Design and Implementation of Sparse Global Analyses for C-like Languages

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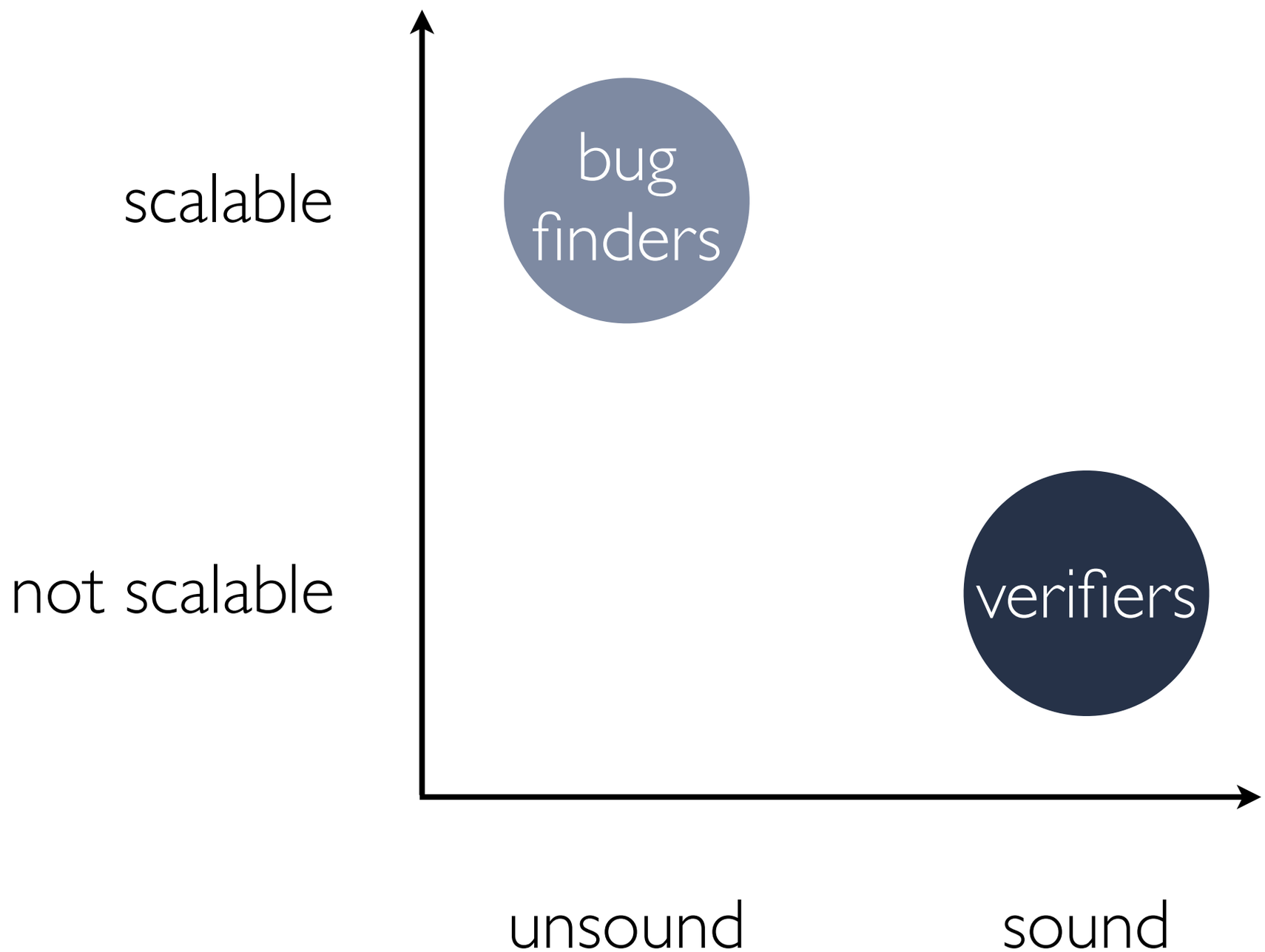
(with Hakjoo Oh, Kihong Heo, Woosuk Lee, and Kwangkeun Yi)

April 3rd, 2012
@Sunblaze group meeting

Dichotomy: “Bug-finders” vs. “Verifiers”



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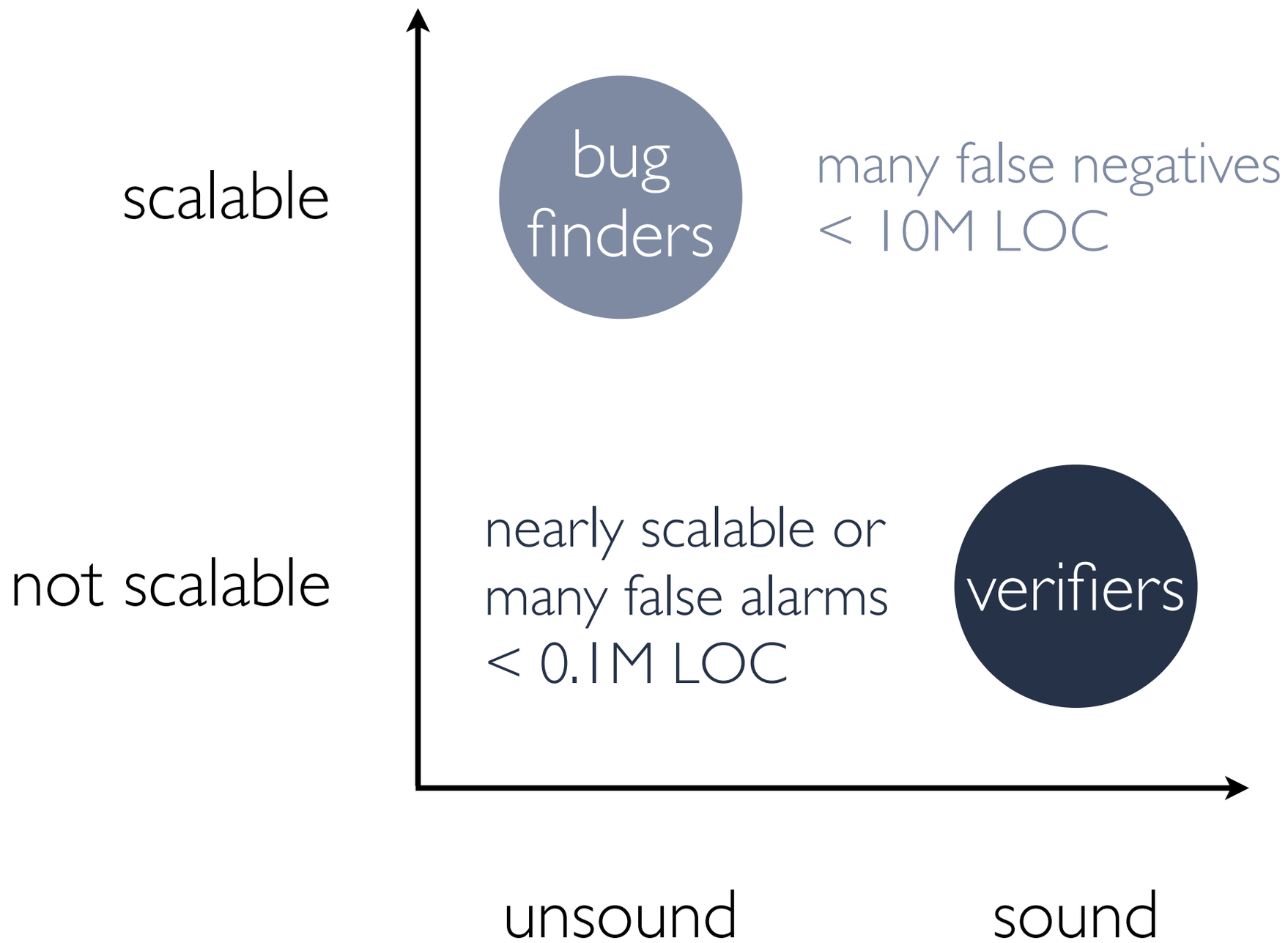
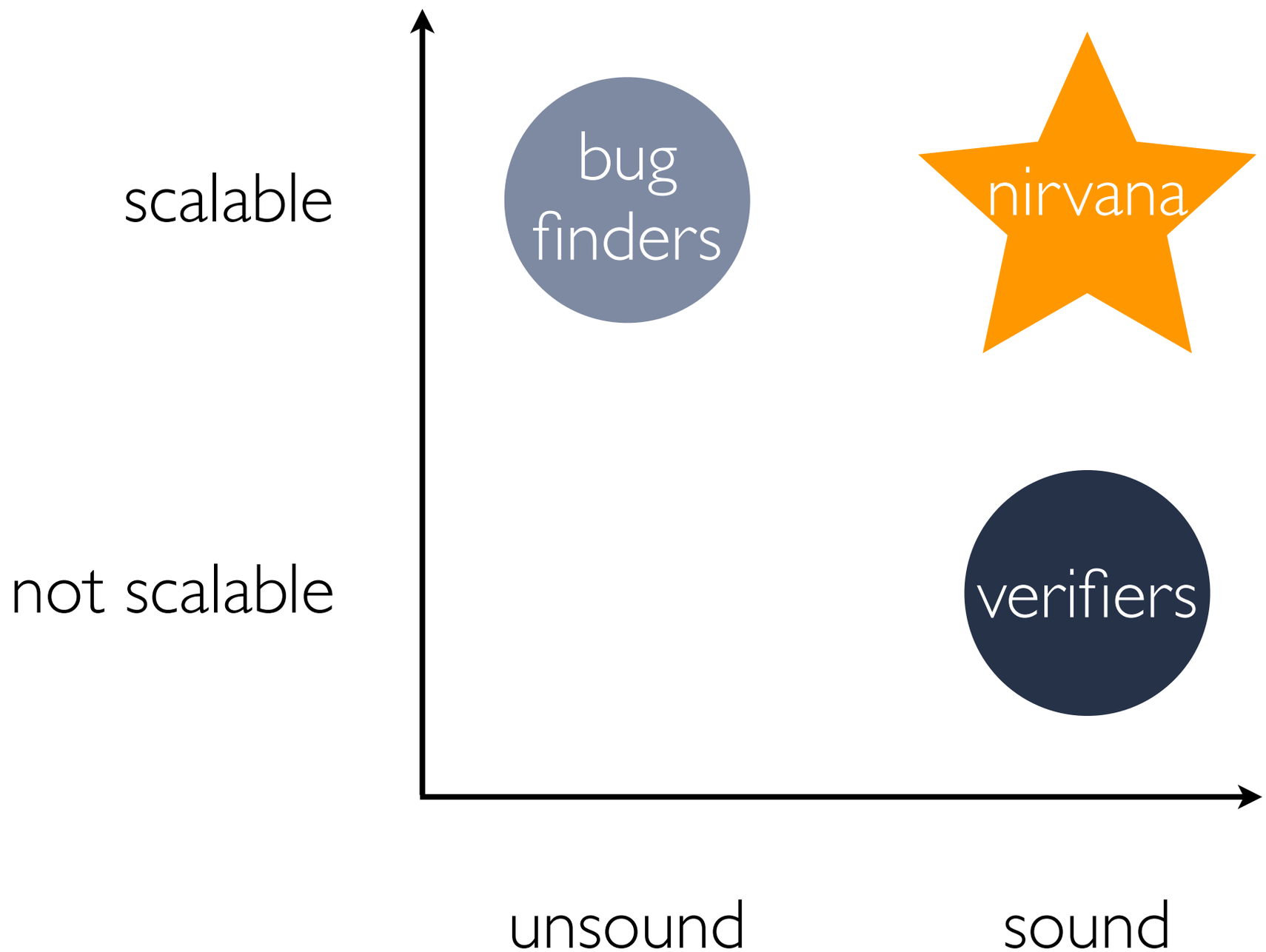
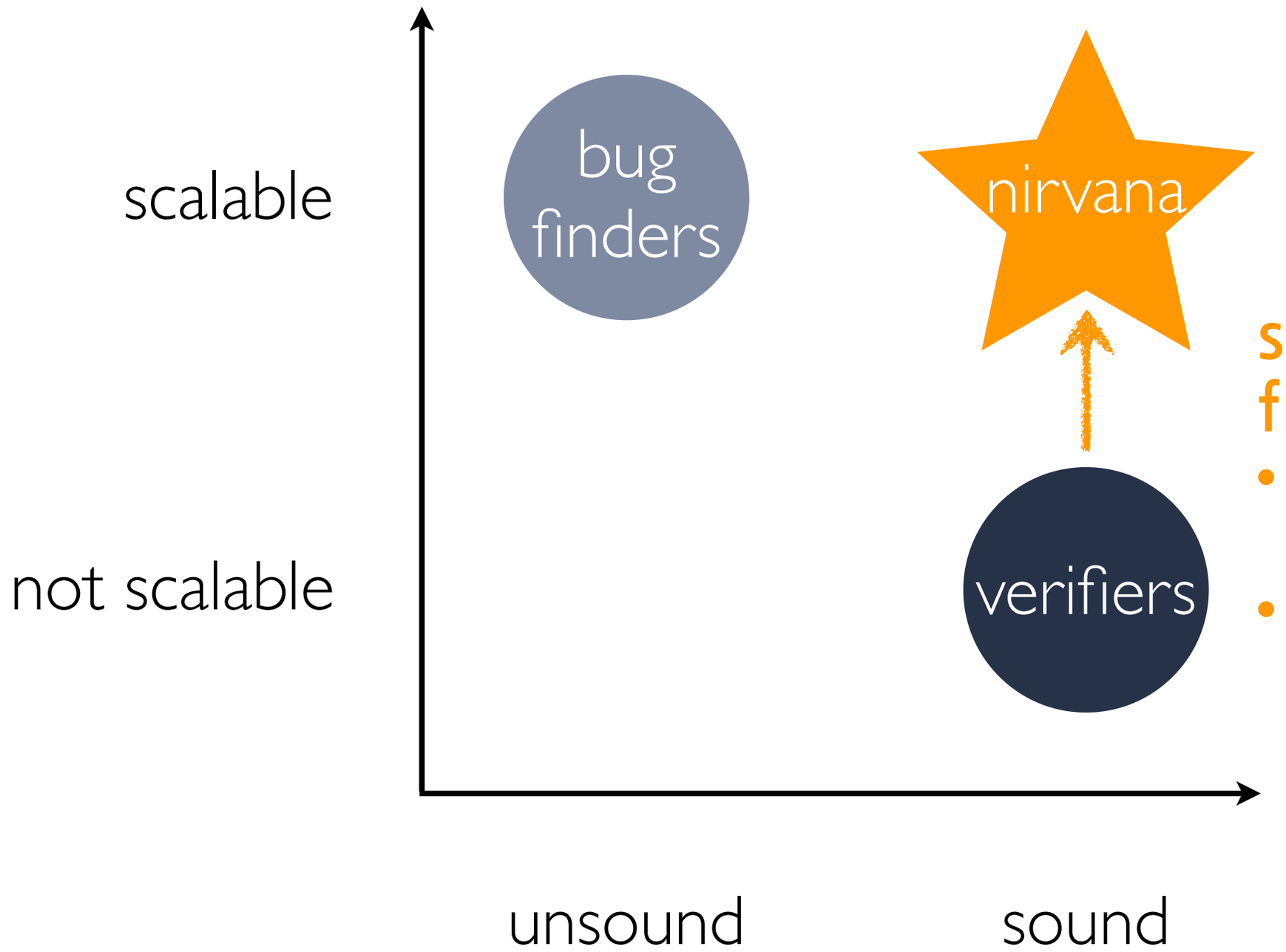


