

# Exam Questions

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TEACHING ASSISTANT: DAVID TRABISH

# Question

The program contains a string constant.

compiler construction

compiling

linking

runtime

# Question

The program contains a string constant.

compiler construction

compiling

linking

runtime

# Question

Every time the command  $x = y + 42$  is executed, the value of  $y$  is 0.

compiler construction

compiling

linking

runtime

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Every time the command  $x = y + 42$  is executed, the value of  $y$  is 0.

compiler construction

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linking

runtime

# Question

All the variable names start with x.

compiler construction

compiling

linking

runtime

# Question

All the variable names start with x.

compiler construction

compiling

linking

runtime

# Question

The program contains a nested loop.

compiler construction

compiling

linking

runtime



# Question

The program contains a nested loop.

compiler construction

compiling

linking

runtime

# Question

The program contains a string constant with at least 200 characters.

compiler construction

compiling

linking

runtime

# Question

The program contains a string constant with at least 200 characters.

compiler construction

compiling

linking

runtime

# Question

The size of the stack exceeds 400 bytes.

compiler construction

compiling

linking

runtime

# Question

The size of the stack exceeds 400 bytes.

compiler construction

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# Question

The only method invocations are of methods which are located at offset 4 in the virtual table.

compiler construction

compiling

linking

runtime

# Question

The only method invocations are of methods which are located at offset 4 in the virtual table.

compiler construction

compiling

linking

runtime

# Question

There is an addition operation which is never executed in any run.

compiler construction

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# Question

There is an addition operation which is never executed in any run.

compiler construction

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runtime

# LR(0) Item

An LR(0) item with the dot at the end is called **reduce** item:

- $N \rightarrow \alpha\beta.$

Otherwise, it's a **shift** item:

- $N \rightarrow .\alpha\beta$
- $N \rightarrow \alpha.\beta$

# LR(0) Item Closure Set

The LR(0) closure set of an LR(0) item  $i$  is a set  $S$  such that:

- $i \in S$
- If  $A \rightarrow \alpha.N\beta \in S$  then for each rule  $N \rightarrow \gamma$ :
  - $N \rightarrow.\gamma \in S$

# SLR(1)

- Same push-down automaton as in LR(0)
- But reduce items has a look-ahead set
  - $A \rightarrow \alpha. \{t_1, t_2, \dots\}$
  - where  $Follow(A) = \{t_1, t_2, \dots\}$

# LR(1)

An LR(1) item is of the form:

- $N \rightarrow \alpha.\beta \{\sigma\}$
- where  $\sigma = t_1, t_2, \dots$  (terminals)

# LR(1) Item Closure Set

The **LR(1) closure set** of an LR(1) item  $i$  is a set  $S$  such that:

- $i \in S$
- If  $A \rightarrow \alpha.N\beta \{ \sigma \} \in S$  then for each rule  $N \rightarrow \gamma$ :
  - $N \rightarrow .\gamma \{ \tau \} \in S$ , where  $\tau = First(\beta, \{ \sigma \})$

Definition for  $First(\beta, \{ \sigma \})$ :

- If  $\beta$  is not nullable:
  - $First(\beta)$
- Otherwise:
  - $(First(\beta) \cup \{ \sigma \}) \setminus \{ \epsilon \}$

# Question

Is the following CFG LR(0) / SLR(1) / LR(1)?

- $S \rightarrow A\$$
- $A \rightarrow Axx$
- $A \rightarrow x$

**$s_0$ :**

$S \rightarrow .A\$$

$A \rightarrow .Axx$

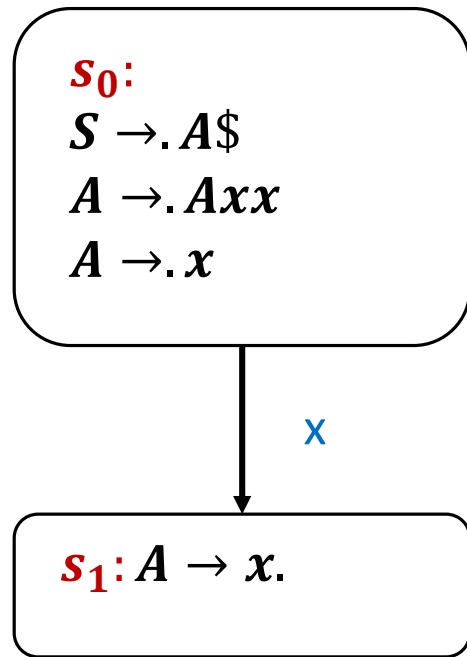
$A \rightarrow .x$

$S \rightarrow A\$$

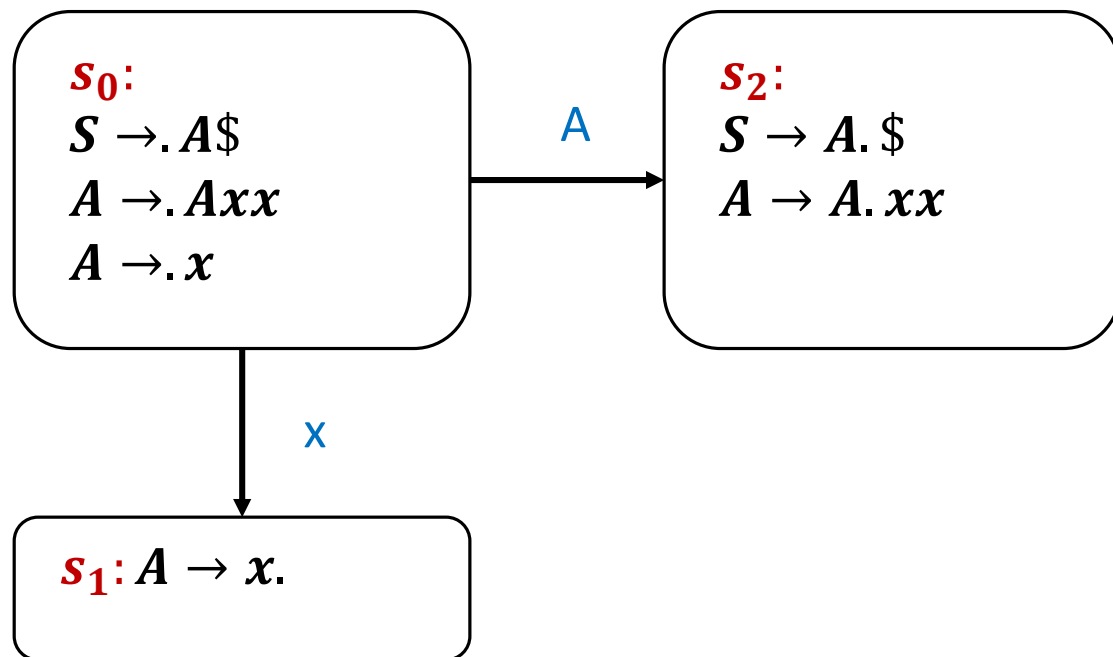
$A \rightarrow Axx$

$A \rightarrow x$

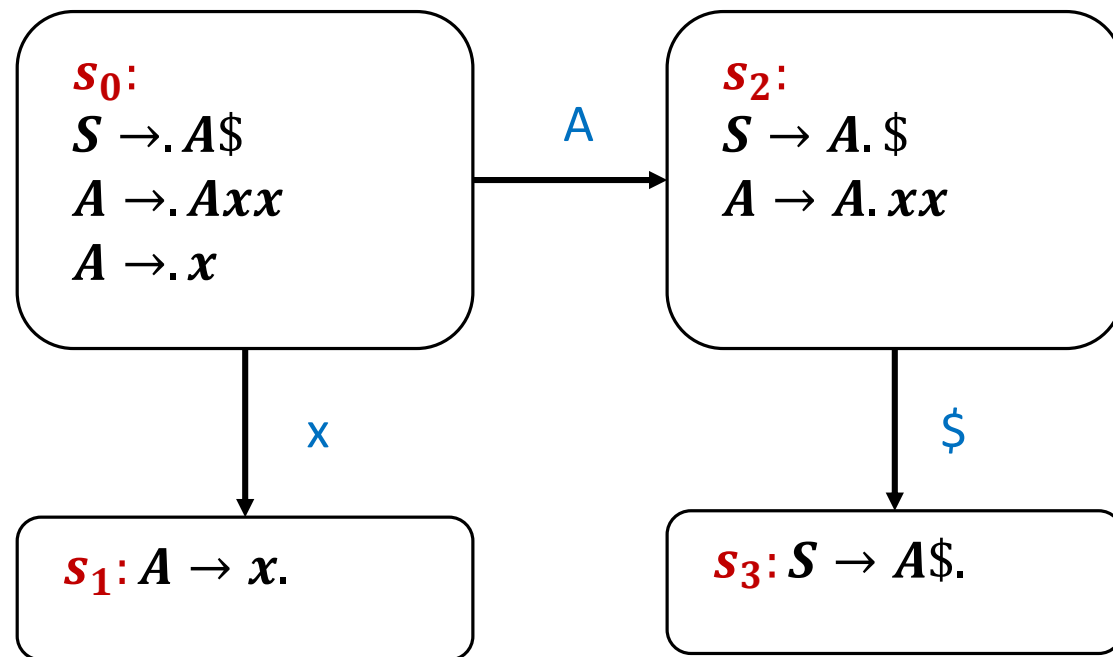




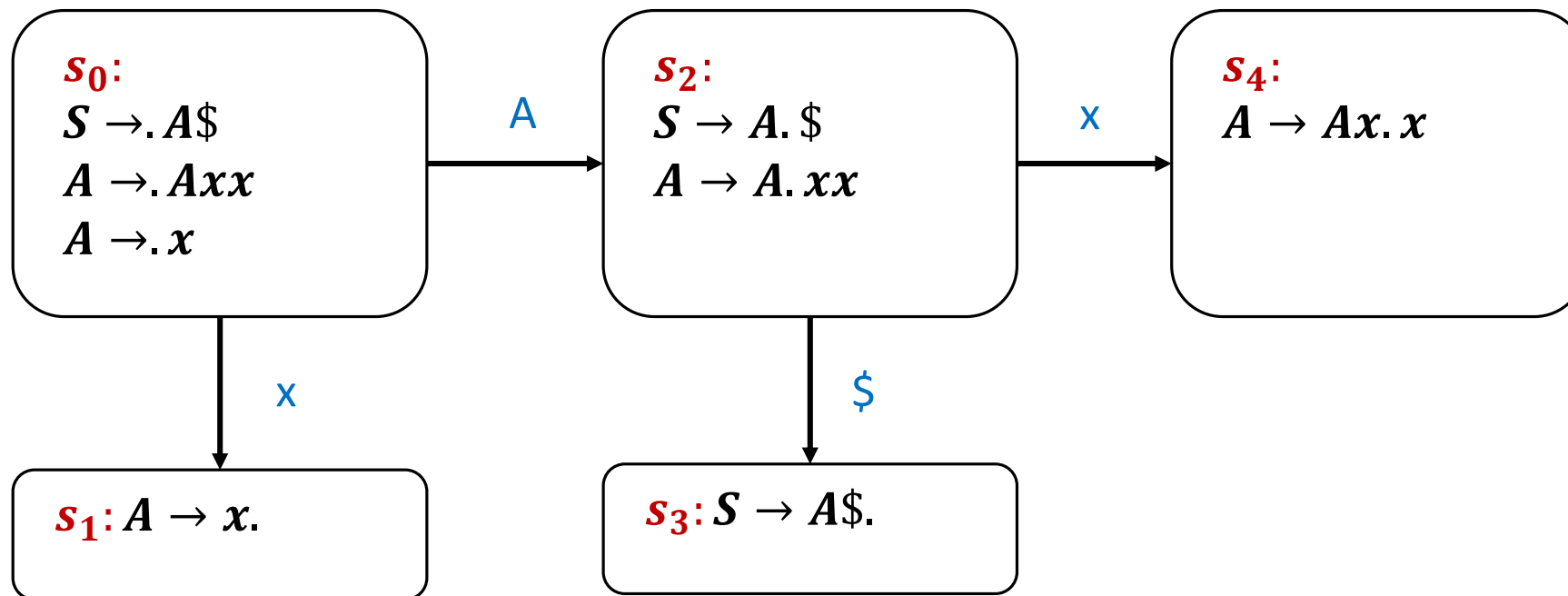
$S \rightarrow A \$$   
 $A \rightarrow A x x$   
 $A \rightarrow x$



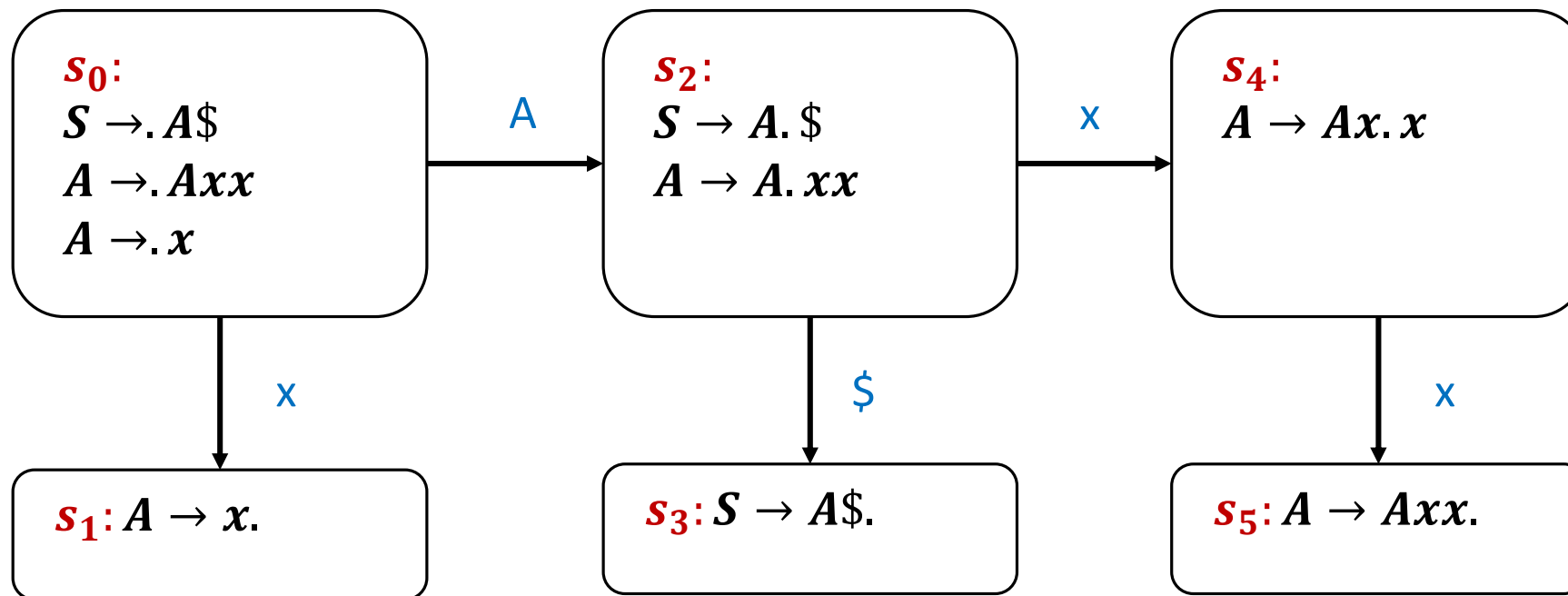
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$S \rightarrow A \$$   
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 $A \rightarrow A x x$   
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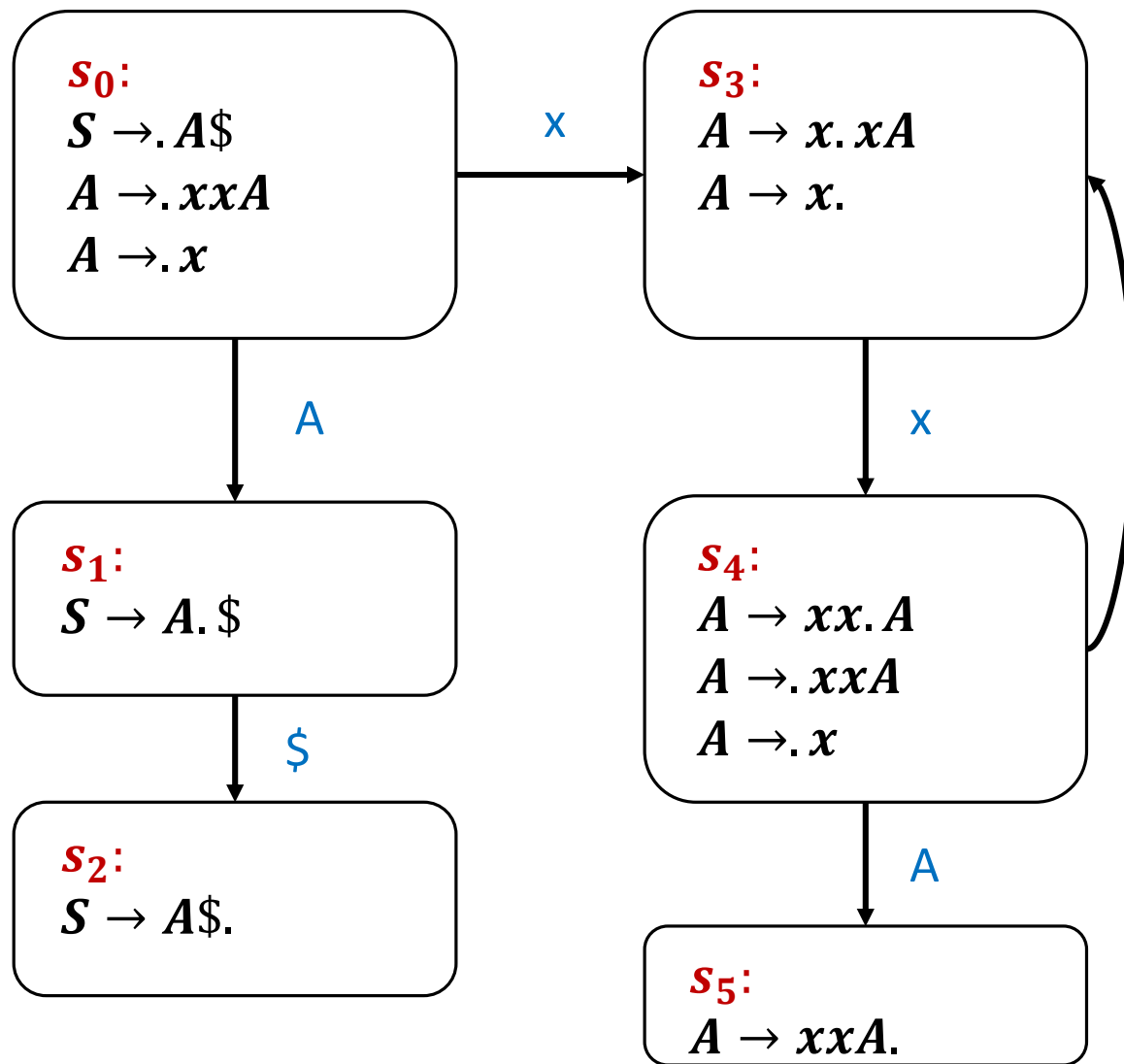


