

جامعة نيويورك أبوظبي



NYU ABU DHABI

Context Sensitivity

CS-UH 3260

Static Program Analysis

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Previously

- Inter-Procedural Data-Flow
- Inherited vs Synthesized Analysis Info
- Caller-Callee Relationships
- Valid/Invalid Paths
- Staircase of Calls and Returns
- Demand-Driven Analysis
- Types of Contexts
- Important Language Features

How can we conduct
context-sensitive
analyses?

Method Cloning

Method Cloning

```
int i = 0;  
int j = inc(i);  
int k = inc(j);
```

Method Cloning

```
int inc(x){  
    int y = x+1;  
    return y;  
}
```

```
int i = 0;  
int j = inc(i);  
int k = inc(j);
```

Method Cloning

```
int inc1(x){  
    int y = x+1;  
    return y;  
}
```

```
int inc2(x){  
    int y = x+1;  
    return y;  
}
```

```
int i = 0;  
int j = inc1(i);  
int k = inc2(j);
```

Method Cloning

- ✗ Inefficient: too many copies for real programs
- ✗ Expensive operation
- ✗ Recursion!
- ✓ Yet simple and easy to understand

```
int inc1(x){  
    int y = x+1;  
    return y;  
}
```

```
int inc2(x){  
    int y = x+1;  
    return y;  
}
```

```
int i = 0;  
int j = inc1(i);  
int k = inc2(j);
```


Method Inlining

Method Inlining

```
int i = 0;  
int j = inc(i);  
int k = inc(j);
```

Method Inlining

```
int inc(x){  
    int y = x+1;  
    return y;  
}
```

```
int i = 0;  
int j = inc(i);  
int k = inc(j);
```

Method Inlining

```
int inc(x){  
    int y = x+1;  
    return y;  
}
```

```
int i = 0;
```

```
int x1 = i;
```

```
int y1 = x1+1;
```

```
int j = y1;
```

```
int k = inc(j);
```

Method Inlining

```
int i = 0;
```

```
int x1 = i;
```

```
int y1 = x1+1;
```

```
int j = y1;
```

```
int x2 = j;
```

```
int y2 = x2+1;
```

```
int k = y2;
```

Method Inlining

- ✗ Lost procedure abstraction
- ✗ Exponential blow-up
- ✗ Recursion!
- ✓ One procedure => intra-procedural

```
int i = 0;
```

```
int x1 = i;  
int y1 = x1+1;  
int j = y1;
```

```
int x2 = j;  
int y2 = x2+1;  
int k = y2;
```

... so what do we do?

Context Sensitivity

Context Sensitivity

Call Strings

Functional

Context Sensitivity

Call Strings

- Extend facts with context strings
- Re-evaluate procedure for each extension
- ✓ Universally applicable
- ✗ Recursion!

Context Sensitivity

Functional

- Compute summary function per callee
- Apply summary to each context
- ✓ Recursion!
- ✗ Not always applicable

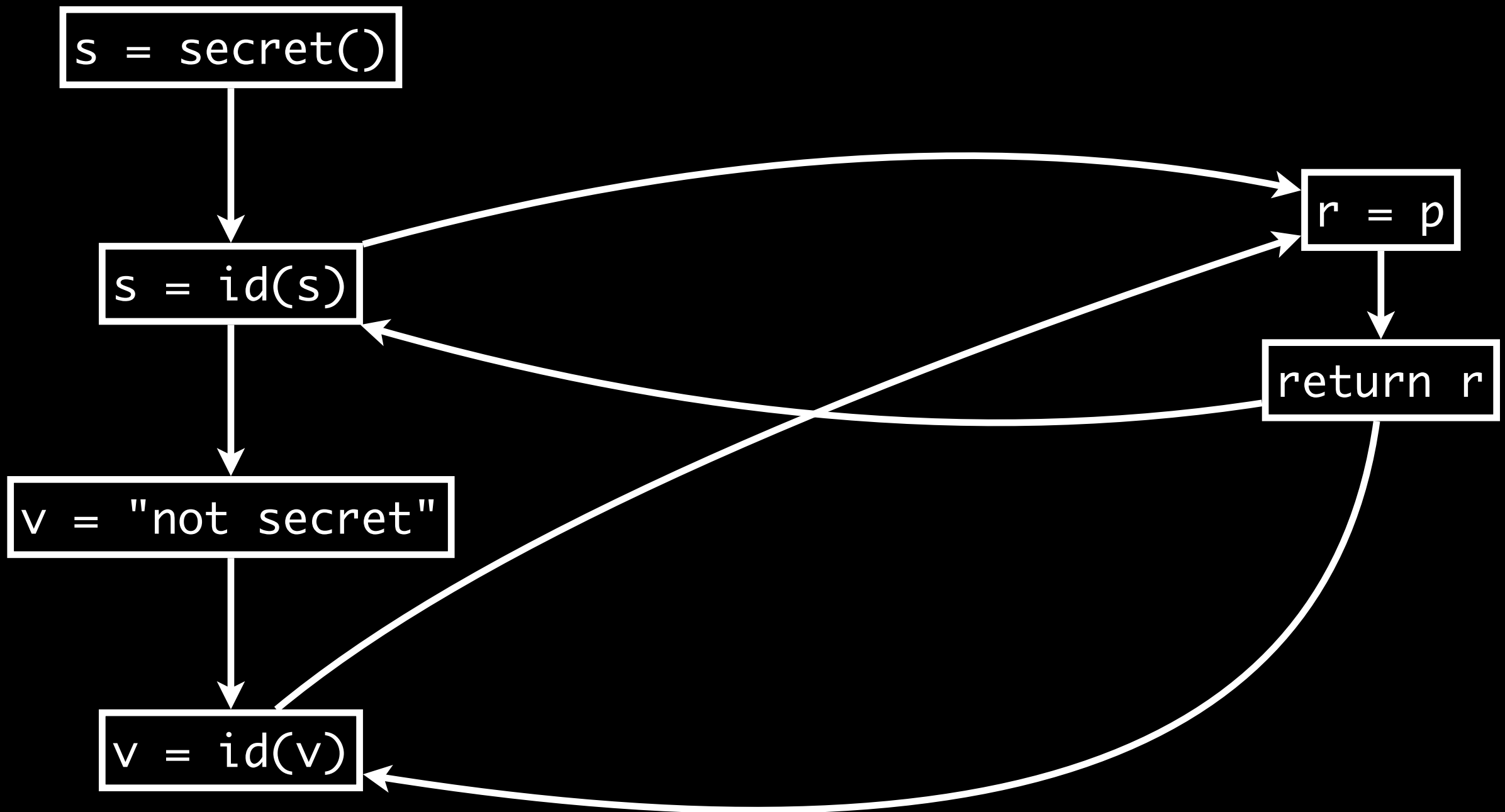
Call Strings

Call Strings

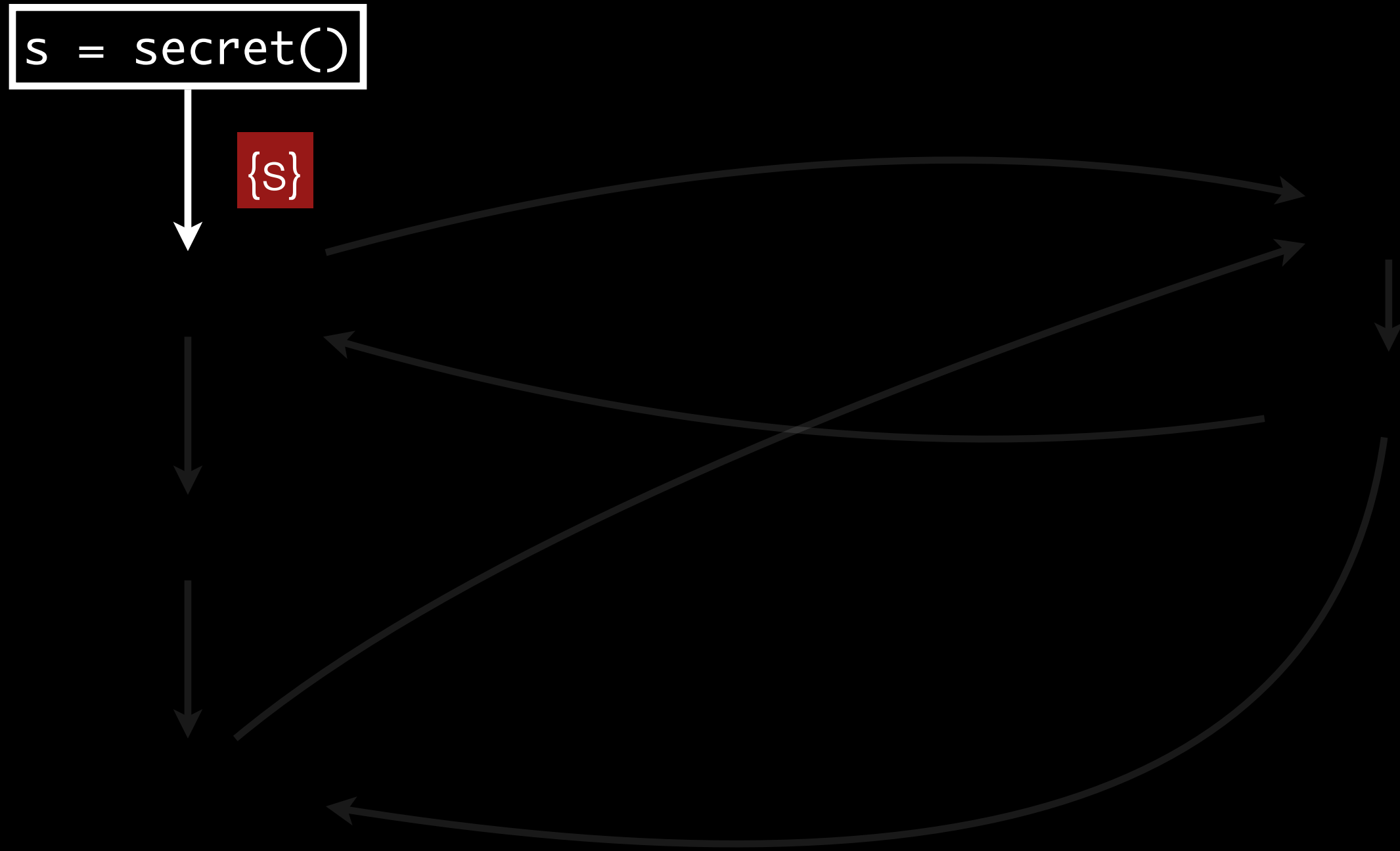
```
main(){  
    s = secret();  
    s = id(s);  
    v = "not secret";  
    v = id(v);  
}
```

```
id(p){  
    r = p;  
    return r;  
}
```

