Scaling Abstraction Refinement via Pruning

PLDI - San Jose, CA June 8, 2011

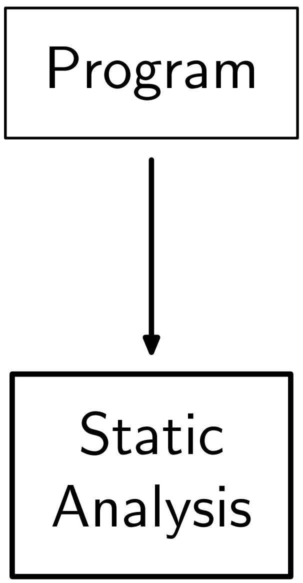
Percy Liang
UC Berkeley

Mayur Naik
Intel Labs Berkeley

The Big Picture

Program

The Big Picture



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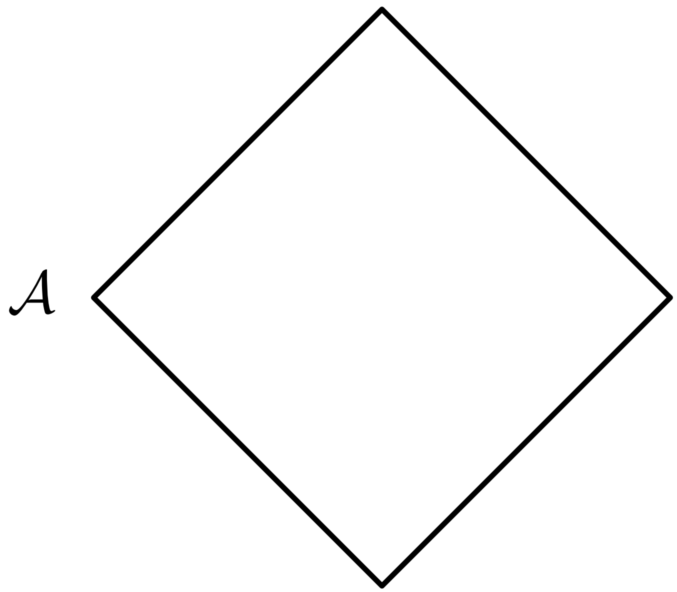

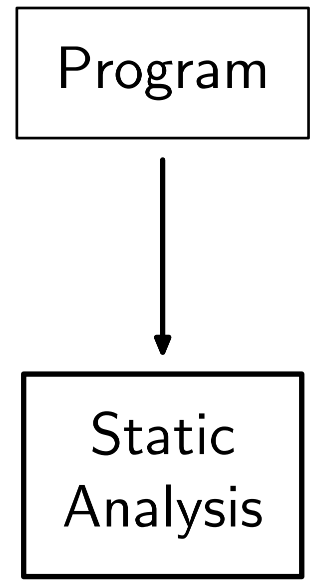

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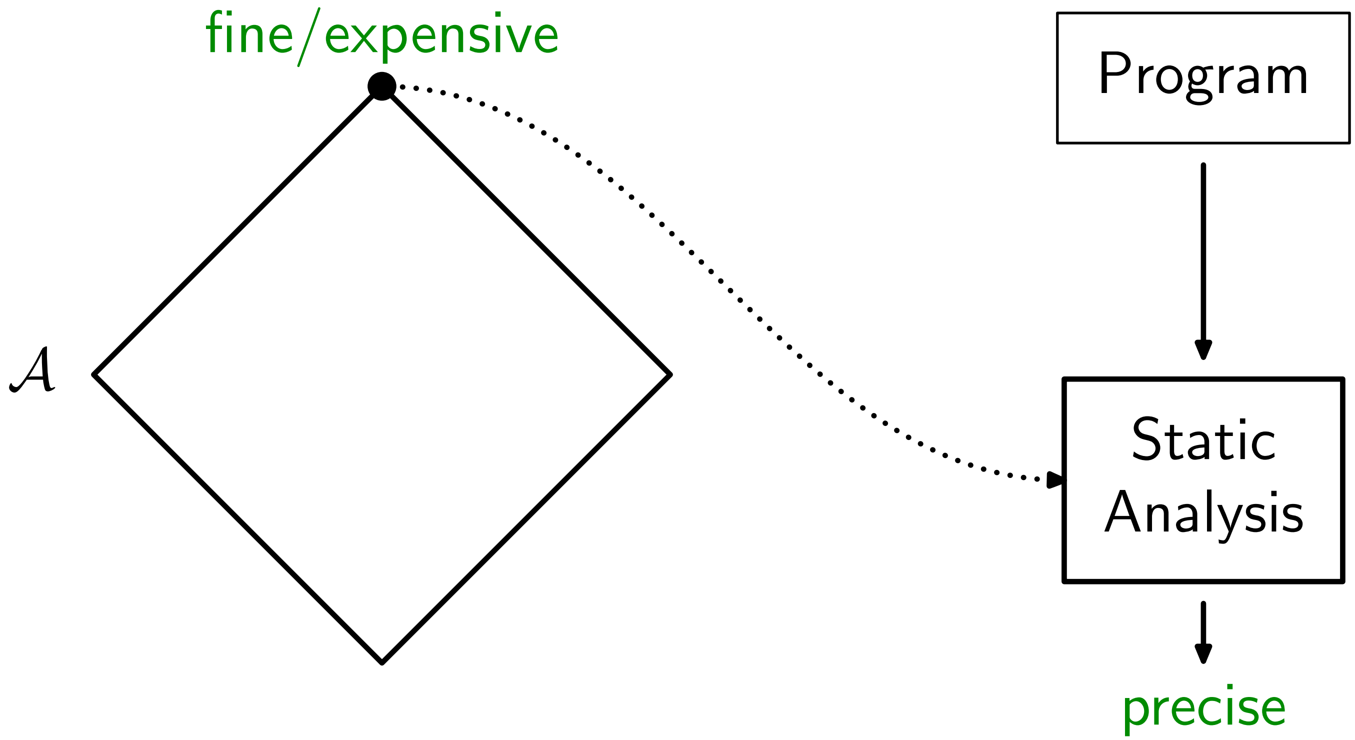

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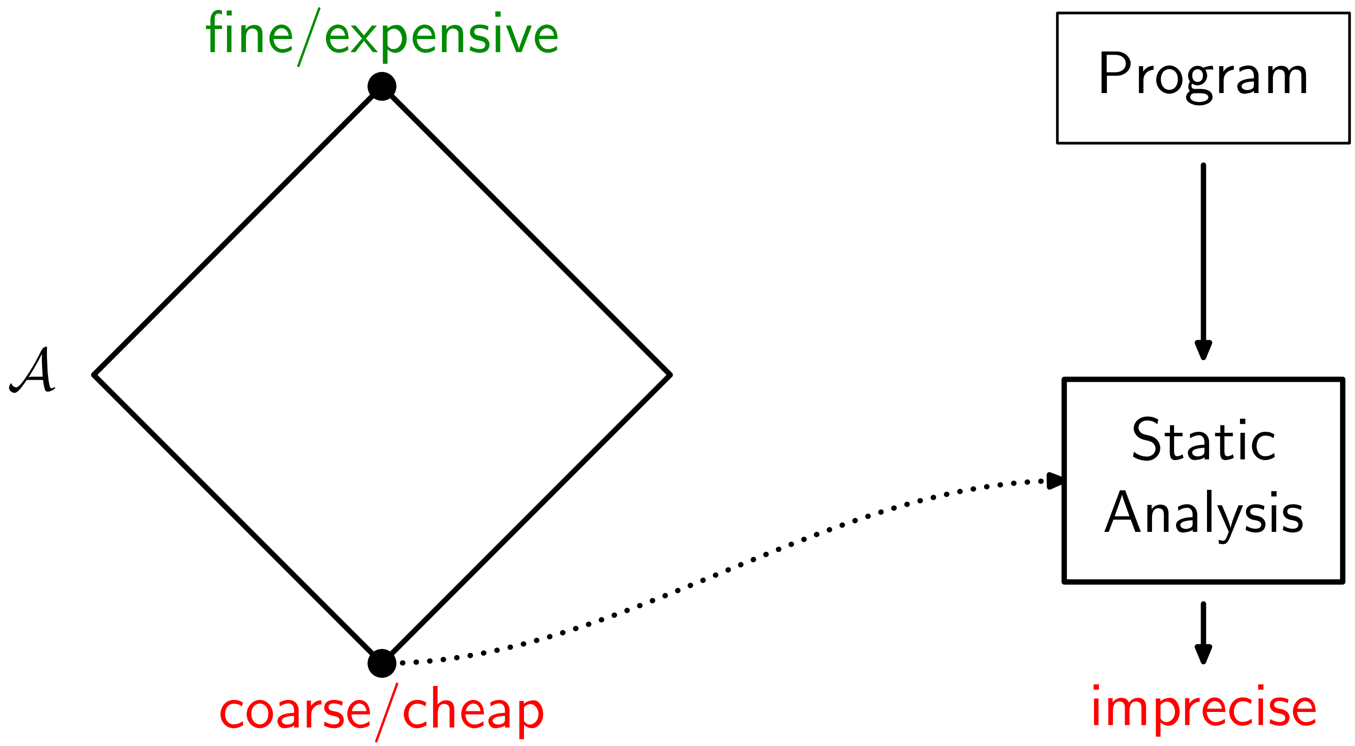