$S \rightarrow A \$$   
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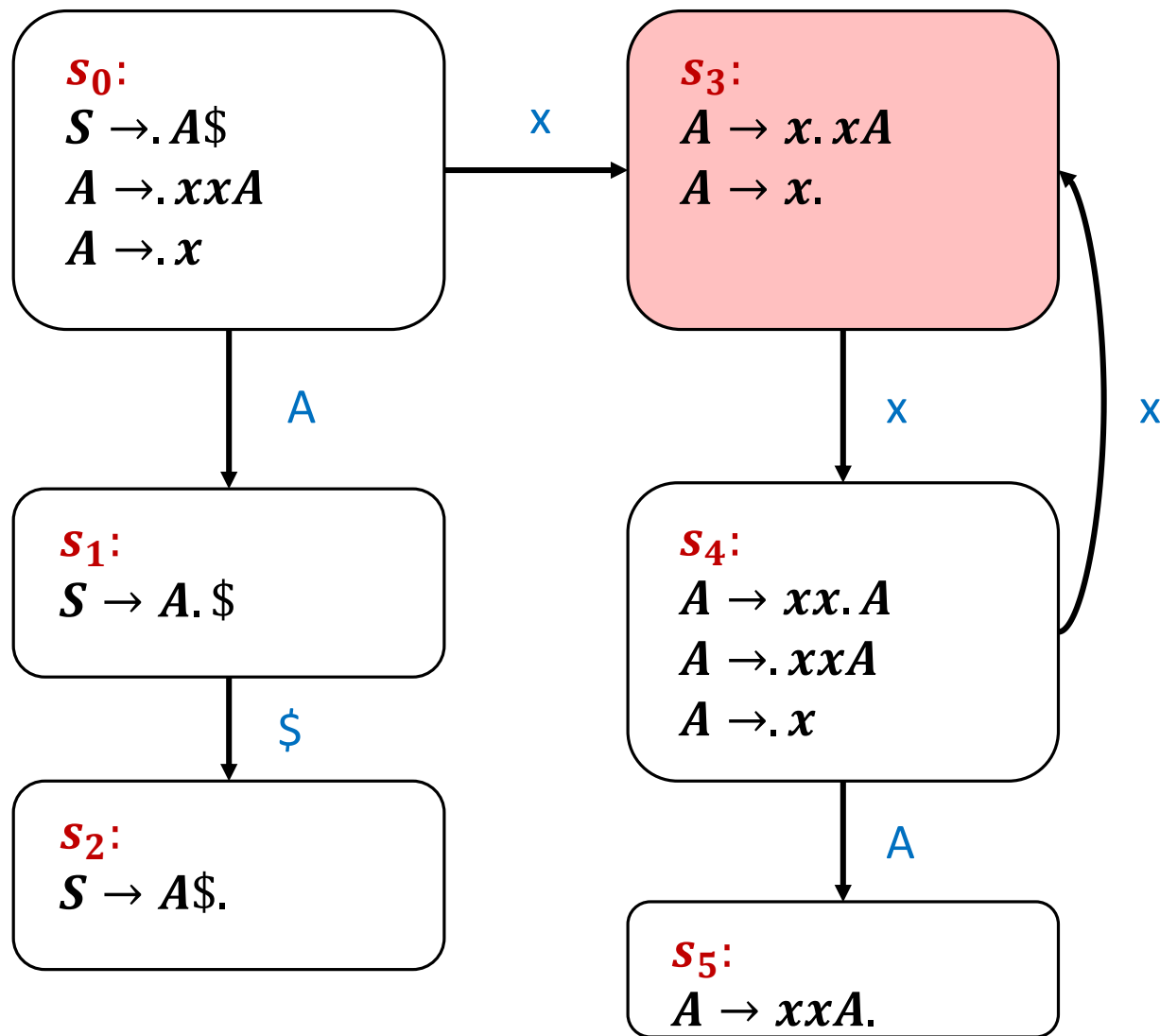
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- $A \rightarrow xxA$
- $A \rightarrow x$

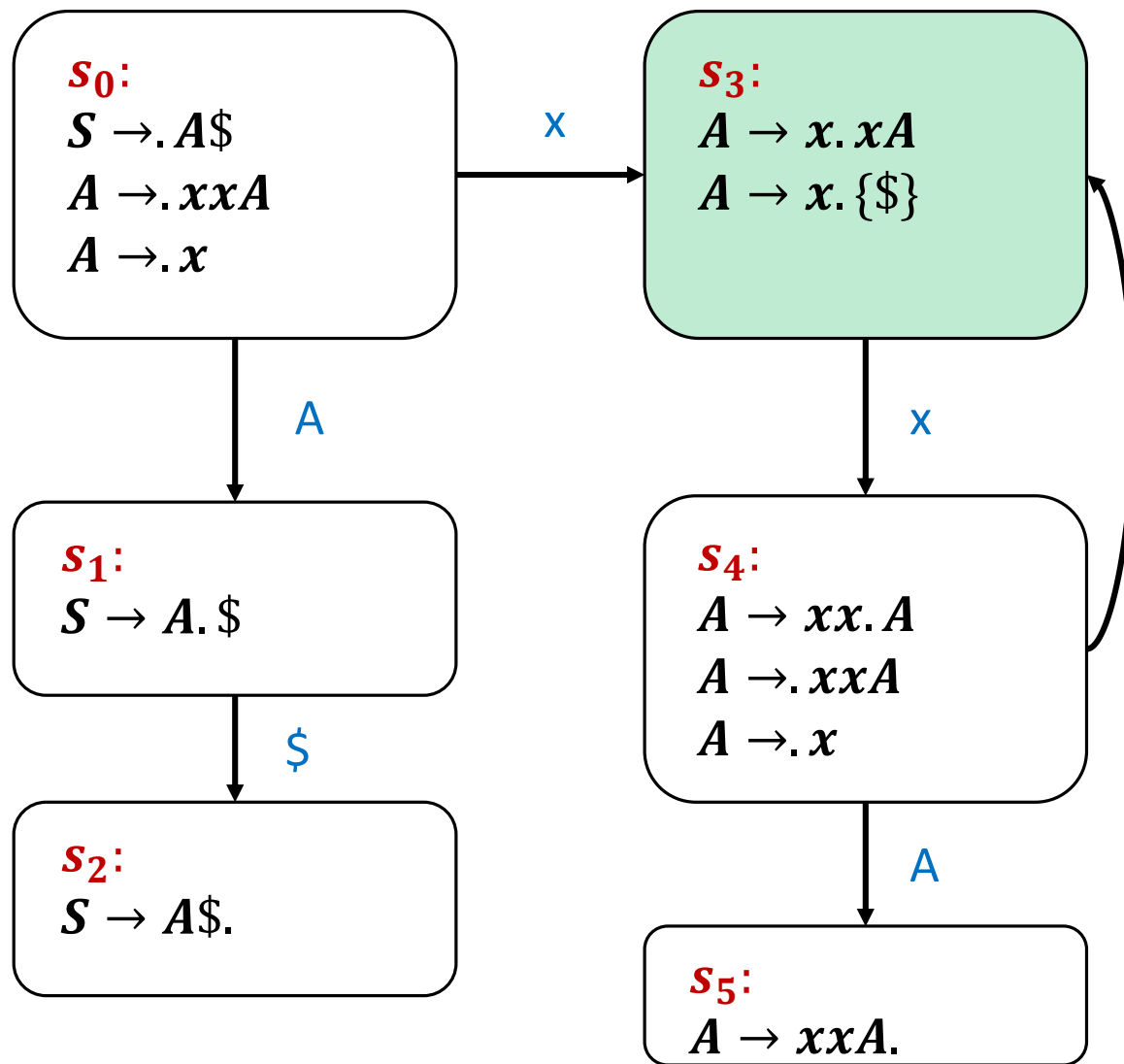


$S \rightarrow A \$$   
 $A \rightarrow xx A$   
 $A \rightarrow x$



$S \rightarrow A \$$   
 $A \rightarrow xx A$   
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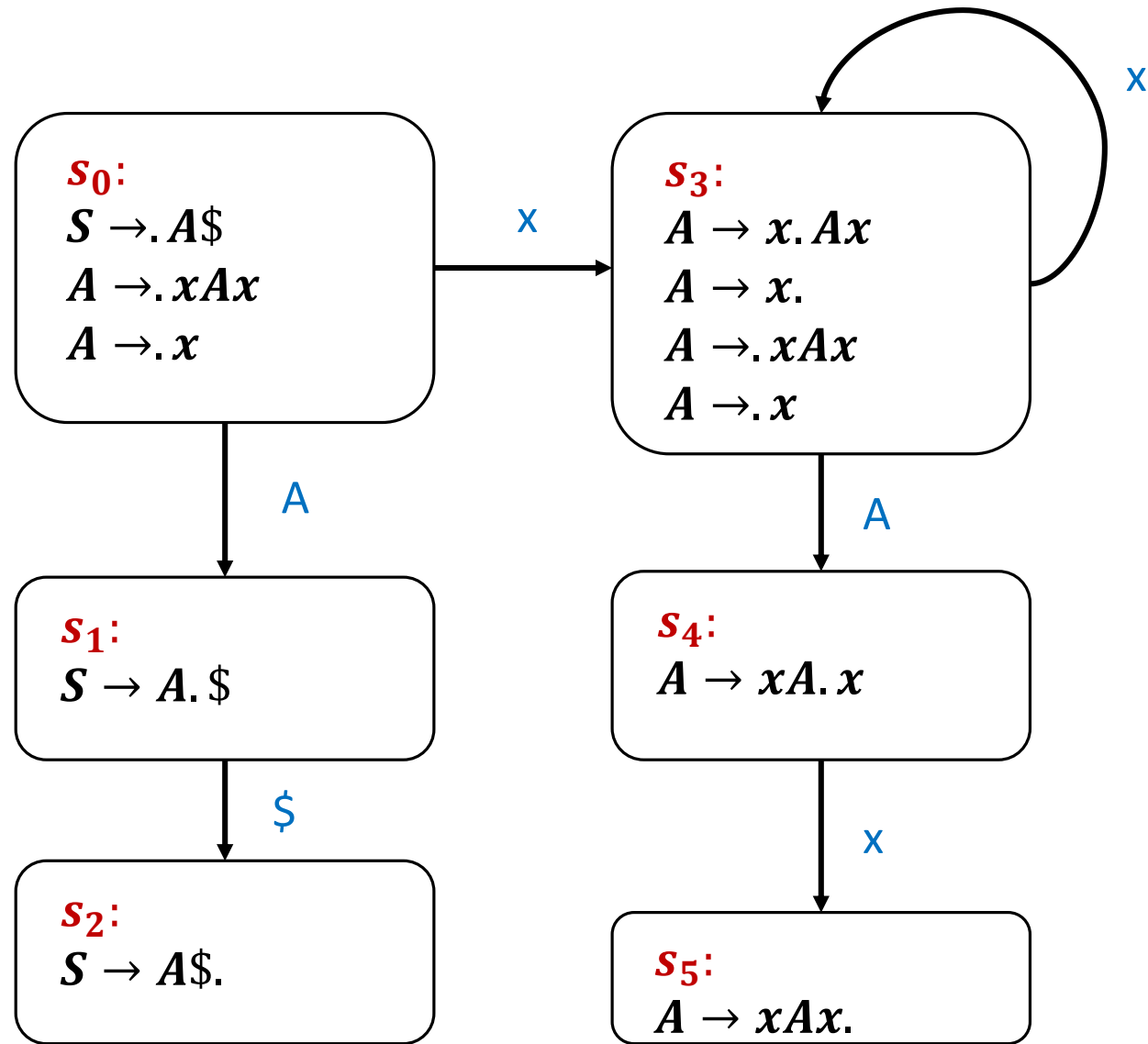
$Follow(A) = \{ \$ \}$

$S \rightarrow A \$$   
 $A \rightarrow x x A$   
 $A \rightarrow x$

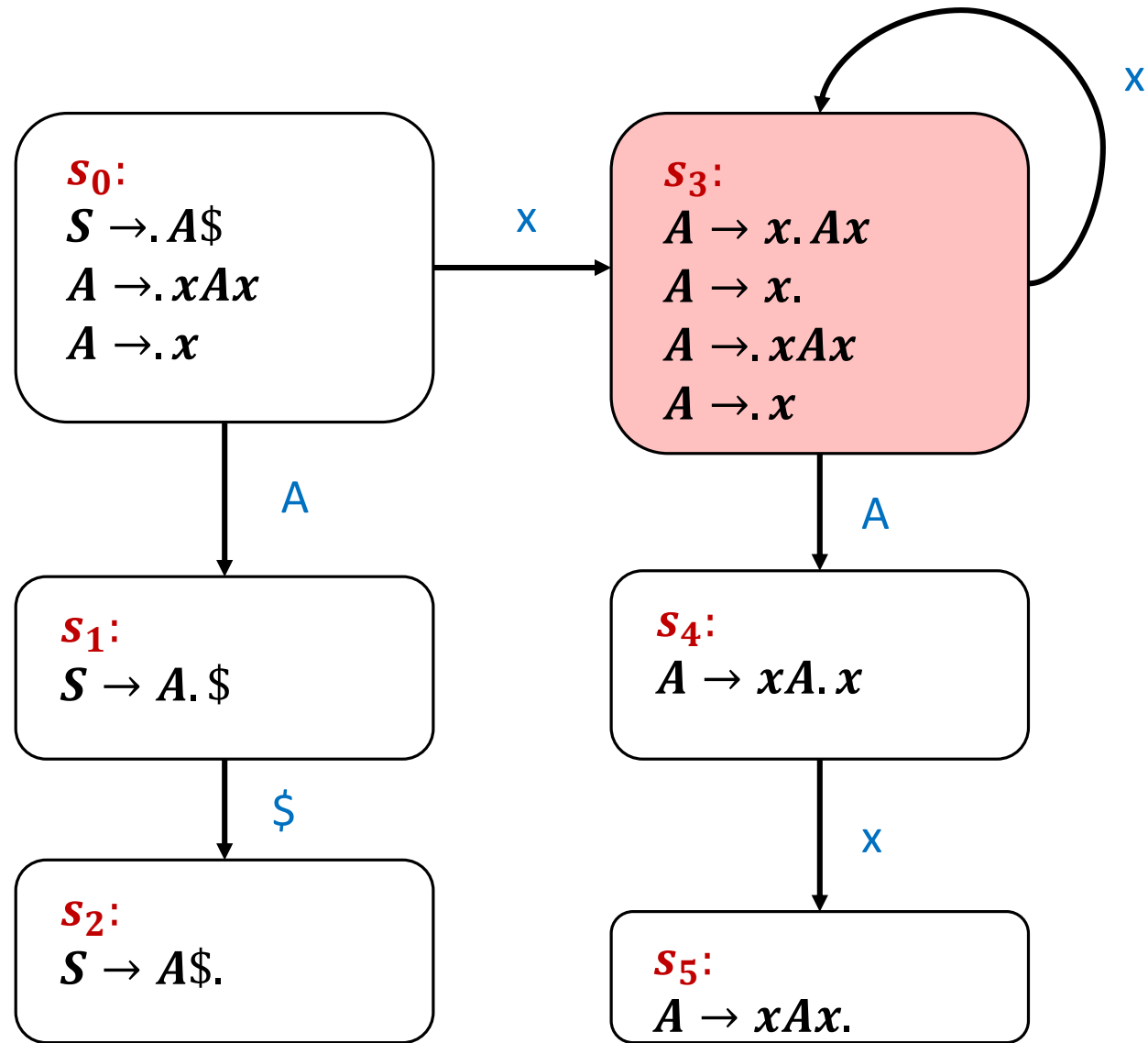
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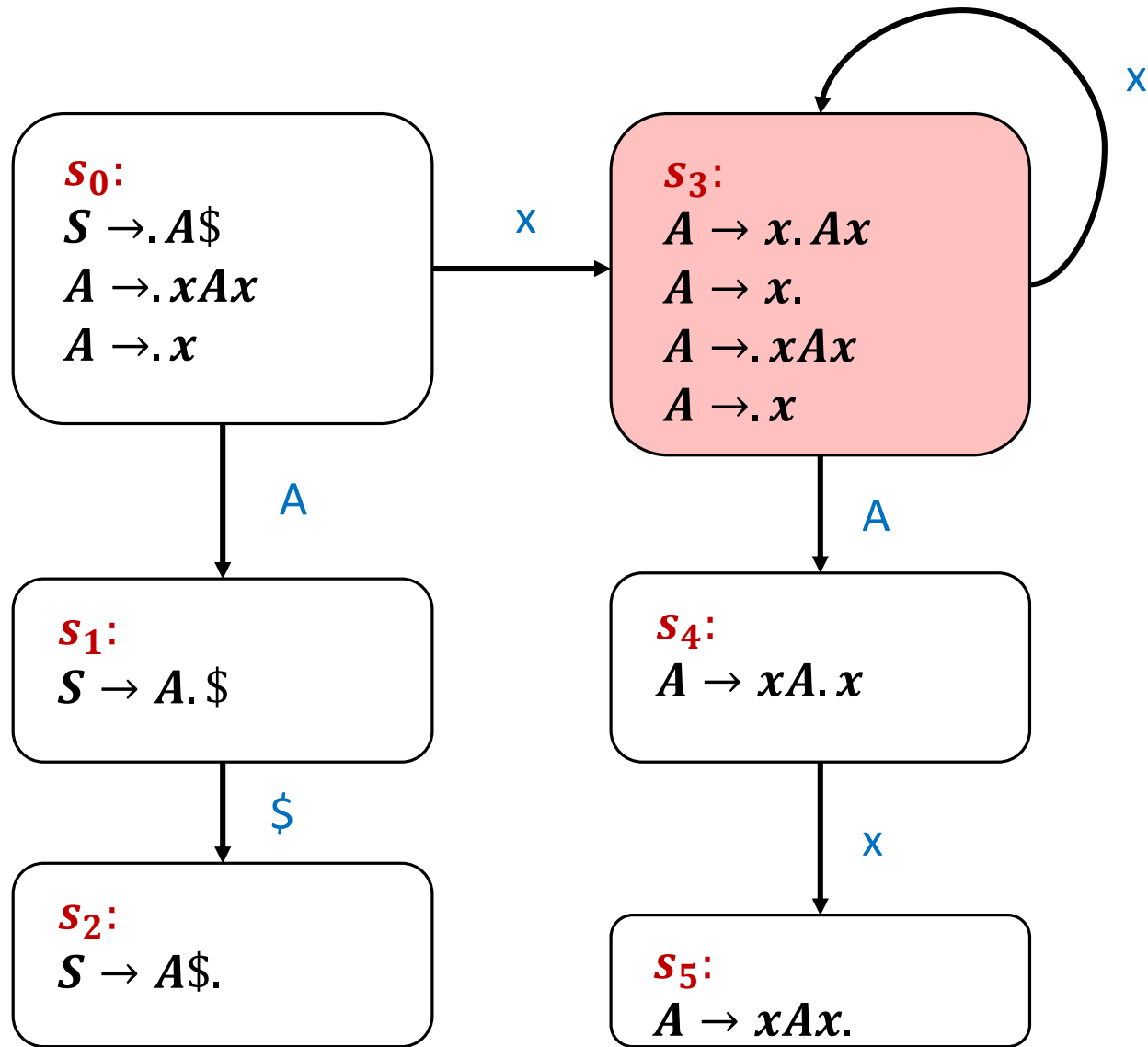
- $S \rightarrow A\$$
- $A \rightarrow xAx$
- $A \rightarrow x$



