Attacking Symbolic Execution Issues

- Sergii Vozniuk

- Advanced Topics in Software Systems
- December 9, 2011

Motivation

- Scalability / Performance (4)
- Usability / Applicability (3)
- Functionality vs Correctness (2)
- The Oracle issue (2)
- Bugs classification

S^2E* Idea

All paths are equal,

but some path are more equal than others.

* V. Chipounov, V. Kuznetsov, G. Candea S2E: A Platform for In-Vivo Multi-Path Analysis of Software Systems, *ASPLOS 2011*

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Mainly attacks performance and applicability issues.

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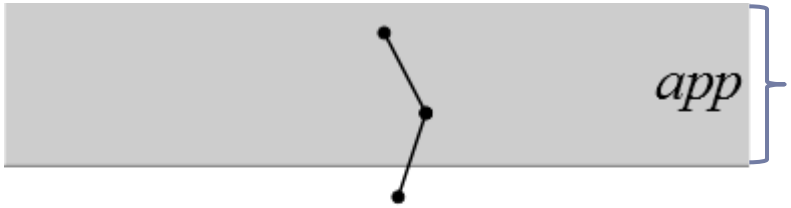
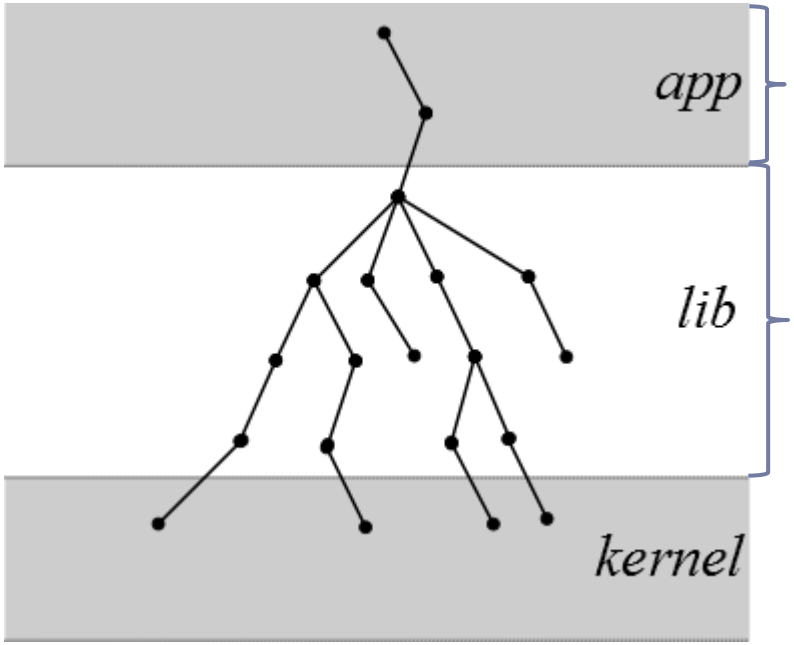
S²E multi-path & single path modes



Single-path (concrete)

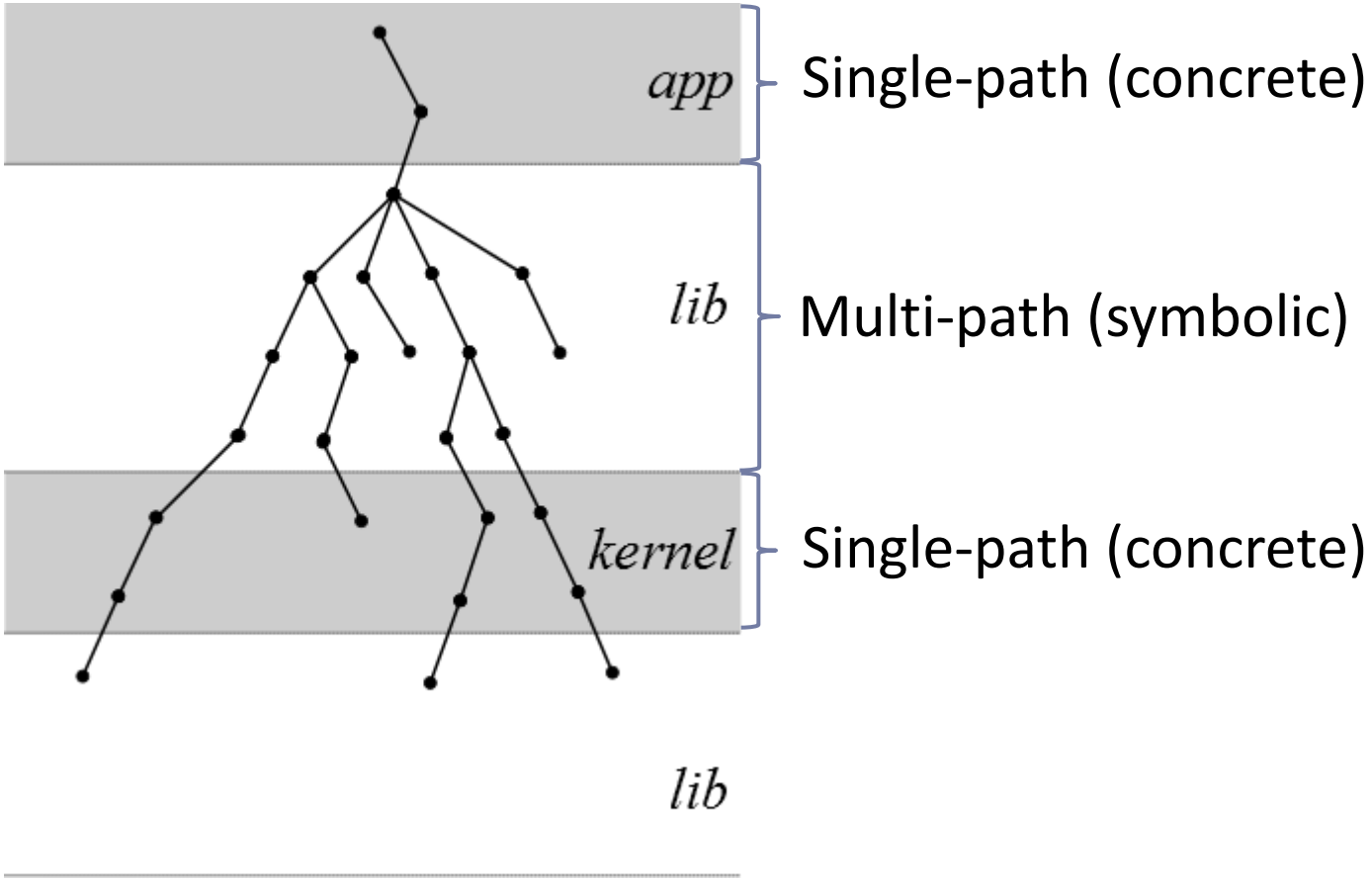
S^{2}E multi-path & single path modes



Single-path (concrete)

Multi-path (symbolic)