Goal: Sound, Precise, and Scalable Analysis



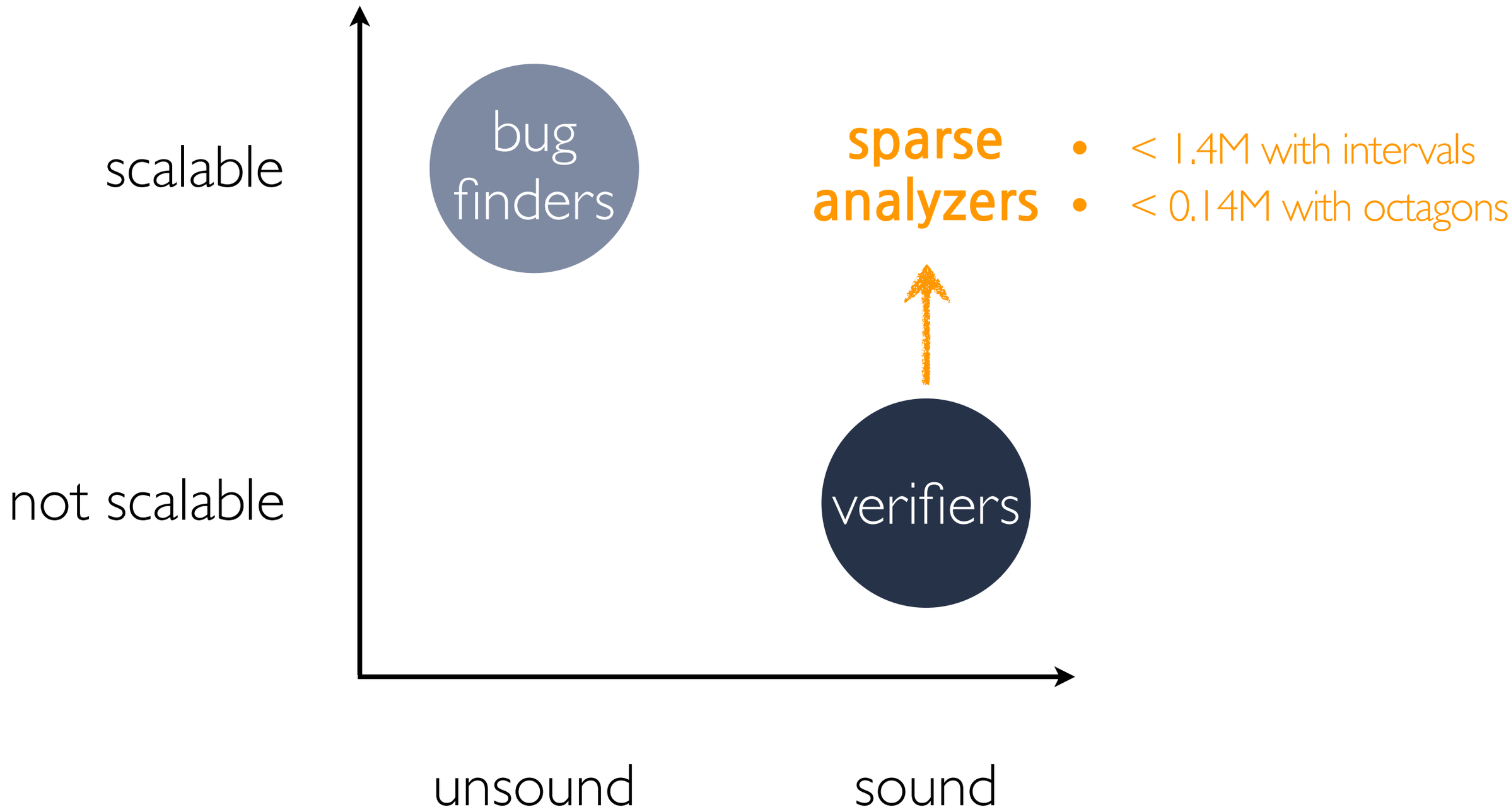
Our Contributions



sparse analysis framework

- general for AI-based analyzers
- precision-preserving

Our Contributions

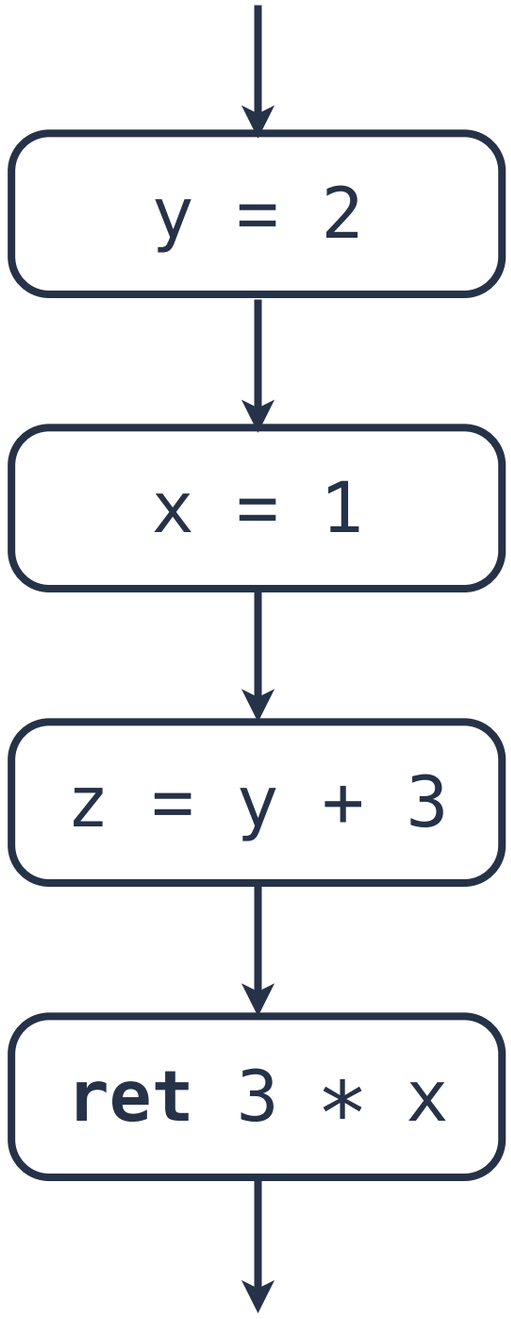


Contents

- Source of inefficiency in static analysis
- Sparse analysis
- Experiment results

