Memory-Efficient Neural Network Training for Wearable Devices

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DIPARTIMENTO
MATEMATICA

Introduction

Problem - High memory demands of neural network training, especially on constrained devices like smartwatches and health monitors.

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Result - 82× peak memory reduction (9.3 GB → 113 MB) with 3.3% accuracy drop (98 % → 95%).

Types of Memory

Model Memory - Stores model parameters

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Optimizer Memory - Stores gradients and momentum buffers

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Other - Framework overhead

Optimization Stack

Configuration 1 (C1)

Resnet-50

Optimization Stack

Configuration 2 (C2)

Resnet-50
Dynamic Sparse Traing

Optimization Stack

Configuration 3 (C3)

Resnet-50
Dynamic Sparse Traing
Gradient Checkpointg

Optimization Stack

Configuration 4 (C4)

Resnet-50
Dynamic Sparse Traing
Gradient Checkpointg
Mictobatching

Optimization Stack

Configuration 5 (C5)

Dynamic Sparse Traing
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Configuration 5 (C5)

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Gradient Checkpointg
Mictobatching
MobileNet

Optimization Stack

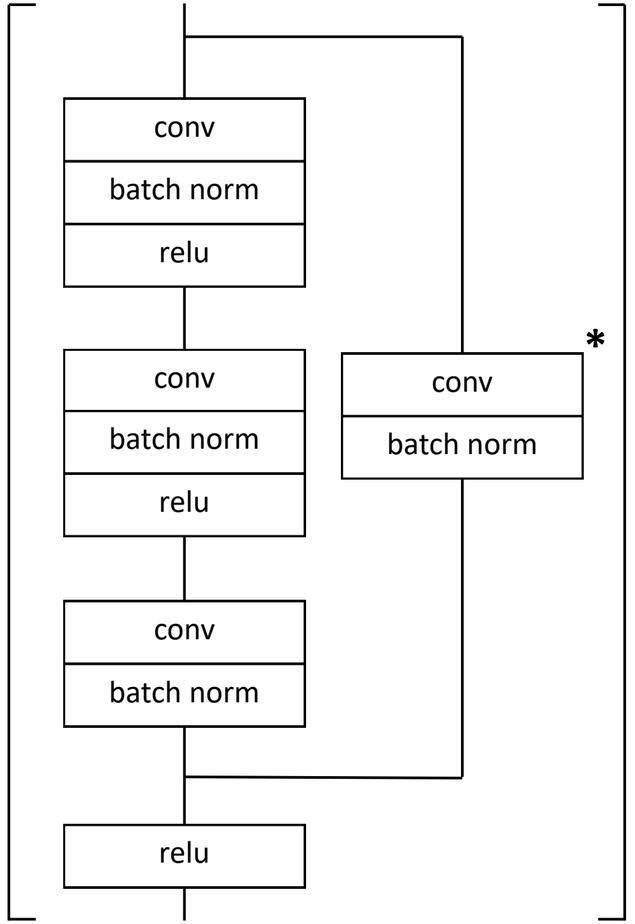
Configuration 6 (C6)

Dynamic Sparse Traing
Gradient Checkpointg
Mictobatching
MobileNet
Patching

Optimization Stack

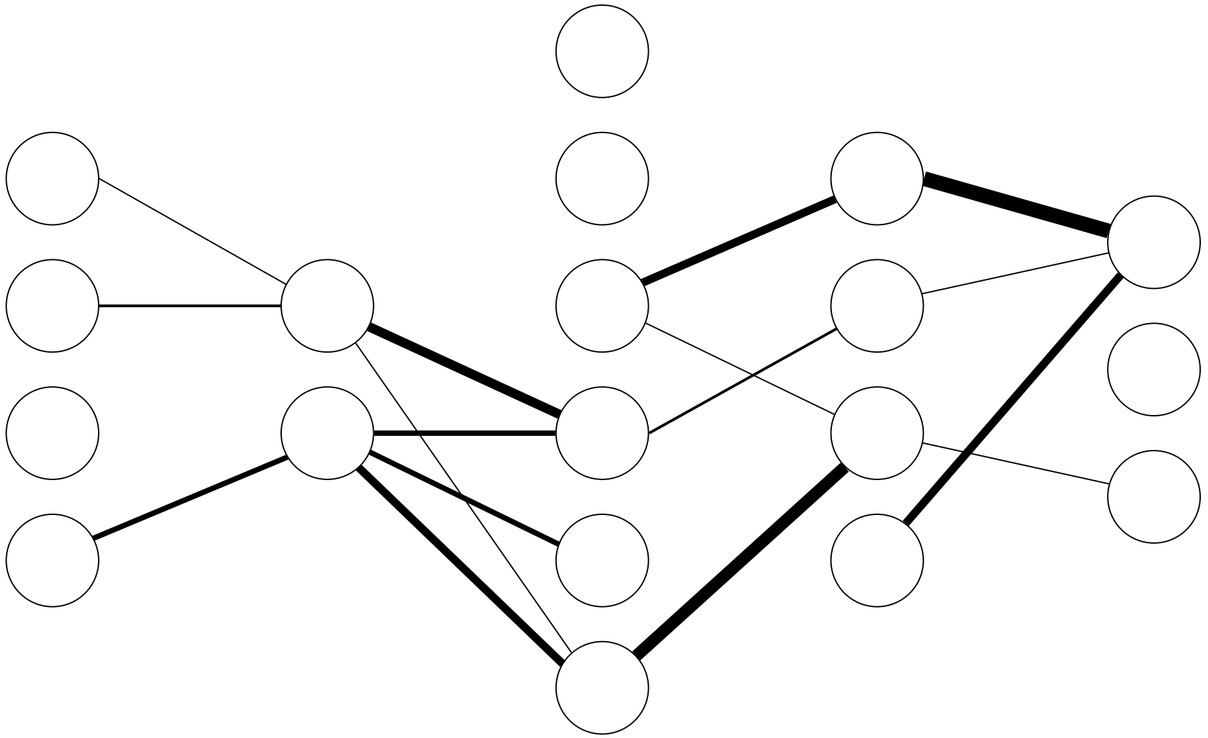
Resnet-50

Layer	Input Size	Output Size	Filter Shape; Stride
Convolution	$224 \times 224 \times 3$	$112 \times 112 \times 64$	$7, 7, 3, 64; 2$
Max Pool	$112 \times 112 \times 64$	$56 \times 56 \times 64$	$3, 3; 2$
Residual Stack 1	$56 \times 56 \times 64$	$56 \times 56 \times 256$	$\begin{bmatrix} 1, 1, 64 \vert 256, 64; 1 \\ 3, 3, 64, 64; 1 \\ 1, 1, 64, 256; 1 \end{bmatrix} \times 3$
Residual Stack 2	$56 \times 56 \times 256$	$28 \times 28 \times 512$	$\begin{bmatrix} 1, 1, 256 \vert 512, 128; 2 \vert 1 \\ 3, 3, 128, 128; 1 \\ 1, 1, 128, 512; 1 \end{bmatrix} \times 4$
Residual Stack 3	$28 \times 28 \times 512$	$14 \times 14 \times 1024$	$\begin{bmatrix} 1, 1, 512 \vert 1024, 256; 2 \vert 1 \\ 3, 3, 256, 256; 1 \\ 1, 1, 256, 1024; 1 \end{bmatrix} \times 6$
Residual Stack 4	$14 \times 14 \times 1024$	$7 \times 7 \times 2048$	$\begin{bmatrix} 1, 1, 1024 \vert 2048, 512; 2 \vert 1 \\ 3, 3, 512, 512; 1 \\ 1, 1, 512, 2048; 1 \end{bmatrix} \times 3$
Average Pool	$7 \times 7 \times 2048$	2048	$7, 7$
Fully Connected	2048	8	$2048, 8$



Optimization Stack

Dynamic Sparse Training



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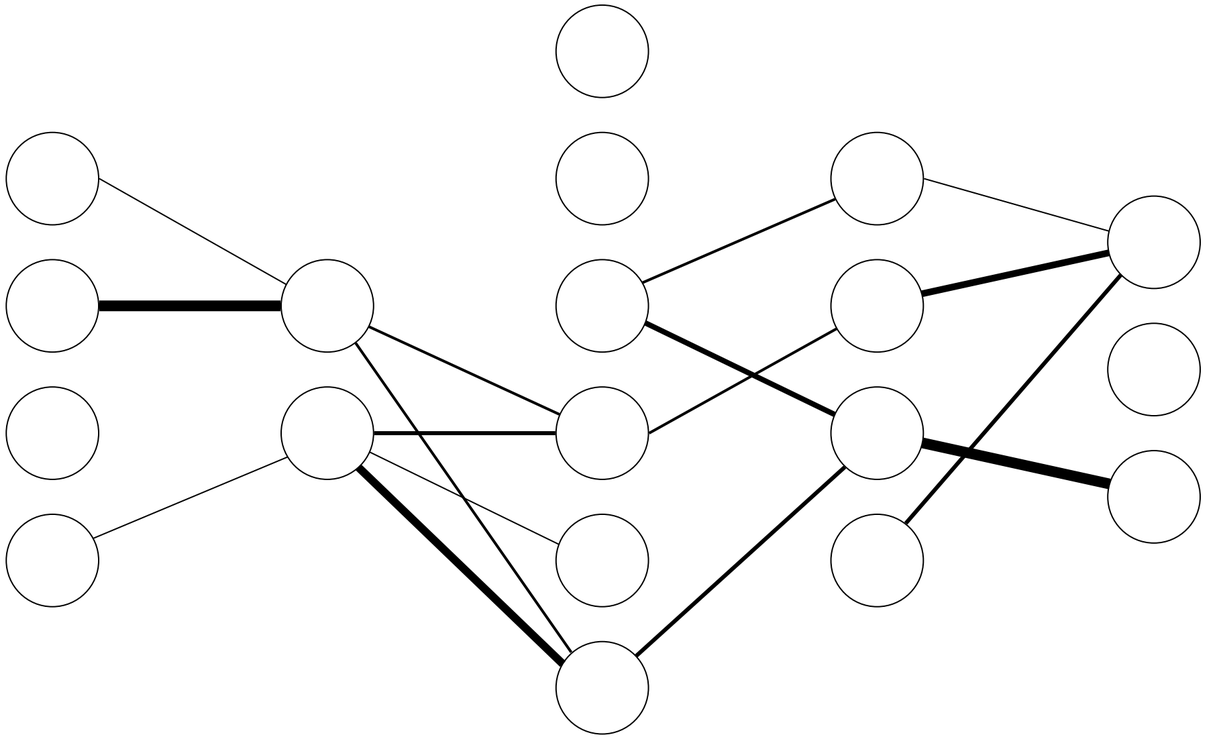

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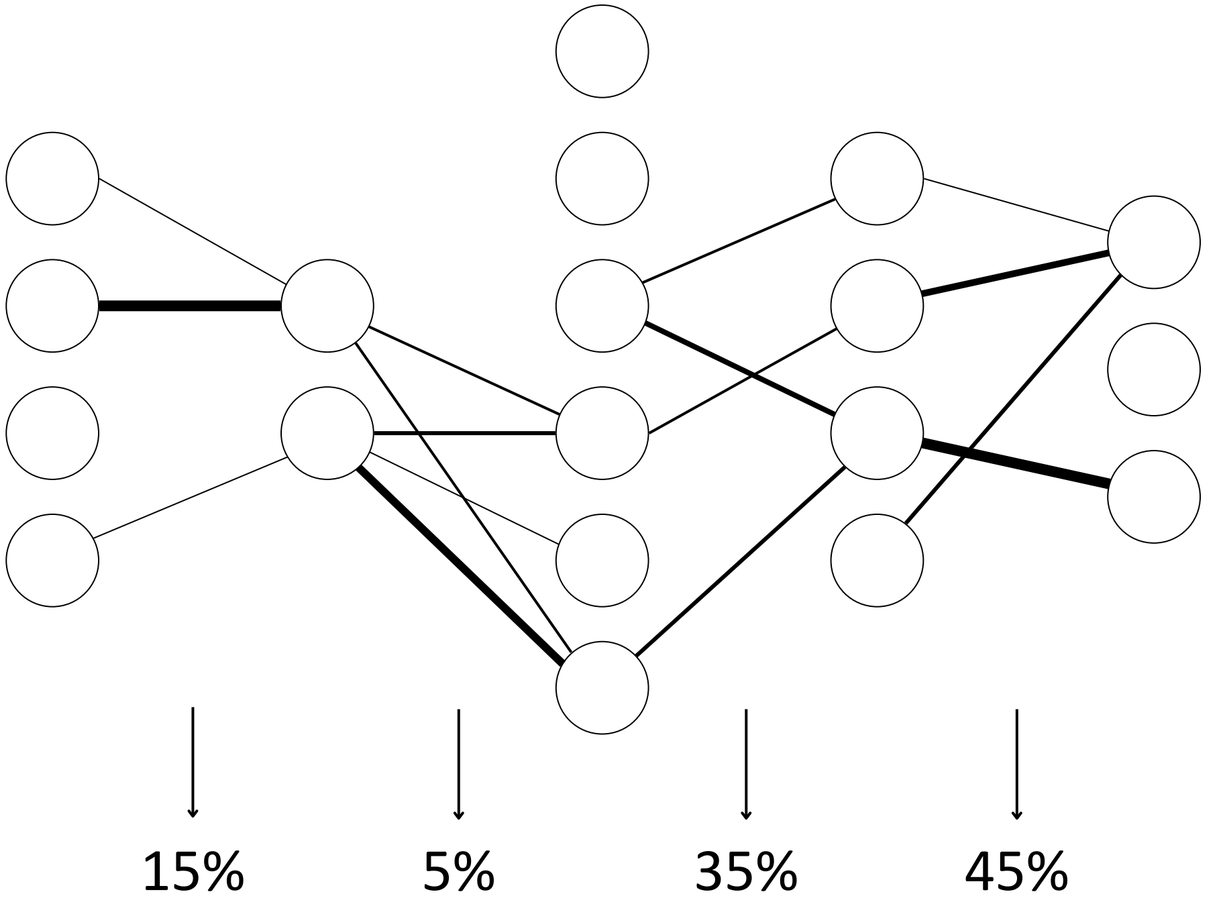

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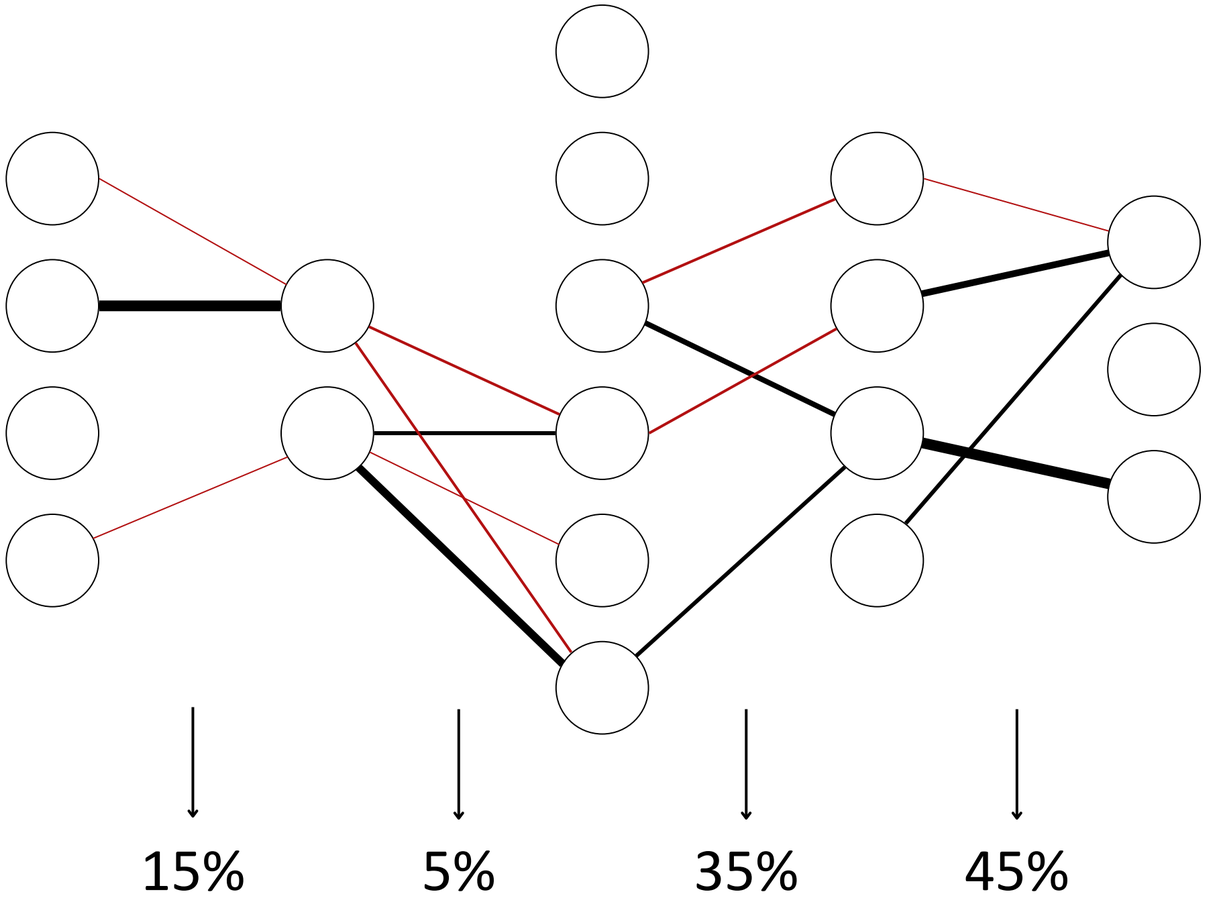