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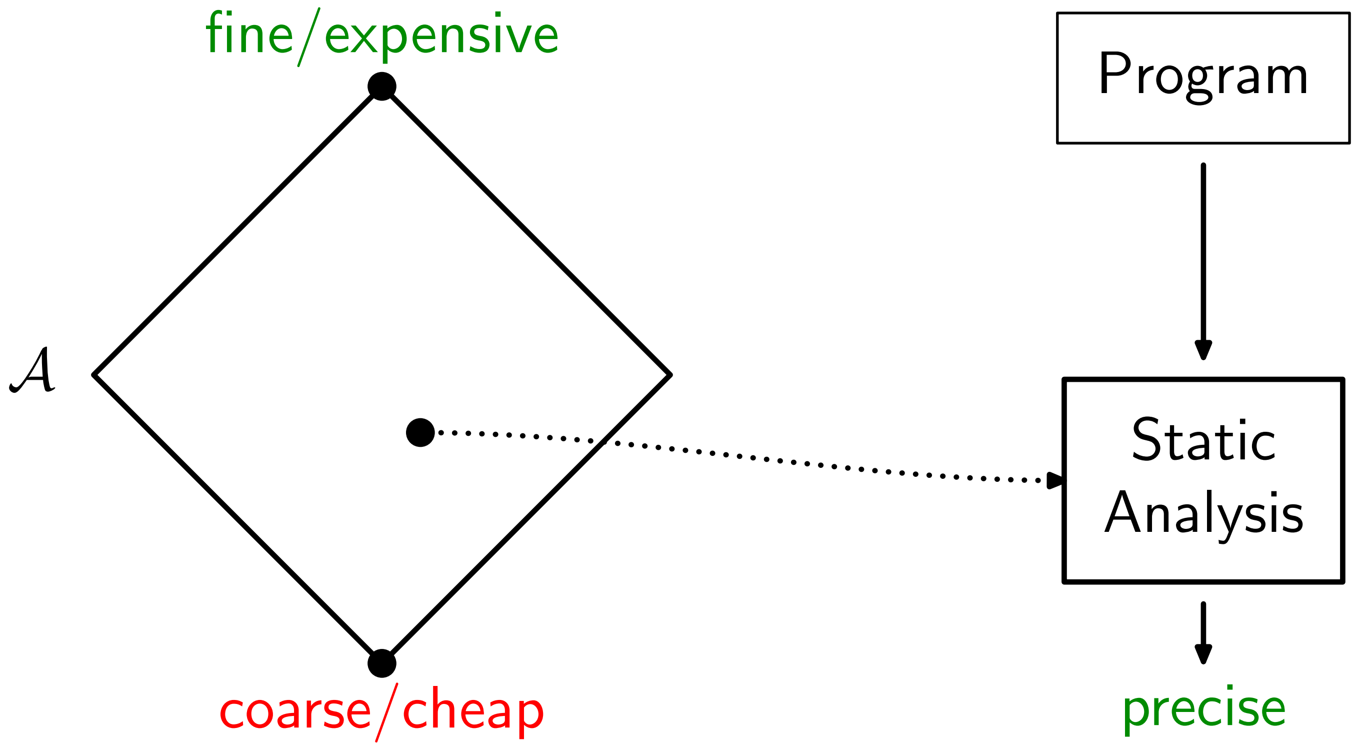

selected refinement

[Heintze & Tardieu 2001]
[Guyer & Lin 2003]
[Sridharan et al. 2005]
[Zheng & Rugina 2008]
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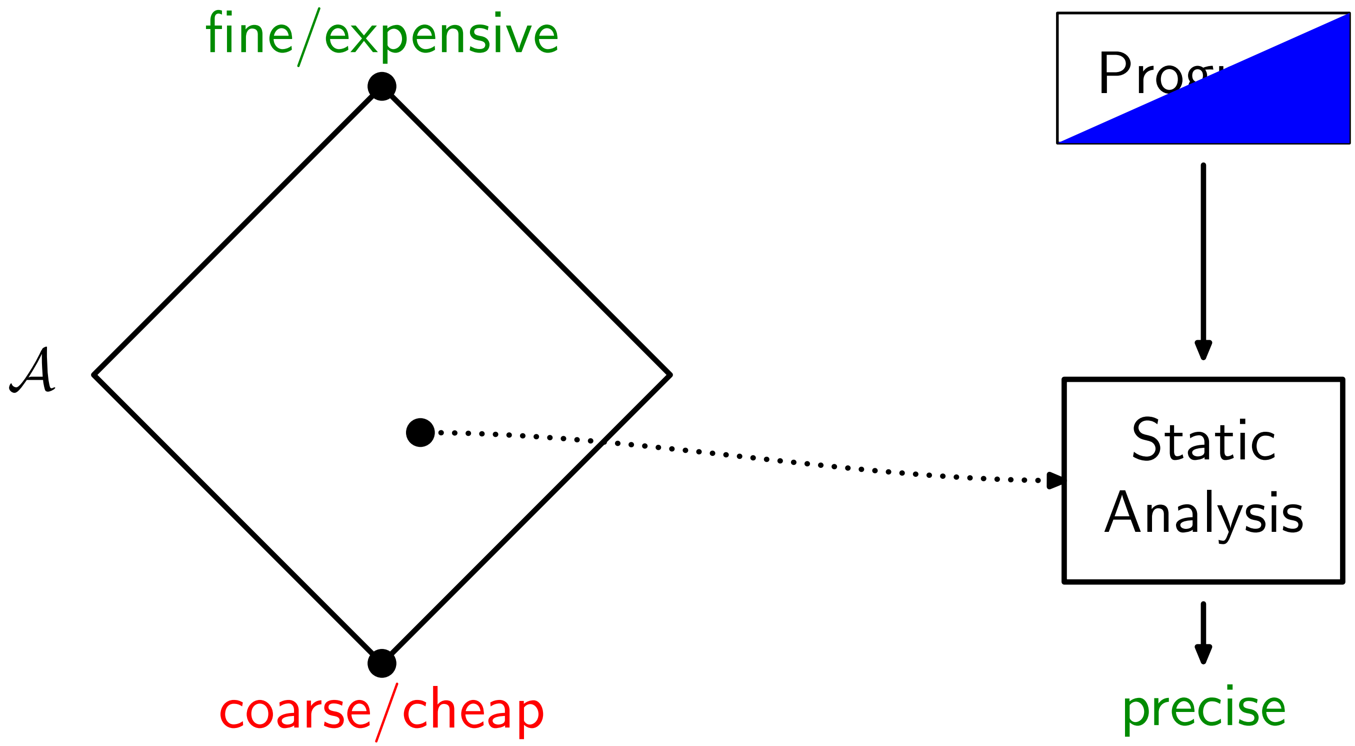

selected refinement

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pruning

NEW!