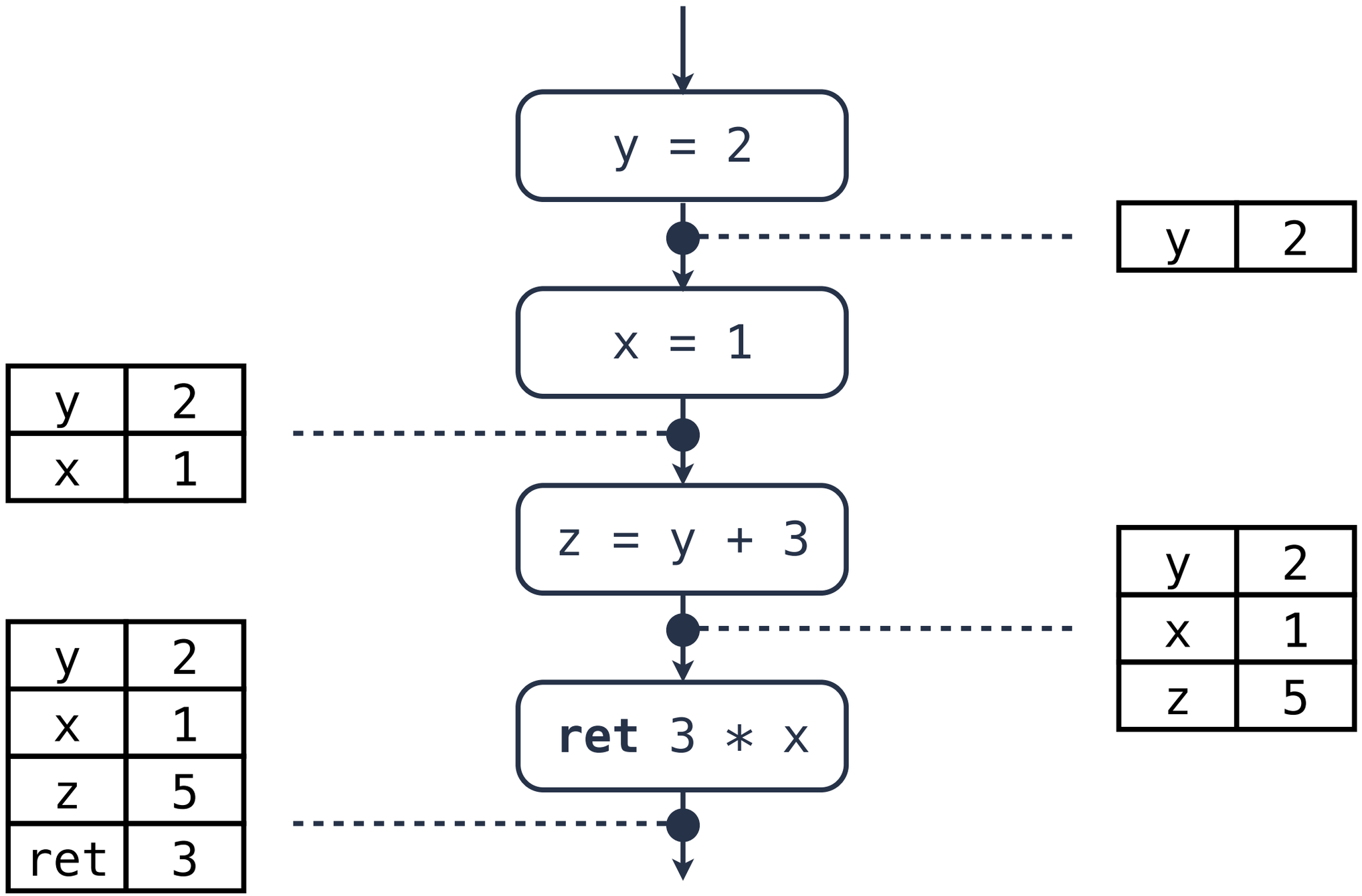
Simple Static Analysis

Reachable states at each control point



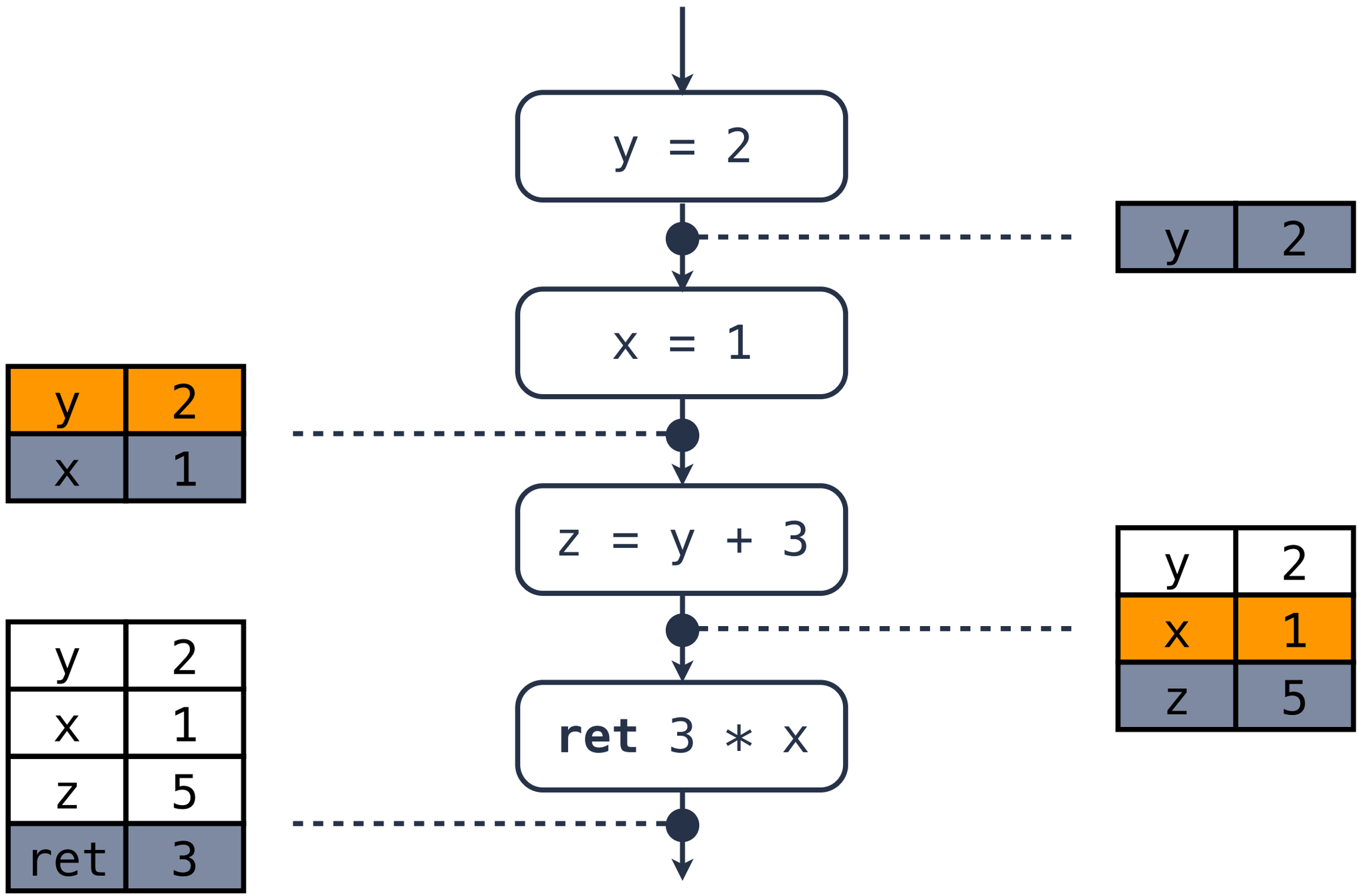
Simple Static Analysis

Reachable states at each control point



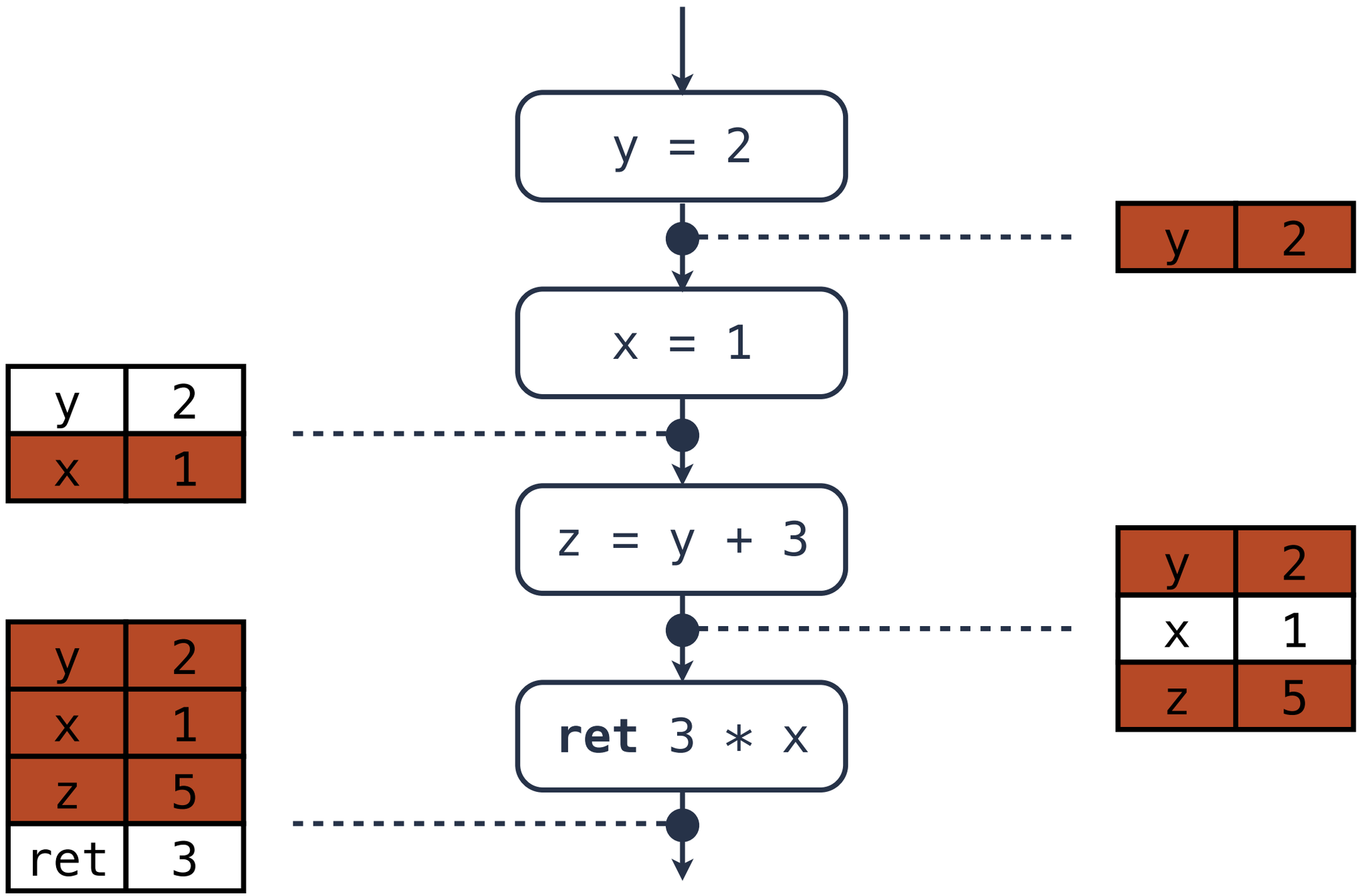
Sparsity in Transfer Function

Values are used and defined in a sparse manner

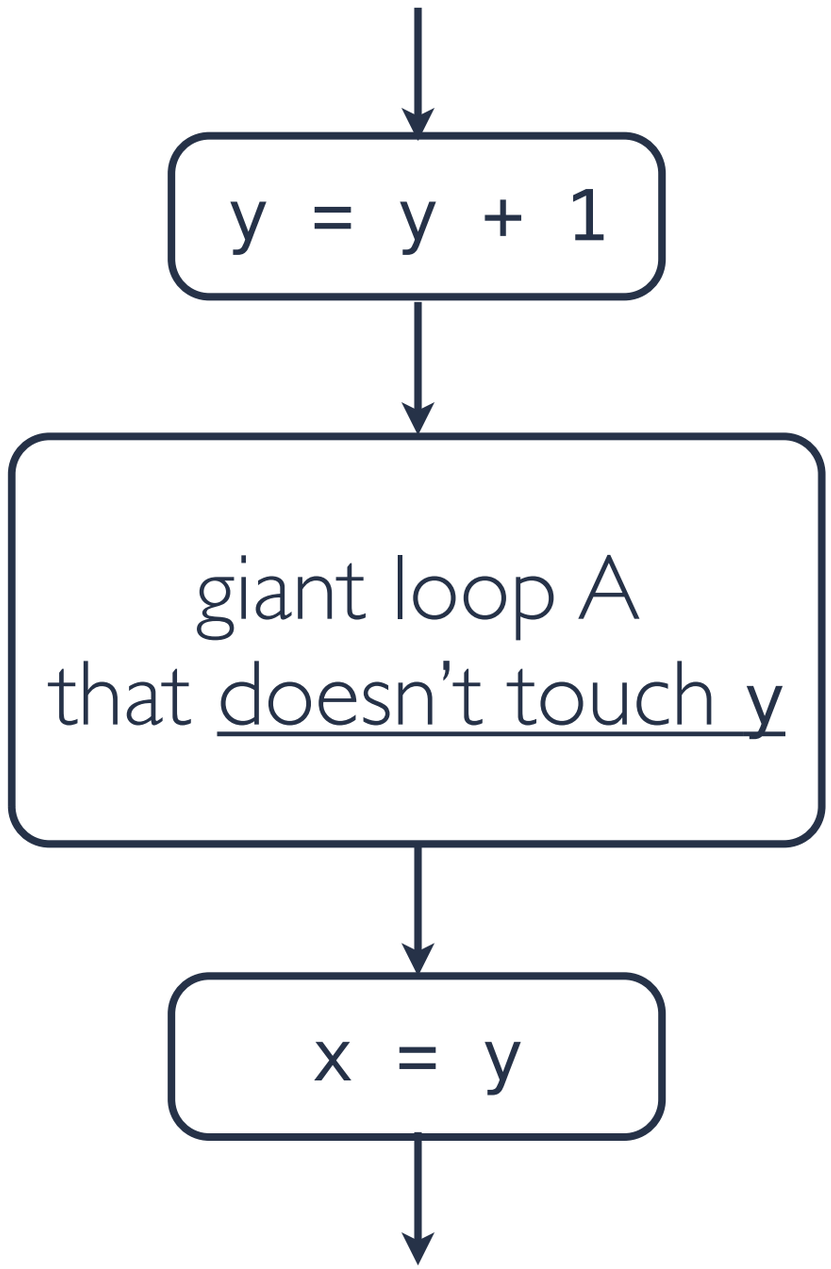


Inefficiency: Unnecessary Propagation

Some values are unnecessarily propagated untill they're actually used



What Really Happens



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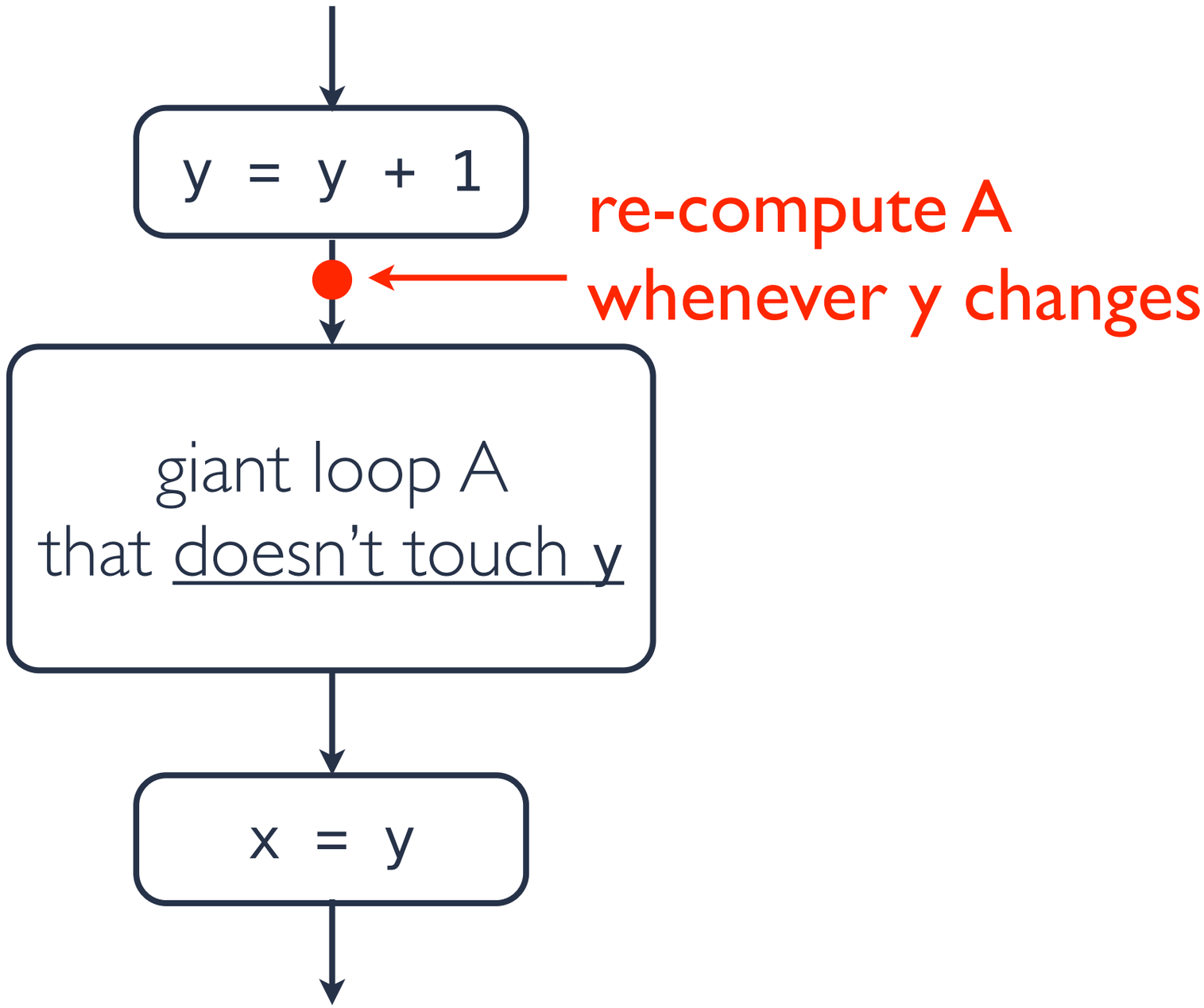
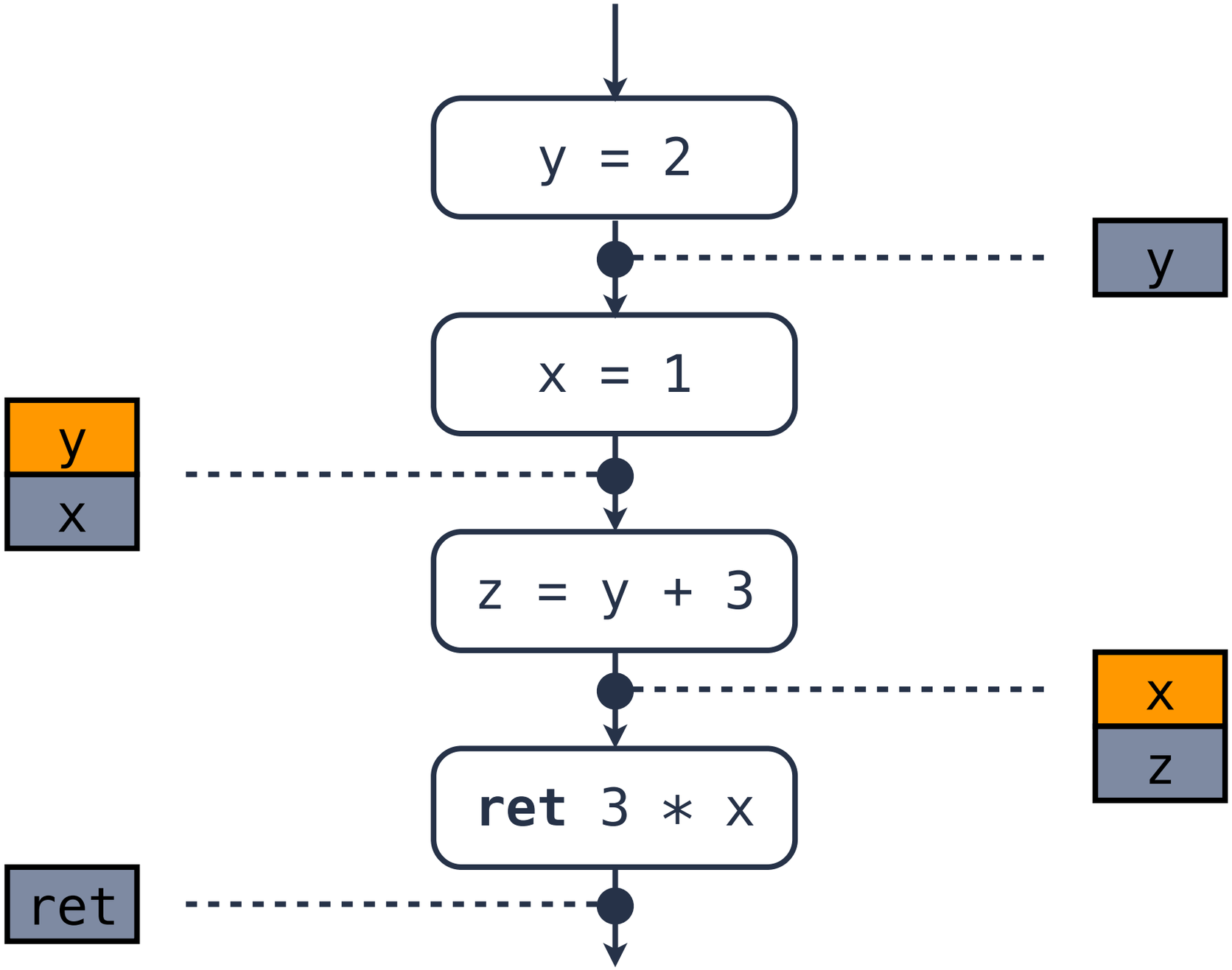


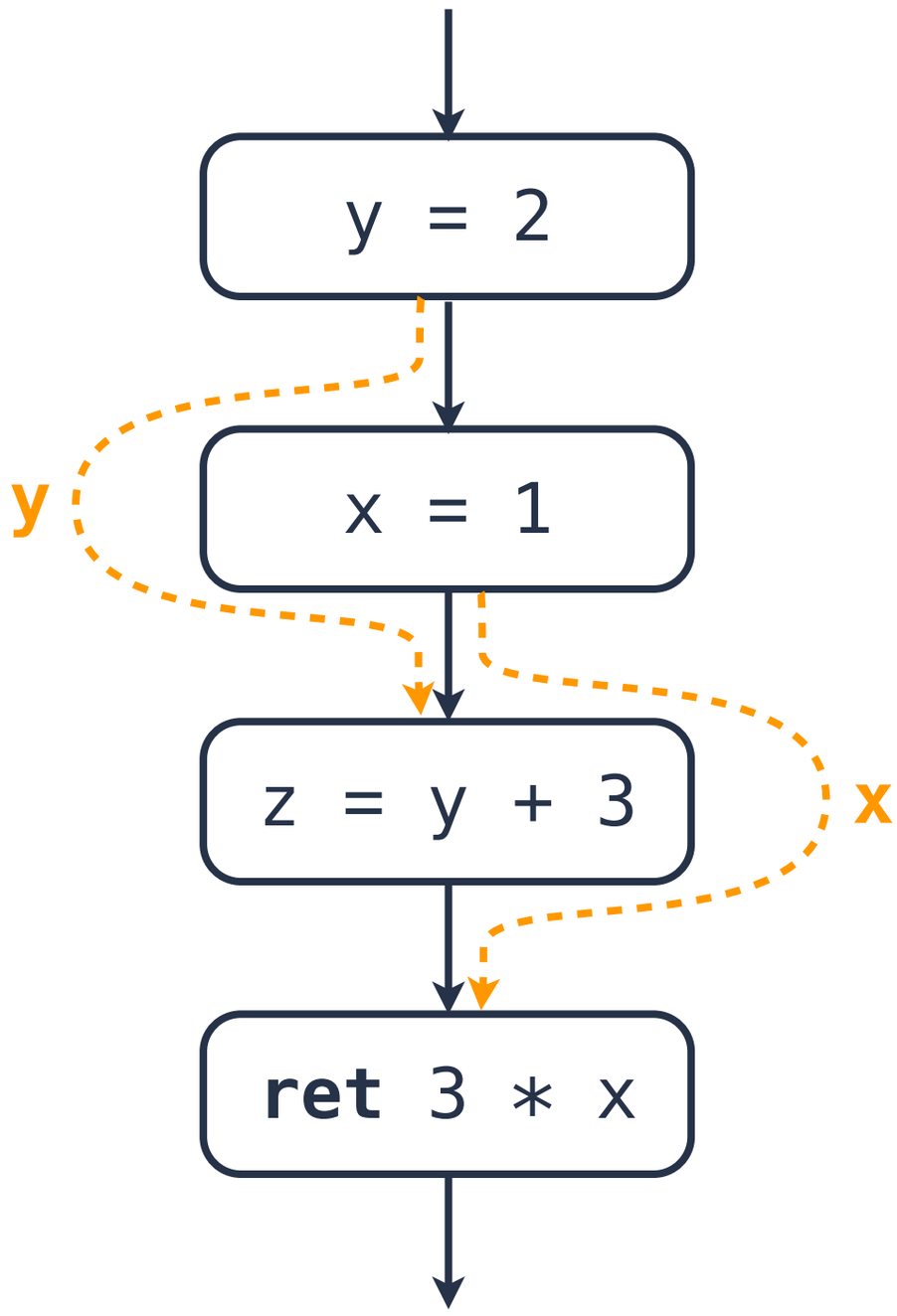
Sparse Analysis: Exploiting Sparsity in TF

