Secure Programs via Game-based Synthesis

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One-slide summary

- Secure programming on a conventional OS is *intractable*
- Privilege-aware OS's take secure programming from *intractable* to *challenging*
- Our program rewriter takes secure programming from *challenging* to *simple*

Outline

1. Motivation, problem statement
2. Previous work: Capsicum [CAV '12, Oakland '13]
3. Ongoing work: HiStar
4. Open challenges

Outline

1. Motivation, problem statement

Secure Programming is *Intractable*

- 81 exploits in CVE since Sept. 2013
- Many exploit a software bug
  to carry out undesirable system operations
  - 2013-5751: exploit SAP NetWeaver
    to traverse a directory
  - 2013-5979: exploit bad filename handling in
    Xibo to read arbitrary files
  - 2013-5725: exploit ByWord
    to overwrite files

How to Carry Out an Exploit

software vulnerability

+

OS privilege

=

security exploit

The Conventional-OS Solution

software vulnerability

+

OS privilege

=

security exploit

The Conventional-OS Solution

software vulnerability

+

~~OS privilege~~

=

security exploit

The Conventional-OS Solution

software vulnerability

+

~~OS privilege~~

≠

security exploit

The Program-Verification Solution

software vulnerability

+

OS privilege

=

security exploit

The Program-Verification Solution

~~software vulnerability~~

+

OS privilege

=

security exploit

The Program-Verification Solution

~~software vulnerability~~

+

OS privilege

≠

security exploit

Priv.-aware OS

- Introduce **explicit** privileges over all system objects, **primitives** that update privileges
- Programs call primitives to manage privilege

The Priv.-aware OS Solution

software vulnerability

+

OS privilege

=

security exploit

The Priv.-aware OS Solution

(software vulnerability

+

primitives)

+

OS privilege monitor

=

security exploit

The Priv.-aware OS Solution

$$\left(\begin{array}{c}\text{software vulnerability}\\ +\\ \text{primitives}\end{array}\right)$$

\+

OS privilege monitor

≠

security exploit

The Capsicum Priv.-aware OS [Watson '10]

- Privilege: **ambient authority (Amb)** to open descriptors to system objects
- Primitives: program calls `cap_enter()` to manage Amb

Rules of Capsicum's Amb

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1. When a process is created, it has the Amb value of its parent

Rules of Capsicum's Amb

1. When a process is created,
   it has the Amb value of its parent
2. After a process calls `cap_enter()`,
   it does not have Amb

Rules of Capsicum's Amb

1. When a process is created, it has the Amb value of its parent
2. After a process calls `cap_enter()`, it does not have Amb
3. If a process does not have Amb, then it can never obtain Amb

gzip

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);
L1: compress(in, out);
}
```

gzip

```
main() {
   file_nms = parse_cl();
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   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);
L1: compress(in, out);
}
```

http://evil.com

gzip

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);
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```

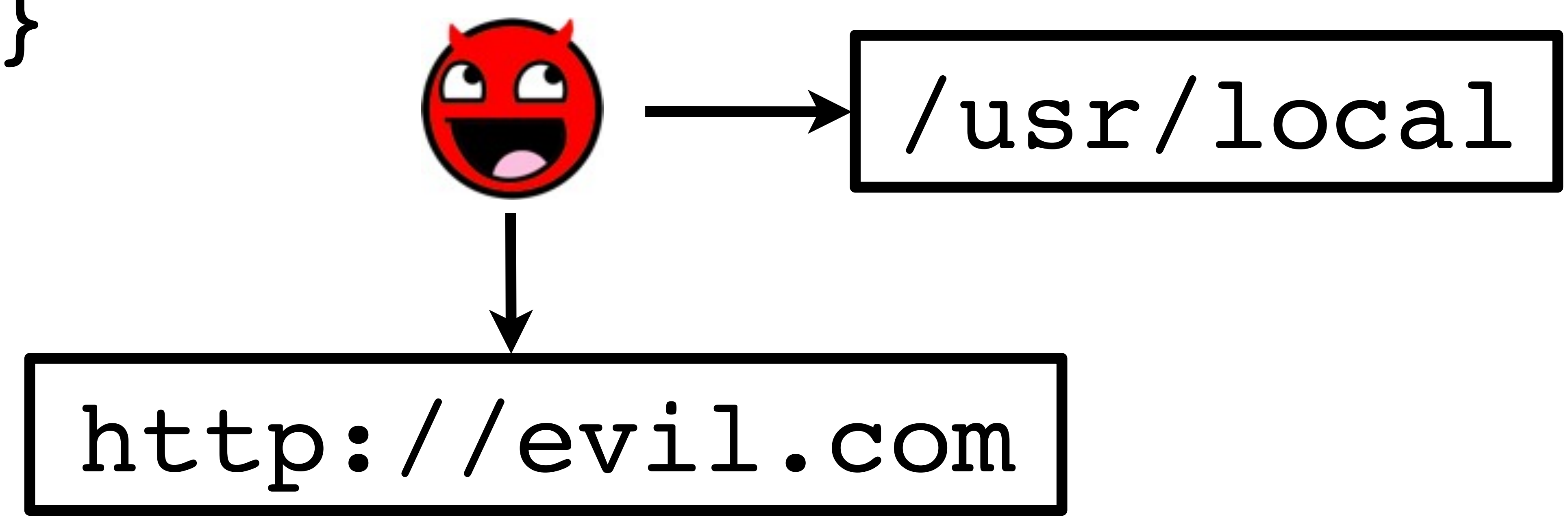

A simple `gzip` policy

- When `gzip` calls `open2()` at `L0`, it should be able to open descriptors
- When `gzip` calls `compress()` at `L1`, it should not able to open descriptors

A simple `gzip` policy with AMB

- When `gzip` calls `open2()` at `L0`, it should have AMB
- When `gzip` calls `compress()` at `L1`, it should not have AMB

`gzip` with AMB

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);
L1: compress(in, out);
}
```

gzip with AMB

```
main() {
  file_nms = parse_cl();
  for (f in file_nms):
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gzip with AMB

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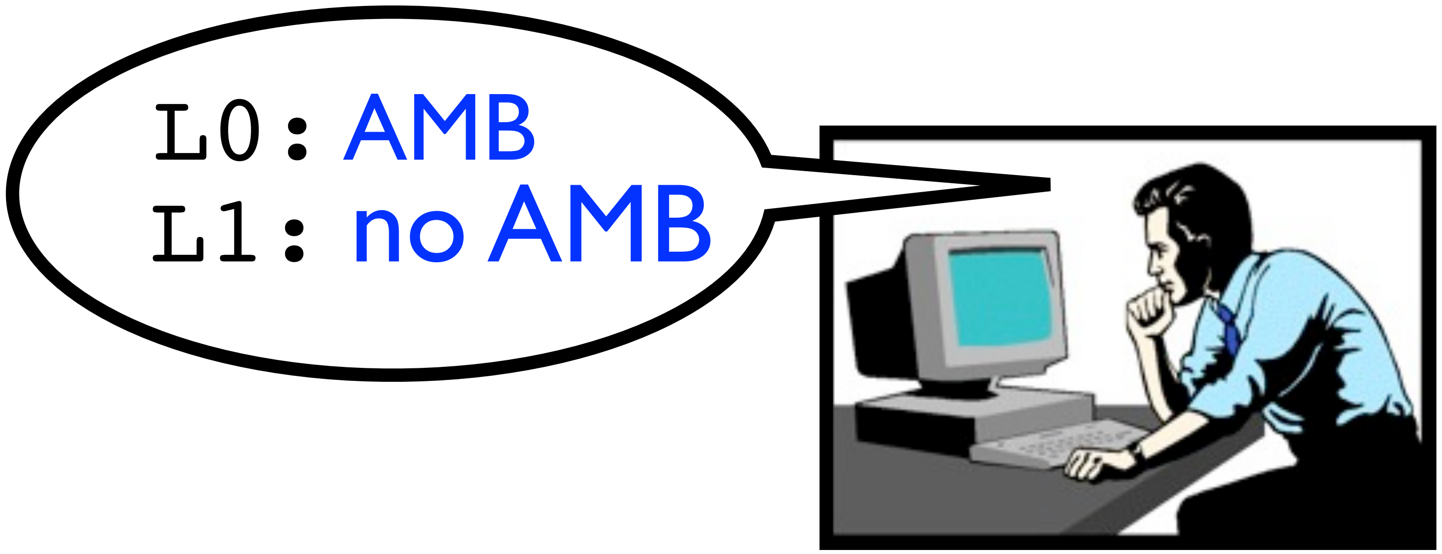

gzip with AMB

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main() {
   file_nms = parse_cl();
   for (f in file_nms):
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L1: compress(in, out);
}
```
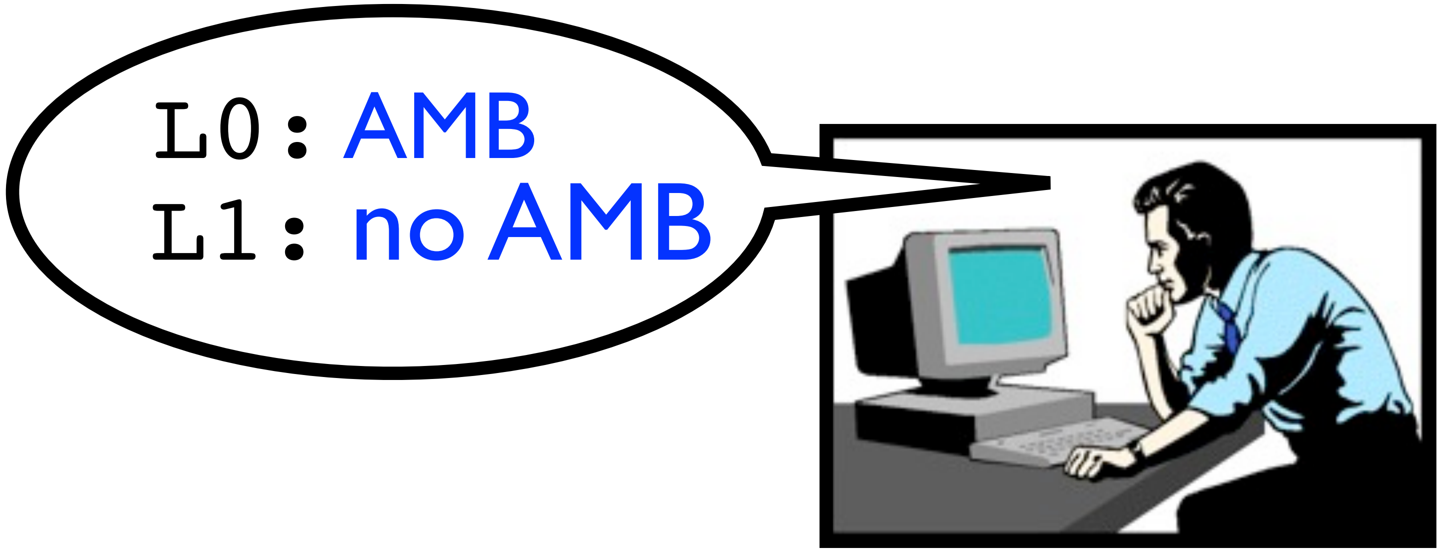
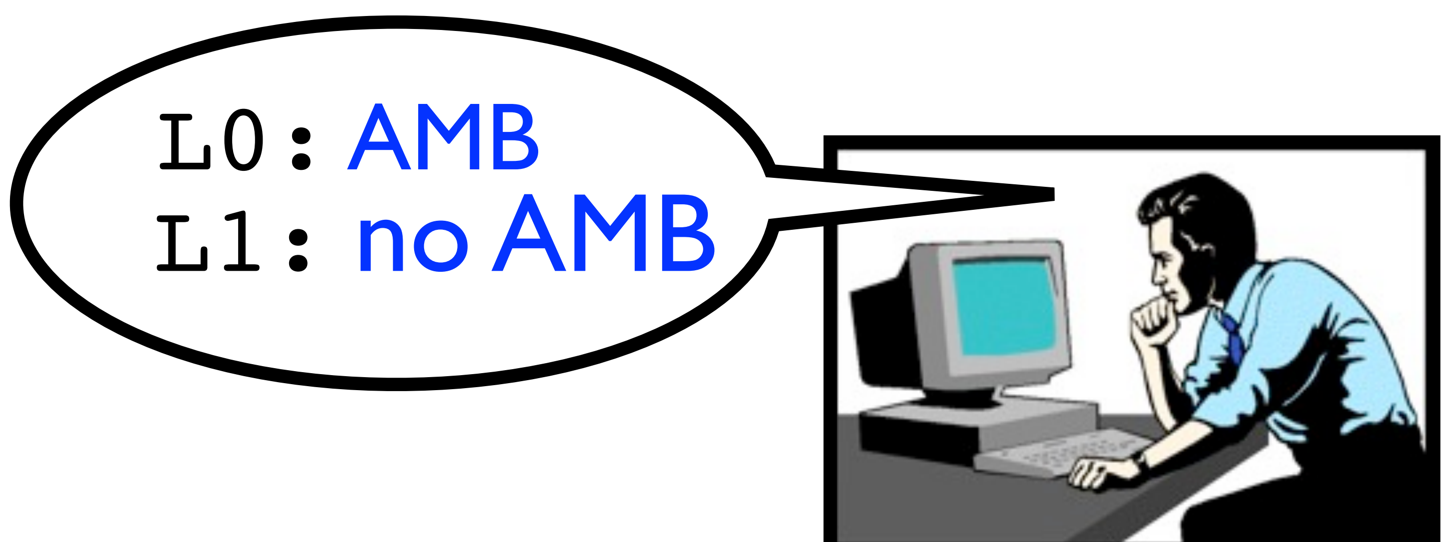

cap_enter()



gzip with AMB

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):        ?  cap_enter()
L0: (in, out) = open2(f);      ?
L1: compress(in, out);
}
```



Capsicum Programming Challenges

1. Amb policies are not explicit
2. cap_enter primitive has subtle temporal effects

gzip
Programming Challenges

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);

L1: compress(in, out);
}
```

L0: AMB
L1: no AMB

gzip
Programming Challenges

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
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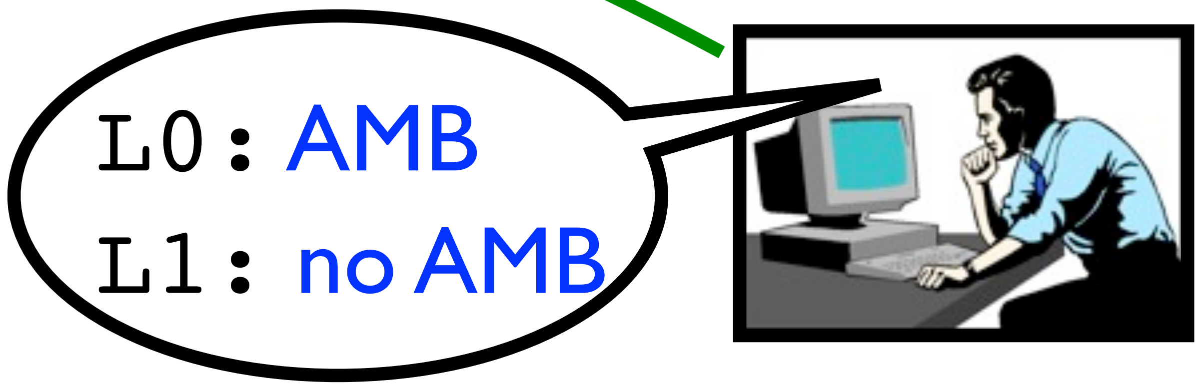

gzip Programming Challenges

```
main() {
   file_nms = parse_cl(); AMB
   for (f in file_nms):
L0: (in, out) = open2(f);
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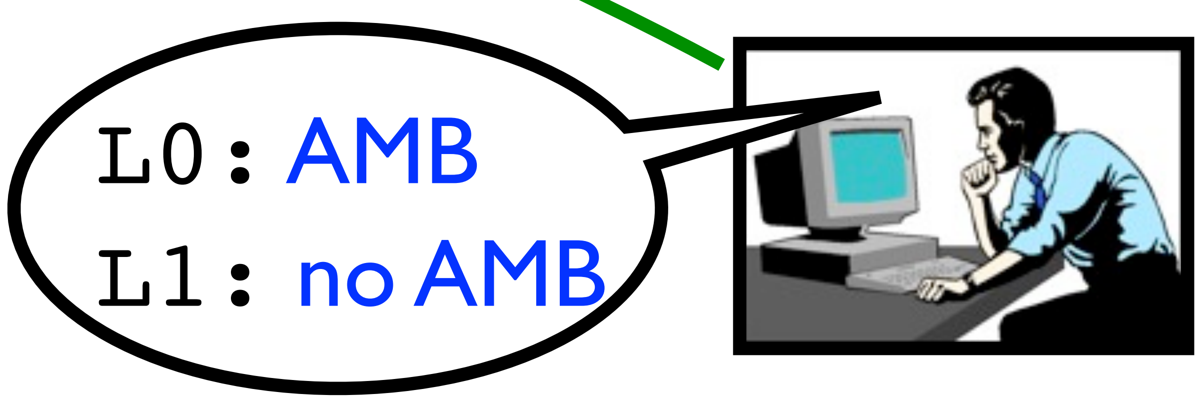
}
```



gzip
Programming Challenges

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):       AMB
L0: (in, out) = open2(f);
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}
```

L0: AMB
L1: no AMB

gzip
Programming Challenges

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f); AMB
     cap_enter();
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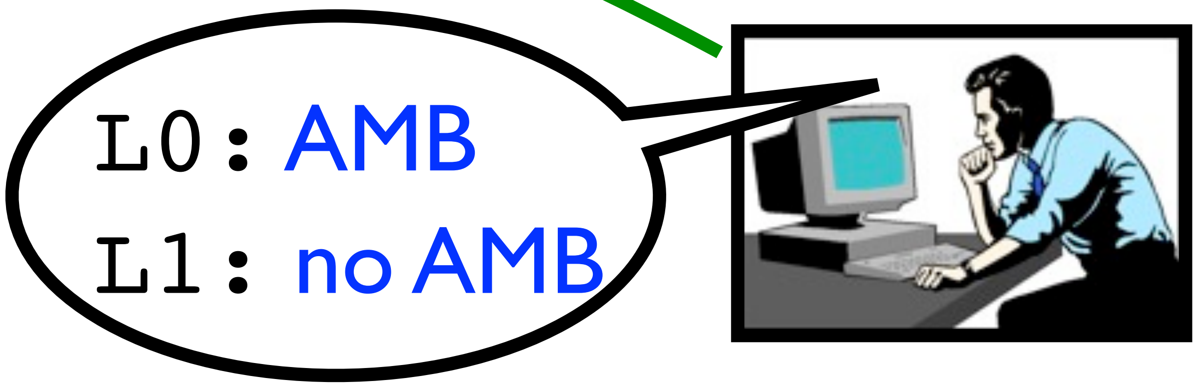

gzip
Programming Challenges

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main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);
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}
```

no AMB

L0: AMB
L1: no AMB

gzip Programming Challenges

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main() {
  file_nms = parse_cl();
  for (f in file_nms):
L0: (in, out) = open2(f);
    cap_enter();
L1: compress(in, out);
}
```

no AMB

L0: AMB

L1: no AMB

gzip
Programming Challenges

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);  no AMB
     cap_enter();
L1: compress(in, out);
}
```

L0: AMB
L1: no AMB

Rules of Capsicum's Amb

1. When a process is created, it has the AMB value of its parent
2. After a process calls `cap_enter()`, it never has AMB
3. If a process does not have Amb, then it can never obtain Amb

Rules of Capsicum's Amb

1. When a process is created,
   it has the AMB value of its parent

Instrumenting `gzip`

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);

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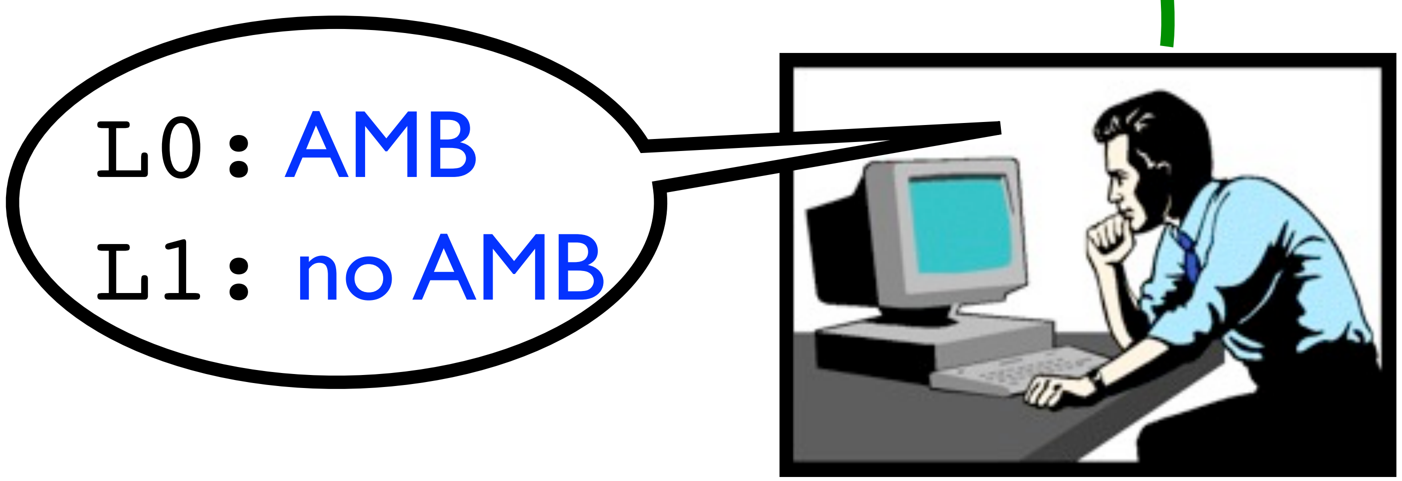

Instrumenting `gzip`

```
main() {
  file_nms = parse_cl();
  for (f in file_nms):
L0: (in, out) = open2(f);
    sync_fork();
    cap_enter();
L1: compress(in, out);
    sync_join();
}
```

L0: AMB
L1: no AMB

Instrumenting `gzip`

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main() {
   file_nms = parse_cl(); AMB
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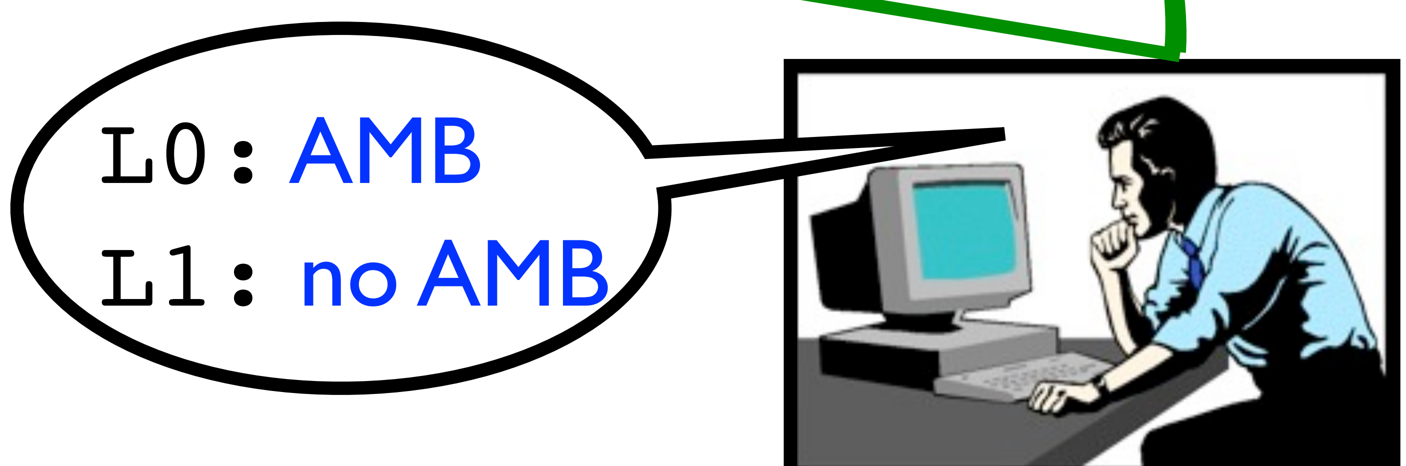

Instrumenting `gzip`

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```

AMB

L0: AMB
L1: no AMB

Instrumenting gzip

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  for (f in file_nms):
L0: (in, out) = open2(f); AMB
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      cap_enter();
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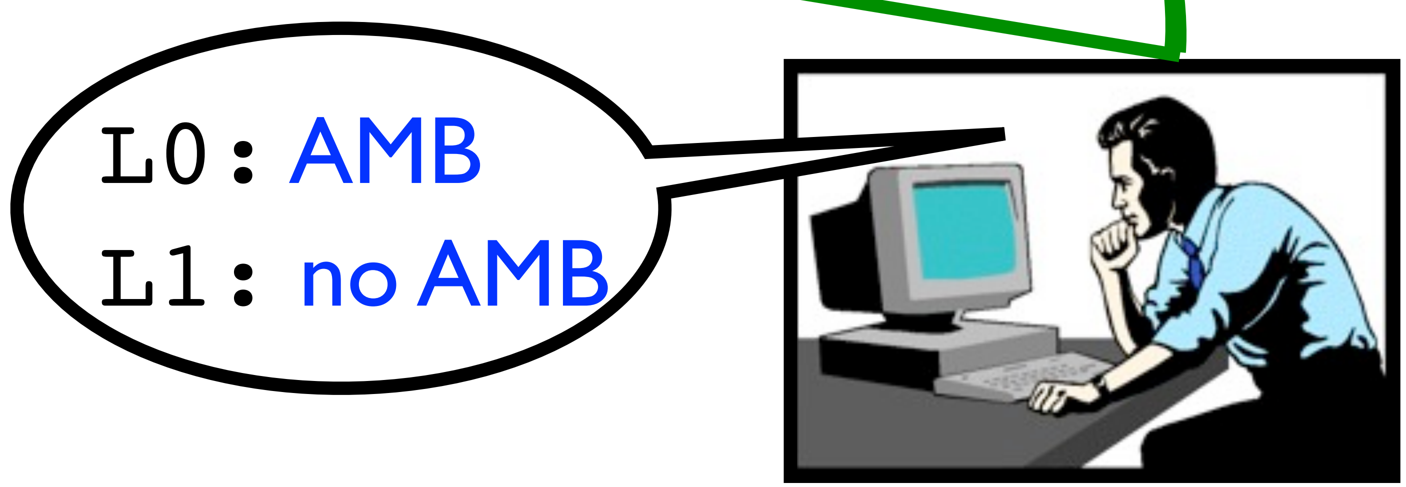
      sync_join();
}
```



Instrumenting `gzip`

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main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);
      sync_fork();
      cap_enter();
L1: compress(in, out);
      sync_join();
}
```

no AMB

L0: AMB
L1: no AMB

Instrumenting `gzip`

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main() {
   file_nms = parse_cl();
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L0: (in, out) = open2(f);
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AMB

L0: AMB
L1: no AMB

Instrumenting `gzip`

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f); AMB
      sync_fork();
      cap_enter();
L1: compress(in, out);
      sync_join();
}
```

L0: AMB
L1: no AMB

Capsicum Challenges Not Appearing in This Talk

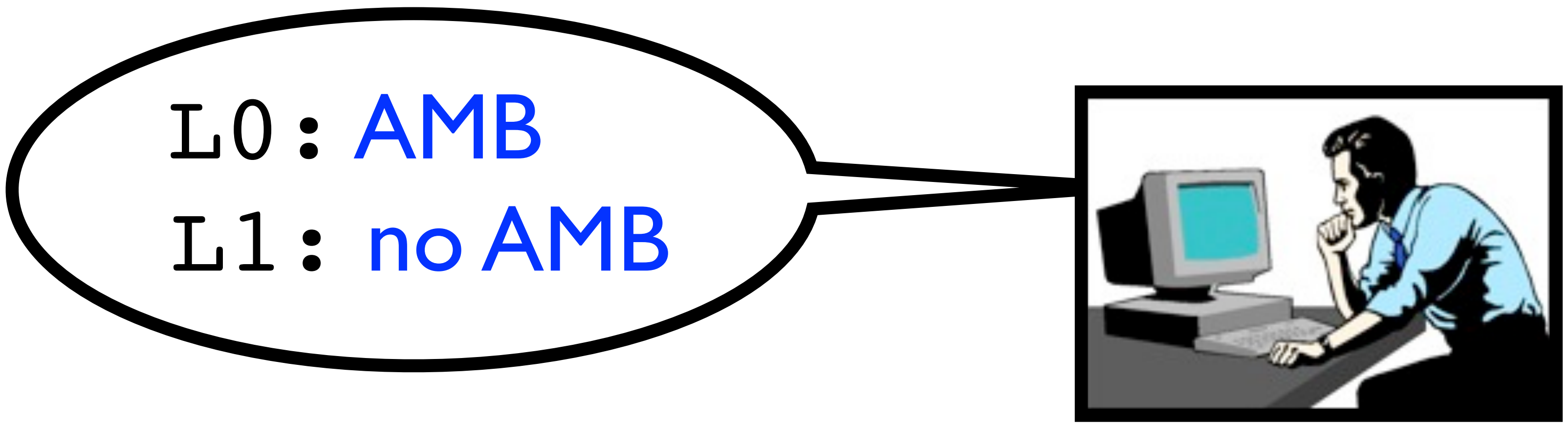
- Program can construct **capability** from each UNIX descriptor
- Capability has a vector of 63 **access rights** (~1 for every system call on a descriptor)
- Programs can assume new capabilities via a Remote Procedure Call (RPC)

Instrumenting Programs with CapWeave

1. Programmer writes an **explicit** Amb policy
2. **CapWeave** instruments program to invoke primitives so that it satisfies the policy

gzip with CapWeave

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);
L1: compress(in, out);
}
```



gzip with CapWeave

```
main() {
   file_nms = parse_cl();
   for (f in file_nms):
L0: (in, out) = open2(f);
L1: compress(in, out);
}
```

Policy

```
Cur(p) => (pc[L0](p) => AMB(p)
          & (pc[L1](p) => !AMB(p))
```

```
main() {
  file_nms = parse_cl();
  for (f in file_nms):
L0: (in, out) = open2(f);
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}
```

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Policy

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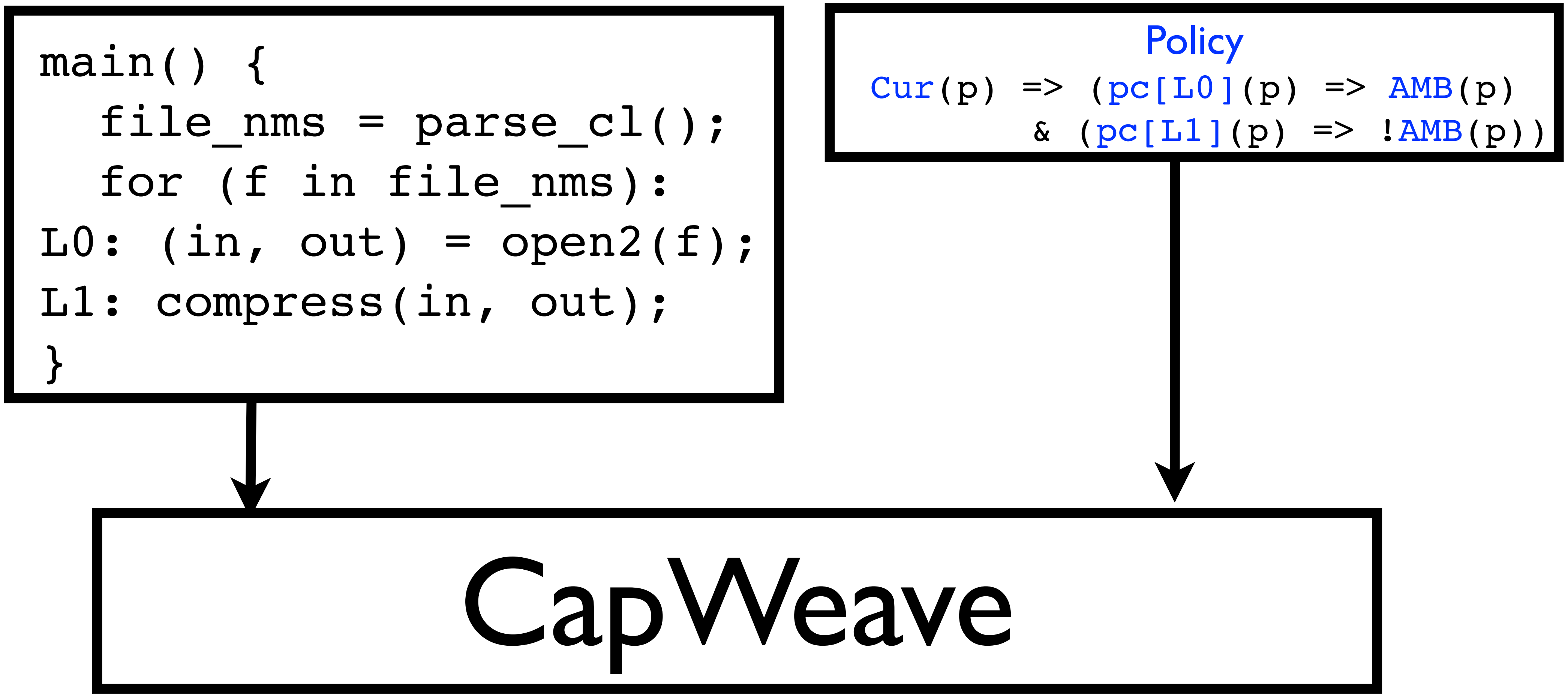

main() {
file_nms = parse_cl();
for (f in file_nms):
L0: (in, out) = open2(f);
L1: compress(in, out);
}
Policy
Cur(p) => (pc[L0](p) => AMB(p)
& (pc[L1](p) => !AMB(p))
CapWeave

```
main() {
  file_nms = parse_cl();
  for (f in file_nms):
L0: (in, out) = open2(f);
L1: compress(in, out);
}
```

