

# **Homogeneous Spiking Neural P Systems with Structural Plasticity**

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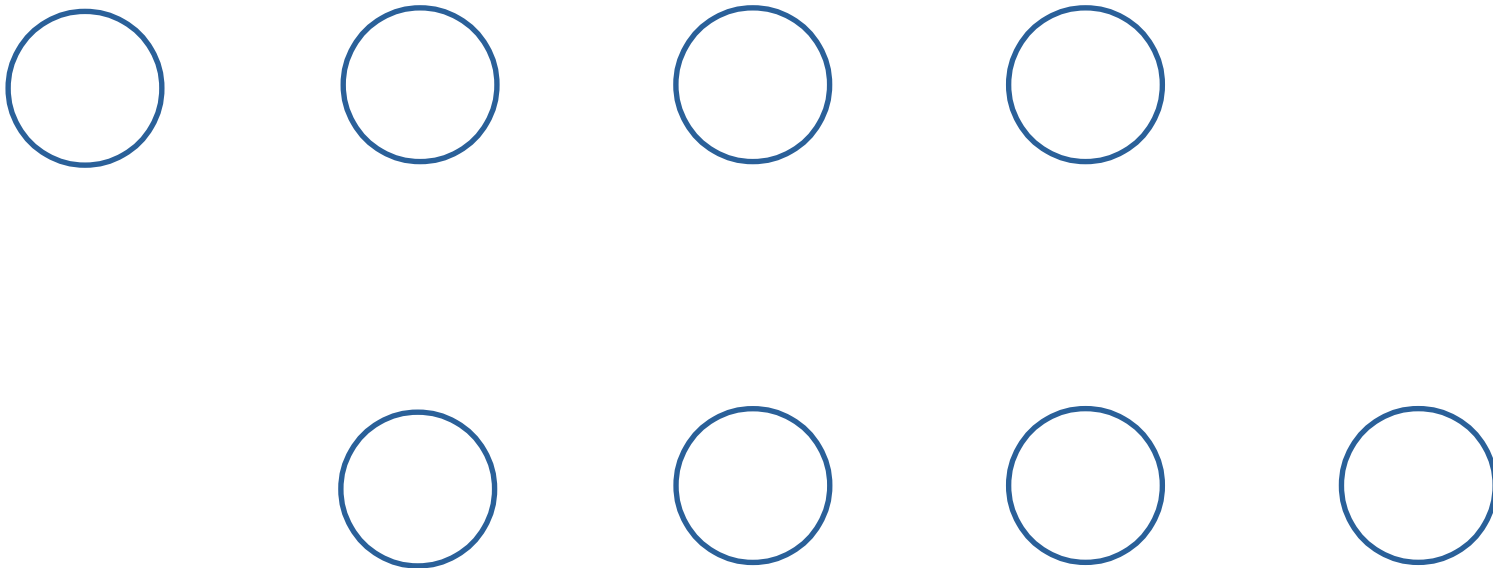
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Changsha, China

**20<sup>th</sup> Conference on Membrane Computing**  
Curtea de Argeș, Romania  
08 August 2019

# Spiking Neural P Systems with Structural Plasticity (SNPSP System)

$$\Pi = (\textcolor{red}{0}, \textcolor{blue}{\sigma}_1, \dots, \textcolor{blue}{\sigma}_m, \textcolor{orange}{syn}, \textcolor{green}{out})$$

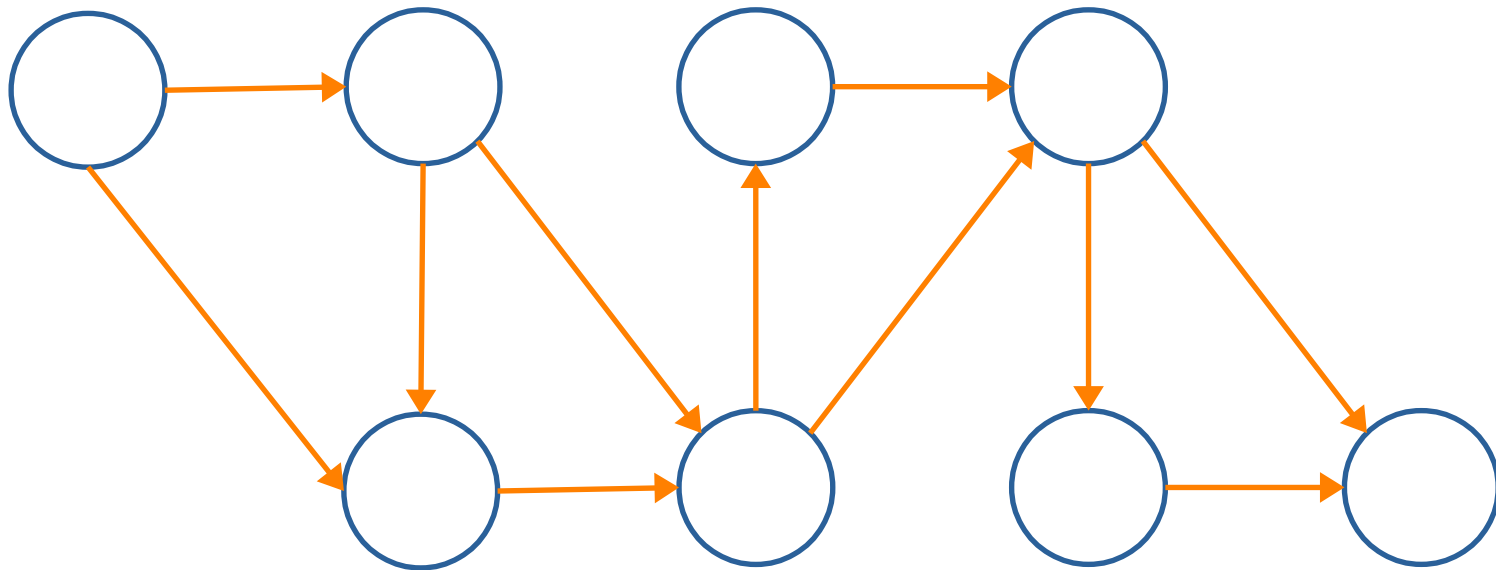
Neurons:  $\textcolor{blue}{\sigma}_1, \dots, \textcolor{blue}{\sigma}_m$



# Spiking Neural P Systems with Structural Plasticity (SNPSP System)

$$\Pi = (\mathbf{0}, \sigma_1, \dots, \sigma_m, \textit{syn}, \textit{out})$$

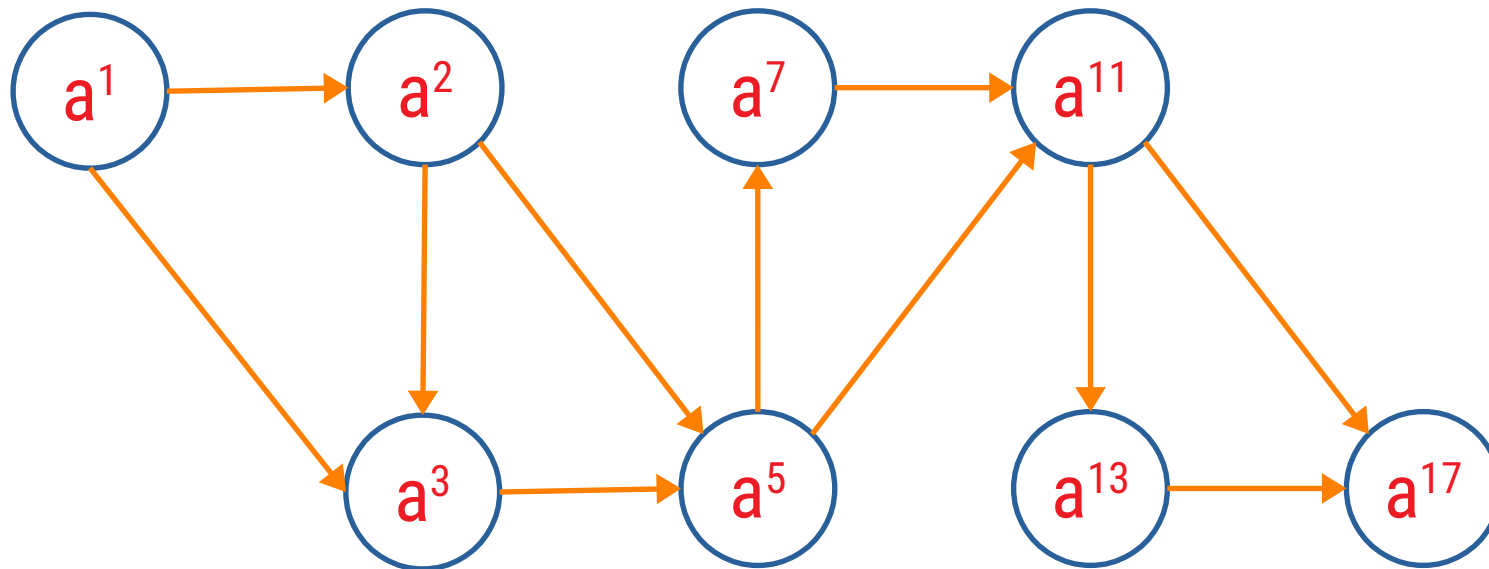
Synapses: *syn*



# Spiking Neural P Systems with Structural Plasticity (SNPSP System)

$$\Pi = (0, \sigma_1, \dots, \sigma_m, \text{syn}, \text{out})$$

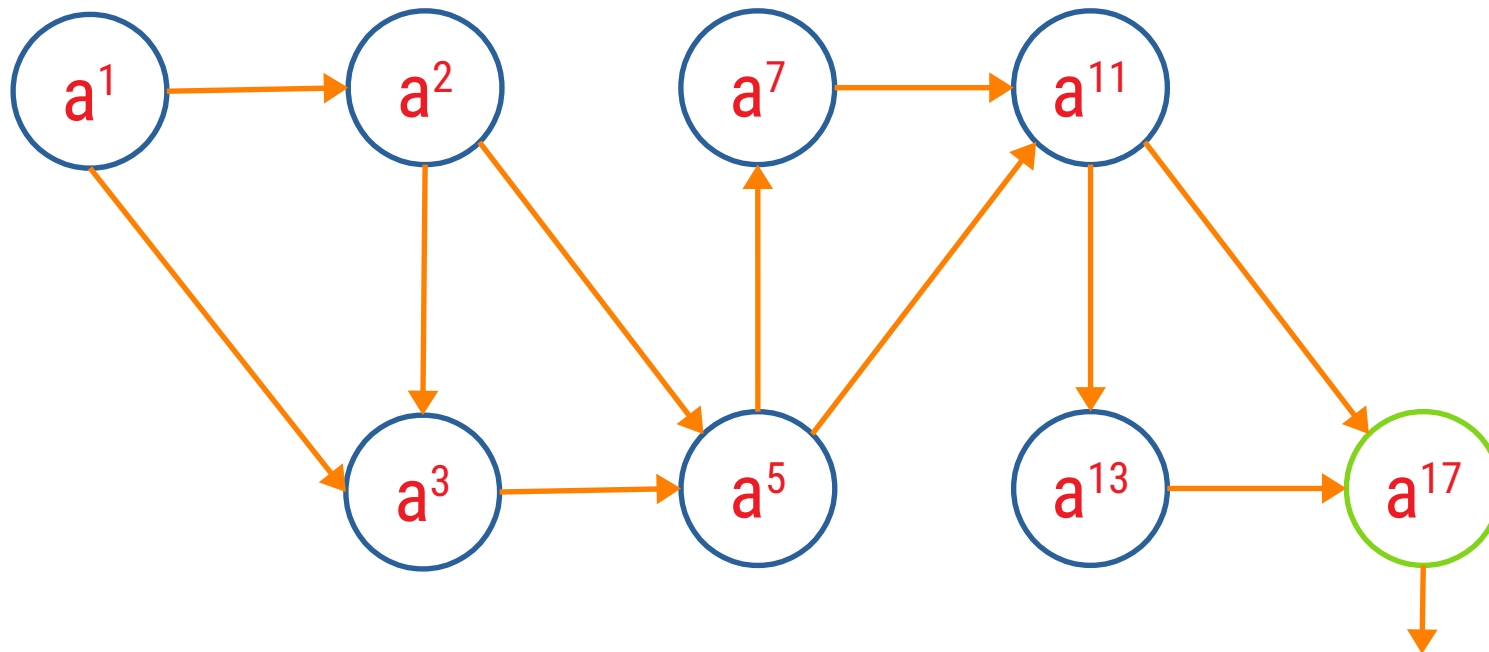
Spike:  $a$   
Alphabet:  $0 = \{a\}$   
Multiset of Spikes:  $a^i$



# Spiking Neural P Systems with Structural Plasticity (SNPSP System)

$$\Pi = (\mathbf{0}, \sigma_1, \dots, \sigma_m, \textit{syn}, \textit{out})$$

Output Neuron: *out*



# Spiking Neural P Systems with Structural Plasticity (SNPSP System)

$$\Pi = (0, \sigma_1, \dots, \sigma_m, syn, out)$$

Spiking Rule :  $E / a^c \rightarrow a$

Plasticity Rule :  $E / a^c \rightarrow \alpha k(N)$

$N$  – target neurons

$$\alpha \in \{+, -, \pm, \mp\}$$

$+k$  – add  $k$  synapses

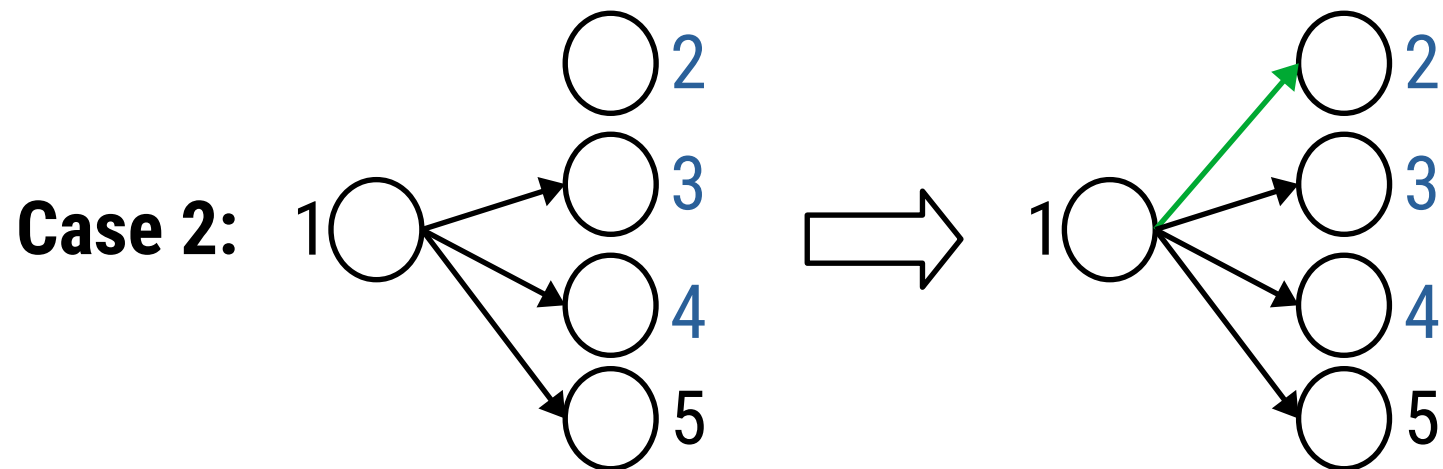
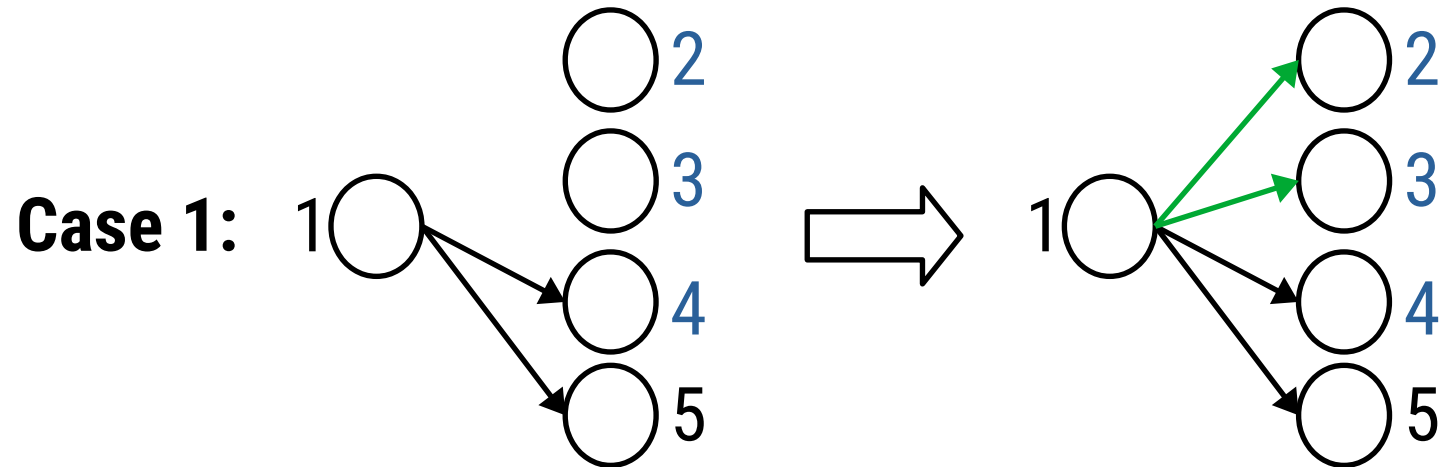
$-k$  – delete  $k$  synapses