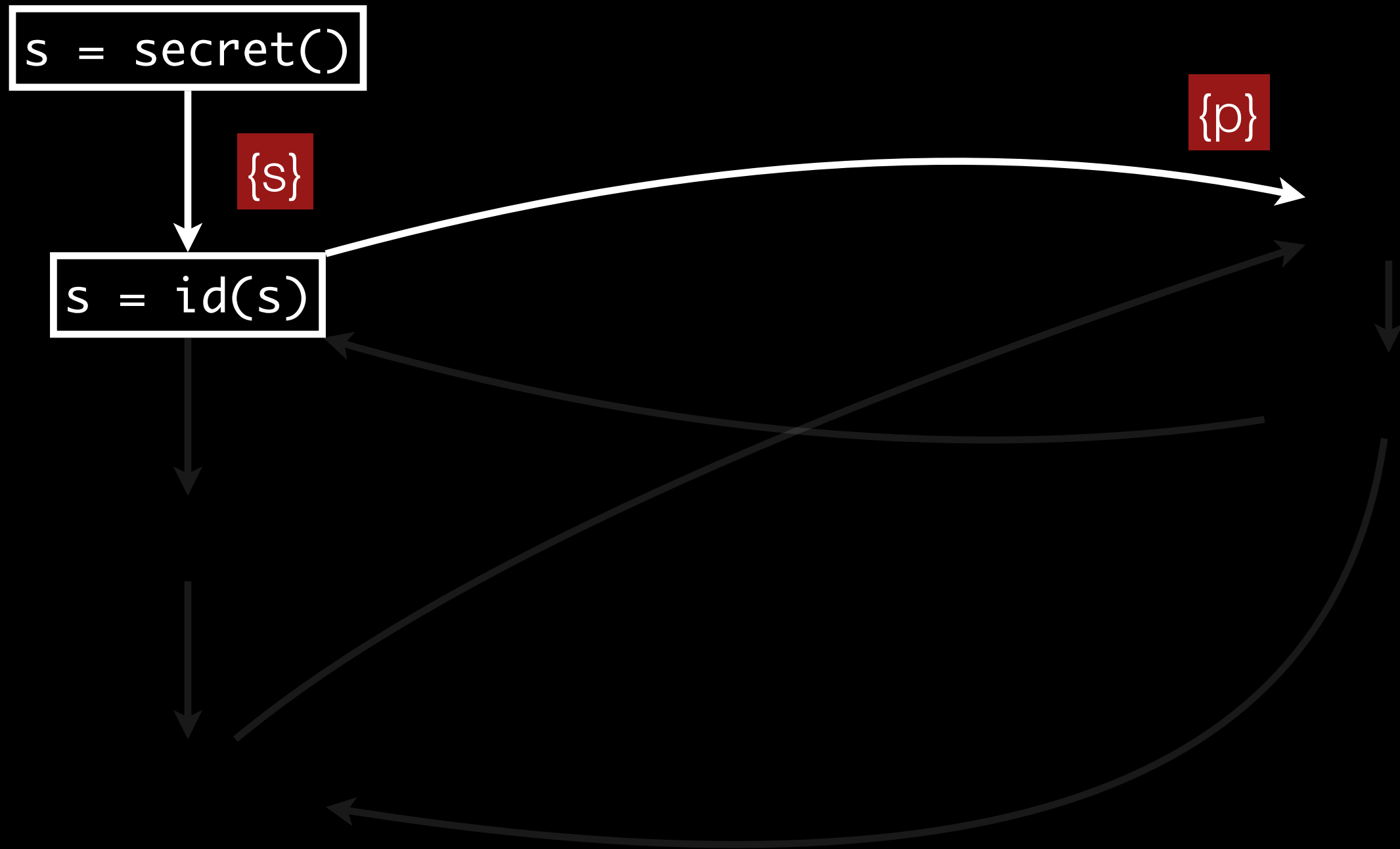
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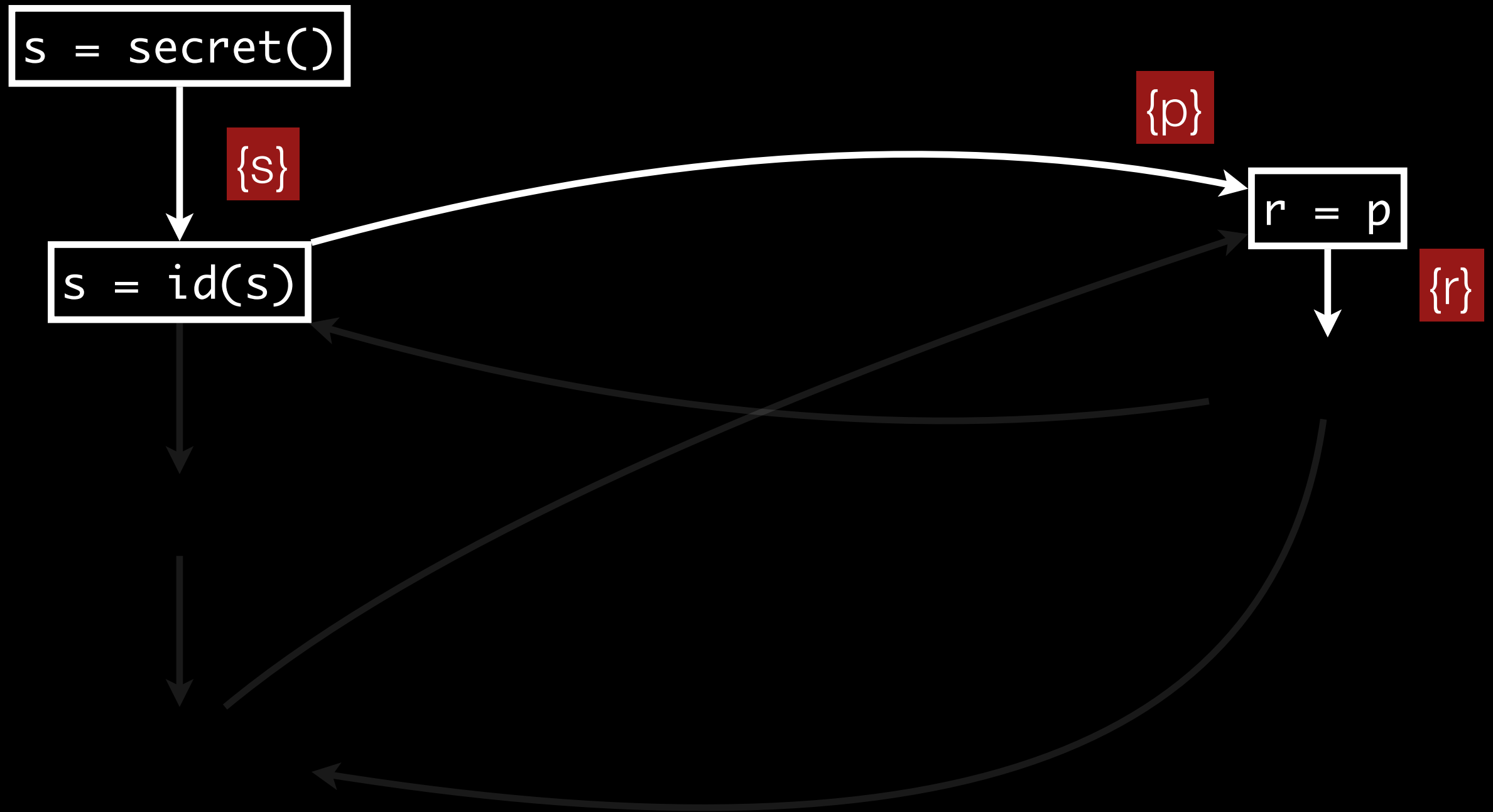
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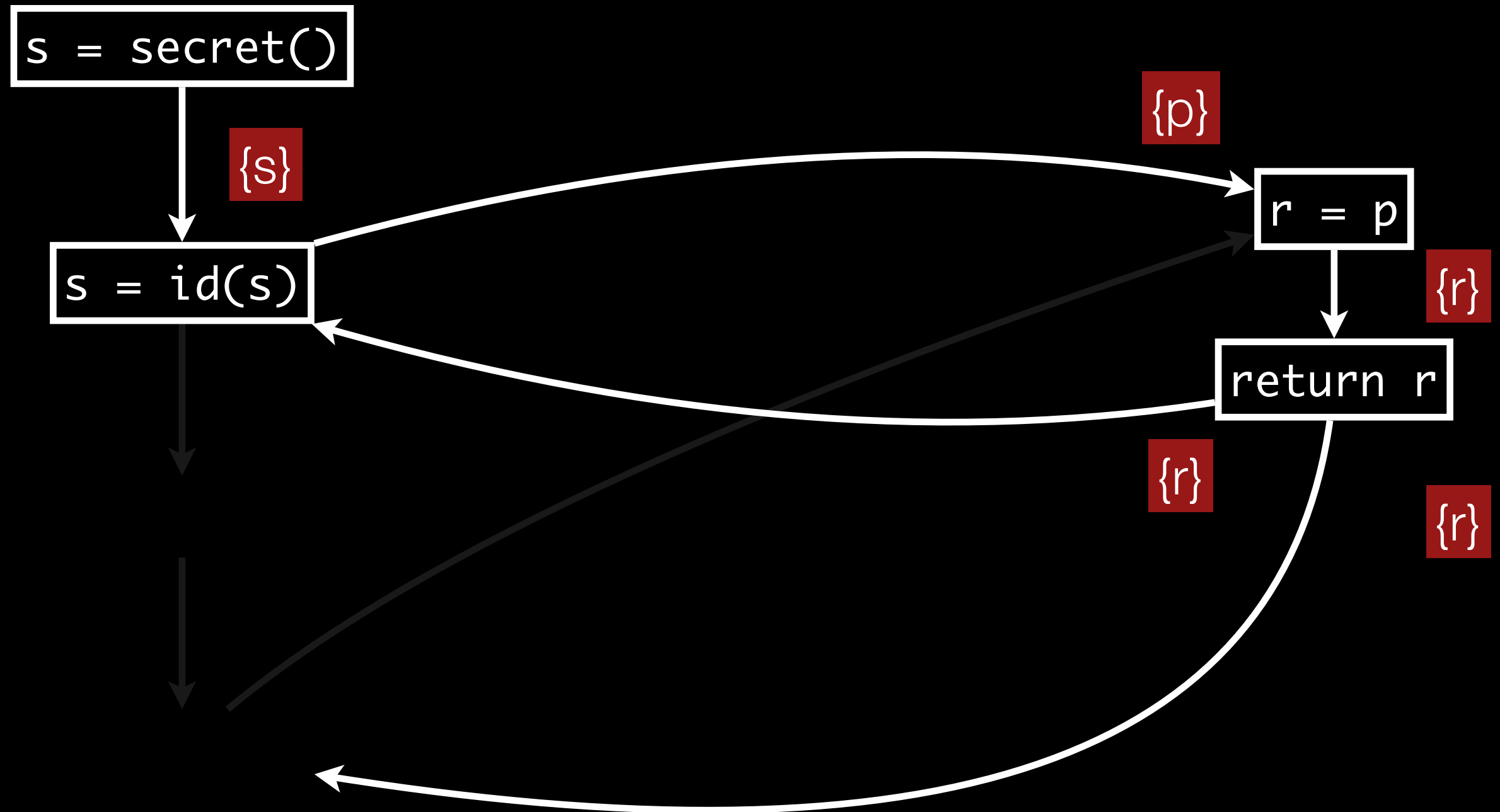
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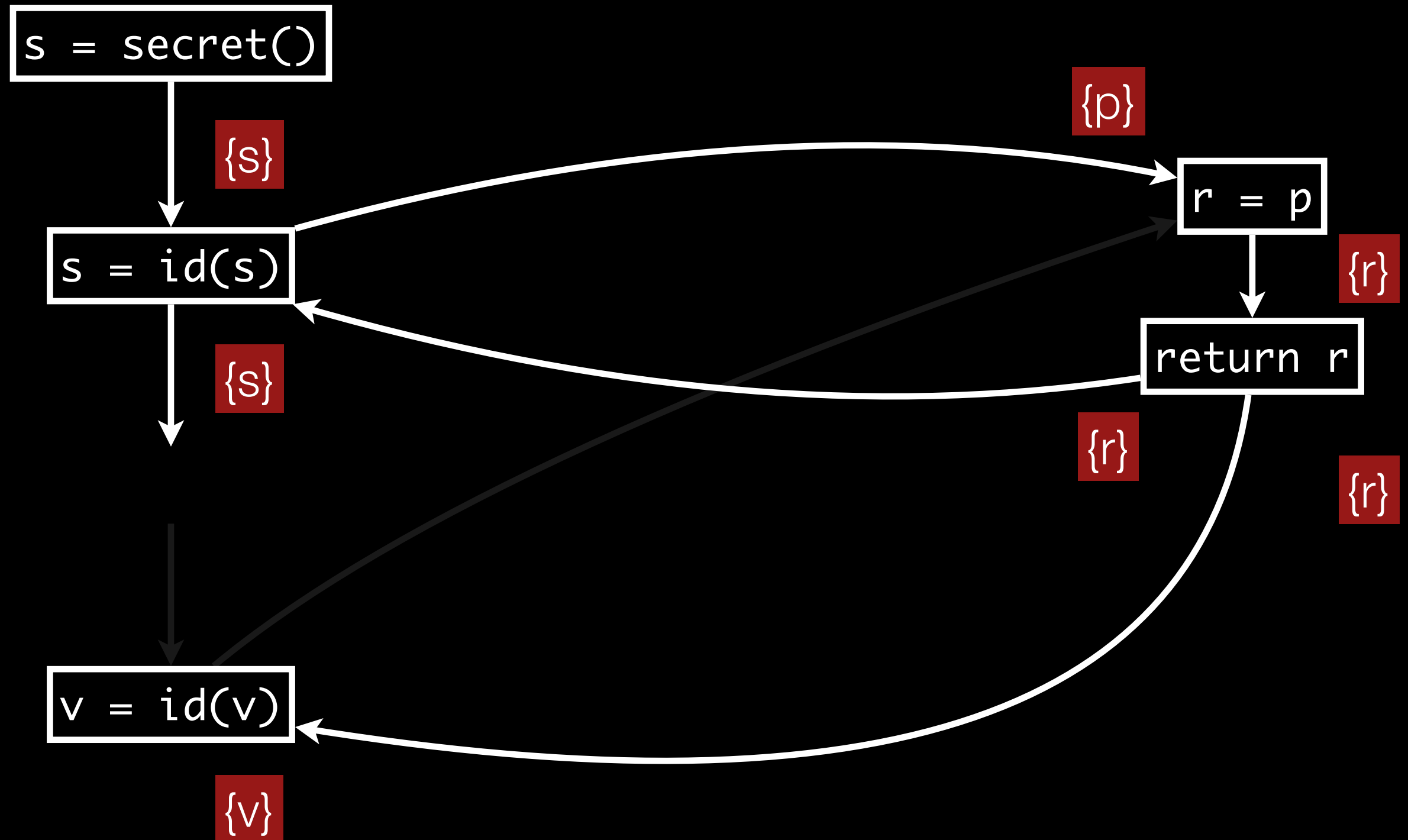
