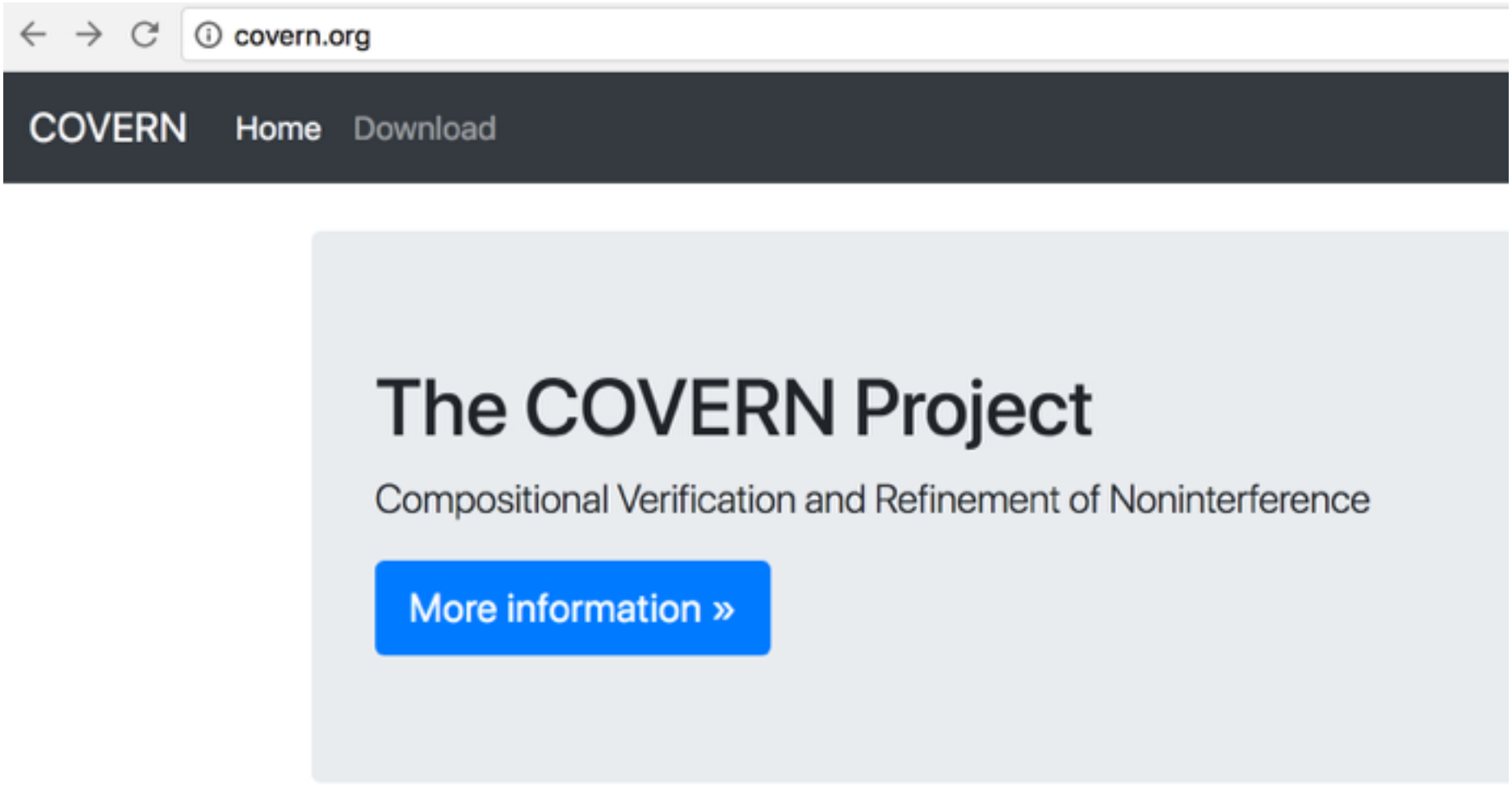
Verified Compilation of Noninterference for Shared-Memory Concurrent Programs

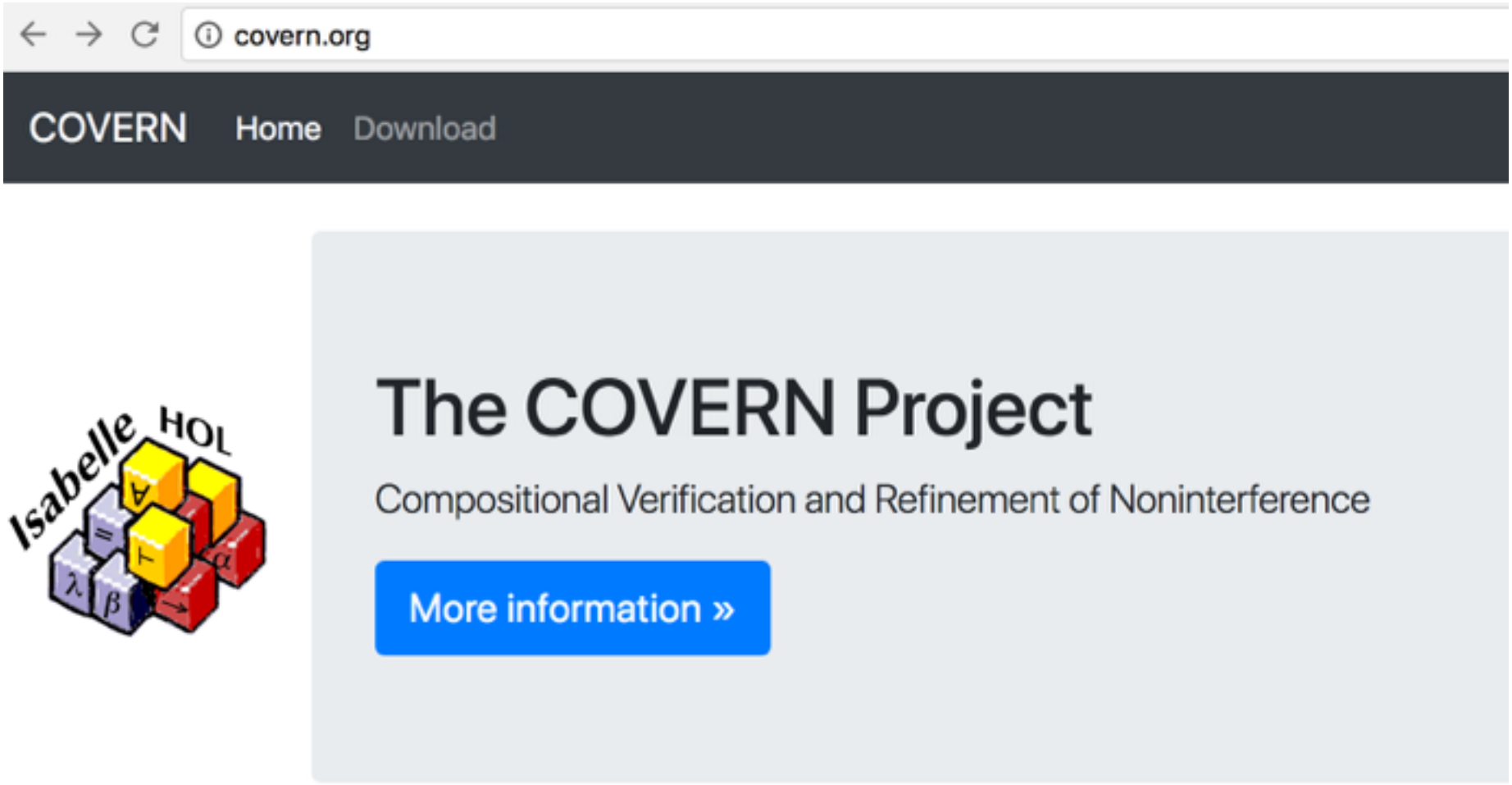
Toby Murray

University of Melbourne &
Data61 (formerly NICTA), CSIRO

http://covern.org



http://covern.org



Confidentiality (Information Flow) Proofs

Confidentiality (Information Flow) Proofs

Confidentiality (Information Flow) Proofs

CoCon

Confidentiality (Information Flow) Proofs

CoCon

CoSMed

Confidentiality (Information Flow) Proofs

CoCon

CoSMed

SAFE

Confidentiality (Information Flow) Proofs

CoCon

CoSMed

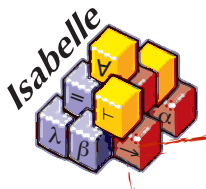
SAFE

Quark

Confidentiality (Information Flow) Proofs

CoCon

CoSMed



SEQUENTIAL

SAFE

Quark

The Cross Domain Desktop Compositor

Australian Government

Department of Defence

Defence Science and Technology Group

Mark Beaumont

CDDC

The Cross Domain Desktop Compositor

Australian Government
Department of Defence
Defence Science and Technology Group

DATA 61

CSIRO

Mark Beaumont

CDC

The Cross Domain Desktop Composit

Toby Murray

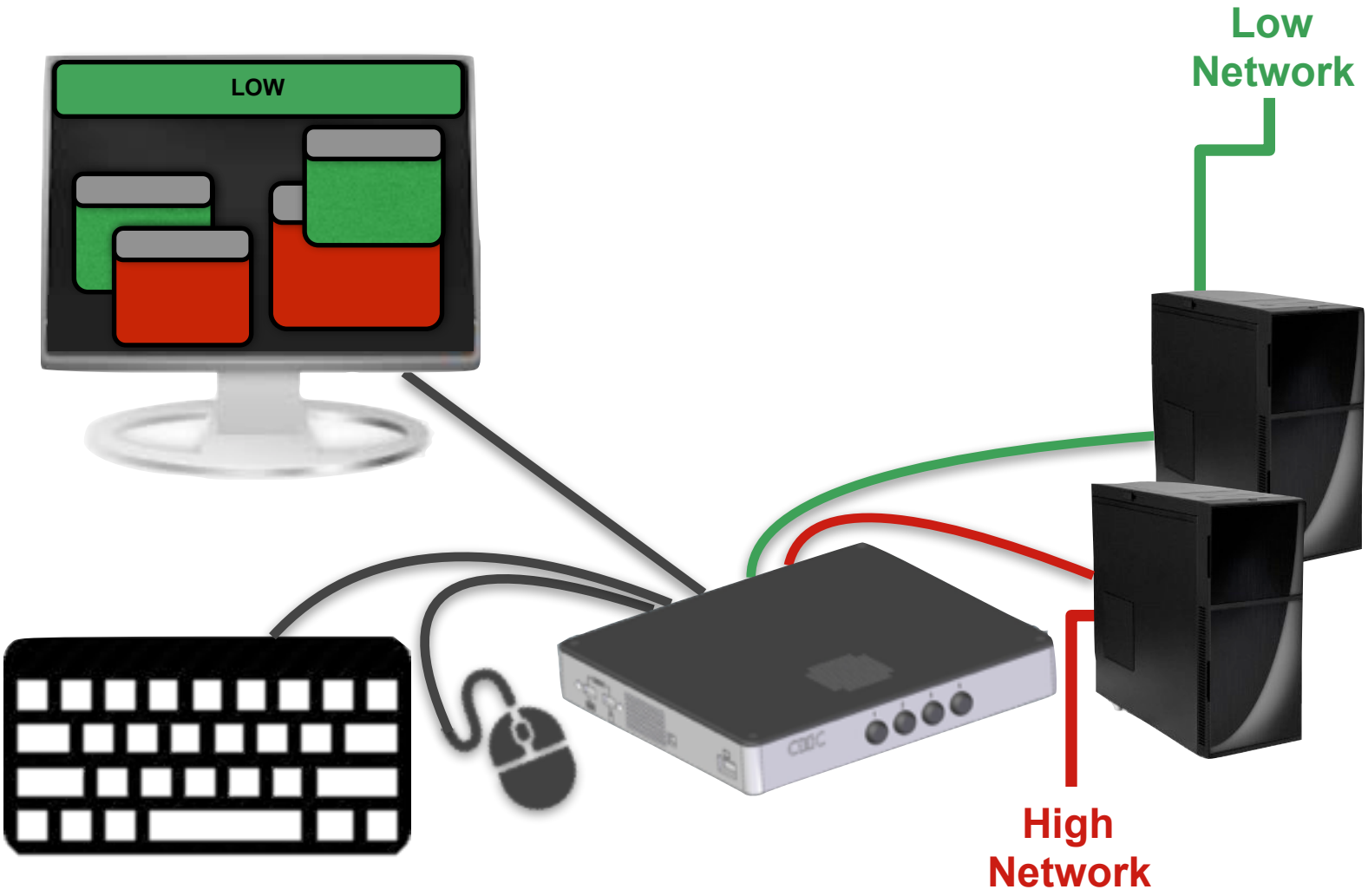
Kevin Elphinstone

Australian Government
Department of Defence
Defence Science and Technology Group

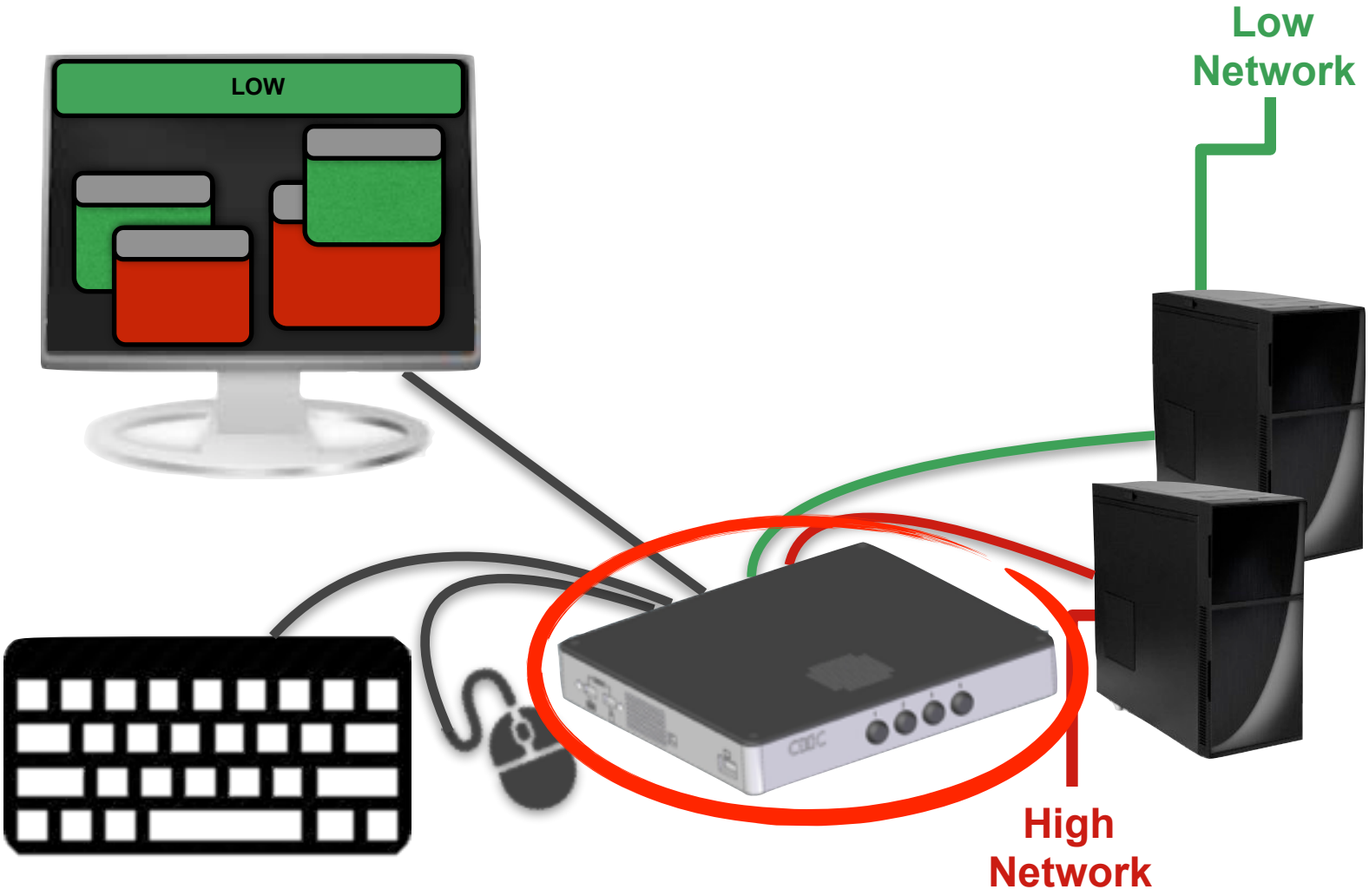
DATA 61

CSIRO

Cross Domain Desktop Compositor

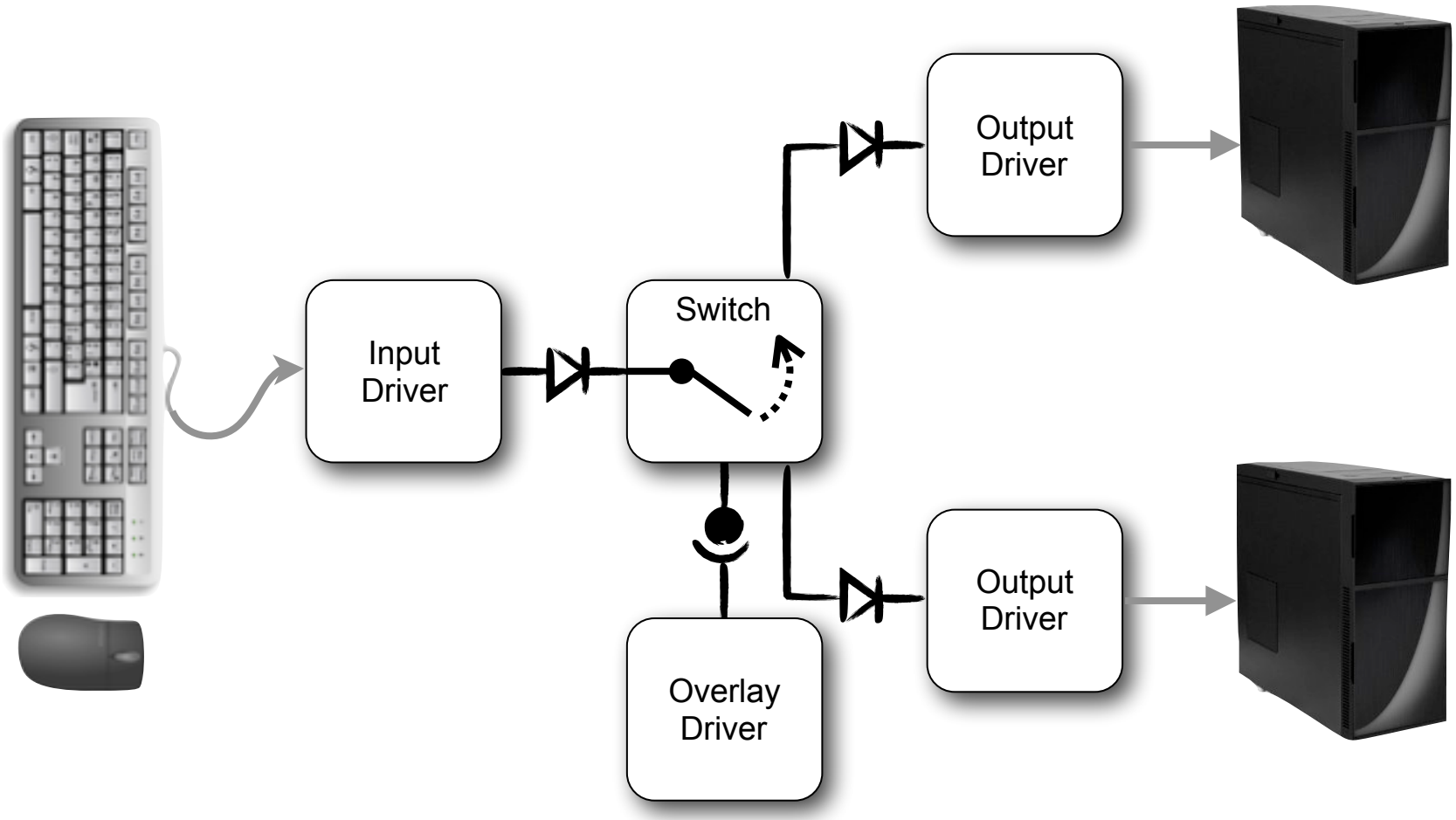


Cross Domain Desktop Compositor



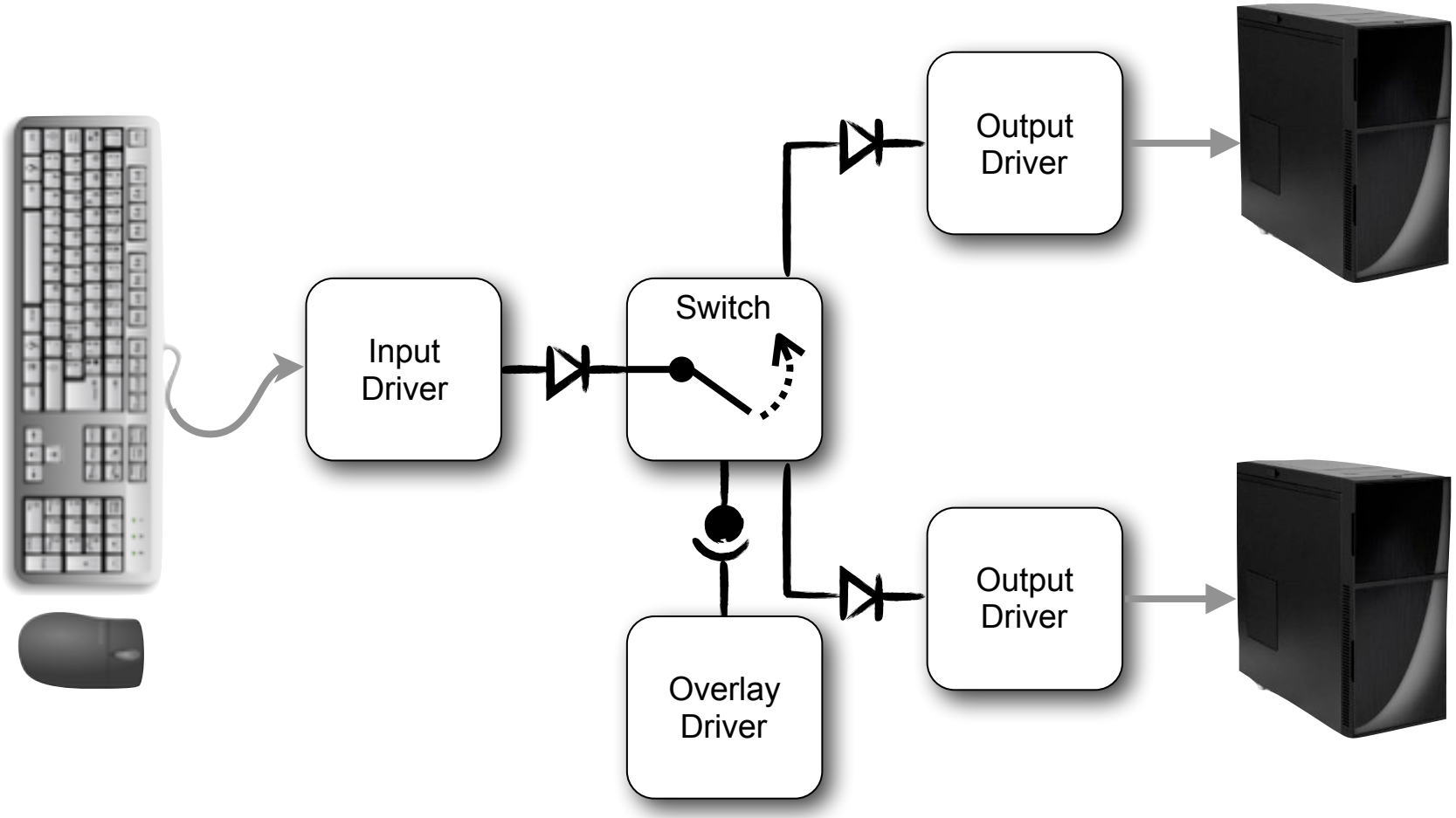
CDDC

seL4-Based Software Architecture



seL4-Based Software Architecture

(ignoring device administration and configuration, plus keyboard LED control)



