

Lightweight and Modular Resource Leak Verification

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What's a Resource Leak?

```
try {  
    Socket s = new Socket(address, port);  
    ...  
    s.close();  
} catch (IOException e) {  
  
}
```

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} catch (IOException e) {  
  
}
```



Missing call to close()

Problems Caused by Resource Leaks

- Resource starvation
- Slowdowns
- System crashes
- Denial-of-service attack
 - E.g. CVE-1999-1127, CVE-2001-0830, CVE-2002-1372

Key Challenge: Pointer Aliasing

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bug-finding tools

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Ownership
type systems

Enforce
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Heuristic
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Ignore aliasing

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Enforce
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Whole-program
static analysis

Track all
aliases

Key Insight

- Resource leak detection is an **accumulation** problem

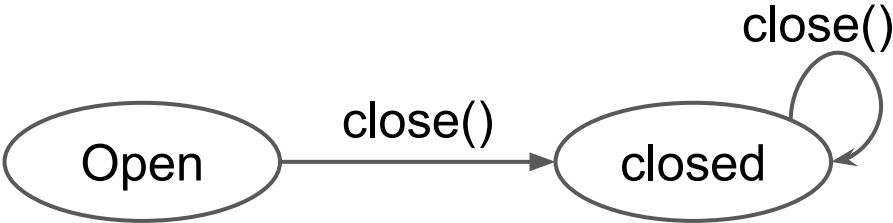
Key Insight

- Resource leak detection is an **accumulation** problem
 - FSM contains no loops

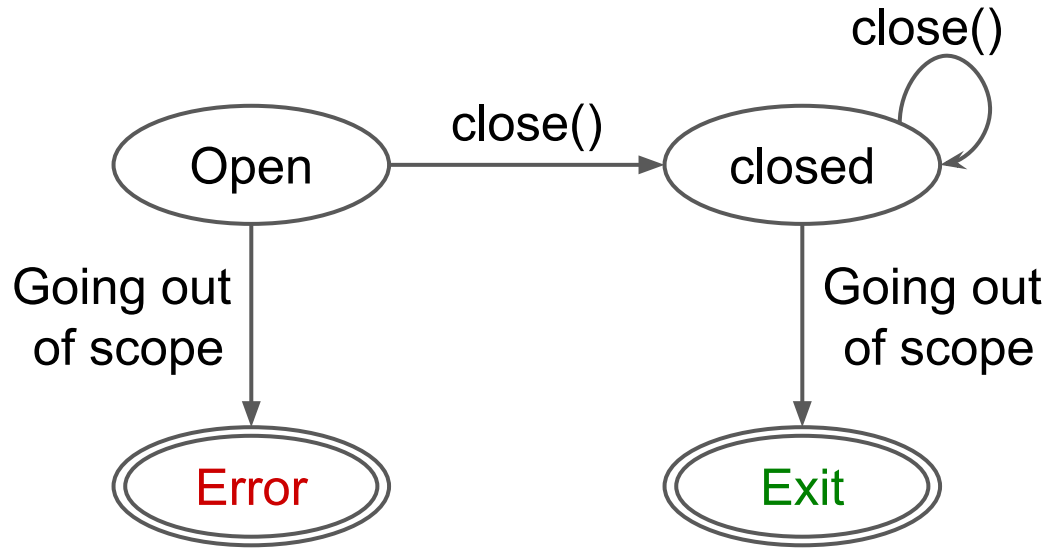
Key Insight

- Resource leak detection is an **accumulation** problem
 - FSM contains no loops
 - **Sound with no alias analysis**

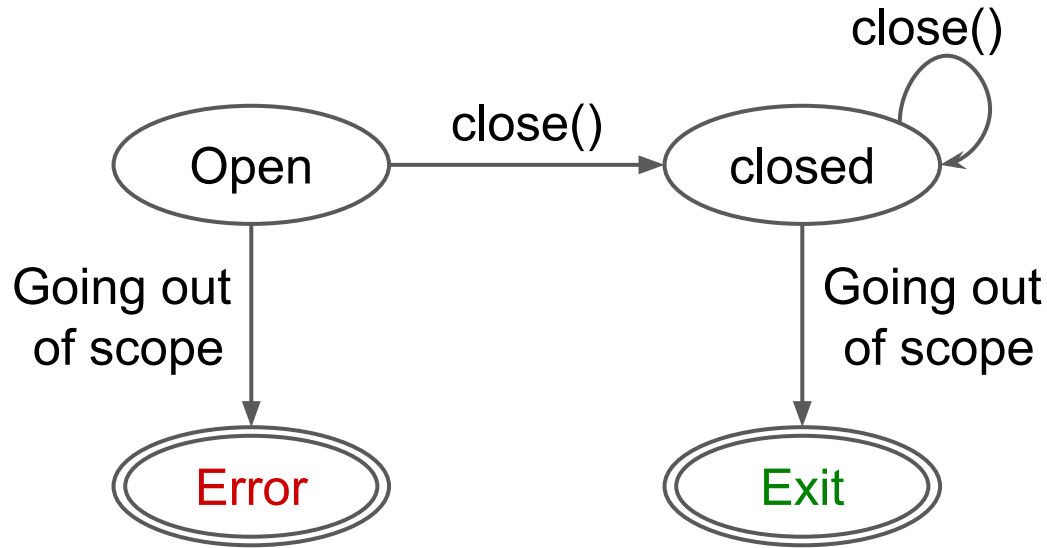
Resource Leaks as Accumulation



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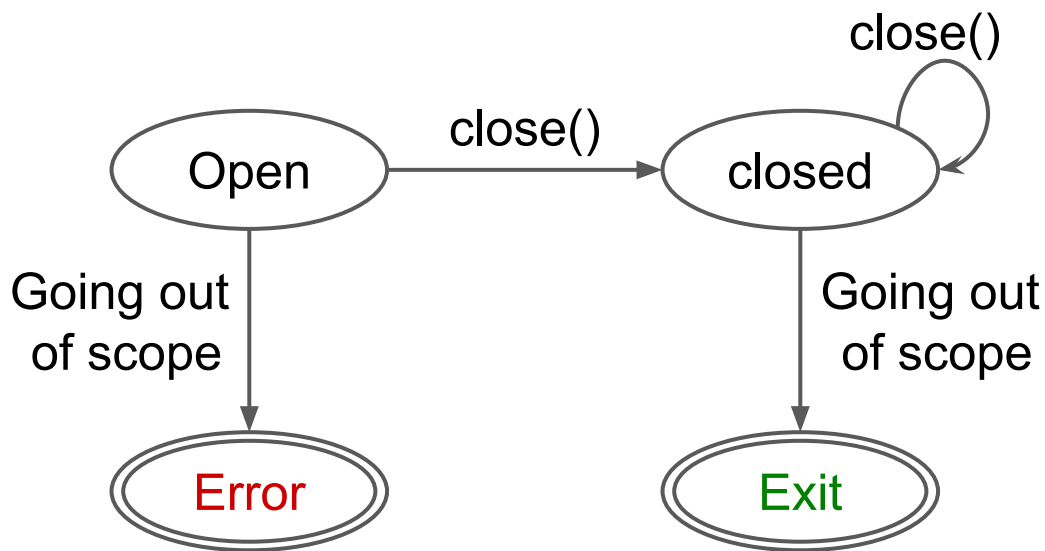


Resource Leaks as Accumulation



FSM contains no loops

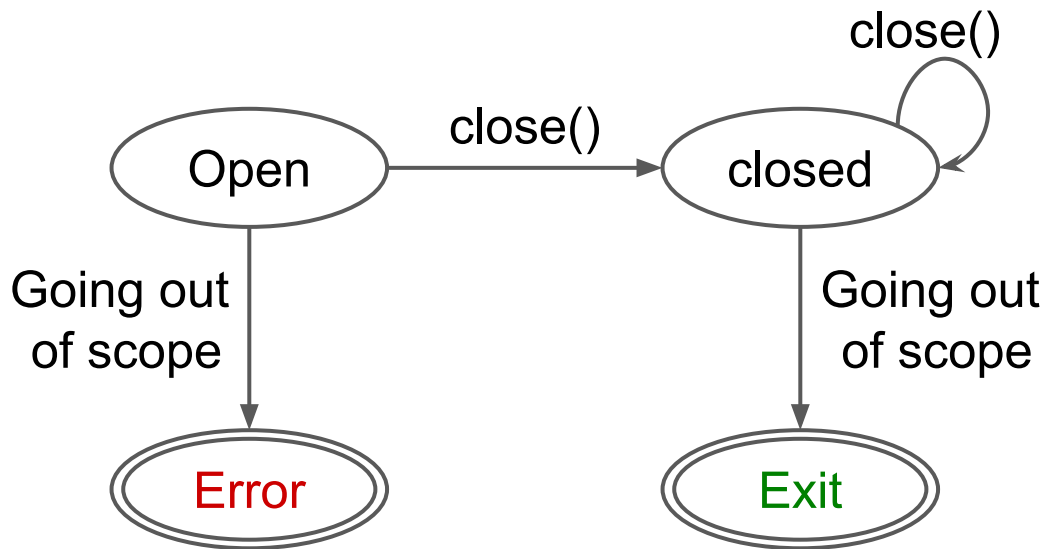
Resource Leaks as Accumulation



FSM contains no loops

Alias analysis not required for soundness

Resource Leaks as Accumulation



FSM contains no loops

Alias analysis not required for soundness

can be implemented modularly

Leak Detection Approach:

1. Compute what methods must be called
2. Compute what methods are called
3. Issue error if mismatch when going out of scope

Example

