CSCI 742 - Compiler Construction

Lecture 34

Available Expressions Analysis

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Recap: Live Variable Analysis

- Compute which variables are live at each program point
- Live variable information flows backward
- Derive a system of constraints between live variable sets

$$\mathit{in}(S) = \big(\mathit{out}(S) \setminus \mathit{def}(S)\big) \ \cup \ \mathit{use}(S)$$
$$\mathit{out}(S) = \bigcup_{S_i \in \mathit{succ}(S)} \mathit{in}(S_i)$$

- Solve constraints in an iterative algorithm

Available Expressions

Idea: some computation may be a redundant repetition of earlier computation within the same program

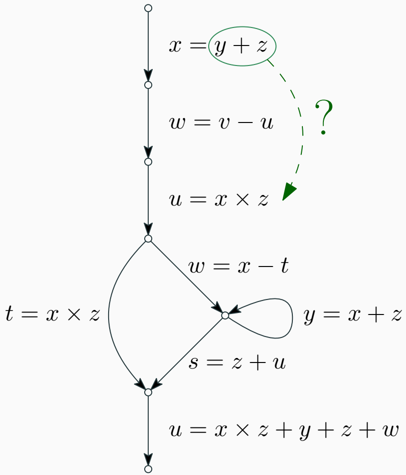
An expression like `x+y` is available at a statement S if

- Every path from the entry node to S compute `x+y` before reaching S
- There are no assignments to `x` or `y` since the last time `x+y` was computed on the paths to S

Optimization: If an expression is available, don't need to recompute it

Example: Available Expression

- Is the expression available?



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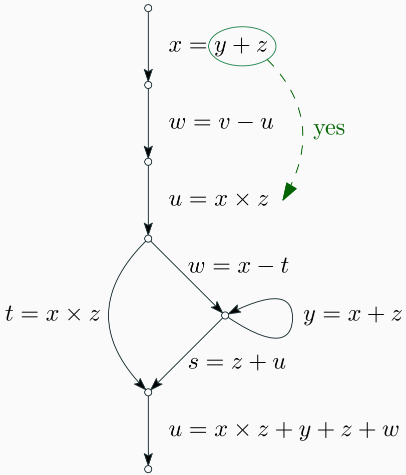

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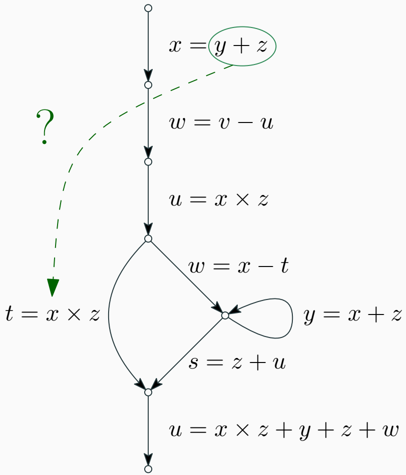

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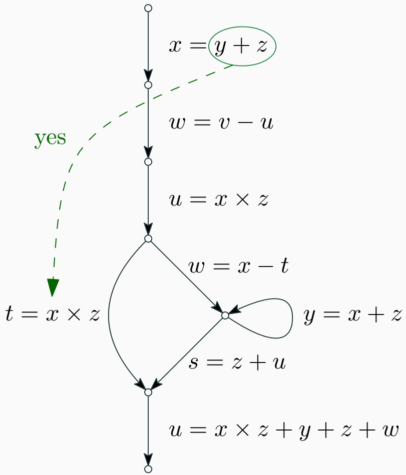

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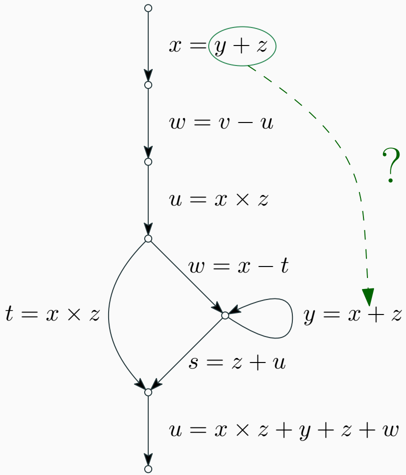

