ObliCheck: Efficient Verification of Oblivious Algorithms with Unobservable State

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Data Encryption is Widely Adopted

Is encryption enough to hide your confidential data?

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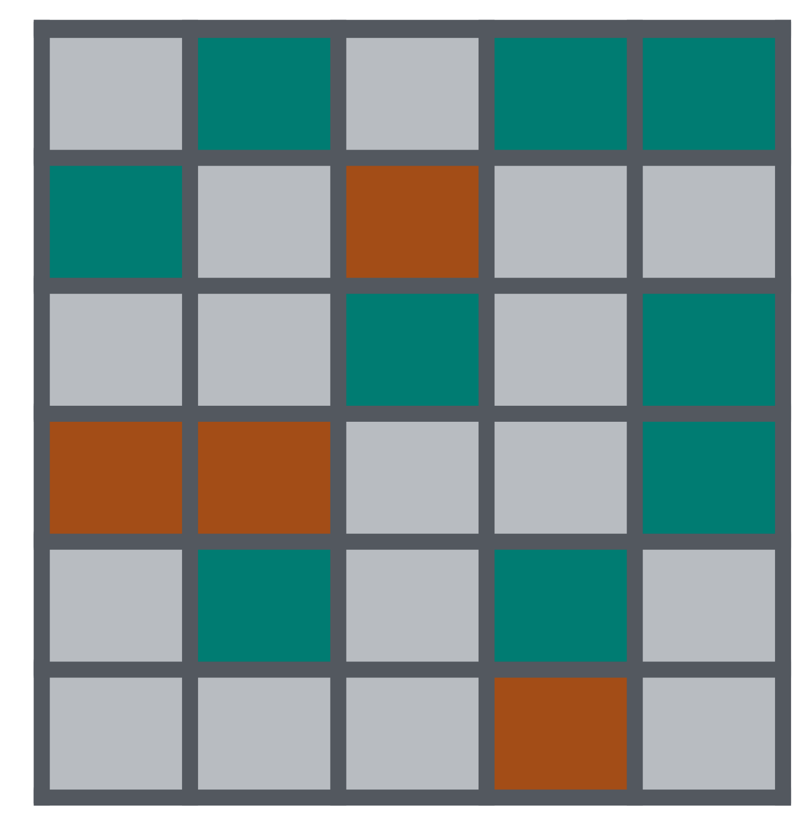
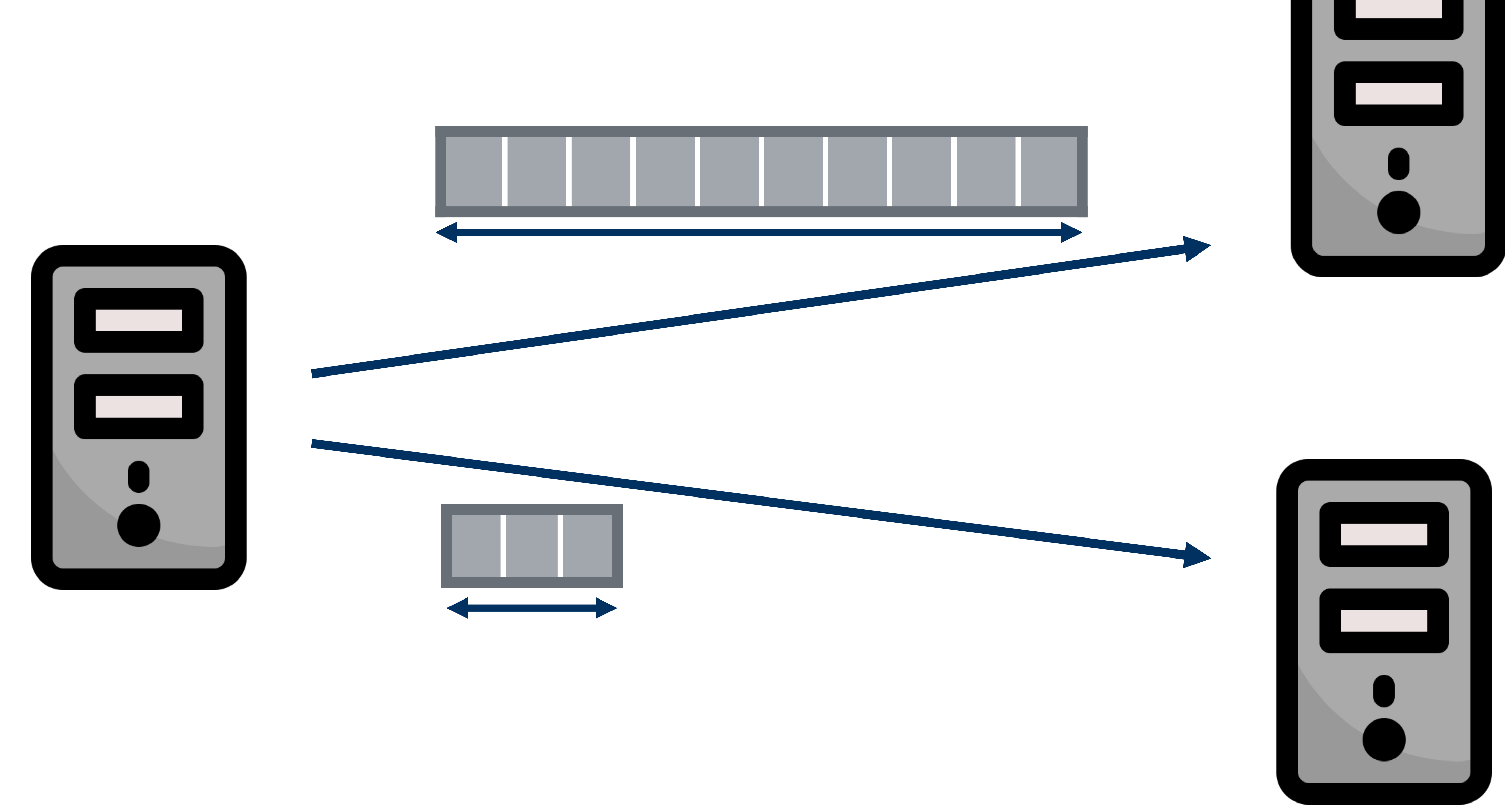
Data Access Patterns Leak Sensitive Information

Data Access Patterns include:



- Accessed Memory Address



- Source / Destination Network Address
- Message Size

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Data Access Patterns Leak Sensitive Information

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Data Access Patterns Leak Sensitive Information

Alice

SELECT.. disease = Flu

Memory

…	Flu
…	Cancer
…	
…	Flu
…	
…	Flu

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Data Access Patterns Leak Sensitive Information

Alice

Bob

SELECT.. disease = Flu

SELECT.. disease = Cancer

Memory

...	Flu
...	Cancer
...	
...	Flu
...	
...	Flu

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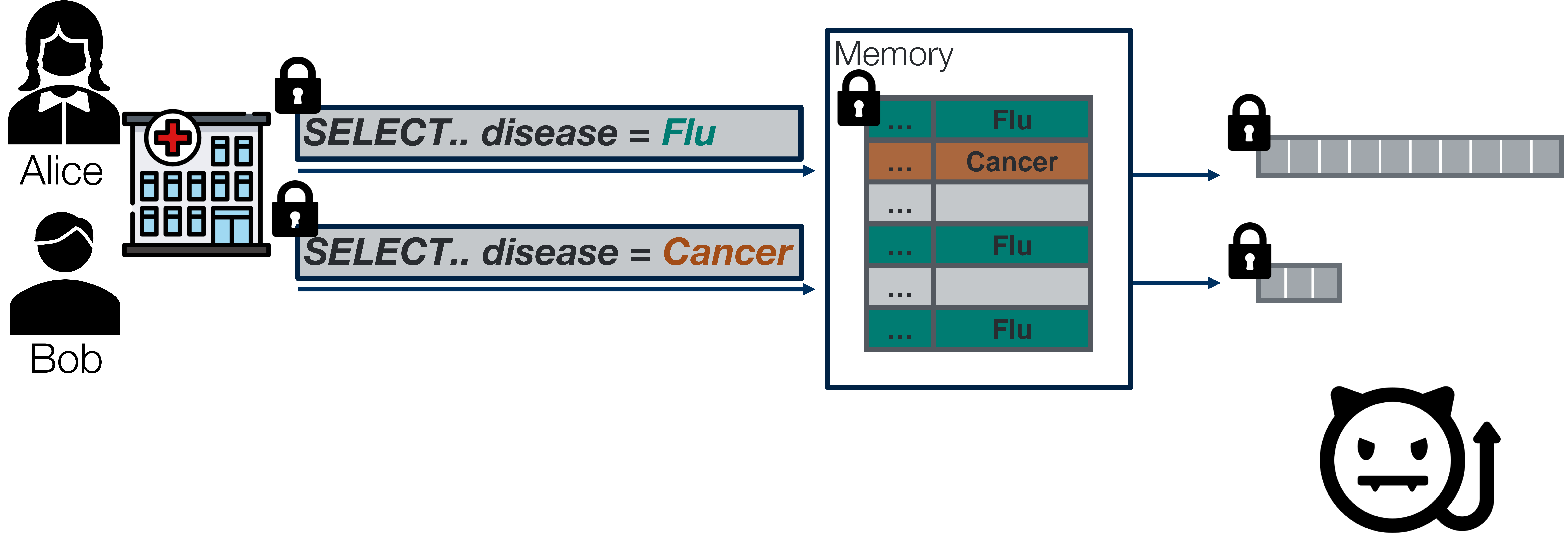
Data Access Patterns Leak Sensitive Information



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Data Access Patterns Leak Sensitive Information

Alice

Bob

SELECT.. disease = *Flu*

SELECT.. disease = *Cancer*

Memory

…	Flu
…	Cancer
…	
…	Flu
…	
…	Flu

Bob has cancer!

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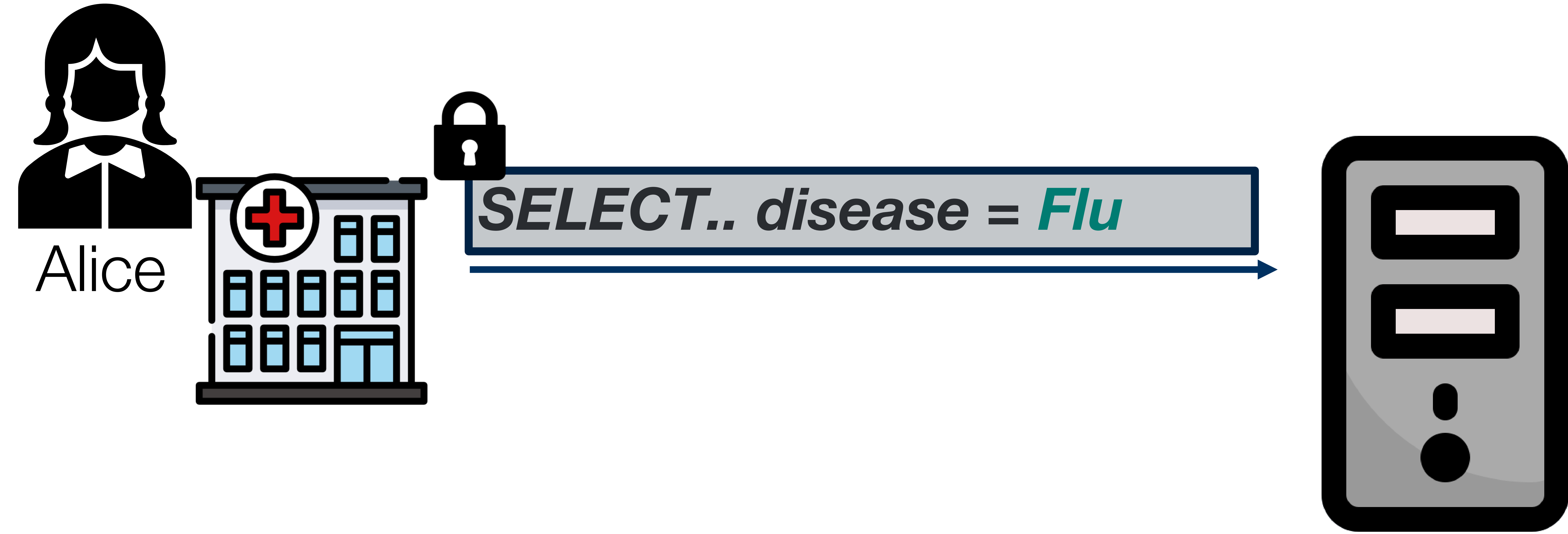
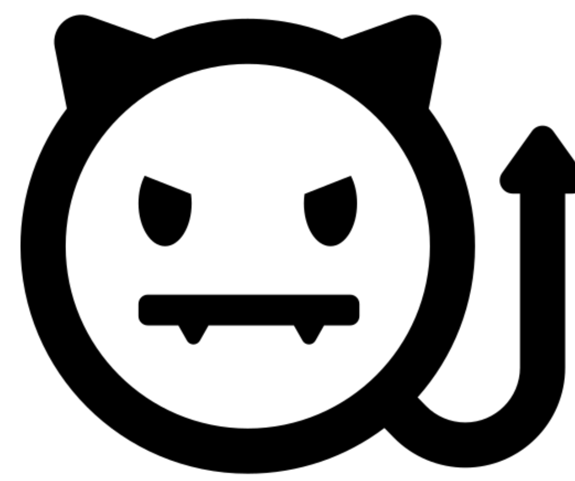
How To Prevent Access Pattern Leakage