Idea: propagating definitions directly to their uses



Exploiting Sparsity with DFG

Idea: propagating definitions directly to their uses with DFG



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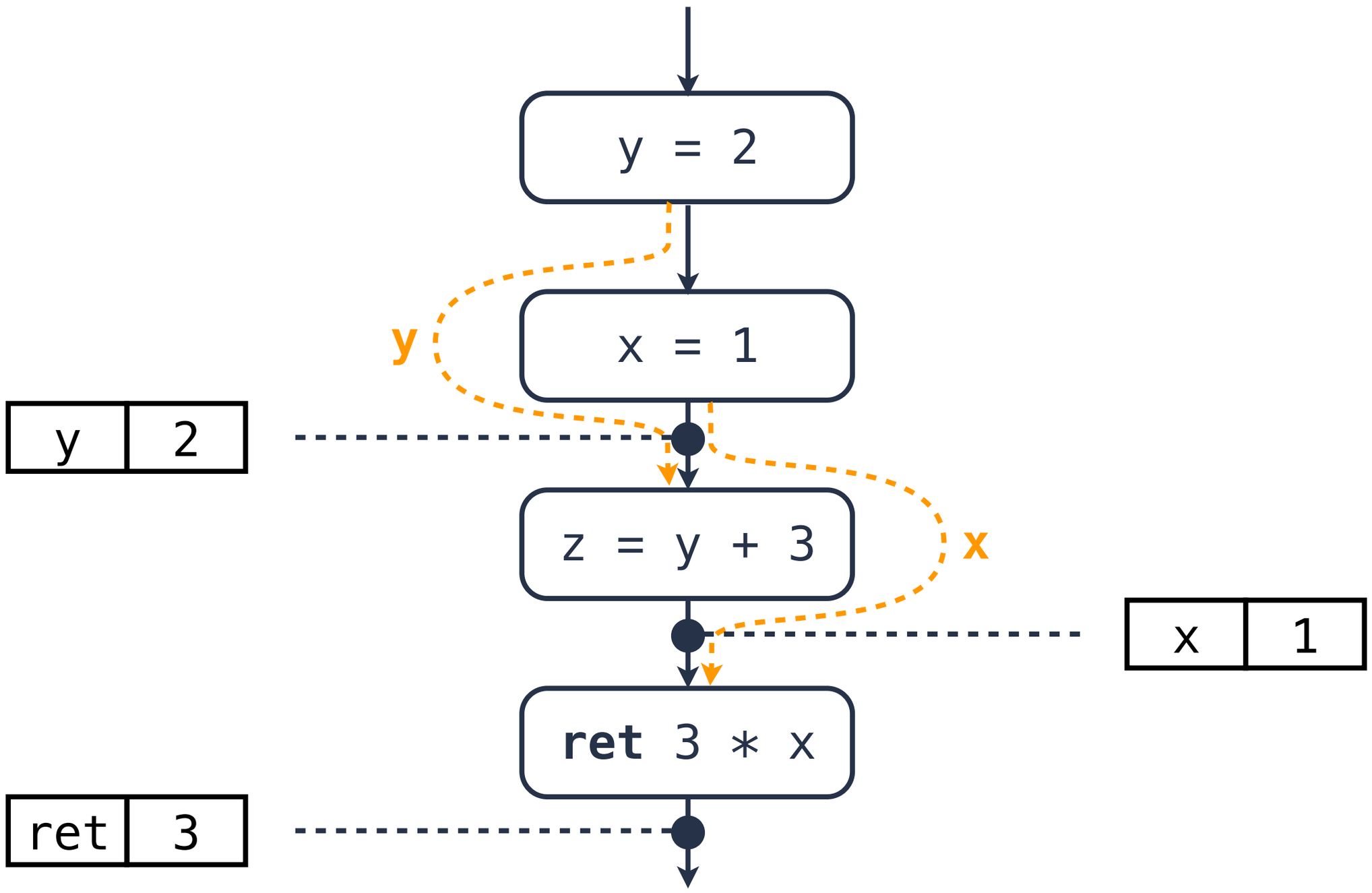
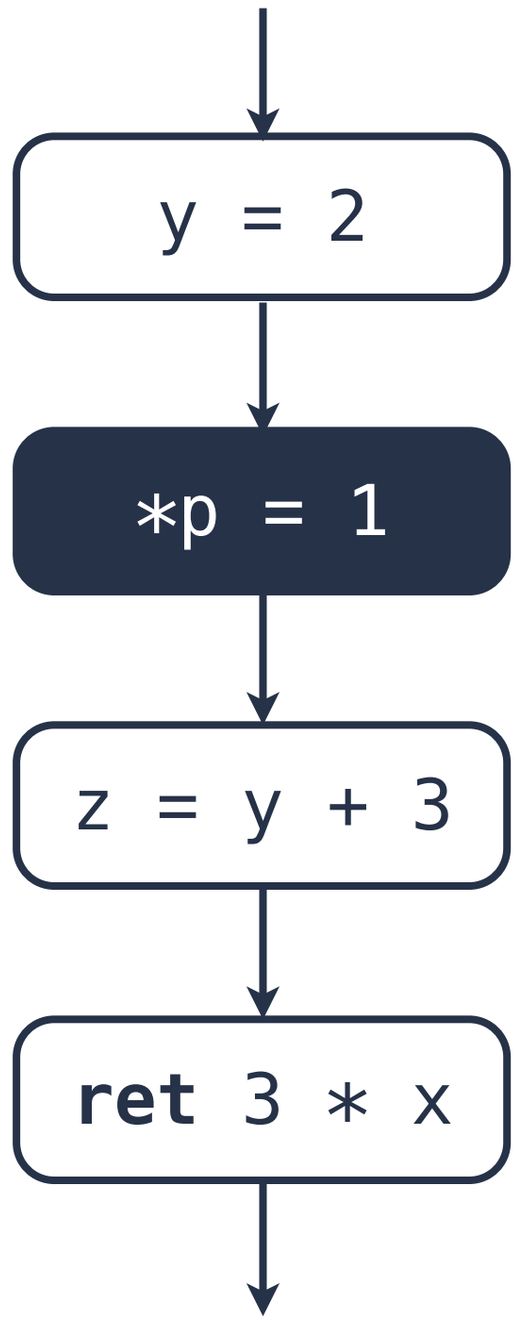


Technical Hurdle

Definitions and uses are sometimes determined at runtime
- Mostly because of pointers in C-like languages



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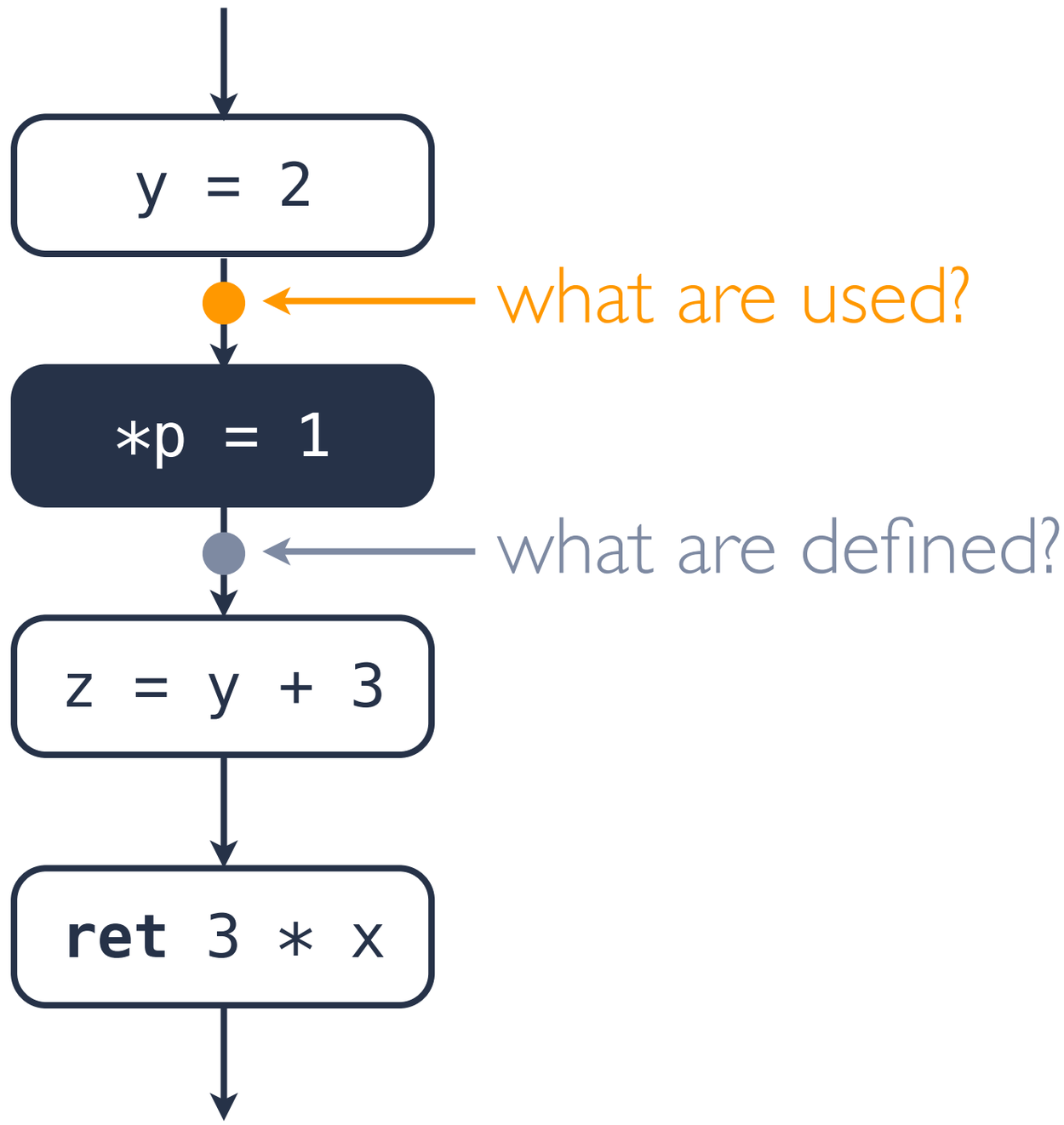

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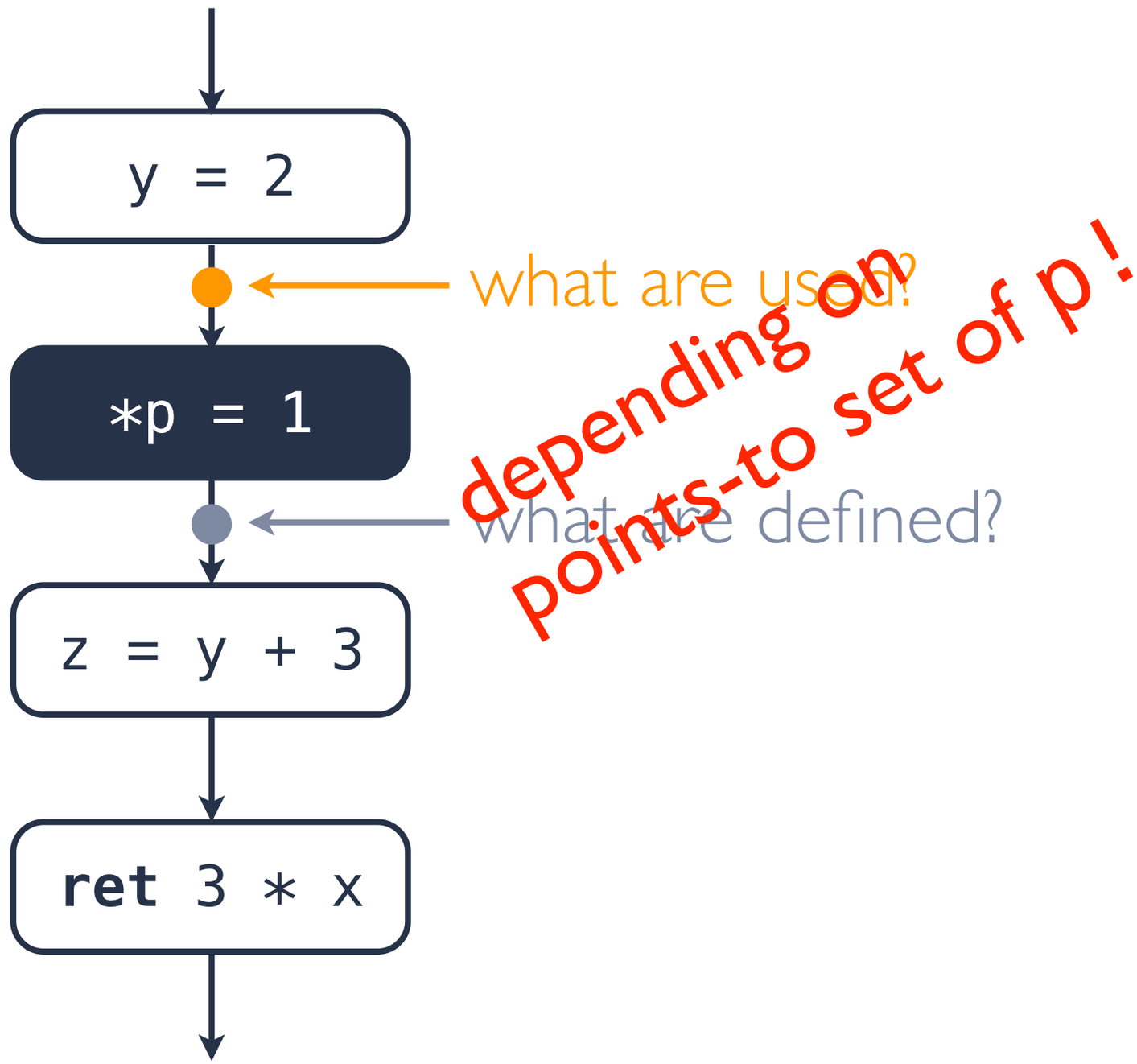
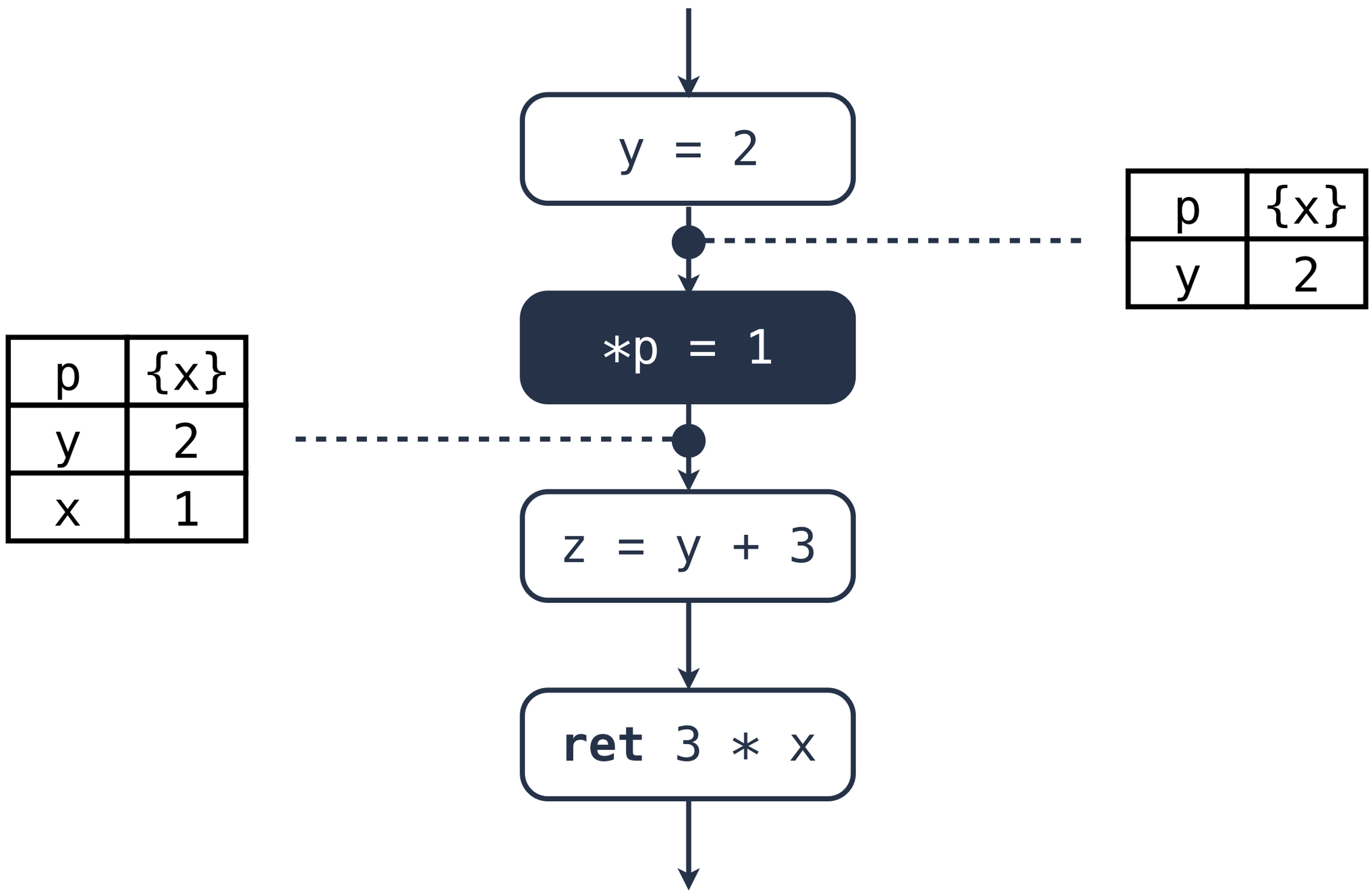