$\pm k$  – add then delete  $k$  synapses

$\mp k$  – delete then add  $k$  synapses

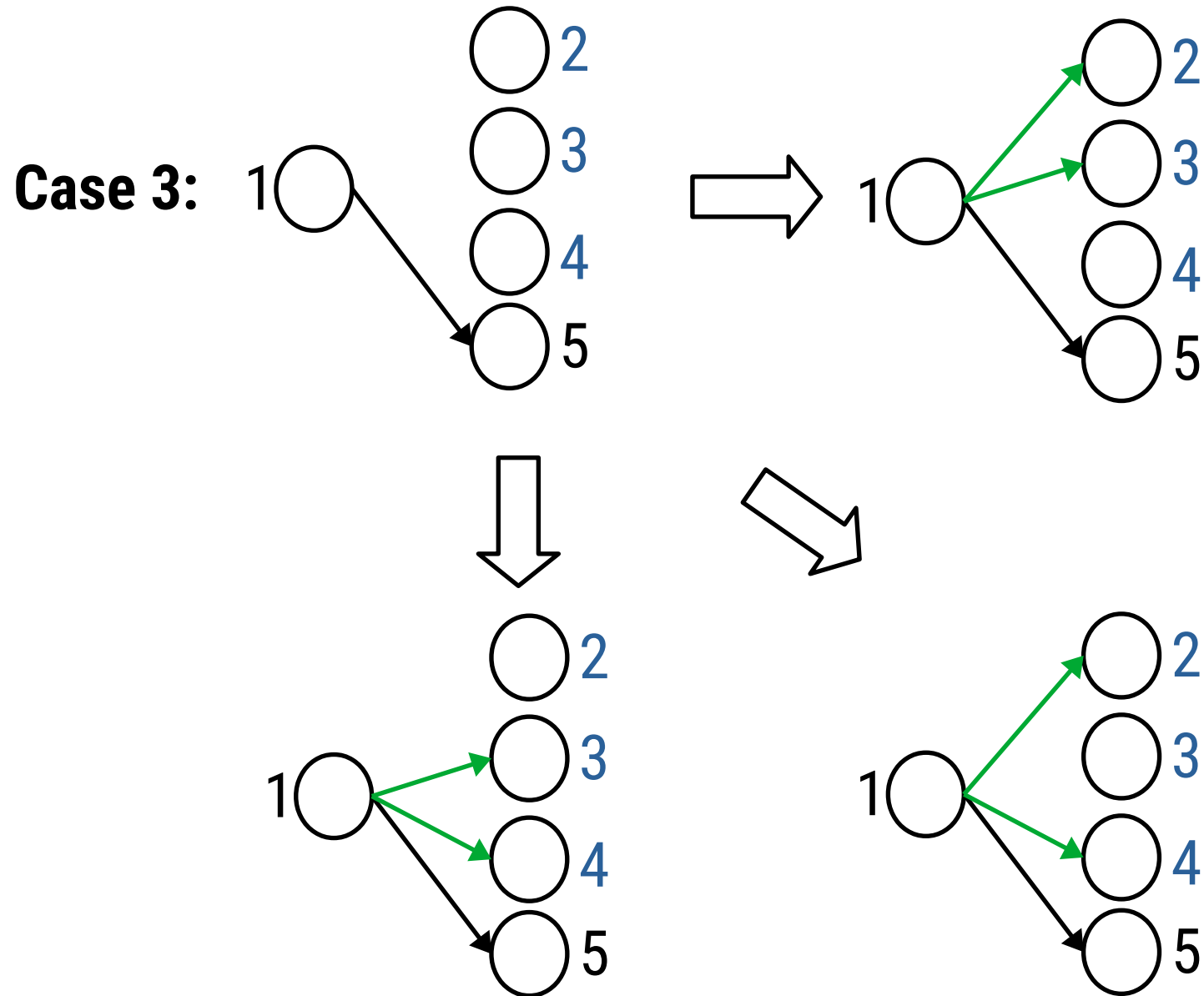
**Plasticity Rule:**  $E / a^c \rightarrow \text{ak}(N)$

In neuron 1:  $E / a^c \rightarrow +2(\{2,3,4\})$



**Plasticity Rule:**  $E / a^c \rightarrow \text{ak}(N)$

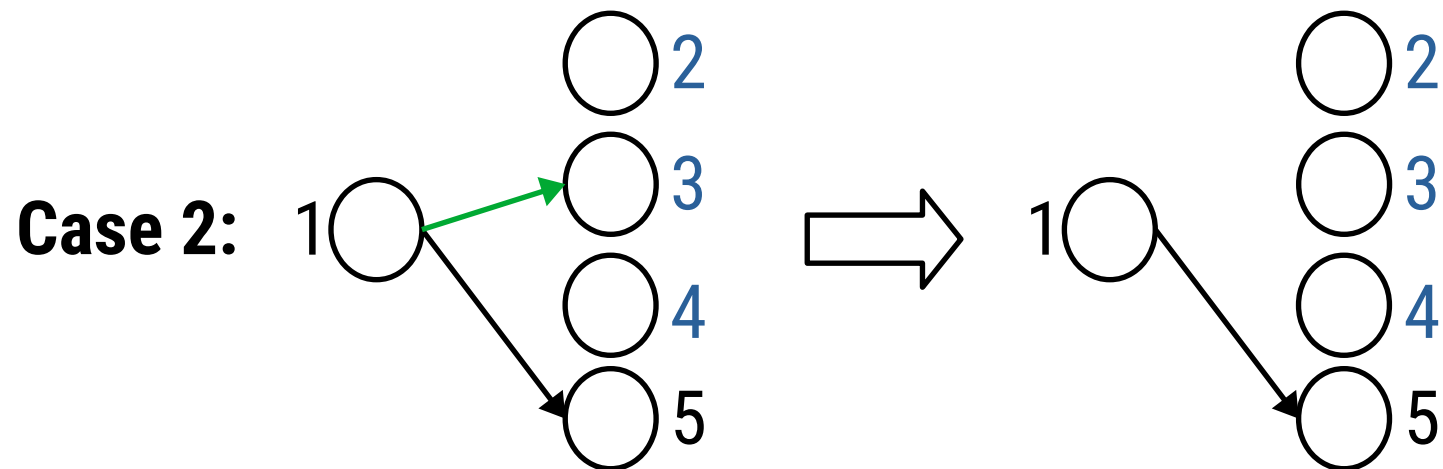
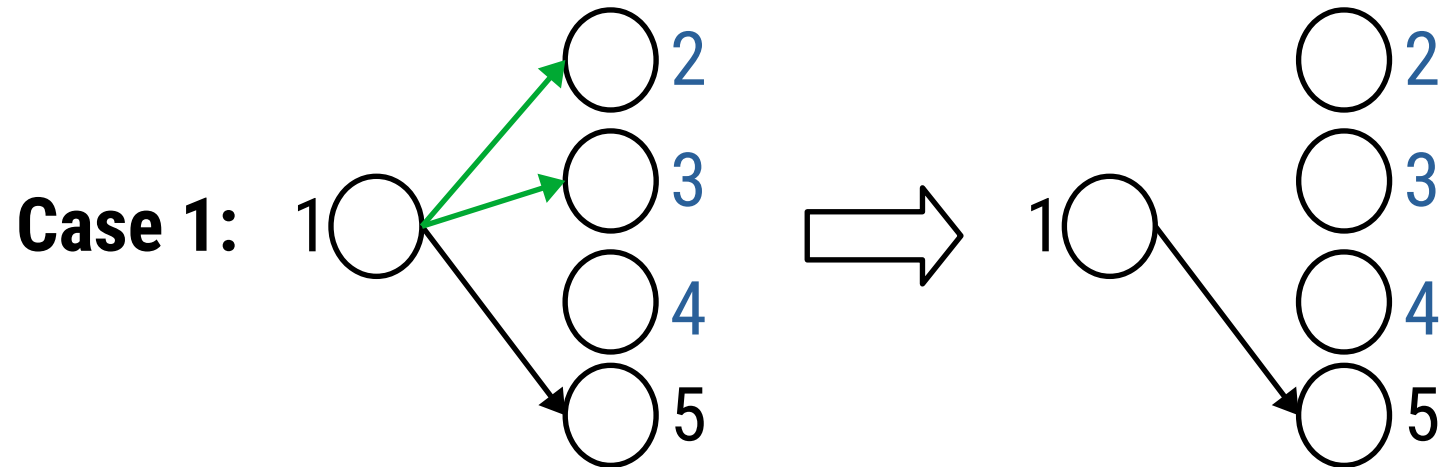
In neuron 1:  $E / a^c \rightarrow +2(\{2,3,4\})$





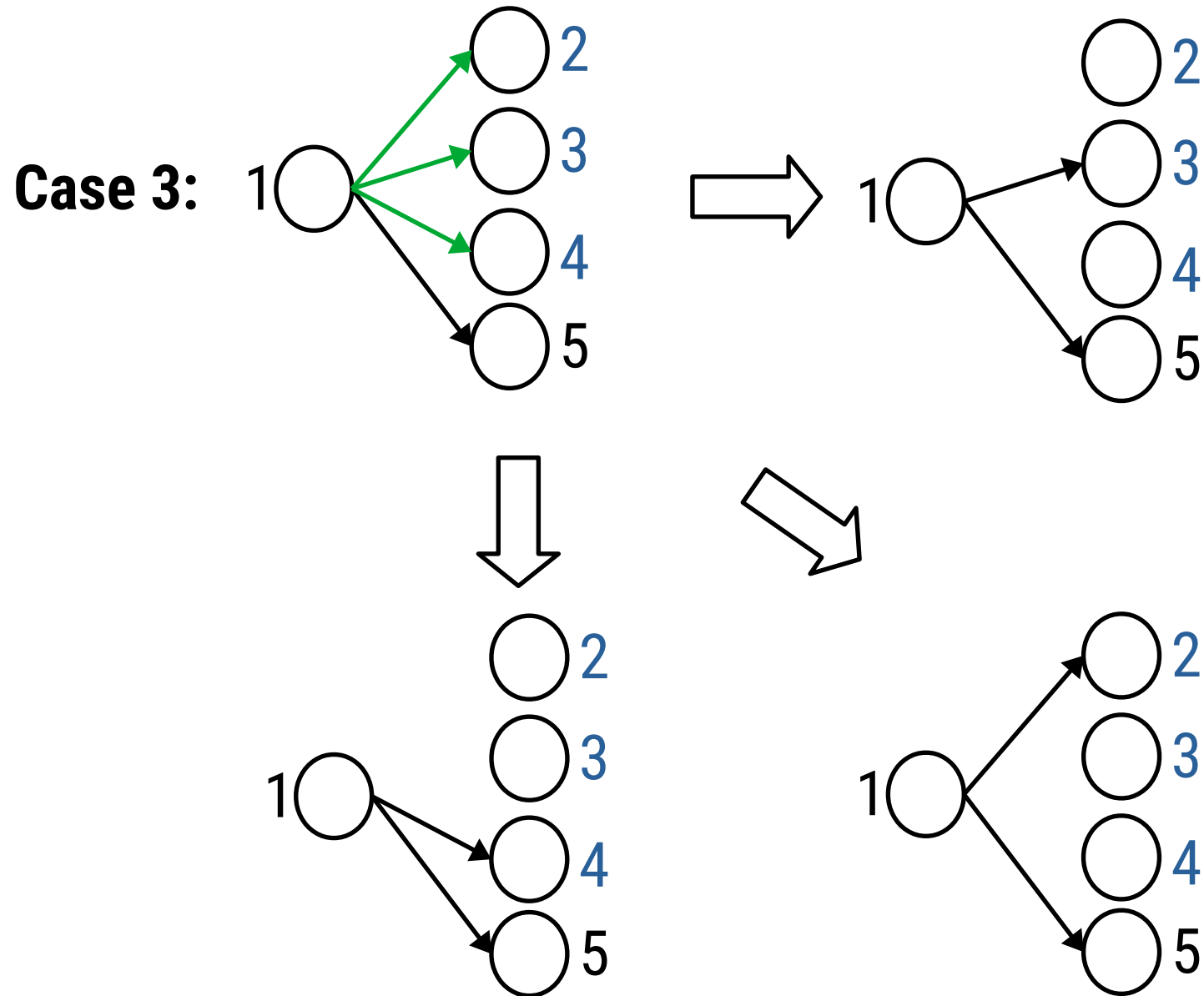
**Plasticity Rule:**  $E / a^c \rightarrow \text{ak}(N)$

In neuron 1:  $E / a^c \rightarrow -2(\{2,3,4\})$



**Plasticity Rule:**  $E / a^c \rightarrow \text{ak}(N)$

In neuron 1:  $E / a^c \rightarrow -2(\{2,3,4\})$



**Plasticity Rule:**  $E / a^c \rightarrow \text{ak}(\text{N})$

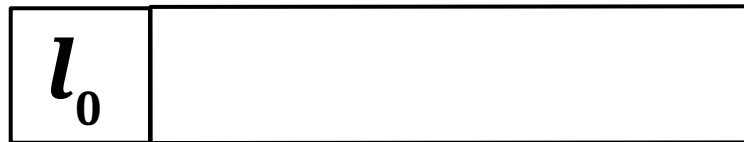
Plasticity rules as forgetting rules.