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How To Prevent Access Pattern Leakage

Alice

SELECT.. disease = Flu

Memory

...	Flu
...	Cancer
...	
...	Flu
...	
...	Flu

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How To Prevent Access Pattern Leakage

Alice

Bob

SELECT.. disease = Flu

SELECT.. disease = Cancer

Memory

...	Flu
...	Cancer
...	
...	Flu
...	
...	Flu

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How To Prevent Access Pattern Leakage

Alice

Bob

SELECT.. disease = Flu

SELECT.. disease = Cancer

Memory

...	Flu
...	Cancer
...	
...	Flu
...	
...	Flu

???

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How To Prevent Access Pattern Leakage

Alice

Bob

SELECT.. disease = Flu

SELECT.. disease = Cancer

Memory

…	Flu
…	Cancer
…	
…	Flu
…	
…	Flu

???

"Oblivious: Access pattern is independent from private data"

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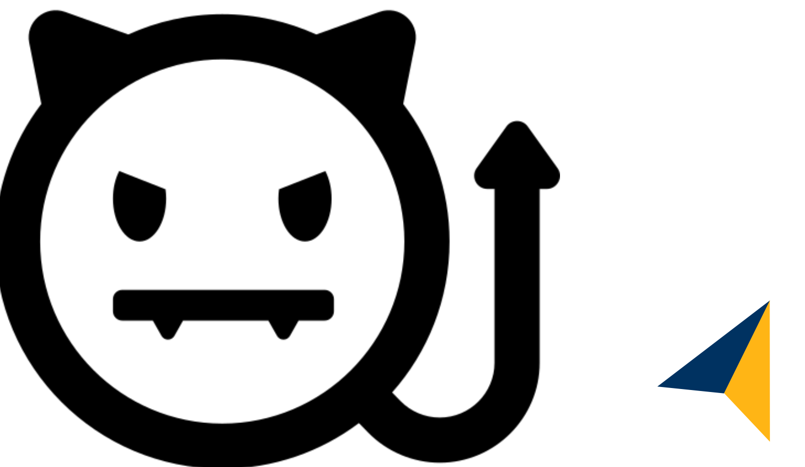
Oblivious Algorithms Are Slow

SELECT..Cancer

Cancer
Flu
Cancer
Flu
Flu
Cancer
Cancer
...

Sorting Network

Cancer
Cancer
Cancer
Cancer
Flu
Flu
Flu
...



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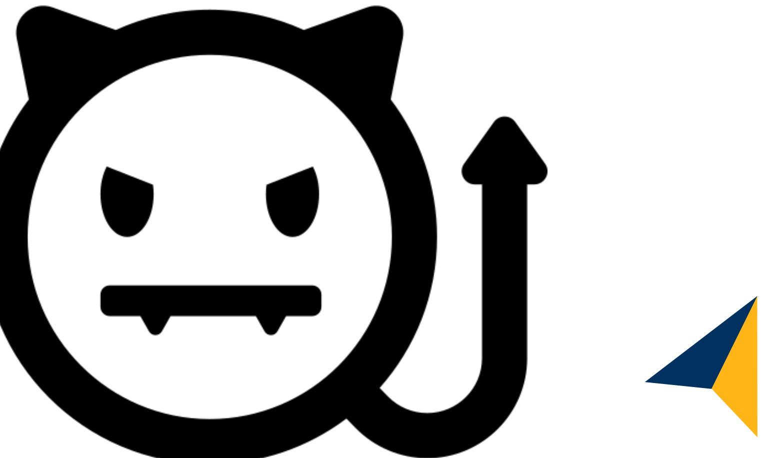
Unobservable Memory Region Speeds Up Oblivious Algorithms

- Oblivious sort operation from Opaque [Zheng et al., USENIX NSDI '17]

SELECT..Cancer

Unobservable Space
(e.g. registers, enclaves)



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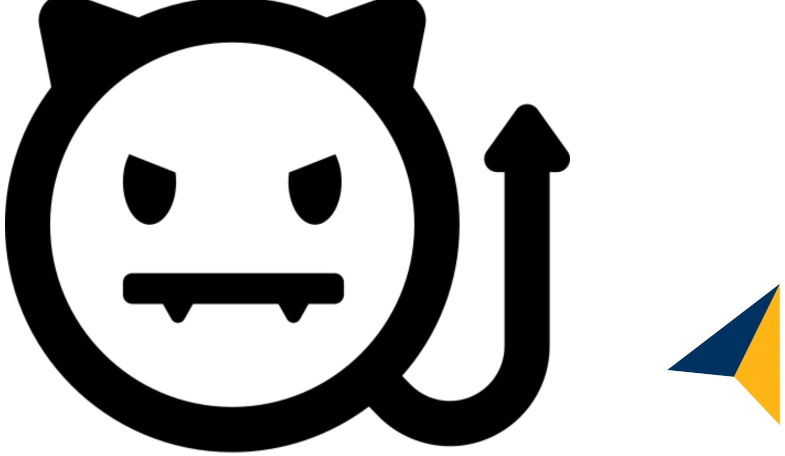
Unobservable Memory Region Speeds Up Oblivious Algorithms

- Oblivious sort operation from Opaque [Zheng et al., USENIX NSDI '17]