S²E multi-path & single path modes



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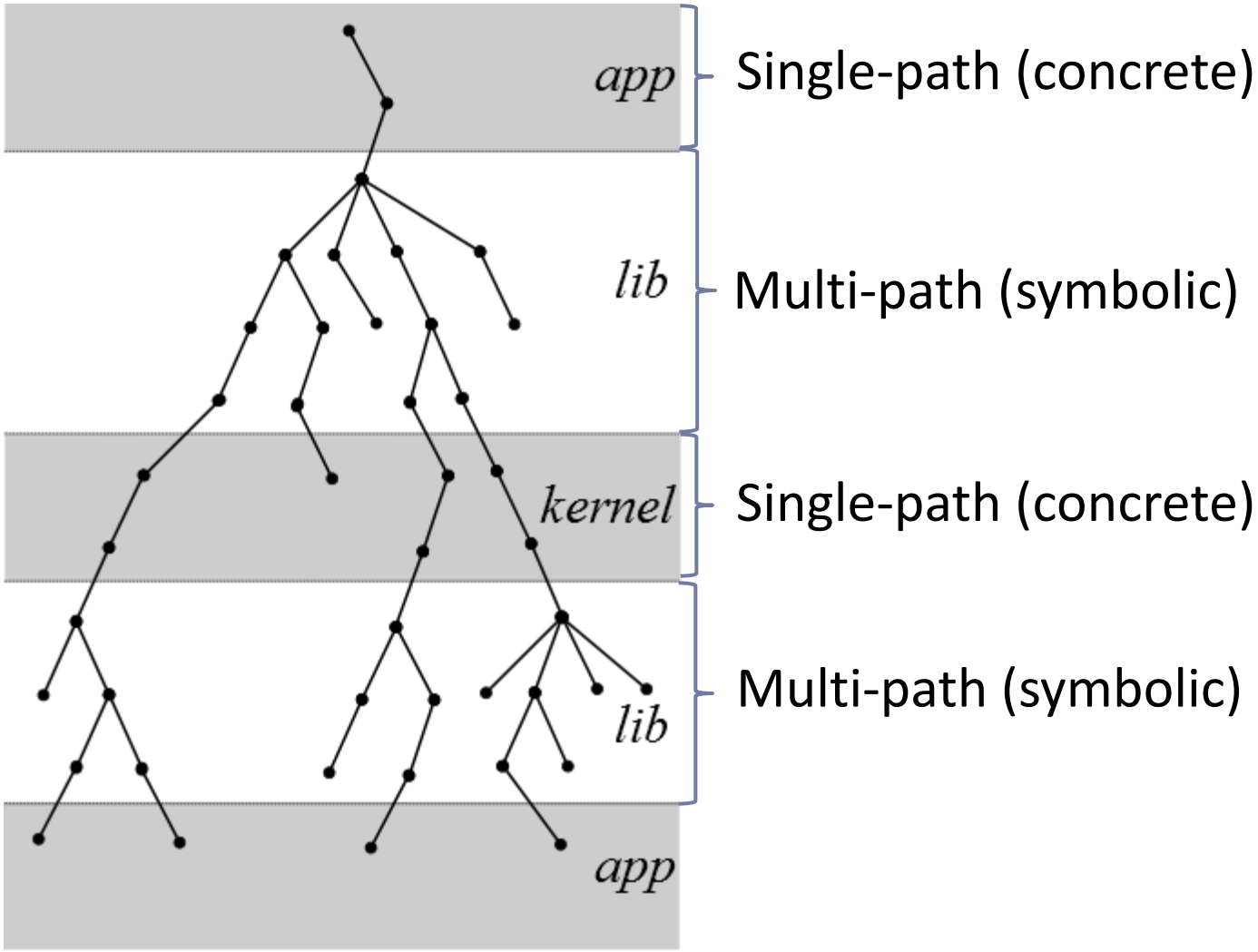

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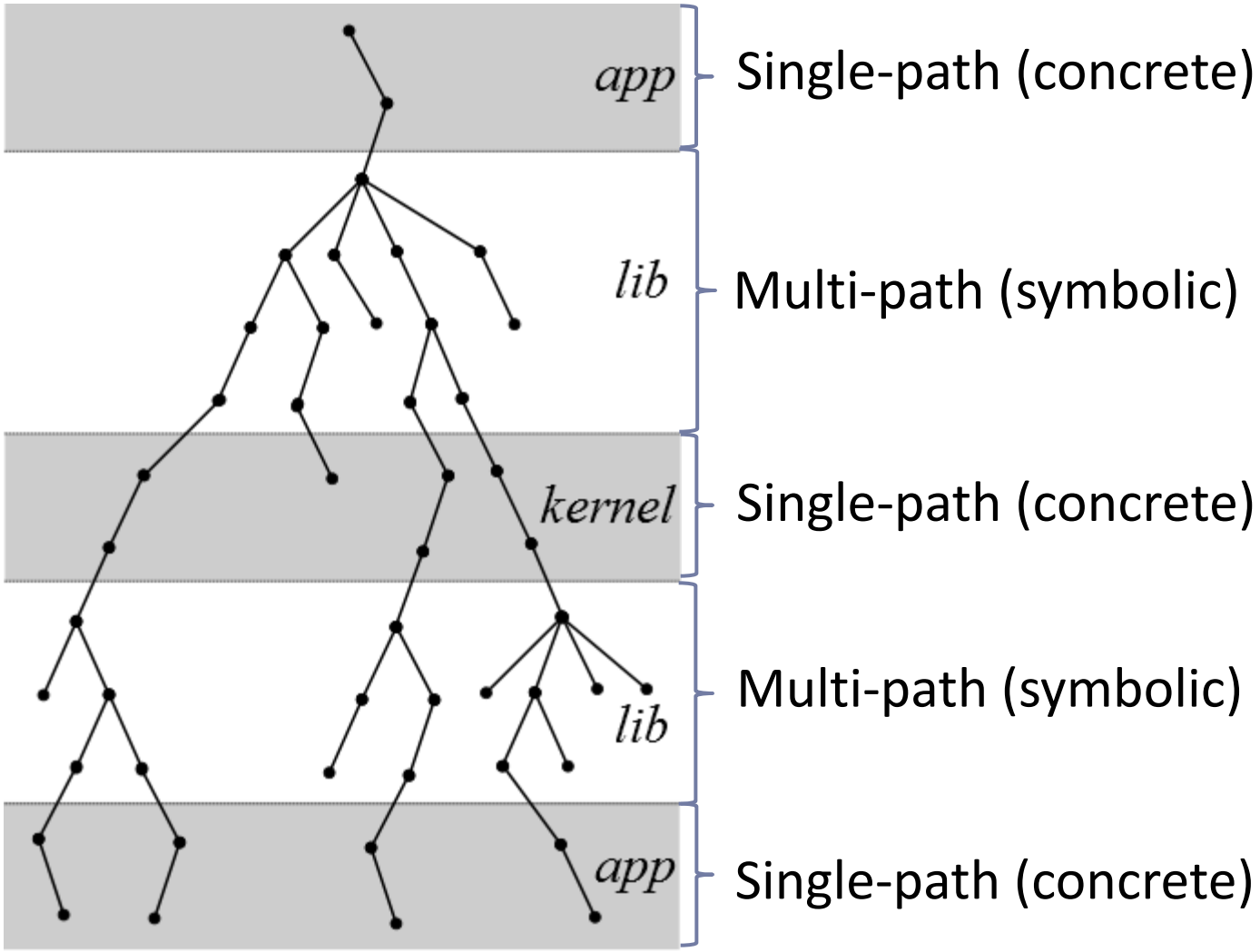
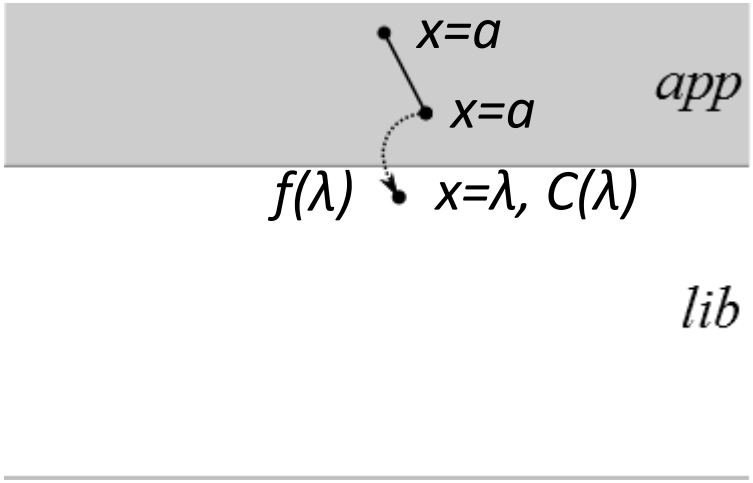


Concrete ⟶ Symbolic Transition & Symbolic ⟶ Concrete Transition



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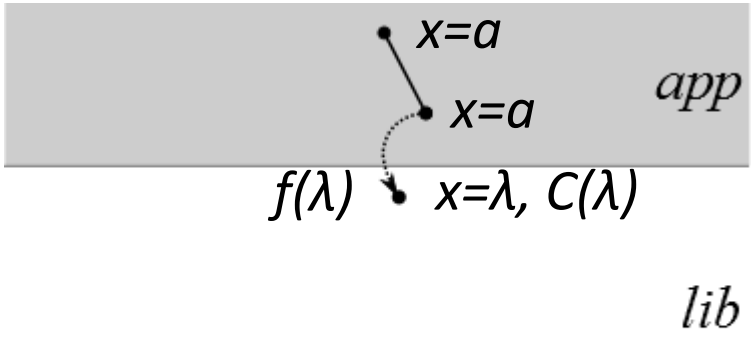
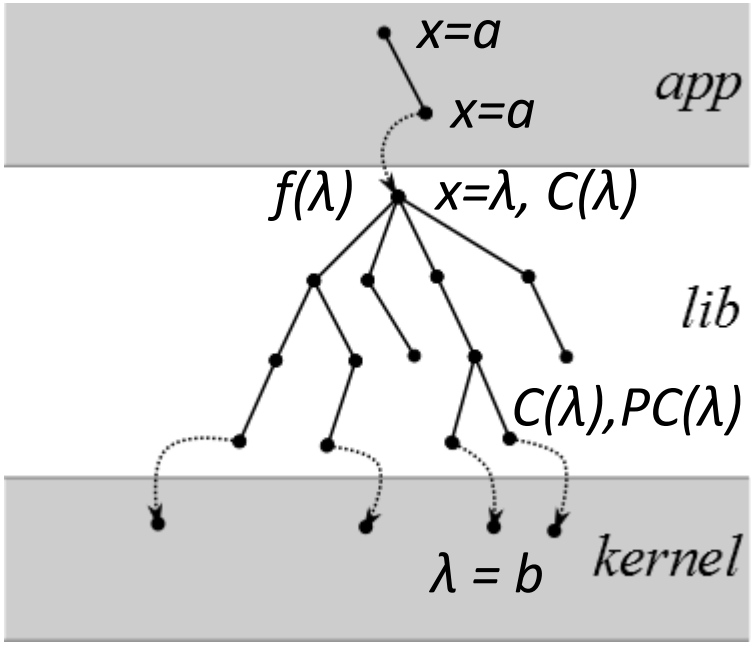