Verification Framework: Requirements

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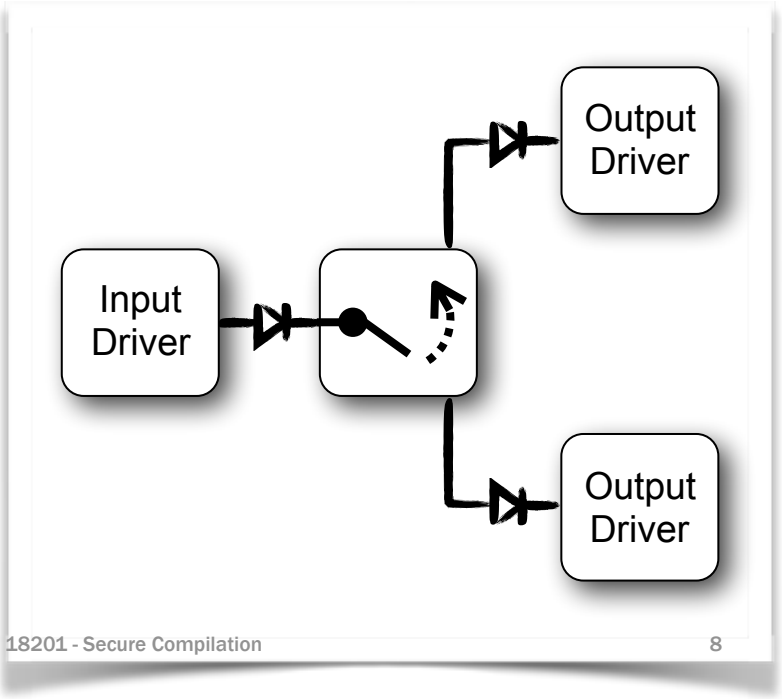
Compositional Security Property

Verification Framework: Requirements

Compositional Security Property



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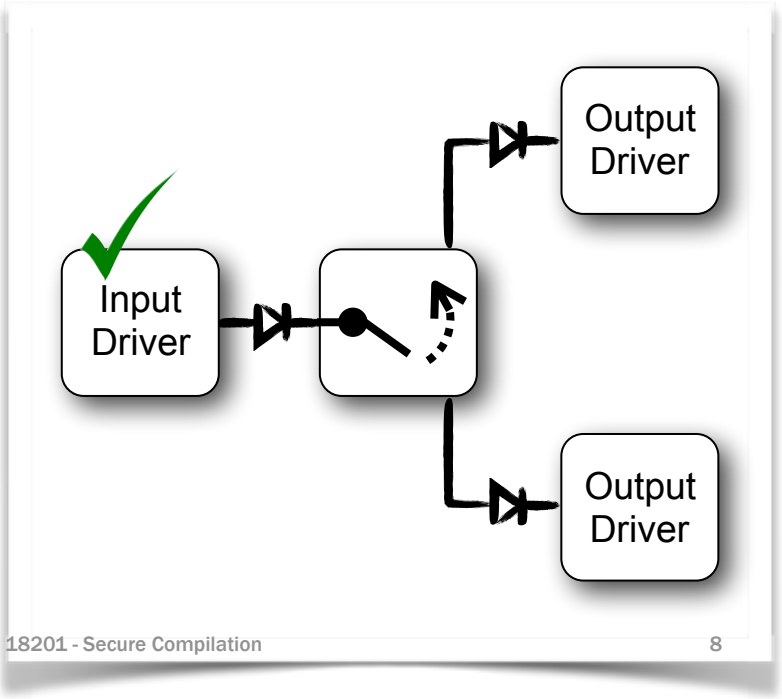

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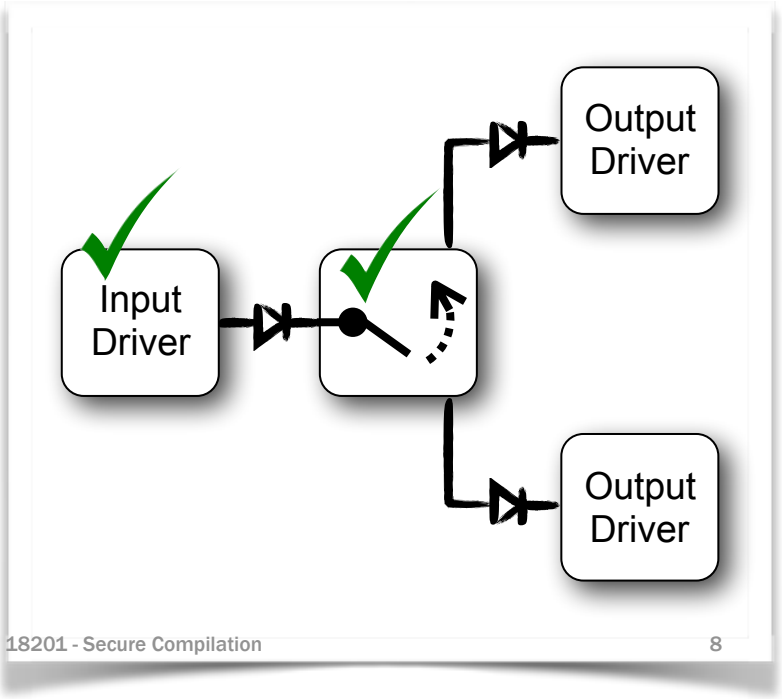

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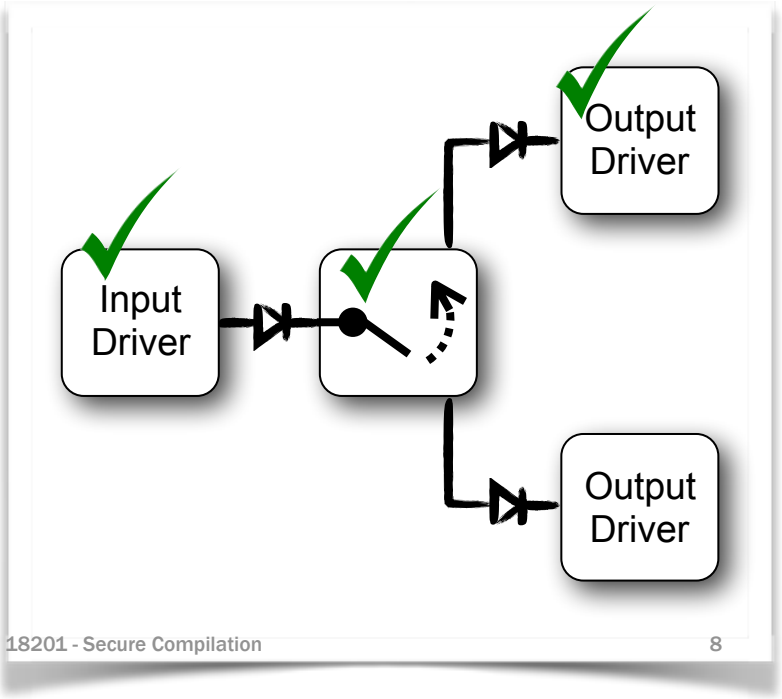

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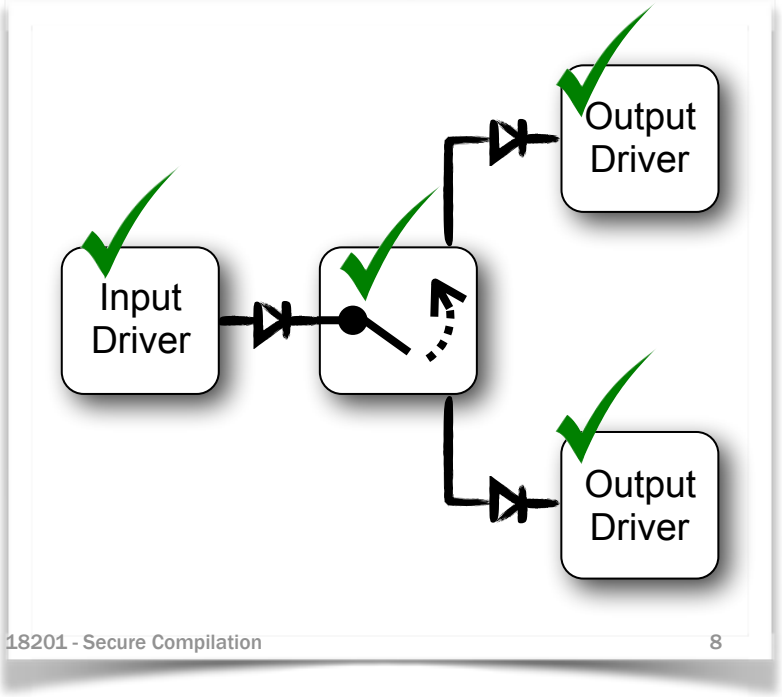

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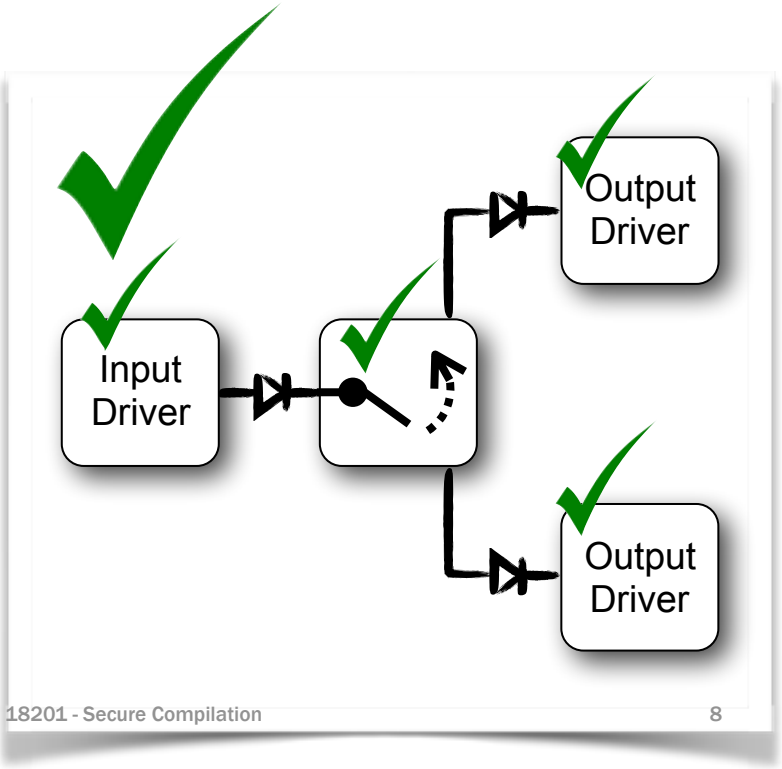

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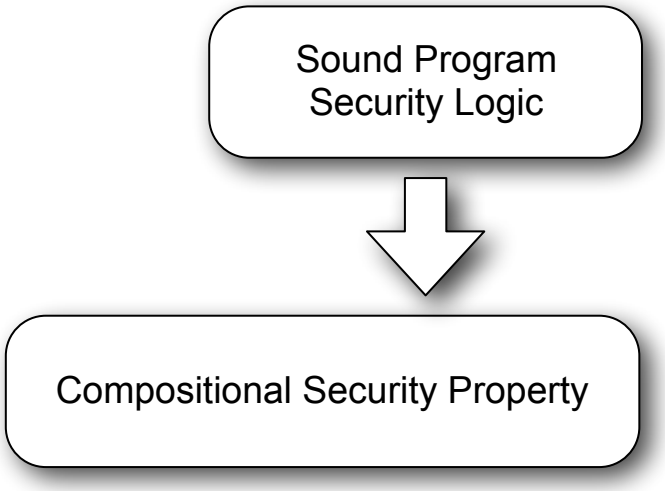

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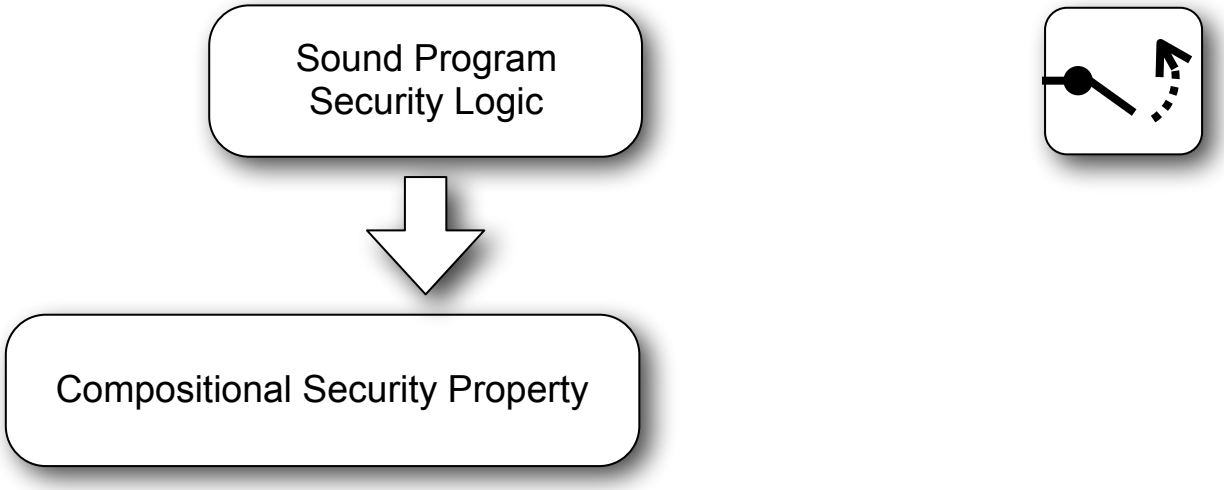

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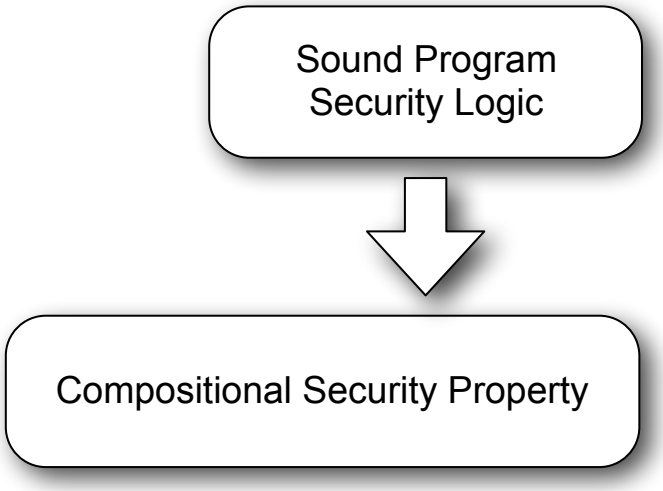
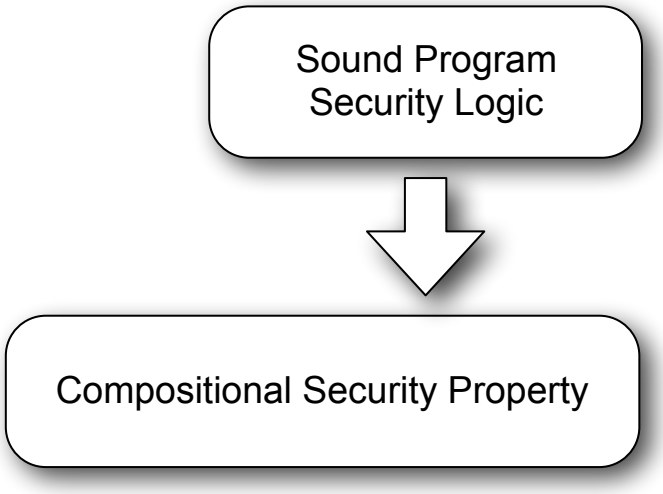



```
skip   /* control +=_m AsmNoW */;
skip   /* temp +=_m AsmNoRW */;
temp := buffer;
if control == 0 then
  low-var := temp
else
  high-var := temp
endif;
temp := 0;
skip   /* temp -=_m AsmNoRW */
```

Verification Framework: Requirements

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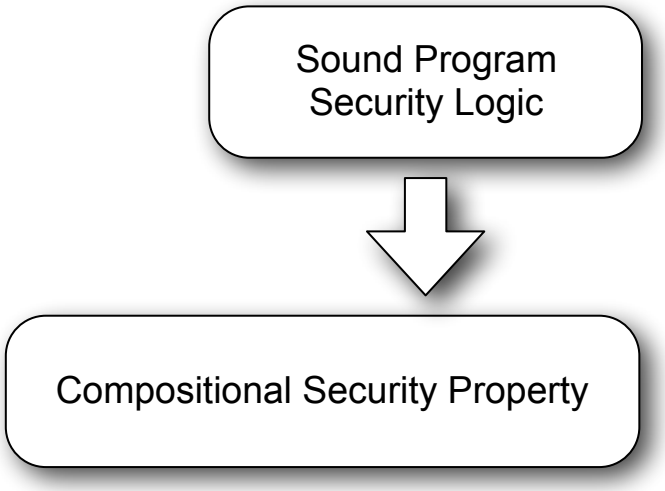

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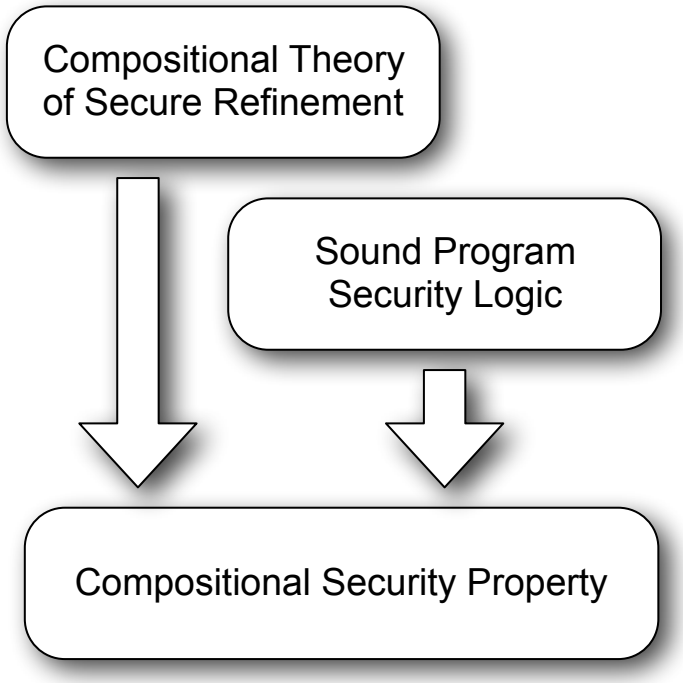

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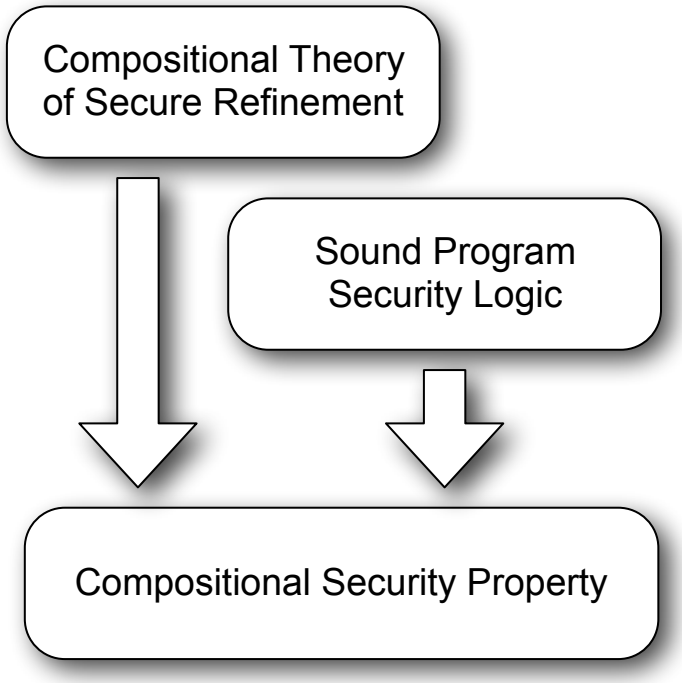

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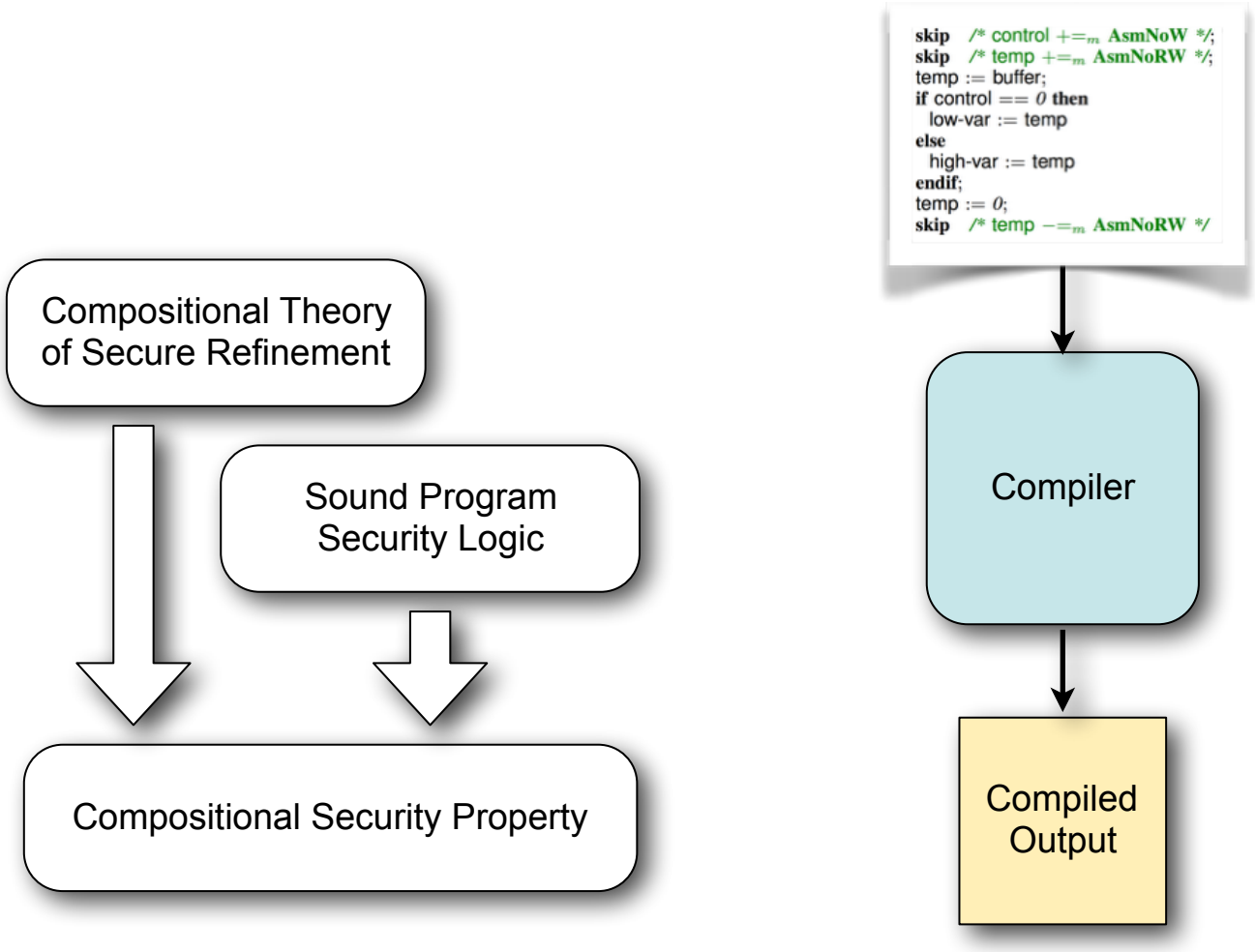