An Example of Pruning

```
    getnew() {
h1:   u = new C
h2:   v = new C
      return v
    }
i1: x = getnew()
i2: y = getnew()
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0-CFA:

$\boxed{\texttt{u = new C}}$ $\boxed{\texttt{v = new C}}$

$\boxed{\texttt{x = getnew()}}$ $\boxed{\texttt{y = getnew()}}$

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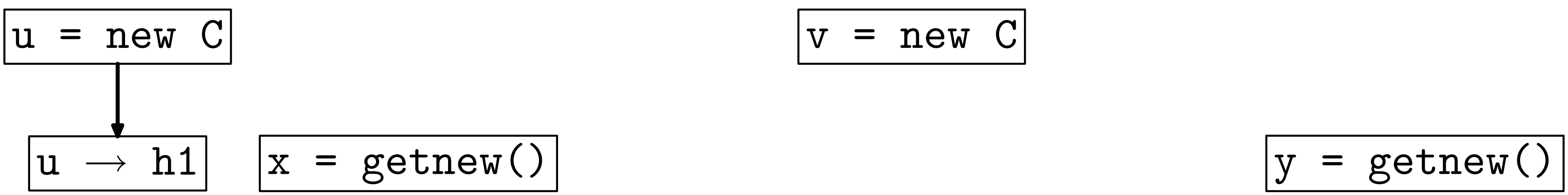

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u = new C

u → h1

x = getnew()

v = new C

v → h2

y = getnew()

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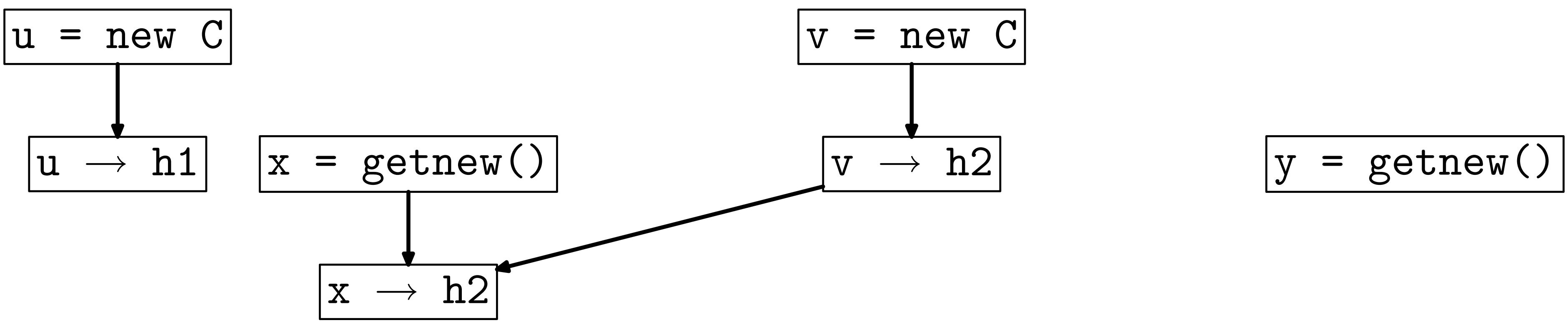

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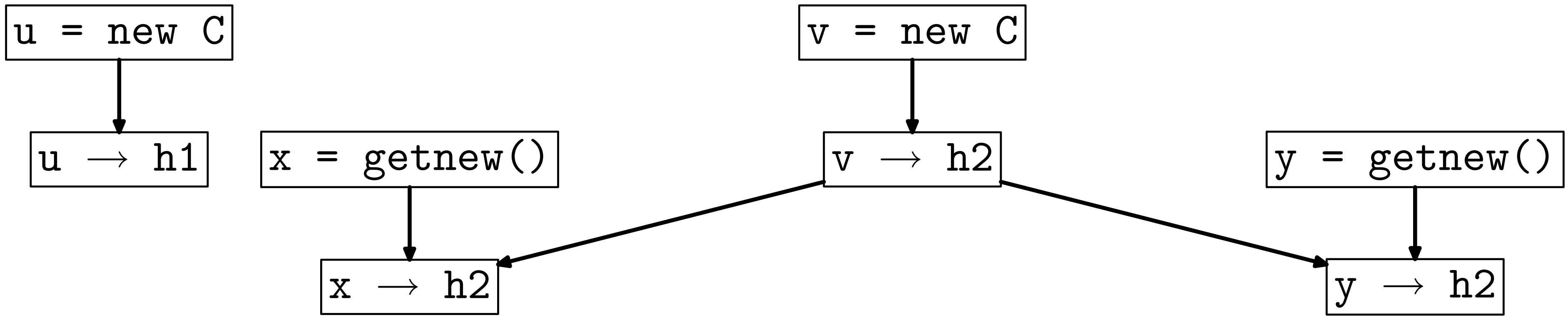

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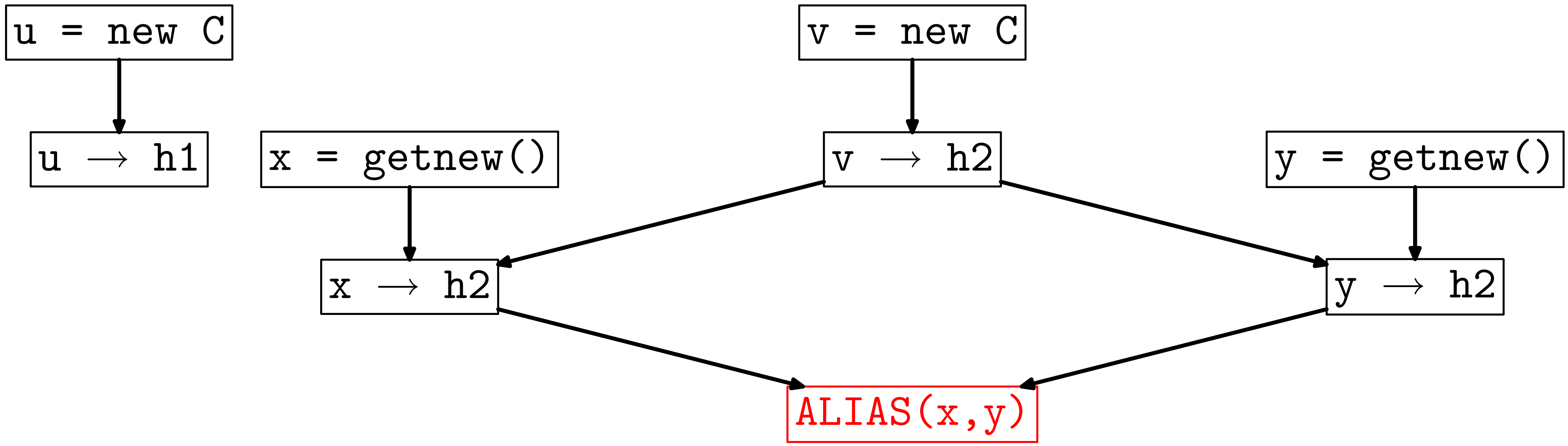

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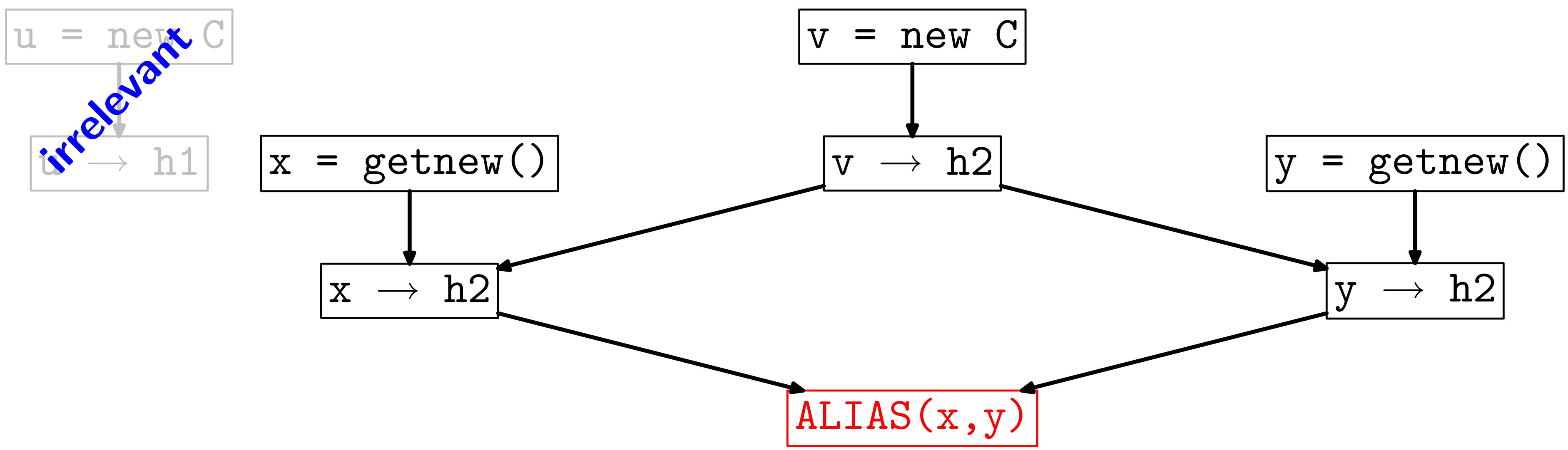

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1-CFA on pruned:

`u = new C`

irrelevant

`u` $\longrightarrow$ `h1`

`x = getnew()`

`v:i1 = new C` `v:i2 = new C`

`y = getnew()`

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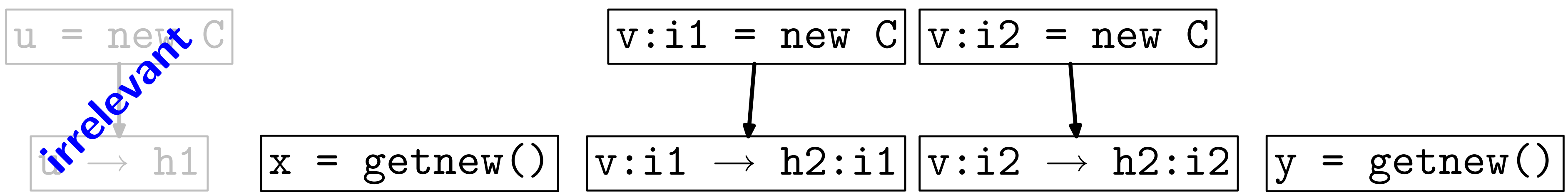

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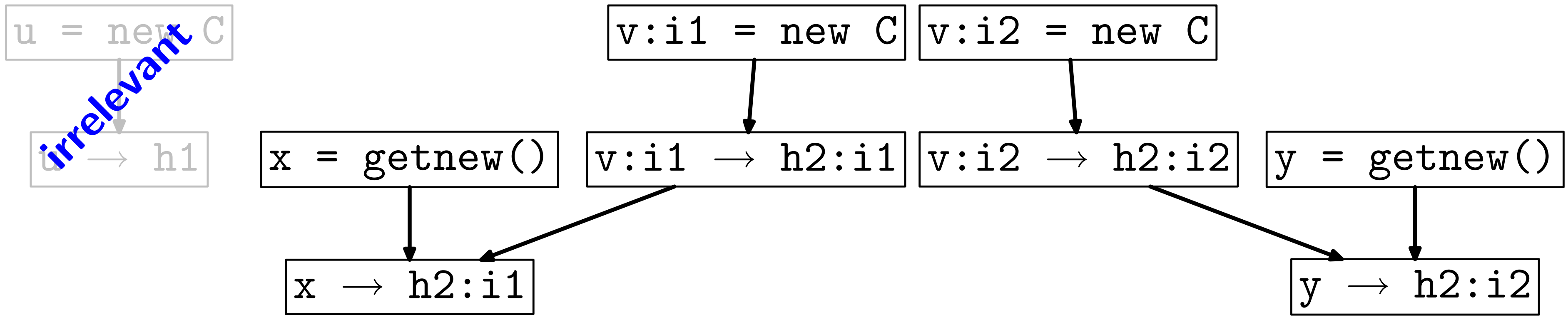

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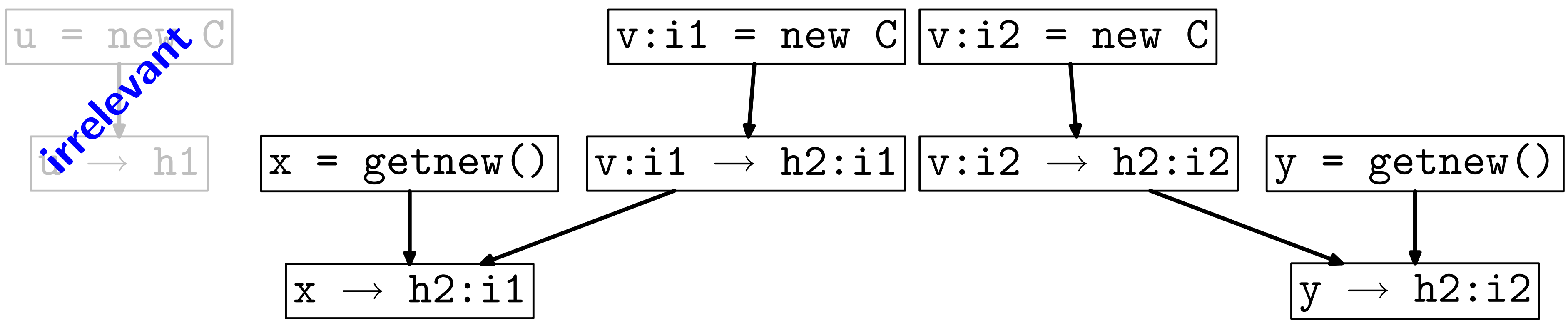

(not aliasing - query proven)

General Pruning Framework

Input tuples A_0 $\boxed{\texttt{v = new C}} \cdots$

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Datalog rules $\boxed{v_2 \ \longrightarrow \ h} \Leftarrow \boxed{v_2 \ \texttt{=} \ v_1} \texttt{,} \boxed{v_1 \ \longrightarrow \ h}$

$\cdots$

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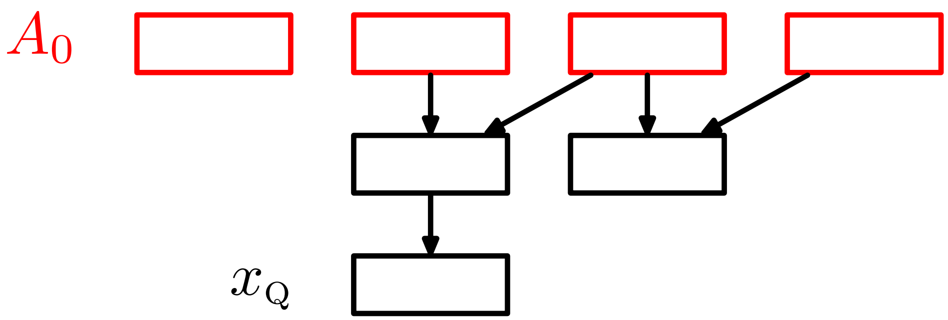
Prune/prove operator $\mathbf{P}$ $A_0 \xrightarrow{\mathbf{P}}$ subset of A_0 used to derive x_Q



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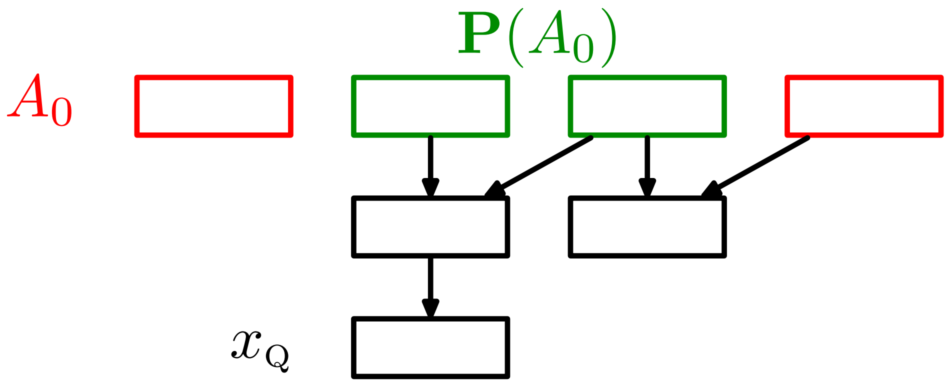