$S \rightarrow A \$$   
 $A \rightarrow x A x$   
 $A \rightarrow x$



$S \rightarrow A \$$   
 $A \rightarrow x A x$   
 $A \rightarrow x$



$$\text{Follow}(A) = \{\$, x\}$$

$S \rightarrow A \$$   
 $A \rightarrow x A x$   
 $A \rightarrow x$

**$s_0$ :**

$S \rightarrow .A\$ \{\$ \}$

$A \rightarrow .xAx \{\$ \}$

$A \rightarrow .x \{\$ \}$

$S \rightarrow A\$$

$A \rightarrow xAx$

$A \rightarrow x$

**$s_0$ :**

$S \rightarrow \cdot A \$ \{ \$ \}$

$A \rightarrow \cdot x A x \{ \$ \}$

$A \rightarrow \cdot x \{ \$ \}$

$A$

**$s_1$ :**

$S \rightarrow A \cdot \$ \{ \$ \}$

$S \rightarrow A \$$

$A \rightarrow x A x$

$A \rightarrow x$

**$s_0$ :**  
 $S \rightarrow \cdot A \$ \{ \$ \}$   
 $A \rightarrow \cdot x A x \{ \$ \}$   
 $A \rightarrow \cdot x \{ \$ \}$



$A$

**$s_1$ :**  
 $S \rightarrow A \cdot \$ \{ \$ \}$

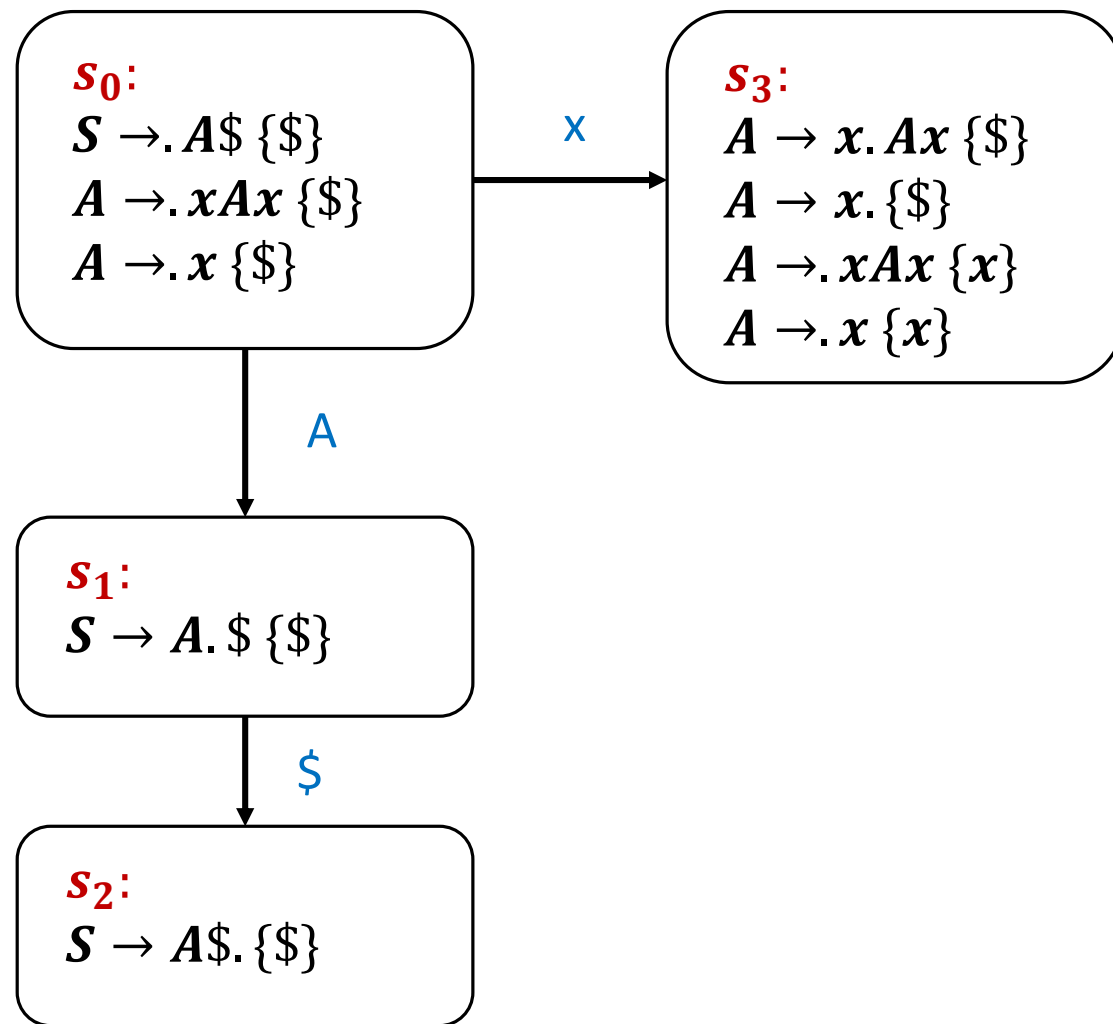


$\$$

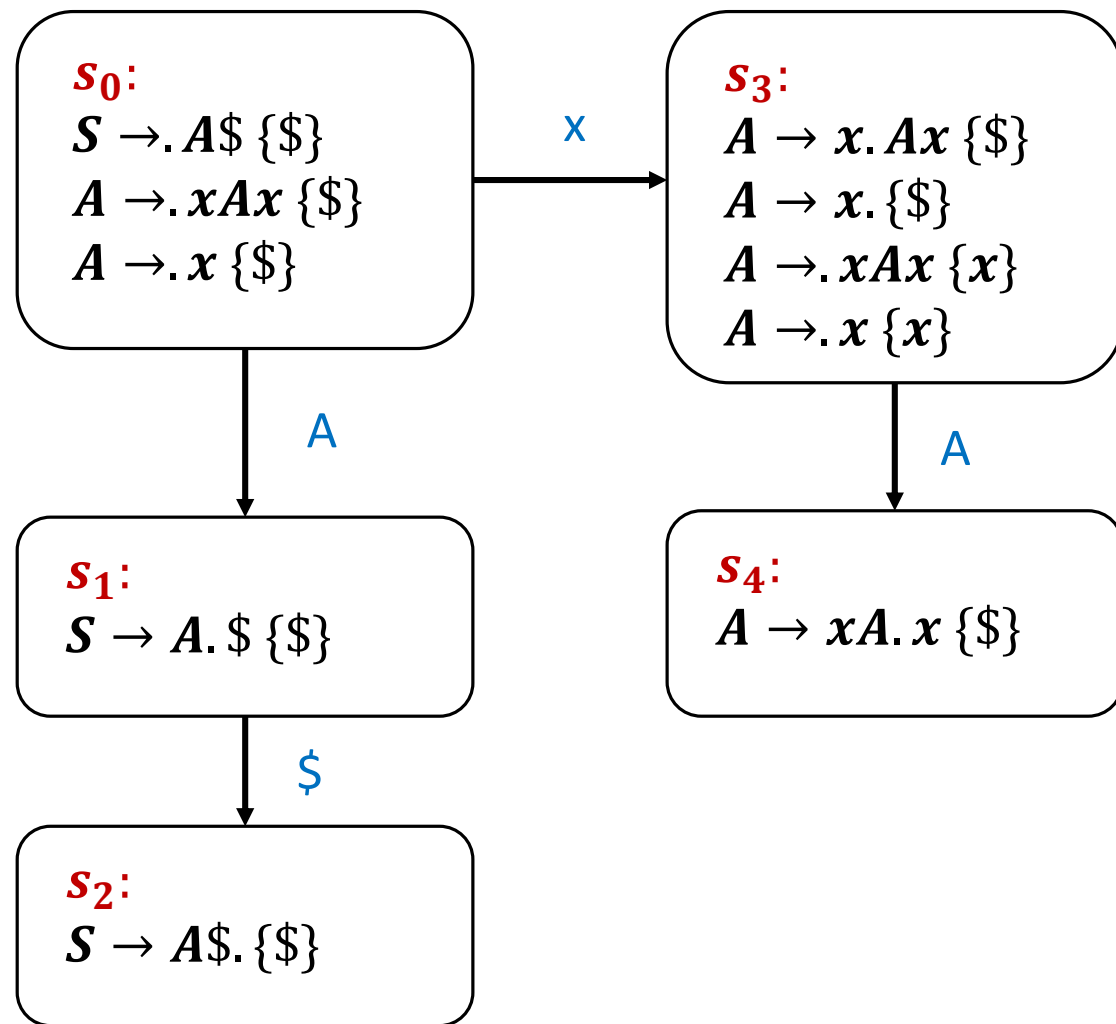
**$s_2$ :**  
 $S \rightarrow A \$ \cdot \{ \$ \}$

$S \rightarrow A \$$   
 $A \rightarrow x A x$   
 $A \rightarrow x$

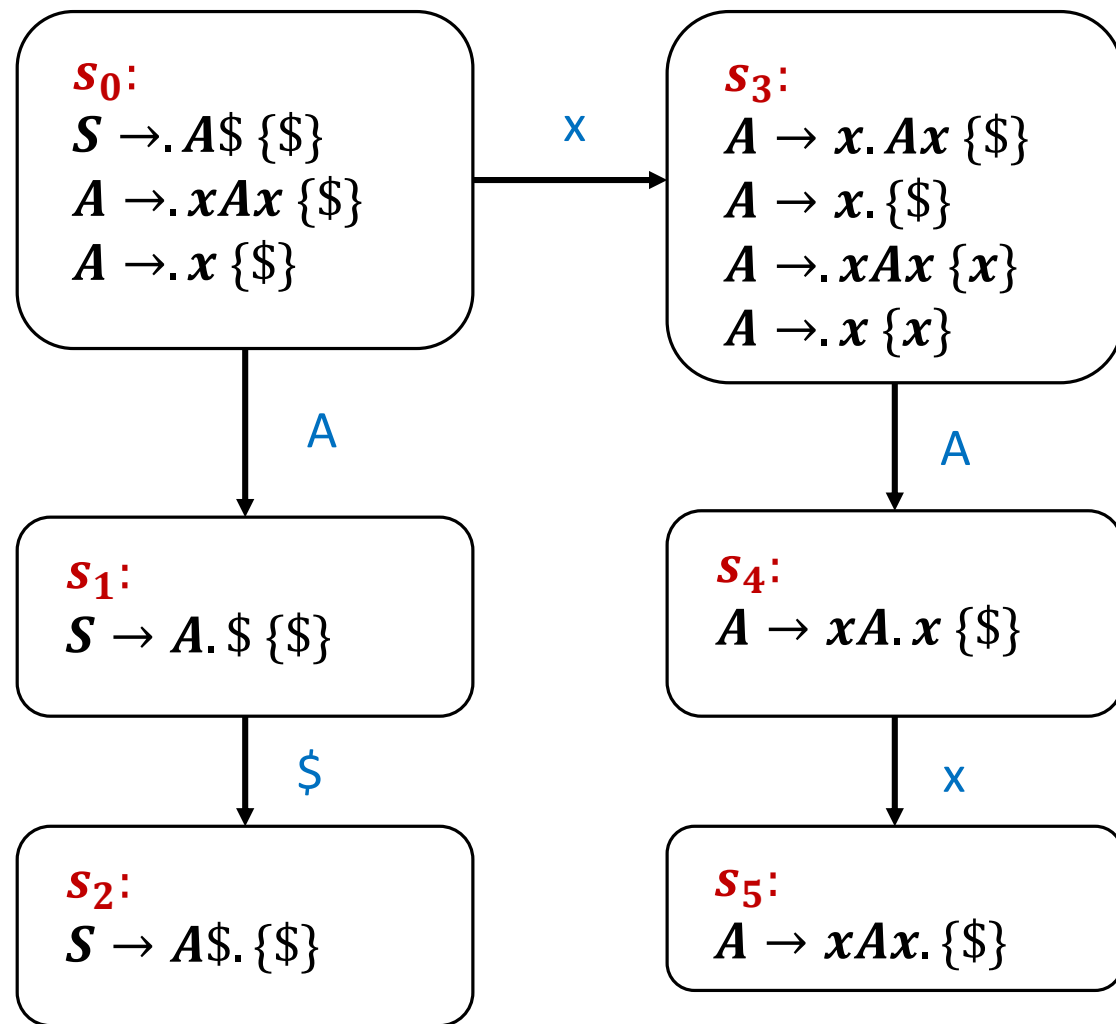




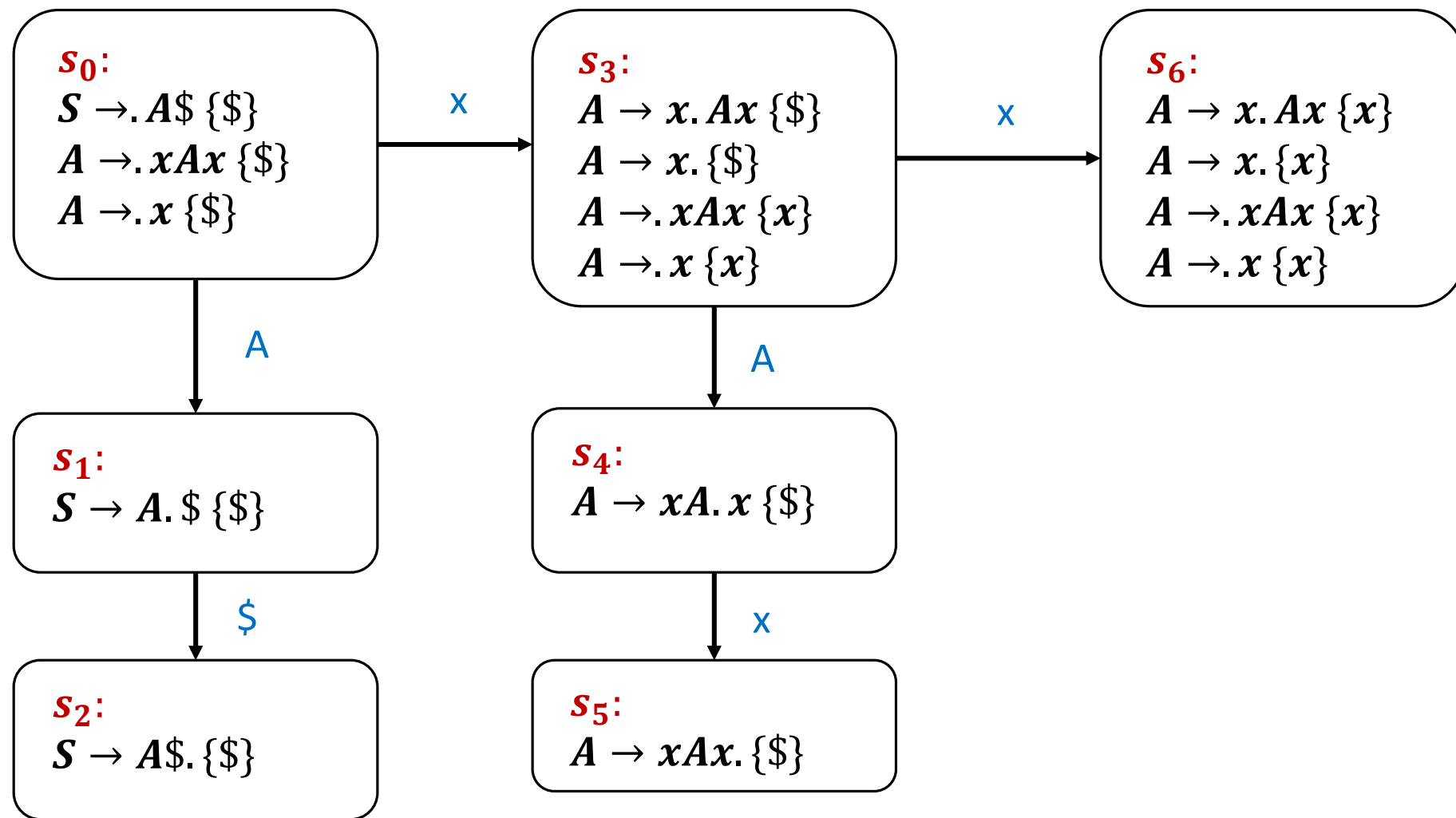
$S \rightarrow A \$$   
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 $A \rightarrow x$



