NOKIA Bell Labs

Plugging Information Leaks Introduced by Compiler Transformations

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“To talk of many things…”

1. **Leaky Transformations**
   Dead store elimination (DSE), SSA conversion

2. **Translation Validation for Leak-Freedom?**
   With compiler-generated witnesses

3. **Plugging Leaks**
   Designing leak-free forms of DSE and SSA

4. **(Many) (Open?) Questions**
   Mostly exposing my ignorance of this topic ☺

“Leak this against my wishes.”

[New Yorker, 2003]

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Leaky Transformations
Example: Dead Store Elimination (DSE)

```
x := password();
check(x);
x := 0; // clear secret
  .
  .
  .
```


```
x := password();
check(x);
skip;
  .
  .
  .
```


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Leaky Transformations

Example: Static Single Assignment (SSA) and Live Range Splitting

```
x := password();
check(x);
x := 0; // clear secret
  .
  .
  .
```


```
x1 := password();
check(x1);
x2 := 0;
  .
  .
  .
```


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When is a Transformation Leaky?

Leaky Program

A deterministic program P with secret input H and non-secret input L

P is **leaky** if there are input values (H=a, L=c) and (H=b, L=c) such that on the corresponding executions, either

1. the sequence of output values differ, or
2. both executions terminate but in states with different non-secret values

We'll call (H=a, H=b, L=c) a **leaky triple** for P.

Leaky Transformation

A transformation from program P to program Q (with input variables unchanged) is **leak-free** if every leaky triple for Q is also a leaky triple for P.

The DSE transform is leaky as the triple (pwd=0, pwd=1, -) is leaky for Q but not for P.

Leak-freedom **does not** assert that P (or Q) have no leaks – only that no *new* leaks are introduced by the transformation.

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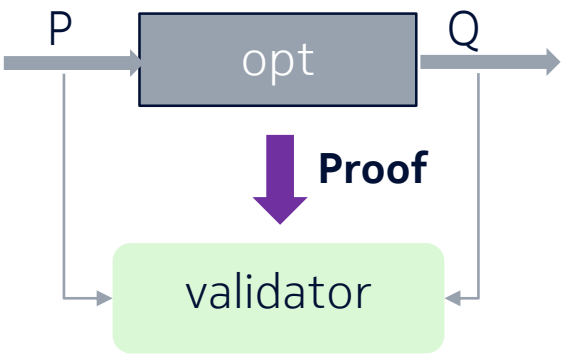
Aside: Translation Validation with Proof Witnesses



With proof witnesses, validation amounts to proof checking.

Theorem: If the proof object R is a refinement relation from Q to P, the transformation is correct.

Questions: Could one similarly validate leak-freedom?
What is the corresponding proof object?

"Credible Compilation"
[Rinard-Marinov, 1999]

"Witnessing" [N.-Zuck, 2013]

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Translation Validation is Undecidable for Leak-Freedom
(even restricted to DSE)

```
x := password();
check(x);
M;
x := 0;
```


```
x := password();
check(x);
M;
skip;
```

- If M terminates, this transformation is leaky
- If M does not terminate, the transformation is leak-free

Note: validating correctness is easy for DSE

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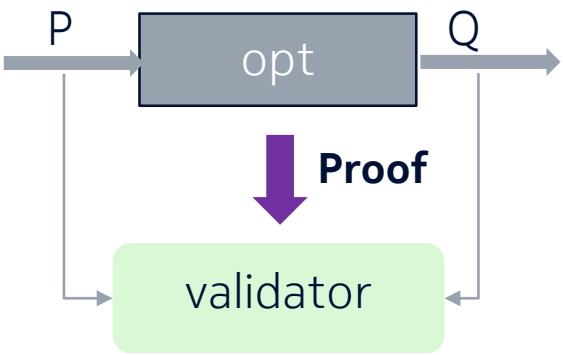
Refinement Witnesses Ensuring Leak-Freedom



Theorem: Given a proof object R, if

- R is a refinement, and
- R(t,s) and R(t',s') implies that $t \sim_Q t'$ iff $s \sim_P s'$,

then the transformation is leak-free.

