Homogeneous Spiking Neural P Systems with Structural Plasticity

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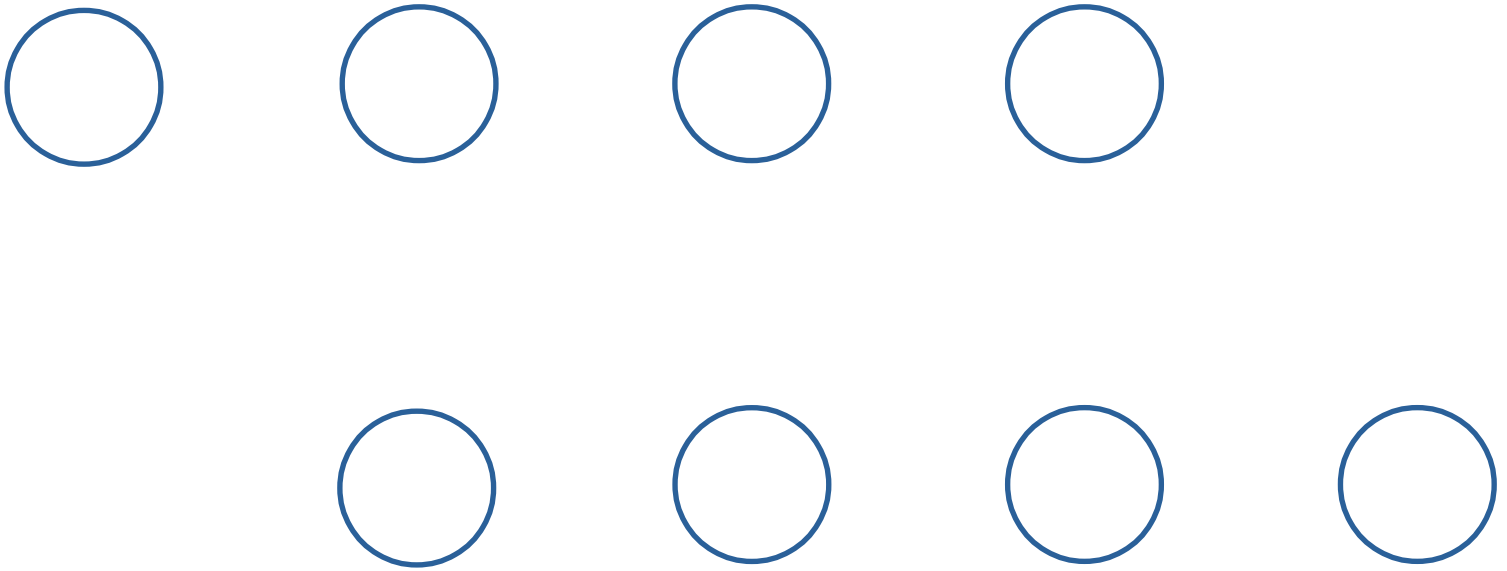
Spiking Neural P Systems with Structural Plasticity (SNPSP System)

$\Pi = (O, \sigma_1, \ldots, \sigma_m, syn, out)$

Neurons: $\sigma_1, \ldots, \sigma_m$



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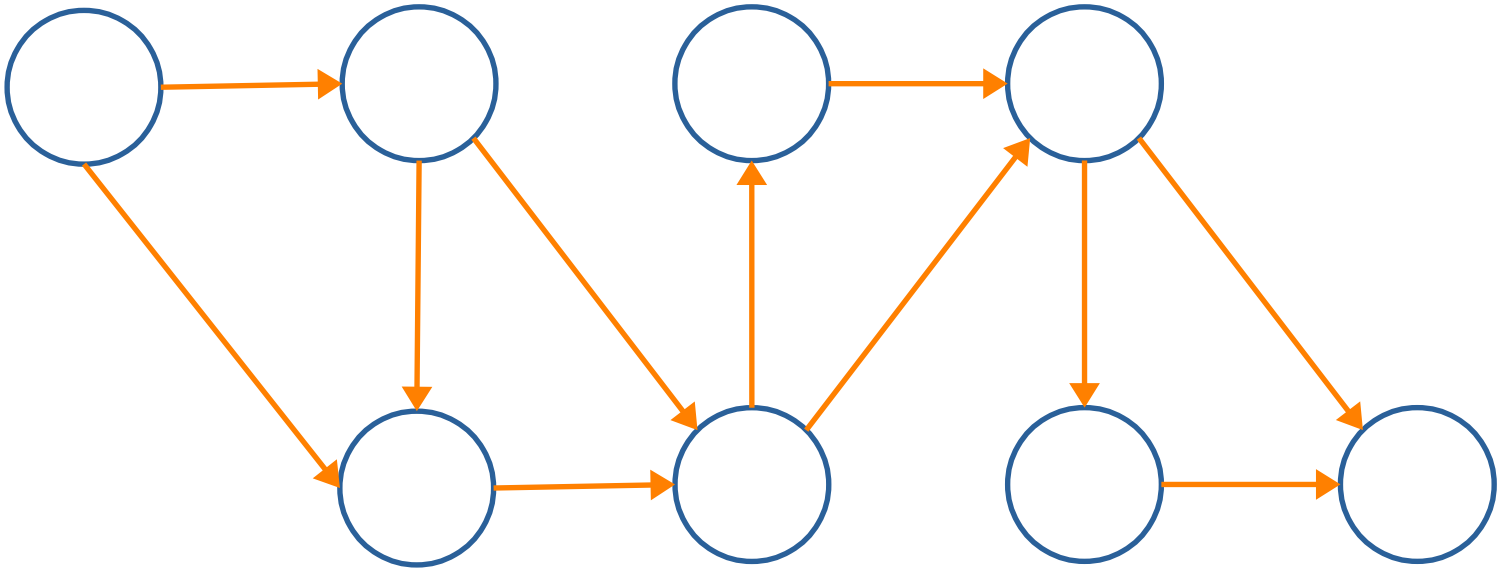
Synapses: syn



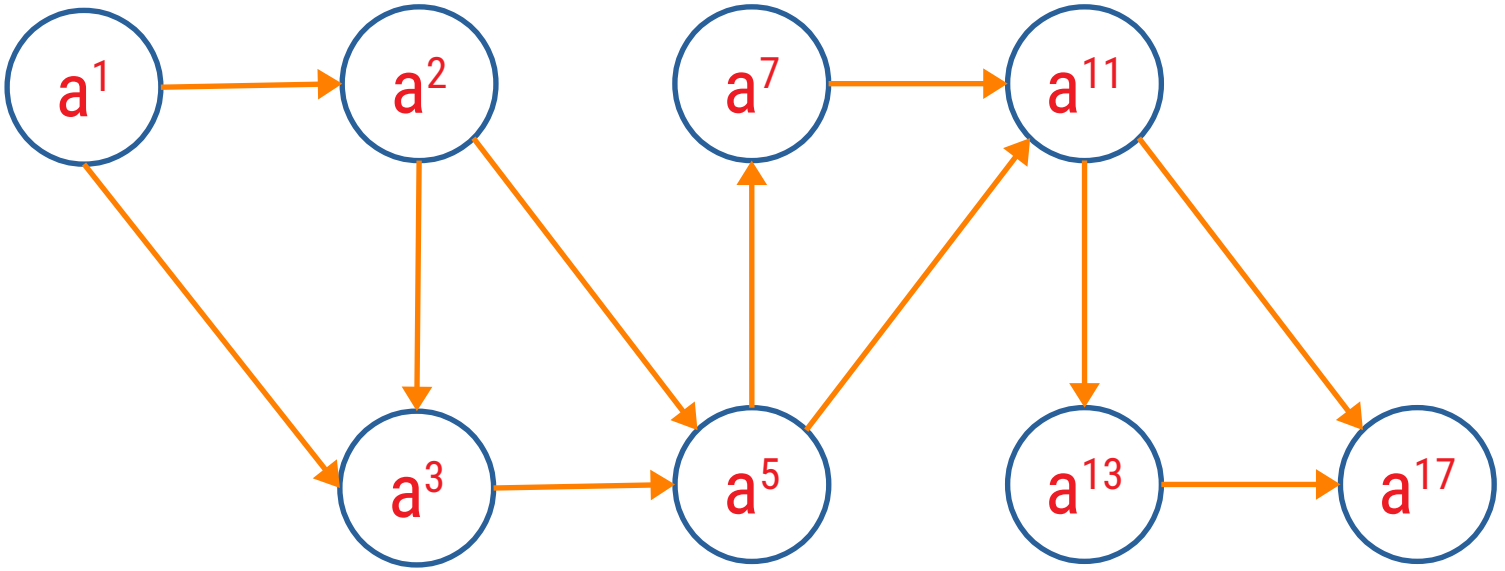
Spiking Neural P Systems with Structural Plasticity (SNPSP System)

$$\Pi = (O, \sigma_1, \ldots, \sigma_m, syn, out)$$

Spike: a

Alphabet: $O = \{a\}$

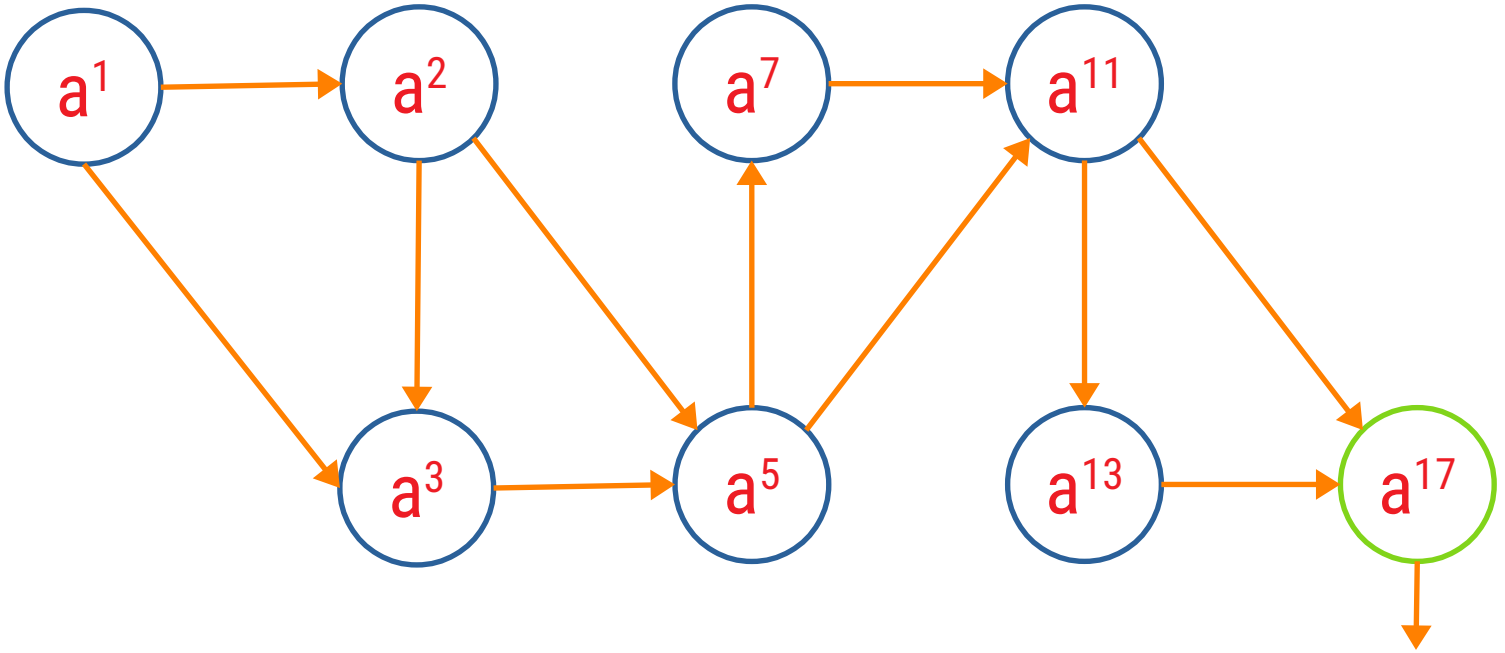
Multiset of Spikes: a^i



Spiking Neural P Systems with Structural Plasticity (SNPSP System)

$$\Pi = (O, \sigma_1, \ldots, \sigma_m, syn, out)$$

Output Nueron: *out*



Spiking Neural P Systems with Structural Plasticity (SNPSP System)

$$\Pi = (O, \sigma_1, \ldots, \sigma_m, syn, out)$$

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

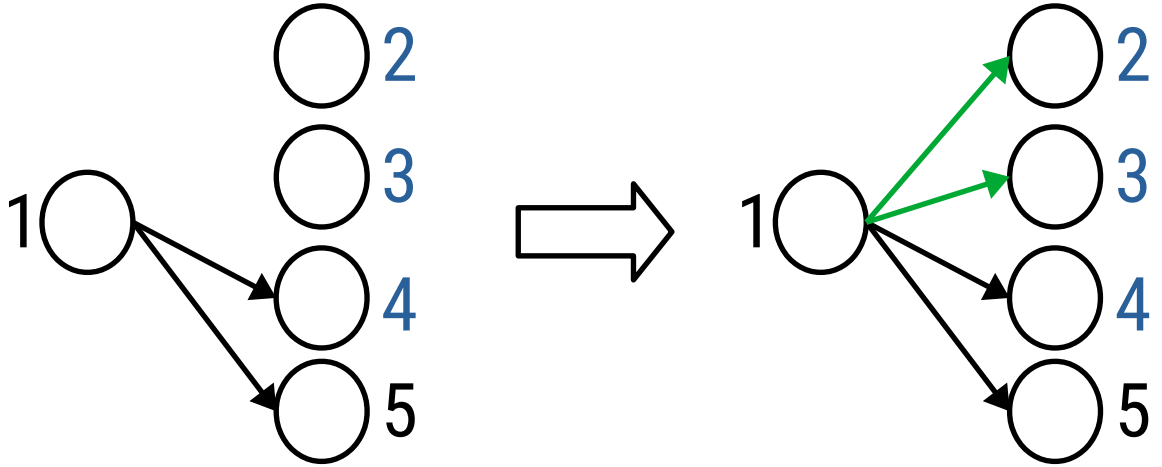
$\pm k$ – add then delete k synapses

$\mp k$ – delete then add k synapses

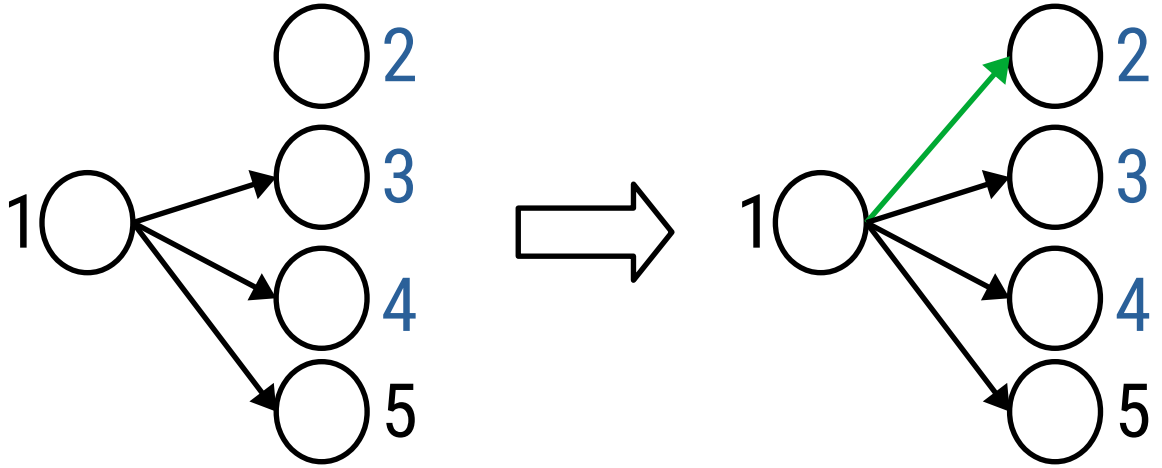
Plasticity Rule: $E / a^c \rightarrow \alpha k(N)$

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

Case 1:



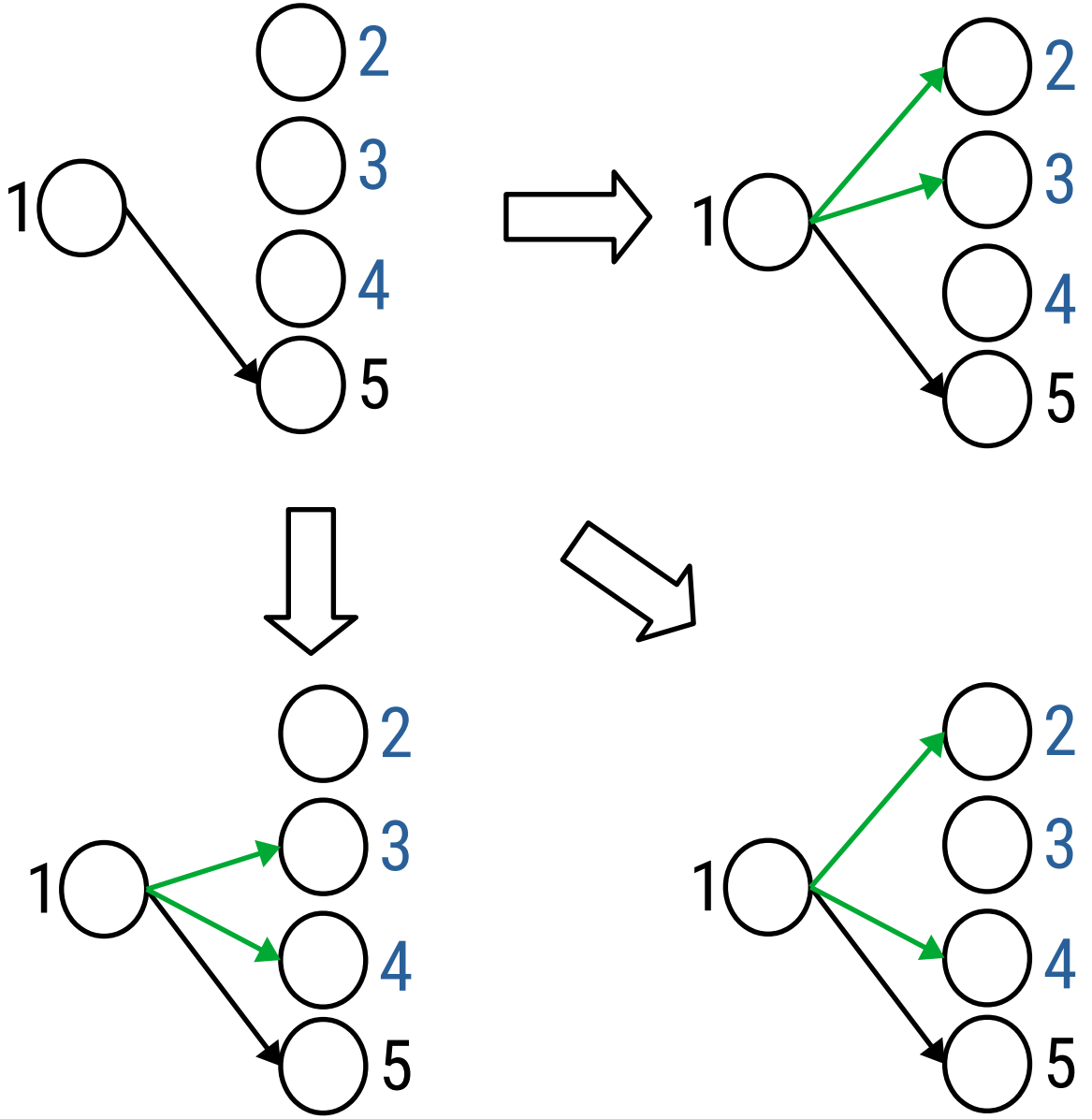
Case 2:



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

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

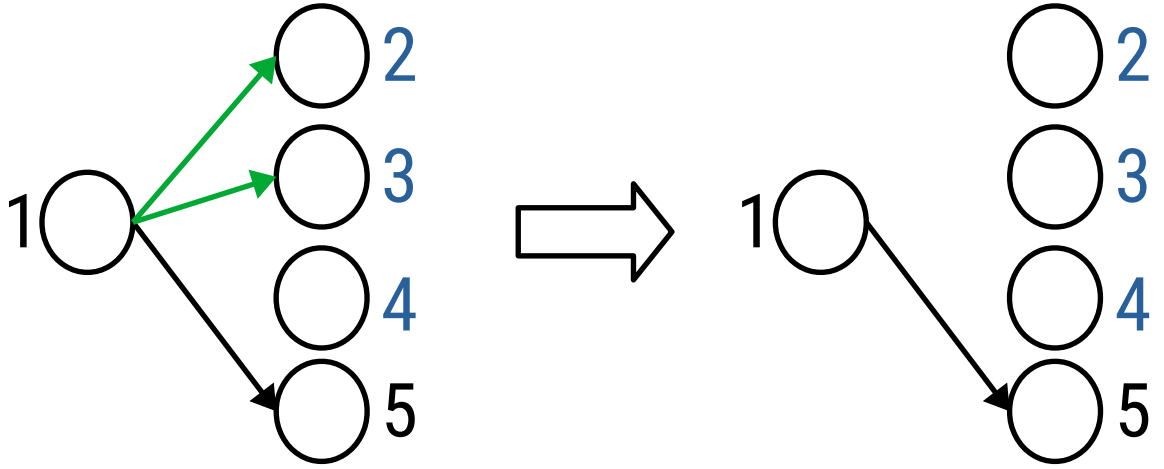
Case 3:



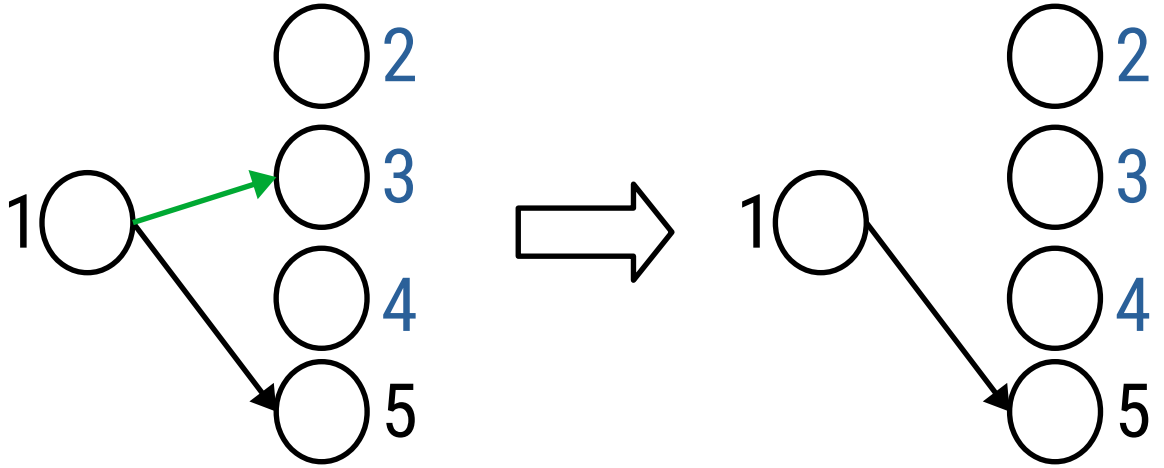
Plasticity Rule: $E / a^c \rightarrow \alpha k(N)$

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

Case 1:



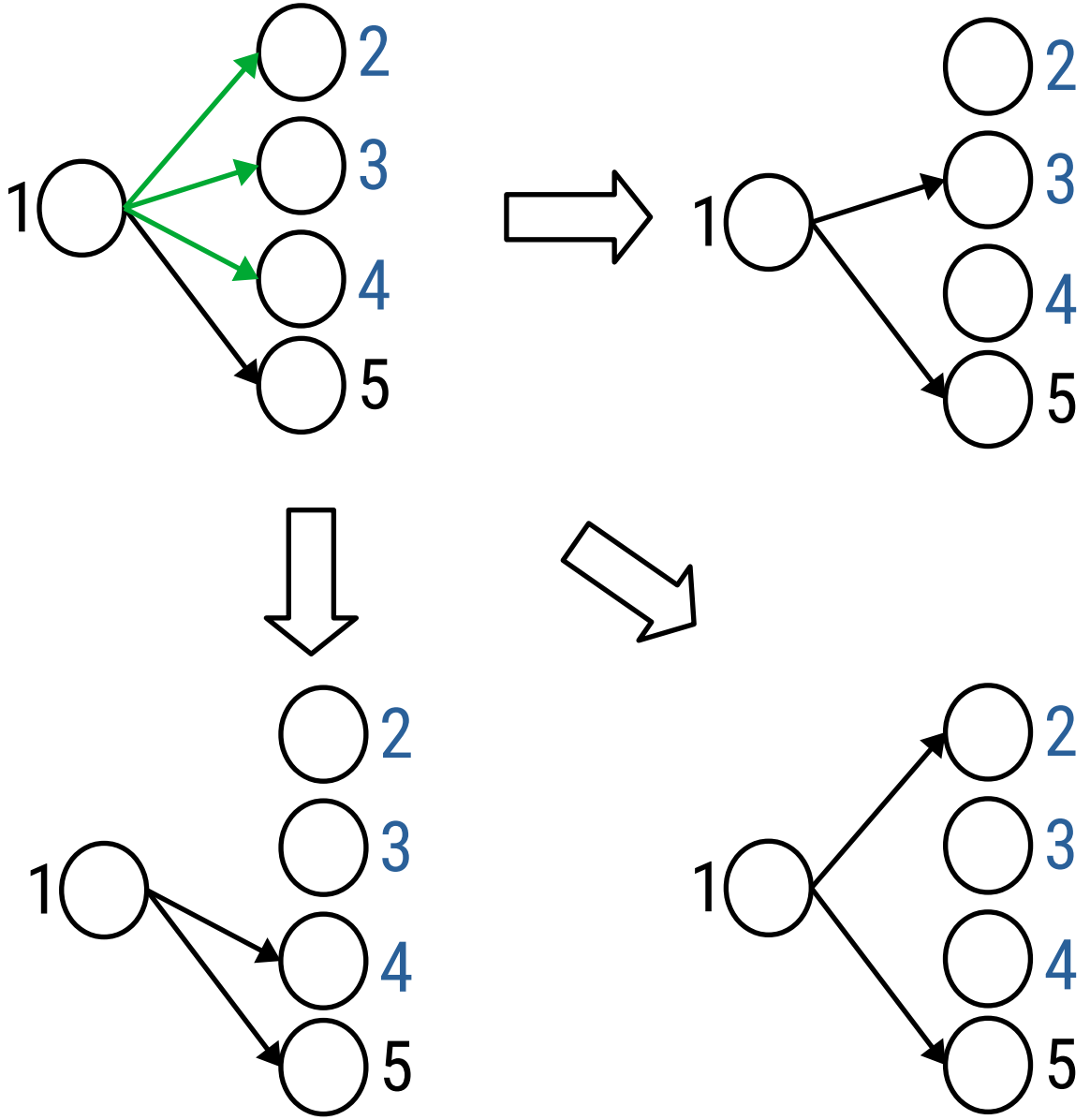
Case 2:



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

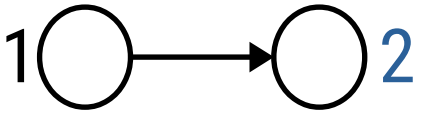
In neuron 1: $E / a^c \rightarrow -2(\{2,3,4\})$

Case 3:



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

Plasticity rules as forgetting rules.

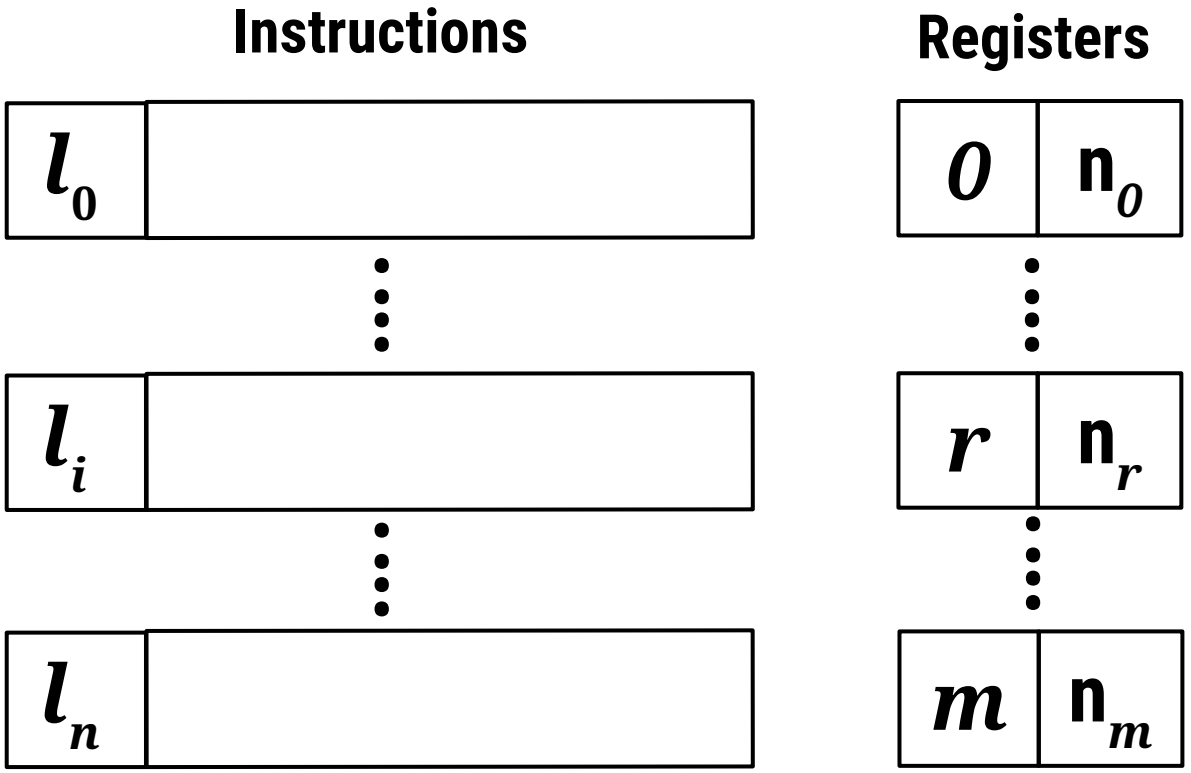
Case 1: 

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

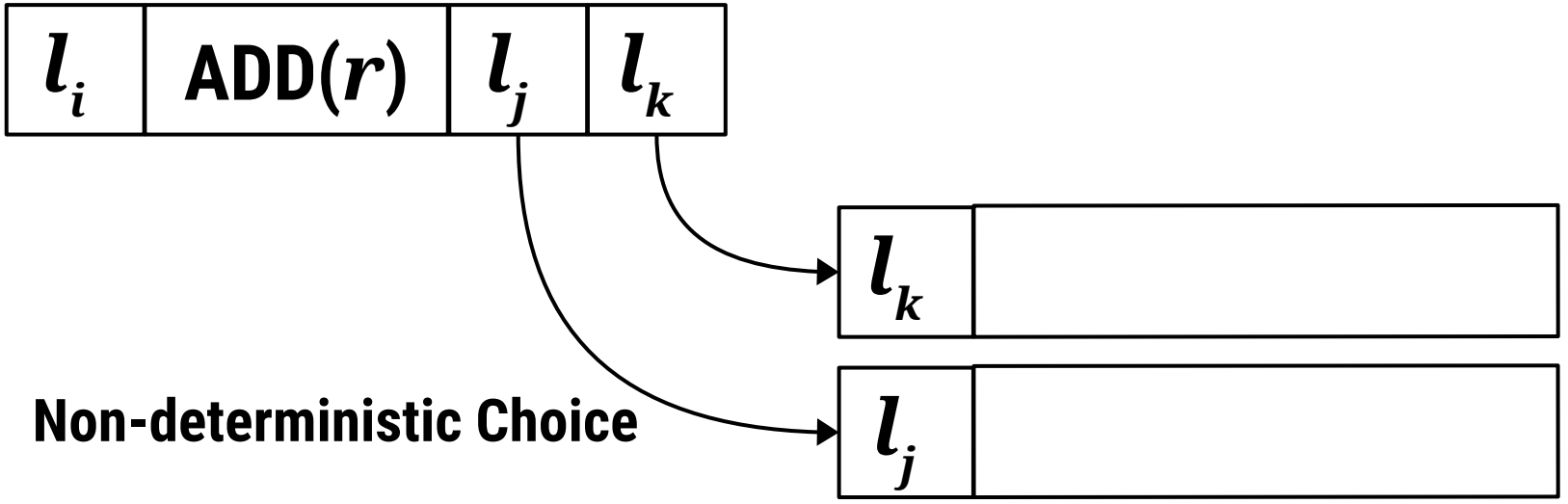
Case 2: 