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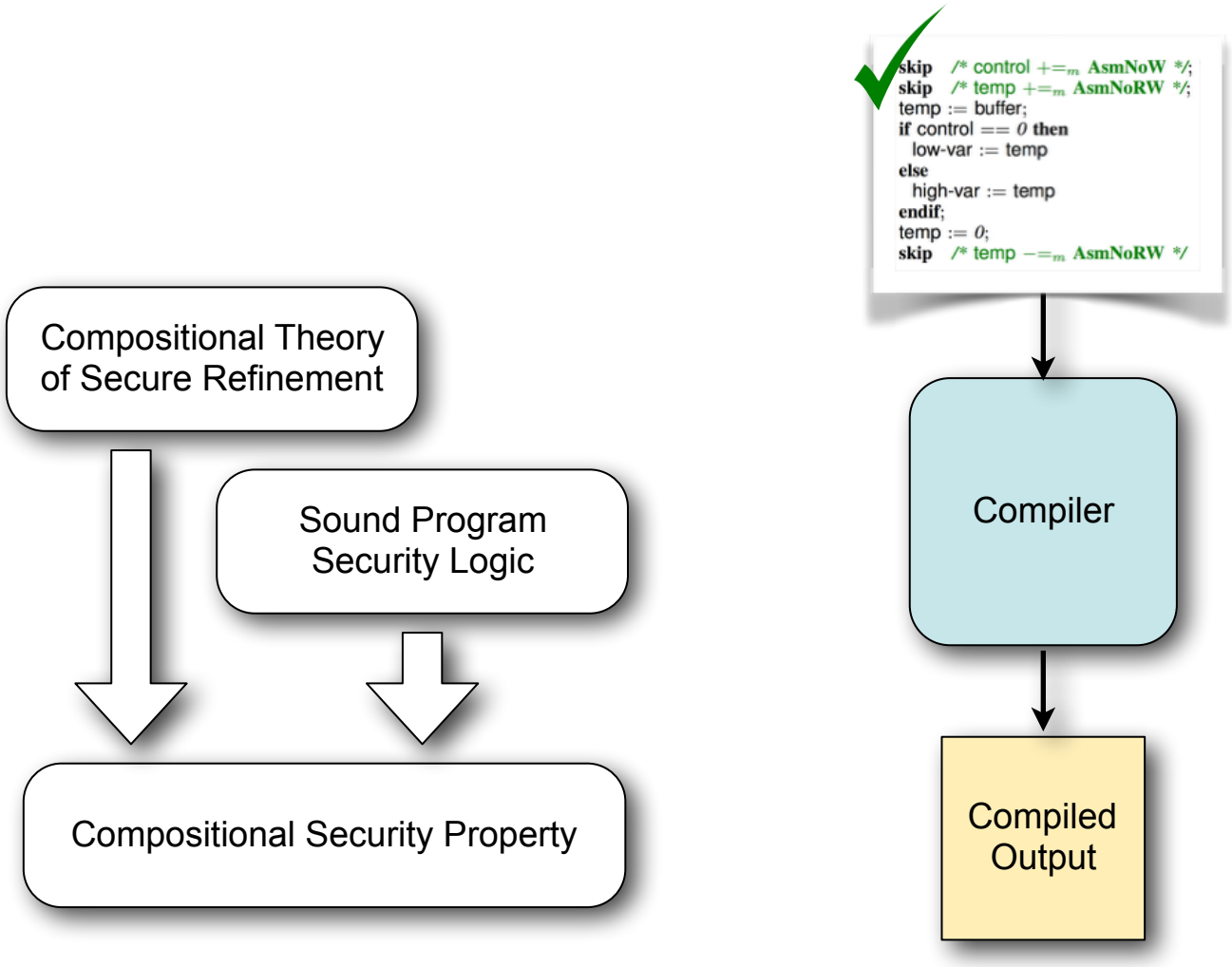

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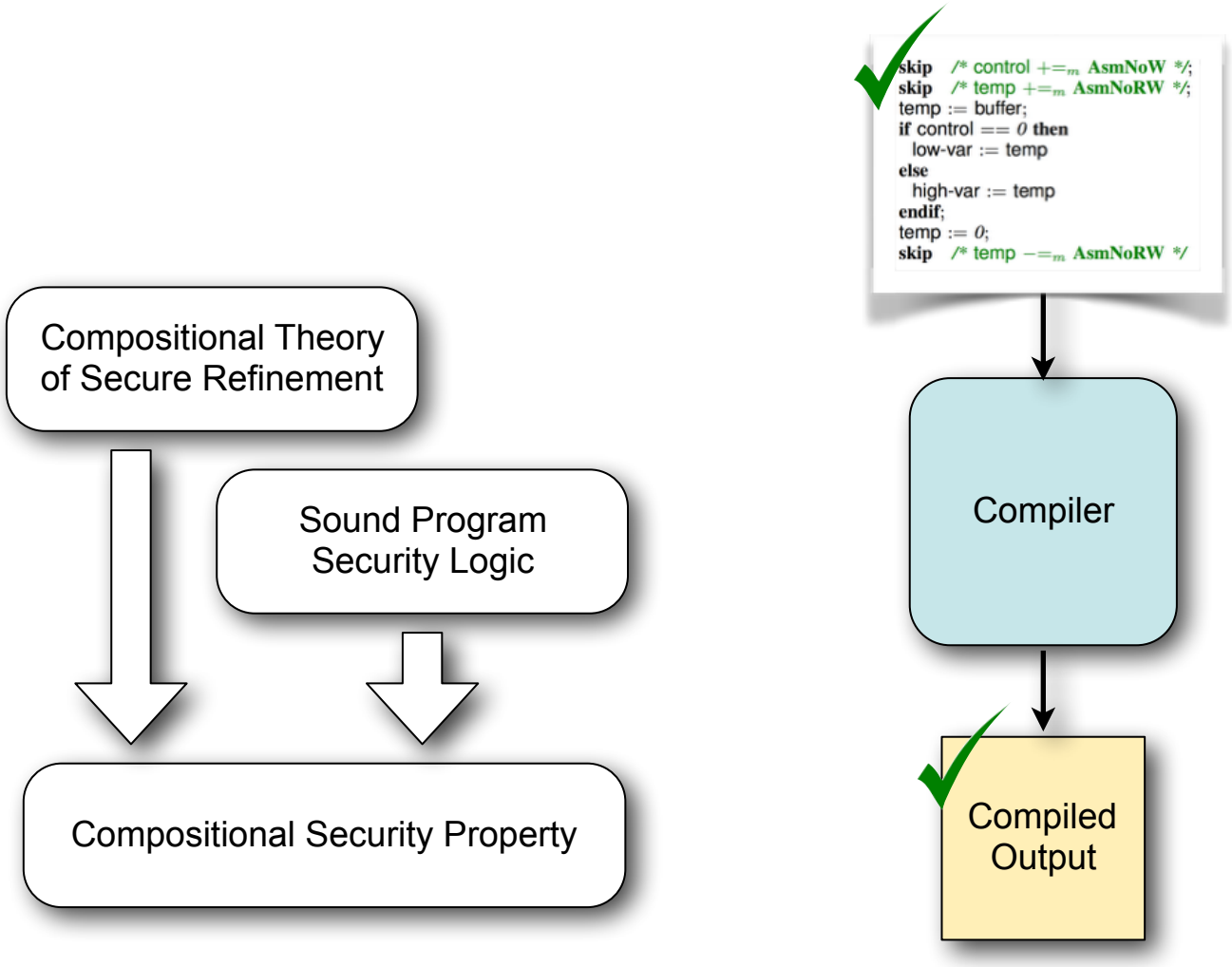

Verification Framework: Operation

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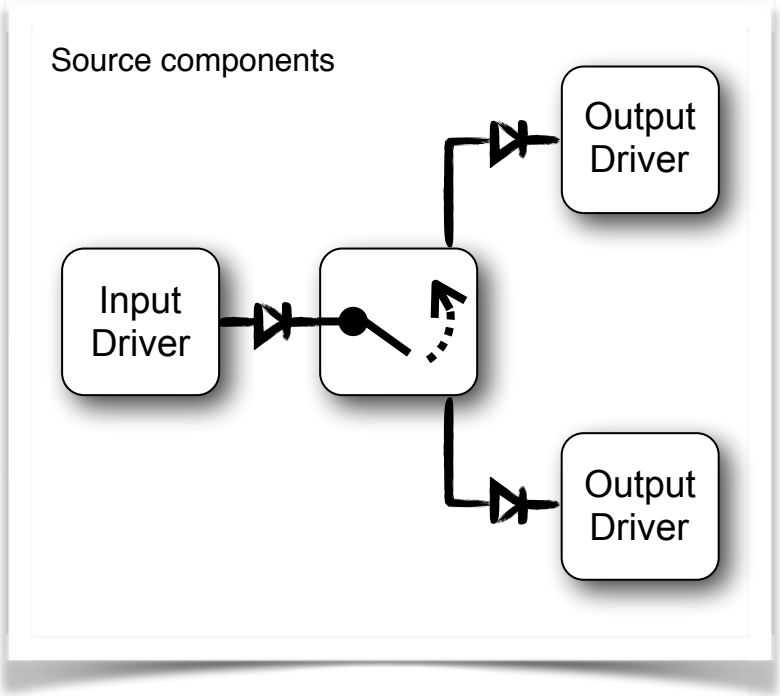

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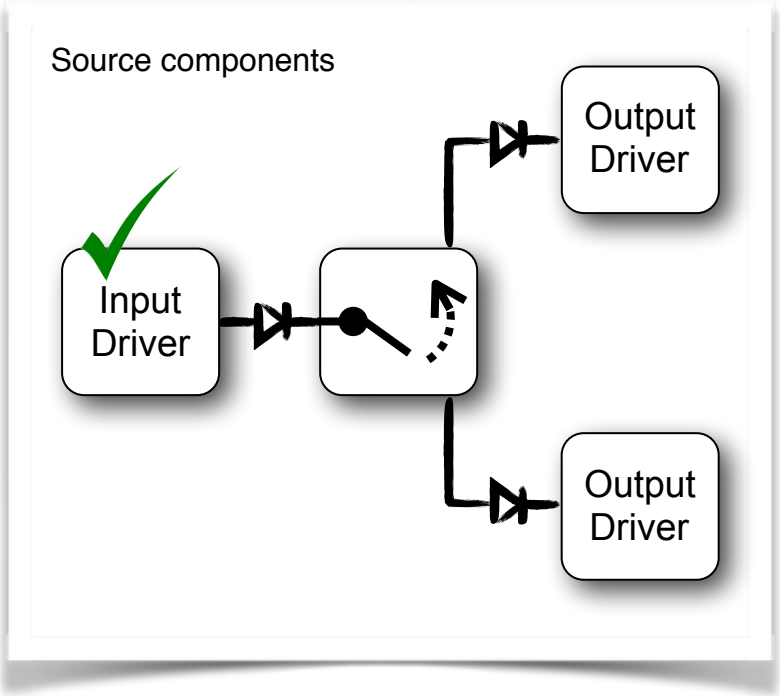

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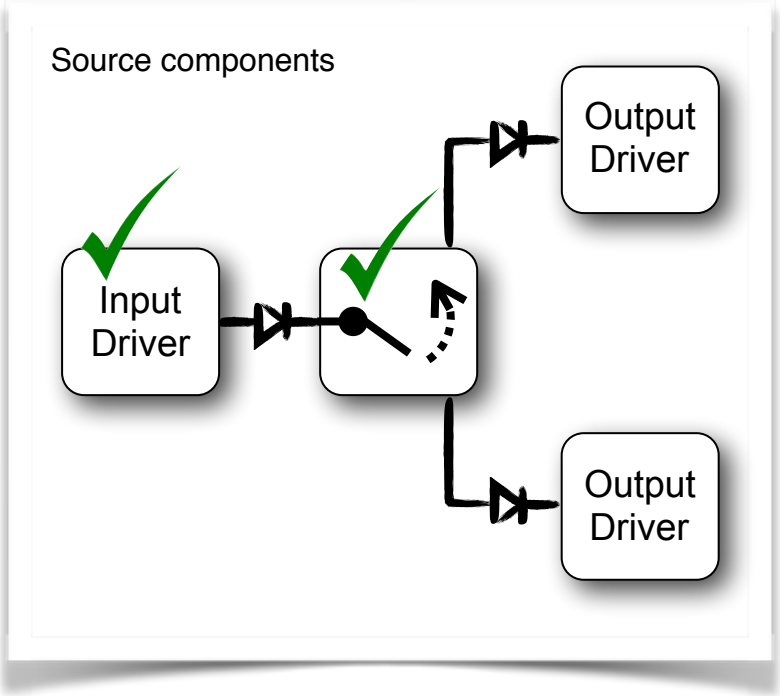

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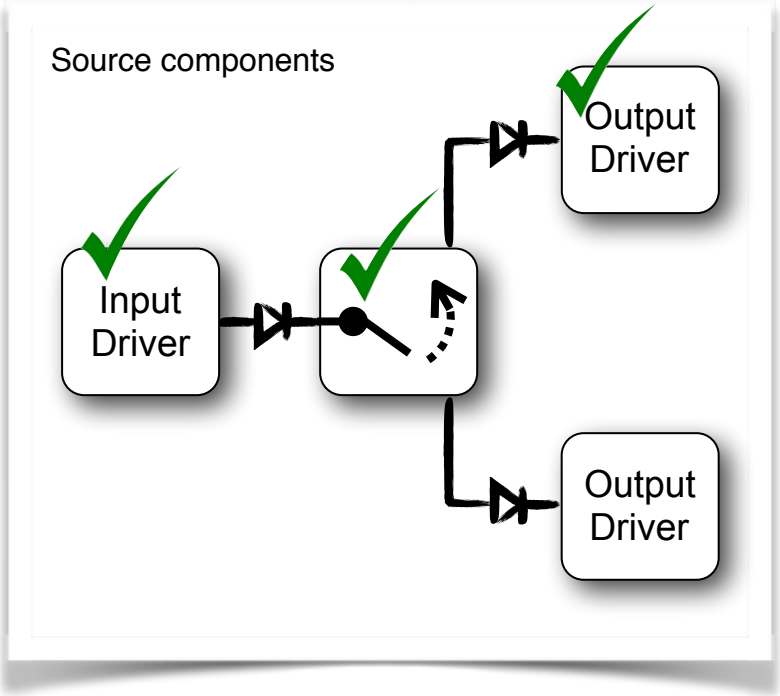

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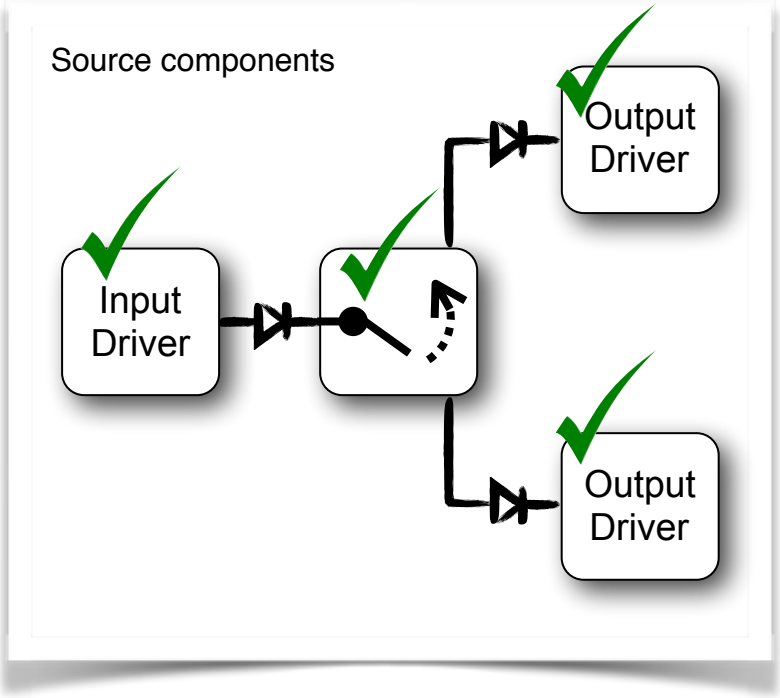

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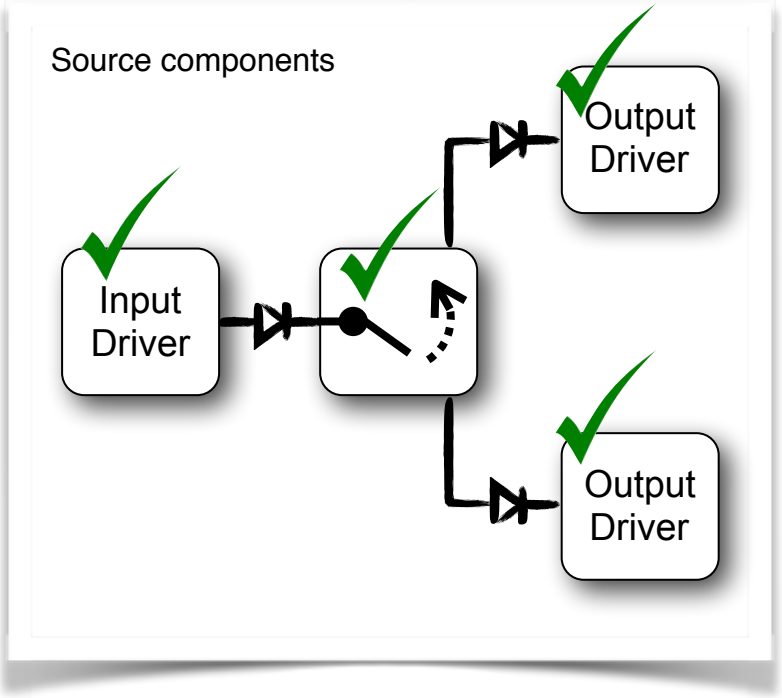

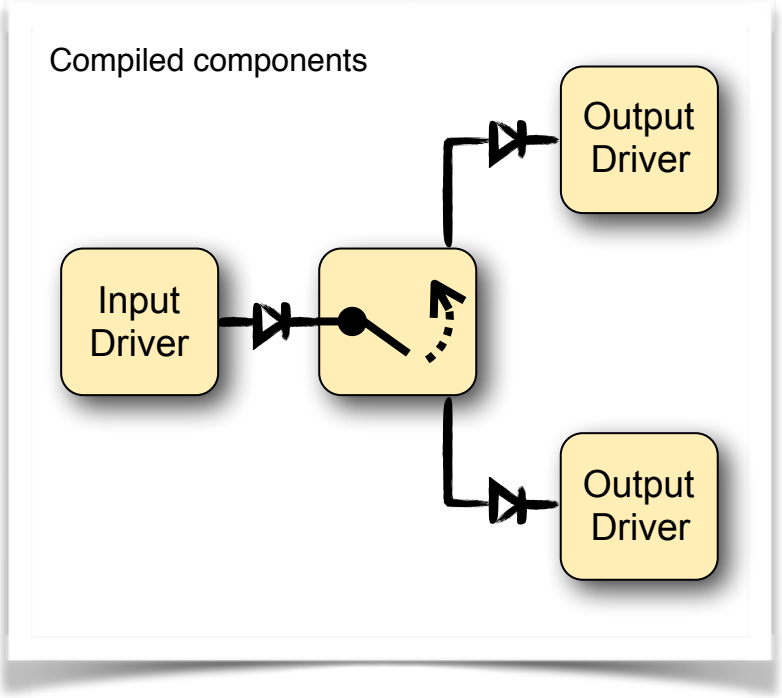

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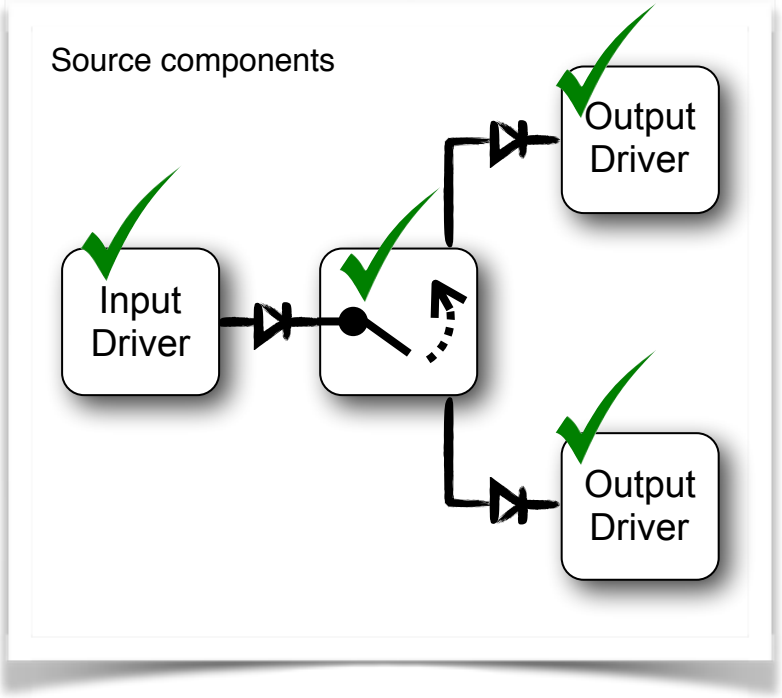

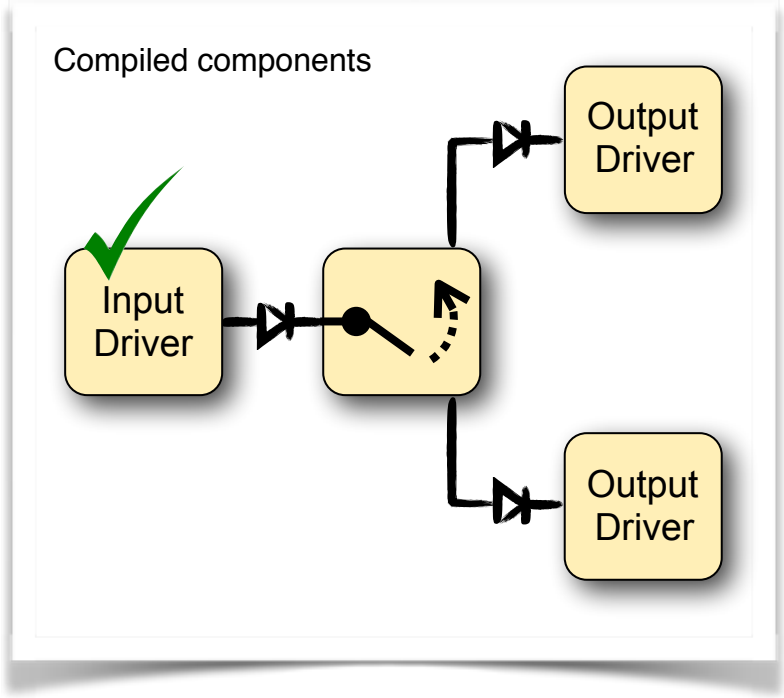

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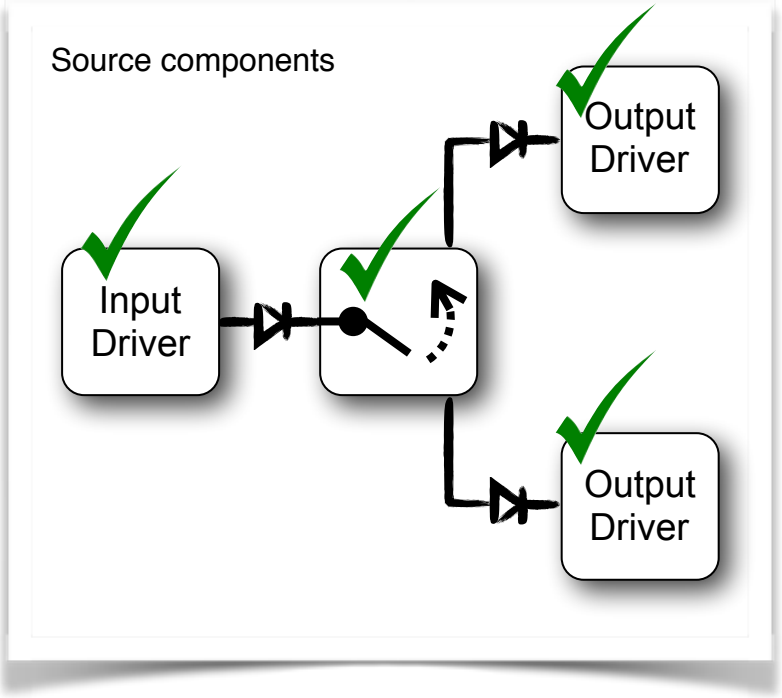

