Detecting Manipulated Remote Call Streams

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Intrusion Detection and Specification-Based Monitoring

- The Condor attack
  - How to easily do dangerous and malicious things to a running job
- Binary analysis
  - How to detect attempted intrusions with pre-execution static analysis and runtime monitoring
- Program instrumentation
  - How to improve model precision & performance

Intrusion Detection

Misuse Detection	Specification-Based Monitoring	Anomaly Detection
• Specify patterns of attack or misuse	• Specify constraints upon program behavior	• Learn typical behavior of application
• Ensure misuse patterns do not arise at runtime	• Ensure execution does not violate specification	• Variations indicate potential intrusions
• Snort	• Our work; Ko, et al.	• IDES
• Rigid: cannot adapt to novel attacks	• Specifications can be cumbersome to create	• High false alarm rate

Specification

- Analyst or Administrator
- Training Sets
- Static Source Code Analysis
- Static Binary Code Analysis

- Execution Obeys Static Rule Set
- Execution Matches Model of Application

Enforcement

Our Approach: Specification

Static analysis of binary code

- Specifications are automatically generated
- Not reliant upon analysts to produce accurate specifications
- Analyzes all execution paths
- Source code may be unavailable

Our Approach: Enforcement

Operate an automaton modeling correct system call sequences

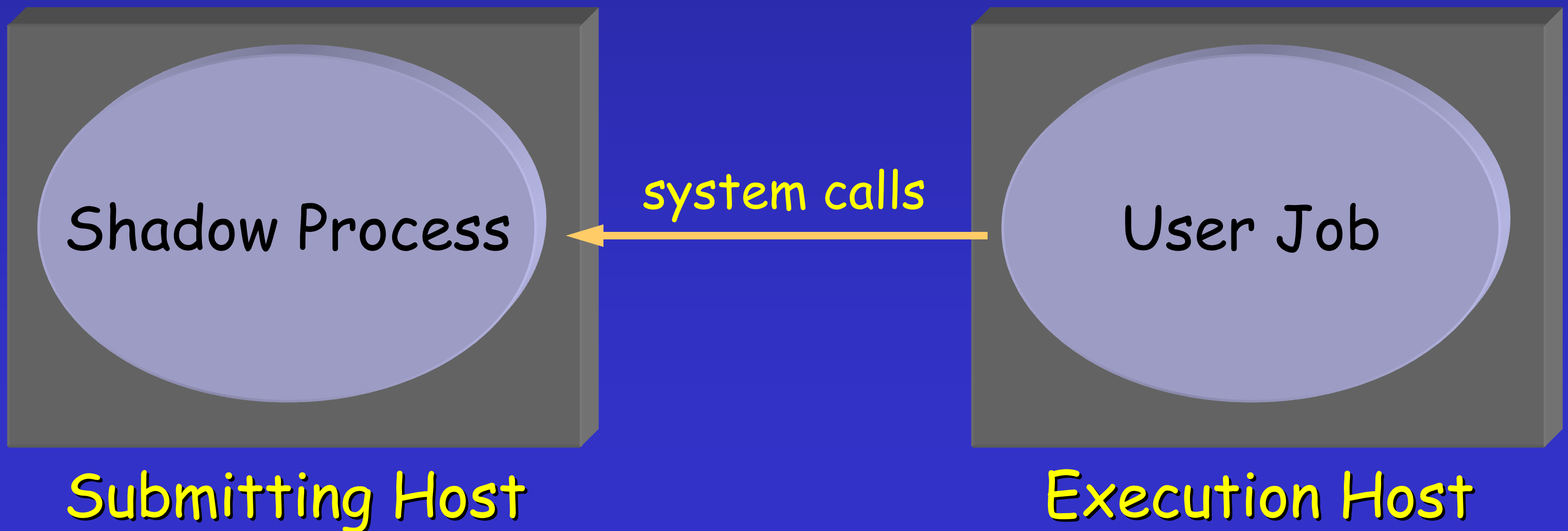
- Dynamic ruleset

Technical Contributions

- Binary analysis
- Model comparisons
- Techniques to improve precision
  - Null call insertion
  - Call site renaming
- Techniques to improve performance
  - Stack abstractions
  - Null call insertion: Practical results using push-down automaton (PDA) models

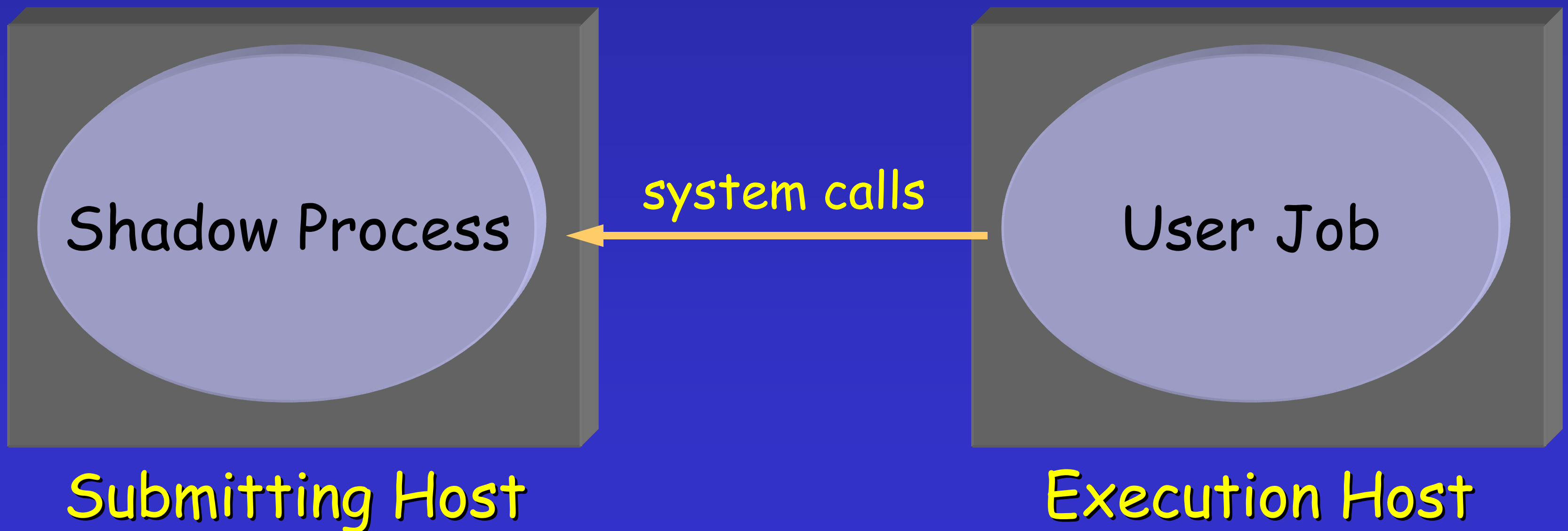
Example: The Condor Attack

- Users dispatch programs for remote execution
- Remote jobs send critical system calls back to local machine for execution



Example: The Condor Attack

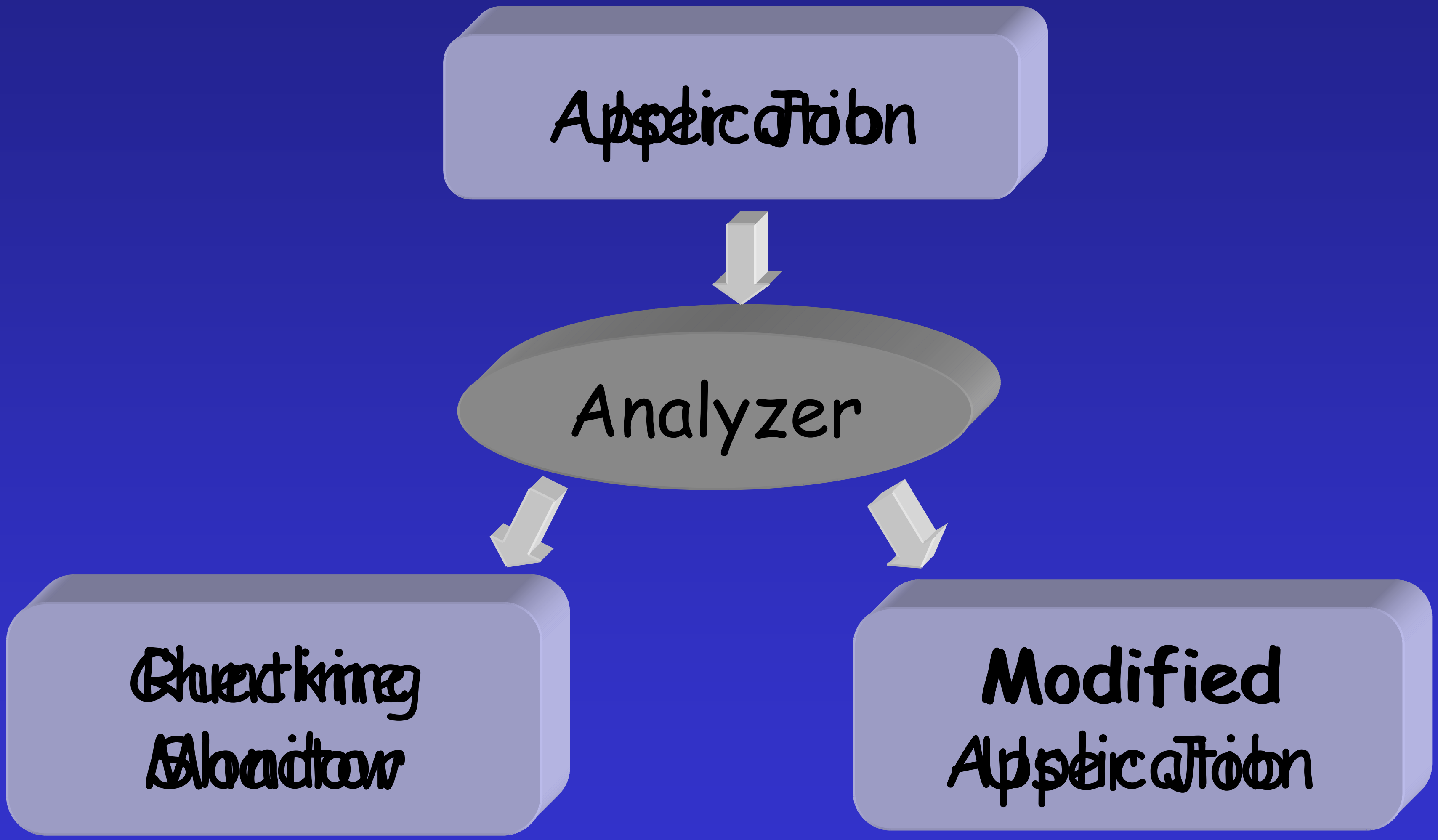
- Attackers can manipulate remotely executing program to gain access to user's machine