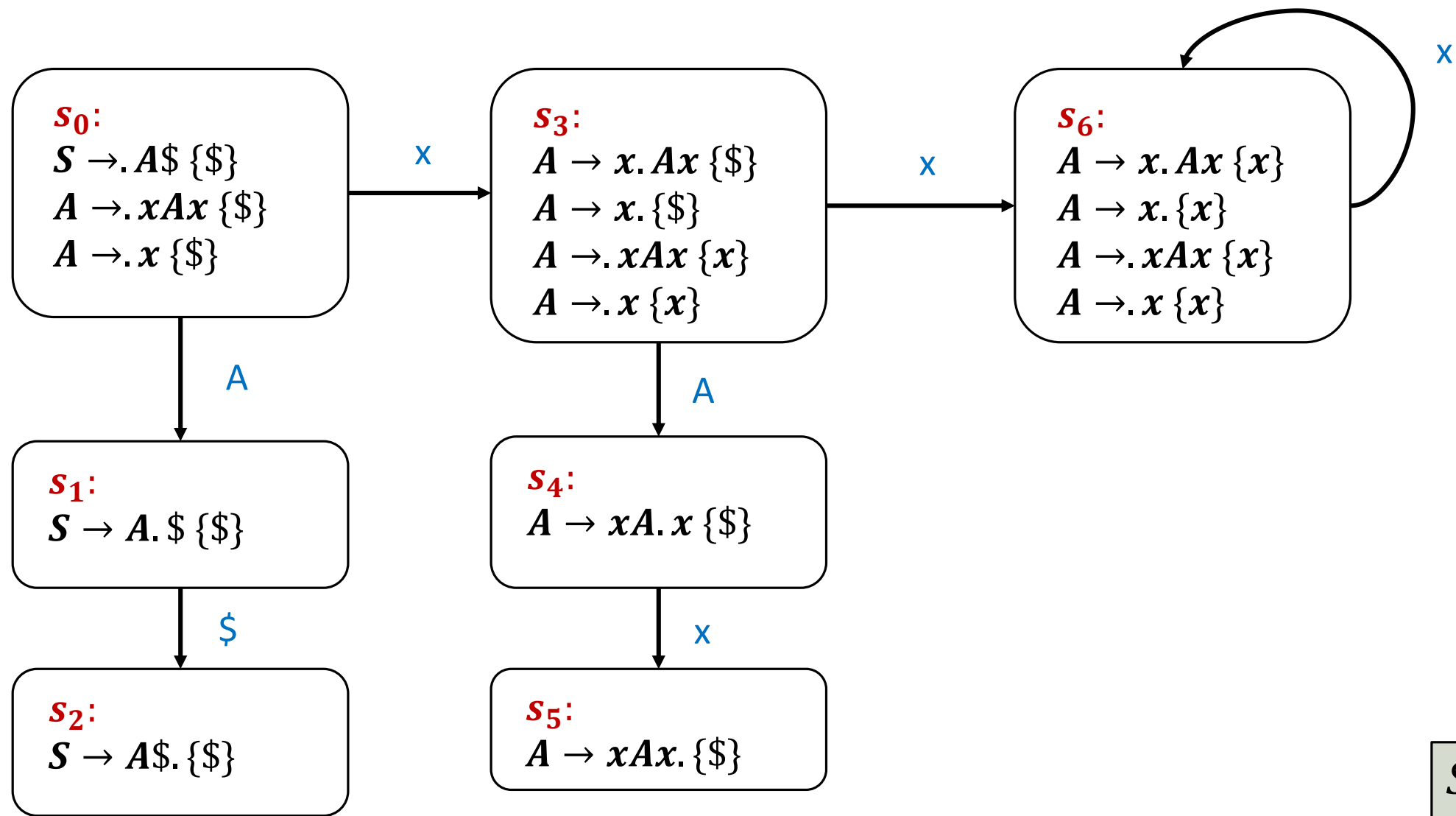
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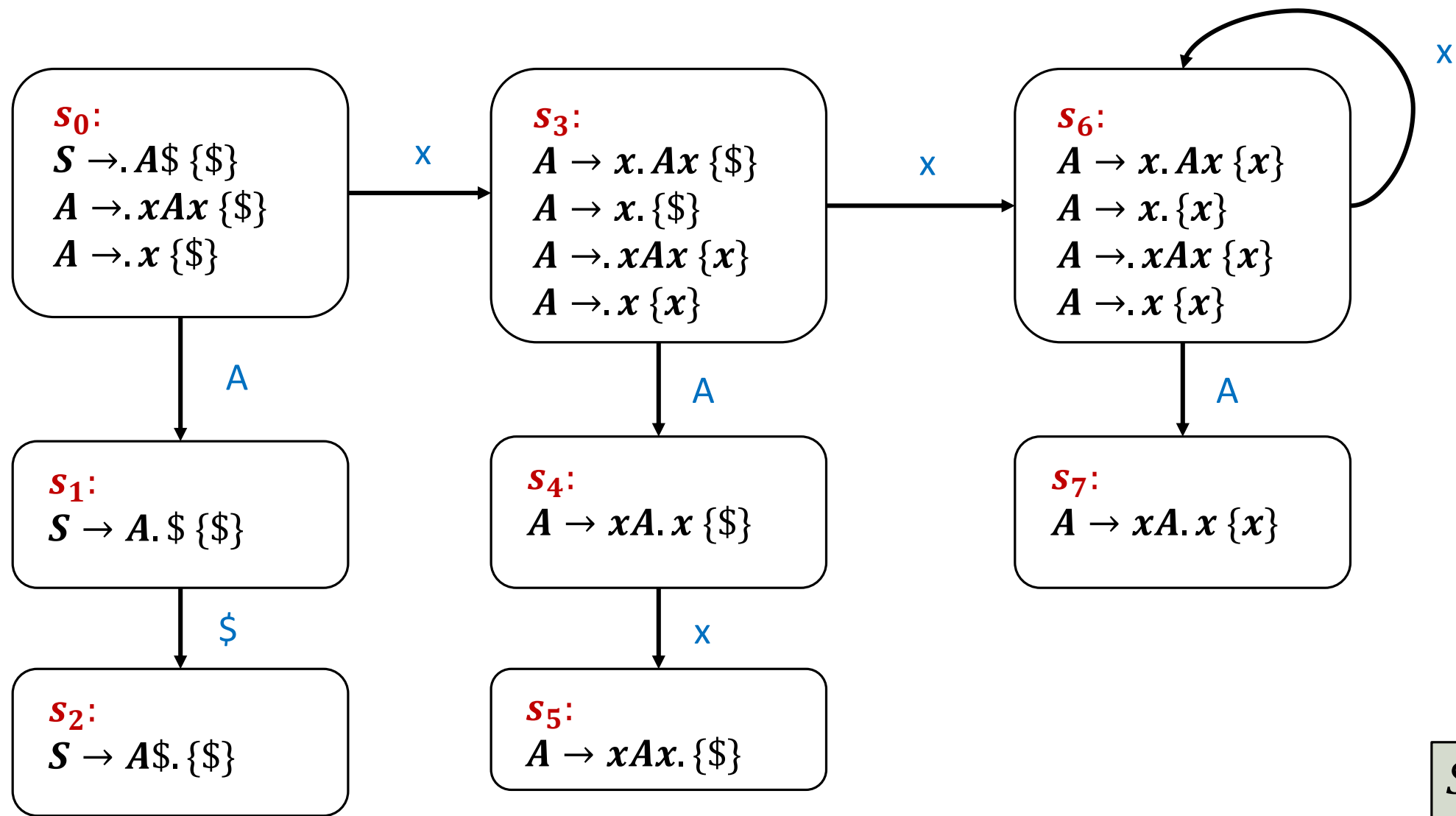
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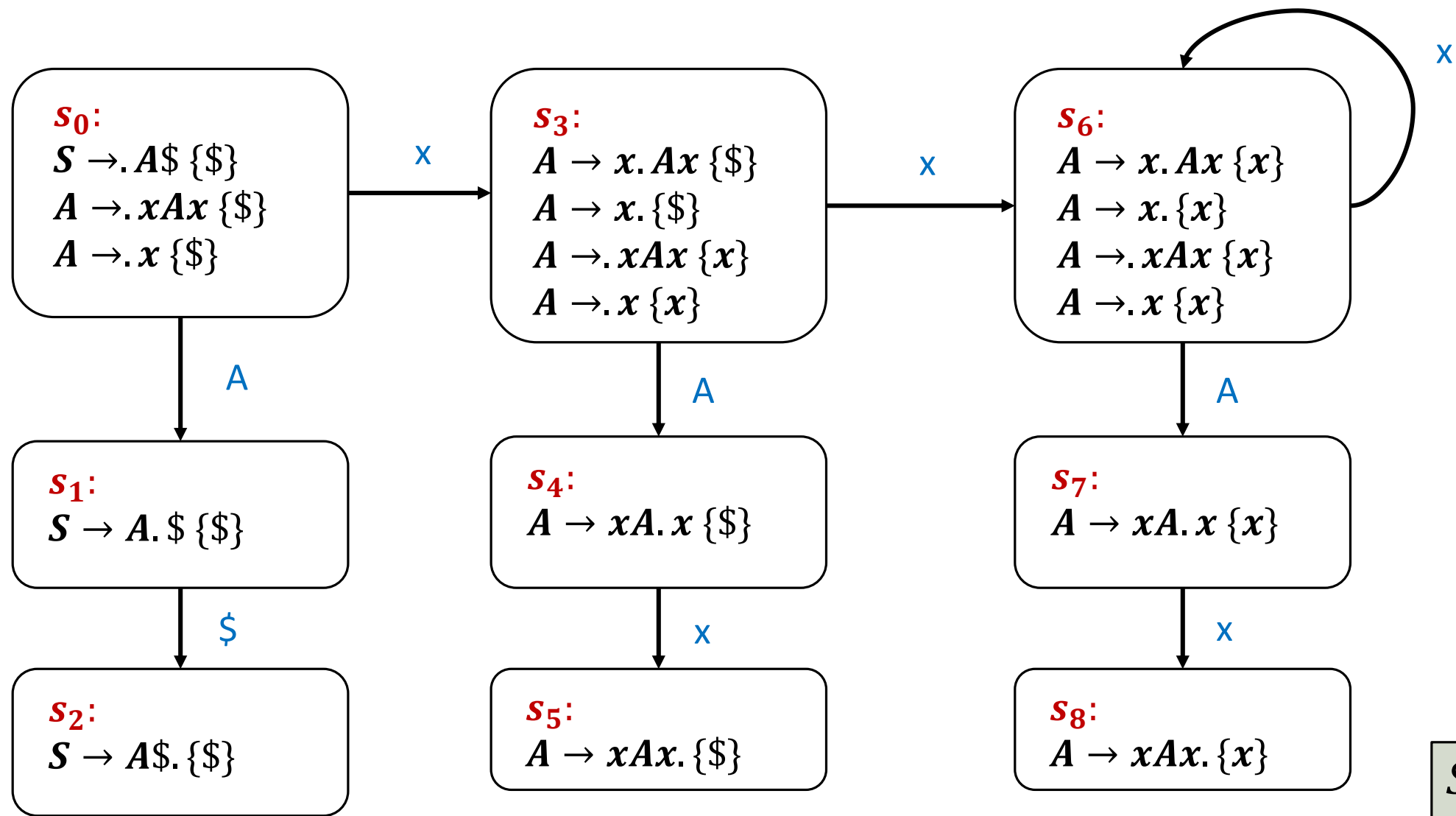
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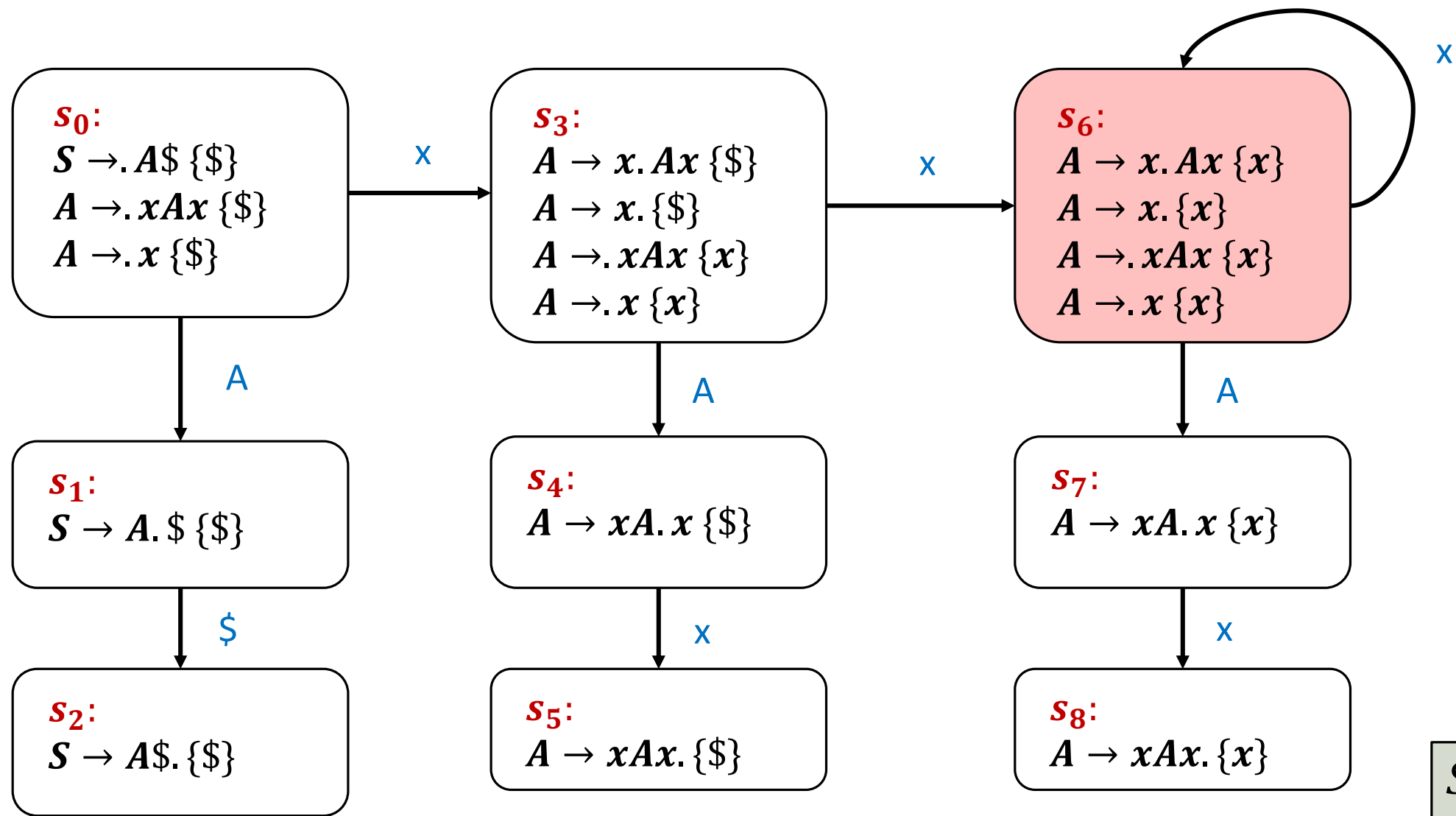
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$S \rightarrow A \$$   
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$S \rightarrow A \$$   
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 $A \rightarrow x$



# Question

We extend the language with automatic type inference:

- Can use **auto** when the declaration has an initial value

Describe the changes required in:

- Lexical analysis
- Syntactic analysis
- Semantic analysis

```
auto i := 8 + 100;  
auto s := "1234";  
class A {}  
A a := new A;  
auto b := a;
```

# Question

A variable  $x$  **depends** on a variable  $y$  if  $y$  is used (directly or indirectly) to compute  $x$ . For example,  $c$  depends on  $x, y, b, z$  but not on  $t$ .

- Define a static analysis in terms of  $(D, V, \sqcup, F, I)$
- Run on the example

```
y := t;  
y := z + 5;  
if (x > 0) {  
    x := y * 2;  
} else {  
    x := y + b;  
}  
c := x;
```

# Abstract Domain

We define  $(D, V, \sqcup, F, I)$ :

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  - $Var \mapsto P(Var)$  (e.g.,  $\{a : \{b, c\}\}$ )

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- $V$  contains maps of the form:
  - $Var \mapsto P(Var)$  (e.g.,  $\{a : \{b, c\}\}$ )
- Join operator:
  - $m_1 \sqcup m_2 := \lambda v. m_1[v] \cup m_2[v]$ 
    - $\{a : \{b\}\} \sqcup \{a : \{c\}, d : \{e\}\} = \{a : \{b, c\}, d : \{e\}\}$

# Abstract Domain

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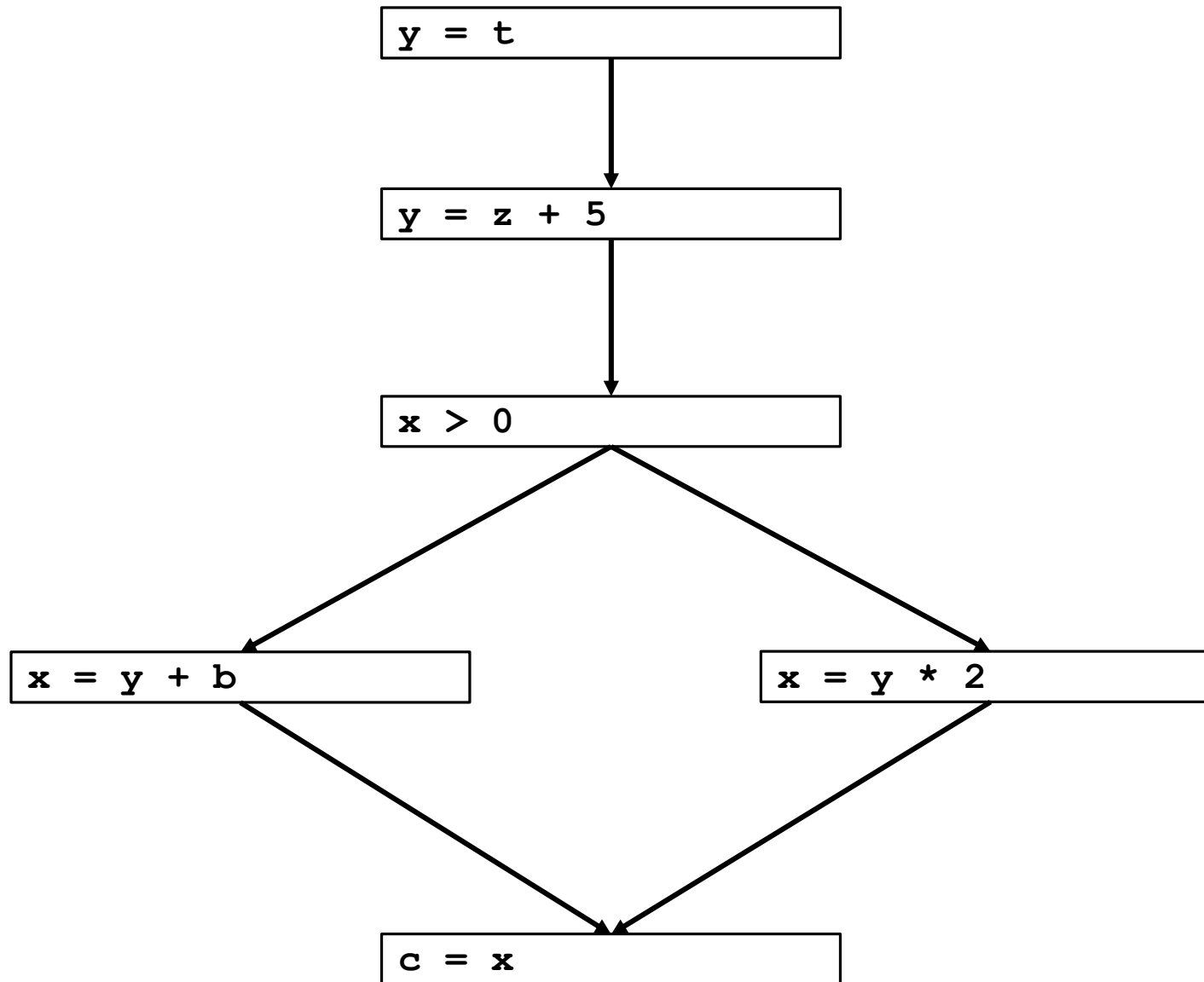
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    - $\{a : \{b\}\} \sqcup \{a : \{c\}, d : \{e\}\} = \{a : \{b, c\}, d : \{e\}\}$
- For example, for  $a = b + c$ :
  - $\{a : s_a, b : s_b, c : s_c, \dots\} \rightarrow \{a : \{b, c\} \cup s_b \cup s_c, b : s_b, c : s_c, \dots\}$