We may add additional constraints on *λ: C(λ)*

Concrete ⟶ Symbolic Transition & Symbolic ⟶ Concrete Transition



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Gathered path constraints on *λ* for some path *PC(λ)*

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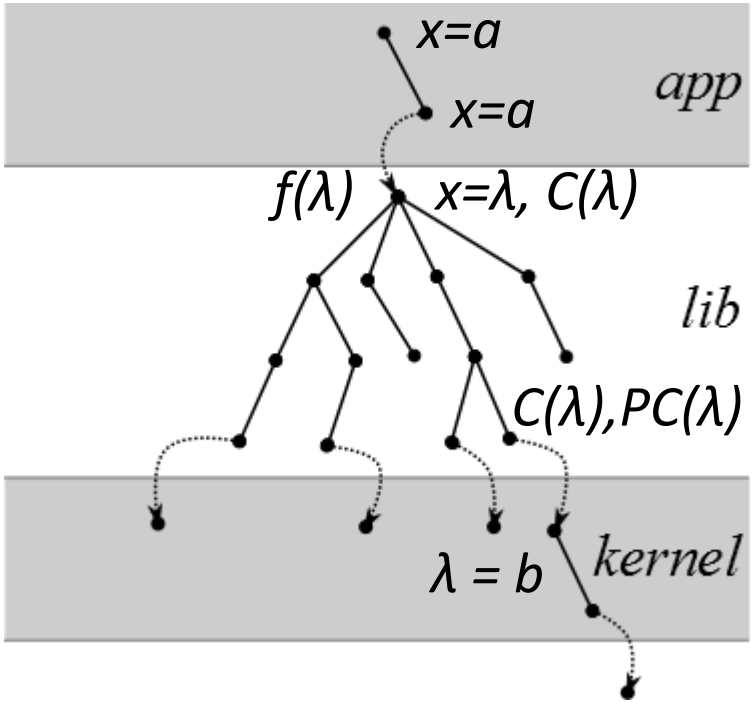

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Concretize *λ=b* such that *PC(b)=T and C(b)=T*

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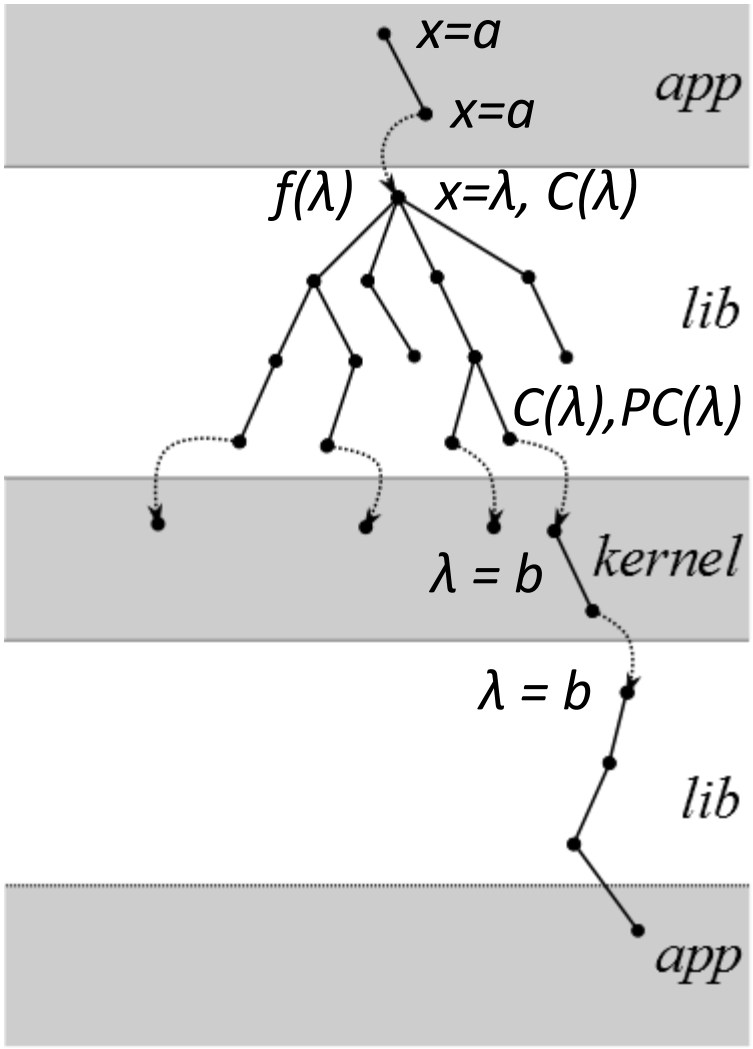


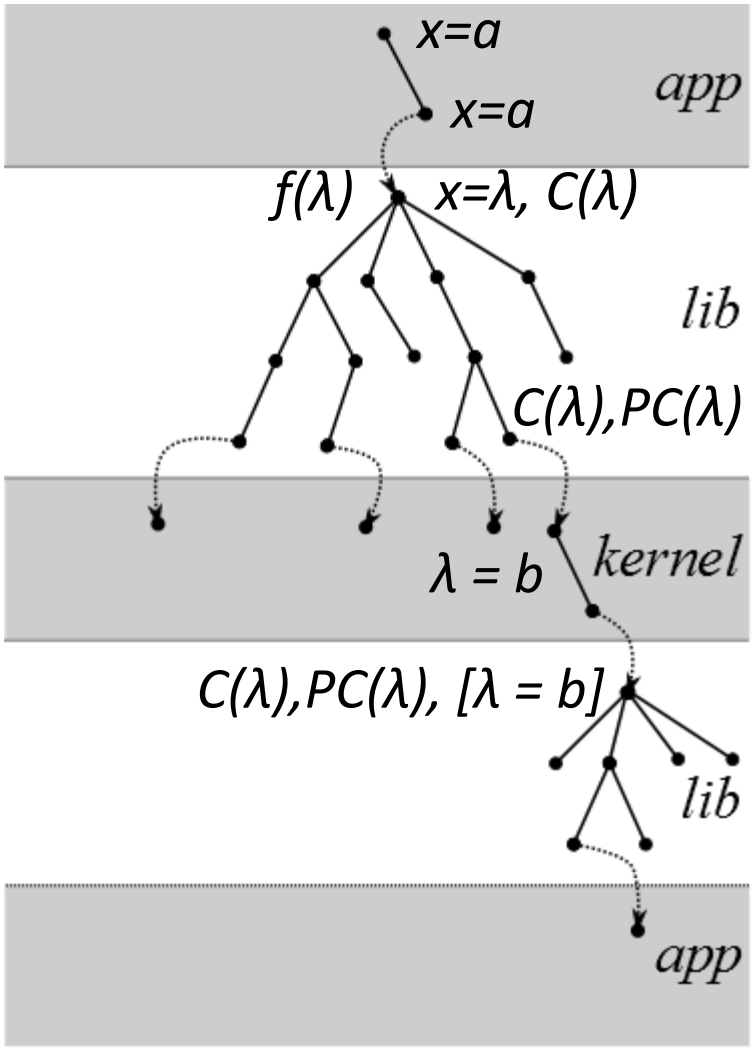
We may add additional constraints on *λ: C(λ)*

Gathered path constraints on *λ* for some path *PC(λ)*

Concretize *λ=b* such that *PC(b)=T and C(b)=T*

Return from concrete domain *λ = b.* Overconstraining. Equivalent to concrete execution from this point.