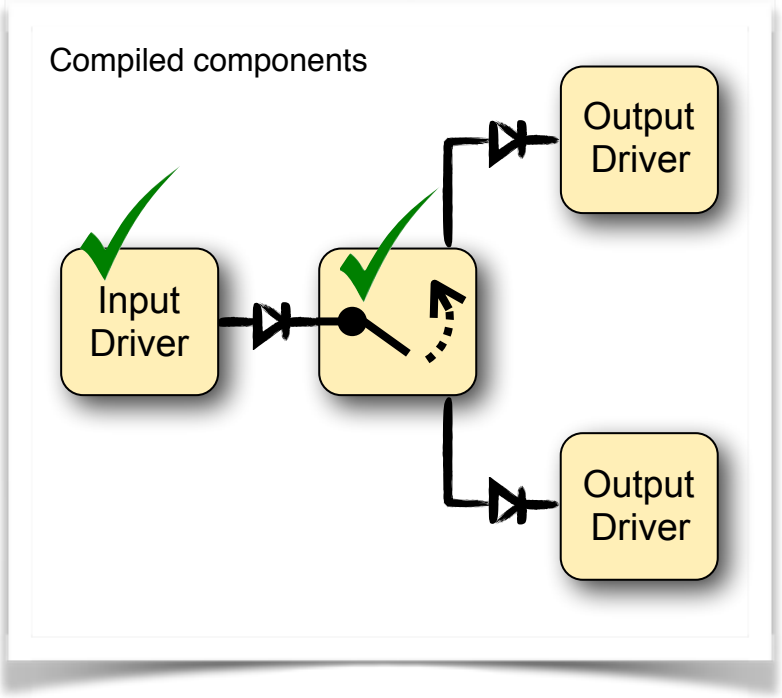

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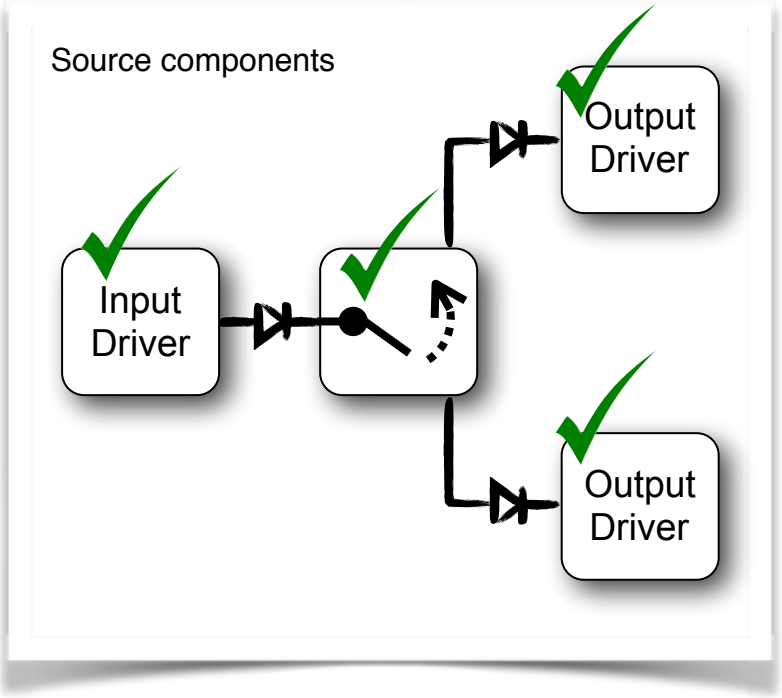

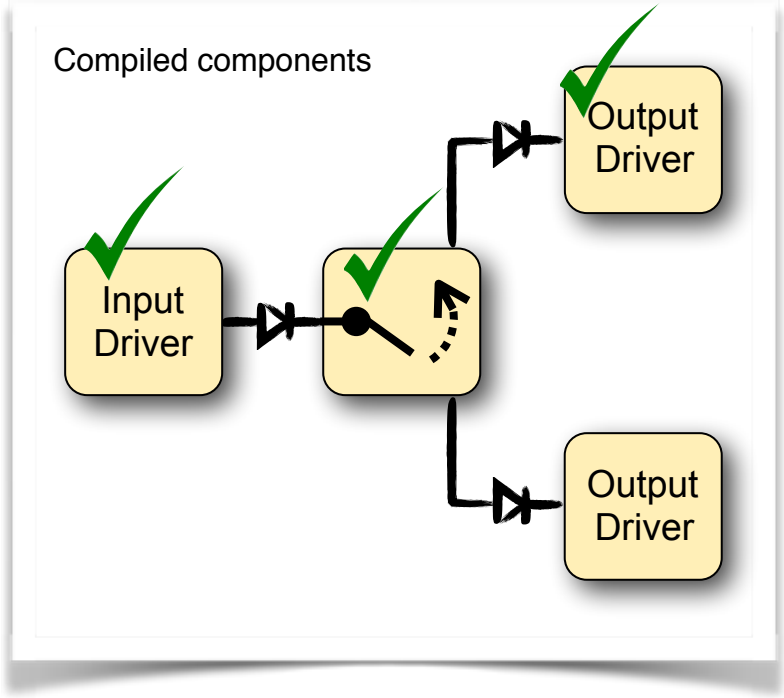

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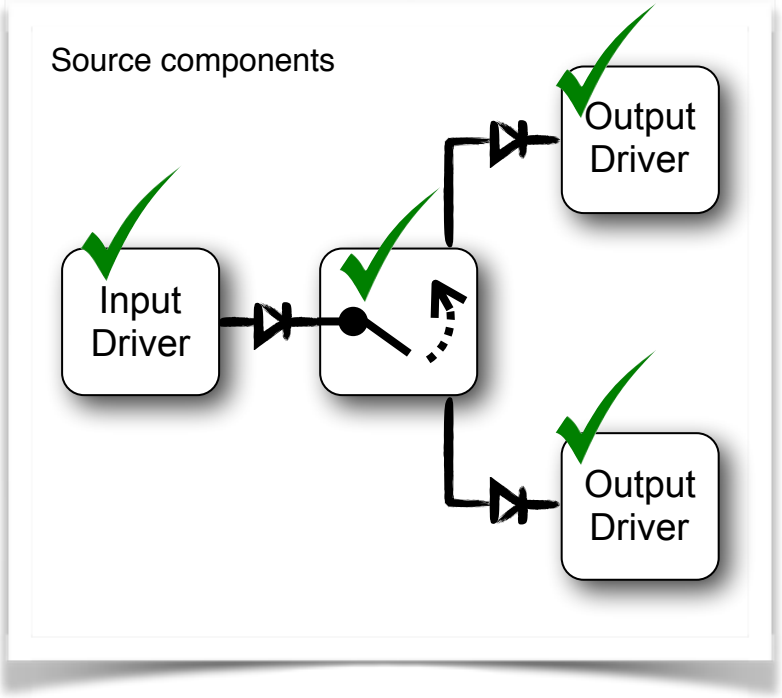

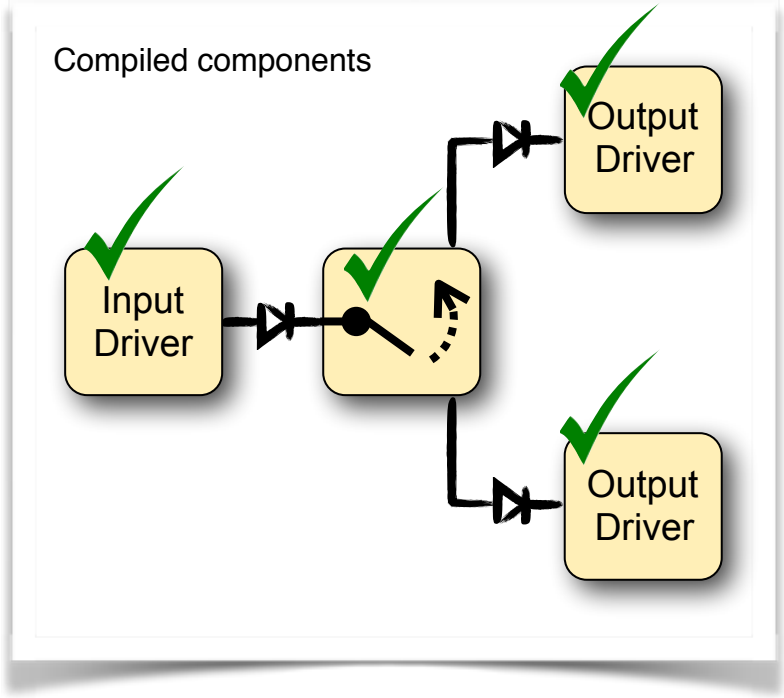

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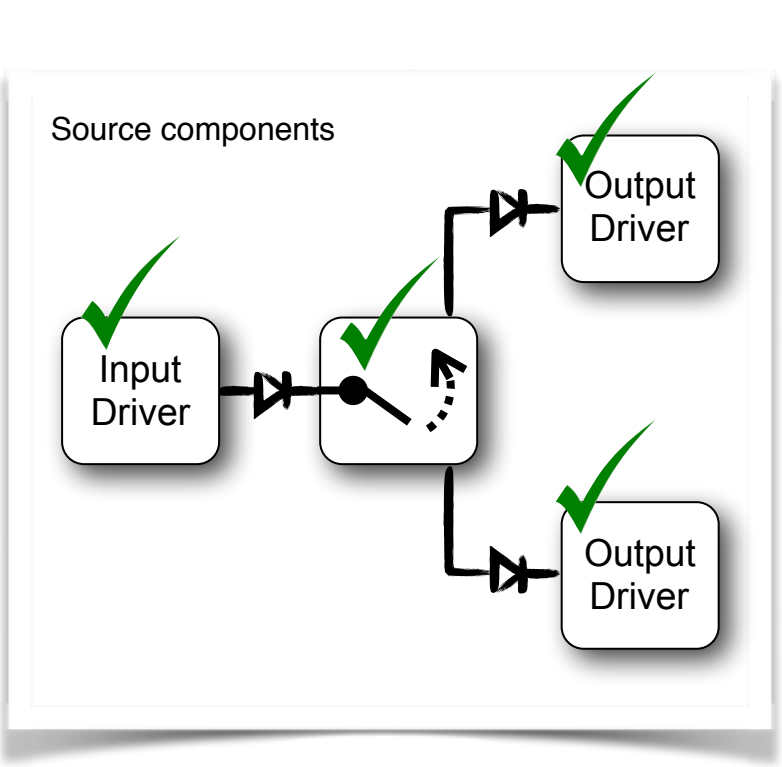

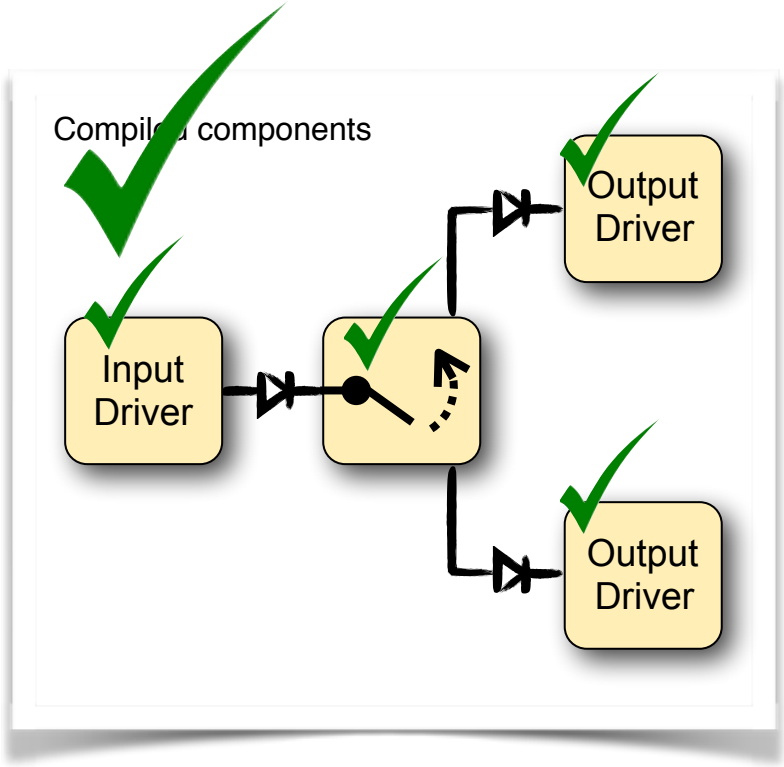

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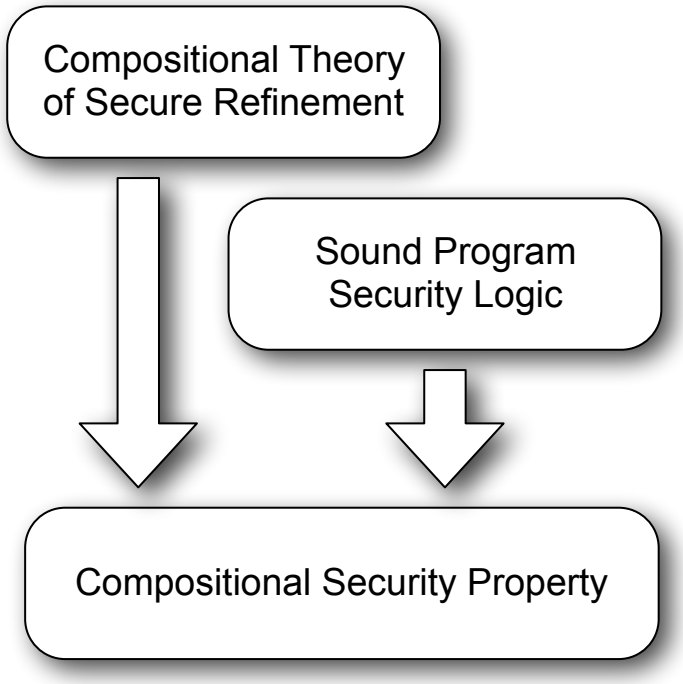

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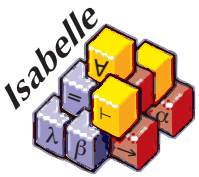
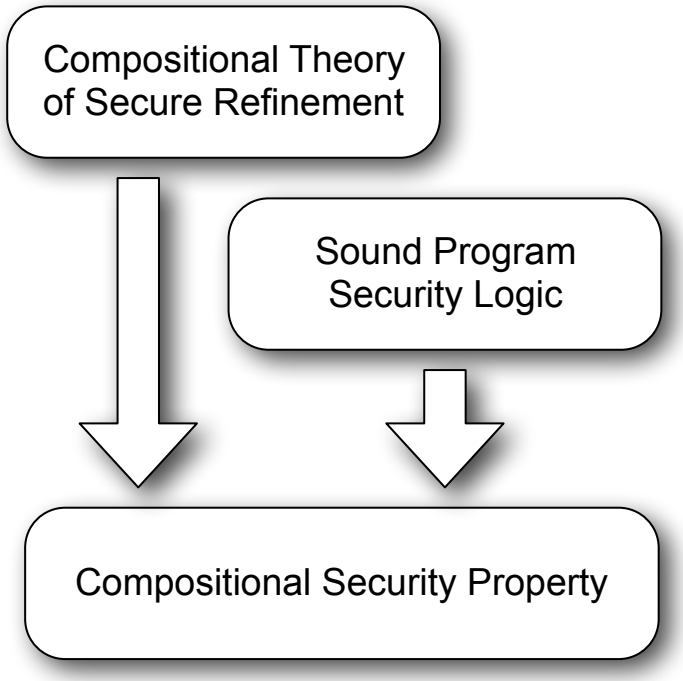
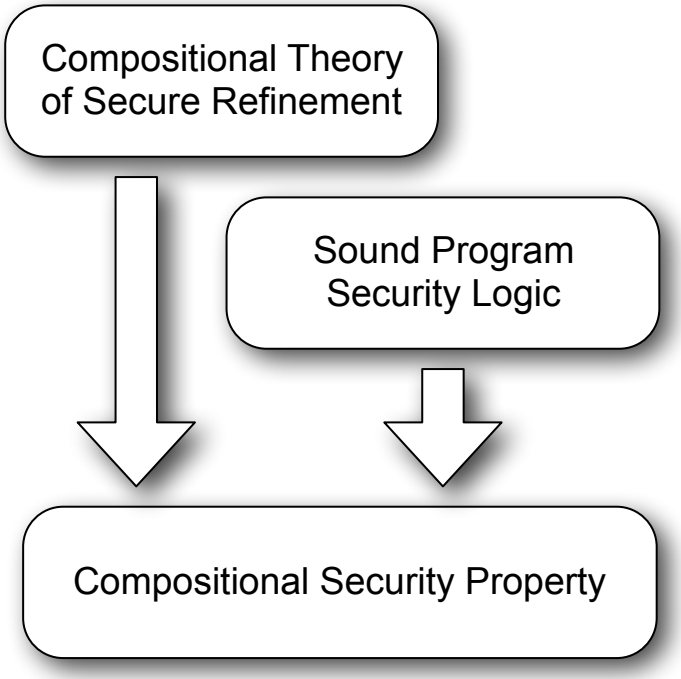




Verification Framework: Status

Earlier version appeared at CSF 2016



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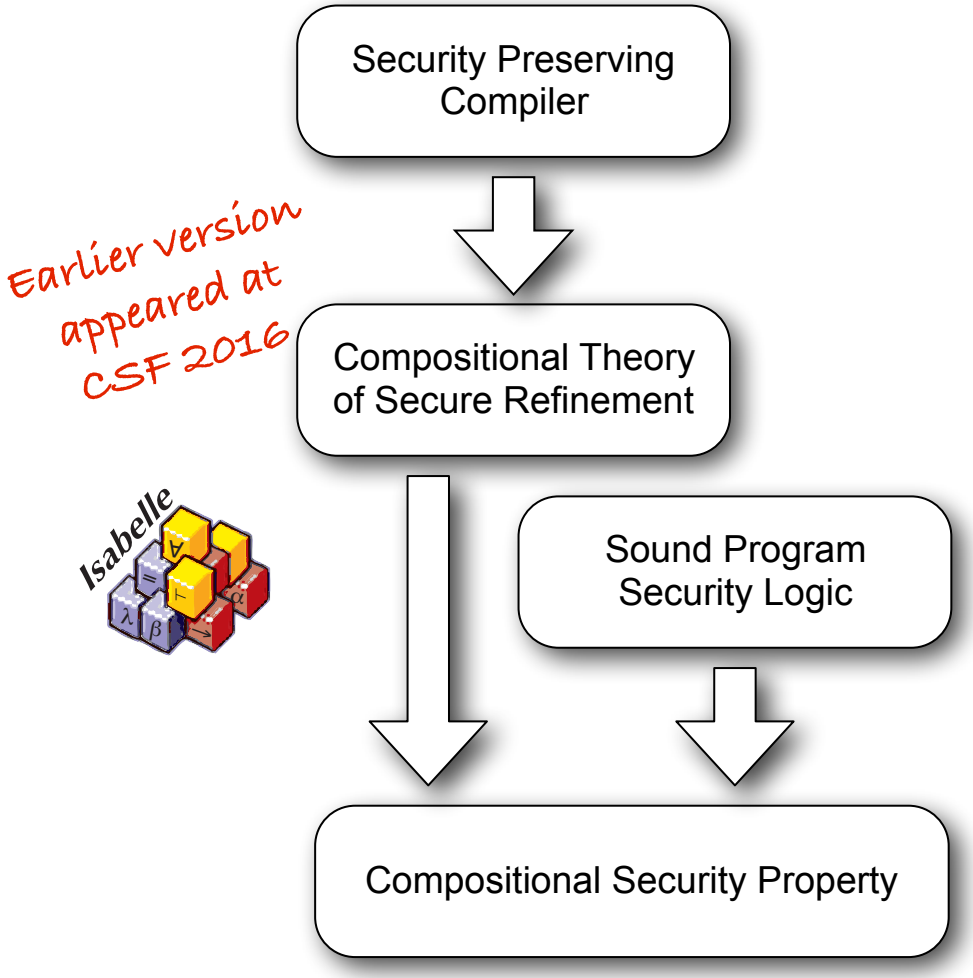


Verification Framework: Status

Robert Sison

Security Preserving Compiler

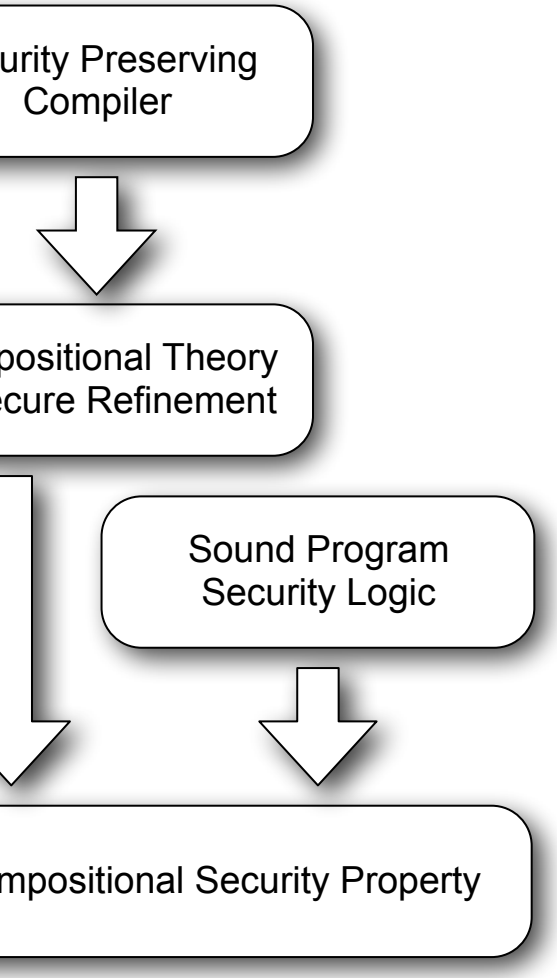
Earlier version appeared at CSF 2016

Compositional Theory of Secure Refinement

Sound Program Security Logic

Compositional Security Property

Verification Framework: Status



Earlier version appeared at CSF 2016

Robert Sison

Christine Rizkallah

Verification Framew

From simple While language to a simple RISC language

(integrated with earlier version of the logic)