```
{  
    s = new Socket(address, port);  
    ...  
    if (...) {  
        s = ...;  
    }  
    s.close();  
}
```

Example

```
{
```

```
  s = new Socket(address, port);
```



Obligation: call close on s

```
  ...
```

```
  if (...) {
```

```
    s = ...;
```

```
  }
```

```
  s.close();
```

```
}
```

Example

```
{
```

```
  s = new Socket(address, port);
```

Obligation: call close on s

```
  ...
```

```
  if (...) {
```

```
    s = ...;
```

Called Methods: {}

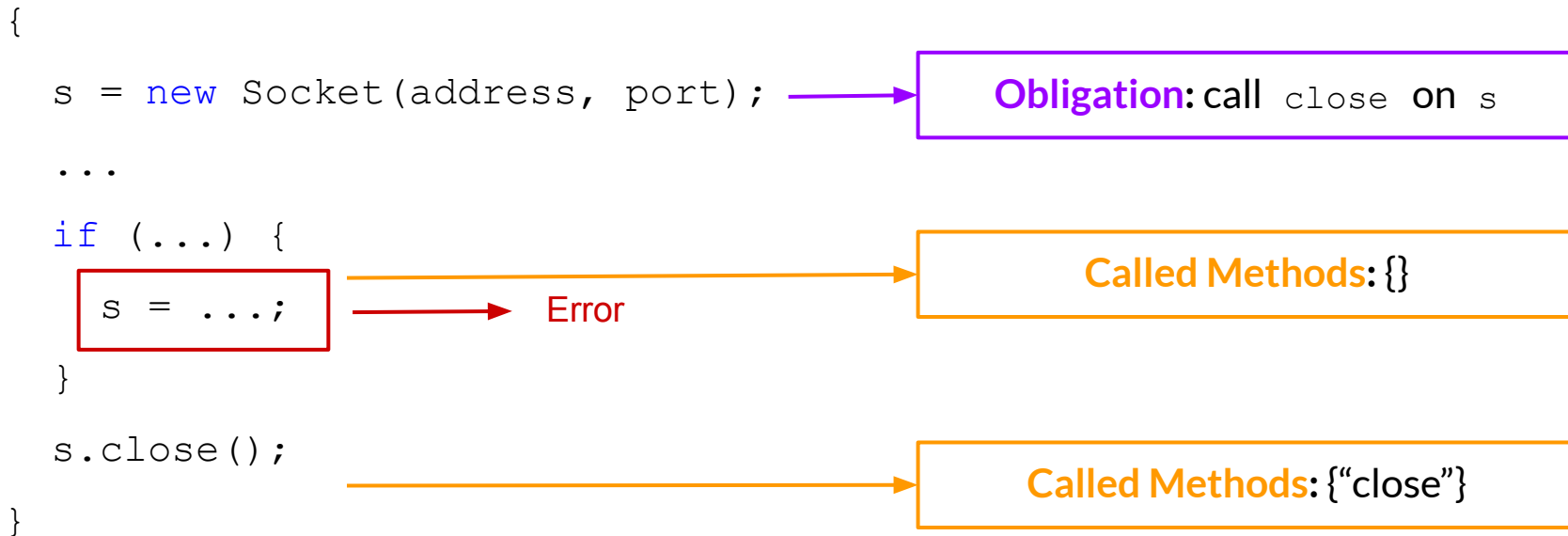
```
  }
```