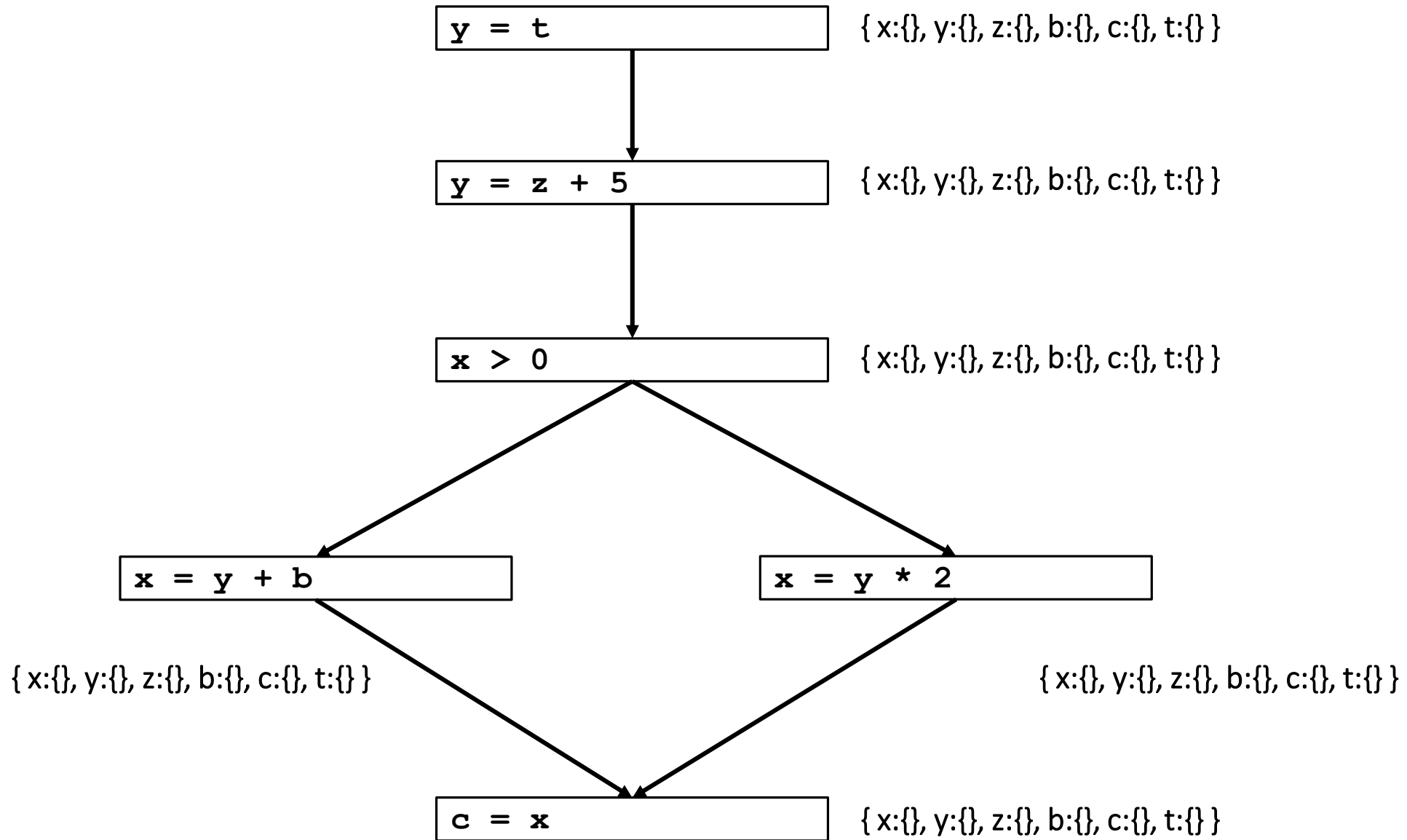
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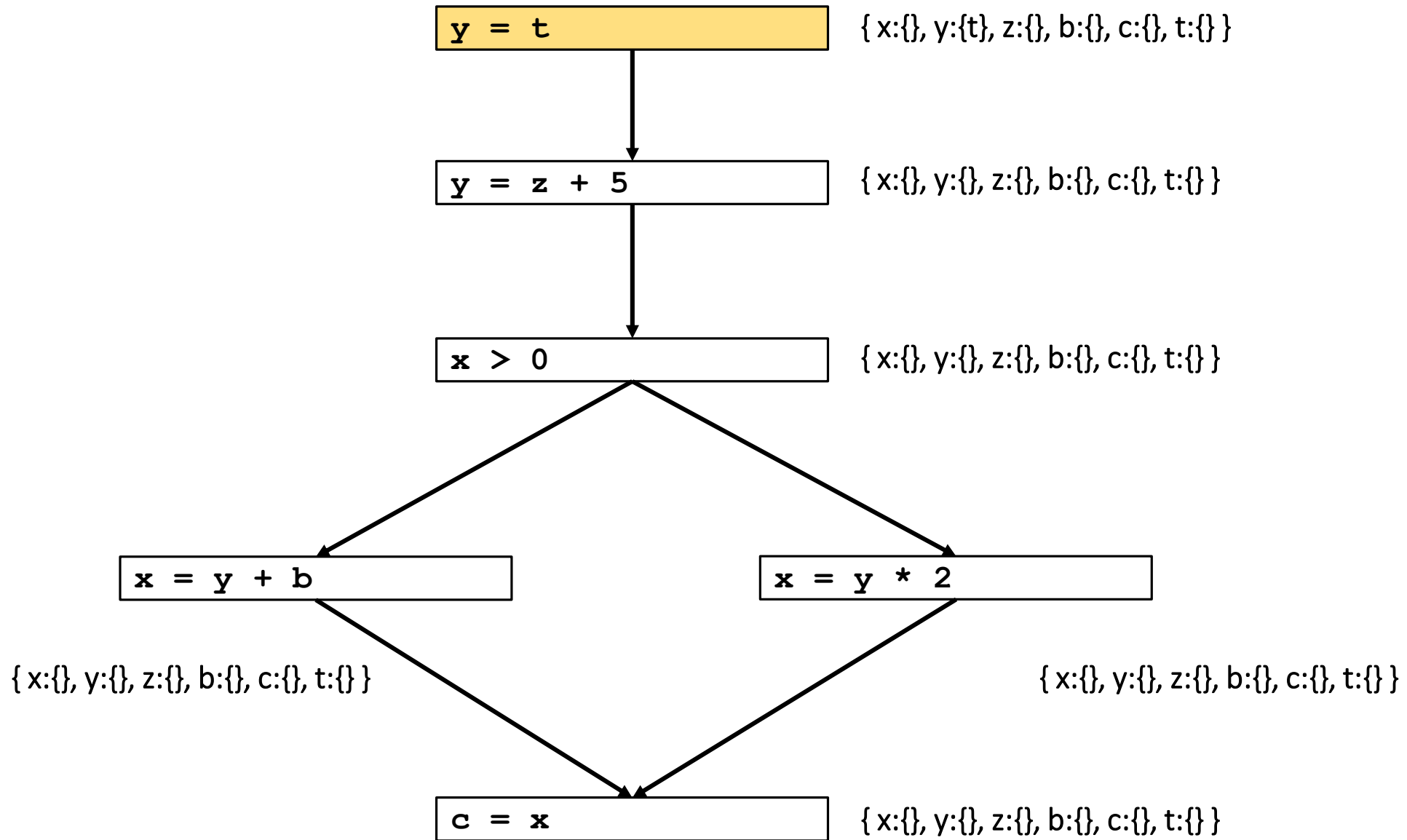
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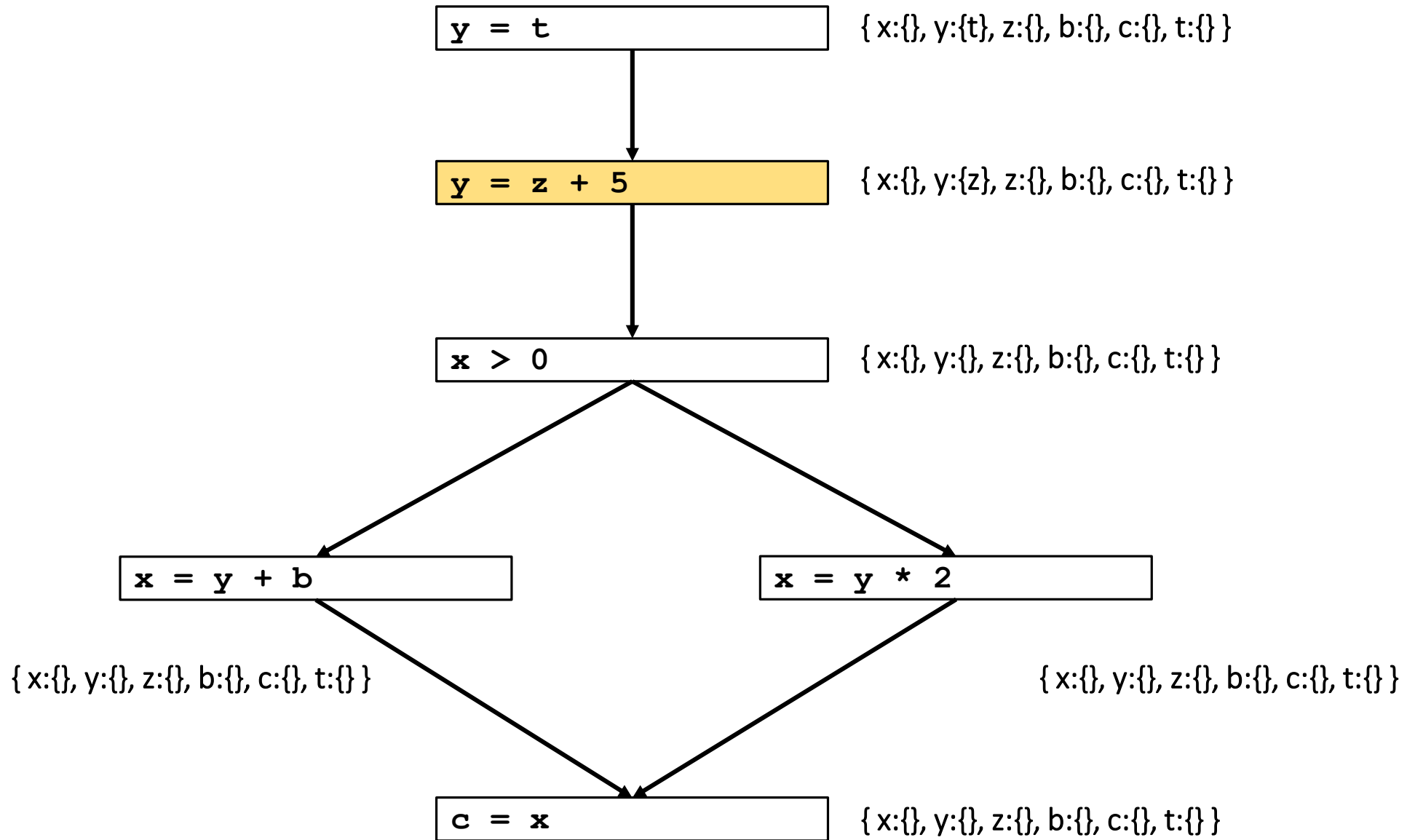
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- For example, for  $a = b + c$ :
  - $\{a : s_a, b : s_b, c : s_c, \dots\} \rightarrow \{a : \{b, c\} \cup s_b \cup s_c, b : s_b, c : s_c, \dots\}$
- Initialize with:
  - $\lambda v. \{\}$