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EuroS&P 2018

Compositional Security Property

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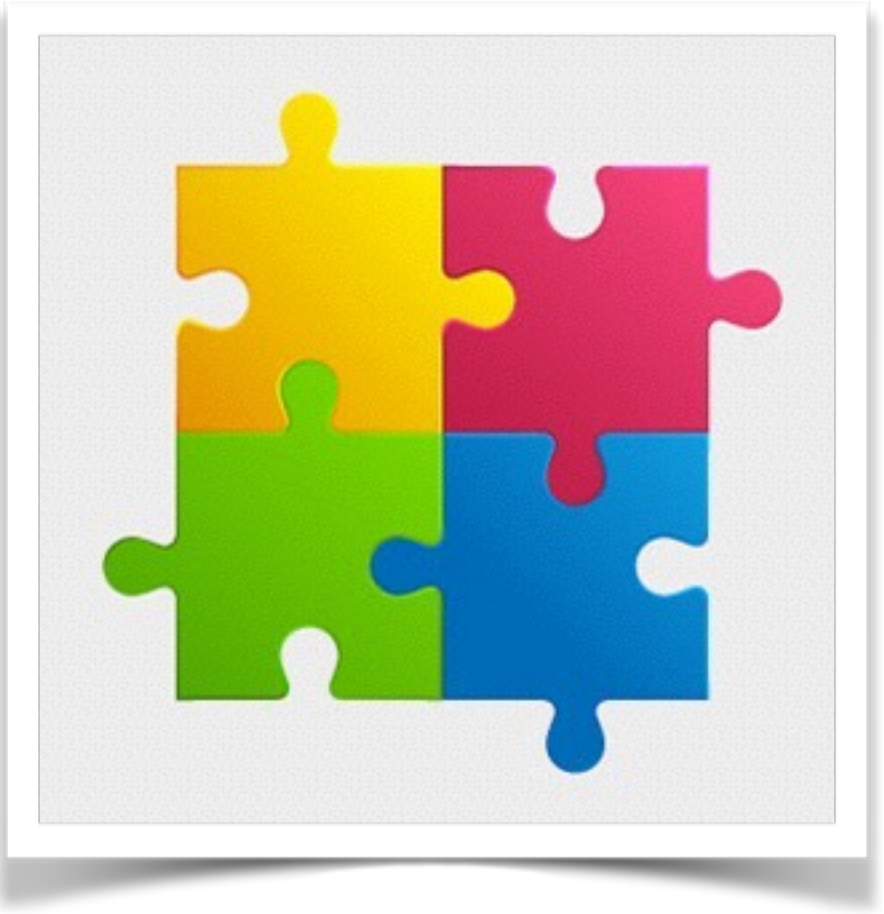
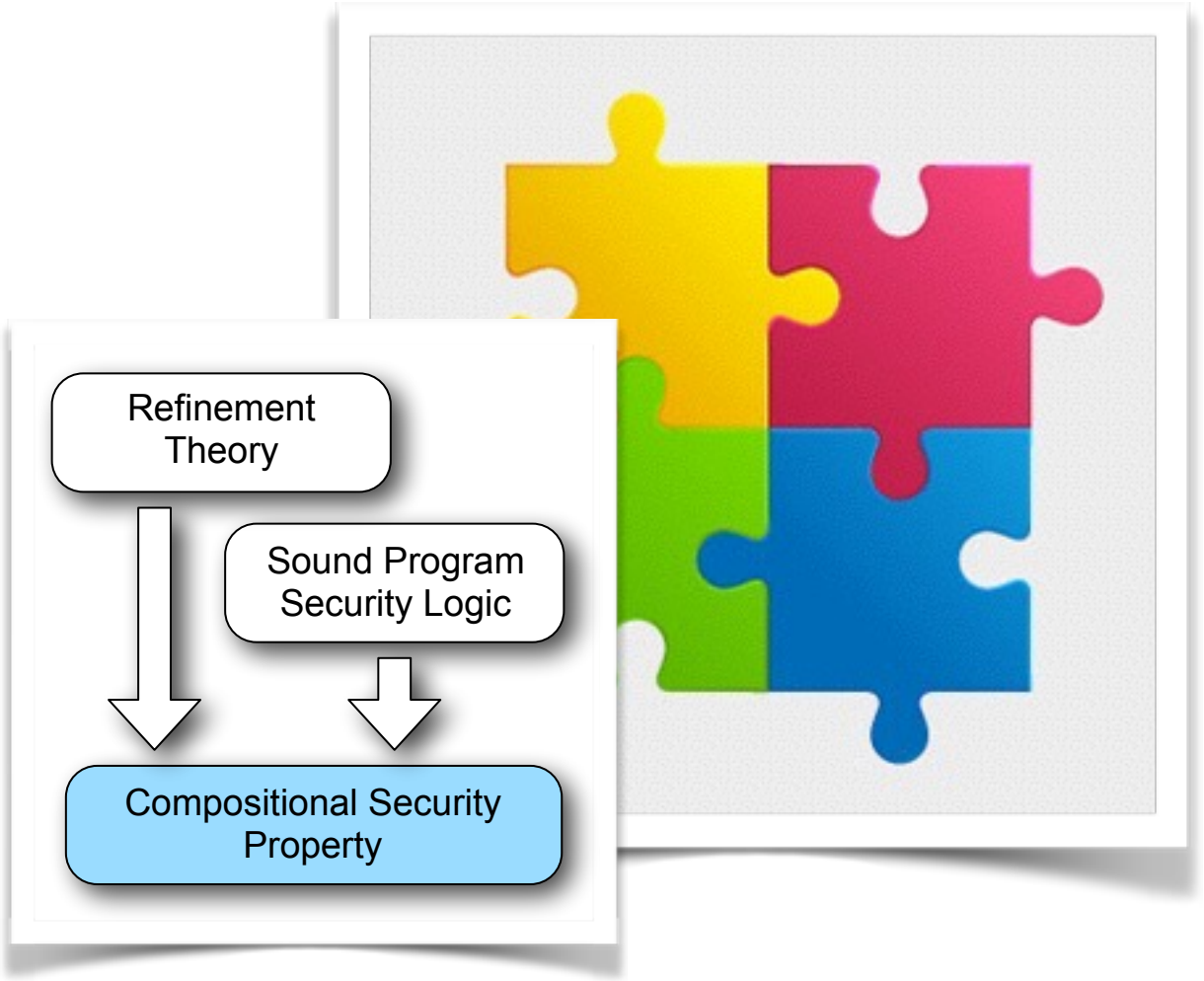
Christine Rizkallah

COMPOSITIONAL SECURITY



COMPOSITIONAL SECURITY



Minimum Requirements

```
l = 0;
if (h){
  h = 0;
}
l = 1;
```

Minimum Requirements

```
l = 0;
if (h){
  h = 0;
}
l = 1;
```

Secure?

Minimum Requirements

```
l = 0;
if (h){
  h = 0;
}
l = 1;
```

Secure?

Timing-Insensitive Security:

Minimum Requirements

```
l = 0;
if (h){
  h = 0;
}
l = 1;
```

Secure?

Timing-Insensitive Security: **YES**

Minimum Requirements

```
l = 0;
if (h){
  h = 0;
}
l = 1;
```

Secure?

Timing-Insensitive Security: **YES**

Timing-Sensitive Security:

Minimum Requirements

```
l = 0;
if (h){
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}
l = 1;
```
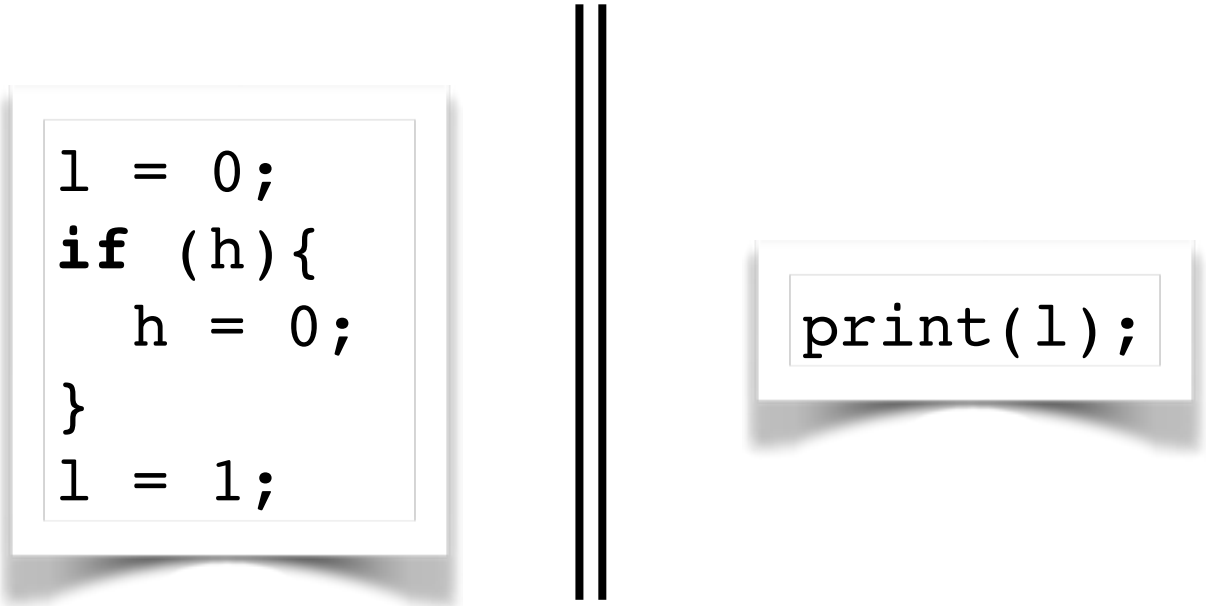

Secure?

Timing-Insensitive Security: **YES**

Timing-Sensitive Security: **NO**

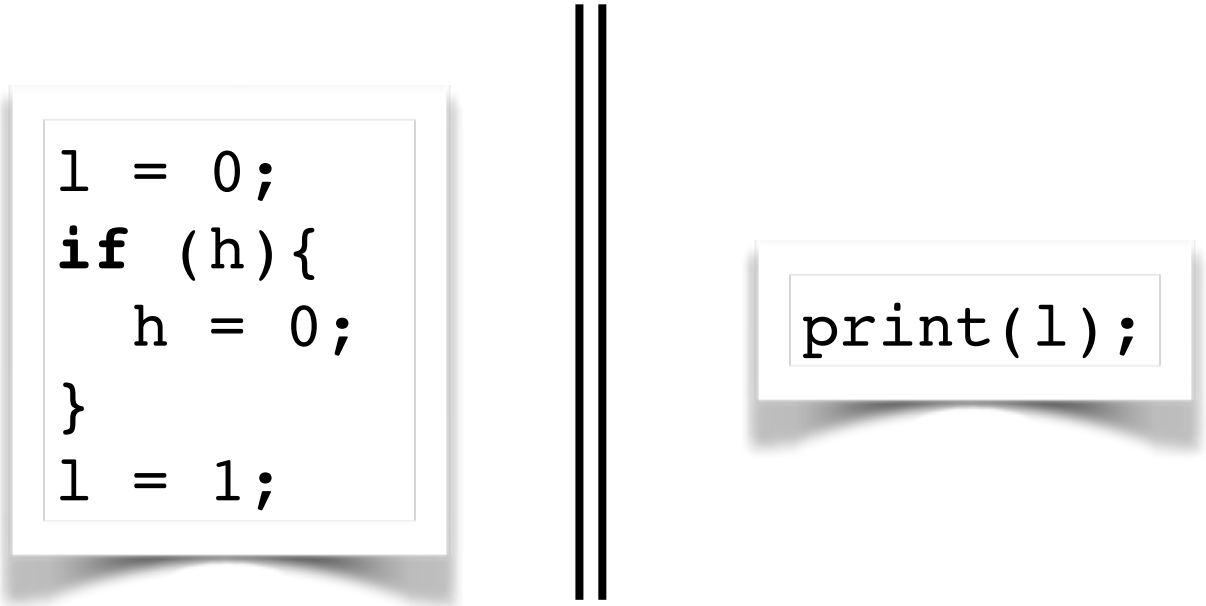
Minimum Requirements



Secure?

Timing-Insensitive Security:

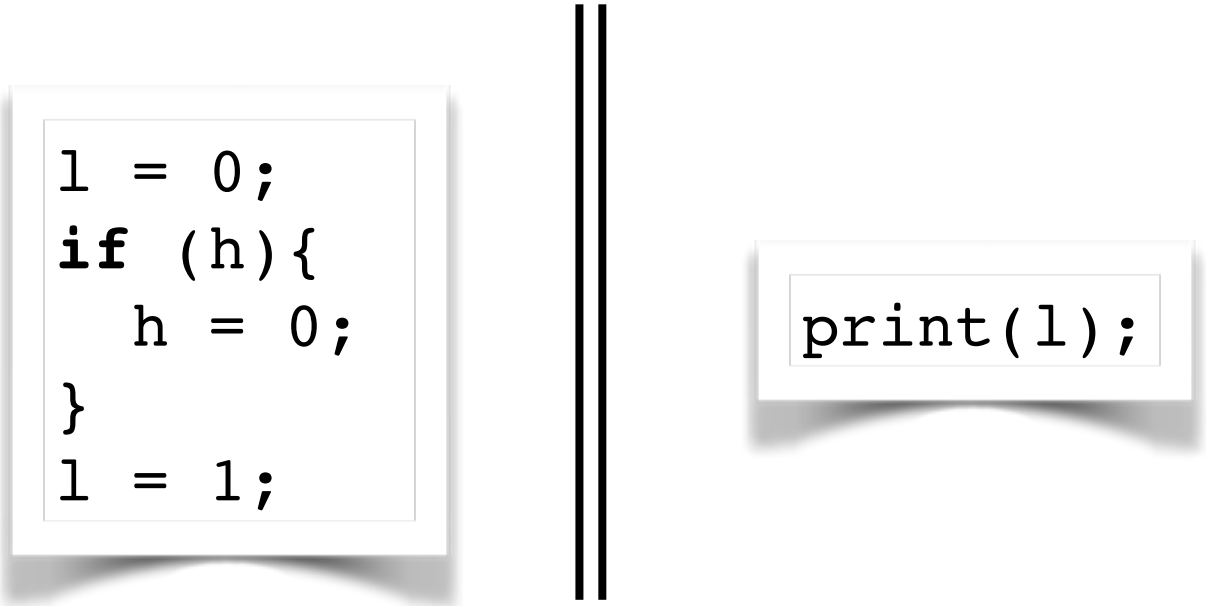
Minimum Requirements



Secure?

Timing-Insensitive Security: **NO**

Minimum Requirements

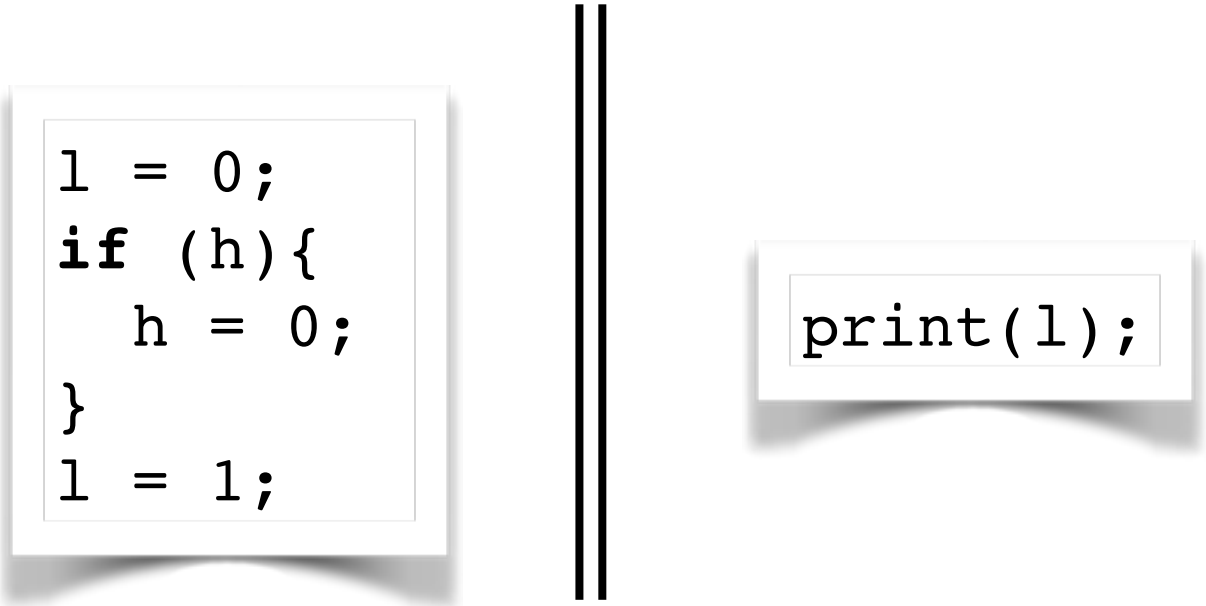


Secure?

Timing-Insensitive Security: **NO**

Timing-Sensitive Security:

Minimum Requirements

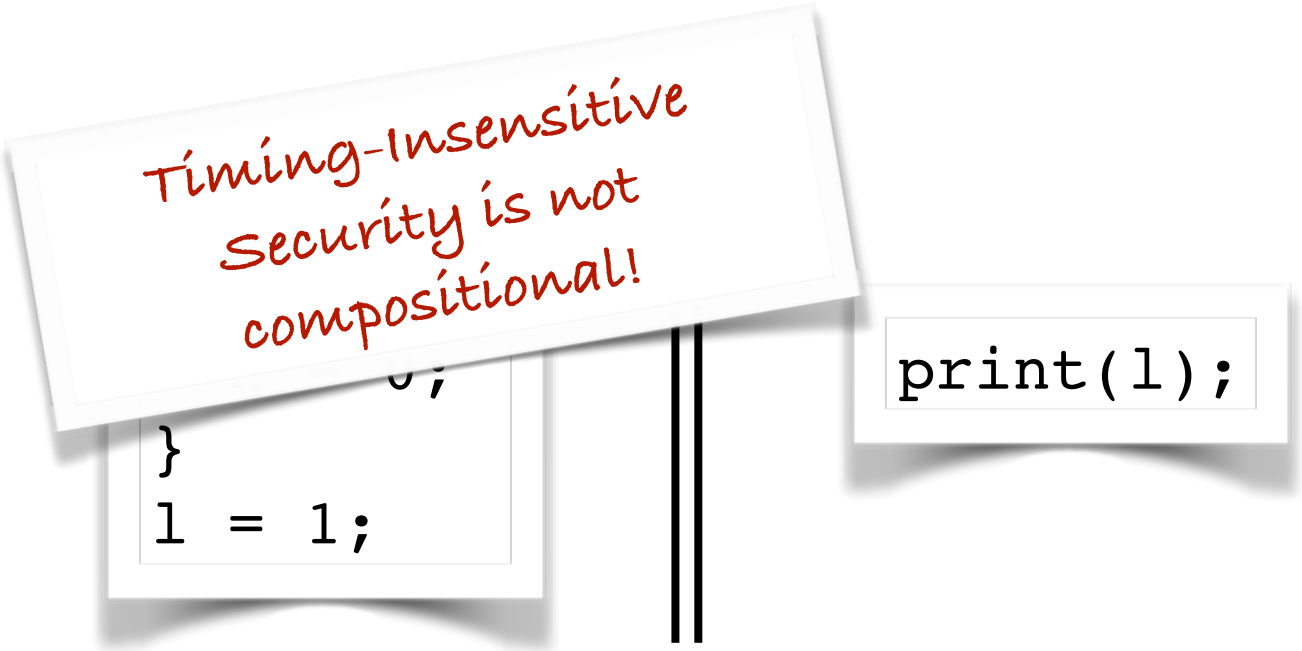


Secure?

Timing-Insensitive Security: **NO**

Timing-Sensitive Security: **NO** (trivially)

Minimum Requirements

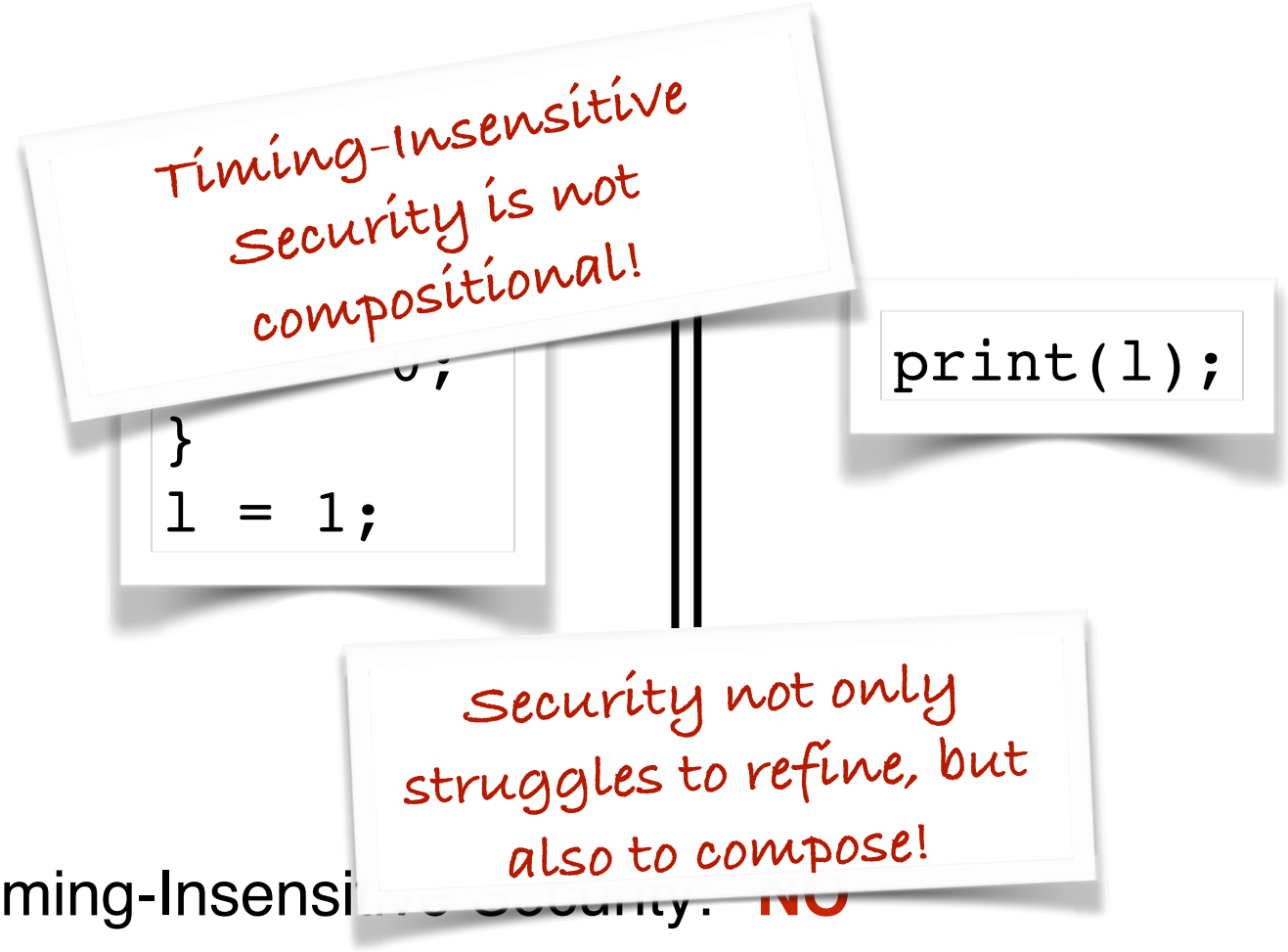


Secure?