Policy

```
Cur(p) => (pc[L0](p) => AMB(p)
        & (pc[L1](p) => !AMB(p))
```

CapWeave

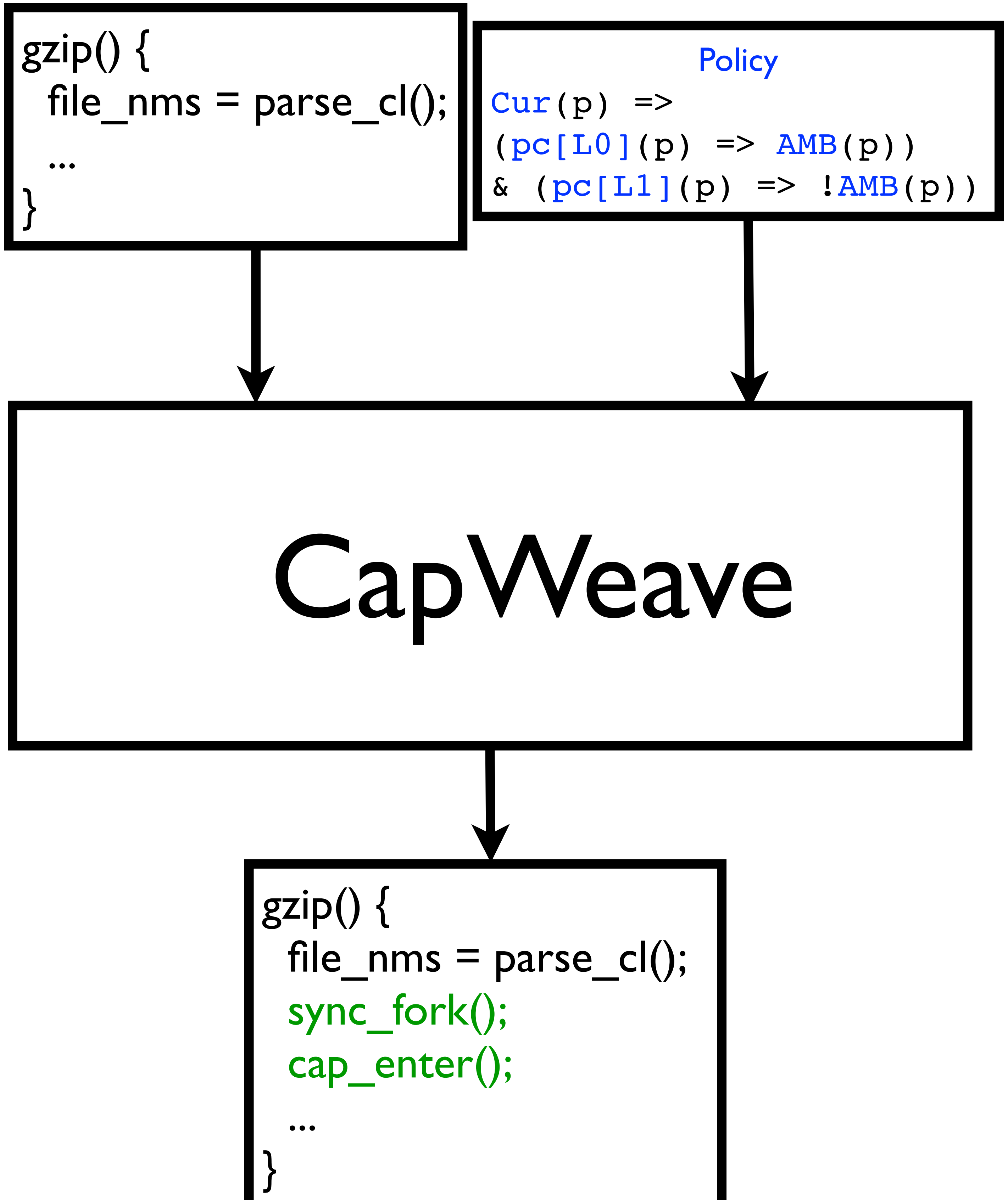
Instrumented Program

```
void main() {
  L0: open2(...);
  sync_fork();
  cap_enter();
  L1: compress();
  sync_join();
}
```

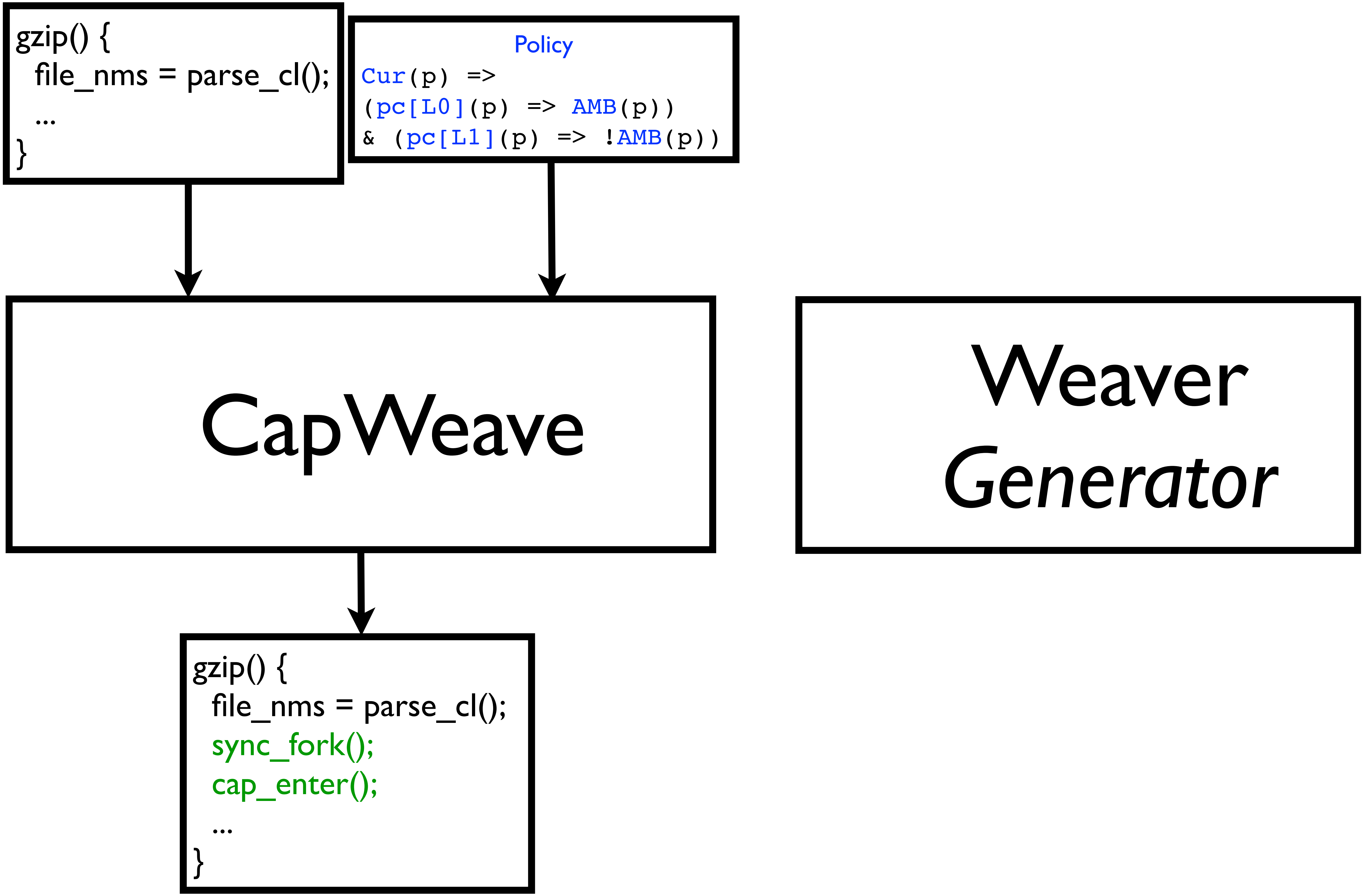
The Next 700 Policy Weavers

Analogous challenges with **Decentralized Information Flow Control (DIFC)**

- Asbestos [Efstathopoulos ‘05]
- HiStar [Zeldovich ’06]
- Flume [Krohn ‘07]


gzip() {
file_nms = parse_cl();
...
}
Policy
Cur(p) =>
(pc[L0](p) => AMB(p))
& (pc[L1](p) => !AMB(p))
CapWeave
gzip() {
file_nms = parse_cl();
sync_fork();
cap_enter();
...
}

Programmer


gzip() {
file_nms = parse_cl();
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Policy
Cur(p) =>
(pc[L0](p) => AMB(p))
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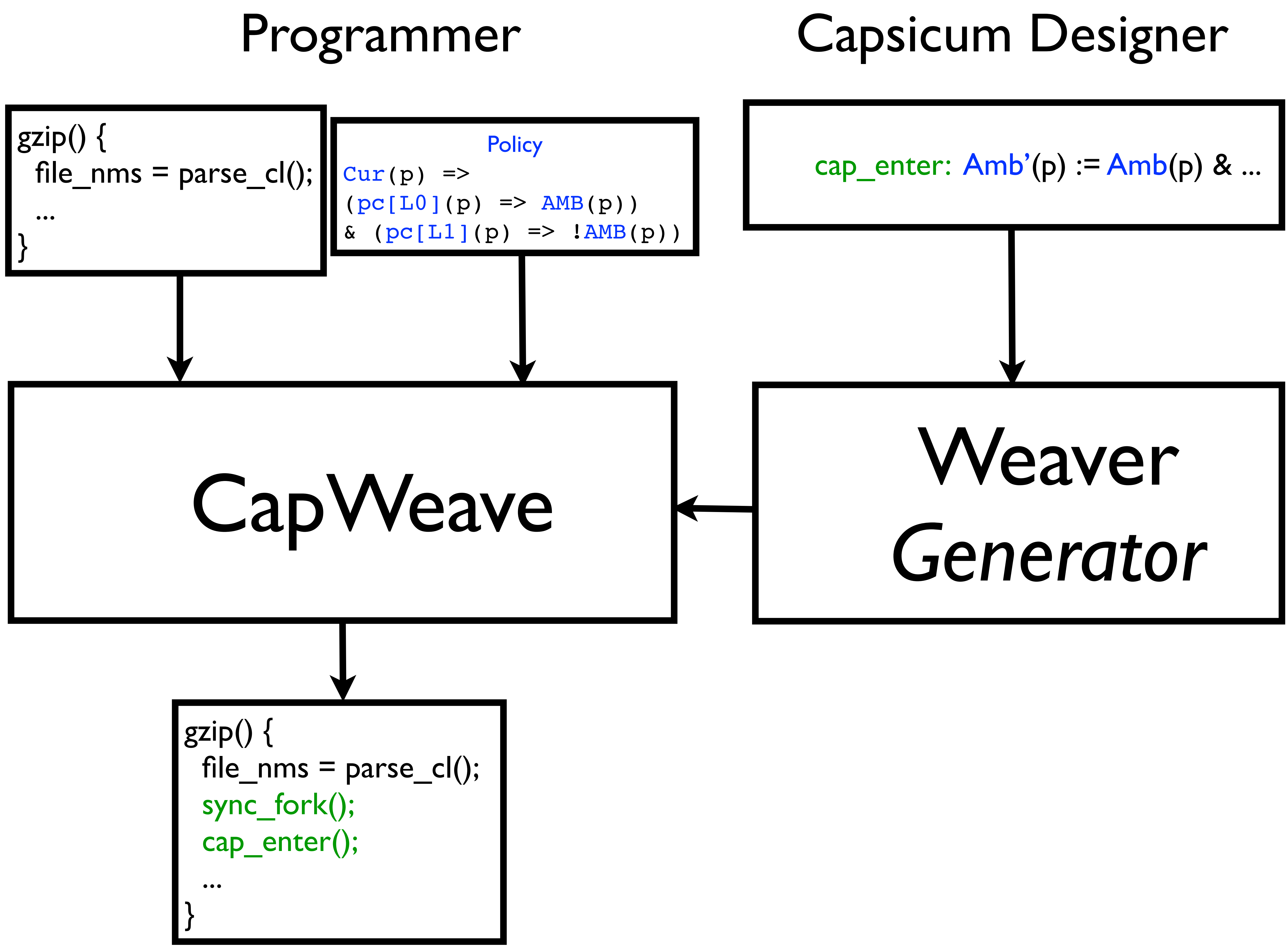
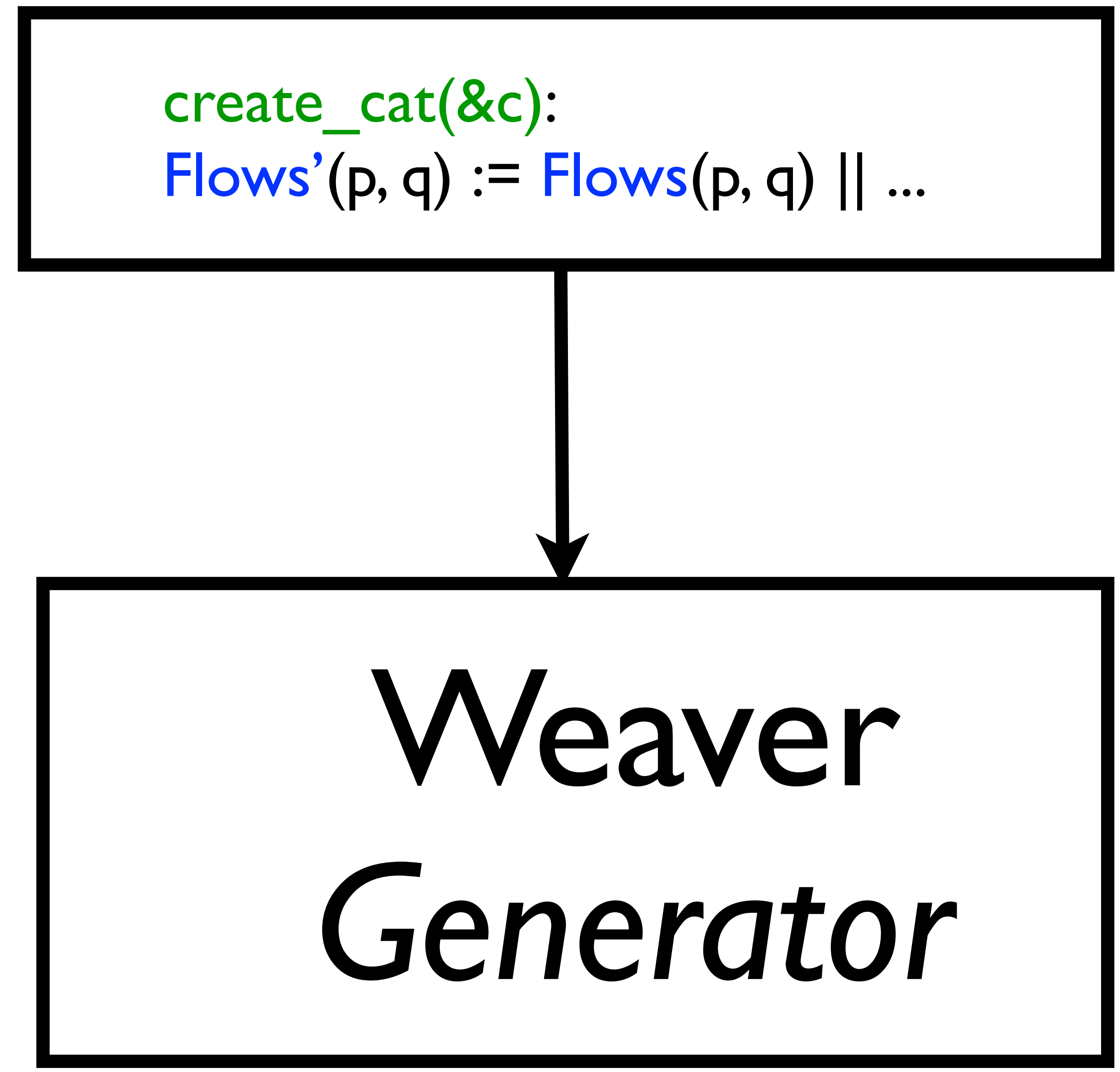
CapWeave
Weaver
Generator
gzip() {
file_nms = parse_cl();
sync_fork();
cap_enter();
...
}

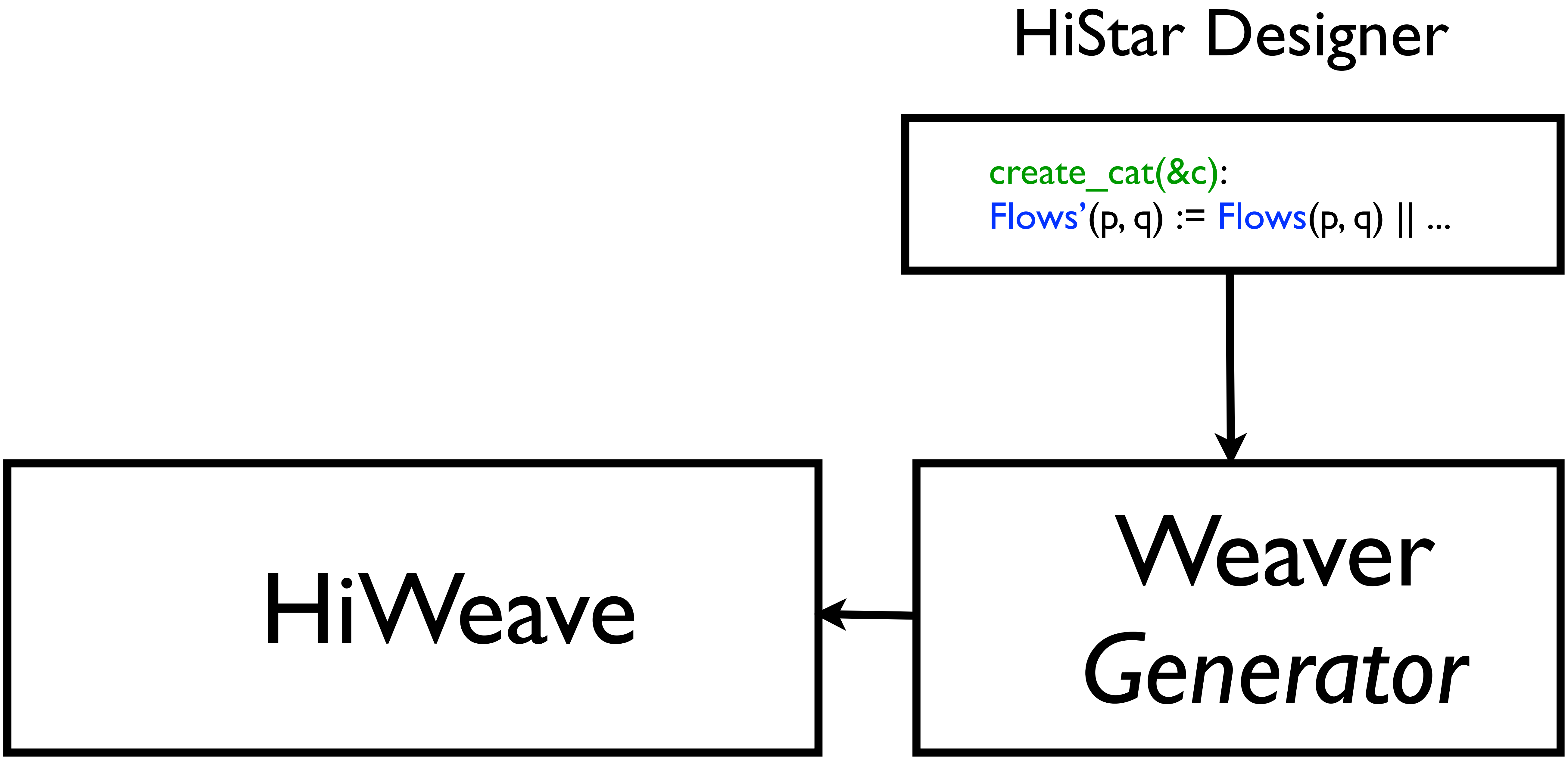

Programmer
Capsicum Designer
gzip() {
file_nms = parse_cl();
...
}
Policy
Cur(p) =>
(pc[L0](p) => AMB(p))
& (pc[L1](p) => !AMB(p))
cap_enter: Amb'(p) := Amb(p) & ...
CapWeave
Weaver
Generator
gzip() {
file_nms = parse_cl();
sync_fork();
cap_enter();
...
}

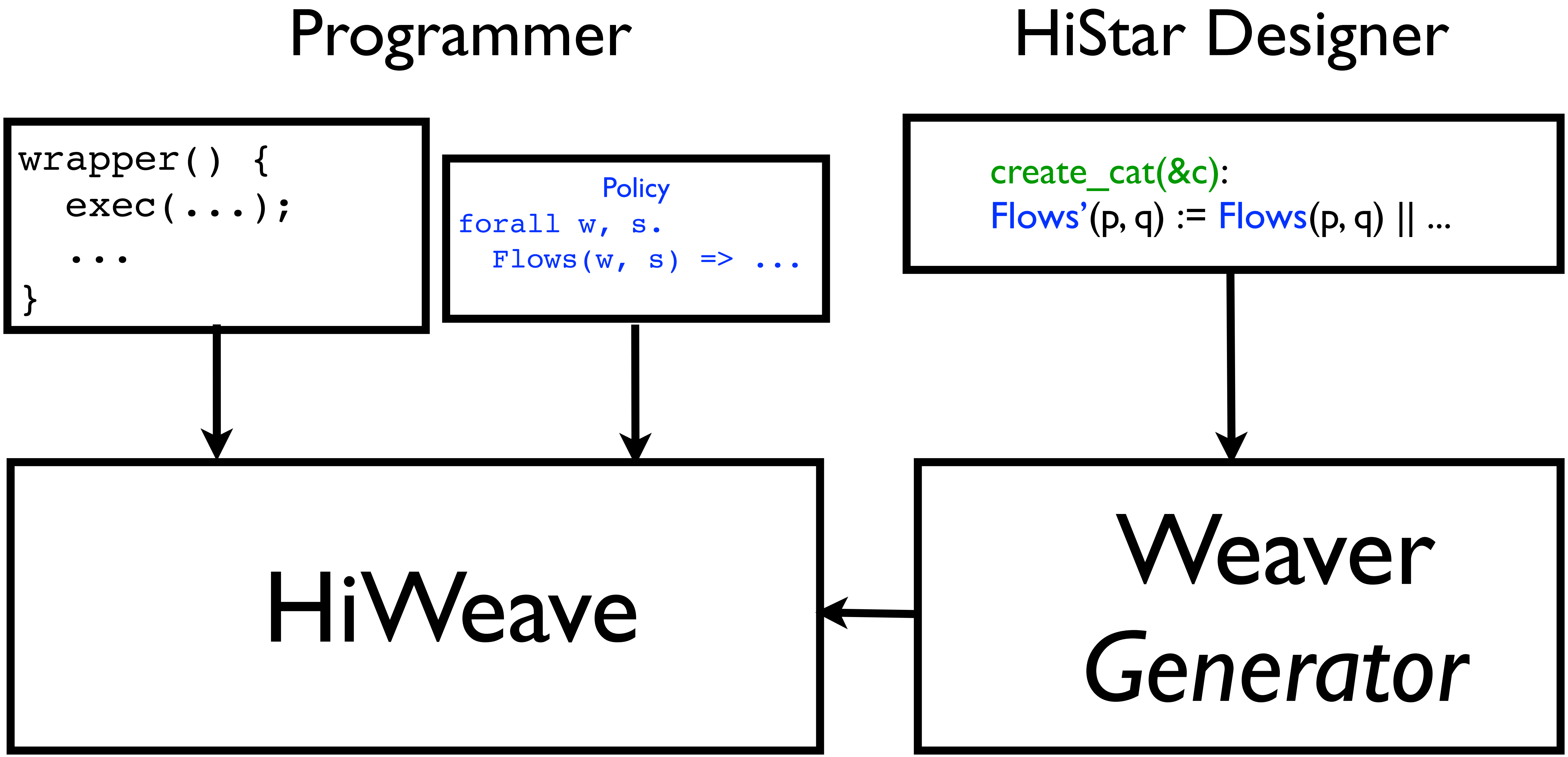
Weaver

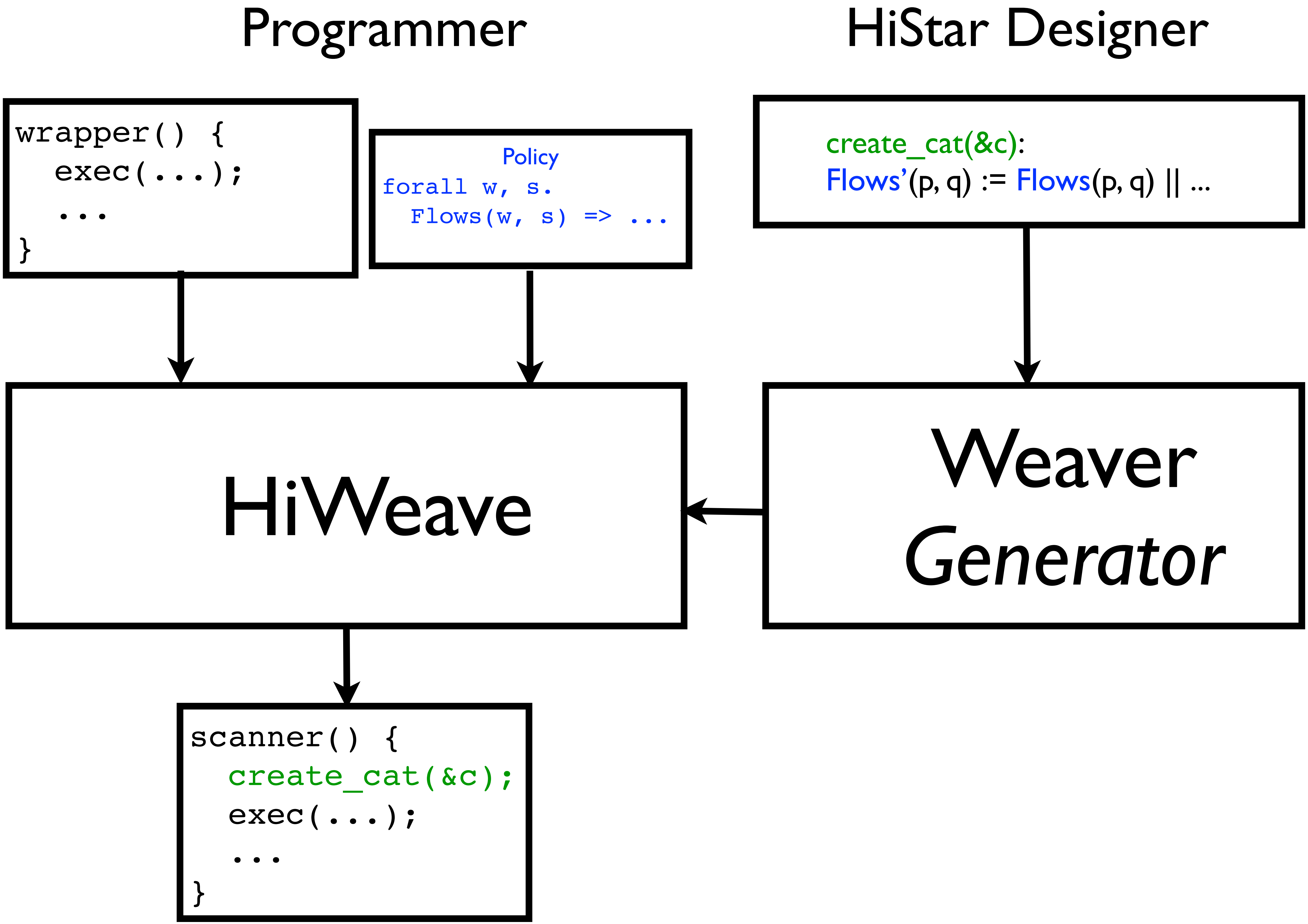
Generator

HiStar Designer




HiStar Designer
create_cat(&c):
Flows'(p, q) := Flows(p, q) || ...
HiWeave
Weaver
Generator


Programmer
HiStar Designer
wrapper() {
exec(...);
...
}
Policy
forall w, s.
Flows(w, s) => ...
create_cat(&c):
Flows'(p, q) := Flows(p, q) || ...
HiWeave
Weaver
Generator


Programmer
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wrapper() {
exec(...);
...
}
Policy
forall w, s.
Flows(w, s) => ...
create_cat(&c):
Flows'(p, q) := Flows(p, q) || ...
HiWeave
Weaver
Generator
scanner() {
create_cat(&c);
exec(...);
...
}

Outline

1. Motivation, problem statement
2. Previous work: Capsicum
3. Ongoing work: HiStar
4. Open challenges

Outline

2. Previous work: Capsicum

CapWeave Algorithm

CapWeave Algorithm

Inputs: Program P, Amb Policy Q

CapWeave Algorithm

Inputs: Program P, Amb Policy Q

Output: Instrumentation of P that always satisfies Q

CapWeave Algorithm

Inputs: Program P, Amb Policy Q

Output: Instrumentation of P that always satisfies Q

1. Build finite **IP#** $\supseteq$ instrumented runs that violate Q

1. Building IP#: Inputs

Program

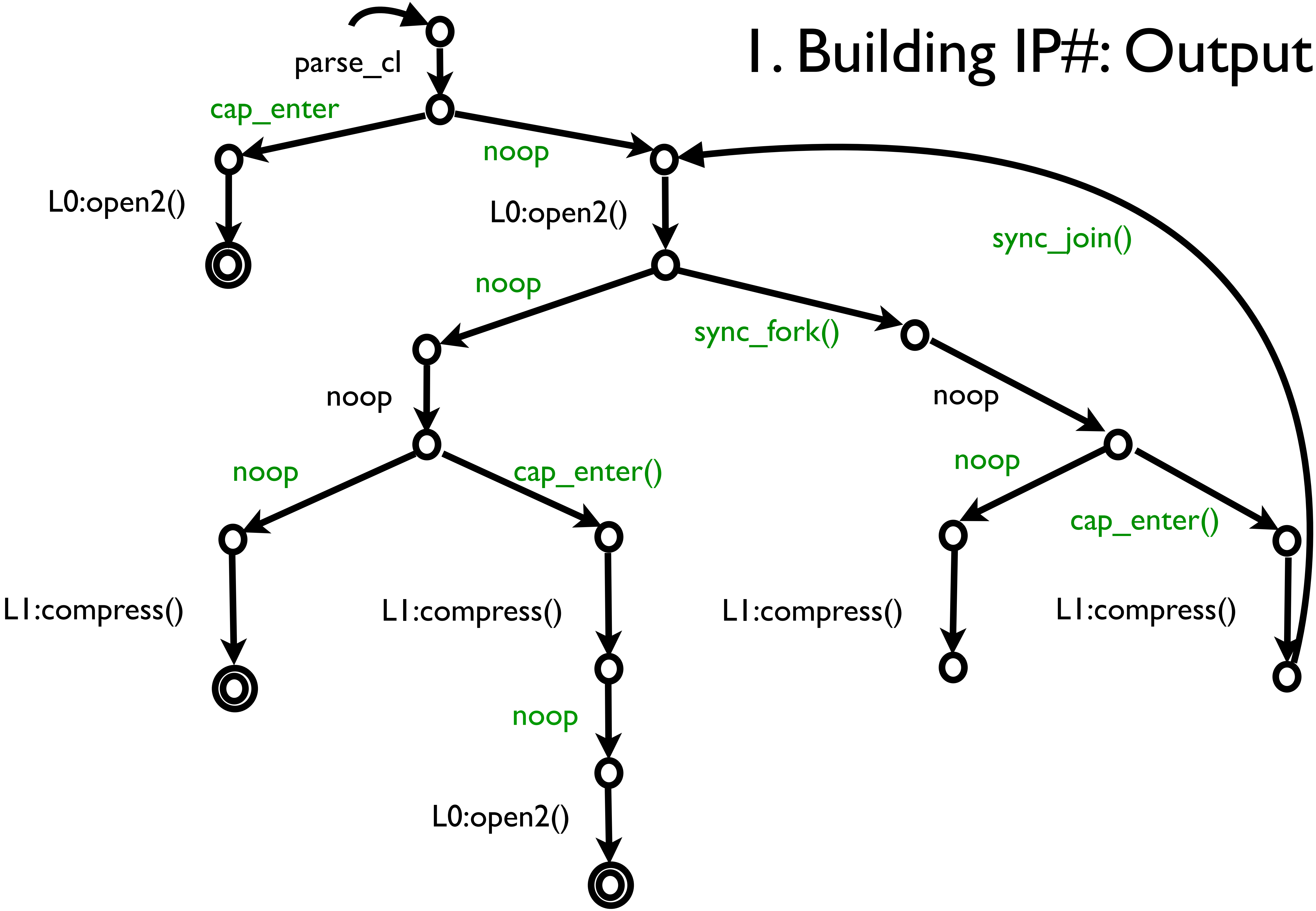
```
main() {
  file_nms = parse_cl();
  for (f in file_nms):
L0: (in, out) = open2(f);
L1: compress(in, out);
}
```