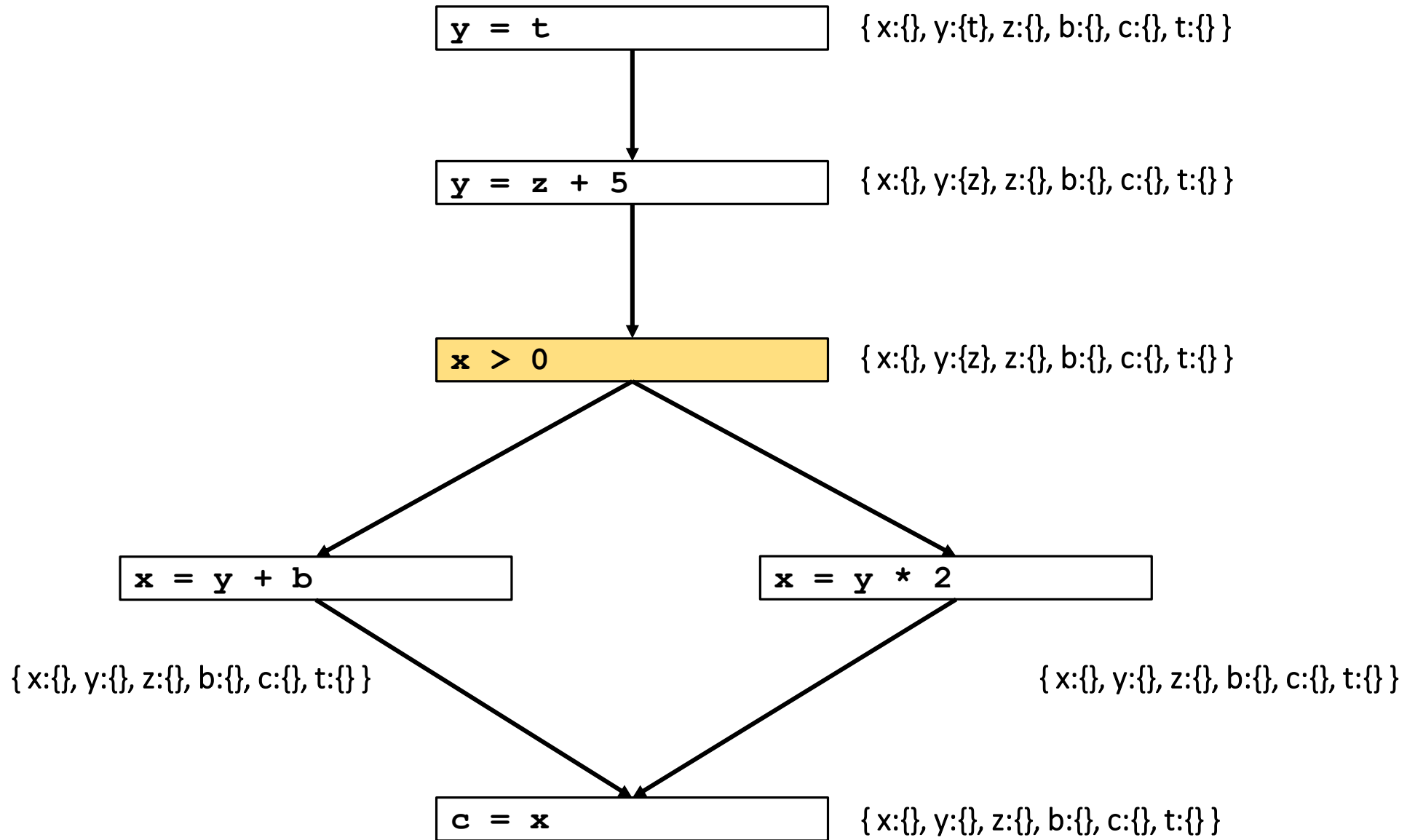


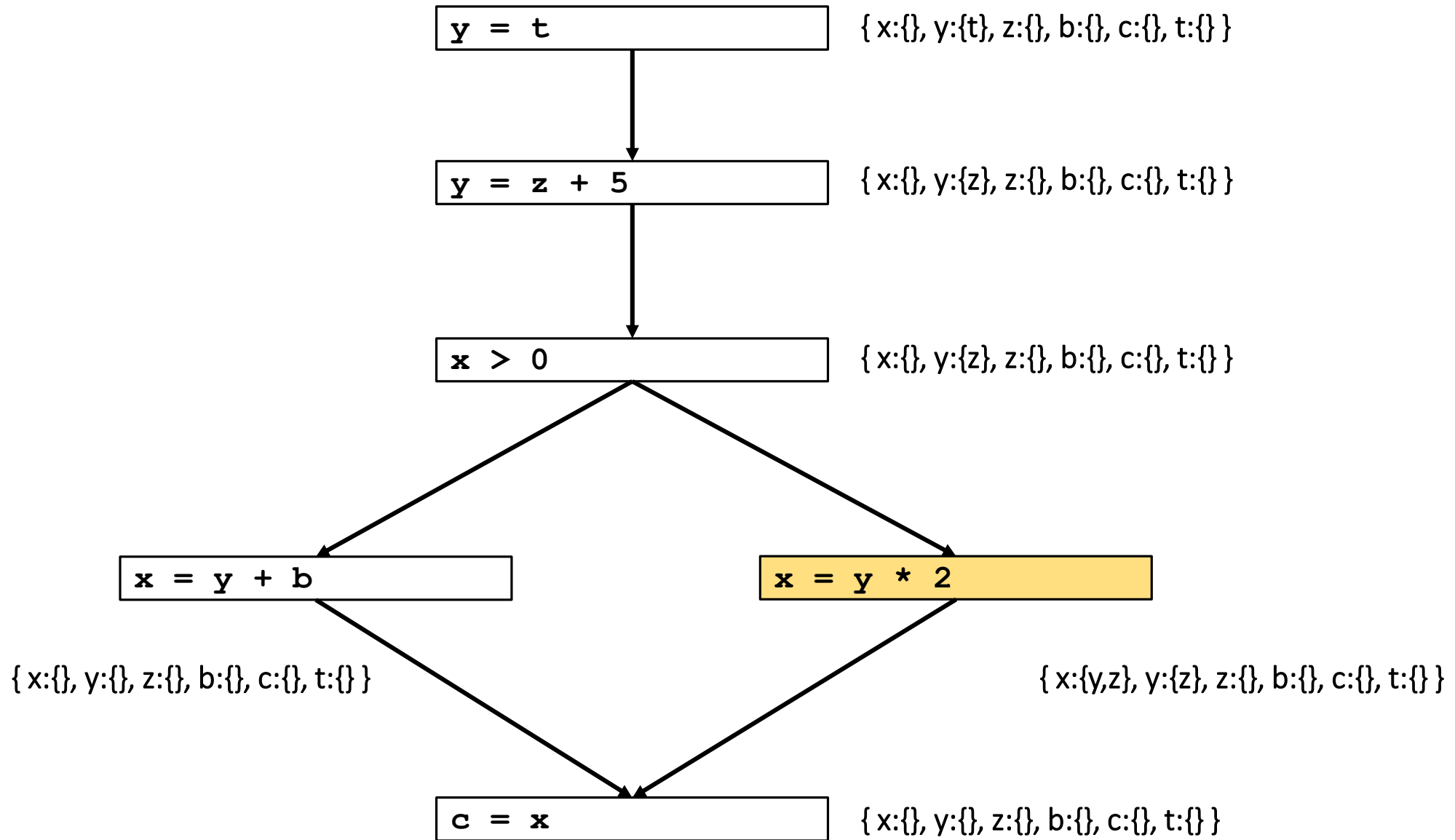


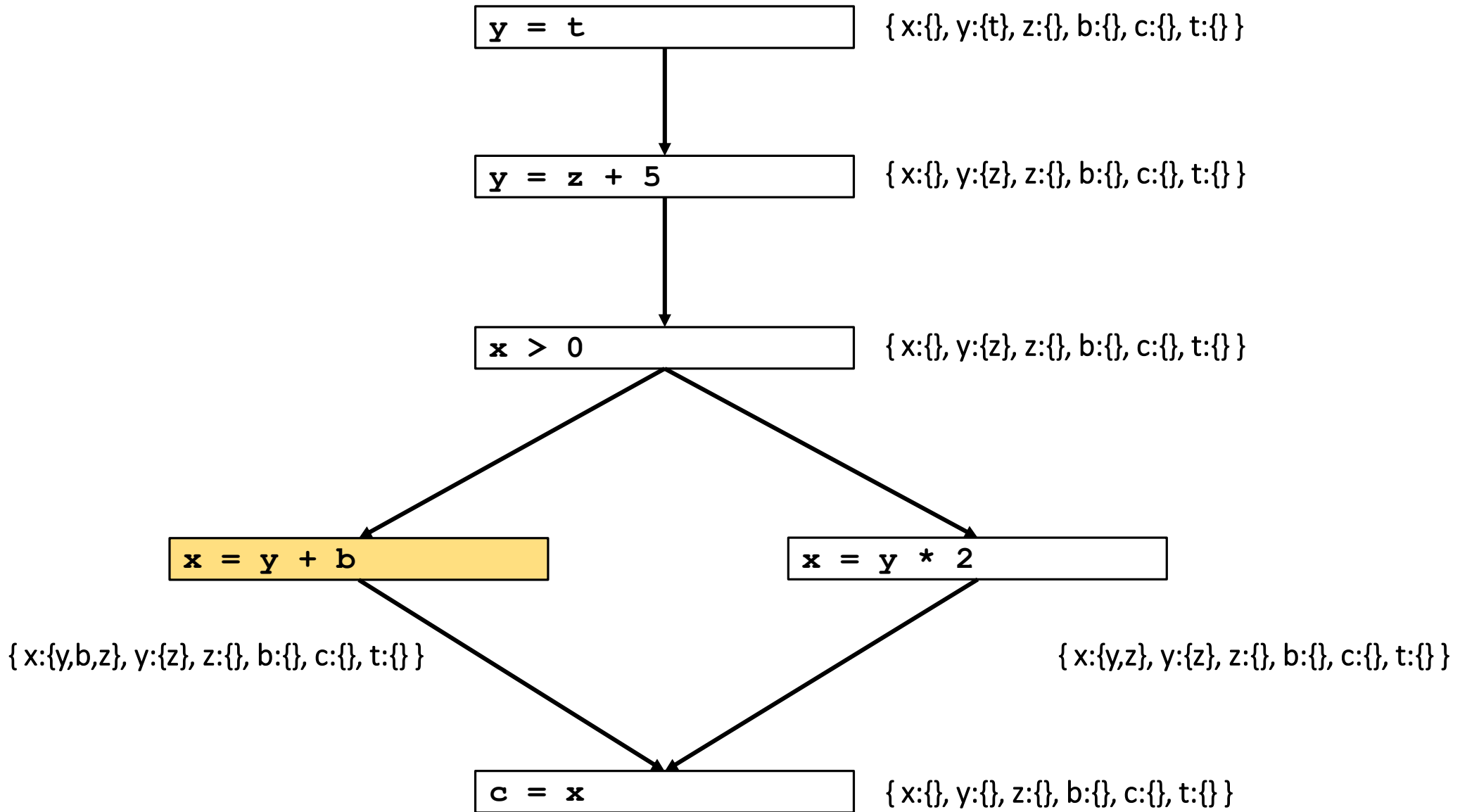


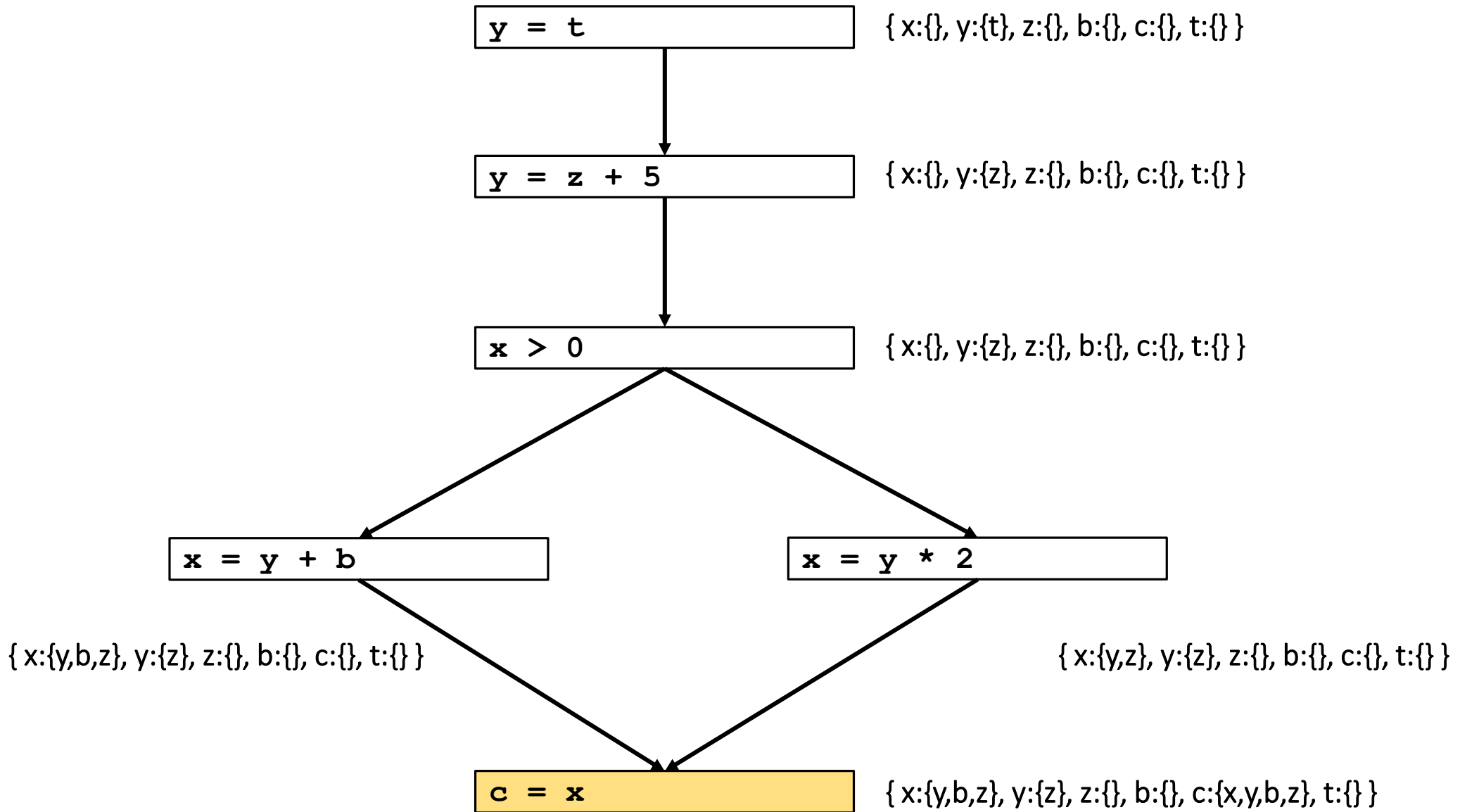














# Question

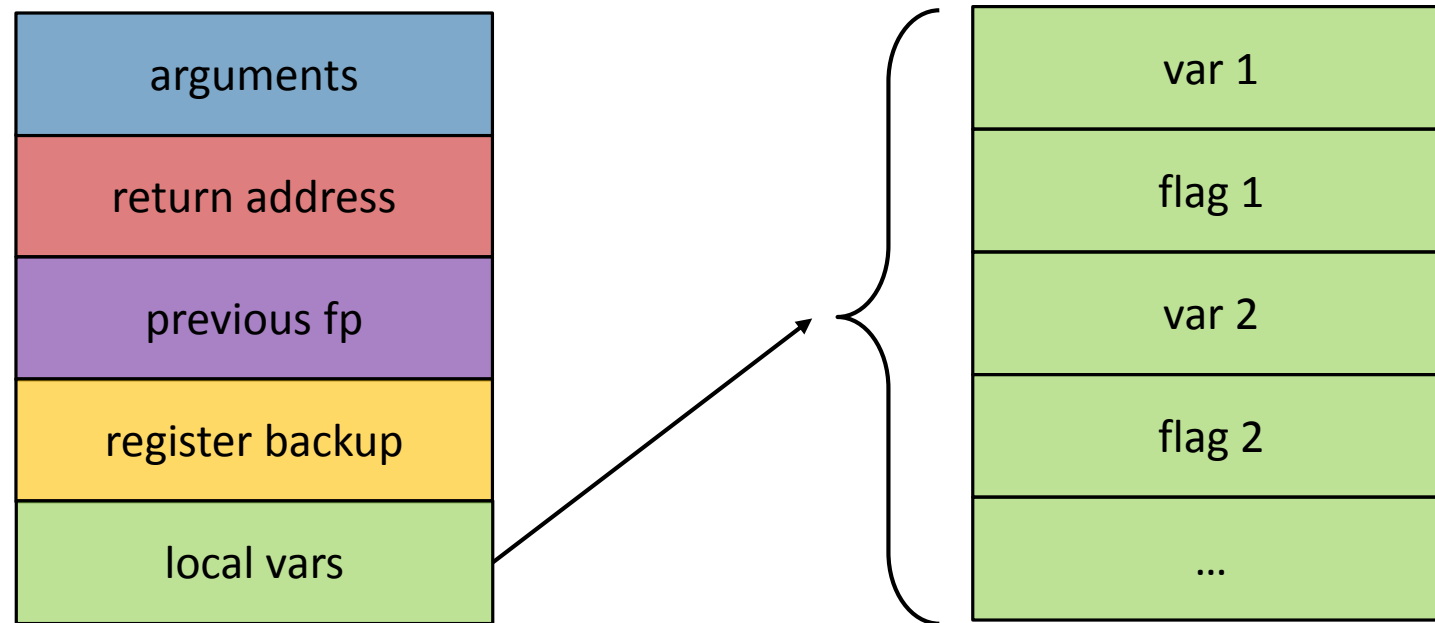
Add support for detecting accesses to uninitialized local variables.  
Describe the required changes in the code generation step.

For example:

```
void f() {  
    int x;  
    int y := 7;  
    if (y > 10) {  
        x := 100;  
    }  
    int z := x + 1;  
}
```

# Solution

High level idea:



# Solution

- Initialize each variable flag to zero on function entry
- When writing to a local variable, set its flag to 1
- When reading a local variable, check if its flag is 1

|        |
|--------|
| var 1  |
| flag 1 |
| var 2  |
| flag 2 |
| ...    |

# Solution

- Initialize each variable flag to zero on function entry
- When writing to a local variable, set its flag to 1
- When reading a local variable, check if its flag is 1

prologue:

```
...  
li $s0, 0  
sw $s0, local_1_flag_offset($fp)  
li $s0, 0  
sw $s0, local_2_flag_offset($fp)  
...
```

|        |
|--------|
| var 1  |
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| ...    |

# Solution

- Initialize each variable flag to zero on function entry
- **When writing to a local variable, set its flag to 1**
- When reading a local variable, check if its flag is 1

**x = t0**

```
sw $t0, x_offset($fp)
li $s0, 1
sw $s0, x_flag_offset($fp)
```

|        |
|--------|
| var 1  |
| flag 1 |
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# Solution

- Initialize each variable flag to zero on function entry
- When writing to a local variable, set its flag to 1
- **When reading a local variable, check if its flag is 1**

`t0 = x`

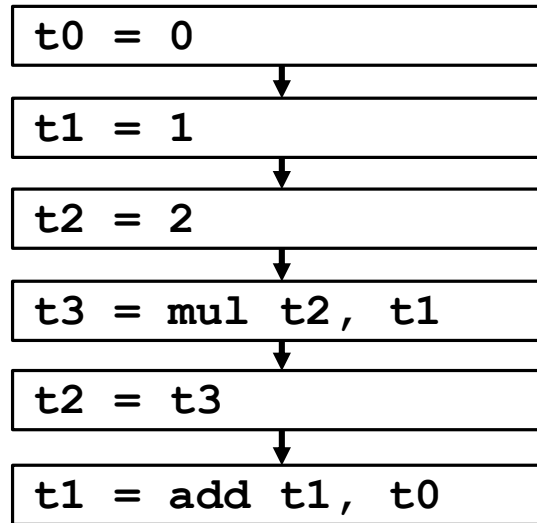
```
lw $s0, x_flag_offset($fp)
beq $s0, 0, abort
lw $t0, x_offset($fp)
```

|        |
|--------|
| var 1  |
| flag 1 |
| var 2  |
| flag 2 |
| ...    |

# Question

Apply the register allocation algorithm with 3 registers (R1,R2,R3)  
R1 can't hold a result of a multiplication operation.

```
t0 = 0
t1 = 1
t2 = 2
t3 = t2 * t1
t2 = t3
t1 = t1 + t0
```