```
  s.close();
```

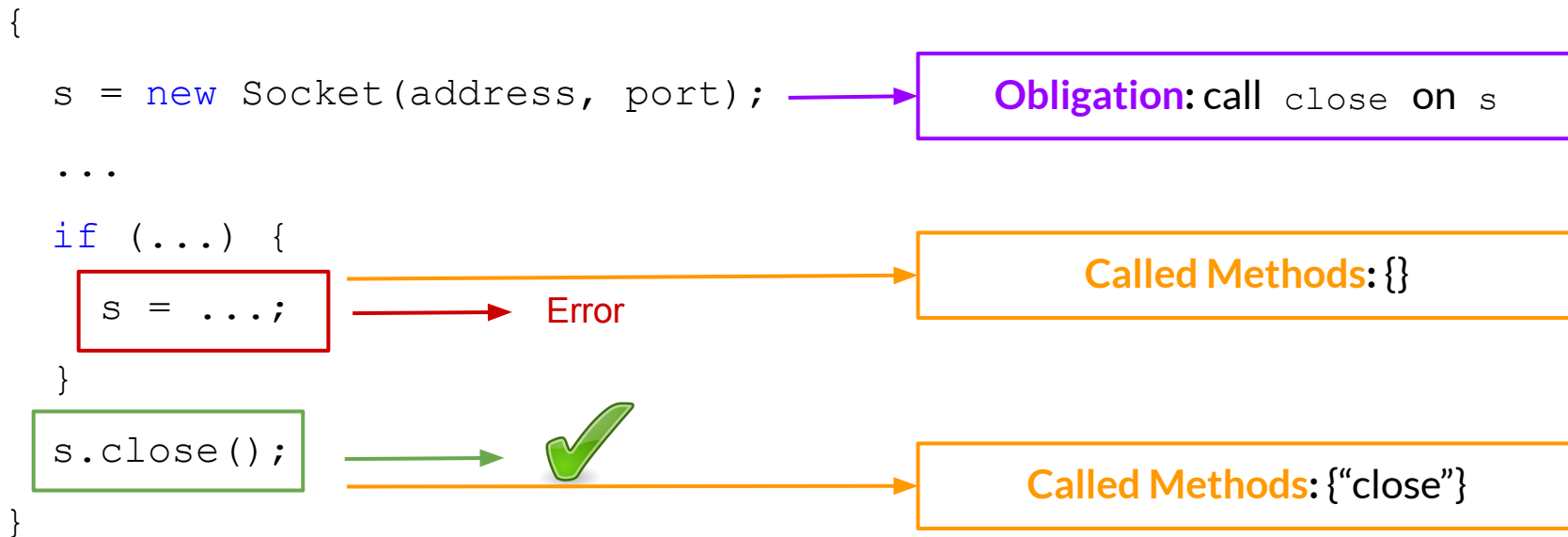
Called Methods: {"close"}

