IFDS/IDE-based Inter-procedural Static Analysis of Software Product Lines

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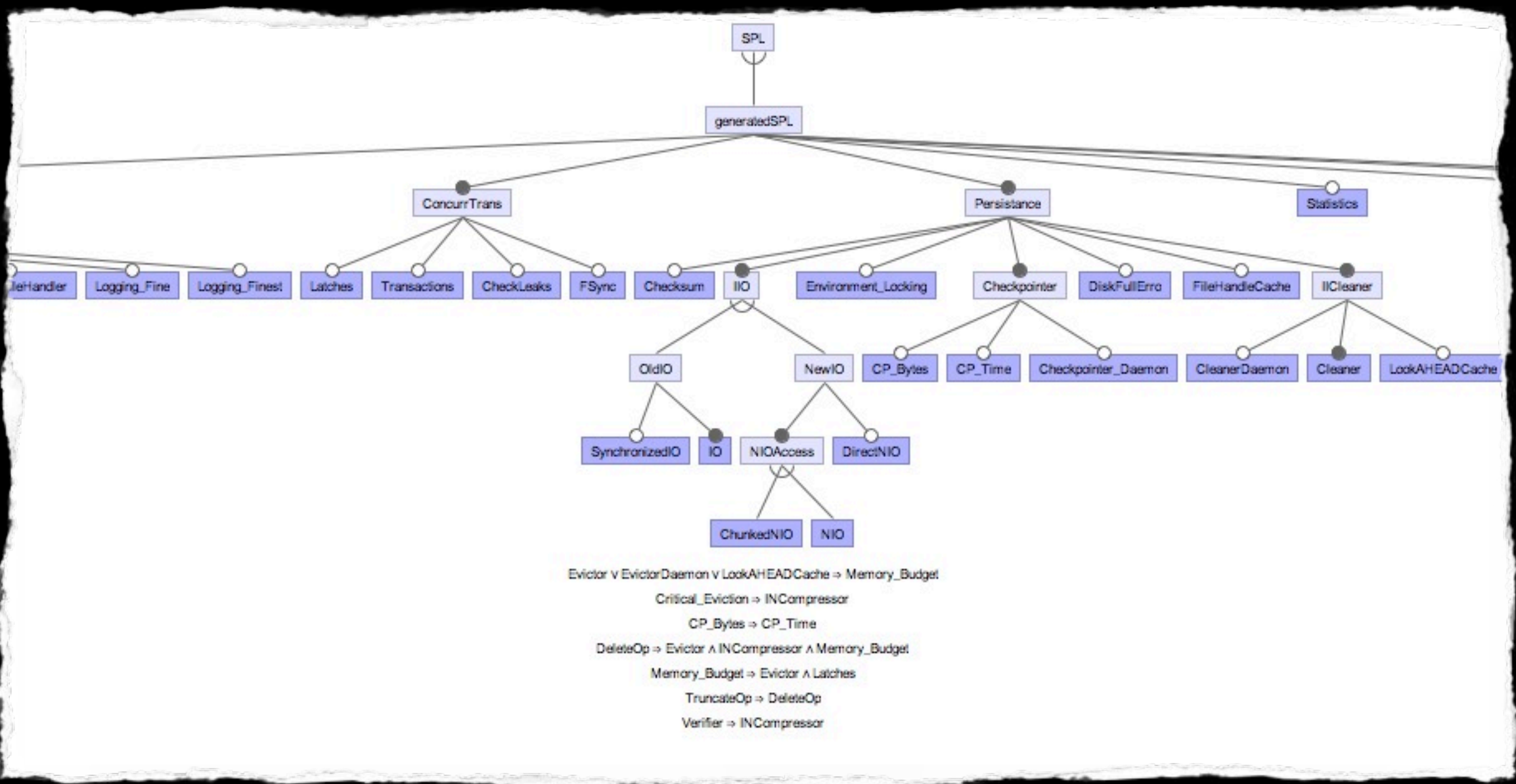
Product lines model variability

```
/**
 * Javadoc for this public method is generated via
 * the doc templates in the doc_src directory.
 */
public Sequence openSequence(Transaction txn,
                             DatabaseEntry key,
                             SequenceConfig config)
    throws DatabaseException {

    checkEnv();
    DatabaseUtil.checkForNullDbt(key, "key", true);
    checkRequiredDbState(OPEN, "Can't call Database.openSequence:");
    checkWritable("openSequence");
    trace(Level.FINEST, "Database.openSequence", txn, key, null, null);

    return new Sequence(this, txn, key, config);
}
```

Feature model of BerkelyDB



(excerpt)

Analyzing SPLs

- May just re-use existing analyses:
  - Generate all possible products, analyzing one at a time
  - Every product is a plain old Java program
    - Problem: may be millions
- Better: design analysis that is product-line aware!
  - Just analyze entire SPL in one shot!

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This Talk!

Traditional info-flow analysis

```
void main() {
    int x = secret();
    int y = 0;
    x = 0;
    y = foo(x);
    print(y);
}

int foo(int p) {
    p = 0;
    return p;
}
```

Traditional info-flow analysis

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    p = 0;
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}
```

FALSE

Now for SW Product Lines

```
void main() {
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    x = 0;
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```

Feature F

Feature G

Feature H

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```

Feature F

Feature G

Feature H

¬F ∧ G ∧ ¬ H

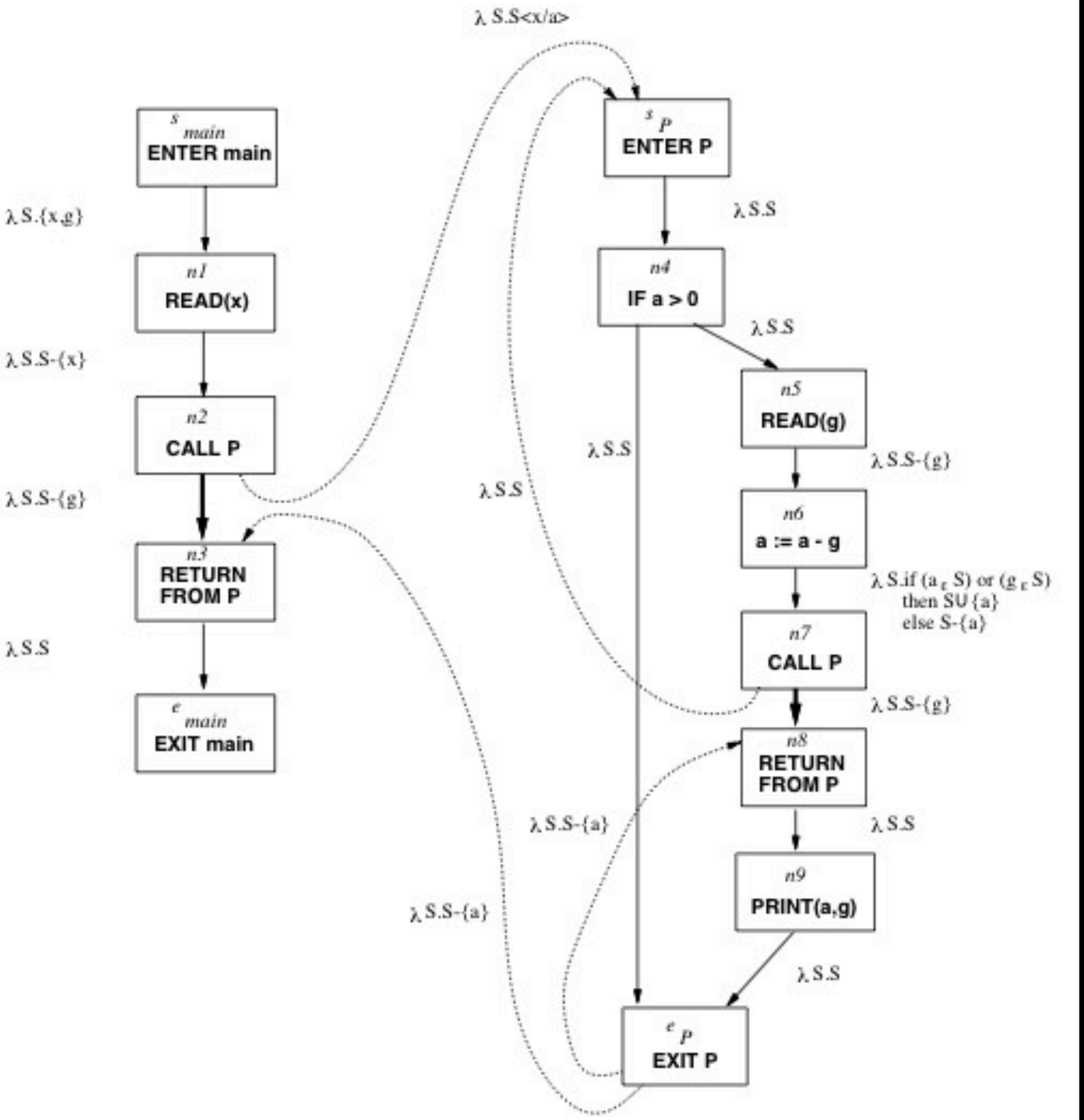
IFDS Framework

- Invented in 1995 by Reps, Horwitz and Sagiv
- Idea: reduce inter-procedural program-analysis problem to graph-reachability
- Works for any flow functions over finite domains that are distributive over the merge operator
- Covers a surprisingly large class of problems

Example Program

```
declare g: integer

program main
begin
  declare x: integer
  read(x)
  call P(x)
end


procedure P(value a: integer)
begin
  if (a > 0) then
    read(g)
    a := a - g
    call P(a)
    print(a, g)
  fi
end
```

Program Super graph



Idea: Specialize graph

Program Super Graph

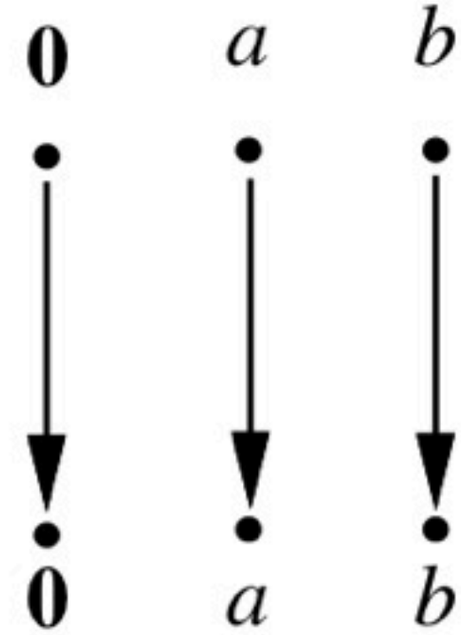
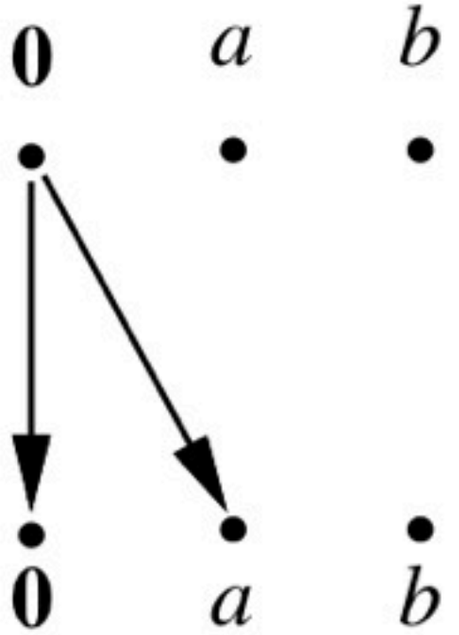
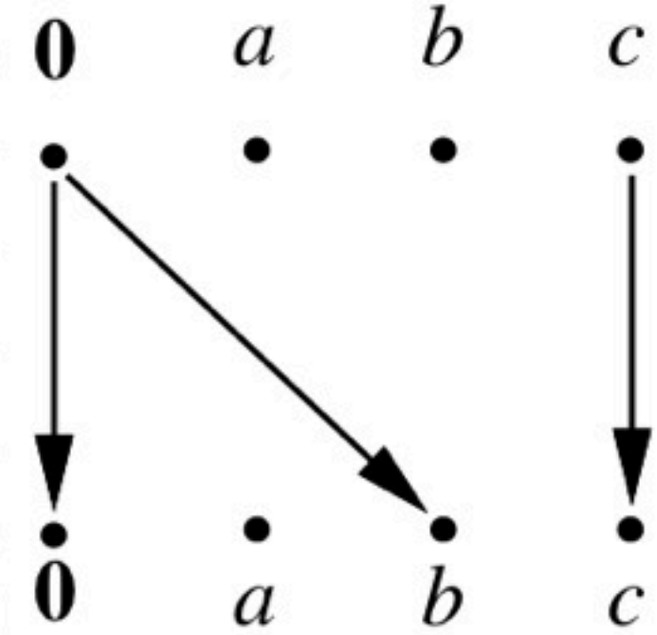
$\otimes$

Flow Functions

$=$

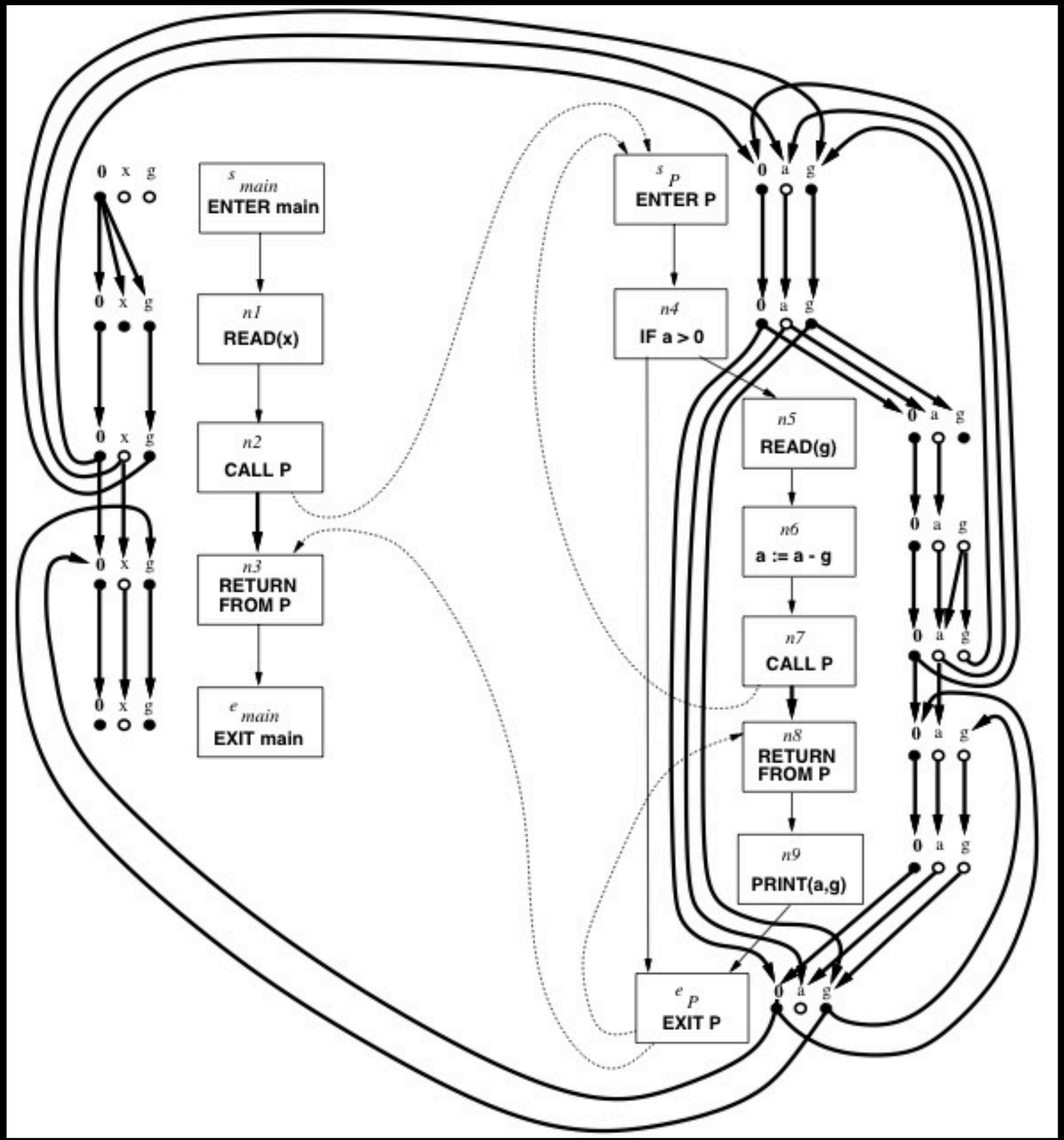
Exploded Super Graph

Flow functions as edges

id: $2^{\{a,b\}} \rightarrow 2^{\{a,b\}}$ **id** = $\lambda S.S$	**a**: $2^{\{a,b\}} \rightarrow 2^{\{a,b\}}$ **a** = $\lambda S.\{a\}$	**f**: $2^{\{a,b,c\}} \rightarrow 2^{\{a,b,c\}}$ **f** = $\lambda S.(S - \{a\}) \cup \{b\}$
		

Requires finite (or at least enumerable) domain

Exploded Super Graph



Previous example

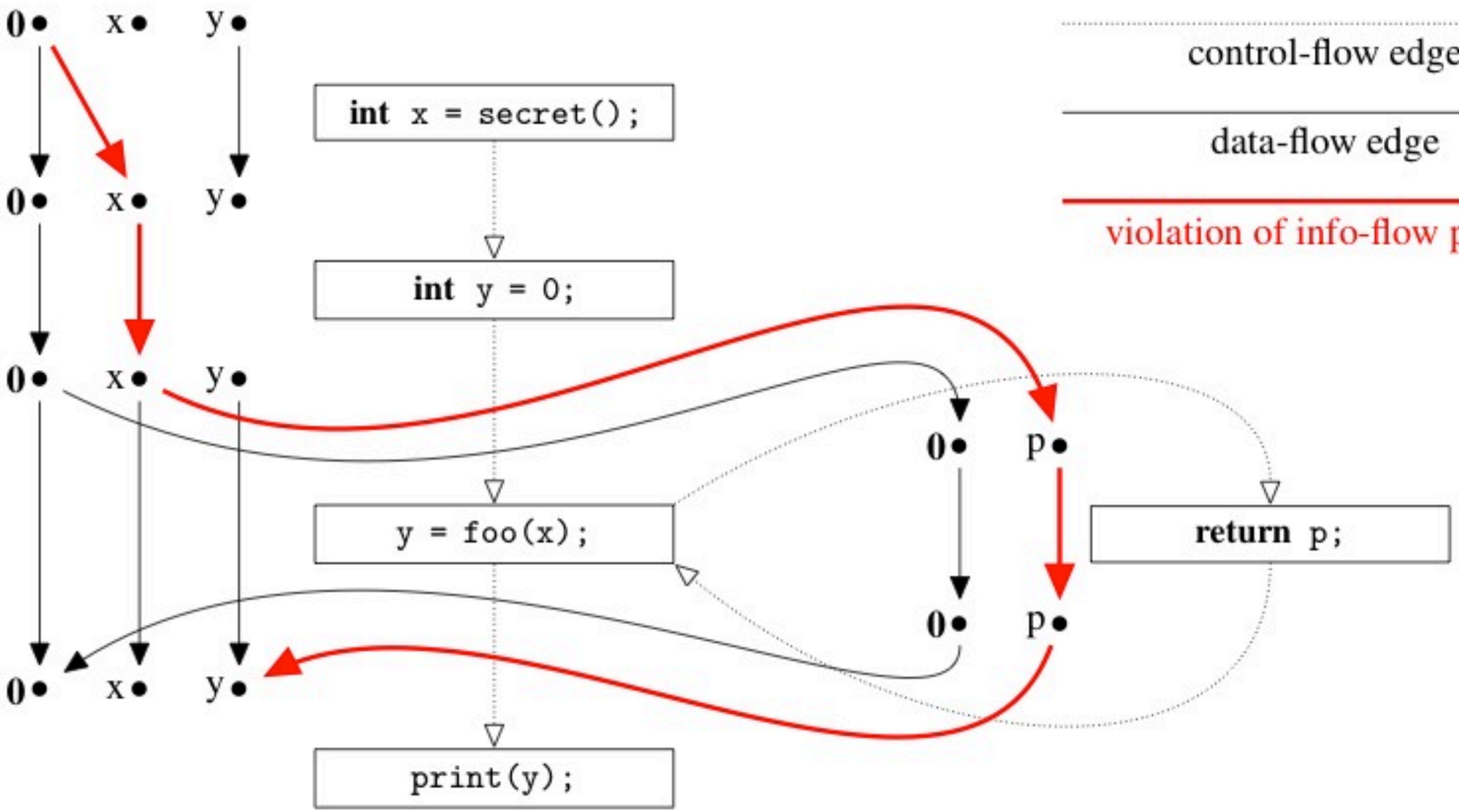
```
void main() {
    int x = secret();
    int y = 0;
    x = 0;          Feature F
    y = foo(x);     Feature G
    print(y);
}

int foo(int p) {
    p = 0;          Feature H
    return p;
}
```

$$\neg F \wedge G \wedge \neg H$$

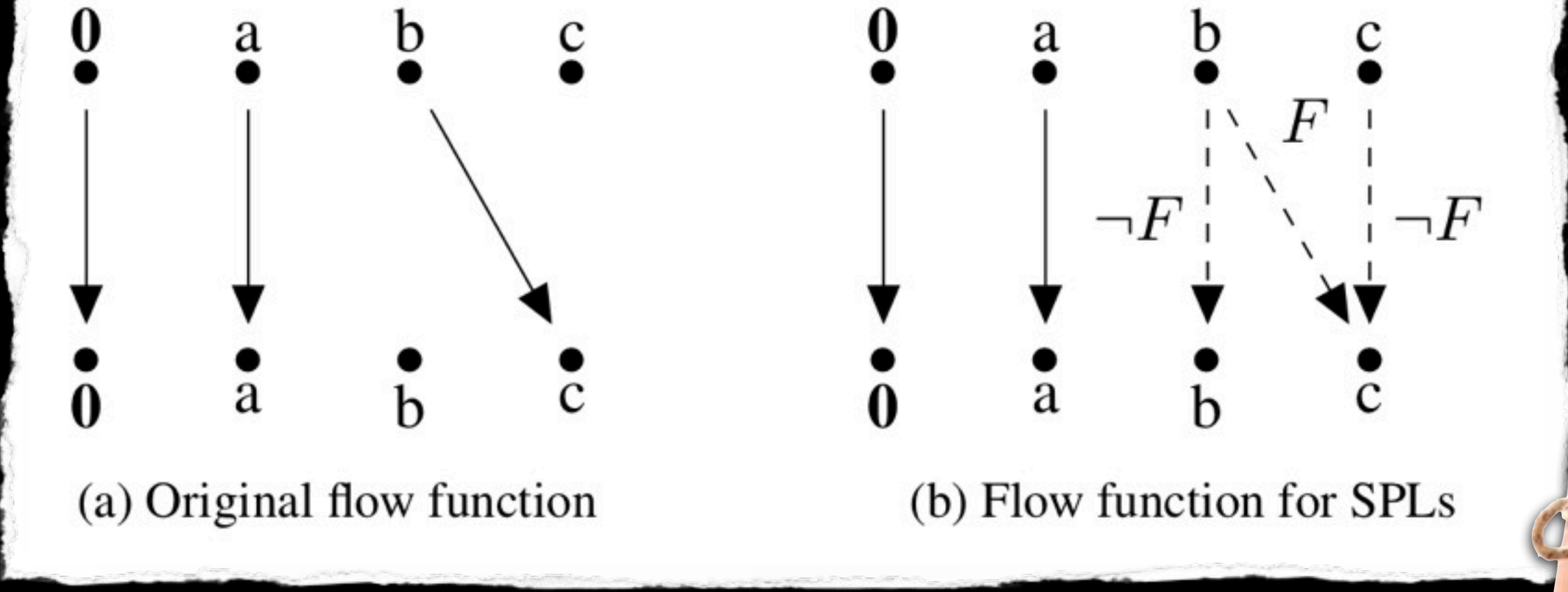
Problematic "Product"

```
void main() {
    int x = secret();
    int y = 0;

    y = foo(x);
    print(y);
}

int foo(int p) {

    return p;
}
```