Amb Policy

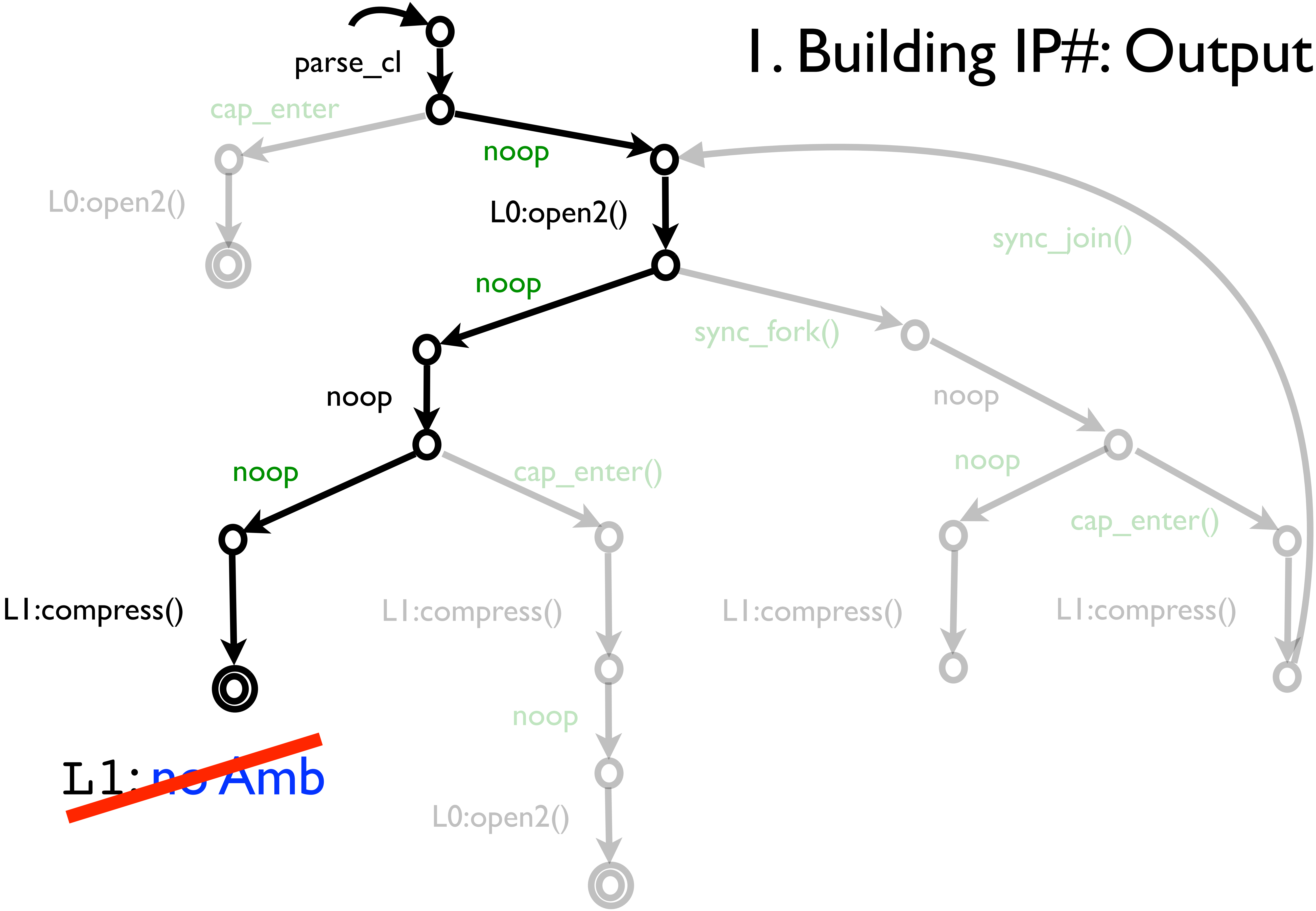
`L0`: Amb

`L1`: no Amb

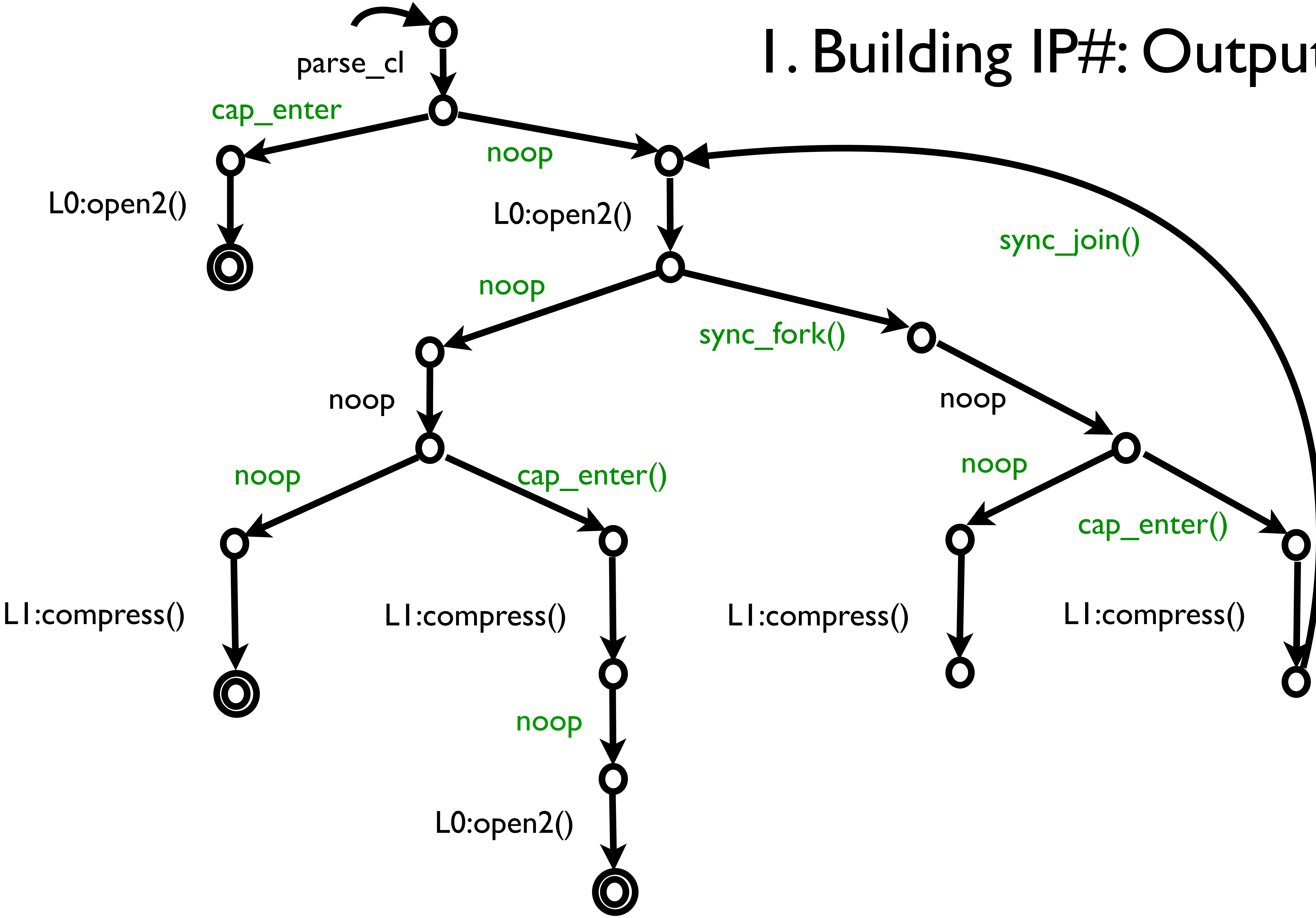
1. Building IP#: Output



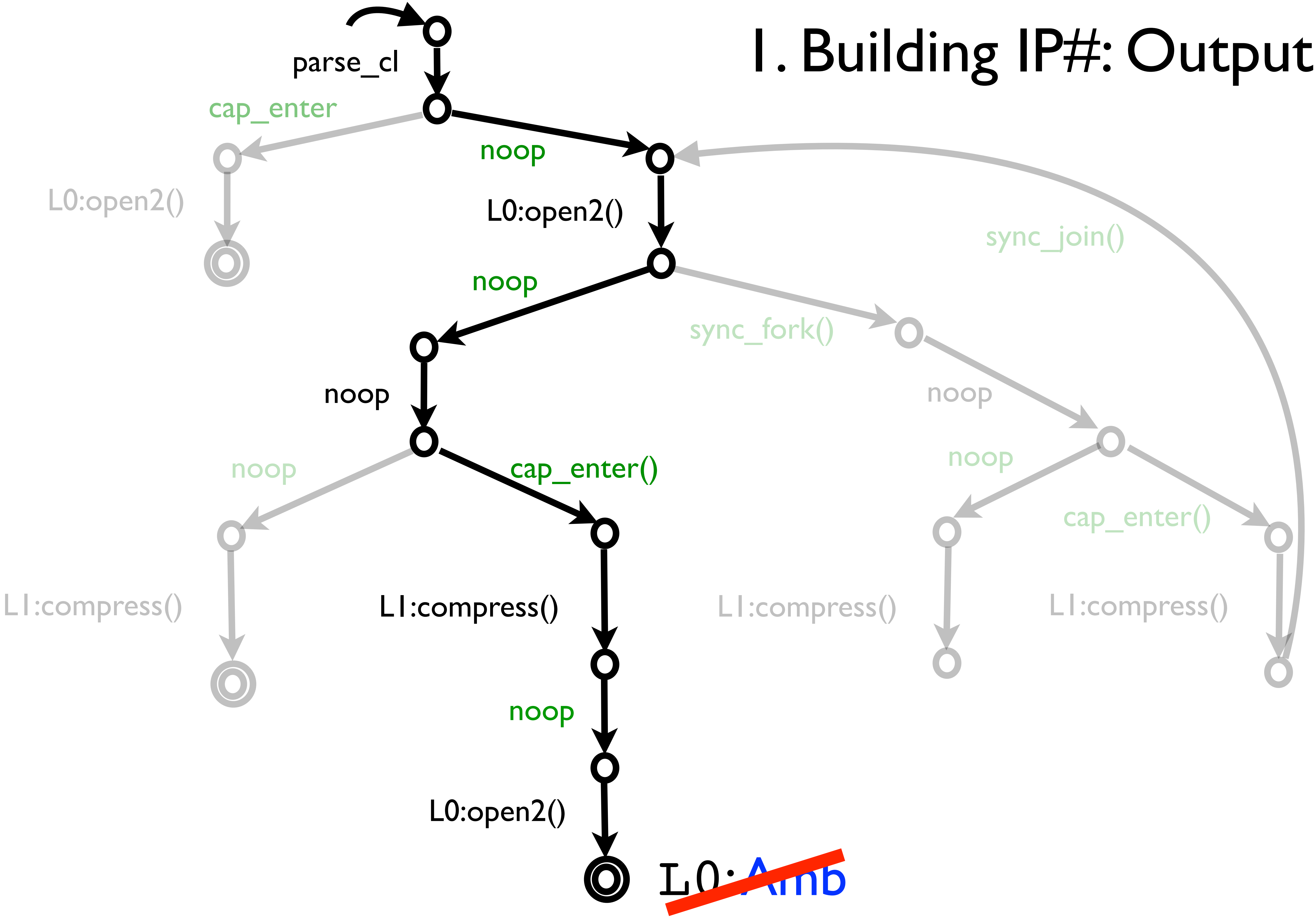
1. Building IP#: Output



1. Building IP#: Output



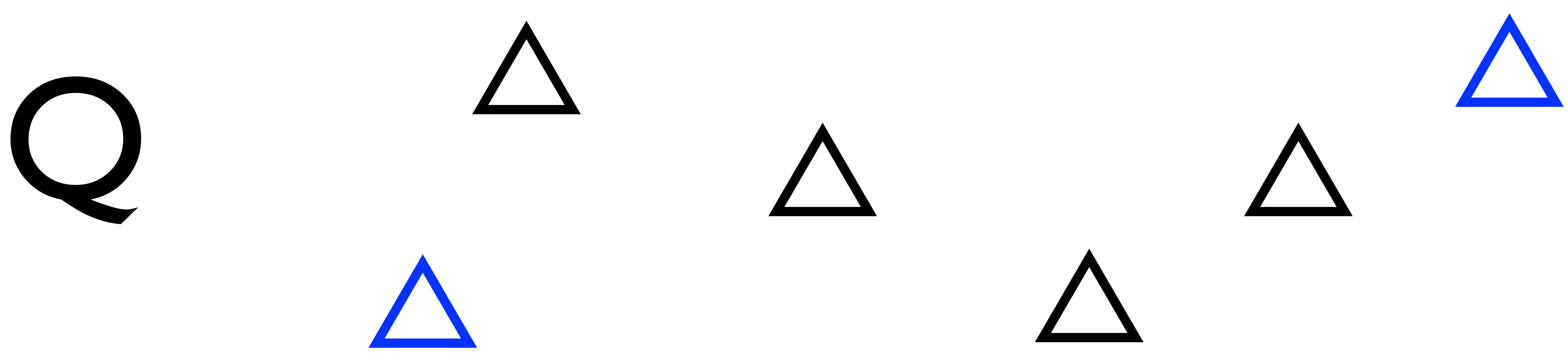
1. Building IP#: Output



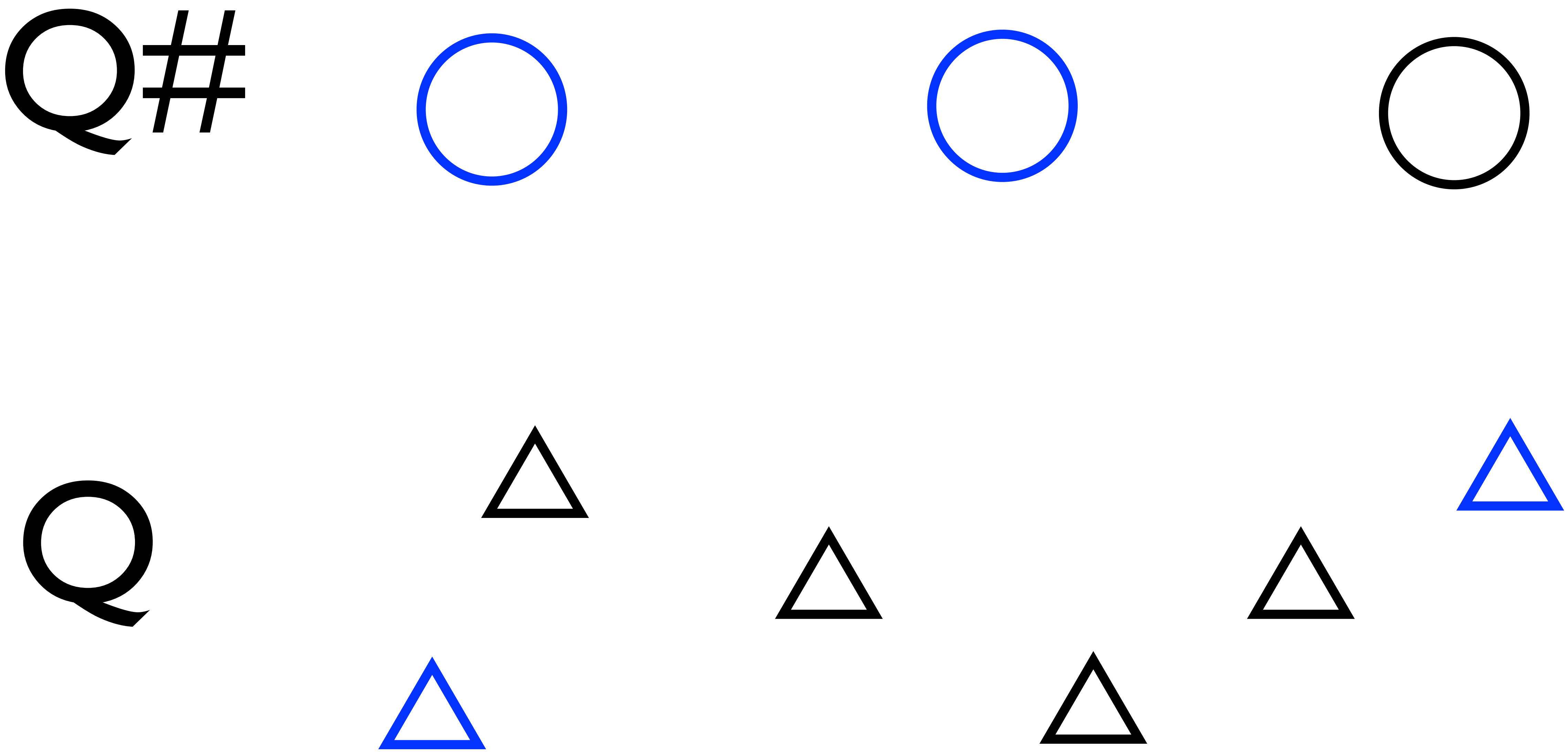
Building IP#

Basic idea: construct IP# as a forward exploration of an abstract state space

1(a). IP#: Define Abstract State-space



1(a). IP#: Define Abstract State-space



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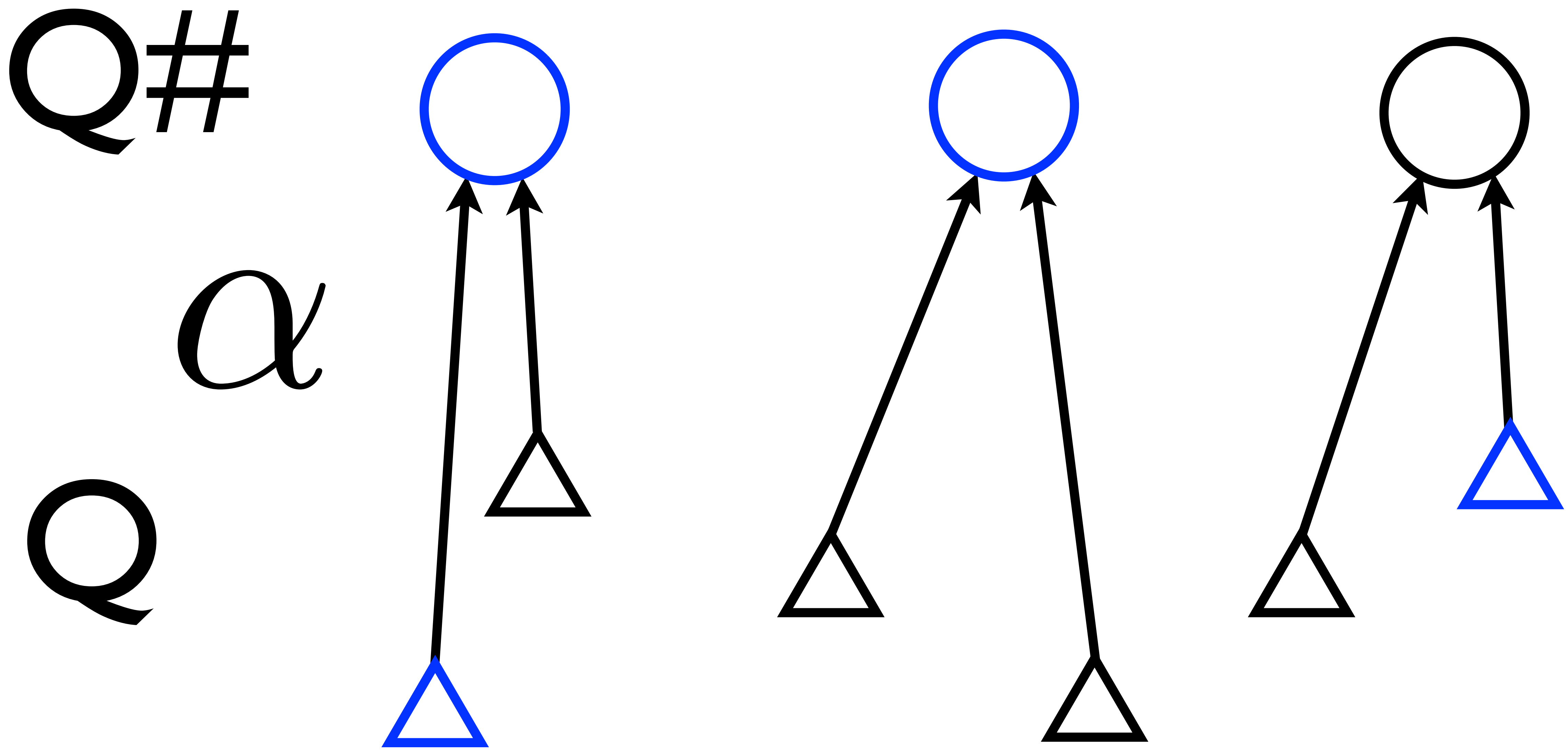
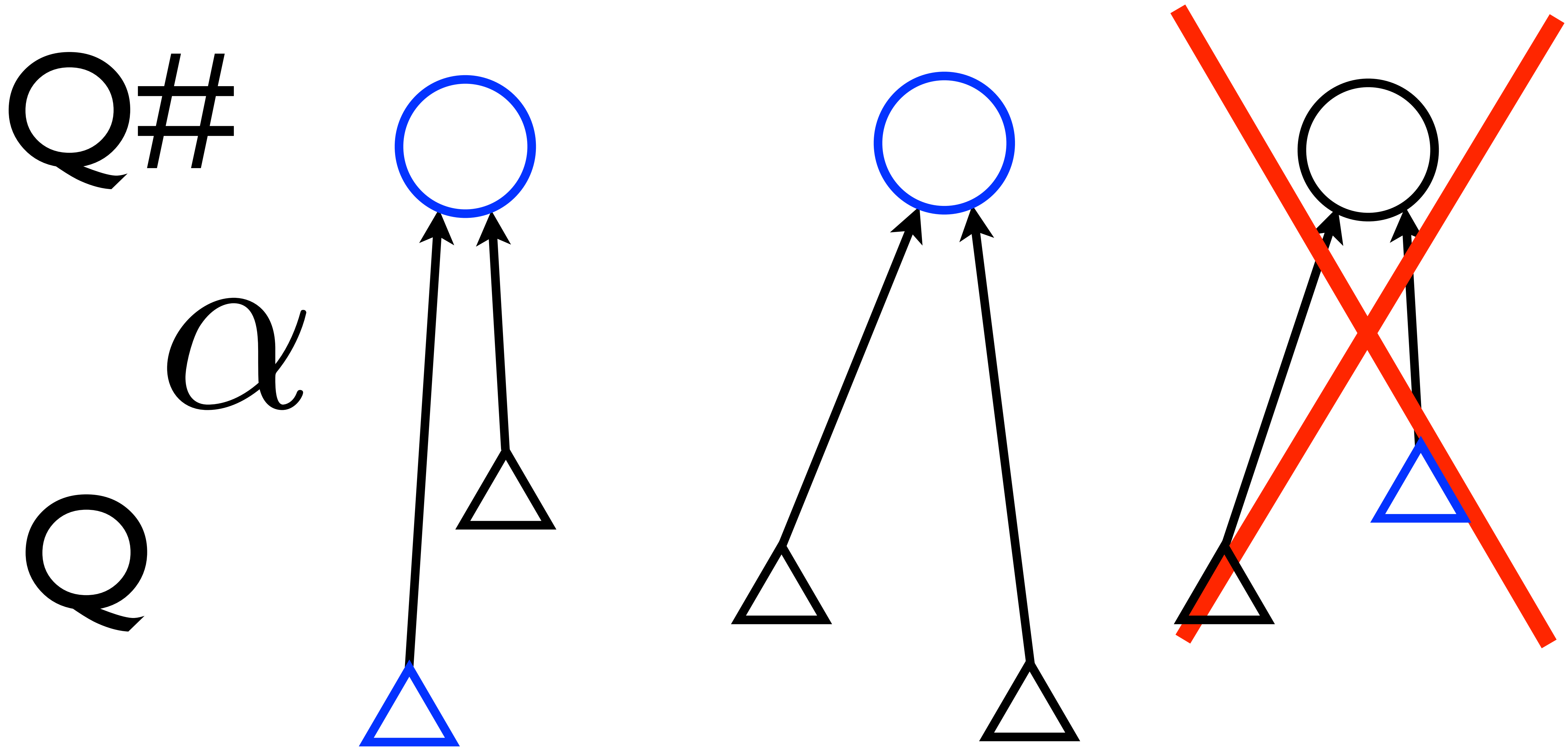
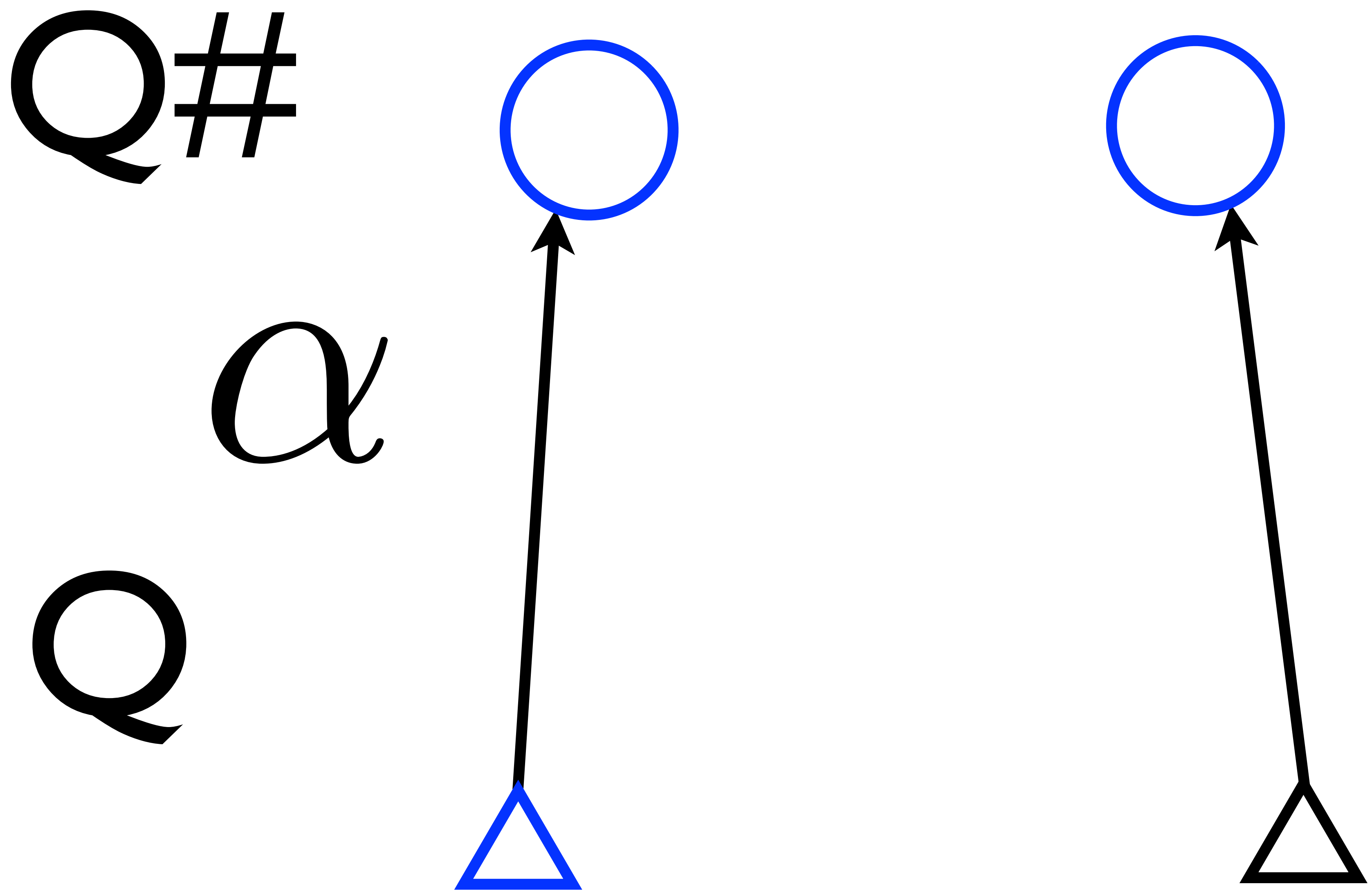