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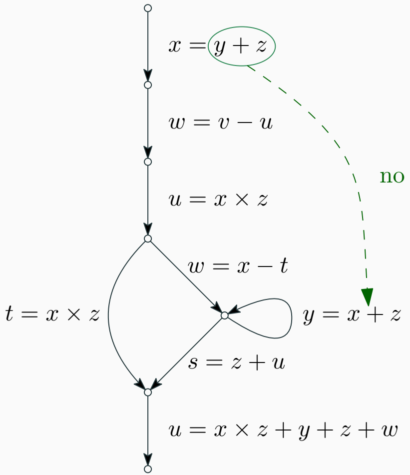

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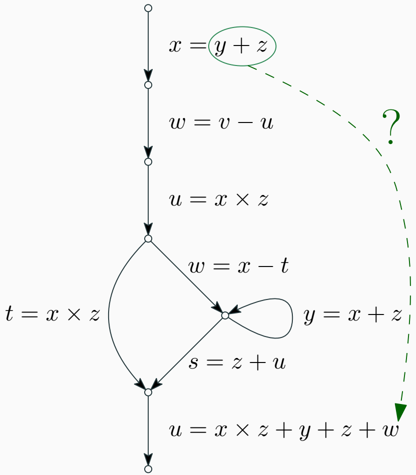

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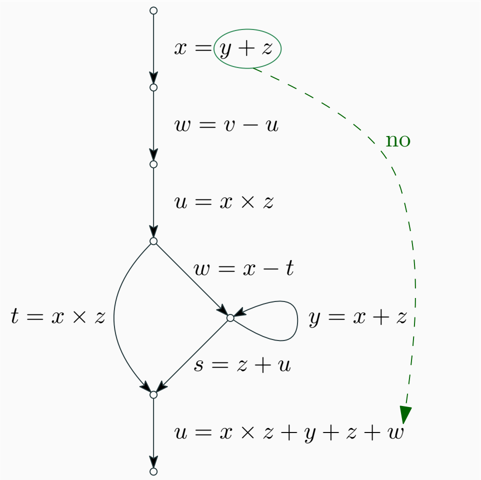

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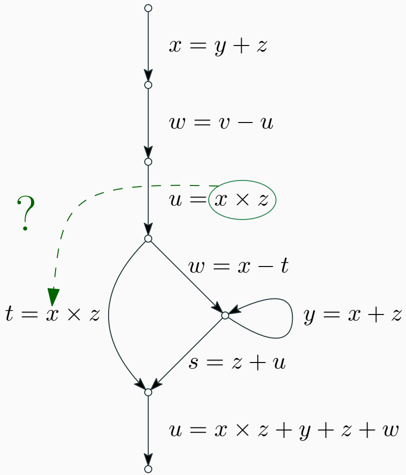

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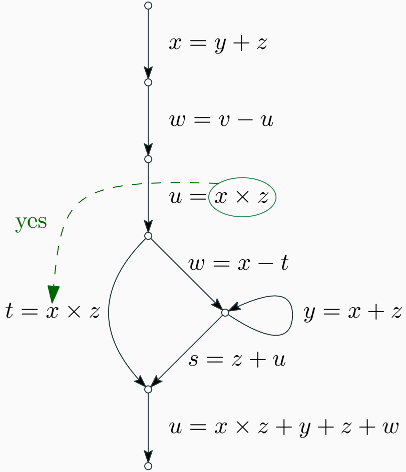

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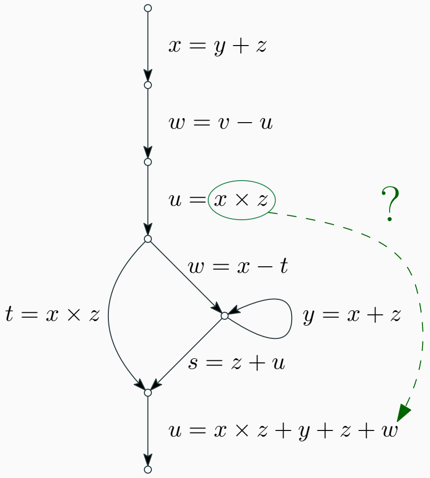

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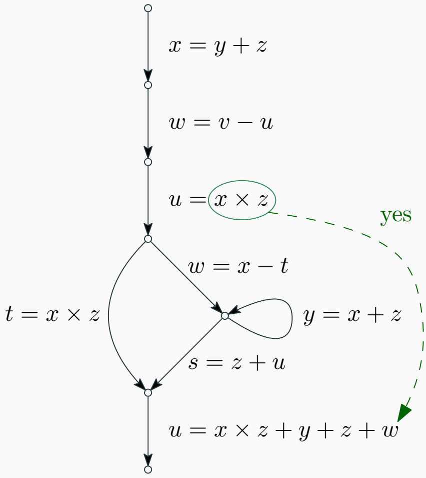