IFDS Info-flow analysis



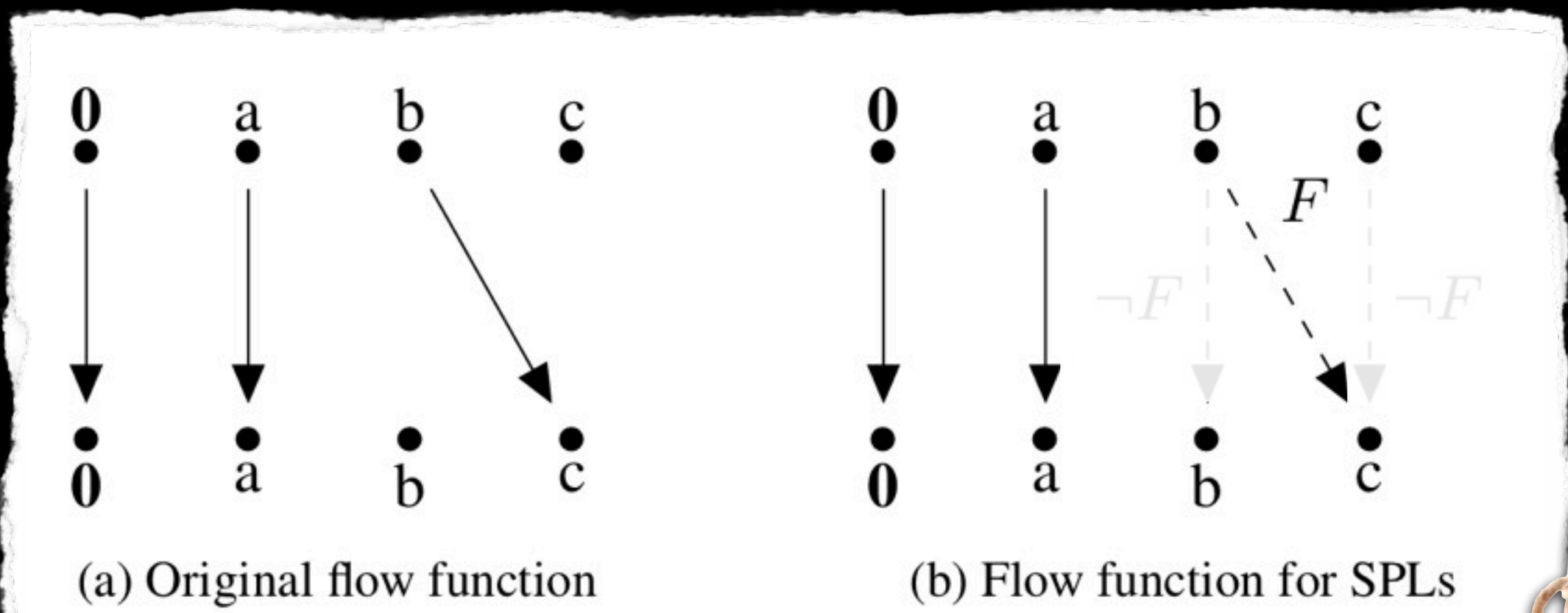
Stmt guarded by F...



(a) Original flow function

(b) Flow function for SPLs

Stmt guarded by F...



(a) Original flow function

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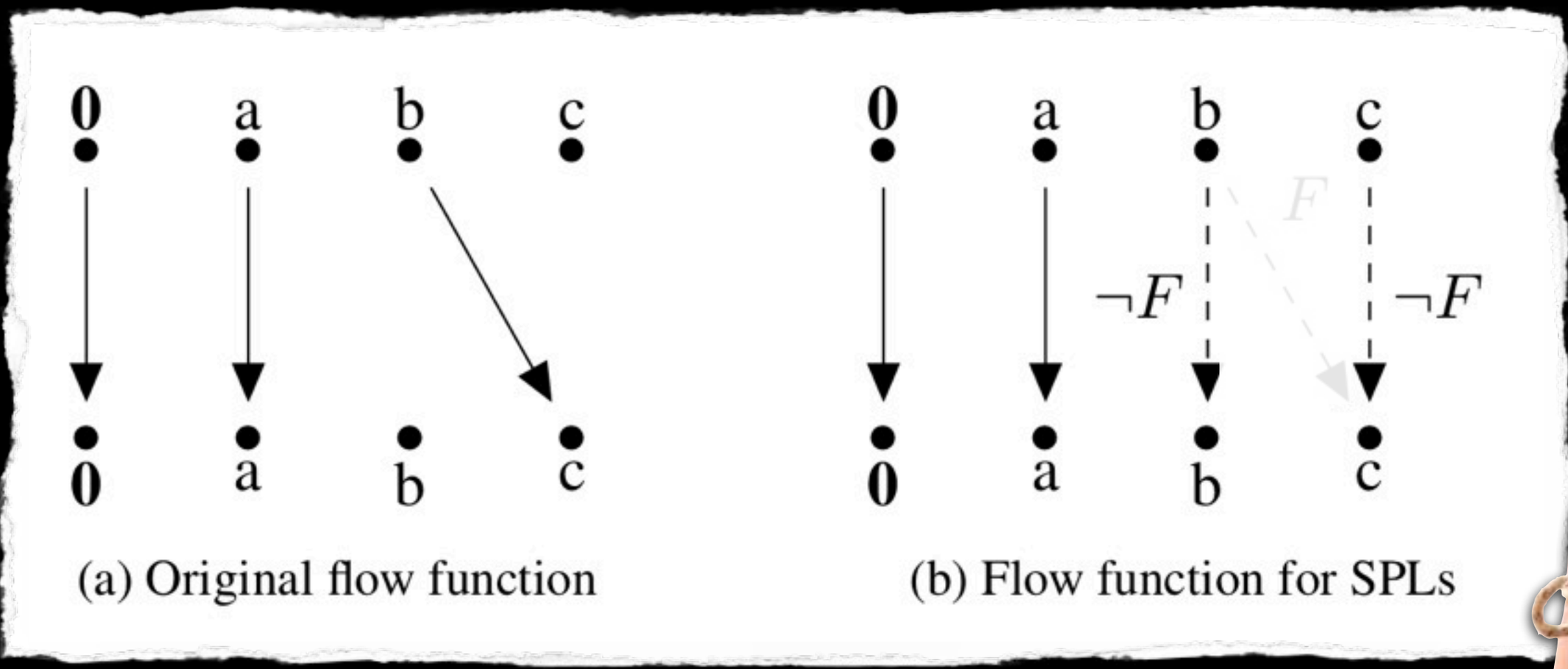
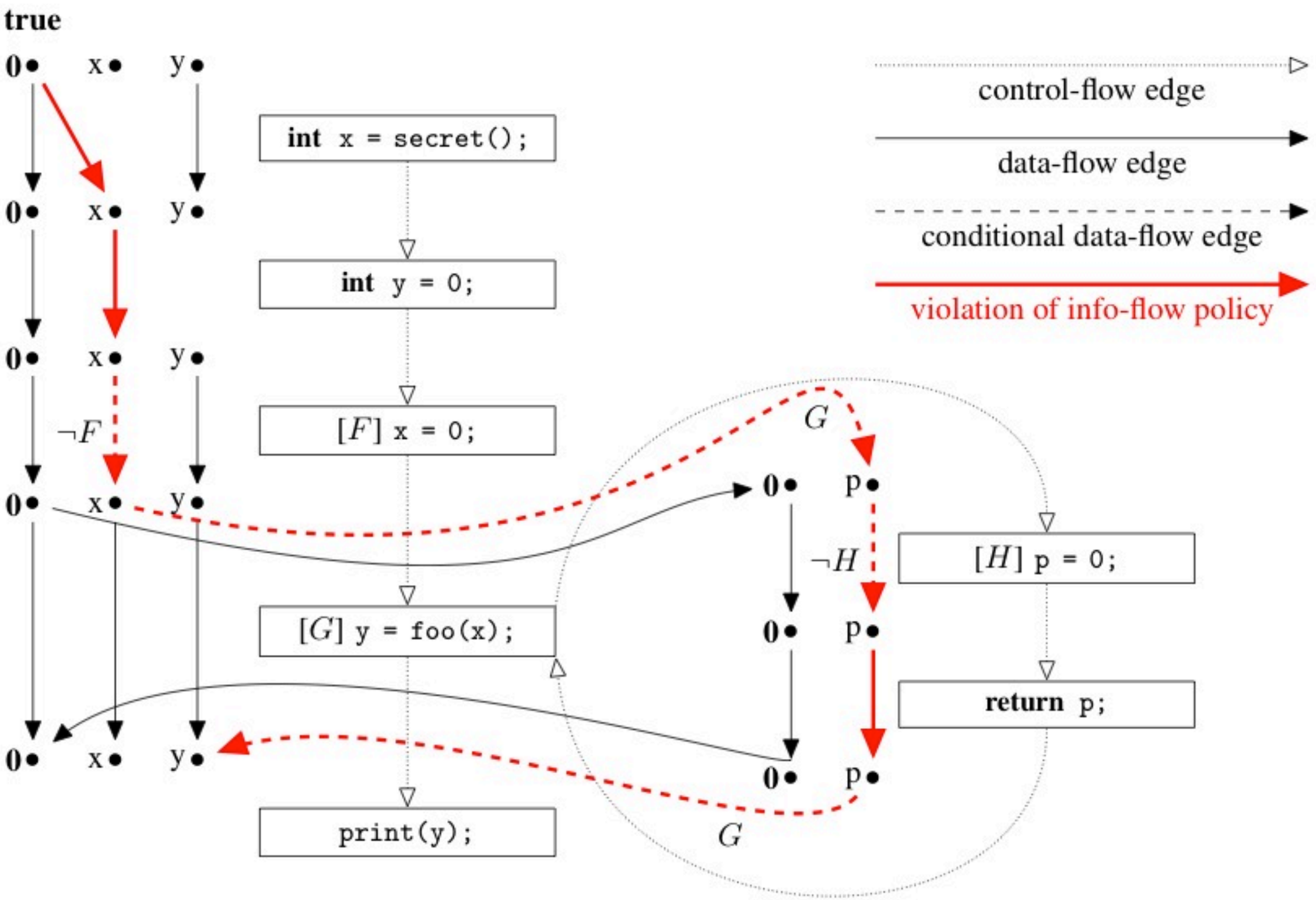
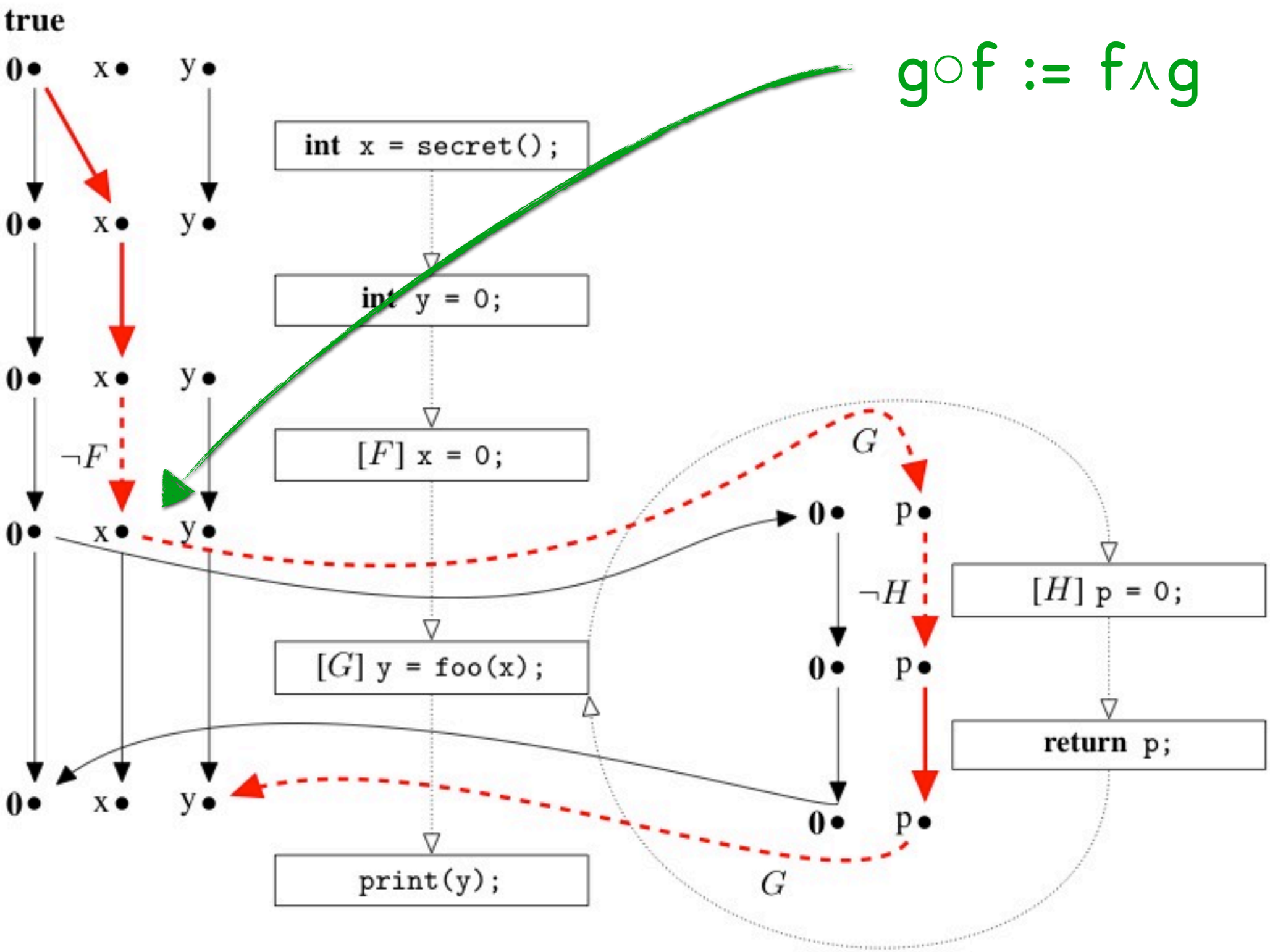
Stmt guarded by F...