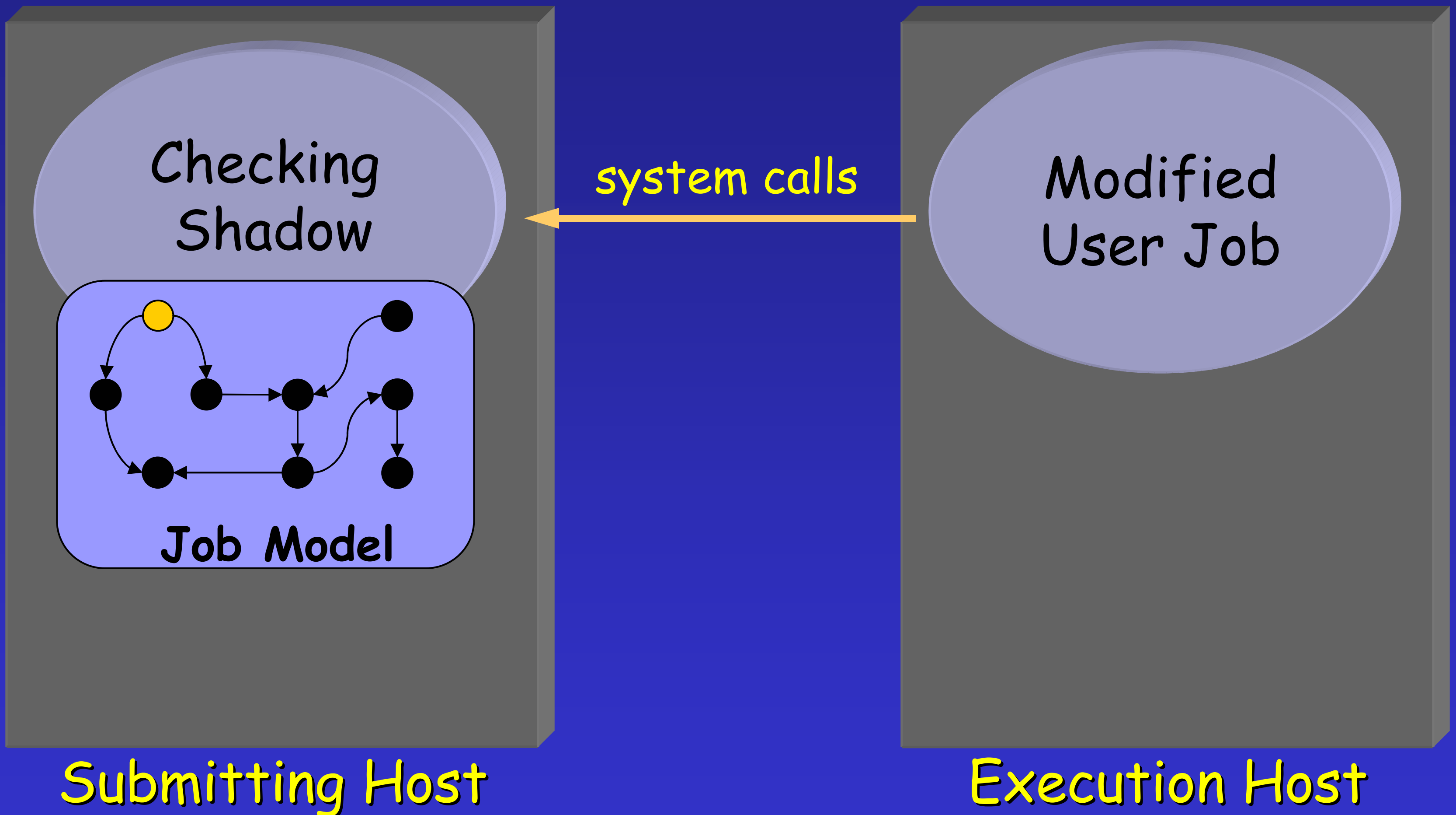
Countering Remote Attacks

- Goal: Even if an intruder can see, examine, and fully control the remote job, no harm can come to the local machine.
- Method: Model all possible sequences of remote system calls. At runtime, update the model with each received call.
- Key technology: Static analysis of binary code.