**Case 1:**  $1 \bigcirc \longrightarrow \bigcirc 2$     In neuron 1:  $E / a^c \rightarrow +1(\{2\})$

**Case 2:**  $1 \bigcirc \quad \bigcirc 2$     In neuron 1:  $E / a^c \rightarrow -1(\{2\})$

# Register Machines

## Instructions



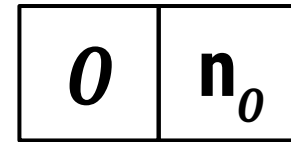
⋮



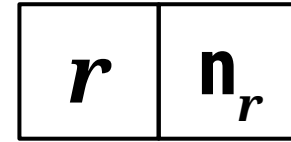
⋮



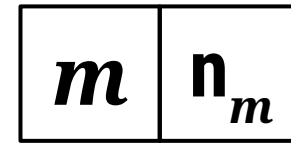
## Registers



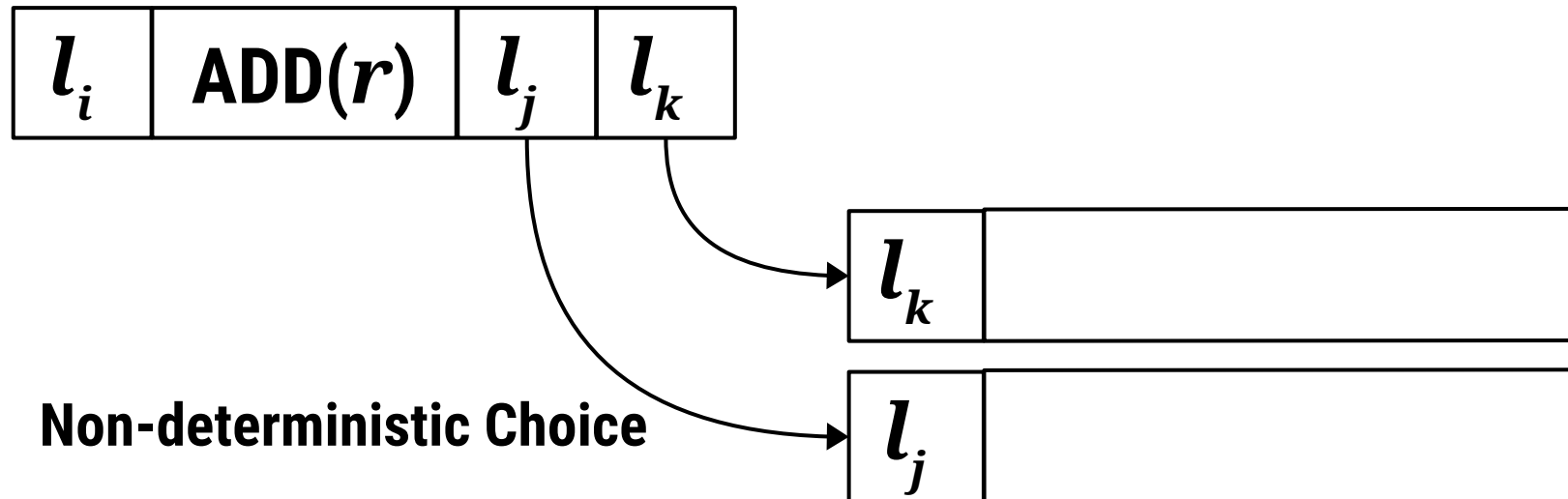
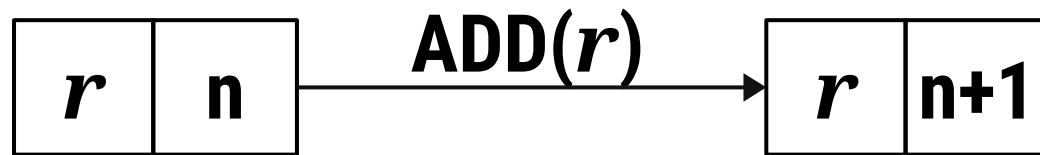
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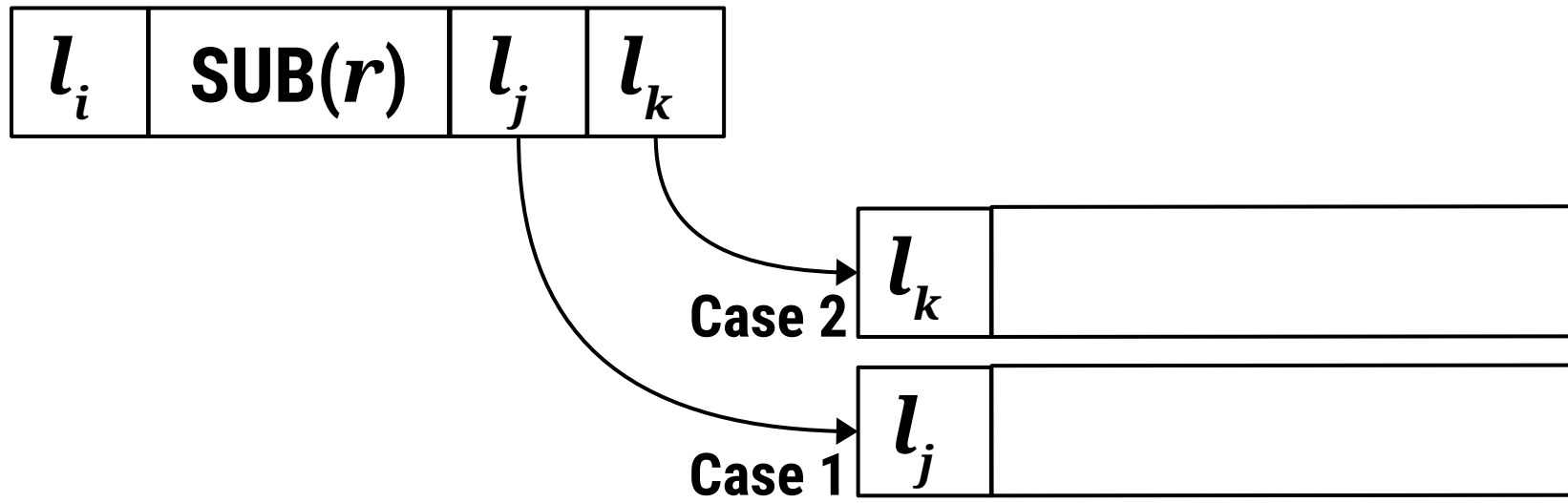
⋮



# Register Machines



# Register Machines



# Register Machines



# Representing Numbers

**$n$**

Number (in Register)

**$Z + 3n$**

Spike Count

$Z$  is some constant spike count.

**$10^{n-1}1$**

Spike Train



## Common Rule Set for All Neurons

$$\text{Rule 0: } a^{X+1} / a^1 \rightarrow \lambda$$

$$\text{Rule 1: } a^{X+2} / a^2 \rightarrow \lambda$$

$$\text{Rule 2: } a^{X+2} / a^2 \rightarrow a$$

$$\text{Rule 3: } a^{Y+1} / a^1 \rightarrow \lambda$$

$$\text{Rule 4: } a^{Y+2} / a^2 \rightarrow a$$

$$\text{Rule 5: } a^{Z+1} / a^1 \rightarrow a$$

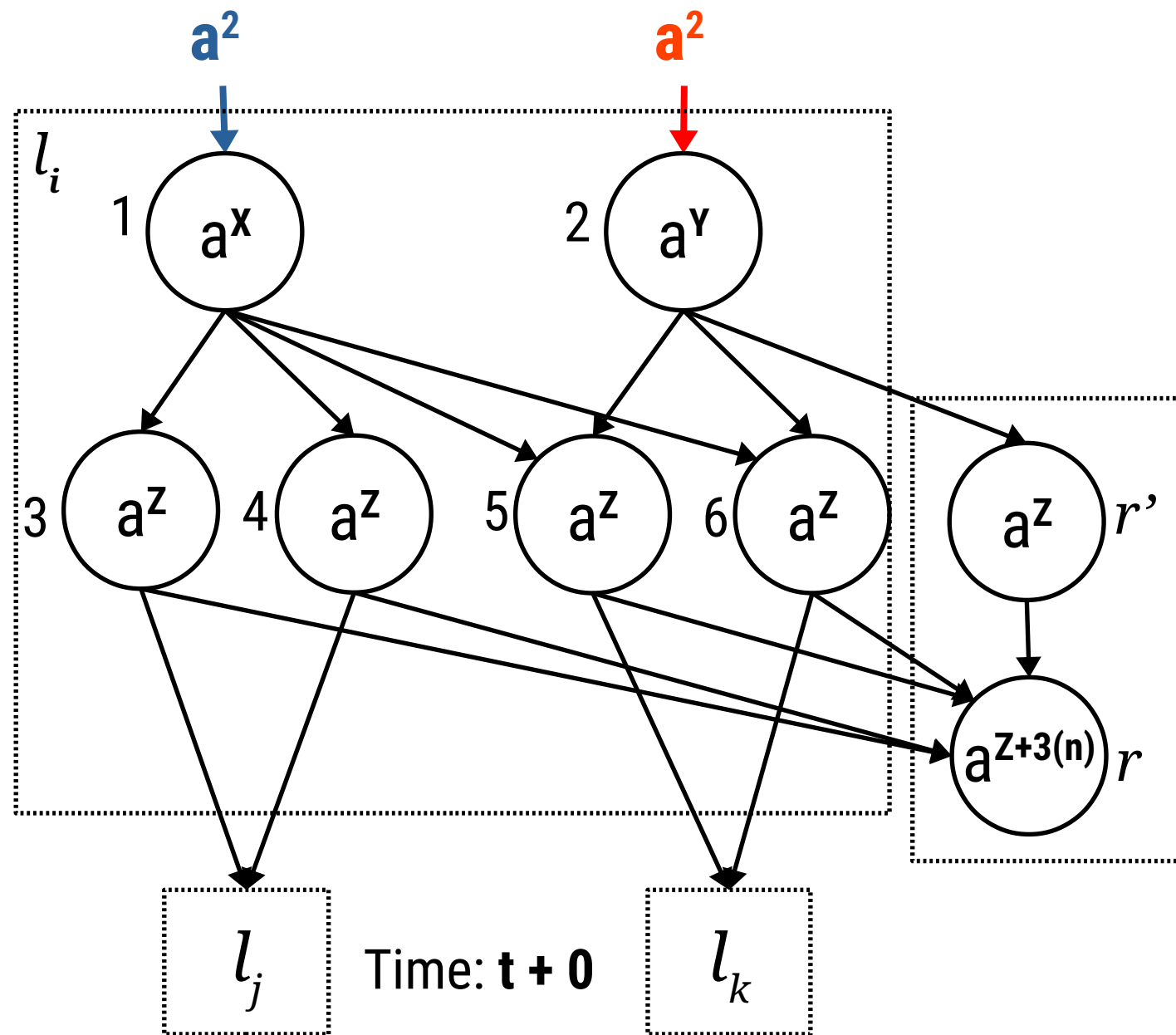
$$\text{Rule 6: } a^{Z+2} / a^2 \rightarrow \lambda$$

$$\text{Rule 7: } a^{Z+1} (a^3)^+ / a^4 \rightarrow \lambda$$

$$\text{Rule 8: } a^{Z+2} (a^3)^+ / a^3 \rightarrow a$$

# ADD Module

$l_i$	<b>ADD(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

Rule 5:  $a^{z+1} / a^1 \rightarrow a$

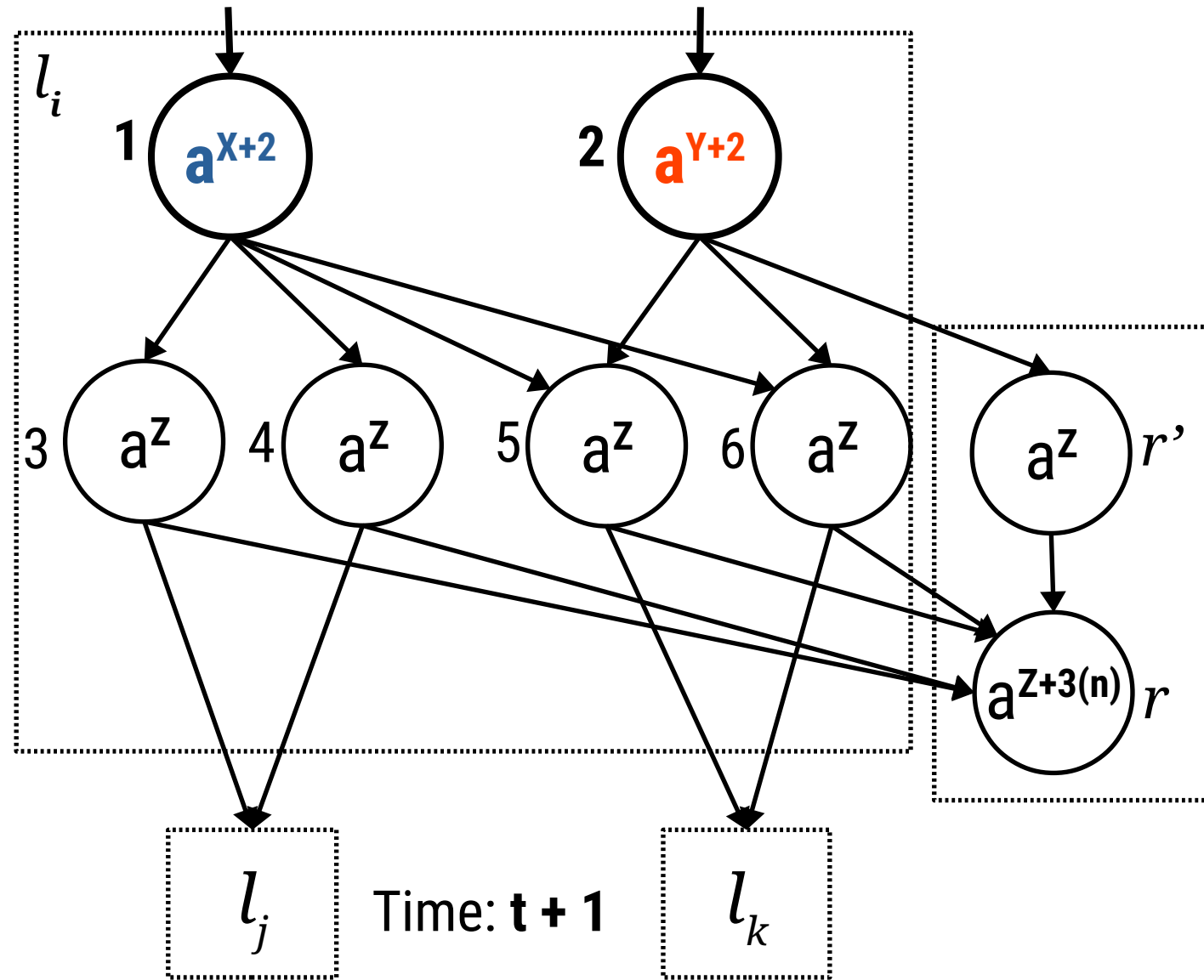
Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

# ADD Module

$l_i$	ADD( $r$ )	$l_j$	$l_k$
-------	------------	-------	-------



Rule 0:  $a^{X+1} / a^1 \rightarrow \lambda$

**Rule 1:**  $a^{X+2} / a^2 \rightarrow \lambda$

**Rule 2:**  $a^{X+2} / a^2 \rightarrow a$

Rule 3:  $a^{Y+1} / a^1 \rightarrow \lambda$

**Rule 4:**  $a^{Y+2} / a^2 \rightarrow a$

Rule 5:  $a^{Z+1} / a^1 \rightarrow a$

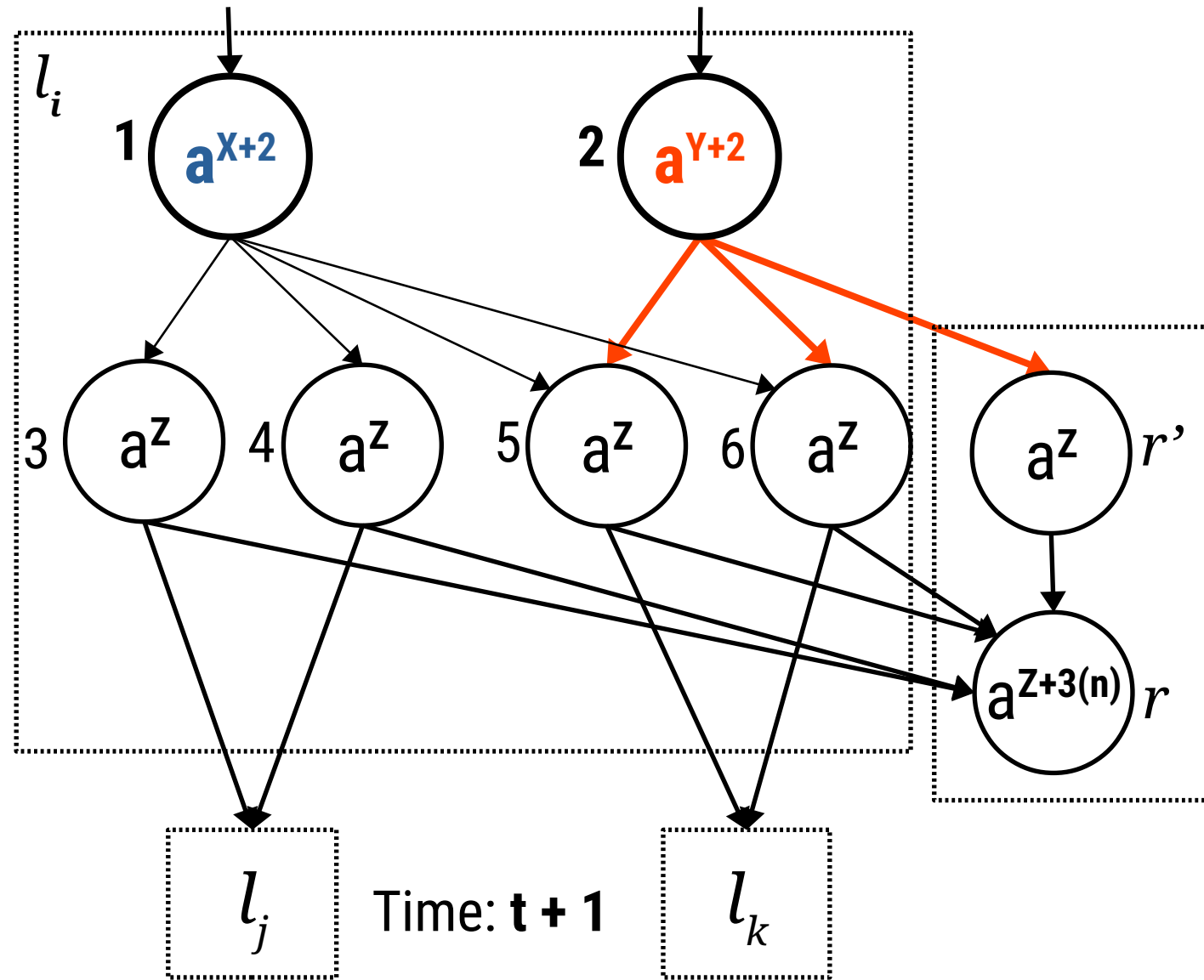
Rule 6:  $a^{Z+2} / a^2 \rightarrow \lambda$

Rule 7:  $a^{Z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{Z+2} (a^3)^+ / a^3 \rightarrow a$