IN

{ }

{ }

{ }

{ }

{ }

{ }

OUT

{ }

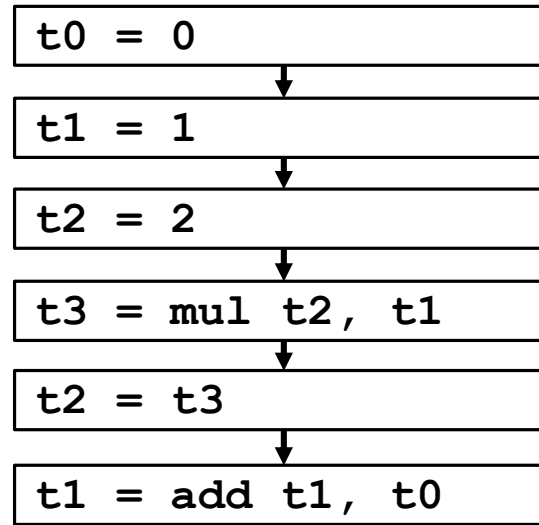
{ }

{ }

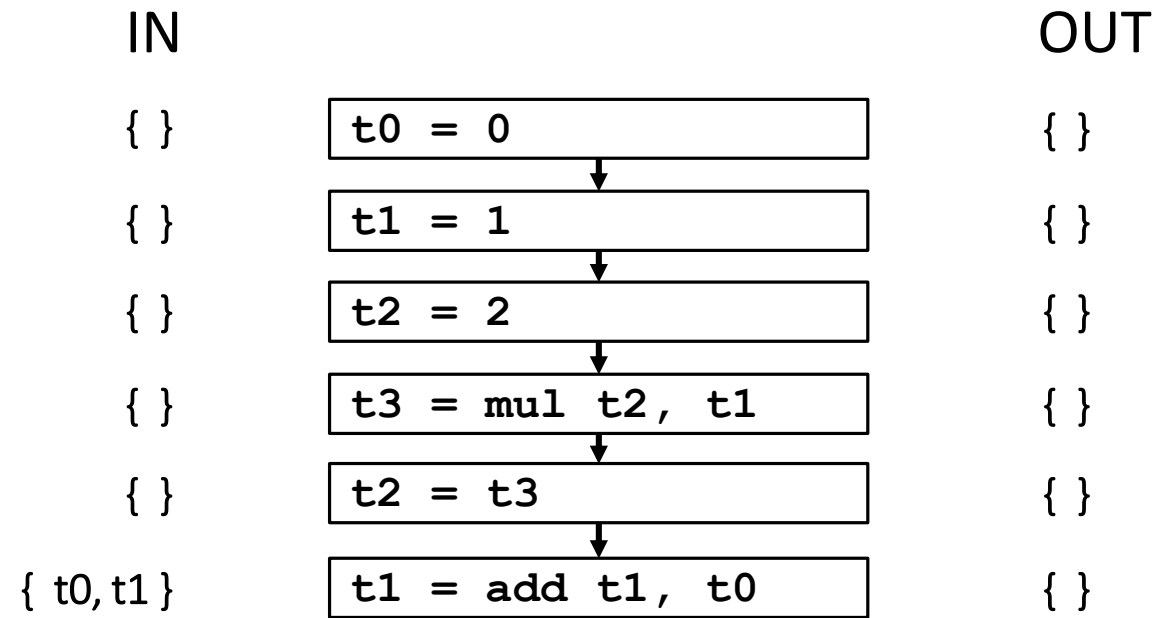
{ }

{ }

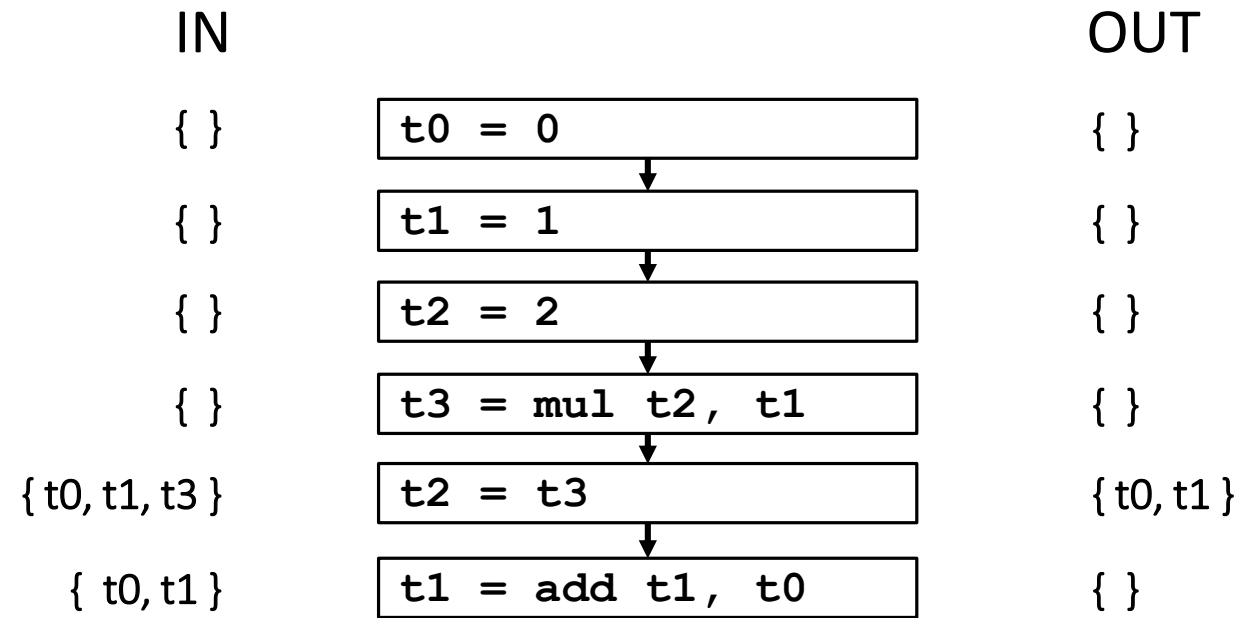
{ }



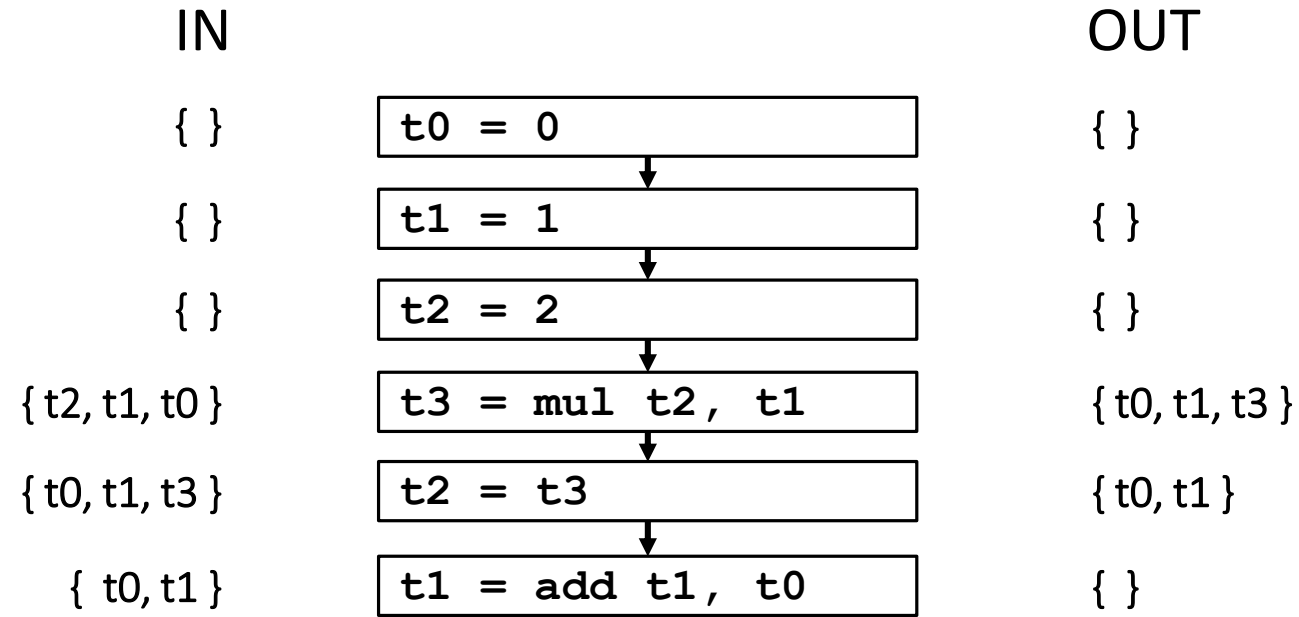
initialization



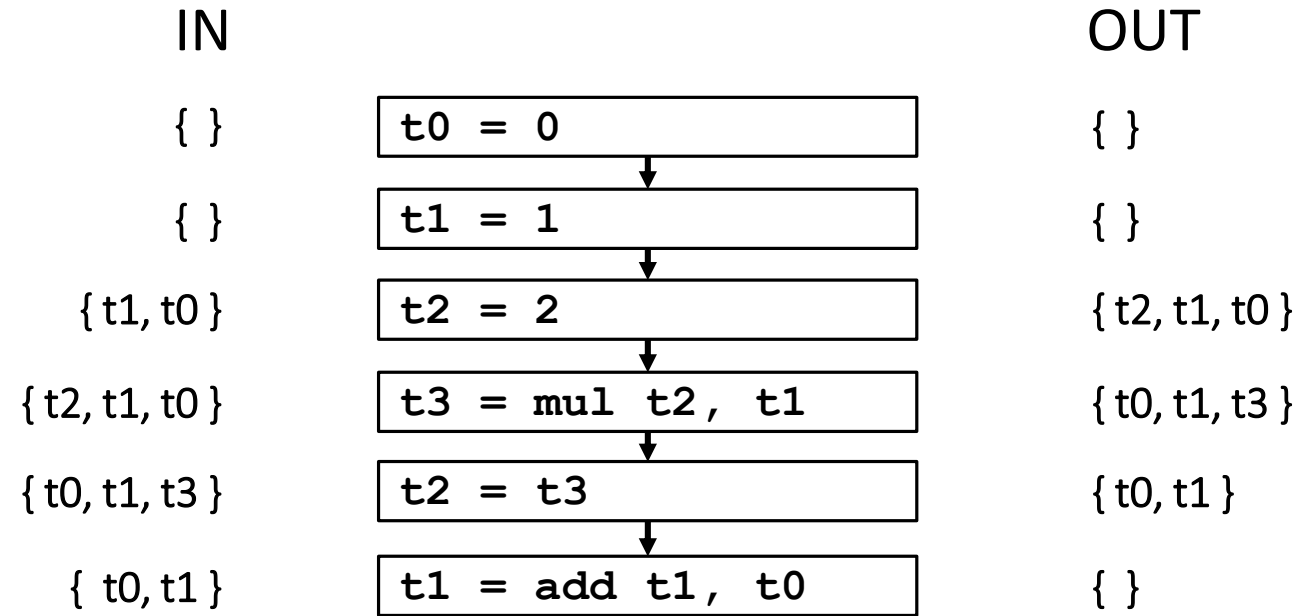
first iteration



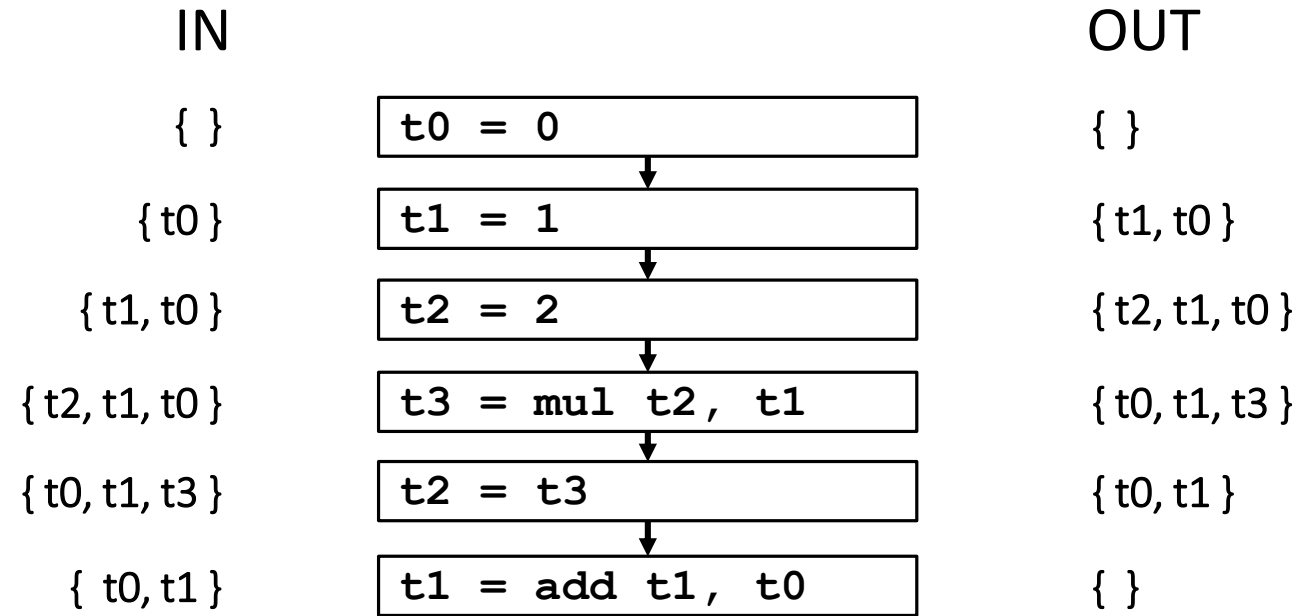
first iteration



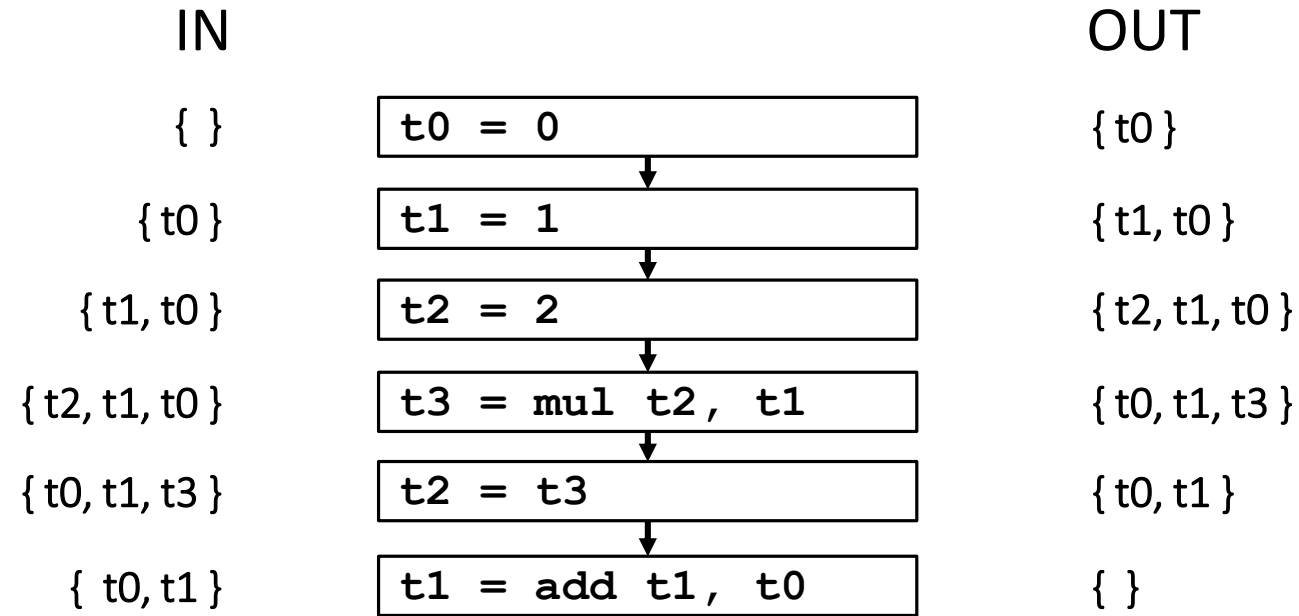
first iteration



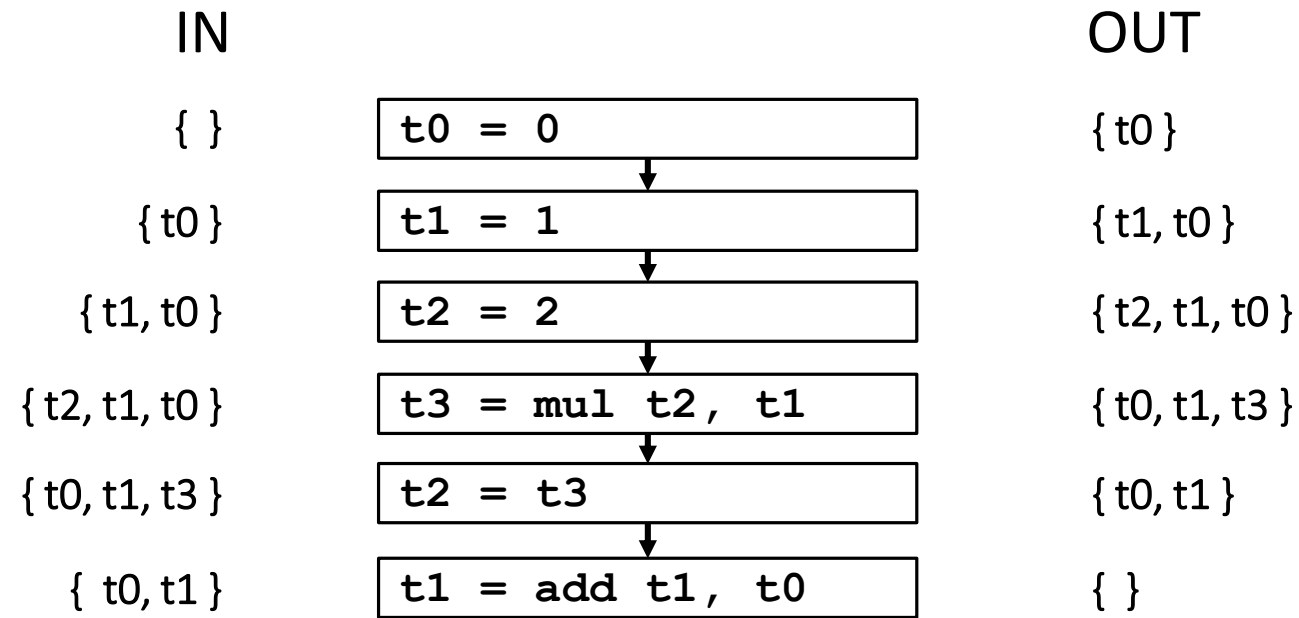
first iteration



first iteration



first iteration



second iteration...



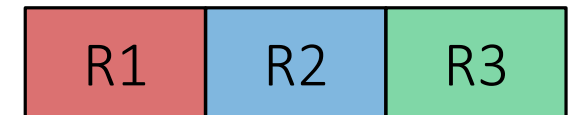
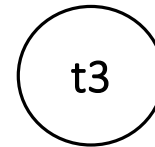
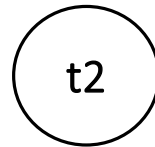
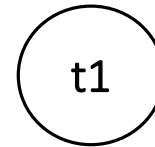
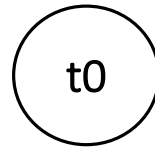
# Interference Graph

$\{t_0\}$

$\{t_0, t_1\}$

$\{t_0, t_2, t_1\}$

$\{t_0, t_3\}$



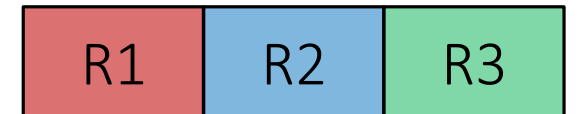
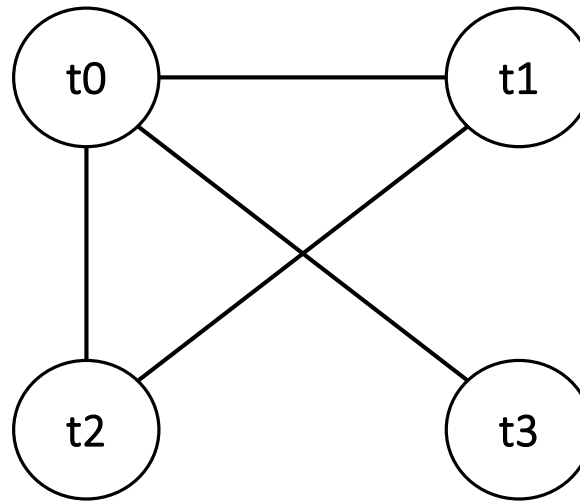
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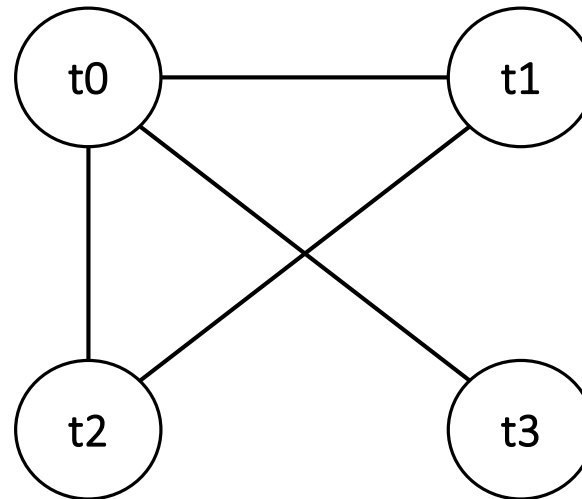
# Interference Graph

{ t0 }

{ t0, t1 }

{ t0, t2, t1 }

{ t0, t3 }



t0 = 0

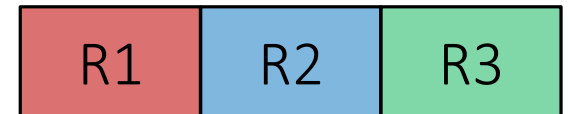
t1 = 1

t2 = 2

t3 = t2 \* t1

t2 = t3

t1 = t1 + t0



# Interference Graph

{ t0 }

{ t0, t1 }

{ t0, t2, t1 }

{ t0, t3 }

t0 = 0

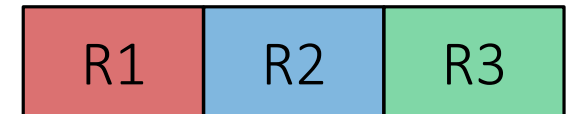
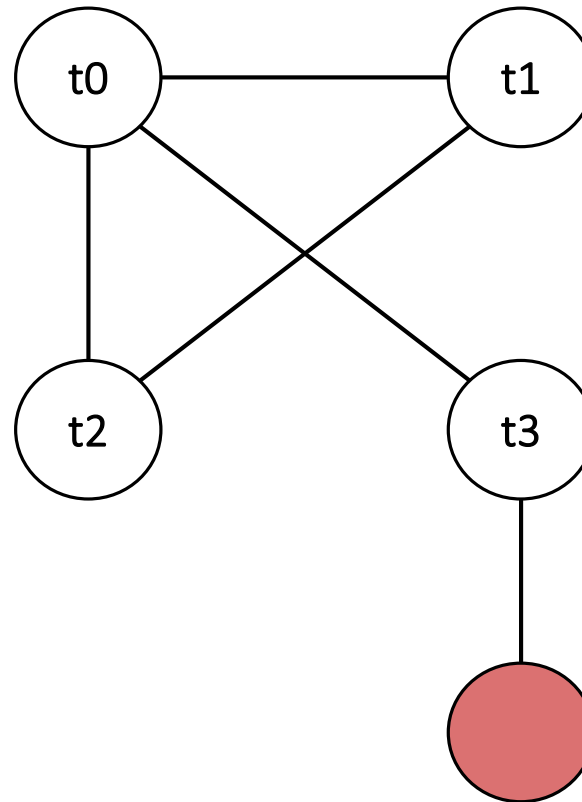
t1 = 1

t2 = 2

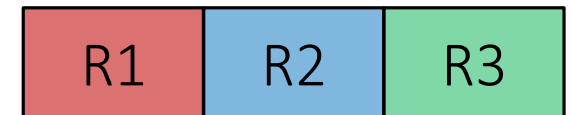
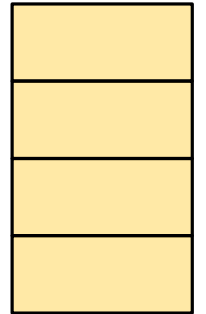
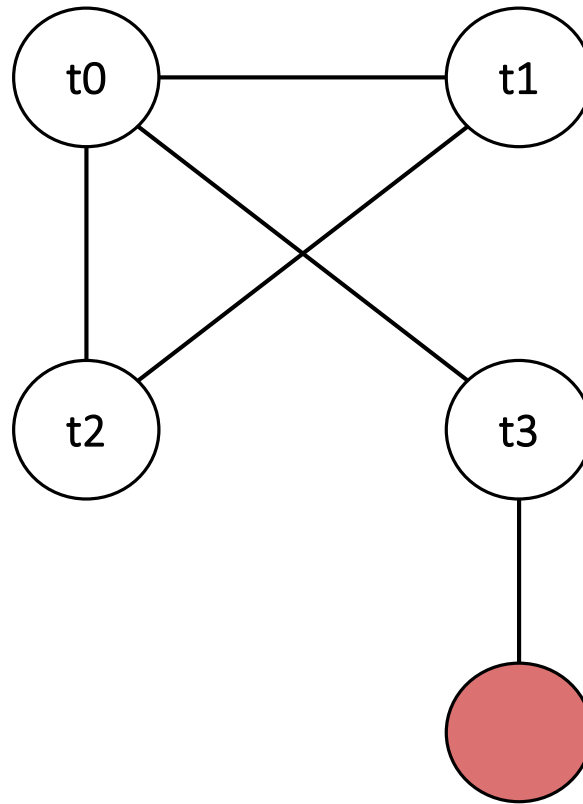
t3 = t2 \* t1

t2 = t3

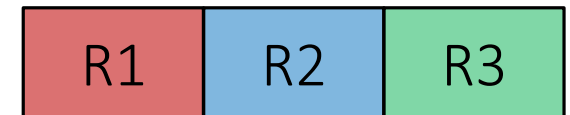
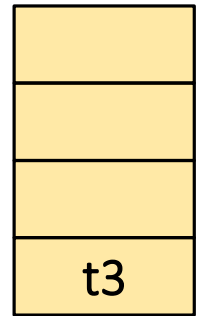
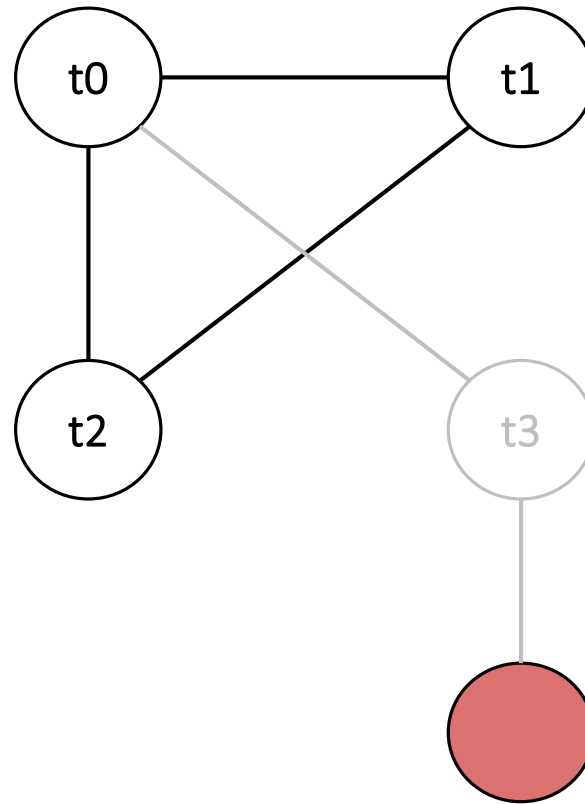
t1 = t1 + t0