Technical Hurdle

Case 1) strong update



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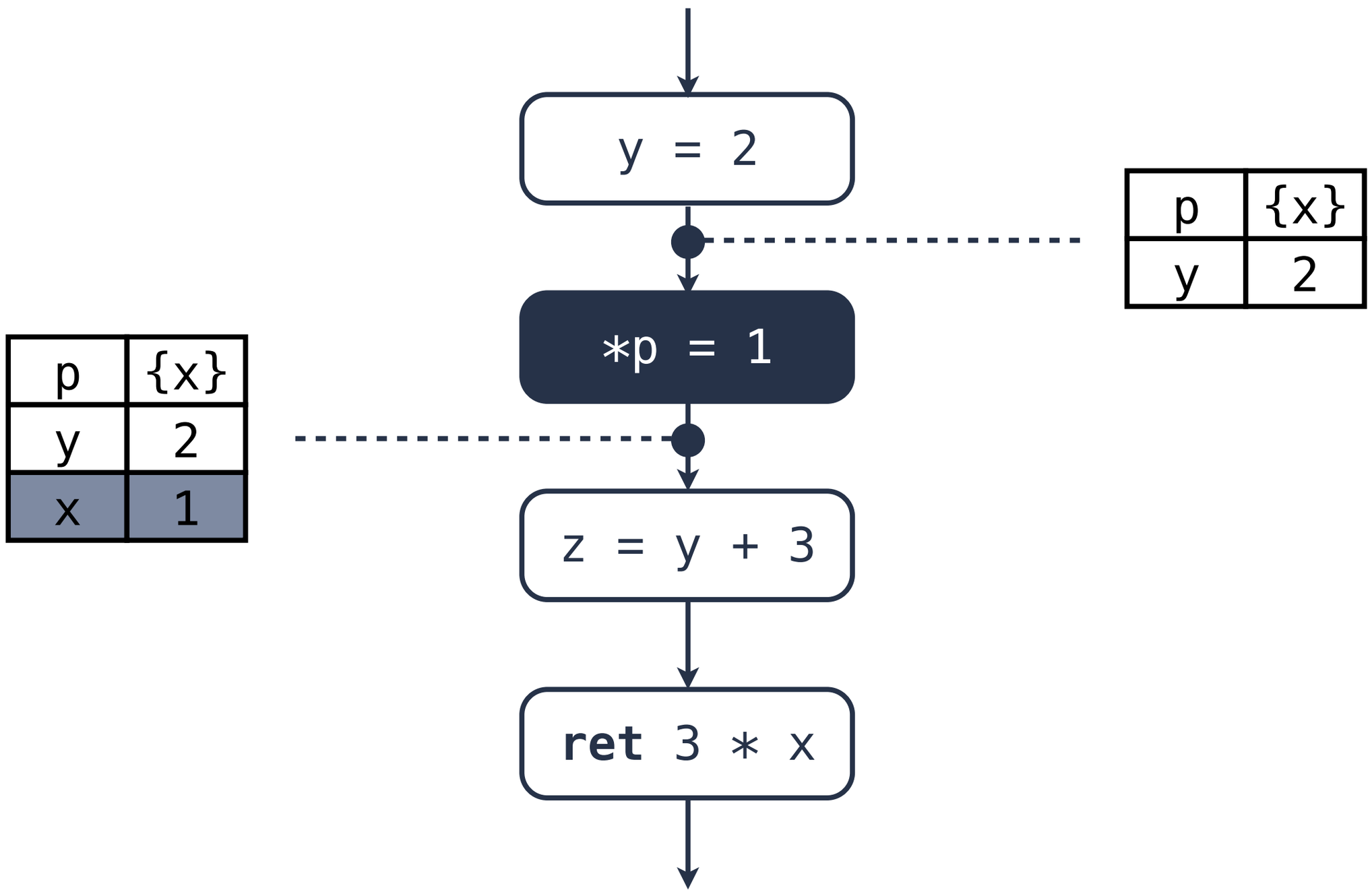
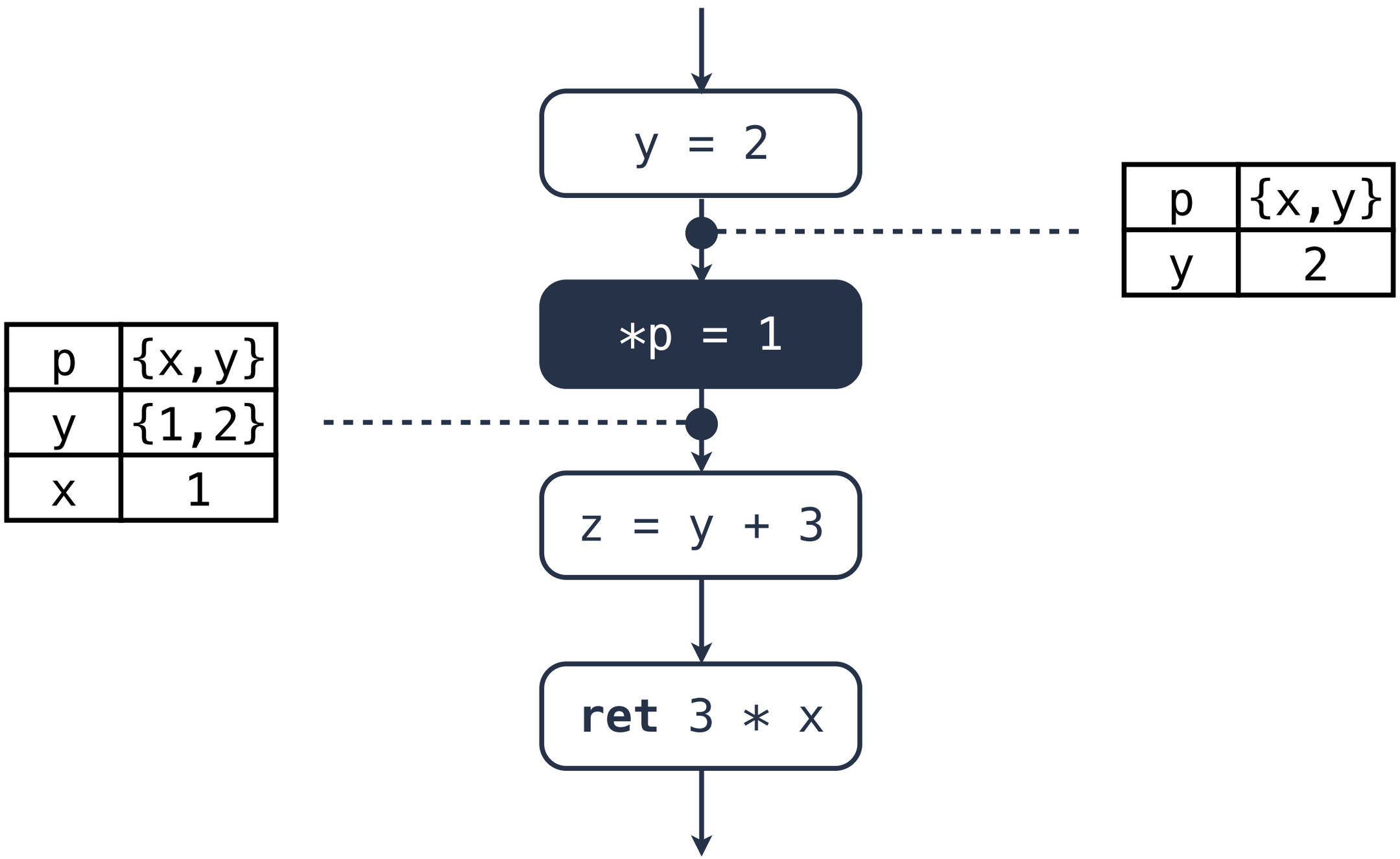


Technical Hurdle

Case 2) weak update



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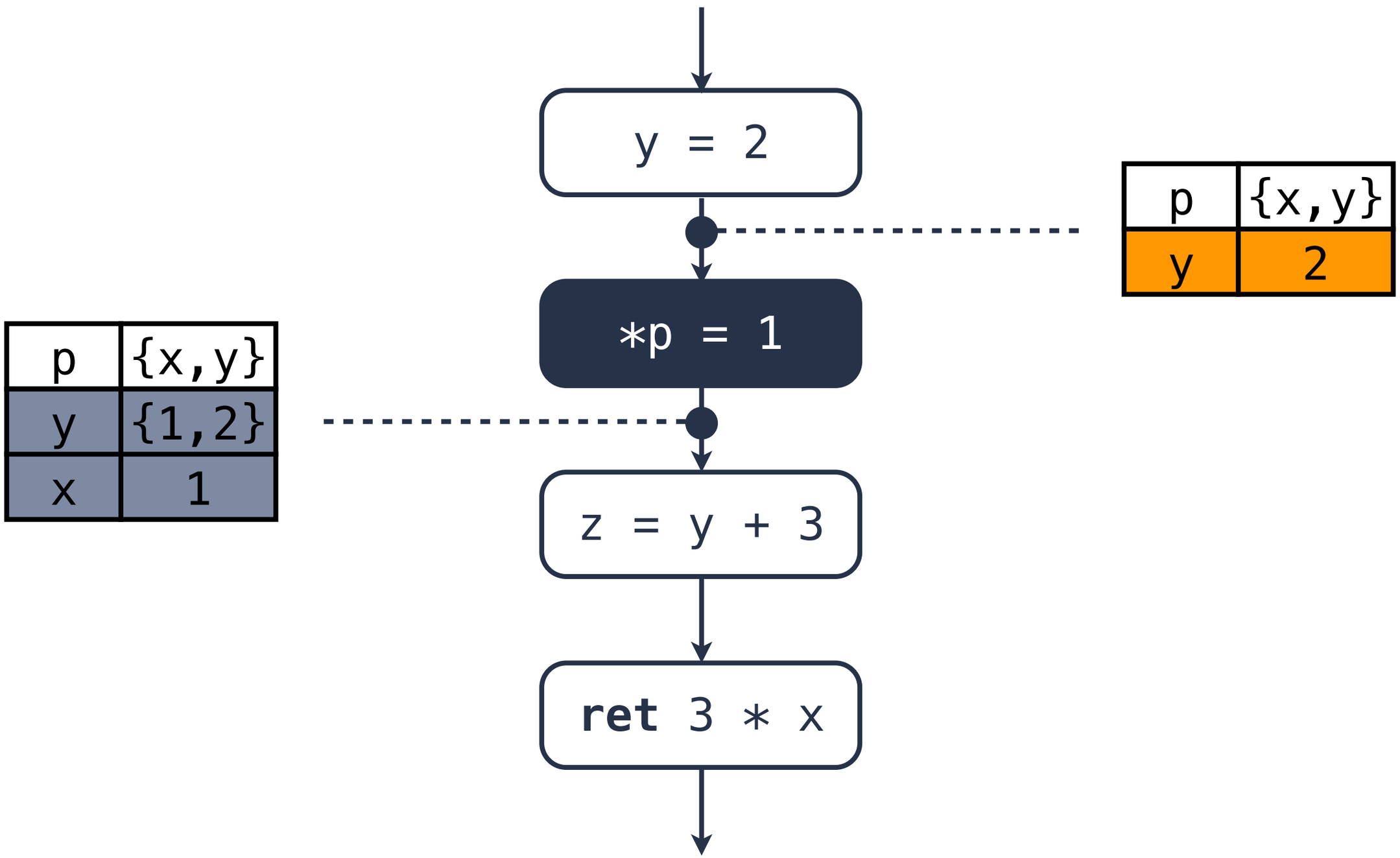

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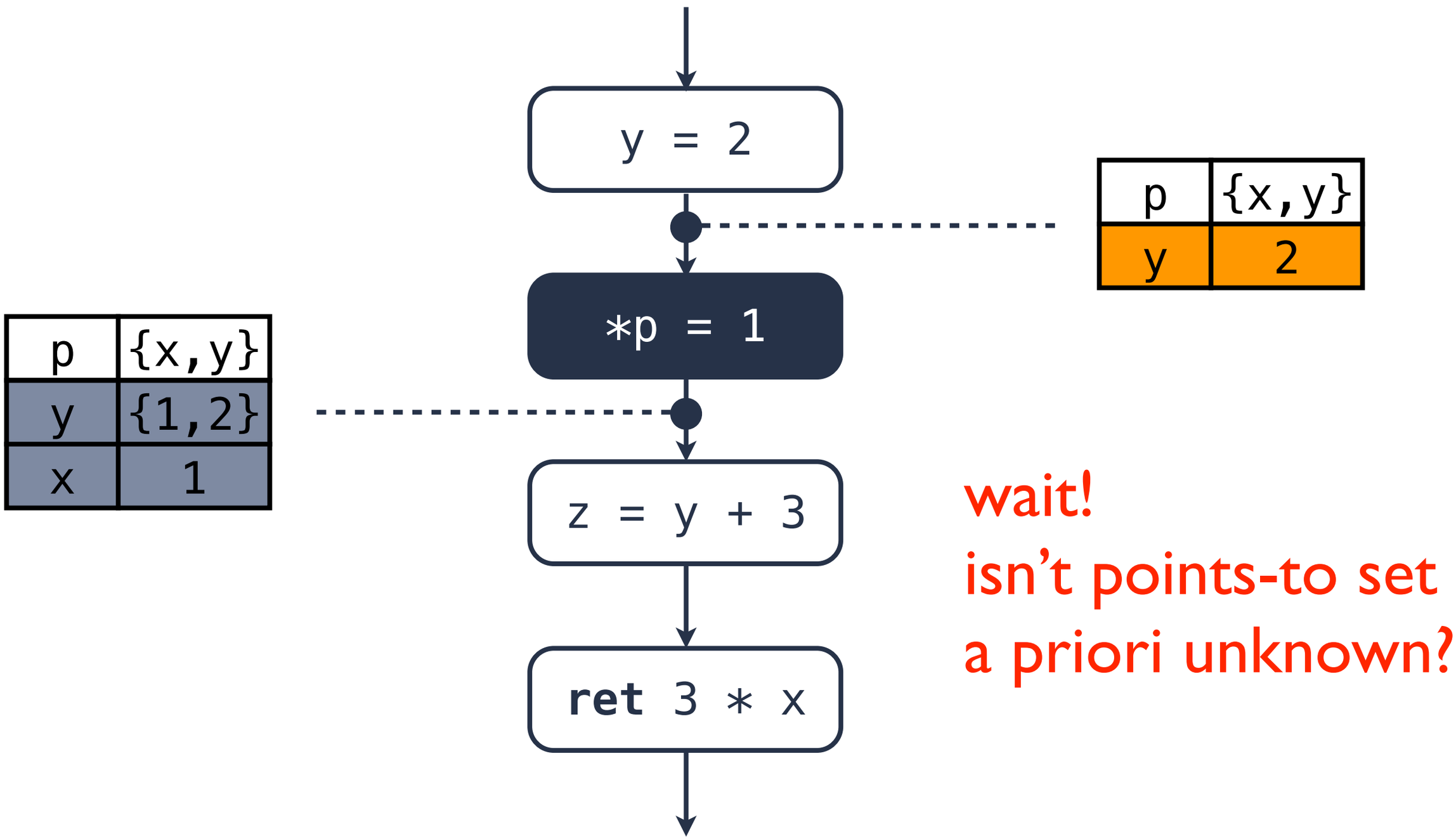