```
}
```

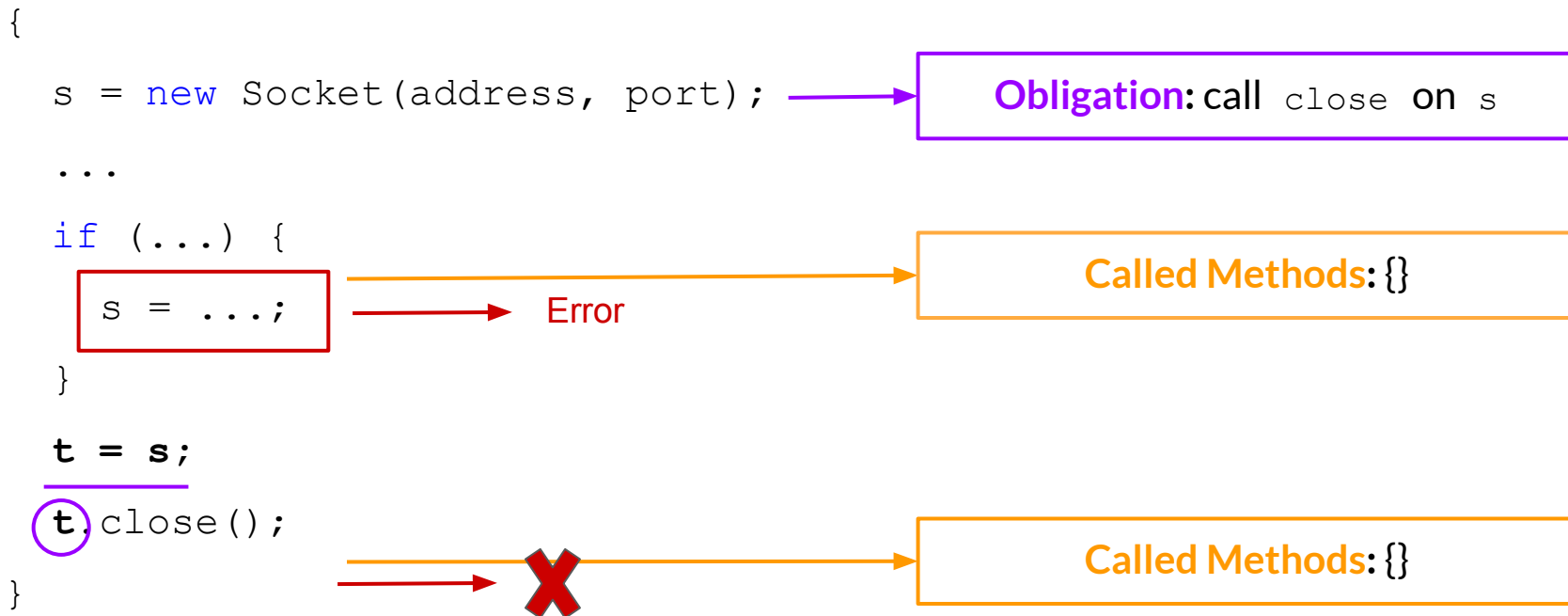
Example



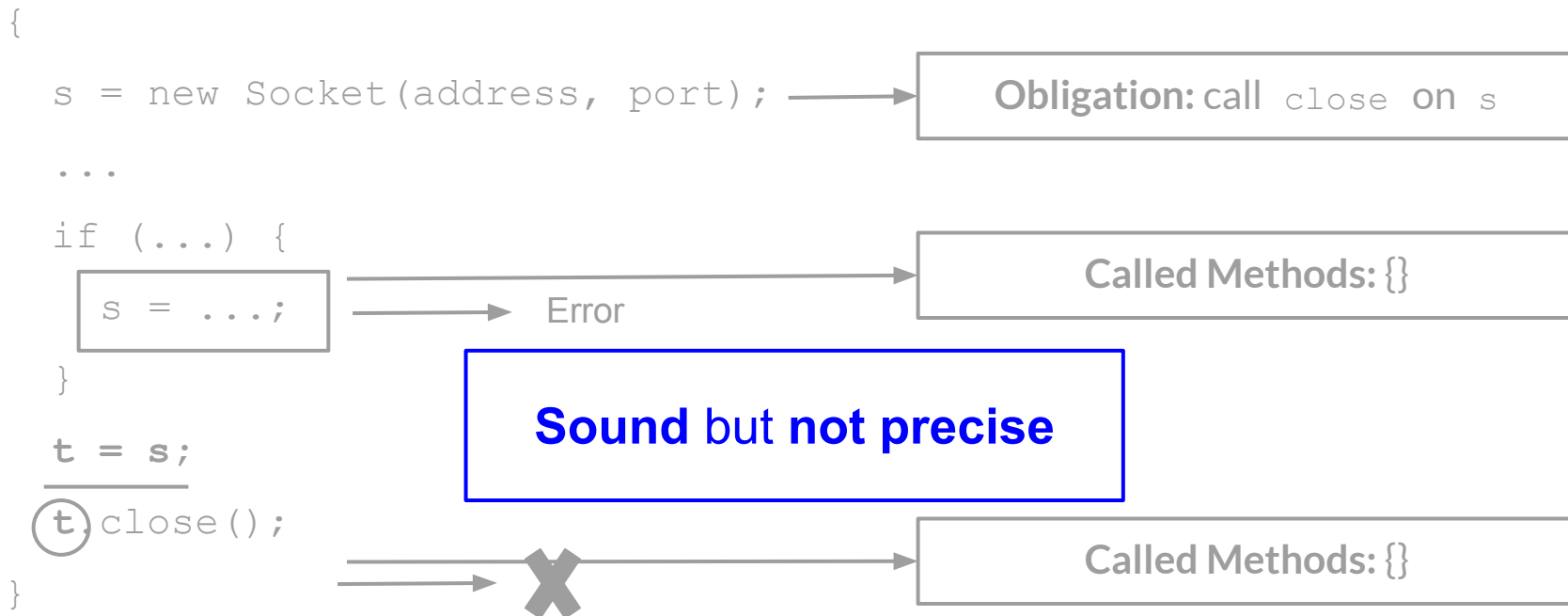
Example



Example



Example



Precision via Local Alias Reasoning

- Local must-aliases
- Lightweight ownership
- Resource aliasing
- Obligation creation

Precision via Local Alias Reasoning

- Local must-aliases
- **Lightweight ownership**
- Resource aliasing
- Obligation creation

Lightweight Ownership