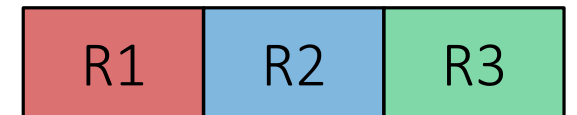
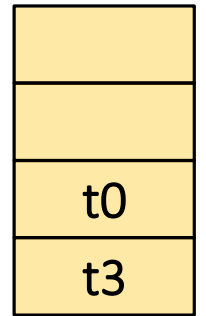
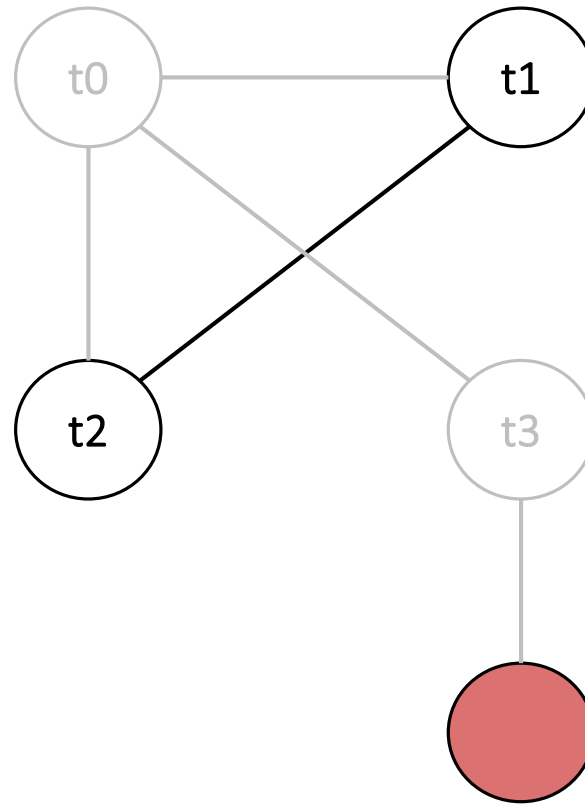
# Graph Coloring



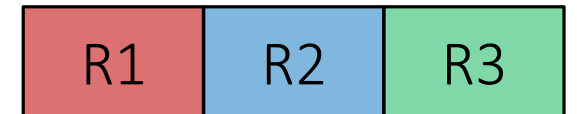
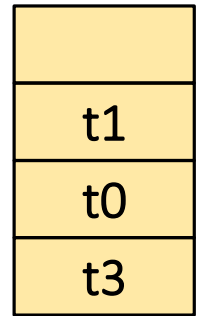
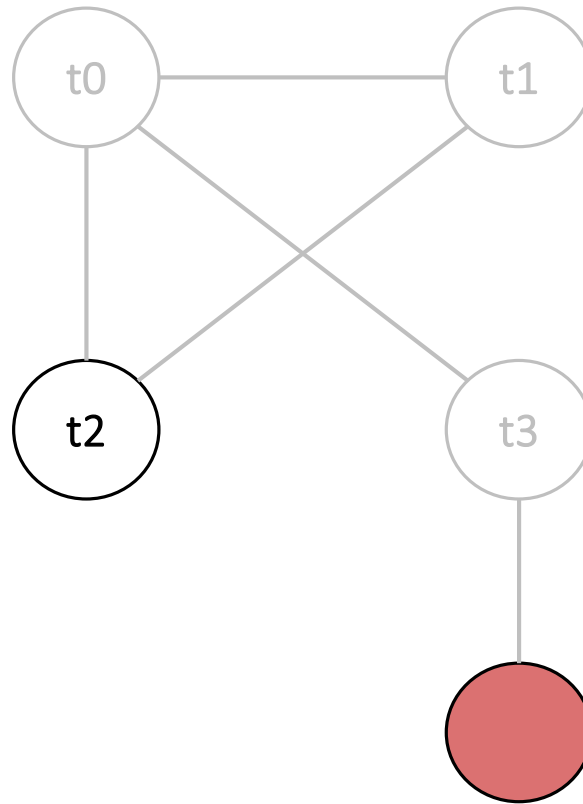
# Graph Coloring



# Graph Coloring

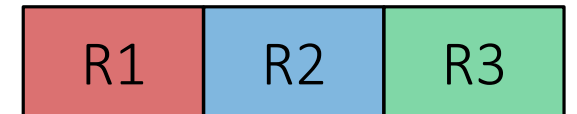
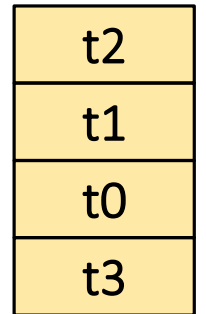
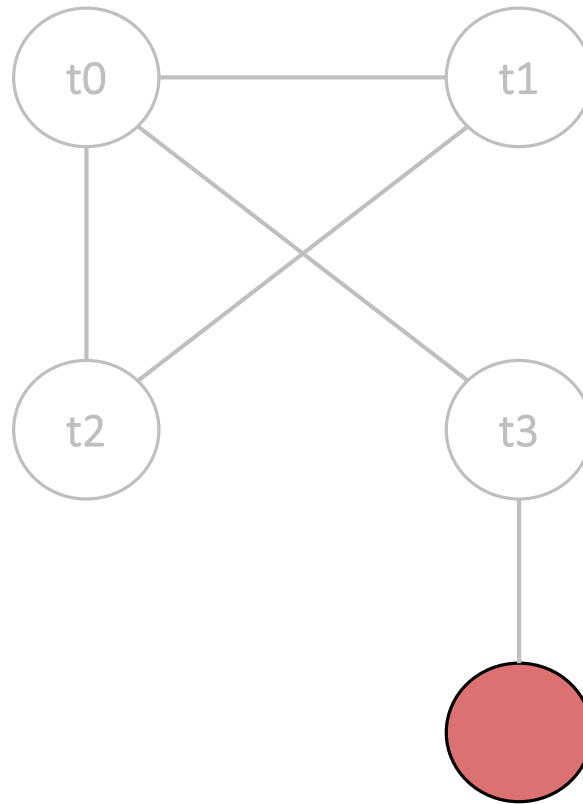


# Graph Coloring

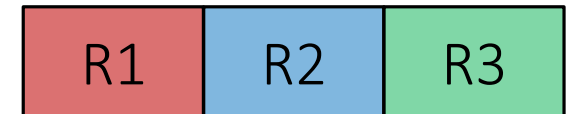
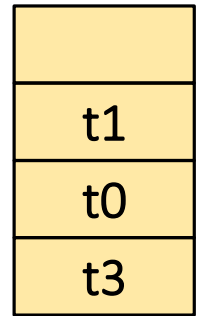
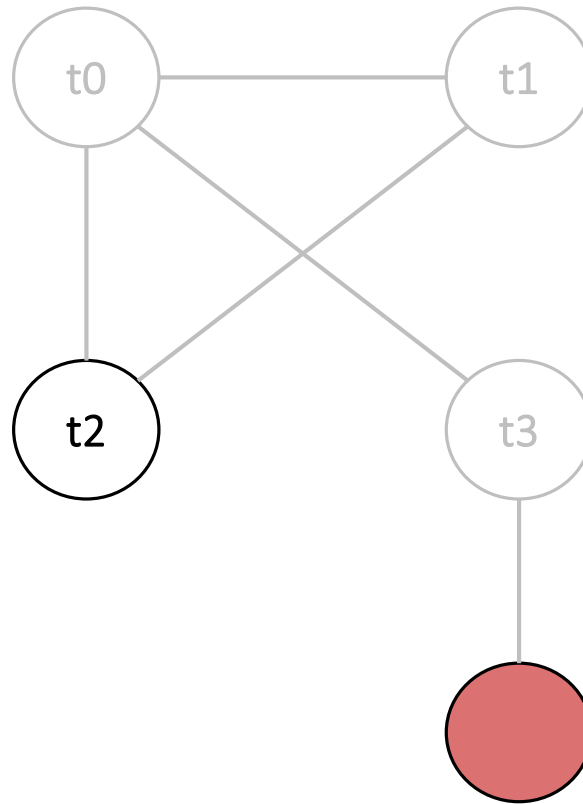




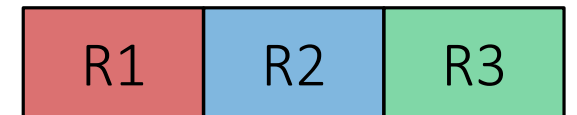
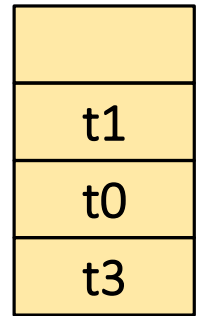
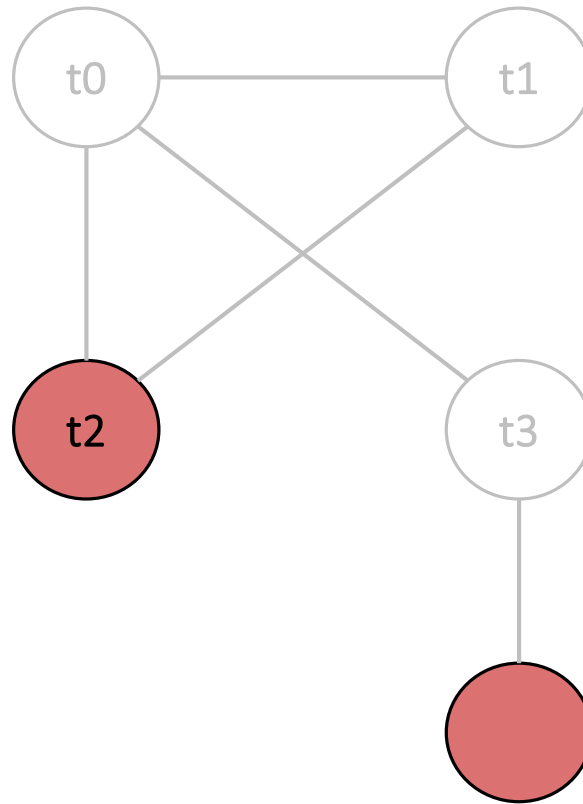
# Graph Coloring



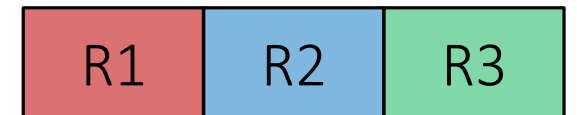
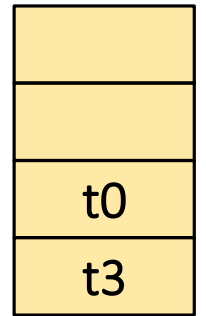
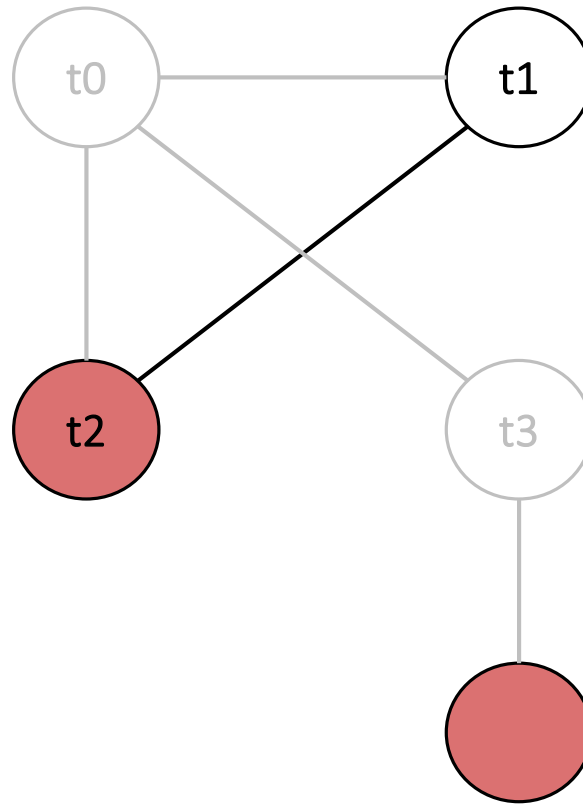
# Graph Coloring



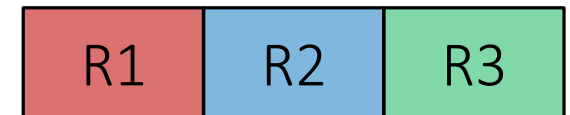
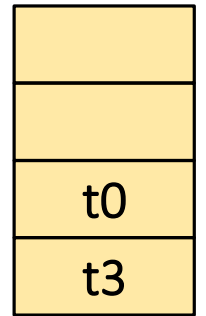
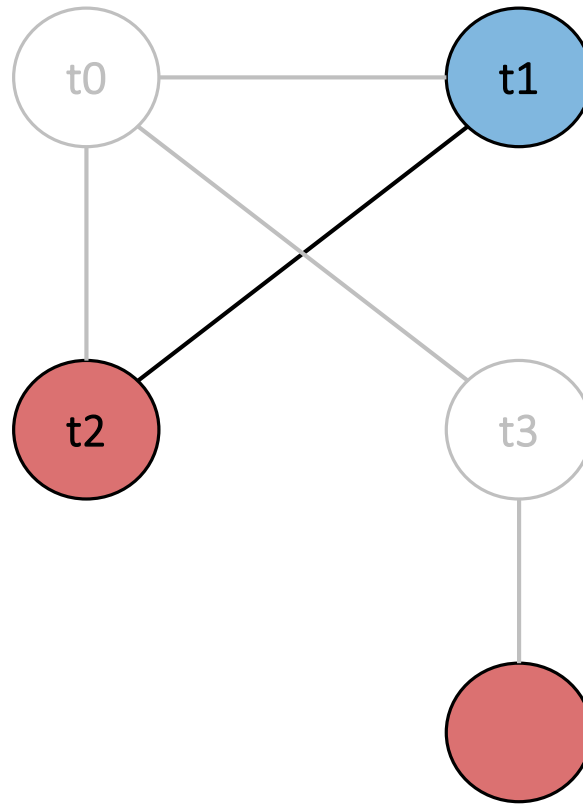
# Graph Coloring



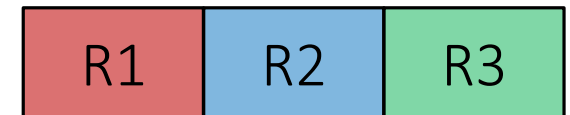
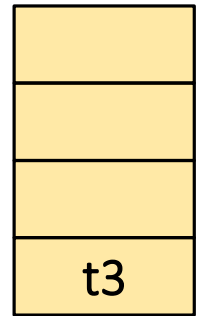
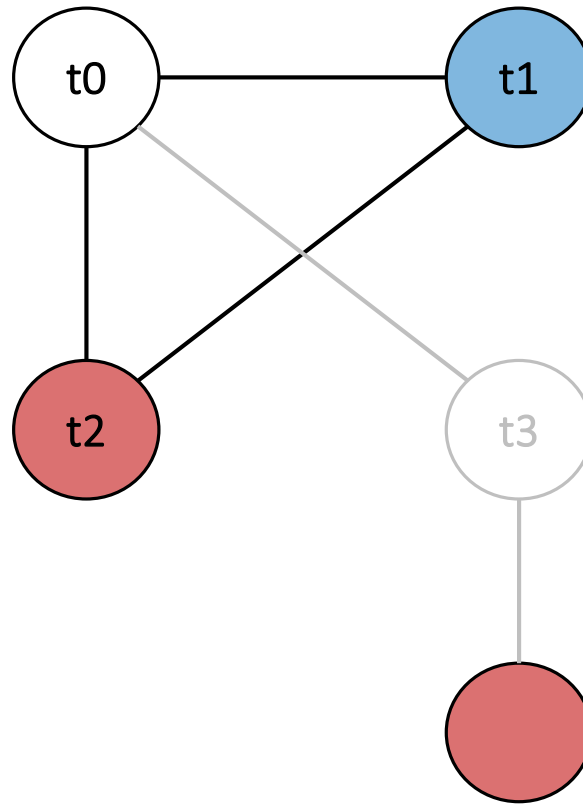
# Graph Coloring



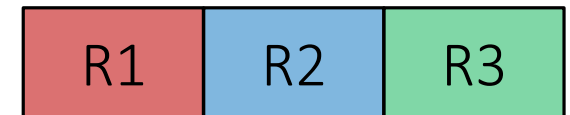
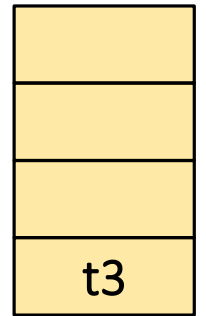
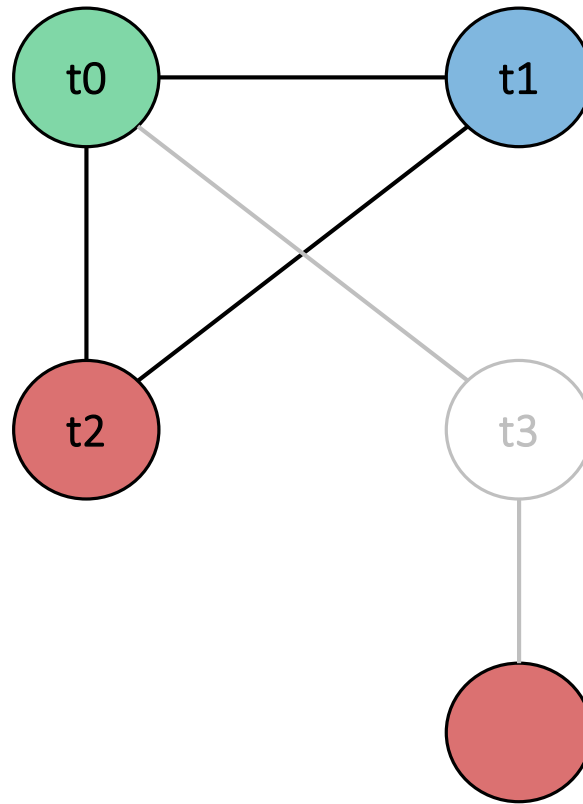
# Graph Coloring



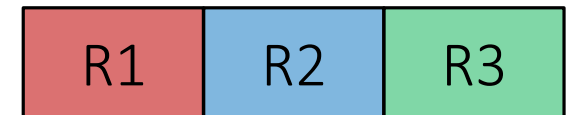
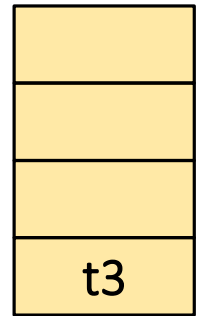
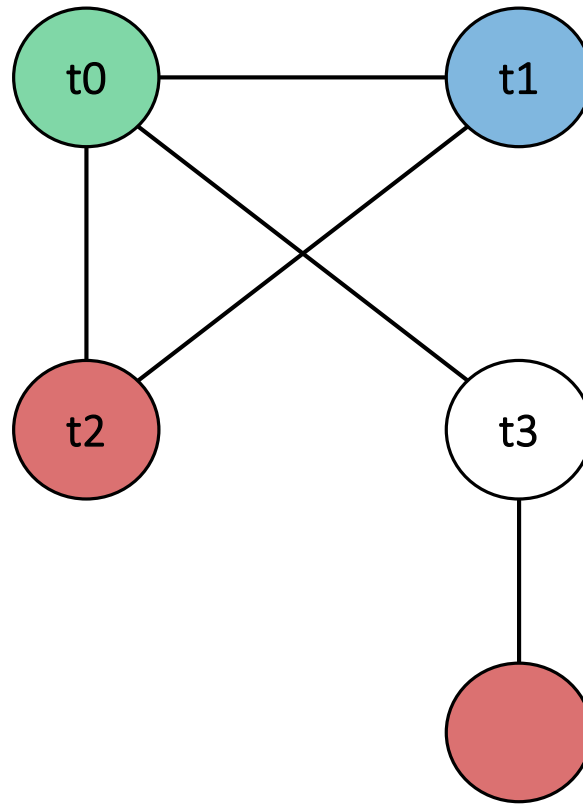
# Graph Coloring



# Graph Coloring



# Graph Coloring





# Graph Coloring