Timing-Insensitive Security: **NO**

Timing-Sensitive Security: **NO** (trivially)

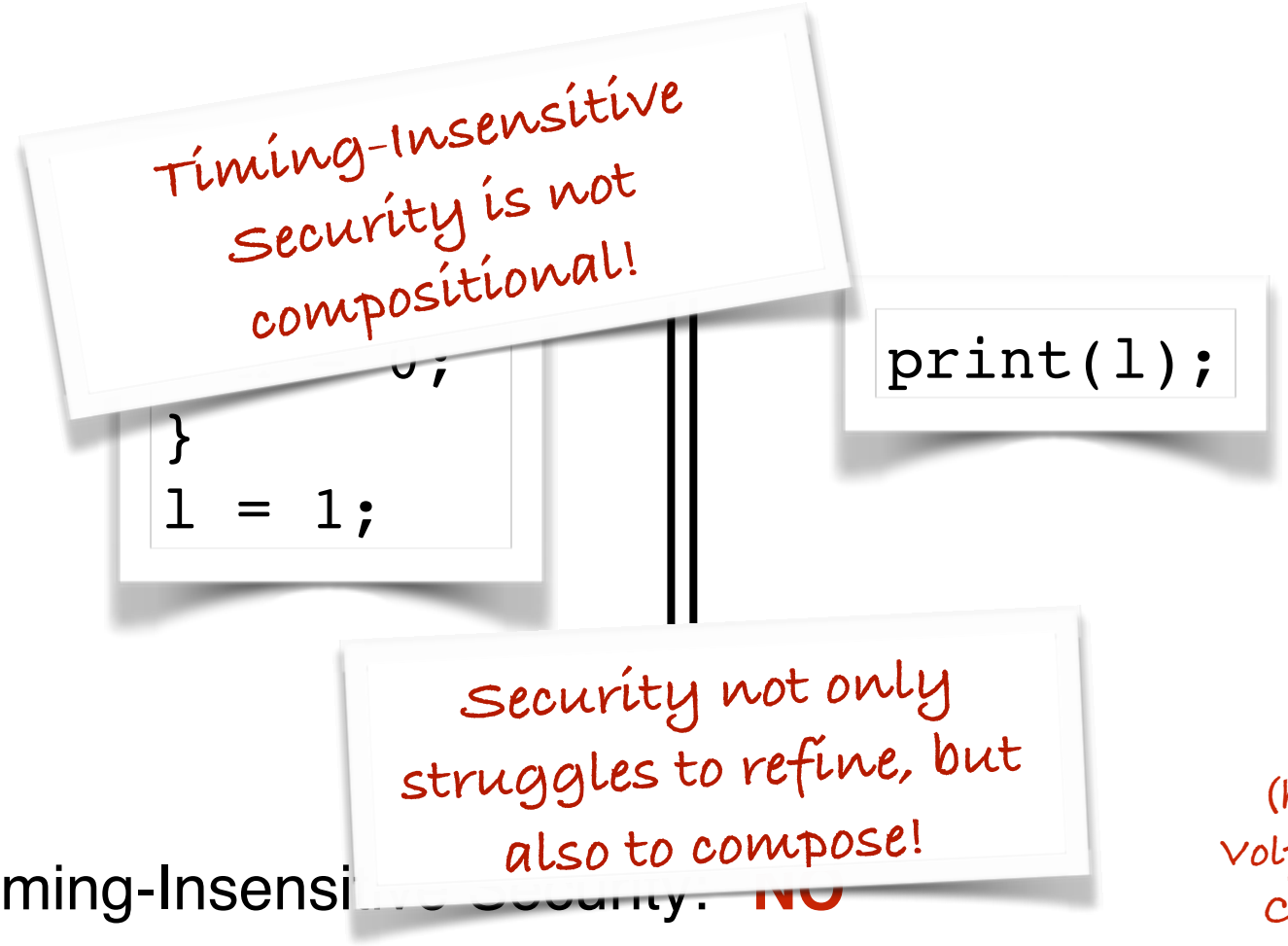
Minimum Requirements



Timing-Insensi… Security: **NO**

Timing-Sensitive Security: **NO** (trivially)

Minimum Requirements

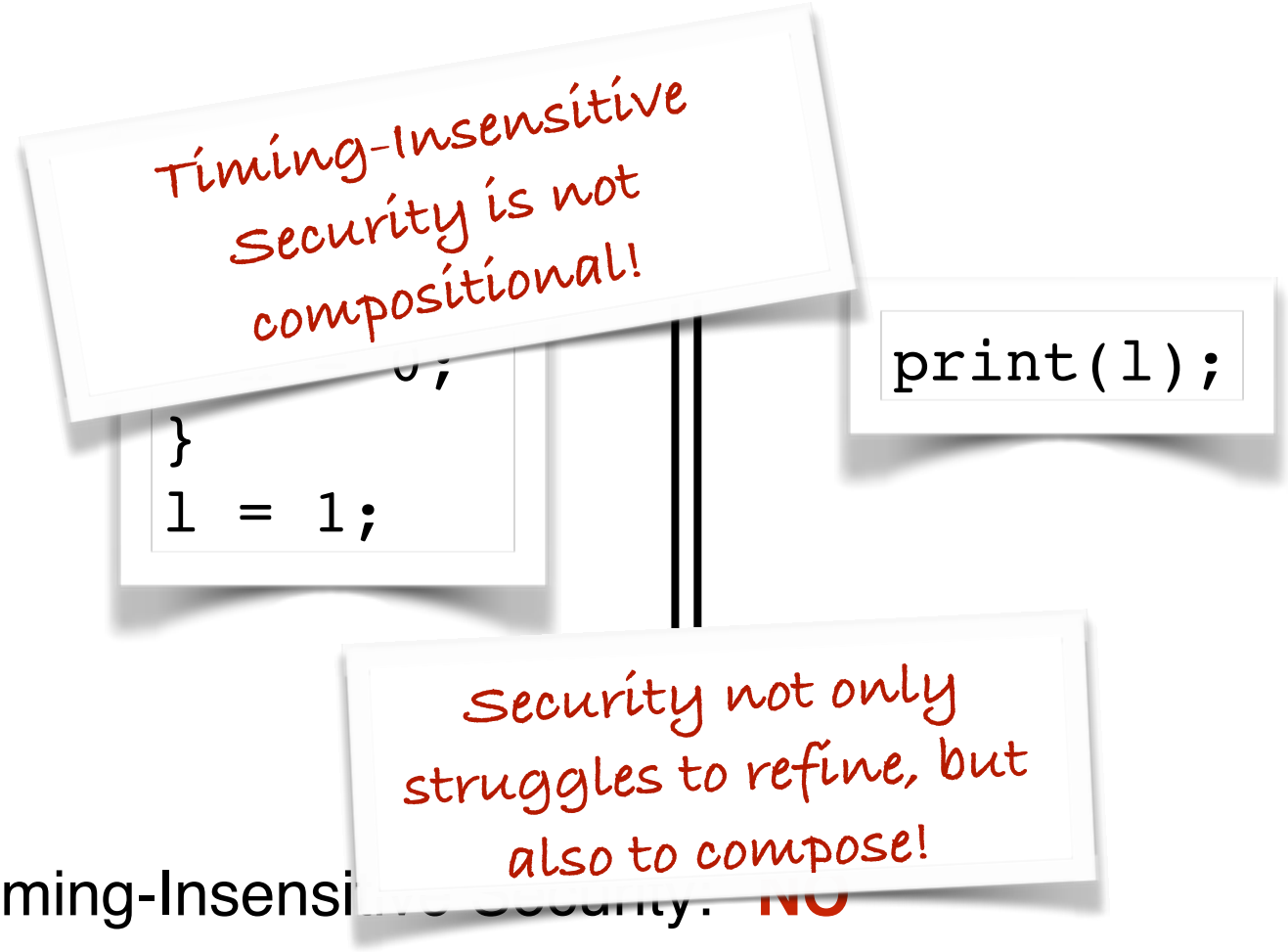


(known since Volpano & Smith, CSFW 1998)

Timing-Insensi… Security: **NO**

Timing-Sensitive Security: **NO** (trivially)

Minimum Requirements



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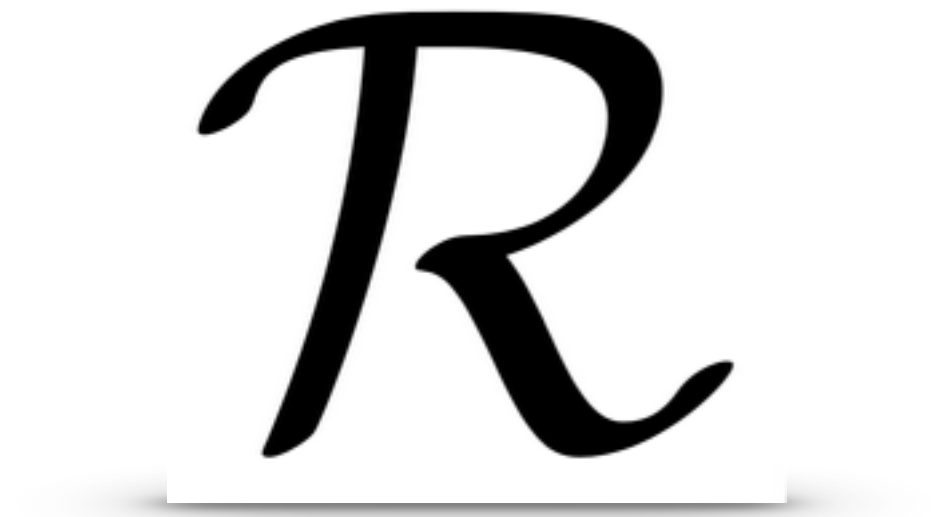
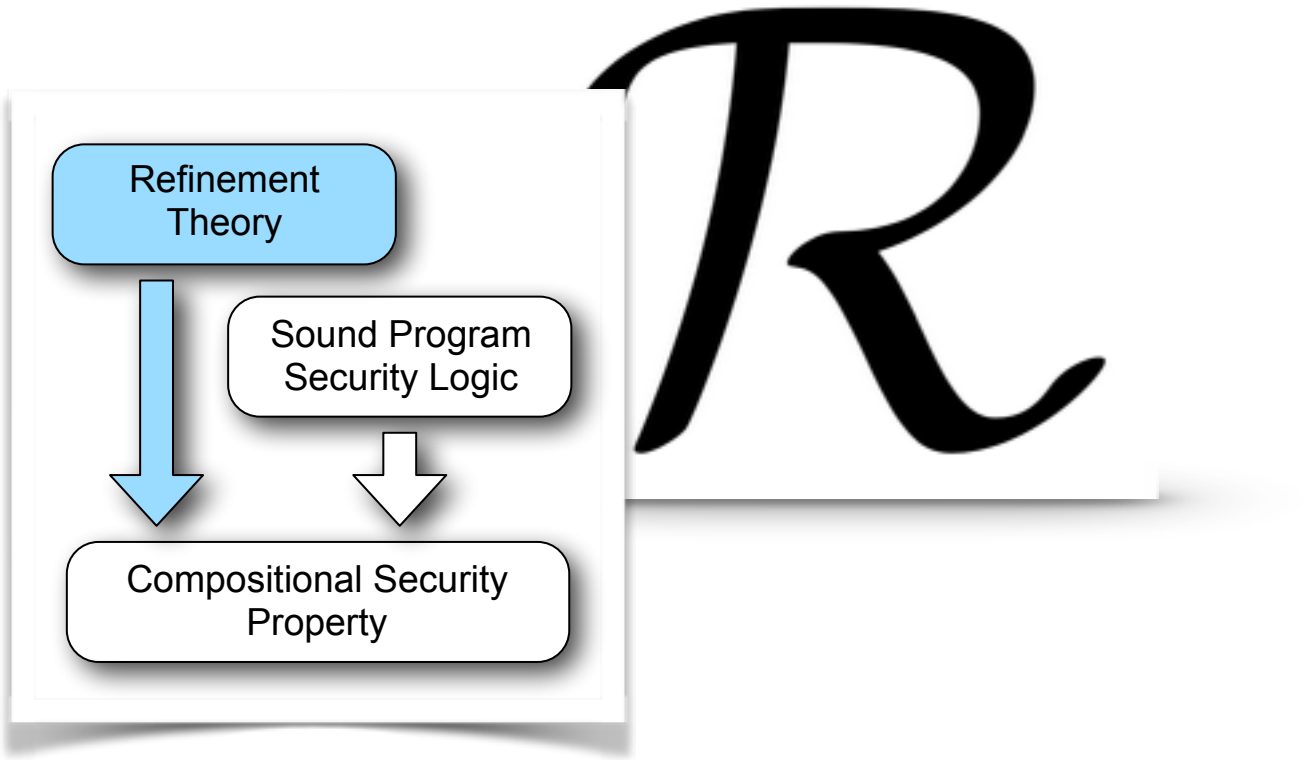
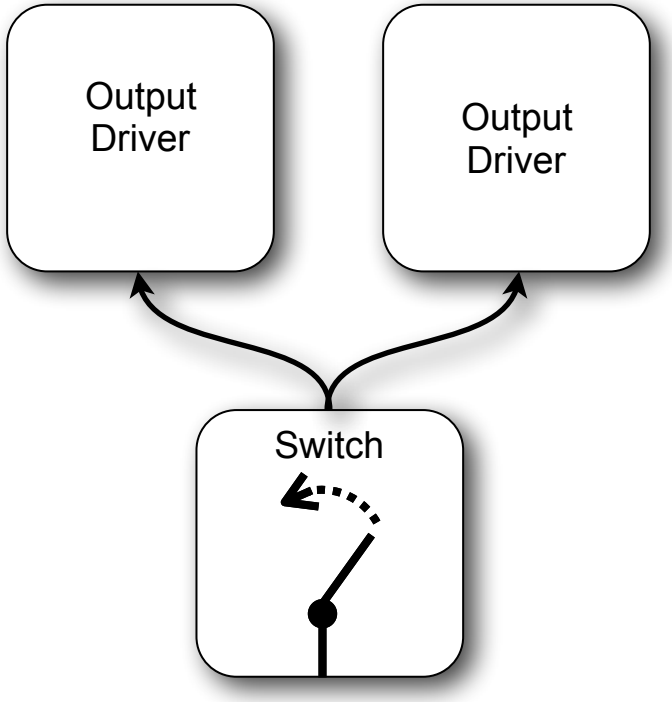
COMPOSITIONAL REFINEMENT



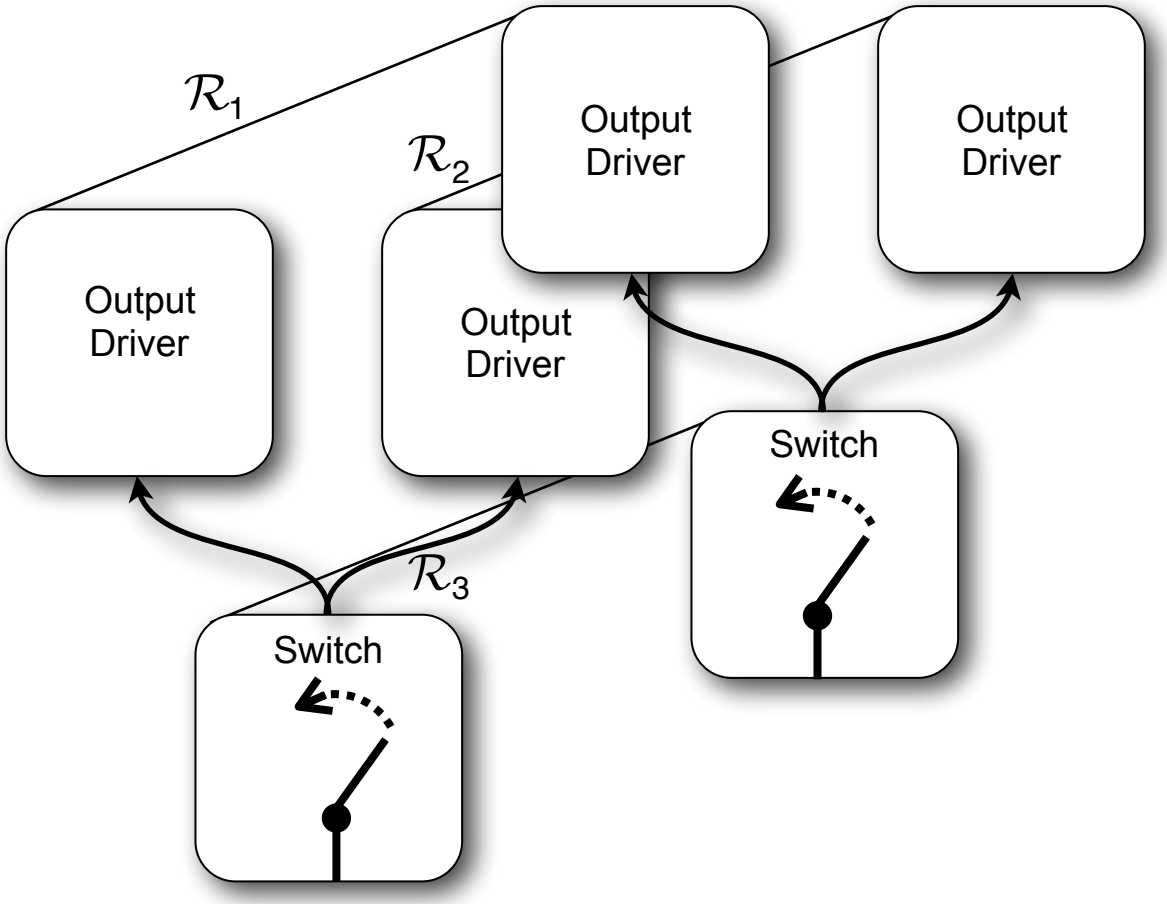
COMPOSITIONAL REFINEMENT



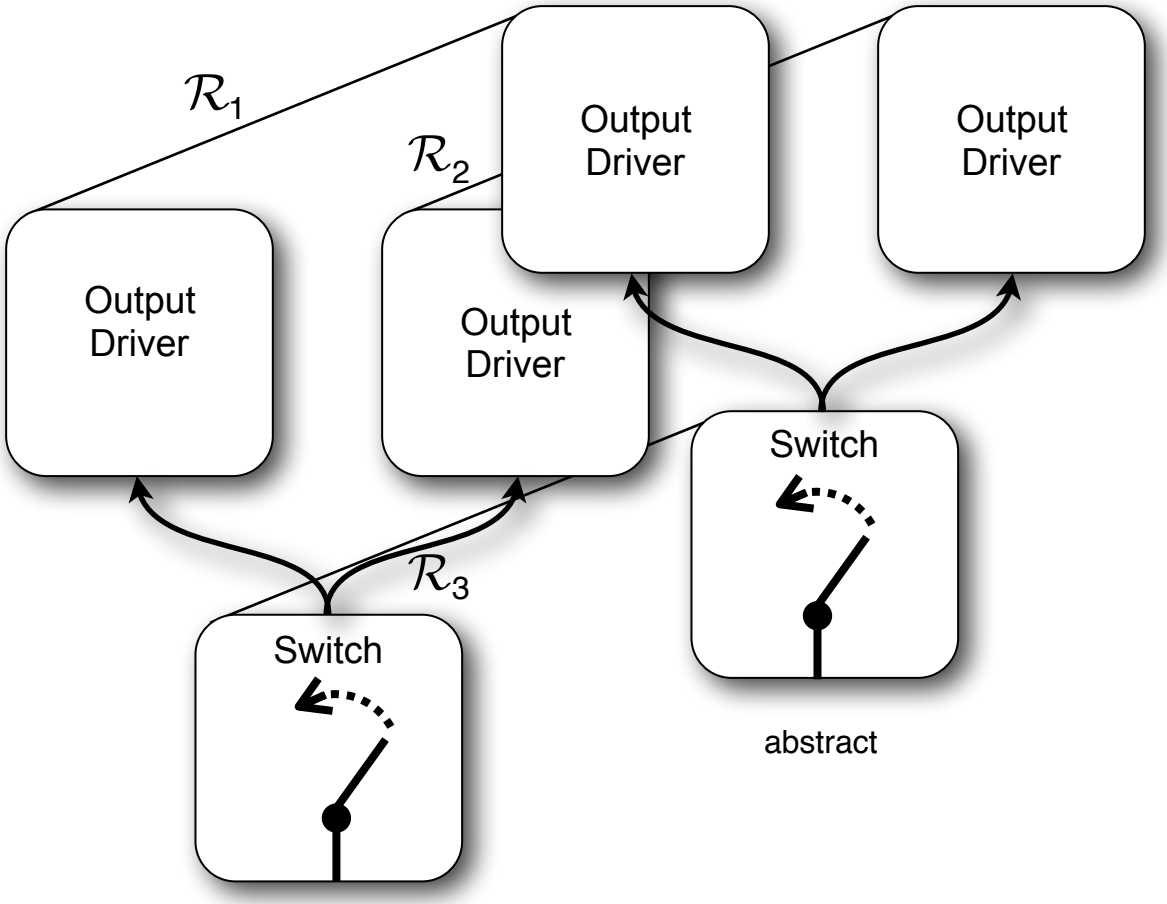
Secure Componentwise Refinement



Secure Componentwise Refinement



Secure Componentwise Refinement



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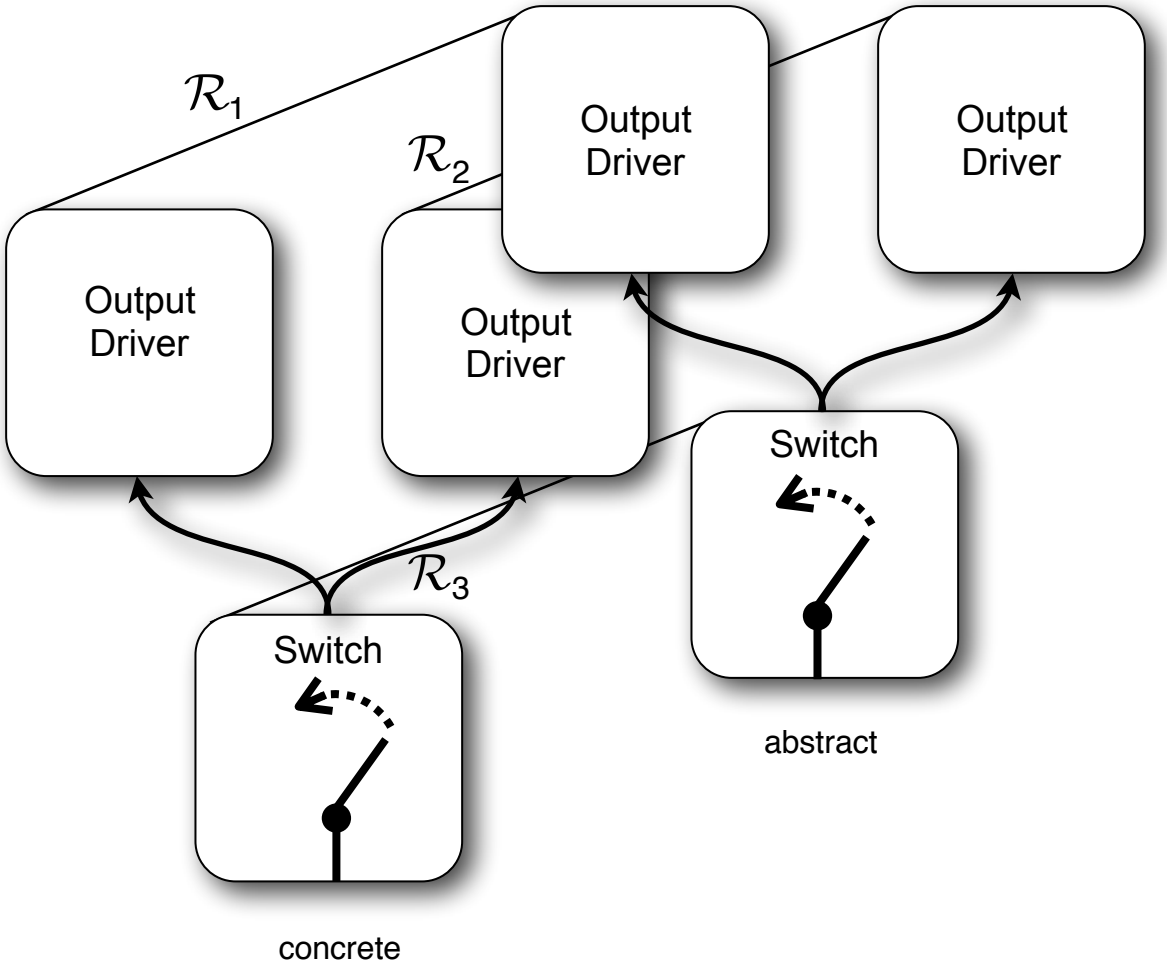
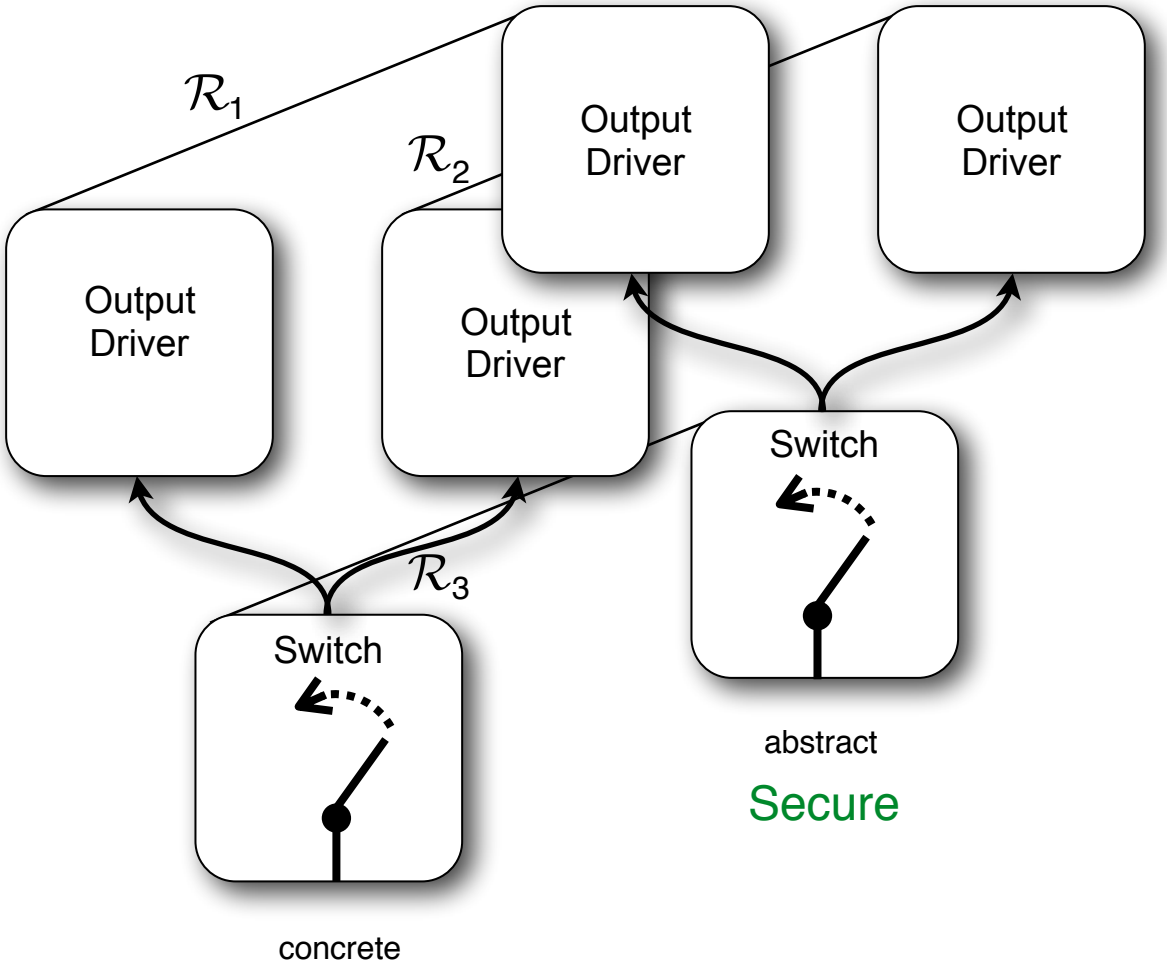