General Pruning Framework

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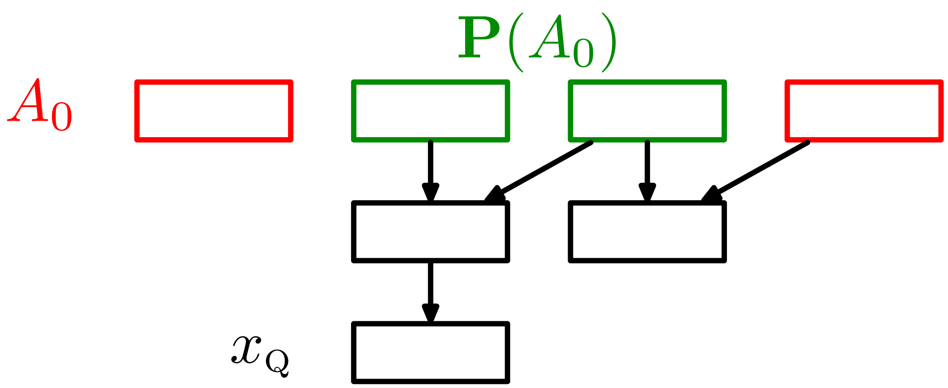

Query proven $\Leftrightarrow$ $\mathbf{P}(A_0) = \emptyset$

Prune and Refine

(abstract tuples) A_0 $\boxed{\texttt{u = new C}}\ \boxed{\texttt{v = new C}}\ \cdots$

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Prune	$\Big\downarrow \mathbf{P}$	run 0-CFA
(relevant tuples)	$\tilde{A}_0$	$\boxed{\cancel{\texttt{u = new C}}}$ $\boxed{\texttt{v = new C}}$

Prune and Refine

(abstract tuples) A_0 `u = new C` `v = new C` $\cdots$

Prune $\big\downarrow \mathbf{P}$ run 0-CFA

(relevant tuples) $\tilde{A}_0$ ~~`u = new C`~~ `v = new C`

Refine $\big\downarrow \alpha_1$

Prune and Refine

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(refined tuples)	A_1	$\boxed{\texttt{v:i1 = new C}}$ $\boxed{\texttt{v:i2 = new C}}$

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Prune and Refine

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(refined tuples) A_1 `v:i1 = new C` `v:i2 = new C`

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$\emptyset$ $\Rightarrow$ query is proven

Prune-Refine Algorithm

Input:

Sequence of abstractions: $\alpha_0 \preceq \alpha_1 \preceq \alpha_2 \preceq \cdots$

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A_0, initial set of tuples

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Sequence of abstractions: $\alpha_0 \preceq \alpha_1 \preceq \alpha_2 \preceq \cdots$
A_0, initial set of tuples

For $t = 0, 1, 2, \ldots:$

Prune: $\tilde{A}_t = \mathbf{P}(A_t)$. If $\tilde{A}_t = \emptyset$: return proven.

Refine: $A_{t+1} = \alpha_{t+1}(\tilde{A}_t)$.

Prune-Refine Algorithm

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Main Result:

Prune-Refine after t iterations

Prune-Refine Algorithm

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fast slow

Rest of Talk

Pre-Pruning Extension

Experiments

Pre-Pruning

$\tilde{A}_{t-1}$