Concrete ⟶ Symbolic Transition & Symbolic ⟶ Concrete Transition



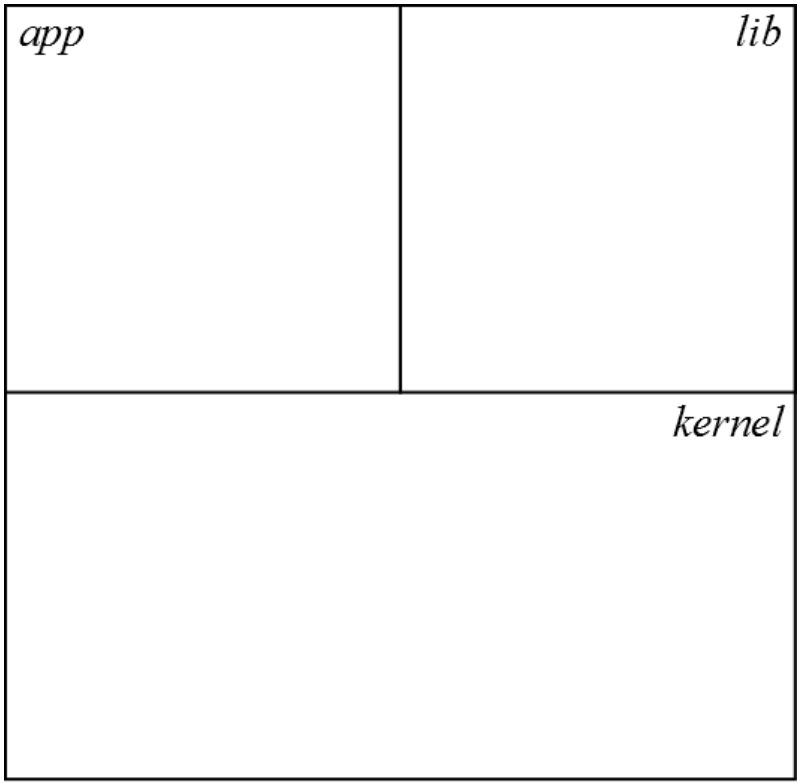
We may add additional constraints on *λ: C(λ)*

Gathered path constraints on *λ* for some path *PC(λ)*

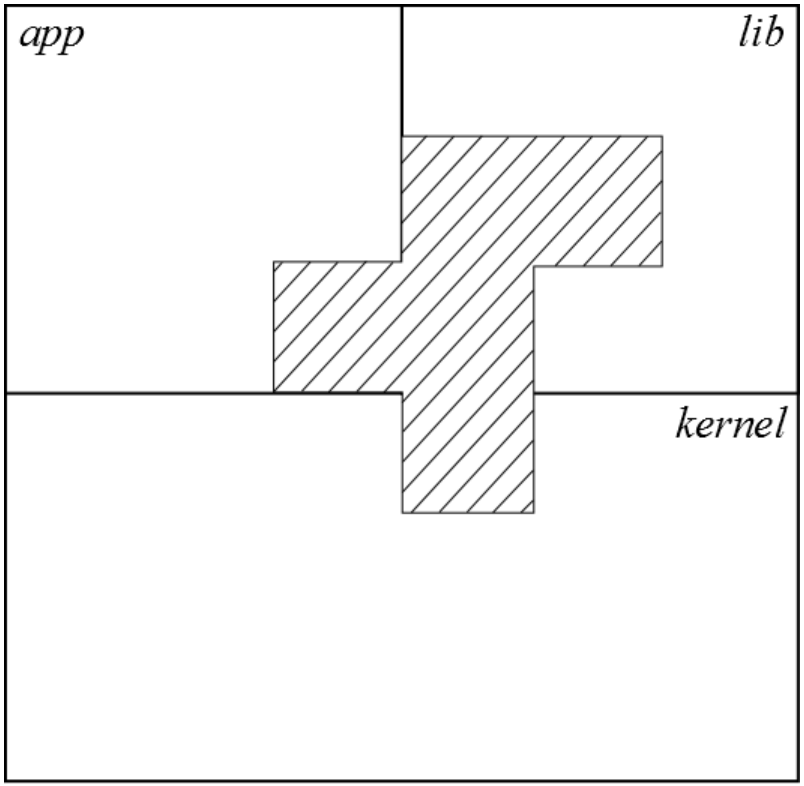
Concretize *λ=b* such that *PC(b)=T and C(b)=T*

Return from concrete domain *λ = b.* Soft constraint. Continue execution symbolically

System, Unit, Environment



System, Unit, Environment



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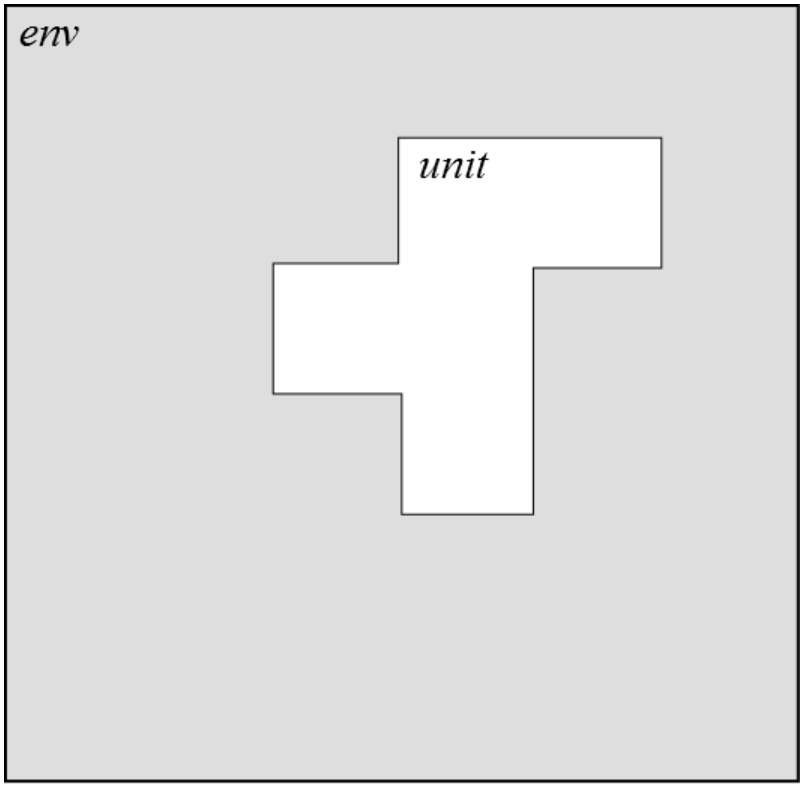