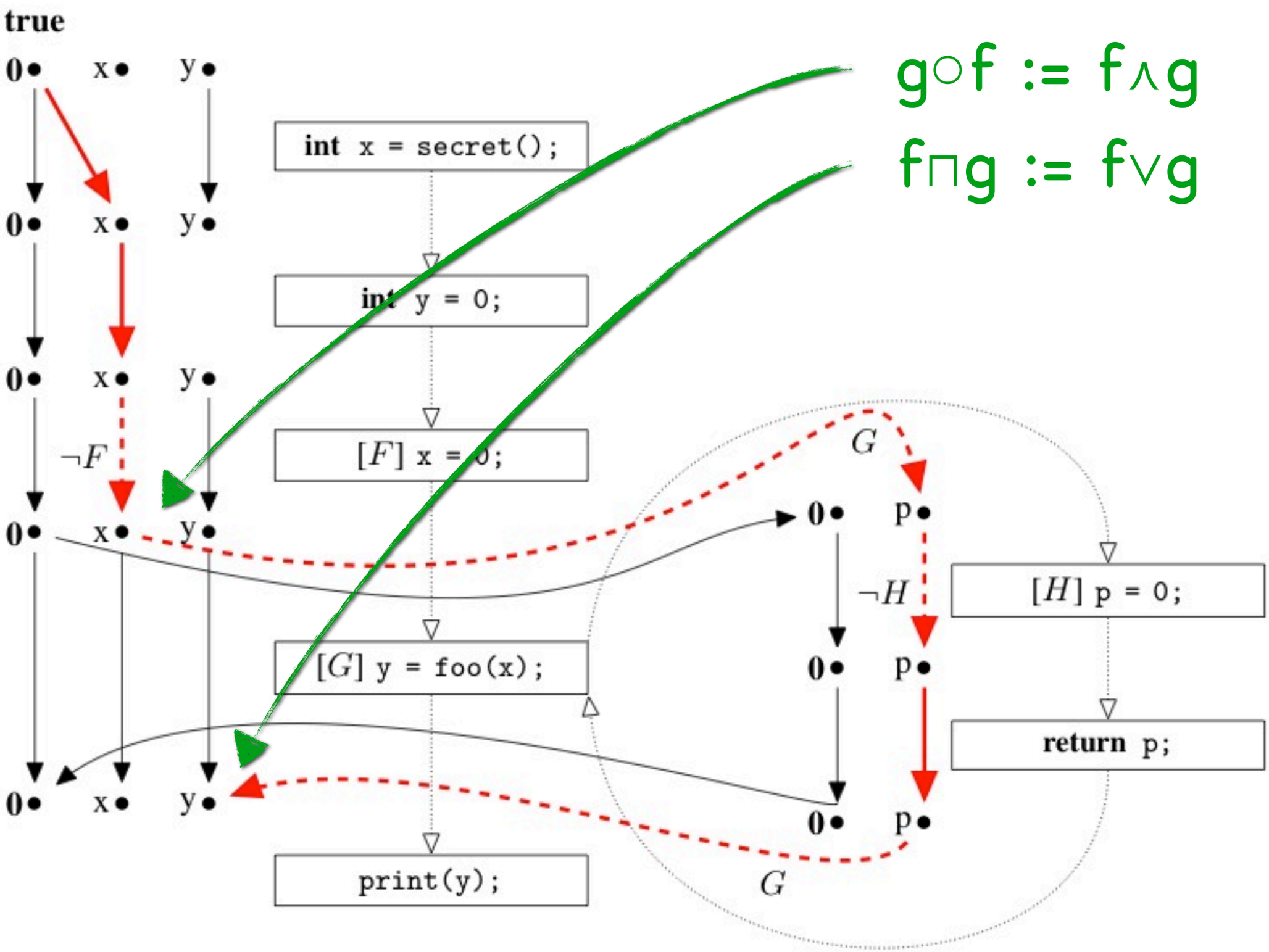


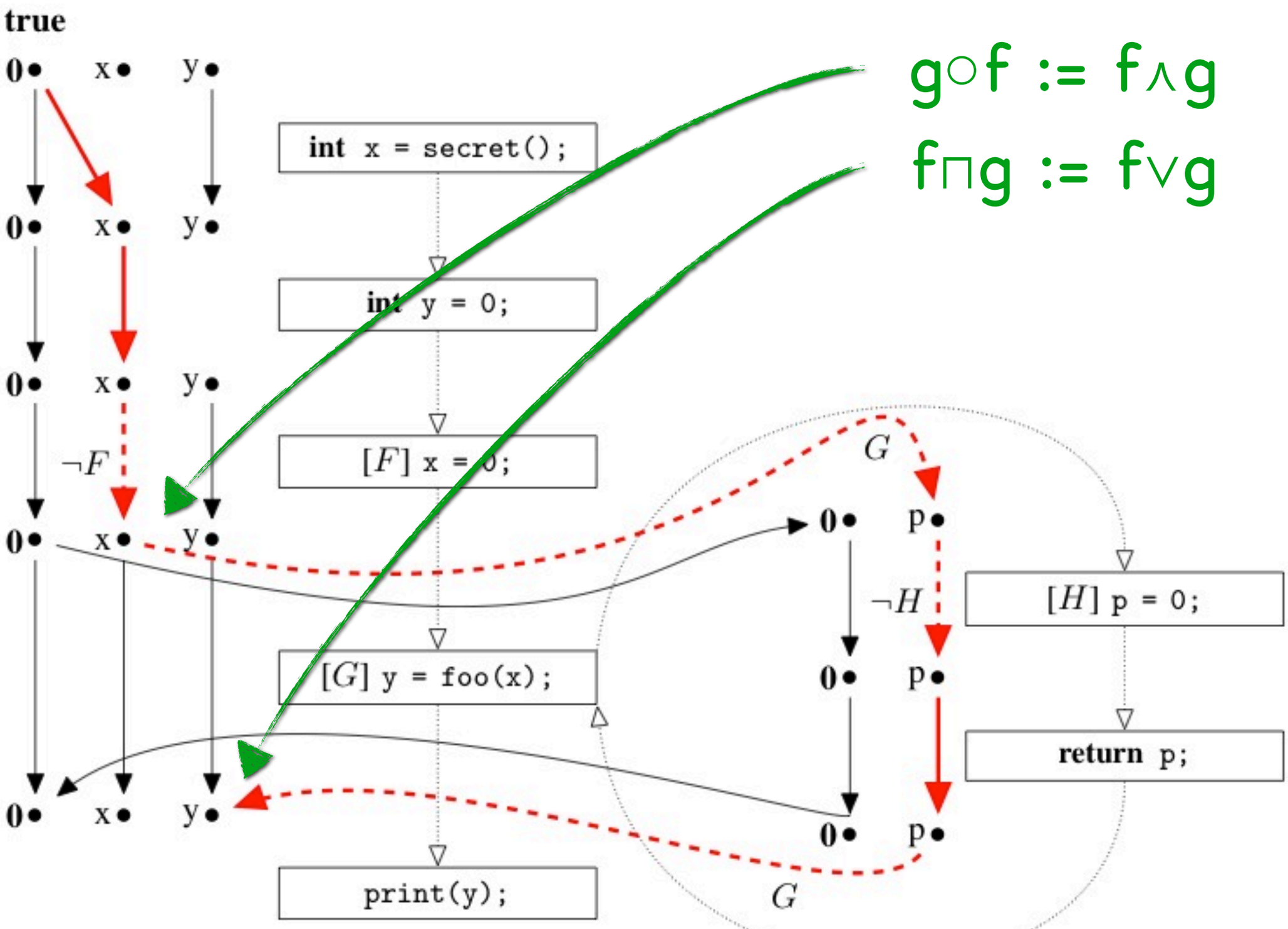
(a) Original flow function

(b) Flow function for SPLs


true
0
x
y
int x = secret();
int y = 0;
[F] x = 0;
¬F
[G] y = foo(x);
print(y);
control-flow edge
data-flow edge
conditional data-flow edge
violation of info-flow policy
G
p
¬H
[H] p = 0;
return p;

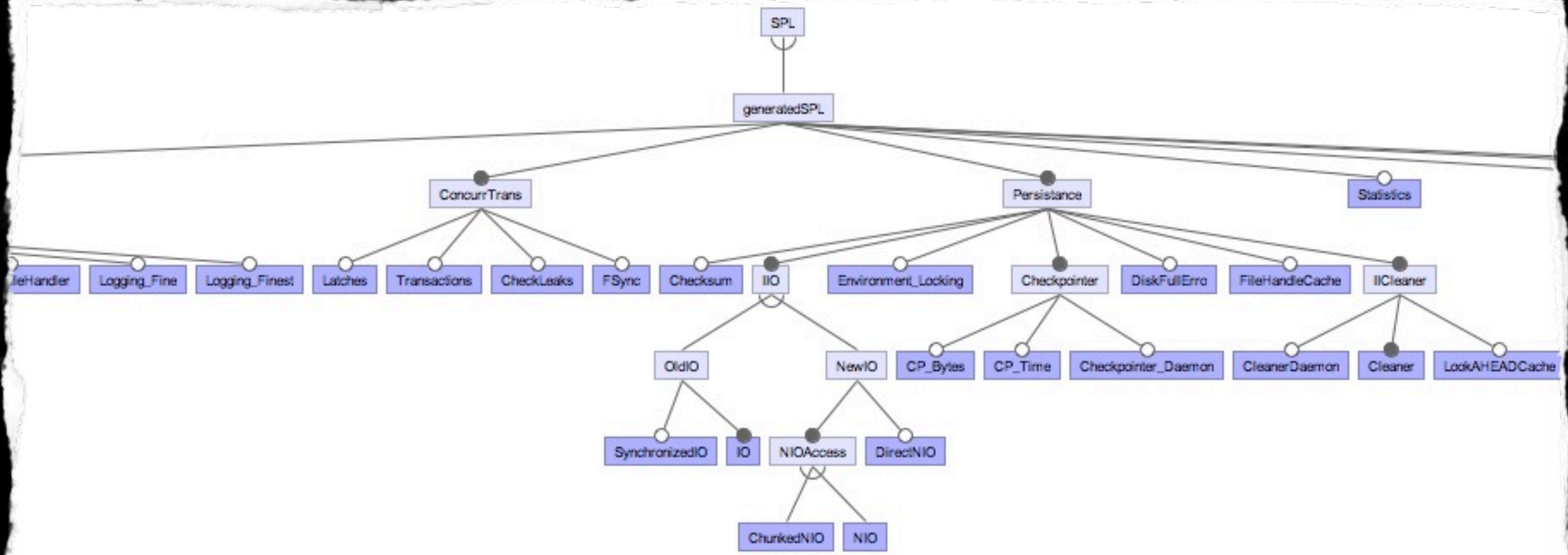

true
0 x y
int x = secret();
int y = 0;
[F] x = 0;
¬F
[G] y = foo(x);
print(y);
G
0 p
¬H
[H] p = 0;
return p;
g∘f := f∧g


true
0
x
y
int x = secret();
int y = 0;
[F] x = 0;
¬F
[G] y = foo(x);
print(y);
G
p
¬H
[H] p = 0;
return p;
g∘f := f∧g
f⊓g := f∨g



$$(\textbf{true} \wedge \neg F \wedge G \wedge \neg H \wedge G) \vee \textbf{false} = \neg F \wedge G \wedge \neg H$$

Exploit Feature Model



Evictor ∨ EvictorDaemon ∨ LookAHEADCache ⇒ Memory_Budget

Critical_Eviction ⇒ INCompressor

CP_Bytes ⇒ CP_Time

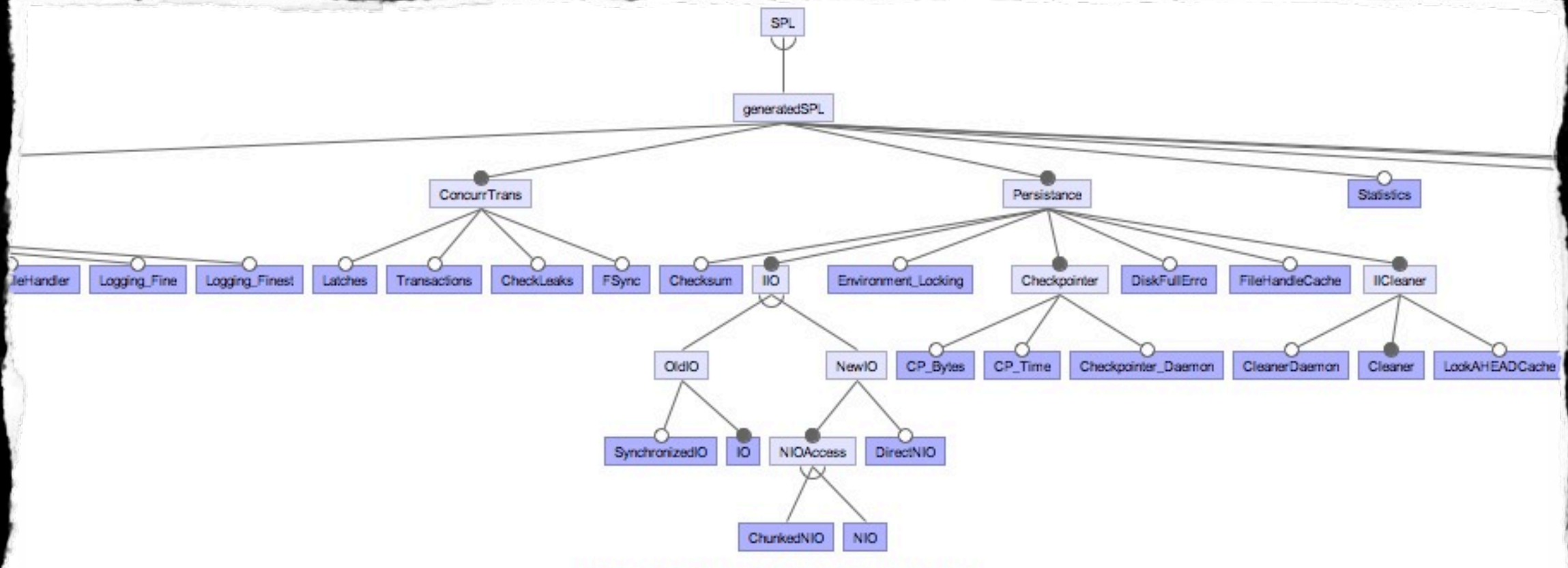
DeleteOp ⇒ Evictor ∧ INCompressor ∧ Memory_Budget

Memory_Budget ⇒ Evictor ∧ Latches

TruncateOp ⇒ DeleteOp

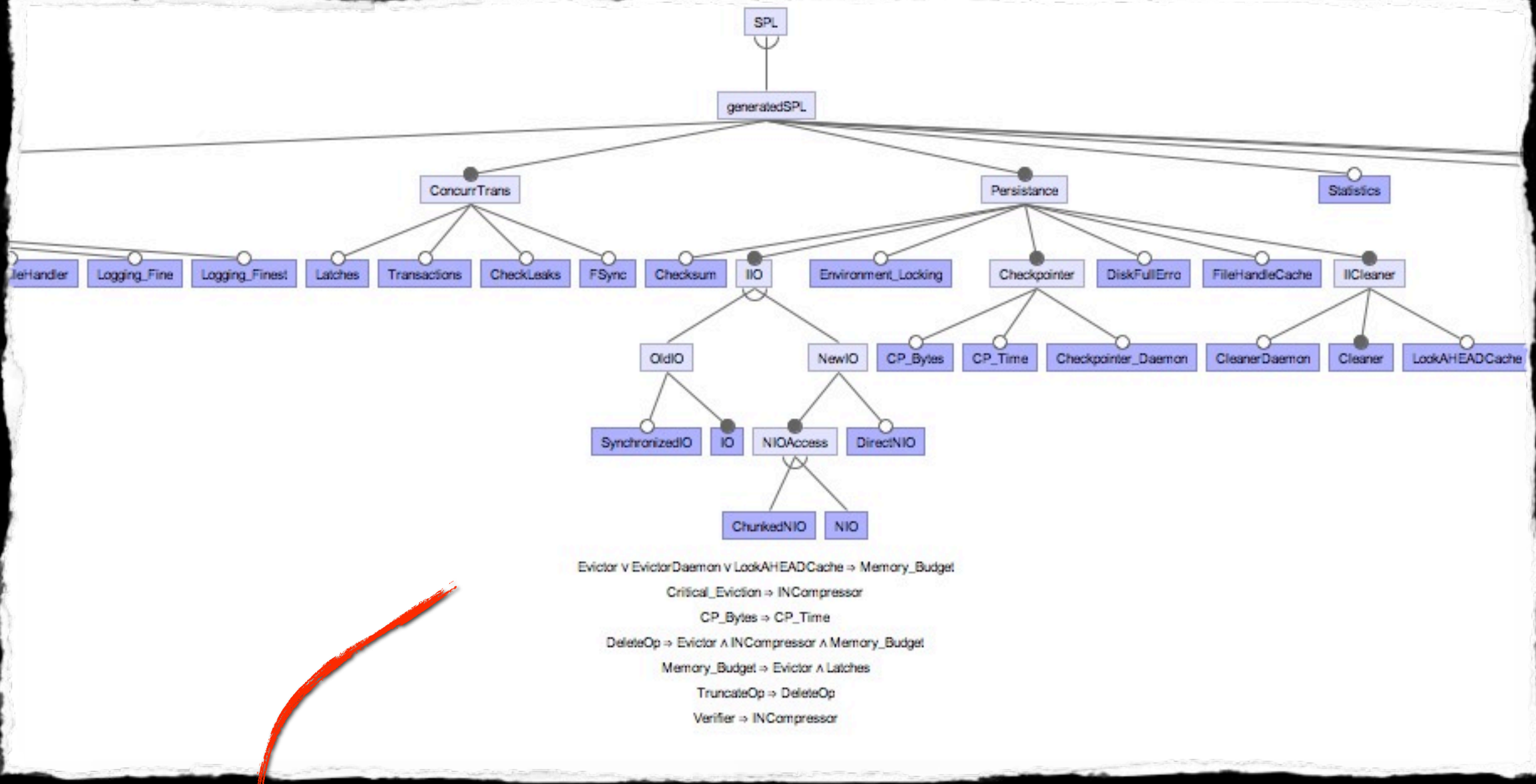
Verifier ⇒ INCompressor

Exploit Feature Model



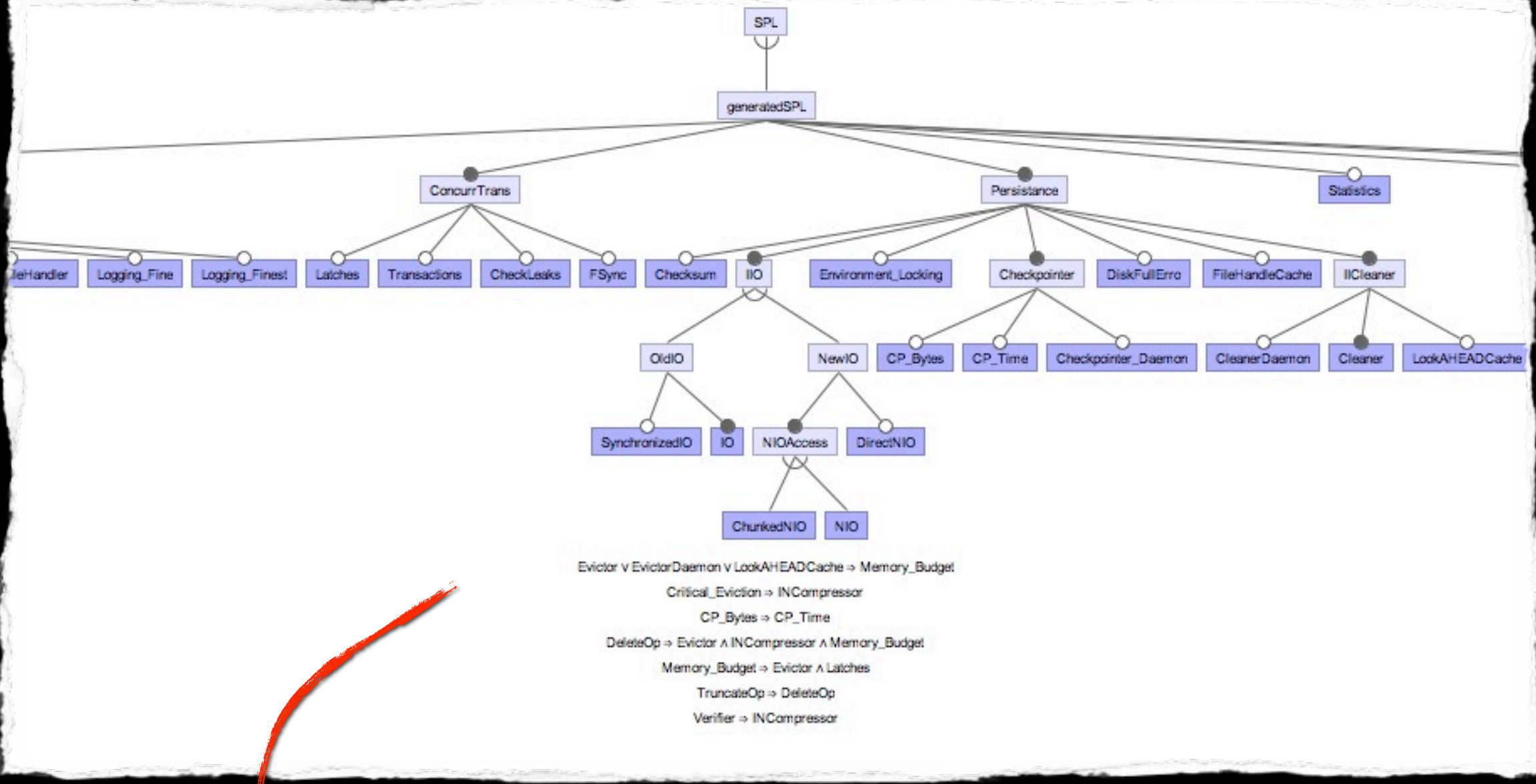
F ⟷ G

Exploit Feature Model

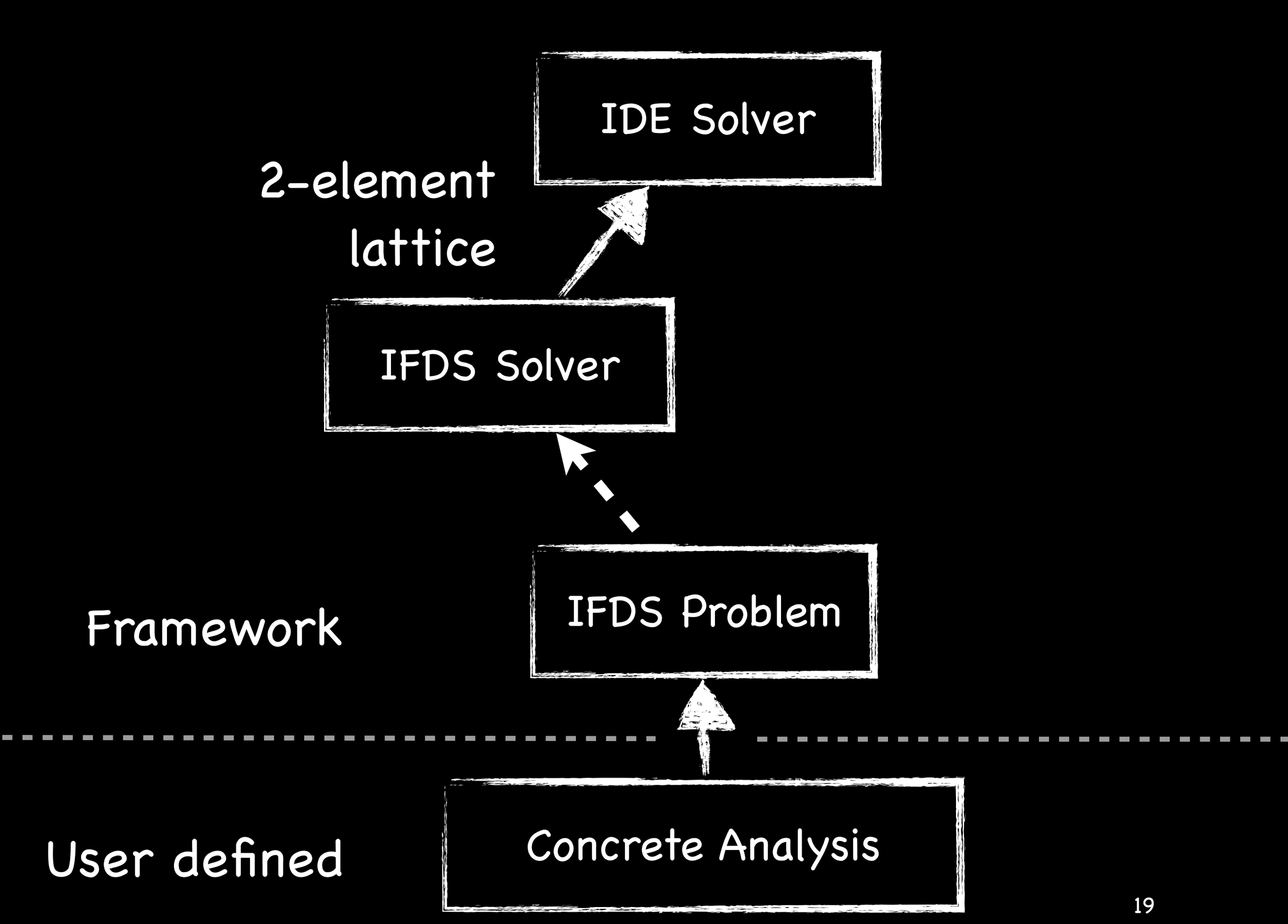


$F \leftrightarrow G$ $\neg F \wedge G \wedge \neg H$

Exploit Feature Model



$$(F \leftrightarrow G) \wedge (\neg F \wedge G \wedge \neg H) == \text{false}$$


IDE Solver
2-element lattice
IFDS Solver
Framework
IFDS Problem
User defined
Concrete Analysis