```
v = new C
```

Pre-Pruning

$\tilde{A}_{t-1}$

```
v = new C
```

$\xrightarrow{\text{Refine } \alpha_t}$

A_t

```
v:h0 = new C
v:h1 = new C
v:h2 = new C
v:h3 = new C
v:h4 = new C
v:h5 = new C
```

Pre-Pruning

$\tilde{A}_{t-1}$

```
v = new C
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$\xrightarrow{\text{Refine } \alpha_t}$

A_t

```
v:h0 = new C
v:h1 = new C
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```

$\xrightarrow{\text{Prune } \mathbf{P}}$

expensive!

Pre-Pruning

$\tilde{A}_{t-1}$

```
v = new C
```

Refine α_t $\longrightarrow$

A_t

```
v:h0 = new C
v:h1 = new C
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```

Prune $\mathbf{P}$ $\longrightarrow$

$\downarrow \beta_t \preceq \alpha_t$

B_t

```
v:t0 = new C
v:t1 = new C
```

Pre-Pruning

$\tilde{A}_{t-1}$

```
v = new C
```

$\xrightarrow{\text{Refine } \alpha_t}$

A_t

```
v:h0 = new C
v:h1 = new C
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v:h3 = new C
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```

$\xrightarrow{\text{Prune } \mathbf{P}}$

$\Big\downarrow \; \beta_t \preceq \alpha_t$

B_t

```
v:t0 = new C
v:t1 = new C
```

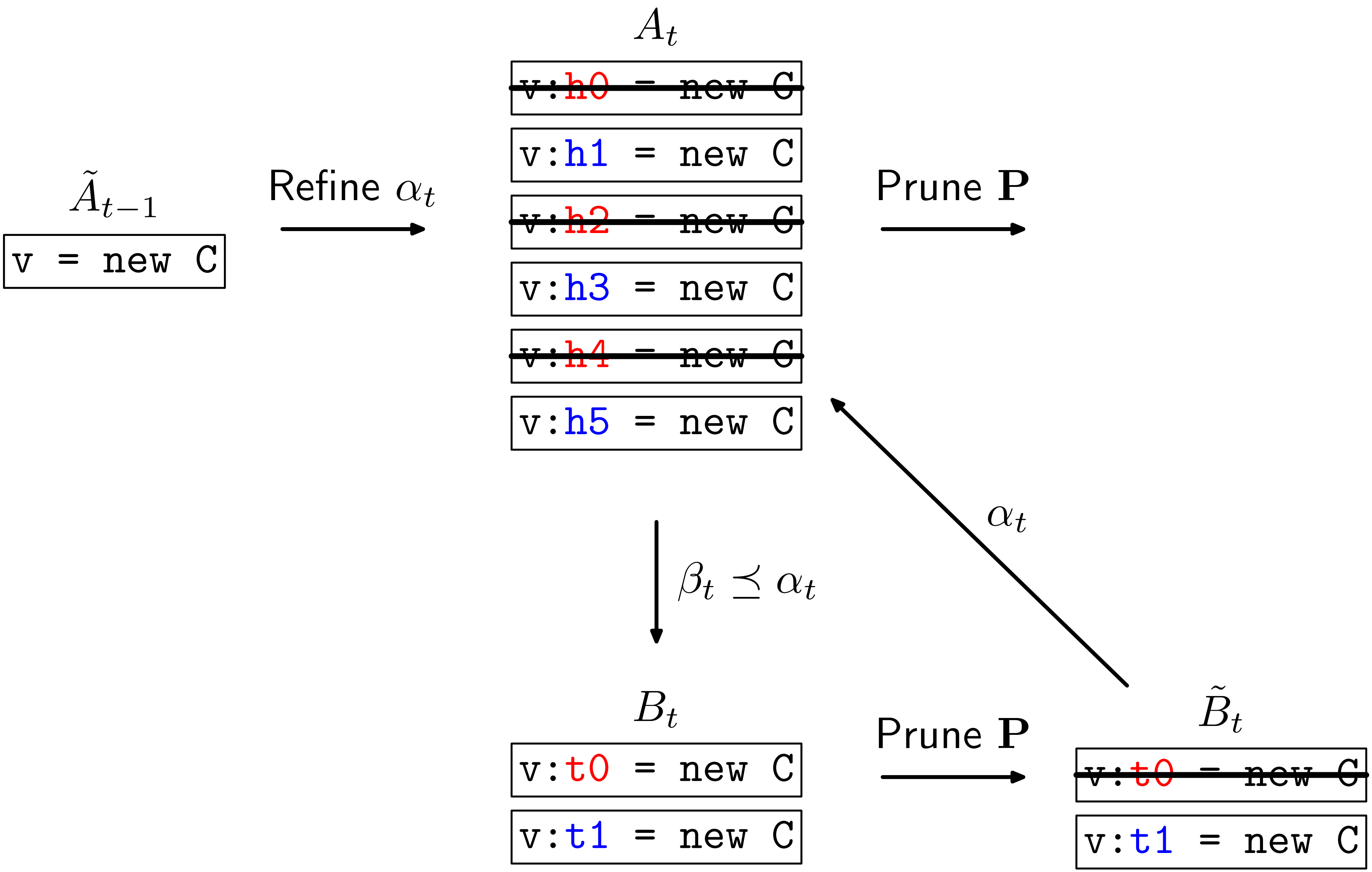
$\xrightarrow{\text{Prune } \mathbf{P}}$

$\tilde{B}_t$

~~`v:t0 = new C`~~