Secure Componentwise Refinement



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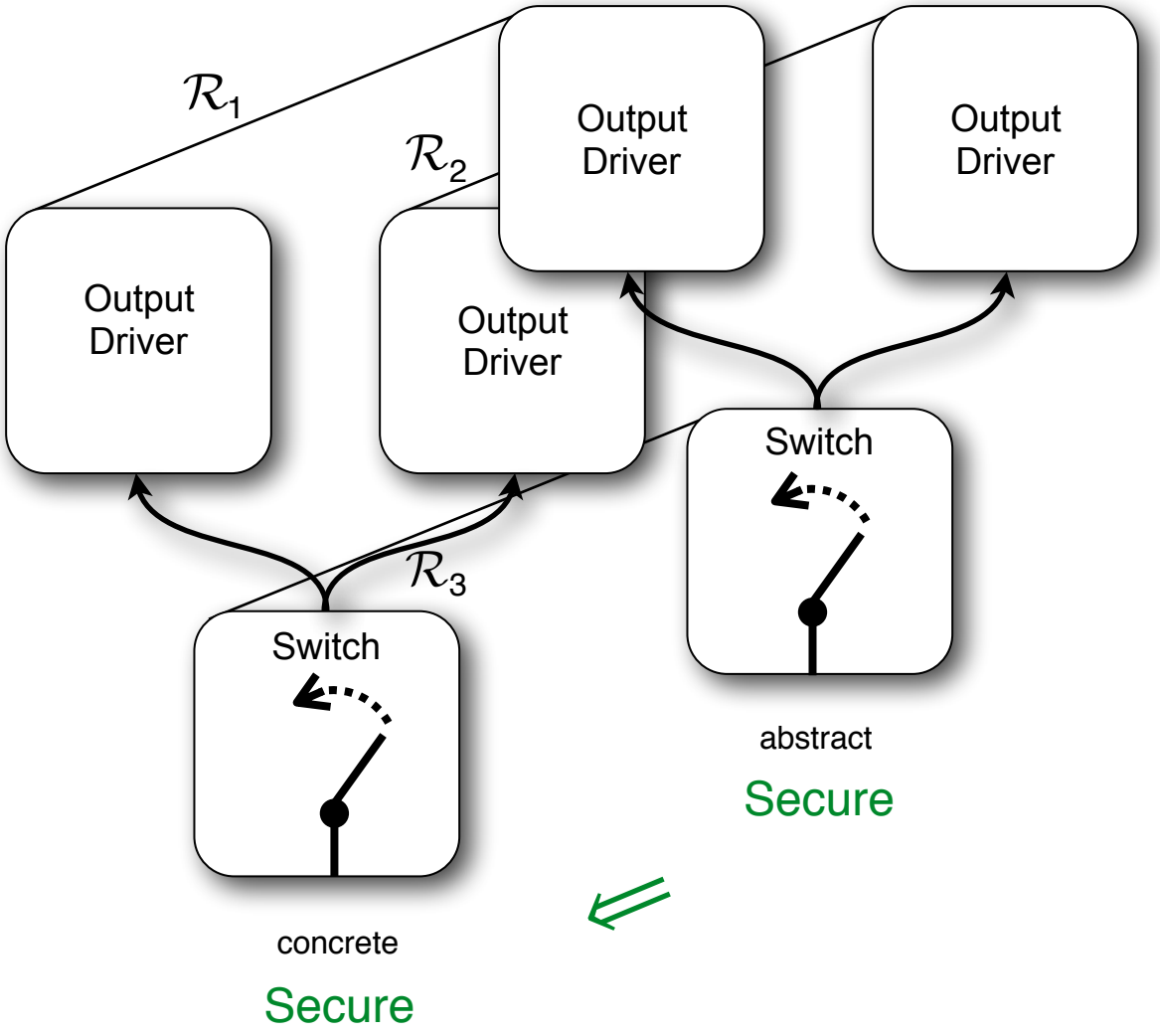

Component Refinement

```
skip   /* control +=_m AsmNoW */;
skip   /* temp +=_m AsmNoRW */;
temp := buffer;
if control == 0 then
  low-var := temp
else
  high-var := temp
endif;
temp := 0;
skip   /* temp -=_m AsmNoRW */
```

```
skip   /* control_C +=_m AsmNoW */;
skip   /* temp_C +=_m AsmNoRW */;
temp_C := buffer_C;
reg_C := control_C;
if reg_C == 0 then
  low-var_C := temp_C
else
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endif;
temp_C := 0;
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Component Refinement

Original Program

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A Trivial Refinement

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Component Refinement

concrete variables implementing abstract ones

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concrete variables implementing abstract ones

concrete variables with no abstract counterpart

A Trivial Refinement

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Abstract Program Security: Bisimulation

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if (h) {
    h = 0;
    l = 1;
} else {
    skip;
    l = 1;
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```

Abstract Program Security: Bisimulation

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$\mathcal{B}$

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Abstract Program Security: Bisimulation

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$\mathcal{B}$

```
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Important:

$\mathcal{B}$ must guarantee that the two memories are always Low-equivalent

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}
```

$\mathcal{B}$

```
if (h) {
     h = 0;
     l = 1;
} else {
     skip;
     l = 1;
}
```

(the soundness proof for the security logic constructs an appropriate $\mathcal{B}$)

Important:

$\mathcal{B}$ must guarantee that the two memories are always Low-equivalent

Refining High Conditionals

```
if (h) {
    h = 0;
    l = 1;
} else {
    skip;
    l = 1;
}
```

Refining High Conditionals

A Secure Program

```
if (h) {
    h = 0;
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} else {
    skip;
    l = 1;
}
```

Refining High Conditionals

A Secure Program

branches need to do the same Low things at the same time

```
if (h) {
     h = 0;
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     l = 1;
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```

Refining High Conditionals

branches need to do the same Low things at the same time

A Secure Program

```
if (h) {
    h = 0;
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} else {
    skip;
    l = 1;
}
```

A Trivial Refinement

```
if (h) {
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} else {
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}
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Refining High Conditionals

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A Trivial Refinement

```
if (h) {
     h = 0;
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} else {
     l = 1;
}
```

insecure

Refining High Conditionals

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A Secure Program

```
if (h) {
    h = 0;
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} else {
    skip;
    l = 1;
}
```

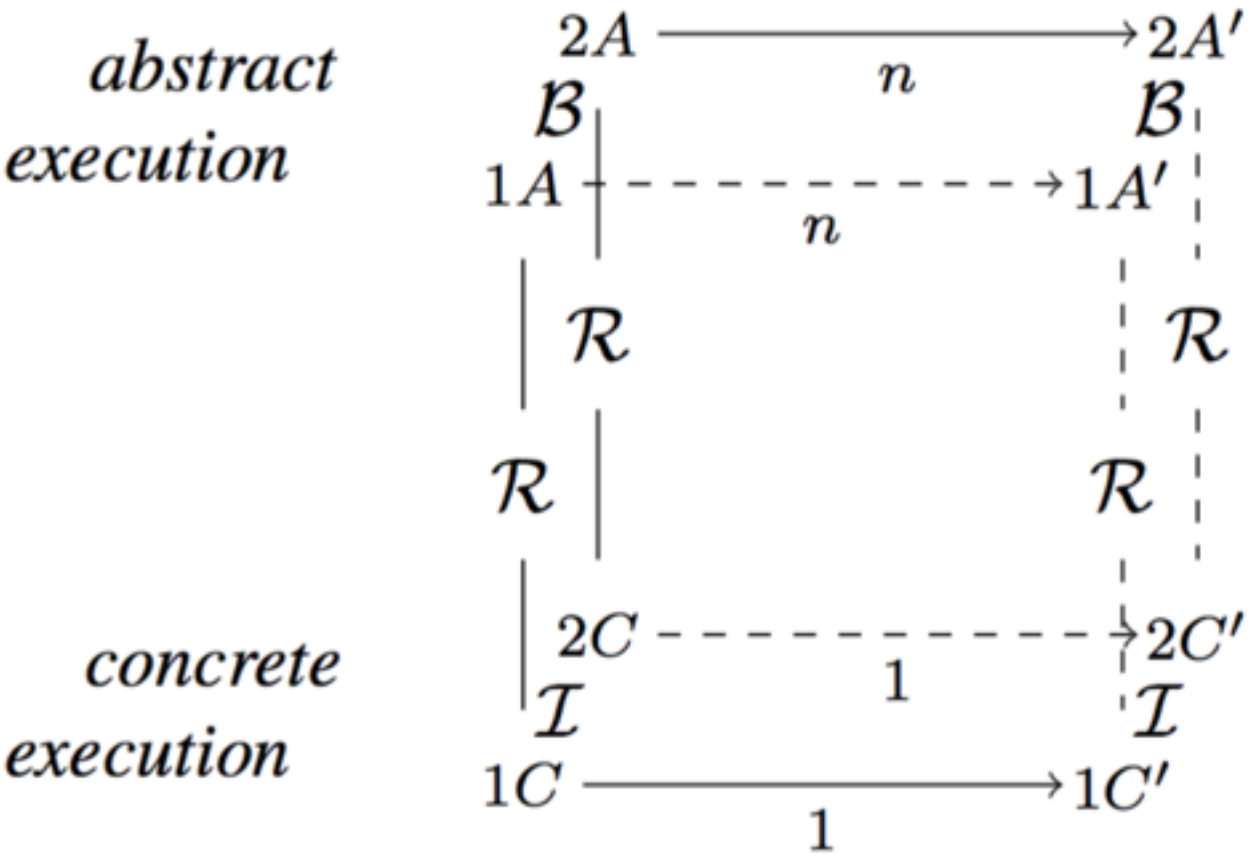
A Trivial Refinement

```
if (h) {
    h = 0;
    l = 1;
} else {
    l = 1;
}
```

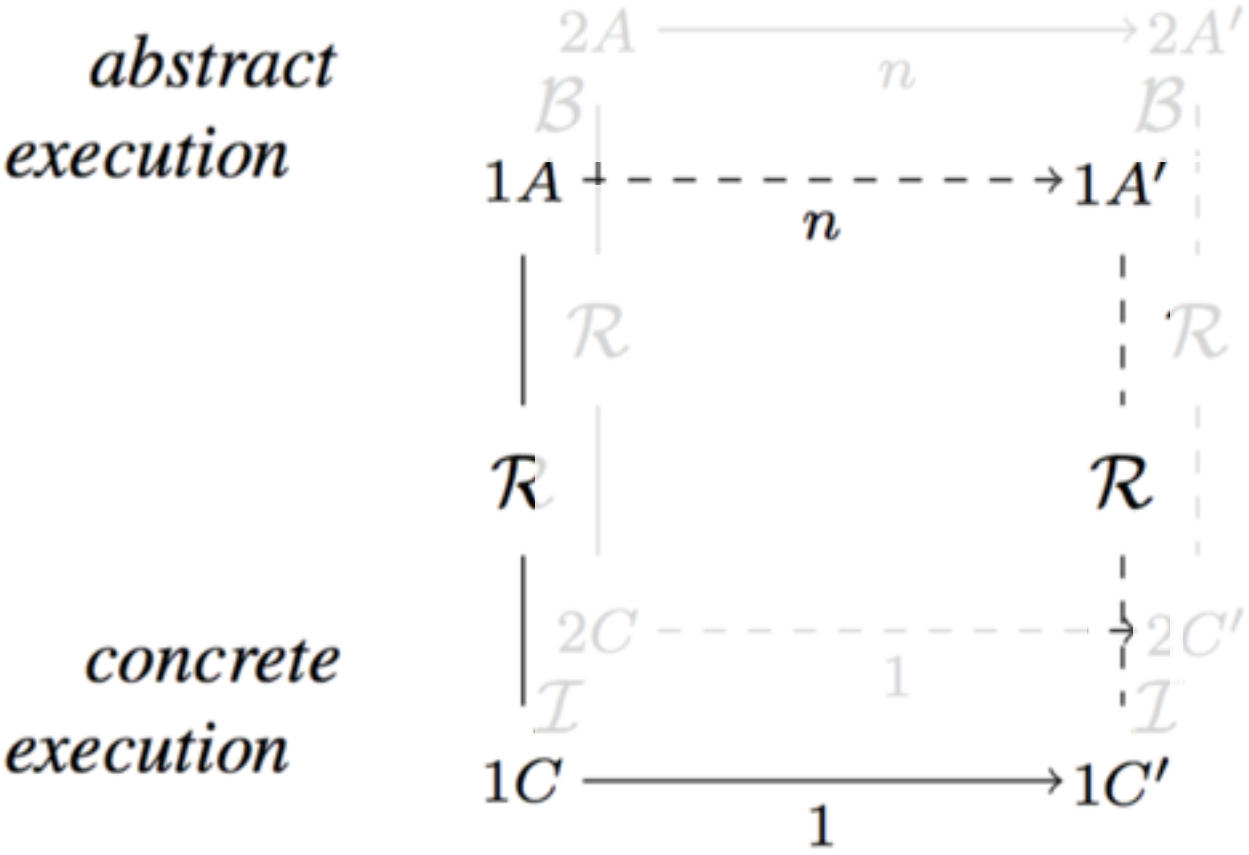
insecure

Need to make sure that the concrete executions stay in sync.

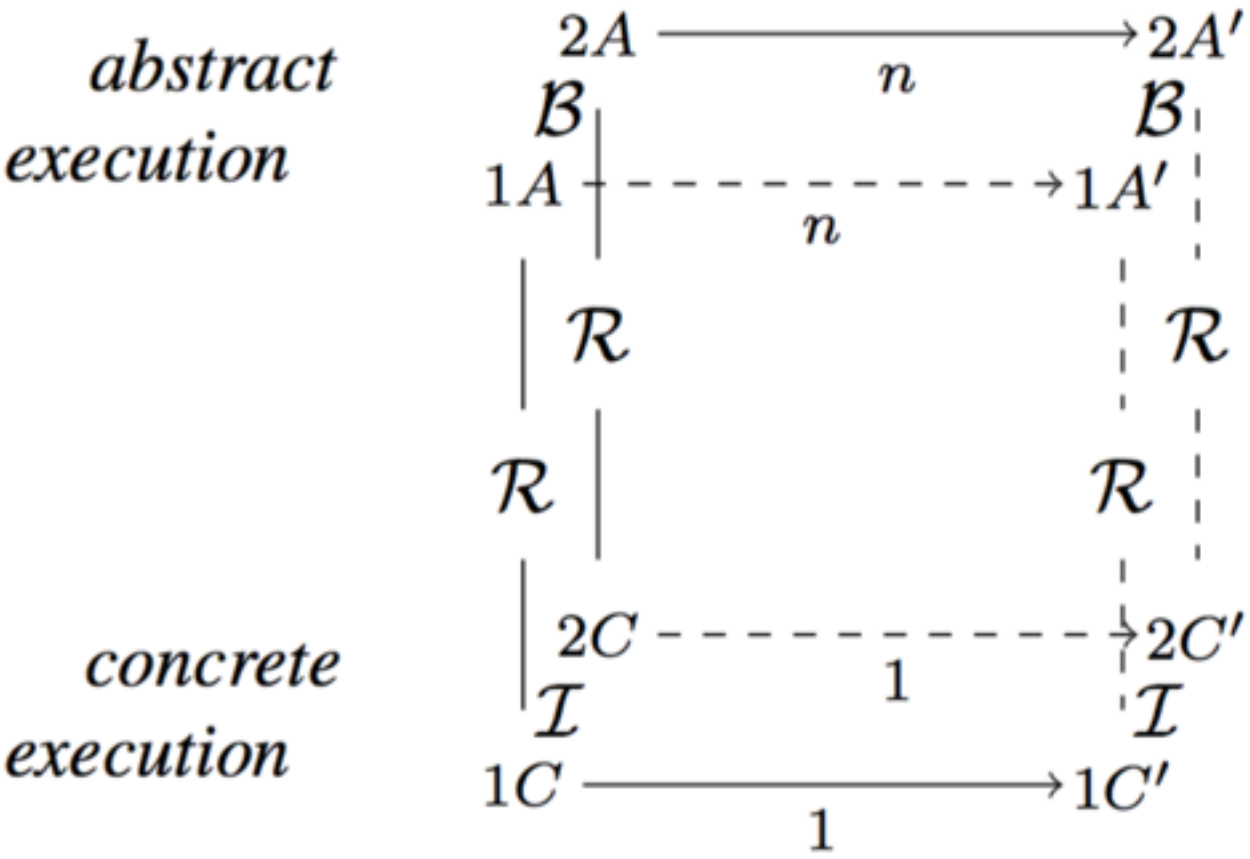
Secure Refinement via Coupling



Secure Refinement via Coupling



Secure Refinement via Coupling



Coupling Invariant: $\mathcal{I}$

```
skip   /* h +=_m AsmNoW */;
skip   /* y +=_m AsmNoW */;
skip   /* z +=_m AsmNoW */;
y := 0;
z := 0;
x := y;
if h != 0 then
  x := y
else
  x := y + z
endif
```

Coupling Invariant: $\mathcal{I}$

```
skip   /* h_C +=_m AsmNoW */;
skip   /* y_C +=_m AsmNoW */;
skip   /* z_C +=_m AsmNoW */;
y_C := 0;
z_C := 0;
x_C := y_C;
reg3_C := h_C;
if reg3_C != 0 then
  skip;
  skip;
  reg0_C := y_C;
  x_C := reg0_C
else
  reg1_C := y_C;
  reg2_C := z_C;
  reg0_C := reg1_C + reg2_C;
  x_C := reg0_C
endif
```

Coupling Invariant: $\mathcal{I}$

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skip   /* h_C +=_m AsmNoW */;
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y_C := 0;
z_C := 0;
x_C := y_C;
reg3_C := h_C;
if reg3_C != 0 then
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  skip;
  reg0_C := y_C;
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else
  reg1_C := y_C;
  reg2_C := z_C;
  reg0_C := reg1_C + reg2_C;
  x_C := reg0_C
endif
```

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skip   /* h_C +=_m AsmNoW */;
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x_C := y_C;
reg3_C := h_C;
if reg3_C != 0 then
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  reg1_C := y_C;
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Important:

$\mathcal{I}$ need not talk at all about memory contents being secure

Concurrency-Aware Refinement

$$x := y + z$$

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Source language semantics evaluates y + z atomically

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(see Liang et al., TOPLAS 2014)

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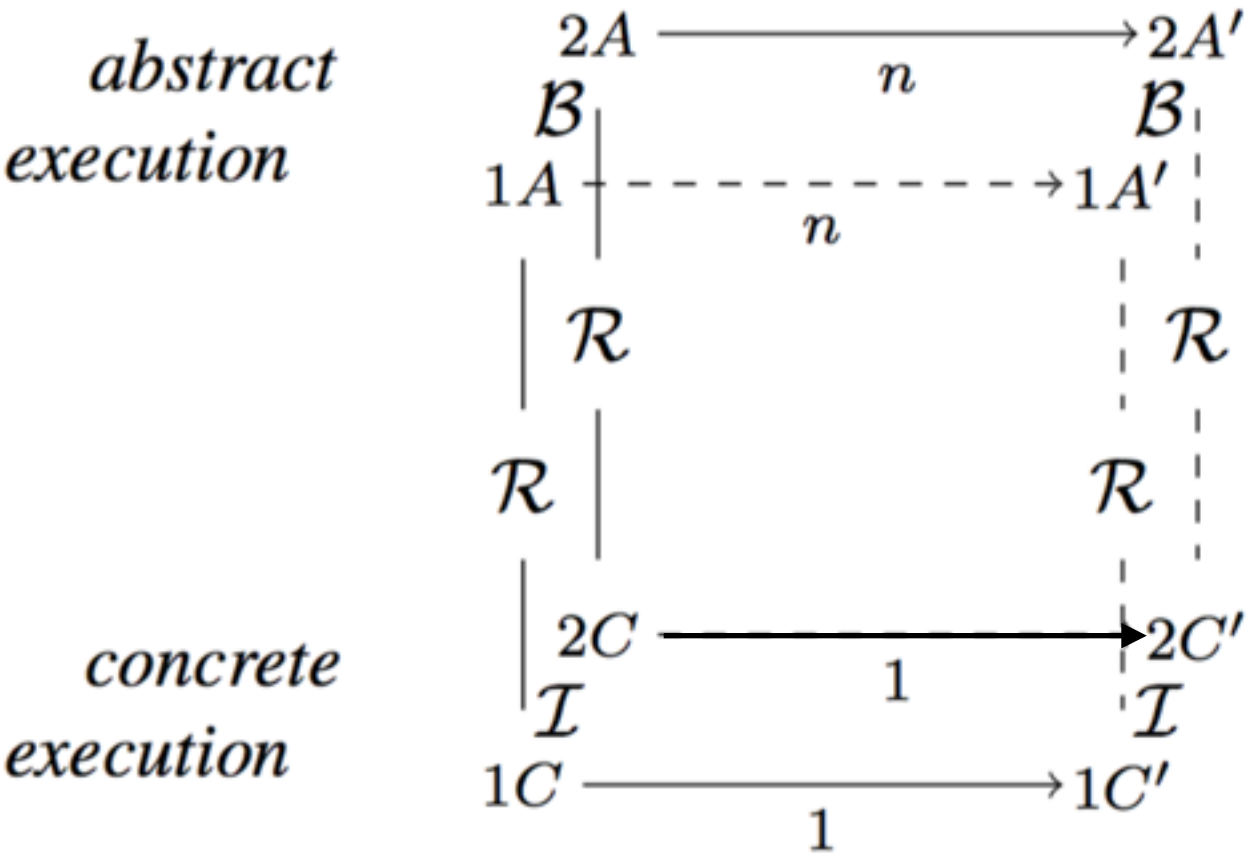
Leveraging Determinism



