Whitebox Fuzzing | "Practical Verification"

Conclusion: Ed Clarke

- A man
- An idea
- A community
- Changing the world



(Elba, 2011)

Thank you !

There is one thing stronger than all the armies in the world; and that is an idea whose time has come. -- Victor Hugo