SELECT..Cancer

Cancer
Flu
Cancer
Flu
Flu
Flu



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Unobservable Memory Region Speeds Up Oblivious Algorithms

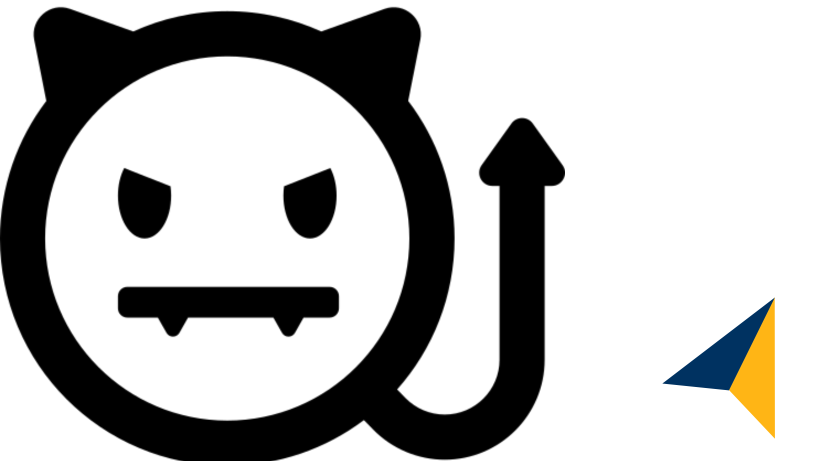
- Oblivious sort operation from Opaque [Zheng et al., USENIX NSDI '17]

SELECT..Cancer

Cancer
Cancer
Flu
Flu
Flu
Flu

Cancer
Cancer
Flu
Flu
Flu
Flu

Sorting Network



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Problem: Oblivious Algorithms Are Complicated

Problem

The algorithms are complicated to be efficient and oblivious at the same time
→ Difficult to check one is indeed oblivious

State-of-the-art

Algorithm designers write pen-and-pencil proofs, and the users manually verify it

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How can we automatically verify oblivious algorithms in a practical manner?

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Existing Solutions Are Insufficient

Code: Oblivious Filter
The program gets a list of private data, compare each element to VALUE and tag either 0 or 1

Threat Model
Attacker can only watch data sent over network, local memory is unobservable

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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Existing Solutions Are Insufficient

Increments the output length by 1 → →

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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Existing Solutions Are Insufficient

Increments the output length by 1 →

Observable output.length is always the same. →
output is encrypted before sent over network.

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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Existing Solutions Are Insufficient

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```

Increments the output length by 1 →

Observable output.length is always the same. →
output is encrypted before sent over network.

The filter algorithm is **oblivious**

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Existing Solutions Are Insufficient

Solution 1. Taint Analysis (Static)
Reject a program with a secret dependent branch

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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Existing Solutions Are Insufficient

Solution 1. Taint Analysis (Static)

Regarded as a problematic branch, →
thus the program gets rejected

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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Existing Solutions Are Insufficient

Solution 1. Taint Analysis (Static)

Shortcoming
Unobservable state propagates taint, which leads to a rejection of an oblivious program

✘ Algorithms leveraging unobservable space are always deemed not oblivious (False-positives)

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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Existing Solutions Are Insufficient

Solution 2. Symbolic Execution

Encounter a branch. Fork the execution →
Path Condition: $e_0 < VALUE$ →

Path Condition: $e_0 \geq VALUE$ →

Path Condition
Constraints possible input values for each execution path
→ Let us reason about all program behaviors

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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Existing Solutions Are Insufficient

e_0 < VALUE

→

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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Existing Solutions Are Insufficient

$e_0 < VALUE$

….append((1, e_0))

….append((0, e_0))

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
→           output.append((1, e));
        } else {
→           output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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Existing Solutions Are Insufficient

2nd Iteration: Fork the execution →

e_0 < VALUE

….append((1, e_0))

….append((0, e_0))

e_1 < VALUE

e_1 < VALUE

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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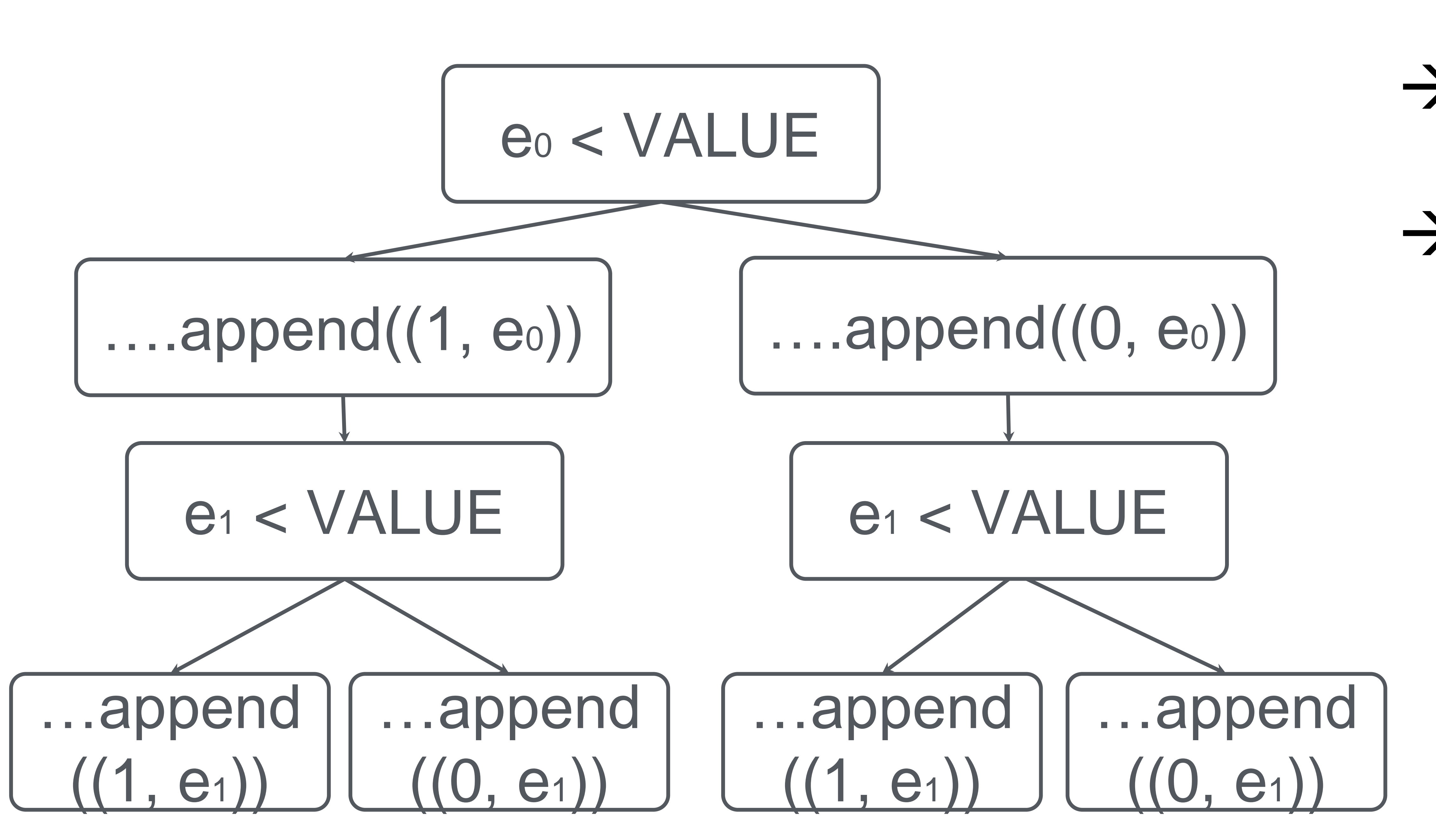
Existing Solutions Are Insufficient




```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
→           output.append((1, e));
        } else {
→           output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```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Existing Solutions Are Insufficient

Solution 2. Symbolic Execution

Shortcoming
Branches on unobservable state makes the number of paths to explore grow exponentially

✘ Analysis time increases exponentially in the length of the input (Path explosion)