# ADD Module

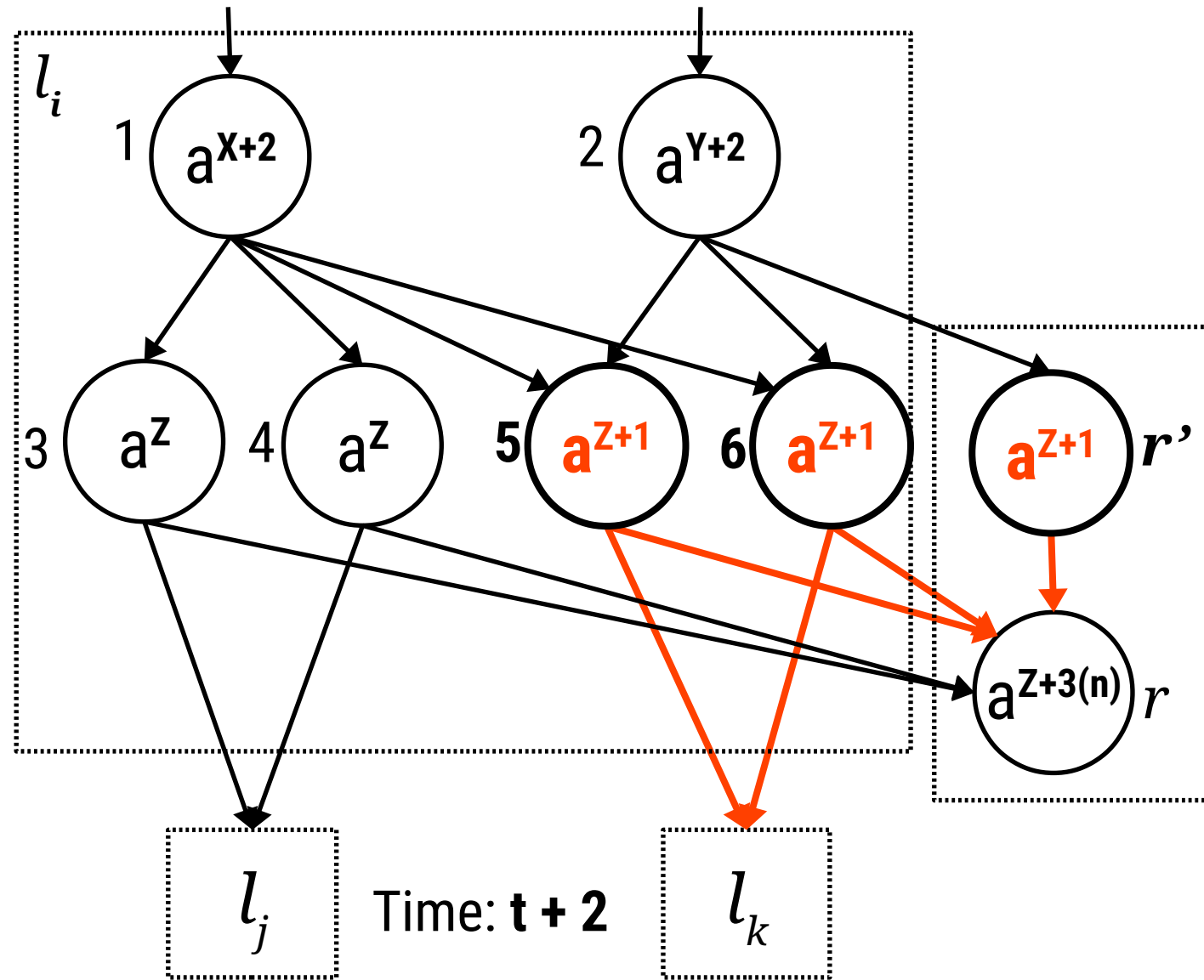
$l_i$	ADD( $r$ )	$l_j$	$l_k$
-------	------------	-------	-------



**Case 1:** Rule 1 is activated.

# ADD Module

$l_i$	<b>ADD(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

**Rule 5:  $a^{z+1} / a^1 \rightarrow a$**

Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

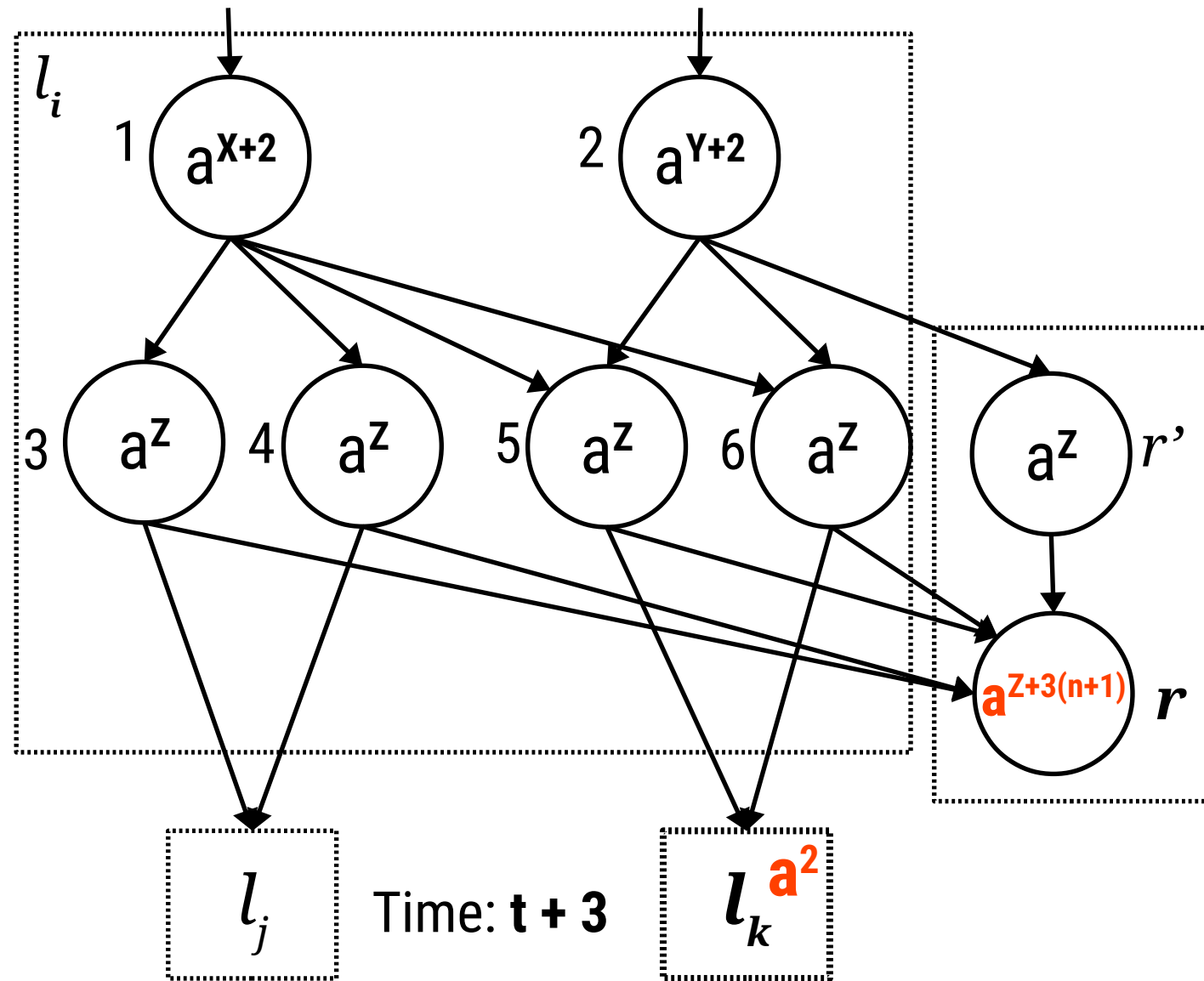
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 1: Rule 1 is activated.**

# ADD Module

$l_i$	<b>ADD(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

Rule 5:  $a^{z+1} / a^1 \rightarrow a$

Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

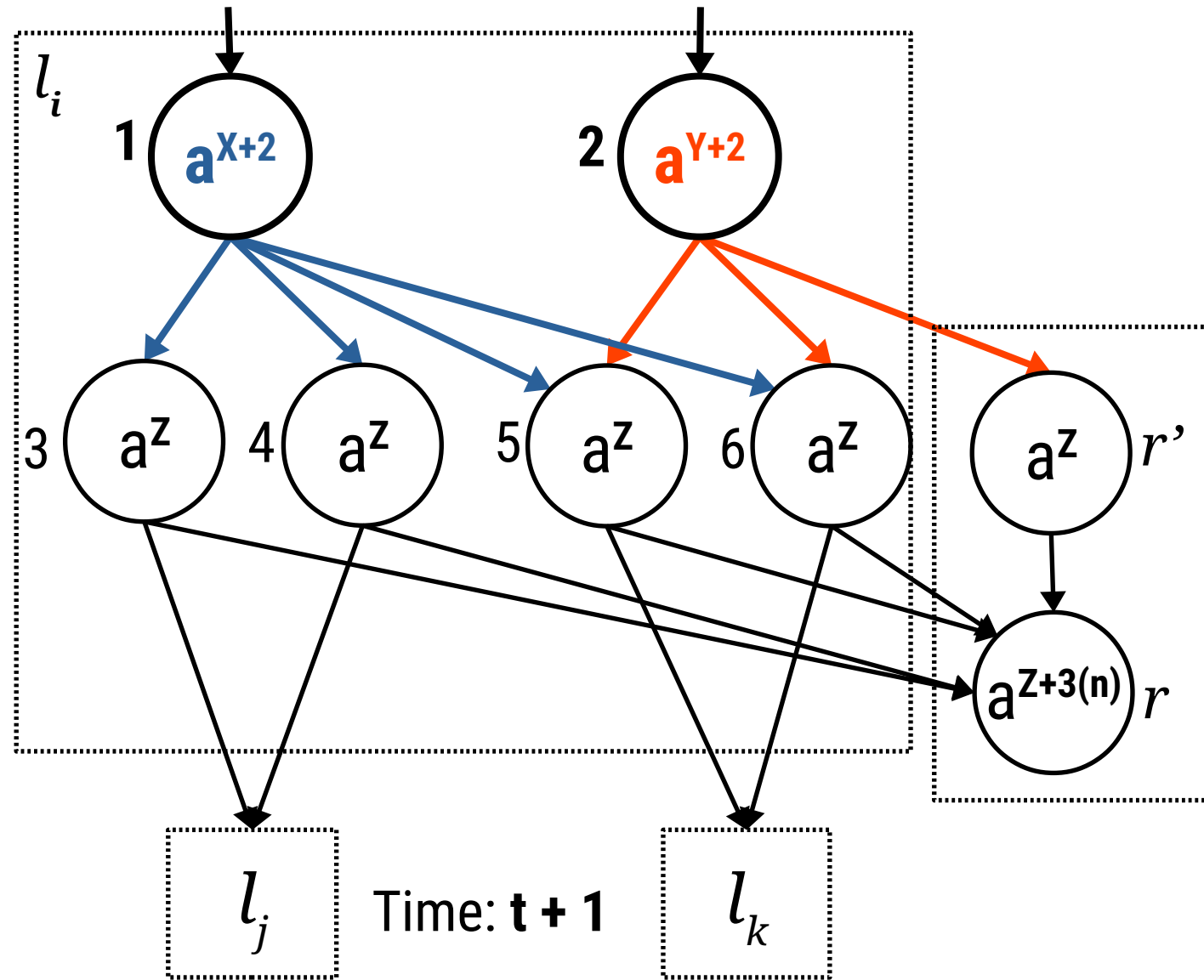
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 1: Rule 1 is activated.**

# ADD Module

$l_i$	ADD( $r$ )	$l_j$	$l_k$
-------	------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

**Rule 2:**  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

**Rule 4:**  $a^{y+2} / a^2 \rightarrow a$

Rule 5:  $a^{z+1} / a^1 \rightarrow a$

Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

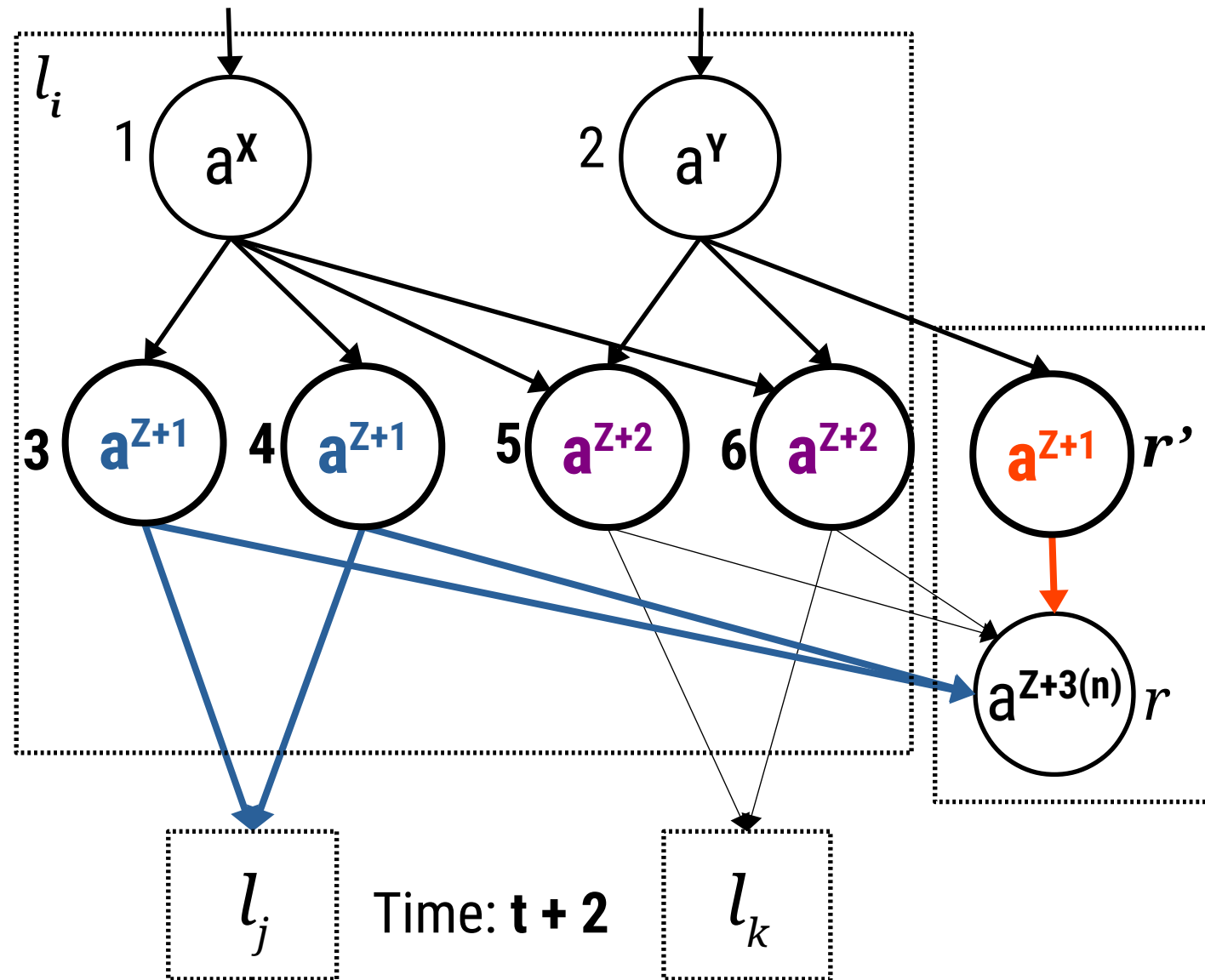
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 2:** Rule 2 is activated.

# ADD Module

$l_i$	<b>ADD(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

**Rule 5:**  $a^{z+1} / a^1 \rightarrow a$

**Rule 5:**  $a^{z+1} / a^1 \rightarrow a$

**Rule 6:**  $a^{z+2} / a^2 \rightarrow \lambda$

Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

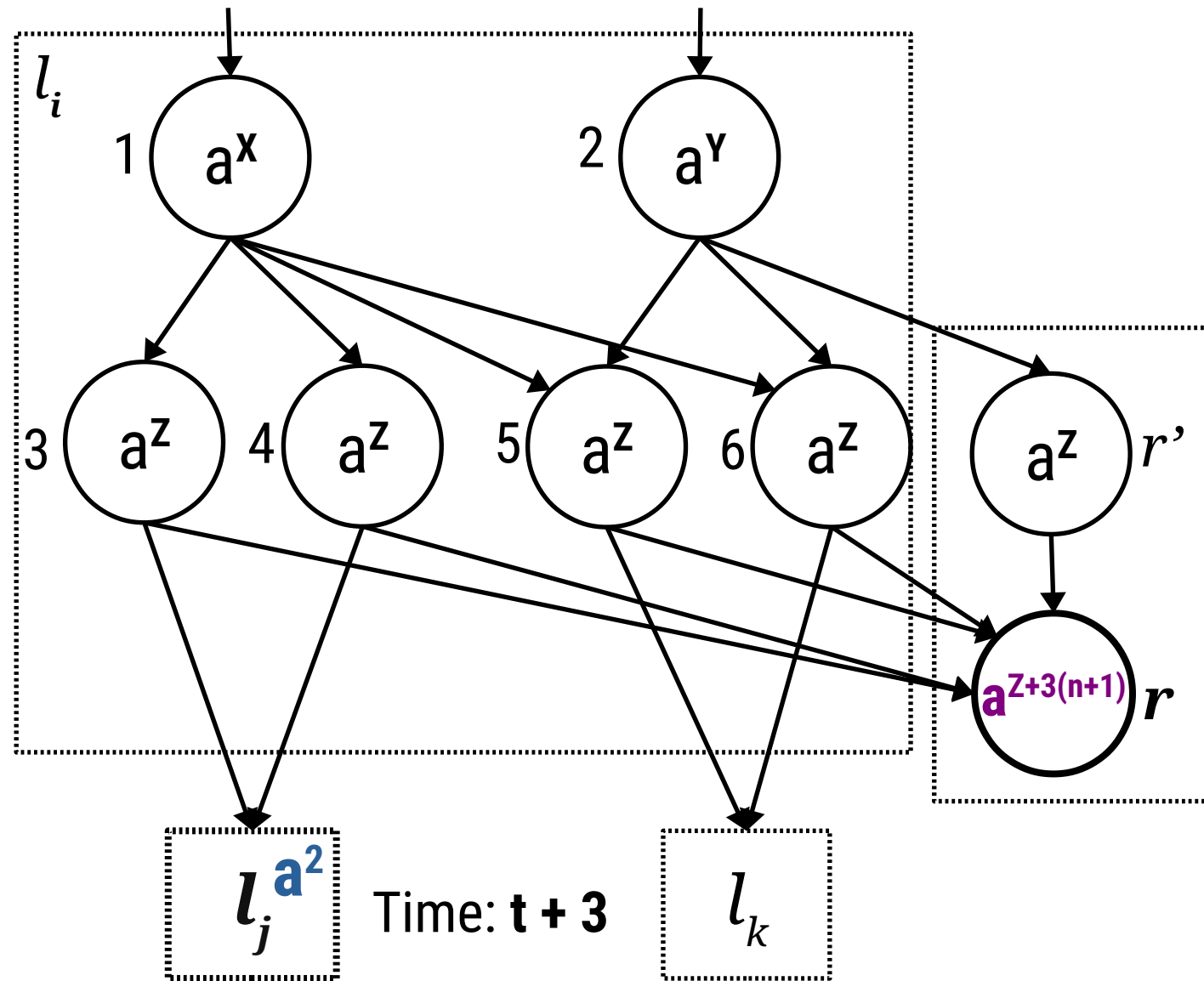
Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 2:** Rule 2 is activated.