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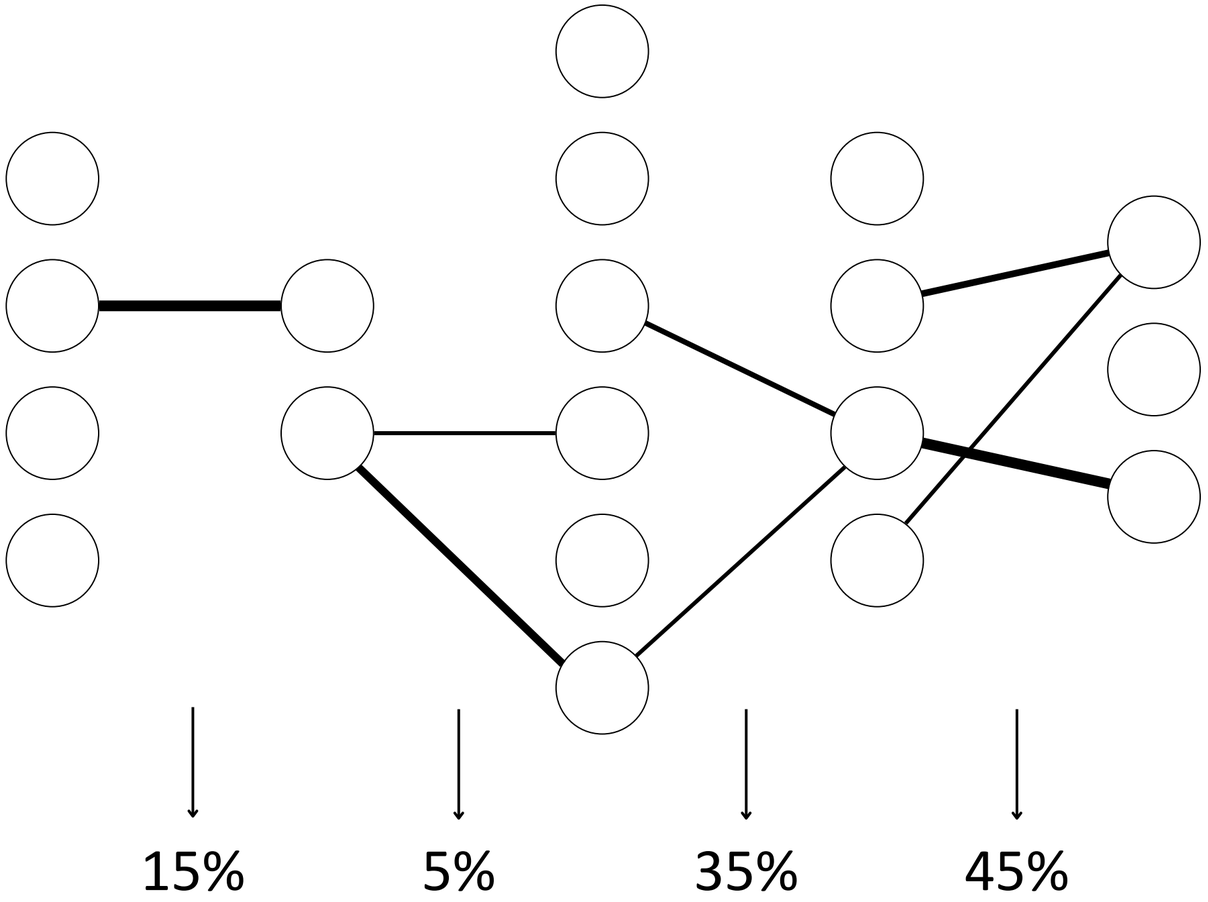

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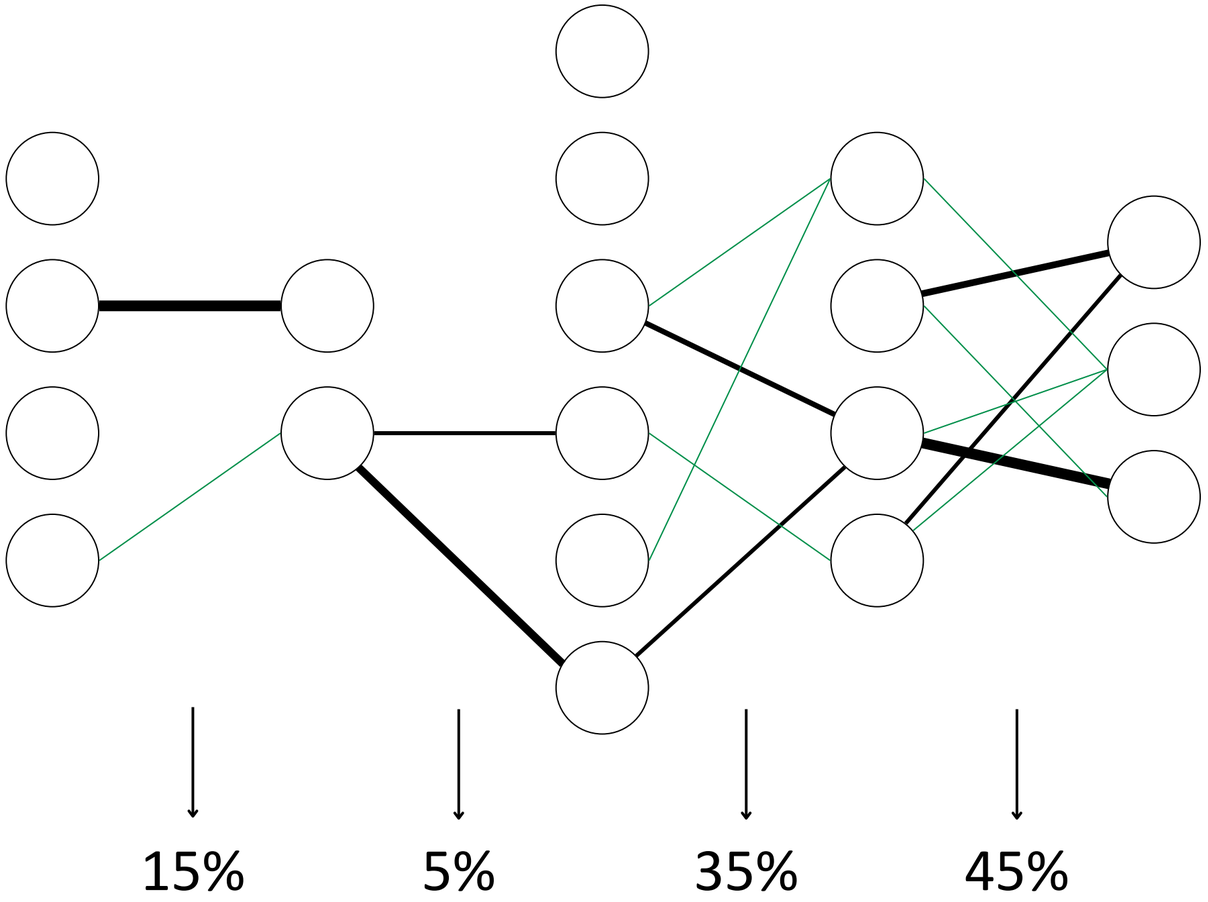

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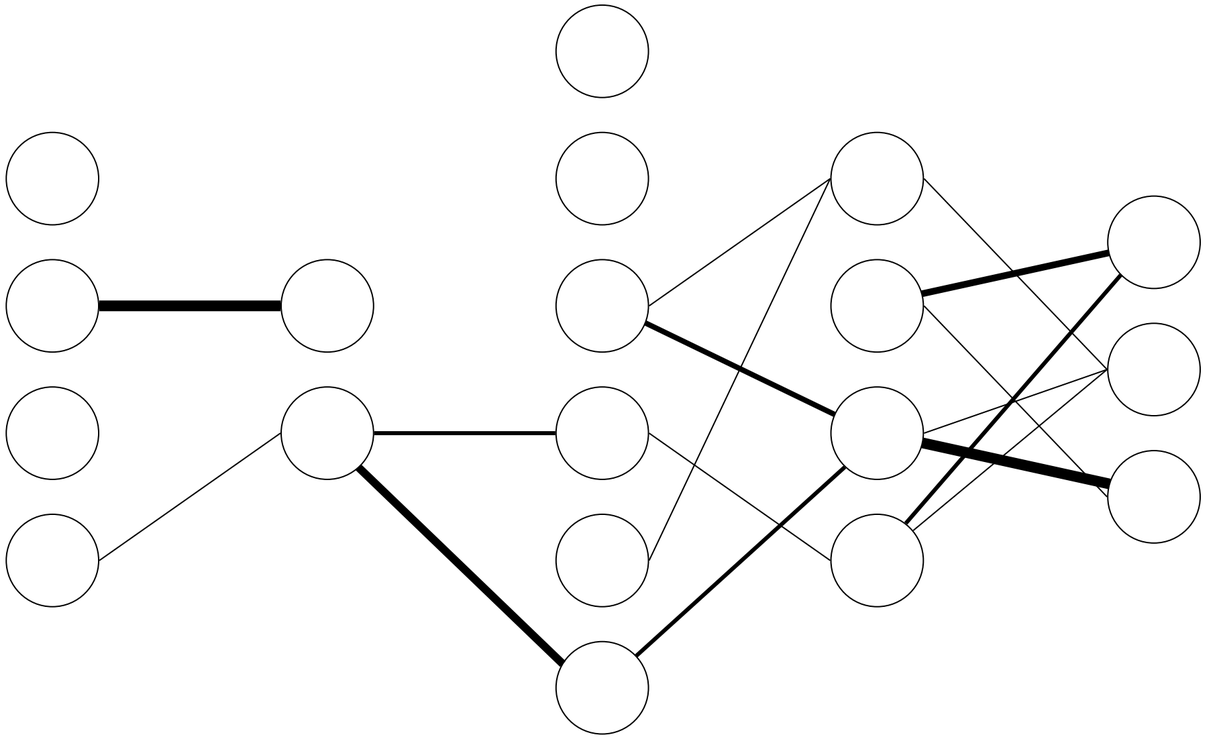

Optimization Stack

Gradient Checkpointing

$$\frac{\partial C}{\partial w_{jk}^{(l)}} = \delta_j^{(l)} \, a_k^{(l-1)} \qquad \frac{\partial C}{\partial b_j^{(l)}} = \delta_j^{(l)}$$

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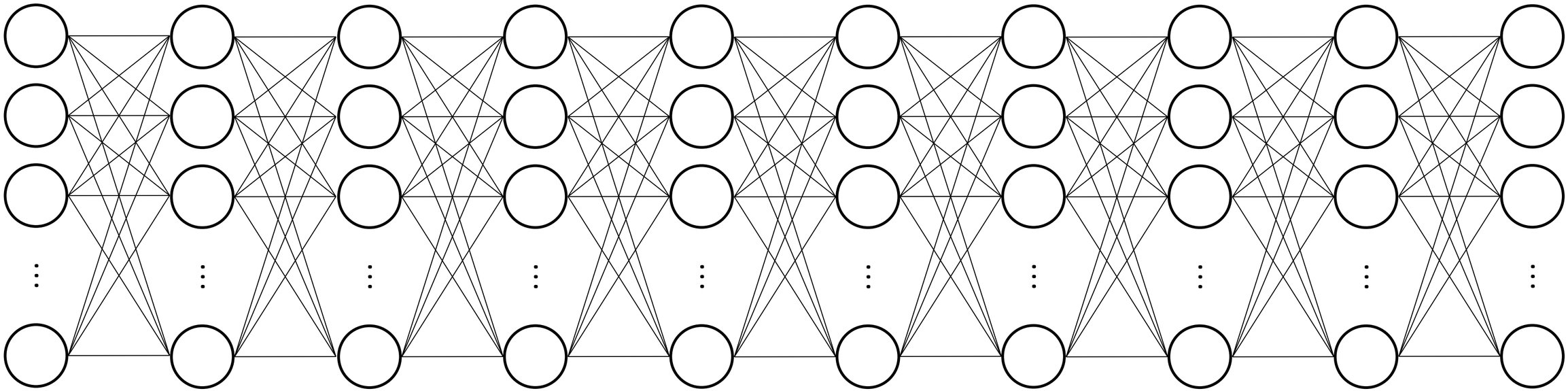

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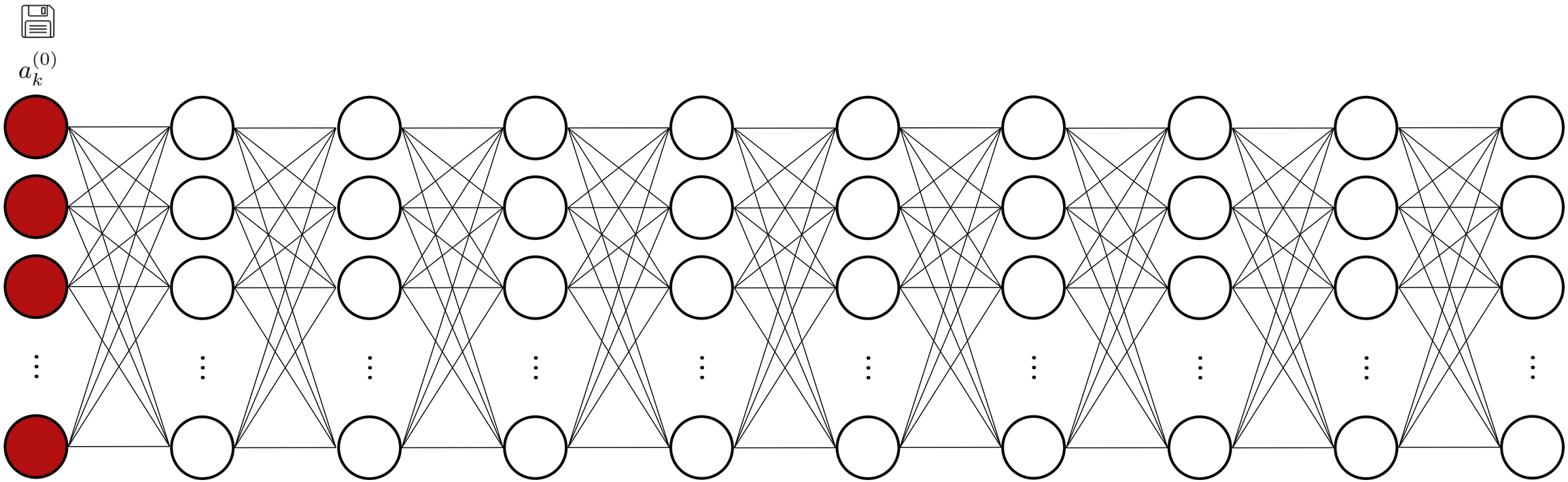