Example: Available Expression

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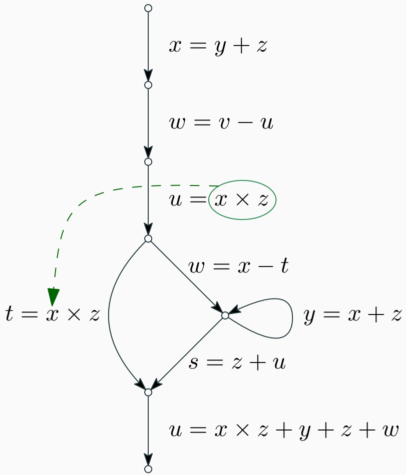

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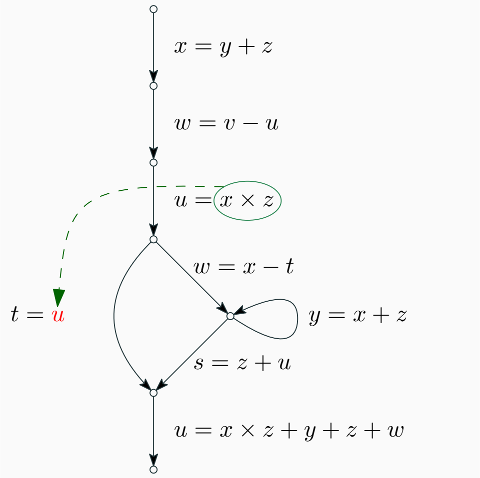

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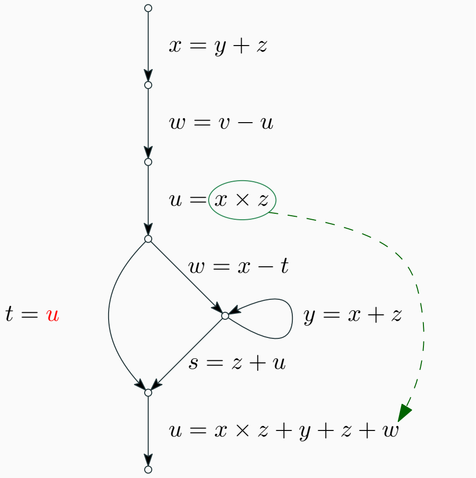

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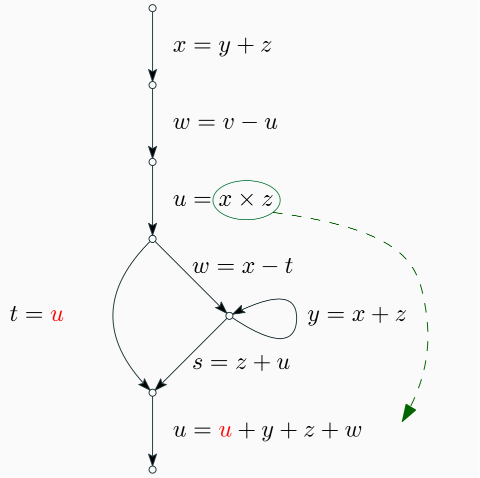
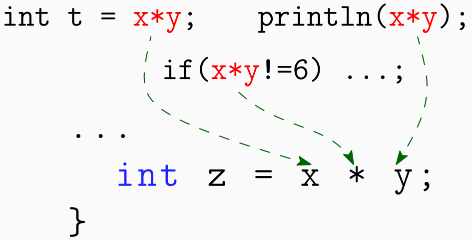


Available Expression Analysis: Forward

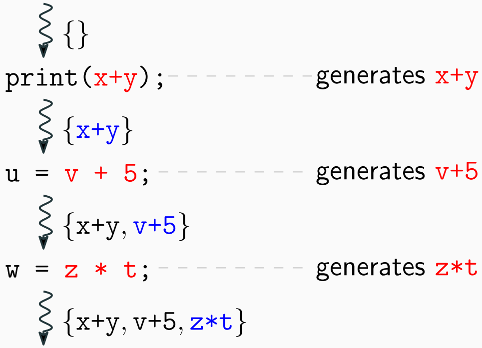
- Available expression analysis is a **forward** data-flow analysis
- Information from past instructions must be propagated forward through the program to discover which expressions are available