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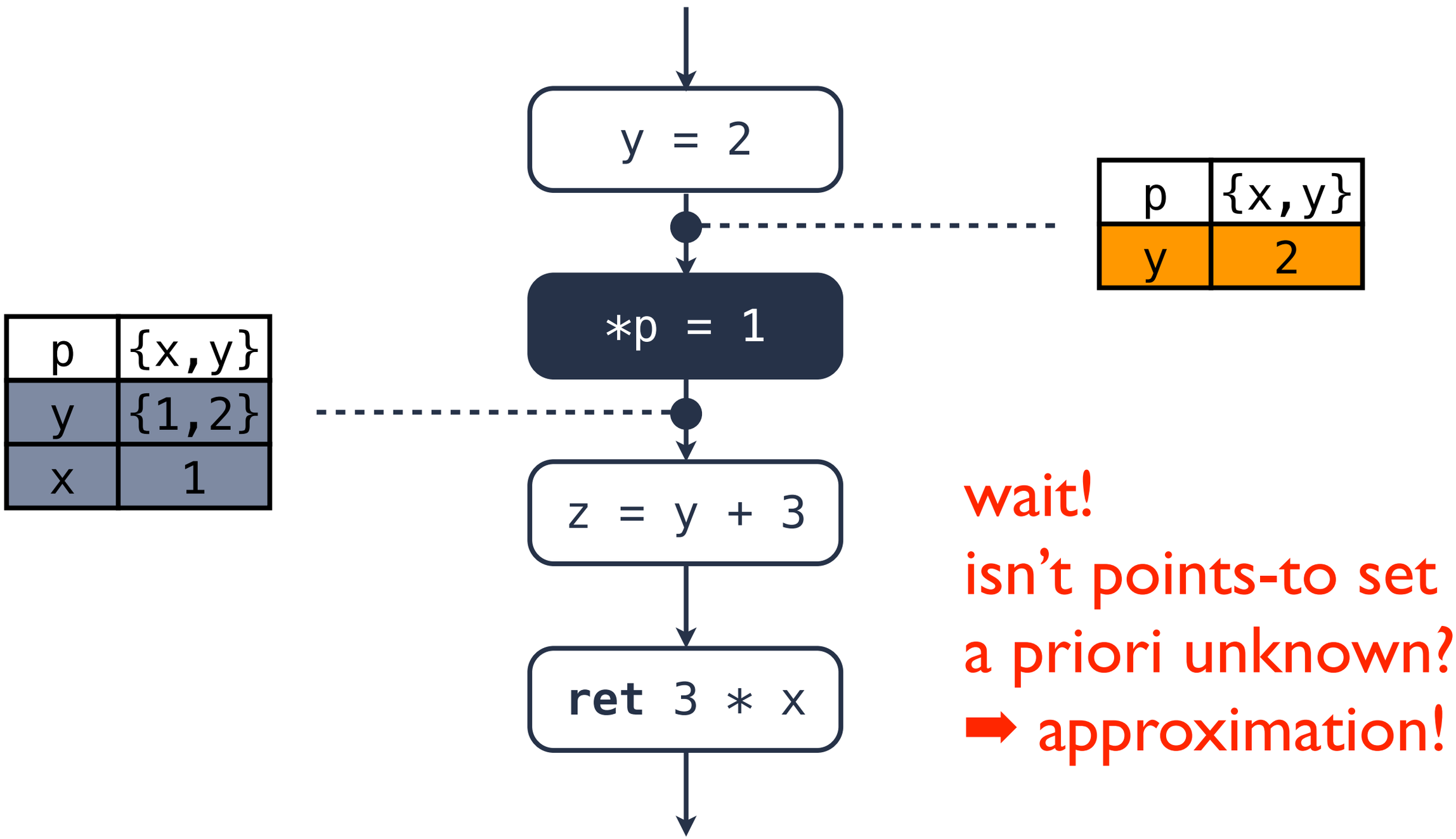
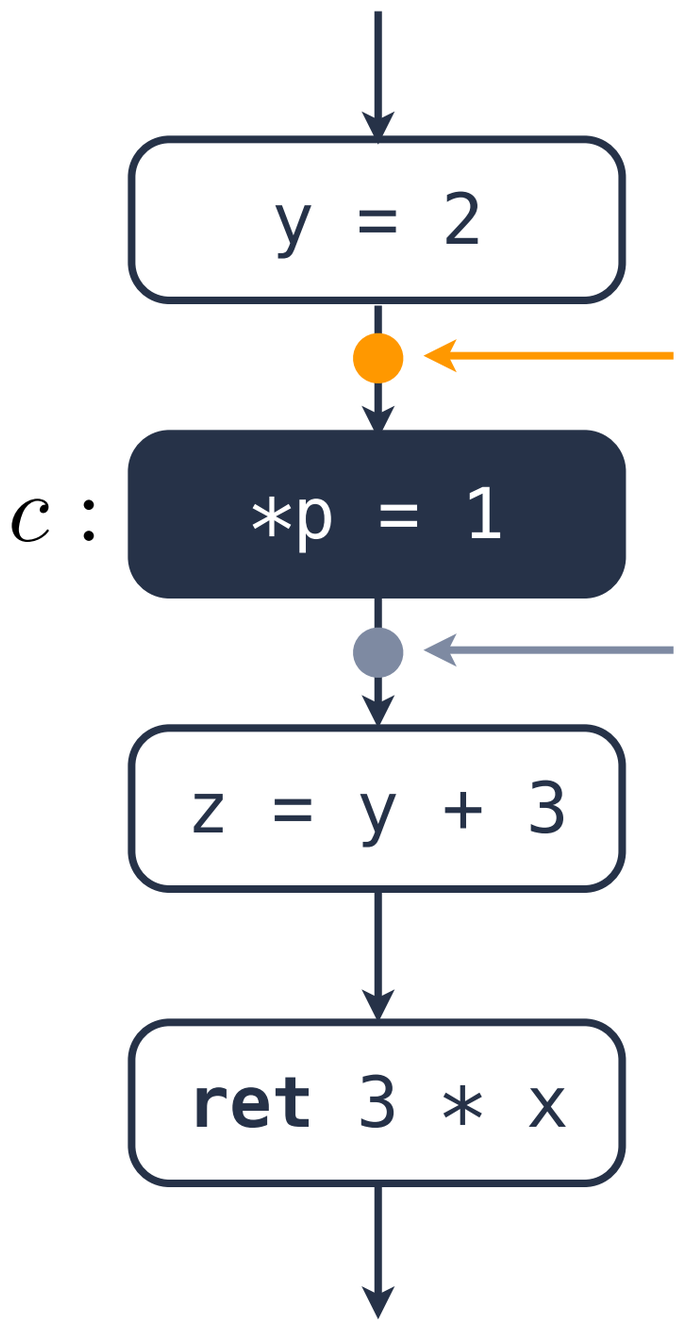


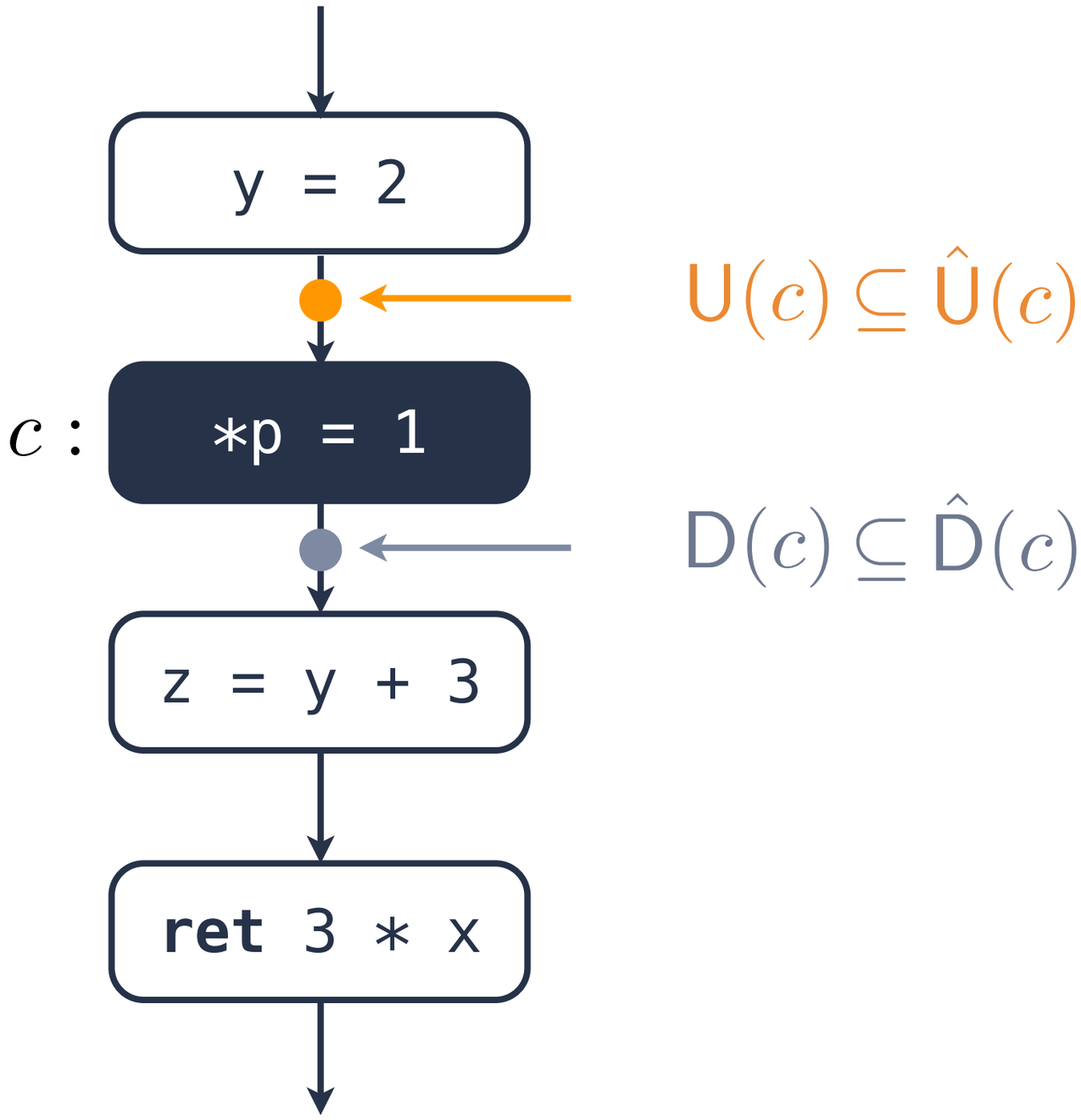
Approximation of Definitions and Uses



$\mathrm{U}(c)$ uses of primary analysis

$\mathrm{D}(c)$ definitions of primary analysis

Approximation of Definitions and Uses



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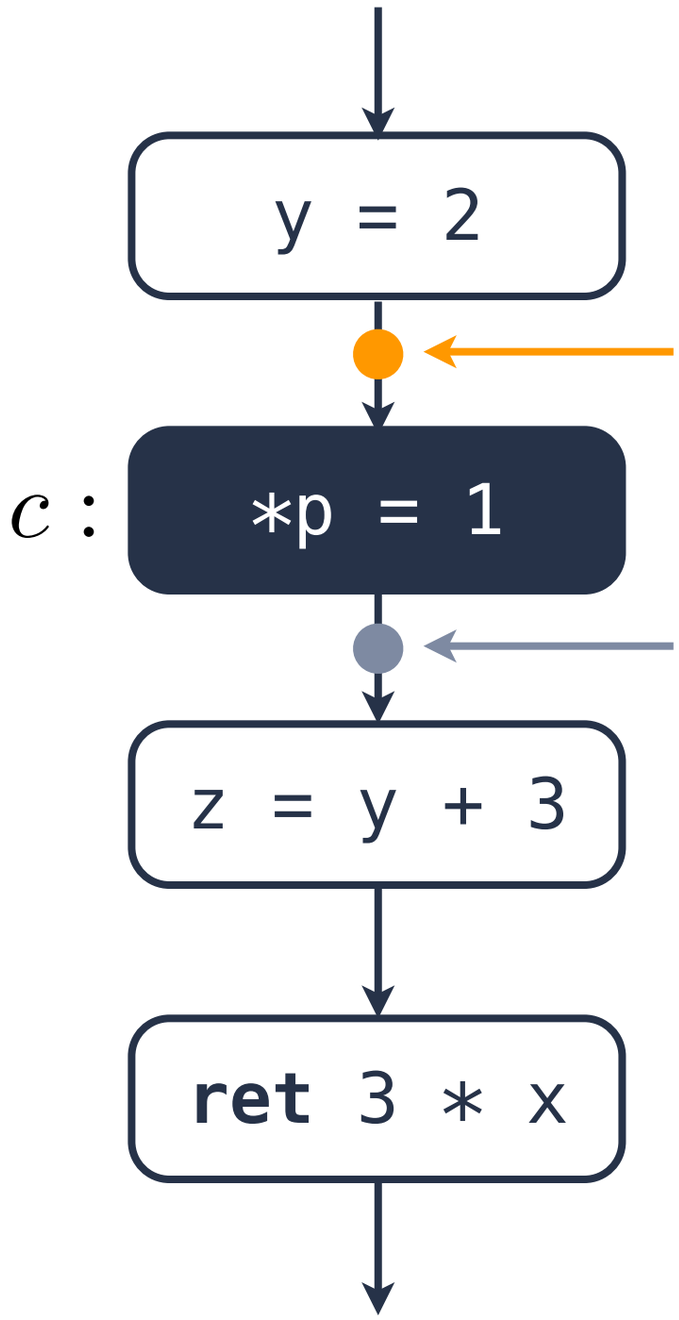


$\mathsf{U}(c) \subseteq \hat{\mathsf{U}}(c)$

$\mathsf{D}(c) \subseteq \hat{\mathsf{D}}(c)$

<u>safety condition</u>

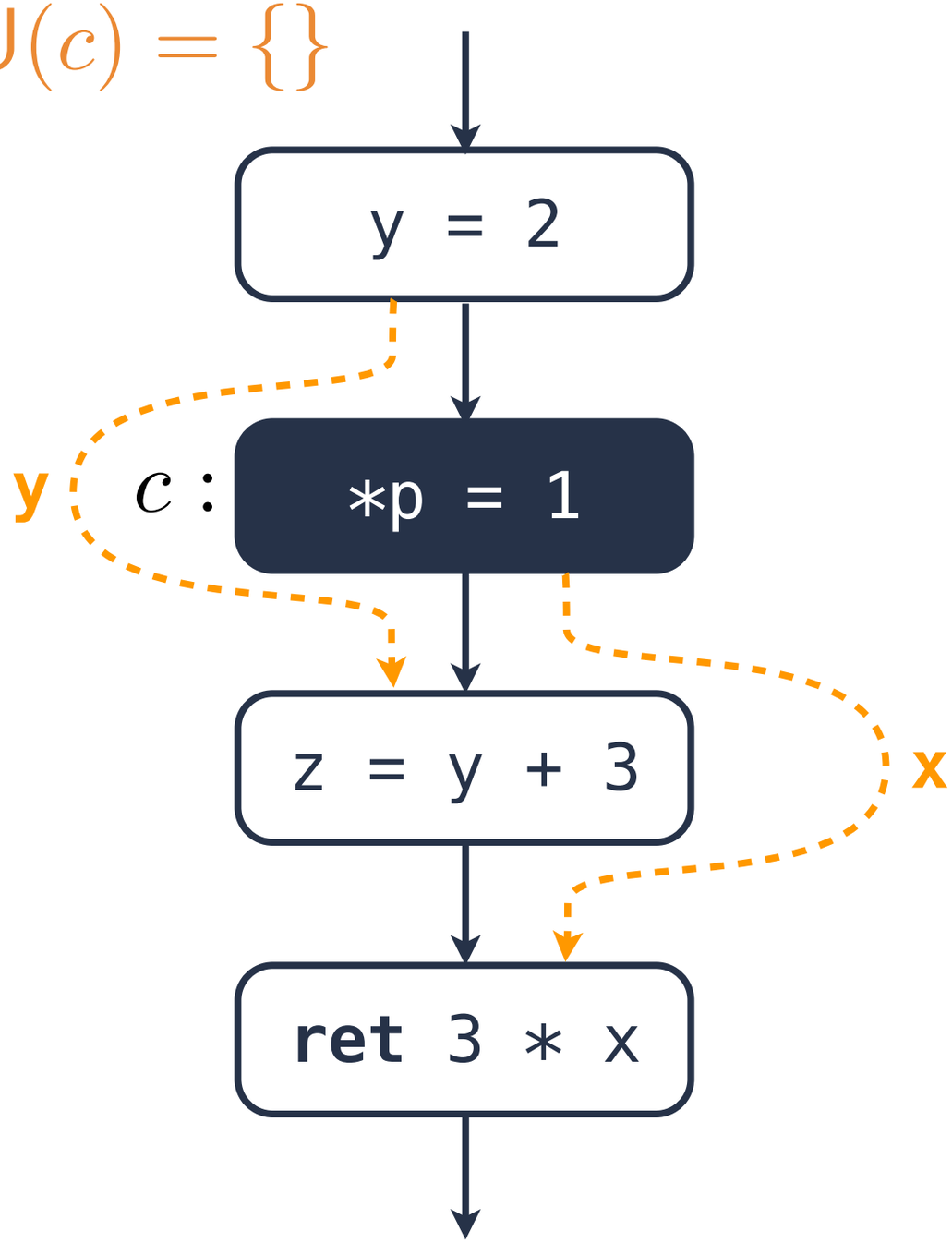
$\hat{\mathsf{D}}(c) - \mathsf{D}(c) \subseteq \hat{\mathsf{U}}(c)$