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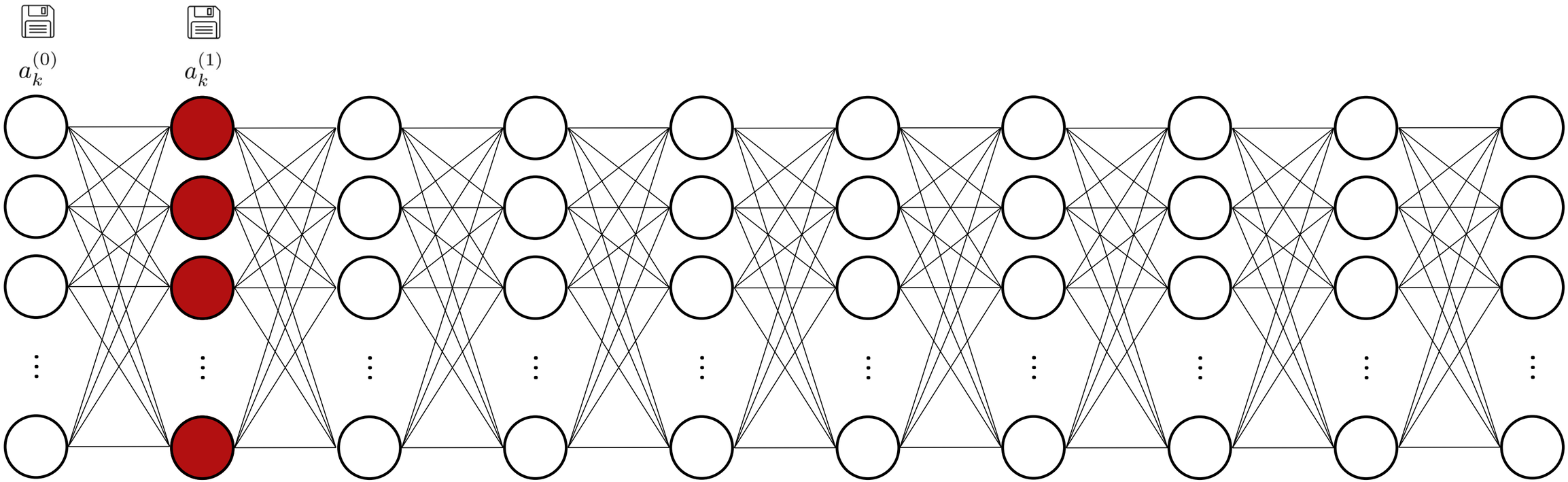

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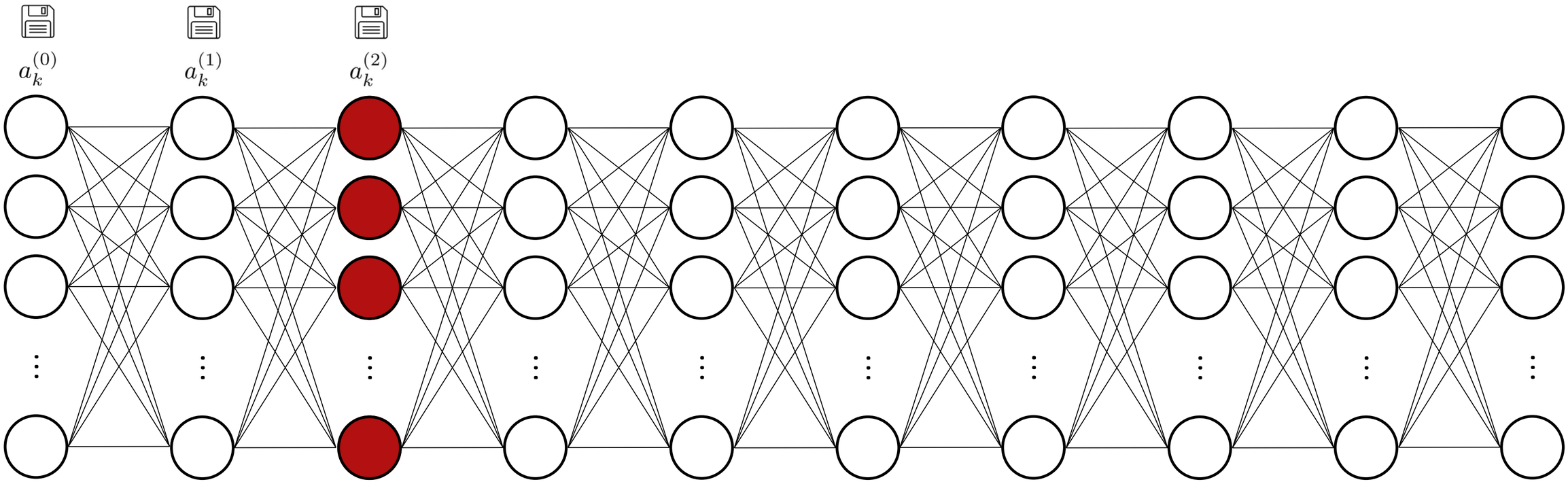

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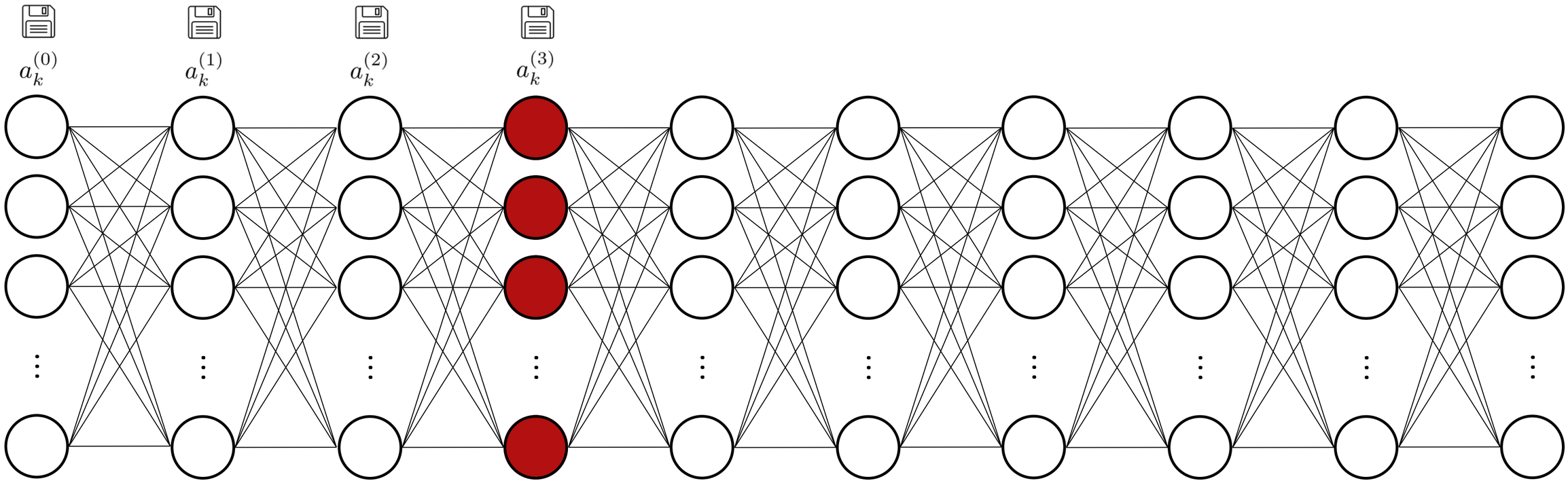

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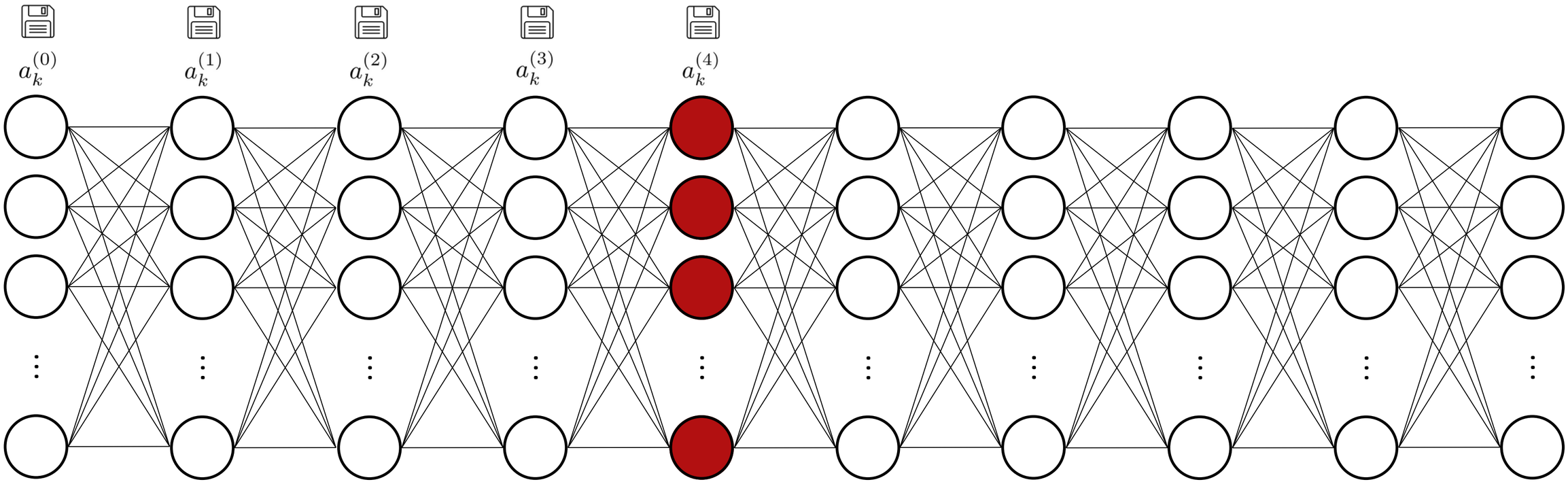

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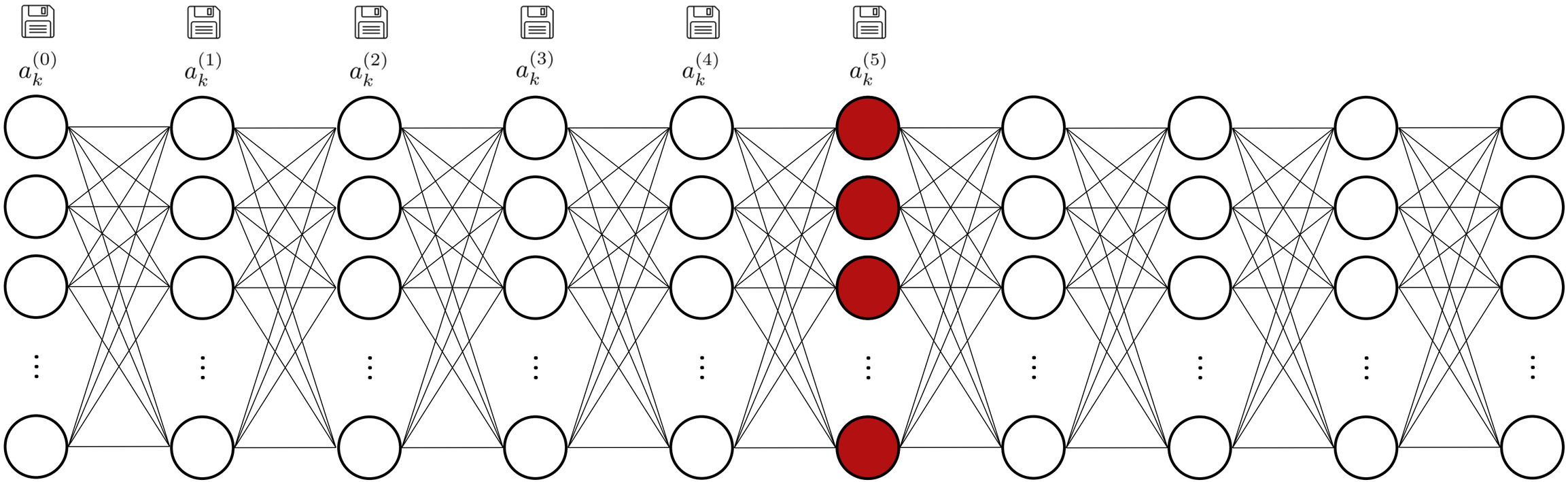

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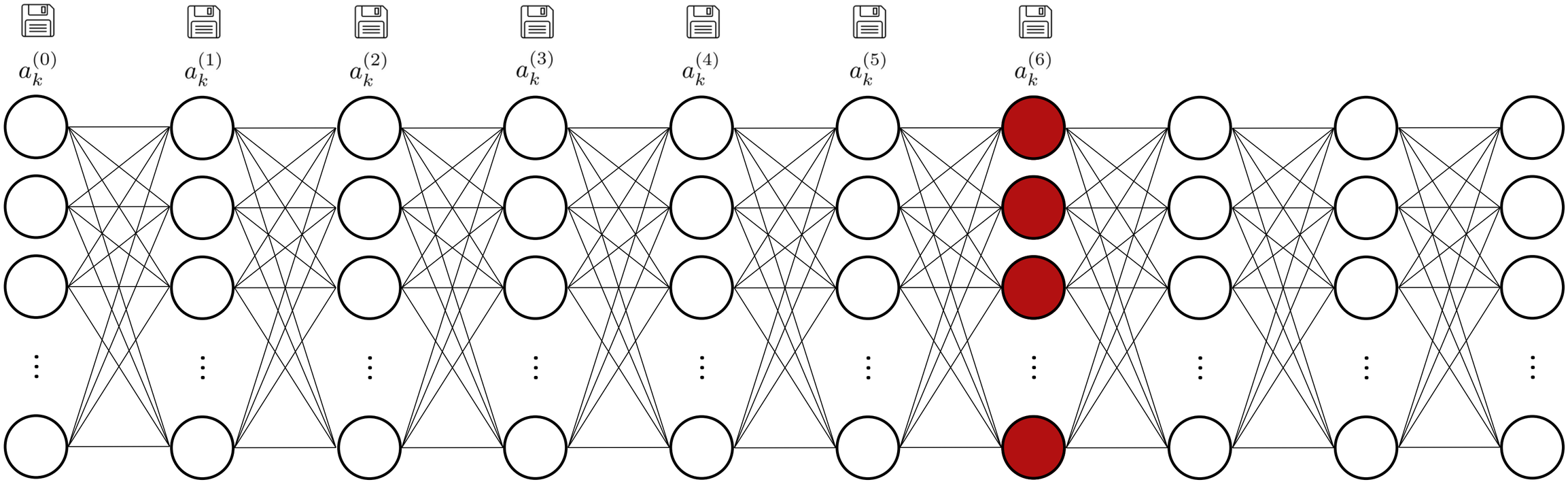