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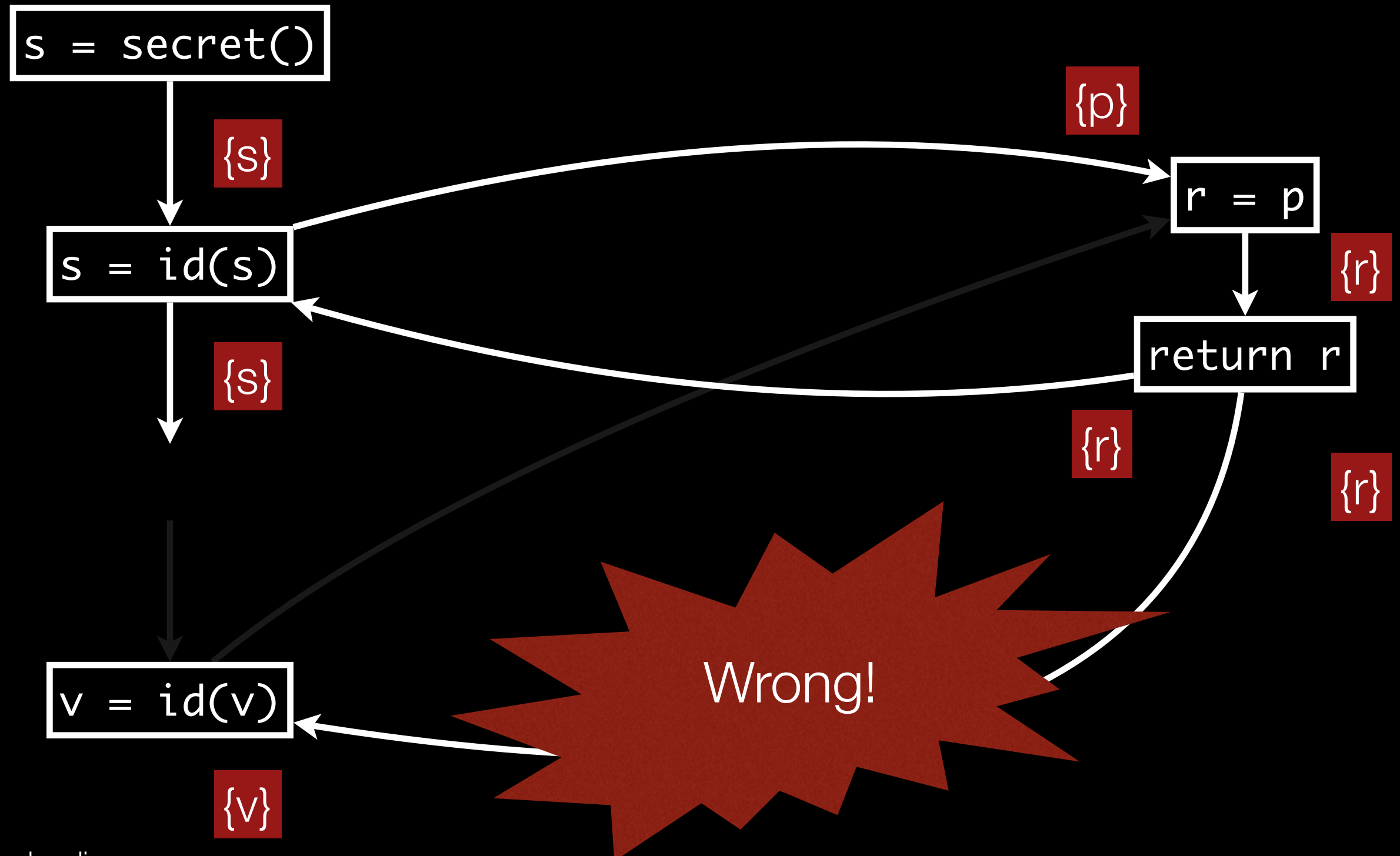
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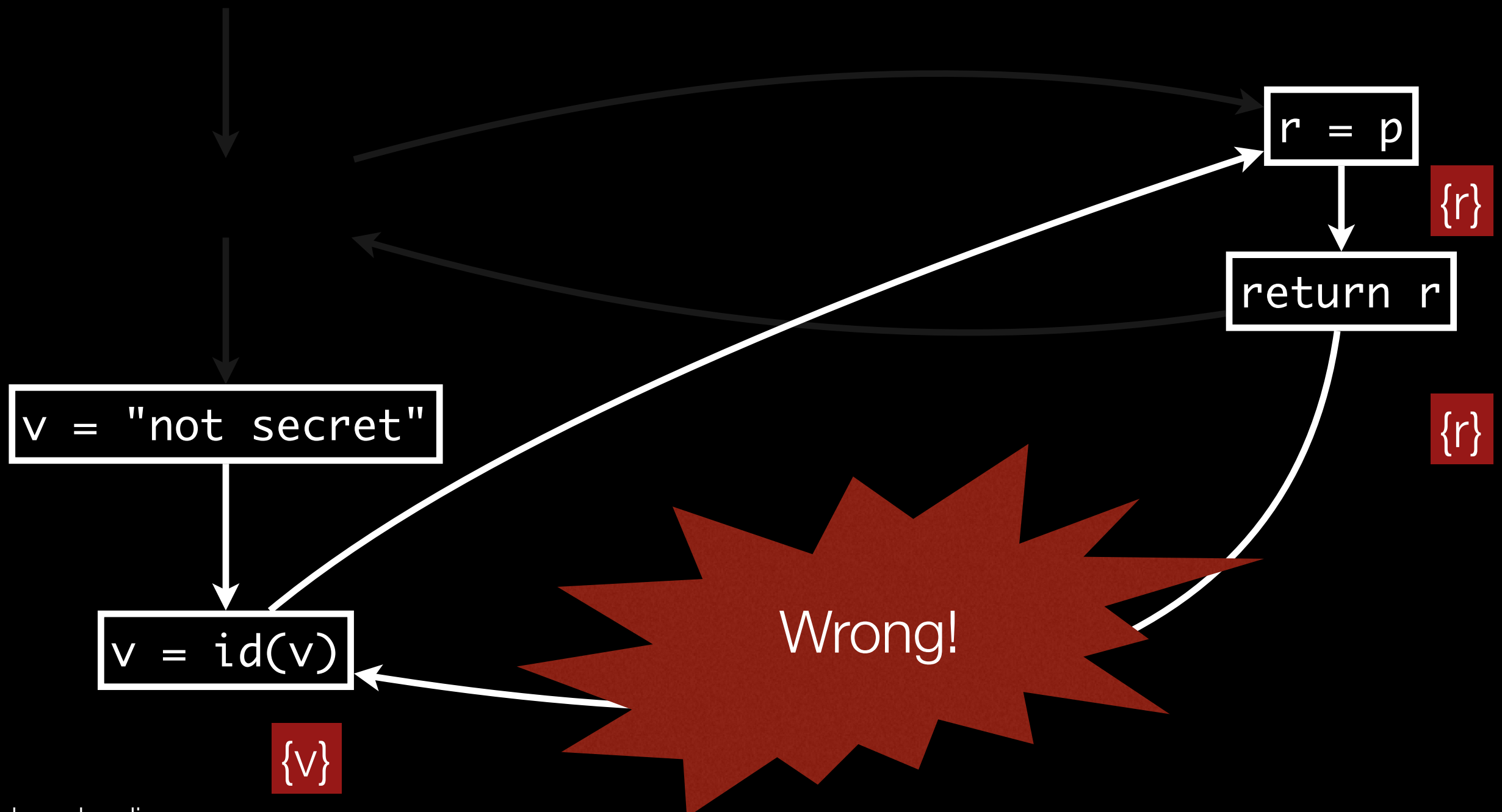
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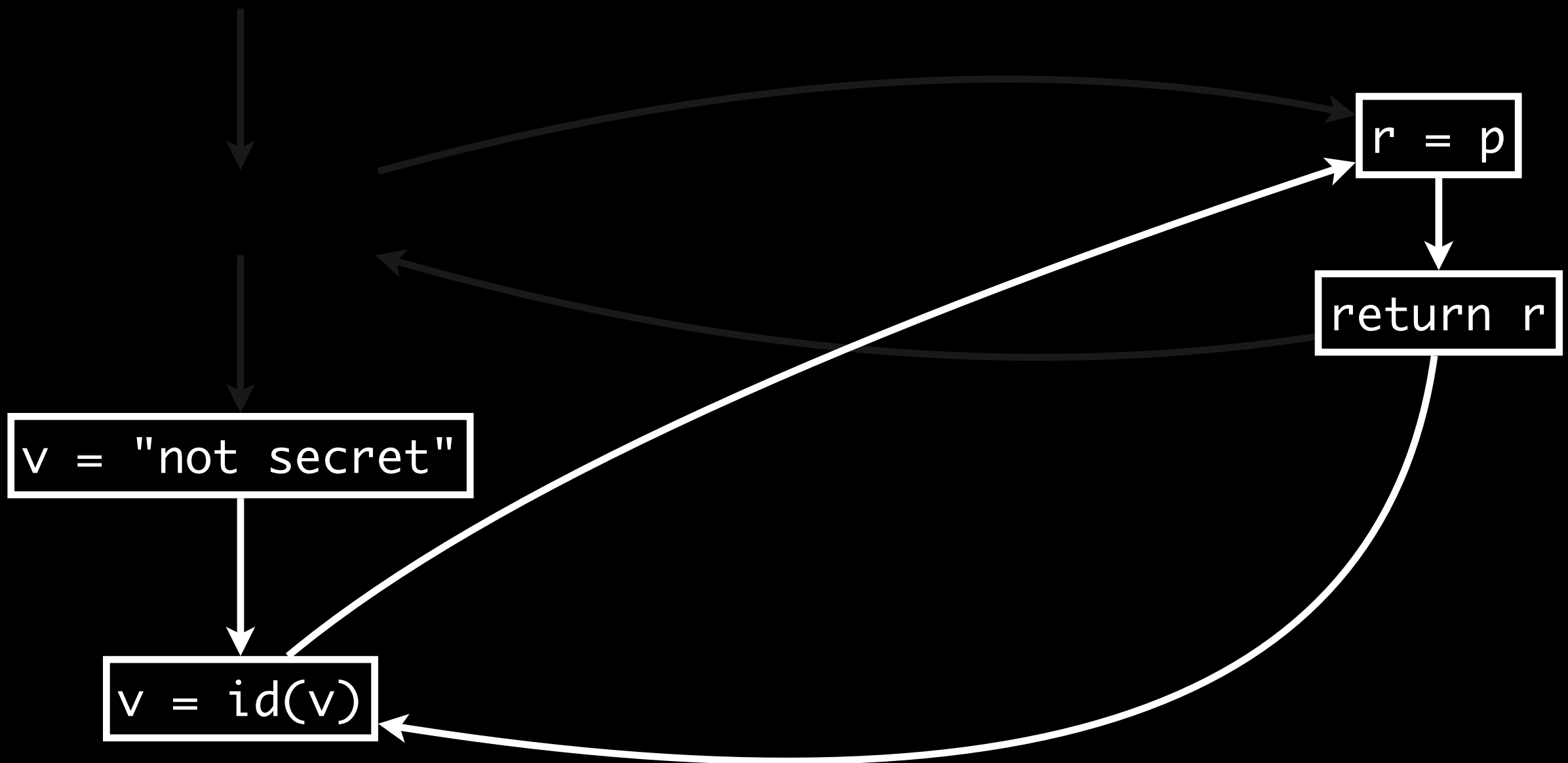