```
closeSocket(mySock);
```

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Obligation: call `close` on `mySock`

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Lightweight Ownership

Obligation: call close on mySock

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Obligation: call close on mySock

```
void closeSocket(@Owning Socket s) {  
    Obligation: call close on s  
    s.close();  
}
```

Lightweight Ownership

Obligation: call `close` on `mySock`

```
closeSocket(mySock);
```

```
void closeSocket(@Owning Socket s) {  
    Obligation: call close on s  
    s.close();  
}
```

- Obligations are neither created nor destroyed
- Doesn't restrict privileges of other aliases

Precision via Local Alias Reasoning

- Local must-aliases
- Lightweight ownership
- **Resource aliasing**
- Obligation creation

Resource Aliasing

```
Socket socket = ...;
```

```
InputStreamReader stream =
```

```
    new InputStreamReader(socket.getInputStream());
```

```
...
```

Resource Aliasing

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Socket socket = ...;
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    new InputStreamReader(socket.getInputStream());
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```
...
```

Which of these should be closed?

Resource Aliasing

```
Socket socket = ...;
```

```
InputStreamReader stream =
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```
    new InputStreamReader(socket.getInputStream());
```

```
...
```

Which of these should be closed?

- Closing either `socket` or `stream` is adequate
- Extensibility

Evaluation:

Evaluation: Case Studies

Four programs: zookeeper, hadoop-hdfs, hbase, plume-util

Lines of code	Resource Leaks Found	False positive warnings	Annotations
427,858	49	121	286

Evaluation: Case Studies

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Precision: 29%

Evaluation: Case Studies

Four programs: zookeeper, hadoop-hdfs, hbase, plume-util

Lines of code	Resource Leaks Found	False positive warnings	Annotations
427,858	49	121	286

~1 per 1,500 LoC

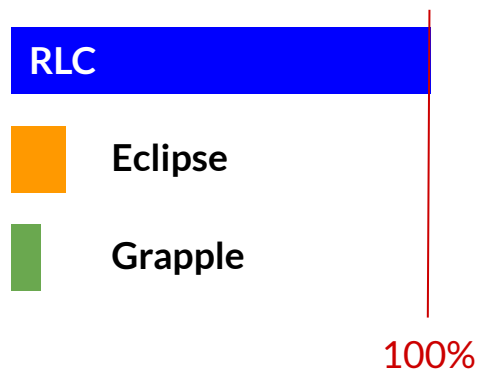
Evaluation: Comparison

3 analyses:

- **RLC**, our type-based analysis
- **Eclipse's** high-confidence heuristic bug-finder
- **Grapple**, a whole-program graph reachability analysis

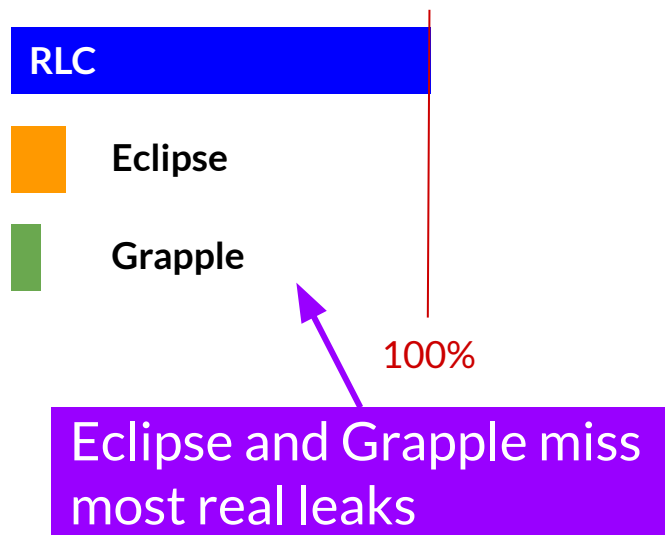
Evaluation: Comparison

Recall



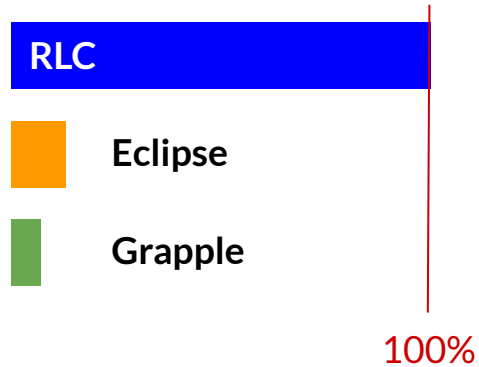
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Recall