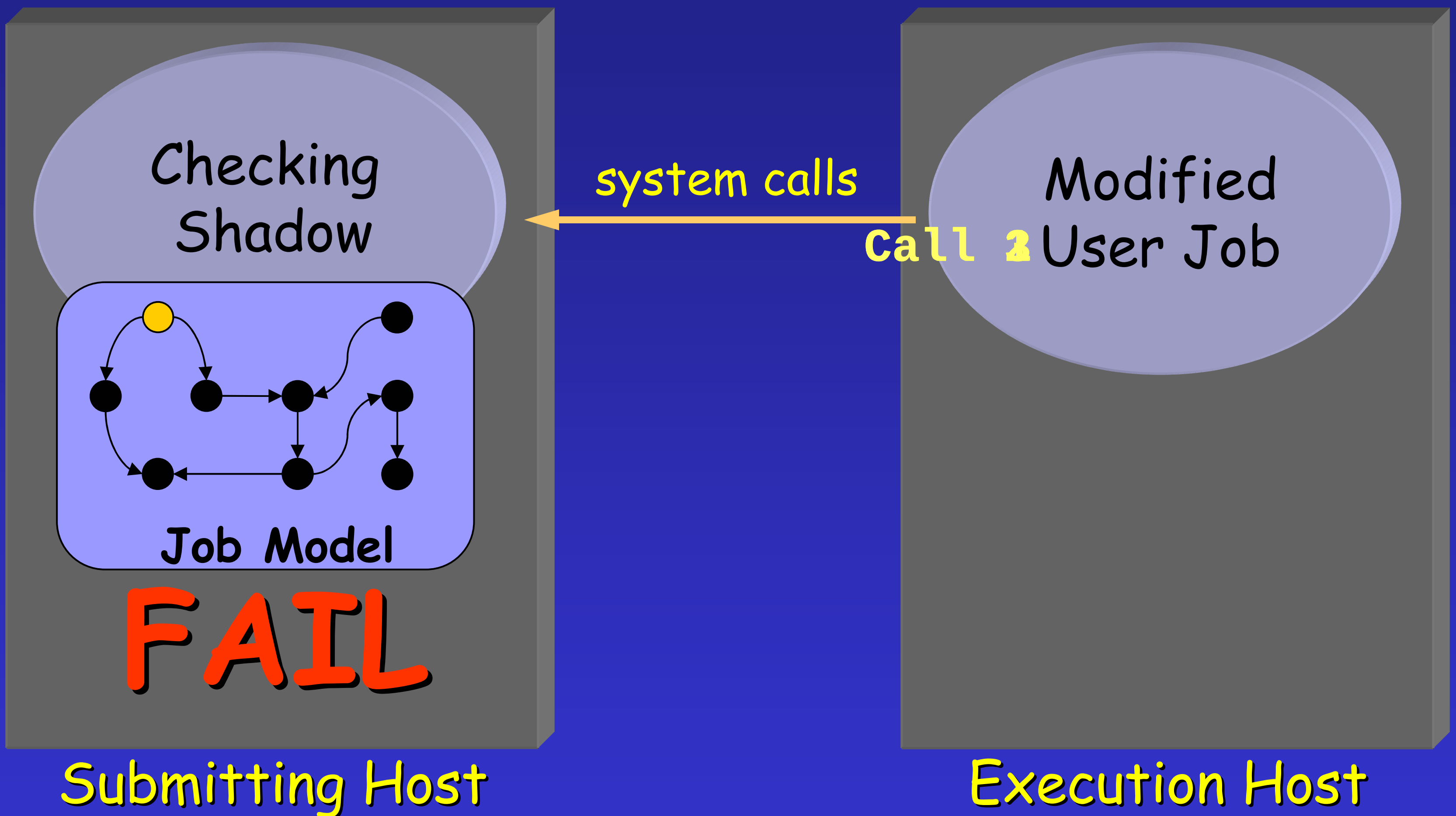
Execution Monitoring



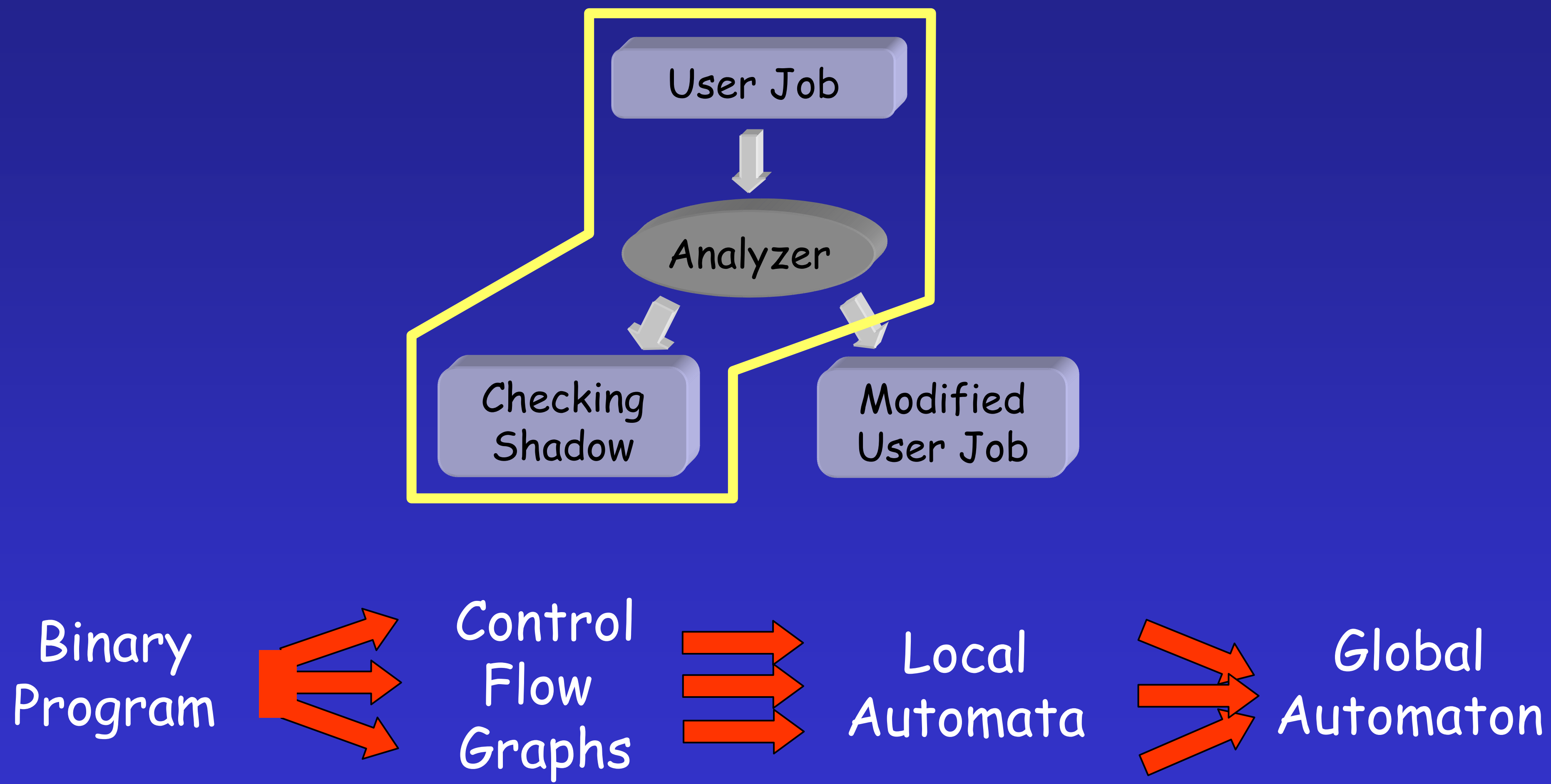
Execution Monitoring



Execution Monitoring



Model Construction



The Binary View (SPARC)

```
function:
  save %sp, 0x96, %sp
  cmp %i0, 0
  bge L1
  mov 15, %o1
  call read
  mov 0, %o0
  call line
  nop
  b L2
  nop
L1:
  call read
  mov %i0, %o0
  call close
  mov %i0, %o0
L2:
  ret
  restore
```

```
function (int a) {
  if (a < 0) {
      read(0, 15);
      line();
  } else {
      read(a, 15);
      close(a);
  }
}
```