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

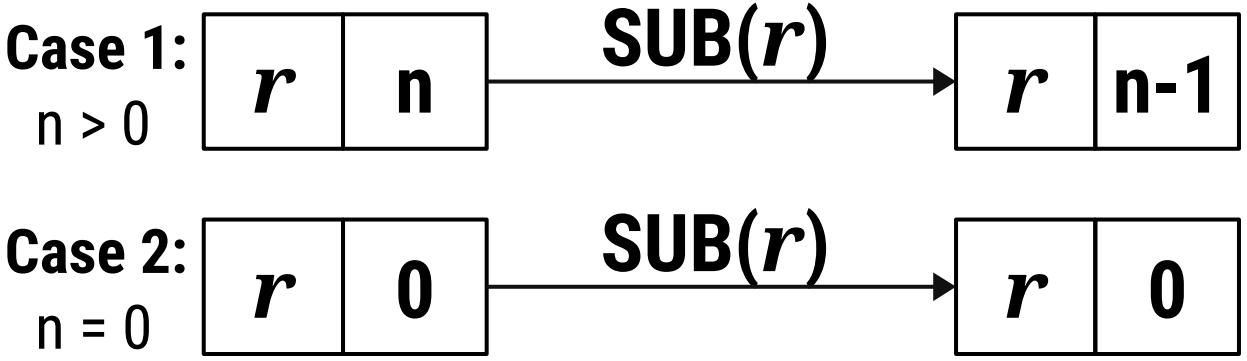
Register Machines

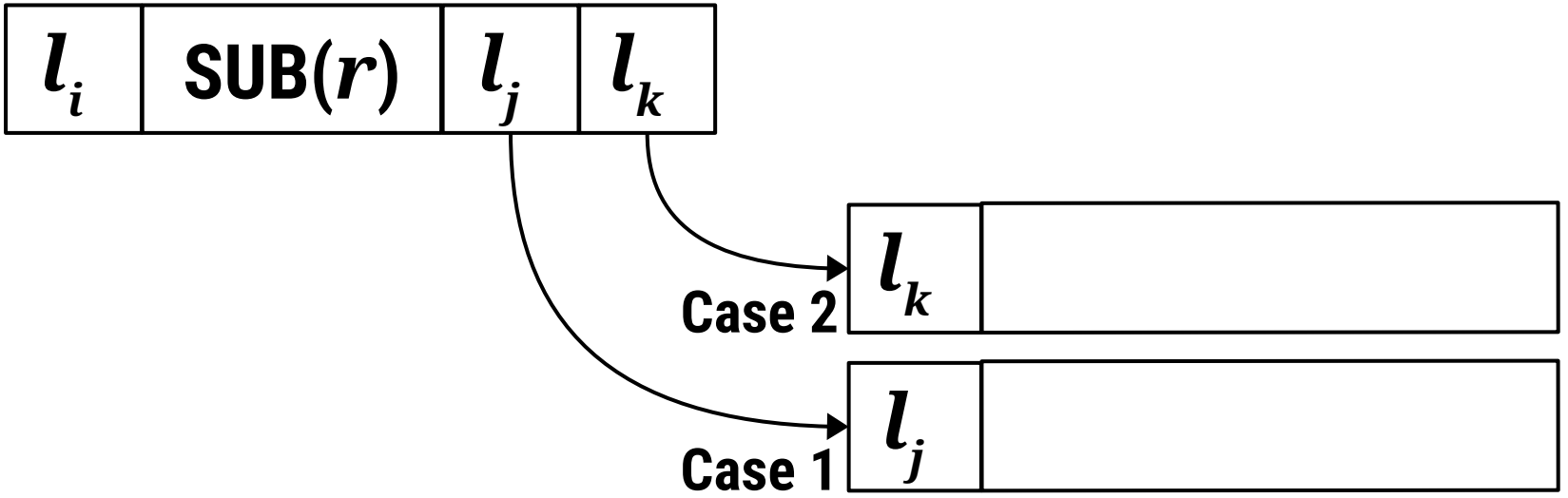


Register Machines



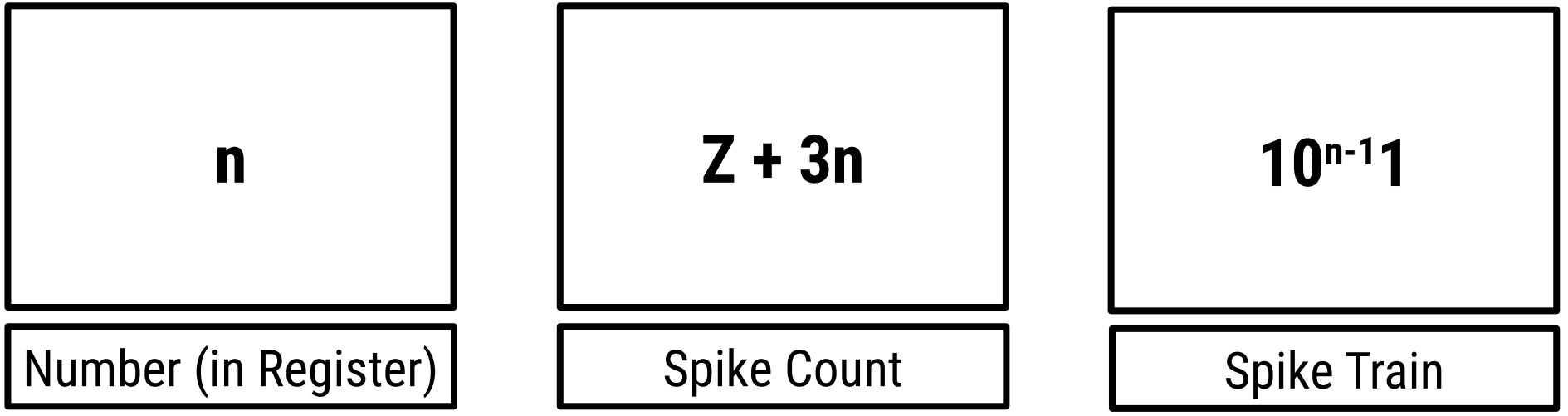
Register Machines





Register Machines

Representing Numbers



Z is some constant spike count.

Common Rule Set for All Neurons

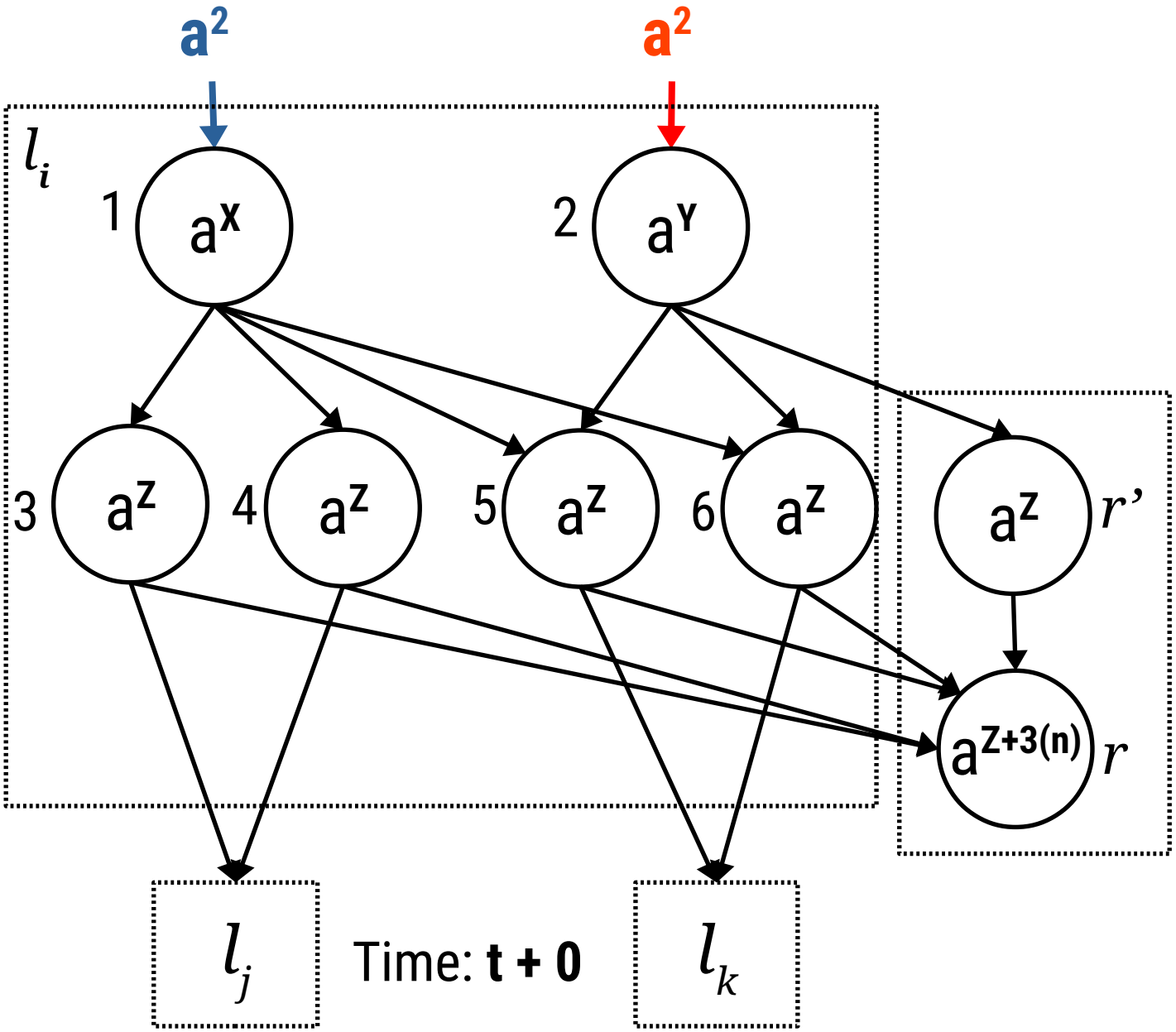
Rule 0: $a^{X+1} / a^{1} \rightarrow \lambda$
Rule 1: $a^{X+2} / a^{2} \rightarrow \lambda$
Rule 2: $a^{X+2} / a^{2} \rightarrow a$

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



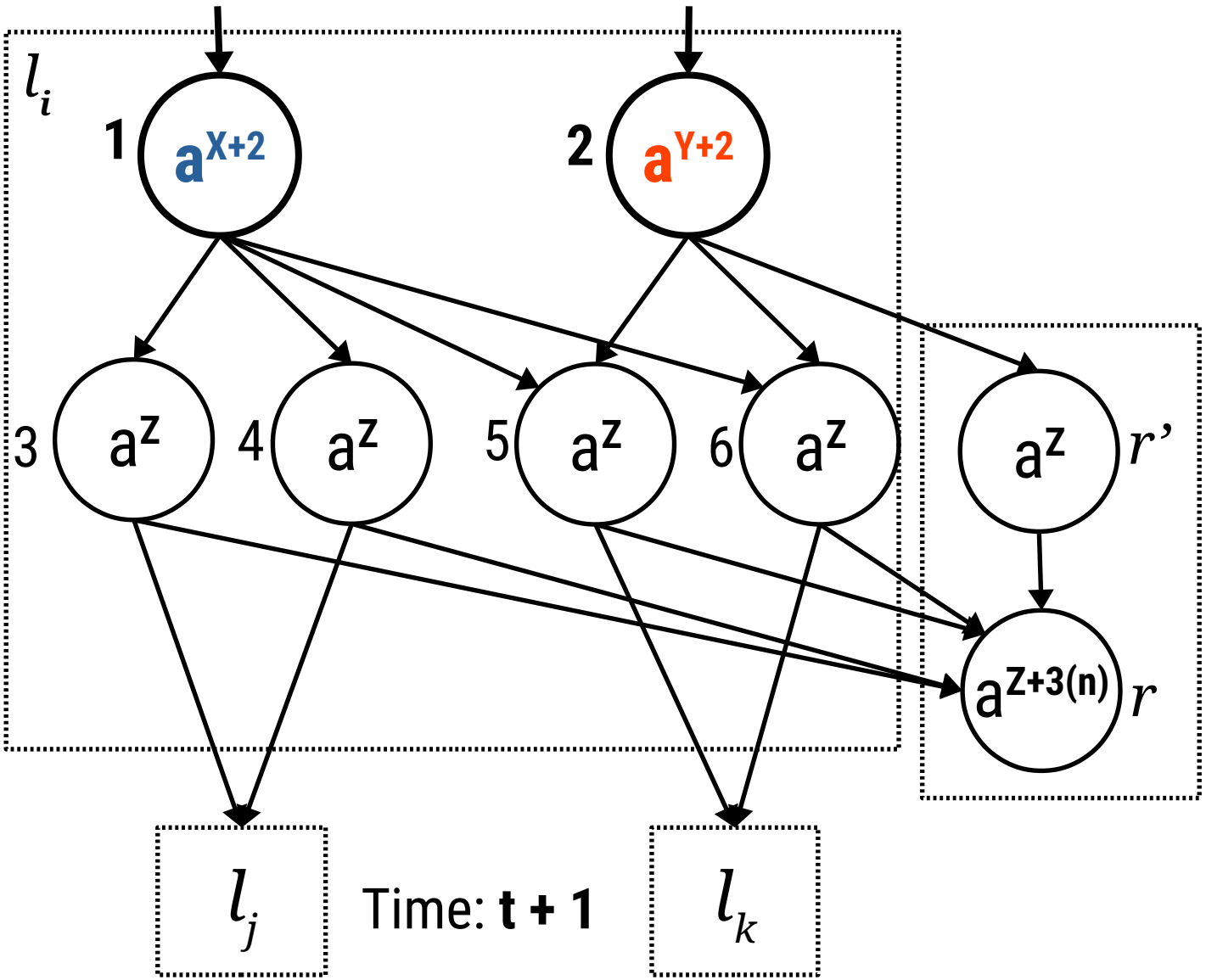
Rule 0: $a^{X+1} / a^1 \rightarrow \lambda$
Rule 1: $a^{X+2} / a^2 \rightarrow \lambda$
Rule 2: $a^{X+2} / a^2 \rightarrow a$

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



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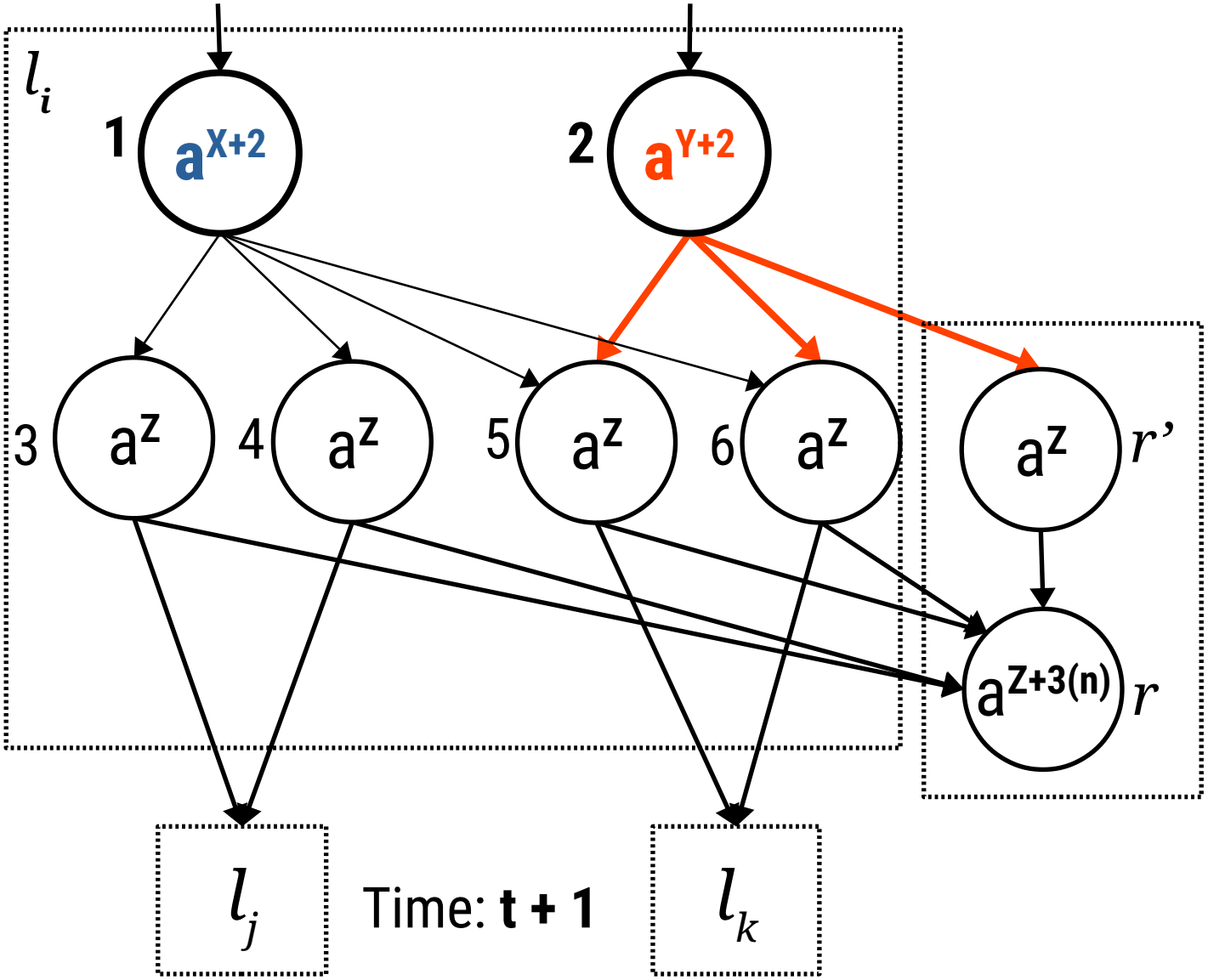
ADD Module