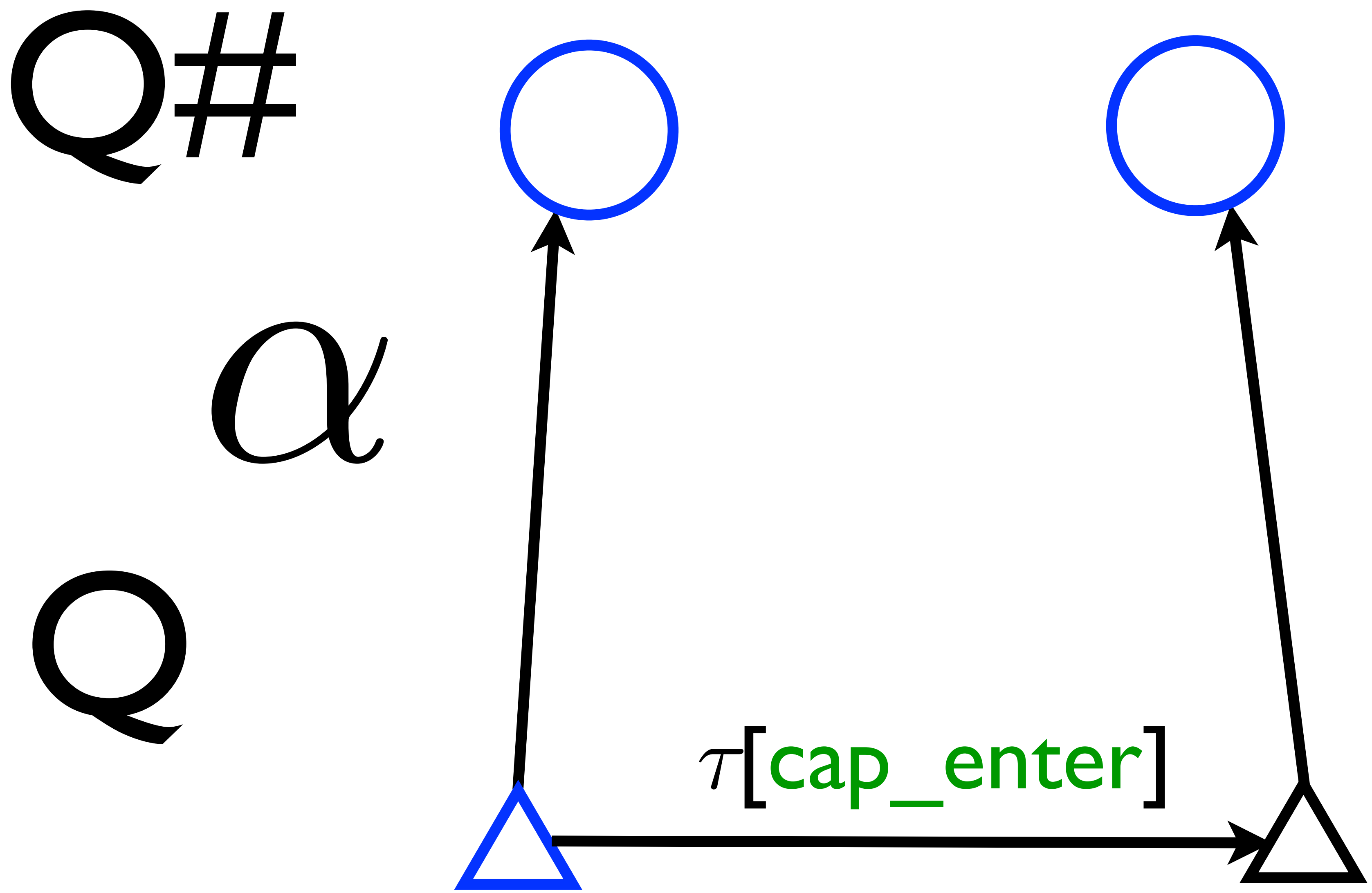
1(a). IP#: Define Abstract State-space



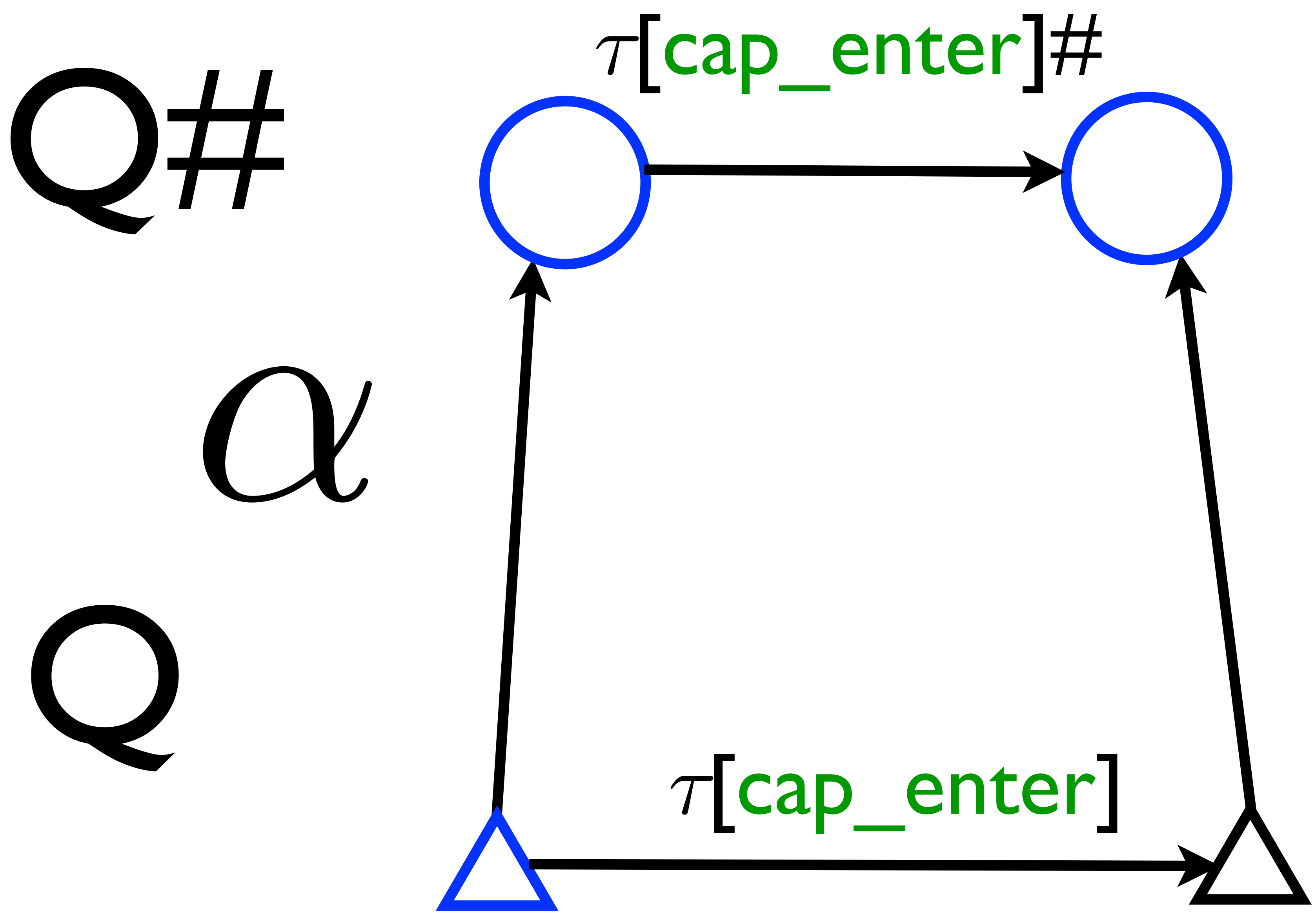
1(b). IP#: Define Abstract Transformers



1(b). IP#: Define Abstract Transformers



1(b). IP#: Define Abstract Transformers

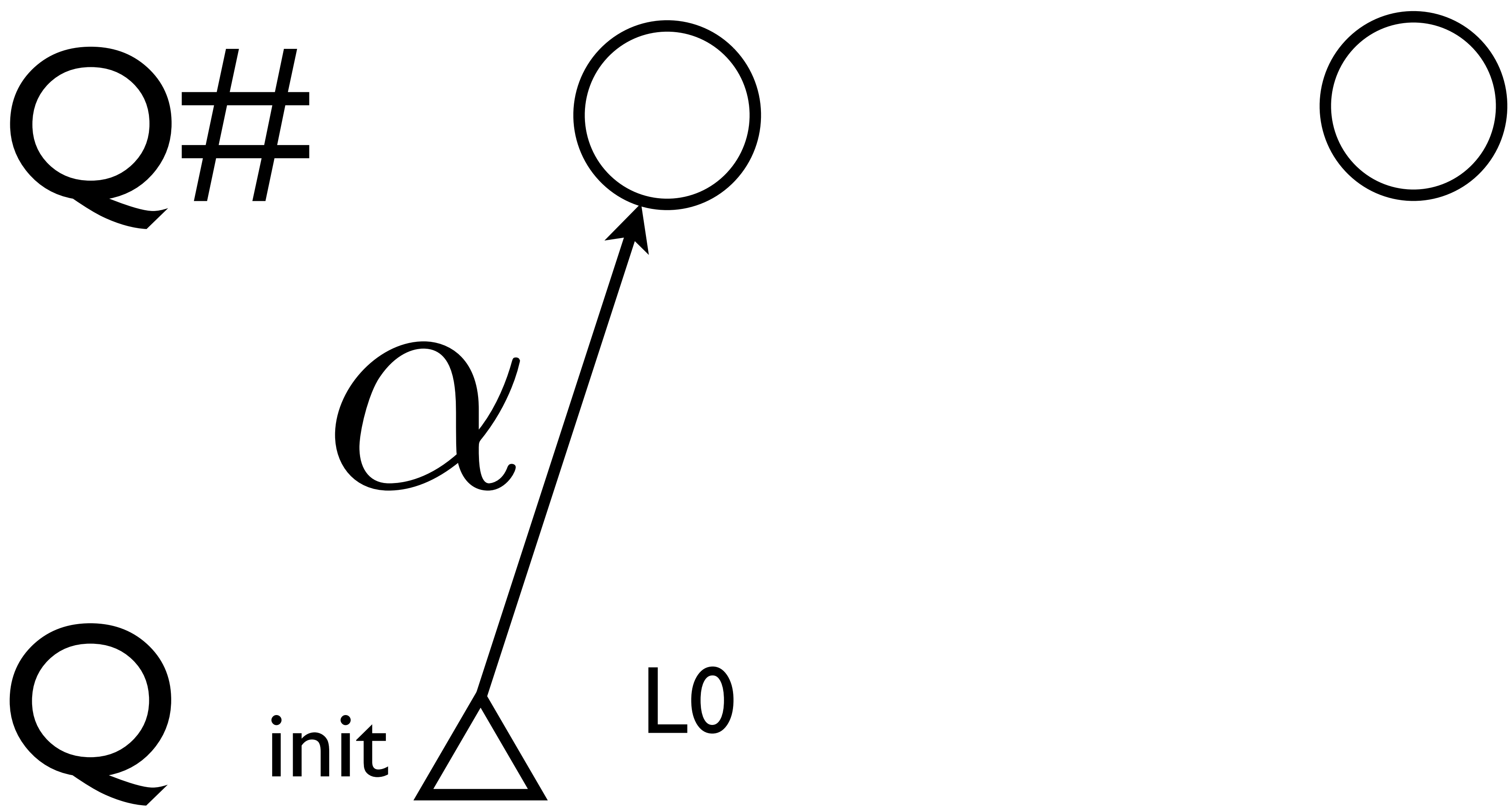


1(c). Explore Abstract State Space

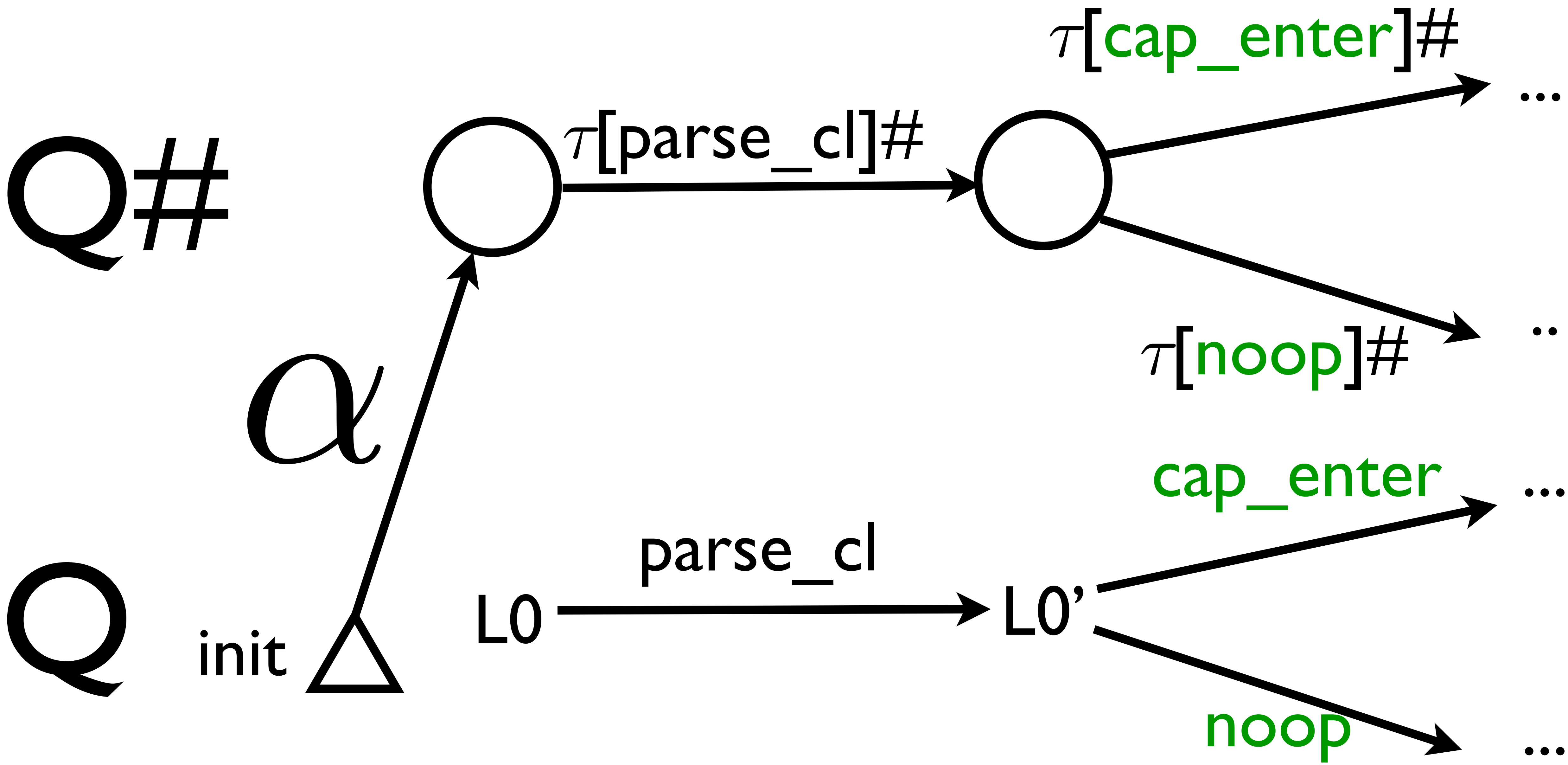
Q#   ○   ○

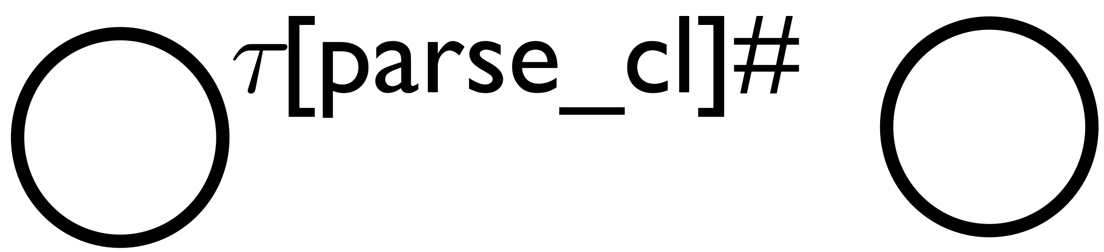
Q   △

1(c). Explore Abstract State Space

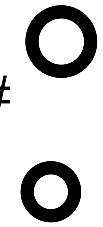


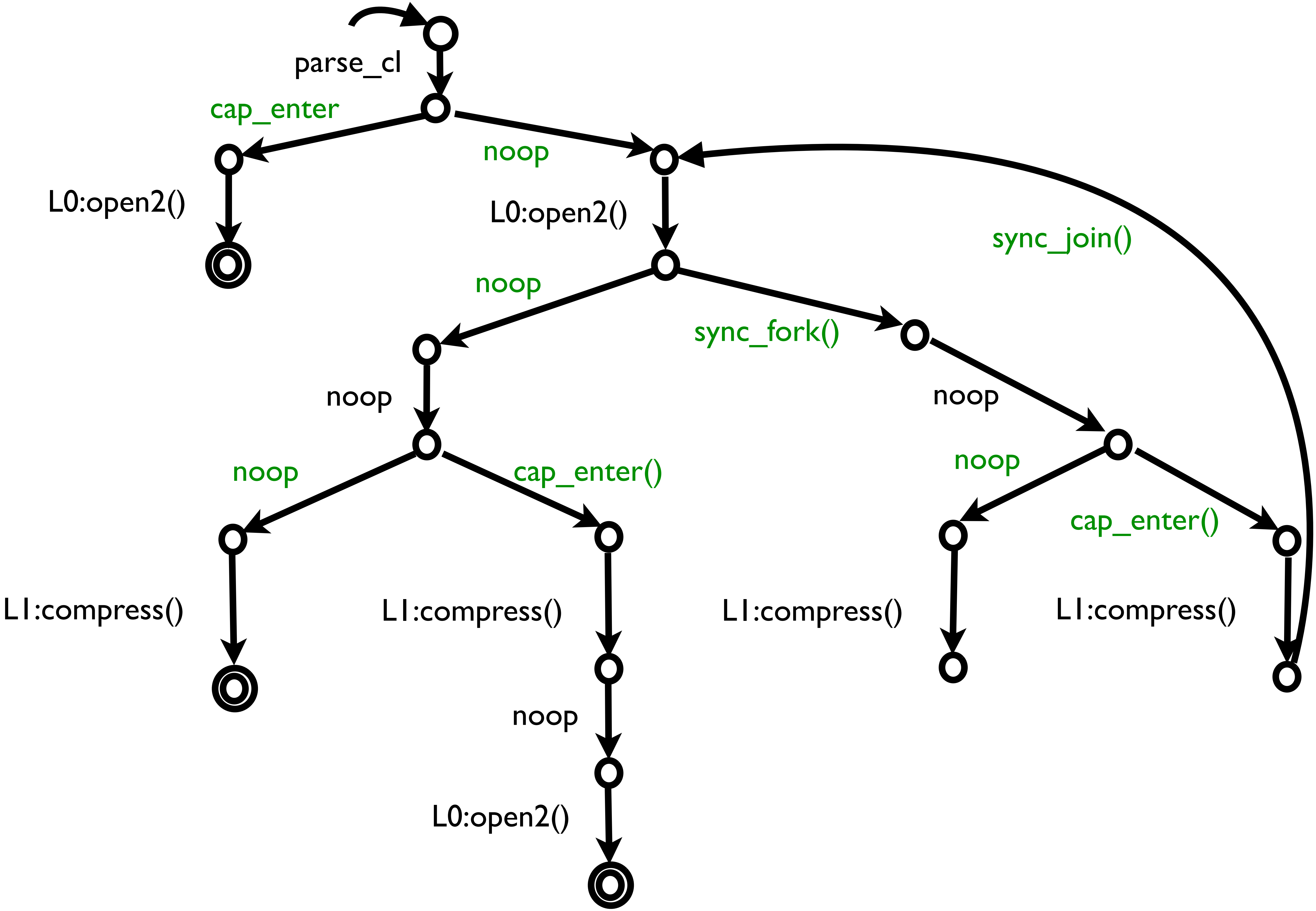
1(c). Explore Abstract State Space




τ[parse_cl]#

τ[parse_cl]#




parse_cl
cap_enter
noop
L0:open2()
L0:open2()
sync_join()
noop
sync_fork()
noop
noop
noop
cap_enter()
noop
cap_enter()
L1:compress()
L1:compress()
L1:compress()
L1:compress()
noop
L0:open2()

State-Structure Exploration

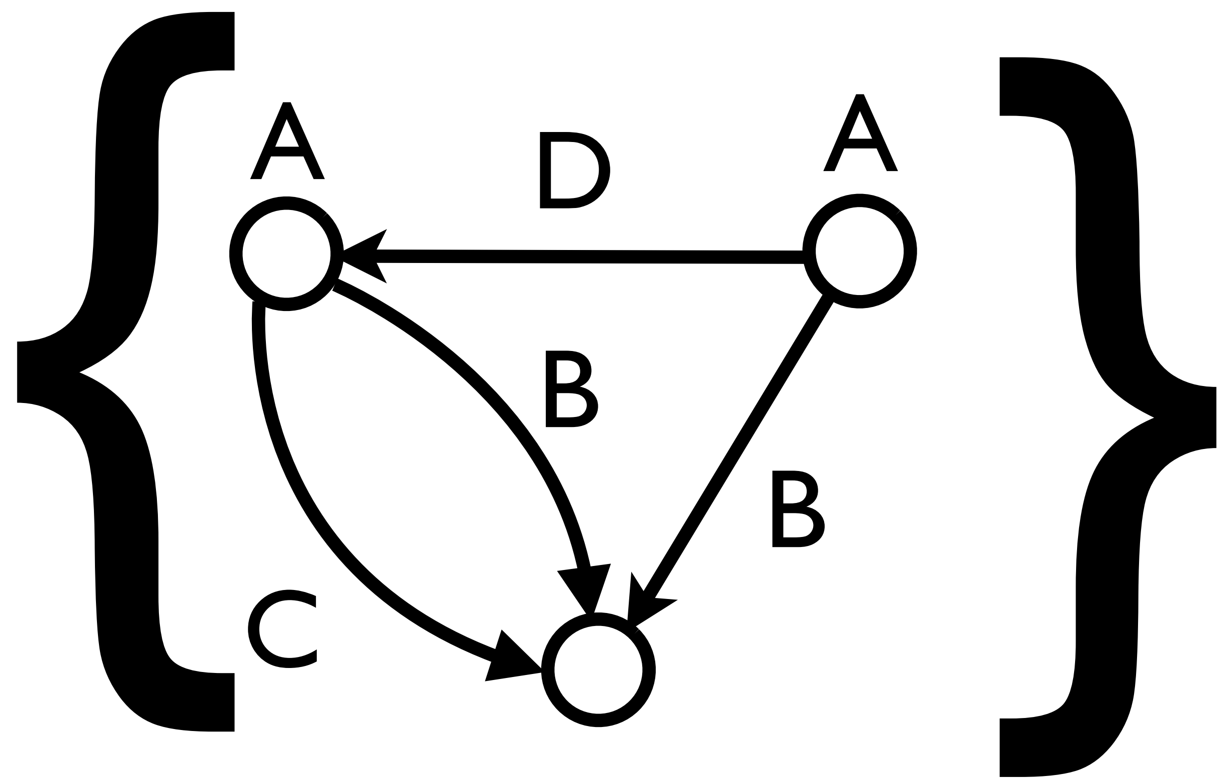
If a concrete state is a logical structure, ...

Q

State-Structure Exploration

If a concrete state is a logical structure, ...

$Q \equiv$



State-Structure Exploration

properties are FOL formulas, ...

$$\forall p. A(p) \Rightarrow ((B(p) \Rightarrow C(p)) \wedge (D(p) \Rightarrow \neg C(p)))$$

State-Structure Exploration

...and semantics is given as predicate updates, ...

$$\tau[\text{action}] \equiv \begin{array}{l} A'(x) = A(x) \vee \exists\, y.\, C(y) \wedge B(q, p) \\ B'(x, y) = B(x, y) \vee (C(x) \wedge D(y)) \\ C'(x) = \ldots \\ D'(x) = \ldots \end{array}$$

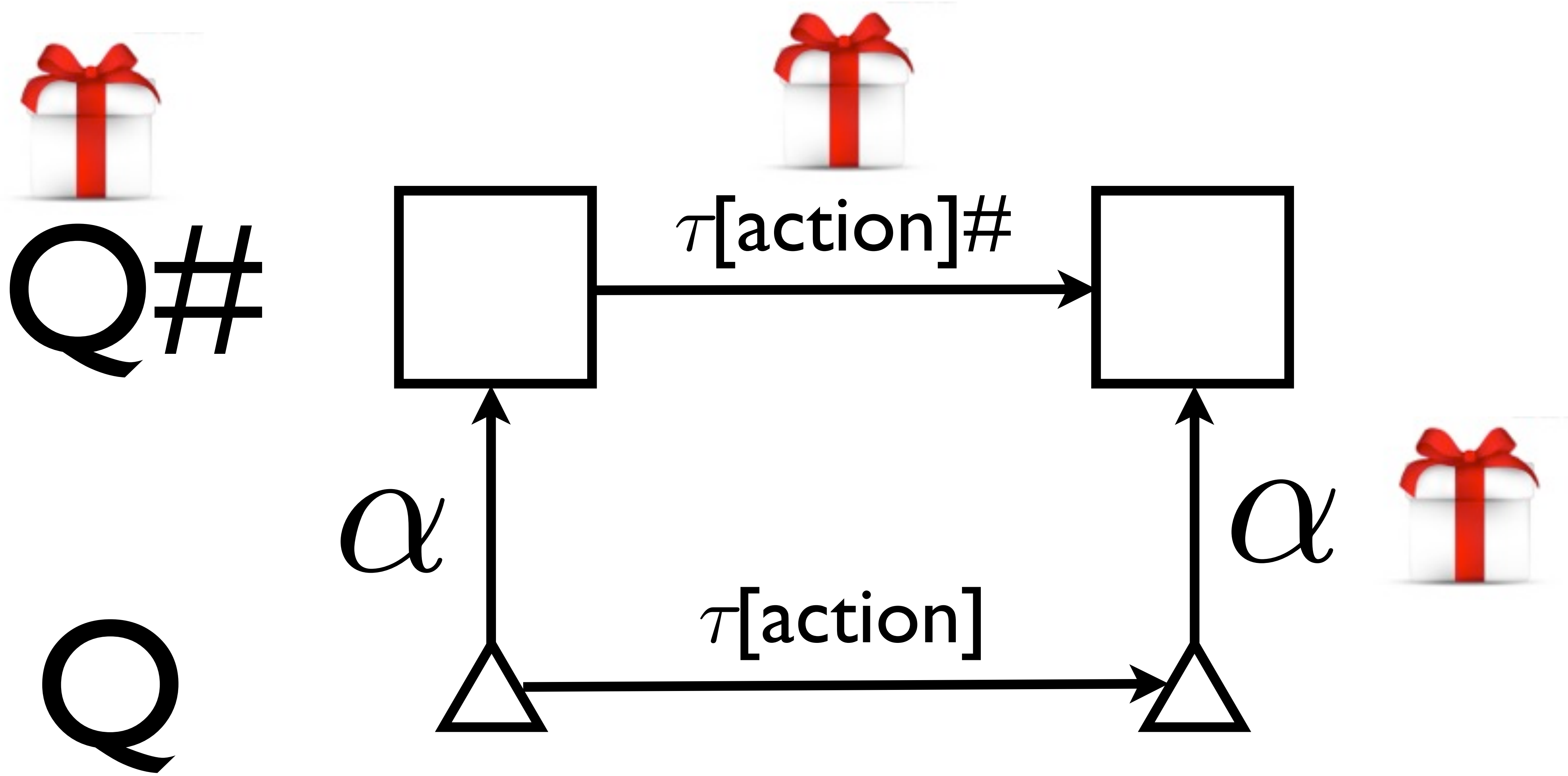
State-Structure Exploration

...then abstract space and transformers
can be generated automatically [Sagiv ’99]

Q △ △

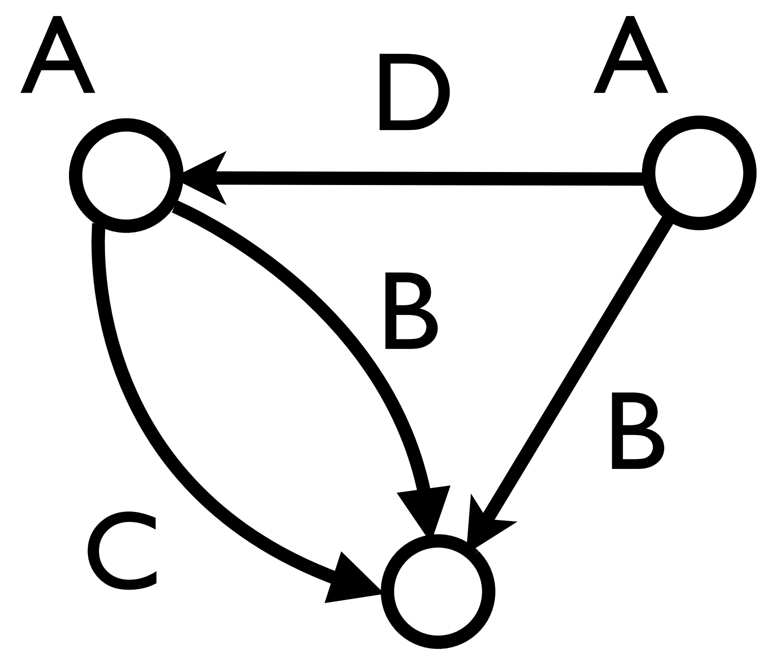
State-Structure Exploration

...then abstract space and transformers
can be generated automatically [Sagiv ’99]



Capsicum Semantics

1. $Q \equiv$



2. τ[action] $\equiv$

A'(x) = A(x) $\vee$ $\exists$ y. C(y) $\wedge$ B(q, p)

B'(x, y) = B(x, y) $\vee$ (C(x) $\wedge$ D(y))

C'(x) = ...

D'(x) = ...

Capsicum State as Structure

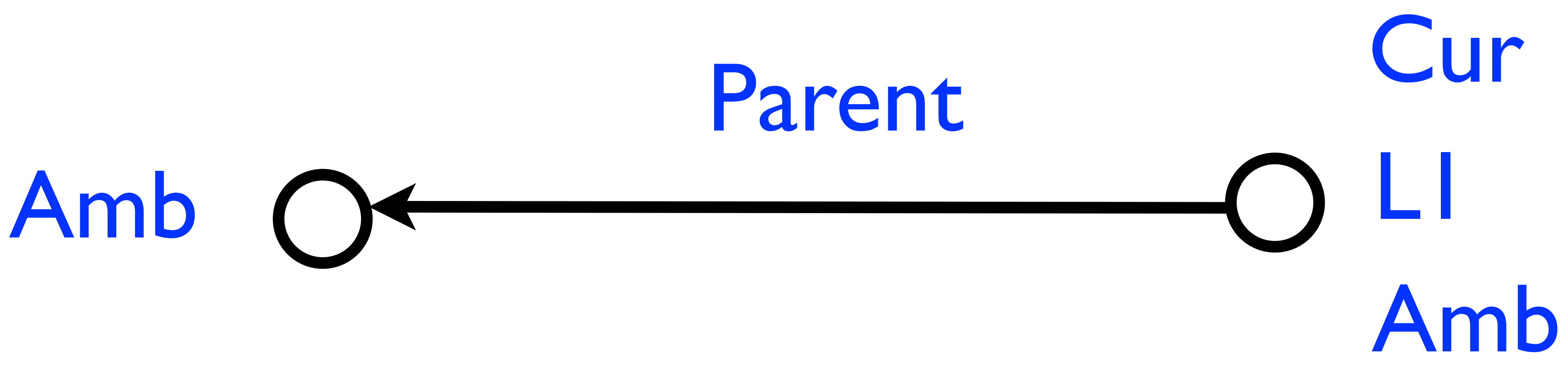
Capsicum State as Structure

Capsicum State as Structure

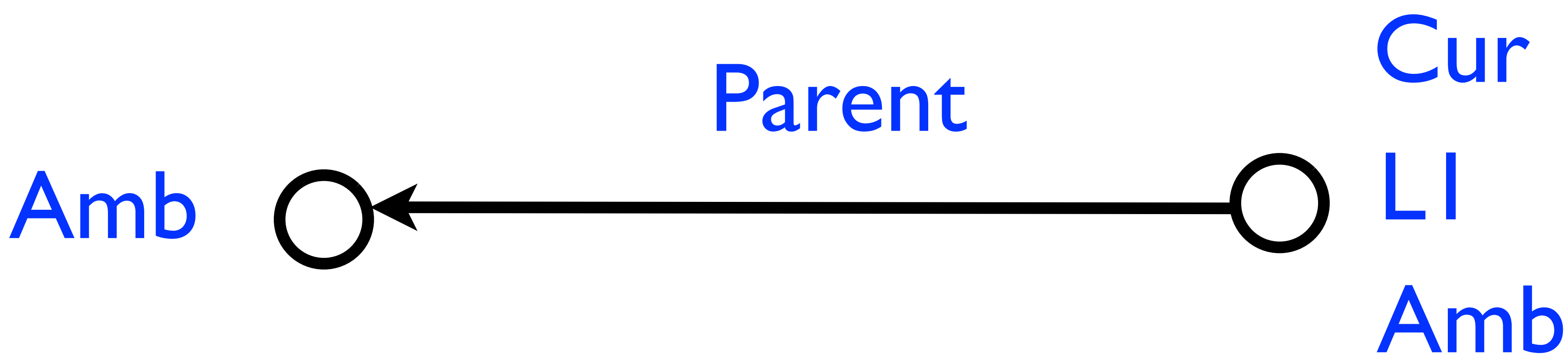
Capsicum State as Structure

Capsicum State as Structure

Capsicum State as Structure

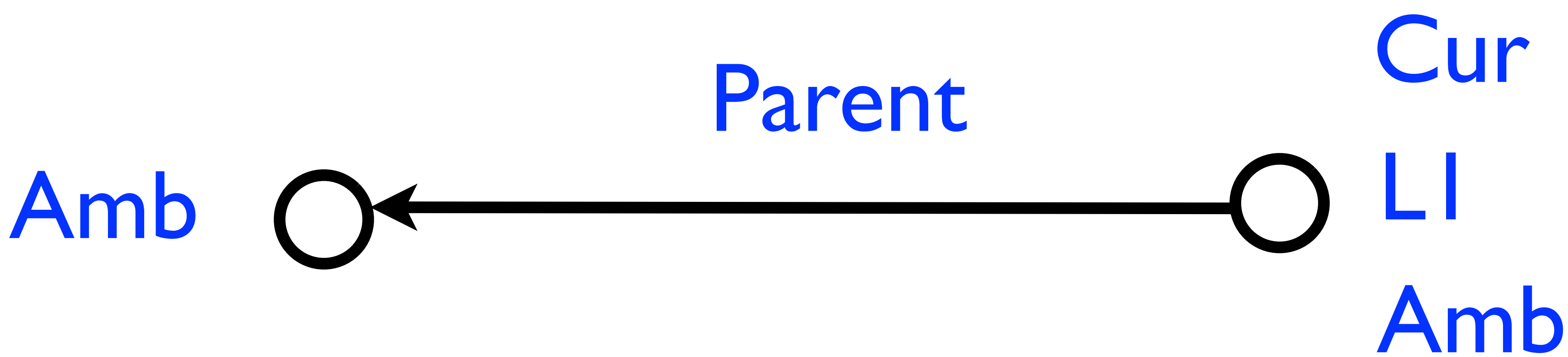


Capsicum State as Structure



$$\forall p.\ \mathrm{Cur}(p) \wedge \mathrm{L1}(p) \Rightarrow \neg\ \mathrm{Amb}(p)$$

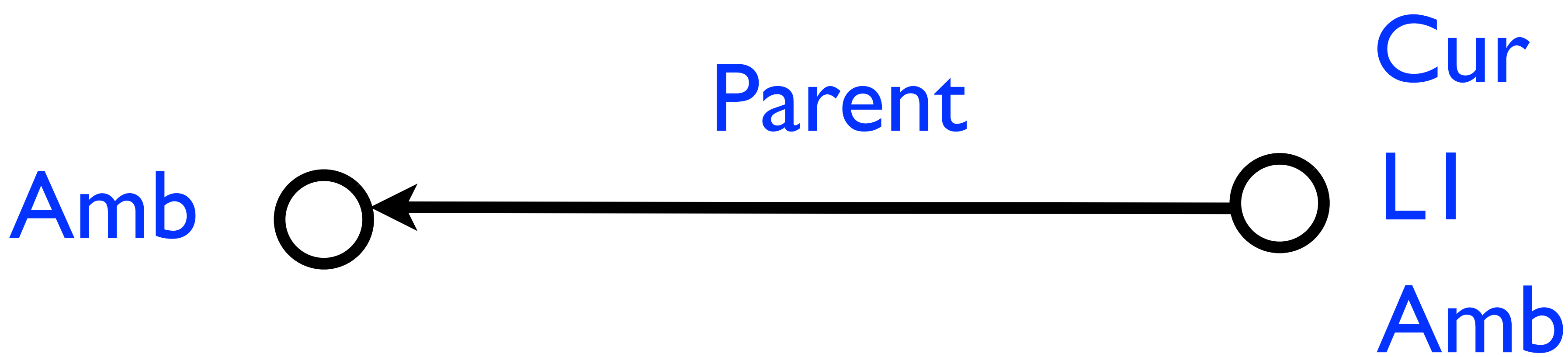
Capsicum State as Structure



$$\not\models$$

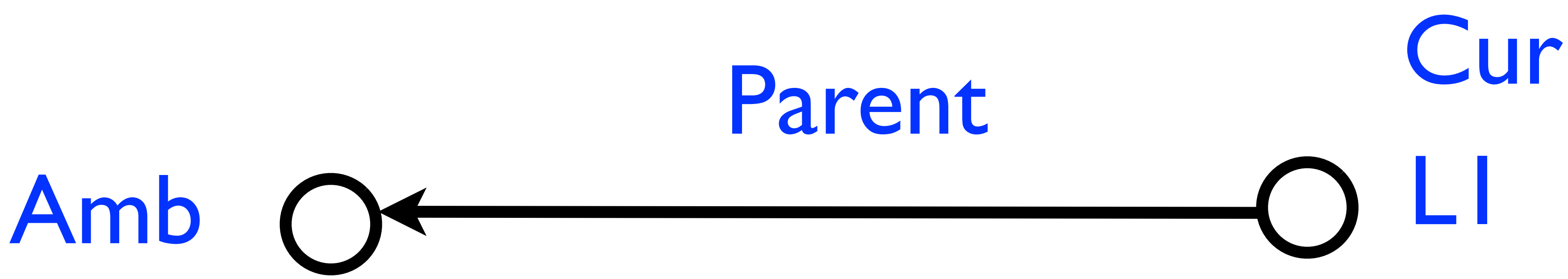
$$\forall\, p.\ \mathrm{Cur}(p) \wedge \mathrm{L1}(p) \Rightarrow \neg\ \mathrm{Amb}(p)$$

Capsicum State as Structure



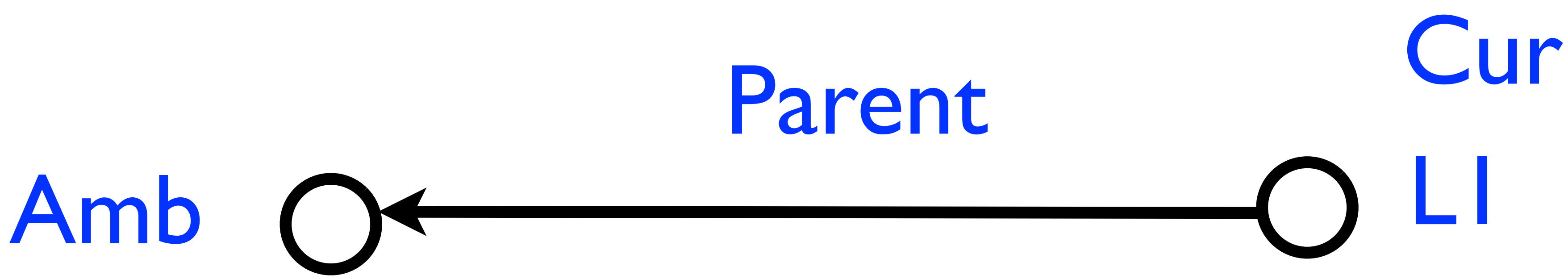
$$\forall\, p.\ \mathrm{Cur}(p) \wedge \mathrm{L1}(p) \Rightarrow \neg\, \mathrm{Amb}(p)$$

Capsicum State as Structure



$$\forall\, p.\ \mathrm{Cur}(p) \wedge \mathrm{L1}(p) \Rightarrow \neg\, \mathrm{Amb}(p)$$

Capsicum State as Structure



$$\models$$

$$\forall\, p.\ \mathrm{Cur}(p) \wedge \mathrm{L1}(p) \Rightarrow \neg\, \mathrm{Amb}(p)$$

Capsicum Structure Transformers

Action	
sync_fork()	

Capsicum Structure Transformers

Cur
Amb ○

Action	
sync_fork()	