Control Flow Graph Generation

```
function:
  save %sp, 0x96, %sp
  cmp %i0, 0
  bge L1
  mov 15, %o1
  call read
  mov 0, %o0
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  restore
```
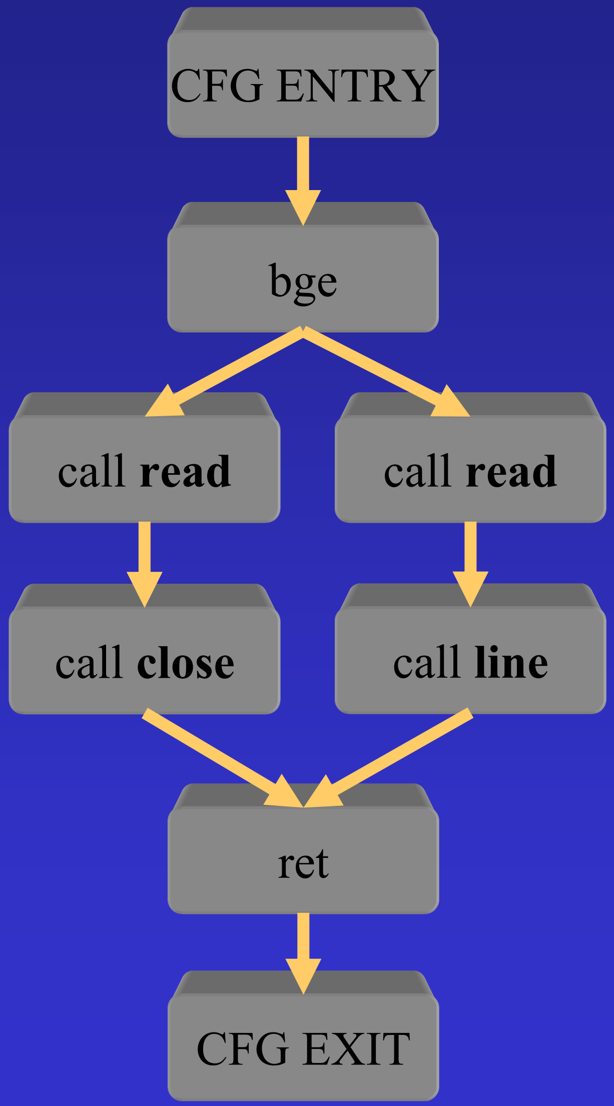
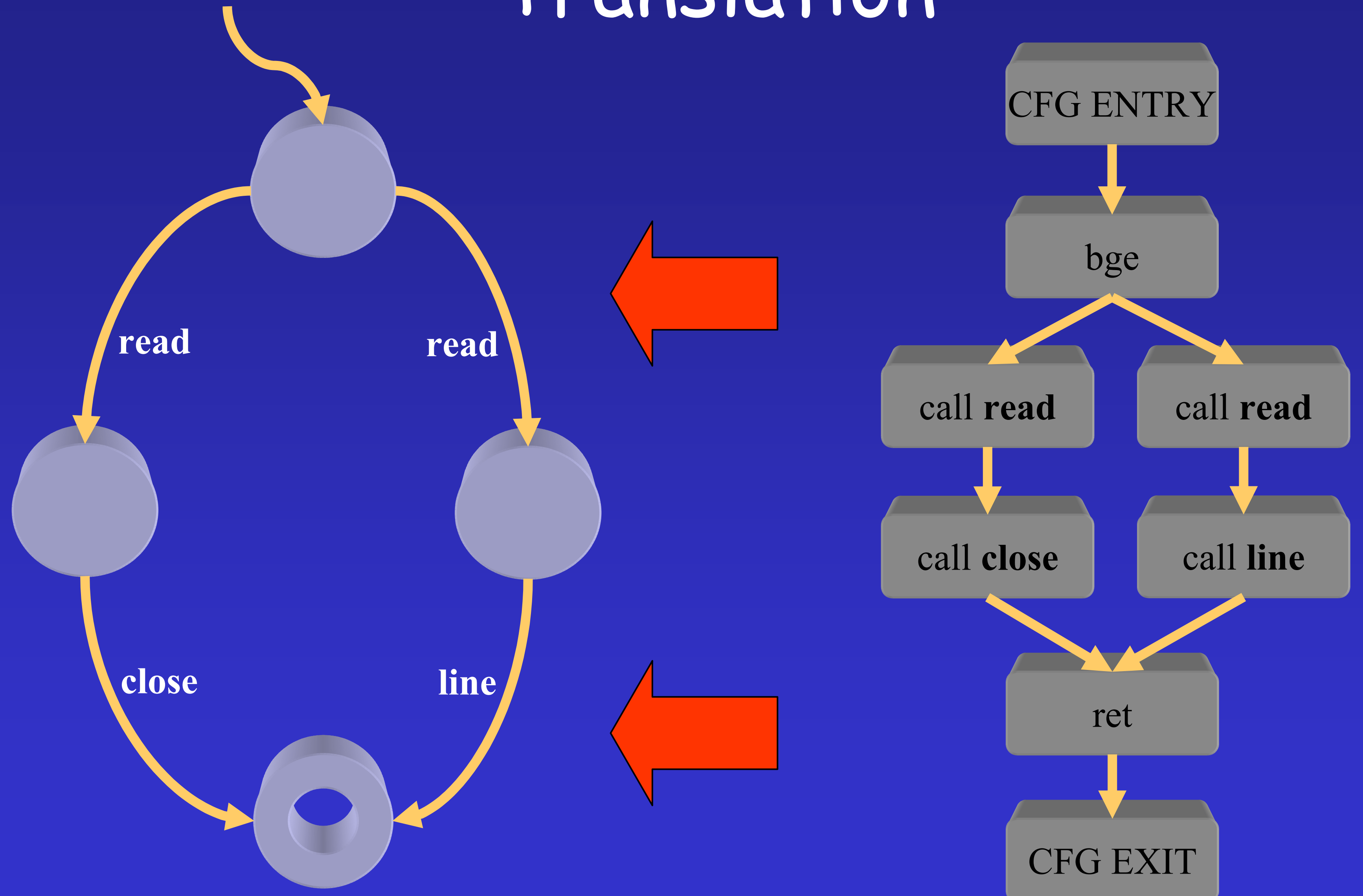
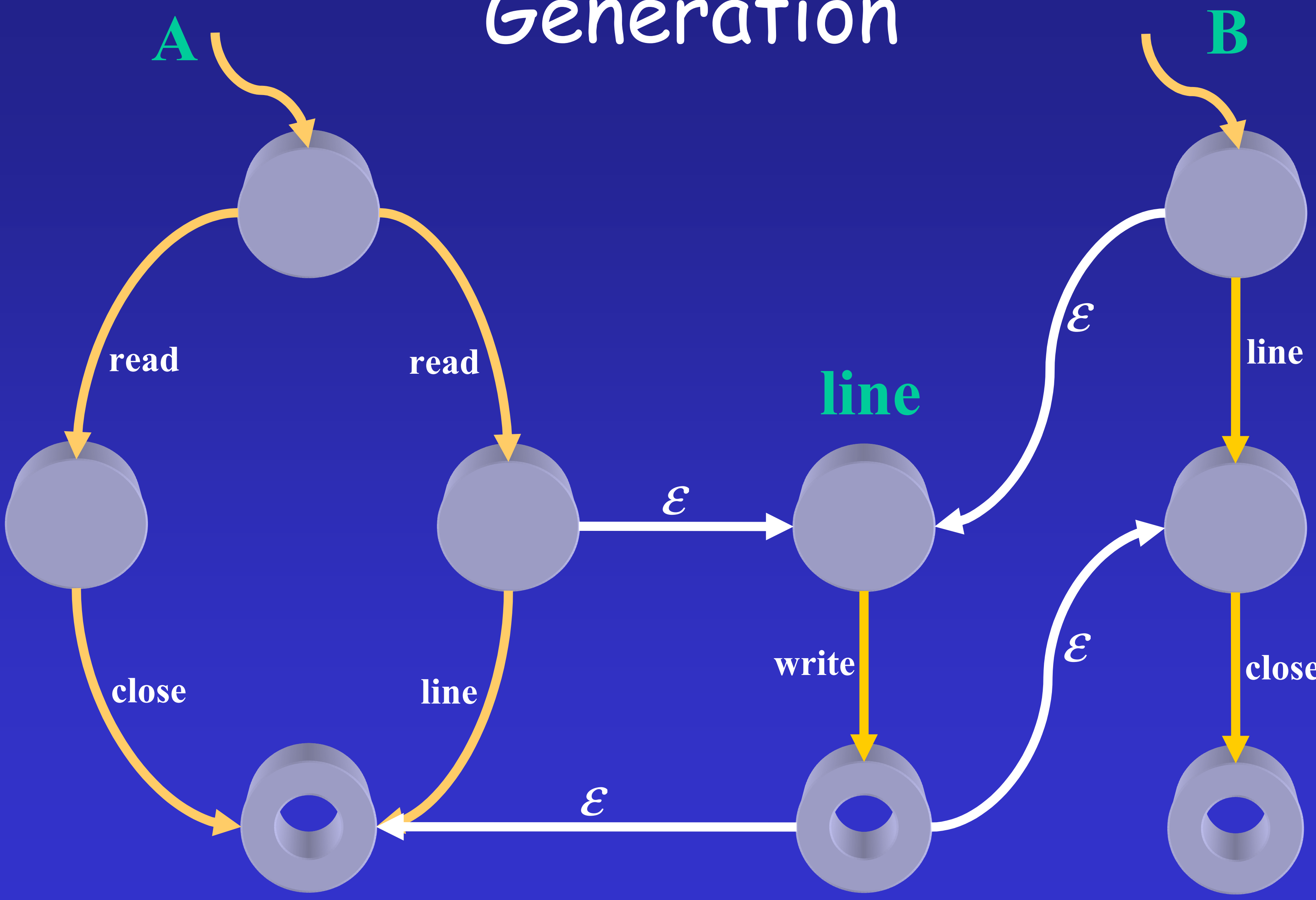