```
function Filter(privateData) {
    ...
    for (e in privateData) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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ObliCheck: Symbolic Execution for Verifying Oblivious Algorithms

1. Let users specify observable and unobservable access
→ **ObliCheck API**

2. Leverage domain specific knowledge to enhance symbolic execution performance
→ **Optimistic State Merging**

3. Remove the false-positives incurred by state merging
→ **Iterative State Unmerging**

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ObliCheck: Symbolic Execution for Verifying Oblivious Algorithms

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API for Accessing Observable Space

Algorithm designers use ObliCheck APIs to express a certain data access is observable

A trace is added to the access sequence under the hood whenever an API is called

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    EncSendTo(NET_ADDR, output);
    ...
}
```


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API for Accessing Observable Space

Algorithm designers use ObliCheck APIs to express a certain data access is observable

A trace is added to the access sequence under the hood whenever an API is called

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
→   ObliCheck.send(NET_ADDR, output);
    ...
}
```


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ObliCheck: Symbolic Execution for Verifying Oblivious Algorithms

1. Let users specify observable and unobservable access
→ **ObliCheck API**

2. Leverage domain specific knowledge to enhance symbolic execution performance
→ **Optimistic State Merging**

3. Remove the false-positives incurred by state merging
→ **Iterative State Unmerging**

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Optimistic State merging

Core Idea
Merge state based on domain specific knowledge of which state is unobservable