$t \sim_P t'$ if t and t' are states of P with identical low values

[see also de Amorim et al, POPL 2014]

Several common optimizations meet this condition.

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A Leak-Free DSE Optimization

Idea: Combine taint and control-flow information to determine stores that can be removed

```
{x:U}
x := password();
{x:T}
check(x);
{x:T}
x := 0;
{x:U}
x := 5;
{x:U}
```


```
{x:U}
x := password();
{x:T}
check(x);
{x:T}
skip;
{x:T}
x := 5;
{x:U}
```

[Deng-N., SAS 2016]

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Heuristics, in a bit more detail…

Consider a dead store to variable x. It may be removed if:

1. This store is post-dominated by some other store to x

   Justification: any leak through x must arise from the dominating stores

2. Variable x is untainted before this store and untainted at the exit from the program

   Justification: the taint proof is unchanged, so a leak cannot arise from x; other flows are preserved

3. Variable x is untainted before this store, other stores to x are unreachable, and this store post-dominates the entry node

   Justification: the taint proof is unchanged, so a leak cannot arise from x; other flows are preserved

4. … *your heuristic here* …

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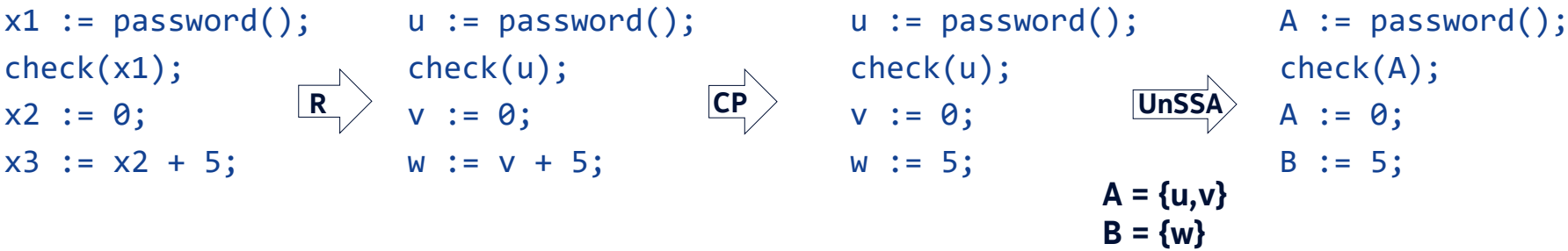
A Leak-Free SSA Conversion

Idea: regroup SSA variables, minimizing grouping using taint and control-flow information.

E.g., the group {`x1`,`x2`} is treated as a single fresh variable, say `z`.

Regrouping can be done only **after** completing all SSA-based transformations.
Track SSA-induced leaks using the refinement proofs generated by the transformations.



[Deng-N., SAS 2017]

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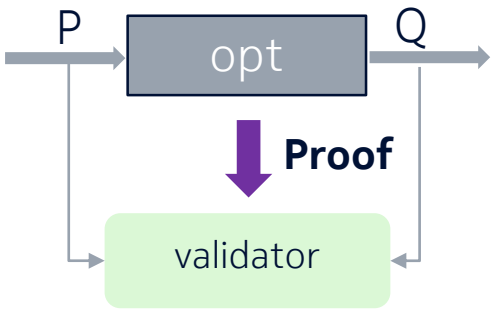
(Open?) Questions



- Proof methods that preserve a large class of security properties? (Back-translation? Simpler sufficient conditions?)
- Are these proof methods usable for translation validation?
- What is the witness format?
- What is the complexity of witness generation and checking?
- What is the analogue of (static) taint analysis for other security properties?

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