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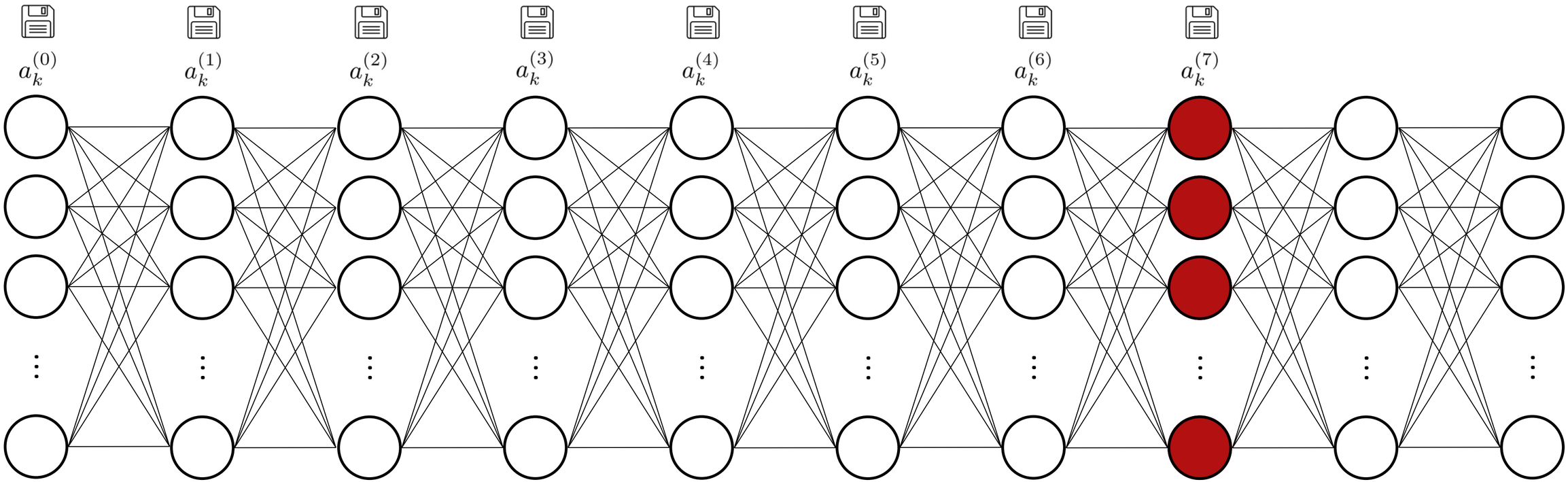

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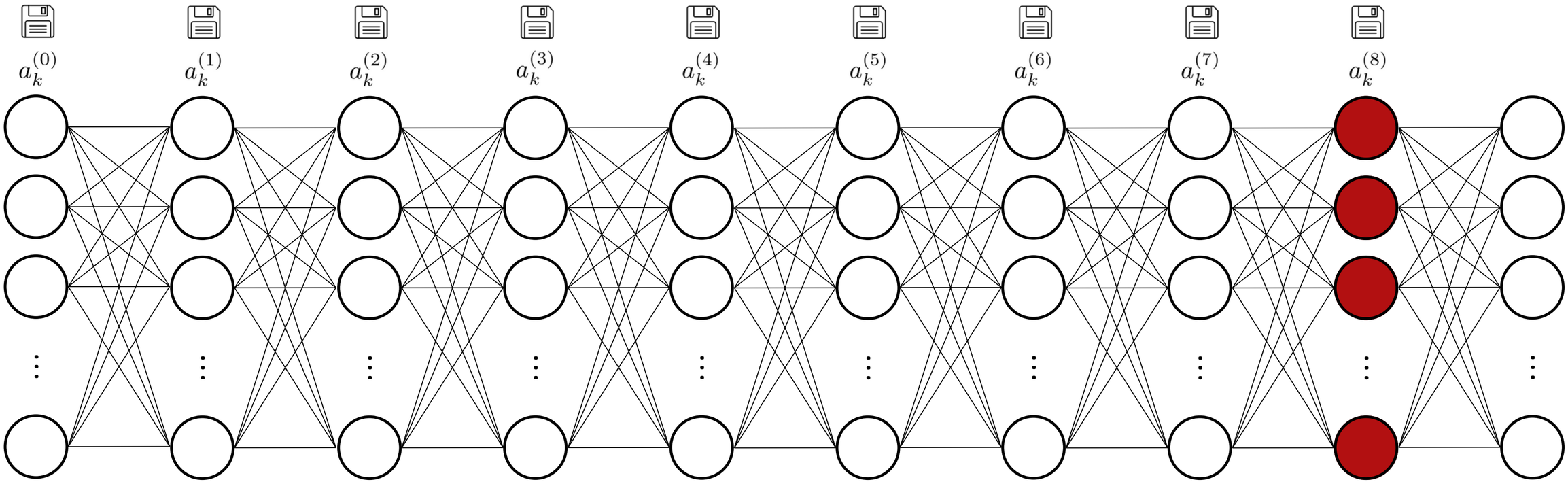

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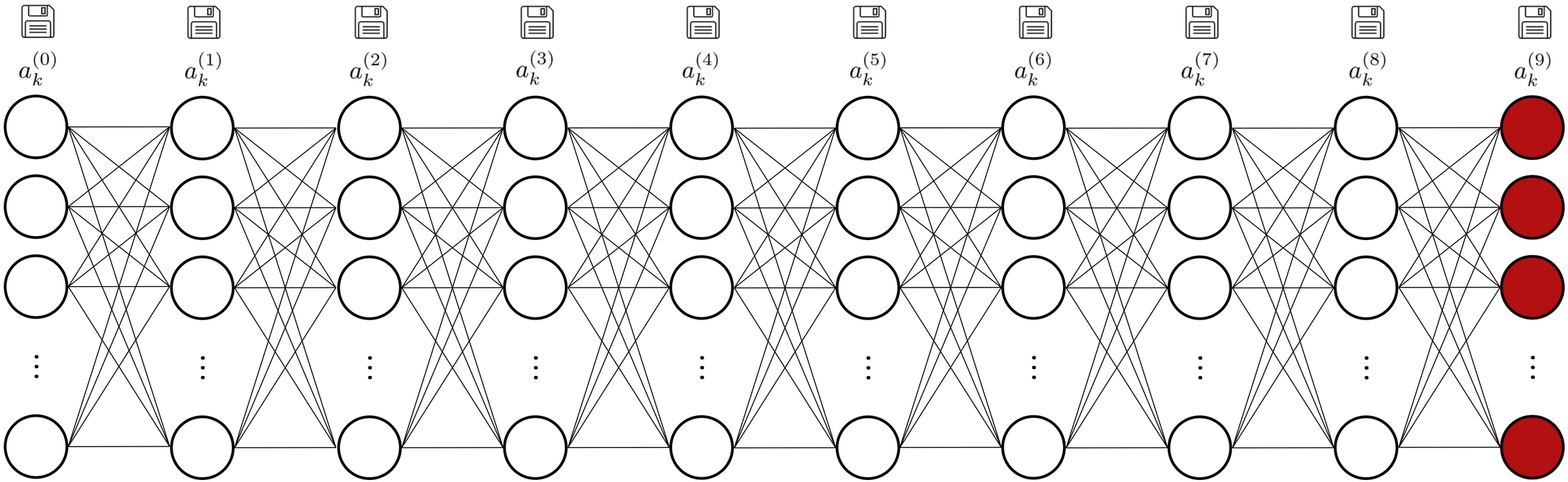

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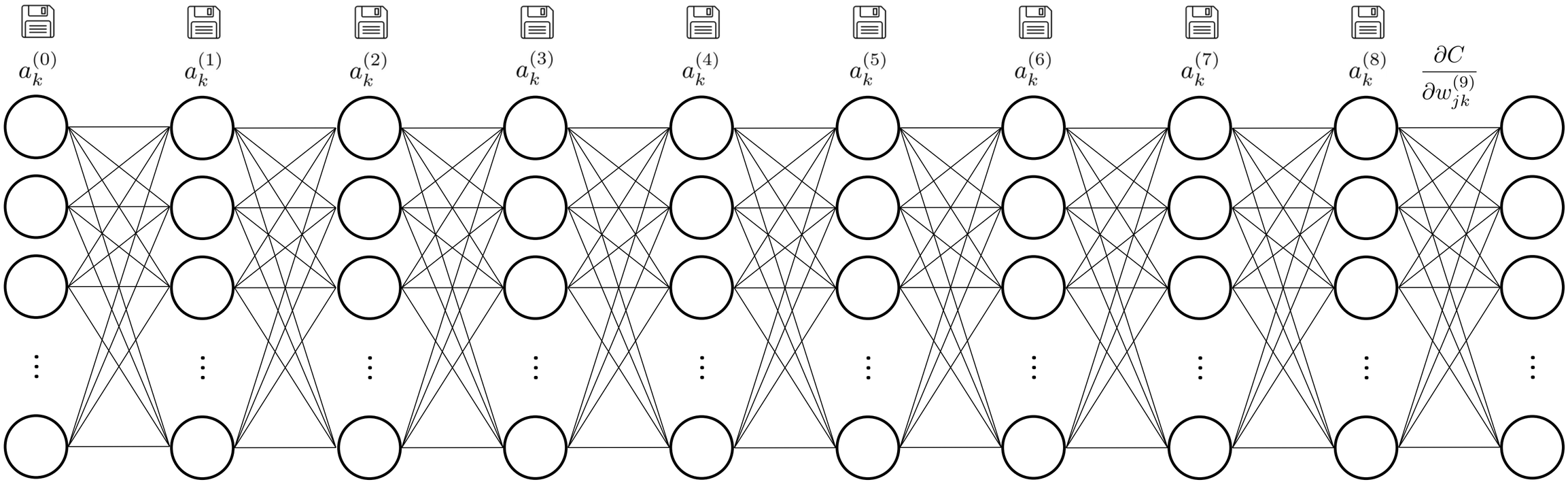

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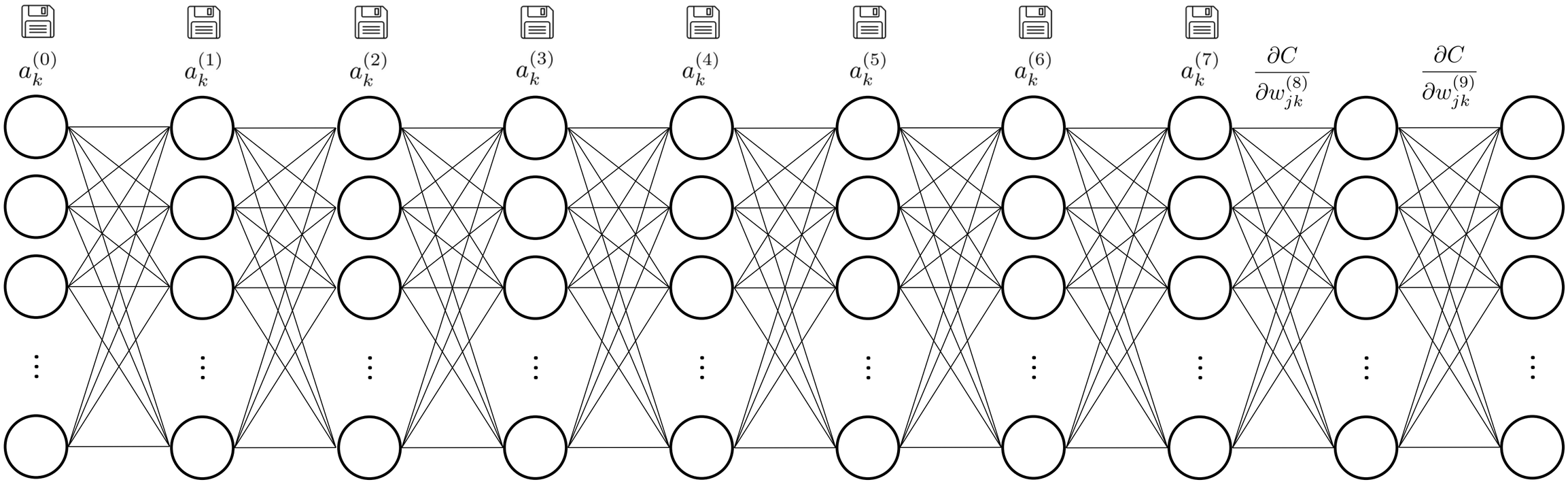

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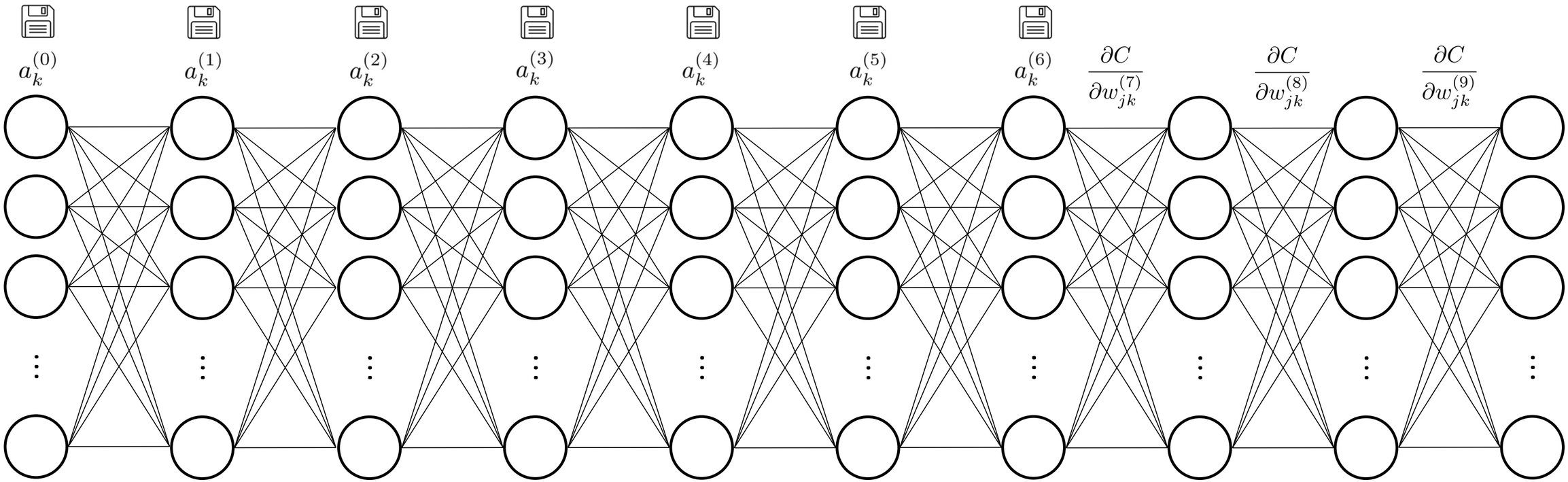

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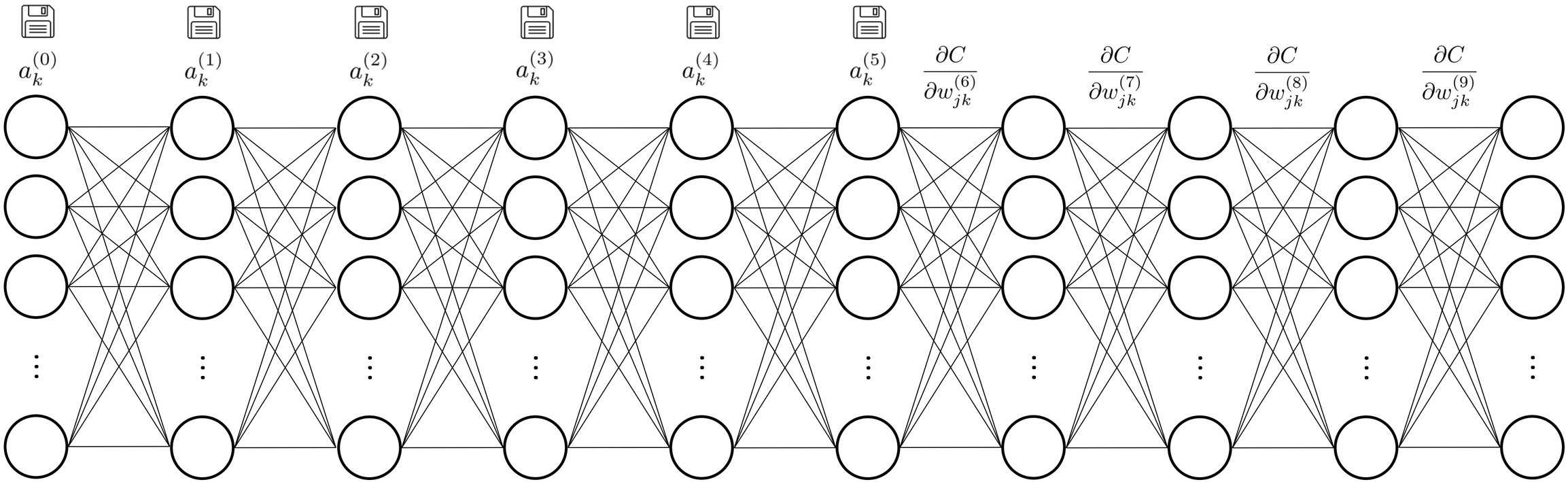