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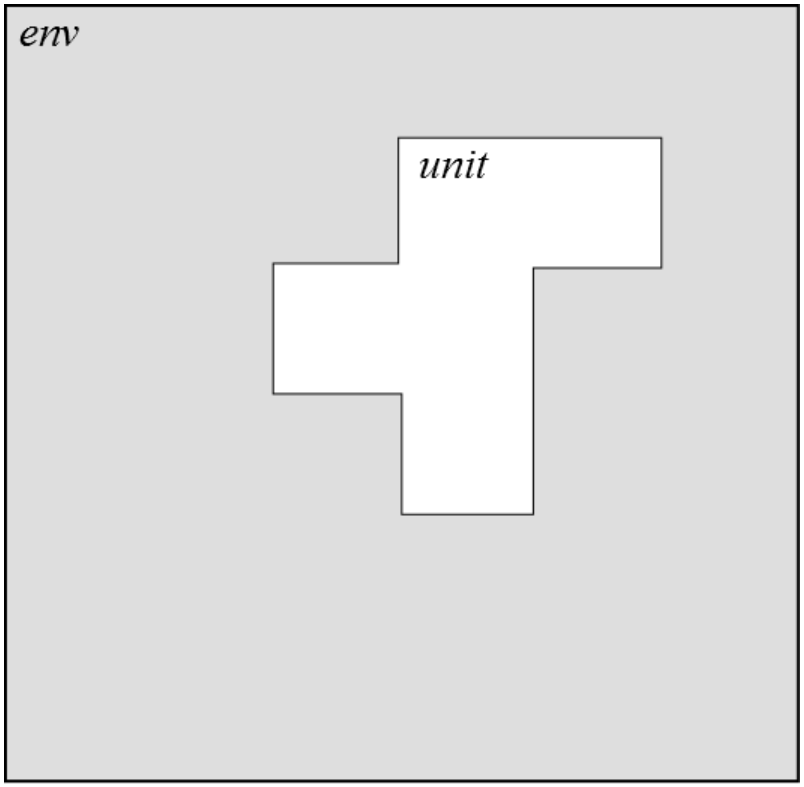
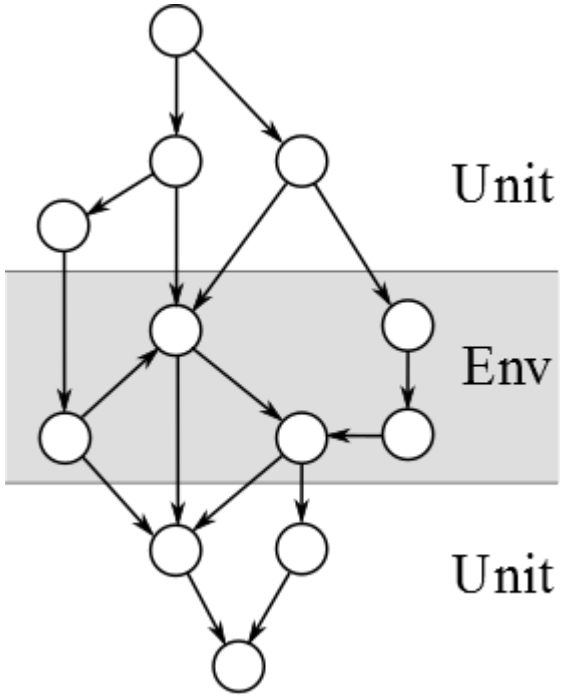
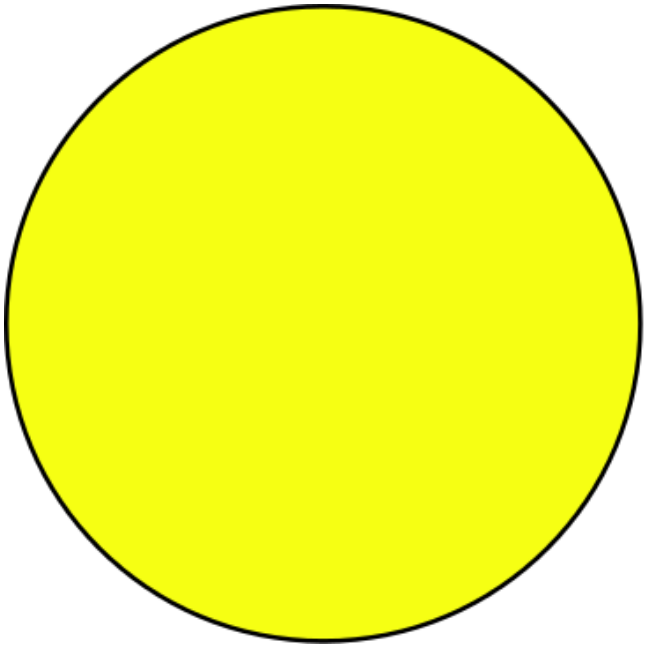
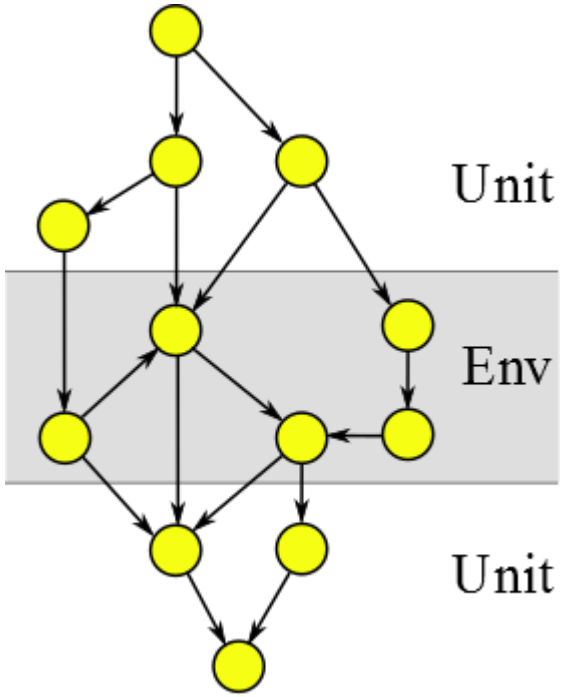




Paths feasibility



Statically feasible



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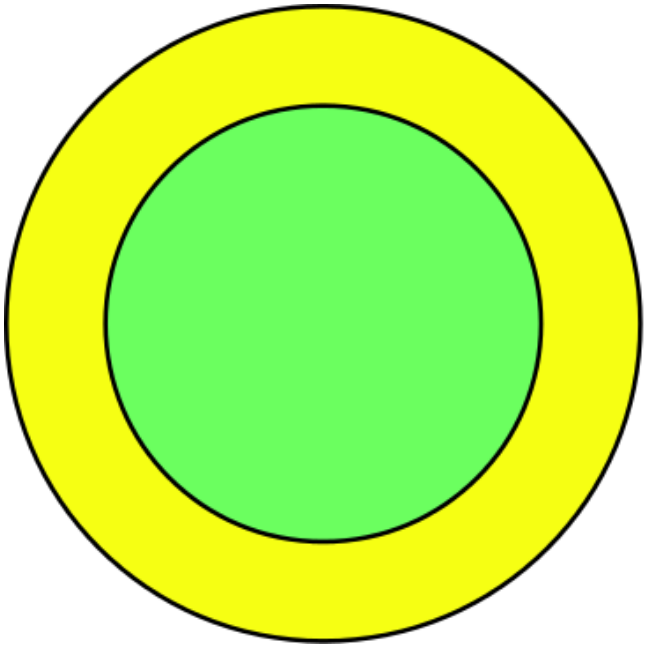
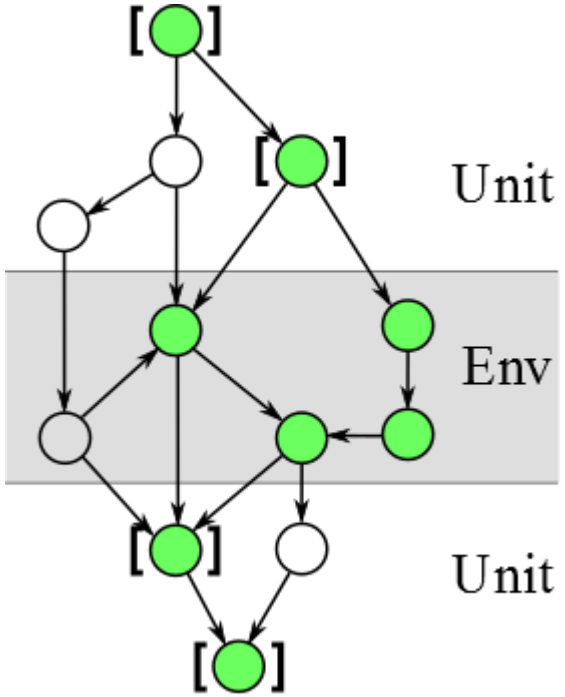


Statically feasible

Locally feasible



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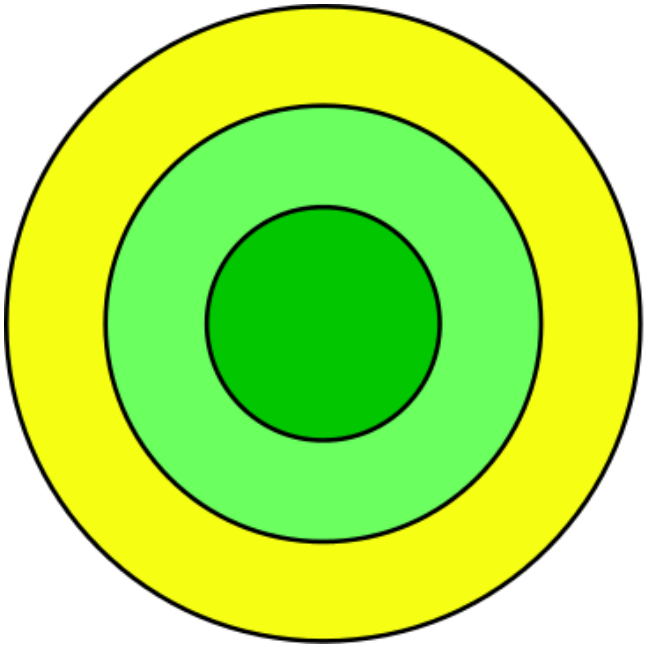
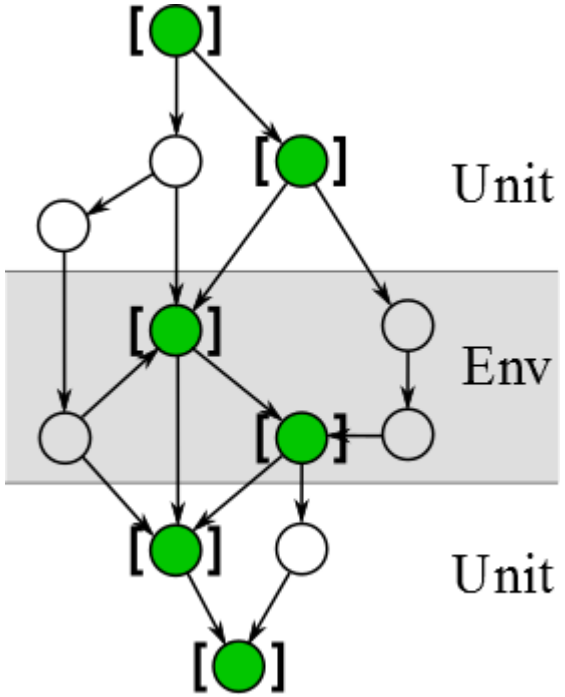