- Unlike variable liveness, expression availability flows forward through the program
- Like liveness, each instruction has an effect on the availability information as it flows past

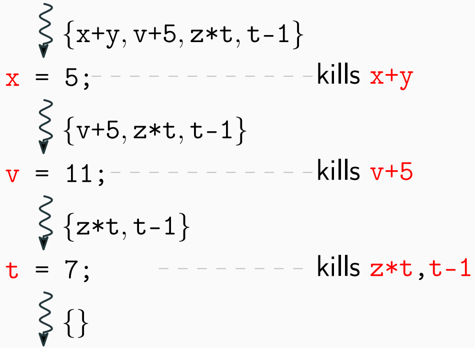
Available Expression Analysis

- A statement makes an expression **available** when it generates (computes) its current value



Available Expression Analysis

- A statement makes an expression **unavailable** when it kills (invalidates) its current value



Available Expression Analysis

- As in Live Variable Analysis, we create functions *gen*(S) and *kill*(S) which give the sets of expressions the statement S generates and kills
- Assignment to a variable $\mathtt{x}$ kills all expressions in the program which contain occurrences of $\mathtt{x}$ ($E_{\mathtt{x}}$)

$\{\mathtt{y-1}\}$

gen(`println(x+5)`) $= \{$ `x+5` $\}$

$\{\mathtt{y-1}, \mathtt{x+5}\}$

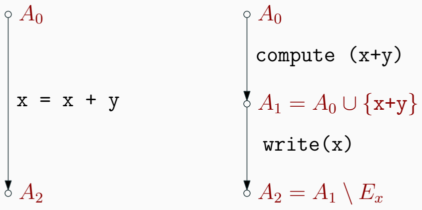
$\{\mathtt{y-1}, \mathtt{x+5}\}$

kill(`x = 3`) $= \{ E_{\mathtt{x}} \}$

$\{\mathtt{y-1}\}$

Available Expression Analysis

- If a statement both generates and kills expressions, remove the killed expressions after adding the generated ones



$\textit{gen}(\texttt{x = x + y}) = \{\texttt{x+y}\}$ $\textit{kill}(\texttt{x = x + y}) = \{\, E_{\texttt{x}} \,\}$

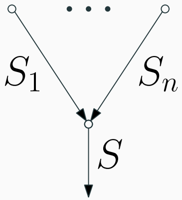
In general:

- $\textit{in}(S)$: set of available expressions immediately before statement S
- $\textit{out}(S)$: set of available expressions immediately after statement S

$$\textit{out}(S) = \big(\textit{in}(S) \cup \textit{gen}(S)\big) \ \setminus \ \textit{kill}(S)$$

Multiple Successors

- An expression is available at beginning of statement S if it is available at the end of all predecessor statements



$$\textit{in}(S) = \bigcap_{S_i \in \textit{pred}(S)} \textit{out}(S_i)$$

Data-flow Equations

- Start with CFG and derive a system of constraints between sets of available expressions

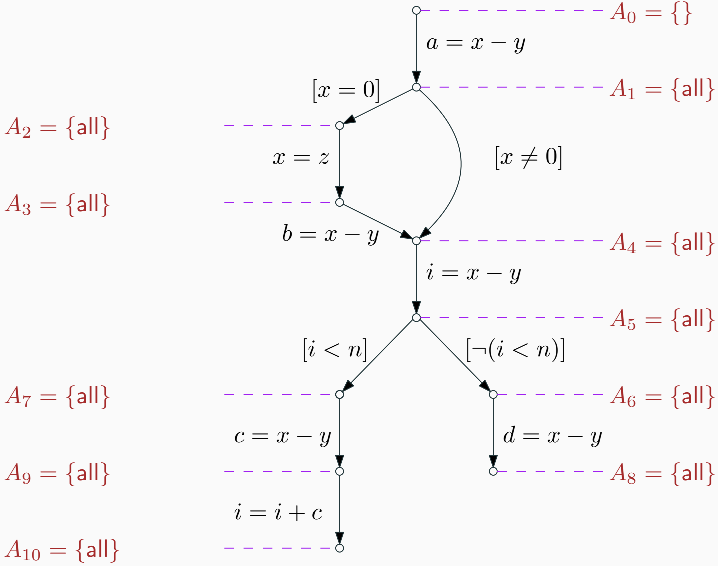
$$\mathit{out}(S) = \big(\mathit{in}(S) \cup \mathit{gen}(S)\big) \ \setminus \ \mathit{kill}(S)$$
$$\mathit{in}(S) = \bigcap_{S_i \in \mathbf{pred}(S)} \mathit{out}(S_i)$$