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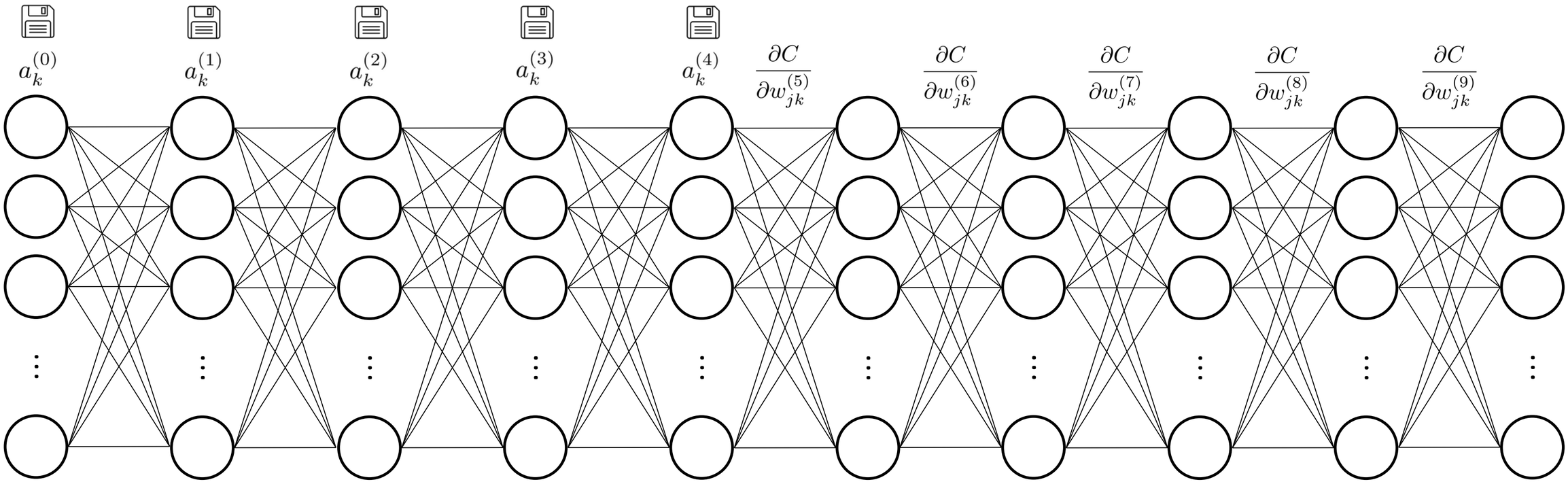

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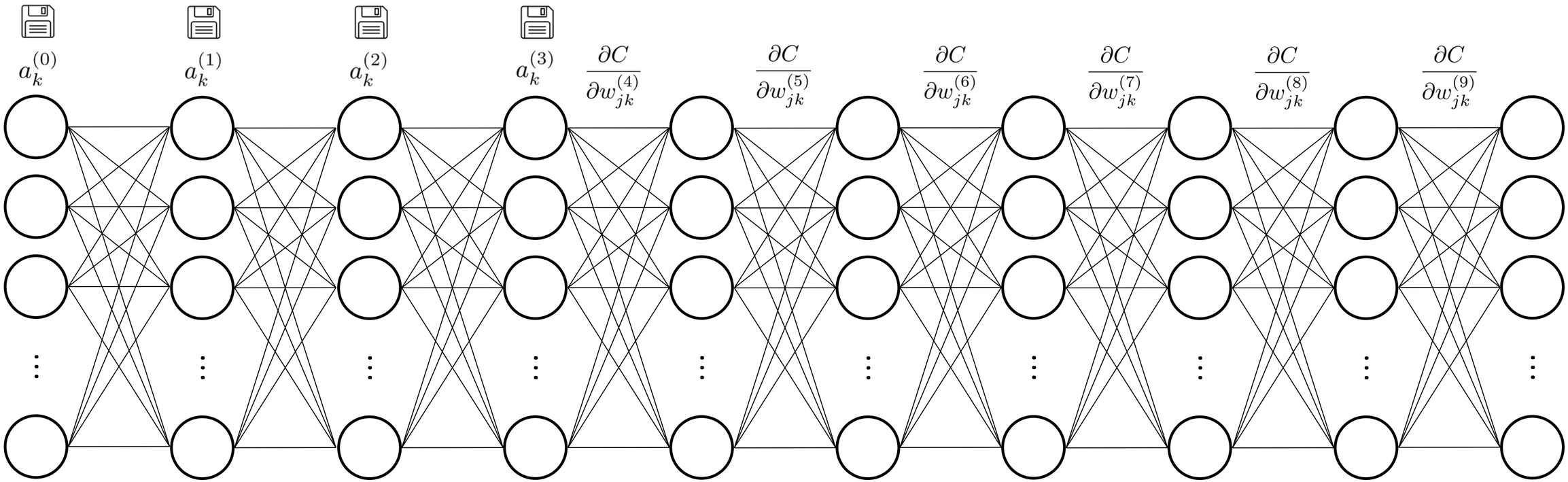

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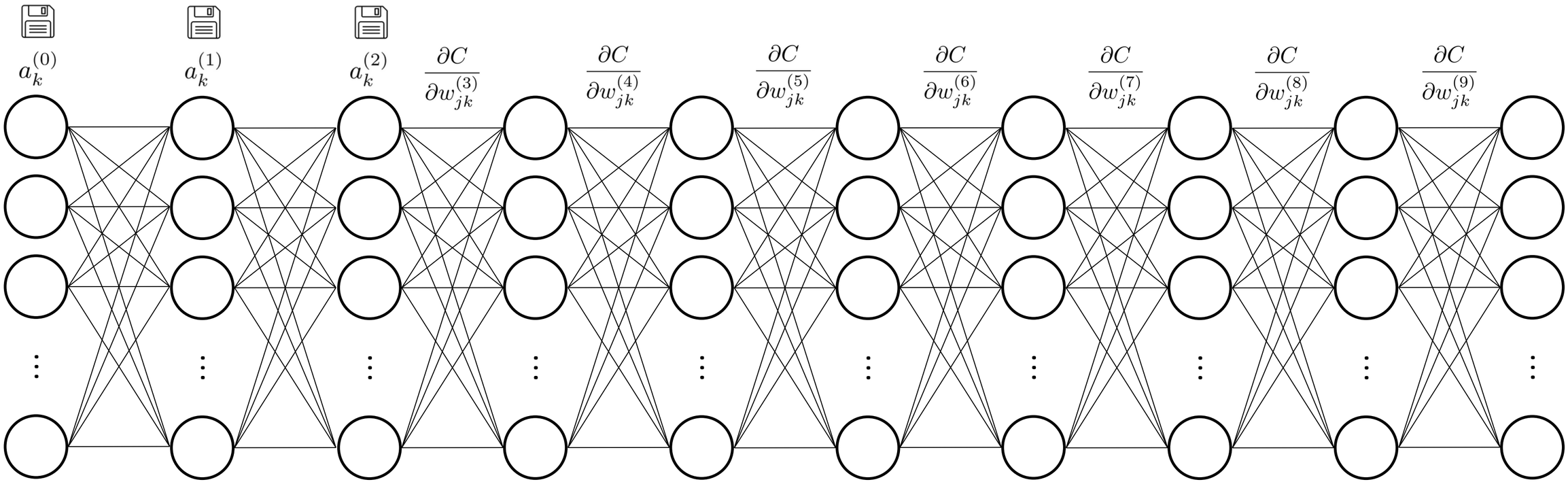

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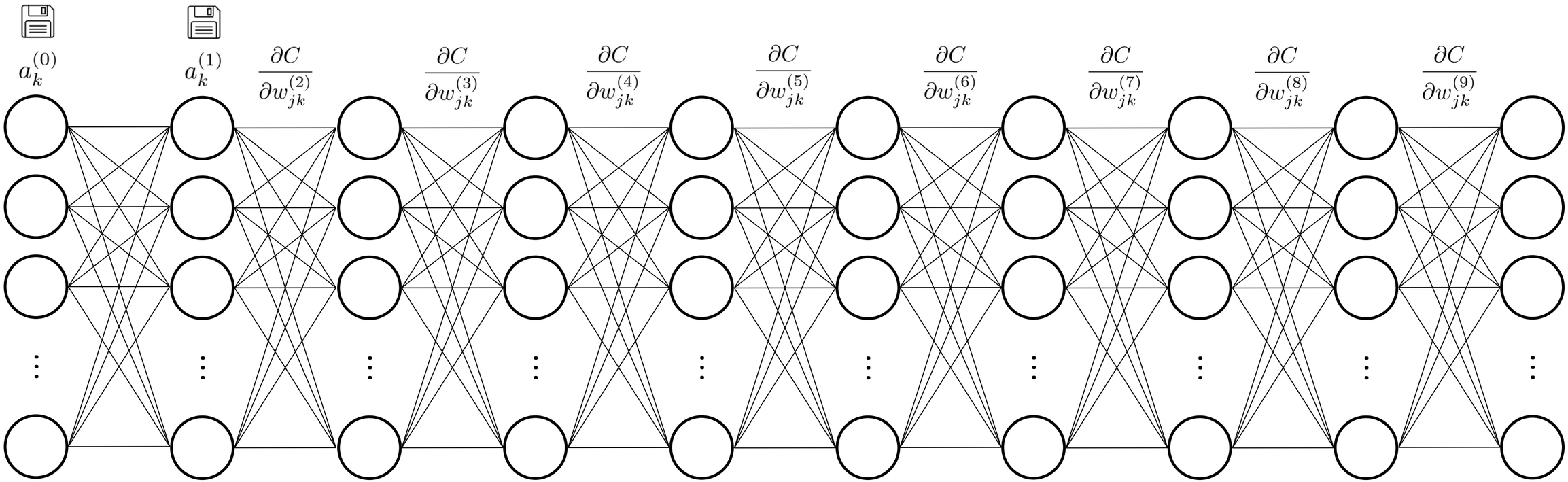

Optimization Stack

Gradient Checkpointing

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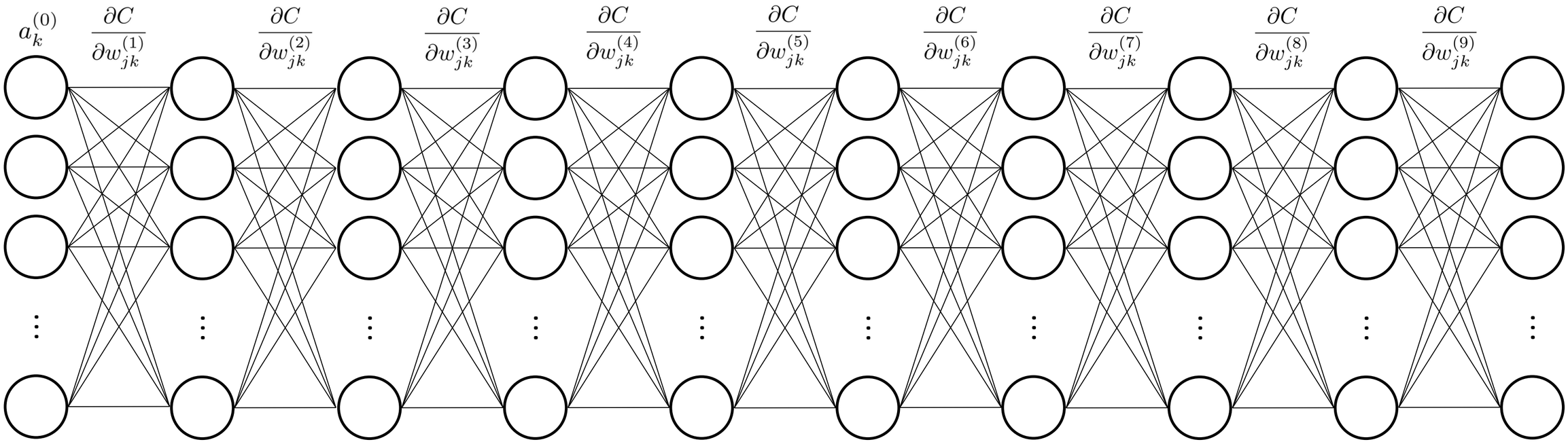

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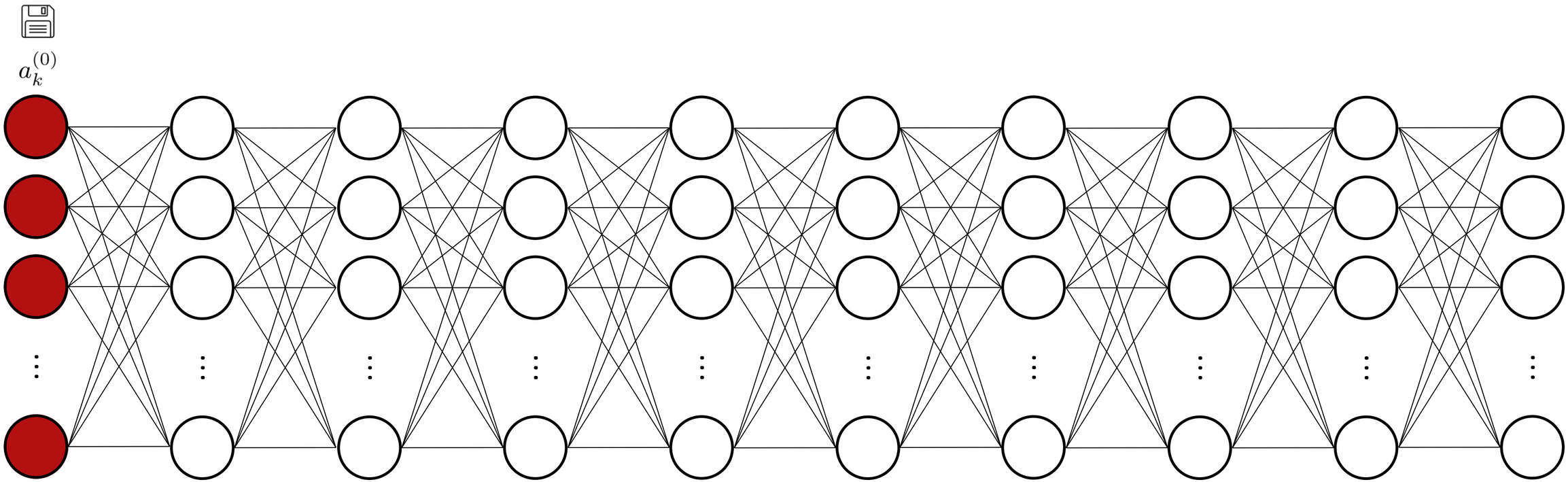