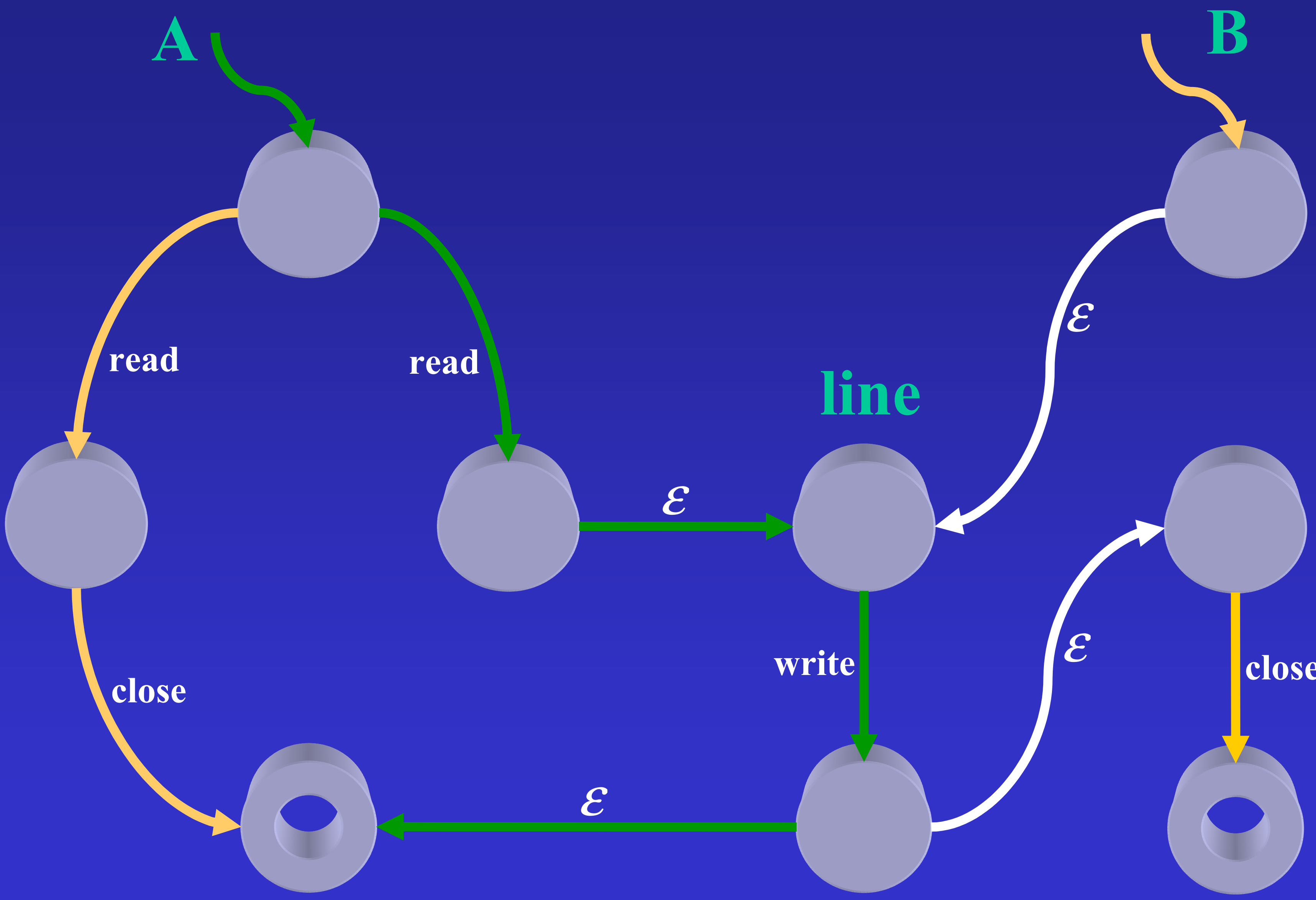
Control Flow Graph Translation



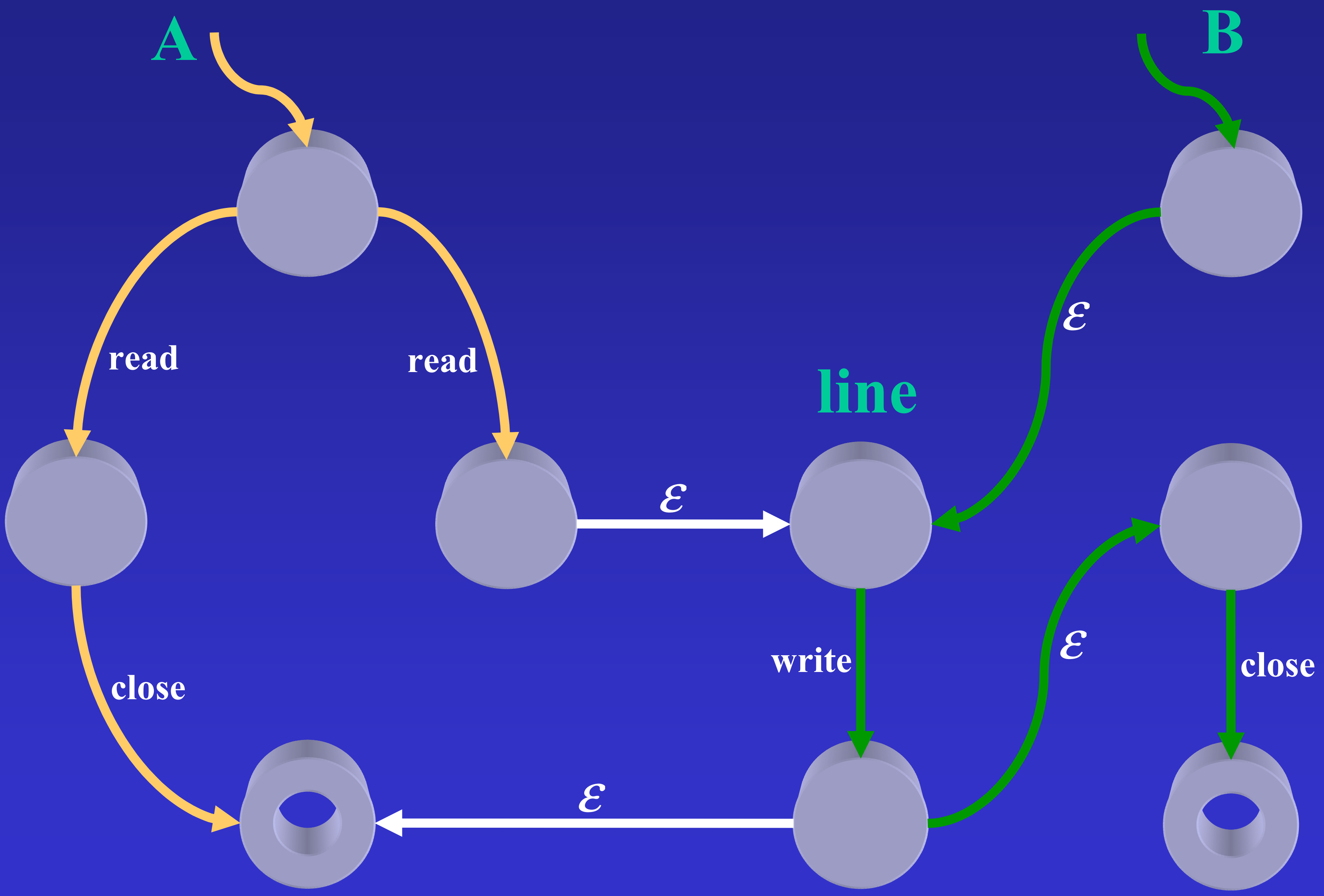
Interprocedural Model Generation



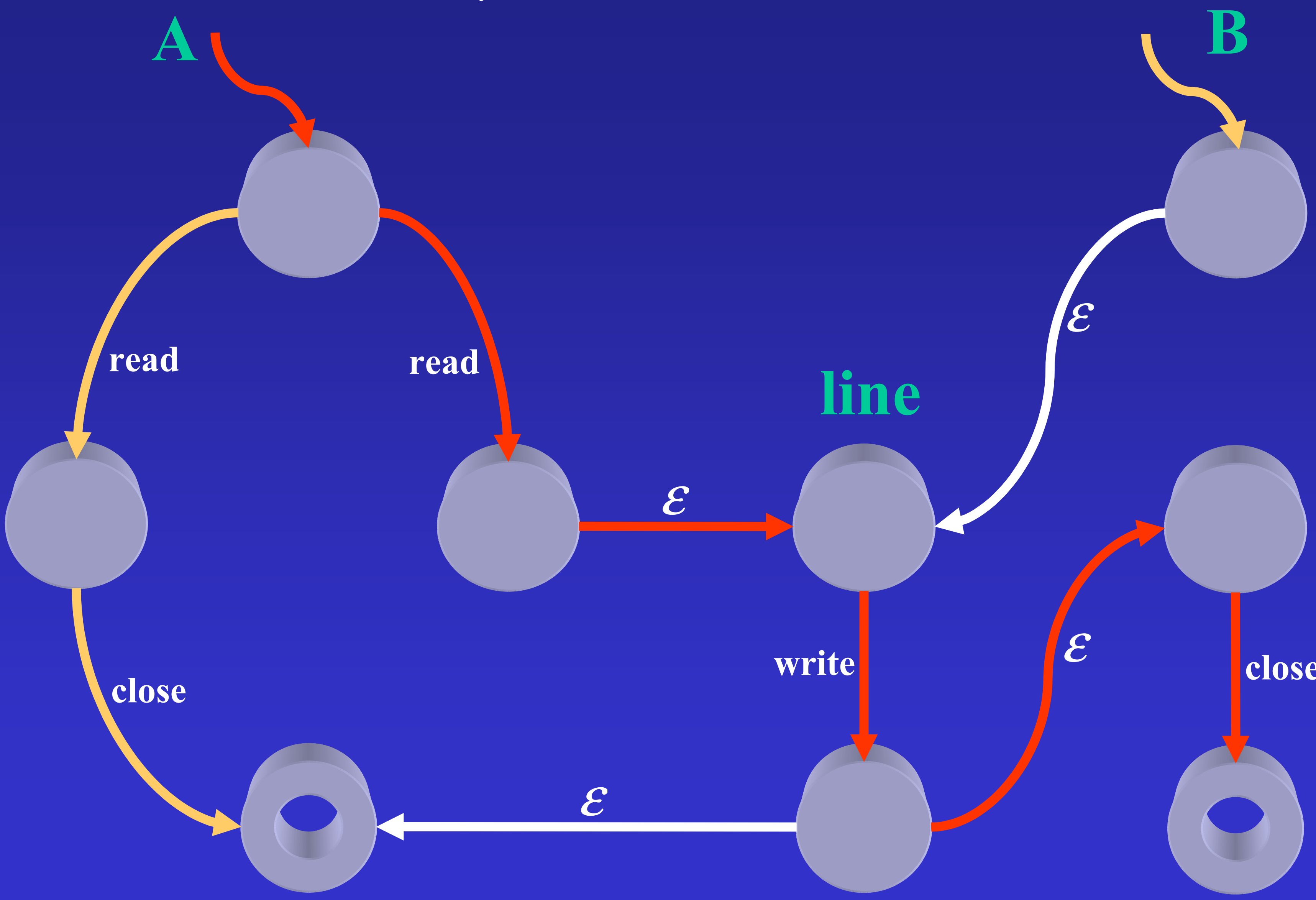
Possible Paths



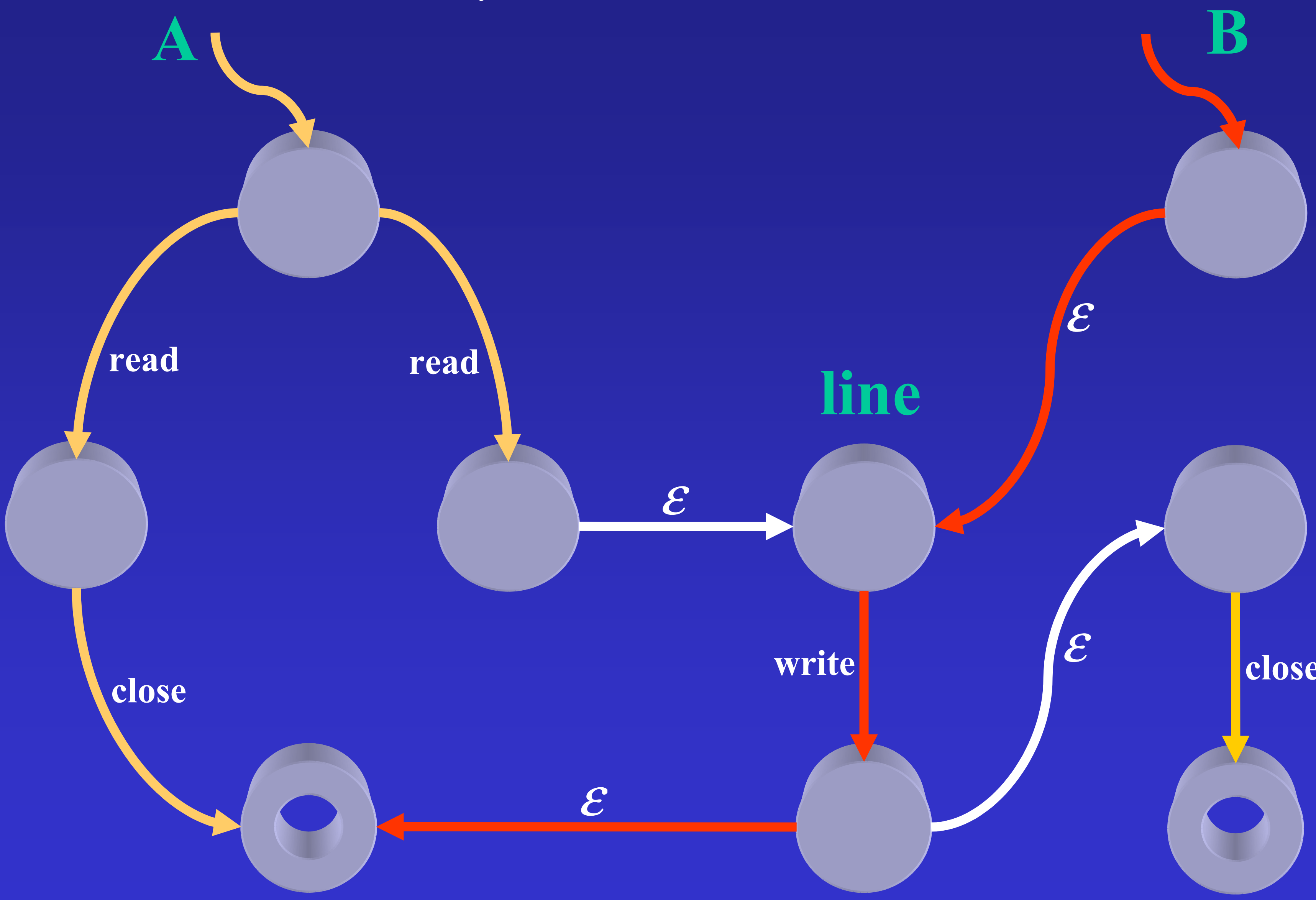
Possible Paths



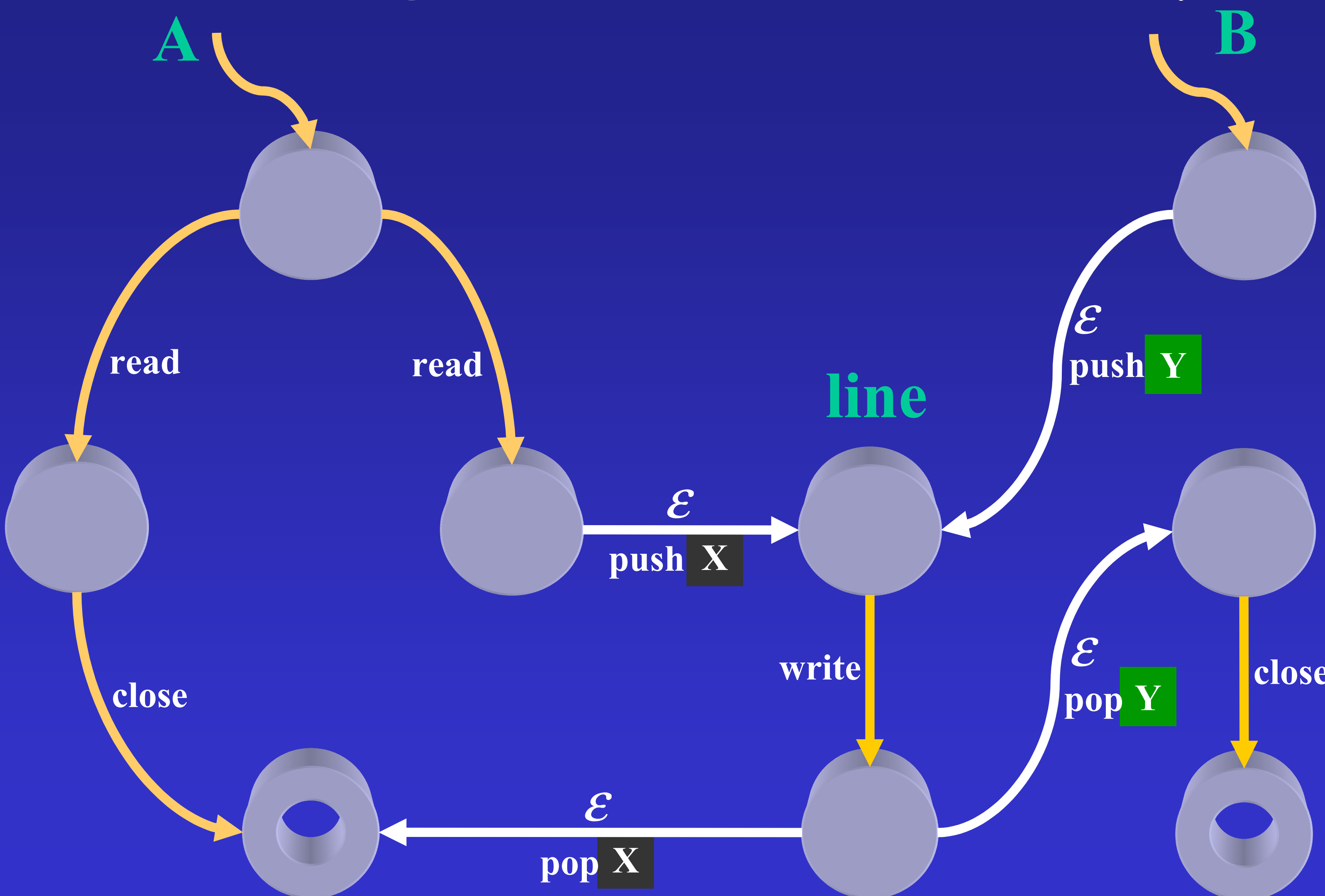
Impossible Paths



Impossible Paths

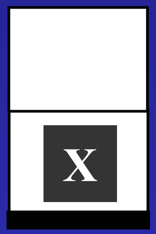


Adding Context Sensitivity



PDA State Explosion

- ε-edge identifiers maintained on a stack
  - Stack may grow to be unbounded



- Solution:
  - Bound the maximum size of the runtime stack
  - A regular language overapproximation of the context-free language of the PDA

Prototype Implementation

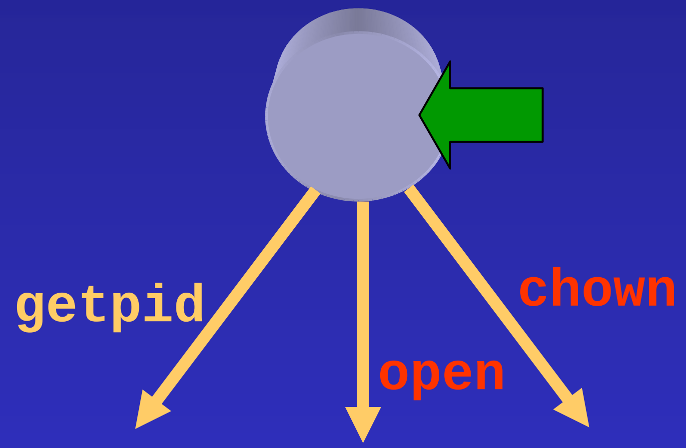
- Simulates remote execution environment
- Measure model precision
- Measure runtime overheads
- Measure the effect of changing maximum stack depth on bounded PDA model

Test Programs

	Program Size in Instructions	Workload
gzip	56,686	Compress a 13 MB file
GNU finger	95,534	Finger 3 non-local users
procmail	107,167	Process 1 incoming email message

