Exam Questions

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Question

The program contains a string constant.

compiler construction
compiling
linking
runtime

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Question

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

compiler construction
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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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Question

All the variable names start with *x*.

compiler construction
compiling
linking
runtime

Question

All the variable names start with *x*.

compiler construction
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linking
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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
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linking
runtime

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

compiler construction
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Question

The size of the stack exceeds 400 bytes.

compiler construction
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Question

The size of the stack exceeds 400 bytes.

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Question

The code contains only invocations of methods which located at offset 4 in the virtual table.

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

SLR(1)

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

LR(1)

An **LR(1) item** is of the form:

- $N \rightarrow \alpha . \beta \; \{\sigma\}$
- where $\sigma = t_1, t_2, \ldots$ (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 $A \to \alpha . N\beta \ \{\sigma\} \in S$ then for each rule $N \to \gamma$:
  - $N \to . \gamma\{\tau\} \in S$, where $\tau = First(\beta, \{\sigma\})$

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

- If β 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:

$S \to . A\$$

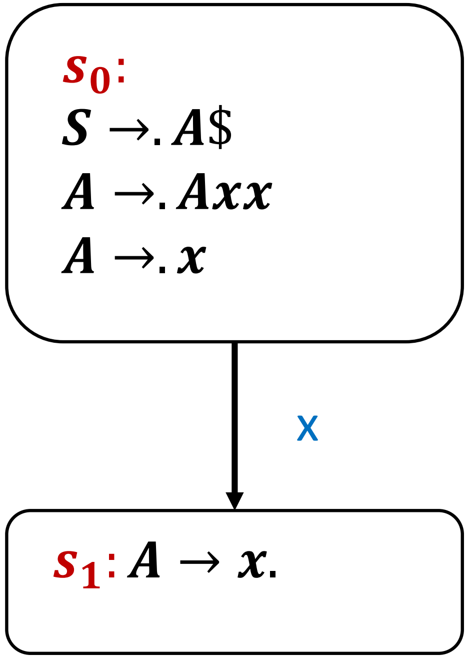
$A \to . Axx$

$A \to . x$

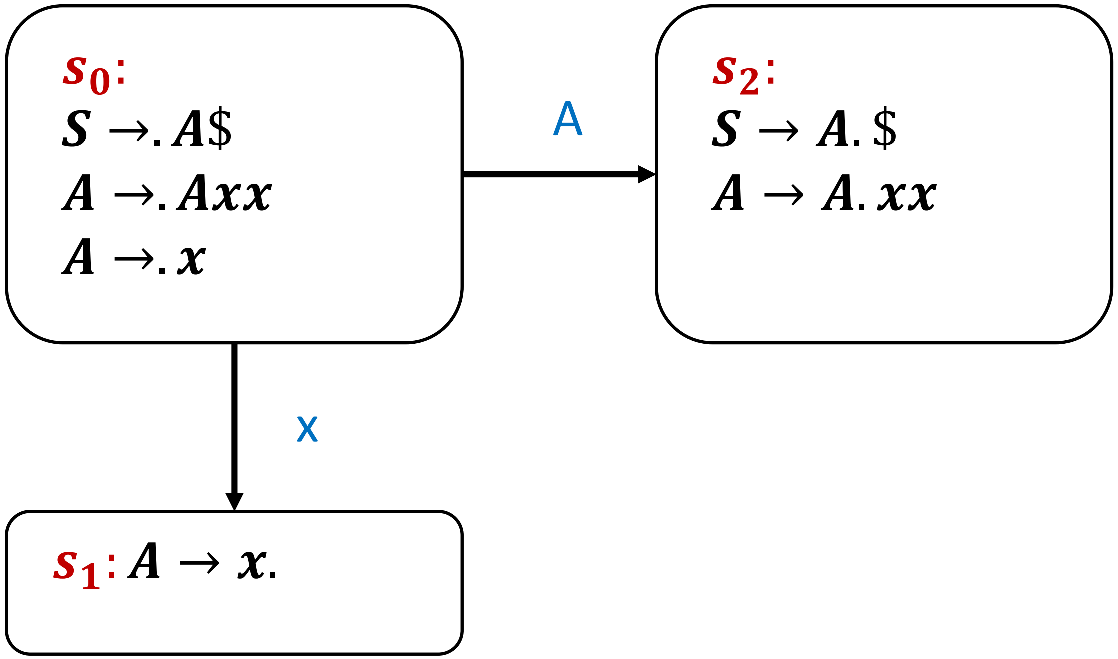
$S \to A\$$

$A \to Axx$

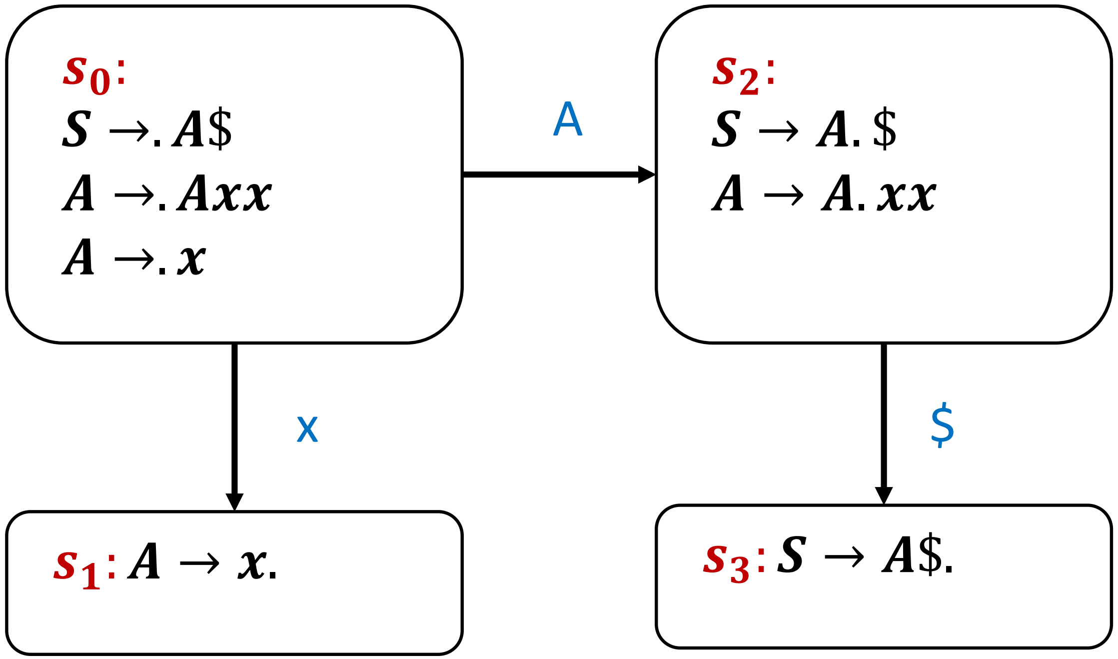
$A \to x$



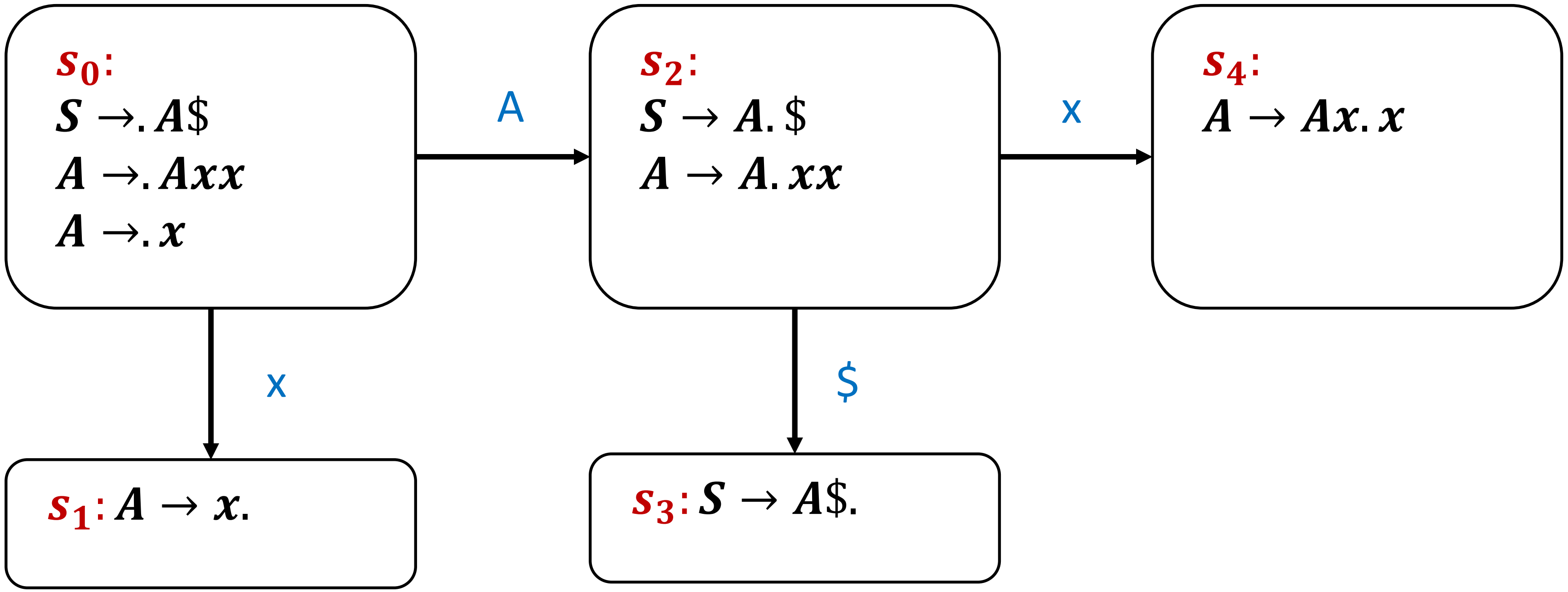
$$S \rightarrow A\$$$
$$A \rightarrow Axx$$
$$A \rightarrow x$$



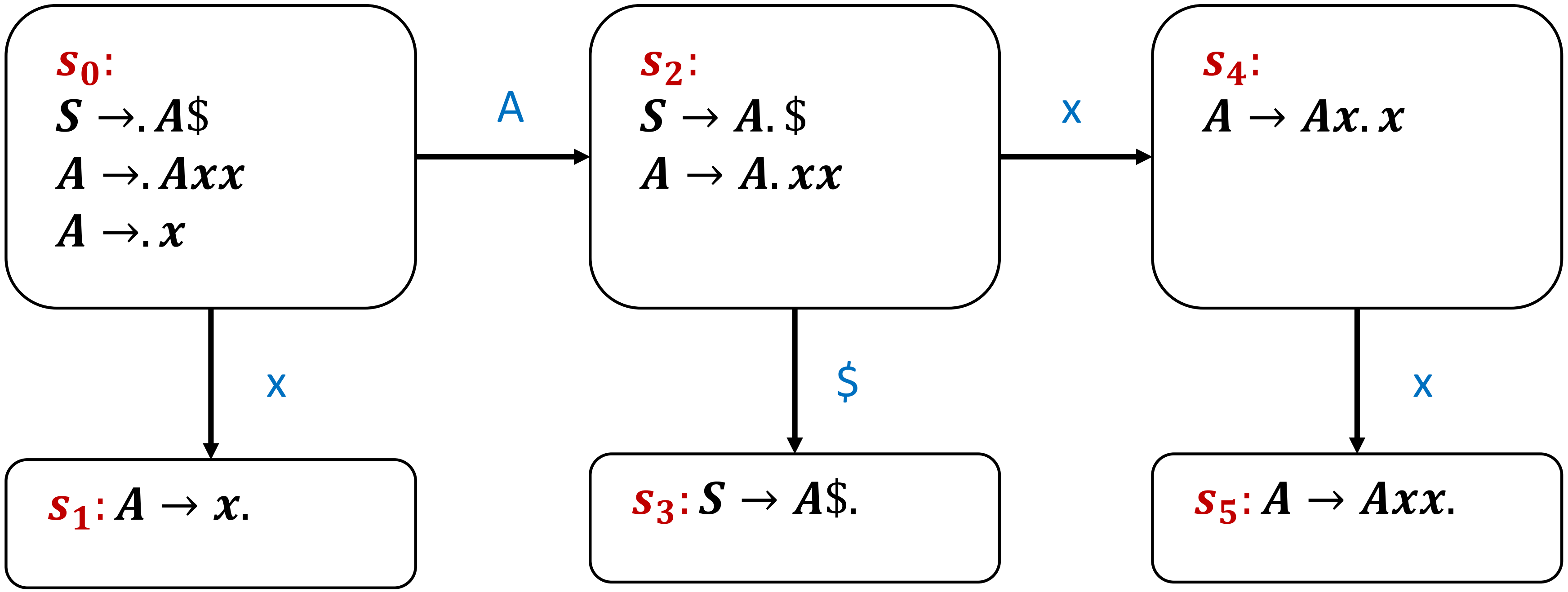
$S \rightarrow A\$$
$A \rightarrow Axx$
$A \rightarrow x$