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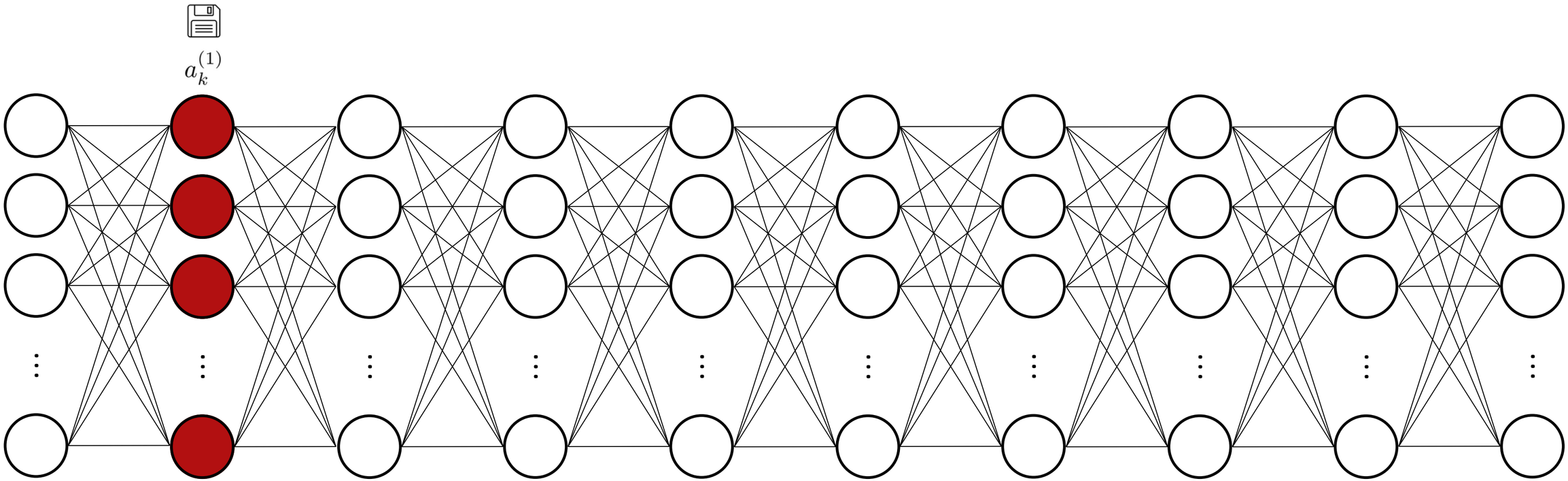

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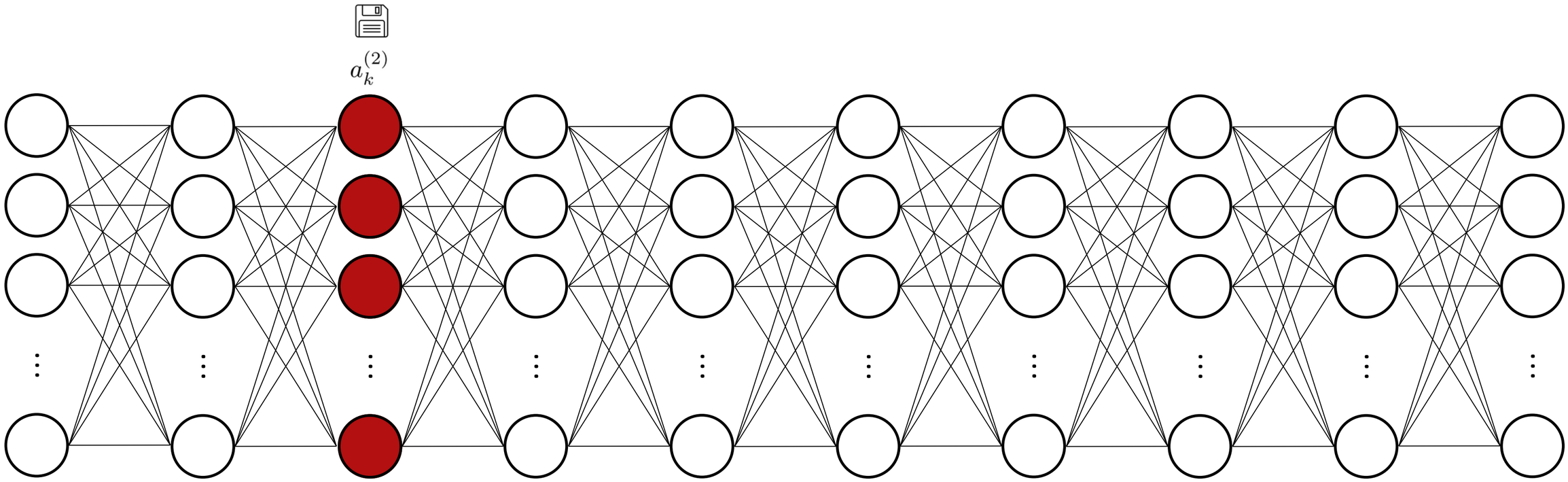

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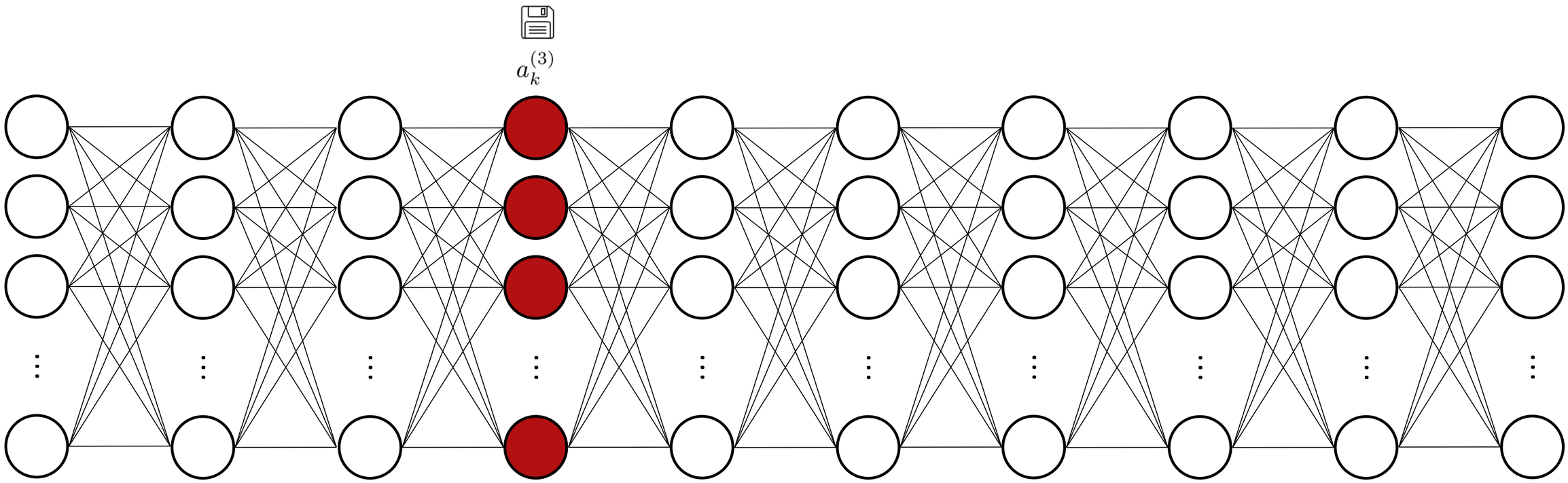

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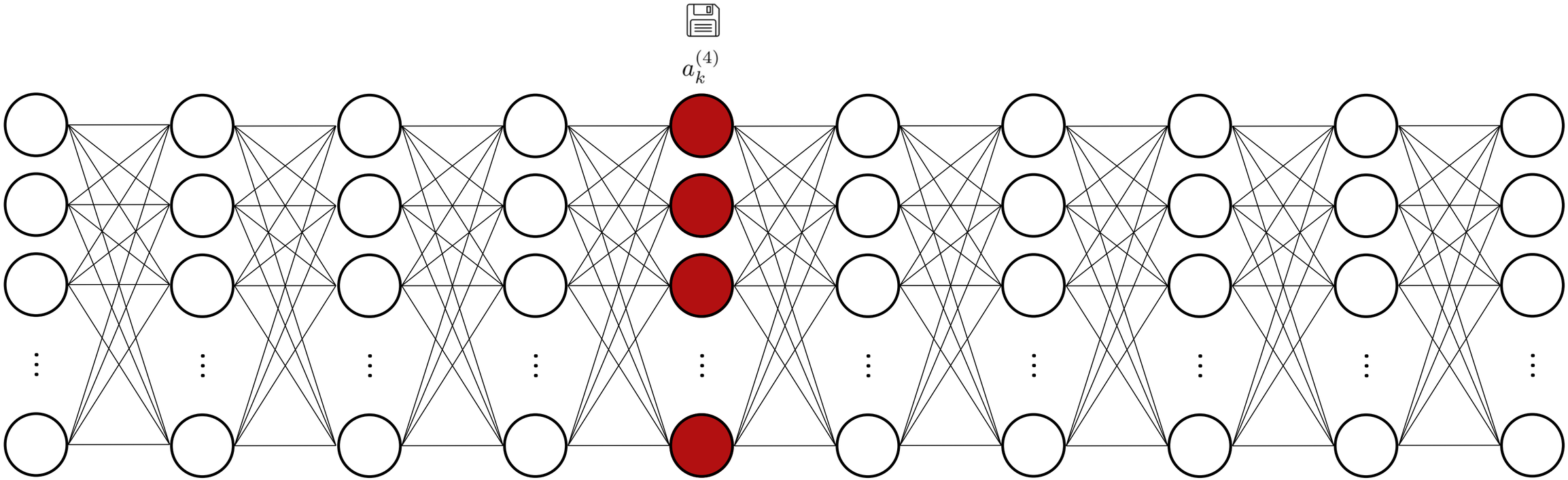

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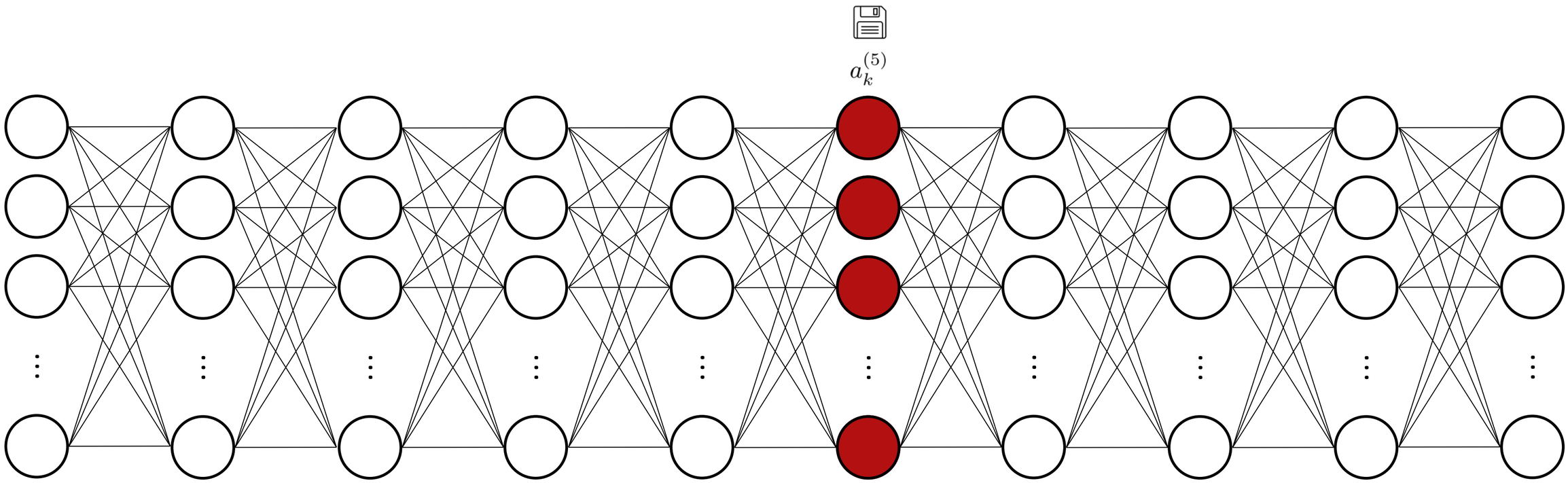

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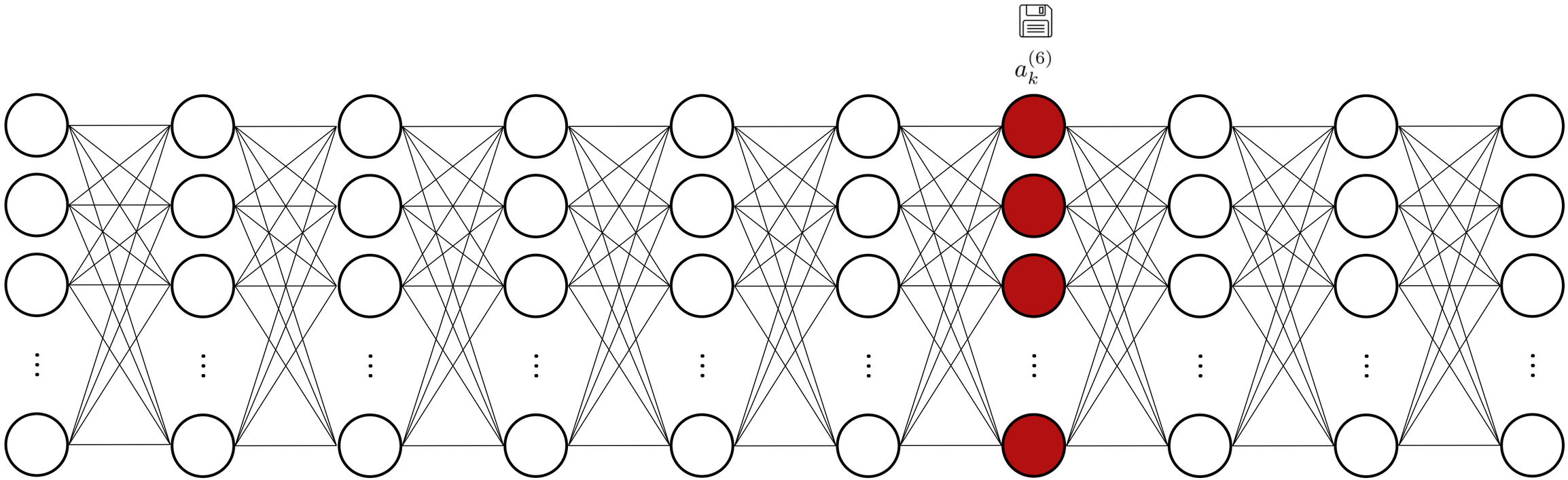

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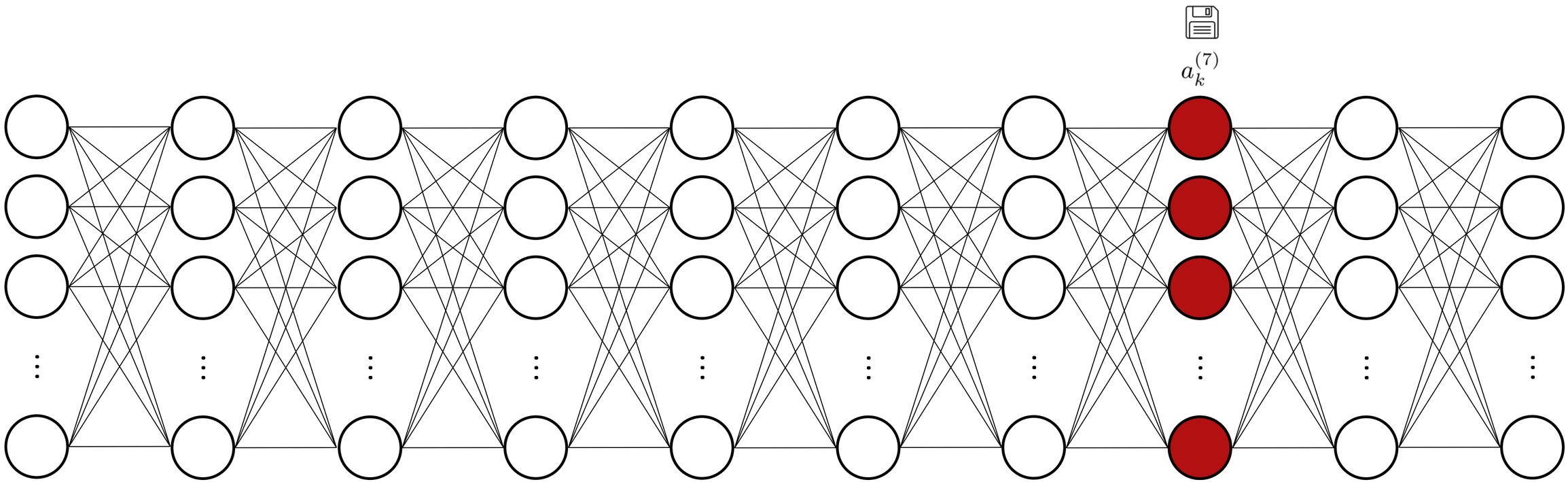