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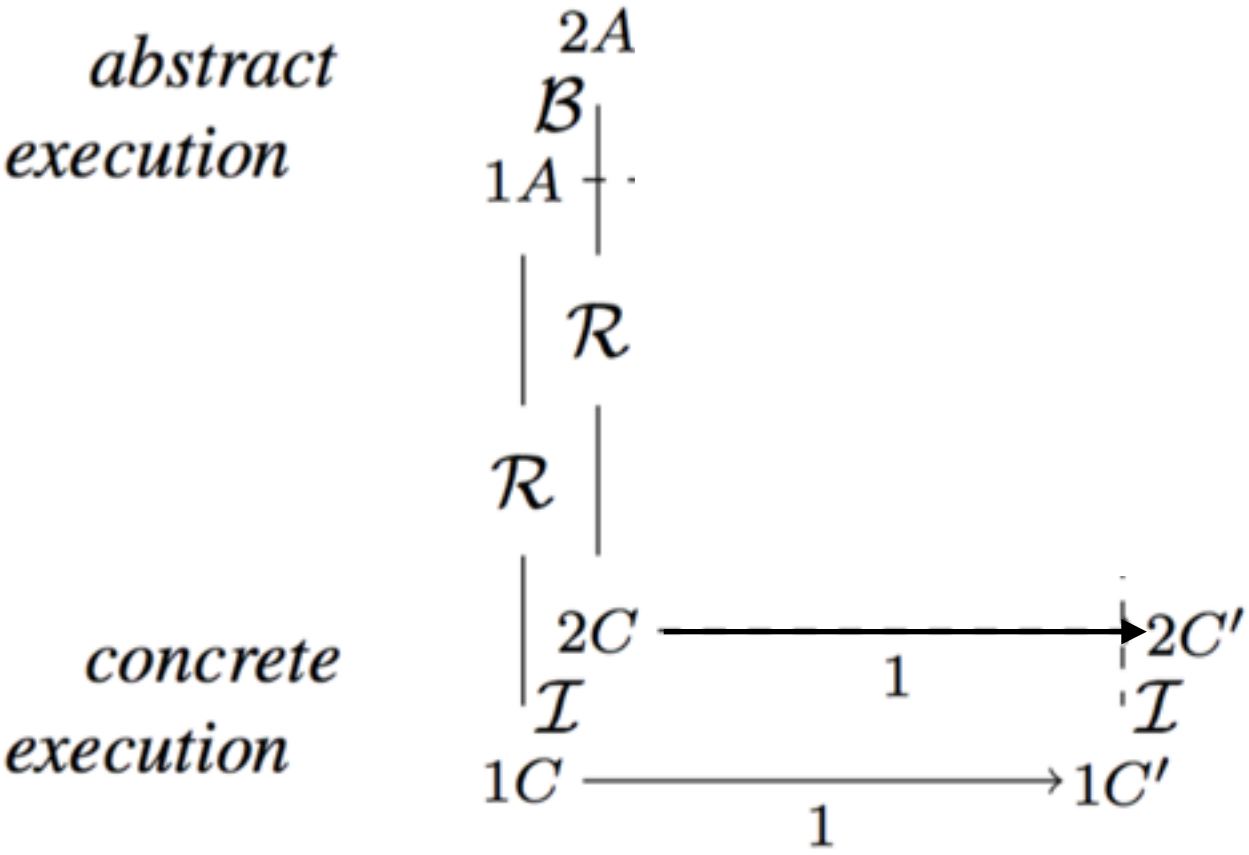

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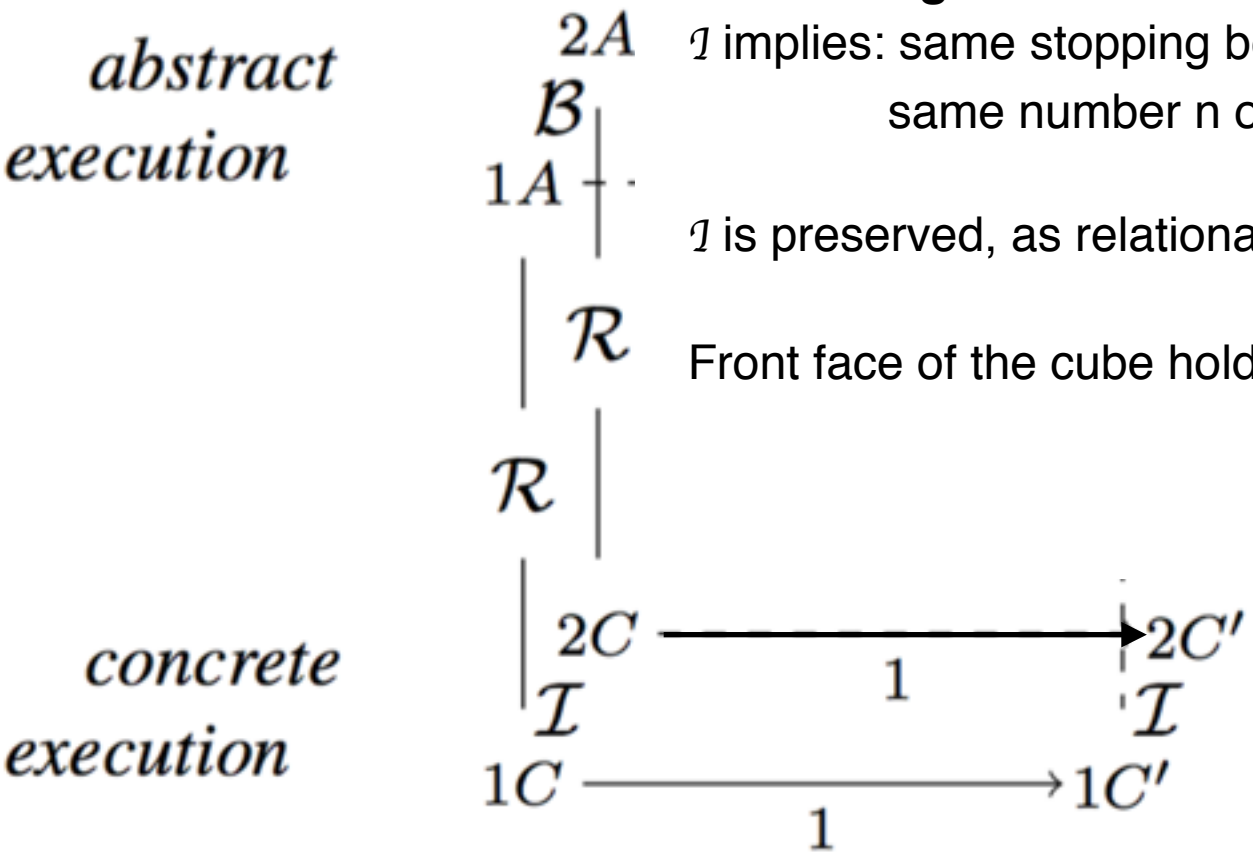

Proof Obligations:

$\mathcal{I}$ implies: same stopping behaviour
same number n of abstract steps

$\mathcal{I}$ is preserved, as relational invariant

Front face of the cube holds

SECURITY-PRESERVING COMPILATION

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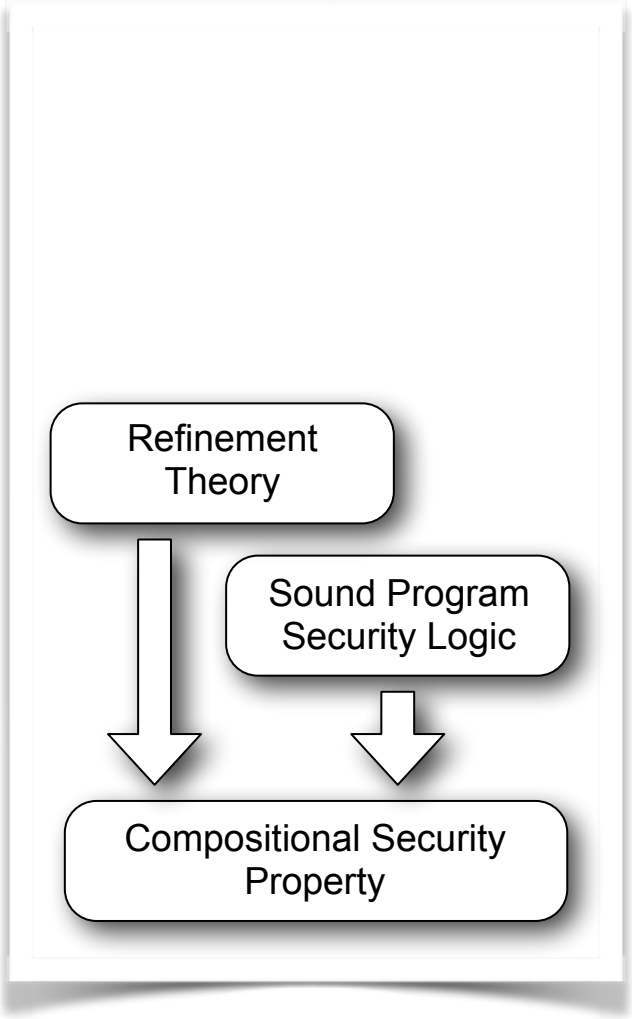

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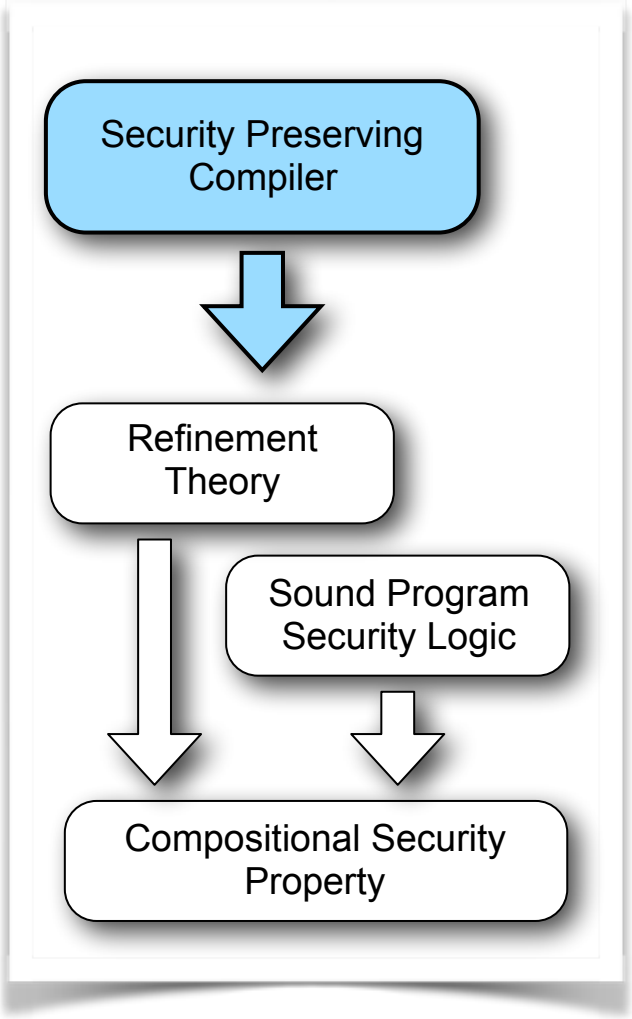

Case Study: Compilation to Idealised RISC

instr ::= **lock** l
| **release** l
| **load** reg x
| **store** x reg
| **Jump** label
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| **Noop**
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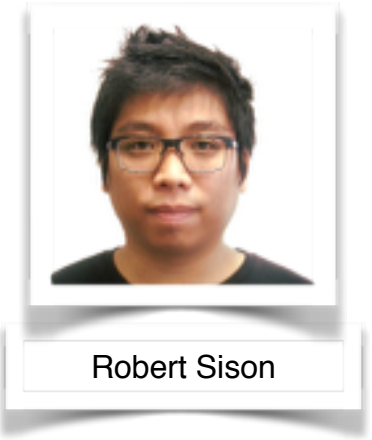
Robert Sison

Current Status

- Proof finished for source programs that are secure and never branch on High data
  - This is the simple case where the compiler doesn't have to do anything except compile the program properly to preserve noninterference
- Sufficient for the CDDC model we have verified
- First example compiler for shared-memory concurrent programs proved to preserve noninterference
- Next steps: High conditionals, weak memory, …

CONCLUSION

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Moving from verified secure kernels to verified secure systems:

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- concurrency ~> compositionality ~>
  timing-sensitivity, assume-guarantee reasoning
- dynamic policies (value-dependence)
- compositional secure refinement ~>
  coupling invariants for preservation of timing-sensitive security

CONCLUSION

Moving from verified secure kernels to verified secure systems:

- concurrency ~> compositionality ~>
  timing-sensitivity, assume-guarantee reasoning
- dynamic policies (value-dependence)
- compositional secure refinement ~>
  coupling invariants for preservation of timing-sensitive security

Still lots more to be done.

Thank You


toby.murray@unimelb.edu.au


http://people.eng.unimelb.edu.au/tobym


@tobycmurray

What about … ?

and various other **intra-device** timing channels?

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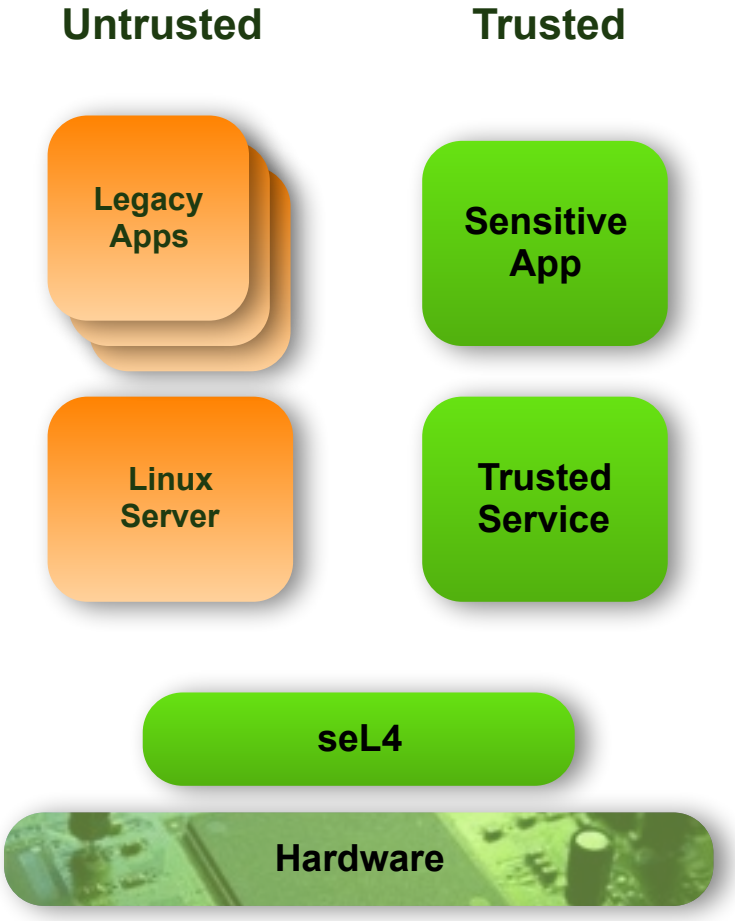

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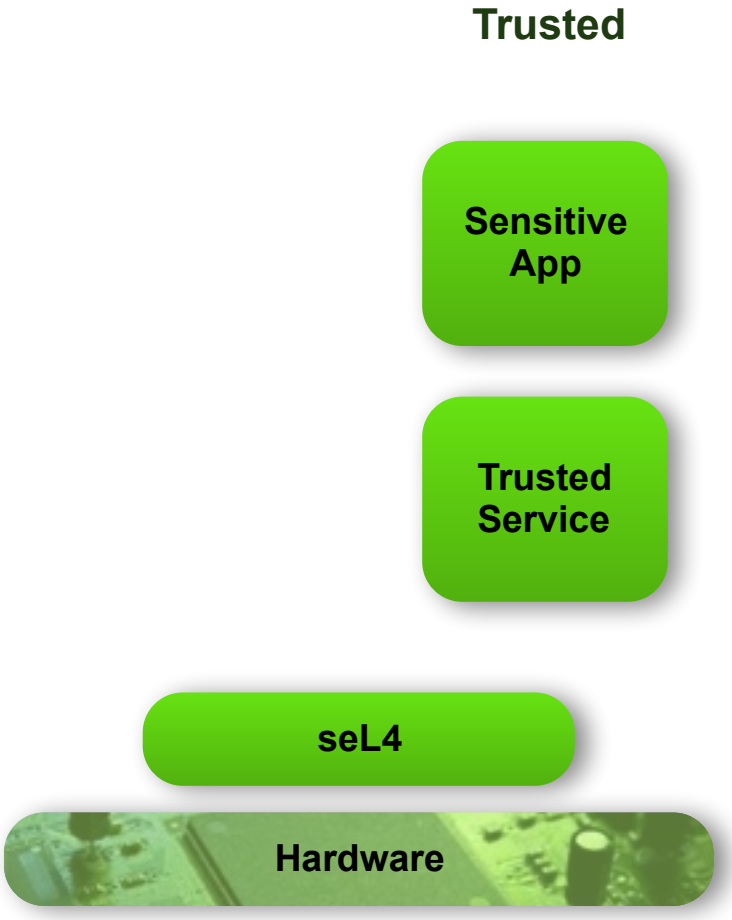

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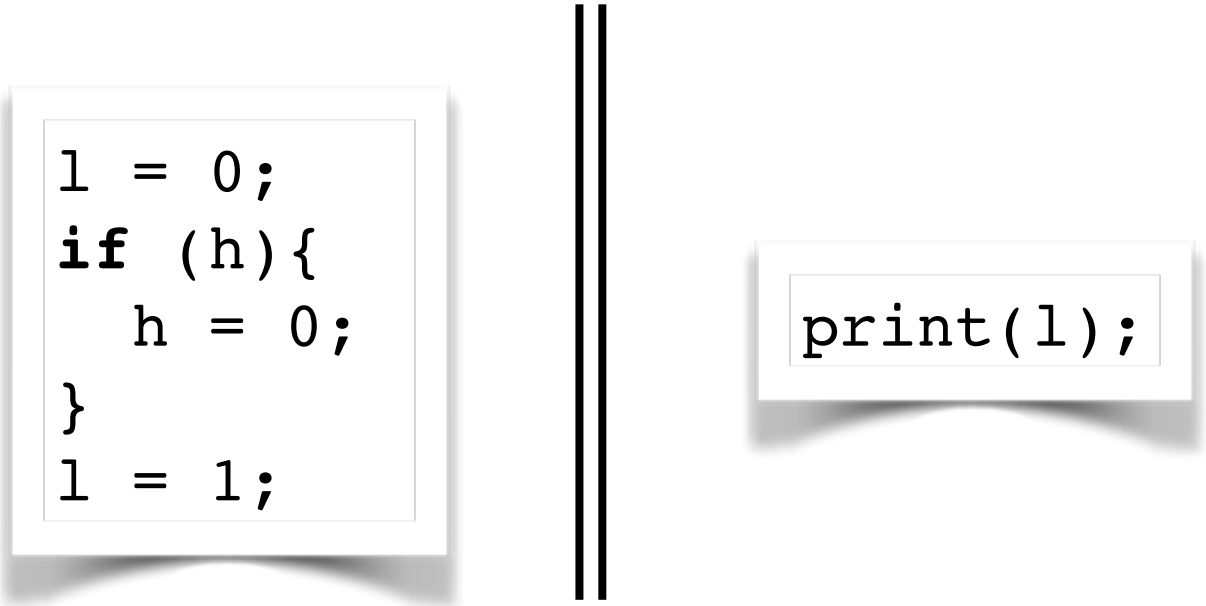

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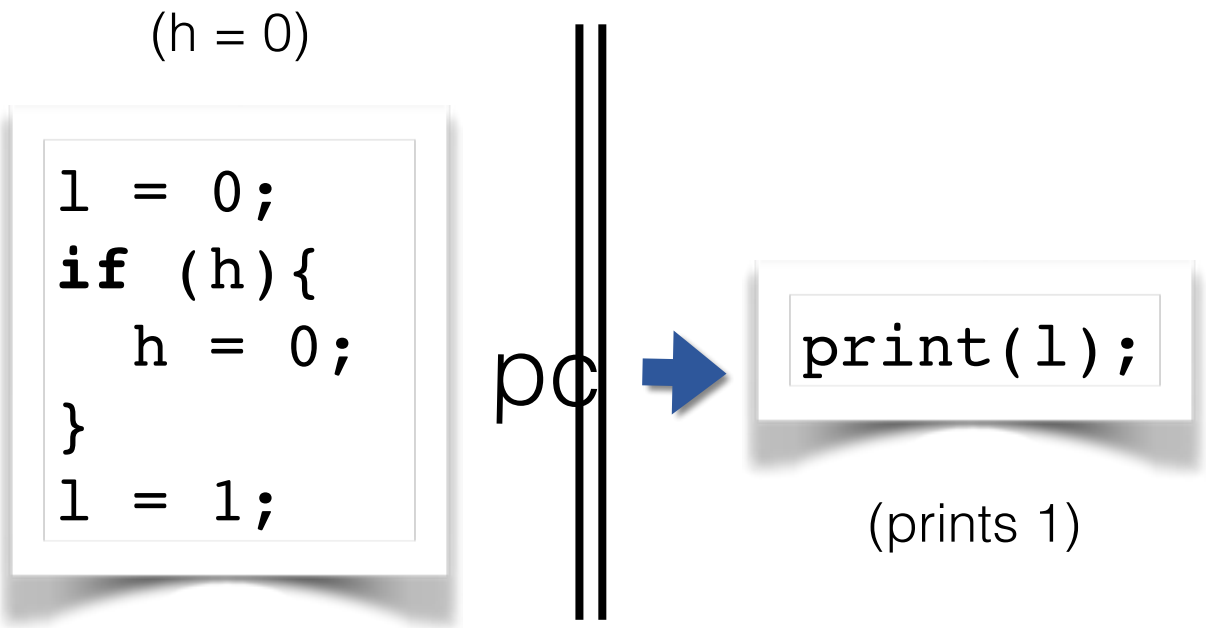

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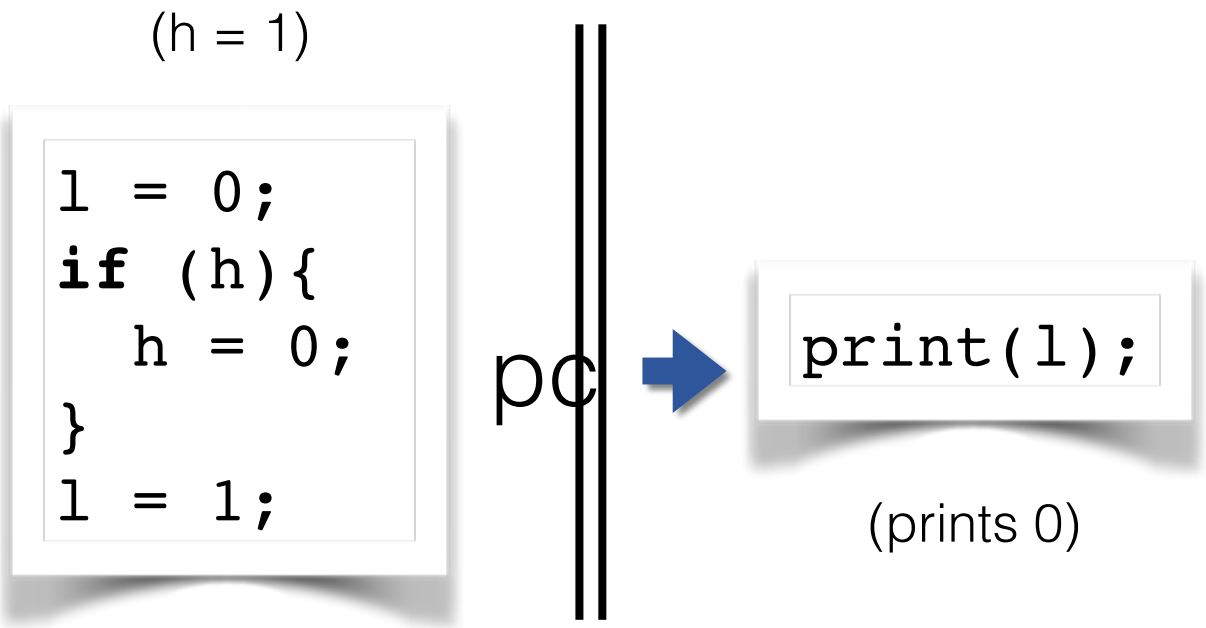

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