# ADD Module

$l_i$	<b>ADD(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

Rule 5:  $a^{z+1} / a^1 \rightarrow a$

Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

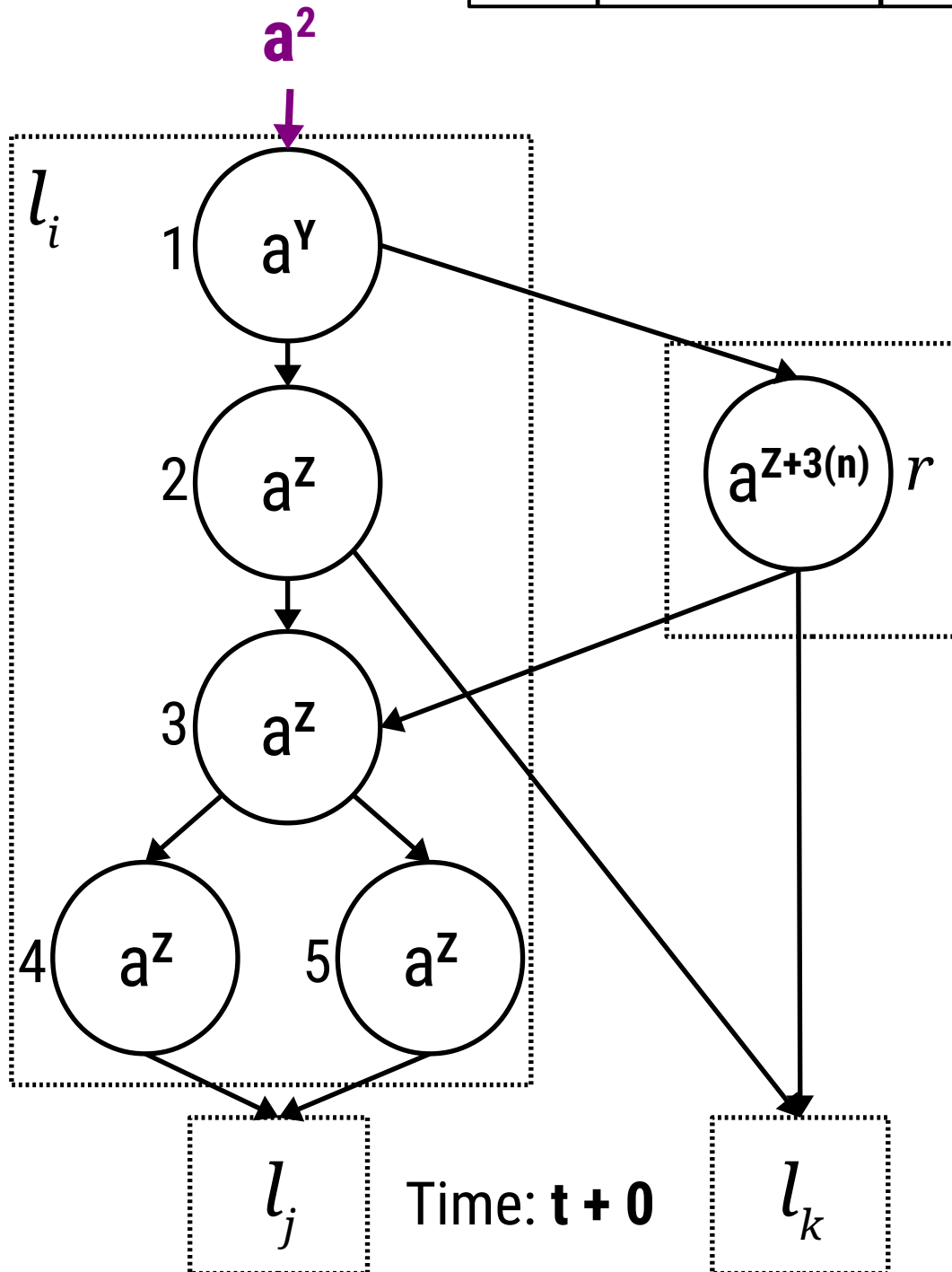
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 2:** Rule 2 is activated.

# SUB Module

$l_i$	<b>SUB(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

Rule 5:  $a^{z+1} / a^1 \rightarrow a$

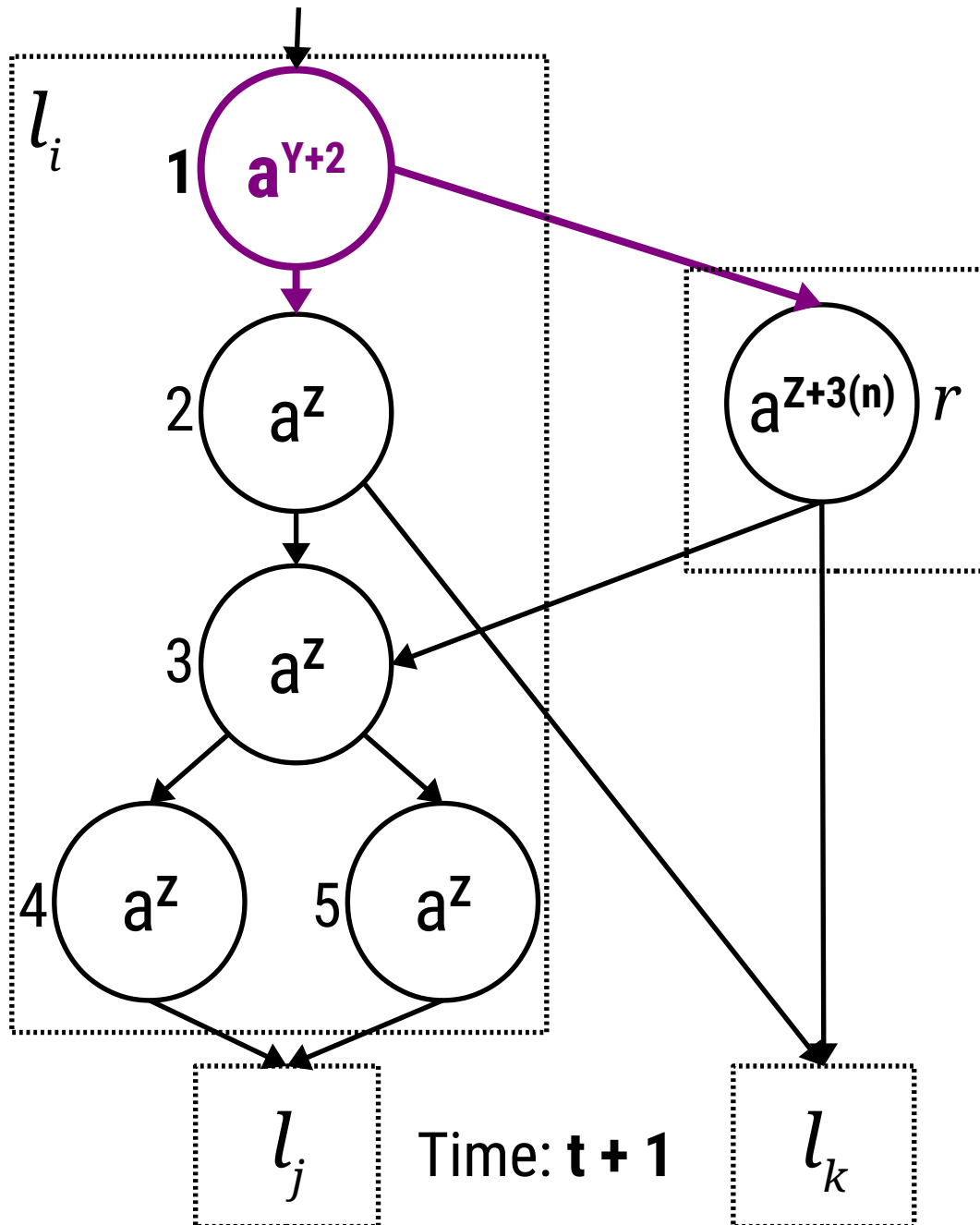
Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

# SUB Module

$l_i$	<b>SUB(<math>r</math>)</b>	$l_j$	$l_k$
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Rule 0:  $a^{X+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{X+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{X+2} / a^2 \rightarrow a$

Rule 3:  $a^{Y+1} / a^1 \rightarrow \lambda$

**Rule 4:  $a^{Y+2} / a^2 \rightarrow a$**

Rule 5:  $a^{Z+1} / a^1 \rightarrow a$

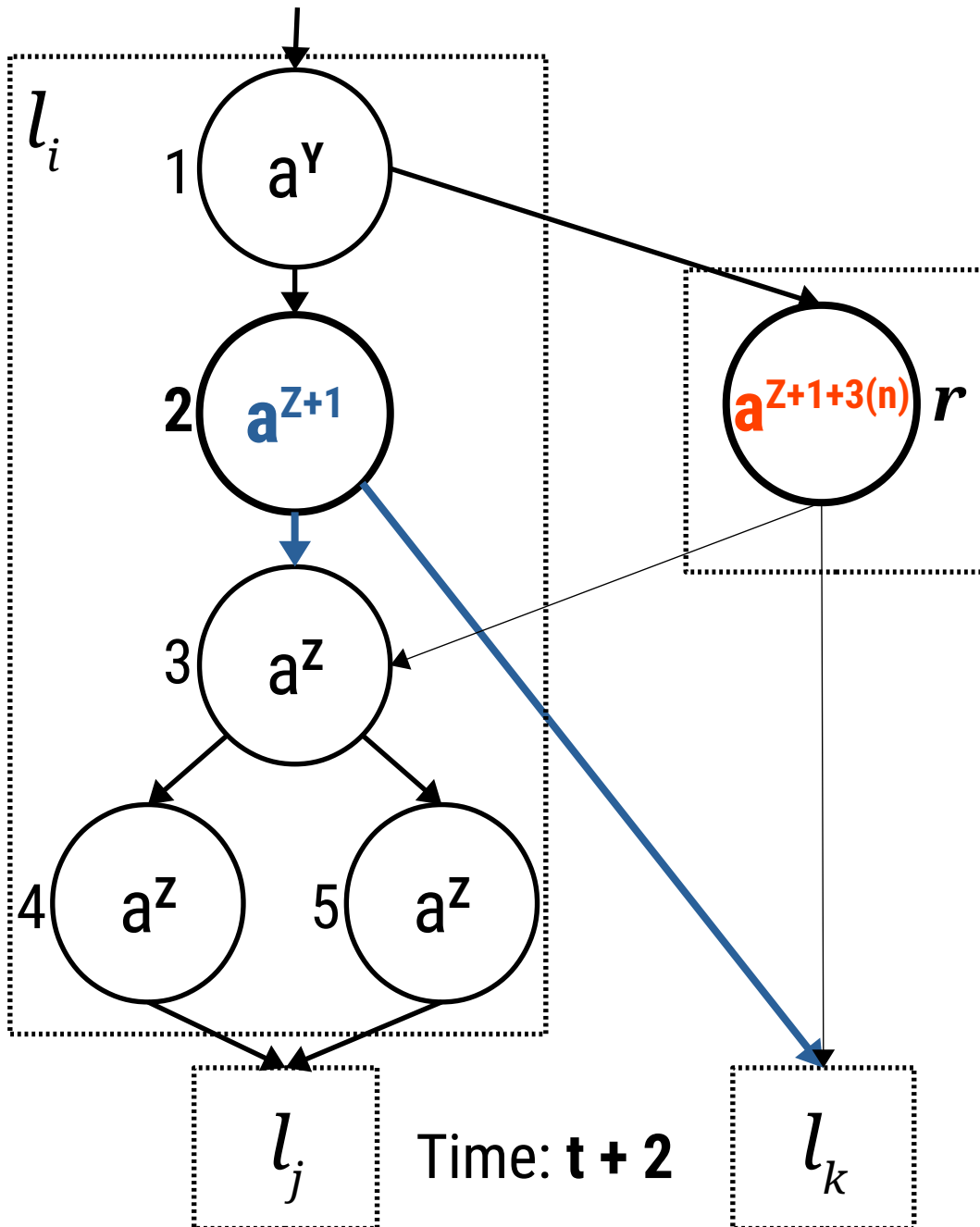
Rule 6:  $a^{Z+2} / a^2 \rightarrow \lambda$

Rule 7:  $a^{Z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{Z+2} (a^3)^+ / a^3 \rightarrow a$

# SUB Module

$l_i$	<b>SUB(<math>r</math>)</b>	$l_j$	$l_k$
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Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

**Rule 5:**  $a^{z+1} / a^1 \rightarrow a$  (highlighted in blue)

Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

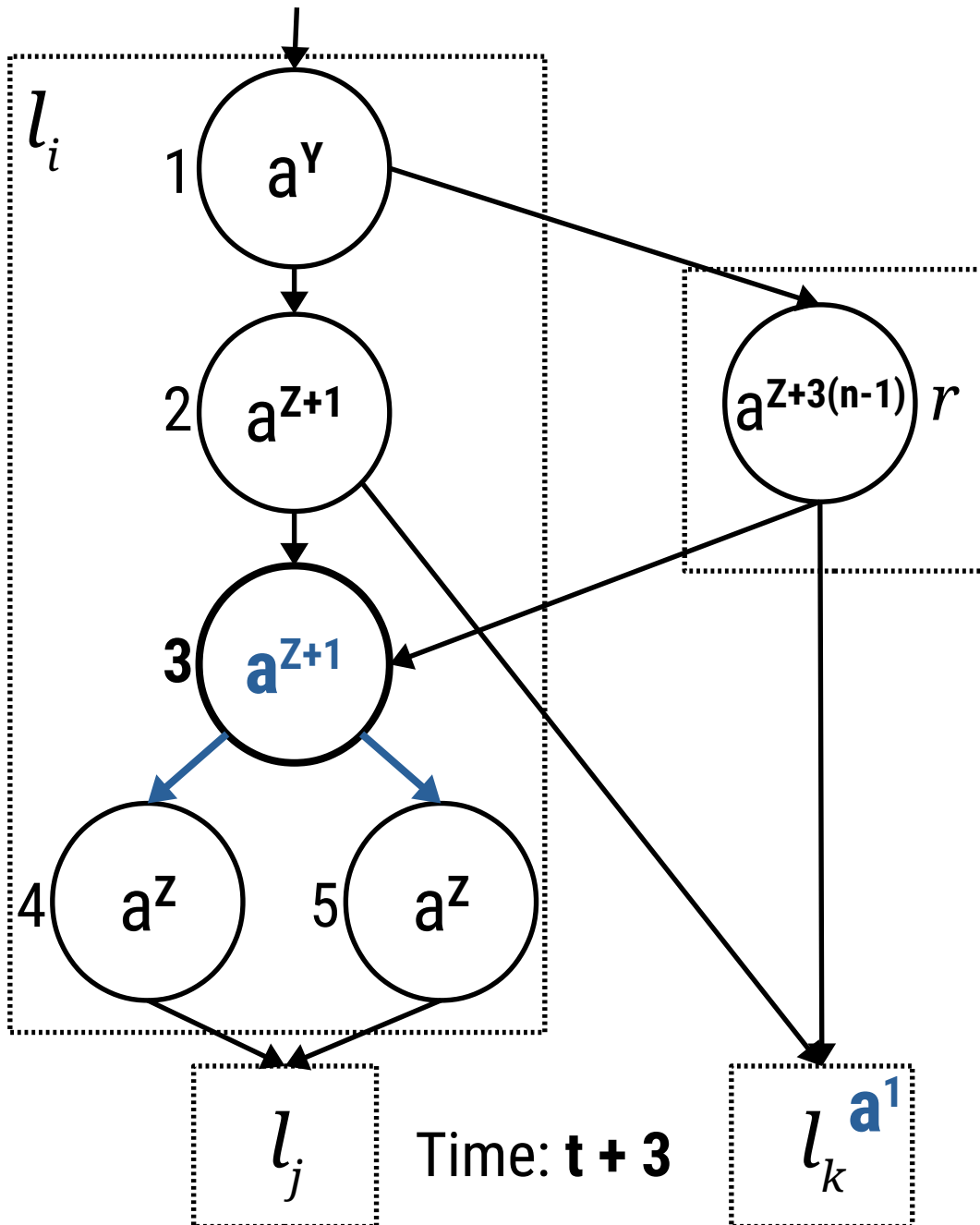
**Rule 7:**  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$  (highlighted in red)