: all spurious definitions should be spurious uses

Example of Unsafe Approximation

$\mathsf{D}(c) = \{x\}$

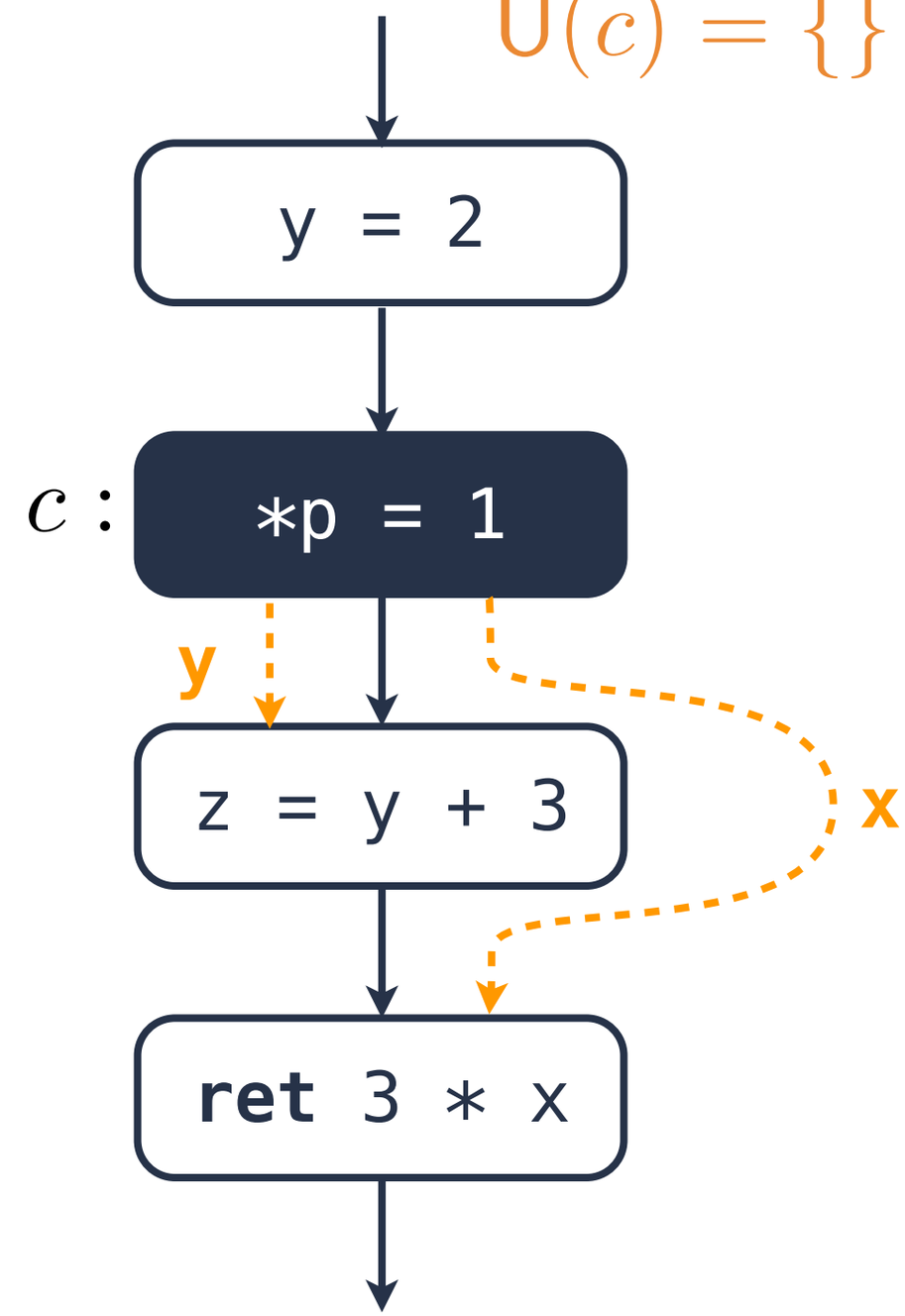
$\mathsf{U}(c) = \{\}$



most precise DFG
when p = {x}

$\hat{\mathsf{D}}(c) = \{x, y\}$

$\hat{\mathsf{U}}(c) = \{\}$



DFG
with approximated def/use

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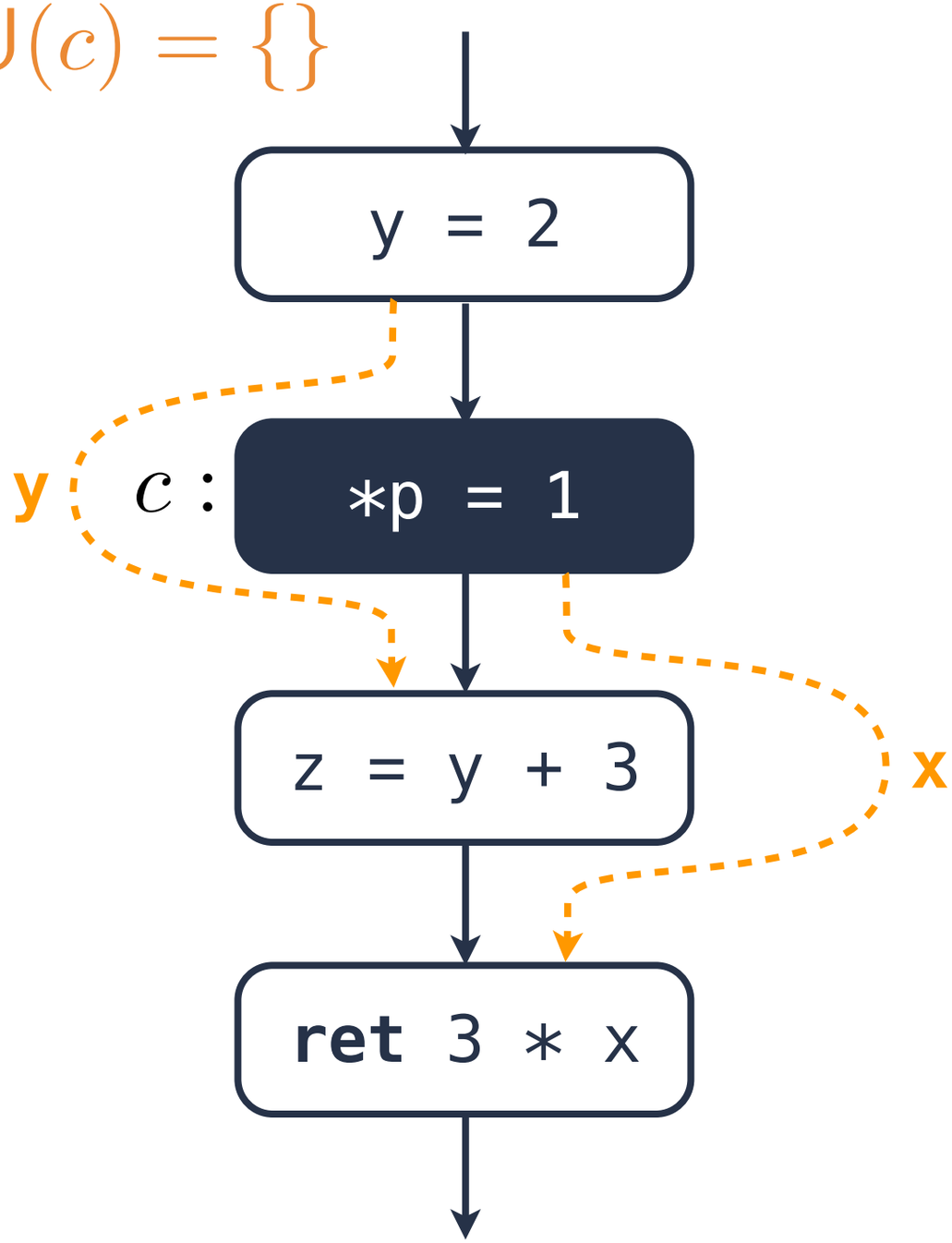

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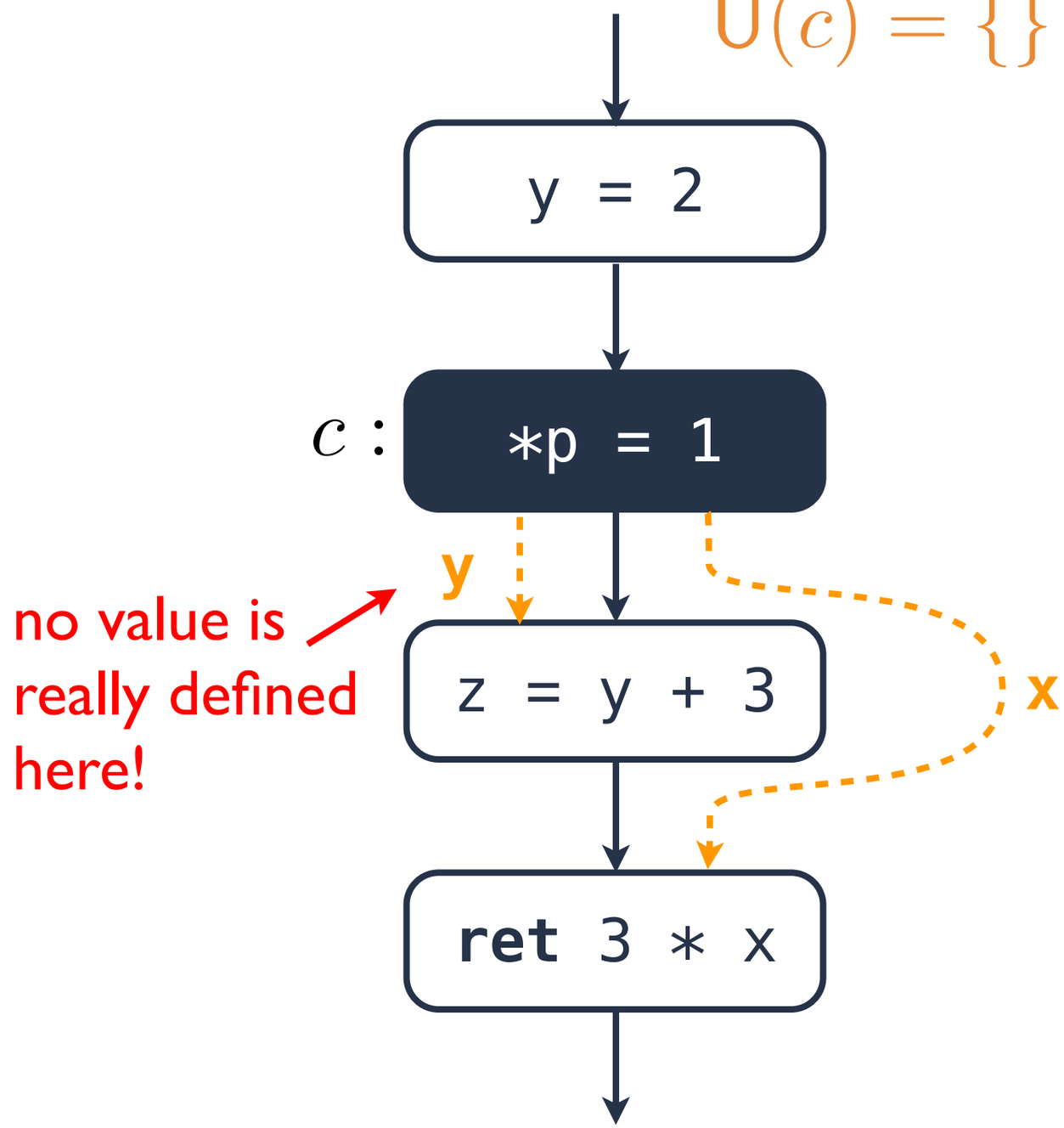

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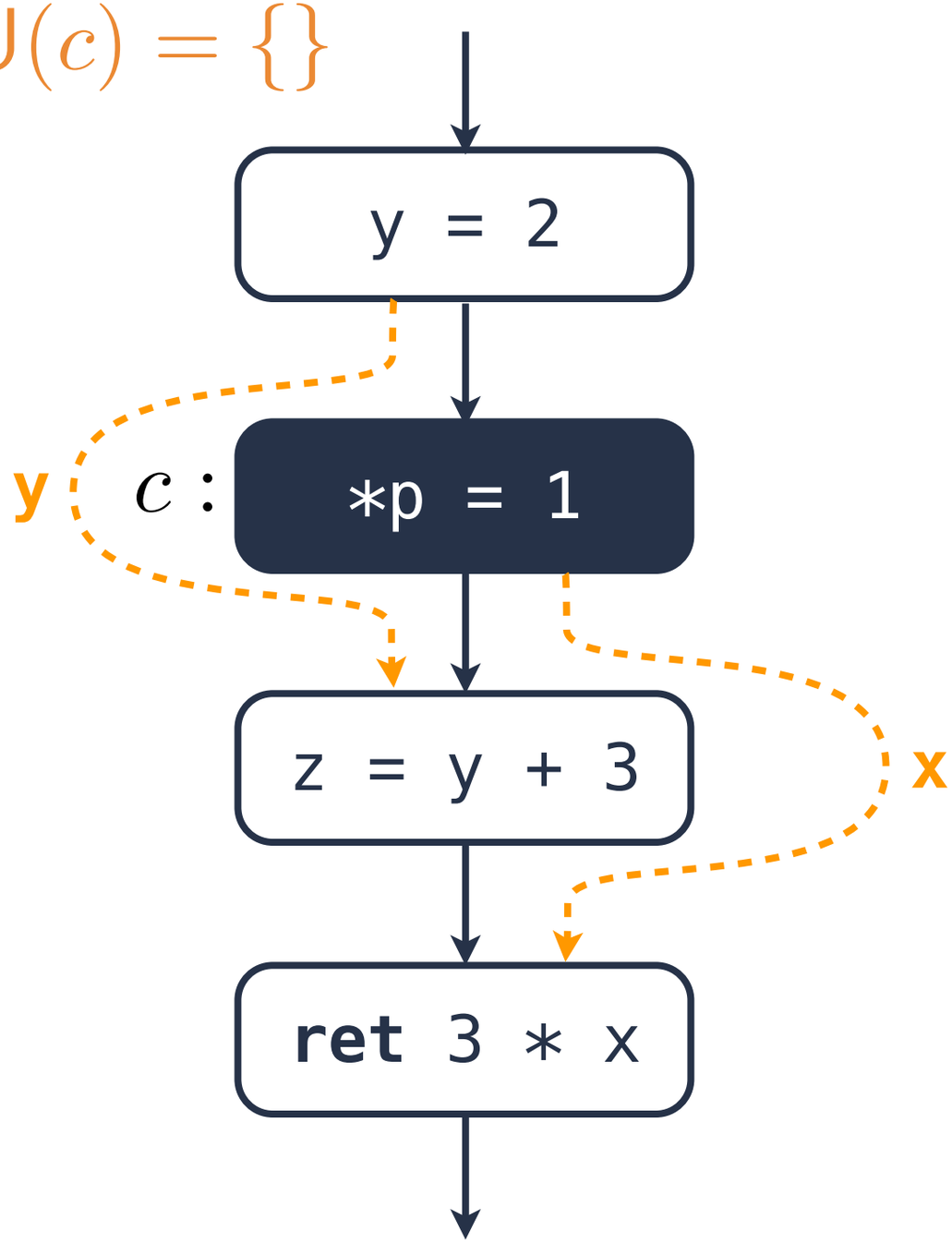