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



$$S \to A\$$$
$$A \to Axx$$
$$A \to x$$

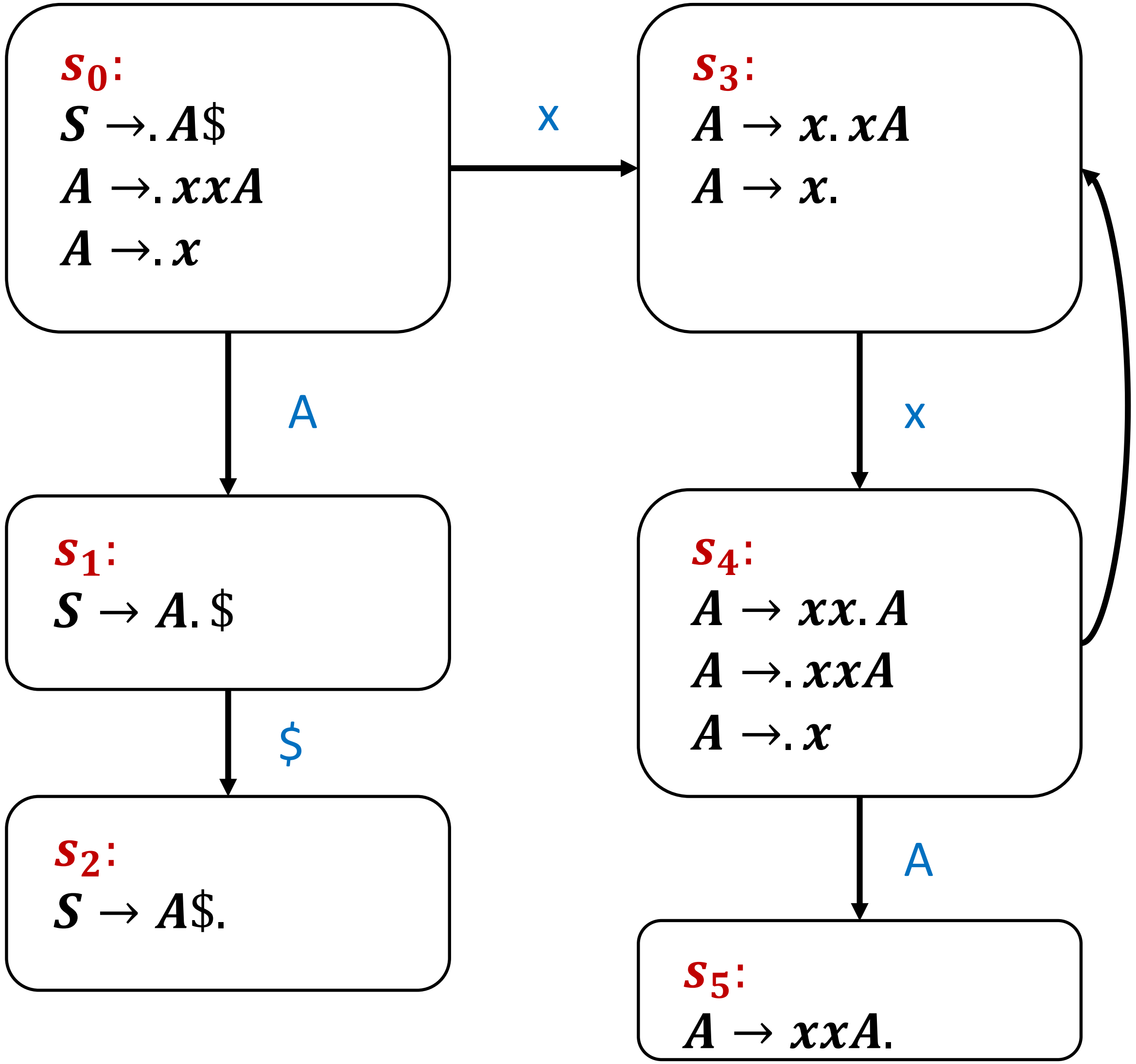


$$S \to A\$$$
$$A \to Axx$$
$$A \to x$$

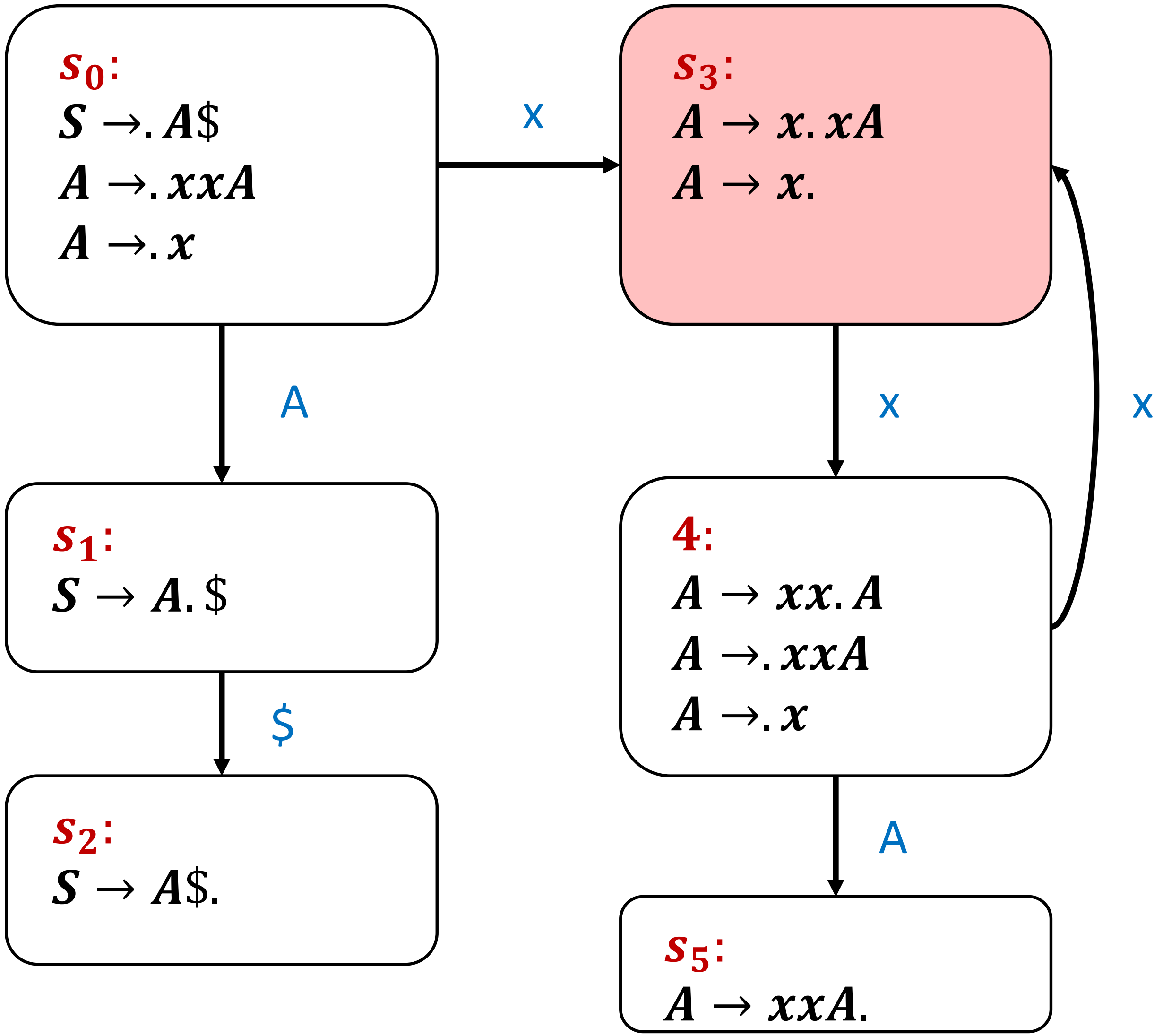
Question

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

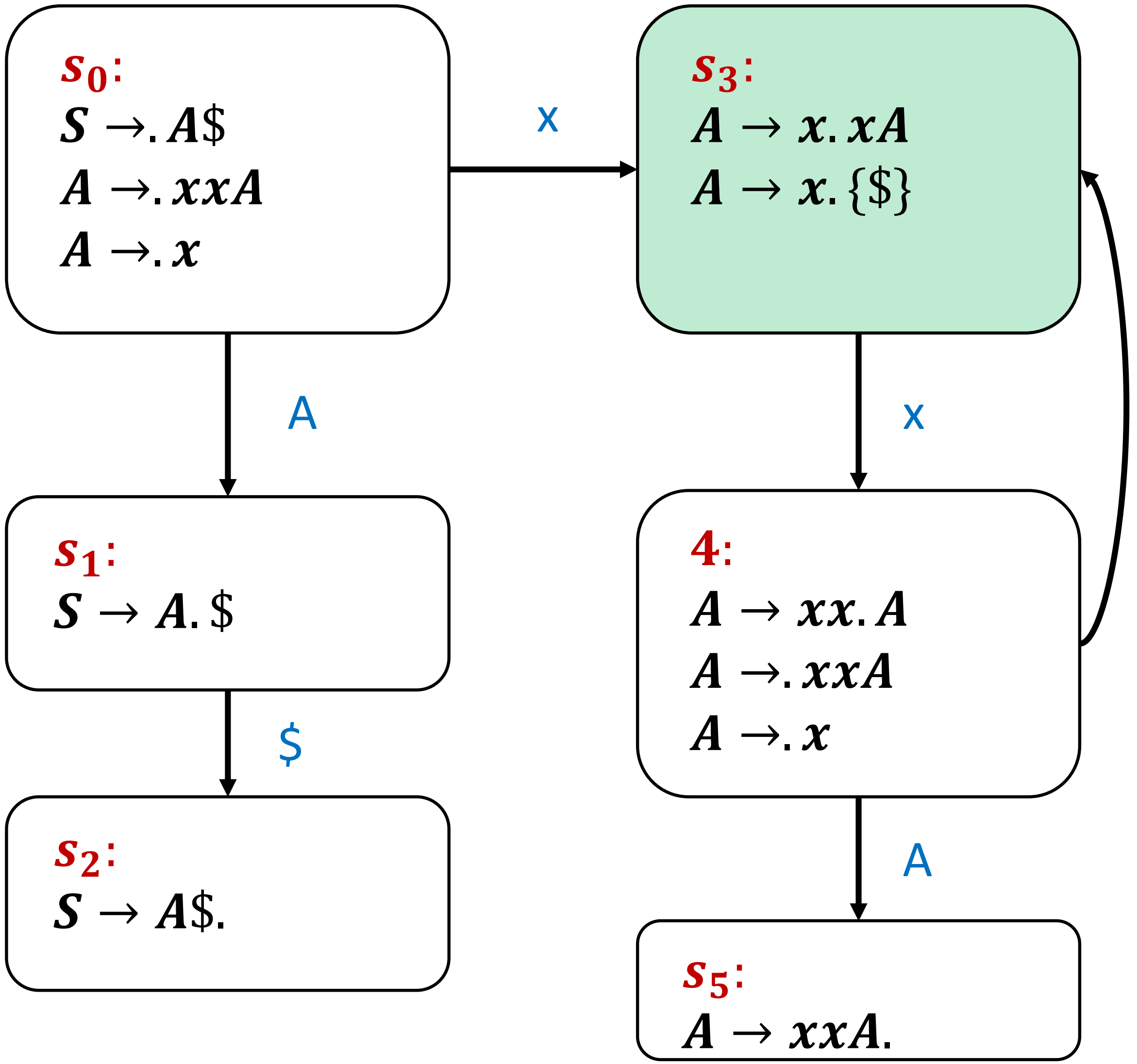
- $S \rightarrow A\$$
- $A \rightarrow xxA$
- $A \rightarrow x$



$S \to A\$$
$A \to xxA$
$A \to x$



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



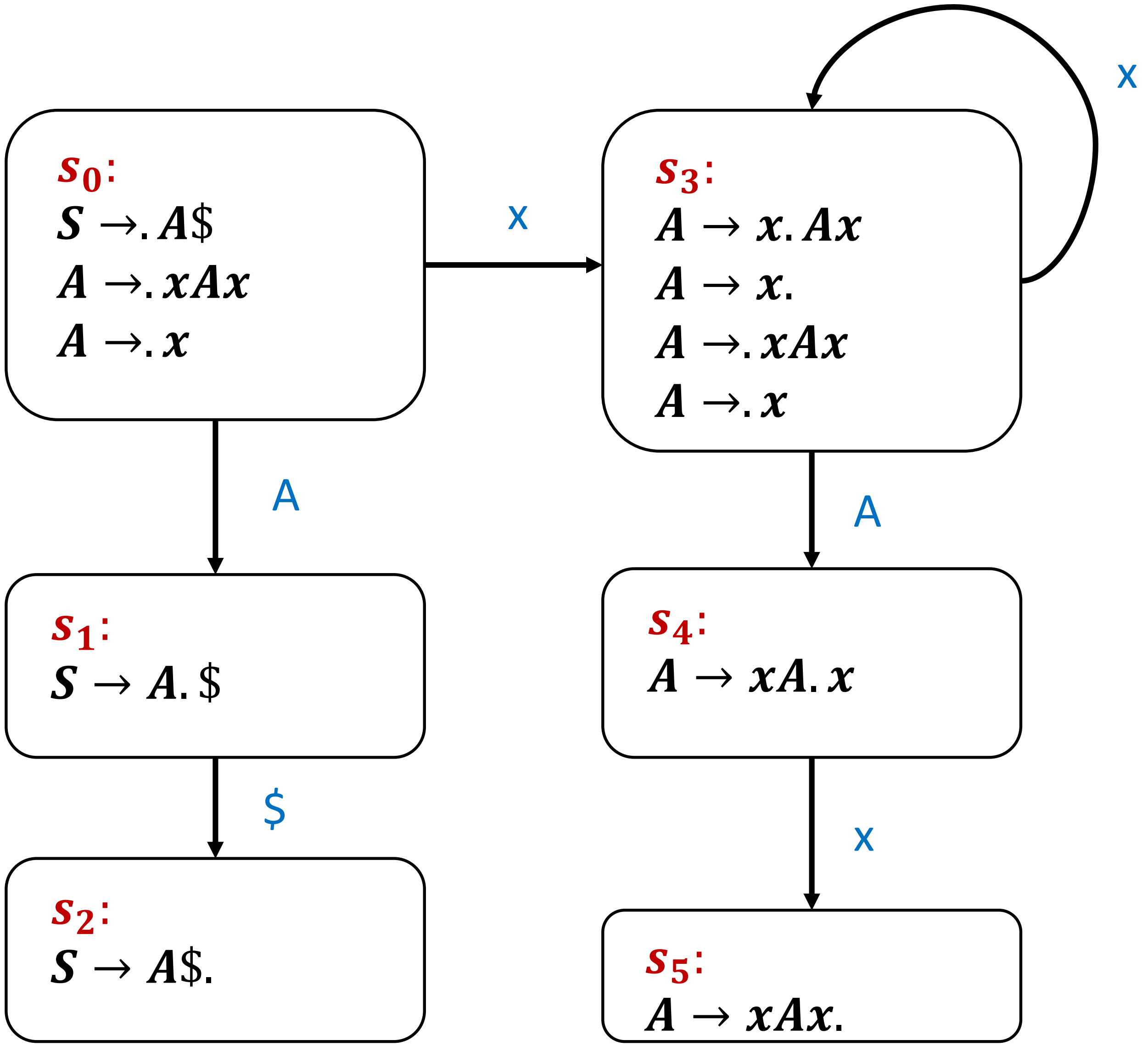
$$Follow(A) = \{\$\}$$

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

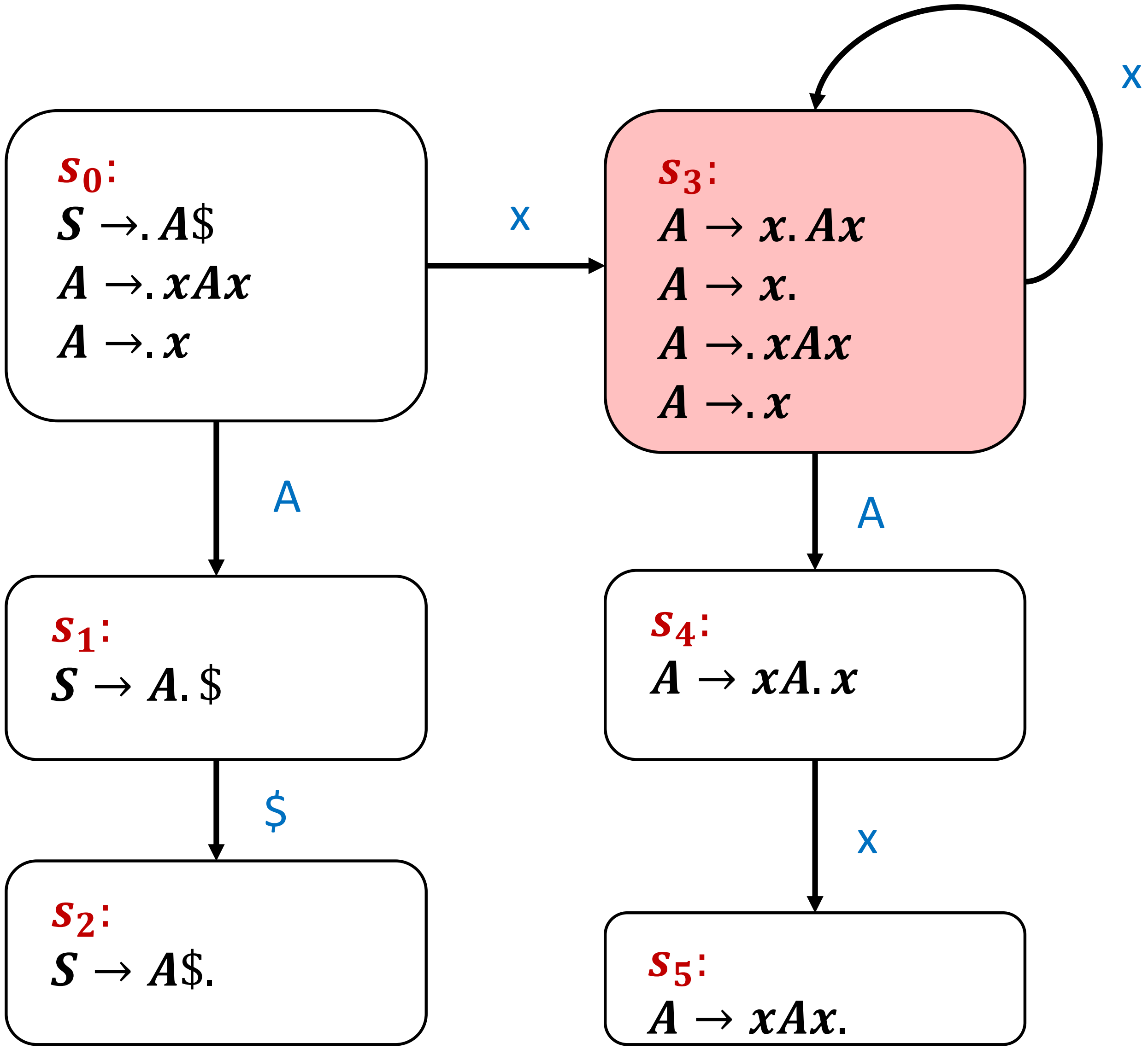
Question

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

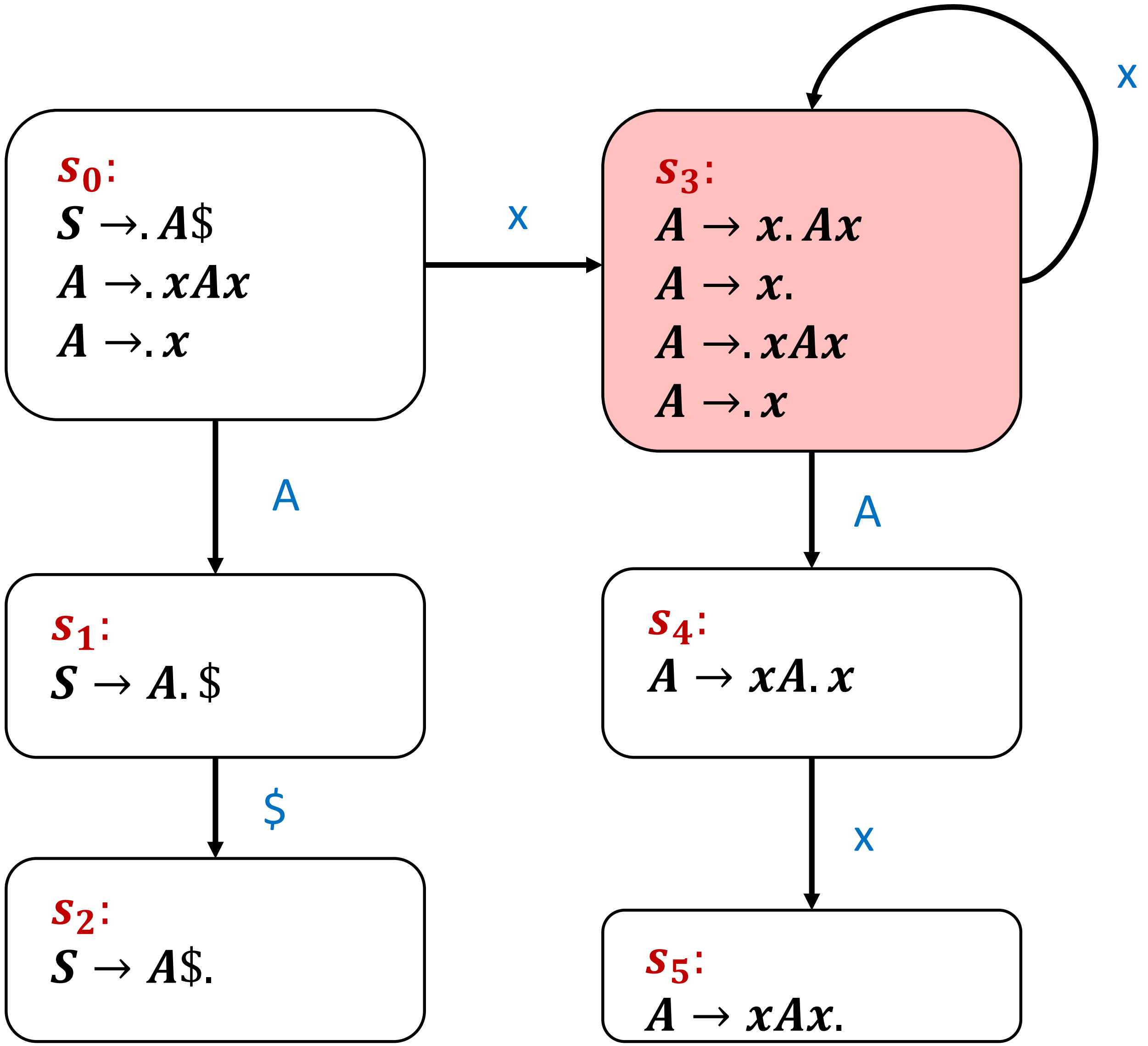
- $S \rightarrow A\$$
- $A \rightarrow xAx$
- $A \rightarrow x$



$S \to A\$$
$A \to xAx$
$A \to x$



$S \to A\$$
$A \to xAx$
$A \to x$



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

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

s_0:

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

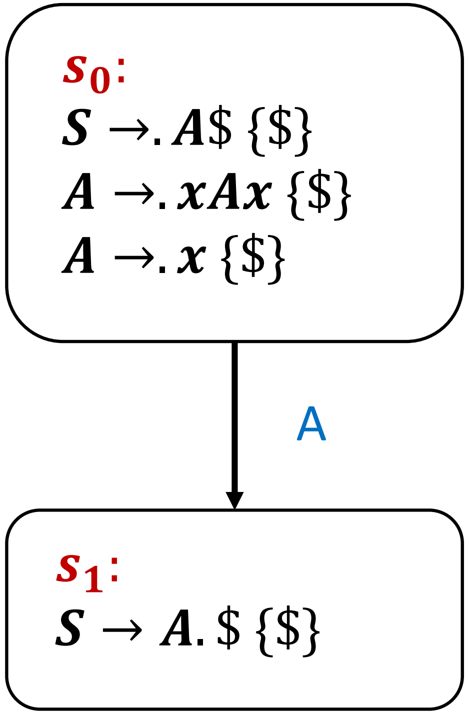
$A \rightarrow .xAx \ \{\$\}$

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

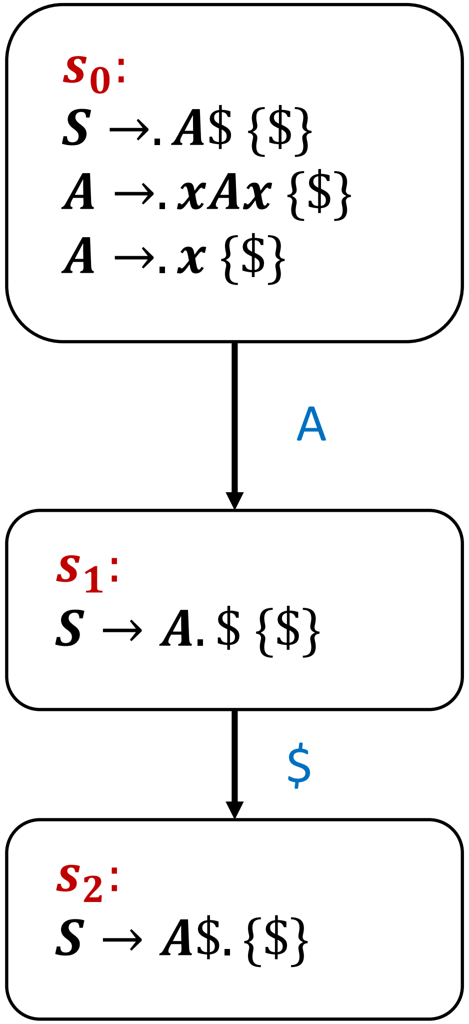
$S \rightarrow A\$$

$A \rightarrow xAx$

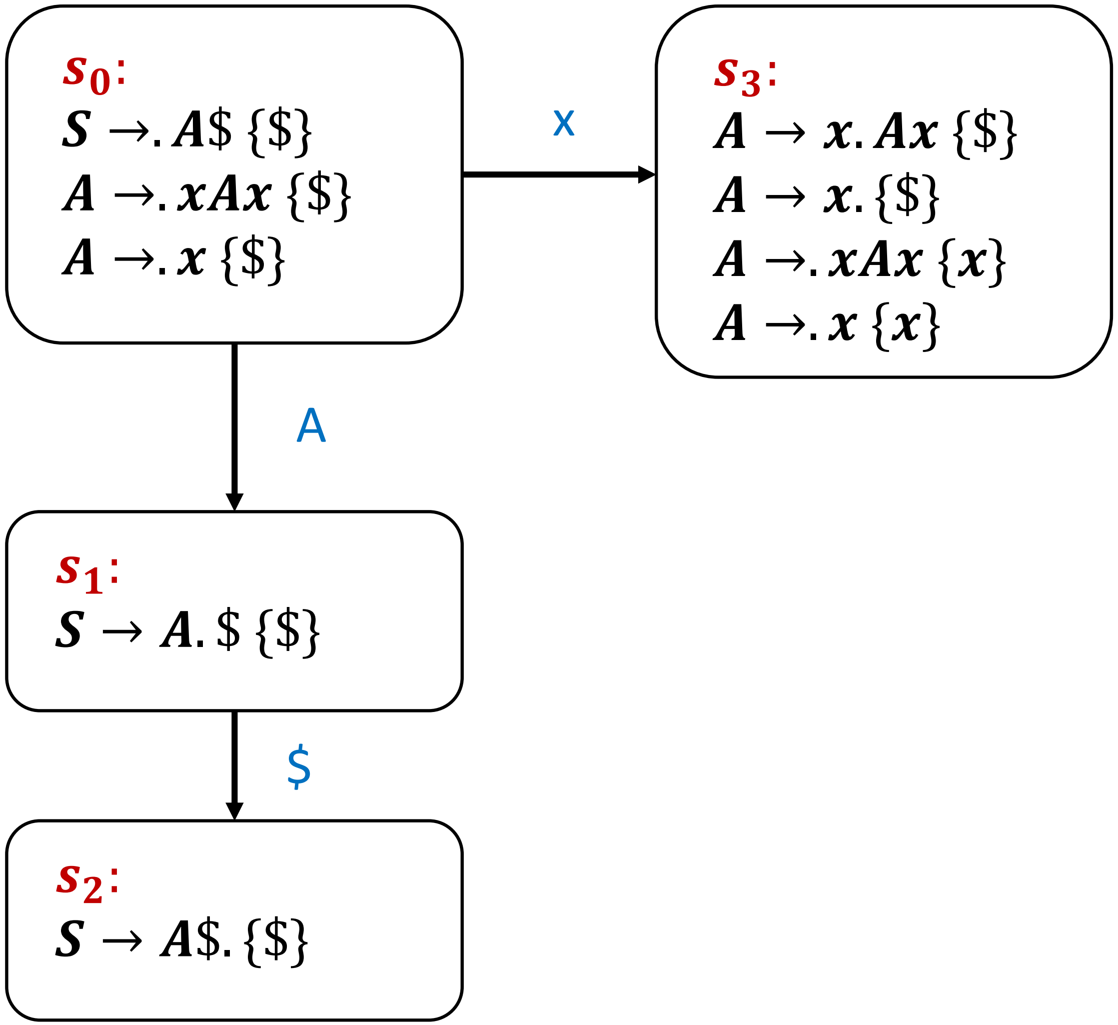
$A \rightarrow x$



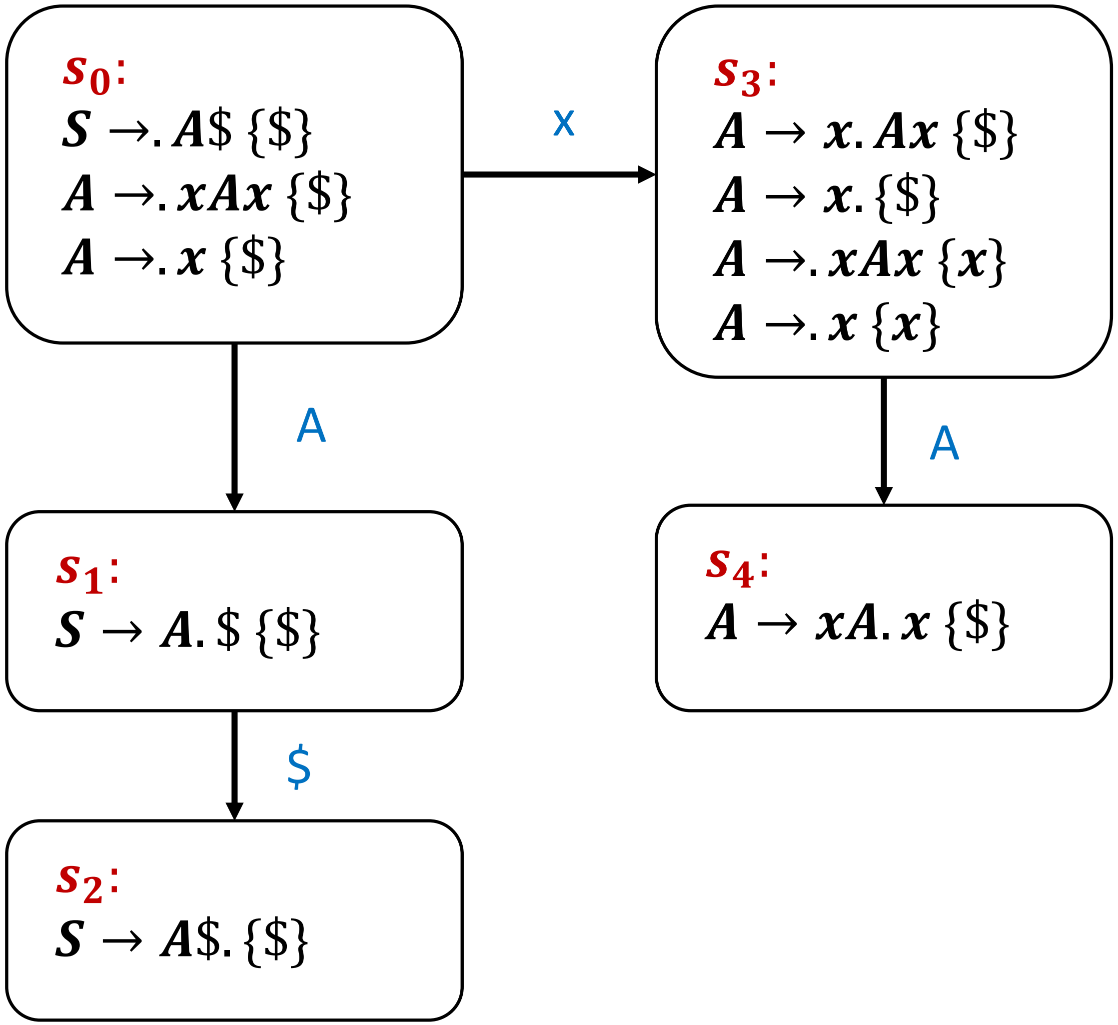
$$
\begin{aligned}
S &\to A\$ \\
A &\to xAx \\
A &\to x
\end{aligned}
$$



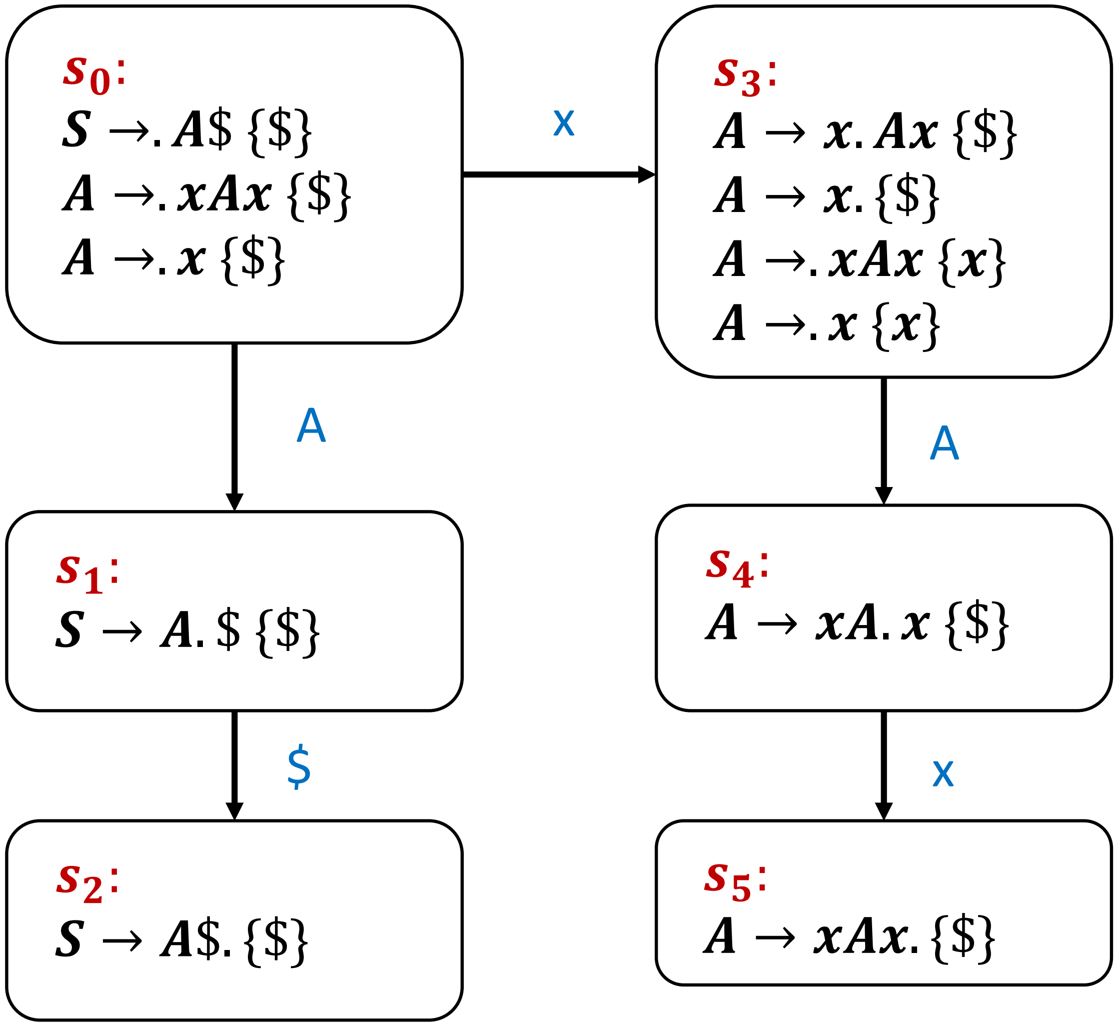
$$S \rightarrow A\$$$
$$A \rightarrow xAx$$
$$A \rightarrow x$$



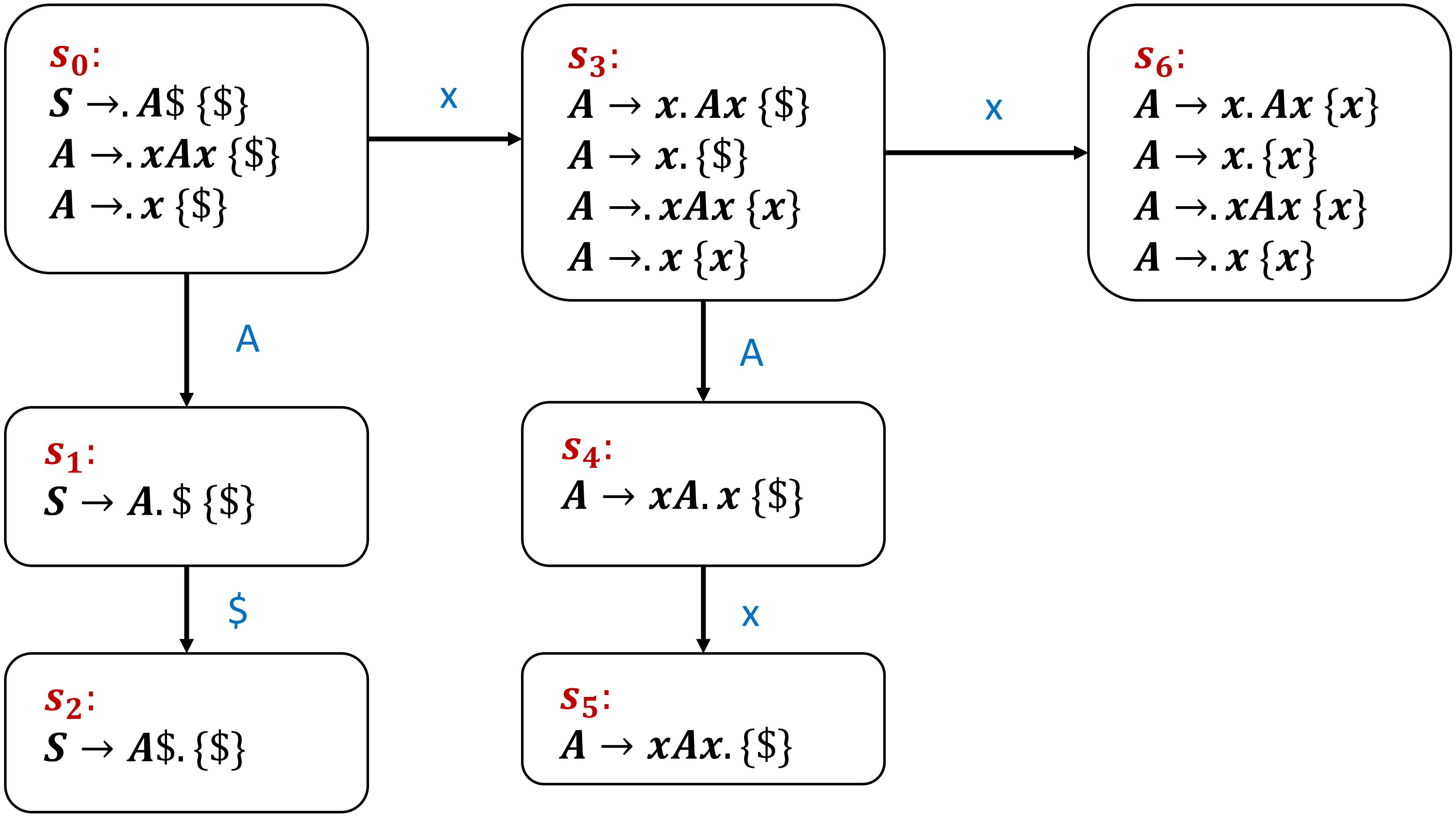
$S \rightarrow A\$$
$A \rightarrow xAx$
$A \rightarrow x$



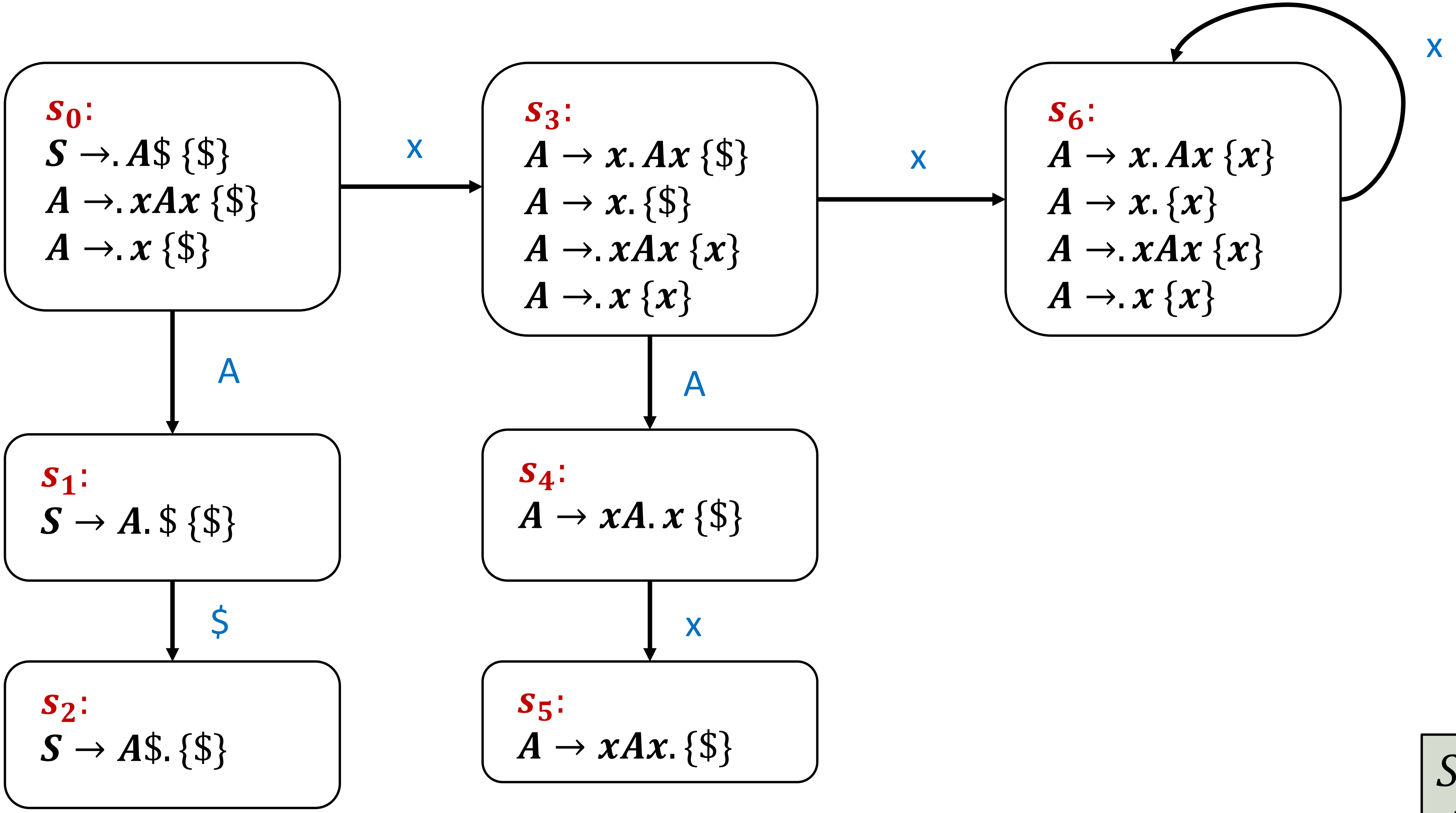
$S \rightarrow A\$$
$A \rightarrow xAx$
$A \rightarrow x$