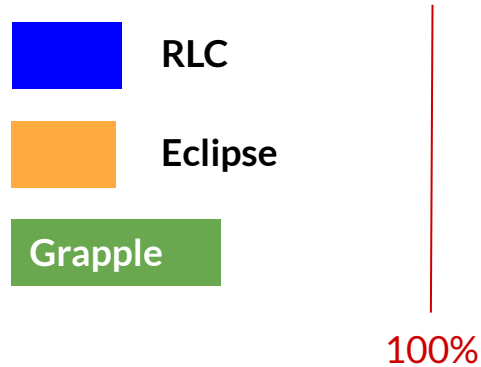


Evaluation: Comparison

Recall

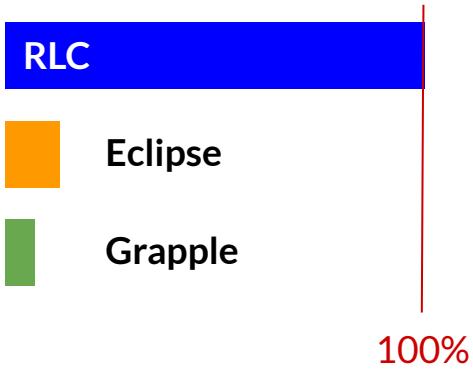


Precision

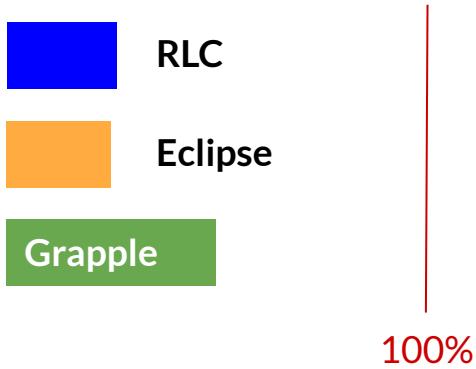


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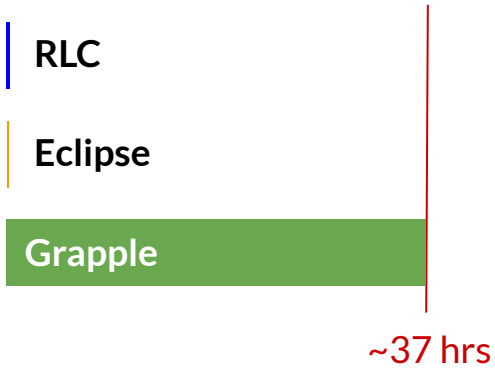
Recall



Precision

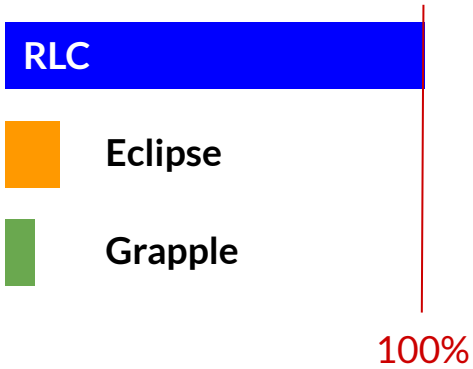


Time

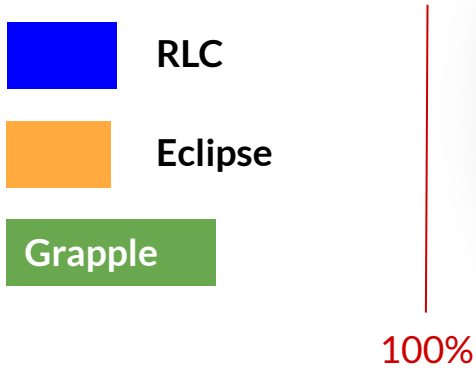


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Precision

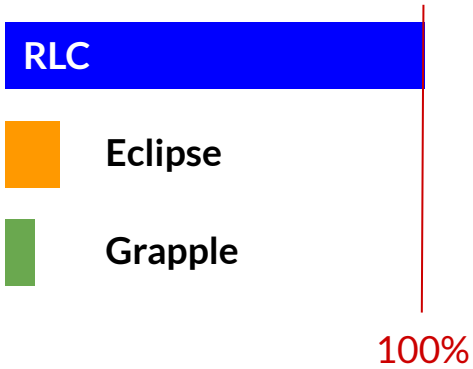


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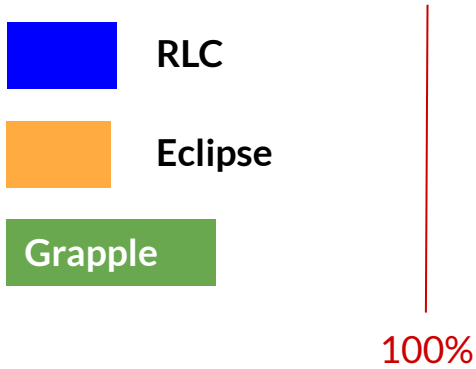


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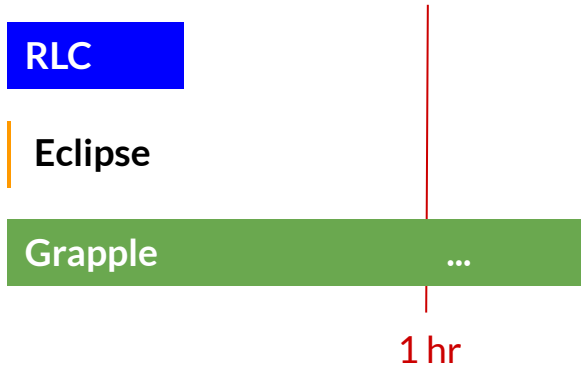
Recall



Precision



Time



Contributions

- **Lightweight and modular resource leak verification** via *accumulation analysis*
- **Local alias reasoning** for precision
- **Extensive evaluation**
- **Open-source implementation** at checkerframework.org