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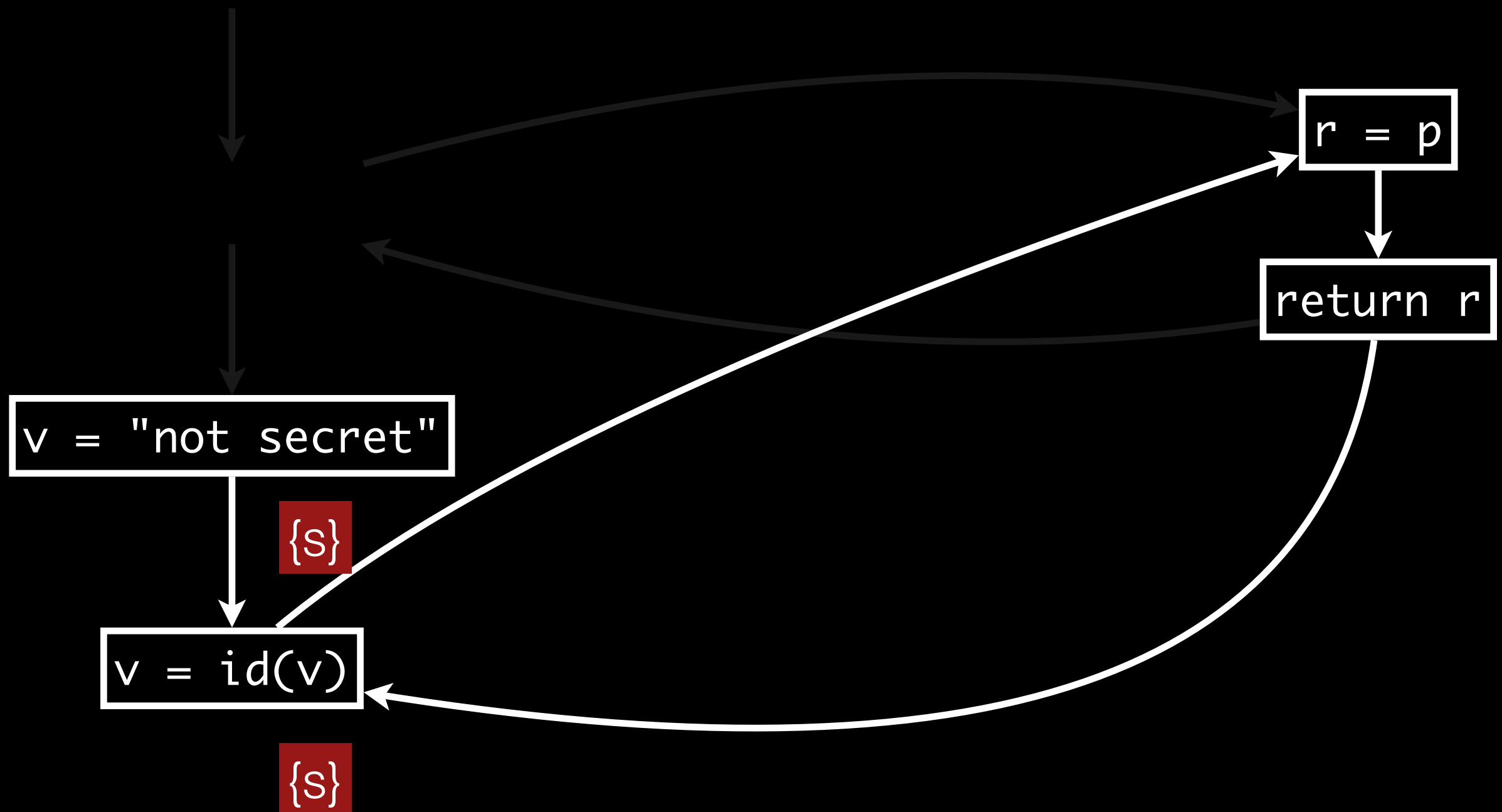
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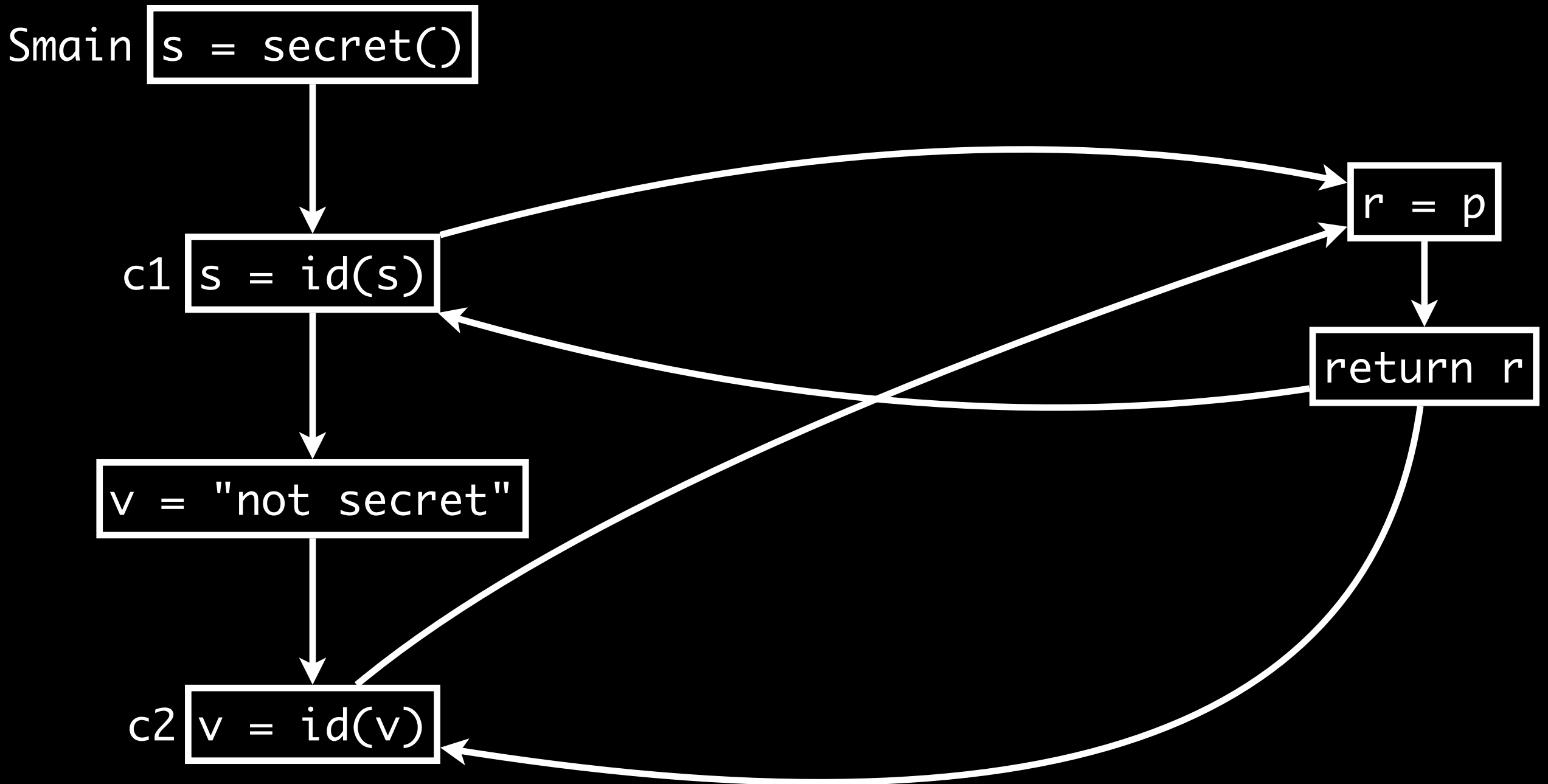
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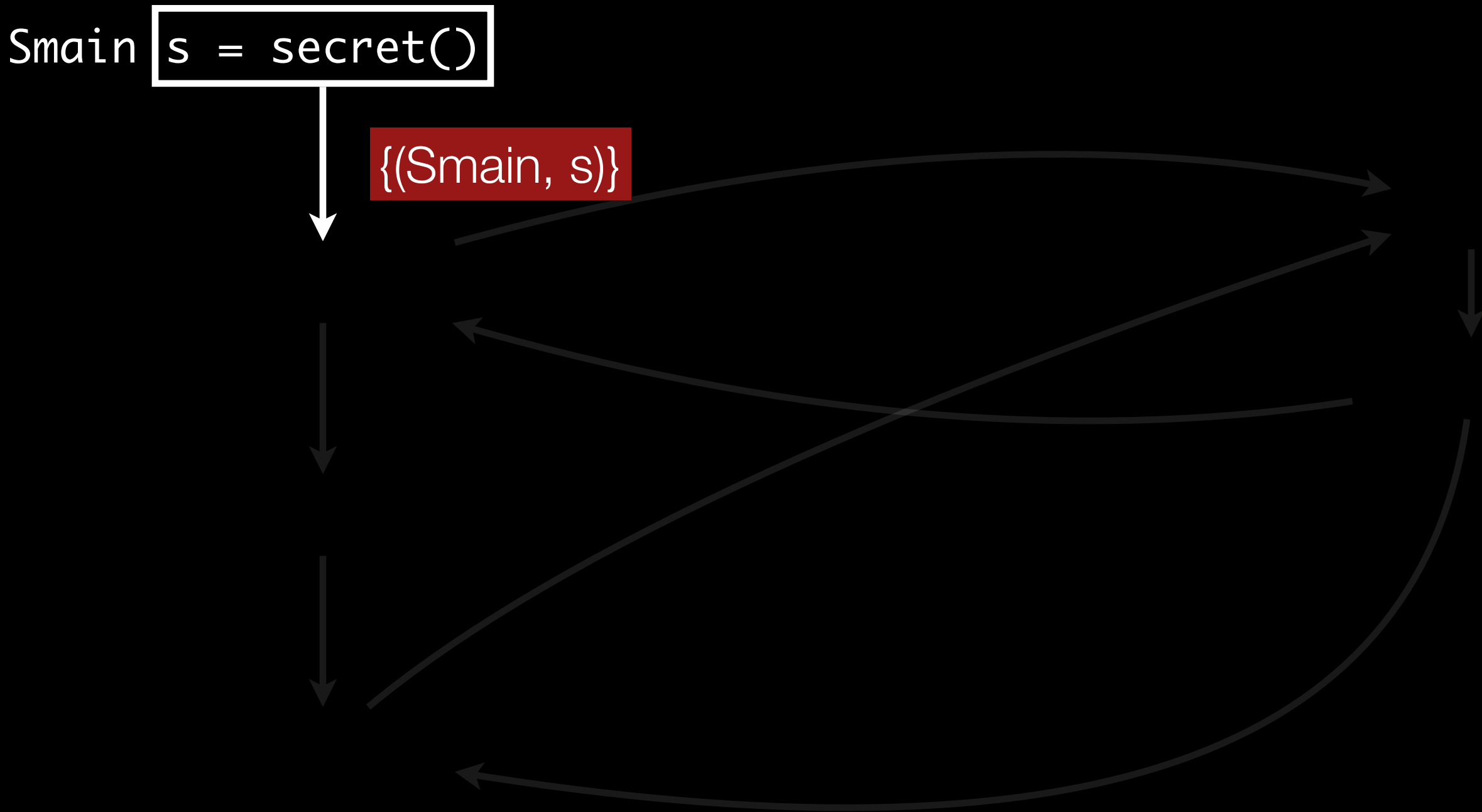
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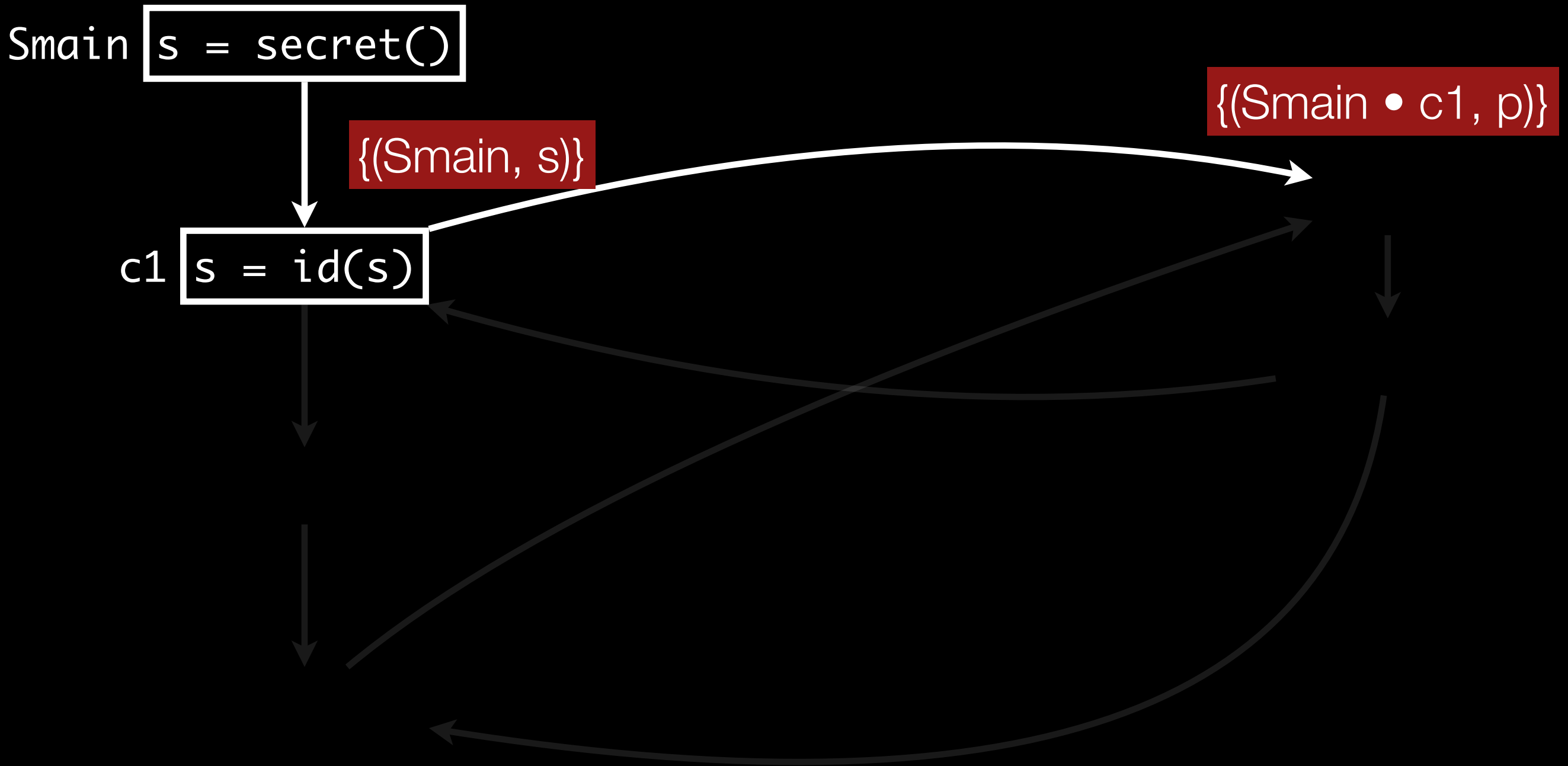