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



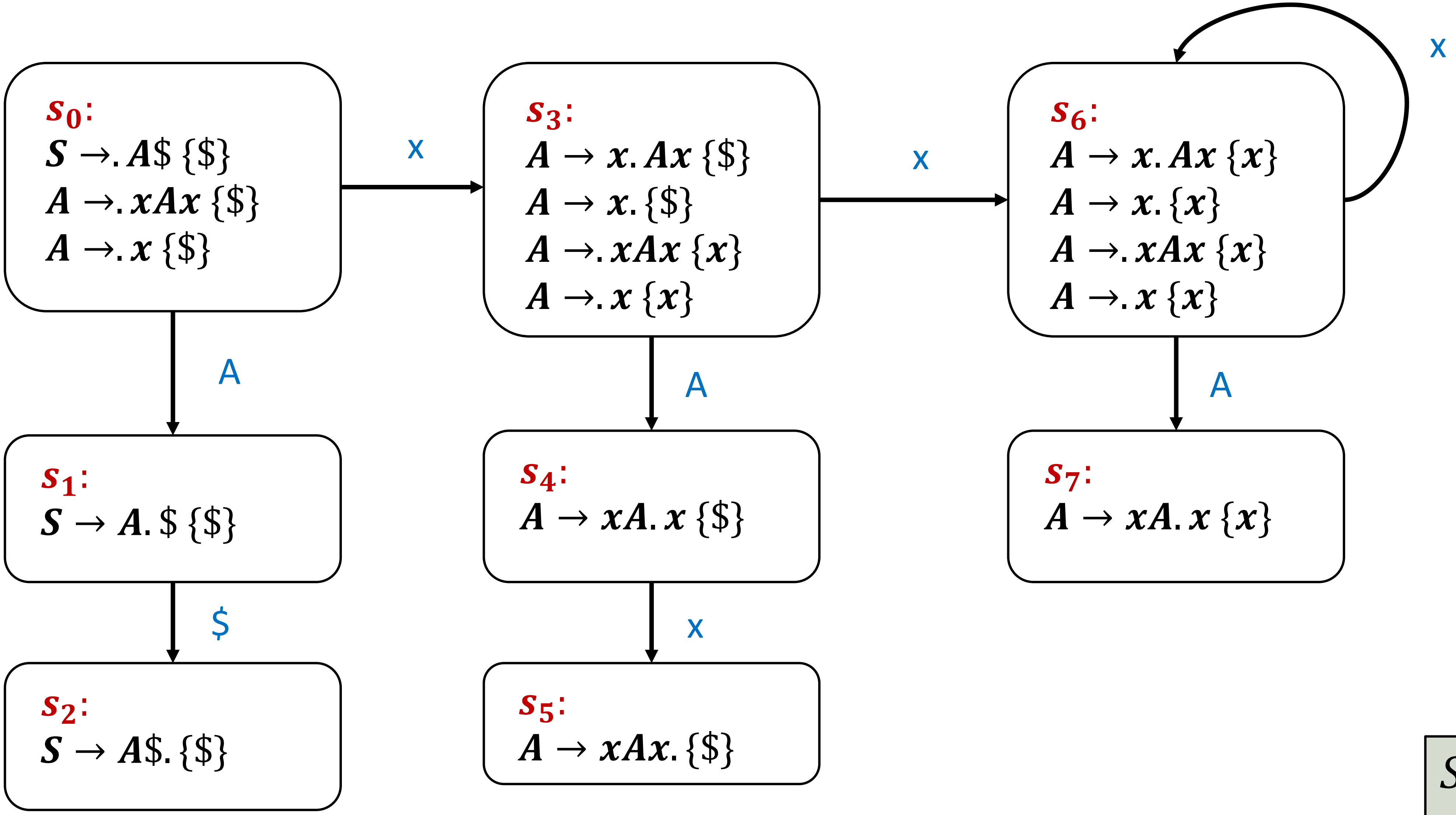
$S \to A\$$
$A \to xAx$
$A \to x$



$S \rightarrow A\$$

$A \rightarrow xAx$

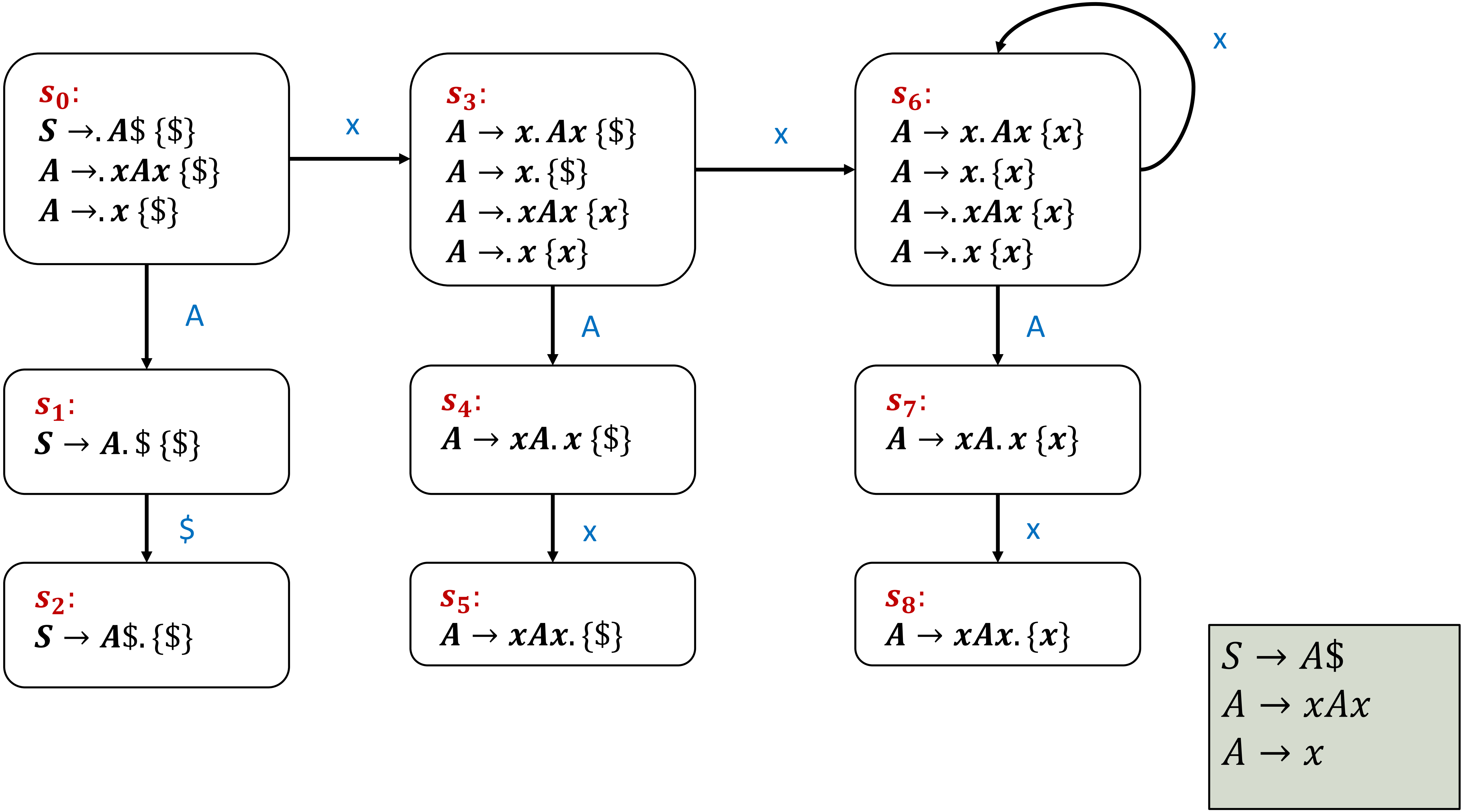
$A \rightarrow x$



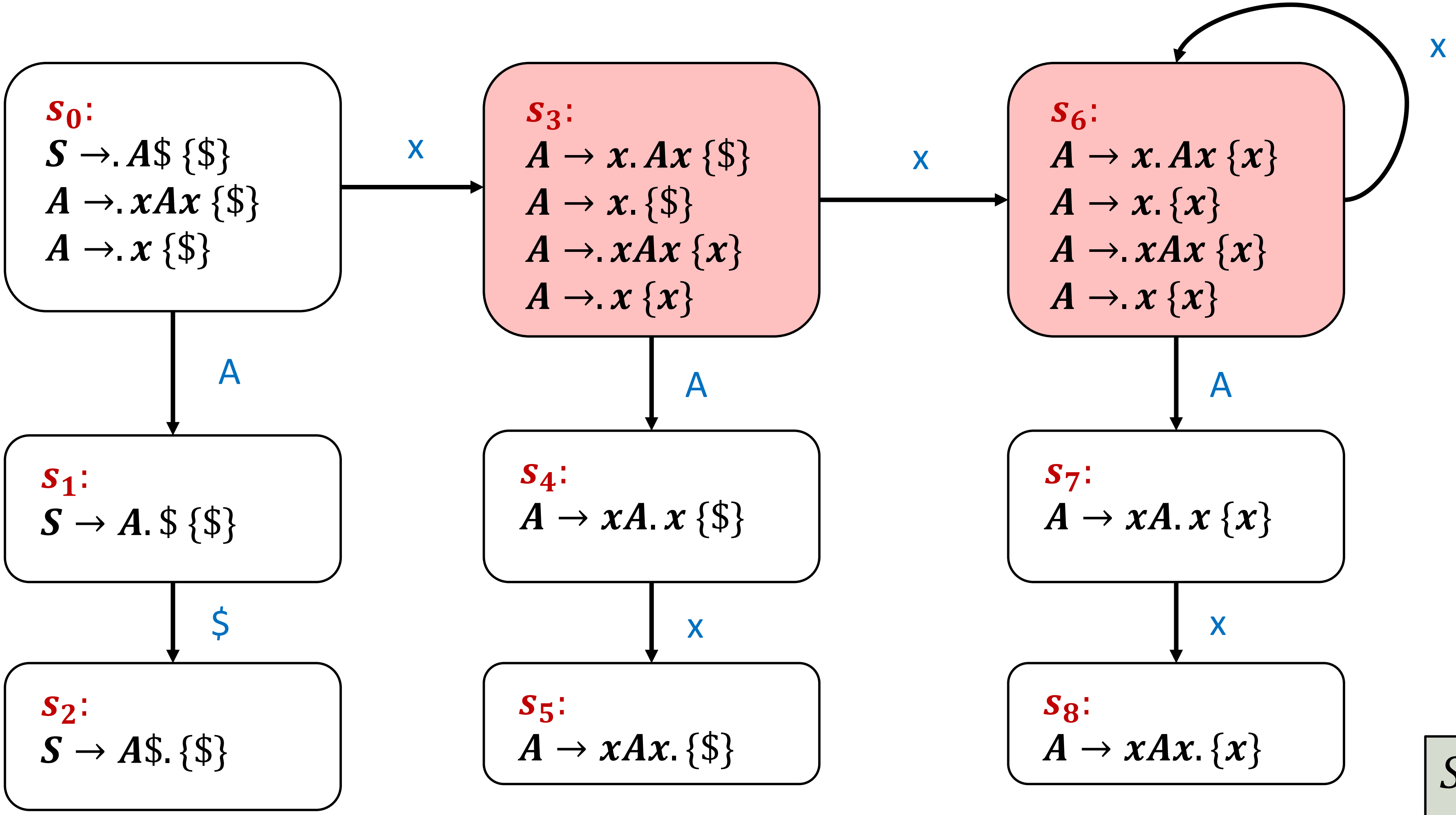
$S \to A\$$

$A \to xAx$

$A \to x$



s_0:
$S \rightarrow .A\$ \{\$\}$
$A \rightarrow .xAx \{\$\}$
$A \rightarrow .x \{\$\}$
x
s_3:
$A \rightarrow x.Ax \{\$\}$
$A \rightarrow x. \{\$\}$
$A \rightarrow .xAx \{x\}$
$A \rightarrow .x \{x\}$
x
s_6:
$A \rightarrow x.Ax \{x\}$
$A \rightarrow x. \{x\}$
$A \rightarrow .xAx \{x\}$
$A \rightarrow .x \{x\}$
x
A
A
A
s_1:
$S \rightarrow A.\$ \{\$\}$
s_4:
$A \rightarrow xA.x \{\$\}$
s_7:
$A \rightarrow xA.x \{x\}$
\$
x
x
s_2:
$S \rightarrow A\$. \{\$\}$
s_5:
$A \rightarrow xAx. \{\$\}$
s_8:
$A \rightarrow xAx. \{x\}$
$S \rightarrow A\$$
$A \rightarrow xAx$
$A \rightarrow x$



$S \to A\$$
$A \to xAx$
$A \to x$

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*.

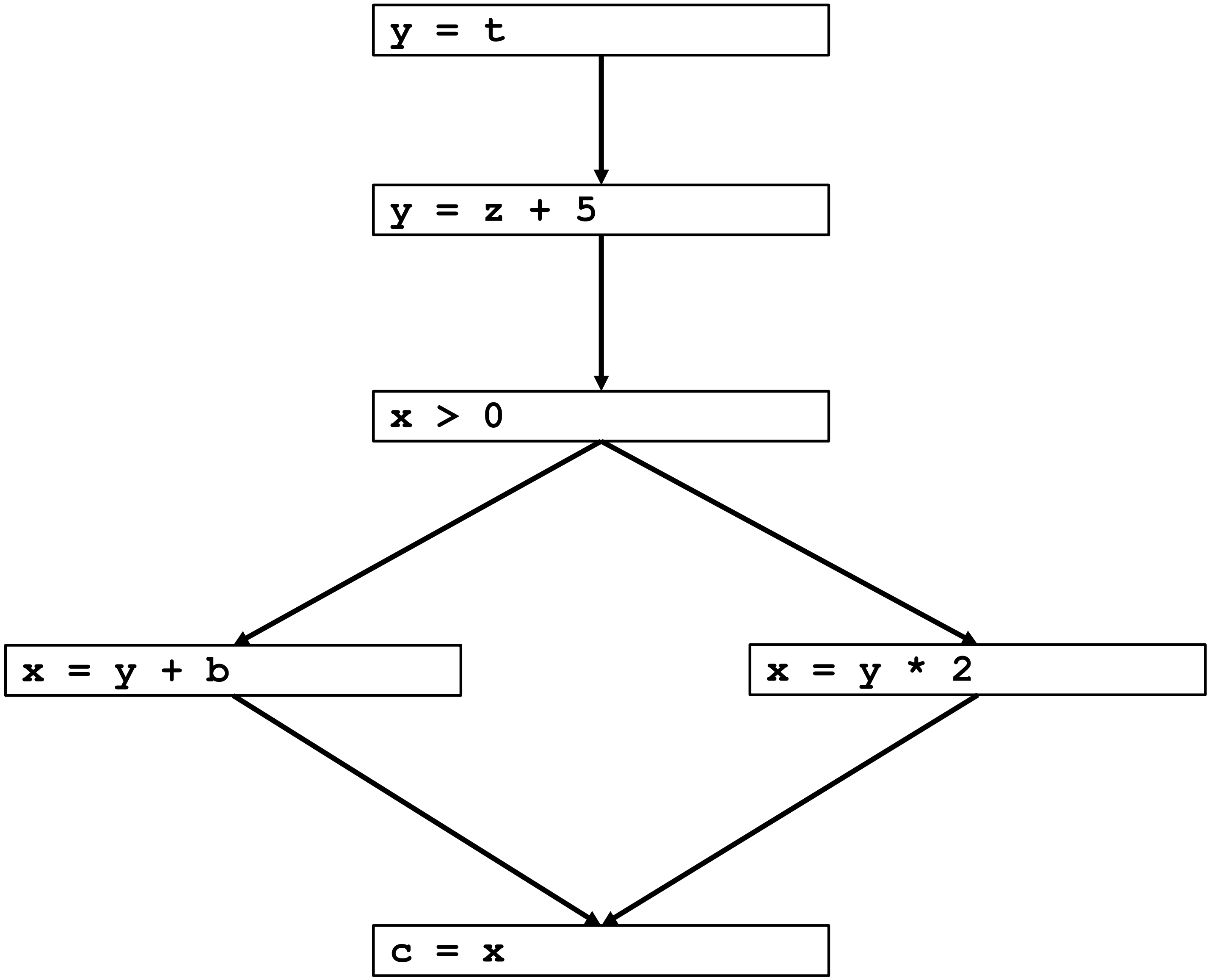
- Define a static analysis in terms of $(D, V, \sqcup, F, I)$
- Run on the example

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

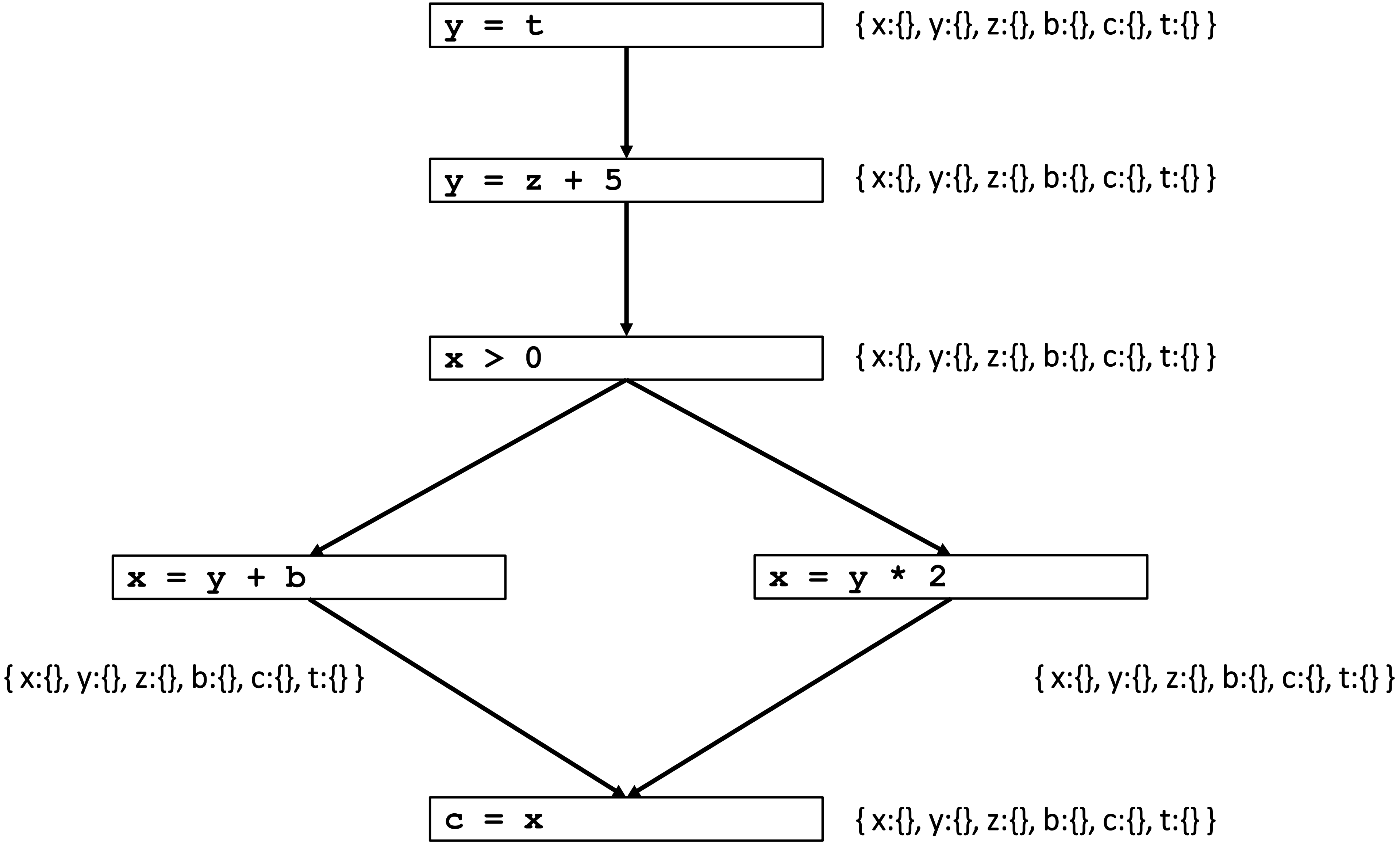
Abstract Domain

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

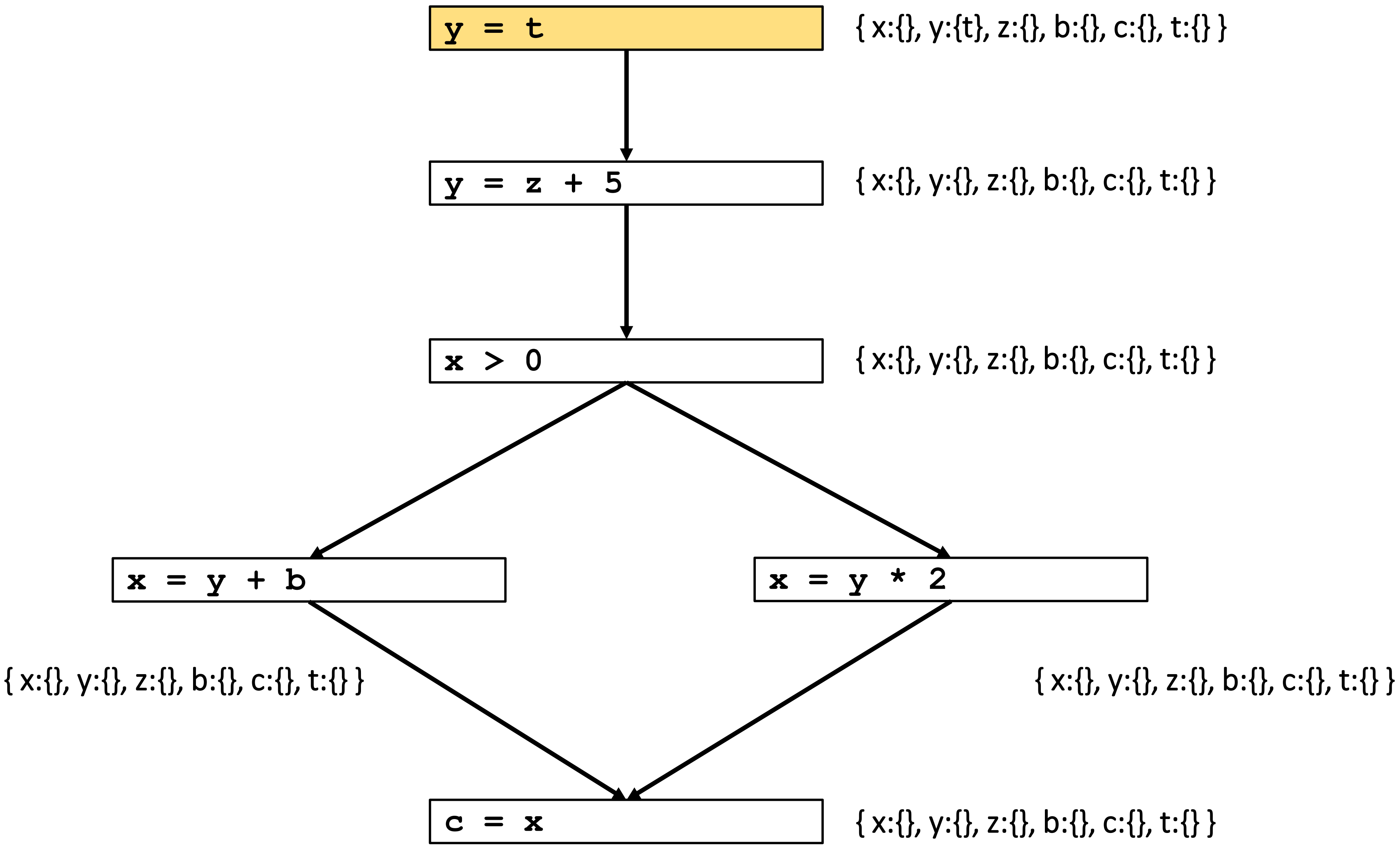
- Forward analysis
- V contains maps of the form:
  - $Var \mapsto P(Var)$ (e.g., $\{a : \{b, c\}\}$)
- Join operator:
  - $m_1 \sqcup m_2 \coloneqq \lambda v. m_1[v] \cup m_2[v]$
    - $\{a : \{b\}\} \sqcup \{a : \{c\}, d : \{e\}\} = \{a : \{b, c\}, d : \{e\}\}$
- On a = b + c:
  - $\{a : s_a, b : s_b, c : s_c, \ldots\} \rightarrow \{a : \{b, c\} \cup s_b \cup s_c, b : s_b, c : s_c, \ldots\}$
- Initialize with:
  - $\lambda v. \{\}$