IDE Solver

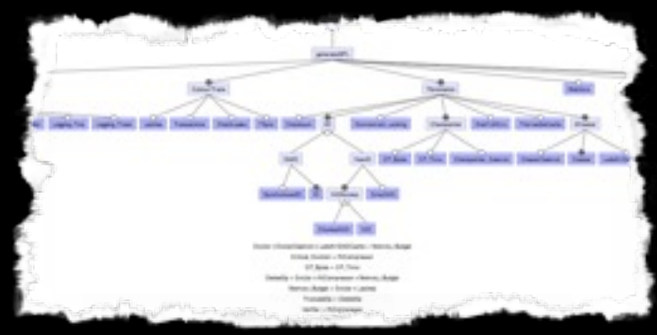
2-element lattice

constraint lattice

IFDS Solver

SPL/IFDS Solver

IFDS Problem

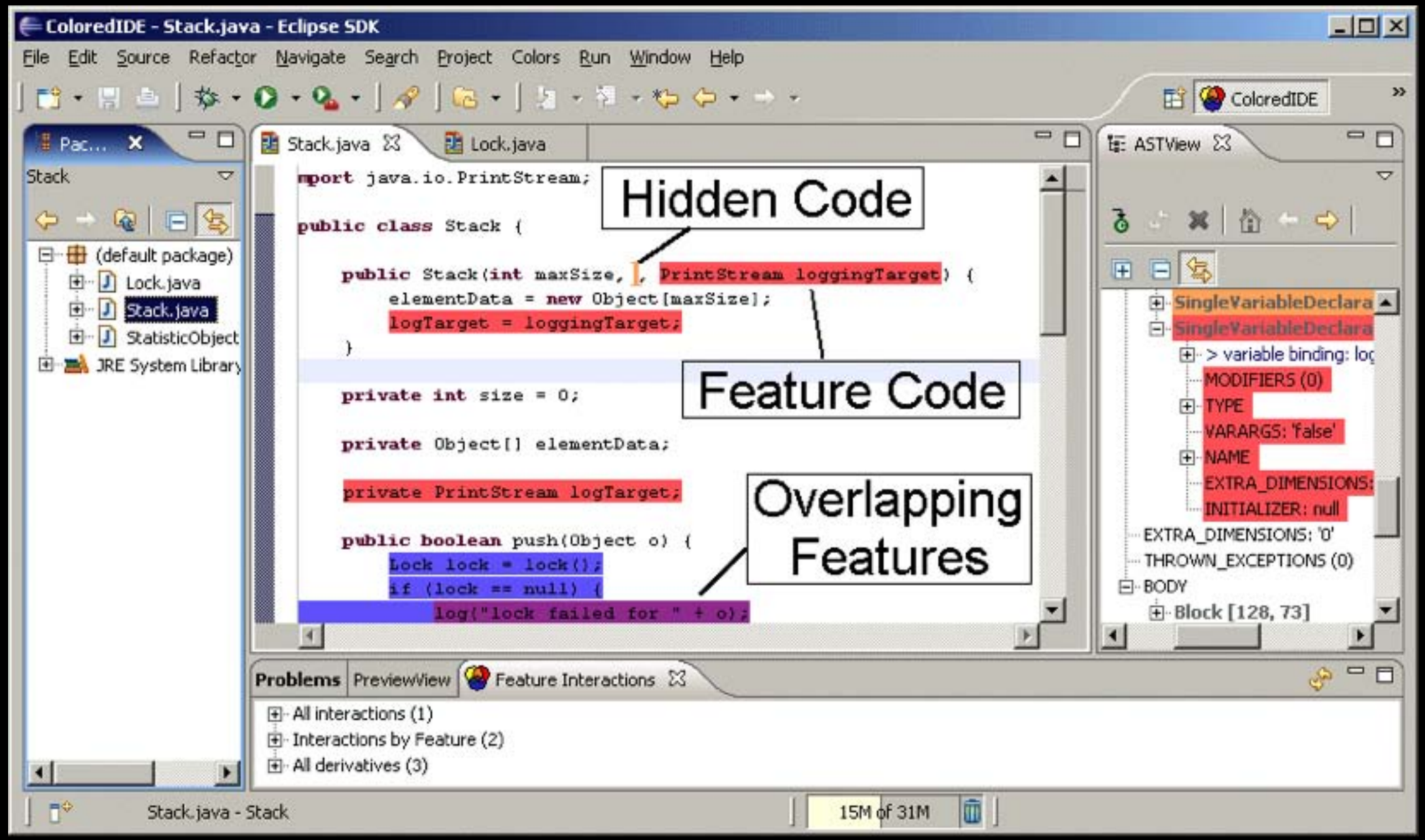


Framework

User defined

Concrete Analysis

We use CIDE


ColoredIDE - Stack.java - Eclipse SDK
File Edit Source Refactor Navigate Search Project Colors Run Window Help
ColoredIDE
Pac...
Stack
(default package)
Lock.java
Stack.java
StatisticObject
JRE System Library
Stack.java
Lock.java
import java.io.PrintStream;
public class Stack {
public Stack(int maxSize, PrintStream loggingTarget) {
elementData = new Object[maxSize];
logTarget = loggingTarget;
}
private int size = 0;
private Object[] elementData;
private PrintStream logTarget;
public boolean push(Object o) {
Lock lock = lock();
if (lock == null) {
log("lock failed for " + o);
Hidden Code
Feature Code
Overlapping Features
ASTView
SingleVariableDeclara
SingleVariableDeclara
> variable binding: log
MODIFIERS (0)
TYPE
VARARGS: 'false'
NAME
EXTRA_DIMENSIONS:
INITIALIZER: null
EXTRA_DIMENSIONS: '0'
THROWN_EXCEPTIONS (0)
BODY
Block [128, 73]
Problems
PreviewView
Feature Interactions
All interactions (1)
Interactions by Feature (2)
All derivatives (3)
Stack.java - Stack
15M of 31M

CIDE: pro/con

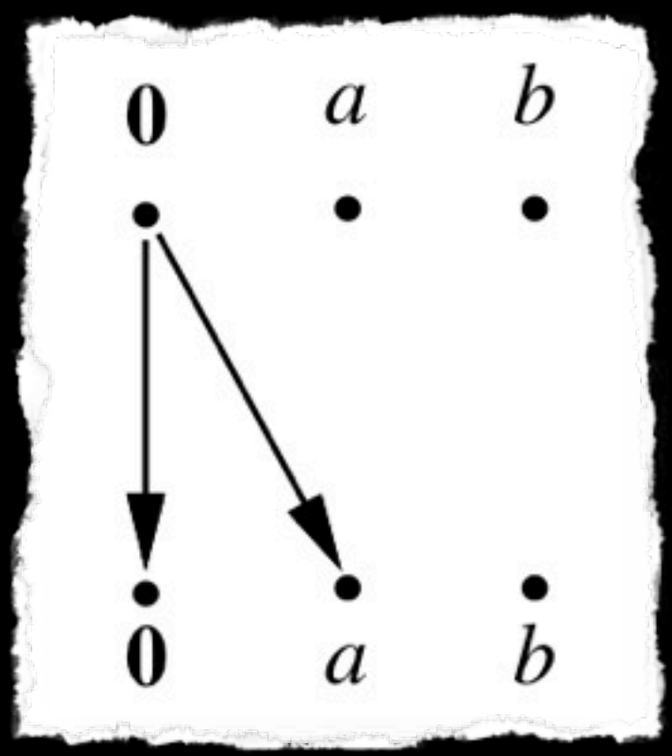
- Advantages:
  - Product line itself is a compileable Java program!
  - Easy to use, decent IDE support
- Limitation:
  - Limited to well-behaved feature annotations (can only color entire statements)
  - In the future want to look at C

Open questions

- How do apply approach to SPLs that are less disciplined (e.g. #ifdef in C)
- How to propagate constraints efficiently?
  - Probably using BDDs
  - Maybe make use of analysis-specific properties...

Locally separable functions

flow function locally separable ≡ function does not depend on input values



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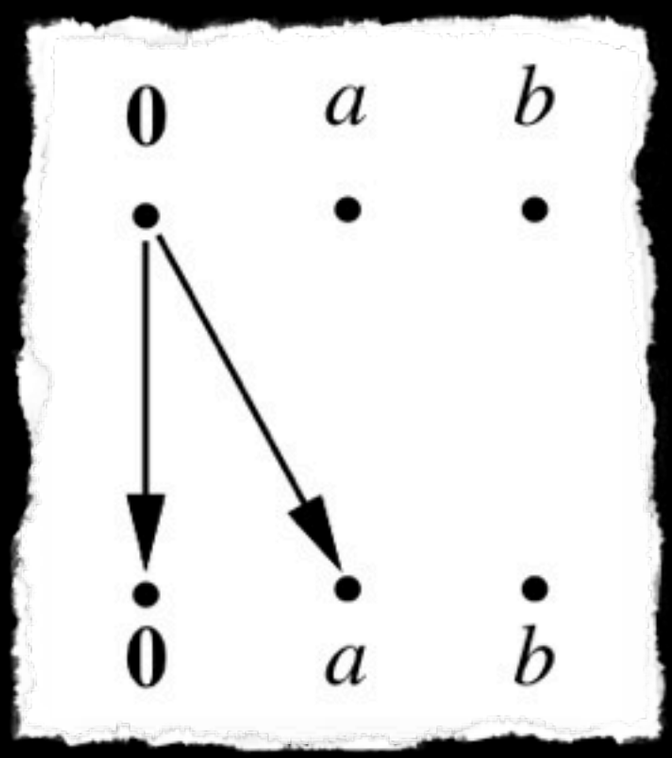

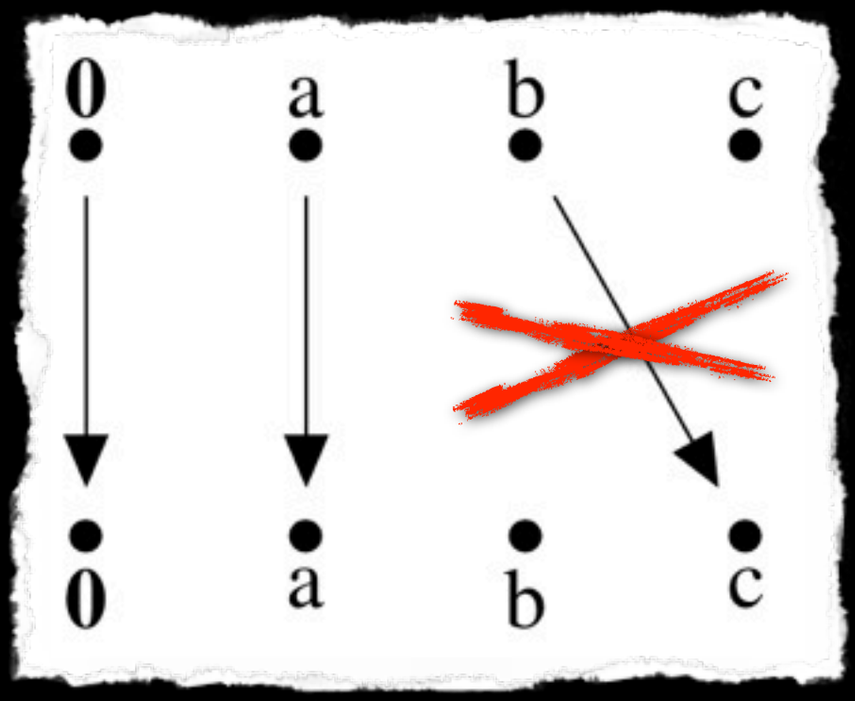

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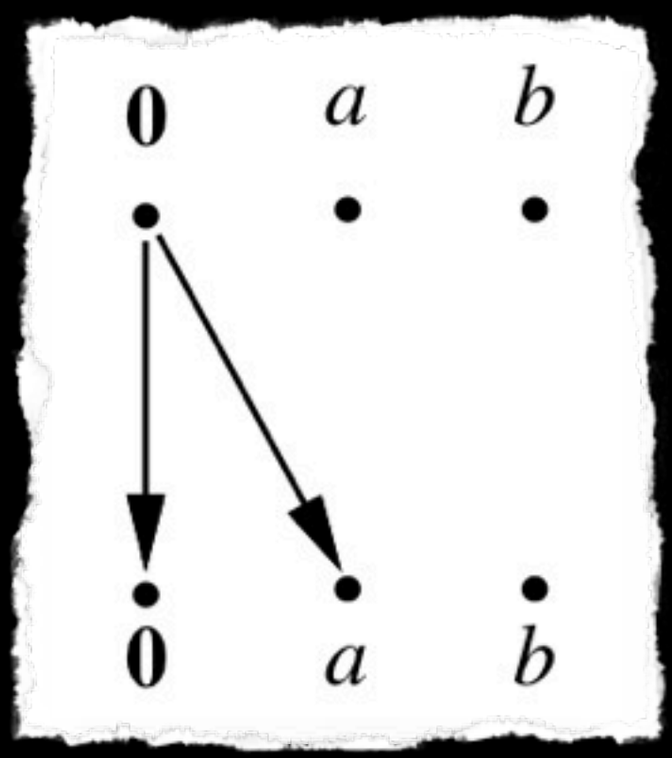
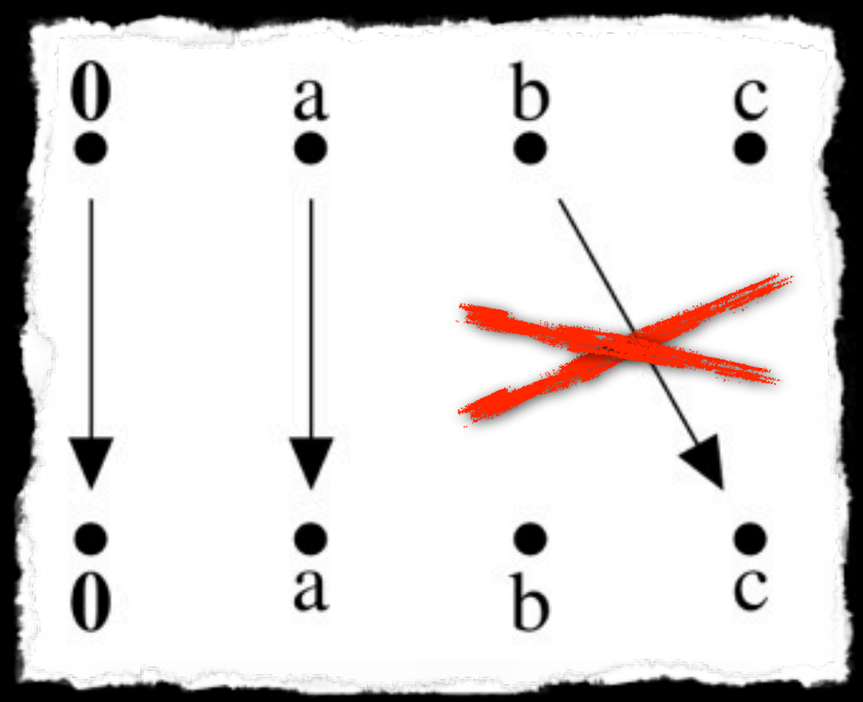
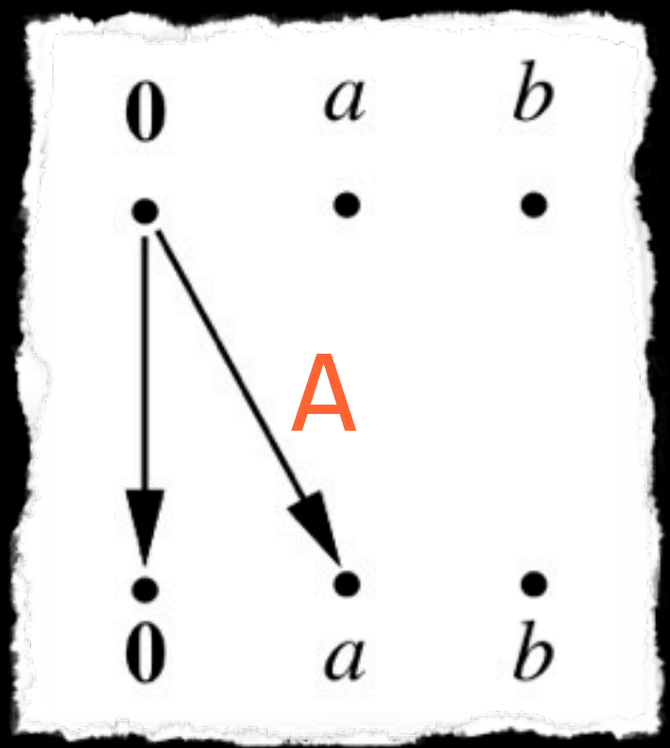




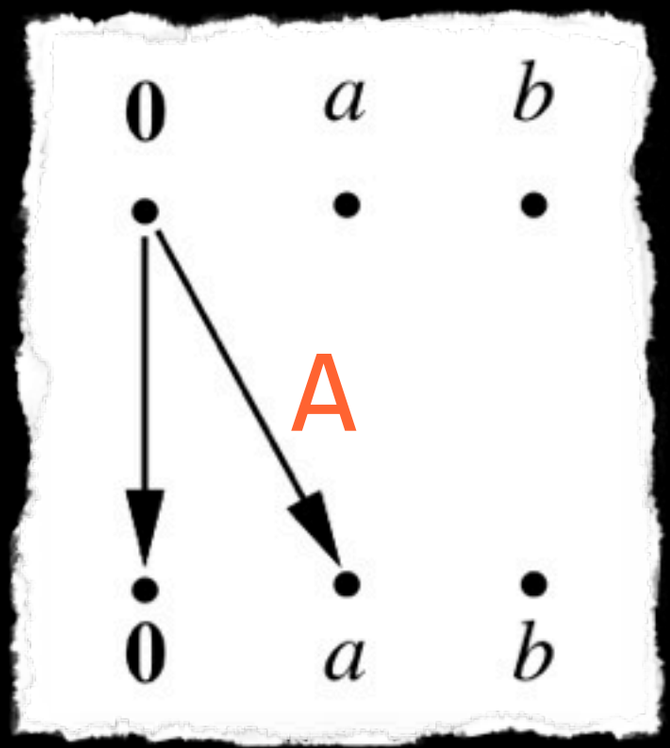
Reaching Definitions, Live Variables …

Yields very special constraints...



A ∧ ¬B ∧ ¬C...

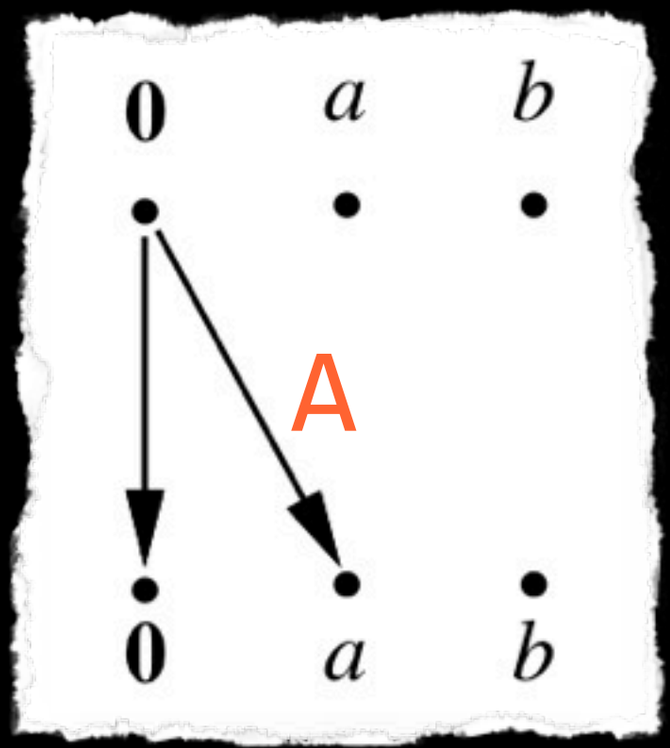
Yields very special constraints...



A ∧ ¬B ∧ ¬C...

Will **not** get: A ∧ B

Yields very special constraints...