Solve constraints:

- Start with empty set of available expressions at start and universal set of available expressions everywhere else
- Iteratively apply constraints
- Stop when we reach a fixed point

Exercise

Compute the set of available expressions at each point of the program



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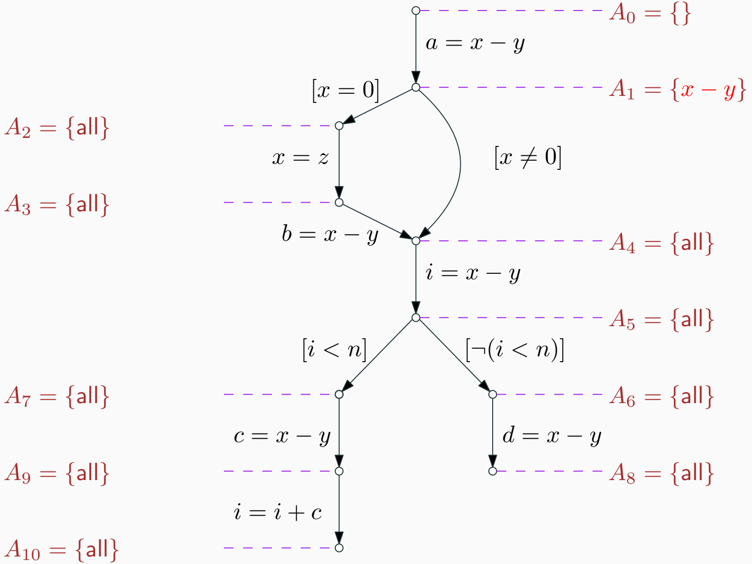

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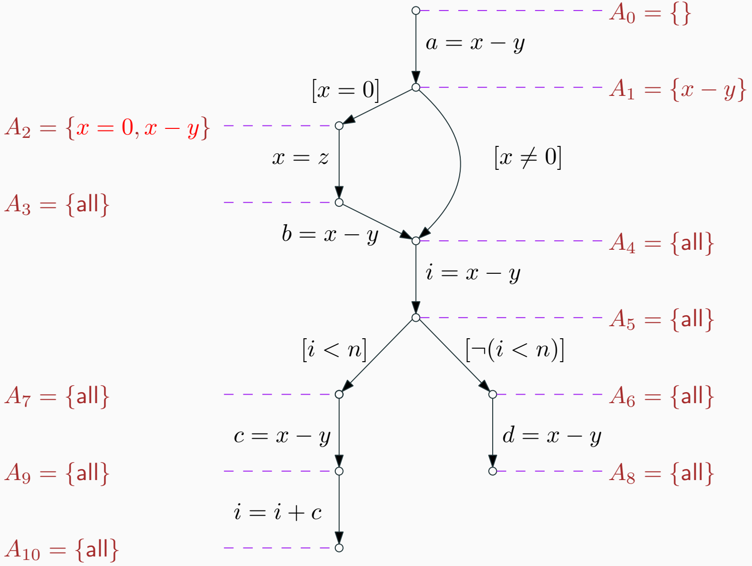

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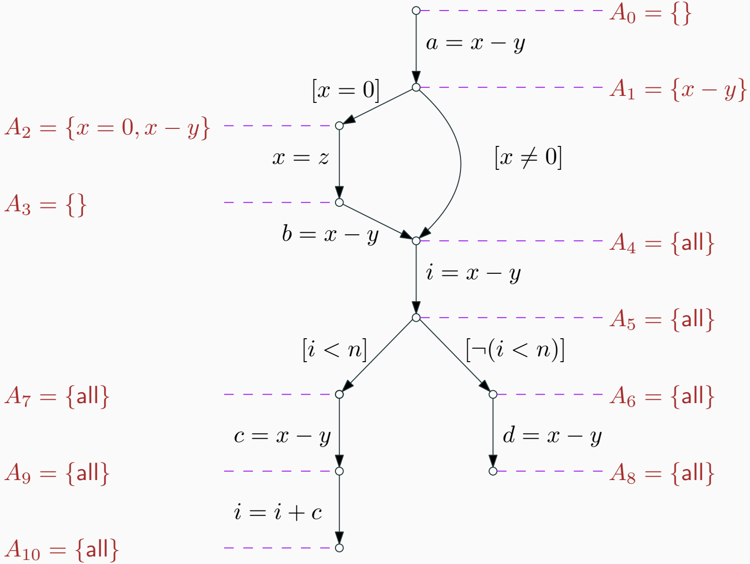