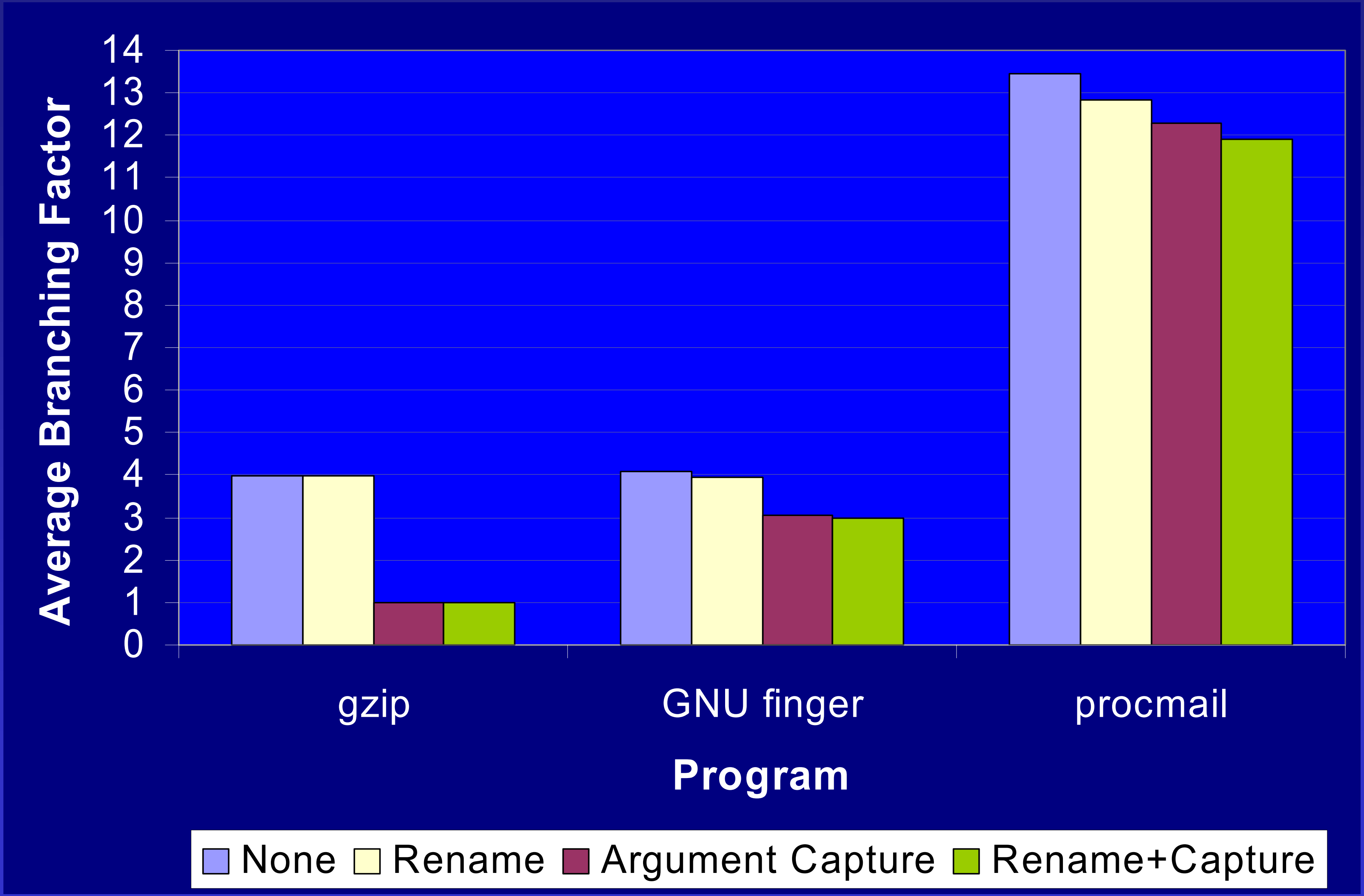
Precision Metric

- Average branching factor

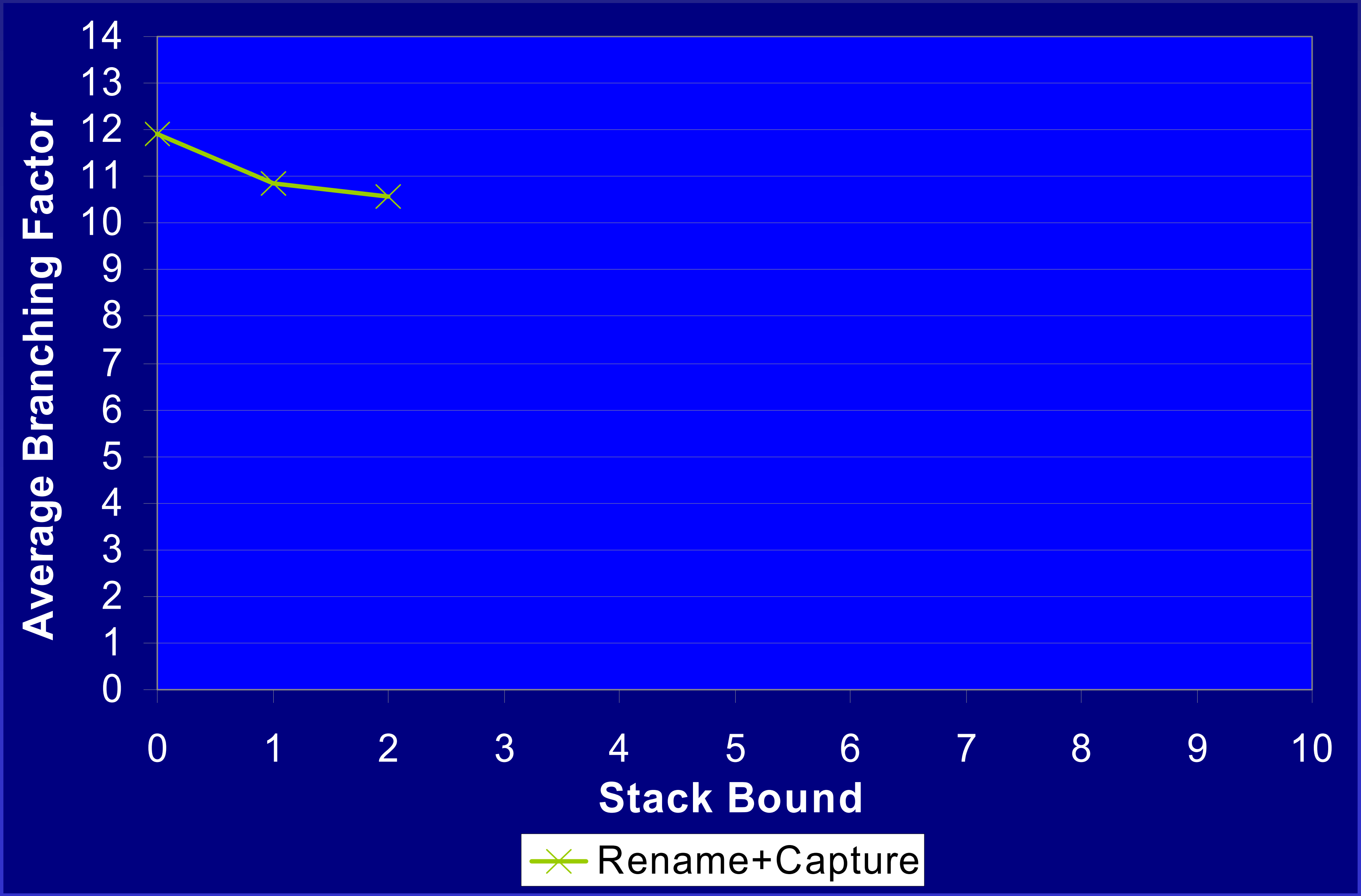


- Lower values indicate greater precision

Precision: NFA Model



Precision: PDA Model, procmail



Optimizations to Improve Precision

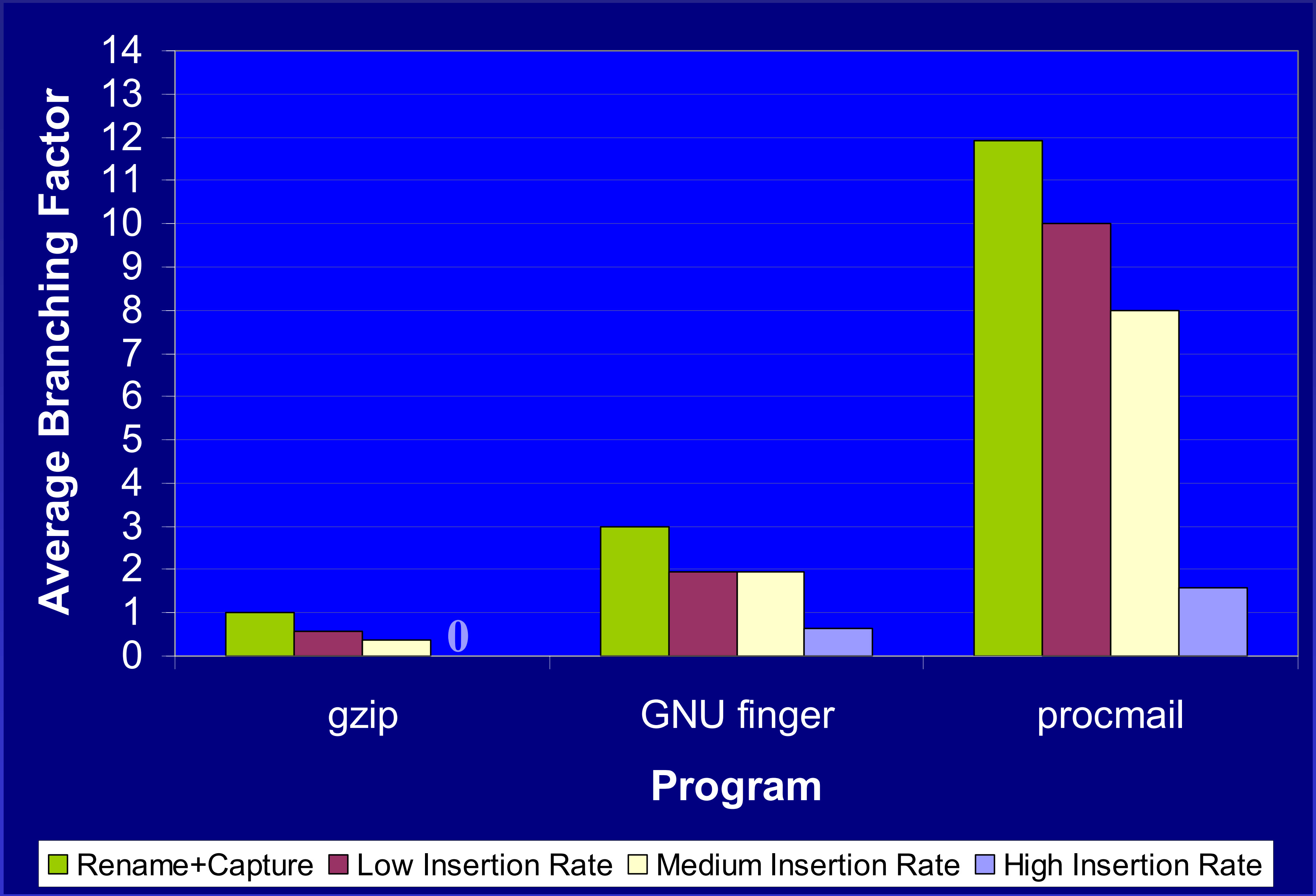
- Observation: PDA is more precise than NFA because it provides context sensitivity