Capsicum Structure Transformers

Cur Amb

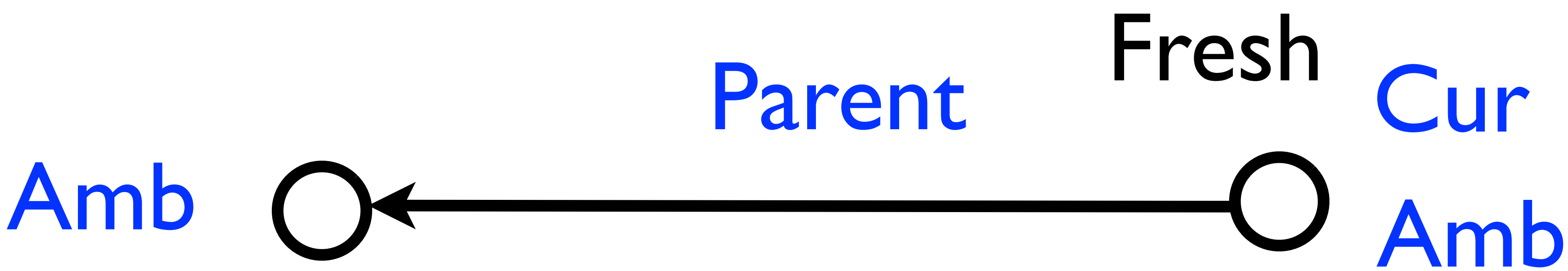
Fresh

Action	
sync_fork()	

Capsicum Structure Transformers

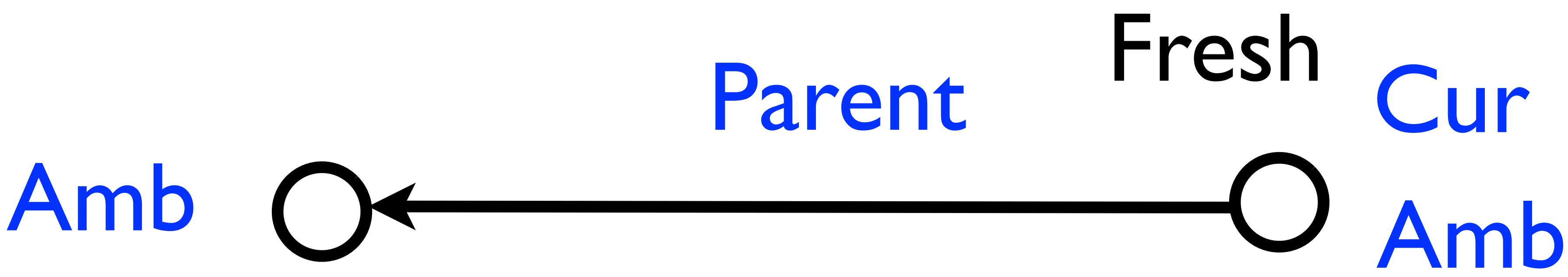
Action	
sync_fork()	

Capsicum Structure Transformers



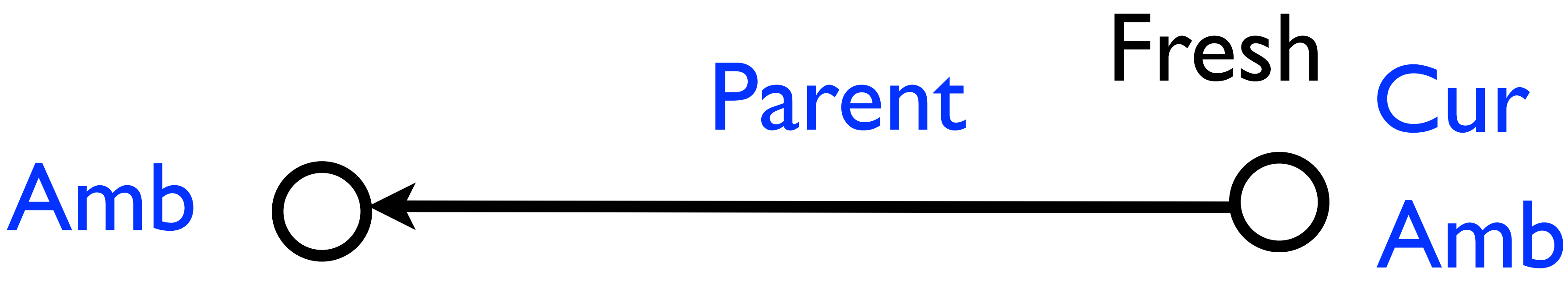
Action	
sync_fork()	

Capsicum Structure Transformers



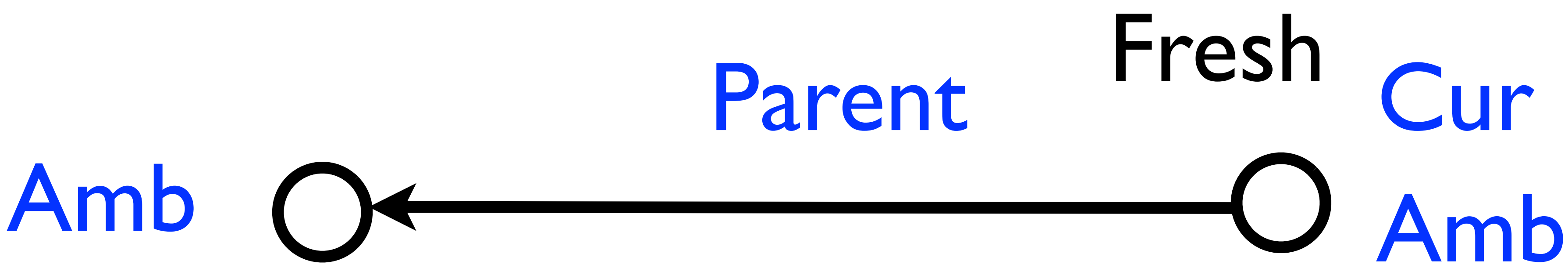
Action	Structure Transformer
sync_fork()	

Capsicum Structure Transformers



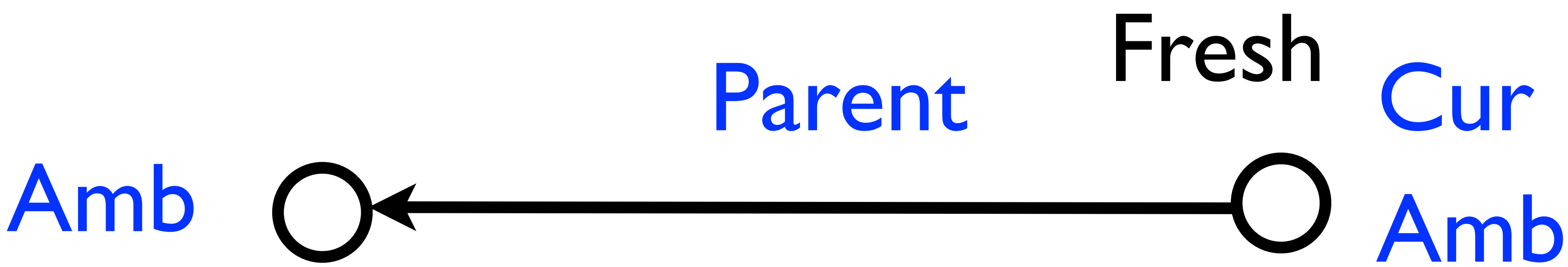
Action	Structure Transformer
sync_fork()	Intro Fresh Amb'(p) := Amb(p) $\vee$ (Fresh(p) $\wedge \exists$ q. Cur(q) $\wedge$ Amb(q))

Capsicum Structure Transformers



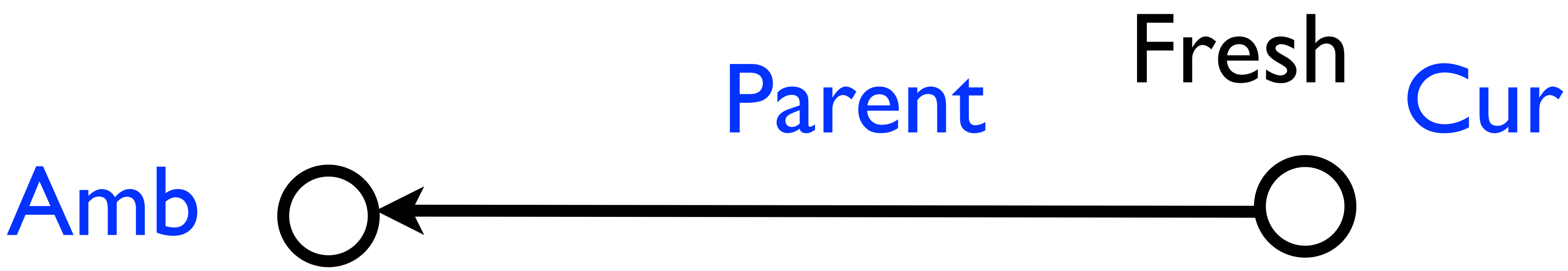
Action	Structure Transformer

Capsicum Structure Transformers



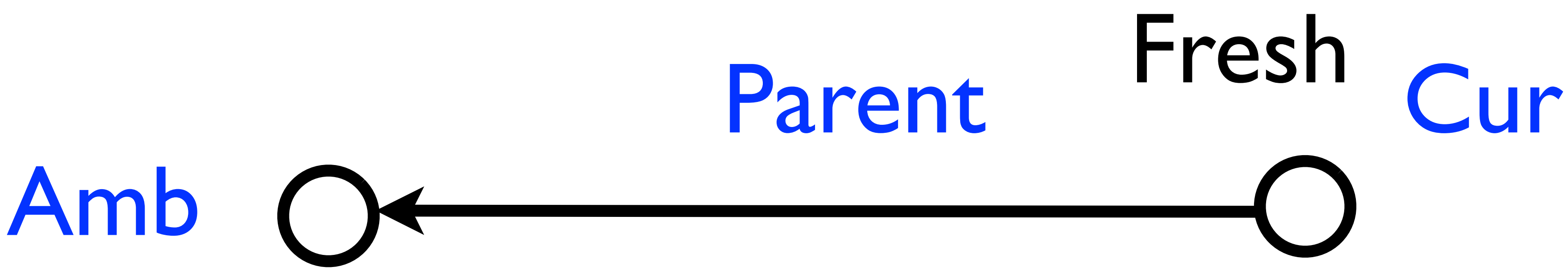
Action	Structure Transformer
cap_enter()	

Capsicum Structure Transformers



Action	Structure Transformer
cap_enter()	

Capsicum Structure Transformers



Action	**Structure Transformer**
cap_enter()	Amb'(p) := Amb(p) $\wedge$ $\neg$ Cur(p)

Building IP#: Summary

- If semantics is given as transforms of logical structures, we can generate an approximation of runs that cause a violation
- Capsicum semantics can be modeled as structure transforms

CapWeave Algorithm

Inputs: Program P, Amb Policy Q
Output: Instrumentation of P that always satisfies Q

1. Build finite **IP#** $\supseteq$ instrumented runs that violate Q

CapWeave Algorithm

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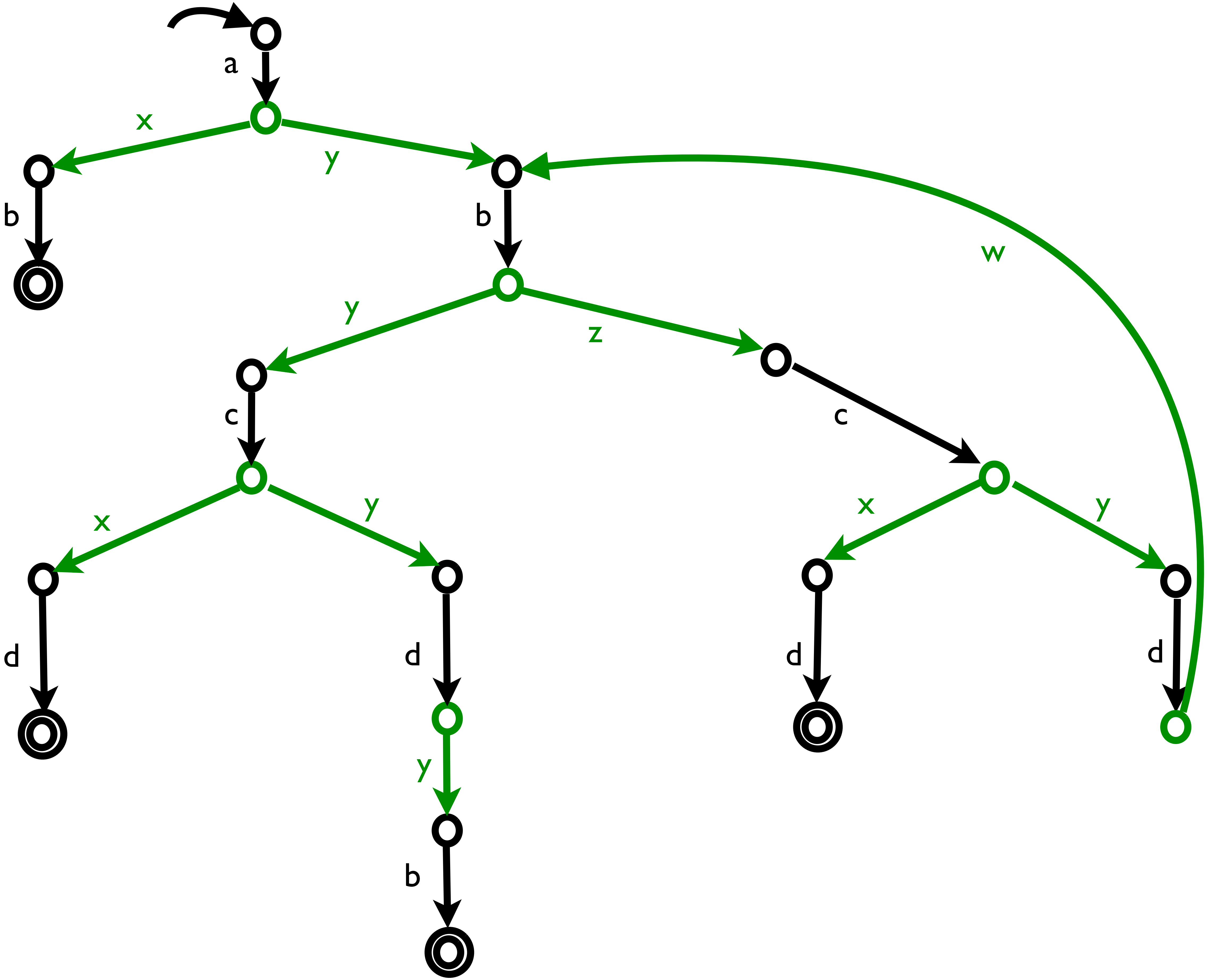
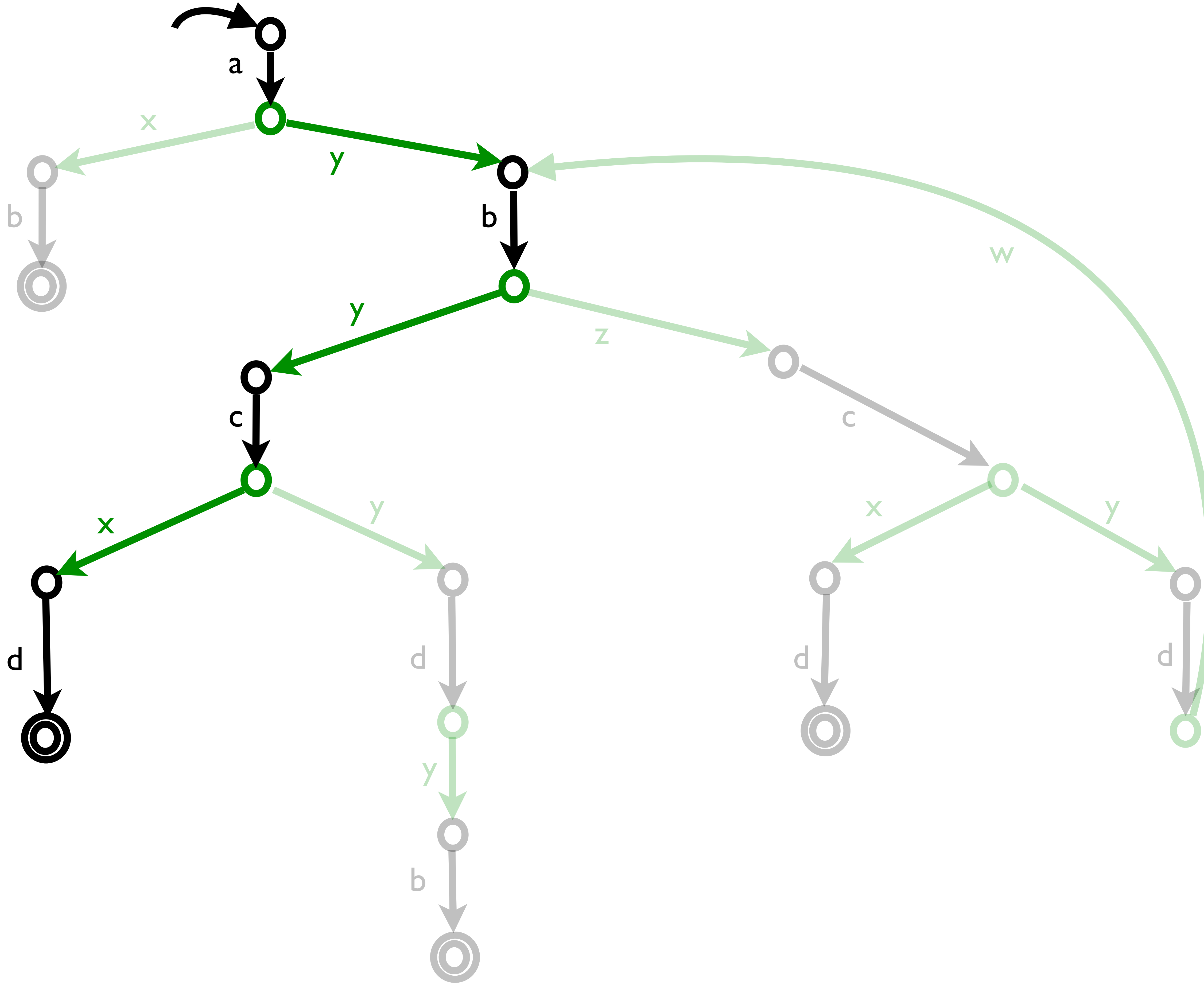
Output: Instrumentation of P that always satisfies Q

1. Build finite **IP#** $\supseteq$ instrumented runs that violate Q
2. From IP#, build **safety game G** won by violations of Q

Two-Player Safety Games

- In an Attacker state,
  the Attacker chooses the next input
- In a Defender state,
  the Defender chooses the next input
- Attacker wants to reach an accepting state


a
x
y
b
b
w
y
z
c
c
x
y
x
y
d
d
d
d
y
b

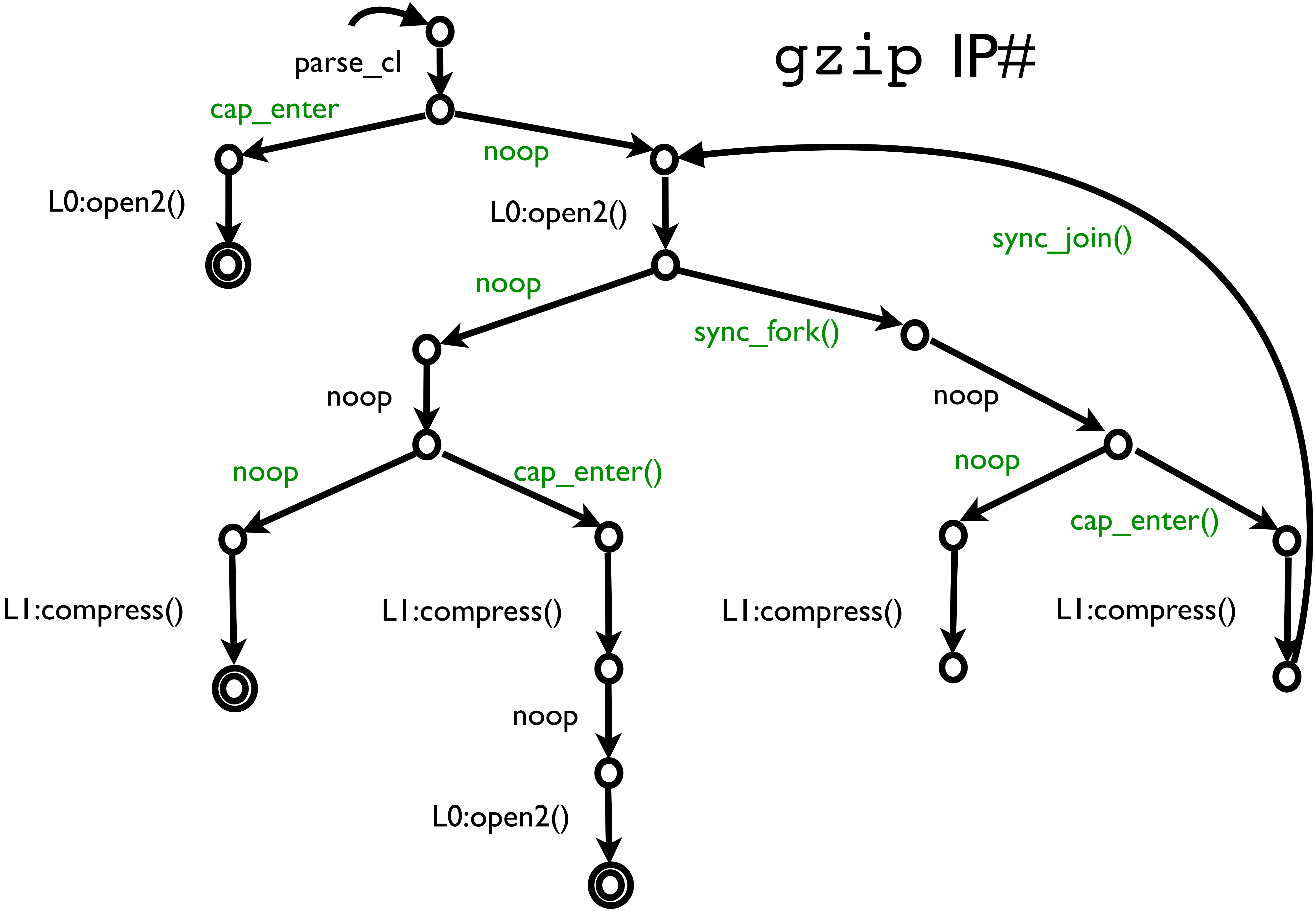


a
x
y
b
b
w
y
z
c
c
x
y
x
y
d
d
d
d
y
b

Instrumentation as a Game

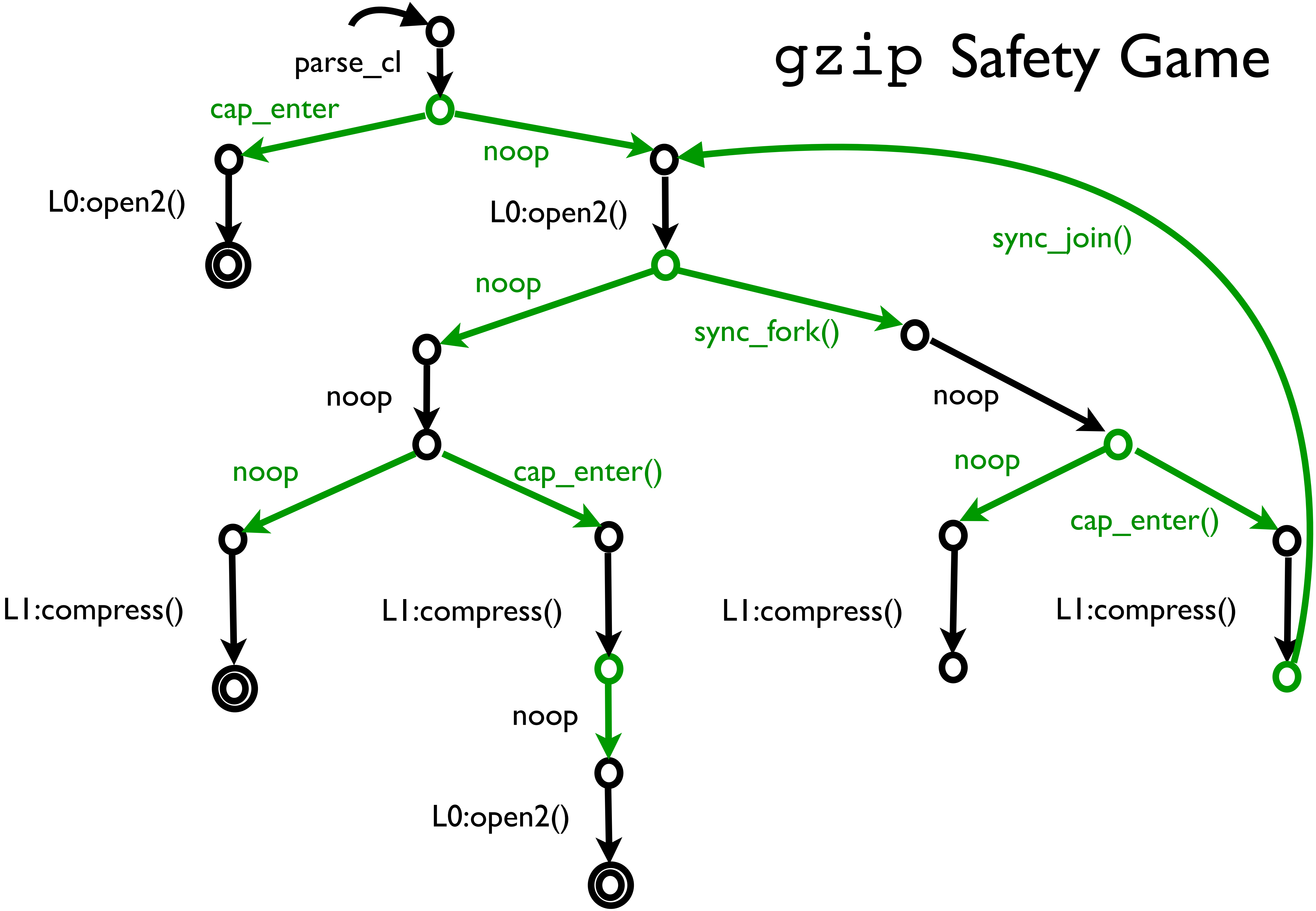
Capsicum Instrumentation	Two-player Games
Program instructions	Attacker actions
Capsicum primitives	Defender actions
Policy violations	Attacker wins
Satisfying instrumentation	Winning Defender strategy

gzip IP#

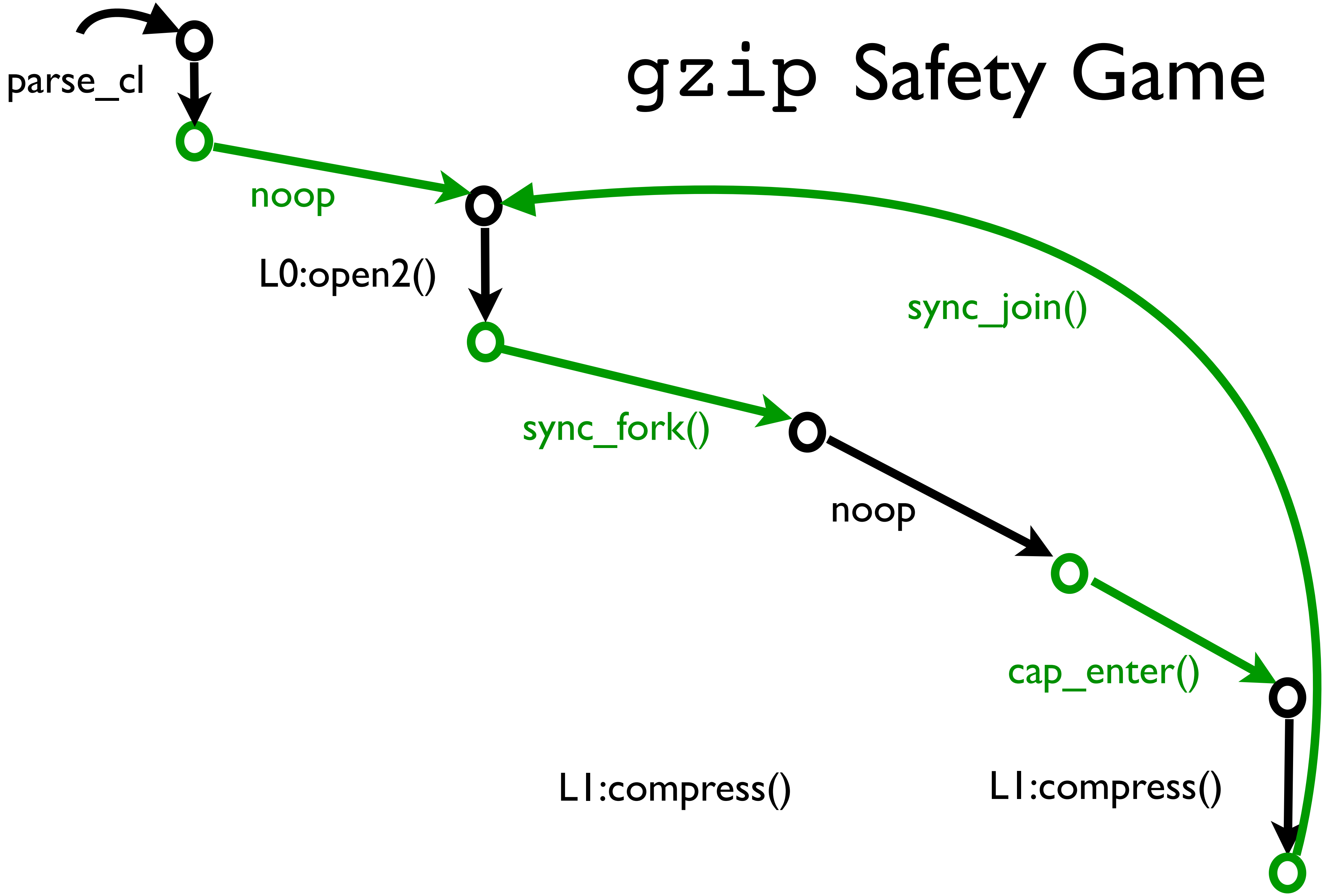


parse_cl
cap_enter
noop
L0:open2()
L0:open2()
sync_join()
noop
sync_fork()
noop
noop
noop
cap_enter()
noop
cap_enter()
L1:compress()
L1:compress()
L1:compress()
L1:compress()
noop
L0:open2()

gzip Safety Game



`gzip` Safety Game



CapWeave Algorithm

Inputs: Program P, Amb Policy Q
Output: Instrumentation of P that always satisfies Q

1. Build finite **IP#** $\supseteq$ instrumented runs that violate Q
2. From IP#, build **safety game G** won by violations of Q

CapWeave Algorithm

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CapWeave Performance

Name	Program kLoC	Policy LoC	Weaving Time
bzip2-1.0.6	8	70	4m57s
gzip-1.2.4	9	68	3m26s
php-cgi-5.3.2	852	114	46m36s
tar-1.25	108	49	0m08s
tcpdump-4.1.1	87	52	0m09s
wget-1.12	64	35	0m10s

Performance on Included Tests

Name	Base Time	Hand Overhd	capweave Overhd	Diff. Overhd (%)
bzip2-1.0.6	0.593s	0.909	1.099	20.90
gzip-1.2.4	0.036s	1.111	1.278	15.03
php-cgi-5.3.2	0.289s	1.170	1.938	65.64
tar-1.25	0.156s	13.301	21.917	64.78
tcpdump-4.1.1	1.328s	0.981	1.224	24.77
wget-1.12	4.539s	1.906	1.106	0.91

Outline

1. Motivation, problem statement
2. Previous work: Capsicum
3. Ongoing work: HiStar
4. Open challenges

Outline

3. Ongoing work: HiStar

The HiStar Priv-aware OS [Zeldovich '06]

- Privilege: OS allows flow between processes
- Primitives: system calls update labels, which define allowed flows
- Very powerful: mutually untrusting login (?!)