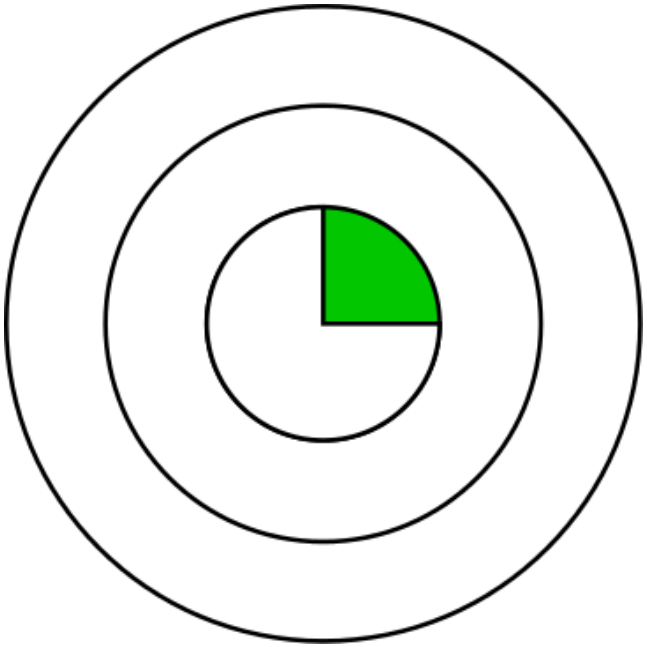
Statically feasible

Locally feasible

Globally feasible



Strictly Consistent Concrete Execution (SC-CE)



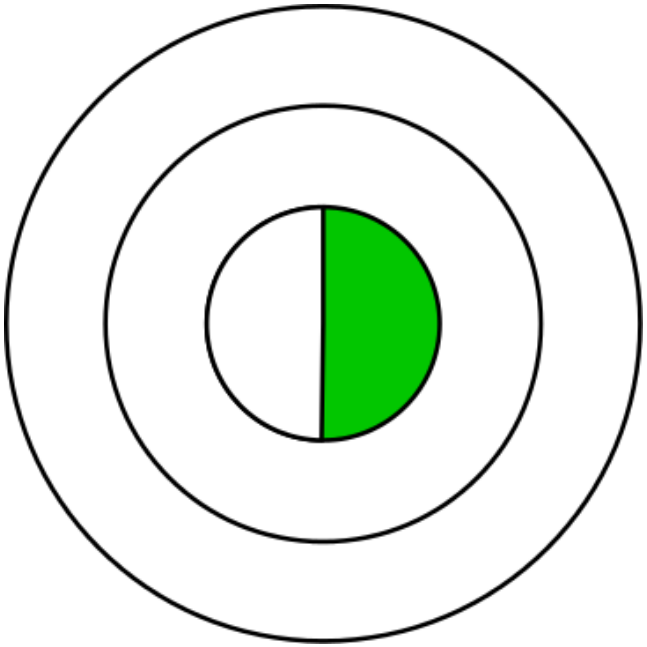
Properties:

- Only globally consistent paths
- Concrete execution

Example:

- Classic fuzzing

Strictly Consistent Unit-level Execution (SC-UE)



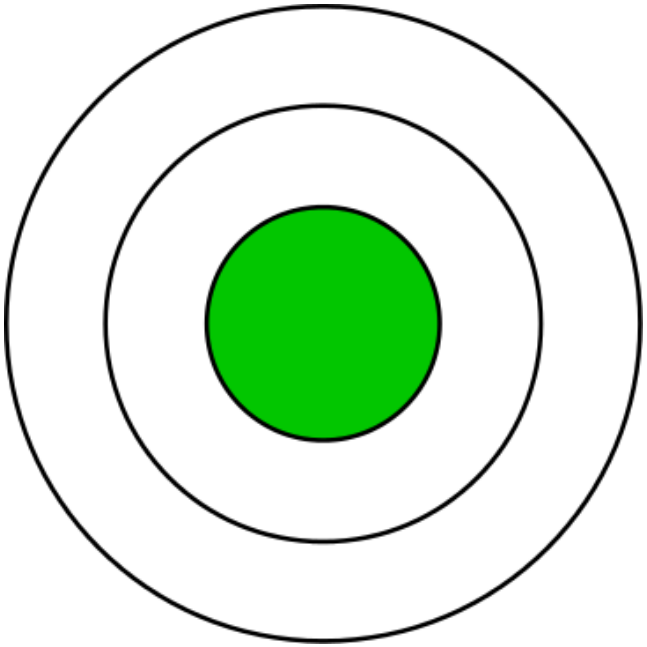
Properties:

- Only globally consistent paths
- **Path constraints for the unit**

Example:

- DART, KLEE

Strictly Consistent System-level Execution (SC-SE)



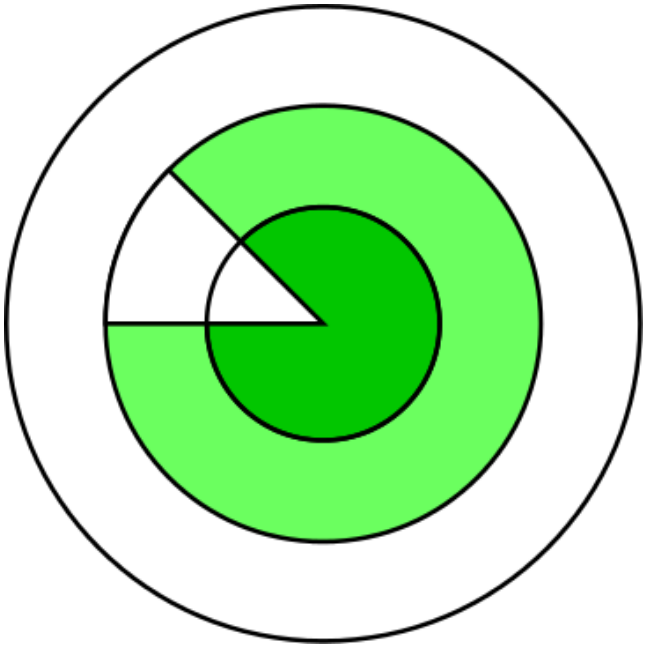
Properties:

- **Complete and consistent**
- **Path constraints for the env.**
- Path constraints for the unit

Example:

- KLEE (if env. is modeled)

Local Consistency (LC)



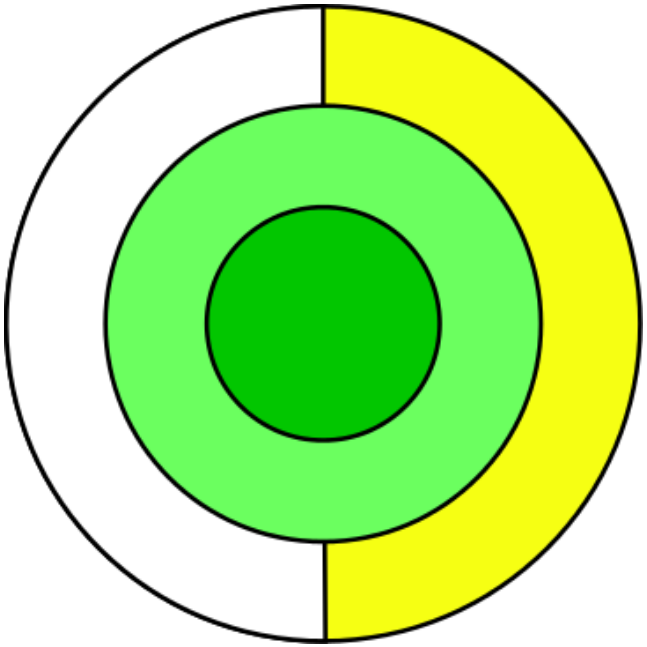
Properties:

- **Incomplete and inconsistent**
- **Locally consistent**
- **Follows environment contracts**

Example:

- S^2E (DDT^+)

Overapproximate Consistency(RC-OC)