l_i	ADD(r)	l_j	l_k

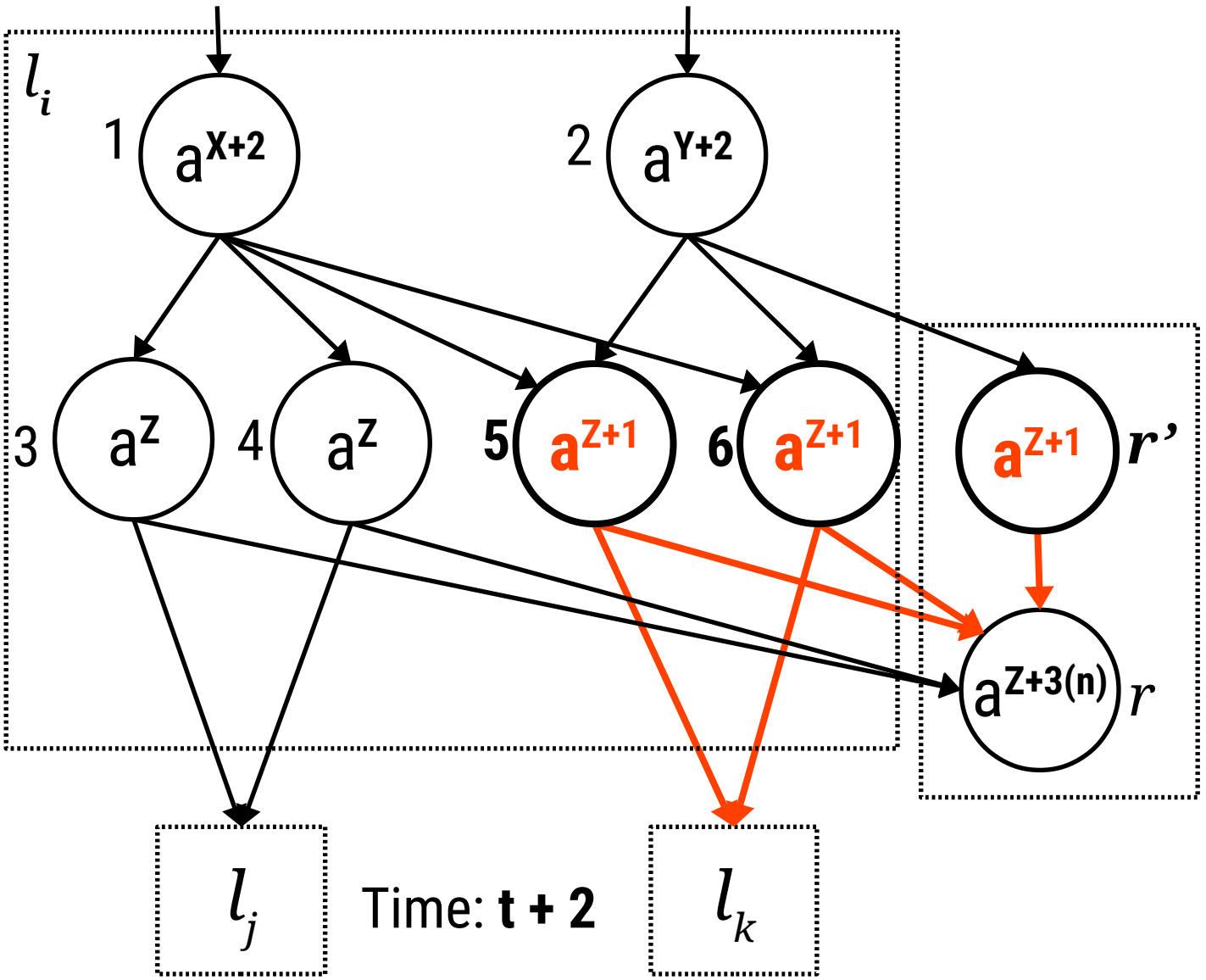


Rule 0:	$a^{X+1} / a^1 \rightarrow \lambda$
Rule 1:	$\mathbf{a^{X+2} / a^2 \rightarrow \lambda}$
Rule 2:	$a^{X+2} / a^2 \rightarrow a$
Rule 3:	$a^{Y+1} / a^1 \rightarrow \lambda$
Rule 4:	$\mathbf{a^{Y+2} / a^2 \rightarrow a}$
Rule 5:	$a^{Z+1} / a^1 \rightarrow a$
Rule 6:	$a^{Z+2} / a^2 \rightarrow \lambda$
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: $a^{Z+2} / a^{2} \rightarrow \lambda$
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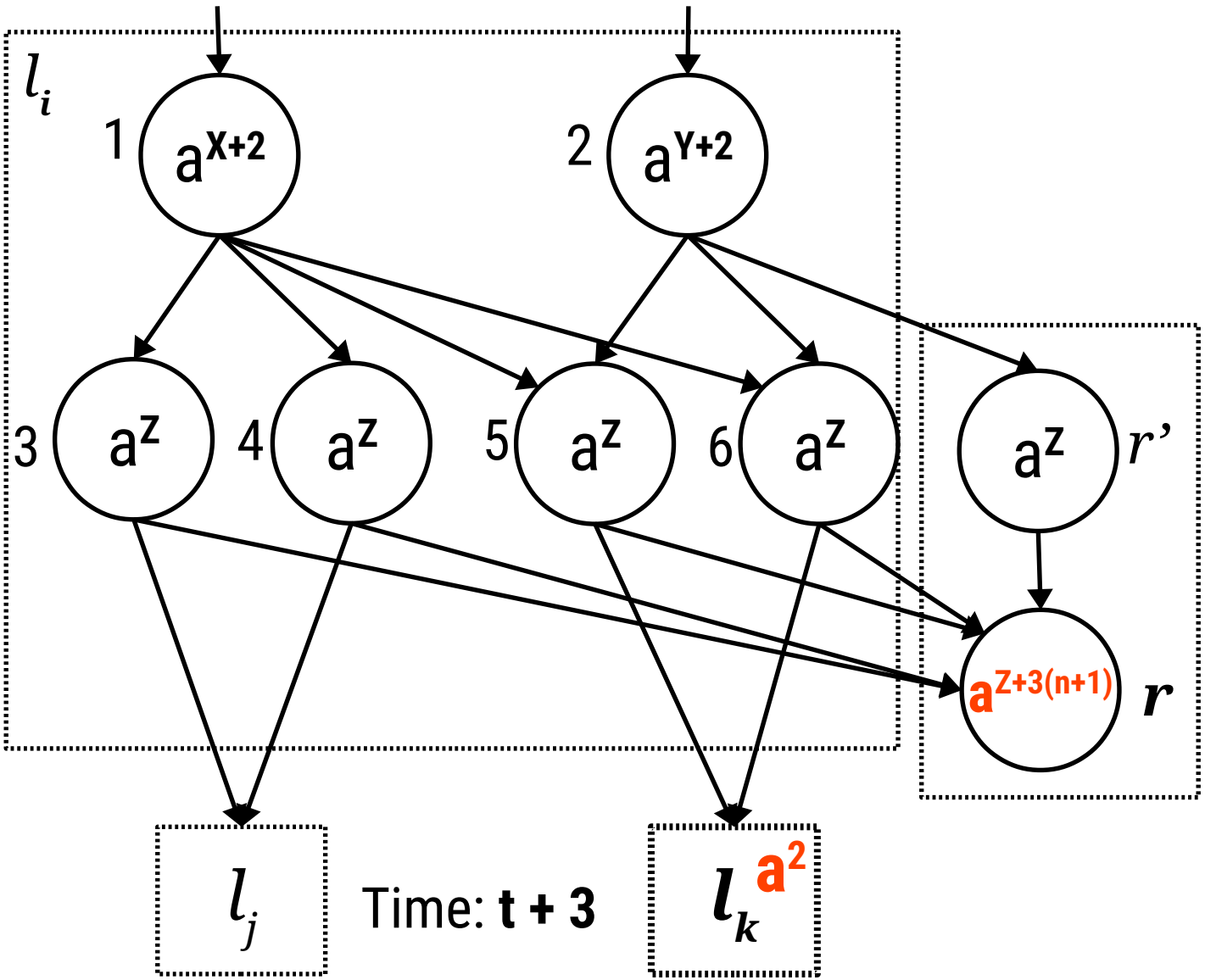
Case 1: Rule 1 is activated.

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

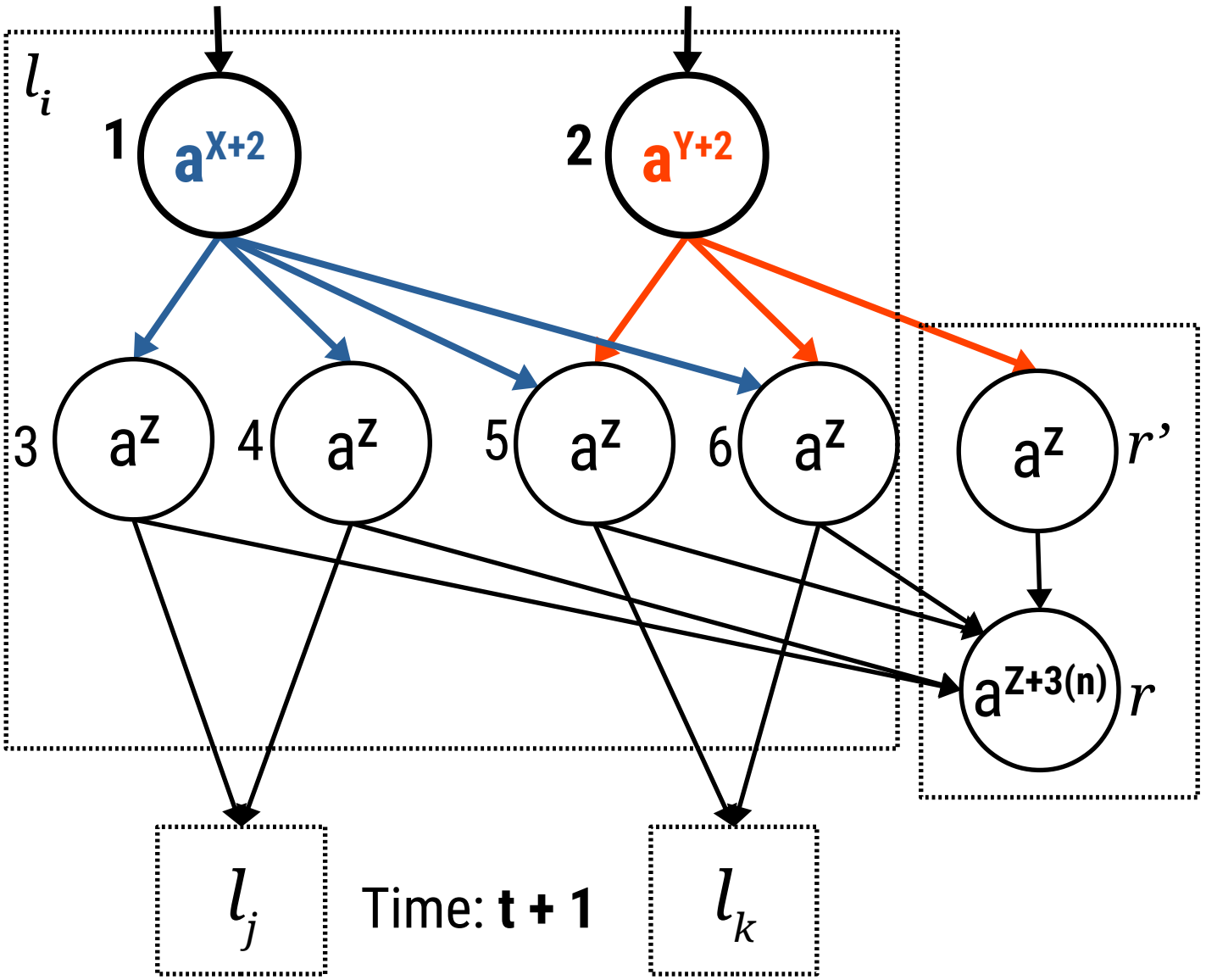
Rule 3:	$a^{Y+1} / a^1 \rightarrow \lambda$
Rule 4:	$a^{Y+2} / a^2 \rightarrow a$

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

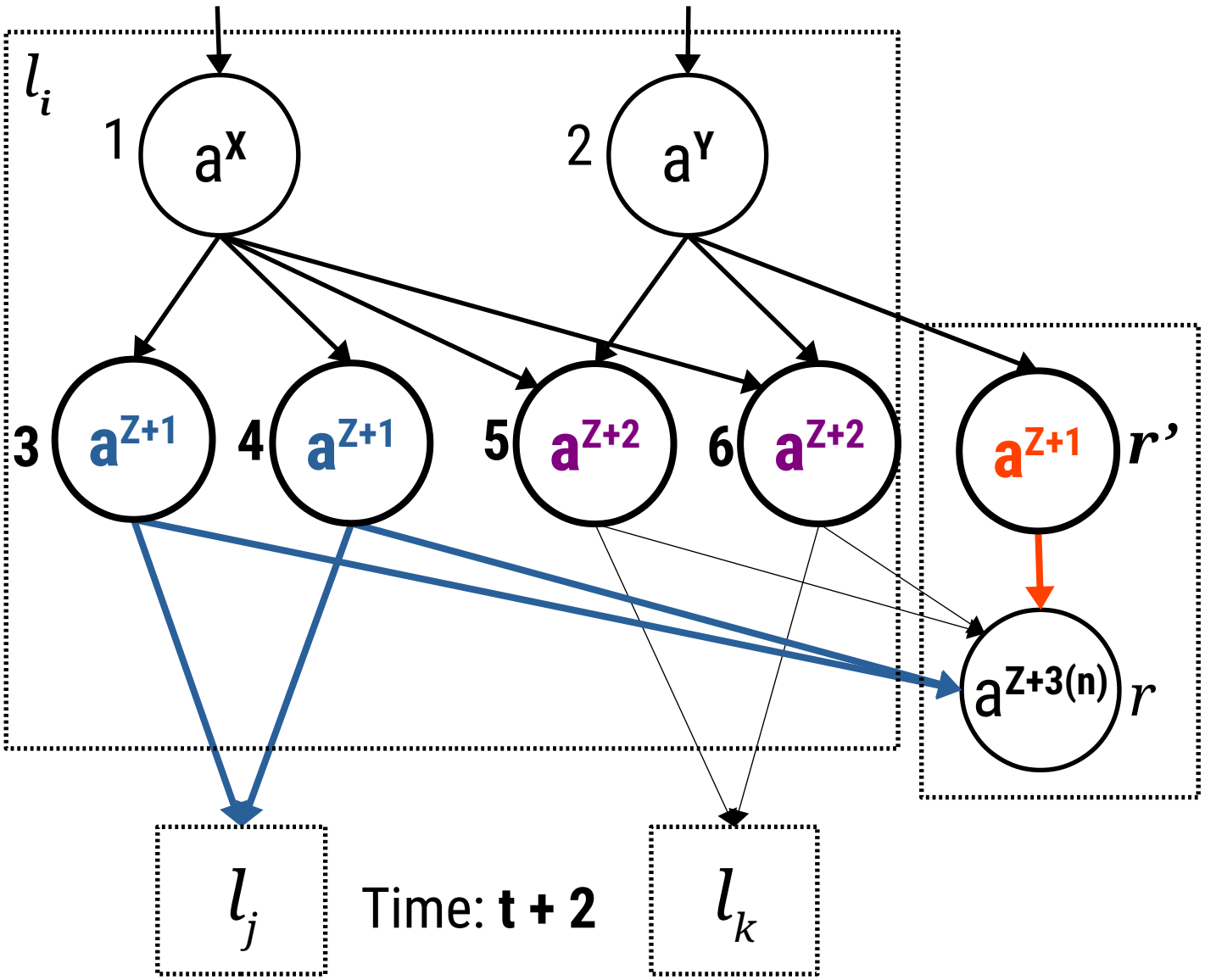
Rule 7: $a^{Z+1} (a^3)^+ / a^4 \rightarrow \lambda$

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

Case 2: Rule 2 is activated.