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 1:**  $n > 0$

# SUB Module

$l_i$	<b>SUB(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

**Rule 5:**  $a^{z+1} / a^1 \rightarrow a$

Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

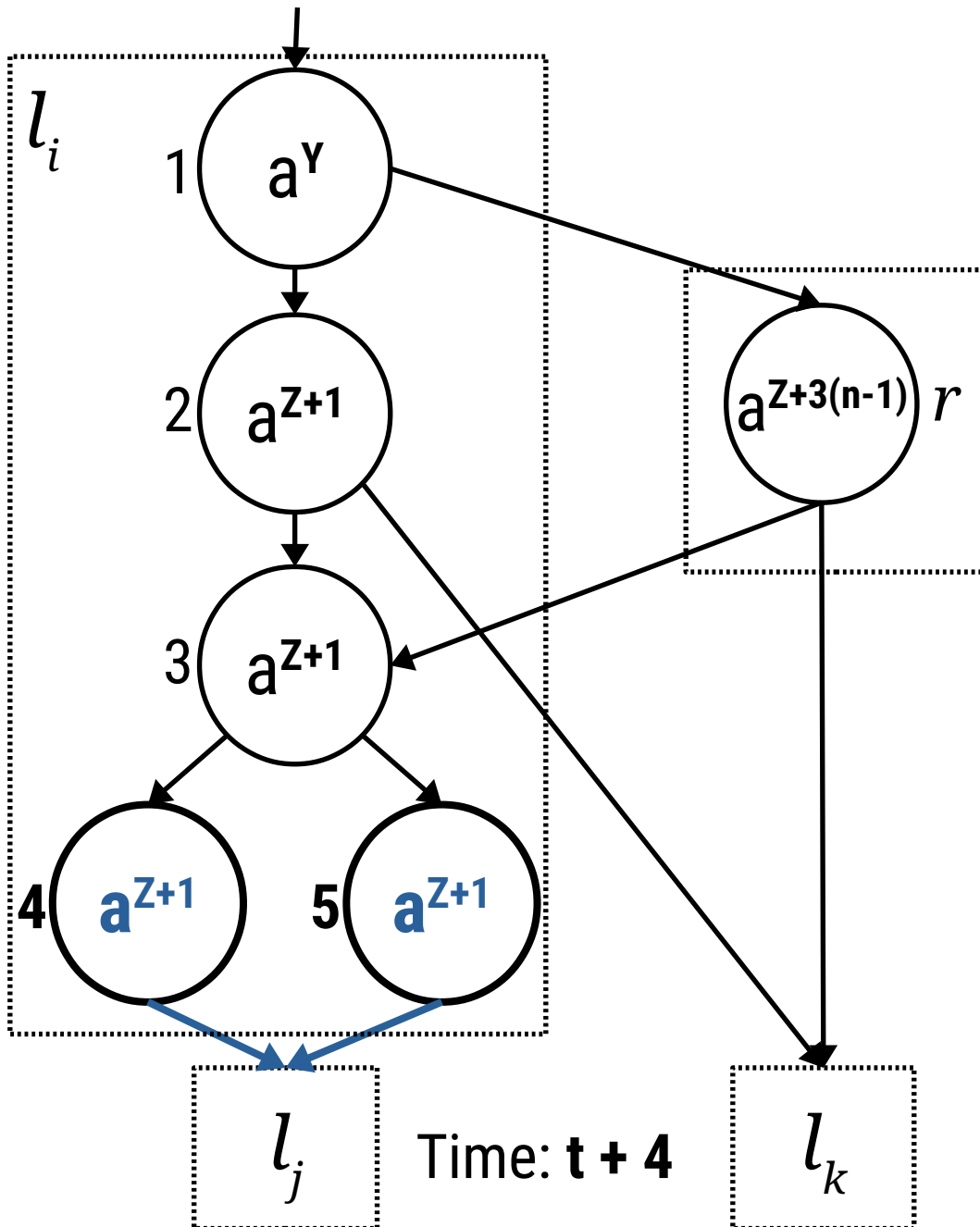
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 1:**  $n > 0$

# SUB Module

$l_i$	<b>SUB(<math>r</math>)</b>	$l_j$	$l_k$
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Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

**Rule 5:  $a^{z+1} / a^1 \rightarrow a$**

Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

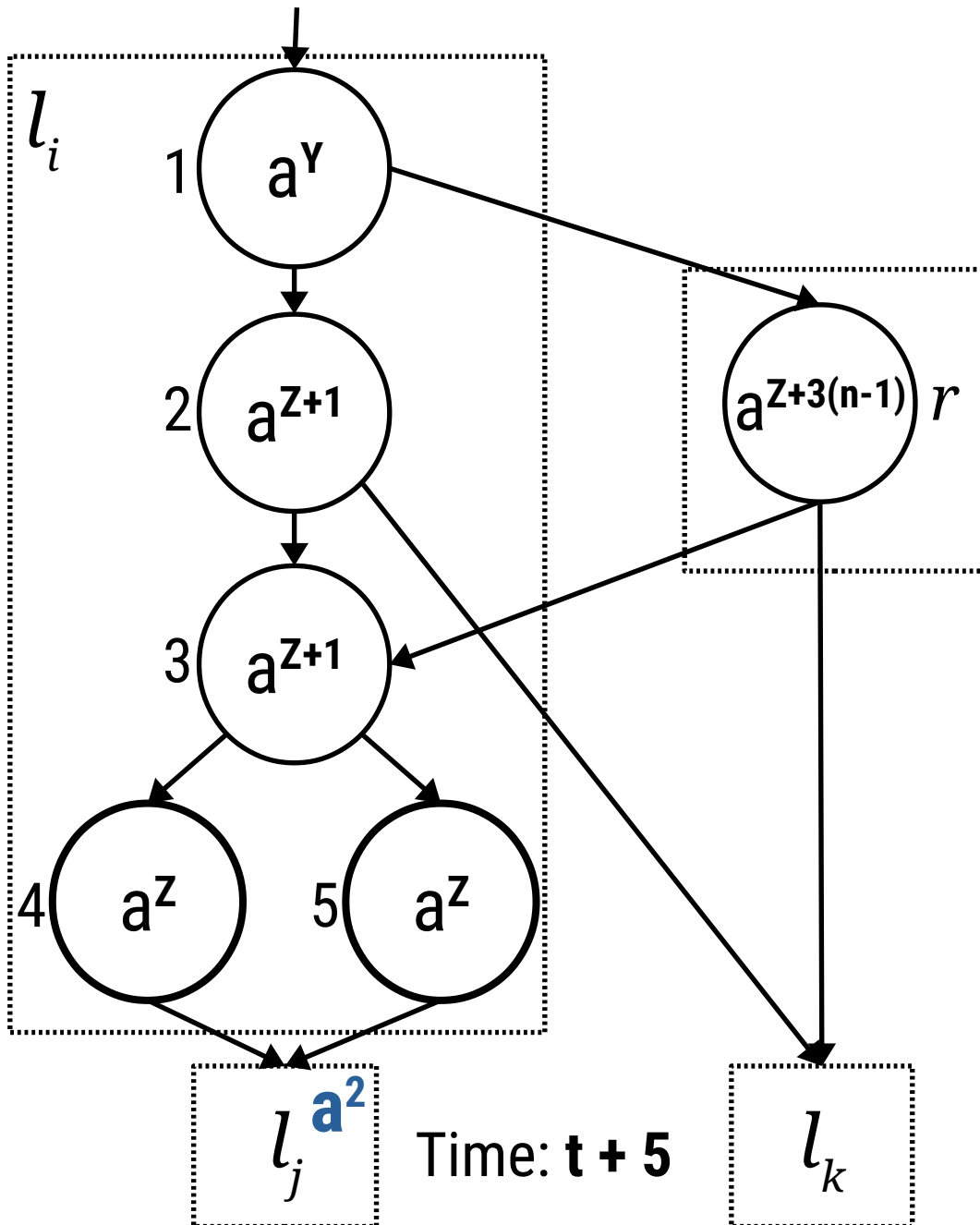
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 1:  $n > 0$**

# SUB Module

$l_i$	<b>SUB(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

Rule 5:  $a^{z+1} / a^1 \rightarrow a$

Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

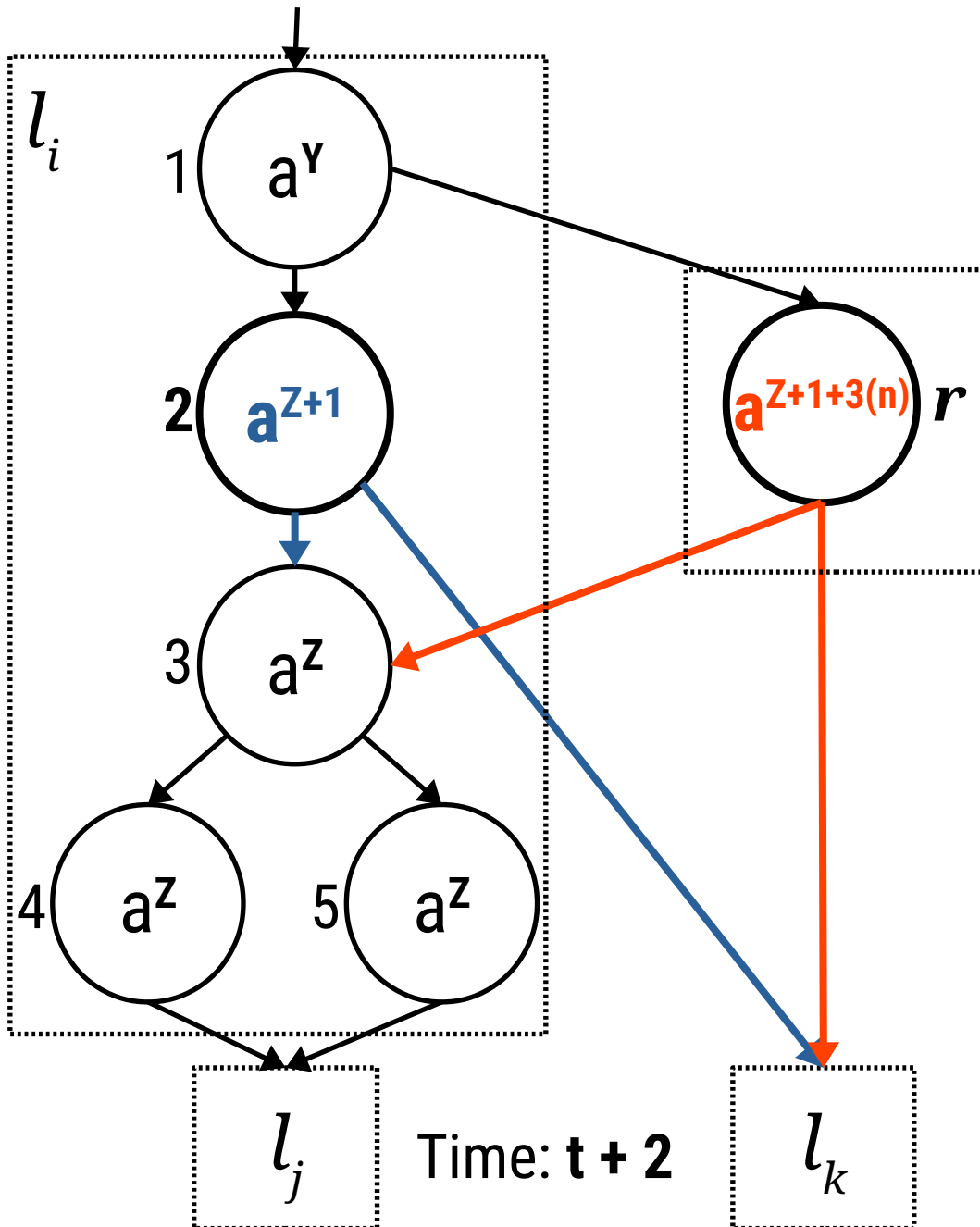
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 1:  $n > 0$**

# SUB Module

$l_i$	<b>SUB(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

**Rule 5:**  $a^{z+1} / a^1 \rightarrow a$

**Rule 5:**  $a^{z+1} / a^1 \rightarrow a$

Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

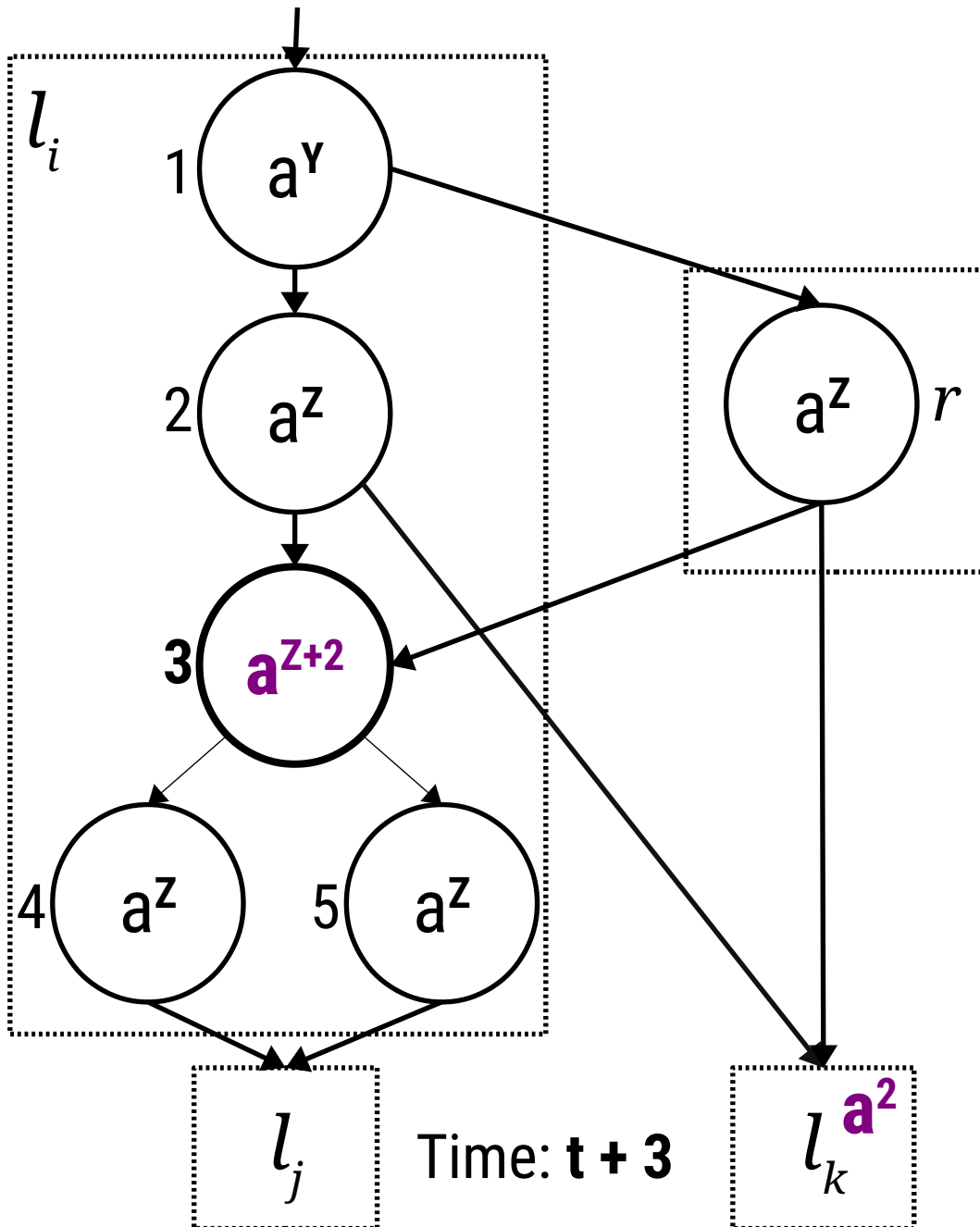
Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 2:**  $n = 0$



