Cloud9

Parallel Symbolic Execution for Automated **Real-World Software Testing**

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
http://dslab.epfl.ch

Stefan Bucur — stefan.bucur@epfl.ch
Vlad Ureche — vlad.ureche@epfl.ch
Cristian Zamfir — cristian.zamfir@epfl.ch
George Candea — george.candea@epfl.ch

Real-World Automated Testing

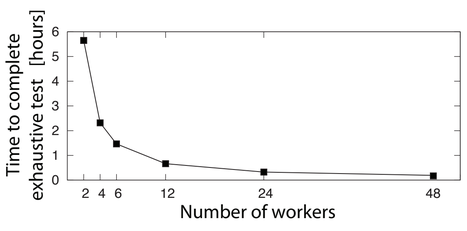
We used Cloud9 to test from system utilities to large networked and distributed systems

LIGHTTPD fly light. · Apache · Memcached · GNU Coreutils · python · cURL

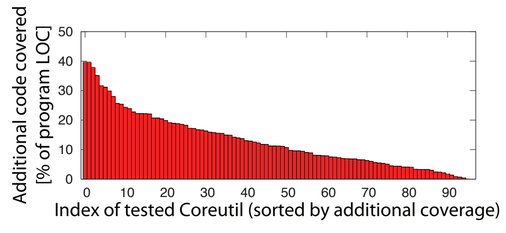
Scalable Cluster-Based Testing

- **Parallel symbolic execution** on large clusters of commodity hardware
- Suitable for running on **cloud infrastructures**

amazon web services™ · Eucalyptus Systems



Time to exhaustively test **memcached** with symbolic packets



Cloud9 code coverage improvements on the **96 Coreutils** (1-worker vs. 12-worker)

Testing Platform API

- An API that developers can use to produce **symbolic test cases** and control the behavior of the OS environment:
  - **Inject symbolic data**
  - **Symbolic packet flow fragmentation**
  - **Symbolic fault injection**
- Cloud9 can test large programs with complex environment interactions:

✔ **multithreading** ✔ **IPC** ✔ **networking** ✔ **multiple processes** ✔ **synchronization**

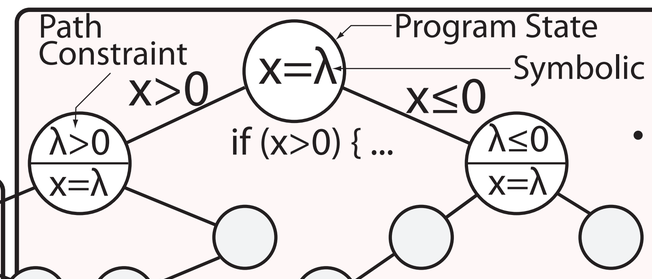
Example: Preparing a symbolic HTTP packet to test a header extension.

```
char httpData[10];
cloud9_make_symbolic(httpData);
strcat(req, "X-NewExtension: ");
strcat(req, hData);

ioctl(ssock, SIO_PKT_FRAGMENT, RD);
ioctl(ssock, SIO_FAULT_INJ, RD | WR);
```

Under The Hood

Parallel Symbolic Execution

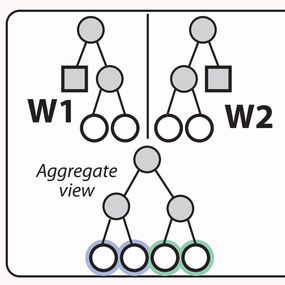


① *Symbolic Execution*

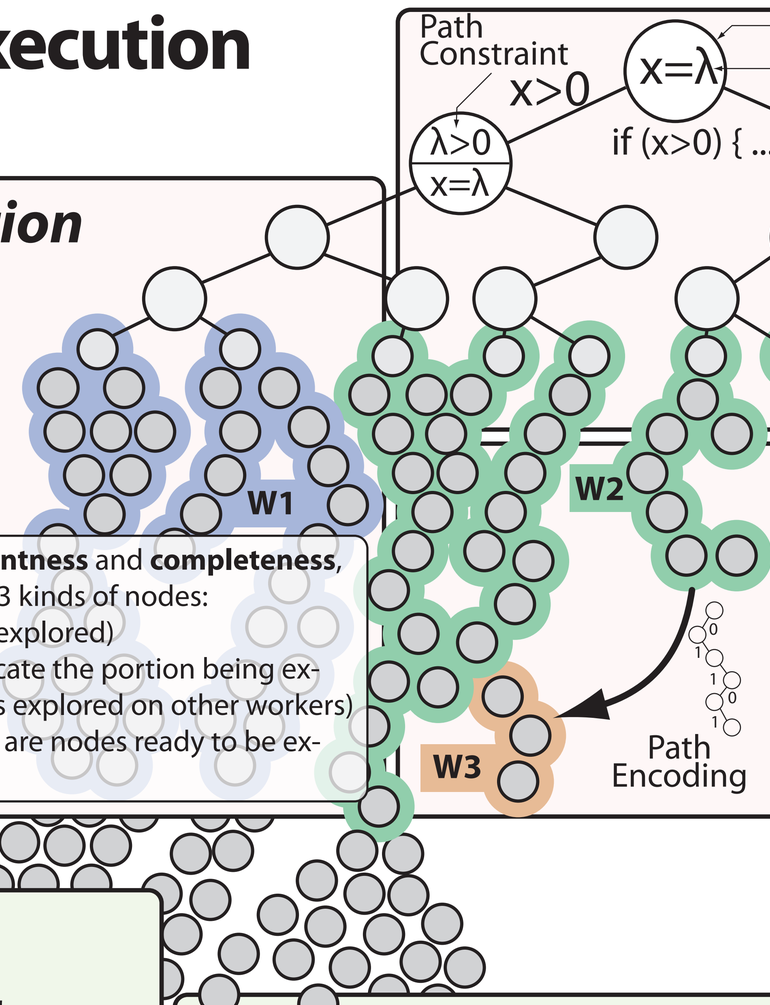
- Unconstrained **symbolic** data.
  - Execution **forks** when a branch involves symbolic values.
  - Resulting **execution tree** increases exponentially with program size - "path explosion" problem.