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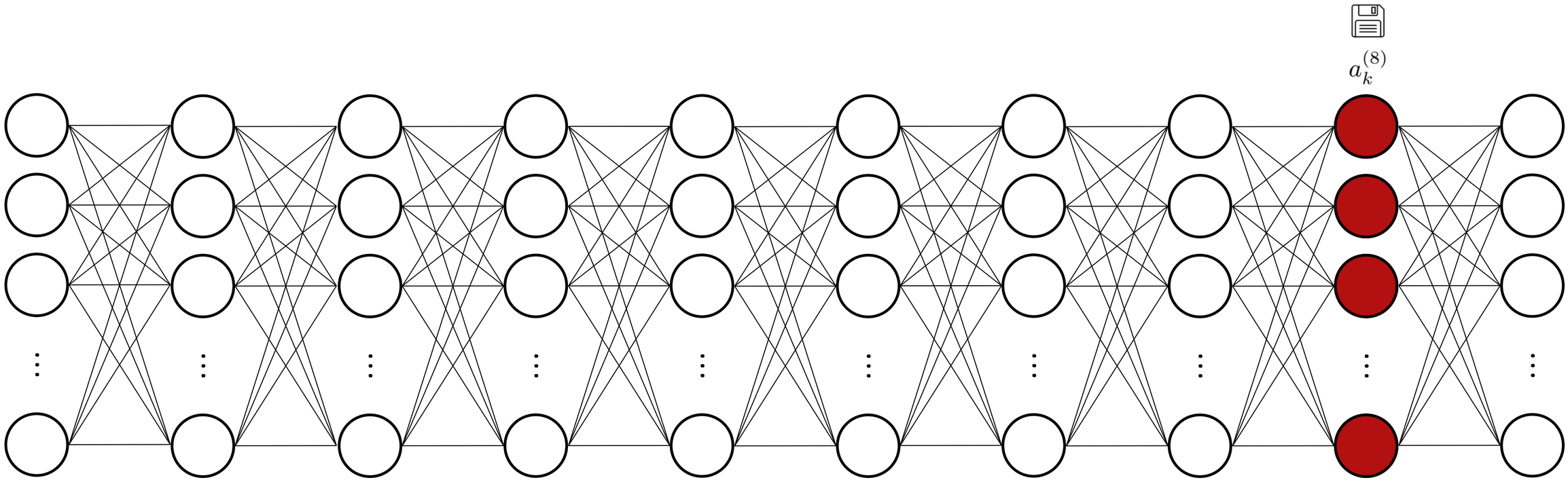

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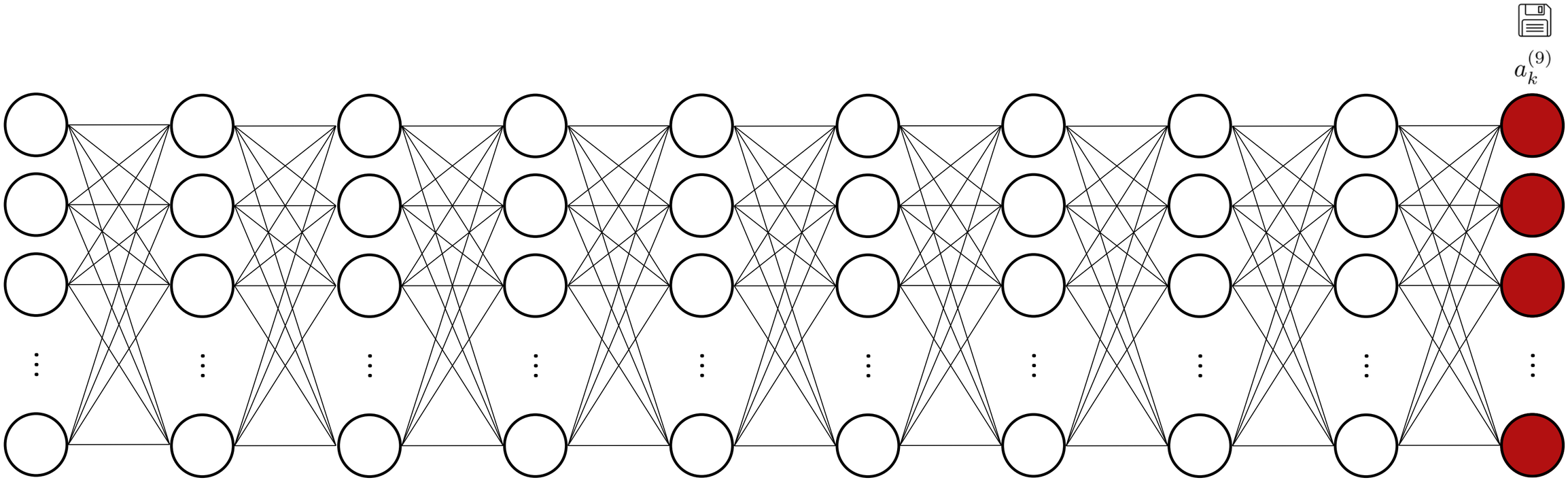

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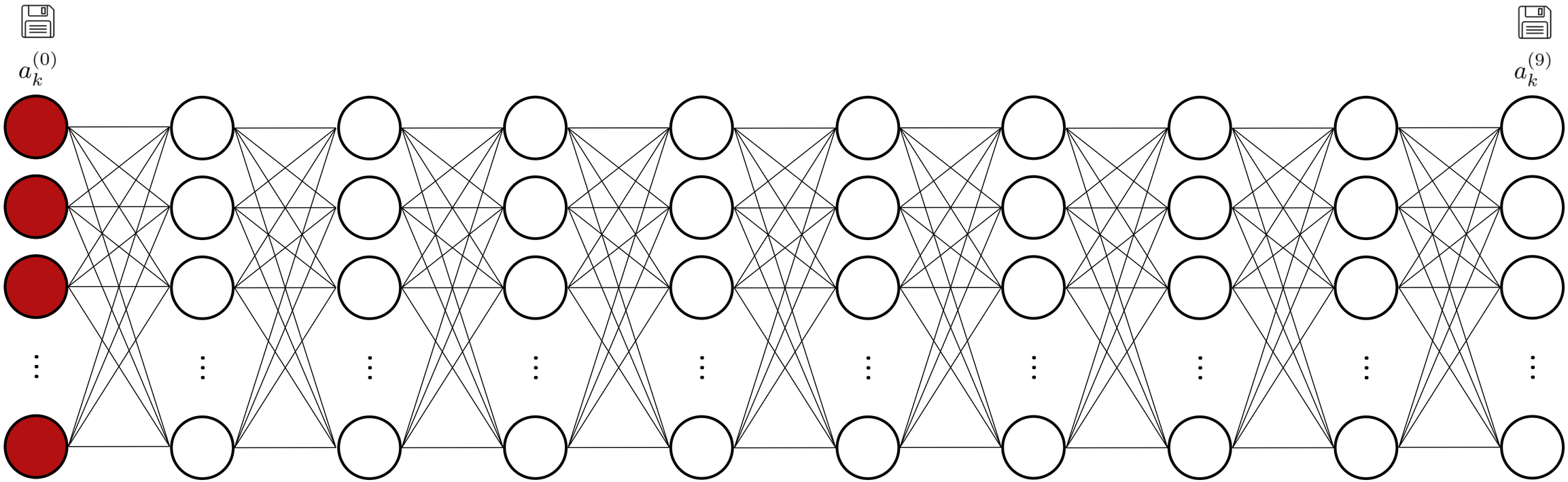

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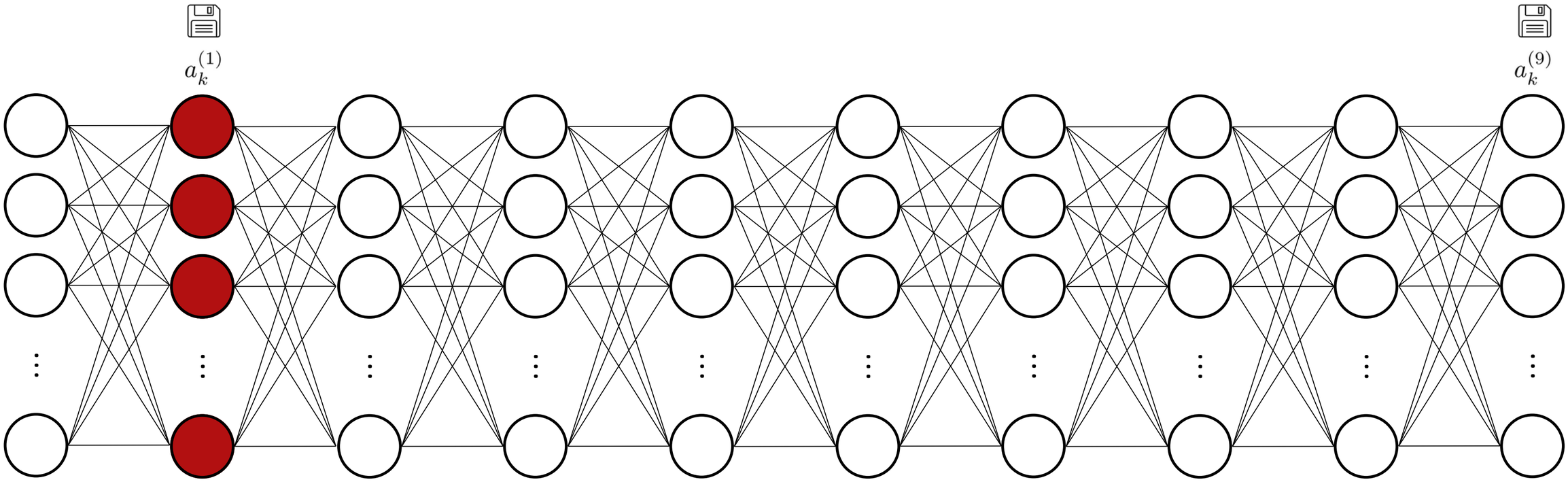

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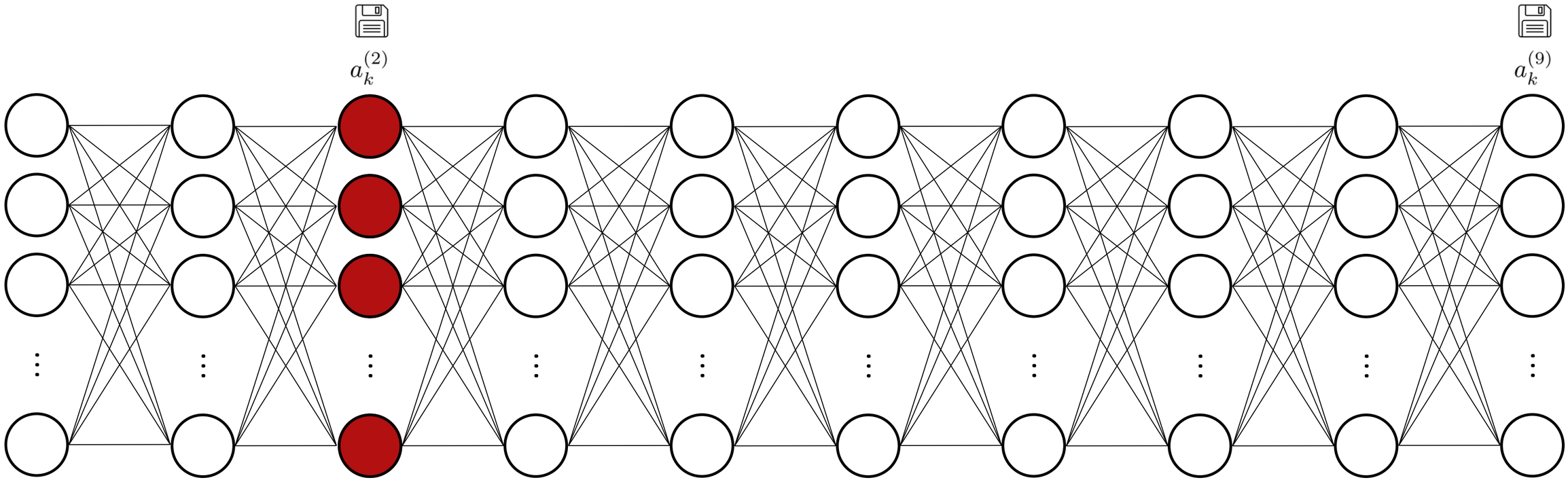

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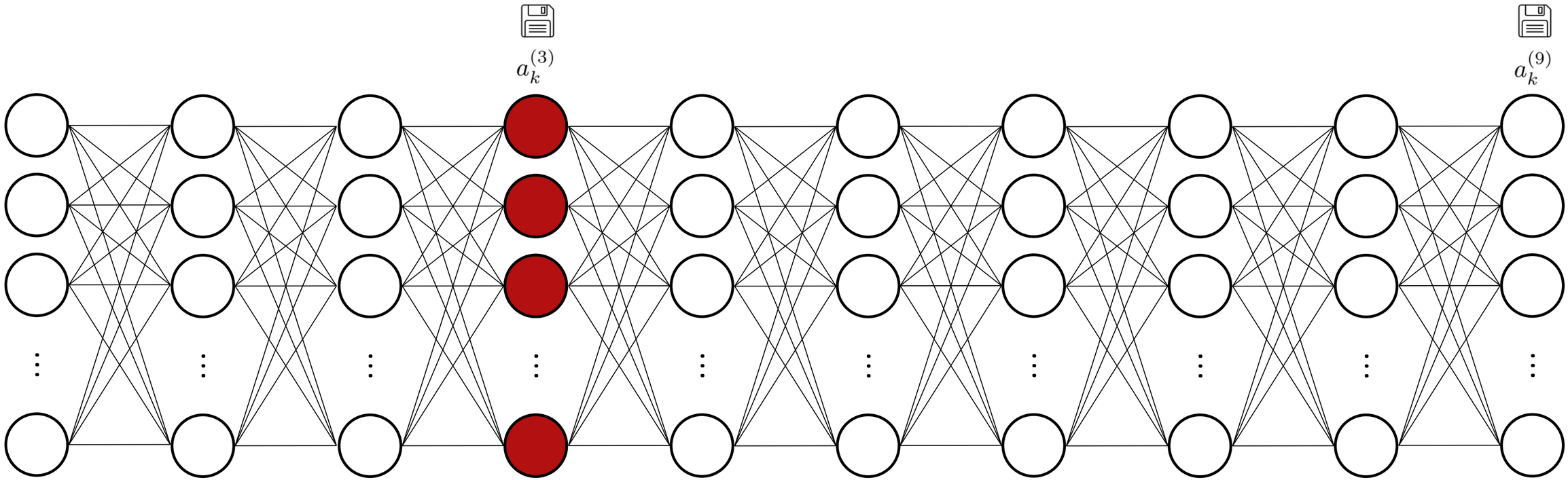