- Idea: Insert null calls into NFA model to add some context sensitivity without suffering runtime cost of PDA

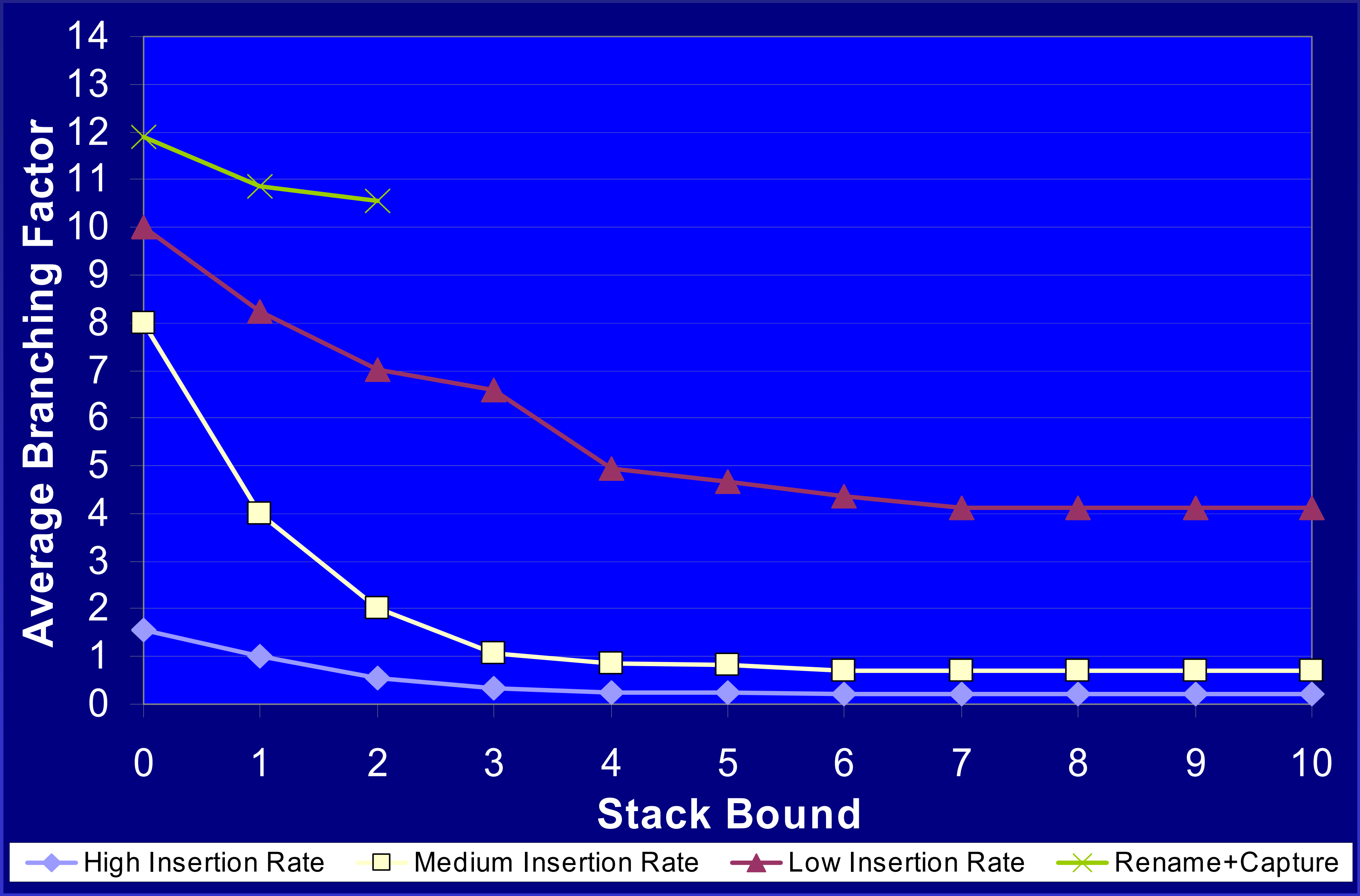
Null Call Experiments

- Inserted null calls at 3 rates
  - High: At entries of functions with fan-in of 2 or greater
  - Medium: At entries of functions with fan-in of 5 or greater
  - Low: At entries of functions with fan-in of 10 or greater

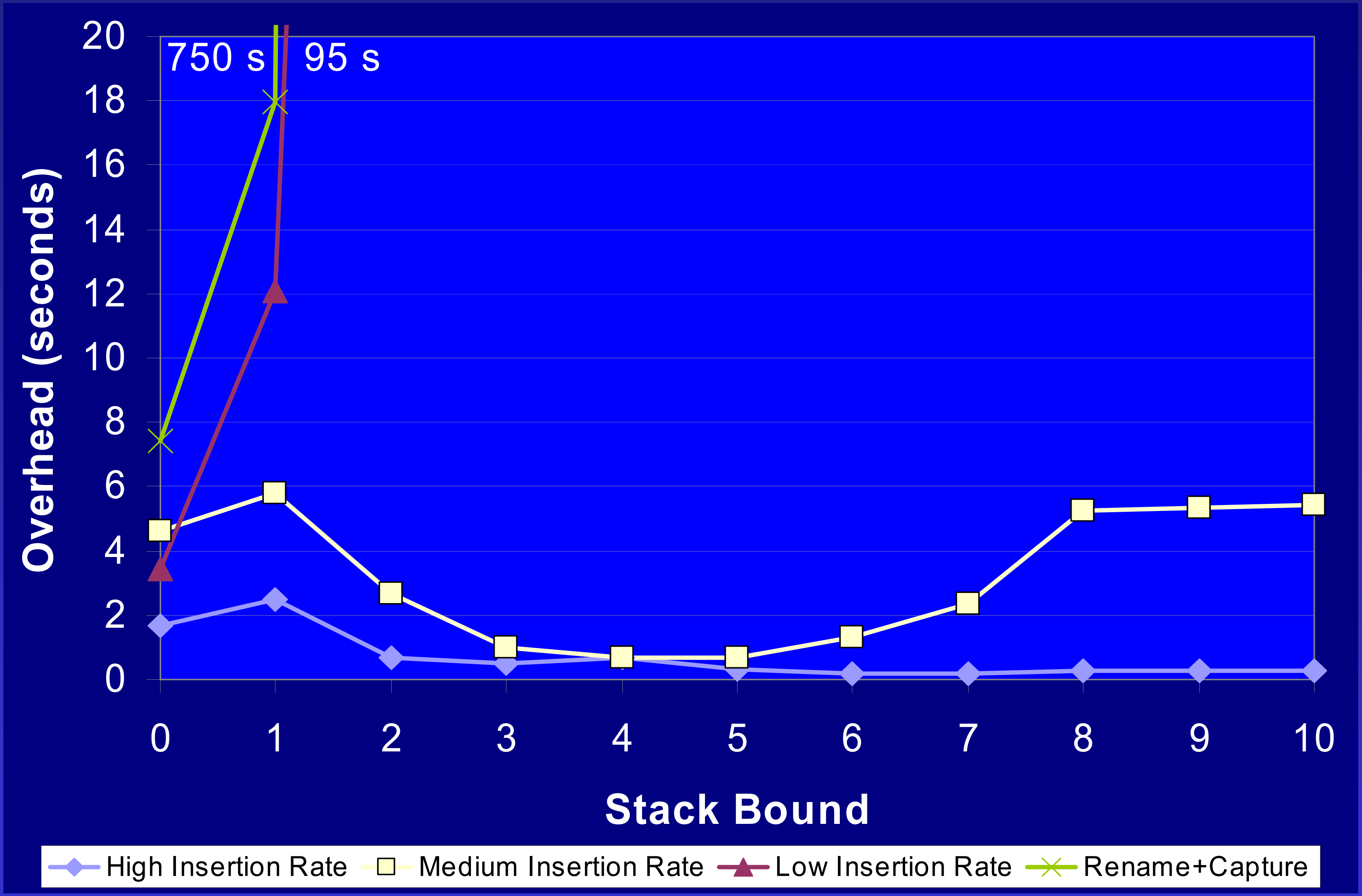
Precision: NFA Model with Null Calls



Precision: PDA Model with Null Calls, procmail



Overhead: PDA Model with Null Calls, procmail



Important Ideas

- Specifications generated automatically from binary code analysis
- Operate a finite state machine modeling correct execution
- PDA model is precise but suffers high overhead
- Bounded PDA stack & null calls allow use of precise PDA model

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