```
v:t1 = new C
```

Pre-Pruning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α_t
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v:t0 = new C
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Prune $\mathbf{P}$
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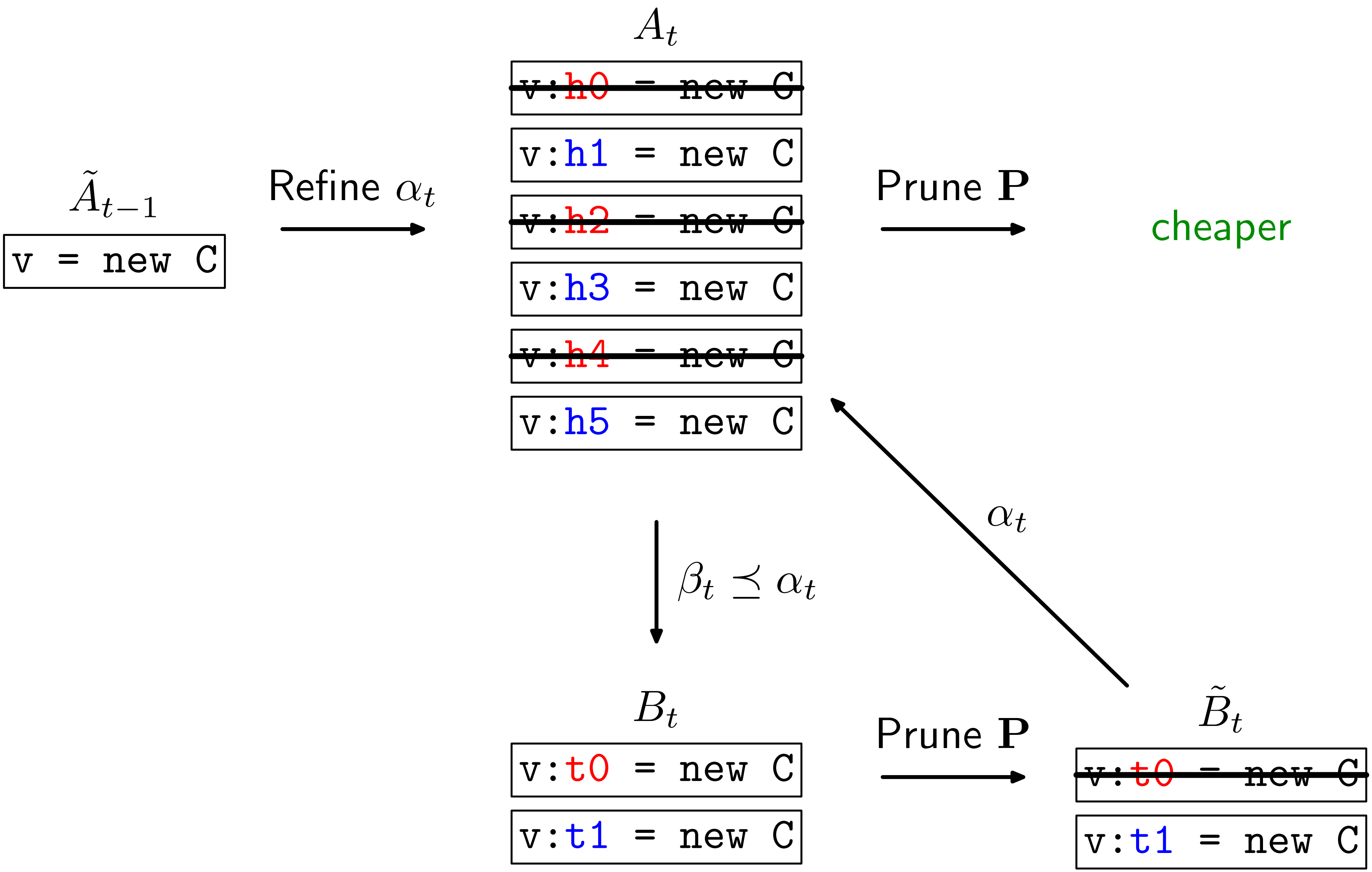
Pre-Pruning



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Prune $\mathbf{P}$
cheaper
α_t
$\beta_t \preceq \alpha_t$
B_t
v:t0 = new C
v:t1 = new C
Prune $\mathbf{P}$
$\tilde{B}_t$
~~v:t0 = new C~~
v:t1 = new C

Which Abstractions for Pre-Pruning?

$$
\begin{array}{lccccccc}
\text{(main)} & \alpha_0 & \preceq & \alpha_1 & \preceq & \alpha_2 & \preceq & \cdots \\
 & \rotatebox{90}{$\preceq$} & & \rotatebox{90}{$\preceq$} & & \rotatebox{90}{$\preceq$} & & \\
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Which Abstractions for Pre-Pruning?

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Choose abstraction τ; set $\beta_t = \alpha_t \circ \tau$

Which Abstractions for Pre-Pruning?

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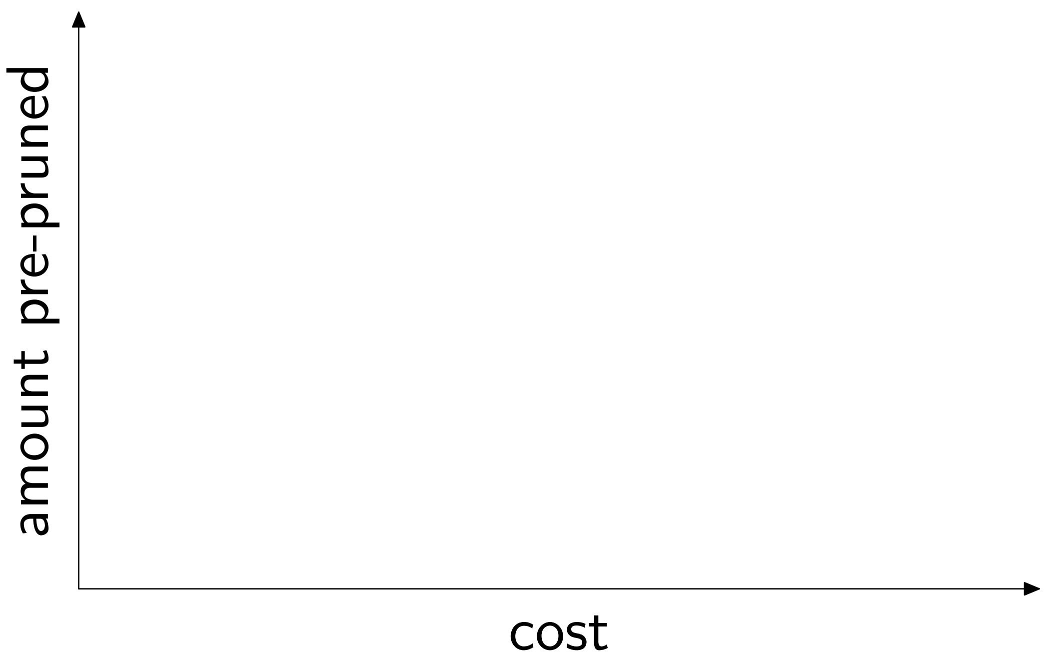

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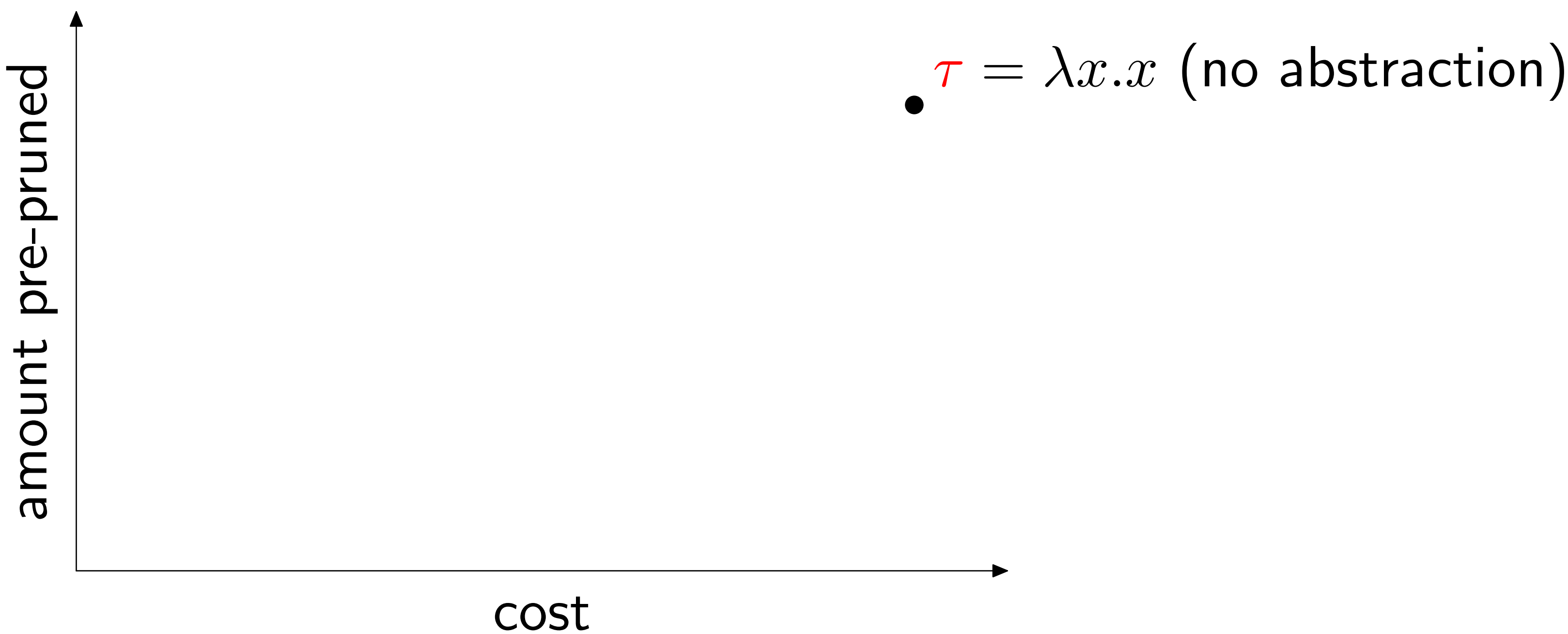