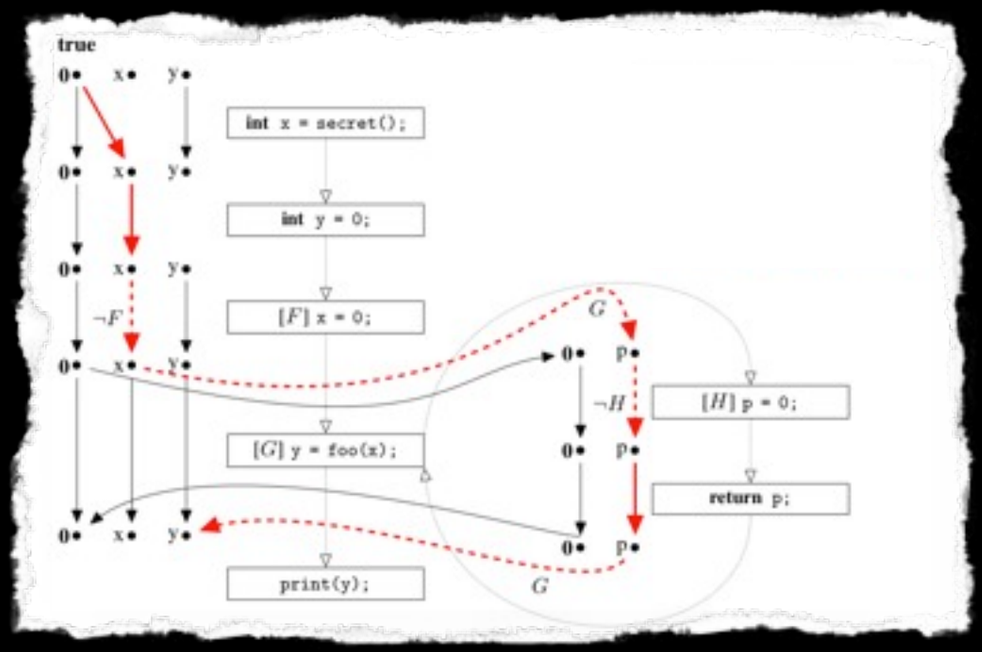
A ∧ ¬B ∧ ¬C...

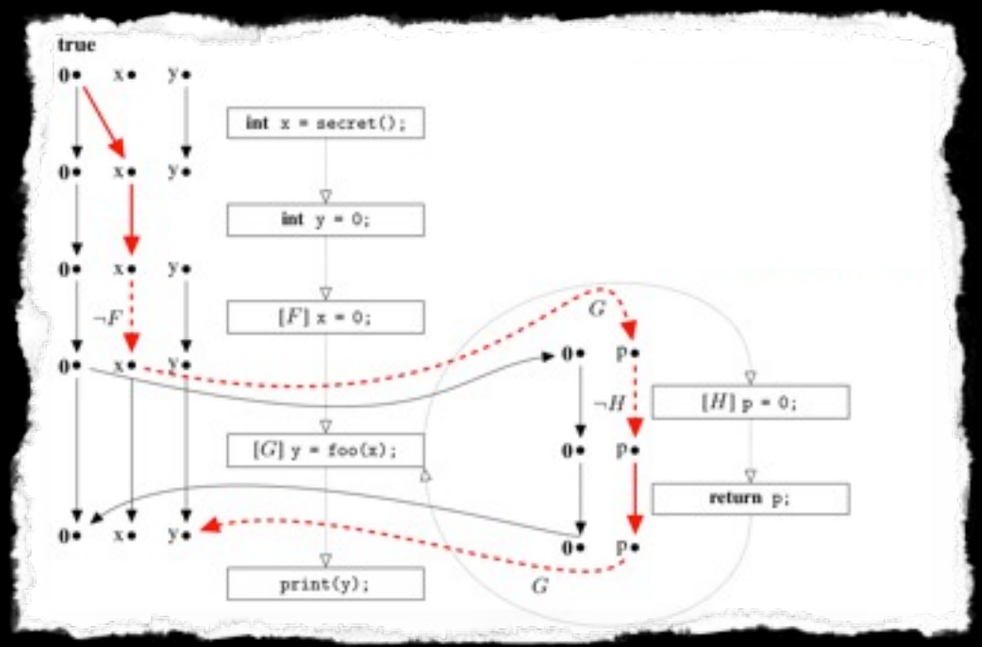
Will **not** get: A ∧ B

But those a feature model could help eliminate best!

Thanks to...

- Claus Braband (ITU Copenhagen)
- Marcio Ribeiro (UFPE Brazil)
- Tarsis Toledo (UFPE Brazil)
- Paulo Borba (UFPE Brazil)
- CIDE developers


true
0• x• y•
int x = secret();
int y = 0;
[F] x = 0;
¬F
G
[G] y = foo(x);
print(y);
p•
¬H
[H] p = 0;
return p;


true
int x = secret();
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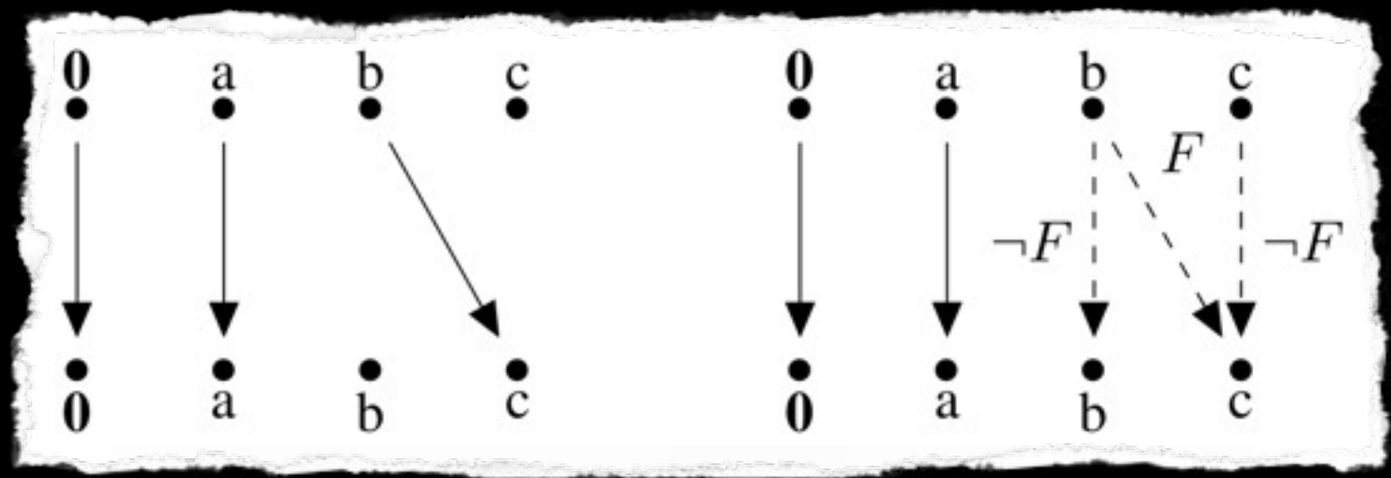
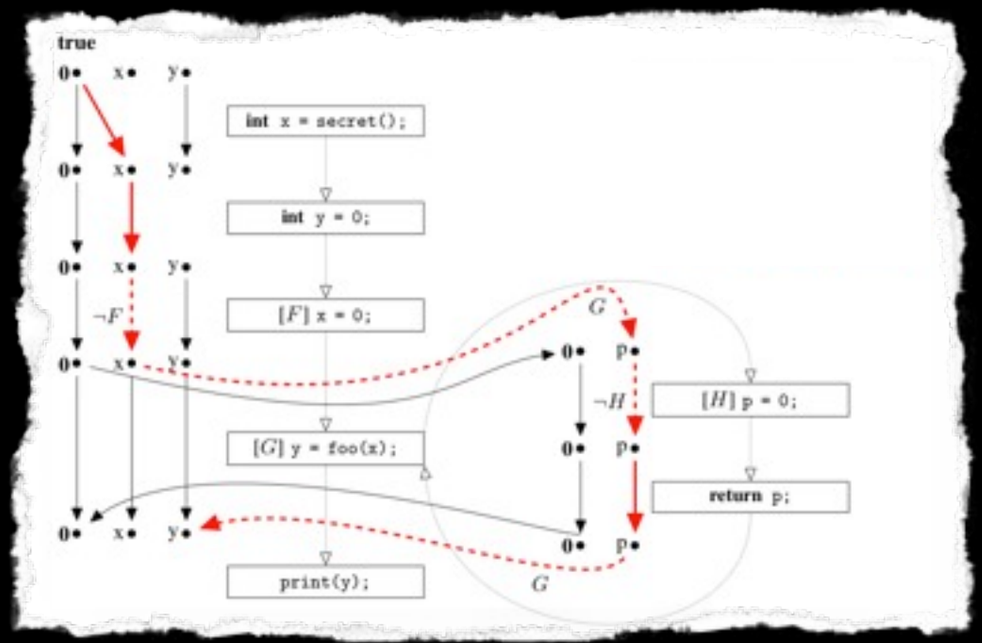
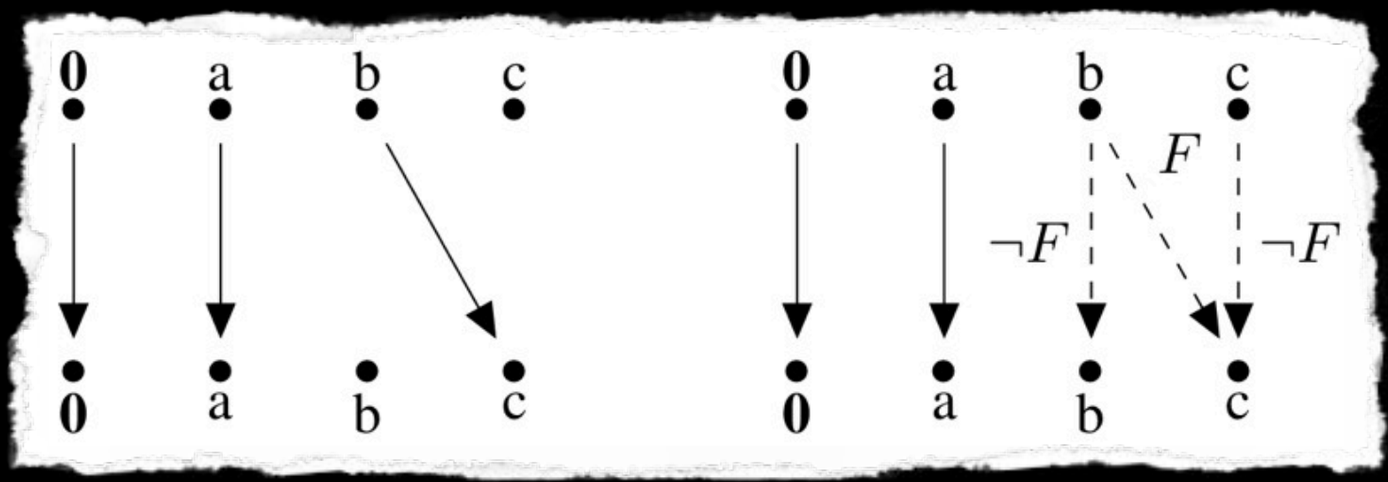
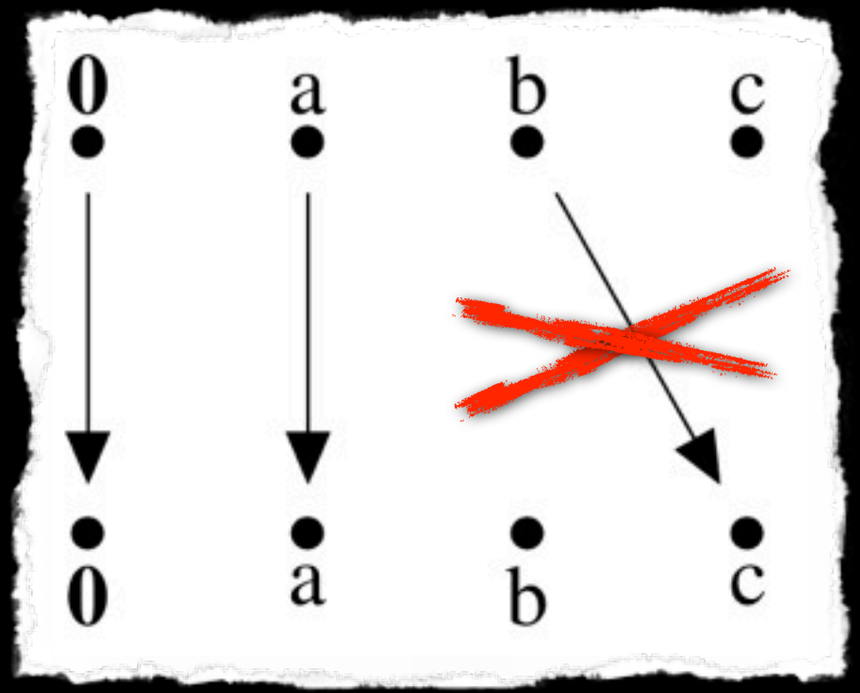
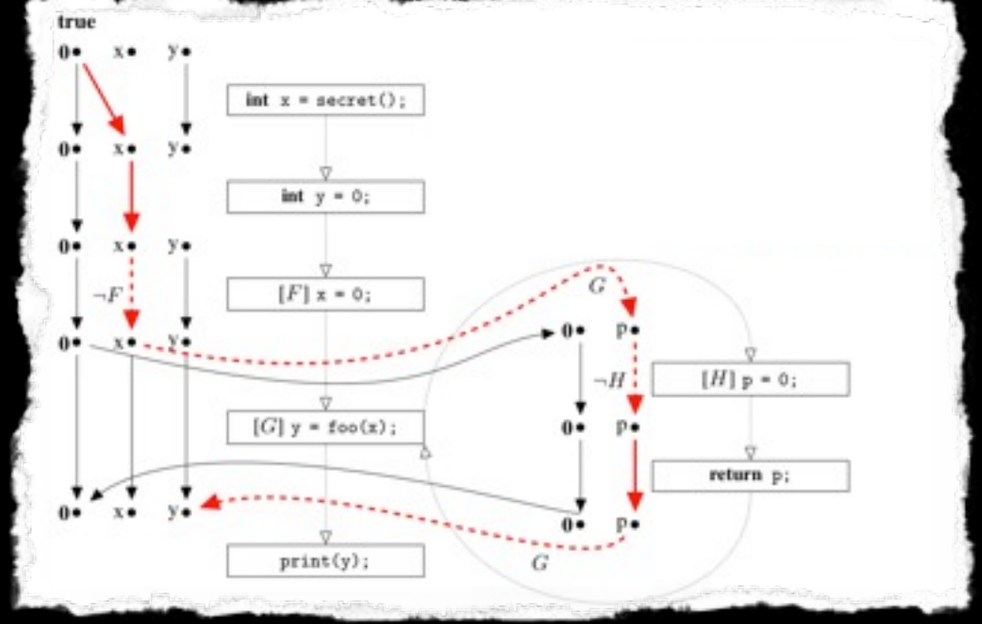
¬F
G
¬H

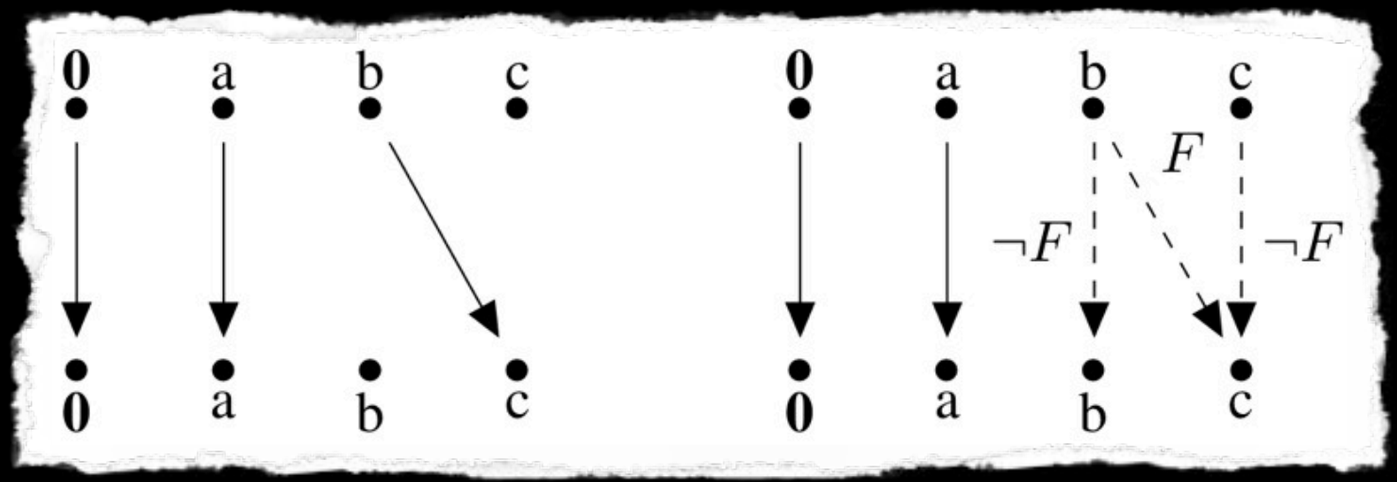

0
a
b
c
F
¬F
¬F

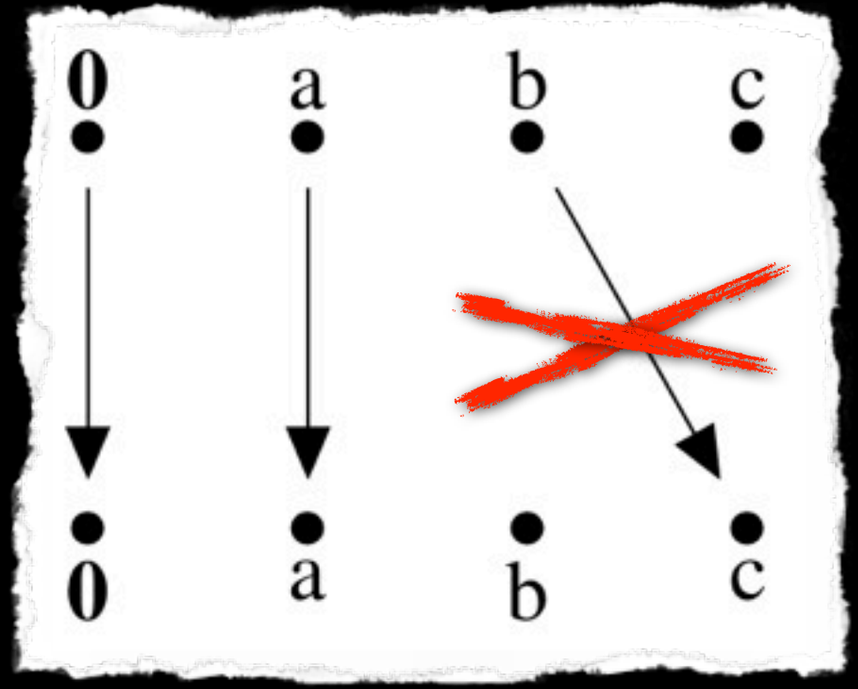

true
0 x y
int x = secret();
int y = 0;
[F] x = 0;
¬F
G
p
¬H
[H] p = 0;
[G] y = foo(x);
return p;
print(y);