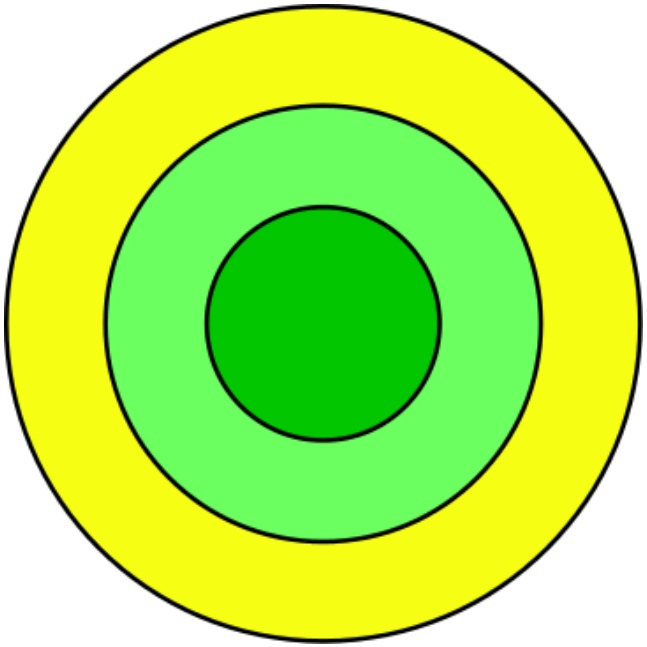
Properties:

- **Complete and inconsistent**
- **Prone to false-positives**
- **Disregard unit/env. interface contracts**

Example:

- Static analyzers
- Reverse engineering tools (REV^{+})

CFG Consistency(RC-CC)



Properties:

- **Complete and inconsistent**
- **Prone to false-positives**
- **May change any system state**

Example:

- Static analyzers
- Reverse engineering tools

User Interface

- Path selection
  - Data based selection
  - Code based selection
  - Priority based selection
- Path analysis
  - Data race detector
  - Memory checker
  - Execution tracer
  - Performance profile analyzer
  - WinDriveMon and WinBugCheck (Windows-specific)

S^2E Use Cases

- S^2E main goal is to enable rapid prototyping of useful, deep system analysis tools
- Tools developed
  - Testing of proprietary device drivers (DDT^+).
  - Reverse engineering of closed-source drivers (REV^+).
  - Multi-path in-vivo performance profiling ($PROF_S$).

Cloud9* Idea

Divide & Conquer

* S. Bucur, V. Ureche, C. Zamfir, G. Candea Parallel Symbolic Execution for Automated Real-World Software Testing, *EUROSYS 2011*

Cloud9* Idea

Divide & Conquer

Scalable parallelization of symbolic execution

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Cloud9* Idea

Divide & Conquer

Scalable parallelization of symbolic execution

Attacks scalability, applicability and usability

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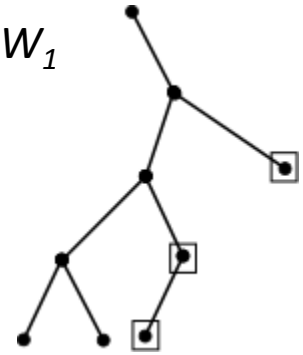
Parallel Symbolic Execution