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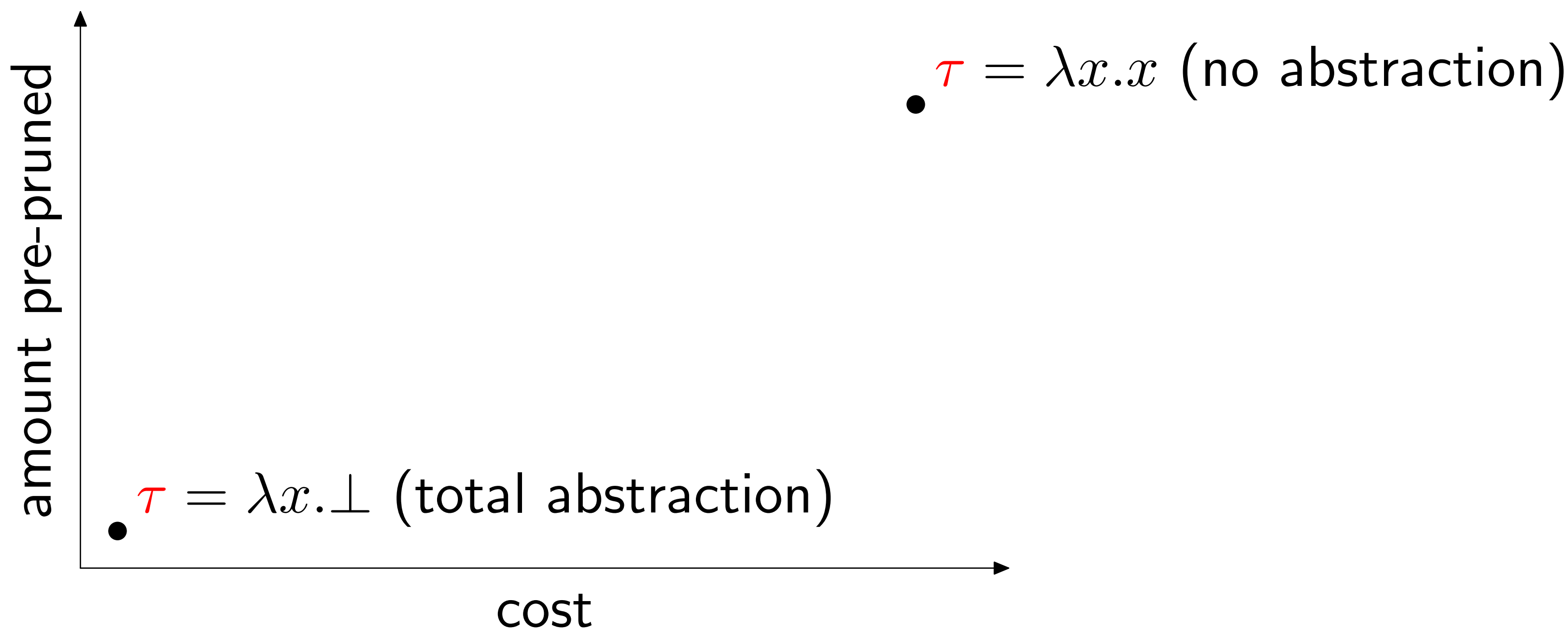

Which Abstractions for Pre-Pruning?

$$
\begin{array}{lccccccc}
\text{(main)} & \alpha_0 & \preceq & \alpha_1 & \preceq & \alpha_2 & \preceq & \cdots \\
 & \rotatebox{90}{$\preceq$} & & \rotatebox{90}{$\preceq$} & & \rotatebox{90}{$\preceq$} & & \\
\text{(auxiliary)} & \beta_0 & \preceq & \beta_1 & \preceq & \beta_2 & \preceq & \cdots
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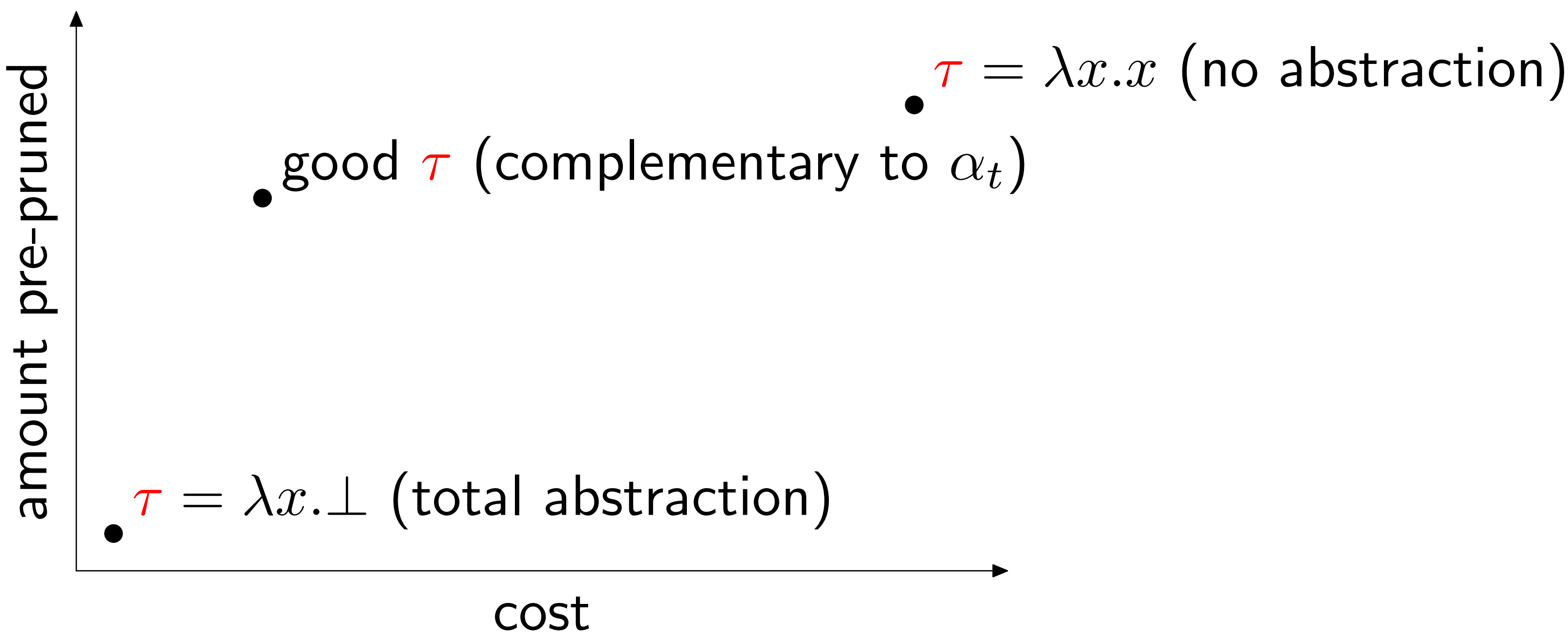

Type-Based Abstractions for Pre-Pruning

k-limited: $\alpha_k =$ take length k prefix

$$\boxed{\texttt{v:h5:h8 = new C}} \xrightarrow{\alpha_1} \boxed{\texttt{v:h5 = new C}}$$

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Composed: $\beta_1 = \alpha_1 \circ \tau$

$$\boxed{\texttt{v:h5:h8 = new C}} \xrightarrow{\beta_1} \boxed{\texttt{v:t1 = new C}}$$

Rest of Talk

Pre-Pruning Extension

Experiments

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Benchmarks:

	description	# bytecodes	# alloc. sites
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Details:

- 64-bit IBM J9VM 1.6, Chord with `bddbddb` Datalog solver