Sandboxing a Virus Scanner

```
launcher() {
  exec(“/bin/scanner”);
}
wrapper() {
  child = sync_fork(&launcher);
  while (true) {
    read(child, buf);
    sanitize(buf);
    write(netd, buf); }
}
```

A Flow Policy for a Virus Scanner

- Information should never transitively flow from the scanner to the network, unless it goes through the wrapper
- Information should always flow from the scanner to the wrapper
- Information should always flow from the wrapper to the network

Rules for HiStar's Flow

- A process's **label** maps each category to **low** or **high**
- If process p calls create_cat, then each process is low in c, and p can declassify c
- Each process may raise its level at each category
- Each process may relinquish declassification

Rules for HiStar's Flow

Information can flow from p to q if for each category:

- The level of p is lower than the level of q at c, or
- p can declassify c

Sandboxing a Virus Scanner

```
launcher() {

 exec("/bin/scanner"); }
wrapper() {



    child = sync_fork(&launcher);
    while (true) {
      read(child, buf);
      sanitize(buf);
      write(netd, buf); } }
```

Sandboxing a Virus Scanner

```
launcher() {

 exec("/bin/scanner"); }
wrapper() {
  create_cat(&x);
  raise(x);
  child = sync_fork(&launcher);
  while (true) {
    read(child, buf);
    sanitize(buf);
    write(netd, buf); } }
```

Sandboxing a Virus Scanner

```
launcher() {
 drop_declass(x);
 exec(“/bin/scanner”); }
wrapper() {
  create_cat(&x);
  raise(x);
  child = sync_fork(&launcher);
  while (true) {
    read(child, buf);
    sanitize(buf);
    write(netd, buf); } }
```

HiStar Challenges Not Appearing in This Talk

- There are actually **four** levels
- Each process has to manage its **clearance**
- Processes can create **labeled closures** (calling a closure implicitly performs two label operations and three ordering checks)

CapWeave Algorithm

Inputs: Program P, Amb Policy Q

Output: Instrumentation of P that satisfies Q

1. Build **IP#** ⊇ instrumented runs that violate Q (using Capsicum semantics)
2. From IP#, build **safety game G** won by violations of Q
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1. Build **IP#** ⊇ instrumented runs that violate Q (using Capsicum semantics)
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3. From winning strategy for G, generate primitive controller for P

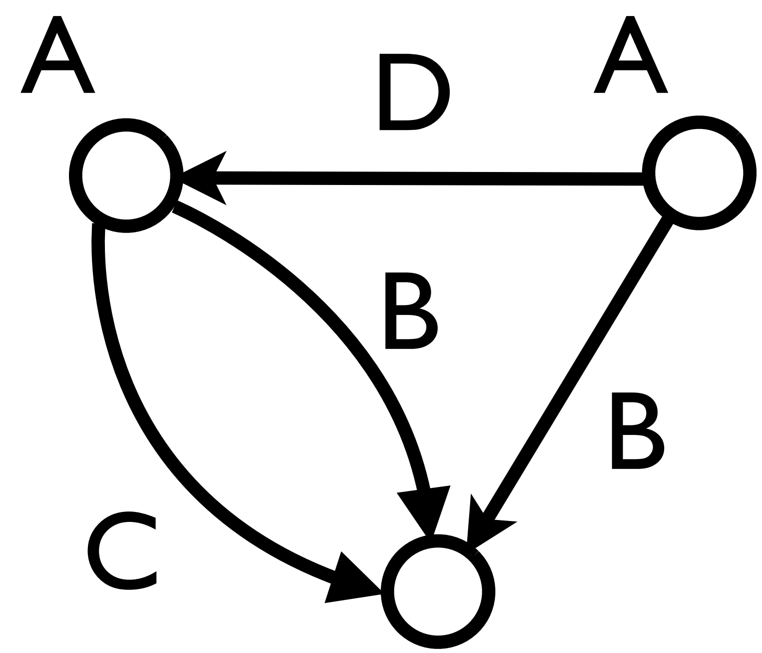
HiWeave Algorithm

Inputs: Program P, Flow Policy Q
Output: Instrumentation of P that satisfies Q

1. Build **IP#** ⊇ instrumented runs that violate Q (using HiStar semantics)
2. From IP#, build **safety game G** won by violations of Q
3. From winning strategy for G, generate primitive controller for P

Capsicum Semantics

1. $Q \equiv$



2. τ[action] $\equiv$

A'(x) = A(x) $\vee$ $\exists$ y. C(y) $\wedge$ B(q, p)

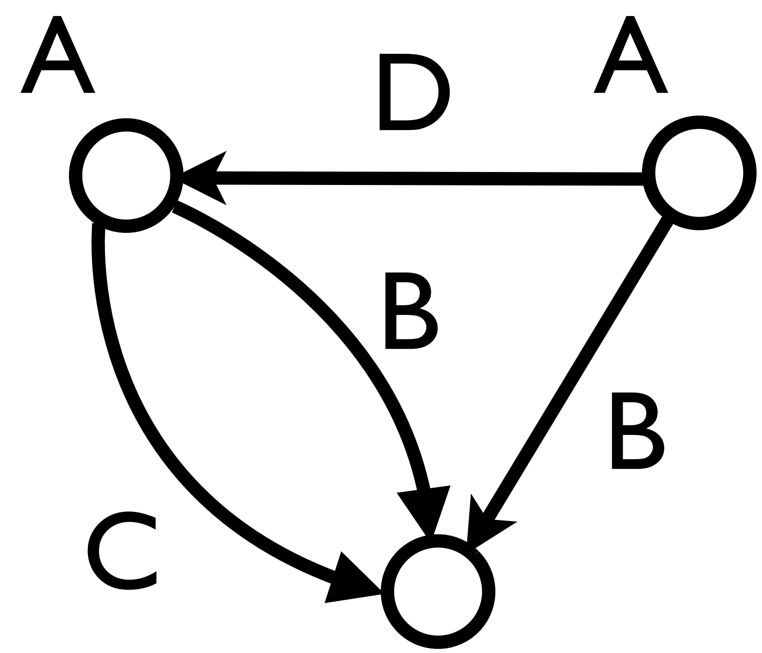
B'(x, y) = B(x, y) $\vee$ (C(x) $\wedge$ D(y))

C'(x) = ...

D'(x) = ...

HiStar Semantics

1. $Q \equiv$



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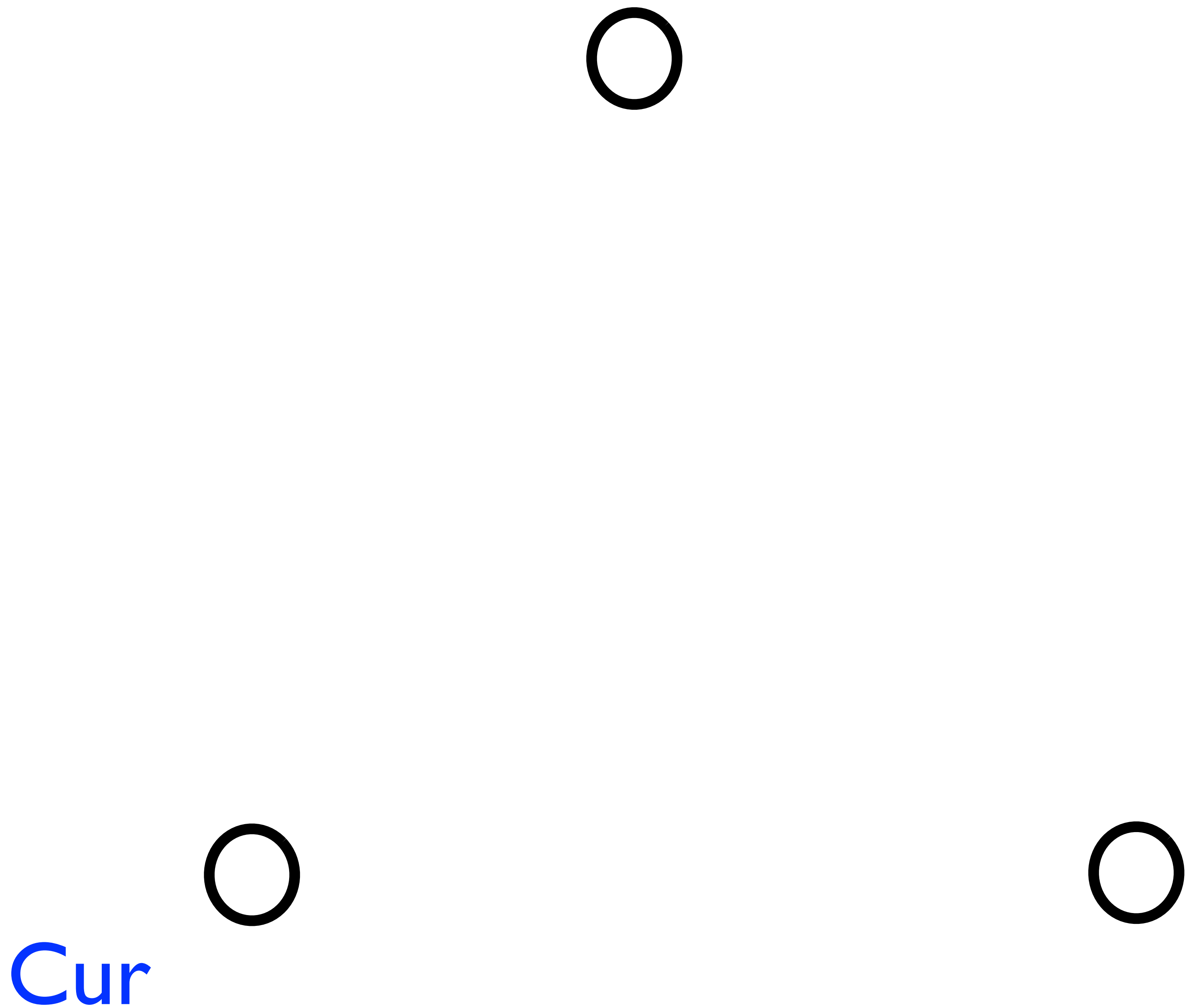
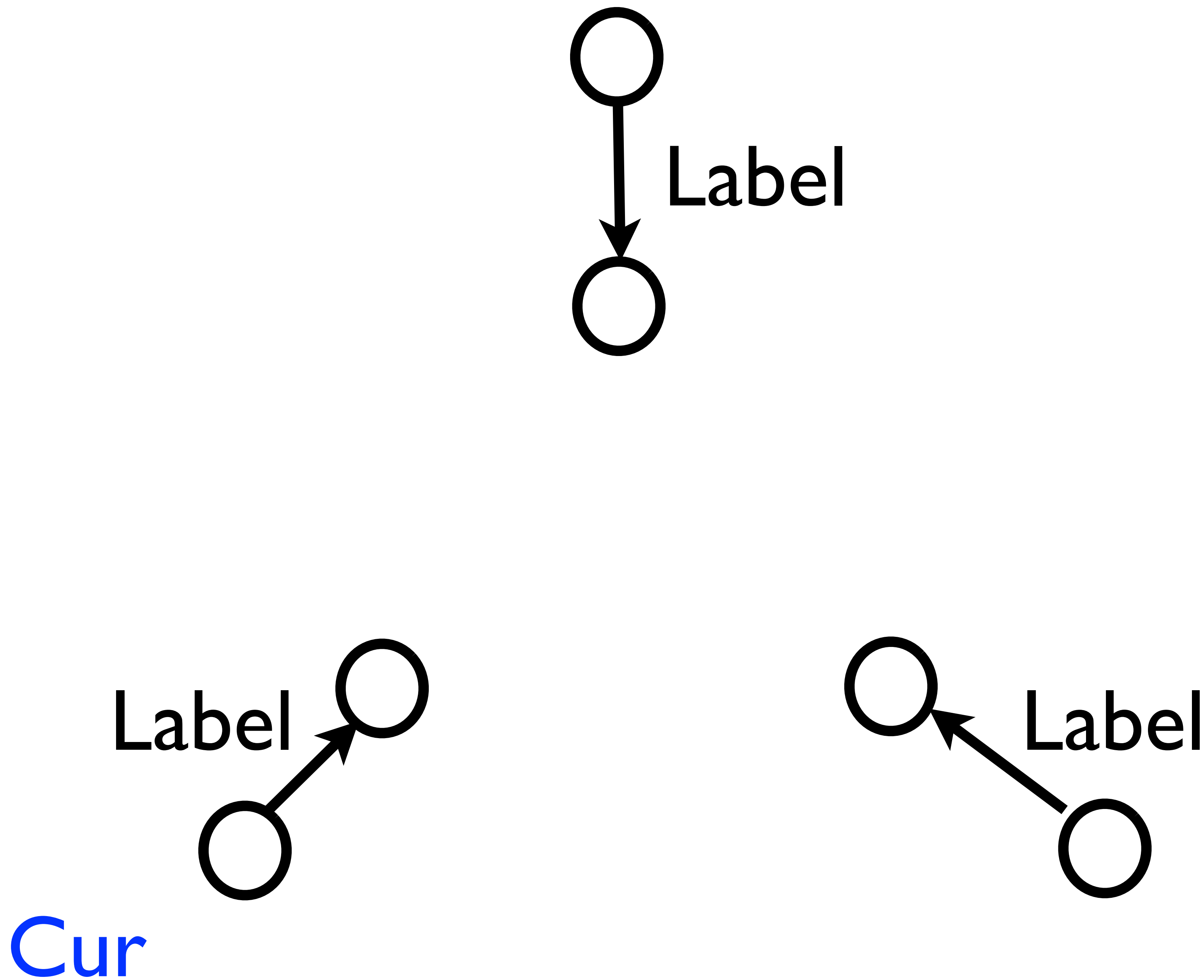
C'(x) = ...
D'(x) = ...

HiStar State as Structure

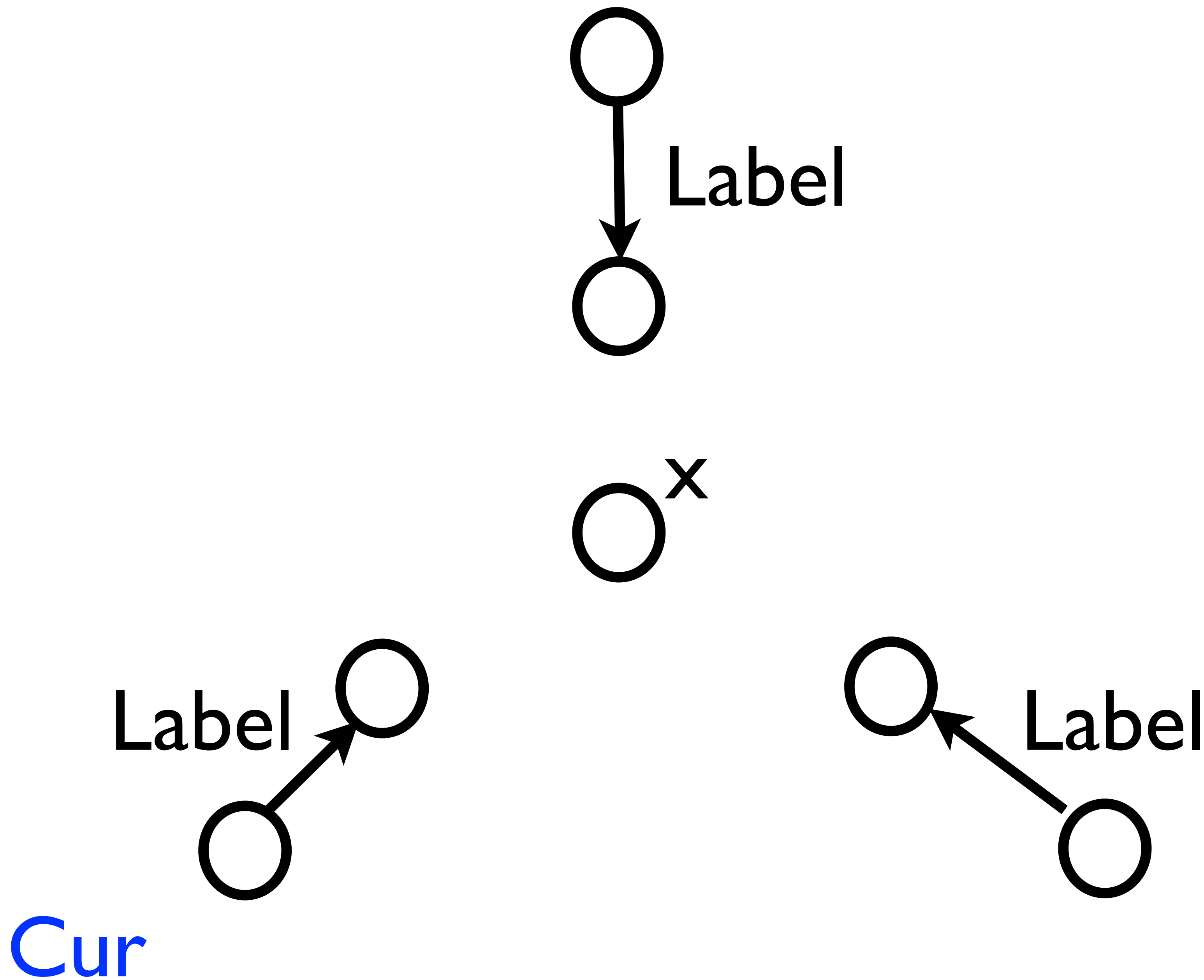
HiStar State as Structure



HiStar State as Structure



HiStar State as Structure



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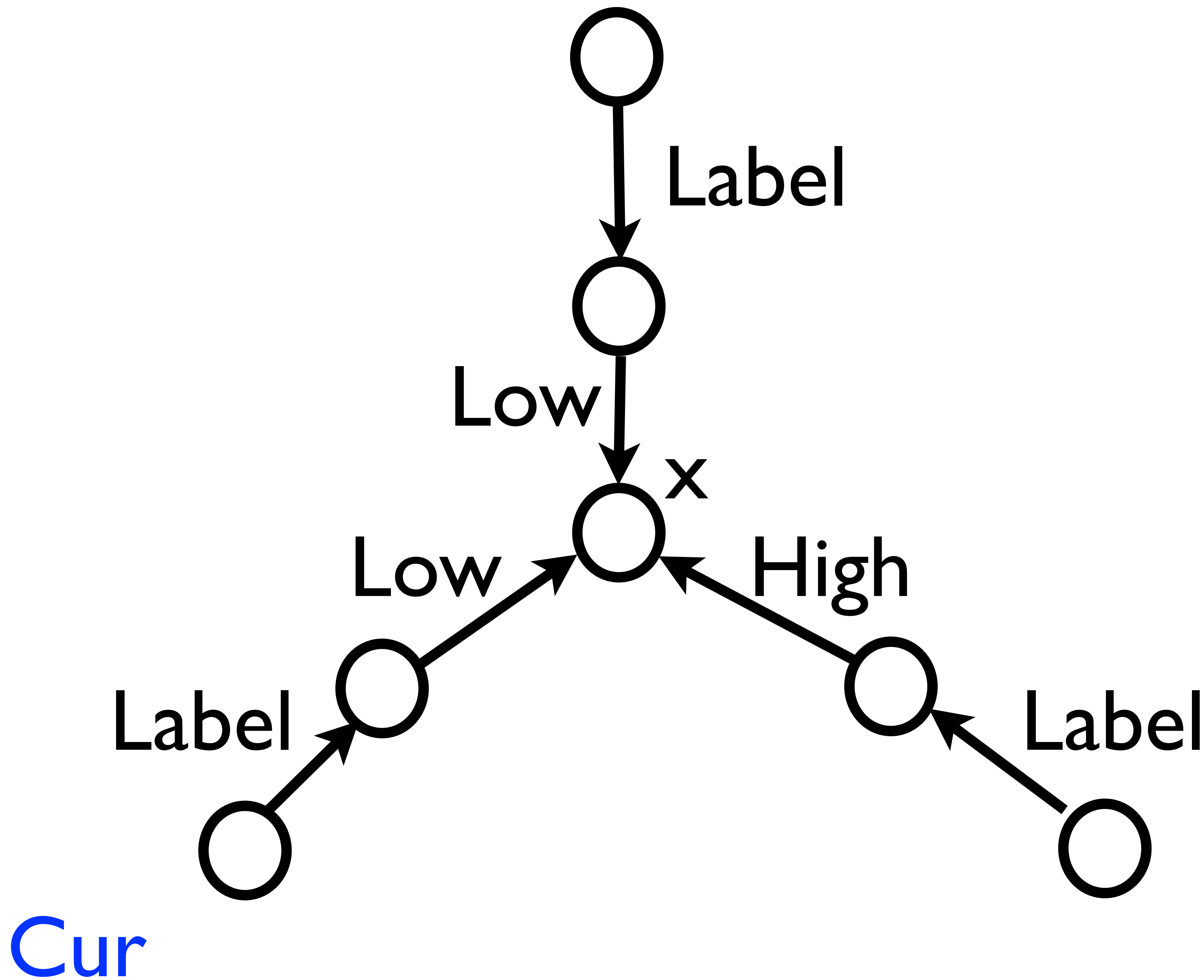
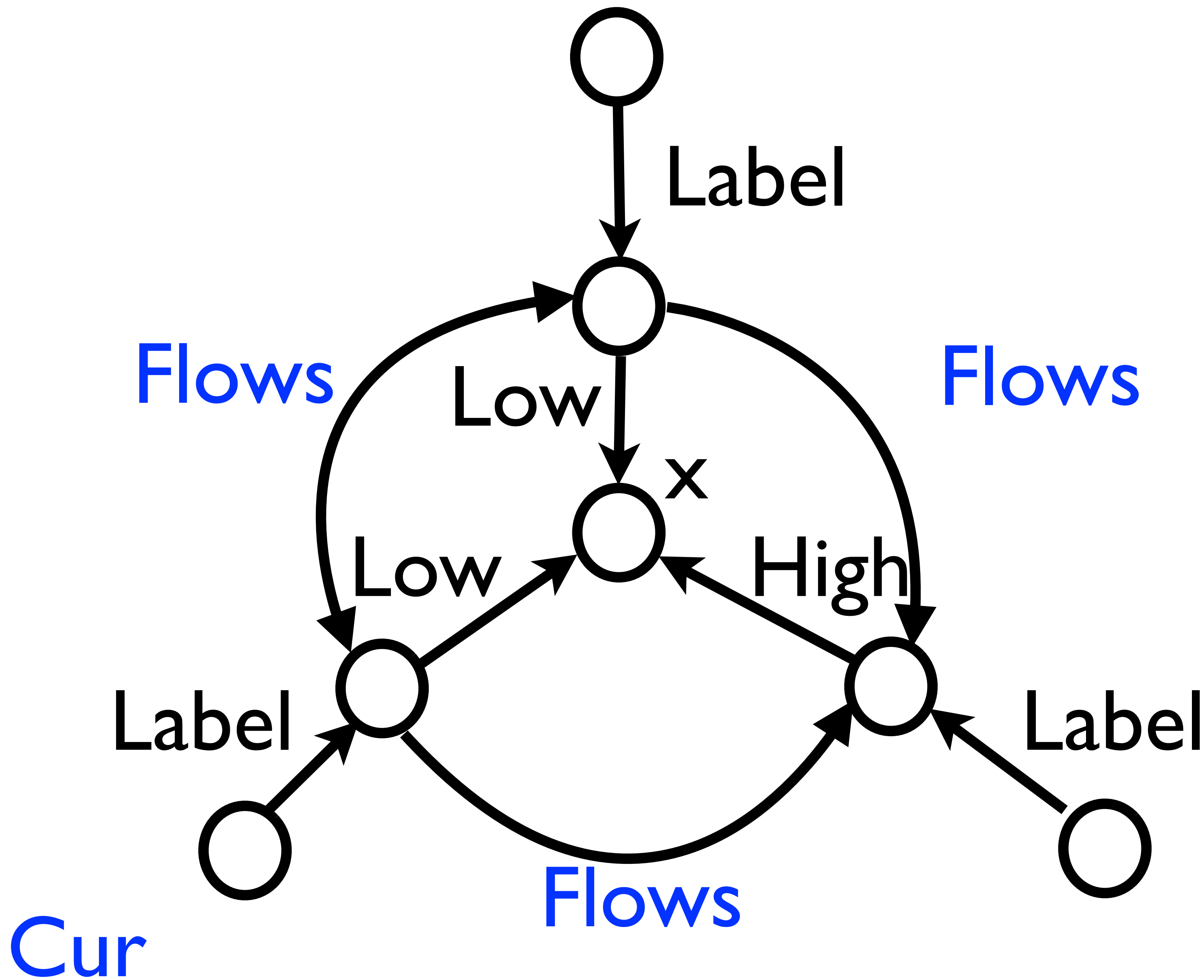
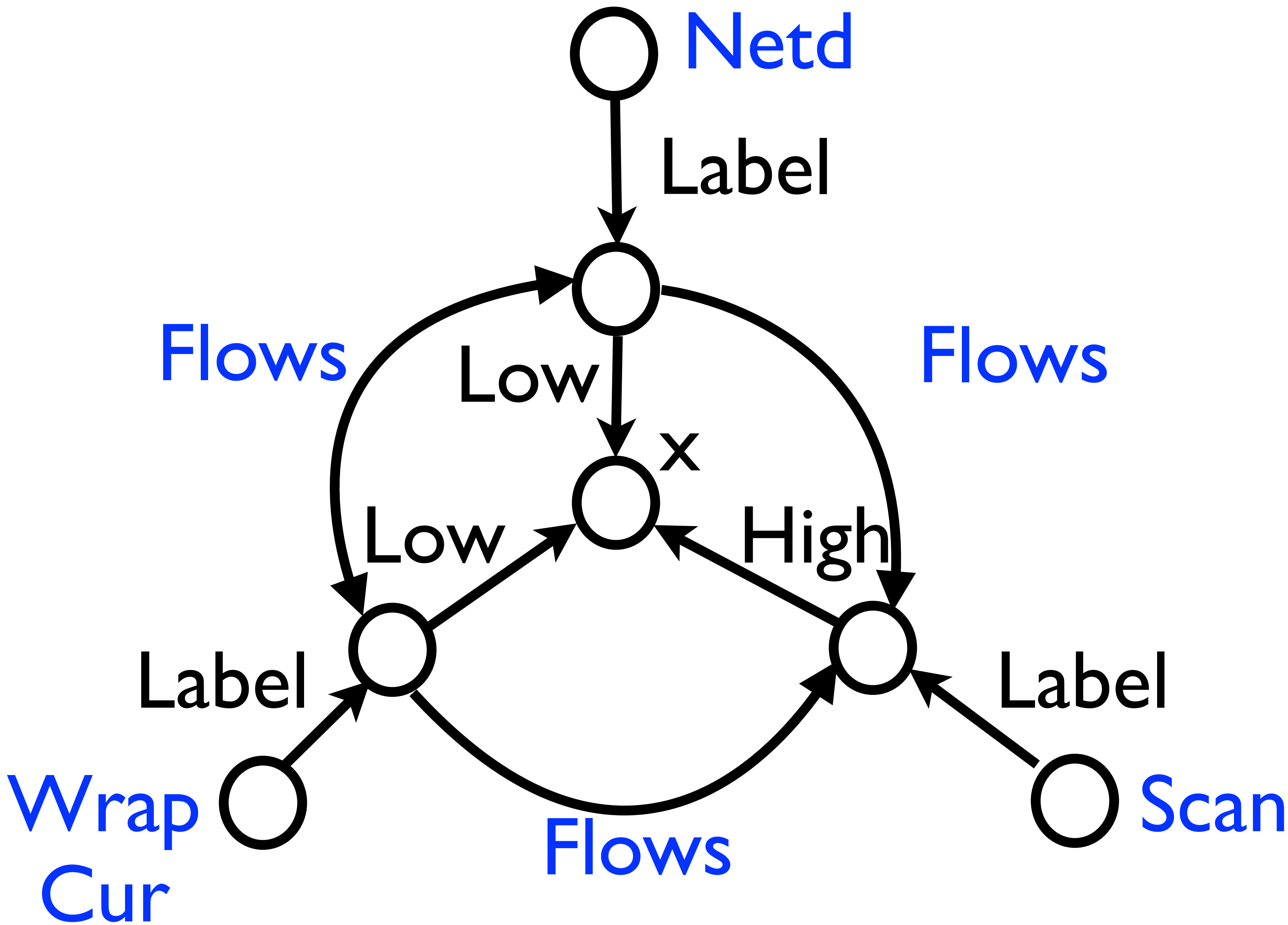


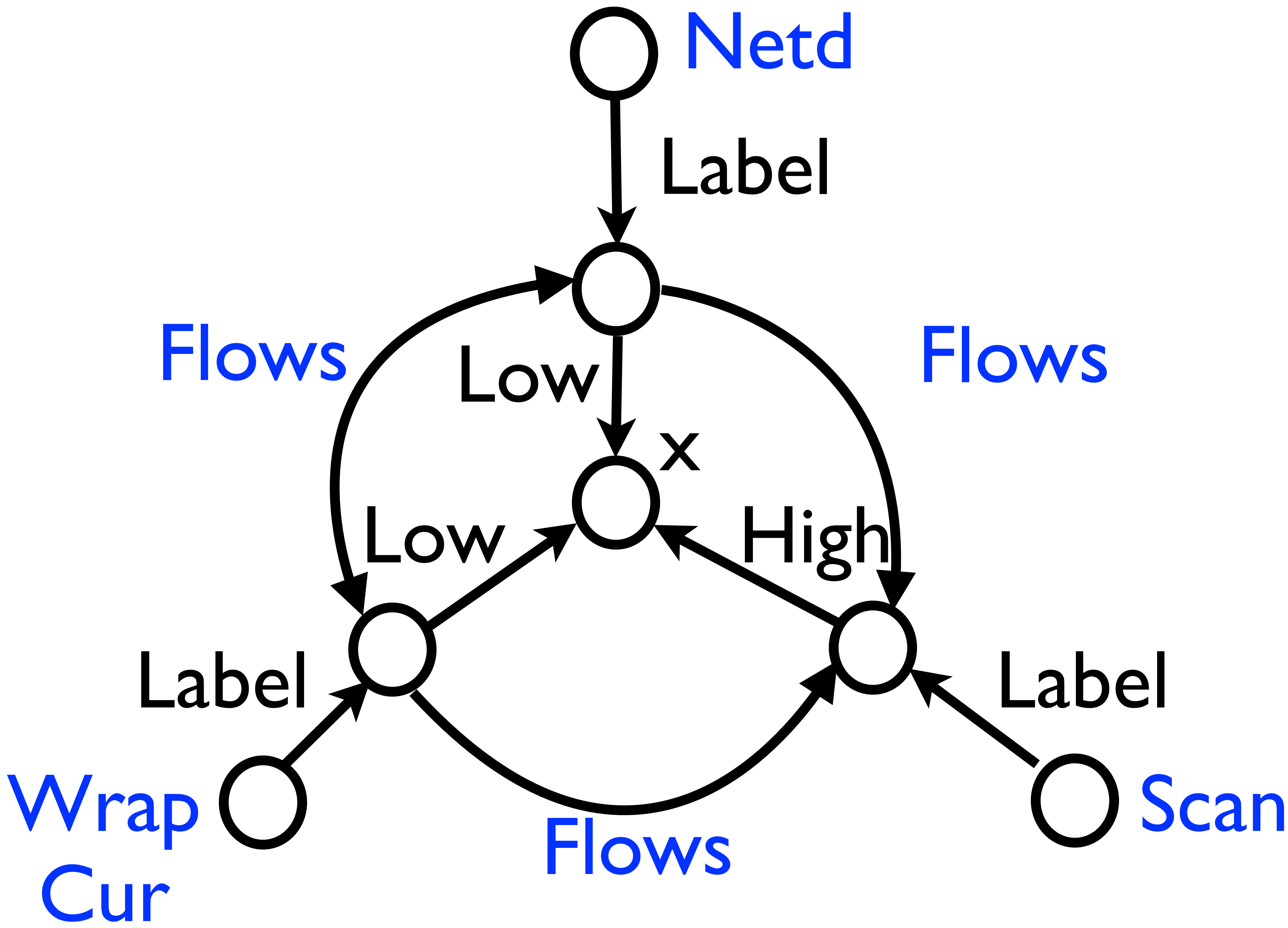
HiStar State as Structure



HiStar State as Structure



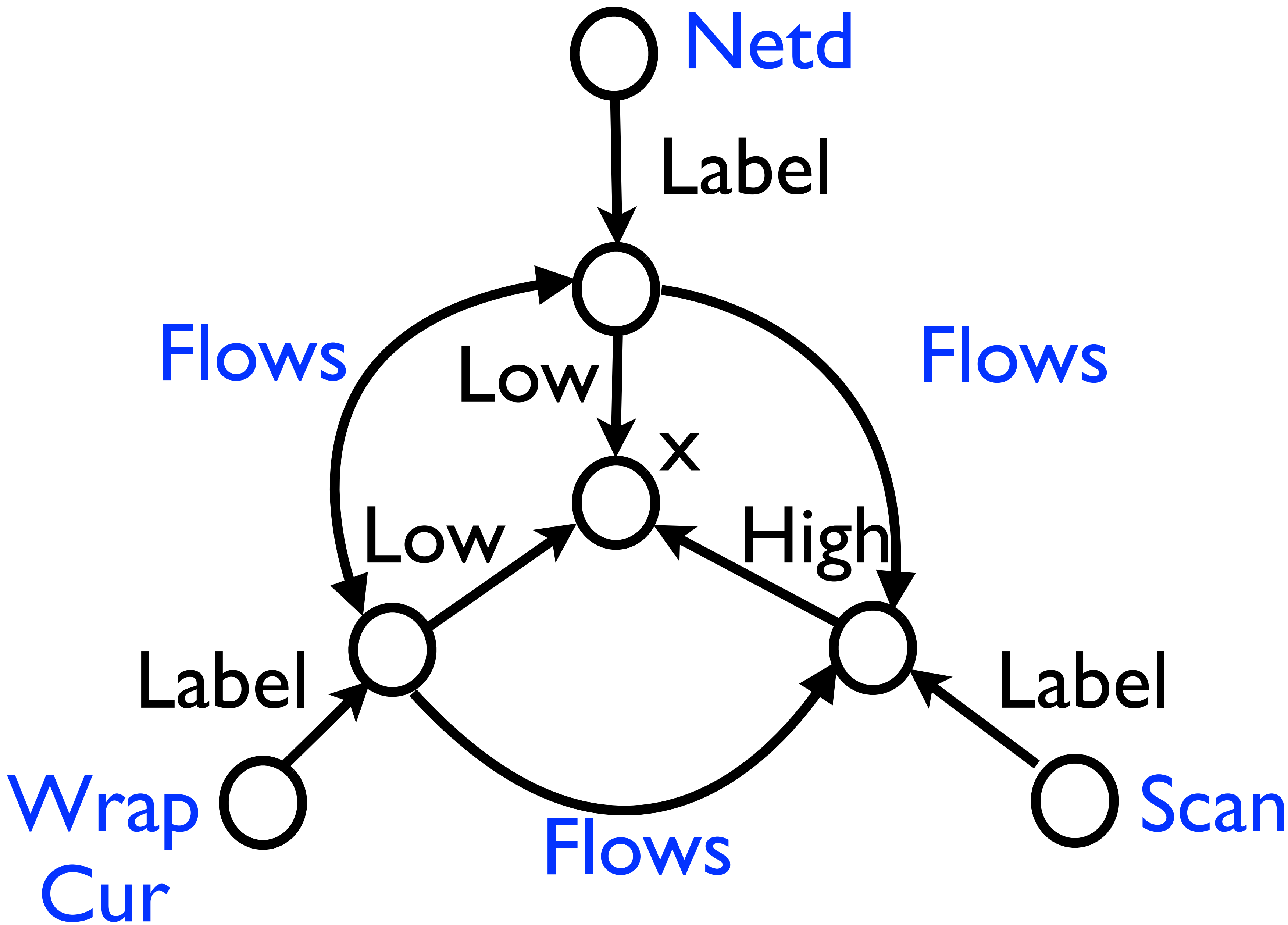
HiStar State as Structure



$$\forall\ w, s, n.\ \mathrm{Wrap}(w) \wedge \mathrm{Scan}(s) \wedge \mathrm{Netd}(n) \Rightarrow$$

$$\mathrm{Flows}(s, w) \wedge \mathrm{Flows}(w, n)$$

HiStar State as Structure



$$\not\models$$

$$\forall\ w, s, n.\ \text{Wrap}(w) \wedge \text{Scan}(s) \wedge \text{Netd}(n) \Rightarrow$$