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

e_0 < VALUE

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
→       if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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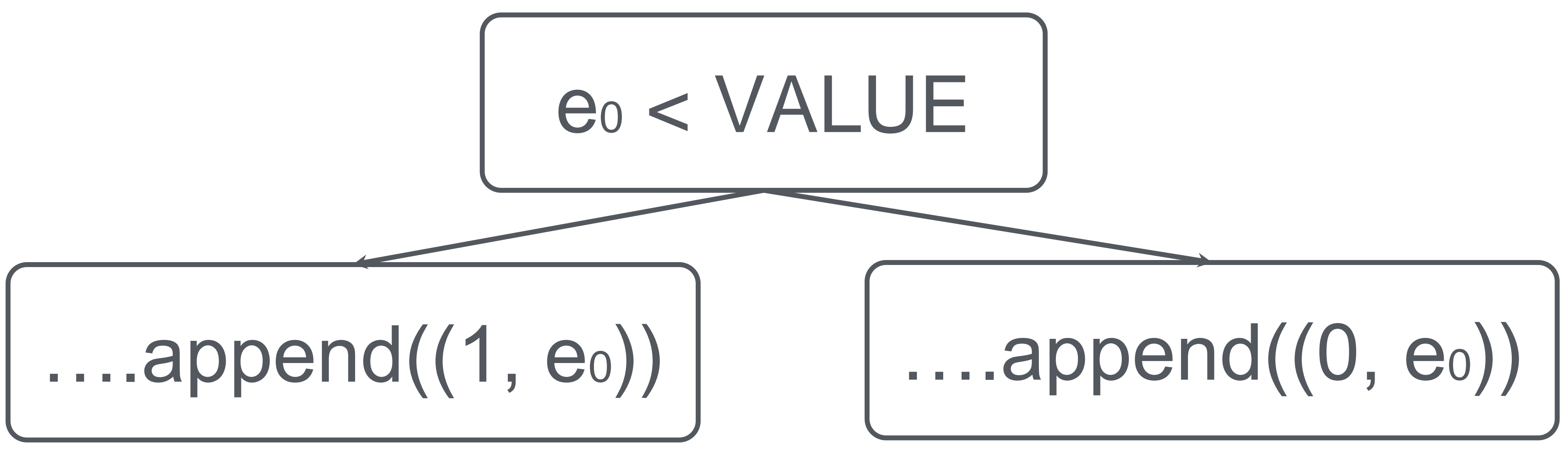
Optimistic State merging




```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
→           output.append((1, e));
        } else {
→           output.append((0, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```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Optimistic State merging

e_0 < VALUE

….append((1, e_0))

output[0] = (1, e_0)
output.length = 1

….append((0, e_0))

output[0] = (0, e_0)
output.length = 1

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
→           output.append((1, e));
        } else {
→           output.append((0, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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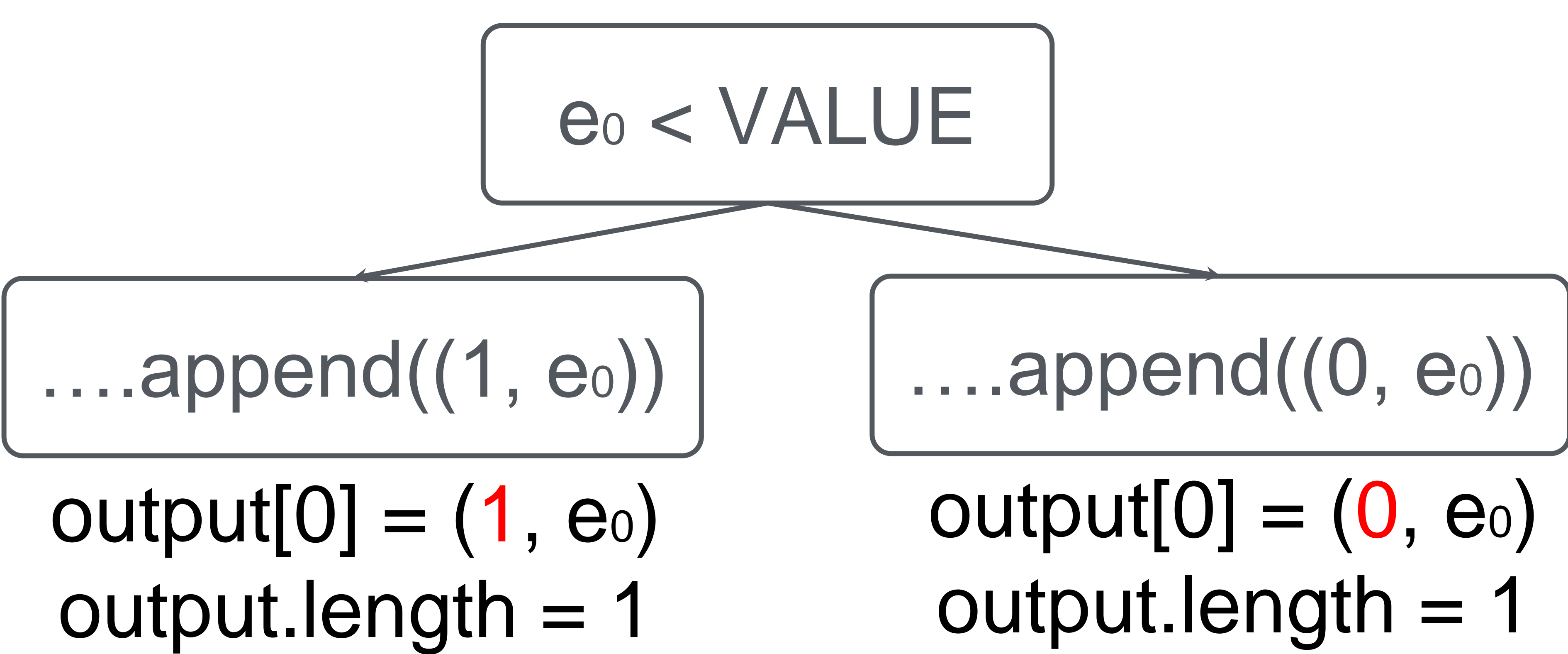
Optimistic State merging



output[0] = (1, e_0)
output.length = 1

output[0] = (0, e_0)
output.length = 1

Cannot merge the state because the variable value is different in the two paths

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
→           output.append((1, e));
        } else {
→           output.append((0, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```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Optimistic State merging

1 and 0 are unobservable and encrypted when sent →
An attacker cannot distinguish the two values
→

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

1 and 0 are unobservable and encrypted when sent →
An attacker cannot distinguish the two values
→

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((⋆, e));
        } else {
            output.append((⋆, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

$e_0 < \text{VALUE}$

….append((1, e_0)) | ….append((0, e_0))

output[0] = (1, e_0)
output.length = 1

output[0] = (0, e_0)
output.length = 1

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((⋆, e));
        } else {
            output.append((⋆, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

e_0 < VALUE

….append((1, e_0))

output[0] = (★, e_0)
output.length = 1

….append((0, e_0))

output[0] = (★, e_0)
output.length = 1

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((★, e));
        } else {
            output.append((★, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

e_0 < VALUE

….append((1, e_0))

output[0] = (s_0, e_0)
output.length = 1

….append((0, e_0))

output[0] = (s_0, e_0)
output.length = 1

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((⋆, e));
        } else {
            output.append((⋆, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

e_0 < VALUE

….append((1, e_0))

….append((0, e_0))

output[0] = (s_0, e_0)
output.length = 1

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((⋆, e));
        } else {
            output.append((⋆, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

e_0 < VALUE

….append((1, e_0))

….append((0, e_0))

output[0] = (s_0, e_0)
output.length = 1

e_1 < VALUE

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((*, e));
        } else {
            output.append((*, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

e_0 < VALUE

….append((1, e_0))

….append((0, e_0))

output[0] = (s_0, e_0)
output.length = 1

e_1 < VALUE

….append((1, e_1))

….append((0, e_1))

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((*, e));
        } else {
            output.append((*, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

e_0 < VALUE

….append((1, e_0))

….append((0, e_0))

output[0] = (s_0, e_0)
output.length = 1

e_1 < VALUE

….append((1, e_1))

….append((0, e_1))

output[0] = (s_1, e_0)
output.length = 2

...

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((*, e));
        } else {
            output.append((*, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

...

output[n] = s_n
output.length = n

```
ObliCheck.send(NET_ADDR, output);
```

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((⋆, e));
        } else {
            output.append((⋆, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

...

output[n] = s_n
output.length = n

```
ObliCheck.send(NET_ADDR, output);
```

ObliCheck reports the algorithm is **oblivious**
(output.length is always n in all paths)

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((⋆, e));
        } else {
            output.append((⋆, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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Optimistic State merging

Benefit
The analysis time grows linearly

Soundness
Over-approximated program includes the cases of the original program

Problem
May falsely reject an oblivious program