② *Parallel Tree Exploration*

- Parallel symbolic execution engine that runs on **commodity clusters**.
- **Worker nodes** run independent SEEs and are coordinated by a **load balancer**.



To ensure exploration **disjointness** and **completeness**, each worker's local tree has 3 kinds of nodes:
- **internal nodes** (already explored)
- **fence nodes** that demarcate the portion being explored (correspond to nodes explored on other workers)
- **candidate nodes**, which are nodes ready to be explored locally.



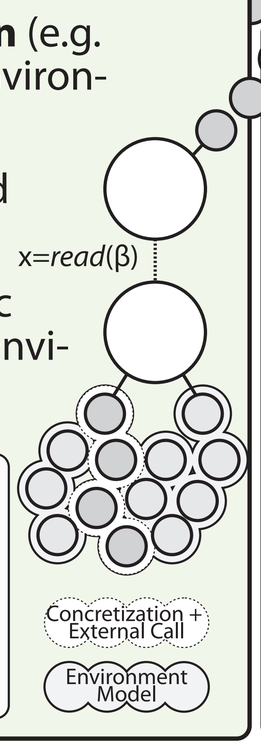
③ *Work Transfer*

- When exploration frontier becomes poorly balanced across workers, the load balancer instructs pairs of workers to transfer jobs.
- Jobs are **encoded as paths** from the tree root to the nodes, and the destination node **"replays"** that path.

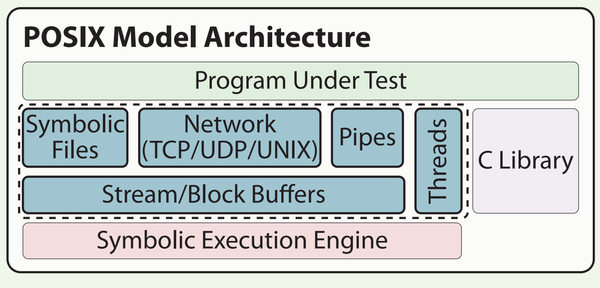
The POSIX Environment Model

④ *POSIX Model*

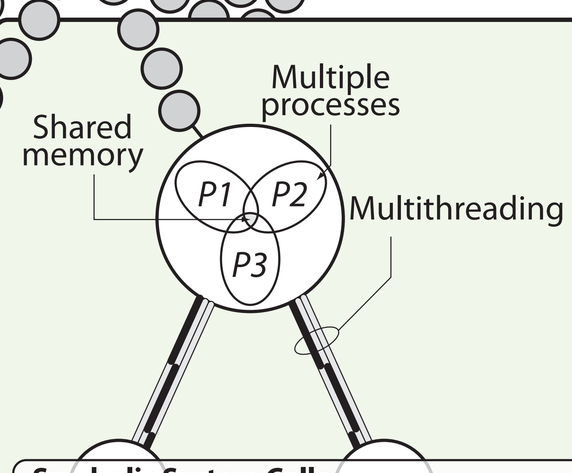
- Outside the **symbolic domain** (e.g. the program under test), the environment is complex.
- One may "concretize" calls and lose completeness.
- A model extends the symbolic domain, while simplifying the environment behavior.



POSIX Model Architecture



⑤ *Symbolic Engine Modifications*



Address Spaces

- Use copy-on-write (CoW) to reuse memory between processess, as well as across states.
- Put address spaces in CoW domains, to permit memory sharing.

Symbolic System Calls

We replaced the standard OS system calls with a simplified set of **calls into the symbolic execution engine**:
- create/destroy threads
- fork/terminate processes
- share memroy across processes
- sleep/wake-up on waiting queues

Multithreading and Scheduling

- Cooperative scheduler simplifies model implementation.
- Deterministic (round-robin) or symbolic scheduling.

Find out more about Cloud9 at

http://cloud9.epfl.ch