ADD Module

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

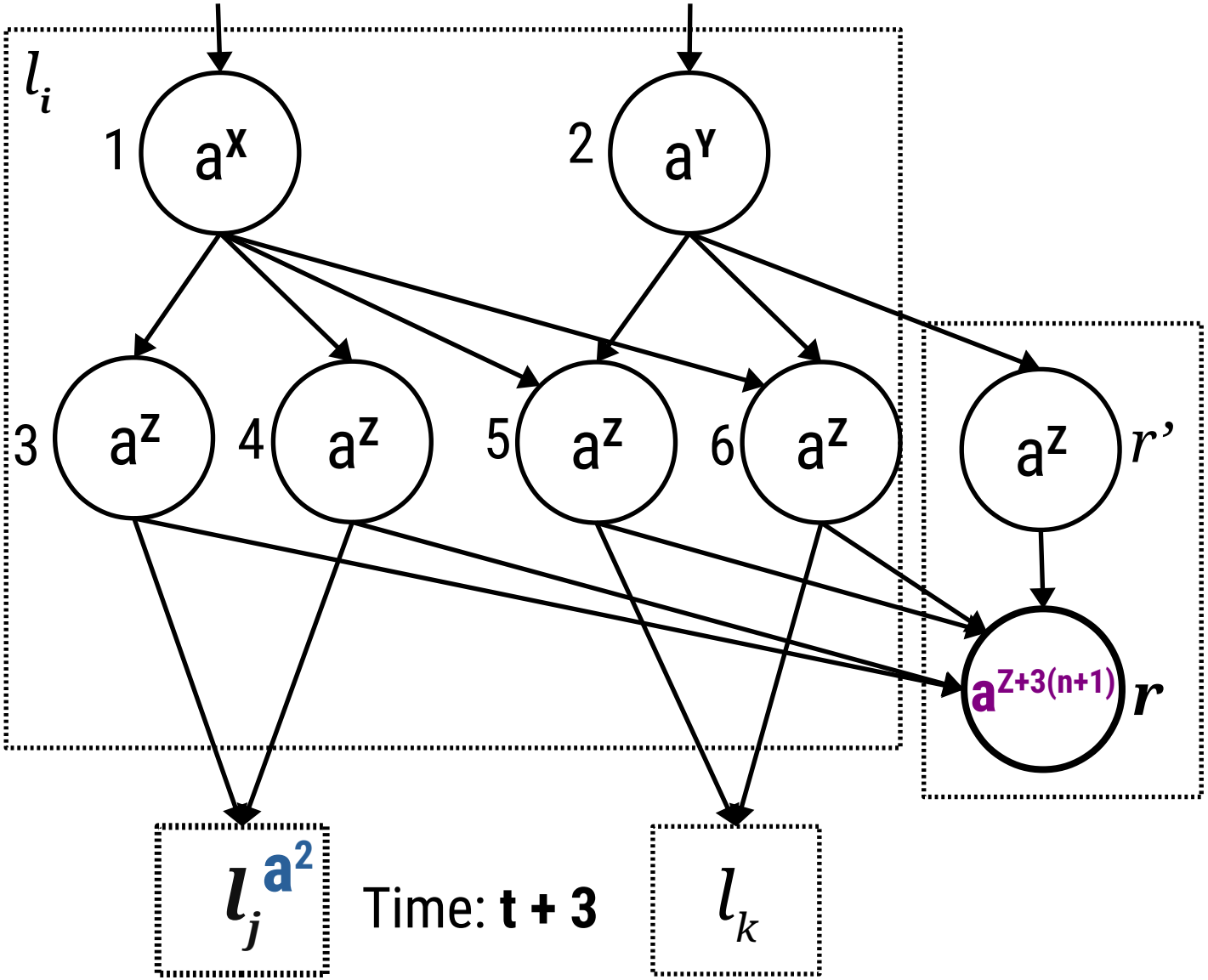
Rule 3: $a^{Y+1} / a^1 \rightarrow \lambda$
Rule 4: $a^{Y+2} / a^2 \rightarrow a$

Rule 5: $a^{Z+1} / a^1 \rightarrow a$
Rule 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	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: $a^{X+2} / a^2 \rightarrow a$

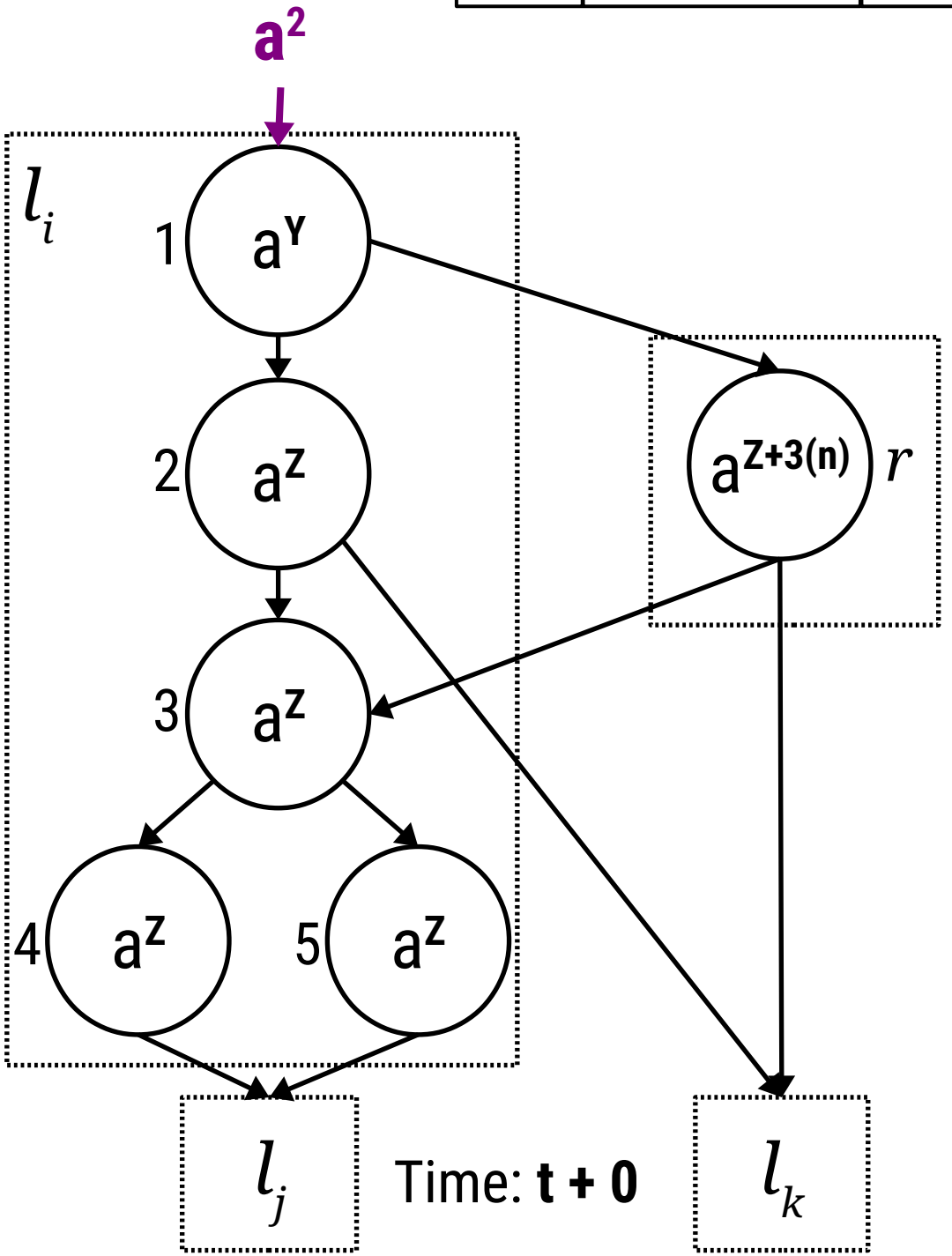
Rule 3: $a^{Y+1} / a^1 \rightarrow \lambda$
Rule 4: $a^{Y+2} / a^2 \rightarrow a$

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.

SUB Module

l_i	SUB(r)	l_j	l_k



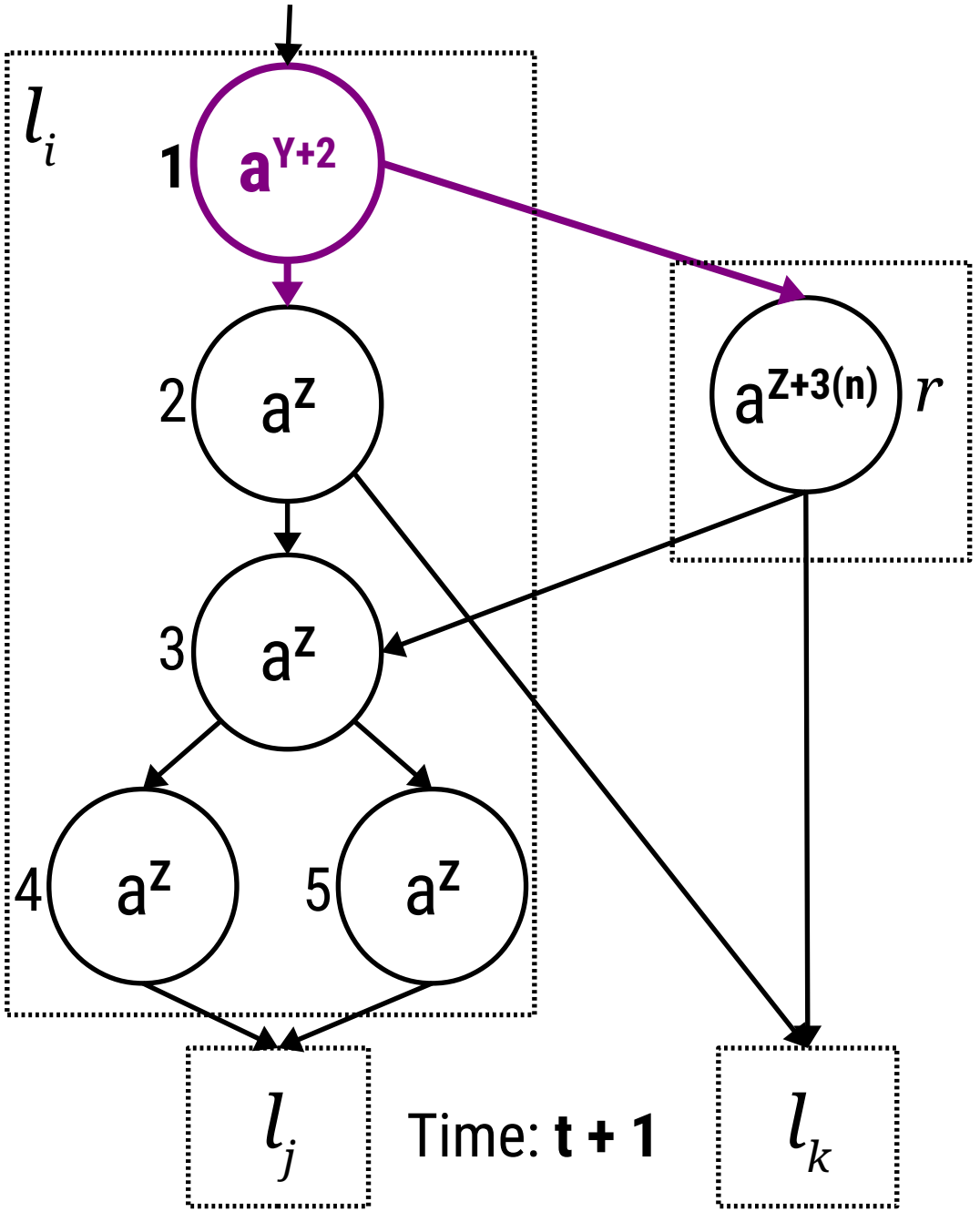
Rule 0: $a^{X+1} / a^1 \rightarrow \lambda$
Rule 1: $a^{X+2} / a^2 \rightarrow \lambda$
Rule 2: $a^{X+2} / a^2 \rightarrow a$

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

SUB Module

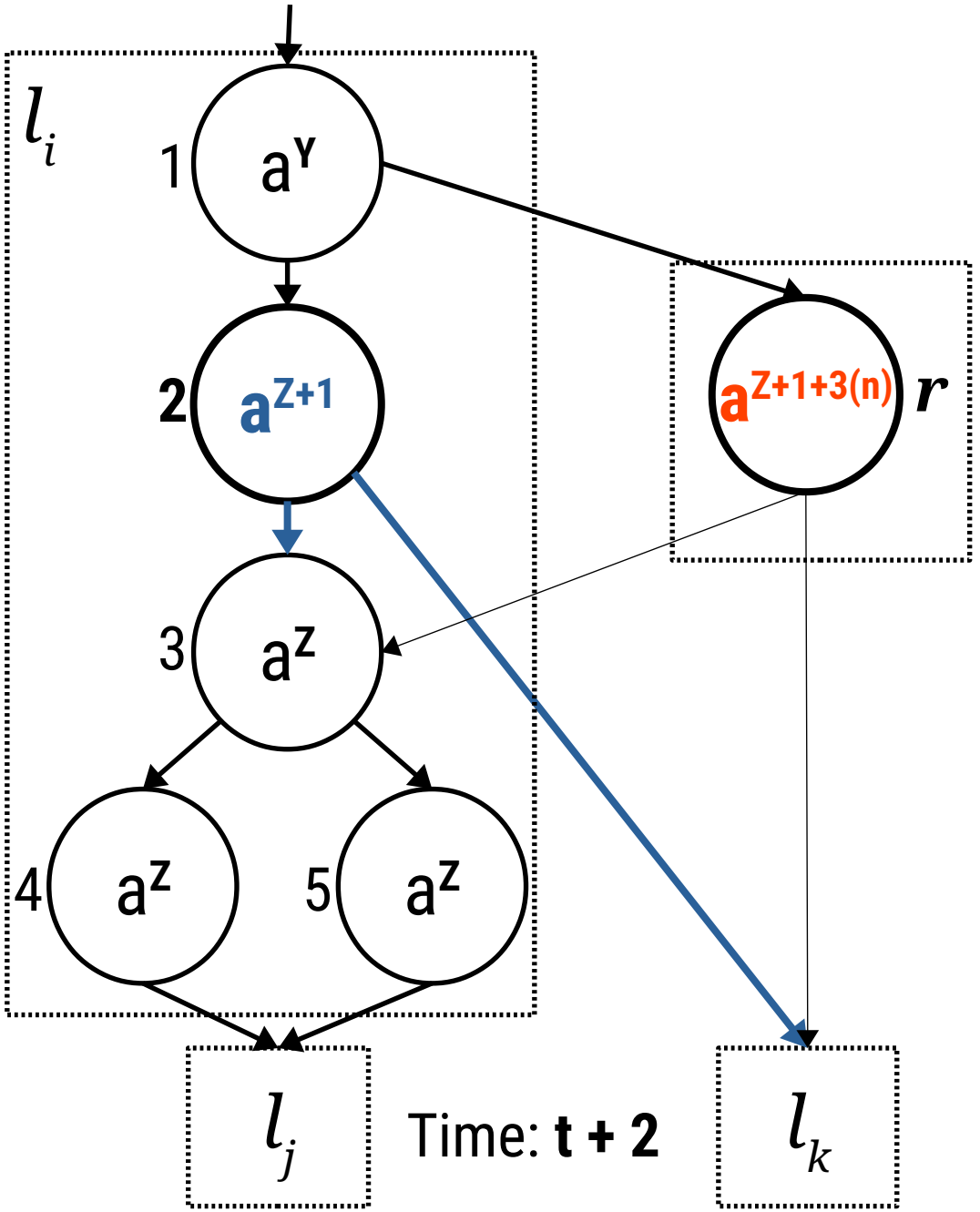
l_i	SUB(r)	l_j	l_k



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:	$\mathbf{a^{Y+2} / a^{2} \rightarrow a}$
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	SUB(r)	l_j	l_k

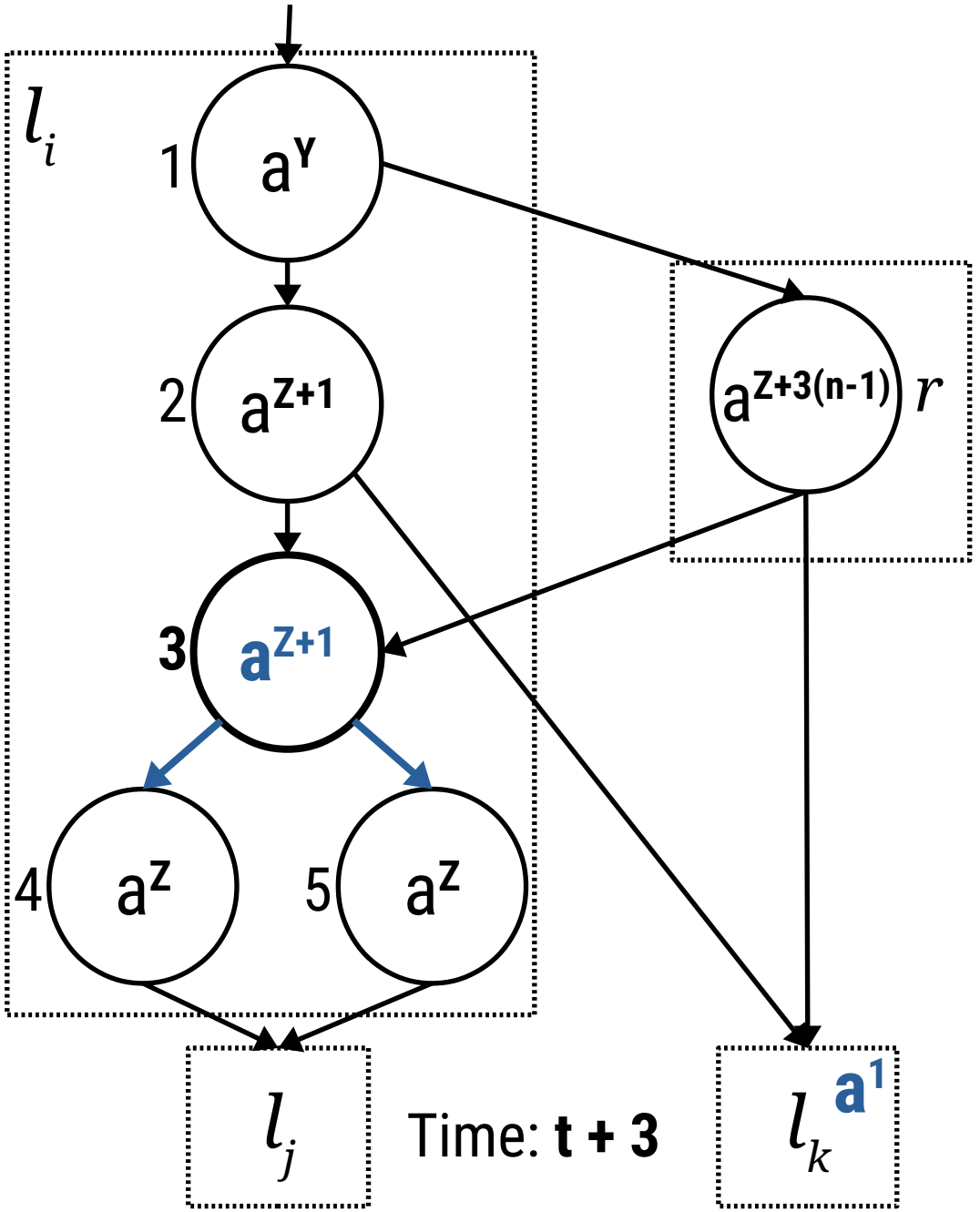


Rule 0:	$a^{X+1} / a^1 \rightarrow \lambda$
Rule 1:	$a^{X+2} / a^2 \rightarrow \lambda$
Rule 2:	$a^{X+2} / a^2 \rightarrow a$
Rule 3:	$a^{Y+1} / a^1 \rightarrow \lambda$
Rule 4:	$a^{Y+2} / a^2 \rightarrow a$
Rule 5:	$a^{Z+1} / a^1 \rightarrow a$
Rule 6:	$a^{Z+2} / a^2 \rightarrow \lambda$
Rule 7:	$a^{Z+1} (a^3)^+ / a^4 \rightarrow \lambda$
Rule 8:	$a^{Z+2} (a^3)^+ / a^3 \rightarrow a$