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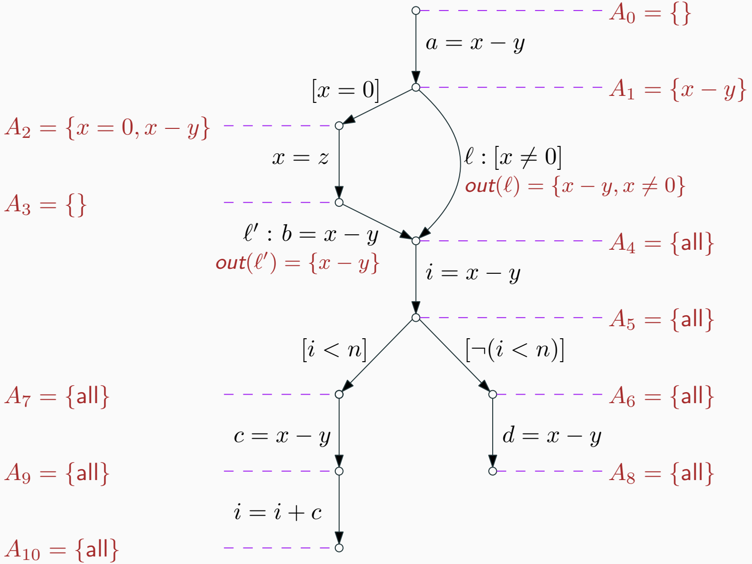

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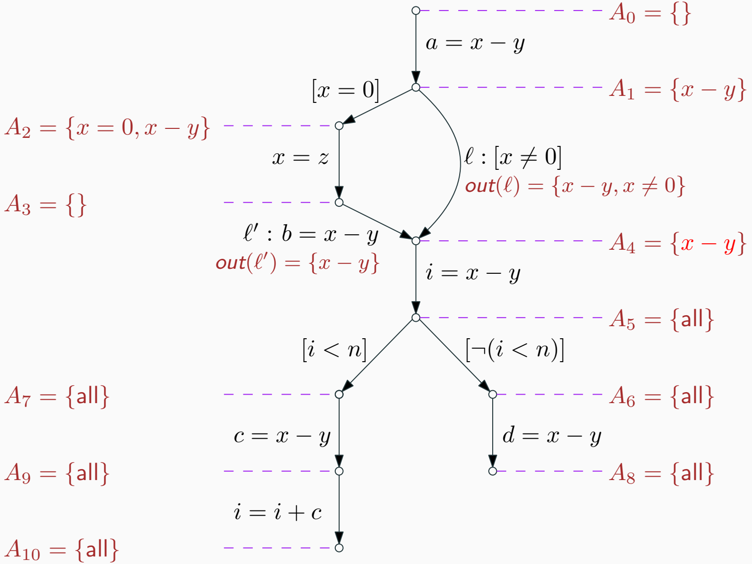

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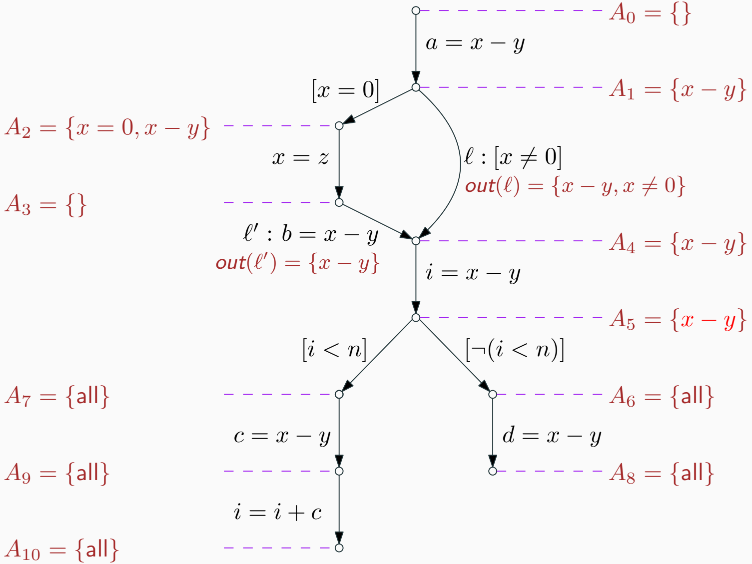