```
function Filter(privateRecords) {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((★, e));
        } else {
            output.append((★, e));
        }
    }
    ObliCheck.send(NET_ADDR, output);
    ...
}
```


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ObliCheck: Symbolic Execution for Verifying Oblivious Algorithms

1. Let users specify observable and unobservable access
→ **ObliCheck API**

2. Leverage domain specific knowledge to enhance symbolic execution performance
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→ **Iterative State Unmerging**

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Optimistic State Merging Incurs False Positives

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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output[0] = (1, e)→
or
output[0] = (0, e)→

t.first = 0 or 1→

→

result.length always increments by 1→

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```

The algorithm is **oblivious**

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...

output[0] = (s_0, e_0)

→

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((*, e));
        } else {
            output.append((*, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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...

output[0] = (s_0, e_0)

t.first == 0

$s_0 \neq 0$

result.length += 1

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((★, e));
        } else {
            output.append((★, e));
        }
    }
    ...
    for (t in output) {
→       if (t.first == 0)
→           result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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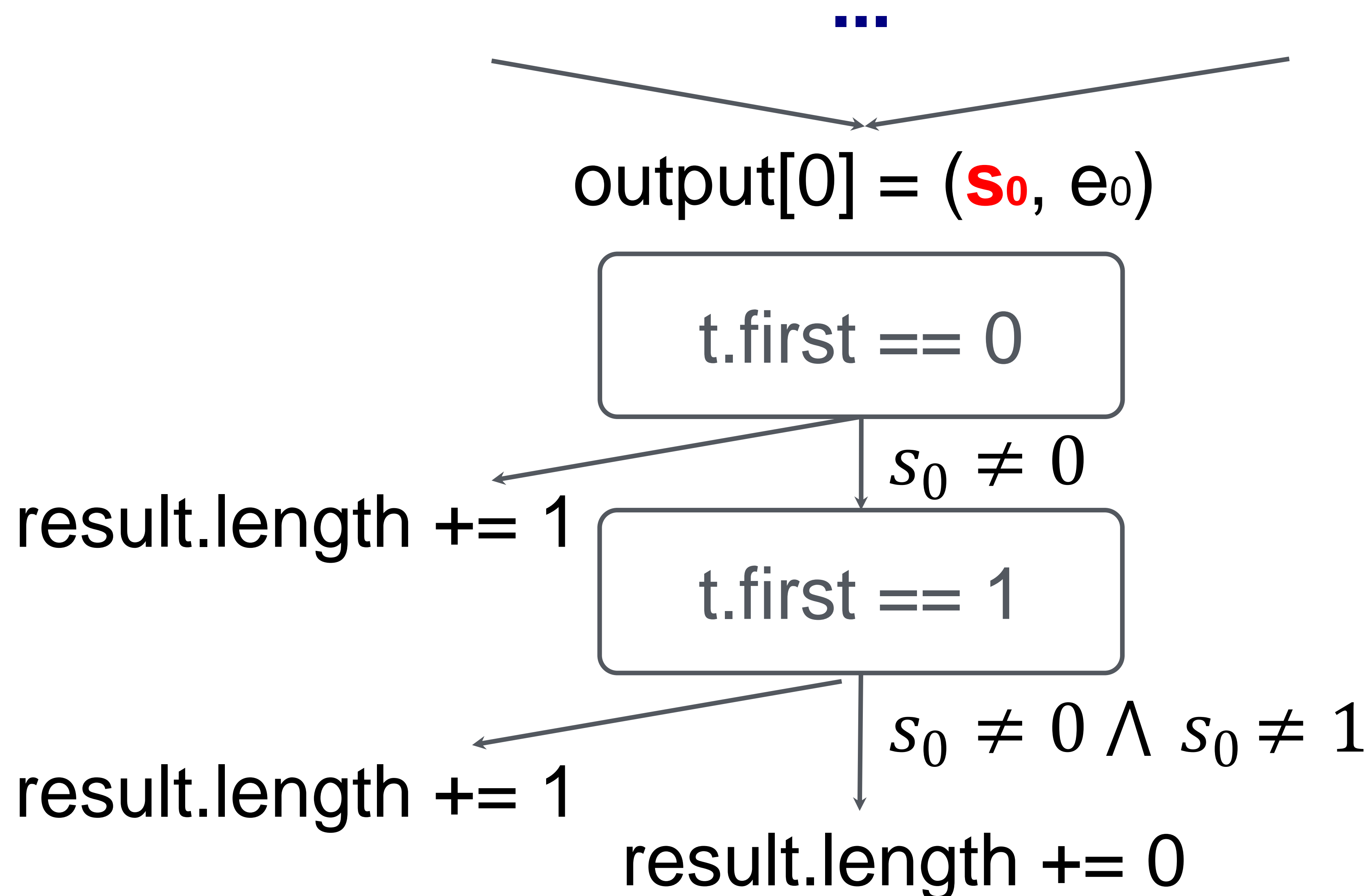