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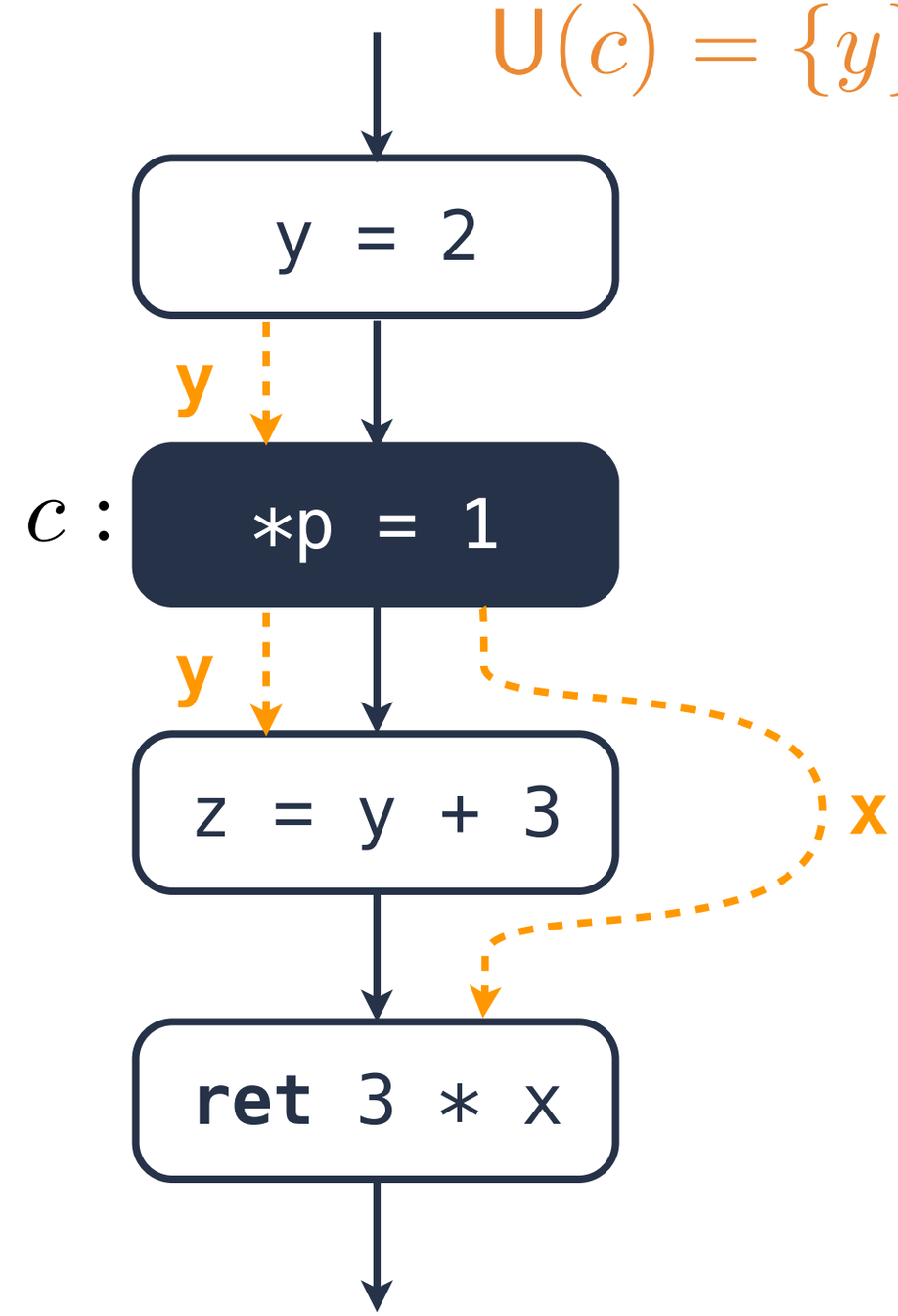

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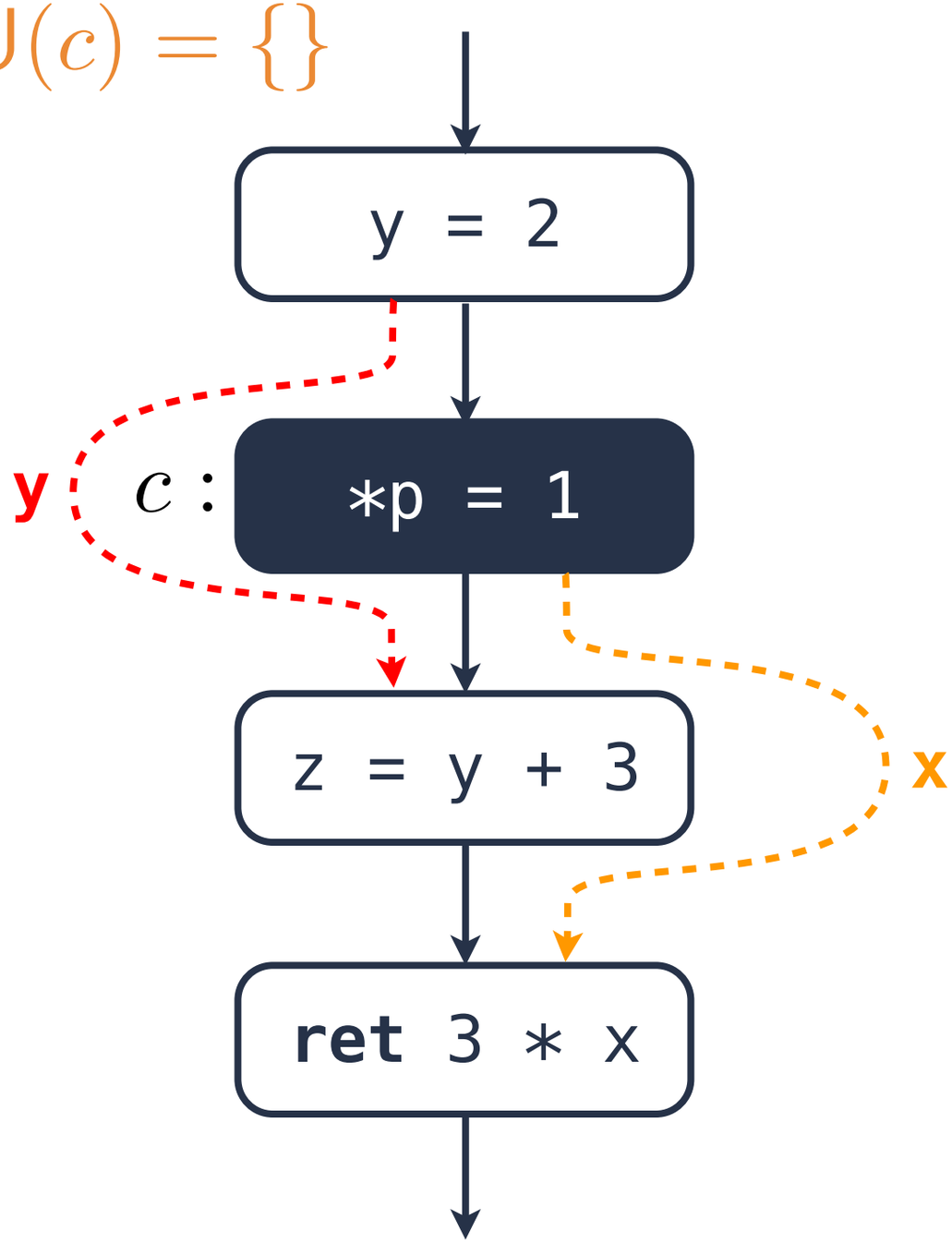
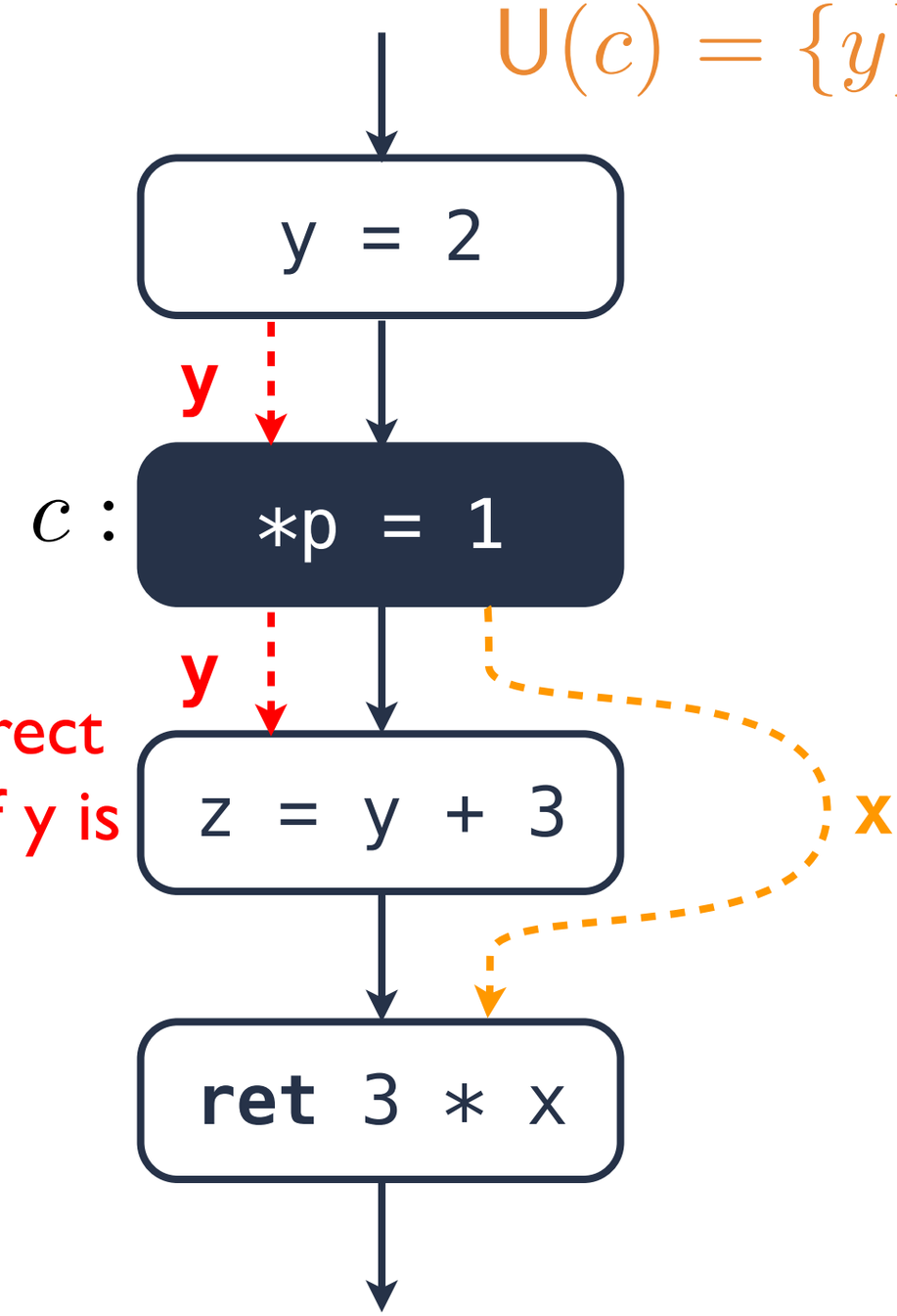


most precise DFG
when p = {x}

still the correct definition of y is propagated!

$\hat{\mathsf{D}}(c) = \{x, y\}$

$\hat{\mathsf{U}}(c) = \{y\}$



DFG
with approximated def/use

Sparse Analysis Preserves Precision

Original Static Analysis

$$\hat{F}(\hat{X}) = \lambda c.\hat{f}_c(\bigsqcup_{c' \hookrightarrow c} \hat{X}(c'))$$

Sparse Static Analysis

$$\hat{F}_s(\hat{X}) = \lambda c.\hat{f}_c(\bigsqcup_{c' \overset{x}{\rightsquigarrow} c} \hat{X}(c')|_x)$$

Sparse Analysis Preserves Precision

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CFG

Sparse Static Analysis

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DFG

Theorem 1. $\mathbf{lfp}(\hat{F}) \simeq \mathbf{lfp}(\hat{F}_s)$

Sparse Analysis Preserves Precision

Original Static Analysis

$$\hat{F}(\hat{X}) = \lambda c.\hat{f}_c(\bigsqcup_{c' \hookrightarrow c} \hat{X}(c'))$$

Sparse Static Analysis

$$\hat{F}_s(\hat{X}) = \lambda c.\hat{f}_c(\bigsqcup_{c' \overset{x}{\rightsquigarrow} c} \hat{X}(c')|_x)$$

Theorem 1. $\mathbf{lfp}(\hat{F}) \simeq \mathbf{lfp}(\hat{F}_s)$

same precision up to actually used locations

Experiment Results

Benchmarks

Program	LOC	Functions	Statements	Blocks	maxSCC	AbsLocs
gzip-1.2.4a	7K	132	6,446	4,152	2	1,784
bc-1.06	13K	132	10,368	4,731	1	1,619
tar-1.13	20K	221	12,199	8,586	13	3,245
less-382	23K	382	23,367	9,207	46	3,658
make-3.76.1	27K	190	14,010	9,094	57	4,527
wget-1.9	35K	433	28,958	14,537	13	6,675
screen-4.0.2	45K	588	39,693	29,498	65	12,566
a2ps-4.14	64K	980	86,867	27,565	6	17,684
sendmail-8.13.6	130K	756	76,630	52,505	60	19,135
nethack-3.3.0	211K	2,207	237,427	157,645	997	54,989
vim60	227K	2,770	150,950	107,629	1,668	40,979
emacs-22.1	399K	3,388	204,865	161,118	1,554	66,413
python-2.5.1	435K	2,996	241,511	99,014	723	51,859
linux-3.0	710K	13,856	345,407	300,203	493	139,667
gimp-2.6	959K	11,728	1,482,230	286,588	2	190,806
ghostscript-9.00	1,363K	12,993	2,891,500	342,293	39	201,161

maxSCC: size of the largest recursive call cycle

Experiment Results

Buffer Overrun Detection with Intervals

Programs	$\text{Interval}_{\text{vanilla}}$	$\text{Interval}_{\text{base}}$	$\text{Spd}\uparrow_1$	$\text{Interval}_{\text{sparse}}$	$\text{Spd}\uparrow_2$
gzip-1.2.4a	772	14	55 x	3	5 x
bc-1.06	1,270	96	13 x	7	14 x
tar-1.13	12,947	338	38 x	8	42 x
less-382	9,561	1,211	8 x	33	37 x
make-3.76.1	24,240	1,893	13 x	21	90 x
wget-1.9	44,092	1,214	36 x	11	110 x
screen-4.0.2	∞	31,324	N/A	767	41 x
a2ps-4.14	∞	3,200	N/A	40	80 x
sendmail-8.13.6	∞	∞	N/A	744	N/A
nethack-3.3.0	∞	∞	N/A	16,373	N/A
vim60	∞	∞	N/A	23,798	N/A
emacs-22.1	∞	∞	N/A	37,830	N/A
python-2.5.1	∞	∞	N/A	11,039	N/A
linux-3.0	∞	∞	N/A	33,618	N/A
gimp-2.6	∞	∞	N/A	3,874	N/A
ghostscript-9.00	∞	∞	N/A	14,814	N/A

$\text{Interval}_{\text{vanilla}}$: worklist-based analyzer with no optimization
$\text{Interval}_{\text{base}}$: $\text{Interval}_{\text{vanilla}}$ + localization optimization (VMCAI'11)
$\text{Interval}_{\text{sparse}}$: sparse version of $\text{Interval}_{\text{vanilla}}$

Experiment Results

Buffer Overrun Detection with Intervals

Programs	$\text{Interval}_{\text{vanilla}}$	$\text{Interval}_{\text{base}}$	$\text{Spd}\uparrow_1$	$\text{Interval}_{\text{sparse}}$	$\text{Spd}\uparrow_2$
gzip-1.2.4a	772	14	55 x	3	5 x
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tar-1.13	12,947	338	38 x	8	42 x
less-382	9,561	1,211	8 x	33	37 x
make-3.76.1	24,240	1,893	13 x	21	90 x
wget-1.9	44,092	1,214	36 x	11	110 x
screen-4.0.2	∞	31,324	N/A	767	41 x
a2ps-4.14	∞	3,200	N/A	40	80 x
sendmail-8.13.6	∞	∞	N/A	744	N/A
nethack-3.3.0	∞	∞	N/A	16,373	N/A
vim60	∞	∞	N/A	23,798	N/A
emacs-22.1	∞	∞	N/A	37,830	N/A
python-2.5.1	∞	∞	N/A	11,039	N/A
linux-3.0	∞	∞	N/A	33,618	N/A
gimp-2.6	∞	∞	N/A	3,874	N/A
ghostscript-9.00	∞	∞	N/A	14,814	N/A

code size is not the only factor for the running time

Experiment Results

Buffer Overrun Detection with Octagons

Programs	$\text{Octagon}_{\text{vanilla}}$	$\text{Octagon}_{\text{base}}$	$\text{Spd}\uparrow_1$	$\text{Octagon}_{\text{sparse}}$	$\text{Spd}\uparrow_2$
gzip-1.2.4a	2,078	273	8 x	21	13 x
bc-1.06	9,536	1,065	9 x	55	19 x
tar-1.13	∞	9,566	N/A	188	51 x
less-382	∞	16,121	N/A	432	37 x
make-3.76.1	∞	17,724	N/A	331	53 x
wget-1.9	∞	15,998	N/A	288	56 x
screen-4.0.2	∞	∞	N/A	16,433	N/A
a2ps-4.14	∞	∞	N/A	8,566	N/A
sendmail-8.13.6	∞	∞	N/A	64,808	N/A

$\text{Octagon}_{\text{vanilla}}$: worklist-based analyzer with no optimization
$\text{Octagon}_{\text{base}}$: $\text{Octagon}_{\text{vanilla}}$ + localization optimization
$\text{Octagon}_{\text{sparse}}$: sparse version of $\text{Octagon}_{\text{vanilla}}$

Conclusion

Sparse analysis makes sound static analysis scalable

Questions?

for technical details:
http://ropas.snu.ac.kr/~wclee/papers/pldi12b.pdf