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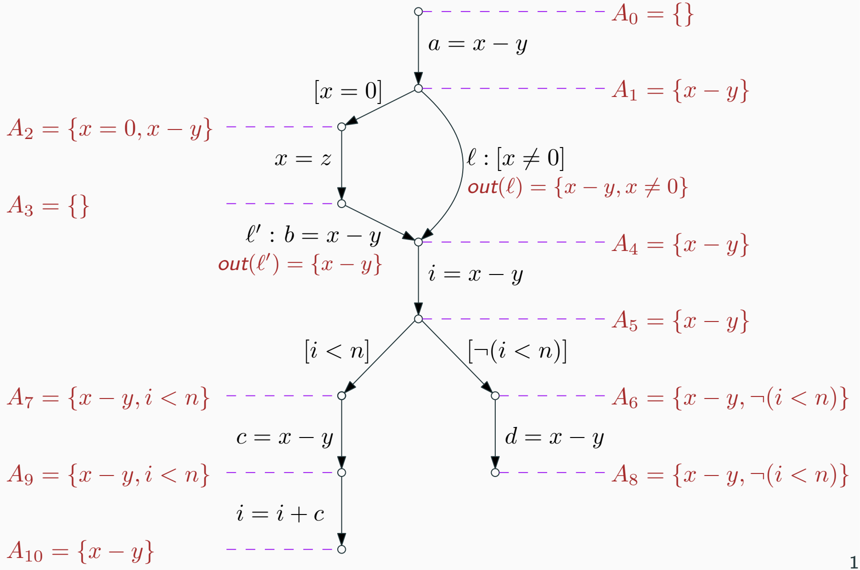

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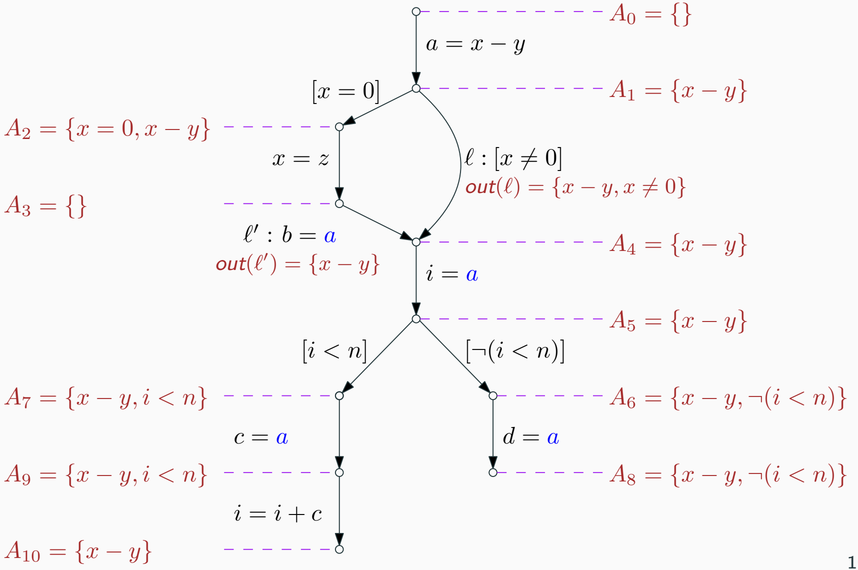

Data-flow Equations Comparison

Live Variable Analysis

$$\textit{in-live}(S) = \big(\textit{out-live}(S) \setminus \textit{def}(S)\big) \;\cup\; \textit{use}(S)$$
$$\textit{out-live}(S) = \bigcup_{S_i \in \textit{succ}(S)} \textit{in-live}(S_i)$$

Available Expression Analysis

$$\textit{out-avail}(S) = \big(\textit{in-avail}(S) \cup \textit{gen}(S)\big) \;\setminus\; \textit{kill}(S)$$
$$\textit{in-avail}(S) = \bigcap_{S_i \in \textit{pred}(S)} \textit{out-avail}(S_i)$$