# SUB Module

$l_i$	<b>SUB(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

Rule 5:  $a^{z+1} / a^1 \rightarrow a$

**Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$**

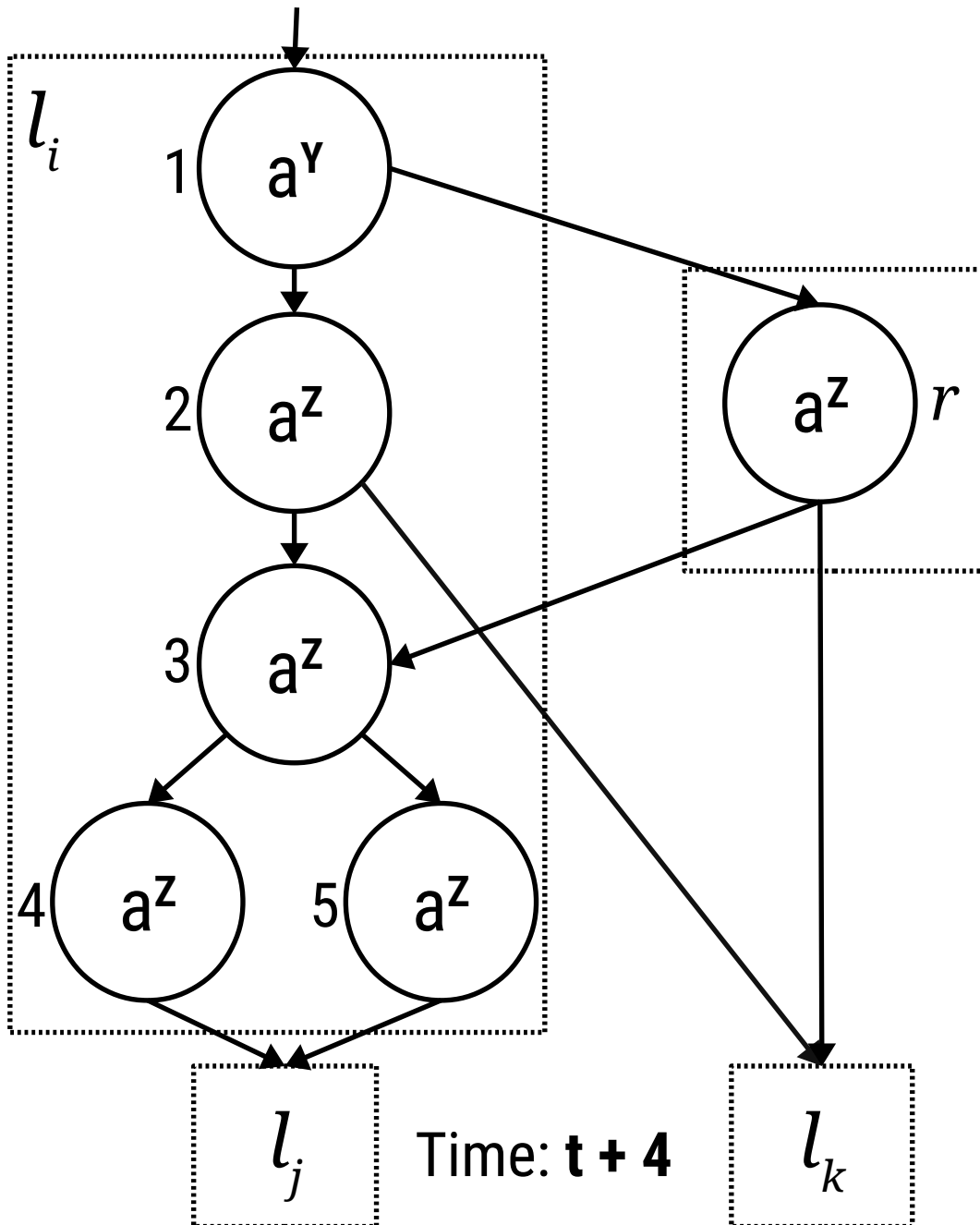
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 2:  $n = 0$**

# SUB Module

$l_i$	<b>SUB(<math>r</math>)</b>	$l_j$	$l_k$
-------	----------------------------	-------	-------



Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

Rule 5:  $a^{z+1} / a^1 \rightarrow a$

**Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$**

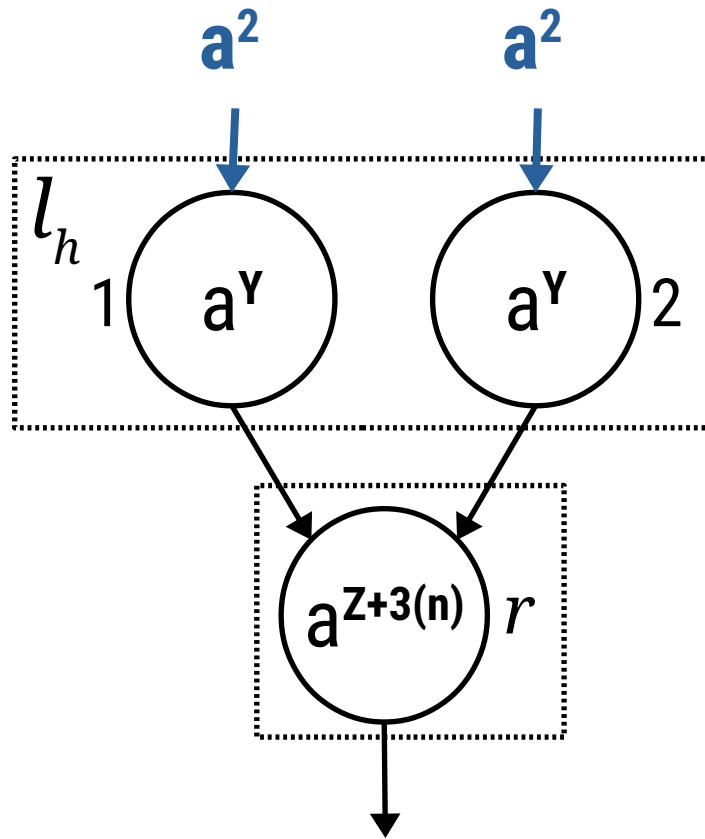
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Case 2:  $n = 0$**

# HALT Module

$l_h$	HALT
-------	------



Time:  $t + 0$

Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

Rule 5:  $a^{z+1} / a^1 \rightarrow a$

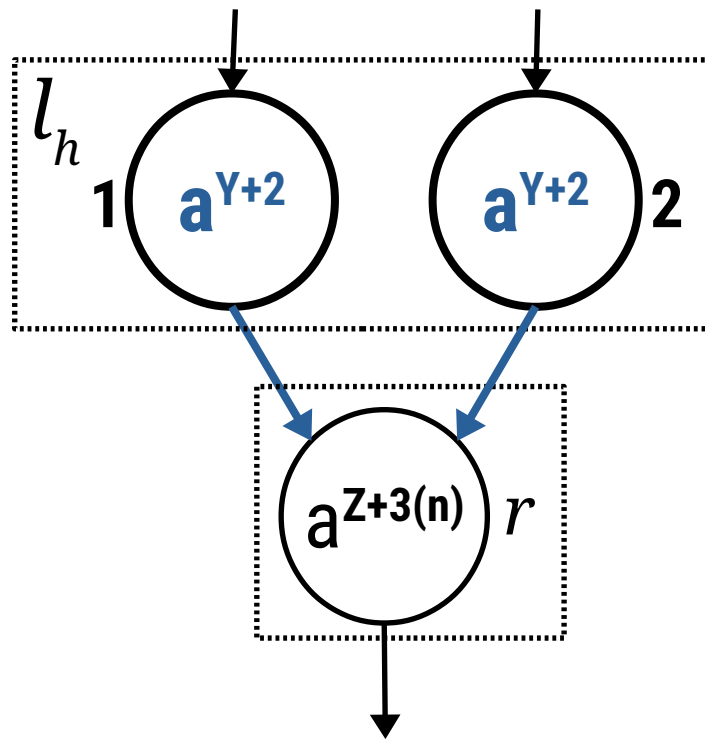
Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

# HALT Module

$l_h$	HALT
-------	------



Time:  $t + 1$

Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

**Rule 4:  $a^{y+2} / a^2 \rightarrow a$**

Rule 5:  $a^{z+1} / a^1 \rightarrow a$

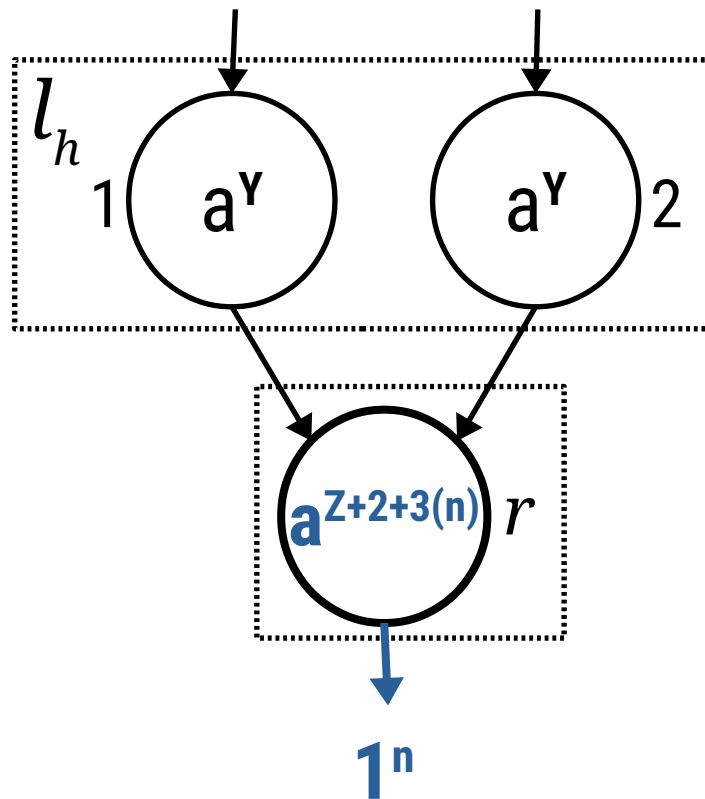
Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

# HALT Module

$l_h$	HALT
-------	------



Time:  $t + 2$

to

Time:  $t + n + 1$

Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{x+2} / a^2 \rightarrow a$

Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{y+2} / a^2 \rightarrow a$

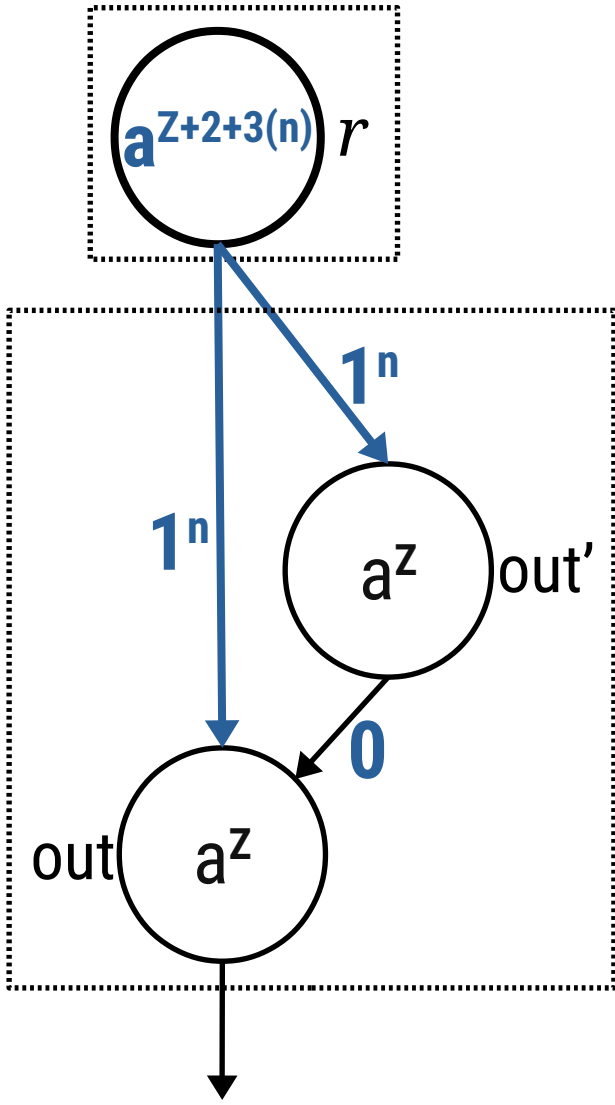
Rule 5:  $a^{z+1} / a^1 \rightarrow a$

Rule 6:  $a^{z+2} / a^2 \rightarrow \lambda$

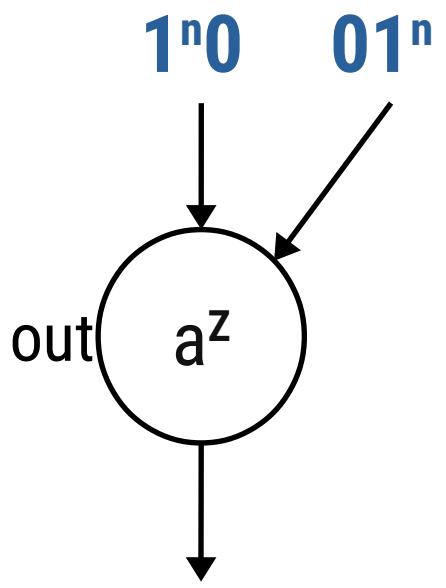
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$

**Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$**

# OUTPUT Module



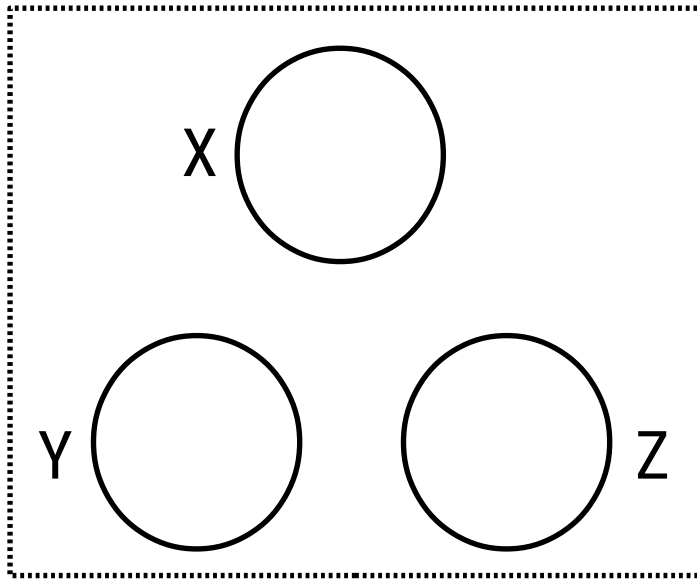
$r$	$1^n$	$0$	
out'	$0$	$1^n$	
out	$1$	$2^{n-1}$	$1$
out	$1$	$0^{n-1}$	$1$



- Rule 0:  $a^{x+1} / a^1 \rightarrow \lambda$   
Rule 1:  $a^{x+2} / a^2 \rightarrow \lambda$   
Rule 2:  $a^{x+2} / a^2 \rightarrow a$
- Rule 3:  $a^{y+1} / a^1 \rightarrow \lambda$   
Rule 4:  $a^{y+2} / a^2 \rightarrow a$
- Rule 5:**  $a^{z+1} / a^1 \rightarrow a$   
**Rule 6:**  $a^{z+2} / a^2 \rightarrow \lambda$   
Rule 7:  $a^{z+1} (a^3)^+ / a^4 \rightarrow \lambda$   
Rule 8:  $a^{z+2} (a^3)^+ / a^3 \rightarrow a$

**Discussion:** On why plasticity rules are only used as forgetting rules.

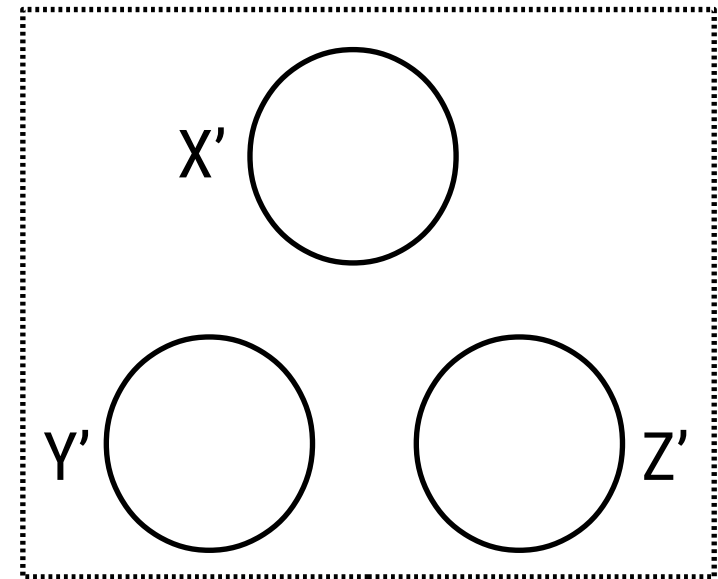
Module A



In neuron X:

Rule 1:  $E / a^c \rightarrow +2(\{Y, Z\})$

Module A'