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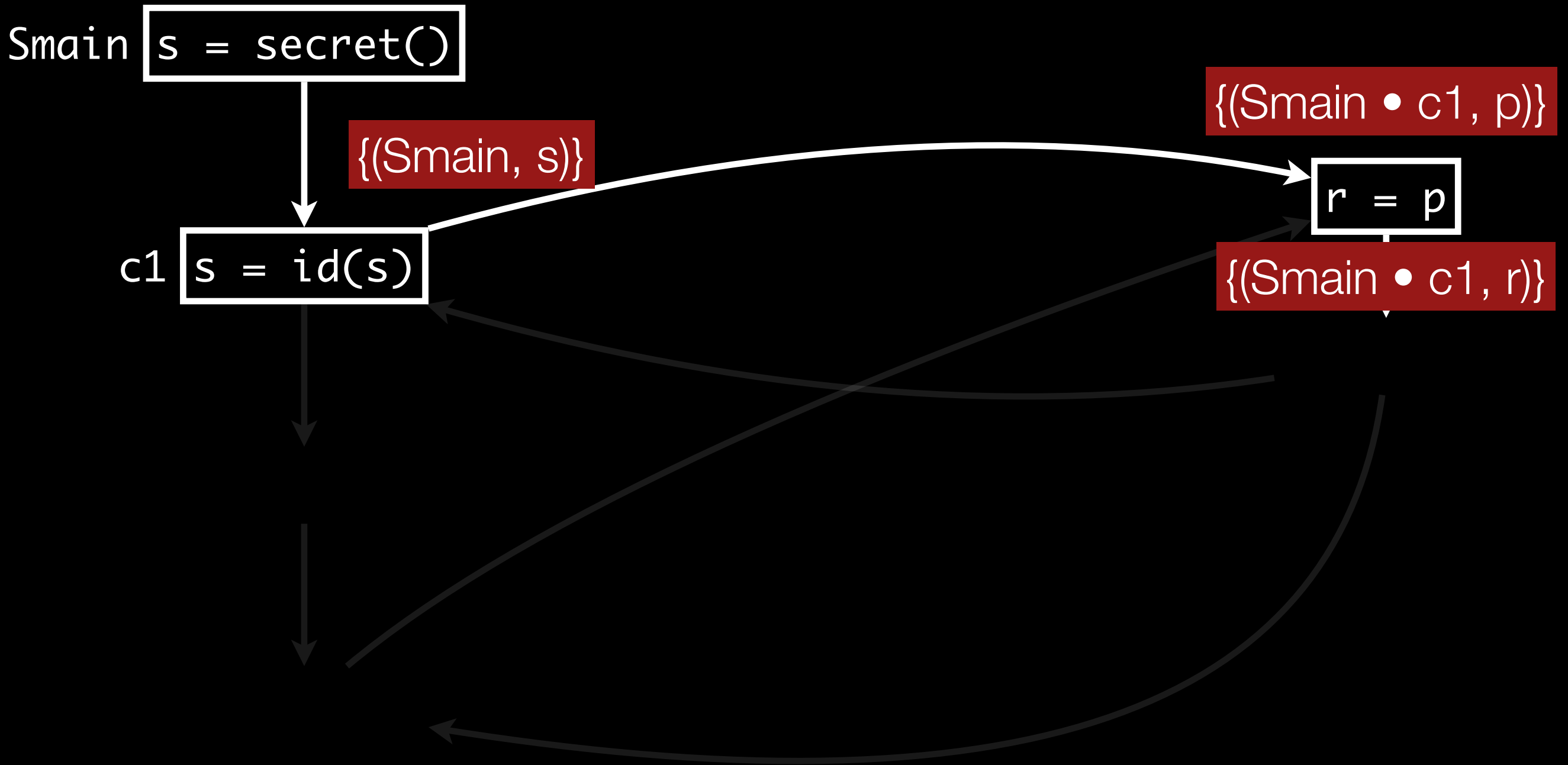
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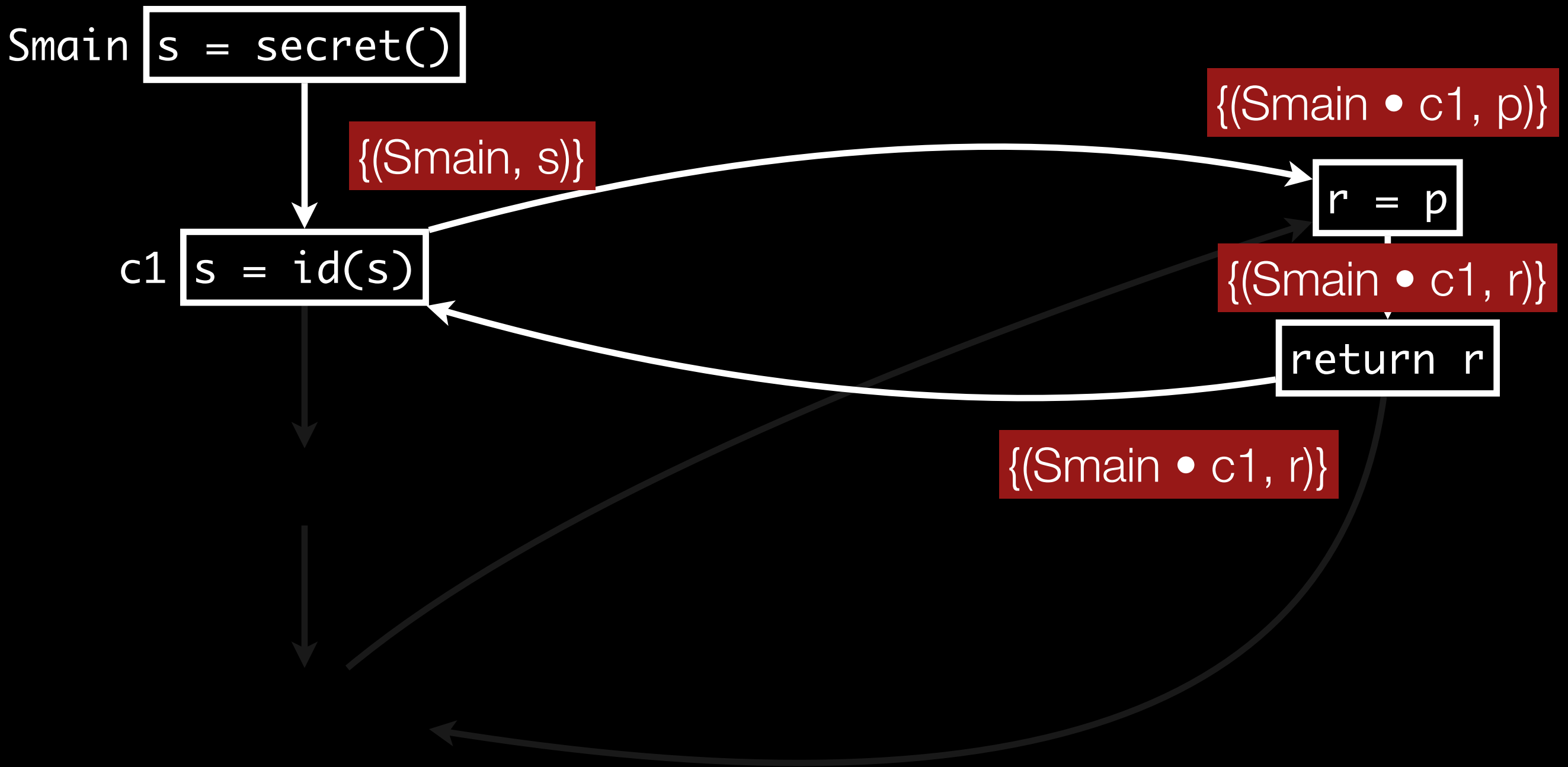
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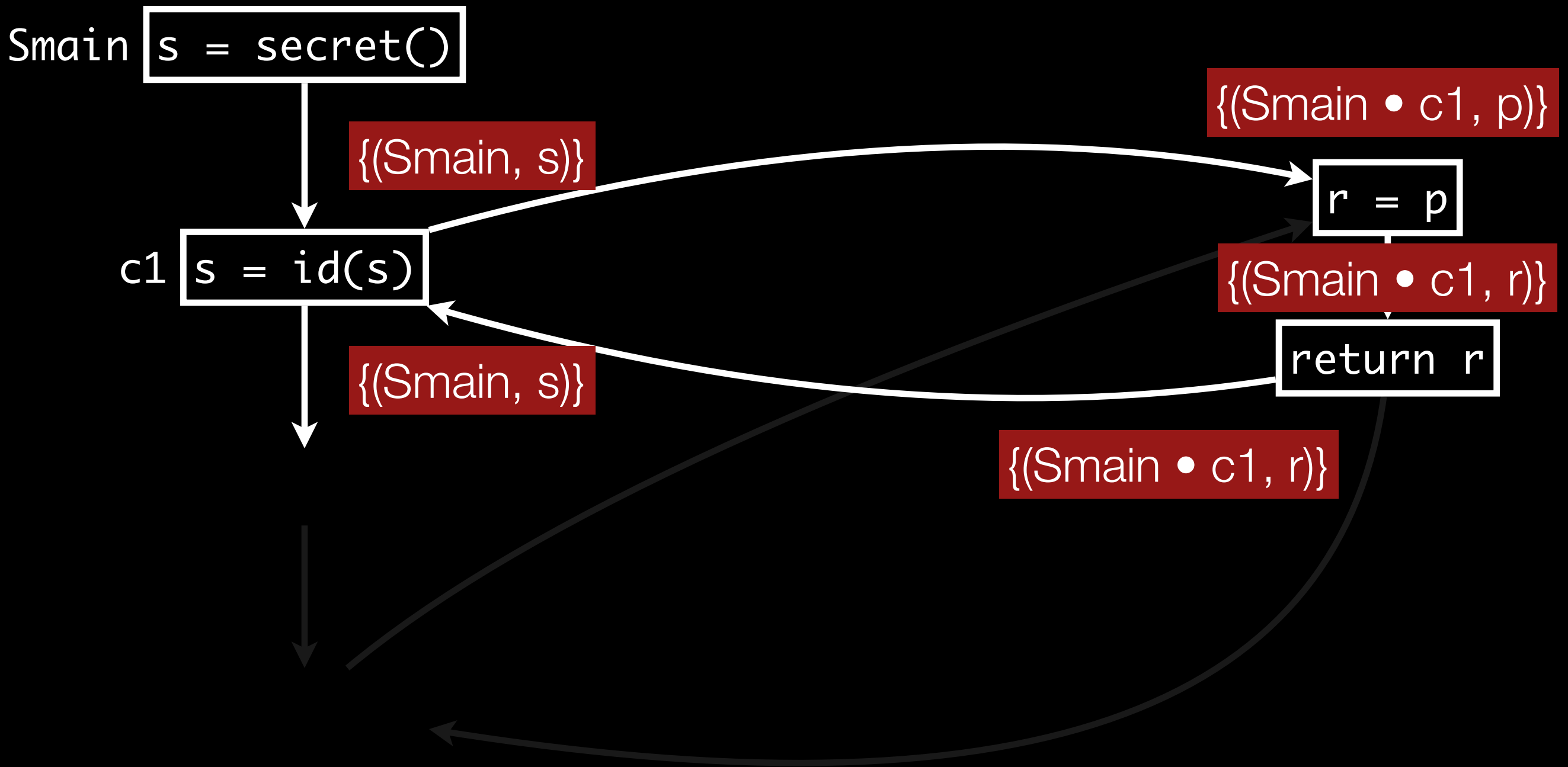
Call Strings