Case 1: n > 0

SUB Module

l_i	SUB(r)	l_j	l_k



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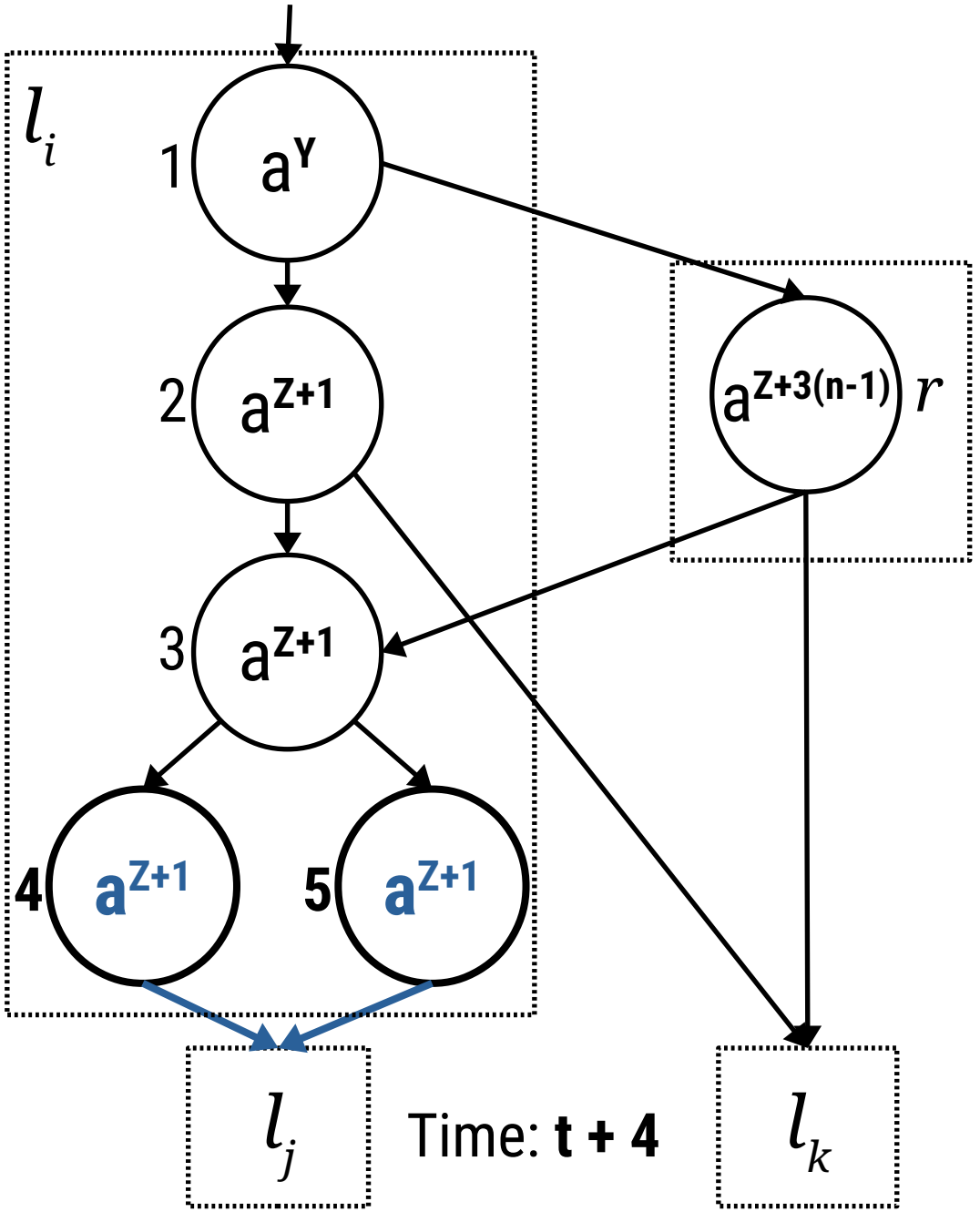
Rule 4:	$a^{Y+2} / a^2 \rightarrow a$
Rule 5:	$a^{Z+1} / a^1 \rightarrow a$
Rule 6:	$a^{Z+2} / a^2 \rightarrow \lambda$
Rule 7:	$a^{Z+1} (a^3)^+ / a^4 \rightarrow \lambda$
Rule 8:	$a^{Z+2} (a^3)^+ / a^3 \rightarrow a$

Case 1: n > 0

SUB Module

l_i	SUB(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: $a^{X+2} / a^2 \rightarrow a$

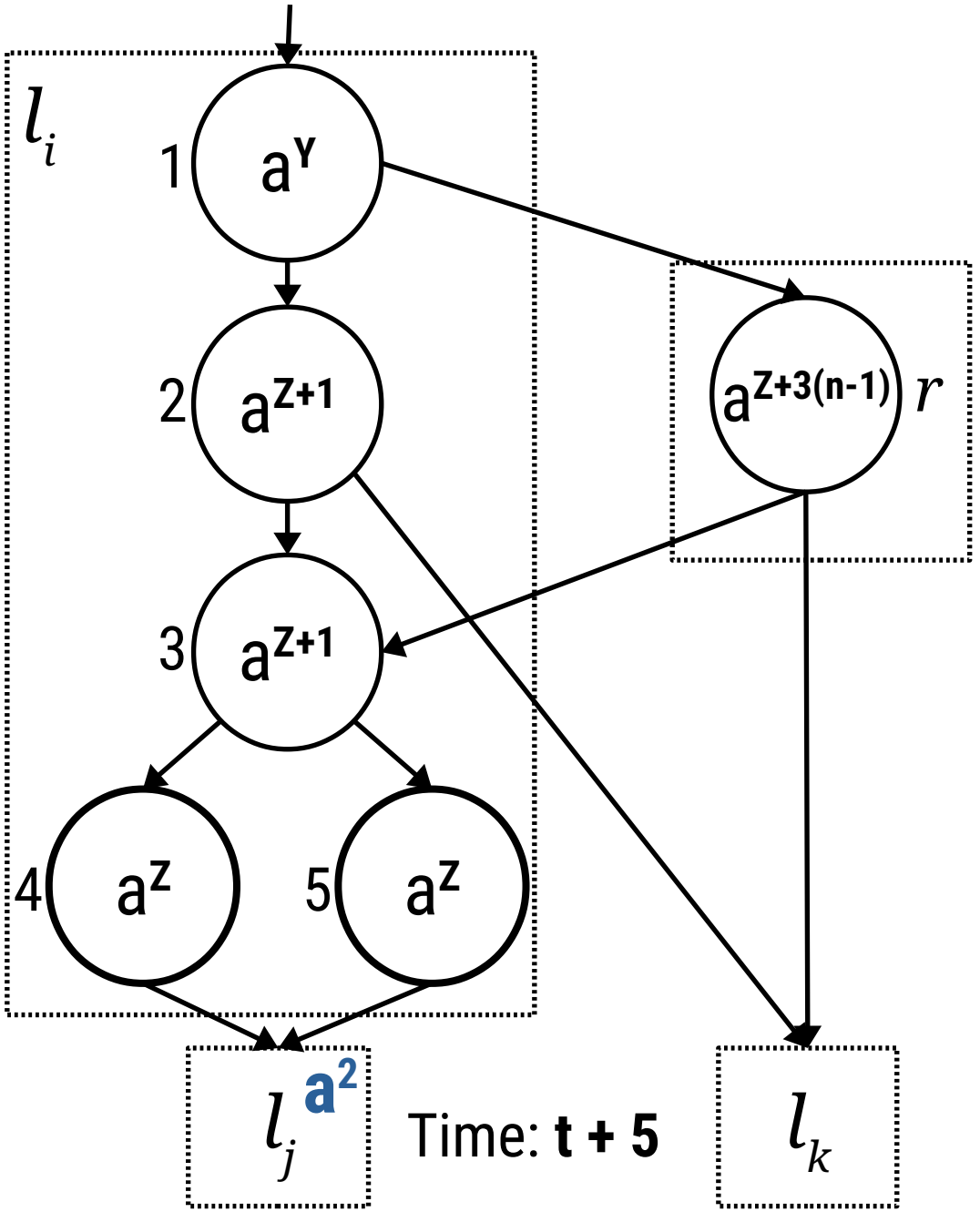
Rule 3: $a^{Y+1} / a^1 \rightarrow \lambda$
Rule 4: $a^{Y+2} / a^2 \rightarrow a$

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 1: n > 0

SUB Module

l_i	SUB(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:	$a^{X+2} / a^2 \rightarrow a$

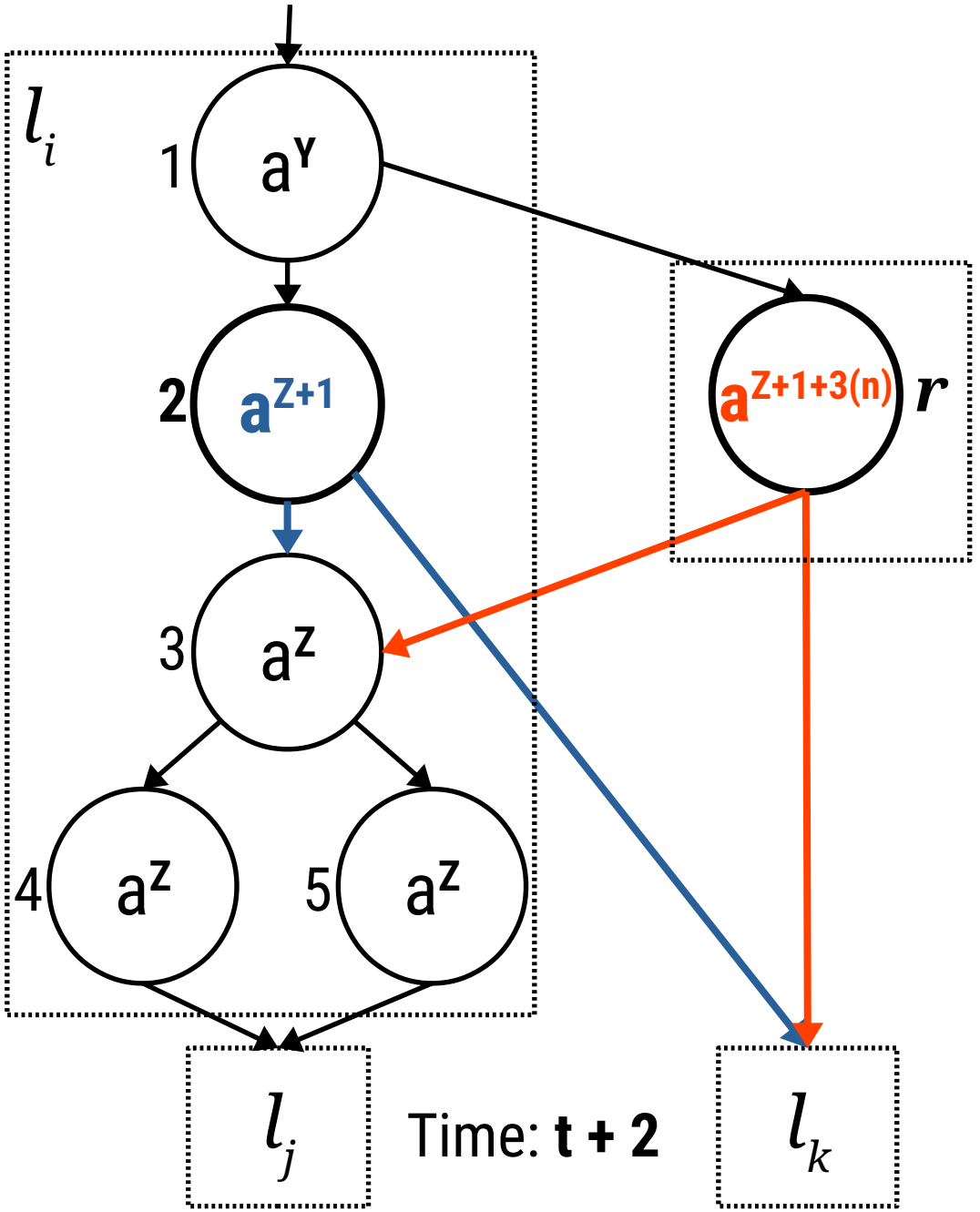
Rule 3:	$a^{Y+1} / a^1 \rightarrow \lambda$
Rule 4:	$a^{Y+2} / a^2 \rightarrow a$

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 1: n > 0

SUB Module

l_i	SUB(r)	l_j	l_k

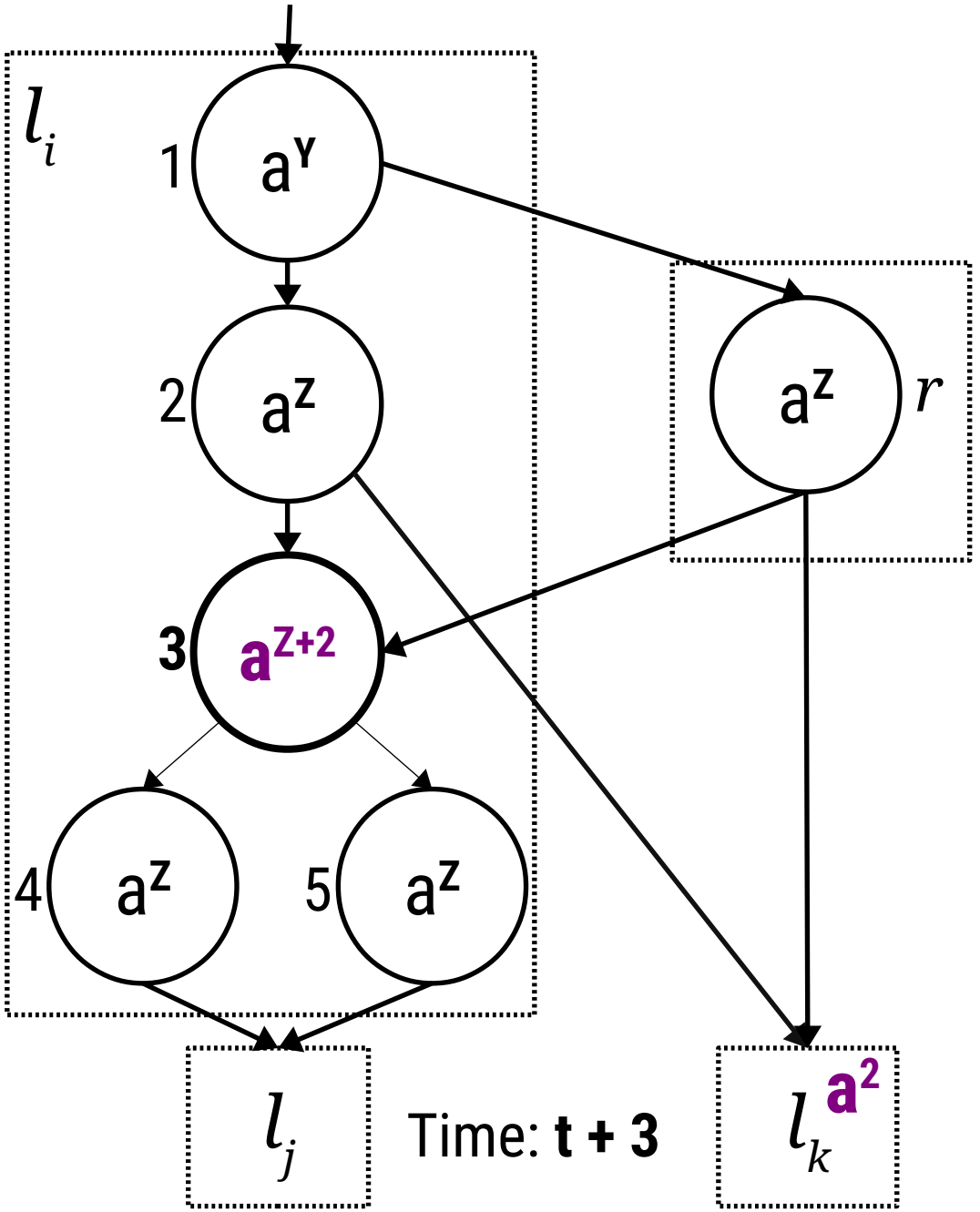


Rule 0:	$a^{X+1} / a^1 \rightarrow \lambda$
Rule 1:	$a^{X+2} / a^2 \rightarrow \lambda$
Rule 2:	$a^{X+2} / a^2 \rightarrow a$
Rule 3:	$a^{Y+1} / a^1 \rightarrow \lambda$
Rule 4:	$a^{Y+2} / a^2 \rightarrow a$
Rule 5:	$\mathbf{a^{Z+1} / a^1 \rightarrow a}$
Rule 5:	$\mathbf{a^{Z+1} / a^1 \rightarrow a}$
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	SUB(r)	l_j	l_k