- Terminate a process if it exceeds 8GB of memory

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Methods:

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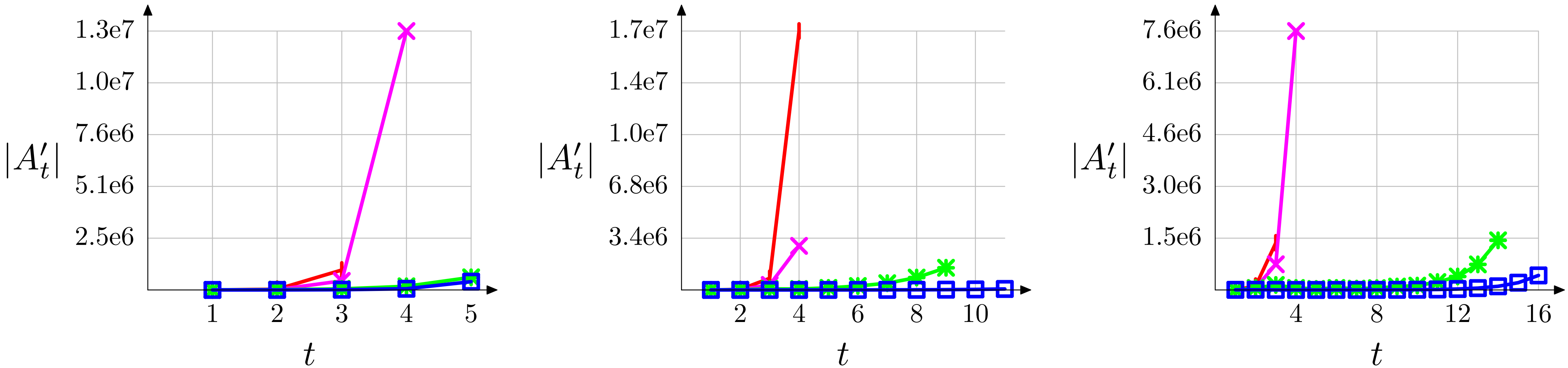

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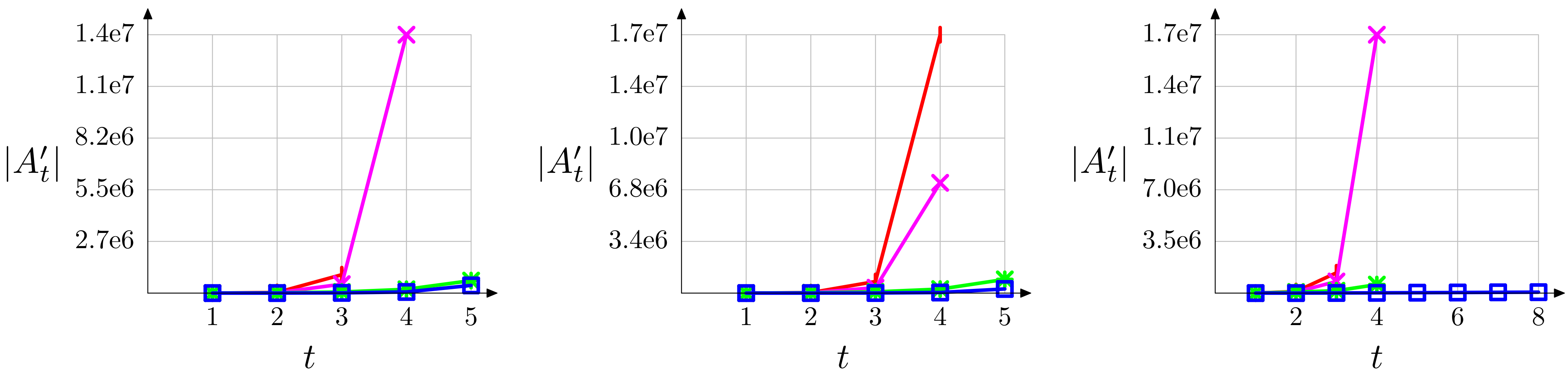

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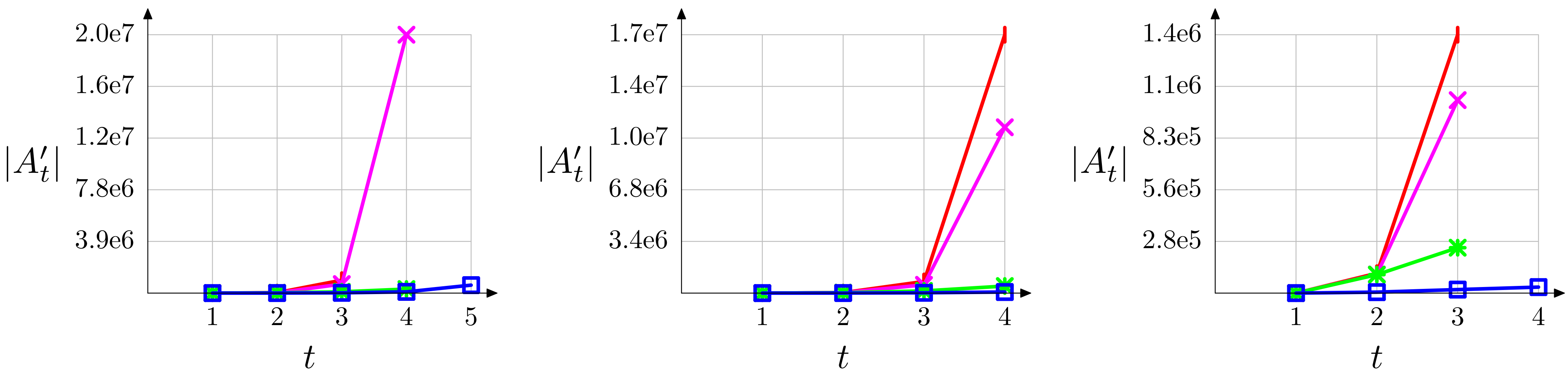

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A_t

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Take Away: Pruning (especially pre-pruning) helps a lot to maintain tractability

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DOWNCAST/`avrora`	12	10	6	**6**	**6**
MONOSITE/`elevator`	1	1	1	1	1
MONOSITE/`hedc`	164	149	149	**149**	-
MONOSITE/`weblech`	273	258	252	**252**	-
MONOSITE/`lusearch`	593	454	447	**447**	-
MONOSITE/`avrora`	288	278	272	-	-
RACE/`elevator`	475	440	437	437	437
RACE/`hedc`	23,033	22,043	21,966	-	-
RACE/`weblech`	7,286	4,742	4,669	-	-
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Take Away: By using Prune-Refine, able to prove two additional queries

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http://code.google.com/p/jchord

Thank you!