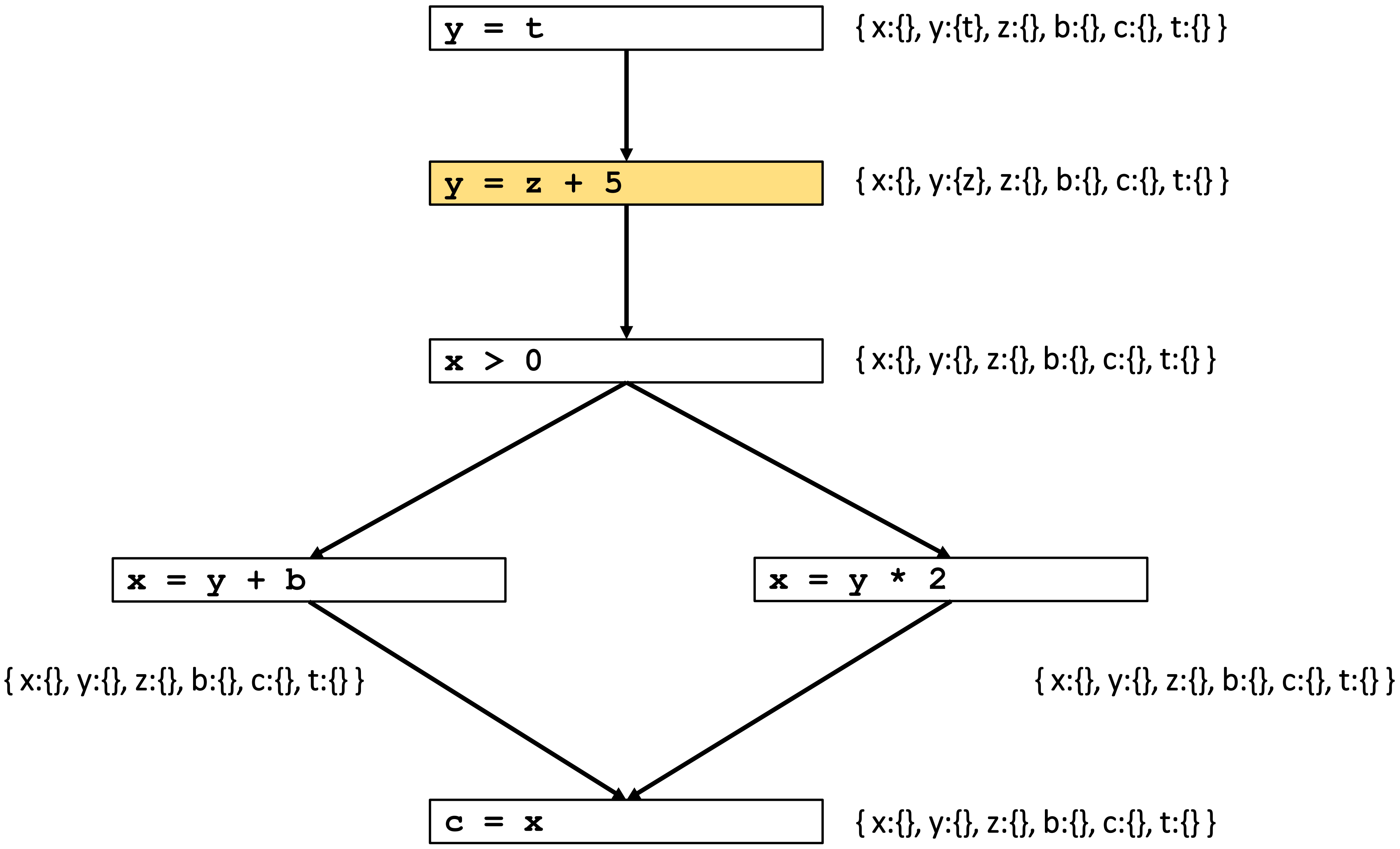


y = t
y = z + 5
x > 0
x = y + b
x = y * 2
c = x

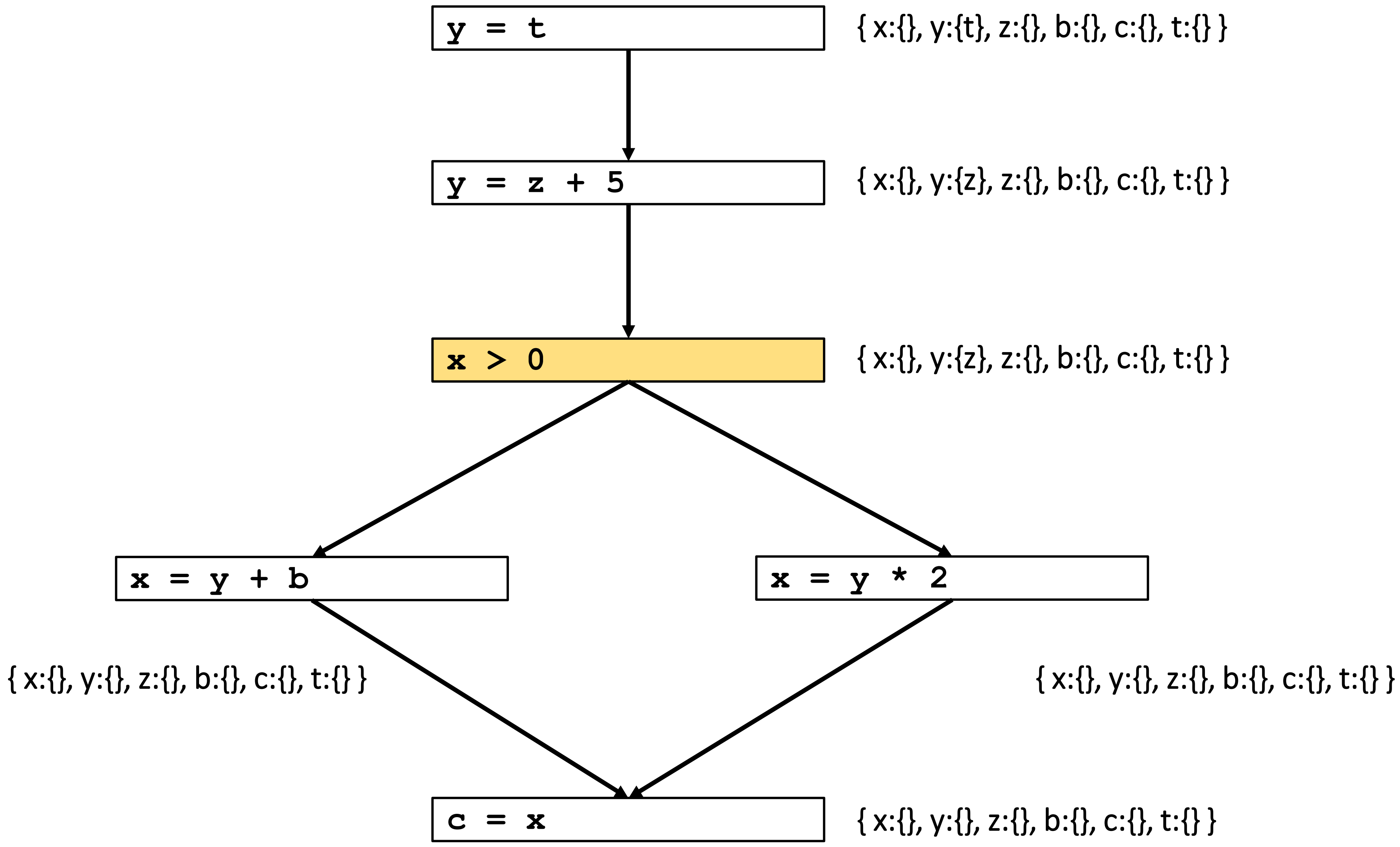


y = t
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
y = z + 5
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
x > 0
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
x = y + b
x = y * 2
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
c = x
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }

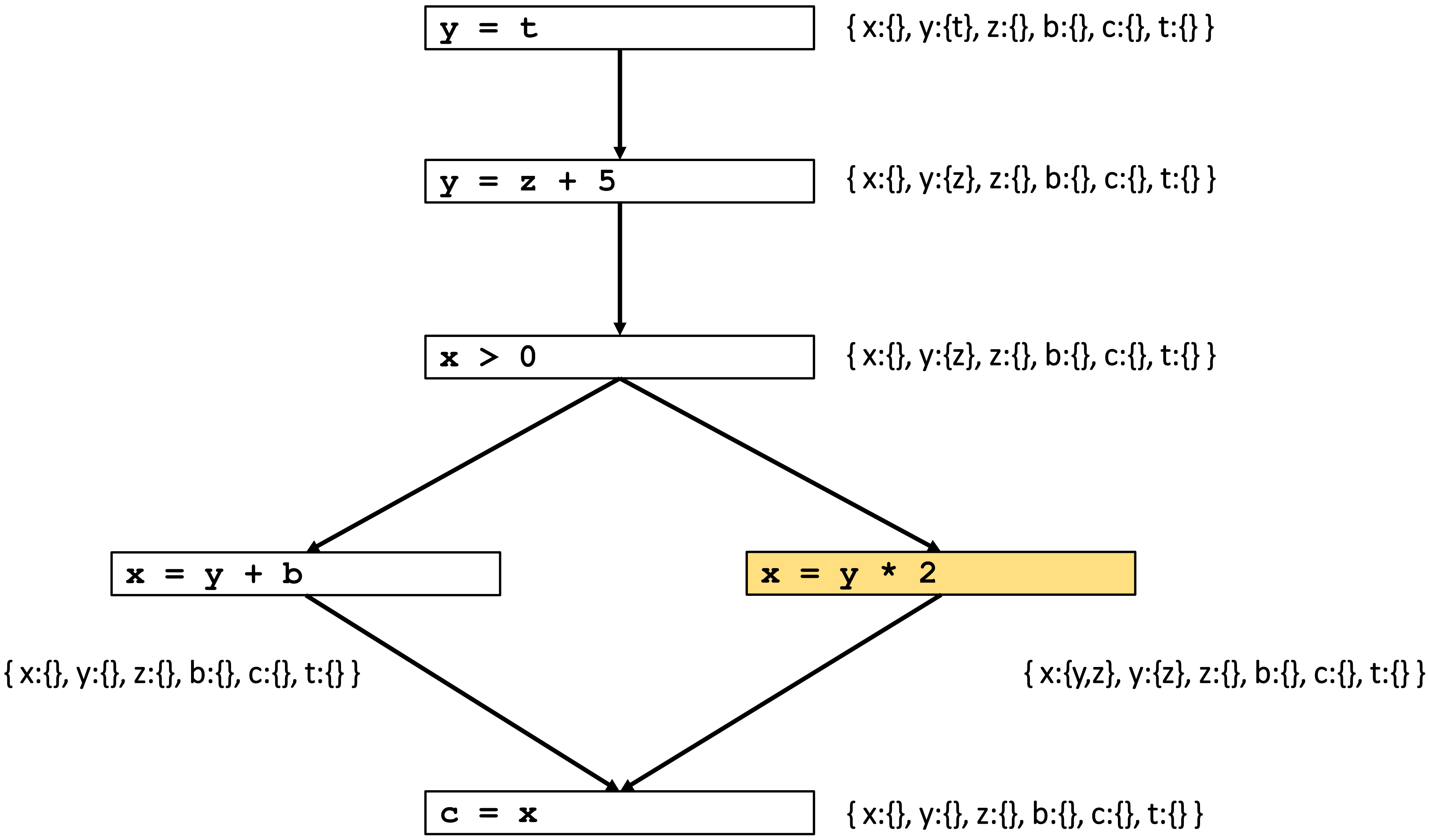

y = t
{ x:{}, y:{t}, z:{}, b:{}, c:{}, t:{} }
y = z + 5
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
x > 0
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
x = y + b
x = y * 2
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
c = x
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }

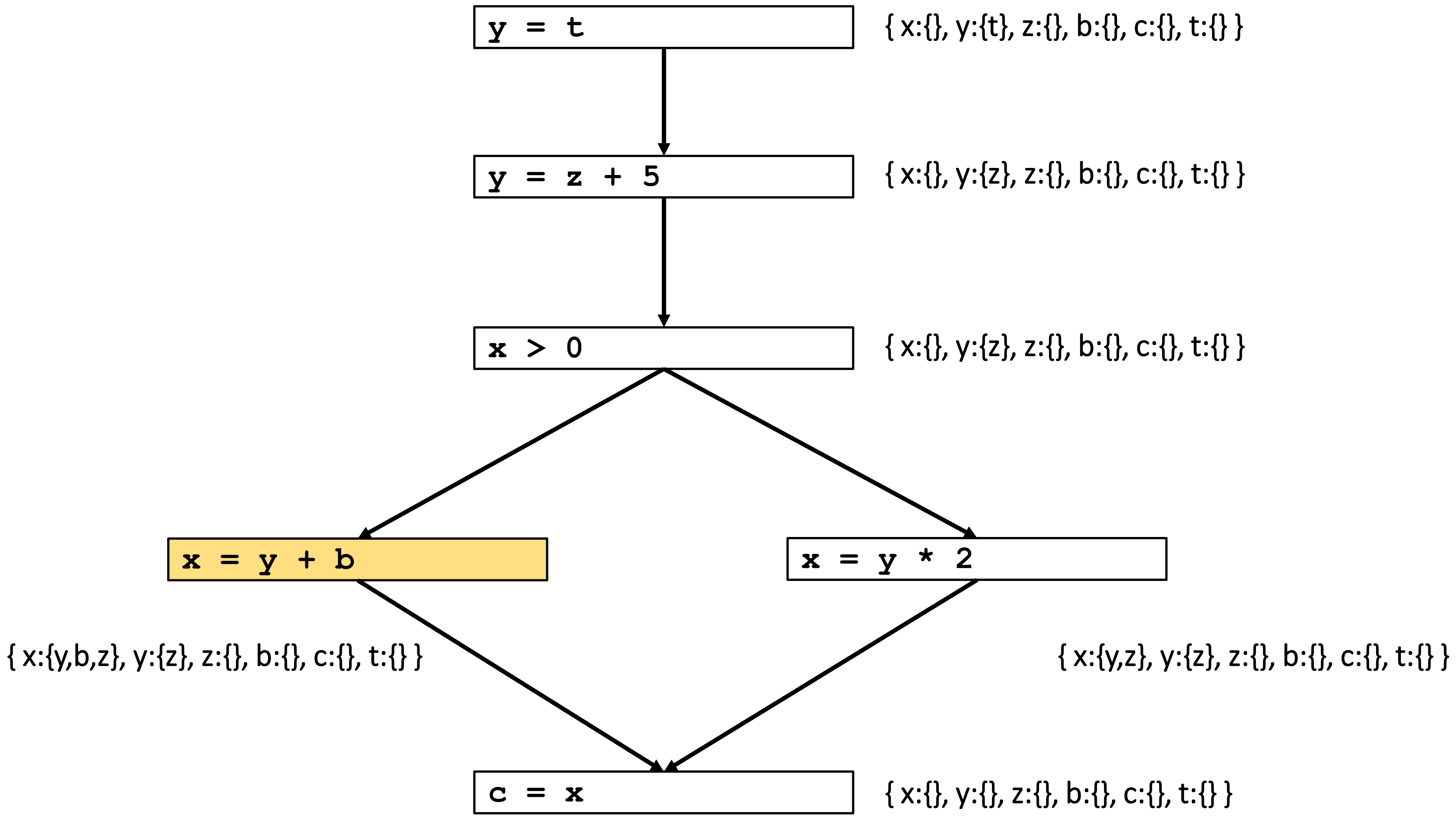


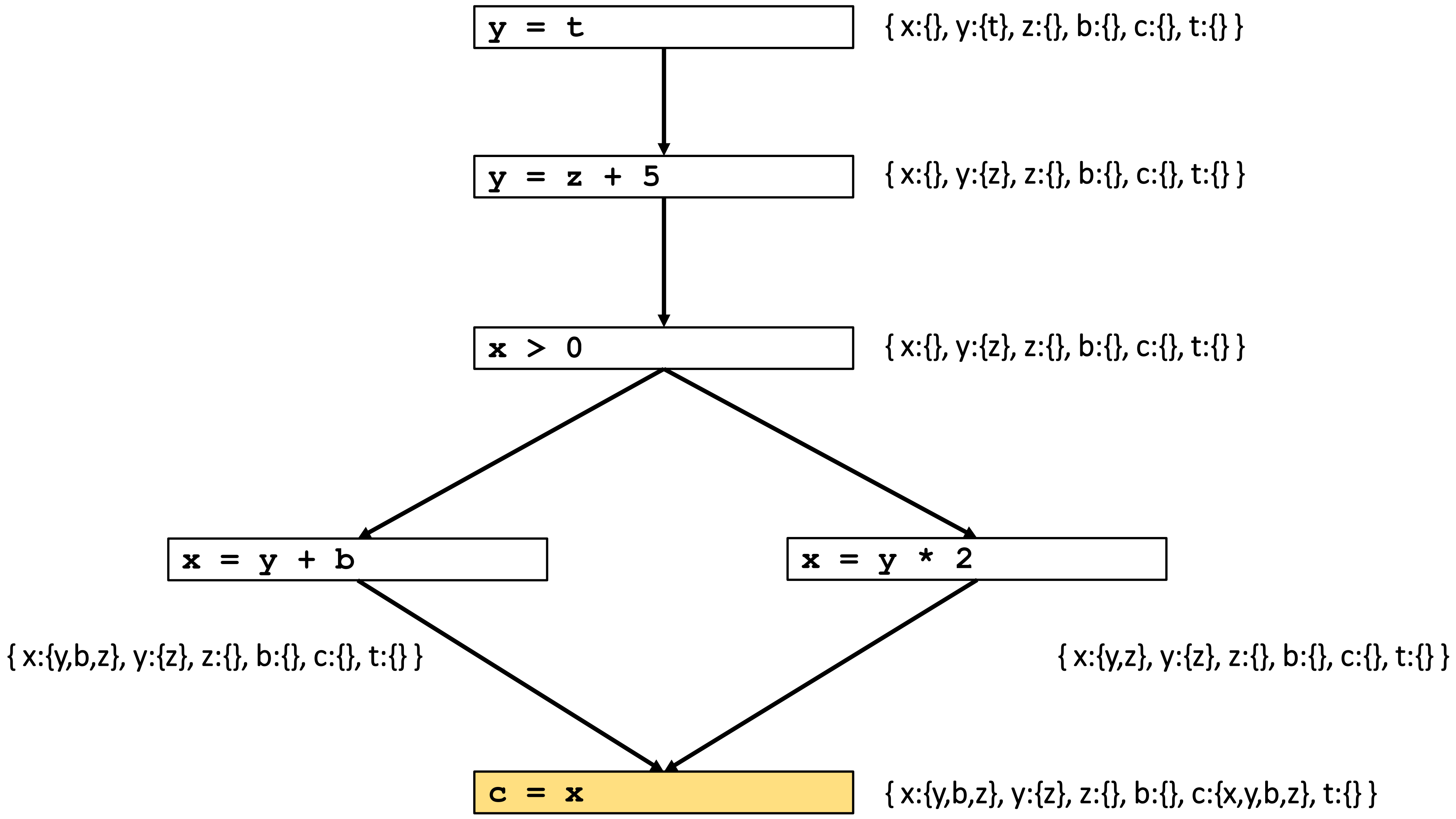
y = t
{ x:{}, y:{t}, z:{}, b:{}, c:{}, t:{} }
y = z + 5
{ x:{}, y:{z}, z:{}, b:{}, c:{}, t:{} }
x > 0
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
x = y + b
x = y * 2
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
c = x
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }



y = t
{ x:{}, y:{t}, z:{}, b:{}, c:{}, t:{} }
y = z + 5
{ x:{}, y:{z}, z:{}, b:{}, c:{}, t:{} }
x > 0
{ x:{}, y:{z}, z:{}, b:{}, c:{}, t:{} }
x = y + b
x = y * 2
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
c = x
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }


y = t
{ x:{}, y:{t}, z:{}, b:{}, c:{}, t:{} }
y = z + 5
{ x:{}, y:{z}, z:{}, b:{}, c:{}, t:{} }
x > 0
{ x:{}, y:{z}, z:{}, b:{}, c:{}, t:{} }
x = y + b
x = y * 2
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }
{ x:{y,z}, y:{z}, z:{}, b:{}, c:{}, t:{} }
c = x
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }


y = t
{ x:{}, y:{t}, z:{}, b:{}, c:{}, t:{} }
y = z + 5
{ x:{}, y:{z}, z:{}, b:{}, c:{}, t:{} }
x > 0
{ x:{}, y:{z}, z:{}, b:{}, c:{}, t:{} }
x = y + b
x = y * 2
{ x:{y,b,z}, y:{z}, z:{}, b:{}, c:{}, t:{} }
{ x:{y,z}, y:{z}, z:{}, b:{}, c:{}, t:{} }
c = x
{ x:{}, y:{}, z:{}, b:{}, c:{}, t:{} }


y = t
{ x:{}, y:{t}, z:{}, b:{}, c:{}, t:{} }
y = z + 5
{ x:{}, y:{z}, z:{}, b:{}, c:{}, t:{} }
x > 0
{ x:{}, y:{z}, z:{}, b:{}, c:{}, t:{} }
x = y + b
x = y * 2
{ x:{y,b,z}, y:{z}, z:{}, b:{}, c:{}, t:{} }
{ x:{y,z}, y:{z}, z:{}, b:{}, c:{}, t:{} }
c = x
{ x:{y,b,z}, y:{z}, z:{}, b:{}, c:{x,y,b,z}, t:{} }

Question

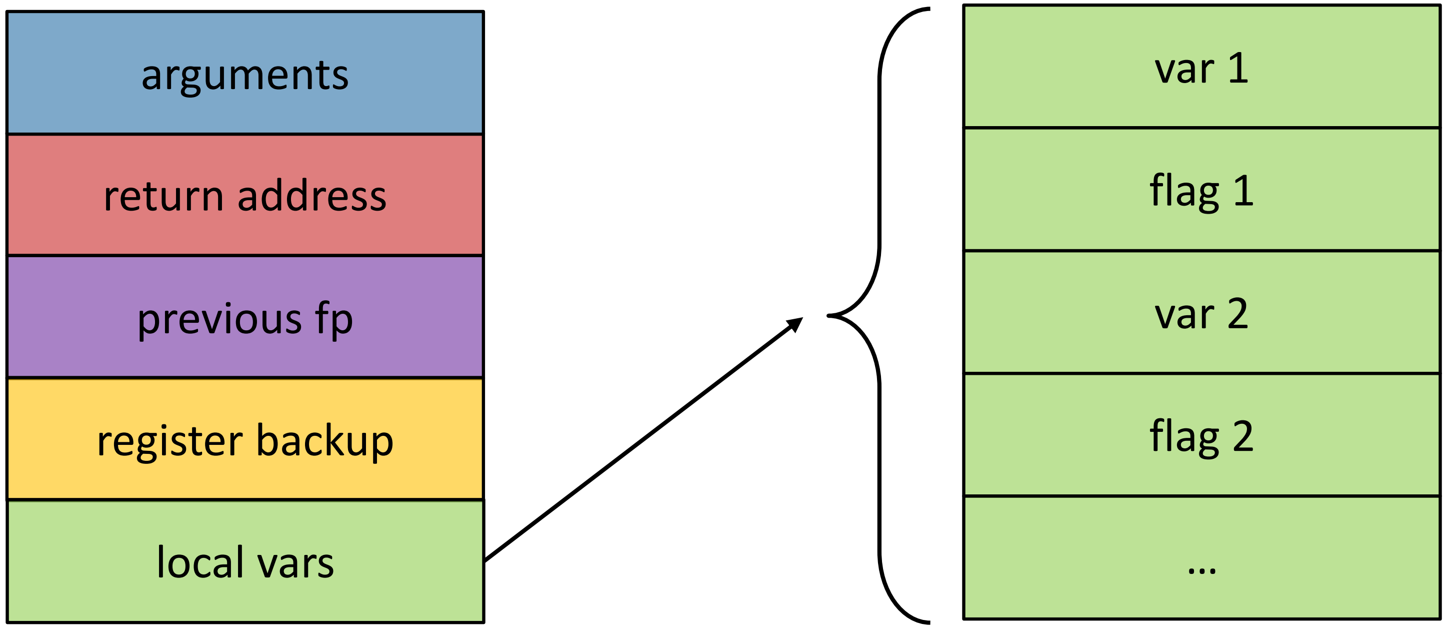
Add support for detecting accesses to uninitialized local variables.
Describe the required changes in the code generation step.

For example:

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

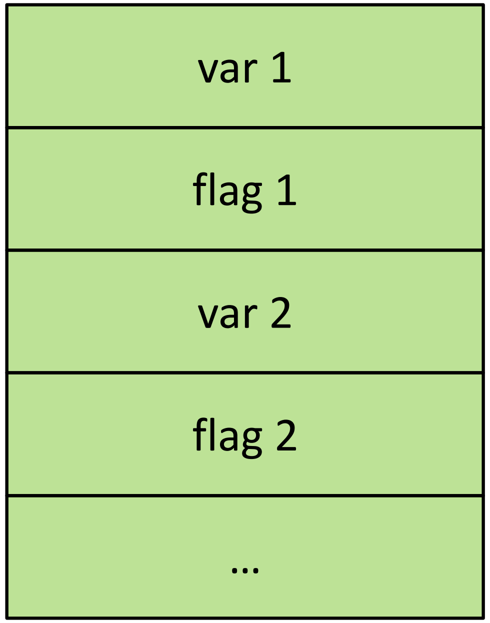
Solution

High level idea:



Solution

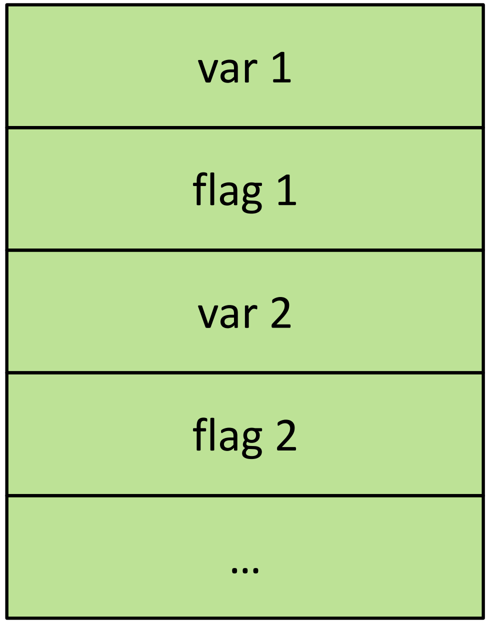
- Initialize each variable flag to zero on function entry
- When writing to a local variable, set its flag to 1
- When reading a local variable, check if its flag is 1



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)
...
```

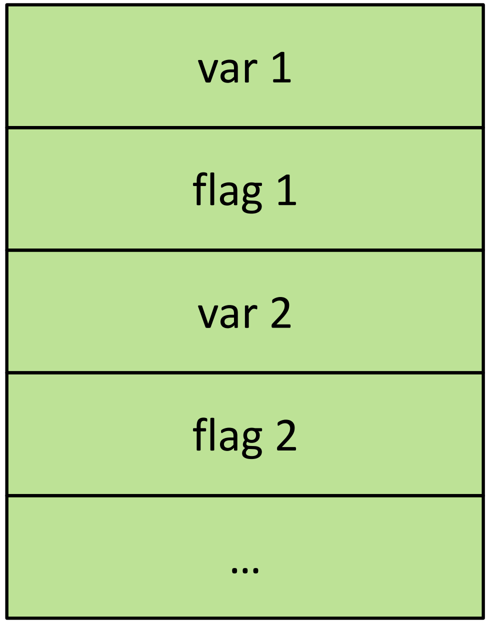


Solution

- 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)
```