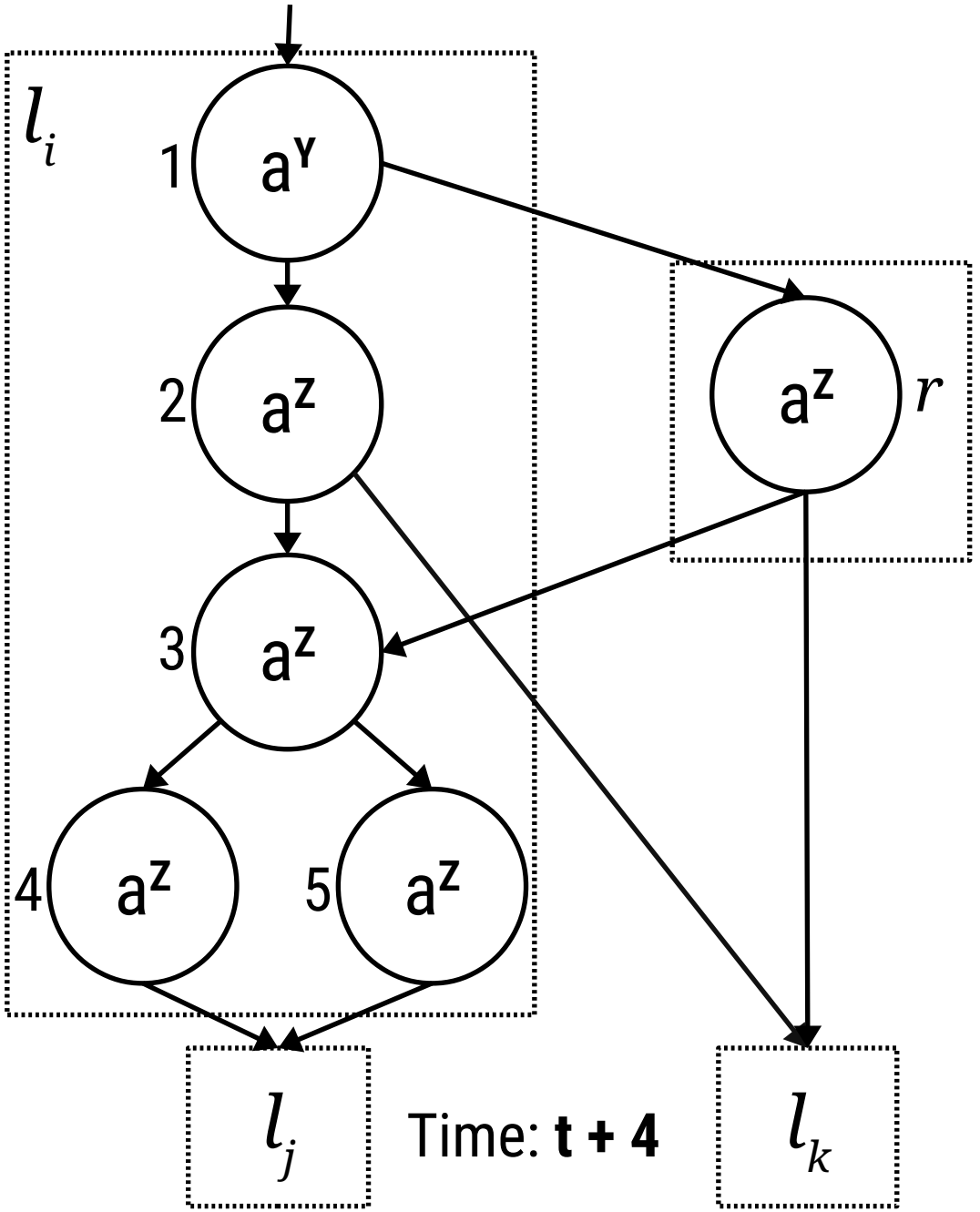


Rule 0:	$a^{X+1} / a^1 \rightarrow \lambda$
Rule 1:	$a^{X+2} / a^2 \rightarrow \lambda$
Rule 2:	$a^{X+2} / a^2 \rightarrow a$
Rule 3:	$a^{Y+1} / a^1 \rightarrow \lambda$
Rule 4:	$a^{Y+2} / a^2 \rightarrow a$
Rule 5:	$a^{Z+1} / a^1 \rightarrow a$
Rule 6:	$\mathbf{a^{Z+2} / a^2 \rightarrow \lambda}$
Rule 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	SUB(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: $a^{X+2} / a^2 \rightarrow a$

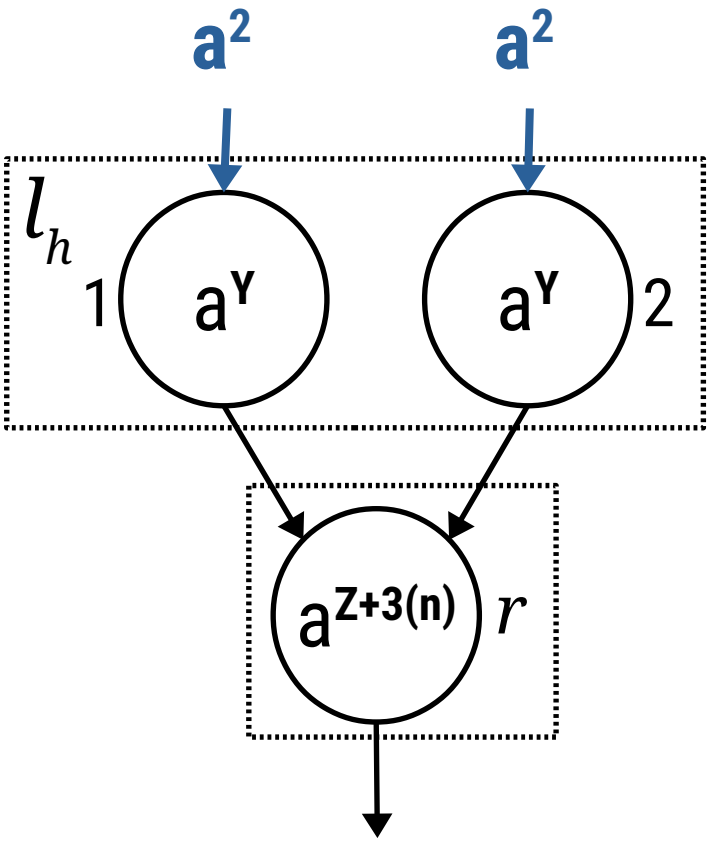
Rule 3: $a^{Y+1} / a^1 \rightarrow \lambda$
Rule 4: $a^{Y+2} / a^2 \rightarrow a$

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: n = 0

HALT Module

l_h	HALT

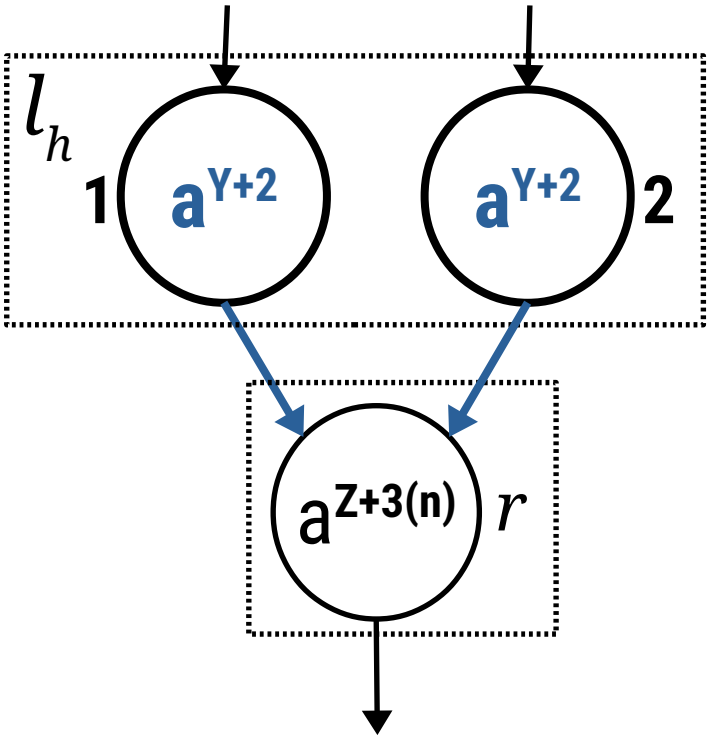


Time: **t + 0**

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

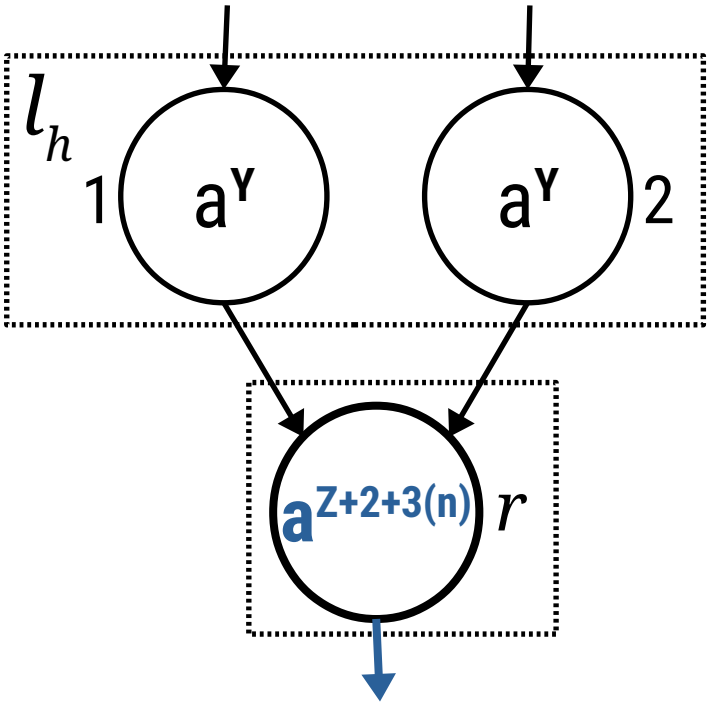


Time: **t + 1**

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



1^n

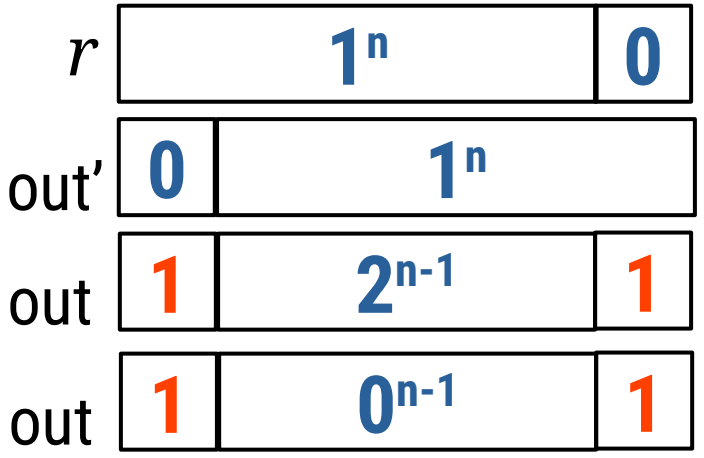
Time: **t + 2**

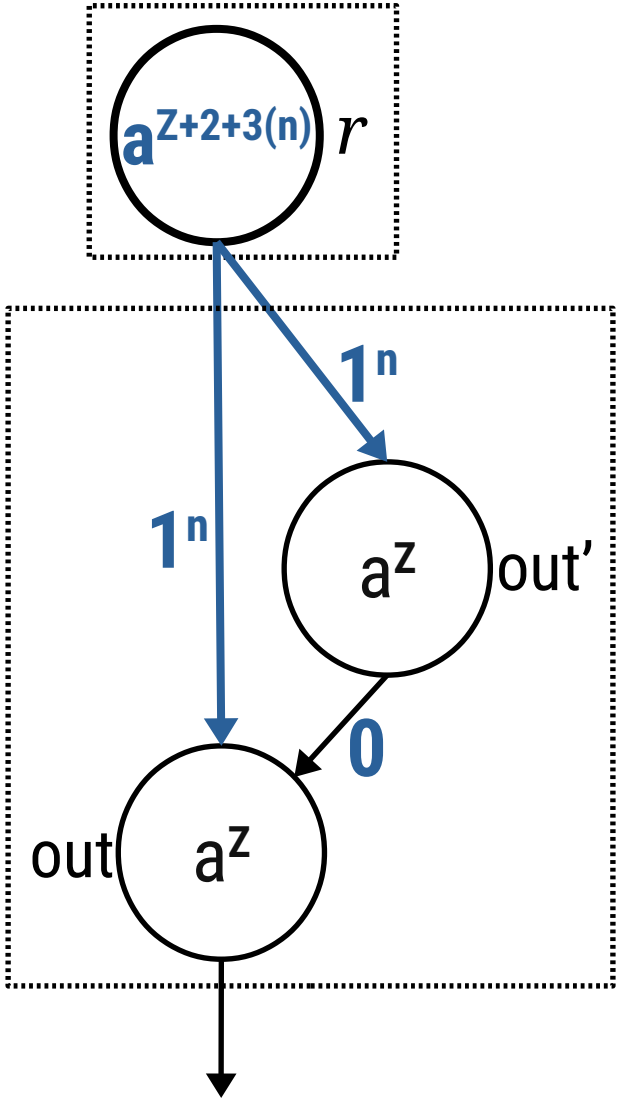
to

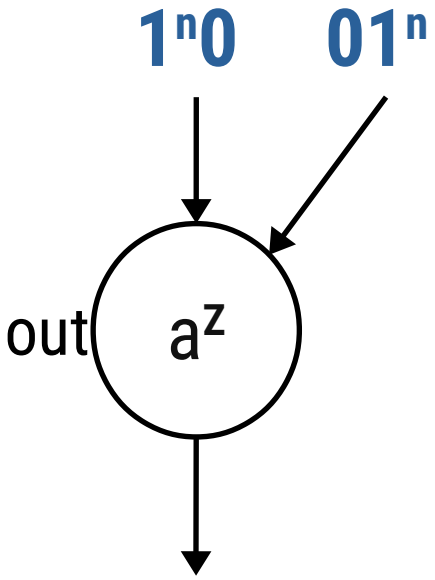
Time: **t + n + 1**

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

OUTPUT Module





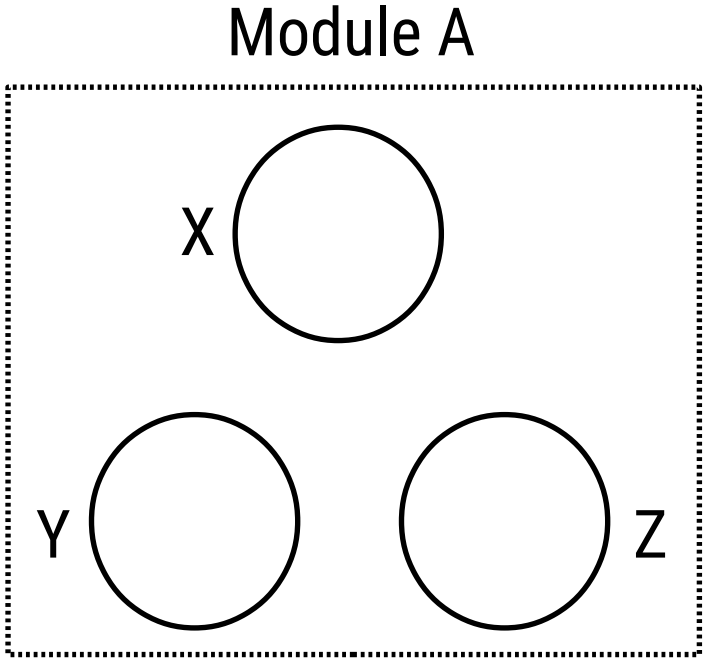


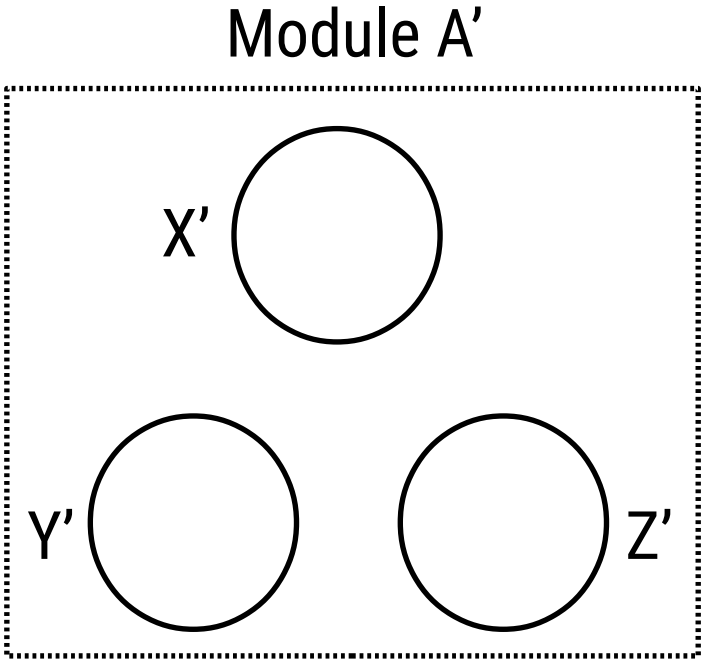
Rule 0: $a^{X+1} / a^1 \rightarrow \lambda$
Rule 1: $a^{X+2} / a^2 \rightarrow \lambda$
Rule 2: $a^{X+2} / a^2 \rightarrow a$

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.