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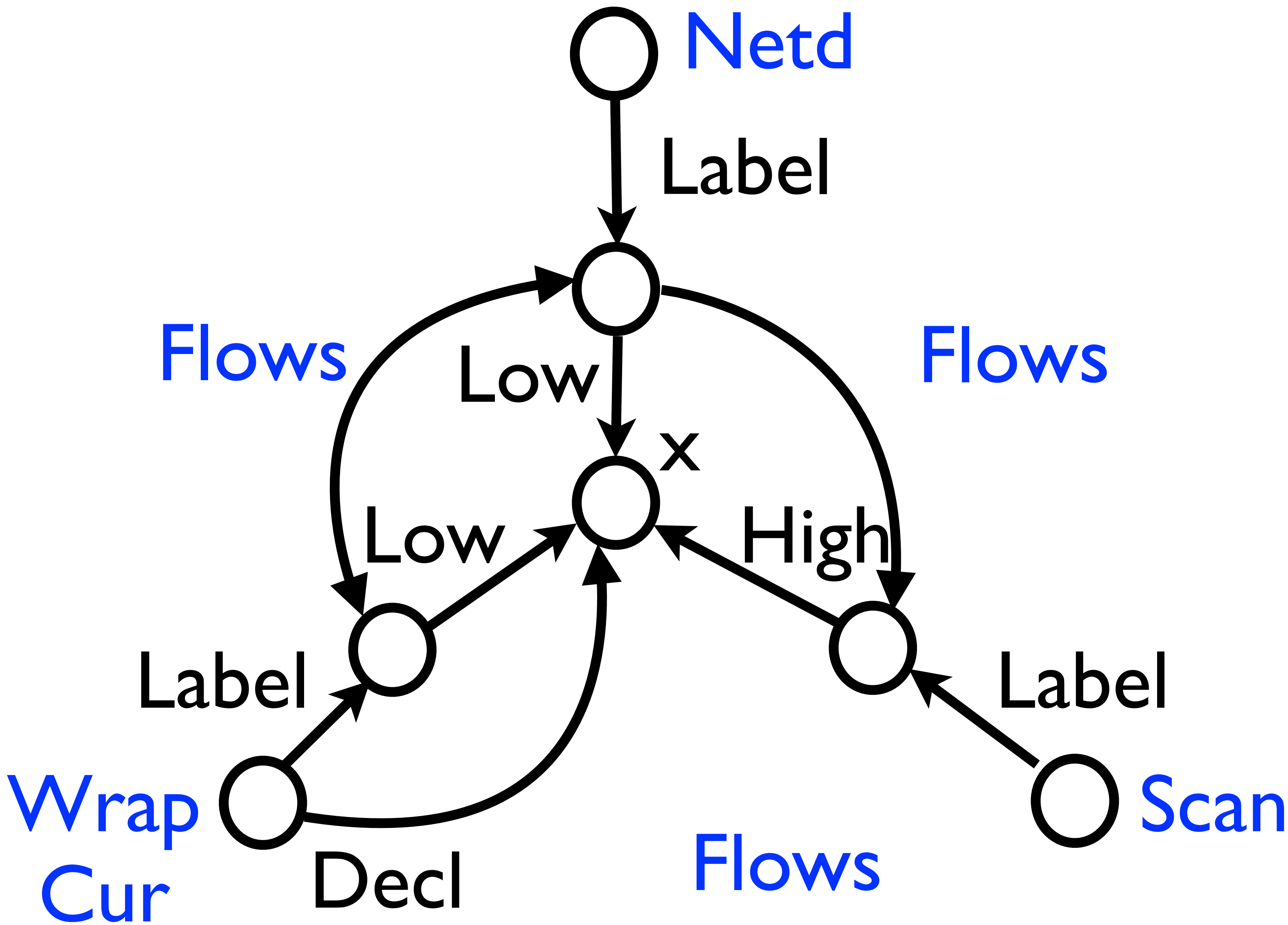
HiStar State as Structure



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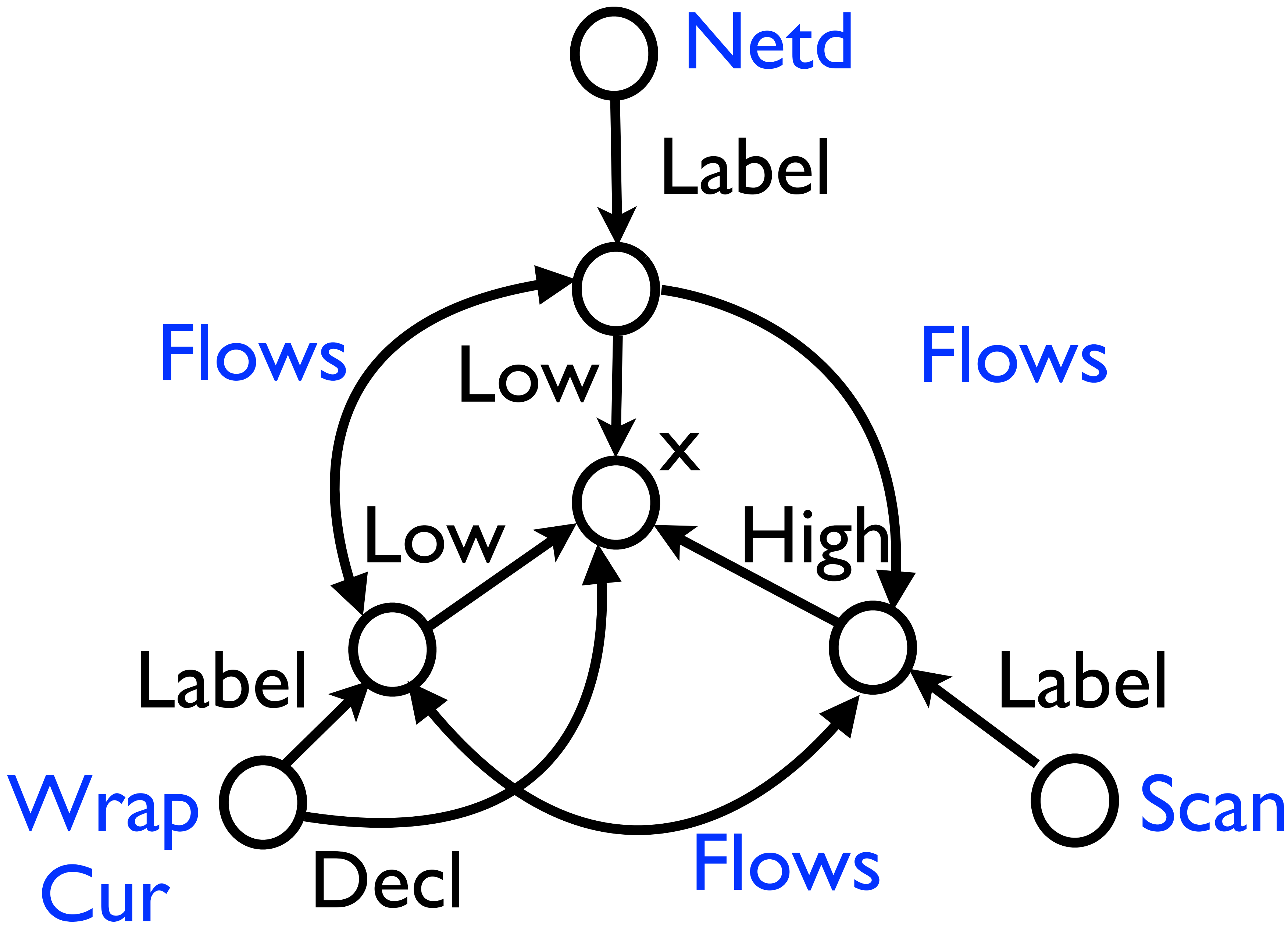
HiStar State as Structure



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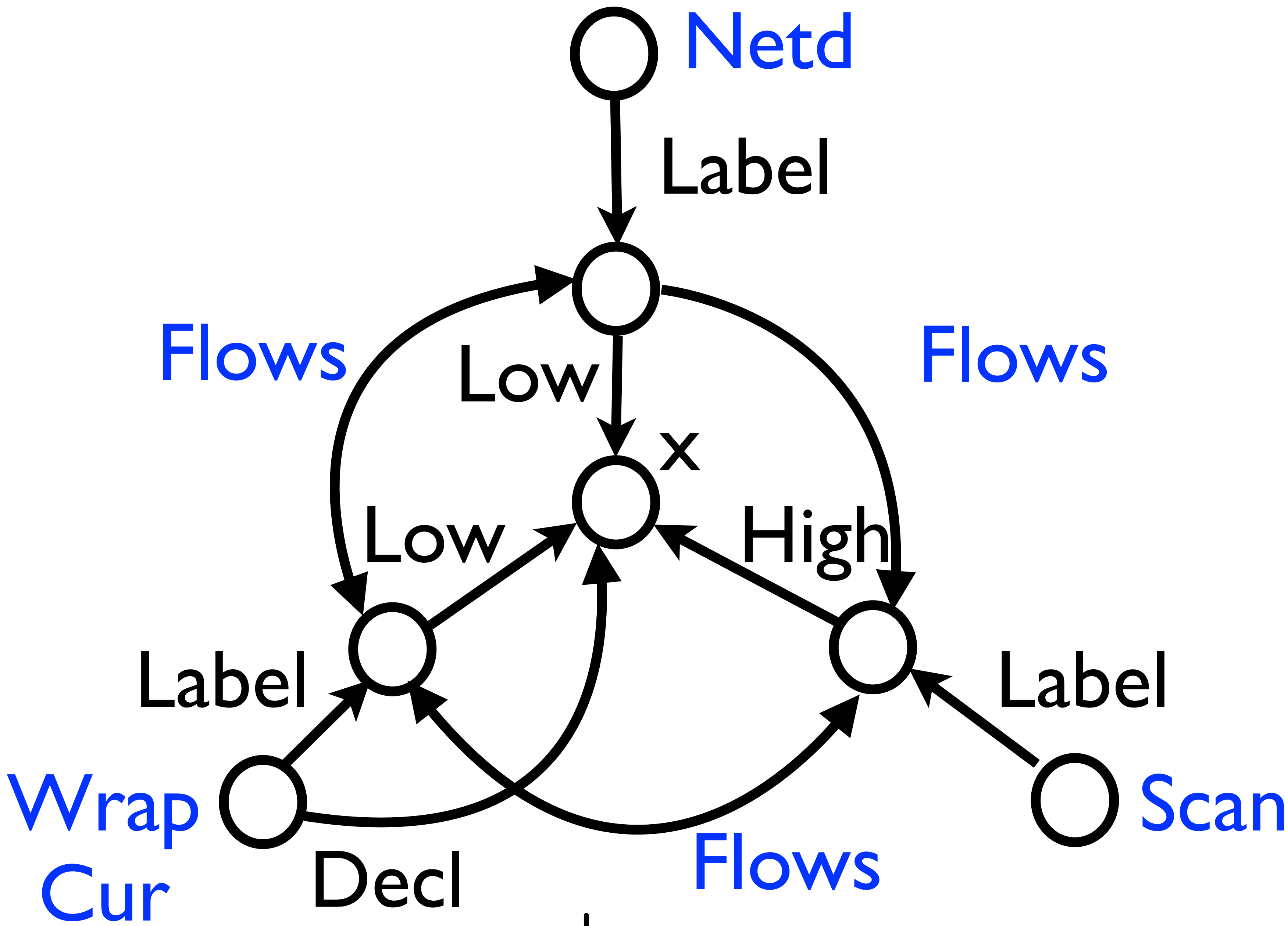
$$\mathrm{Flows}(s, w) \land \mathrm{Flows}(w, n)$$

HiStar State as Structure



$$\models$$

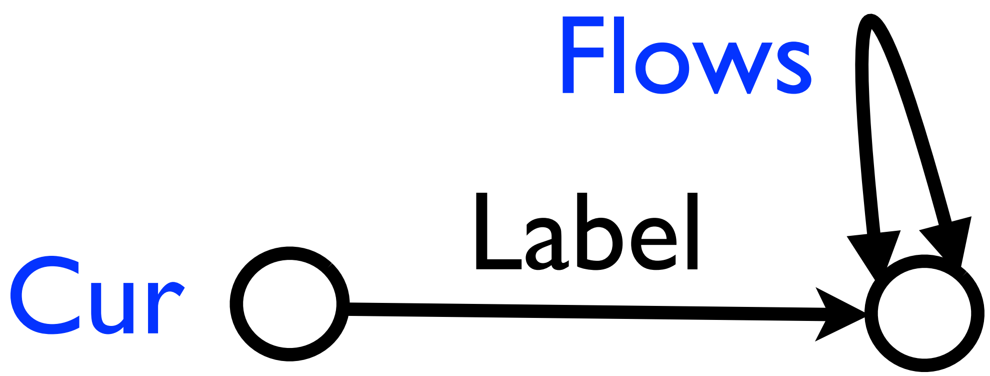
$$\forall\ w, s, n.\ \mathrm{Wrap}(w) \land \mathrm{Scan}(s) \land \mathrm{Netd}(n) \Rightarrow$$

$$\mathrm{Flows}(s, w) \land \mathrm{Flows}(w, n)$$

HiStar State Transformers

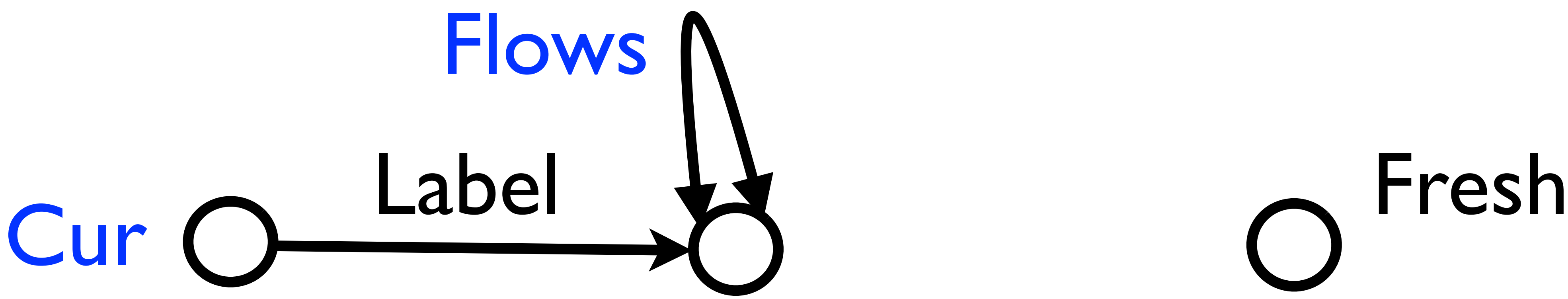
Action	
create_cat(&x)	

HiStar State Transformers



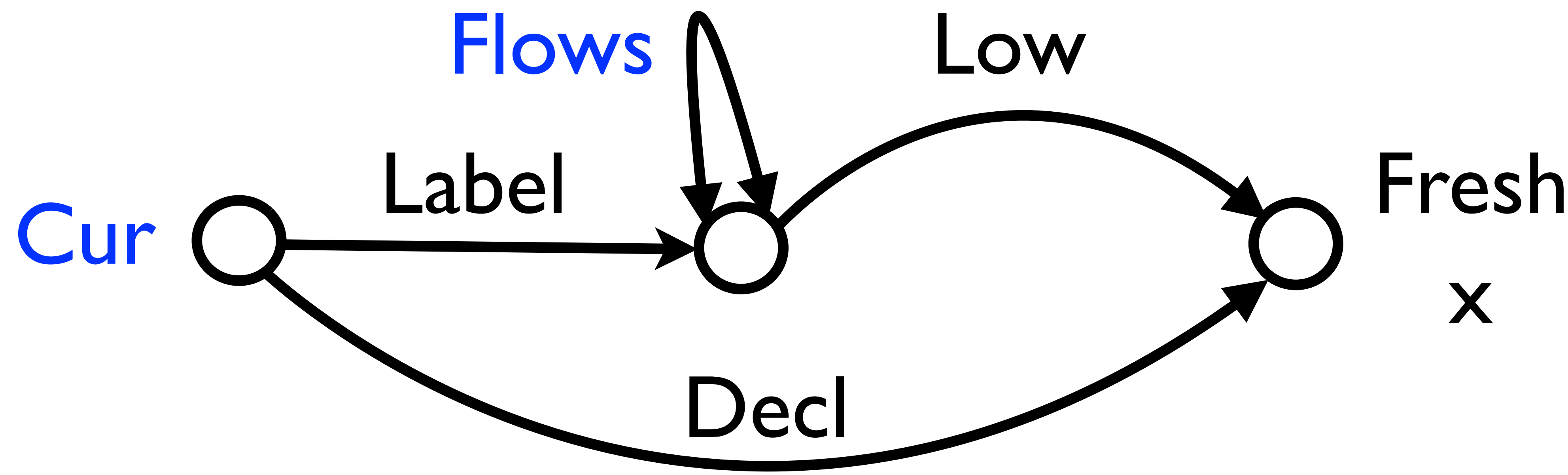
Action	
create_cat(&x)	

HiStar State Transformers



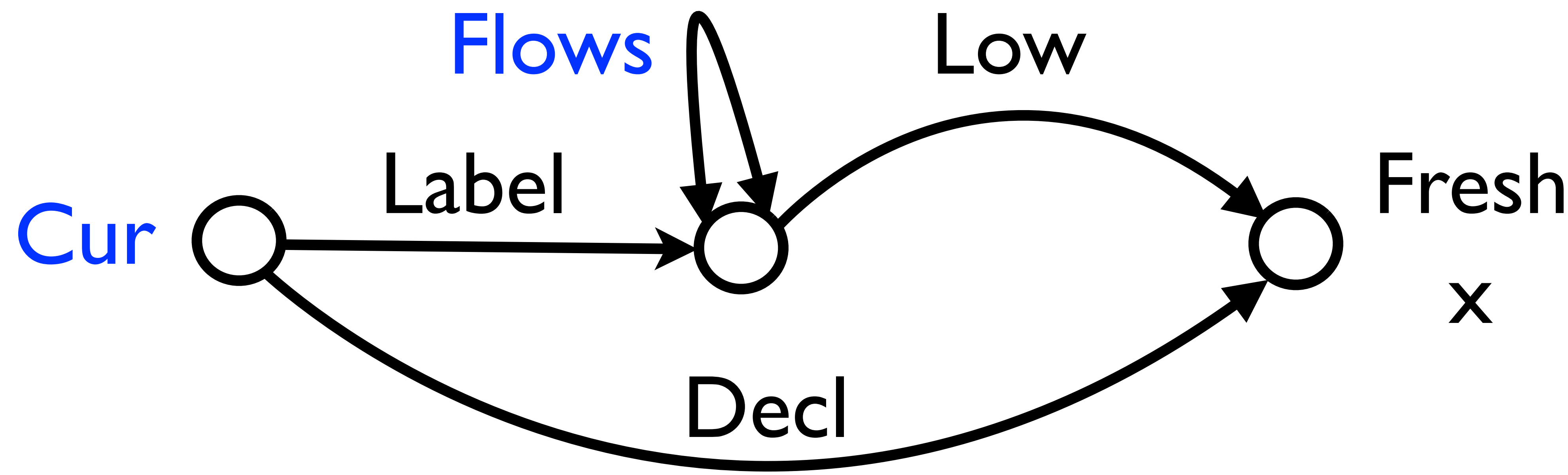
Action	
create_cat(&x)	

HiStar State Transformers



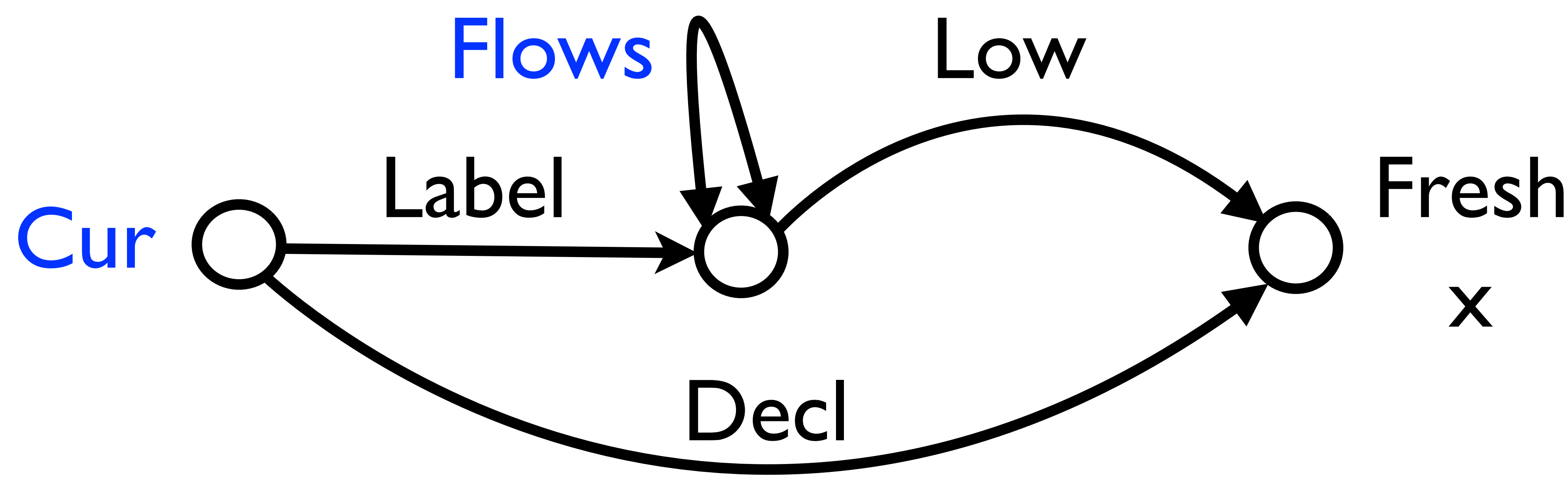
Action	
create_cat(&x)	

HiStar State Transformers



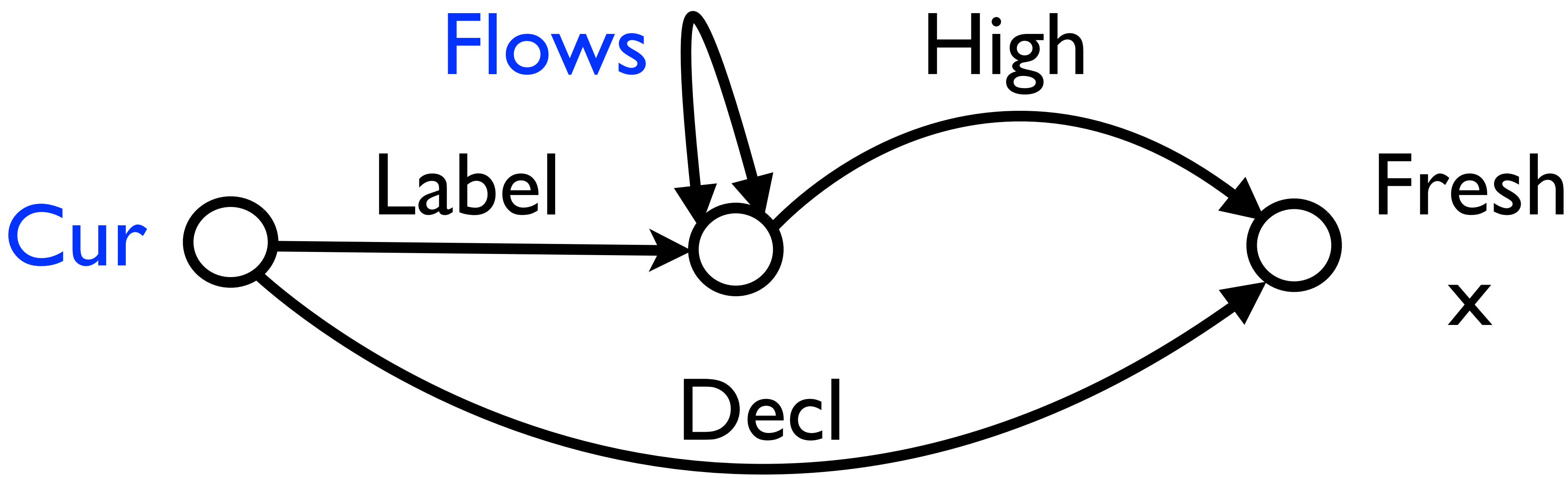
Action	Structure Transform
create_cat(&x)	Intro Fresh Decl'(p, c) := Decl(p, c) $\vee$ (Cur(p) $\wedge$ Fresh(c))

HiStar State Transformers



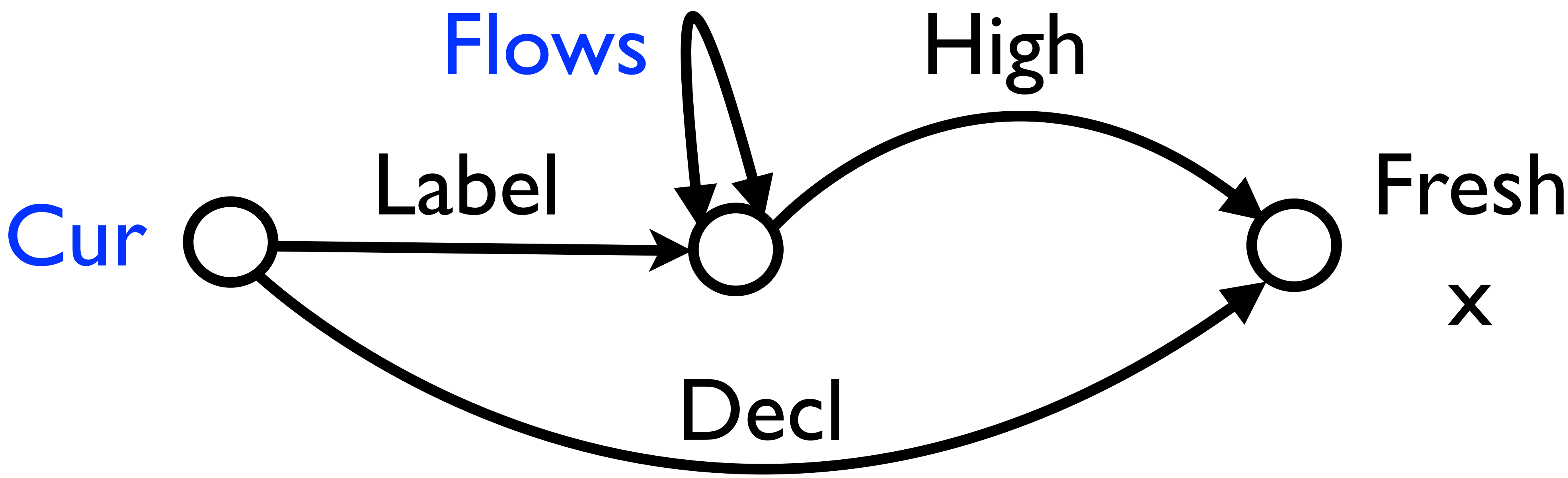
Action	
raise(&x)	

HiStar State Transformers



Action	
raise(&x)	

HiStar State Transformers

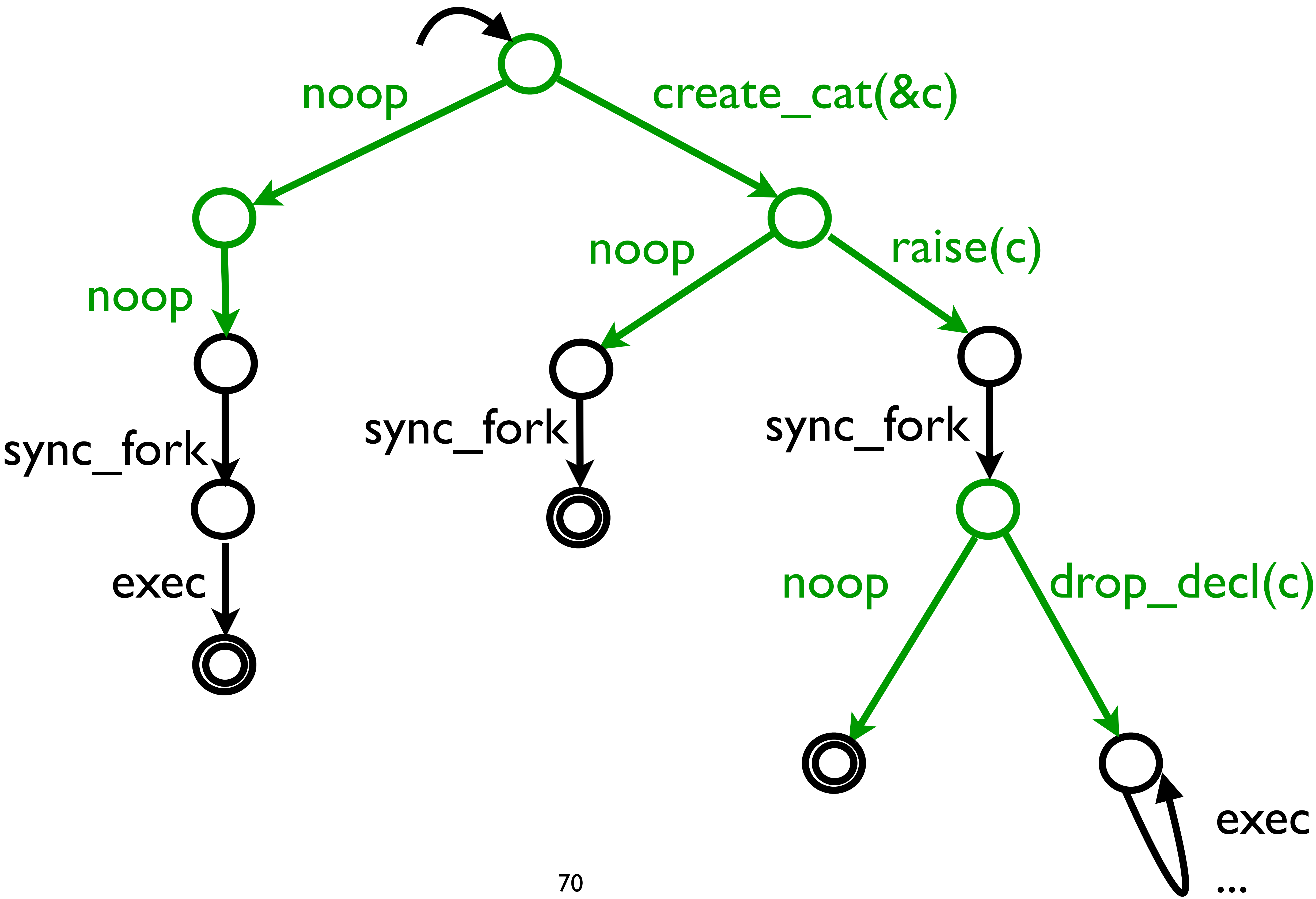


Action	Structure Transform
raise(&x)	Intro Fresh High'(l, c) := High(l, c) $\vee$ $\exists$ p. Cur(p) & Label(p, l) & x(c)

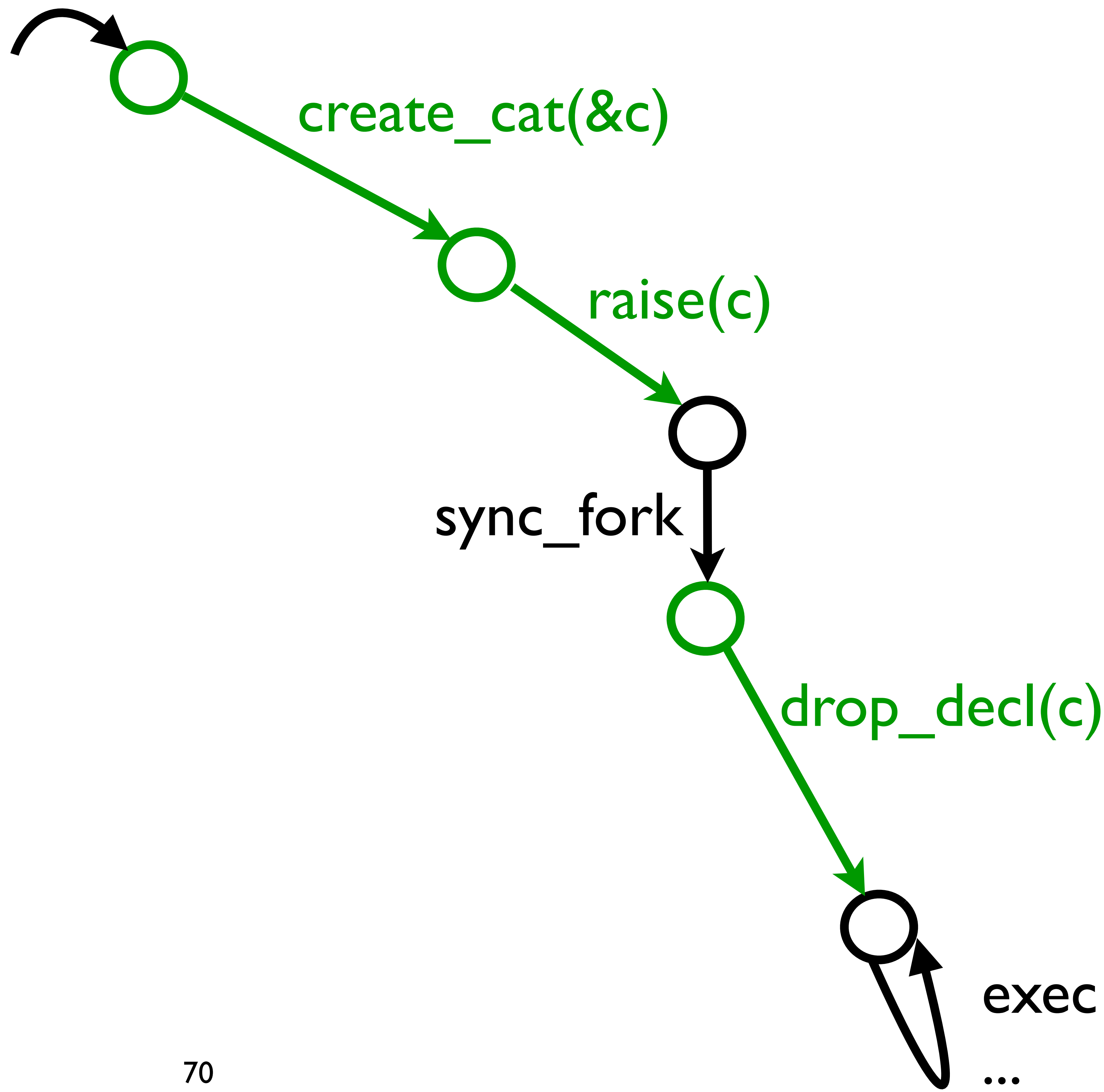
Summary: HiStar Semantics

- We can define the HiStar semantics as FOL predicate transforms and automatically generate a weaver for HiStar
- FOL predicate transforms can describe capability **and DIFC** semantics