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
```

```
t0 = 0
t1 = 1
t2 = 2
t3 = mul t2, t1
t2 = t3
t1 = add t1, t0
```

IN		OUT
{ }	`t0 = 0`	{ }
{ }	`t1 = 1`	{ }
{ }	`t2 = 2`	{ }
{ }	`t3 = mul t2, t1`	{ }
{ }	`t2 = t3`	{ }
{ }	`t1 = add t1, t0`	{ }

initialization

IN		OUT
{ }	`t0 = 0`	{ }
{ }	`t1 = 1`	{ }
{ }	`t2 = 2`	{ }
{ }	`t3 = mul t2, t1`	{ }
{ }	`t2 = t3`	{ }
{ t0, t1 }	`t1 = add t1, t0`	{ }

first iteration

IN		OUT
{ }	`t0 = 0`	{ }
{ }	`t1 = 1`	{ }
{ }	`t2 = 2`	{ }
{ }	`t3 = mul t2, t1`	{ }
{ t0, t1, t3 }	`t2 = t3`	{ t0, t1 }
{ t0, t1 }	`t1 = add t1, t0`	{ }

first iteration

IN		OUT
{ }	`t0 = 0`	{ }
{ }	`t1 = 1`	{ }
{ }	`t2 = 2`	{ }
{ t2, t1, t0 }	`t3 = mul t2, t1`	{ t0, t1, t3 }
{ t0, t1, t3 }	`t2 = t3`	{ t0, t1 }
{ t0, t1 }	`t1 = add t1, t0`	{ }

first iteration

IN		OUT
{ }	`t0 = 0`	{ }
{ }	`t1 = 1`	{ }
{ t1, t0 }	`t2 = 2`	{ t2, t1, t0 }
{ t2, t1, t0 }	`t3 = mul t2, t1`	{ t0, t1, t3 }
{ t0, t1, t3 }	`t2 = t3`	{ t0, t1 }
{ t0, t1 }	`t1 = add t1, t0`	{ }

first iteration

IN		OUT
{ }	`t0 = 0`	{ }
{ t0 }	`t1 = 1`	{ t1, t0 }
{ t1, t0 }	`t2 = 2`	{ t2, t1, t0 }
{ t2, t1, t0 }	`t3 = mul t2, t1`	{ t0, t1, t3 }
{ t0, t1, t3 }	`t2 = t3`	{ t0, t1 }
{ t0, t1 }	`t1 = add t1, t0`	{ }

first iteration

IN		OUT
{ }	`t0 = 0`	{ t0 }
{ t0 }	`t1 = 1`	{ t1, t0 }
{ t1, t0 }	`t2 = 2`	{ t2, t1, t0 }
{ t2, t1, t0 }	`t3 = mul t2, t1`	{ t0, t1, t3 }
{ t0, t1, t3 }	`t2 = t3`	{ t0, t1 }
{ t0, t1 }	`t1 = add t1, t0`	{ }

first iteration

IN		OUT
{ }	`t0 = 0`	{ t0 }
{ t0 }	`t1 = 1`	{ t1, t0 }
{ t1, t0 }	`t2 = 2`	{ t2, t1, t0 }
{ t2, t1, t0 }	`t3 = mul t2, t1`	{ t0, t1, t3 }
{ t0, t1, t3 }	`t2 = t3`	{ t0, t1 }
{ t0, t1 }	`t1 = add t1, t0`	{ }

second iteration…

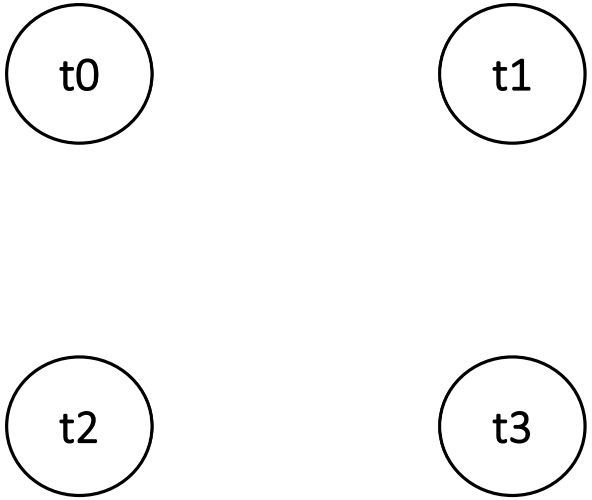