In neuron X:

Rule 1: E / a^c → +2({Y,Z})

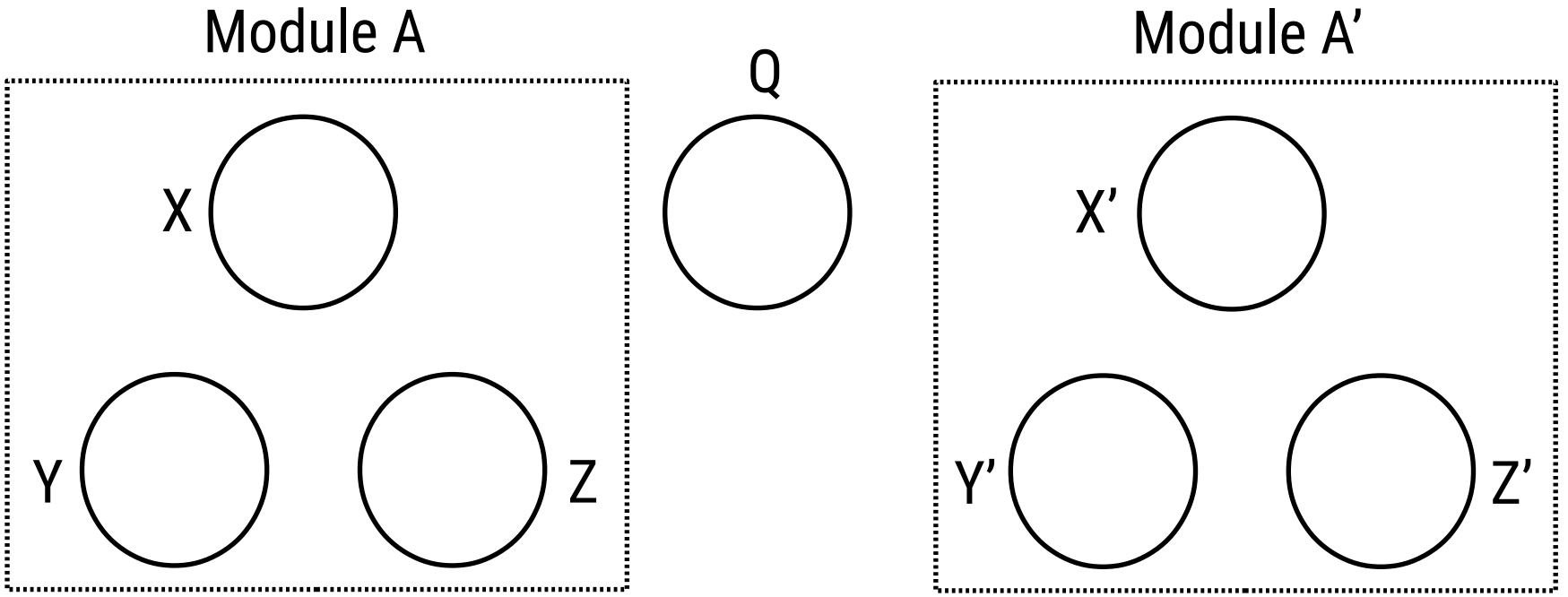
In neuron X':

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

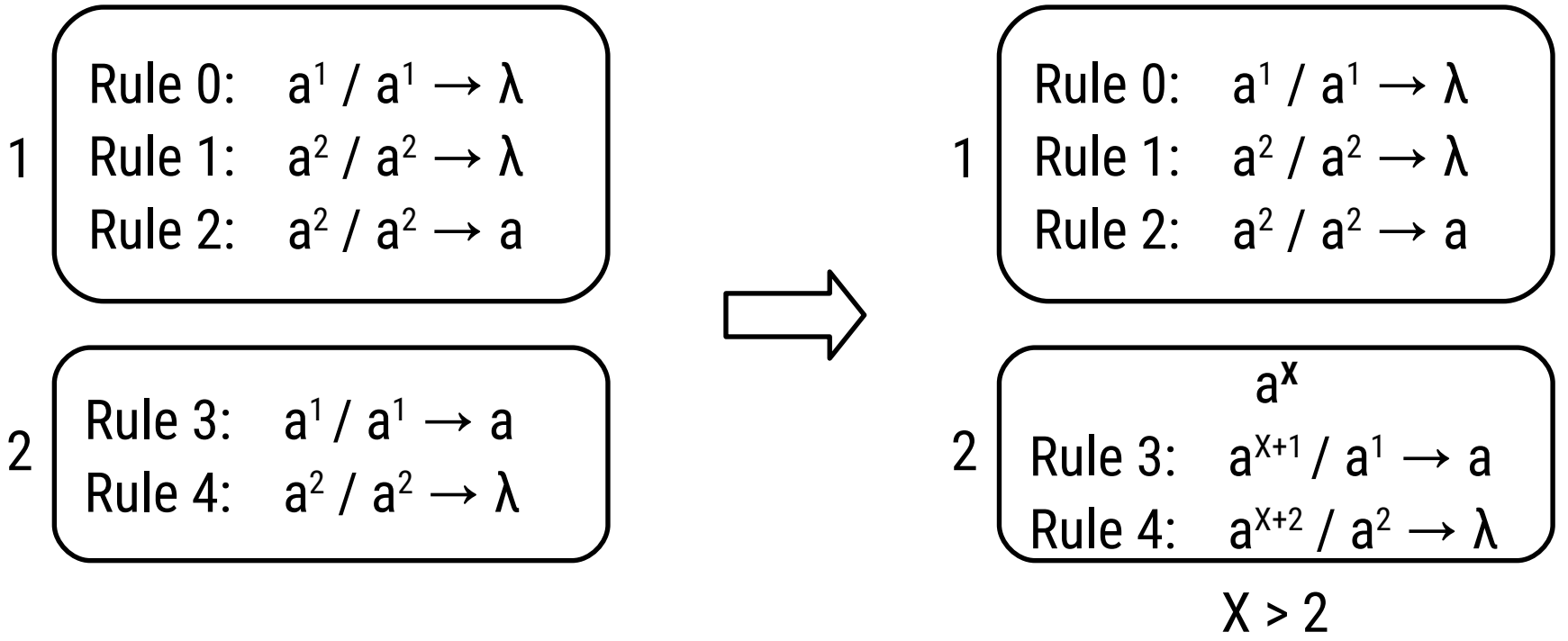
Rule 1: $E / a^c \rightarrow \lambda$

In neuron X':

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

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

Discussion: On “translating” rules

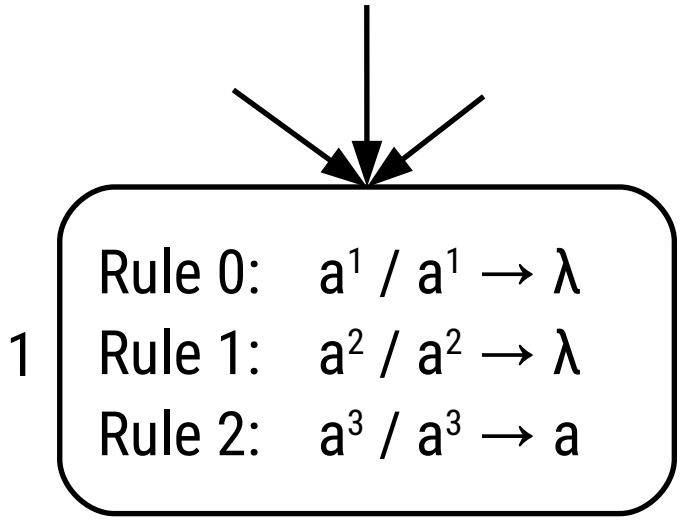


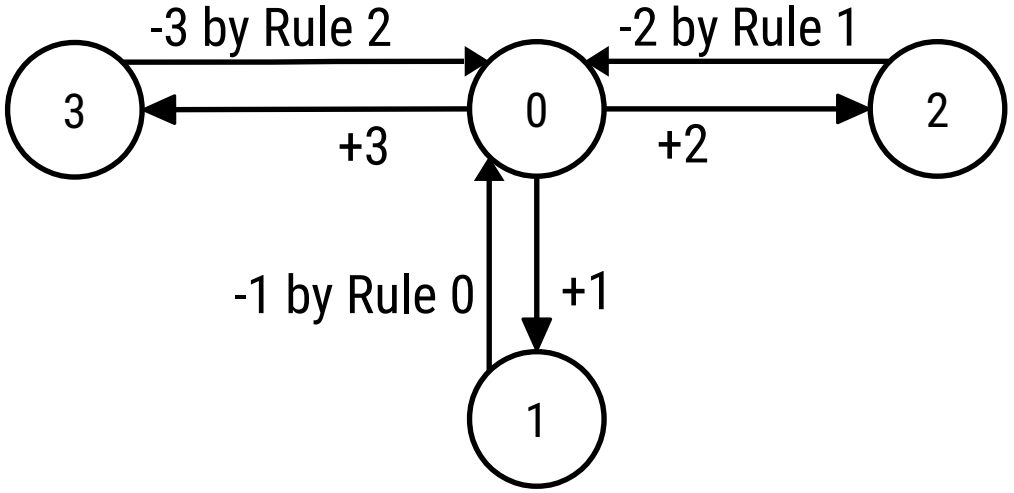
You can easily create a common set of rules by “translating” different rule sets then combining them and adding the appropriate initial spike counts to the neurons.

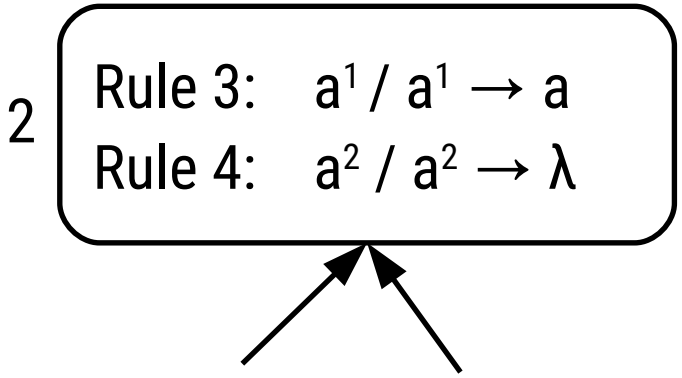
Discussion: On “translating” rules

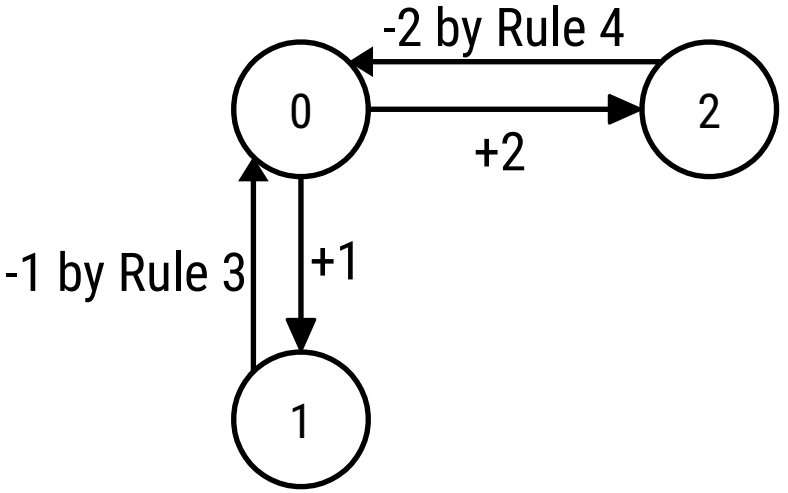
Rule 0:	$a^{X+1} / a^{1} \rightarrow \lambda$
Rule 1:	$a^{X+2} / a^{2} \rightarrow \lambda$
Rule 2:	$a^{X+2} / a^{2} \rightarrow a$
Rule 3:	$a^{Y+1} / a^{1} \rightarrow \lambda$
Rule 4:	$a^{Y+2} / a^{2} \rightarrow a$
Rule 5:	$a^{Z+1} / a^{1} \rightarrow a$
Rule 6:	$a^{Z+2} / a^{2} \rightarrow \lambda$
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

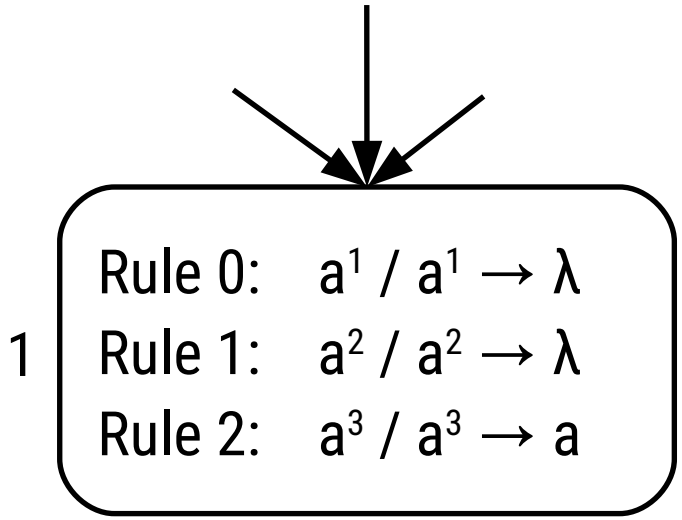


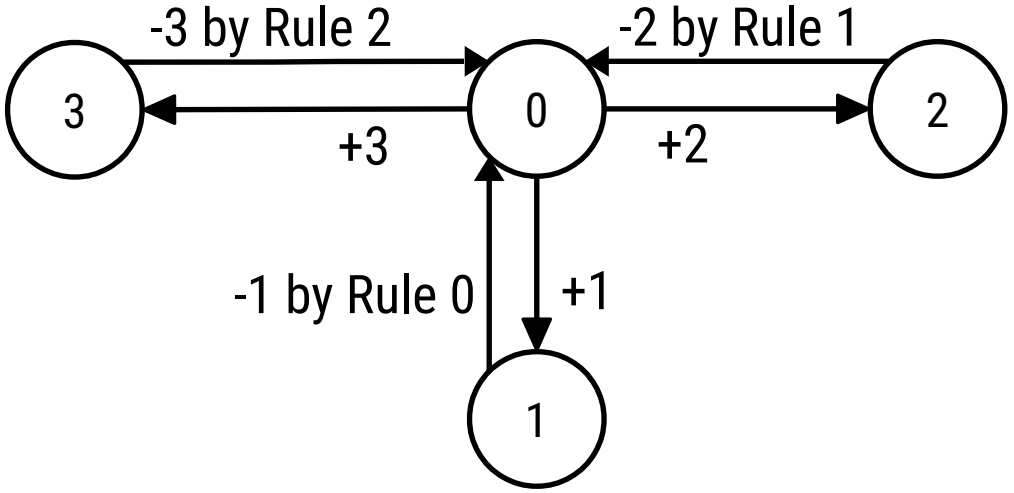


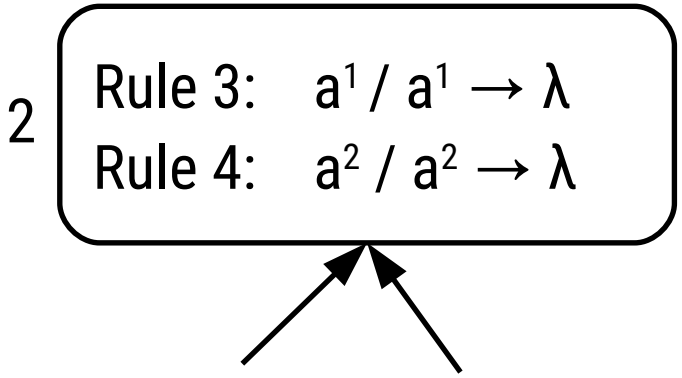


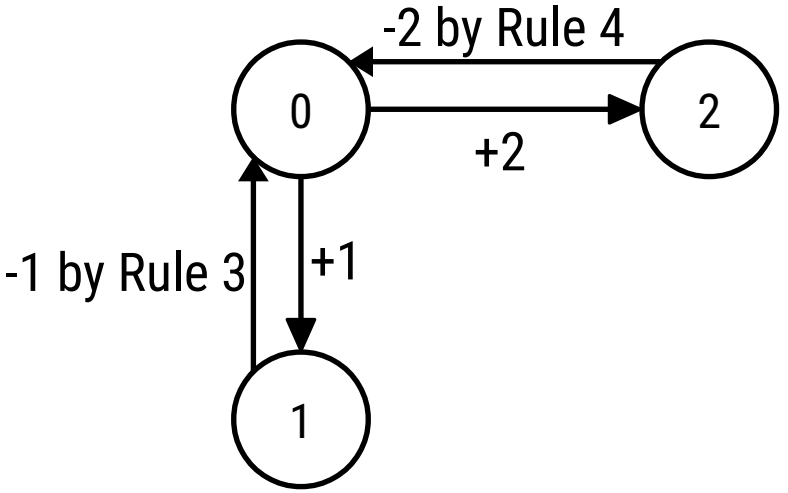


Discussion: On combining rules









End of Presentation. Thank you!

Acknowledgements

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