Scanner Game

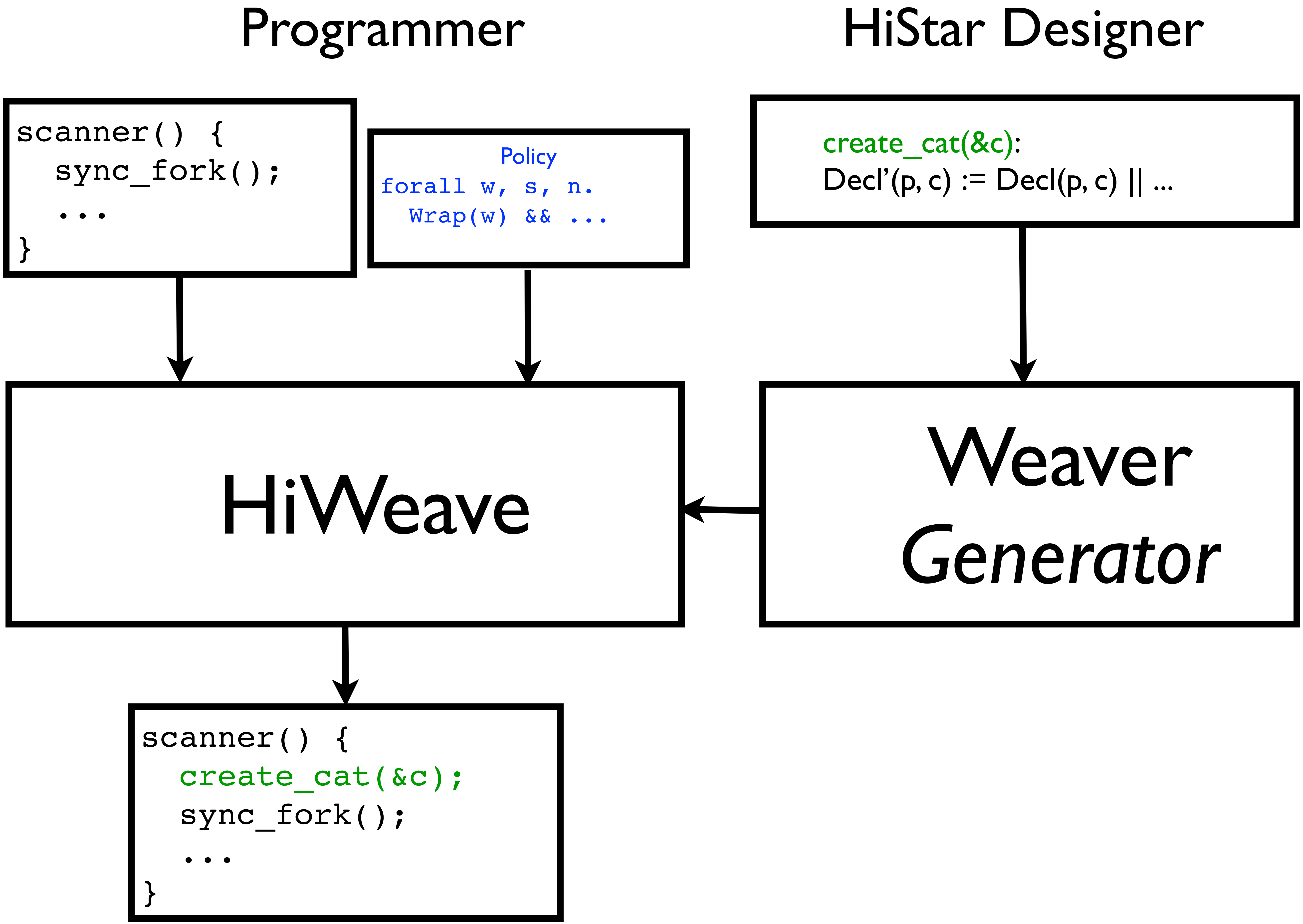


Scanner Game



HiWeave α Performance

Generates code for `clamwrap` in < 3 mins


Programmer
HiStar Designer
scanner() {
sync_fork();
...
}
Policy
forall w, s, n.
Wrap(w) && ...
create_cat(&c):
Decl'(p, c) := Decl(p, c) || ...
HiWeave
Weaver
Generator
scanner() {
create_cat(&c);
sync_fork();
...
}

Outline

1. Motivation, problem statement
2. Previous work: Capsicum
3. Ongoing work: HiStar
4. Open challenges

Open Challenges

- Automating abstraction refinement
- Automating error diagnosis
- Compositional synthesis
- Optimizing generated code
- Designing a policy logic

Automating Abstraction Refinement

- Picking the right abstraction predicates requires a lot of design effort
- Can we refine the abstraction predicates via counter-strategies?

Automating Error Diagnosis

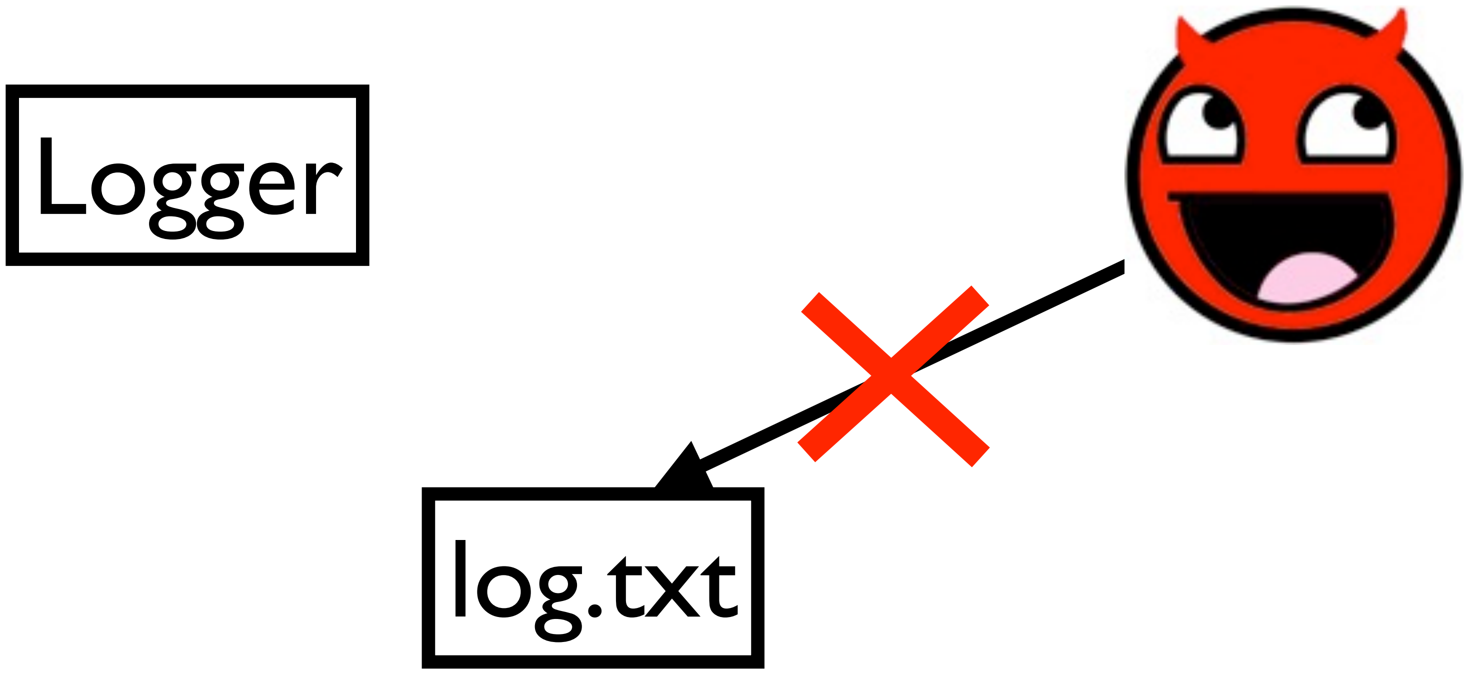
- When weaver fails, it has a counter-strategy
- How can we simplify these when presenting them to the user?

Compositional Synthesis

- Real programs are structured
  as a composition of processes
- Policies are expressed naturally as conjunction of local, global policies
- Can we adapt compositional verification?
  [Long, '89]

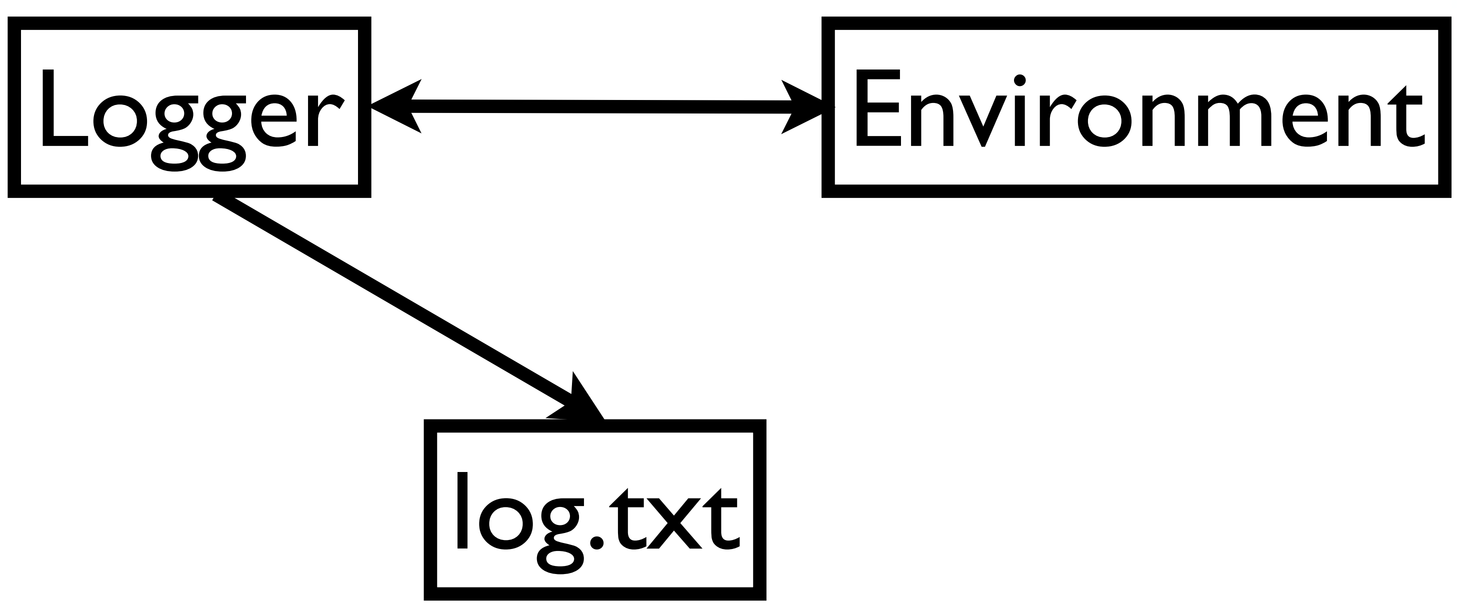
HiStar Logger

Local (security) policy: only Logger should be able to modify log



HiStar Logger

Global (functionality) policy: under certain conditions, Logger will append log on behalf of Environment



Optimizing Generated Code

- Mean-payoff games present an appealing cost model, but have high complexity in general
- Can we apply any domain specific optimizations?

Designing a Policy Logic

- The weaver generator allows a policy writer to declare policies purely over privileges
- What logic over privileges is easiest for a policy writer to understand?
- How do we evaluate value added?

Our Collaborators

Capsicum-dev

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Khilan Gudka

Ben Laurie

Peter Neumann

MIT-LL

Jeffrey Seibert

Michael Zhivich

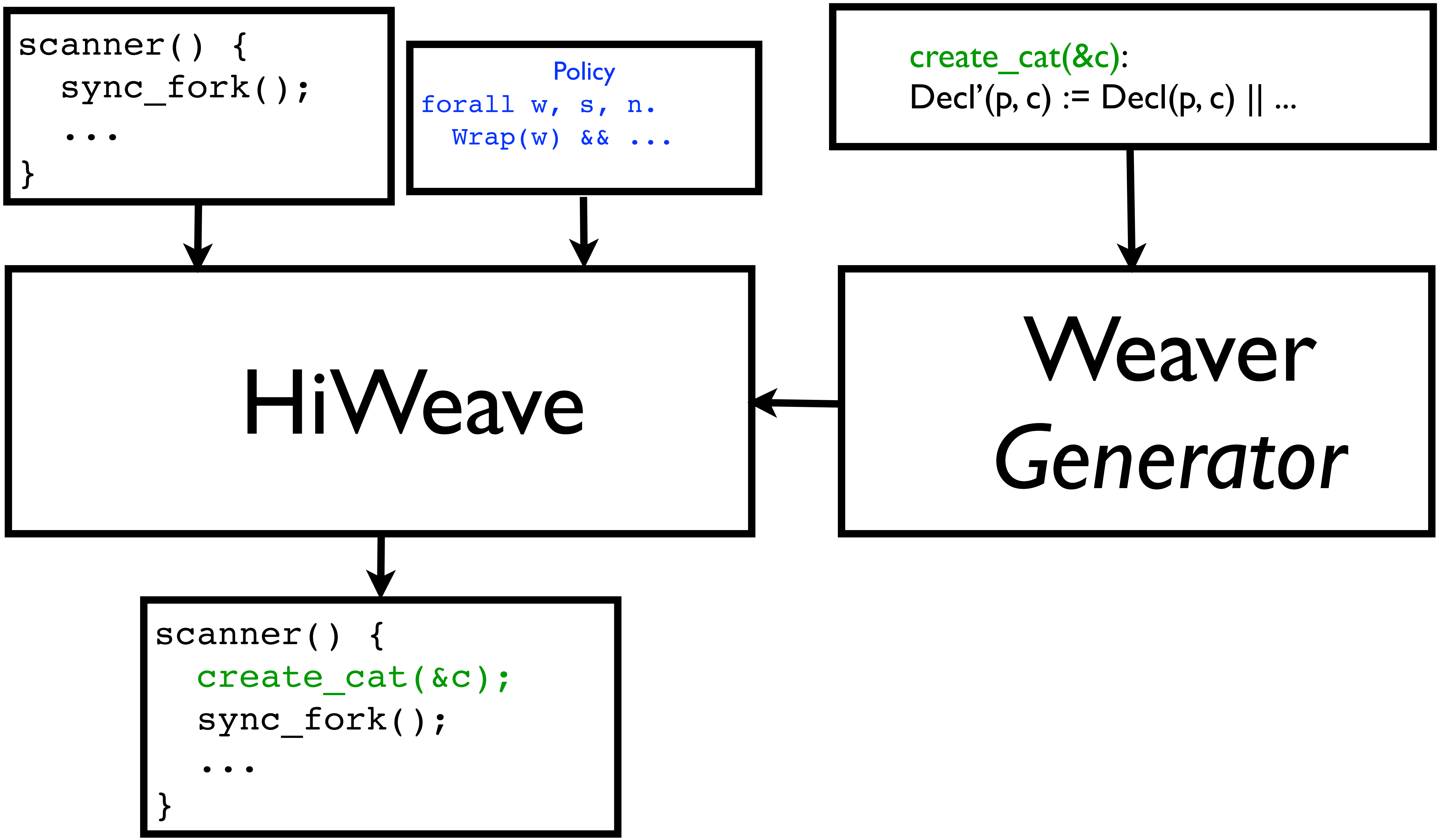
HiStar

Nickolai Zeldovich

TVLA

Mooly Sagiv

Questions?



scanner() {
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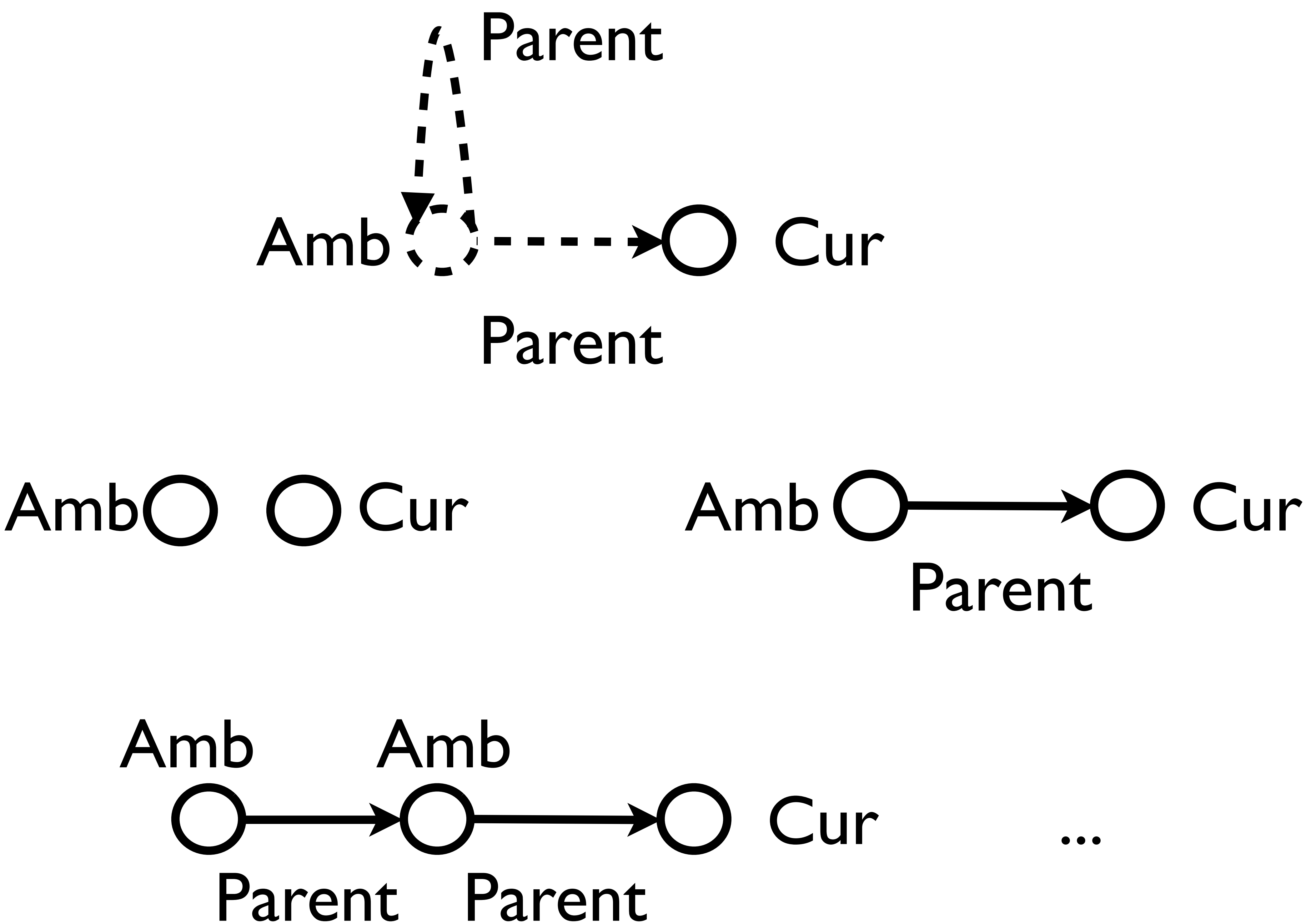
HiWeave
Weaver
Generator
scanner() {
create_cat(&c);
sync_fork();
...
}

Extra Slides

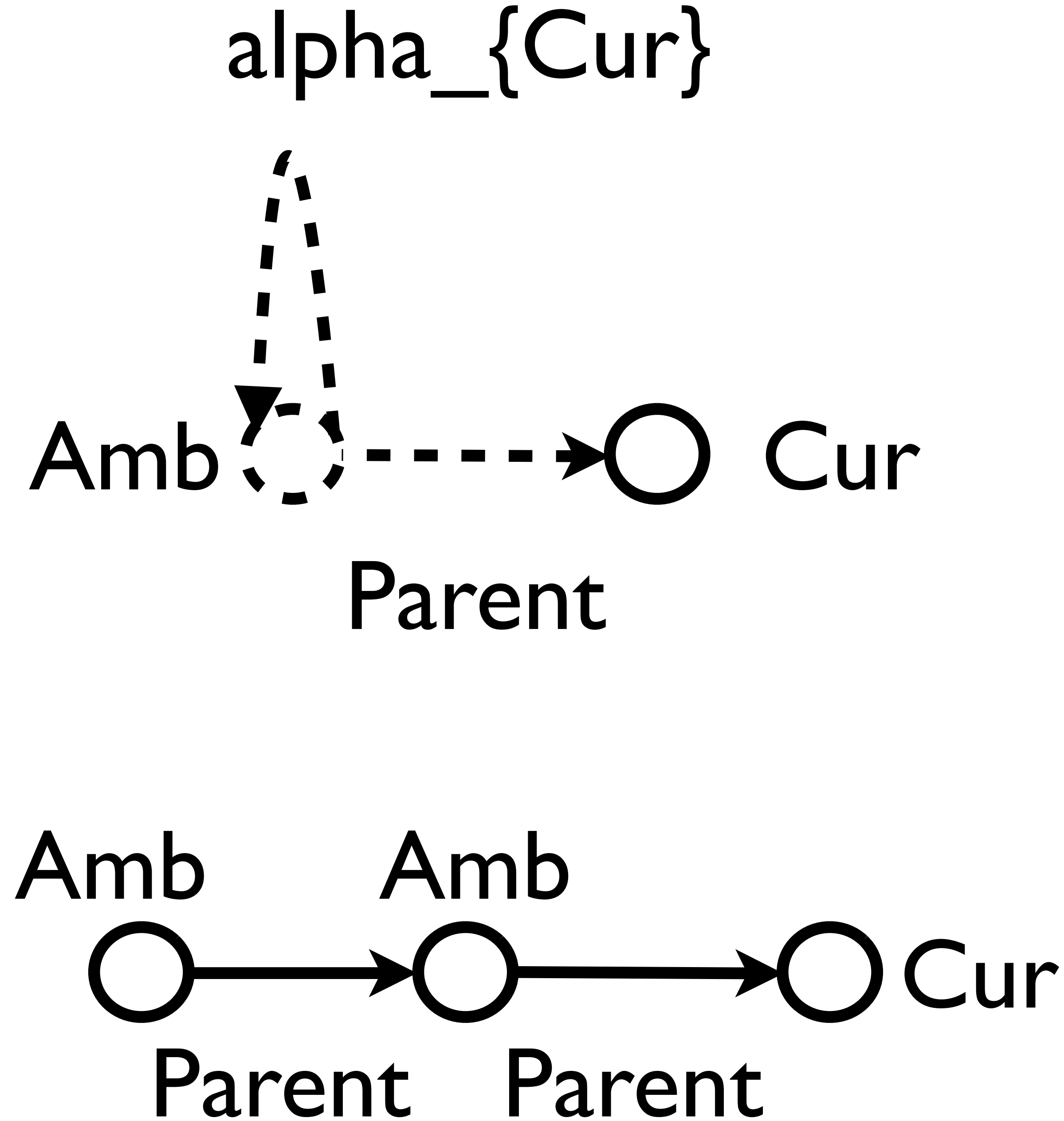
Three-valued logic

- Values: true, false, and *unknown*
- true & *unknown* = *unknown*
- false & *unknown* = false

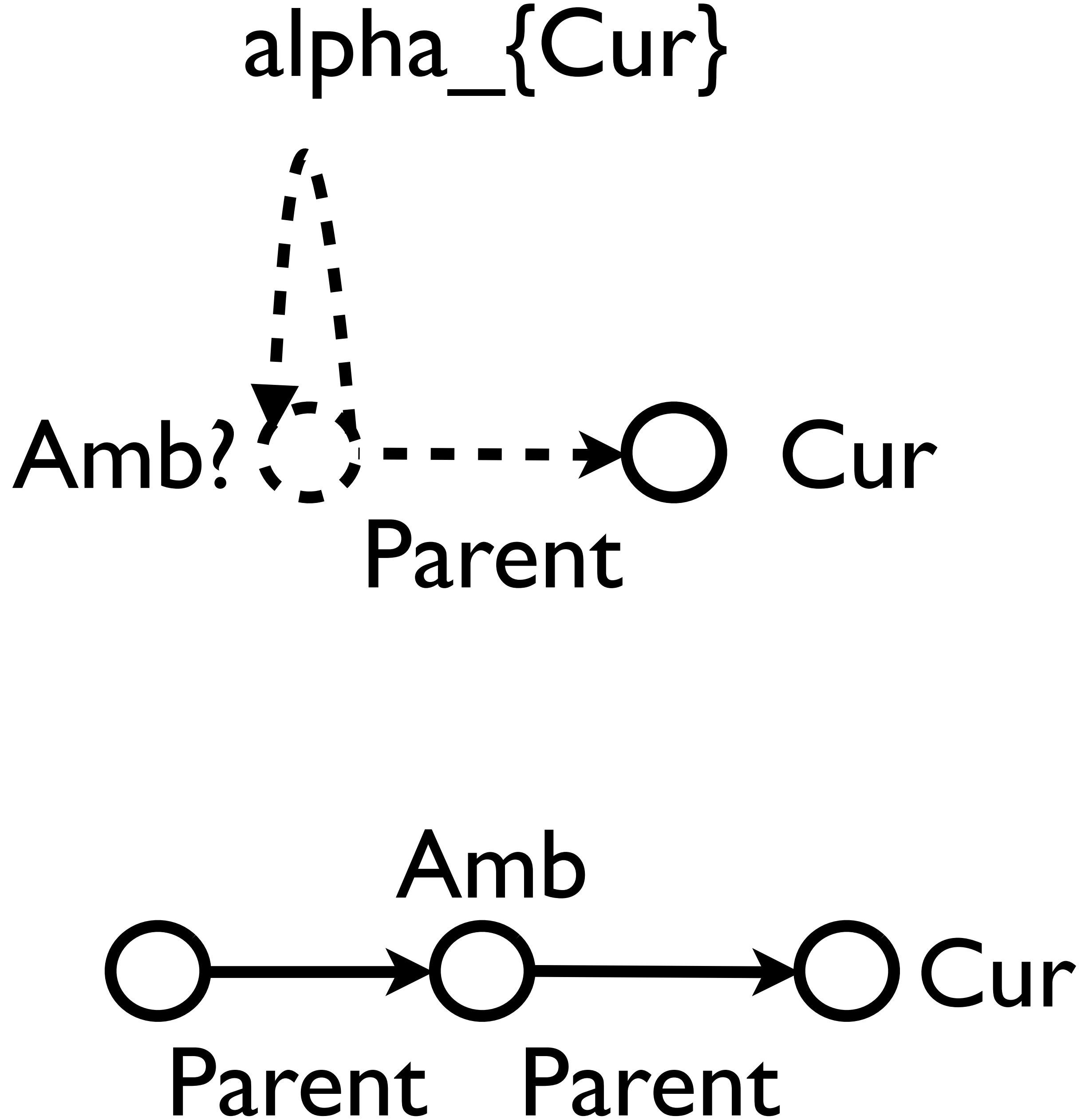
Three-valued Structures



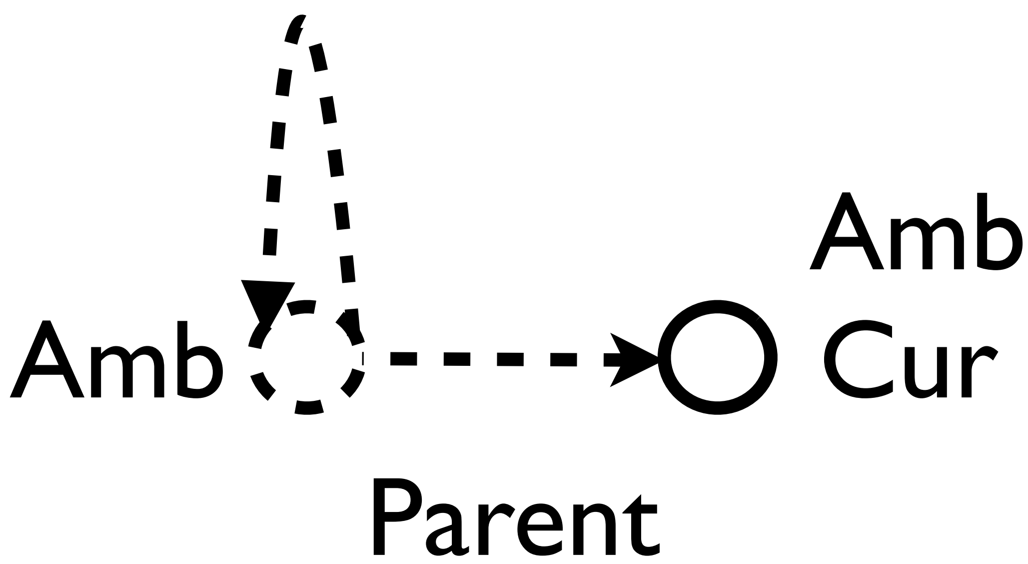
Abstraction Function

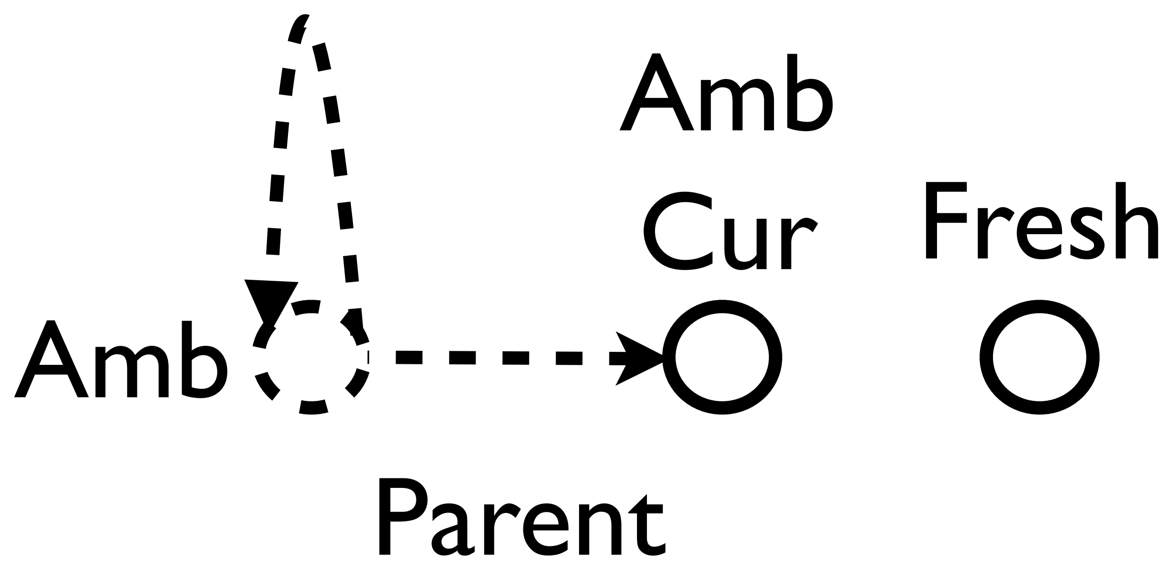


Abstraction Function



Abstract Fork (def)





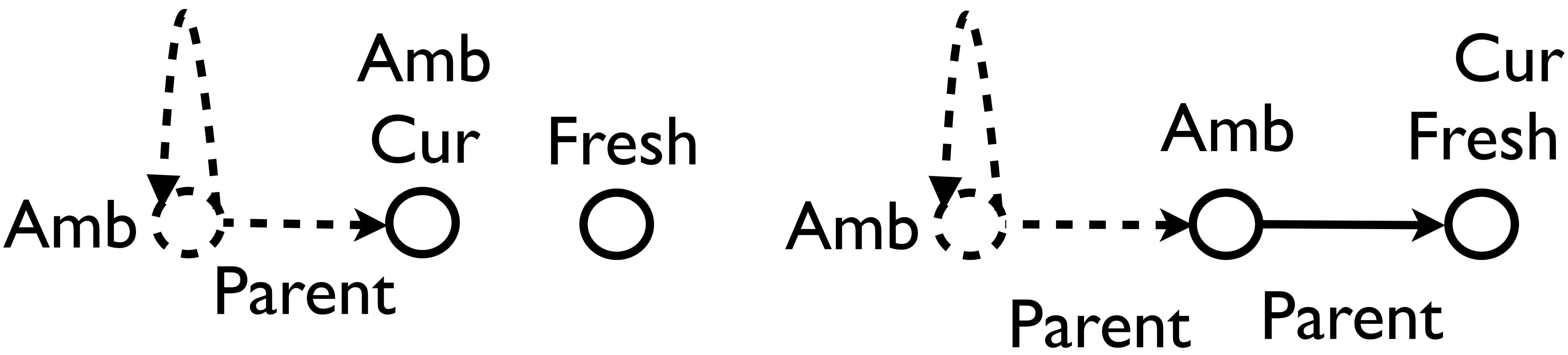
Action

Semantics

fork()

Intro Fresh
Amb(p) := Amb(p)
|| (Fresh(p) & E q. Cur(q) & Amb(q))

Abstract Fork (definite)



Action

Semantics

fork()

Intro Fresh
Amb(p) := Amb(p)
|| (Fresh(p) & E q. Cur(q) & Amb(q))