Interference Graph

{ t0 }

{ t0, t1 }

{ t0, t2, t1 }

{ t0, t3 }



R1	R2	R3

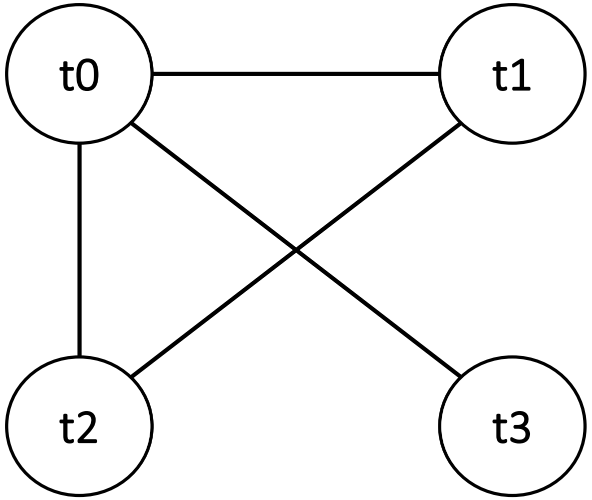
Interference Graph

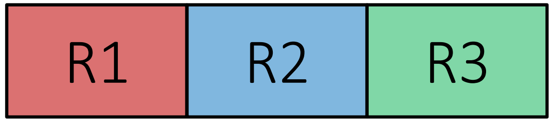
{ t0 }

{ t0, t1 }

{ t0, t2, t1 }

{ t0, t3 }

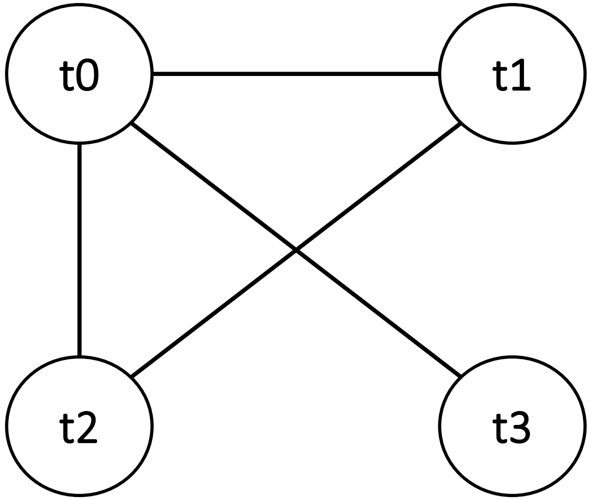


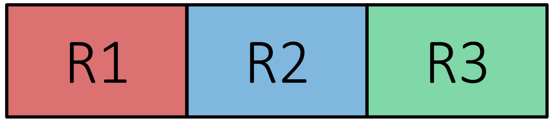


Interference Graph

{ t0 }
{ t0, t1 }
{ t0, t2, t1 }
{ t0, t3 }

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

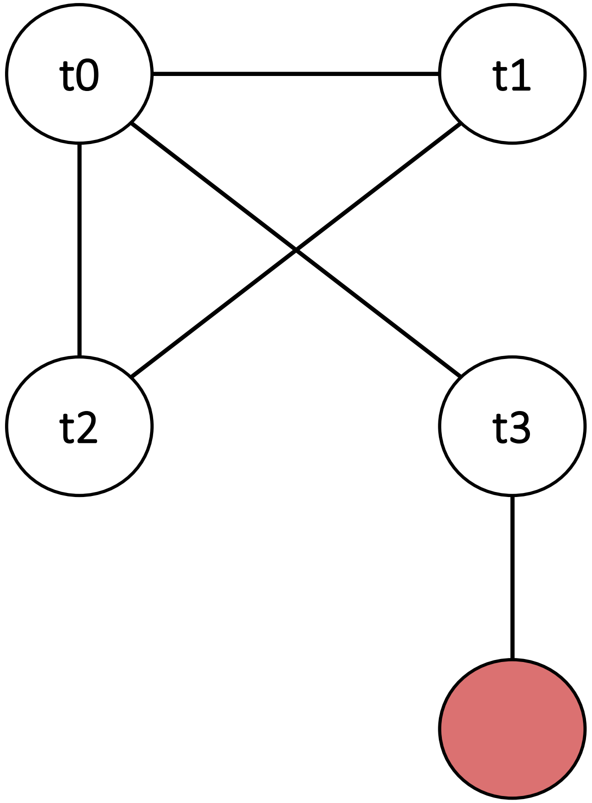


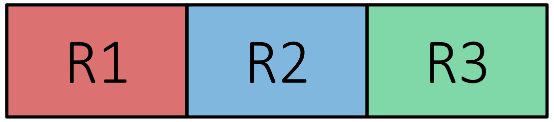


Interference Graph

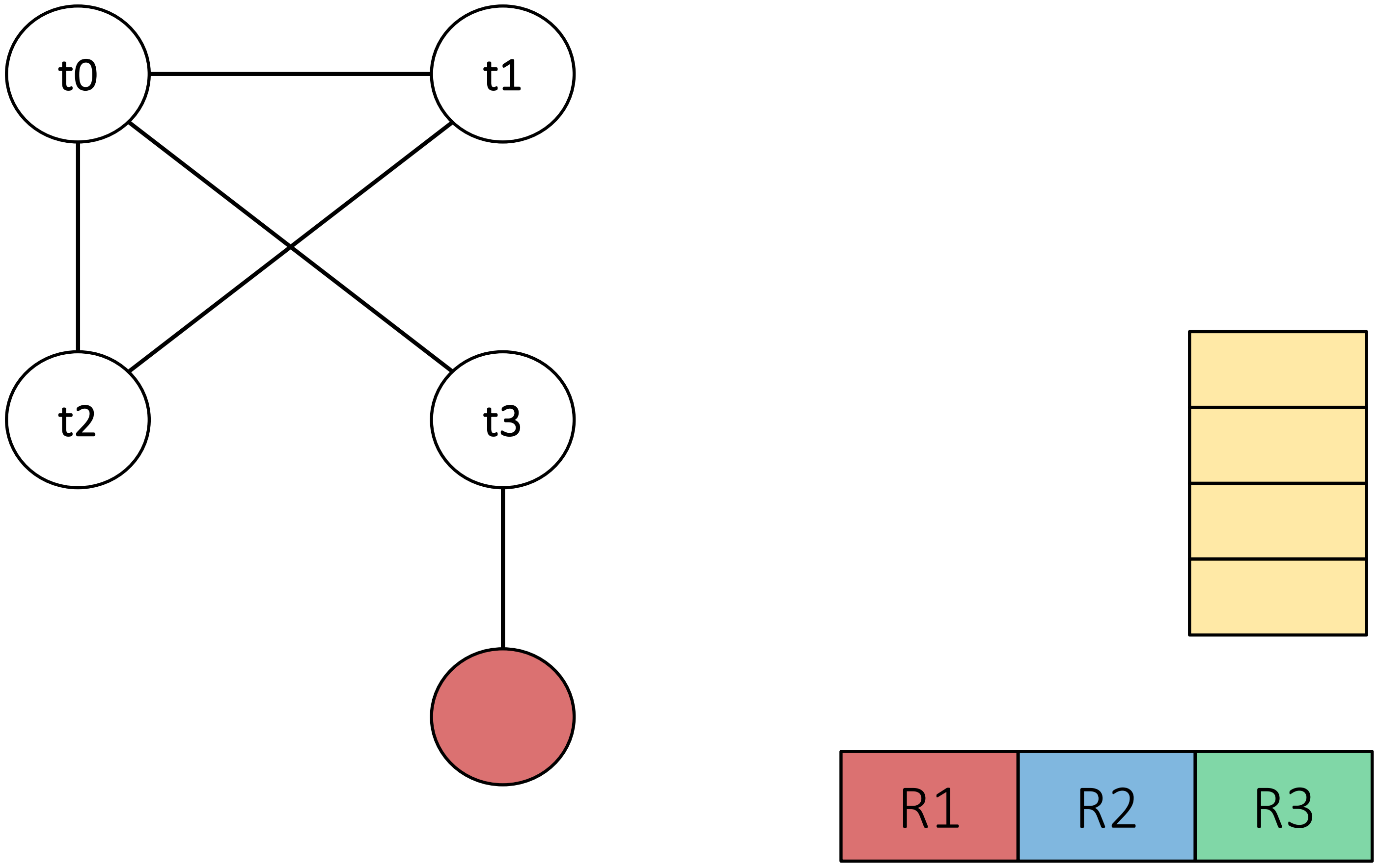
{ t0 }
{ t0, t1 }
{ t0, t2, t1 }
{ t0, t3 }

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

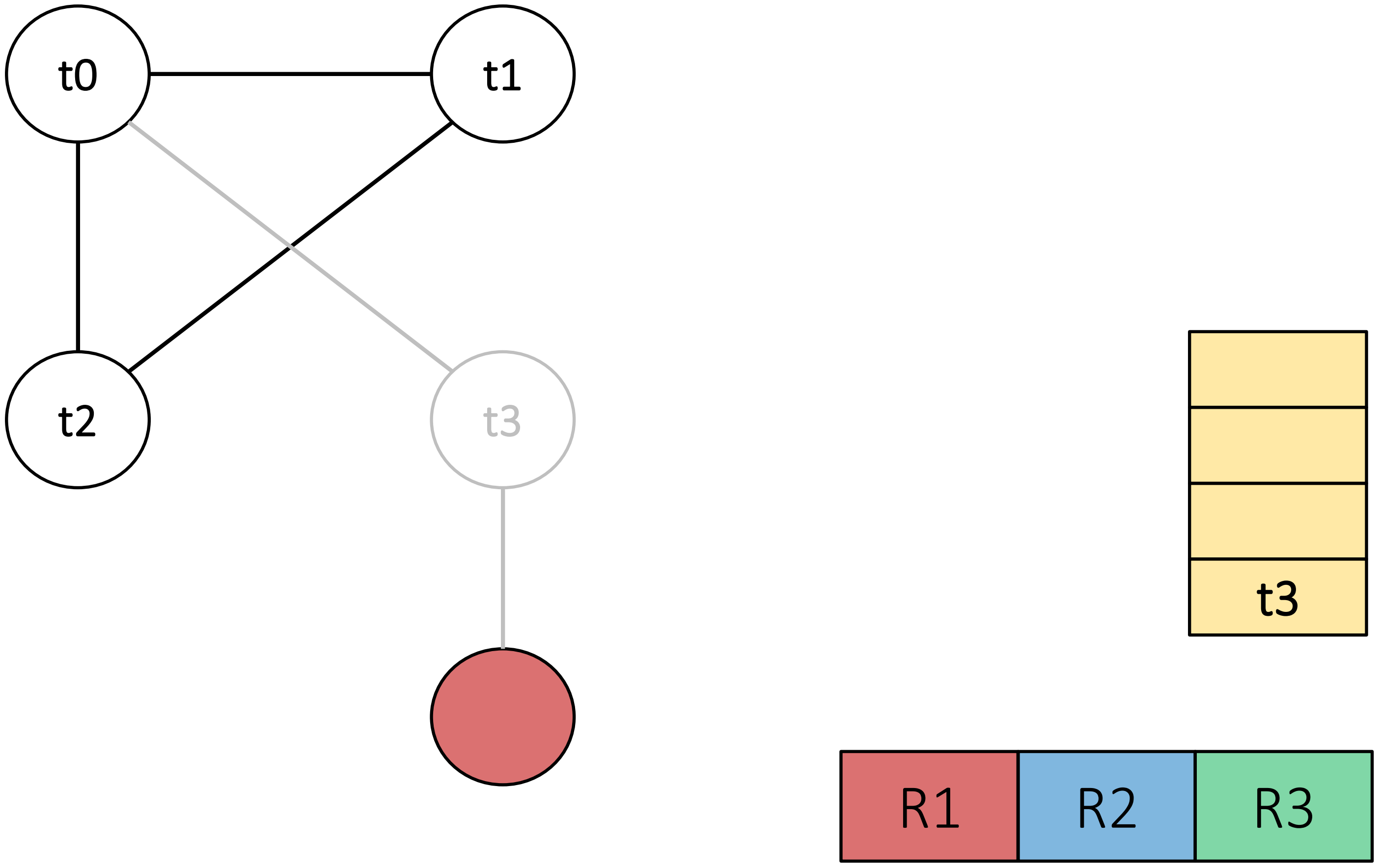




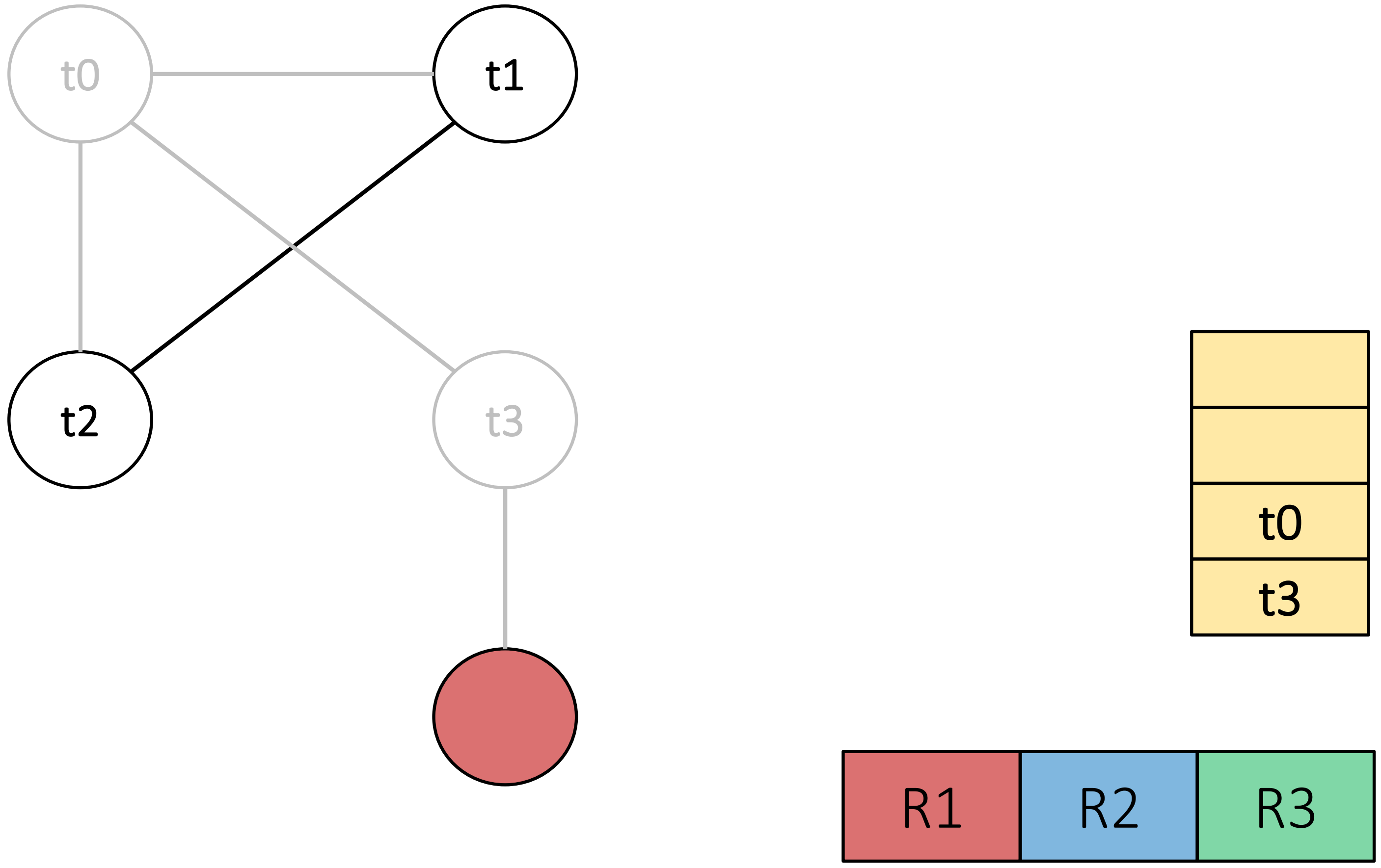
Graph Coloring



Graph Coloring



Graph Coloring



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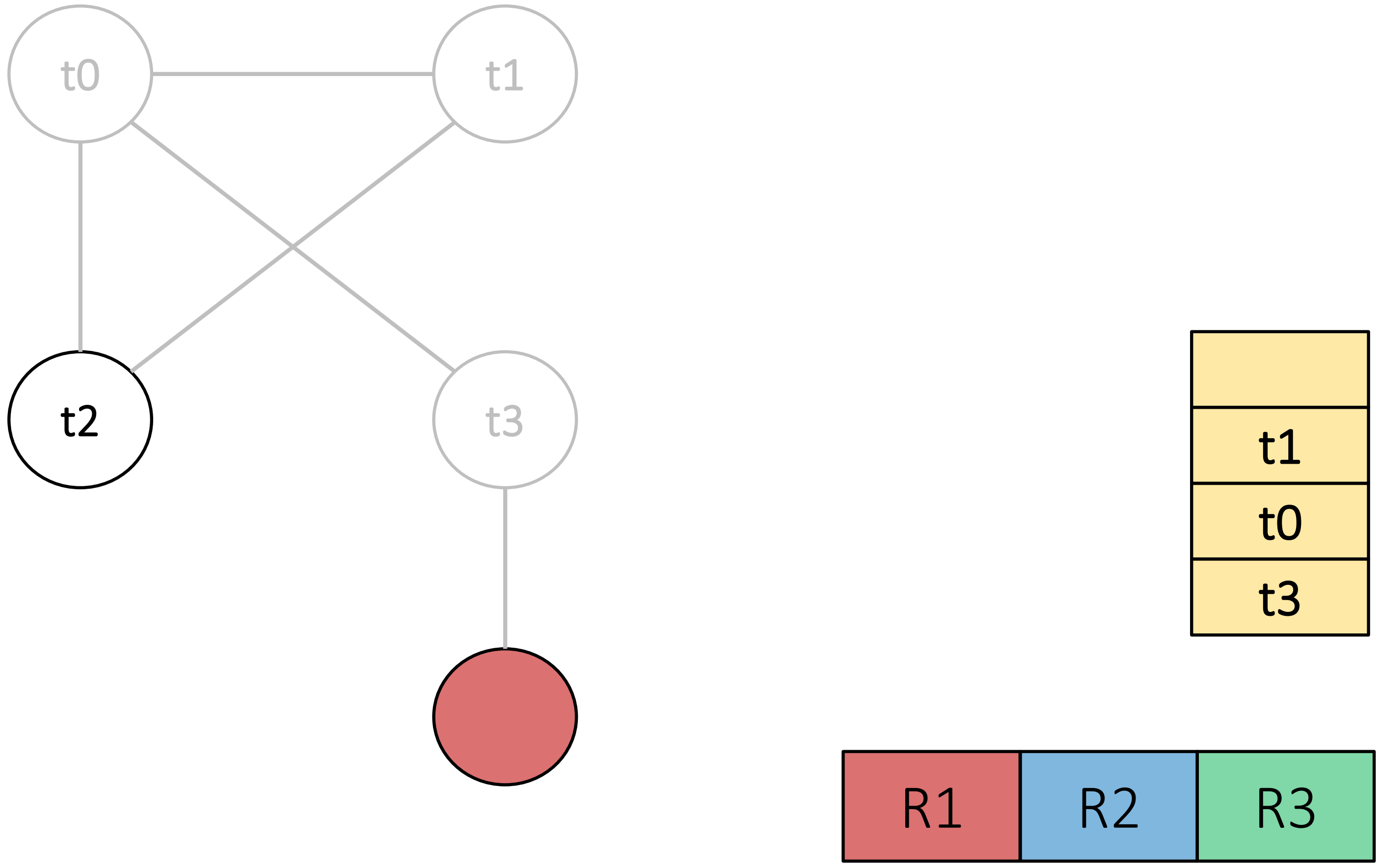

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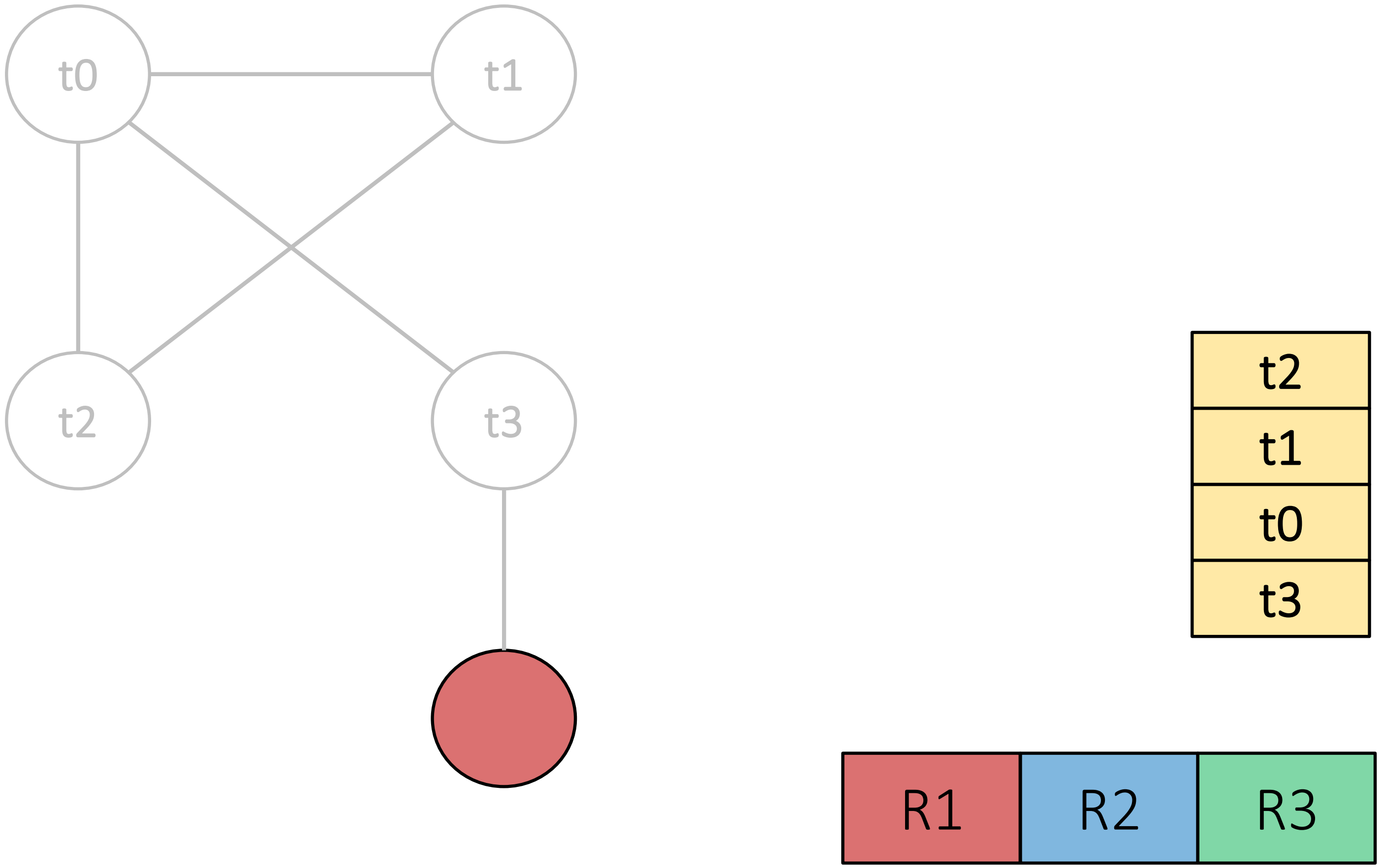
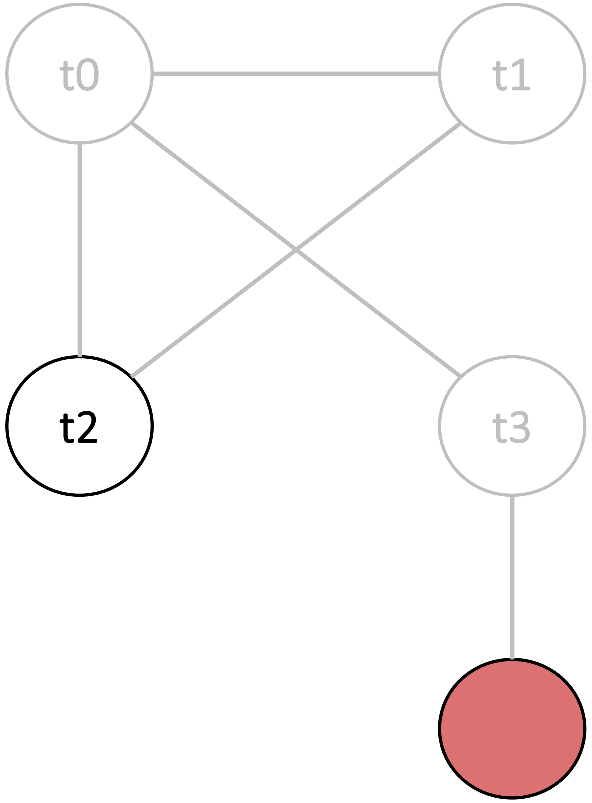
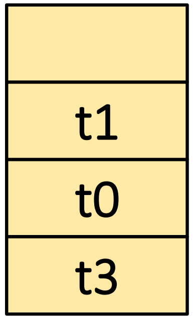
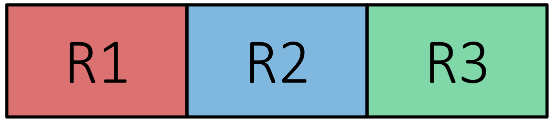


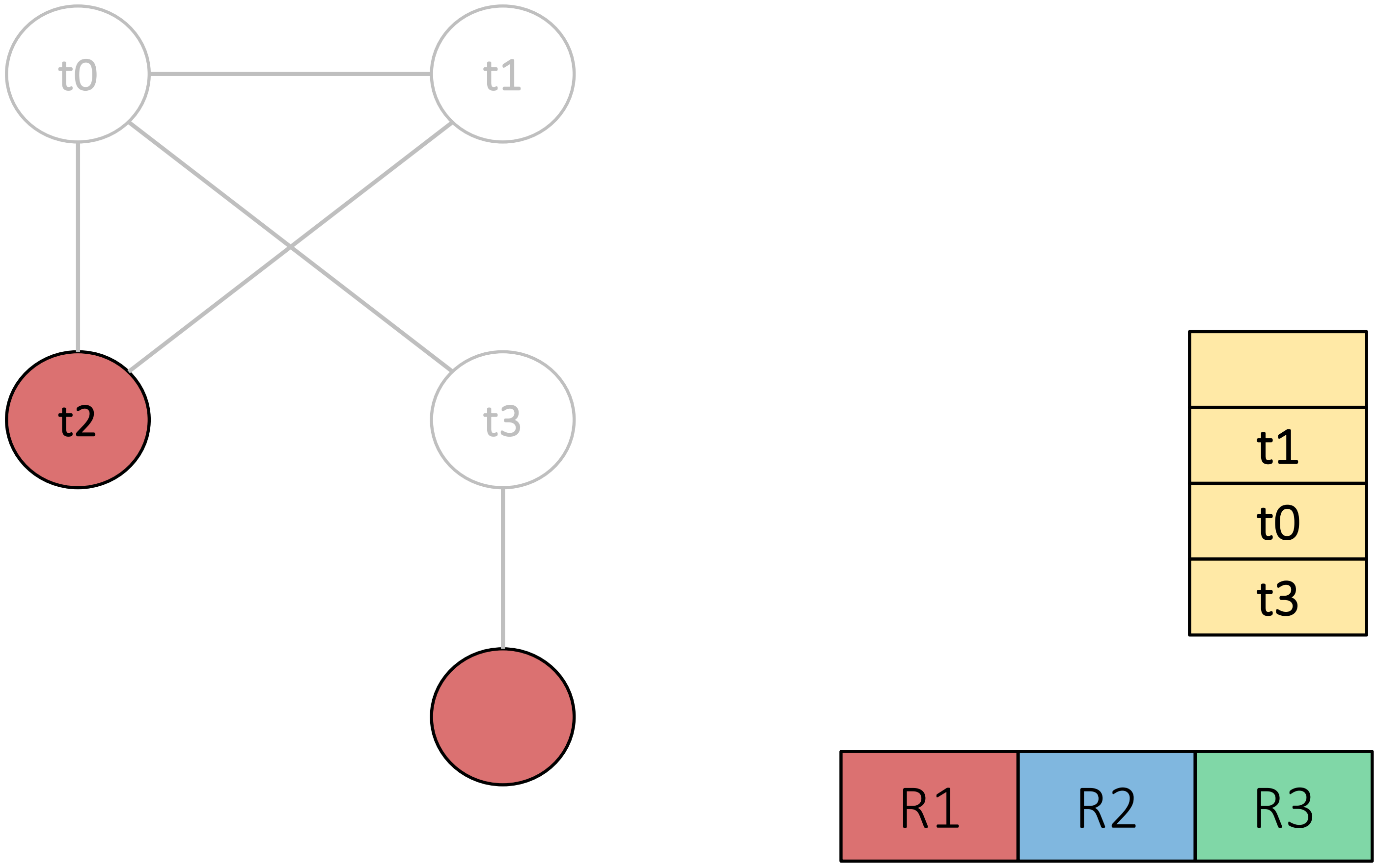
Graph Coloring



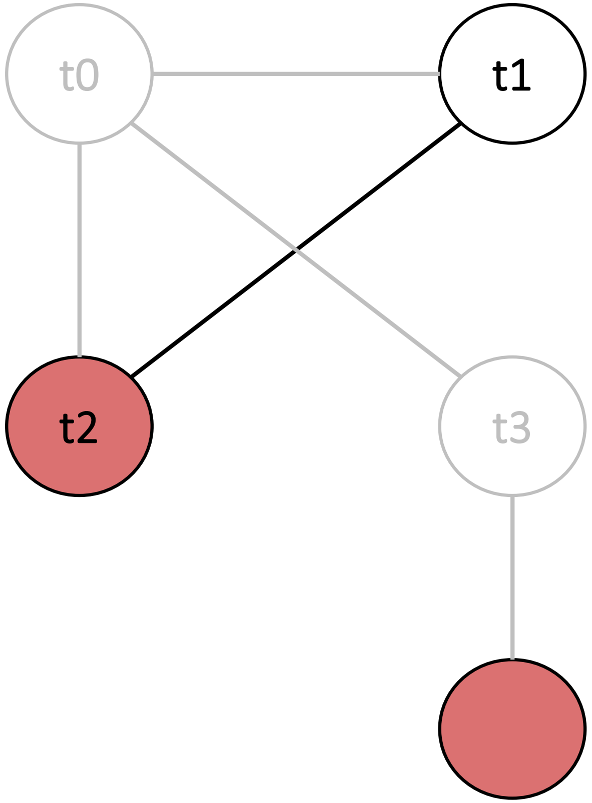


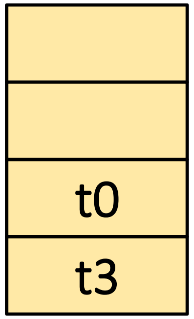


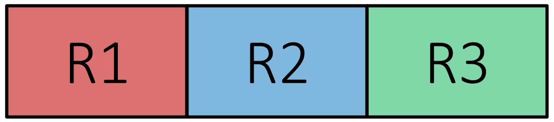
Graph Coloring



Graph Coloring







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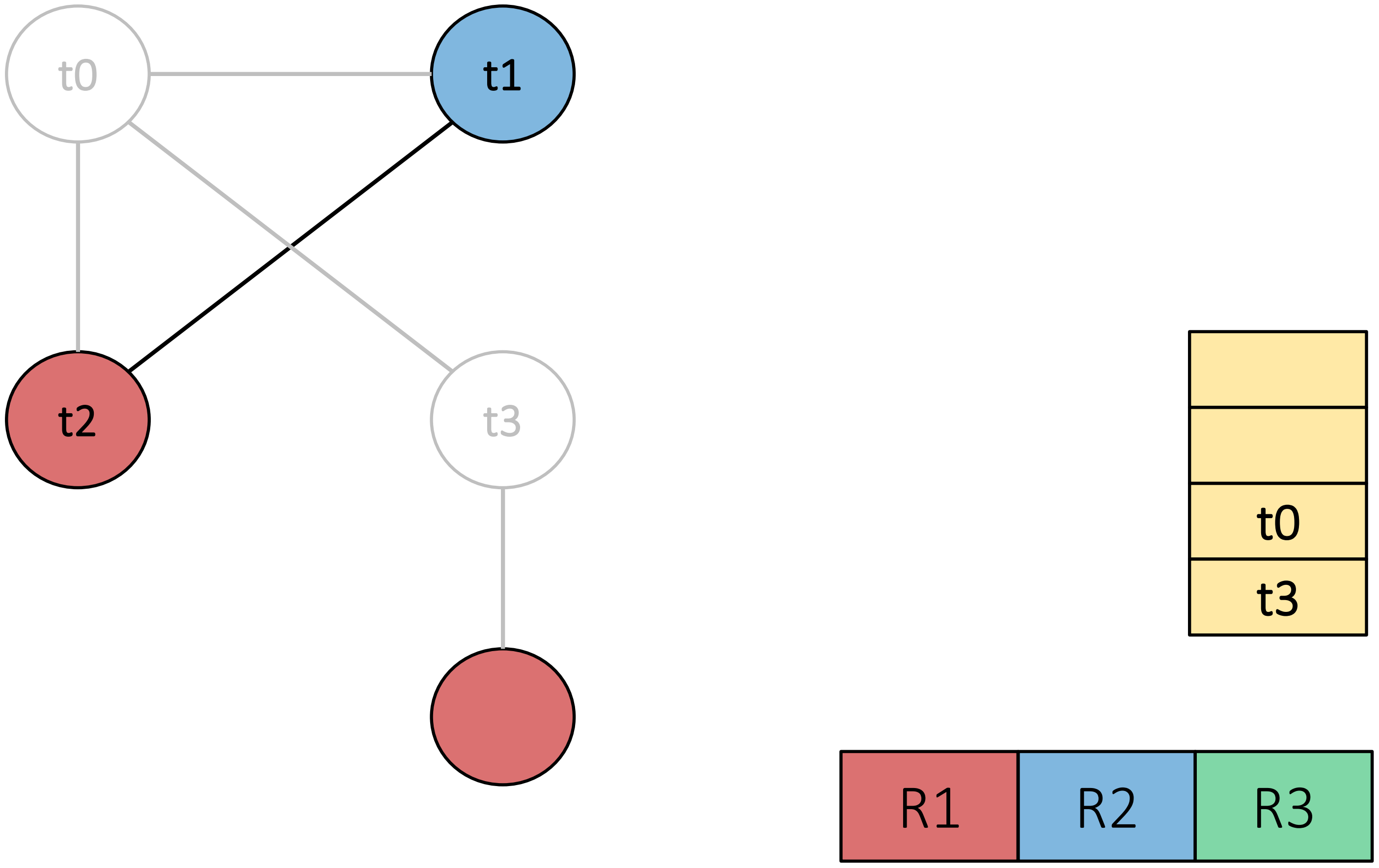

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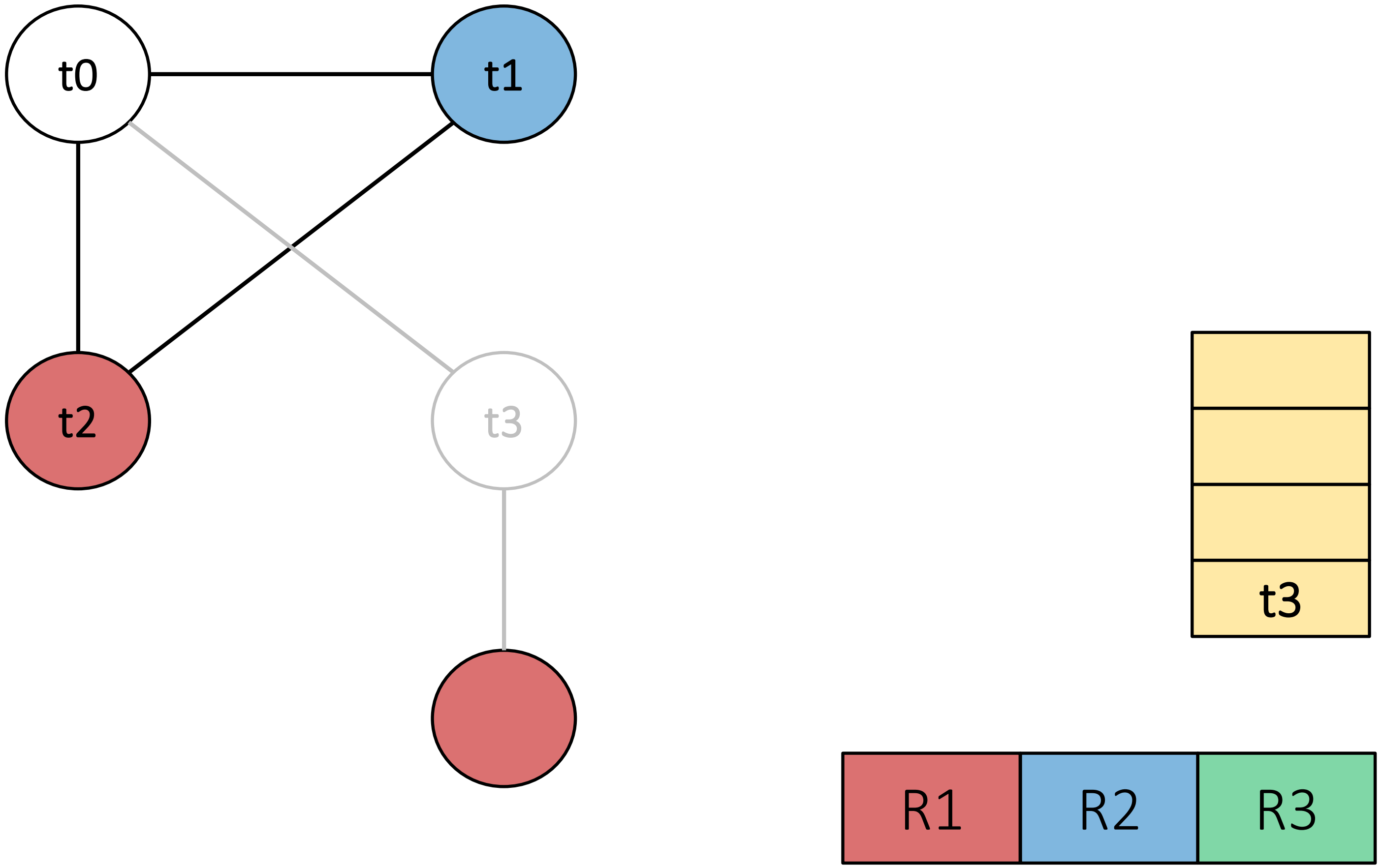
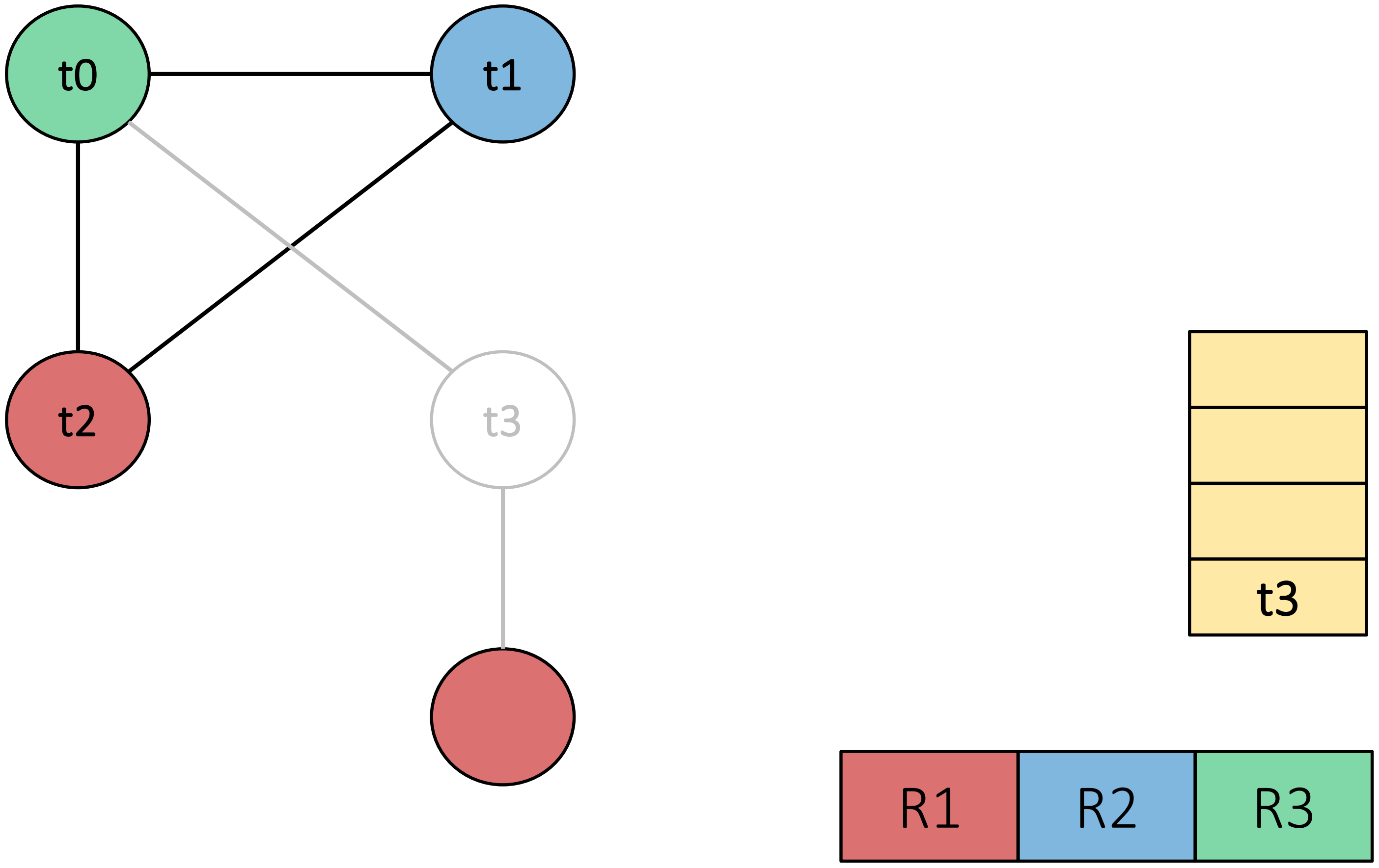


Graph Coloring



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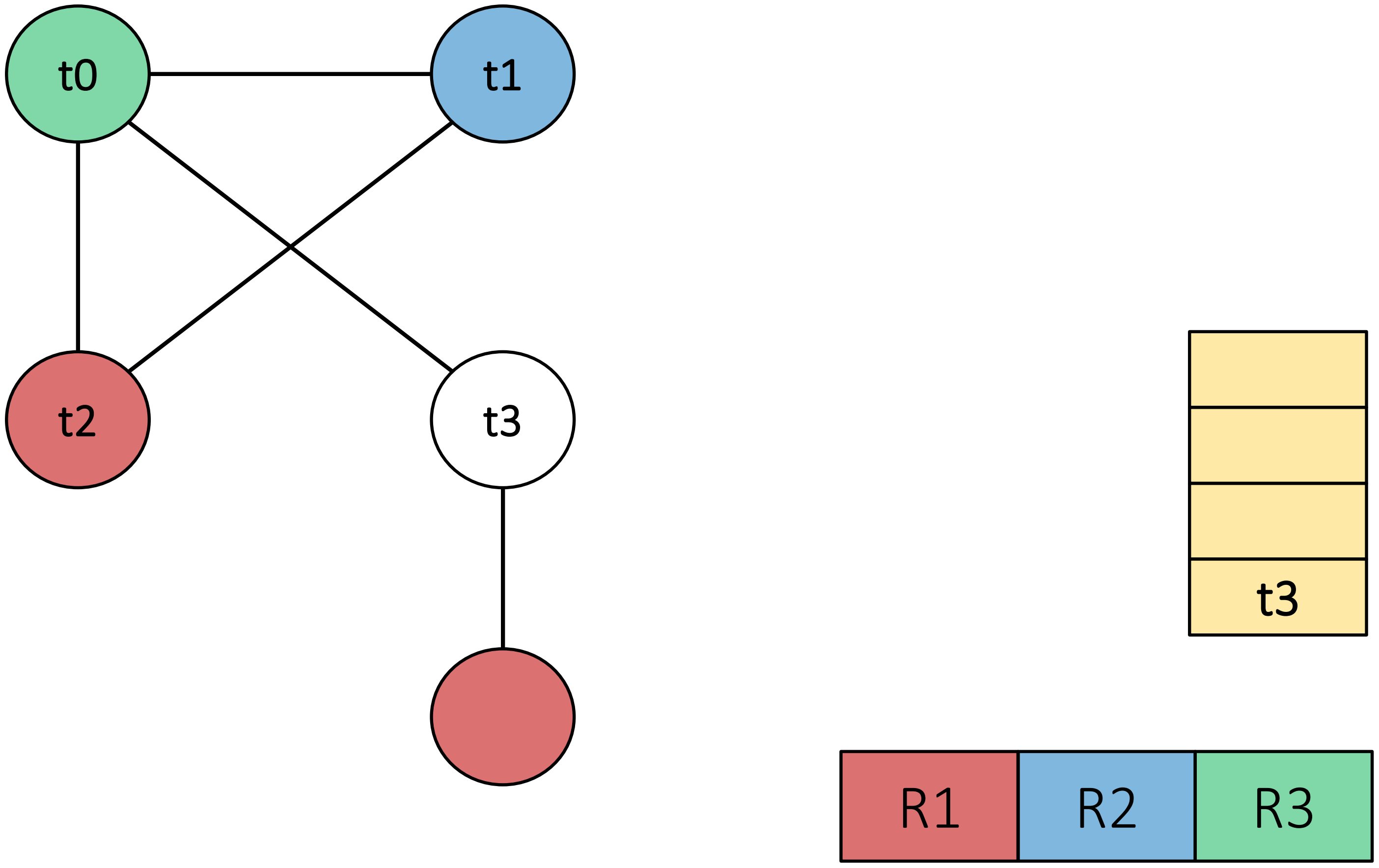

Graph Coloring