0
a
b
c
F
¬F


0
a
b
c







http://bodden.de/spl/

http://sse.ec-spride.de/

SECURE SOFTWARE ENGINEERING GROUP

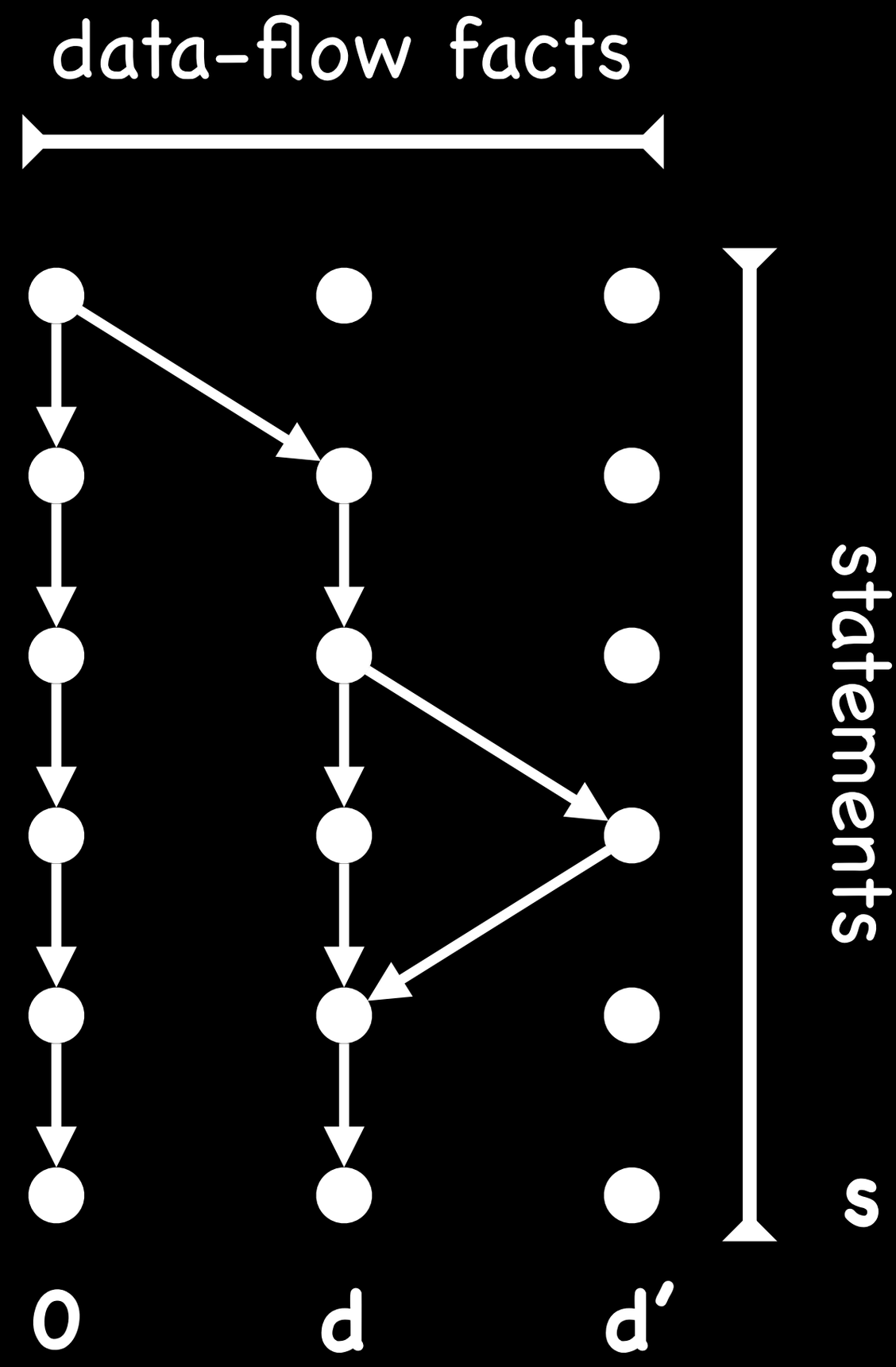
EC SPRIDE
EUROPEAN CENTER FOR SECURITY AND PRIVACY BY DESIGN

TECHNISCHE UNIVERSITÄT DARMSTADT

RHS 95

Static
Super-graph edge

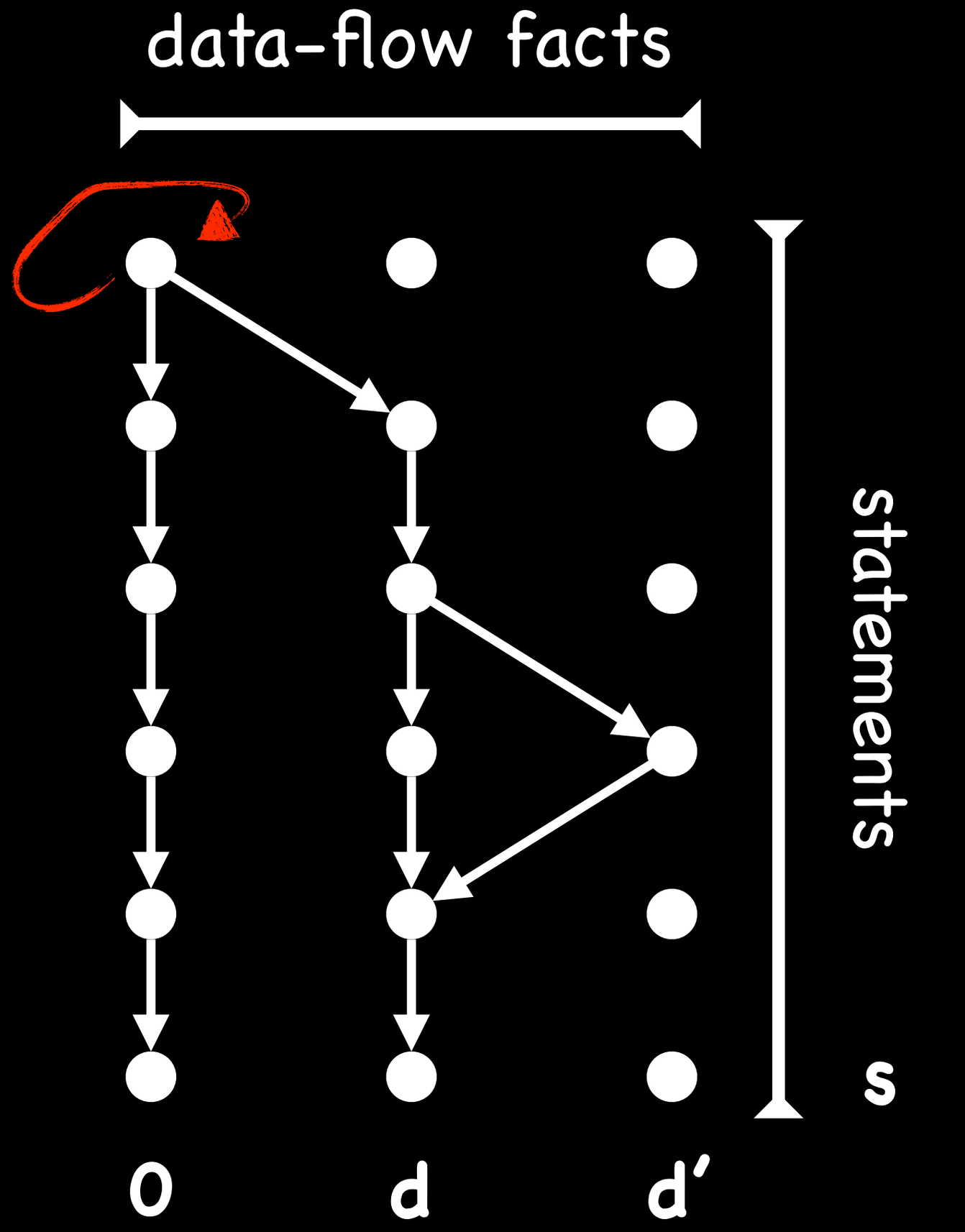
Computed
Summary Edge



RHS 95

Static
Super-graph edge

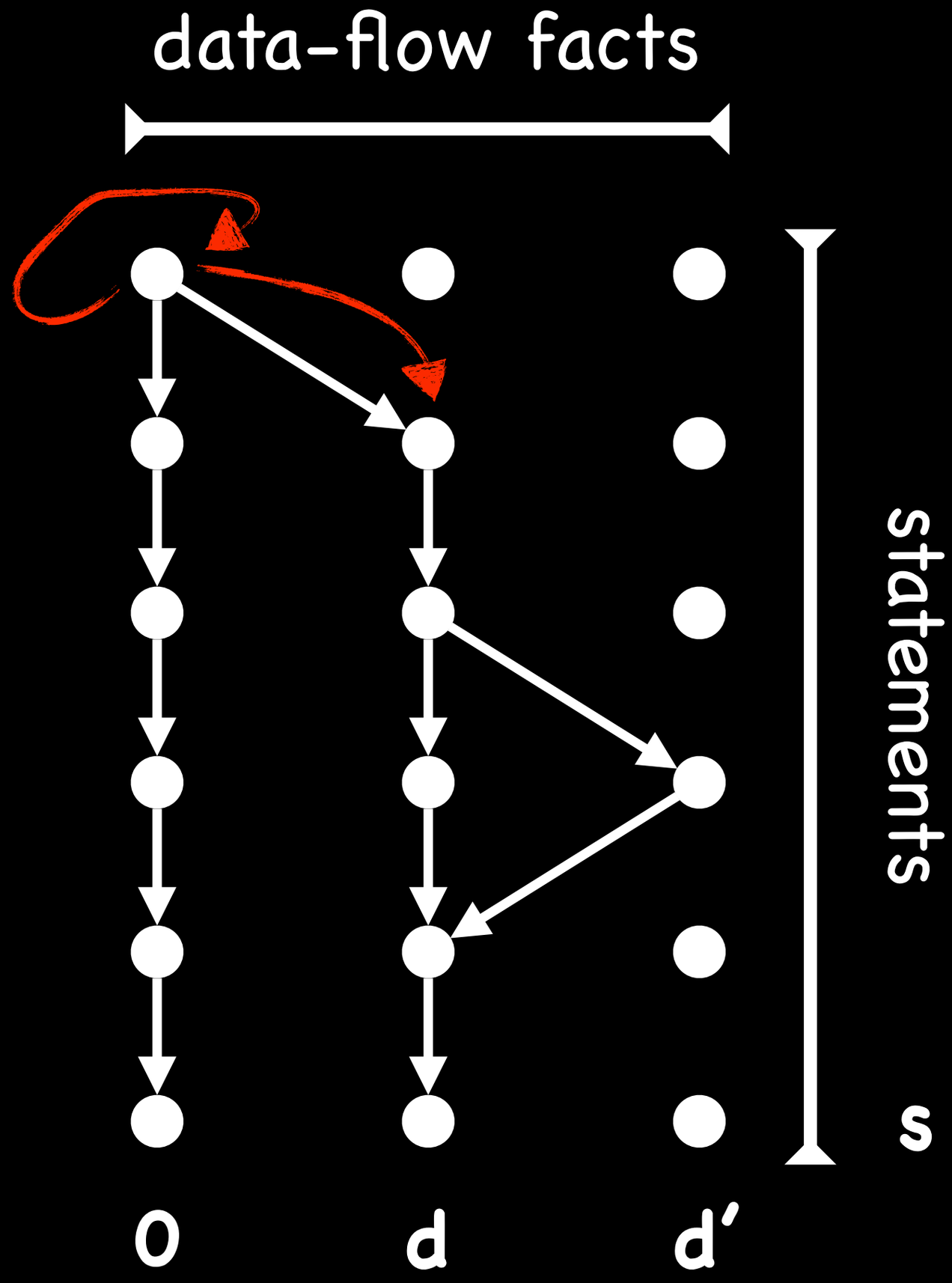
Computed
Summary Edge



RHS 95

Static
Super-graph edge

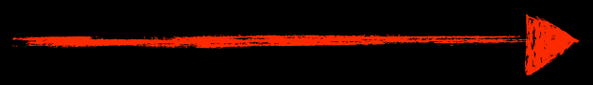
Computed
Summary Edge

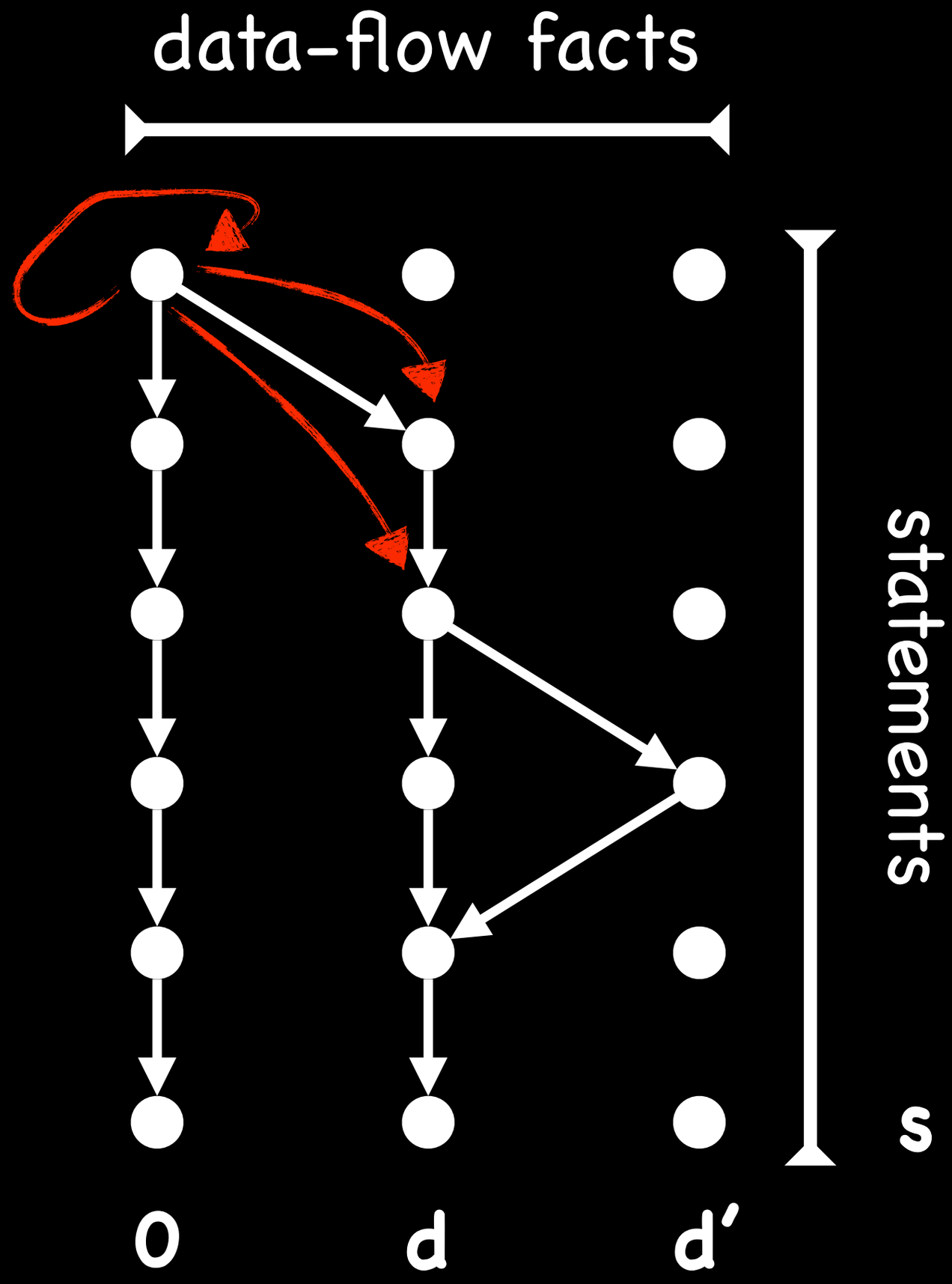


RHS 95

Static
Super-graph edge

Computed
Summary Edge

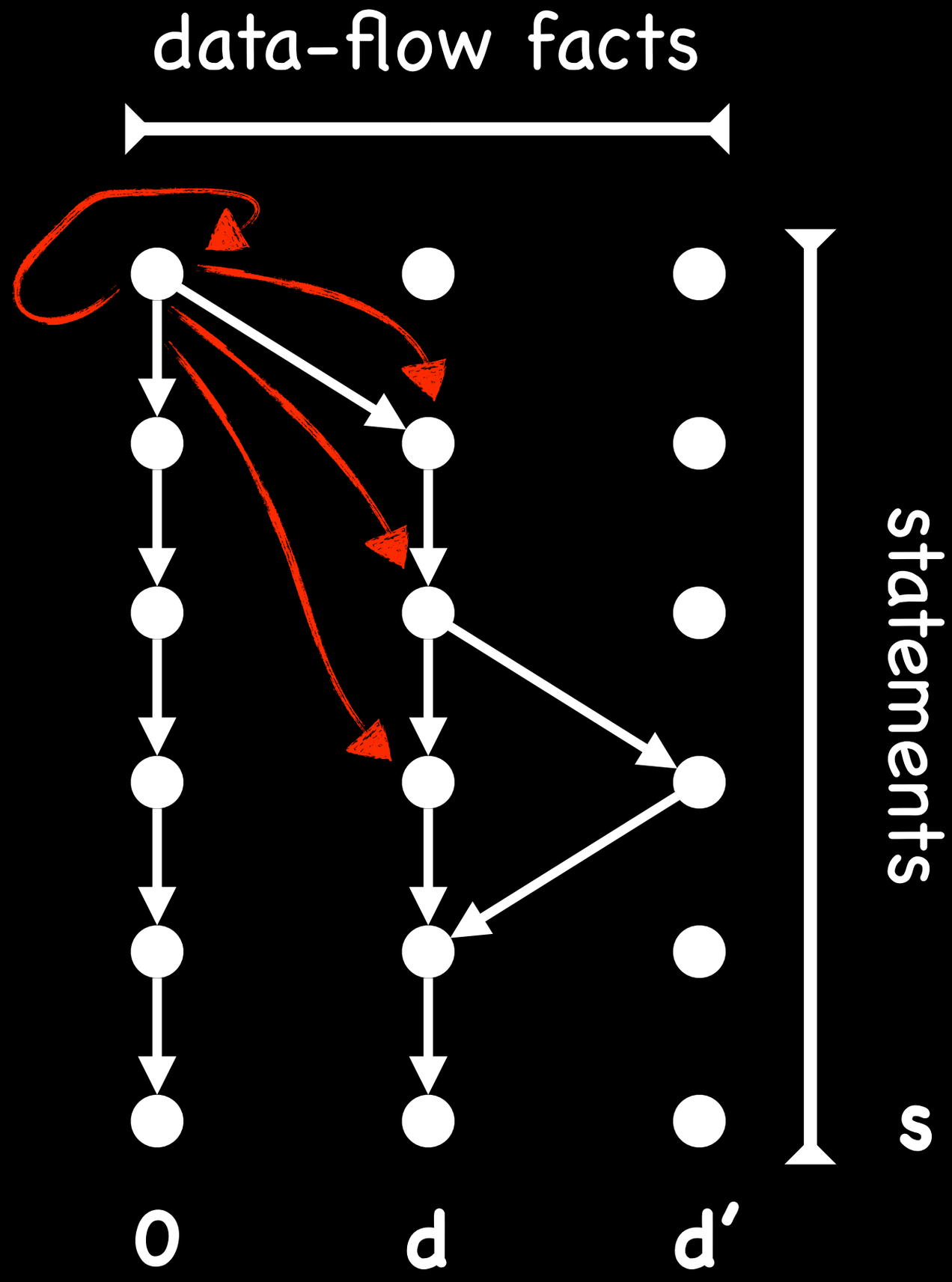