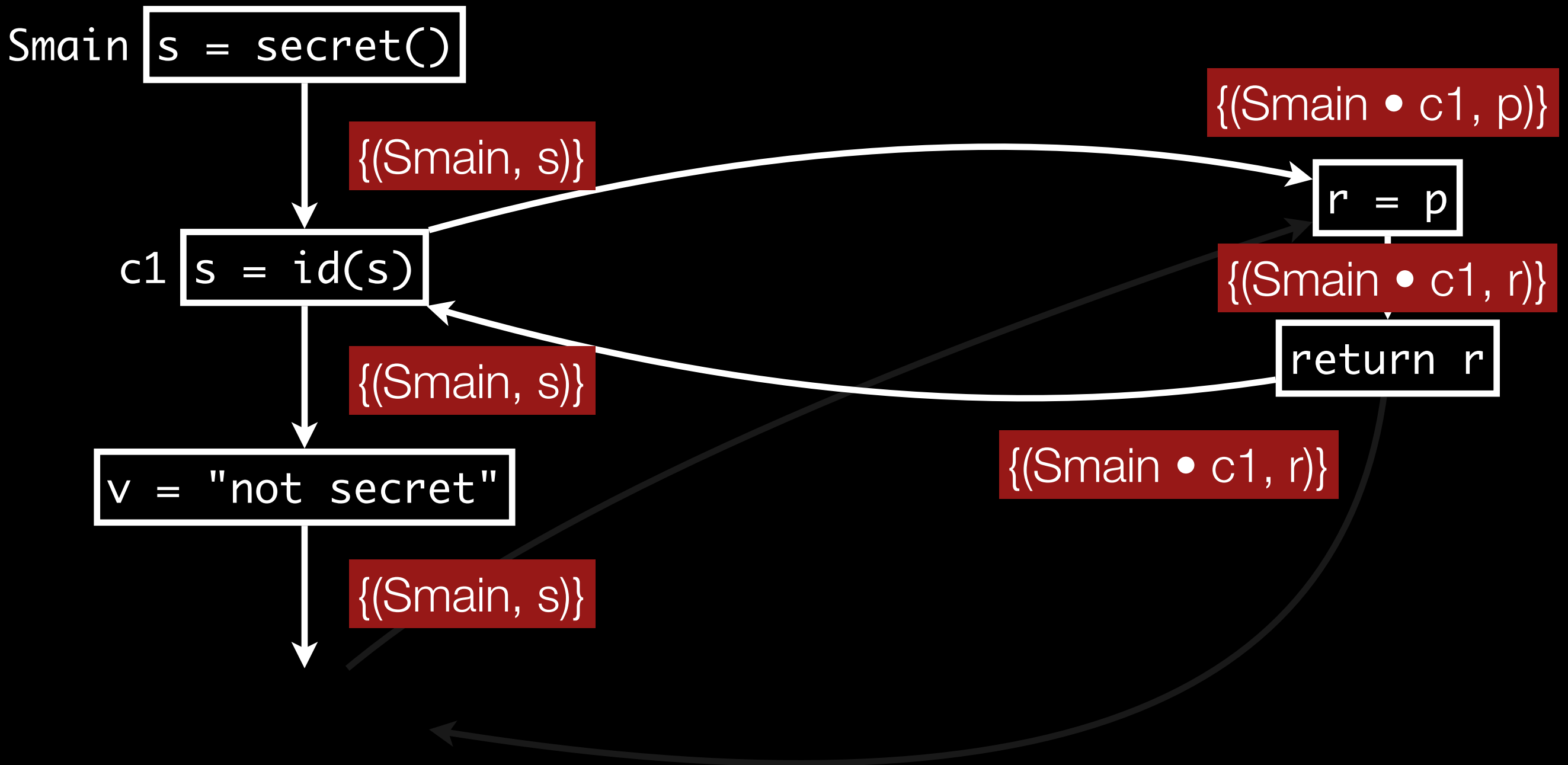
Call Strings



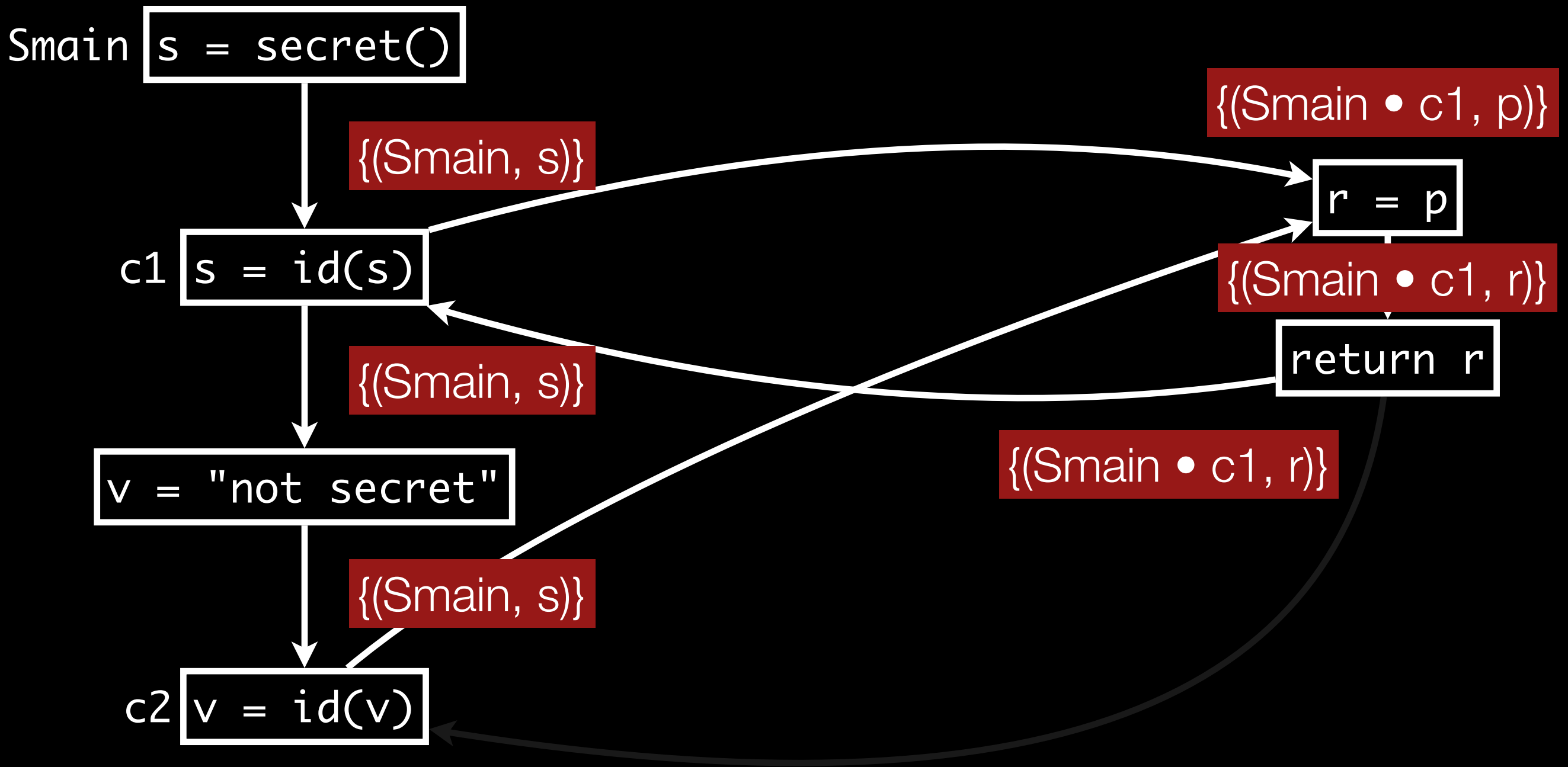
Call Strings



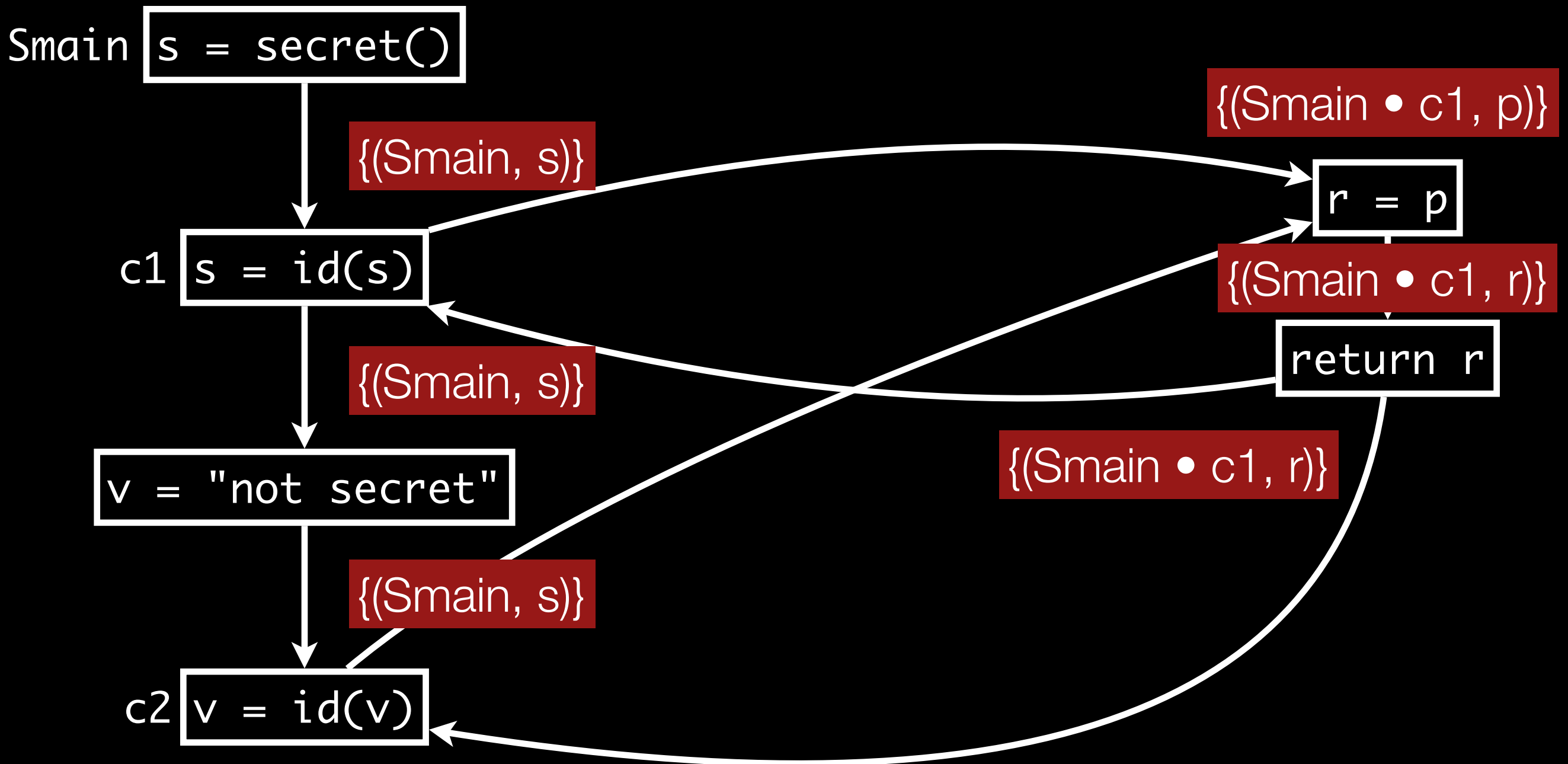
Call Strings



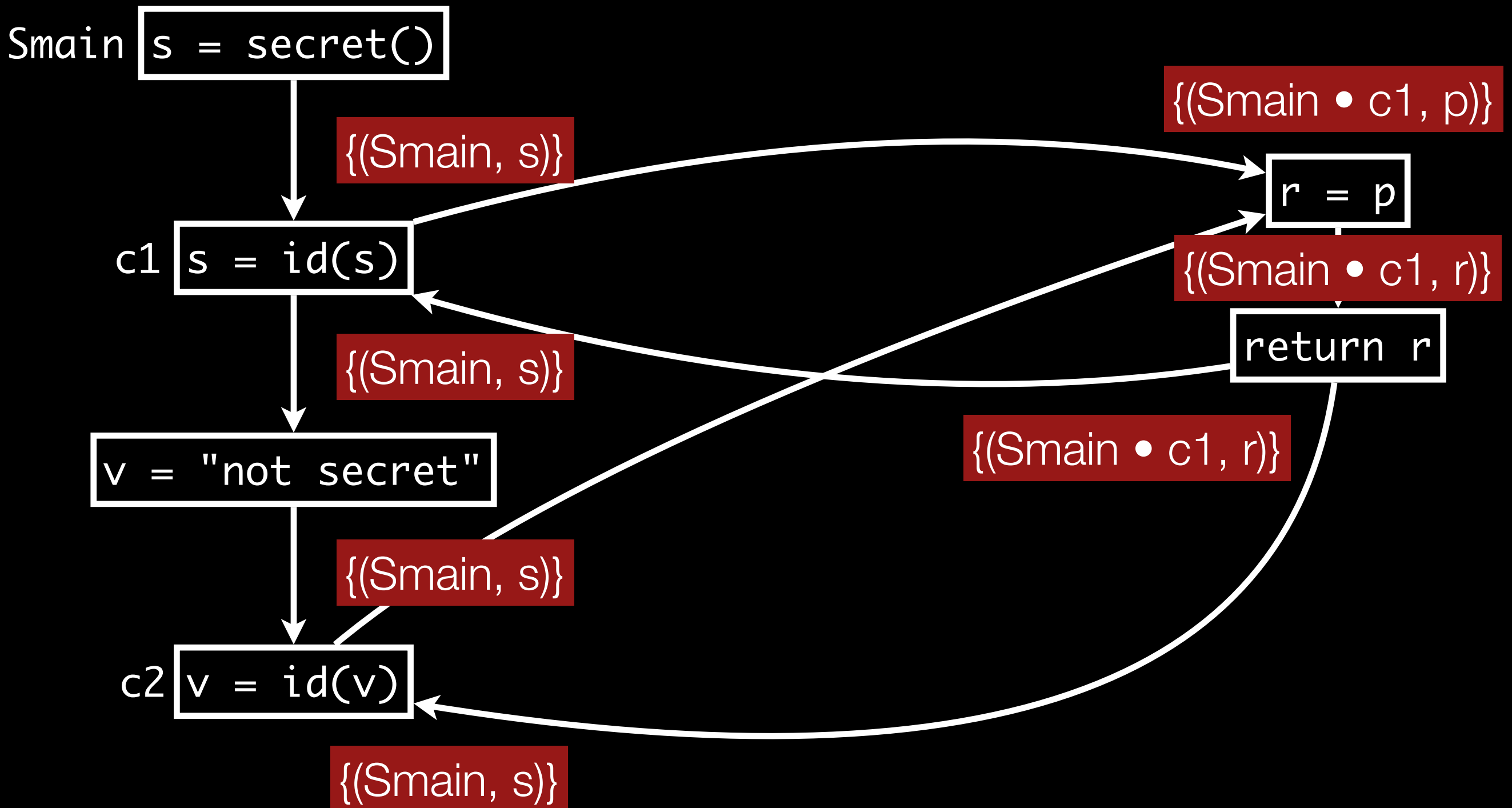
Call Strings



Call Strings



Call Strings



Call Strings

General Algorithm

- Call edges push call site to the stack of calling contexts of each propagated value
- Return edges return only to method on top of the stack of calling contexts
- Handle merge points

Call Strings

Merging Facts

$$\begin{aligned} X \uplus Y = & \{ \langle \sigma, x \sqcup y \rangle \mid \langle \sigma, x \rangle \in X, \langle \sigma, y \rangle \in Y \} \cup \\ & \{ \langle \sigma, x \rangle \mid \langle \sigma, x \rangle \in X, \forall z \in L, \langle \sigma, z \rangle \notin Y \} \cup \\ & \{ \langle \sigma, y \rangle \mid \langle \sigma, y \rangle \in Y, \forall z \in L, \langle \sigma, z \rangle \notin X \} \end{aligned}$$



Not quite...

Problem:
context length!



Small $k \Rightarrow$
imprecise

Solution:
 k -limiting



large $k \Rightarrow$
poor performance

... but how does it
work anyways?

Call Strings k-limiting

$k()$



C_a



$a()$

$(C_0 \bullet C_1 \bullet \dots \bullet C_k)$

maintain suffix of length k

$(C_1 \bullet \dots \bullet C_k \bullet C_a)$

Call Strings k-limiting

- K = length of longest non-recursive call sequence
- $|L|$ = lattice height
- $\# \text{ contexts} = K * (|L| + 1)^2$
- Khedker and Karkare [CC '08]
improved this bound to $K * (|L| + 1)$

Call Strings Recap

- Cloning vs inlining
- Context as string
- Merging call strings
- Context length
- K-limiting

Functional Approach

Functional Approach

... but why bother?