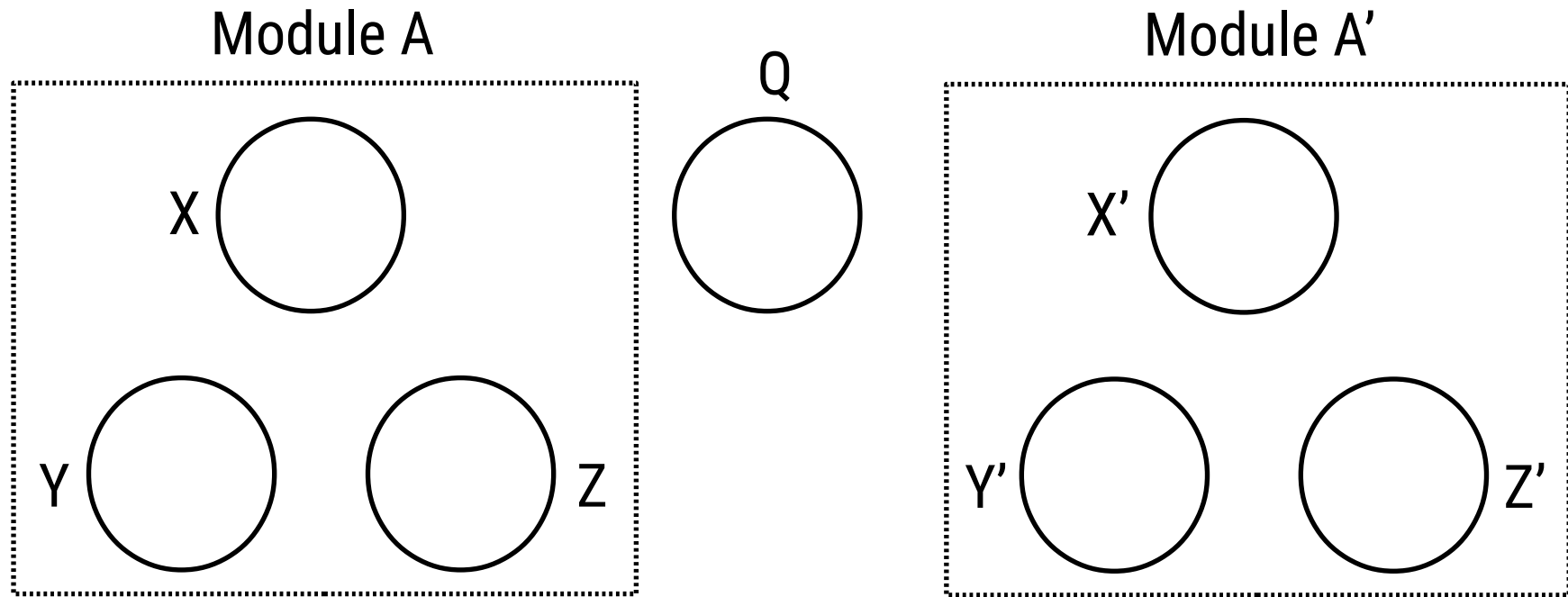


In neuron X':

Rule 1':  $E / a^c \rightarrow +2(\{Y', Z'\})$

Neuron X' can not reuse Rule 1 of neuron X.  
Neuron X can not reuse Rule 1' of neuron X'.

**Discussion:** On why plasticity rules are only used as forgetting rules.



In neuron X:

Rule 1:  $E / a^c \rightarrow -1(\{Q\})$

Rule 1:  $E / a^c \rightarrow \lambda$

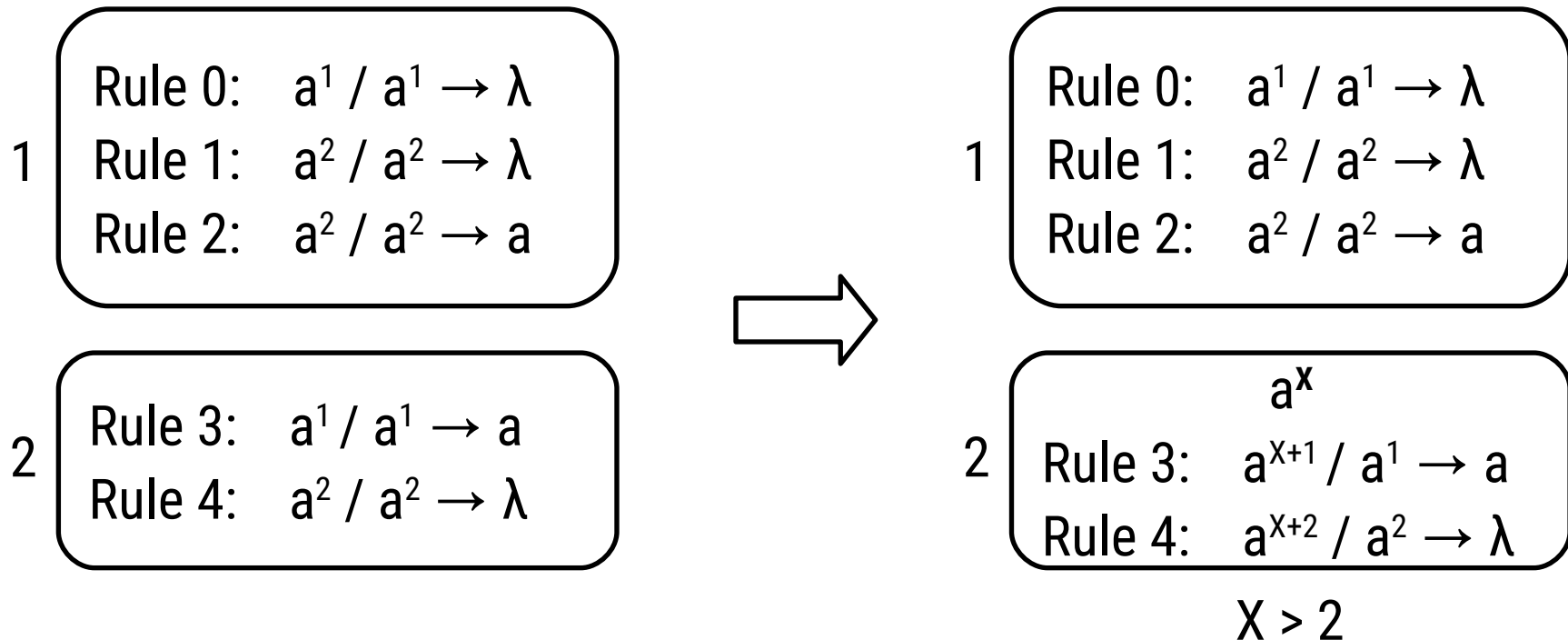
In neuron X':

Rule 1':  $E / a^c \rightarrow -1(\{Q\})$

Rule 1':  $E / a^c \rightarrow \lambda$



## Discussion: On “translating” rules



You can easily create a common set of rules by “translating” different rule sets then combining them and adding the appropriate initial spike counts to the neurons.

## Discussion: On “translating” rules

Rule 0:  $a^{X+1} / a^1 \rightarrow \lambda$

Rule 1:  $a^{X+2} / a^2 \rightarrow \lambda$

Rule 2:  $a^{X+2} / a^2 \rightarrow a$

Rule 3:  $a^{Y+1} / a^1 \rightarrow \lambda$

Rule 4:  $a^{Y+2} / a^2 \rightarrow a$

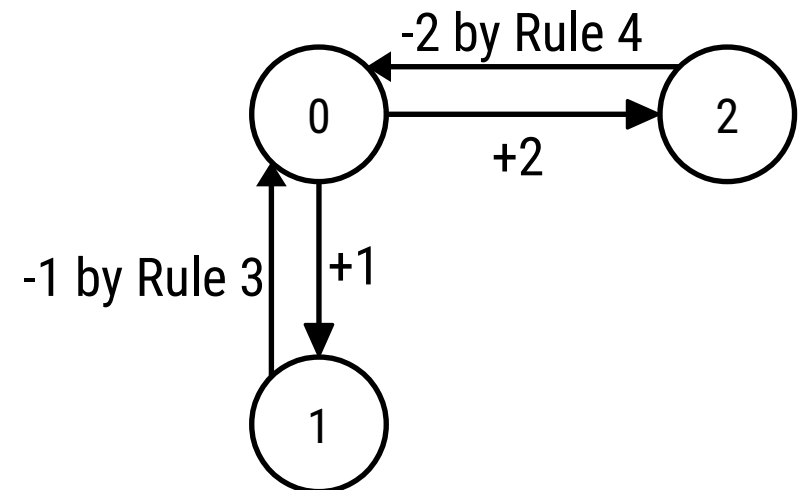
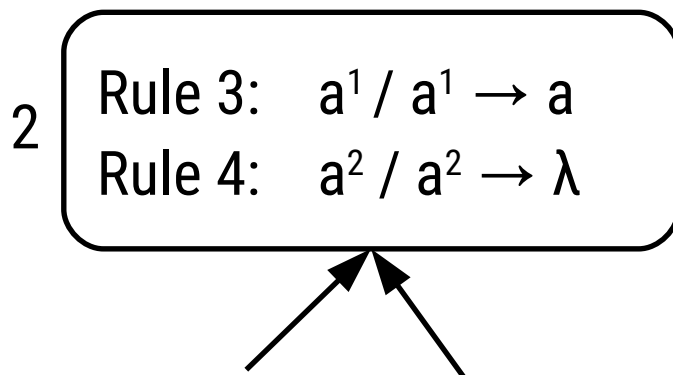
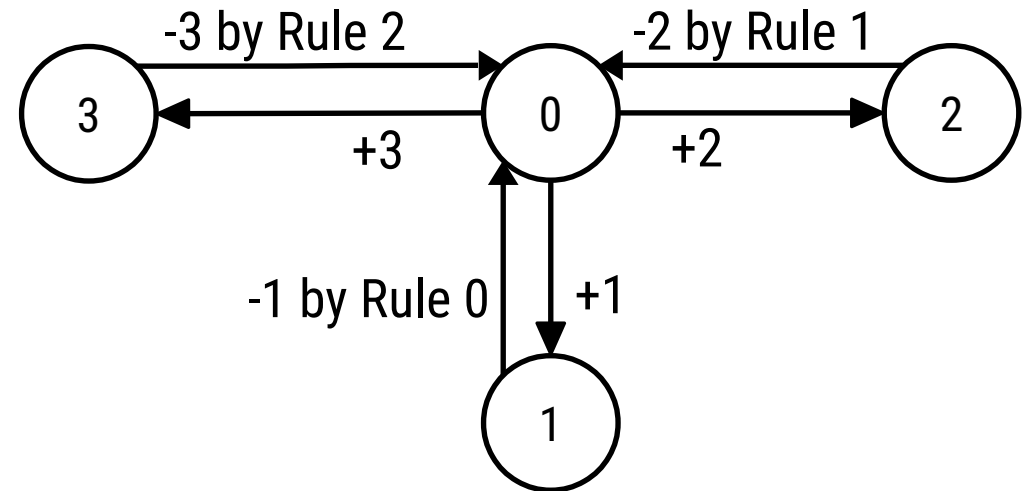
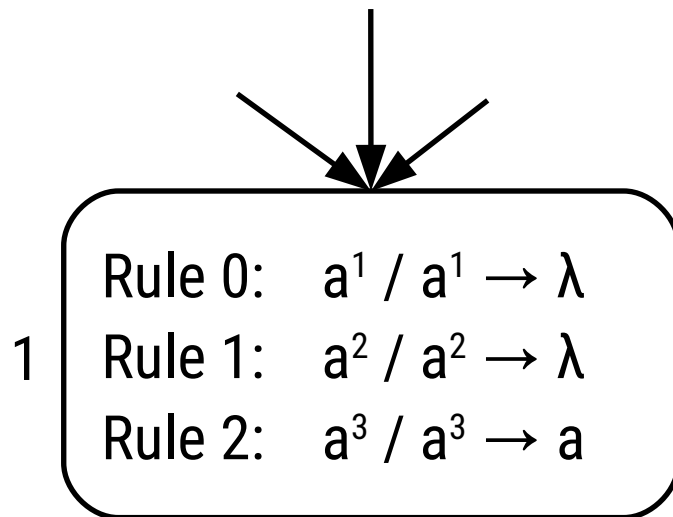
Rule 5:  $a^{Z+1} / a^1 \rightarrow a$

Rule 6:  $a^{Z+2} / a^2 \rightarrow \lambda$

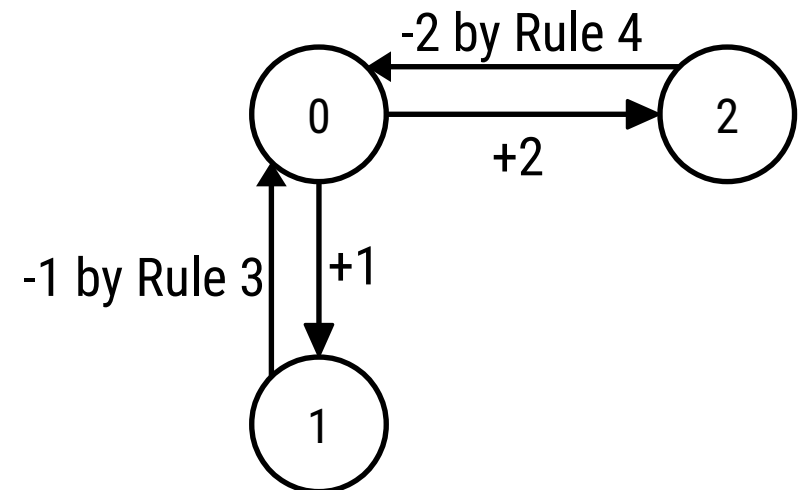
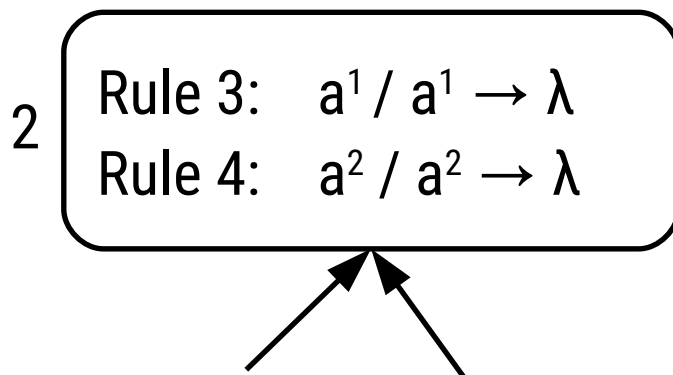
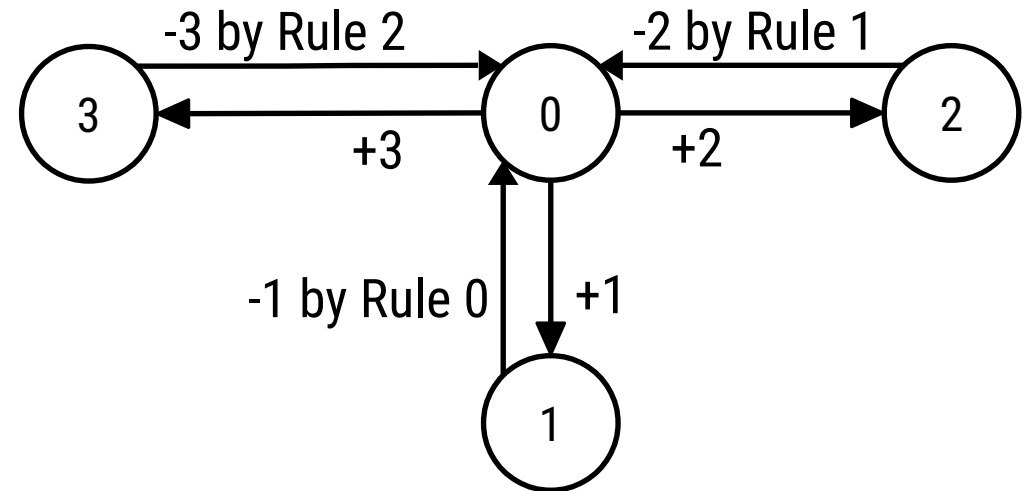
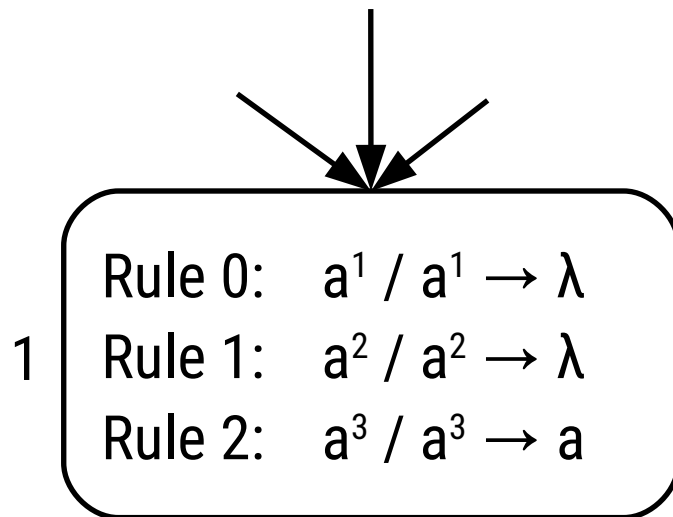
Rule 7:  $a^{Z+1} (a^3)^+ / a^4 \rightarrow \lambda$

Rule 8:  $a^{Z+2} (a^3)^+ / a^3 \rightarrow a$

## Discussion: On combining rules



## Discussion: On combining rules



# End of Presentation. Thank you!

## Acknowledgements

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