RHS 95

Static
Super-graph edge

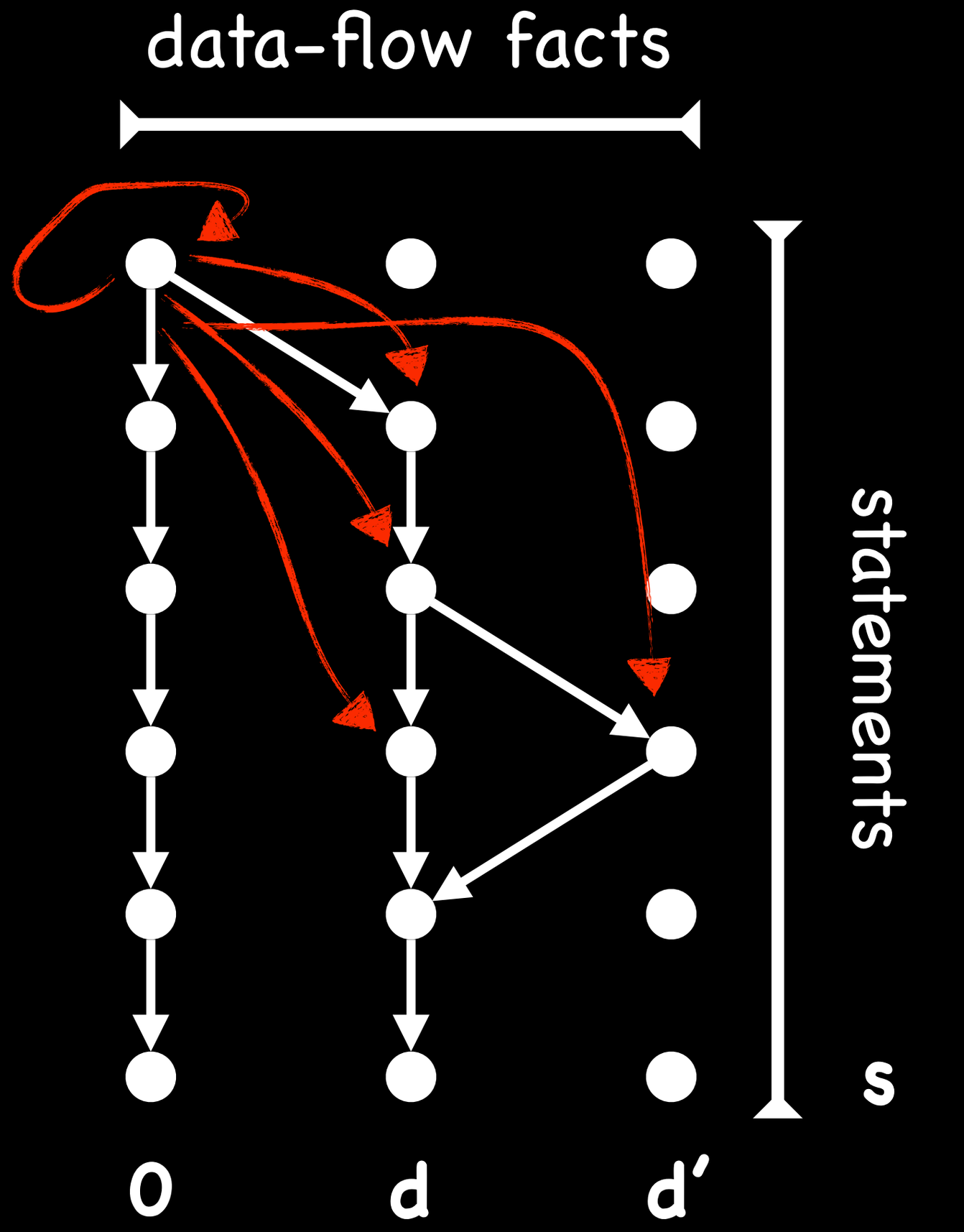
Computed
Summary Edge



RHS 95

Static
Super-graph edge

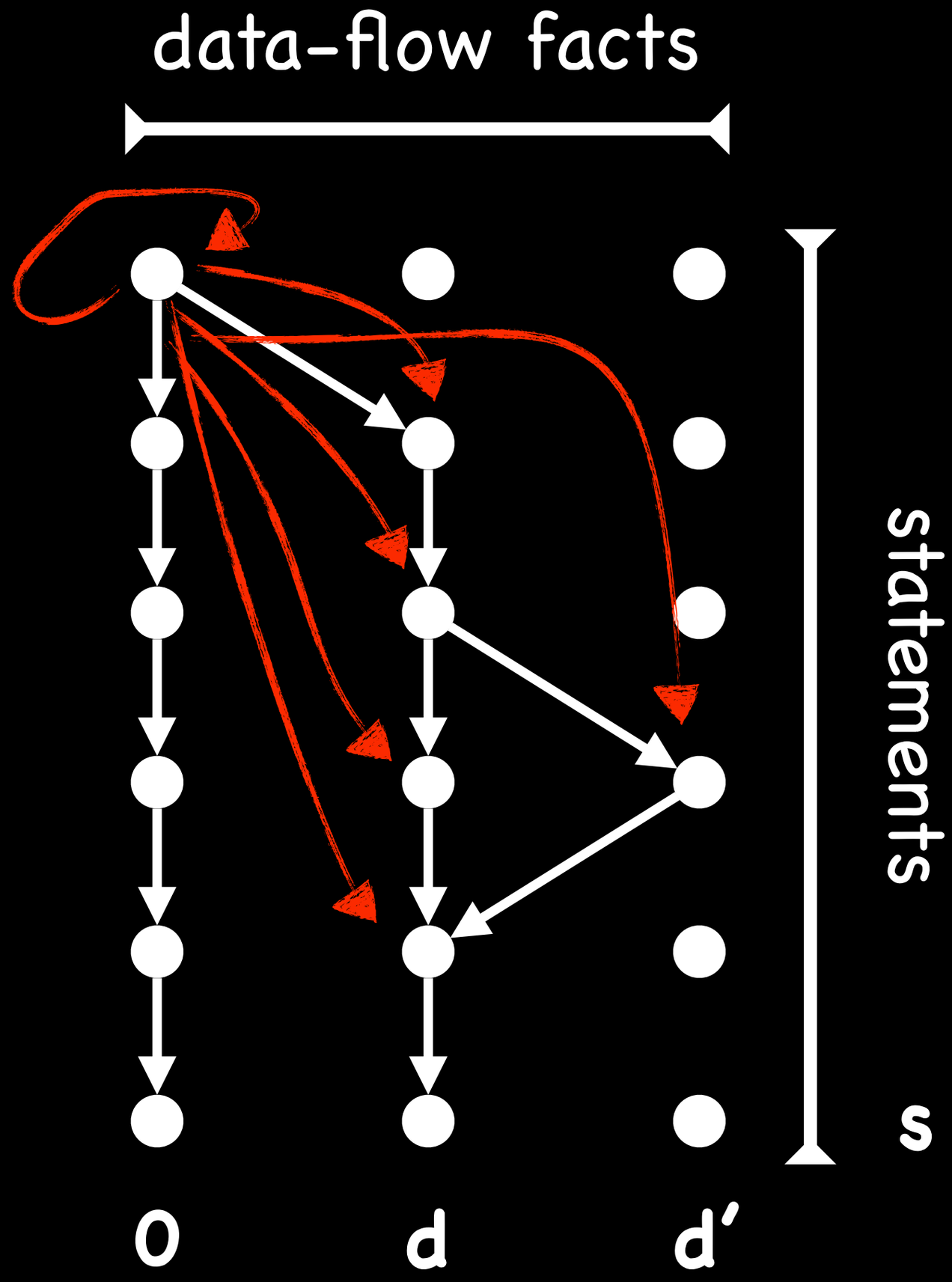
Computed
Summary Edge



RHS 95

Static
Super-graph edge

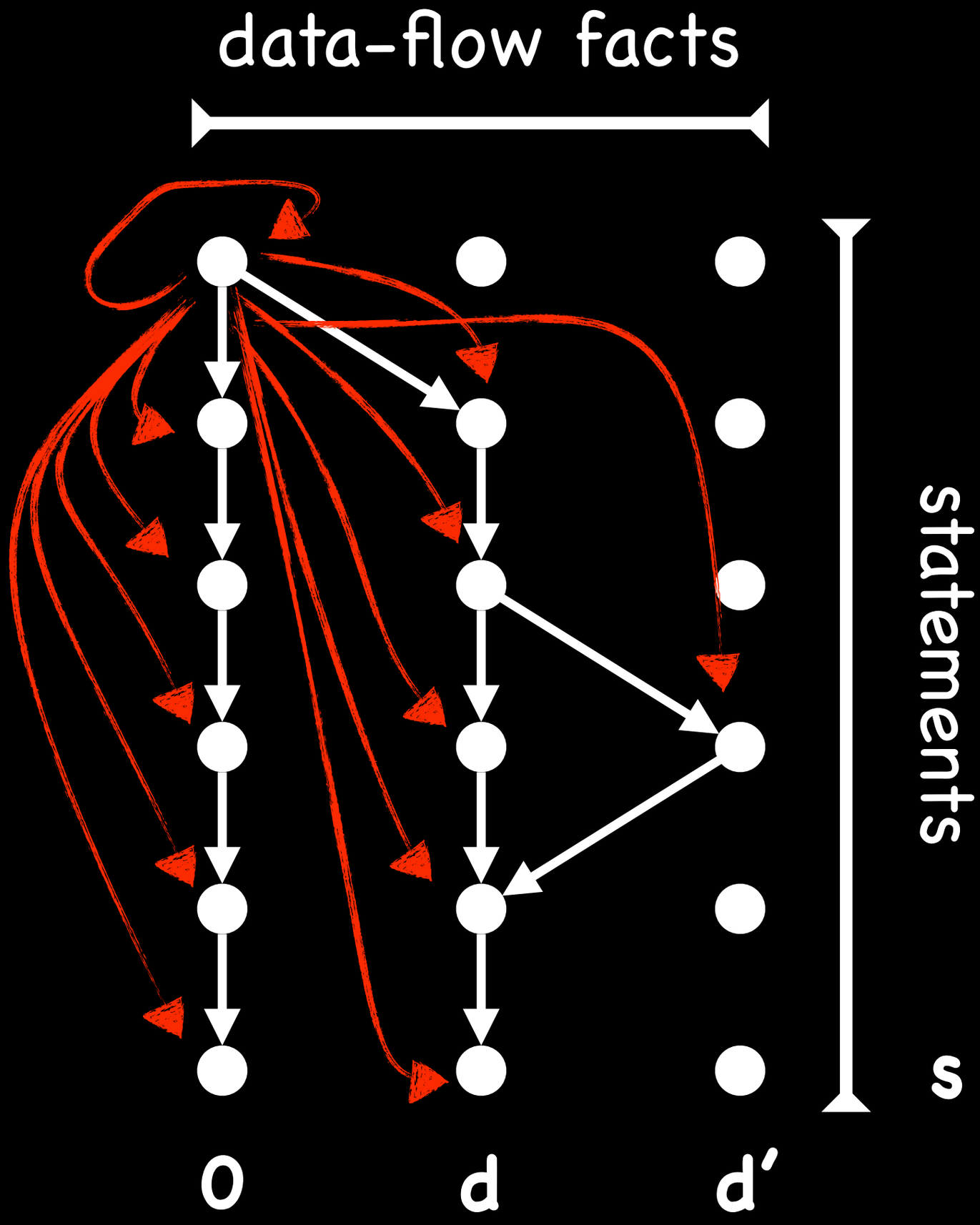
Computed
Summary Edge



RHS 95

Static
Super-graph edge

Computed
Summary Edge

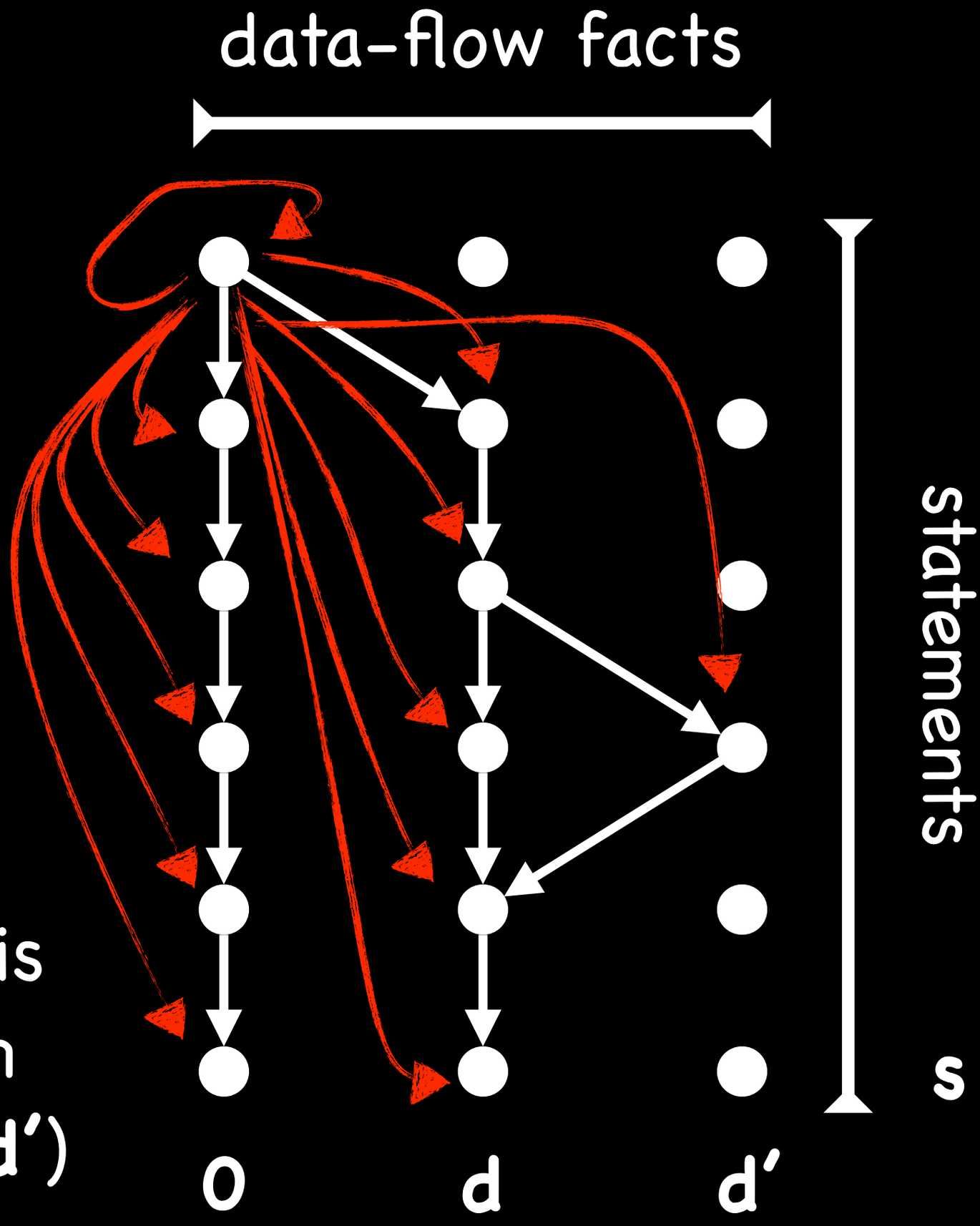


RHS 95

Static
Super-graph edge

Computed
Summary Edge

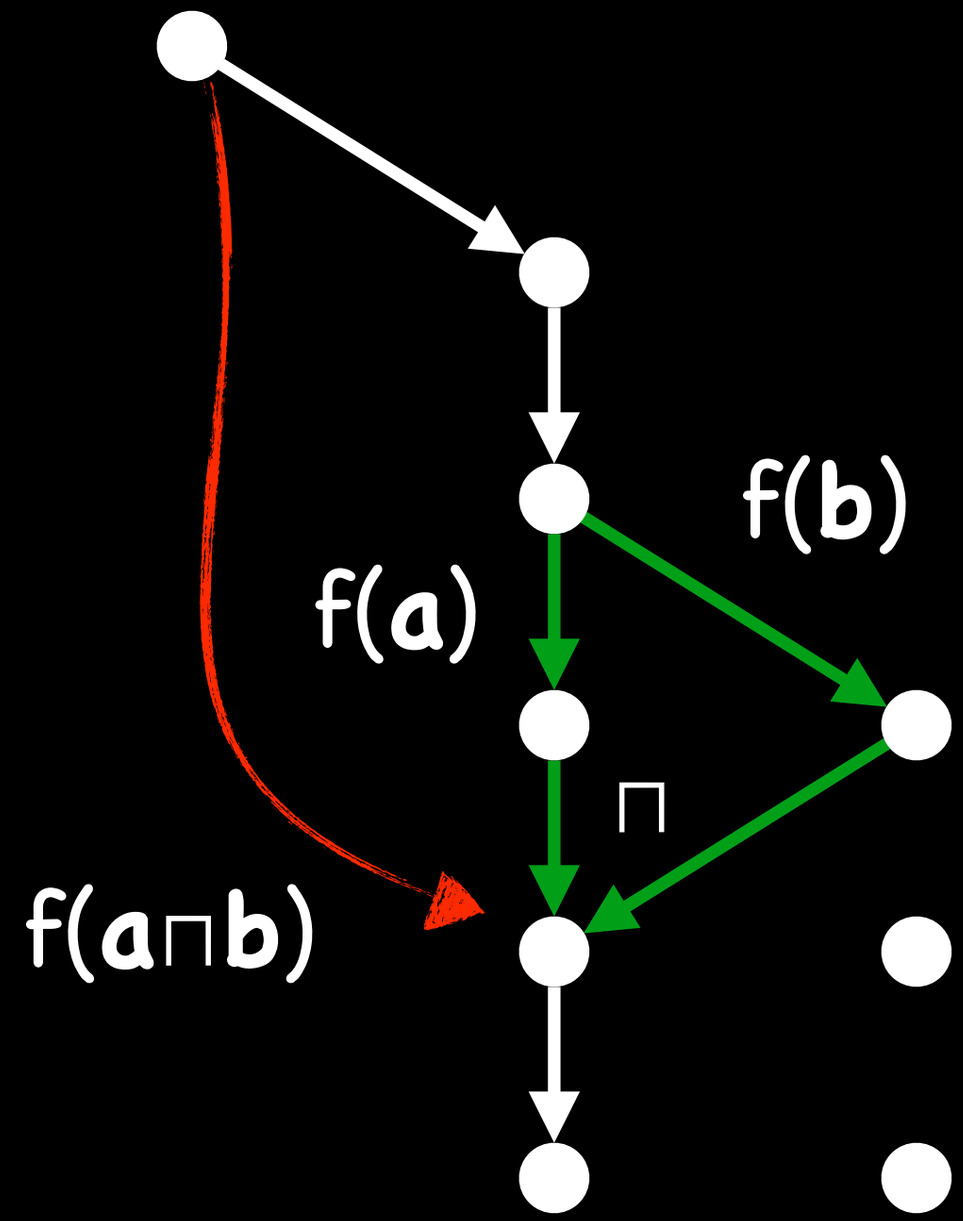
d holds at **s** if there is a summary edge from startOf(methodOf(**s**),**d′**) to (**s**,**d**) for some **d′**



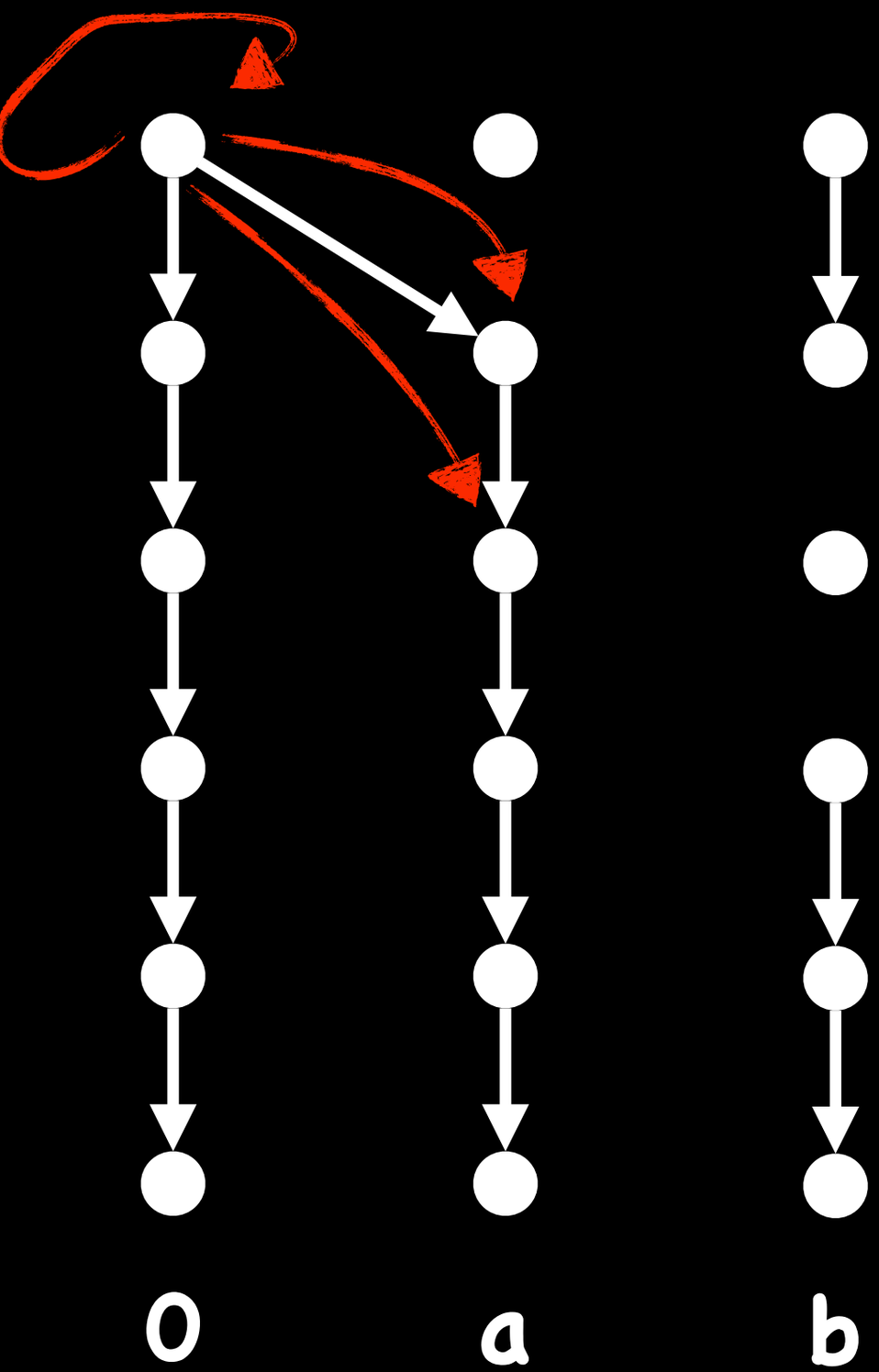
RHS 95

flow functions must be distributive:

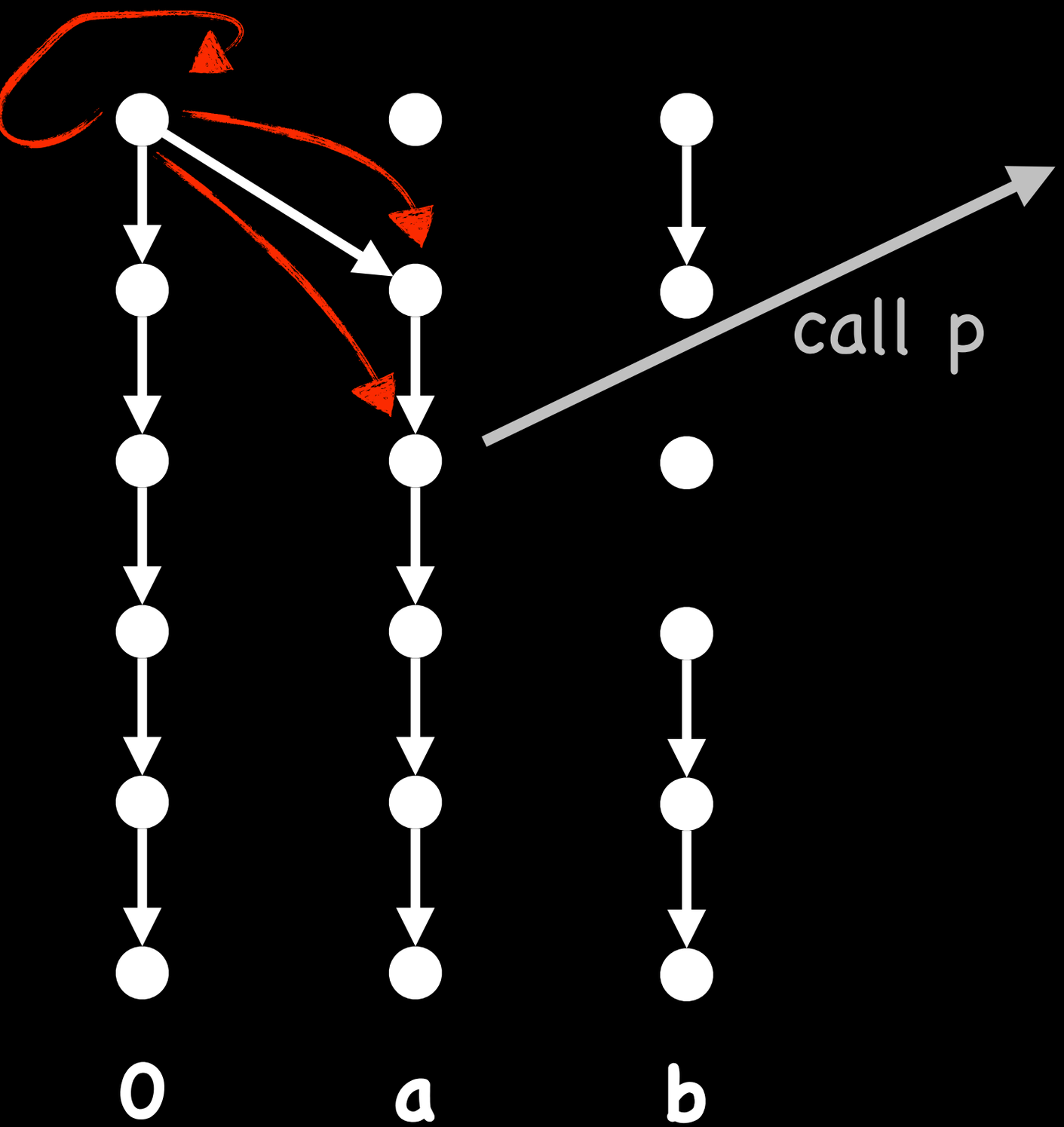
$f(\mathbf{a}) \sqcap f(\mathbf{b}) = f(\mathbf{a} \sqcap \mathbf{b})$



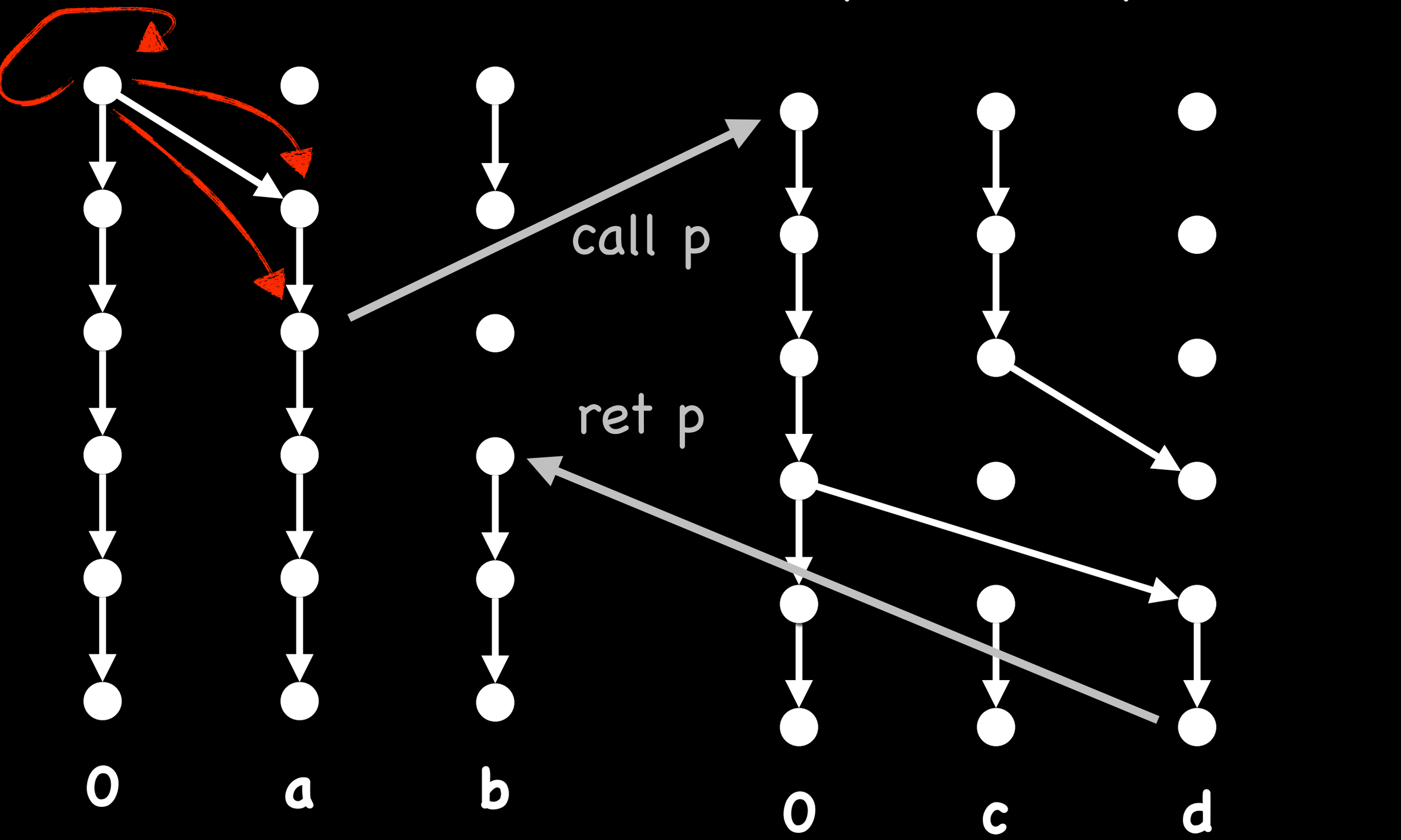
method calls



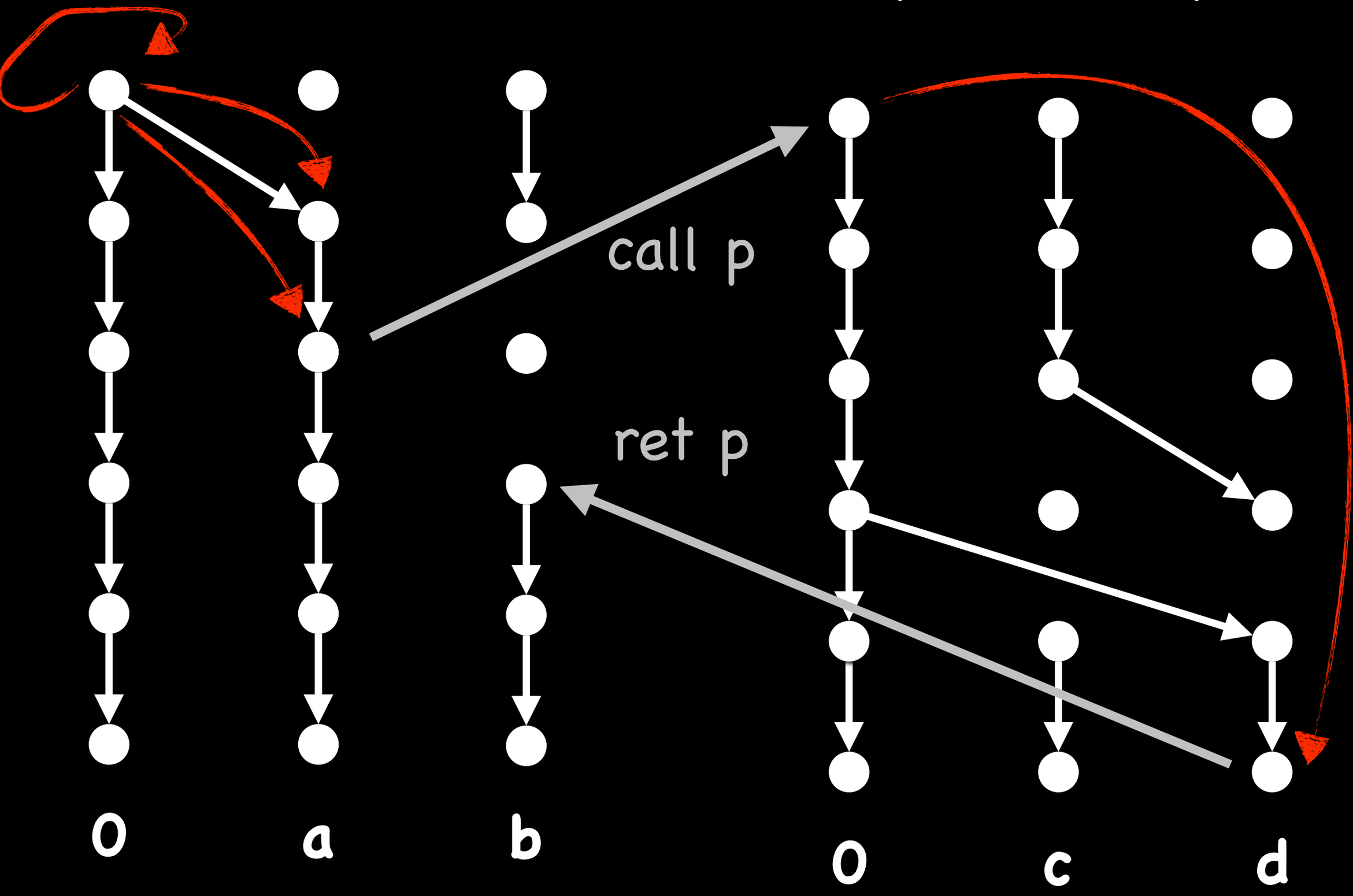
method calls



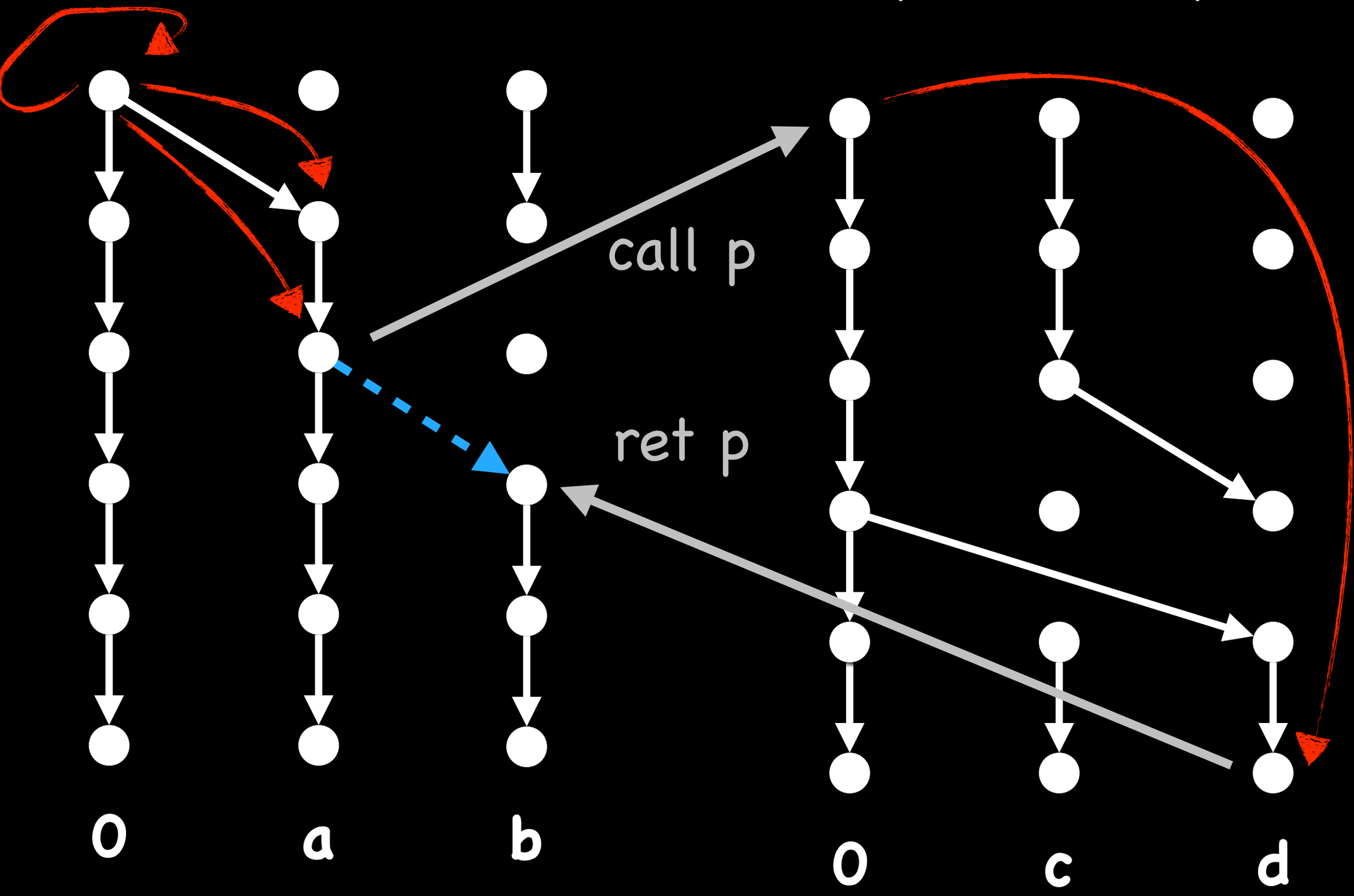
method calls



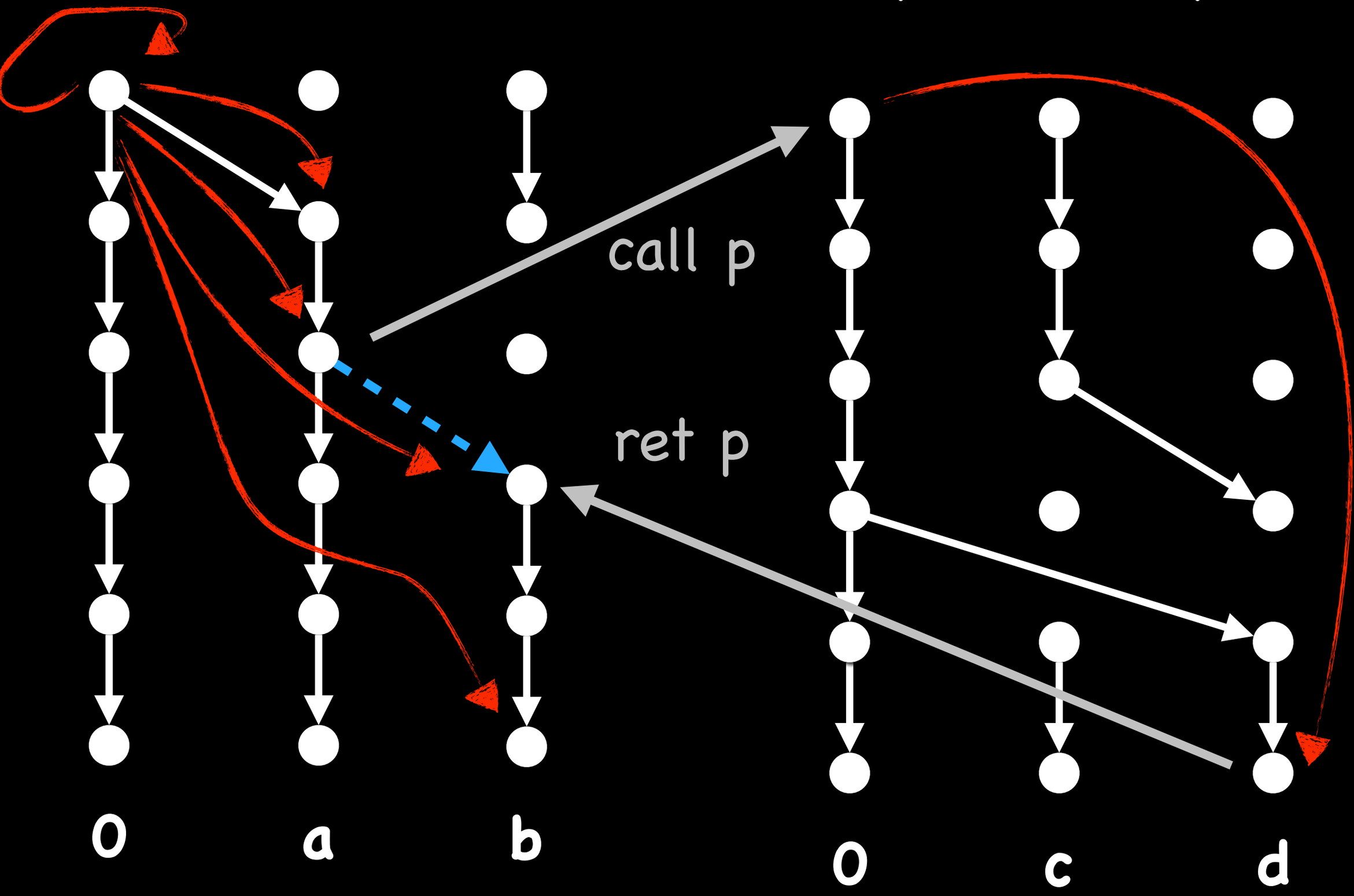
method calls



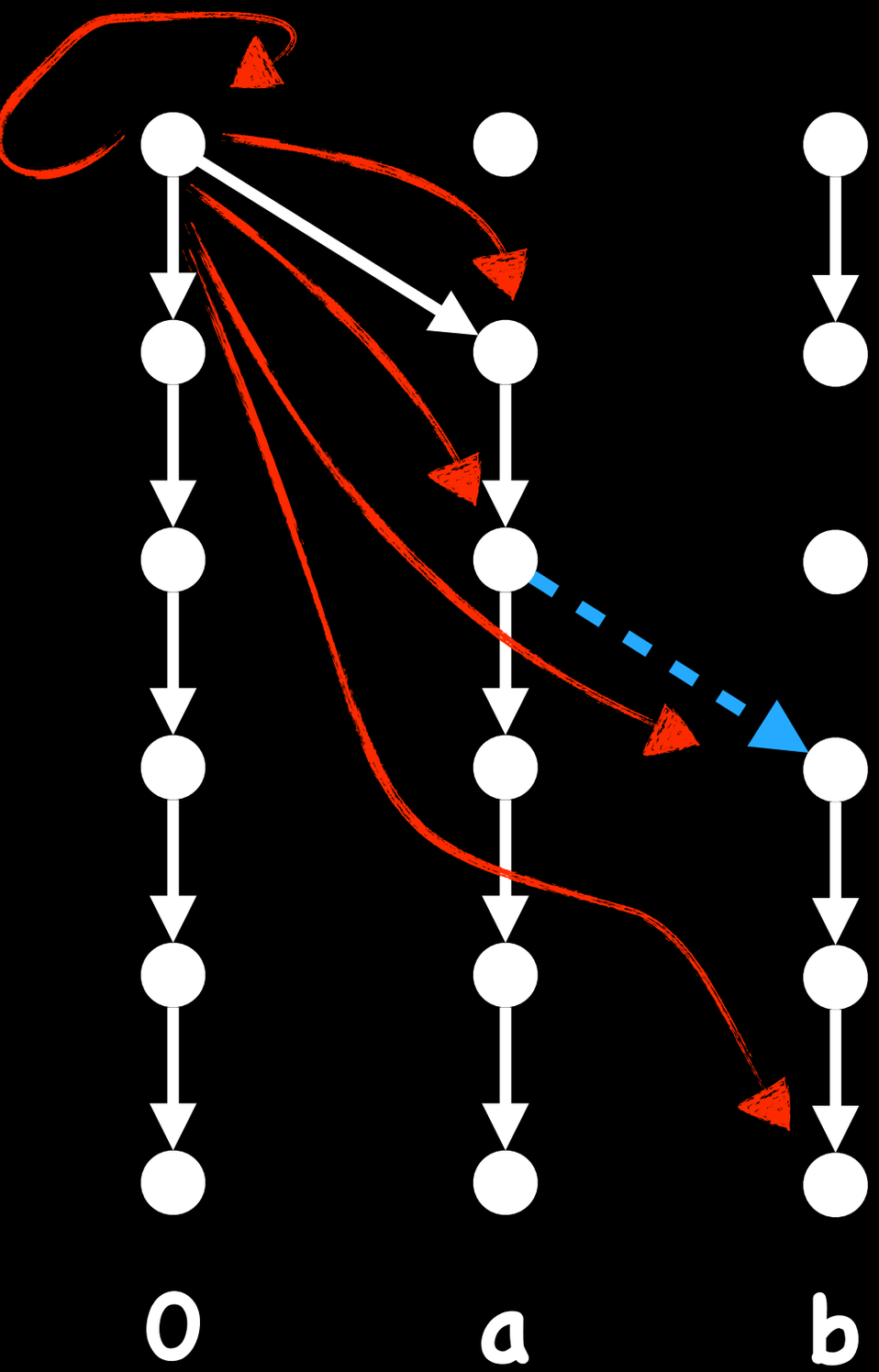
method calls



method calls



method calls



afterwards method-local decision:

b holds at **s** if there is a summary edge from startOf(methodOf(**s**),**d'**) to (**s**,**b**) for some **d'**