W_1

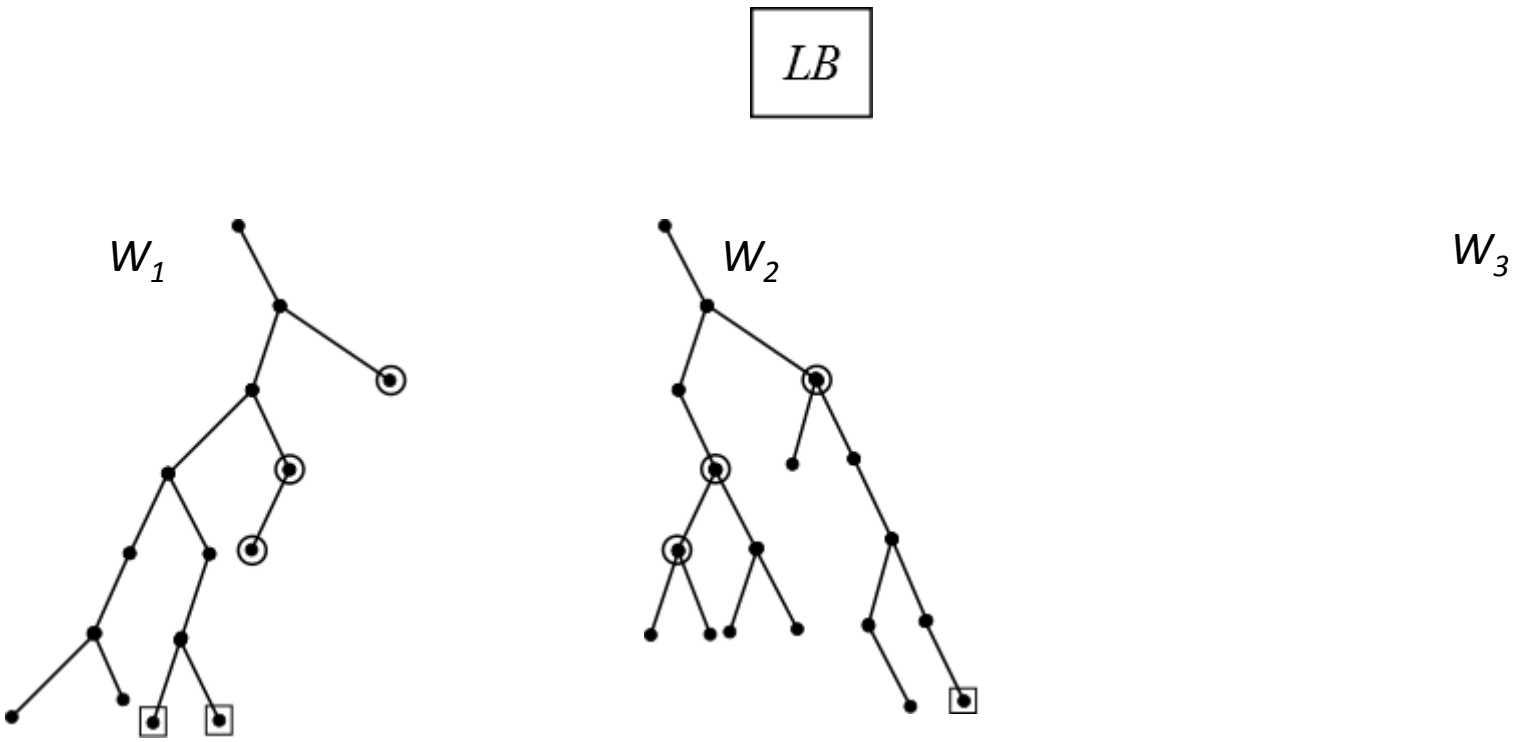
Parallel Symbolic Execution

W_1

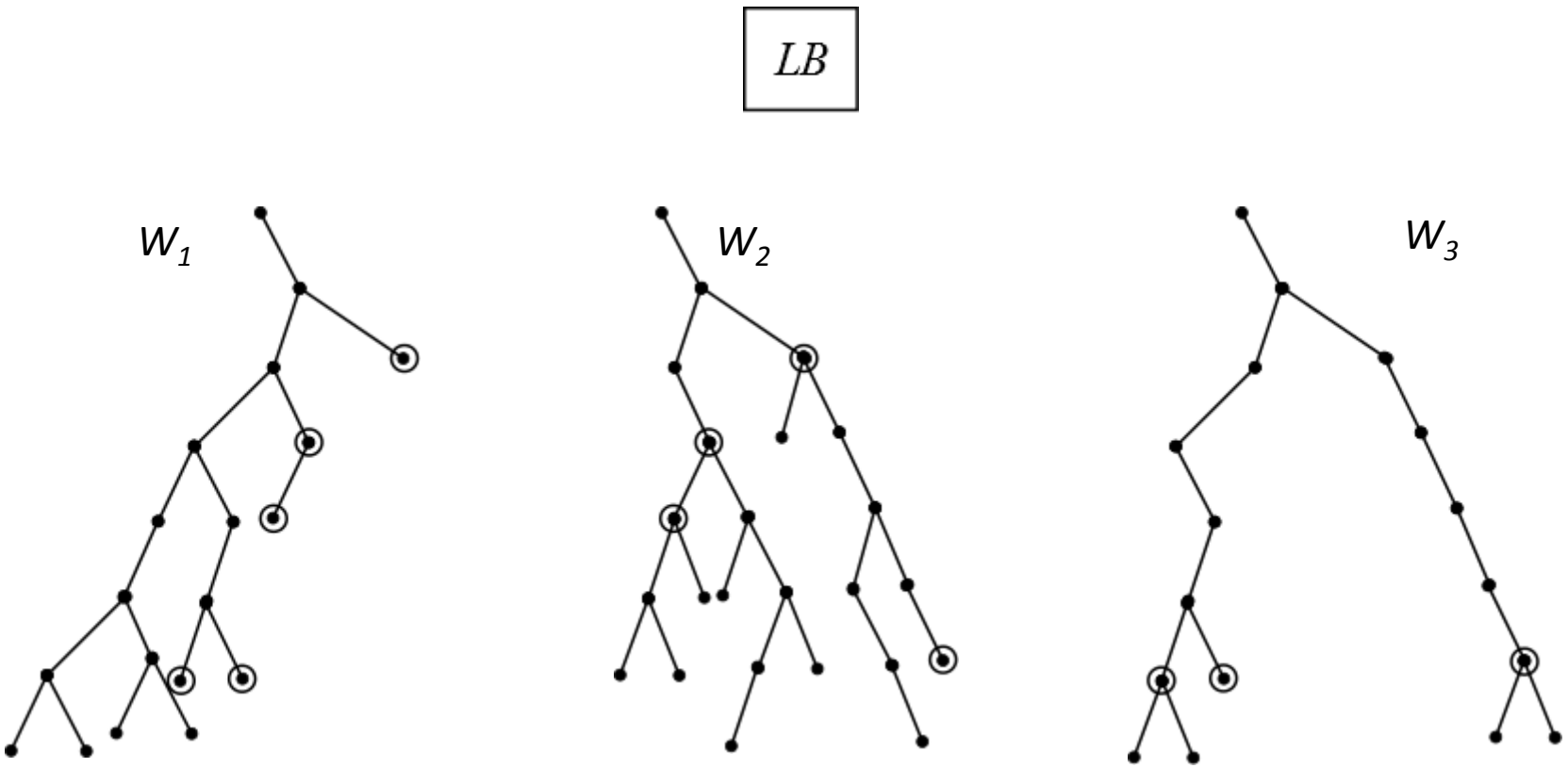


W_2

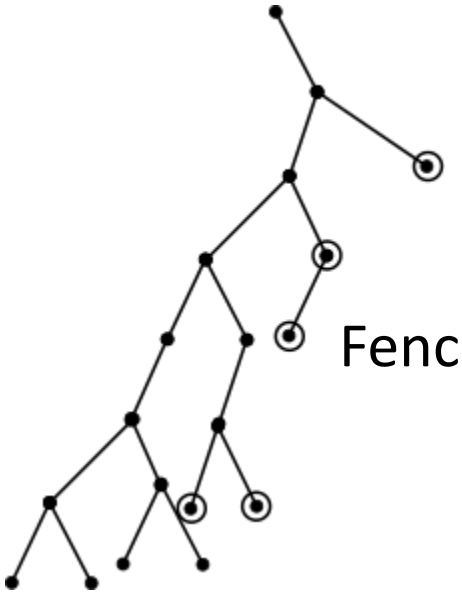
Parallel Symbolic Execution



Parallel Symbolic Execution



Worker-level Operation

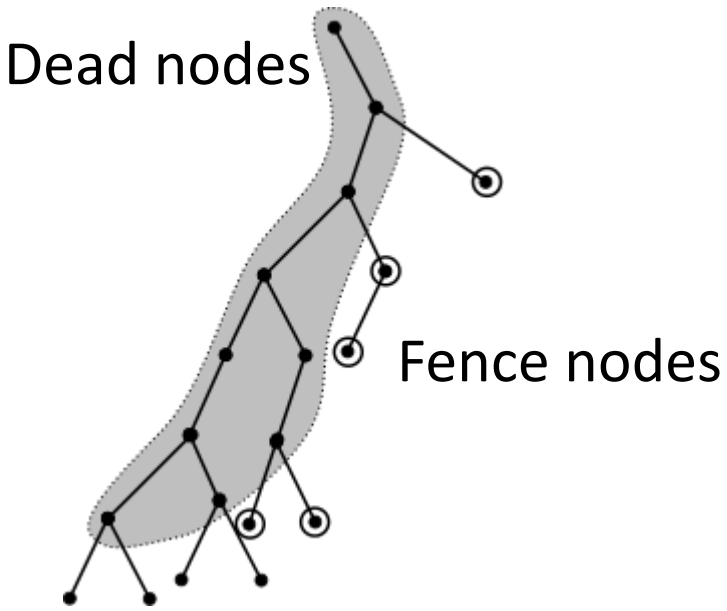


Fence nodes

Nodes:

- Fence – separating the domains of different workers

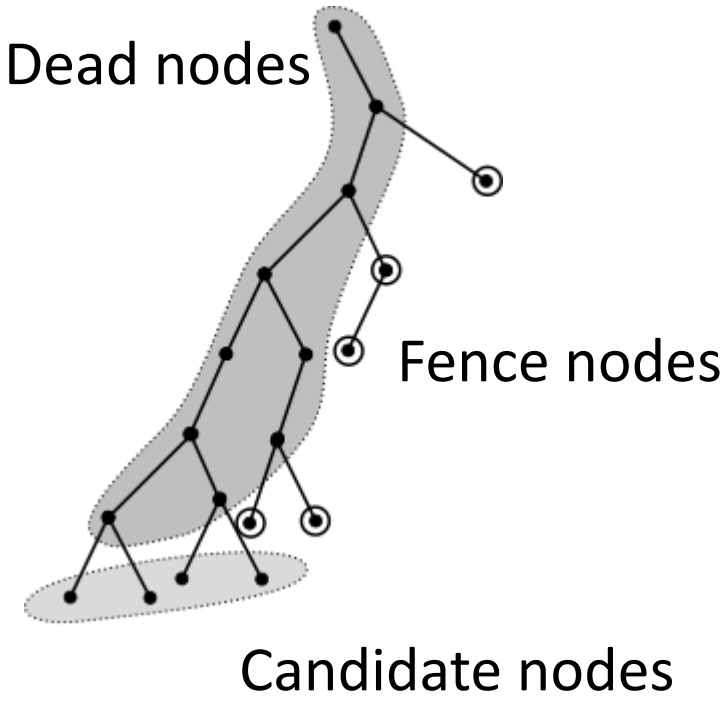
Worker-level Operation



Nodes:

- Fence – separating the domains of different workers
- Dead – have already been explored

Worker-level Operation



Nodes:

- Fence – separating the domains of different workers
- Dead – have already been explored
- Candidates – nodes ready to be explored. Candidates form the exploration frontier.

The POSIX Environment Model

- Goal: simulate behavior of a real execution environment
- Implemented model supports
  - Threads (!)
  - Process management
  - Sockets
  - Pipes
  - etc
- Only stateless or read-only system calls

Symbolic Test Suites

- Encompass many similar concrete test cases
- Programmatically control events in the environment
  - Symbolic data and streams
  - Network conditions
  - Fault injection
  - Symbolic scheduler

Cloud9 Use Cases

- Cloud9 goal is to bridge the gap between symbolic execution and real-world automated software testing
- Software systems analyzed
  - Coreutils
  - Curl
  - Memcached
  - Lighthttpd
  - Bandicot DBMS

Summary

S^2E

- Rapid prototyping of system analysis tools

Cloud9

- Bridge the gap between symbolic execution and real-world automated testing

Summary

S^2E

- Rapid prototyping of system analysis tools
- Performance, applicability

Cloud9

- Bridge the gap between symbolic execution and real-world automated testing
- Scalability, applicability

Summary

S^2E

- Rapid prototyping of system analysis tools
- Performance, applicability
- Selective symbolic execution

Cloud9

- Bridge the gap between symbolic execution and real-world automated testing
- Scalability, applicability
- Parallel symbolic execution

Summary

S^2E

- Rapid prototyping of system analysis tools
- Performance, applicability
- Selective symbolic execution
- Consistency models

Cloud9

- Bridge the gap between symbolic execution and real-world automated testing
- Scalability, applicability
- Parallel symbolic execution
- POSIX Environment model

Summary

S^2E

- Rapid prototyping of system analysis tools
- Performance, applicability
- Selective symbolic execution
- Consistency models
- Uses KLEE SEE

Cloud9

- Bridge the gap between symbolic execution and real-world automated testing
- Scalability, applicability
- Parallel symbolic execution
- POSIX Environment model
- Uses KLEE SEE

Questions

- Is it possible to combine two presented approaches? Is it a good idea? (7)
- Is Cloud9 really scalable? (7)
  - 1000 nodes?
- Why do we have superlinear speedup? (6)
- What metric to use to define the usability? (6)
- What are the core advantages of S2E? (5)
  - Actually useful in practice vs theory?
- Contrast the ways S2E and Cloud9 handle the env. (5)
- Can virtualization hide bugs? Can it cause problems? (5)
- Difference in input formats? How input format influence the performance, applicability, usability? (4)
- How to take advantage of having more hardware? (2)