```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((★, e));
        } else {
            output.append((★, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
→       if (t.first == 1)
→           result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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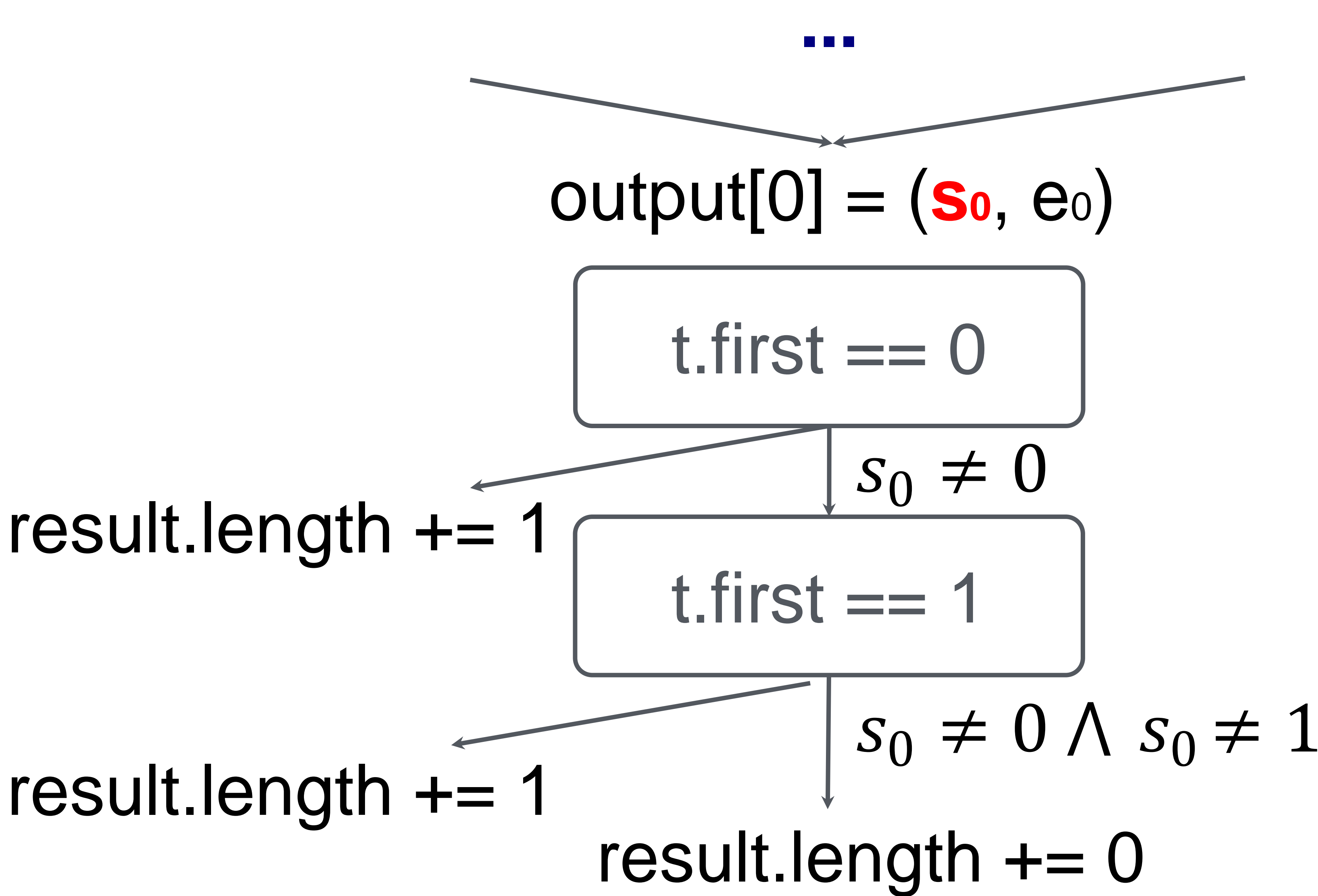


```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((★, e));
        } else {
            output.append((★, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
→   ObliCheck.Write(MEM_ADDR, result);
}
```

ObliCheck reports the algorithm is **not oblivious**

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Optimistic State Merging Incurs False Positives

How should we carefully select variables to merge which do not affect the verification result?

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((⋆, e));
        } else {
            output.append((⋆, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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Optimistic State Merging Incurs False Positives

How should we carefully select variables to merge which do not affect the verification result?

Solution

Conversely, merge every variable and iteratively un-merge relevant one affecting the verification result

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((★, e));
        } else {
            output.append((★, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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Iteratively Un-Merging State Based on the Verification Result

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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1st iteration:

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((⋆, e));
        } else {
            output.append((⋆, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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1st iteration:

Save the mapping from symbolic variables (s_0) → to their location of introduction →

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((⋆, e));
        } else {
            output.append((⋆, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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2nd iteration:

Do not merge states at the saved operations ✓
(s_0 was included in the verification condition)
✓

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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...

output[0] = (1, e_0) or (0, e_0)
output.length = 1

→

2nd iteration:

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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...

output[0] = (1, e_0) or (0, e_0)
output.length = 1

t.first == 0

result.length += 1

2nd iteration:

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ...
    for (t in output) {
→       if (t.first == 0)
→           result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```


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2nd iteration:

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
→       if (t.first == 1)
→           result.append(func1(t.second));
    }
    ObliCheck.Write(MEM_ADDR, result);
}
```

...

output[0] = (1, e_0) or (0, e_0)
output.length = 1

t.first == 0

result.length += 1

t.first == 1

result.length += 1

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2nd iteration:

```
function Filter() {
    ...
    for (e in privateRecords) {
        if (e < VALUE) {
            output.append((1, e));
        } else {
            output.append((0, e));
        }
    }
    ...
    for (t in output) {
        if (t.first == 0)
            result.append(func0(t.second));
        if (t.first == 1)
            result.append(func1(t.second));
    }
→   ObliCheck.Write(MEM_ADDR, result);
}
```

...

output[0] = (1, e_0) or (0, e_0)
output.length = 1

t.first == 0

result.length += 1

t.first == 1

result.length += 1

ObliCheck reports the algorithm is **oblivious**

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Benefit and Cost of Iterative Refinement

Benefit
Achieves better accuracy by only unmerging relevant states
Cost
Extra program runs are added, hence increases the program analysis time

Cost in reality
Turns out the extra cost is tolerable because
(1) Our target programs are intended to be oblivious, extra # of iteration is small
(2) The first iterations are executed quickly, since most paths are merged

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Evaluation

Benchmark Programs

Filter: Oblivious SQL operation devised in Opaque [Zheng et al., USENIX NSDI 2017]

Tag & Apply: Tag a bit to data records and apply corresponding function (Our second oblivious program example)

MapReduce: Oblivious MapReduce [Ohrimenko et al., ACM CCS 2015]

DecisionTree: Oblivious inference on a trained decision tree [Ohrimenko et al., USENIX Security 2015]

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Does ObliCheck Correctly Judge the Obliviousness?

○: Oblivious ×: Non-oblivious : Correct : Wrong

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ObliCheck Correctly Classifies Oblivious Programs

○: Oblivious ×: Non-oblivious [green]: Correct [red]: Wrong

	Oblivious?	Taint Analysis	ObliCheck
Filter	○ (Correct)	× (Wrong)	○ (Correct)
Tag & Apply	○ (Correct)	× (Wrong)	○ (Correct)
MapReduce	× (Correct)	× (Correct)	× (Correct)
Decision Tree	○ (Correct)	× (Wrong)	○ (Correct)

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ObliCheck Perform Better Than Symbolic Execution

	Symbolic Execution Time (s)	ObliCheck Time (s)	Speed Up (×)
Filter	14970.5	0.4	35900.4
Tag & Apply	5148.2	0.3	11167.4
MapReduce	8154.9	9.7	212.8
Decision Tree	9305.5	0.2	50300.0

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Conclusion

- Oblivious algorithms use unobservable space to optimize the performance, which complicates the verification process
- ObliCheck distinguishes unobservable state to optimize the verification of such algorithms
- ObliCheck merges and iteratively unmerges state based on domain specific knowledge to check oblivious program efficiently and accurately

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