Functional Approach

```
h.f = myPassword();  
i.f = myPhoneNo();  
j.f = myCreditCardNo();
```

```
c1 foo(h,x);  
c2 foo(i,y);  
c3 foo(j,z);
```

```
print(x.g);  
print(y.g);  
print(z.g);
```

```
foo(a,b) {  
    c = a.f;  
    b.g = c;  
}
```

Functional Approach

```
h.f = myPassword();  
i.f = myPhoneNo();  
j.f = myCreditCardNo();
```

```
c1 foo(h,x);  
c2 foo(i,y);  
c3 foo(j,z);
```

```
print(x.g);  
print(y.g);  
print(z.g);
```

```
foo(a,b) {  
    c = a.f;  
    b.g = c;  
}
```

(a.f, c1)
(b.g, c1)

Functional Approach

```
h.f = myPassword();  
i.f = myPhoneNo();  
j.f = myCreditCardNo();
```

```
c1 foo(h, x);  
c2 foo(i, y);  
c3 foo(j, z);
```

```
print(x.g);  
print(y.g);  
print(z.g);
```

```
foo(a, b) {  
    c = a.f;  
    b.g = c;  
}
```

(a.f, c2)

(b.g, c2)

Functional Approach

```
h.f = myPassword();  
i.f = myPhoneNo();  
j.f = myCreditCardNo();
```

```
c1 foo(h,x);  
c2 foo(i,y);  
c3 foo(j,z);
```

```
print(x.g);  
print(y.g);  
print(z.g);
```

```
foo(a,b) {  
    c = a.f;  
    b.g = c;  
}
```

(a.f, c3)
(b.g, c3)

Functional Approach

```
h.f = myPassword();  
i.f = myPhoneNumber();  
j.f = myEmailPassword();
```

Same method
analyzed 3 times!!

```
print(x.g);  
print(y.g);  
print(z.g);
```

```
foo(a,b) {  
  c = a.f;  
  b.g = c;  
}
```

(a.f, c1)
(a.f, c2)
(a.f, c3)

(b.g, c3)
(b.g, c2)
(b.g, c1)

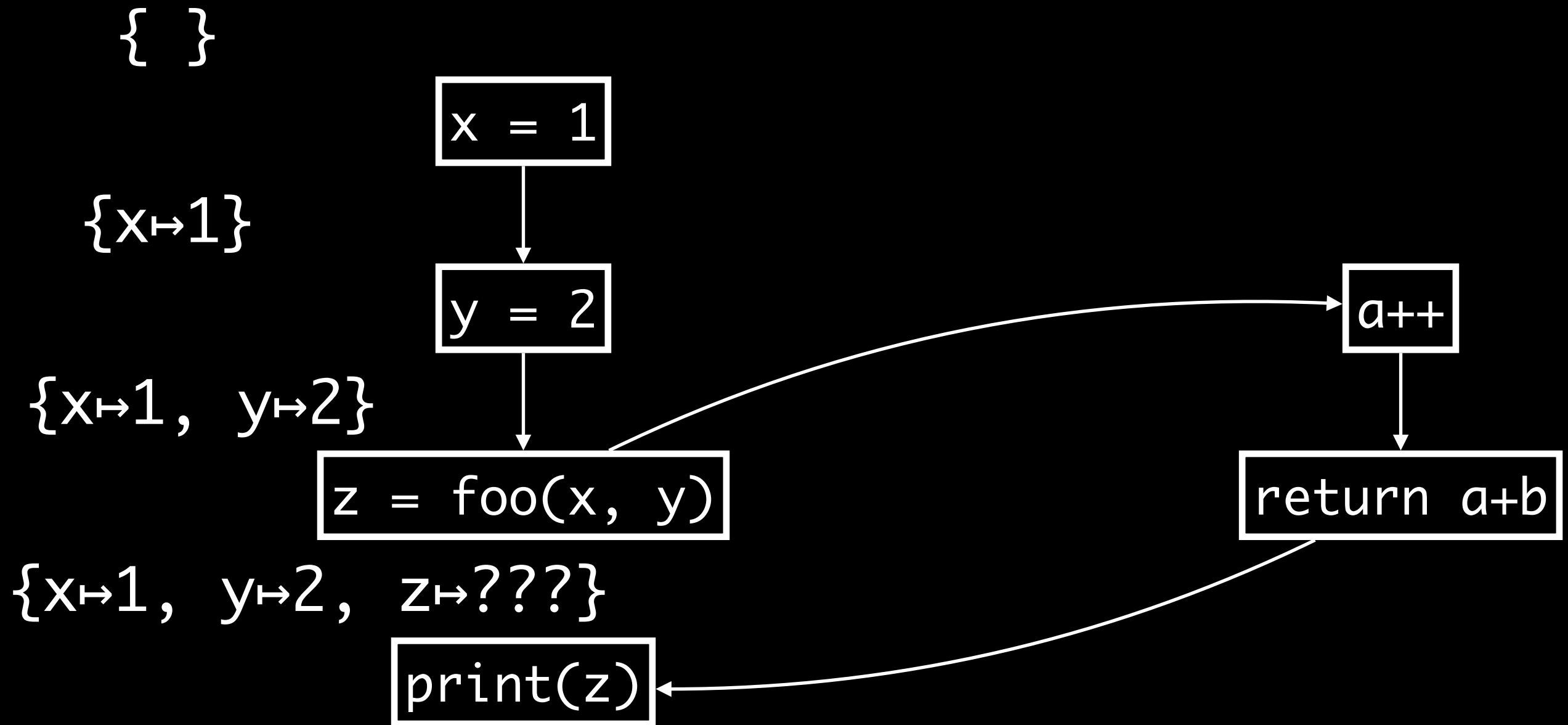
Functional Approach

Example: Constant Propagation

```
foo(a,b) {  
    a++;  
    return a+b;  
}
```

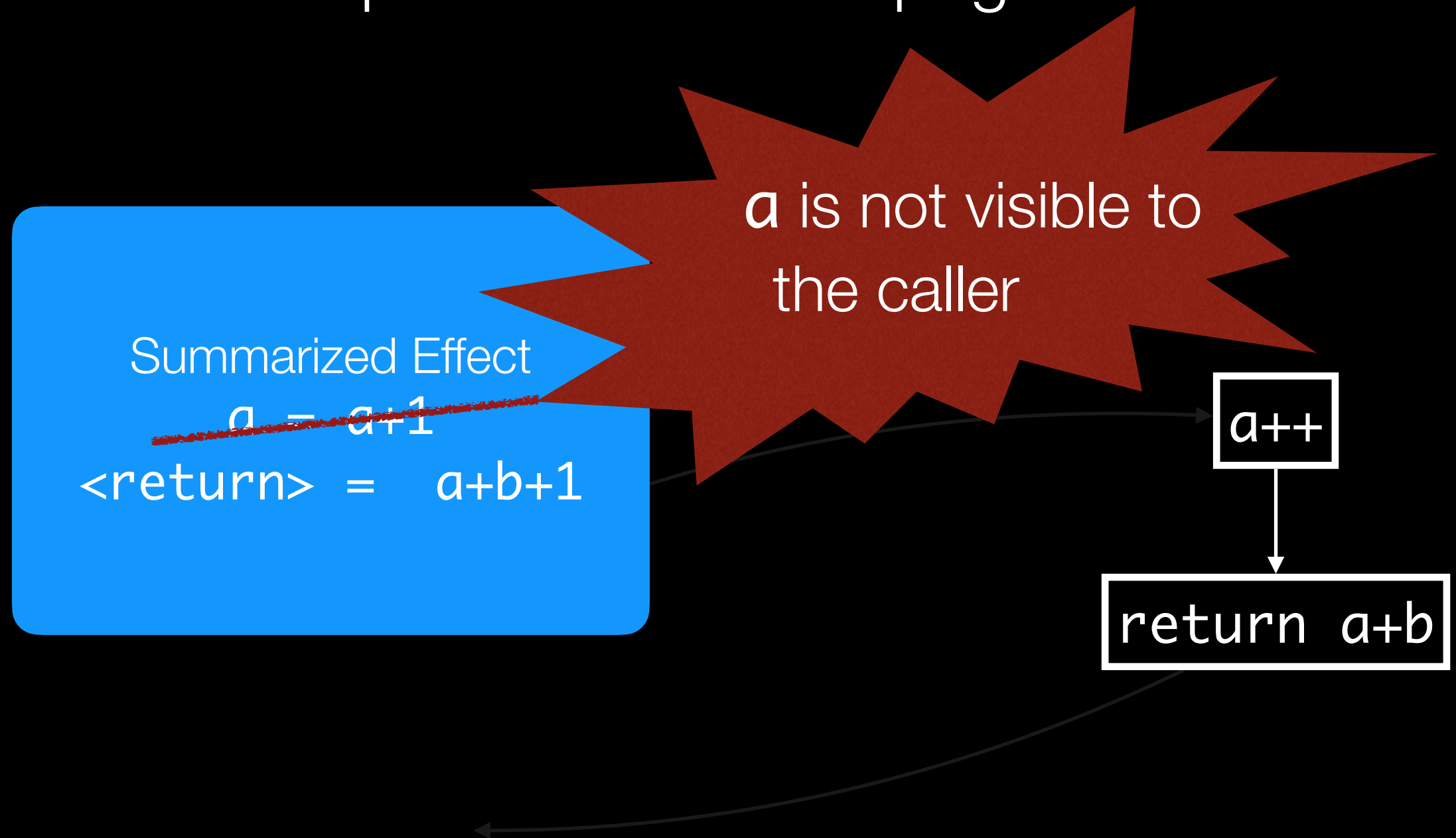
Functional Approach

Example: Constant Propagation



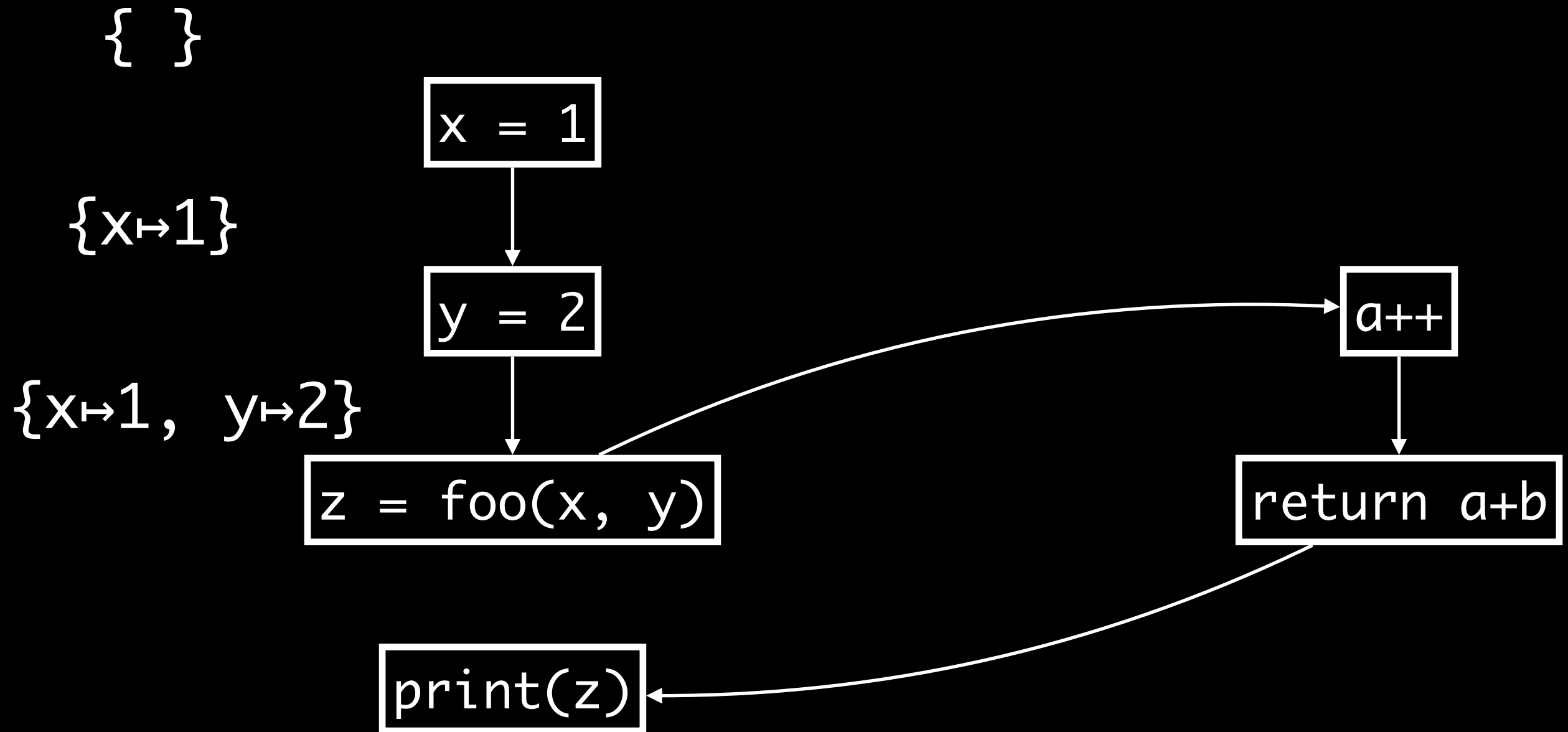
Functional Approach

Example: Constant Propagation



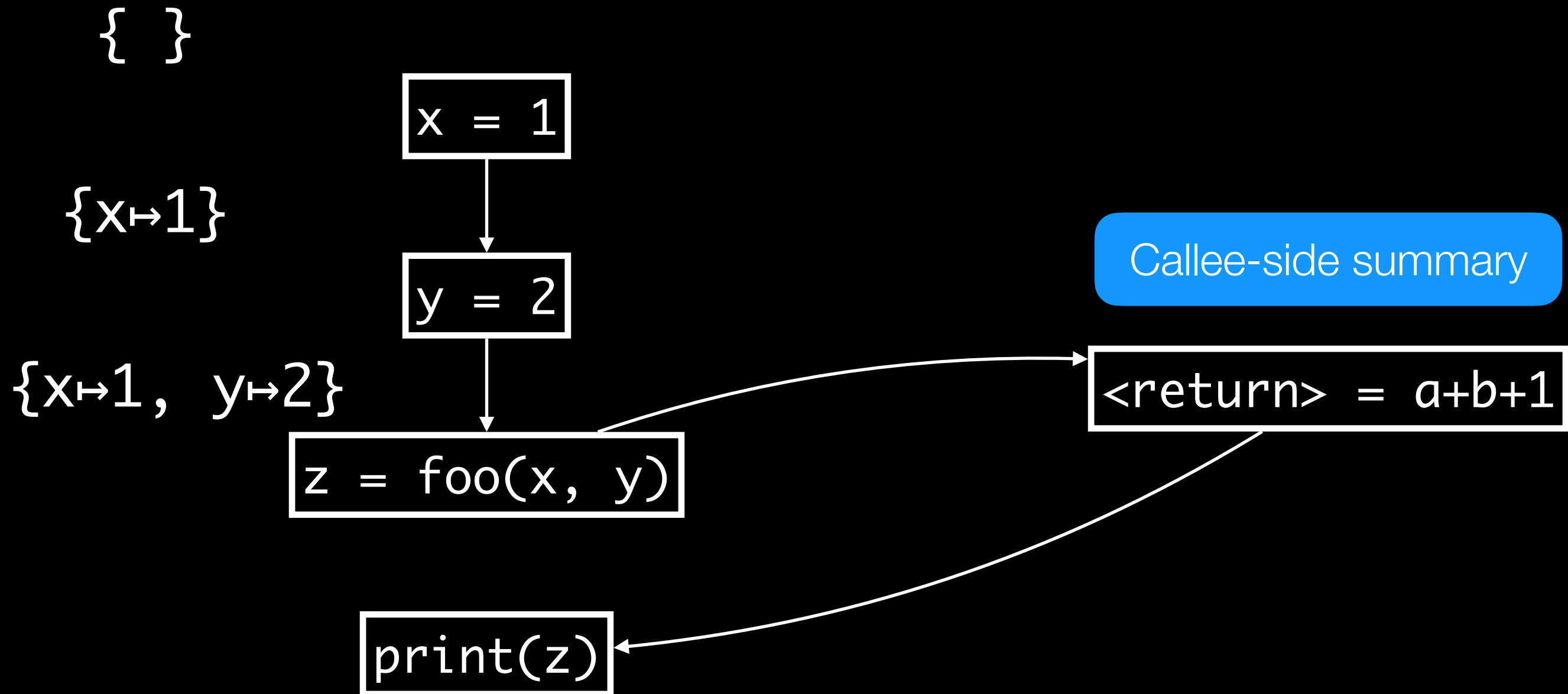
Functional Approach

Example: Constant Propagation



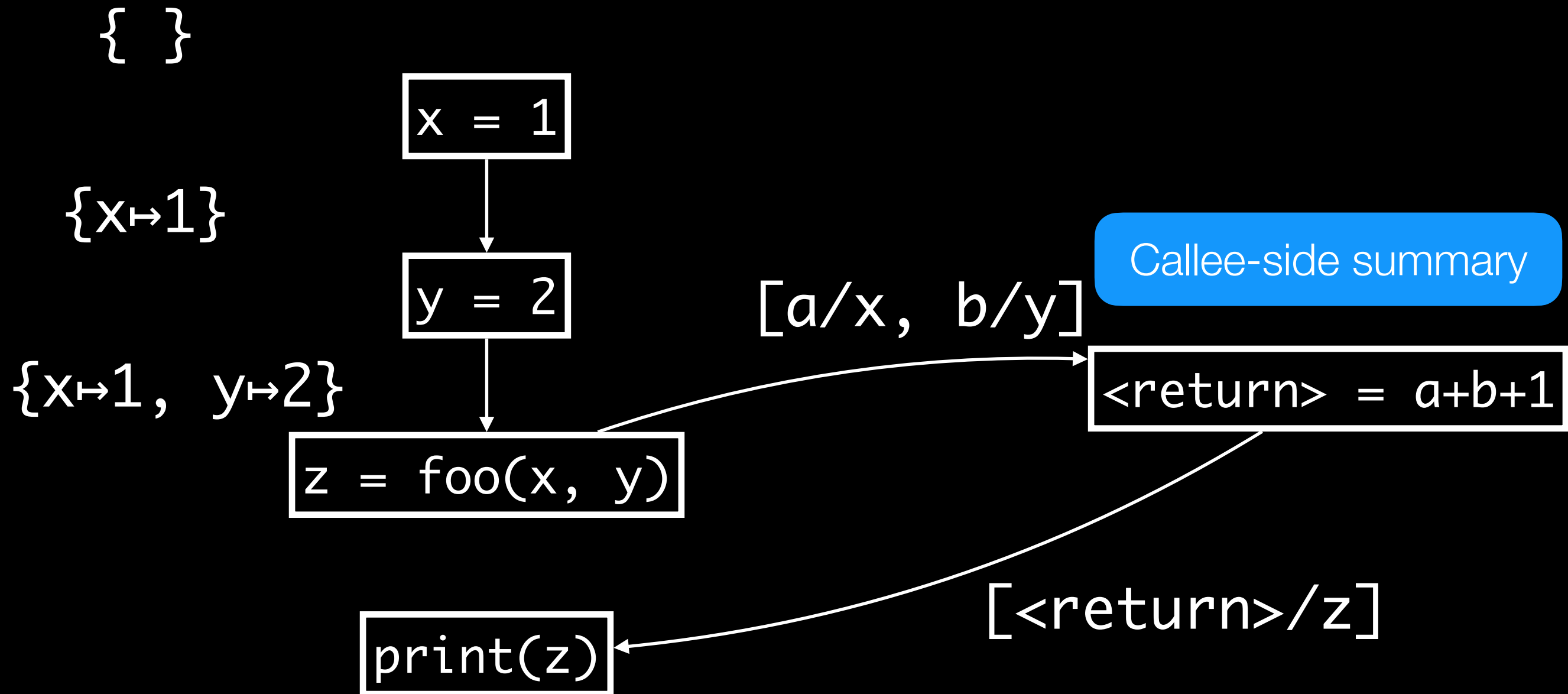
Functional Approach

Example: Constant Propagation



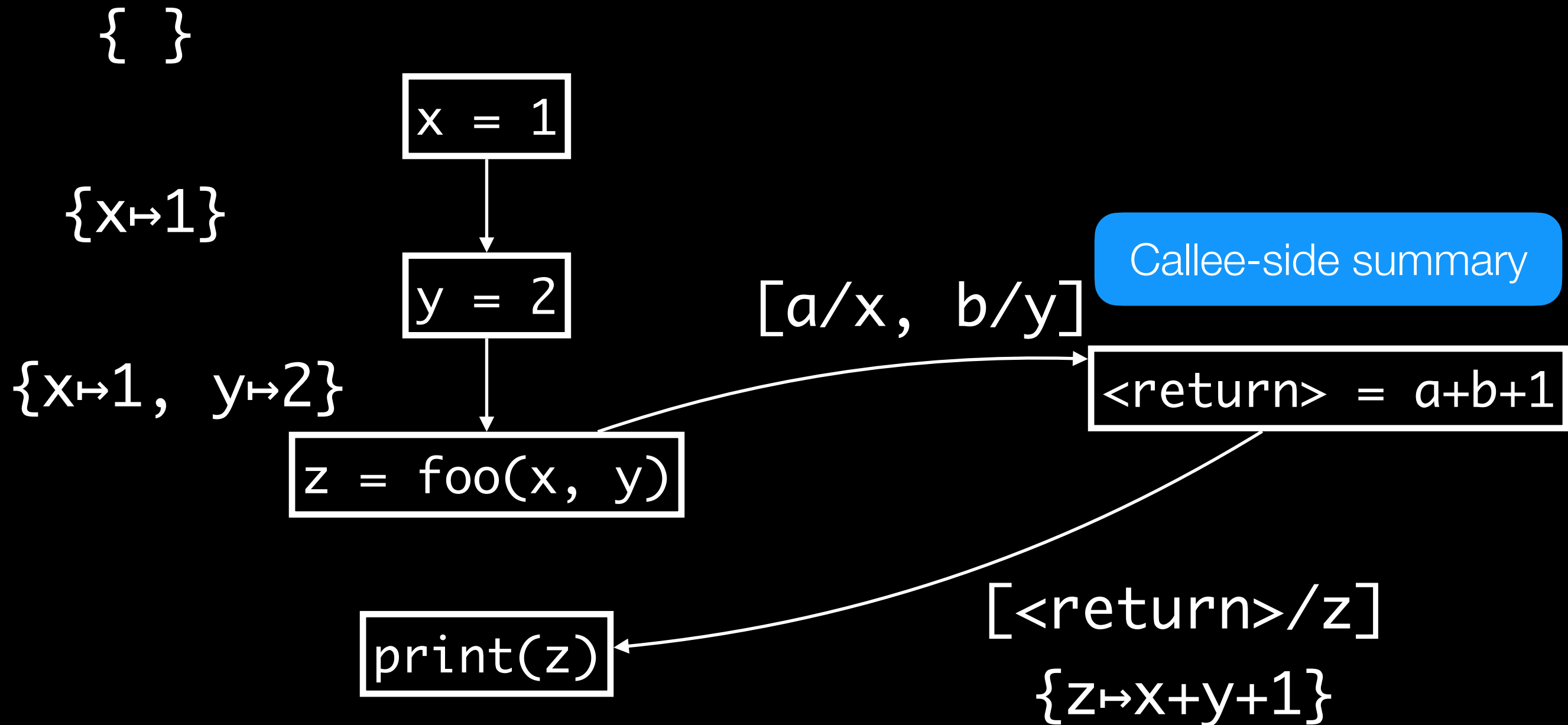
Functional Approach

Example: Constant Propagation



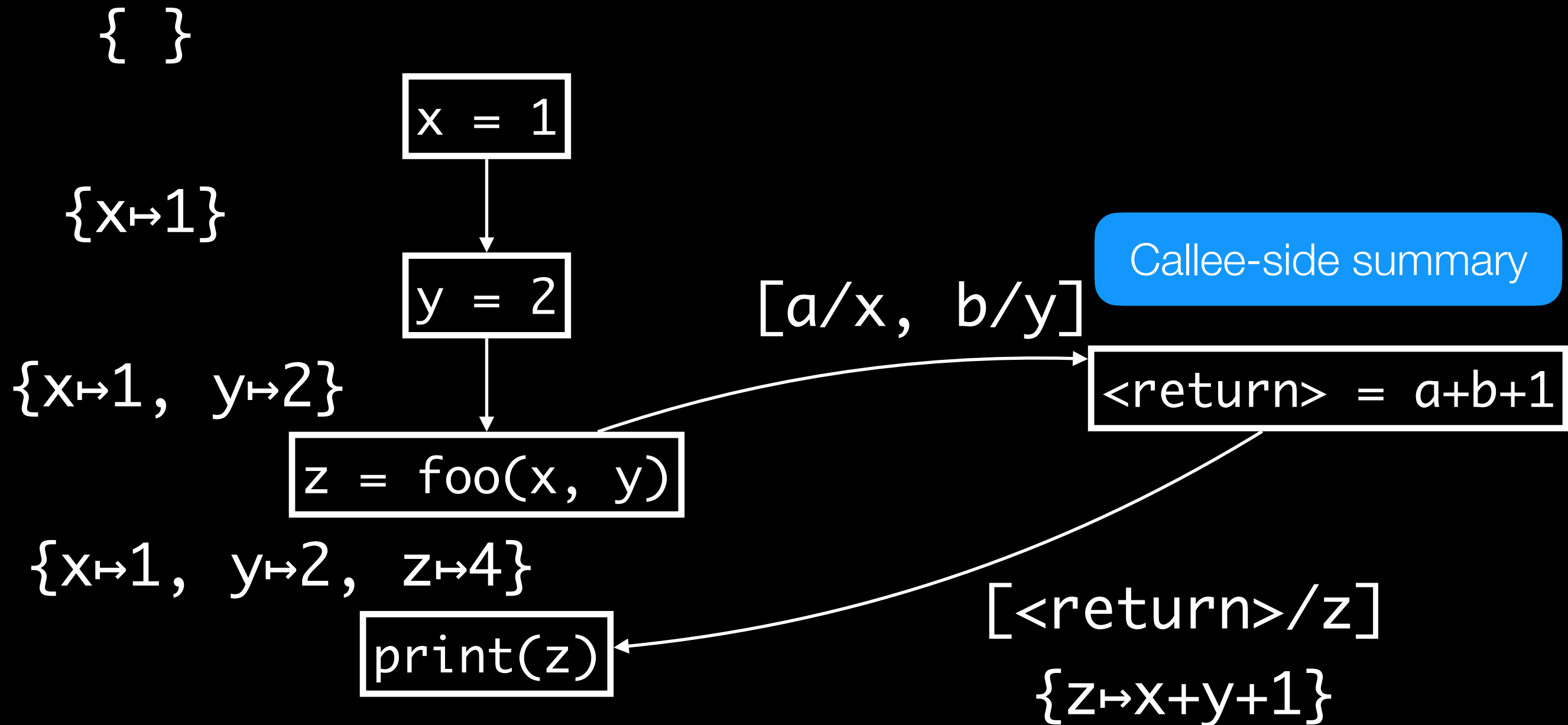
Functional Approach

Example: Constant Propagation



Functional Approach

Example: Constant Propagation



Next

- IFDS