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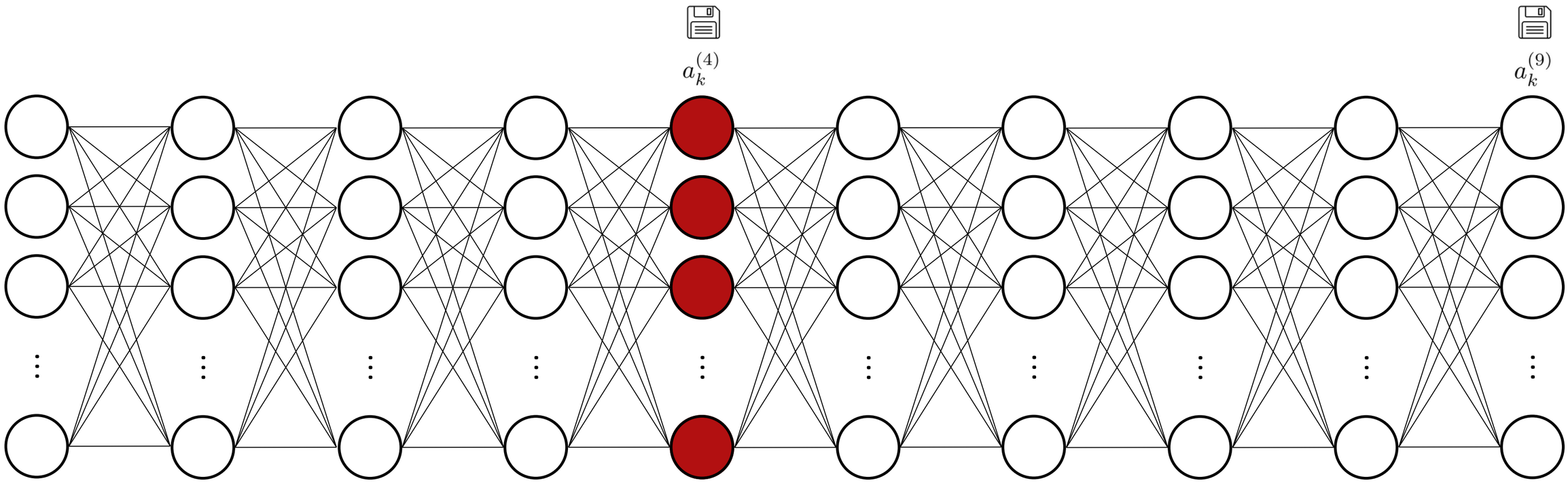

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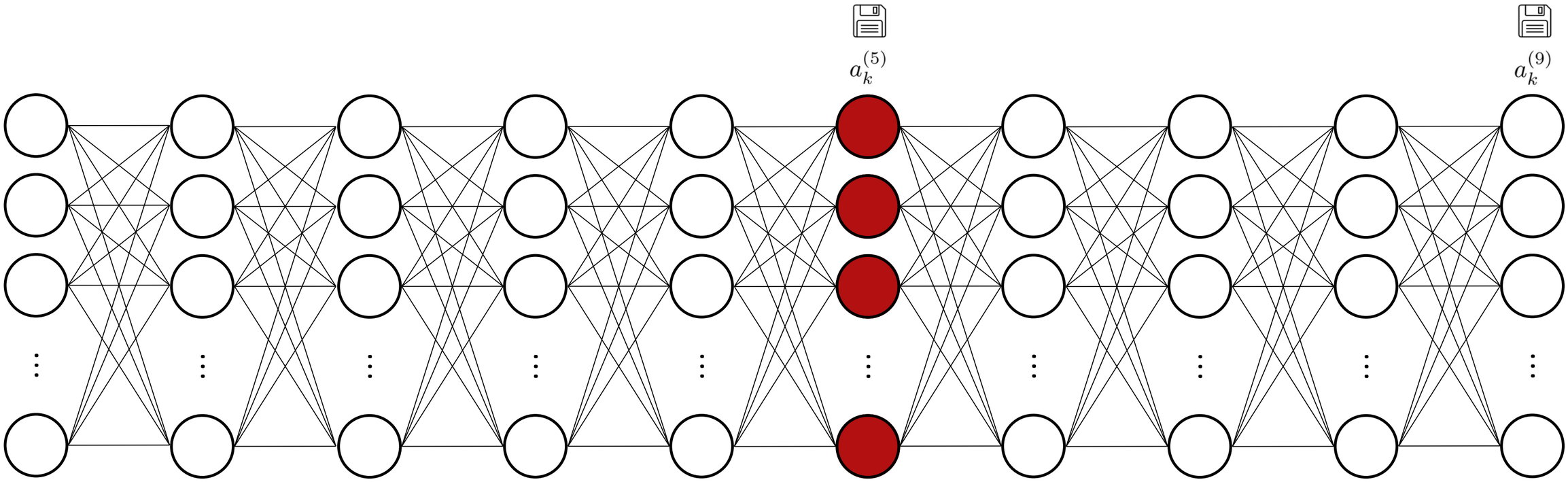

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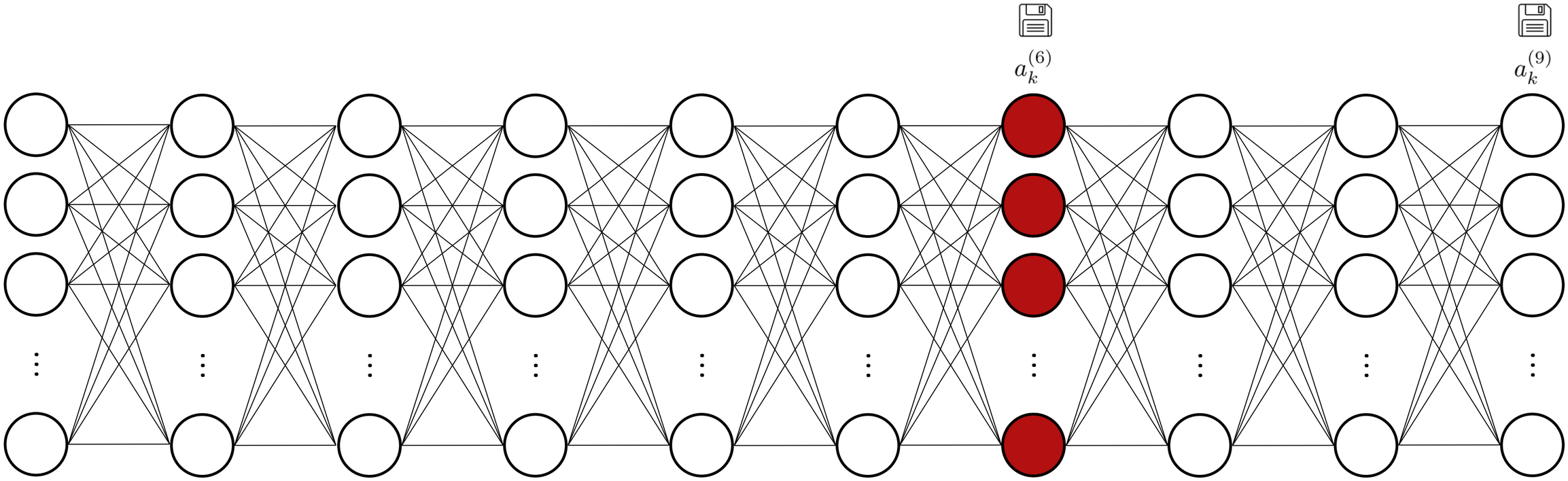

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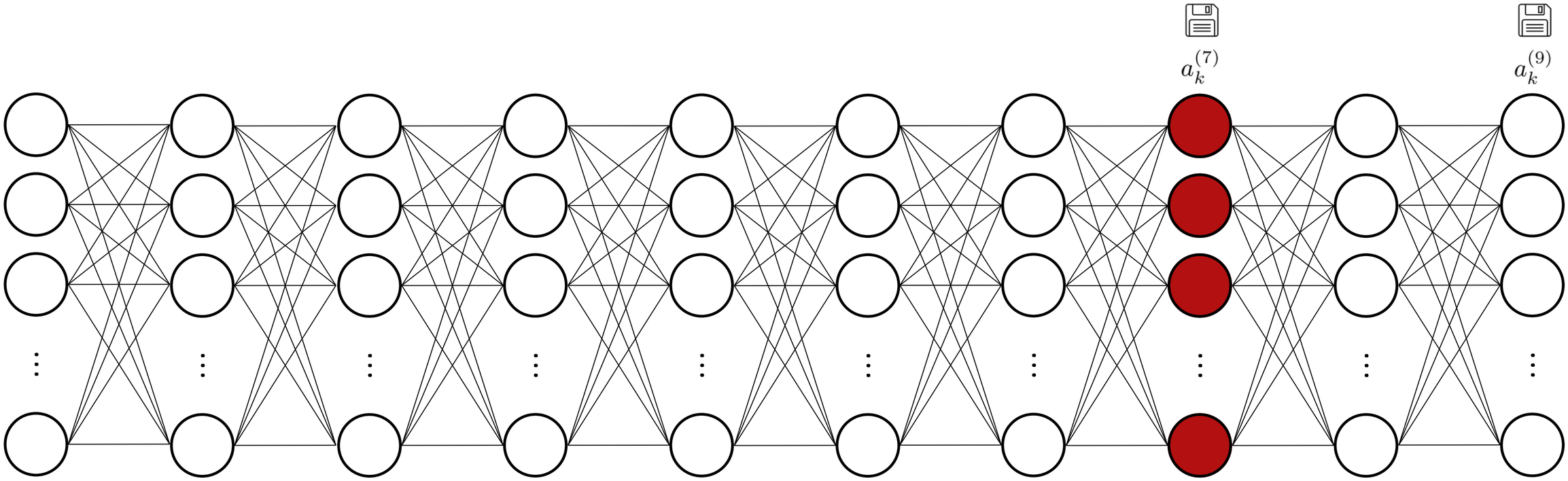

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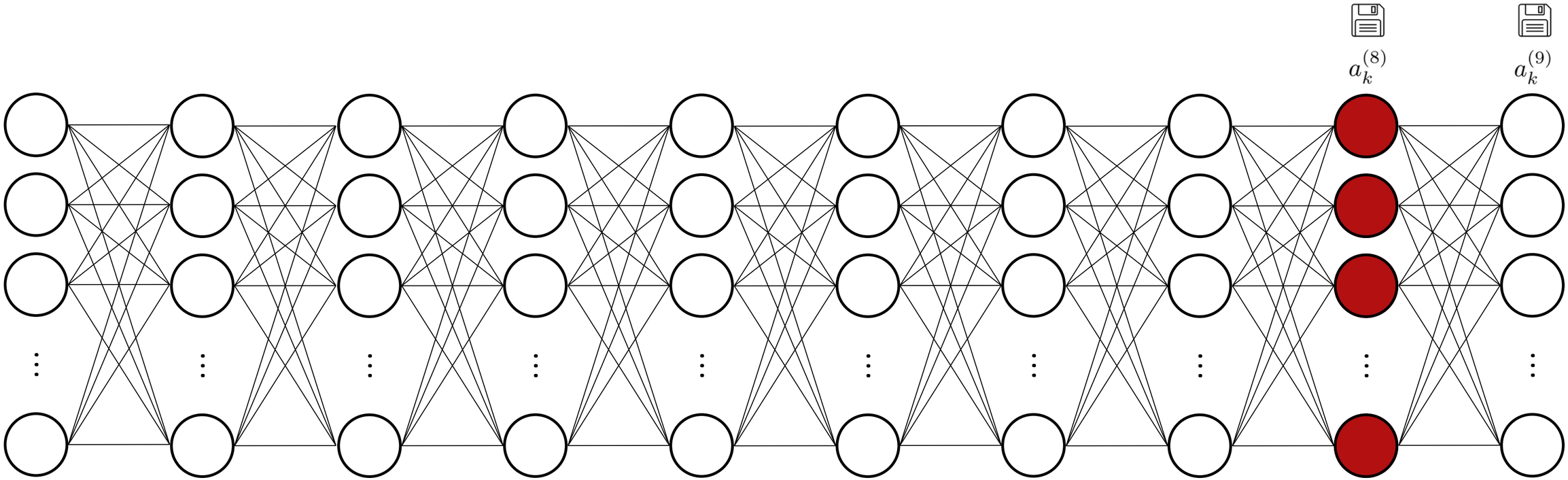

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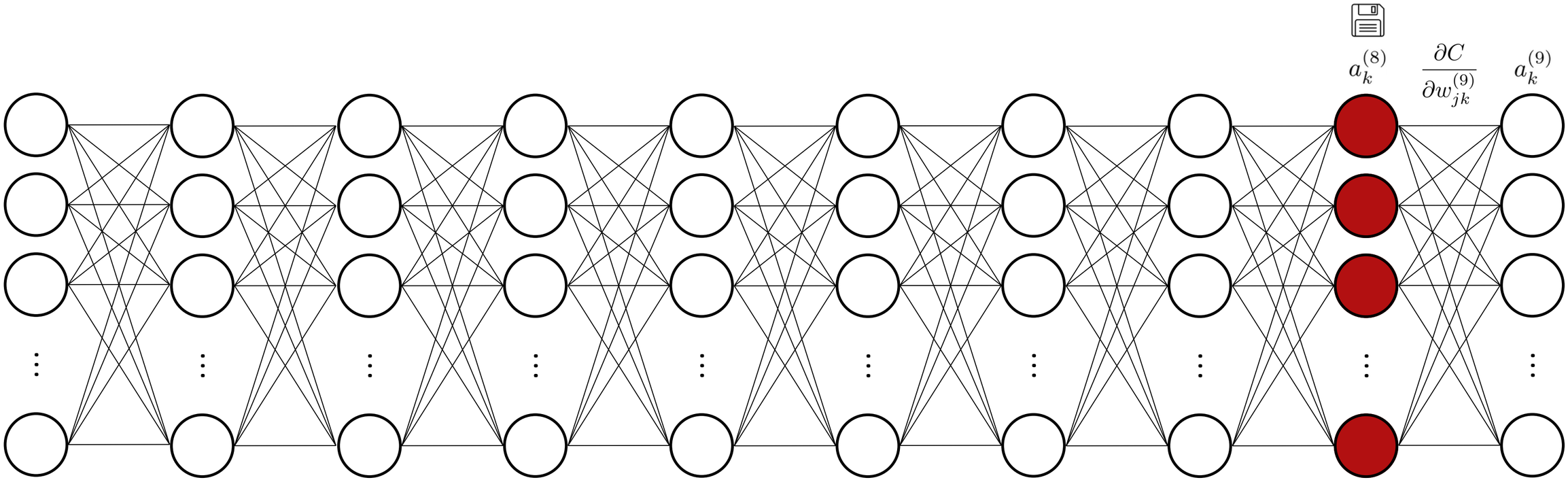

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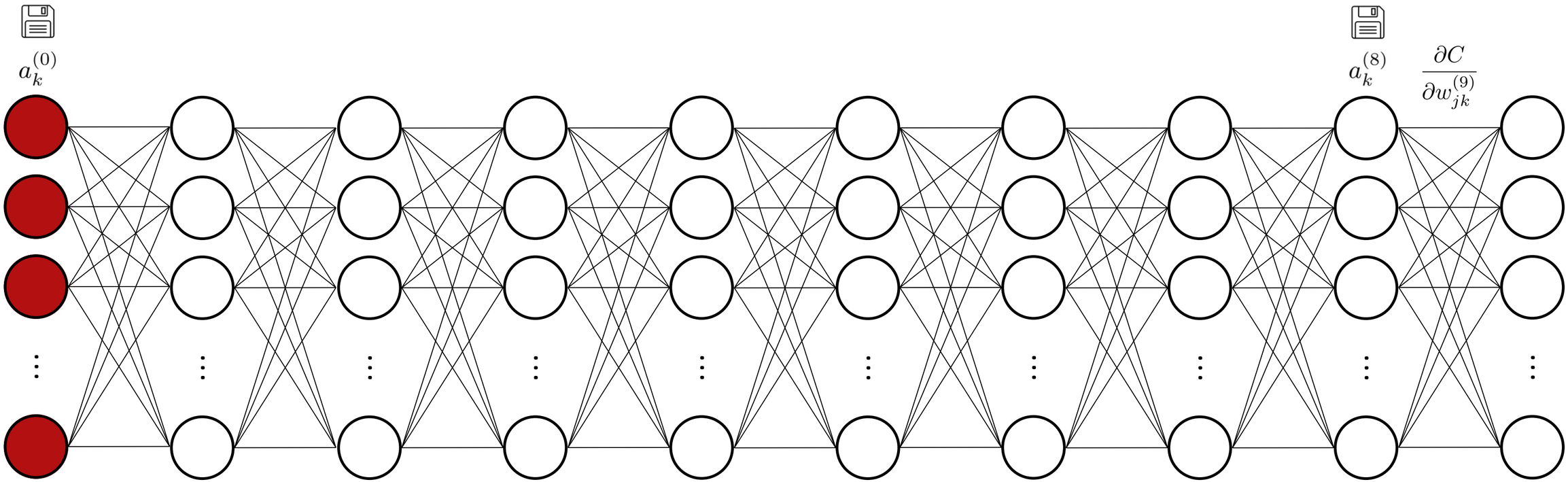

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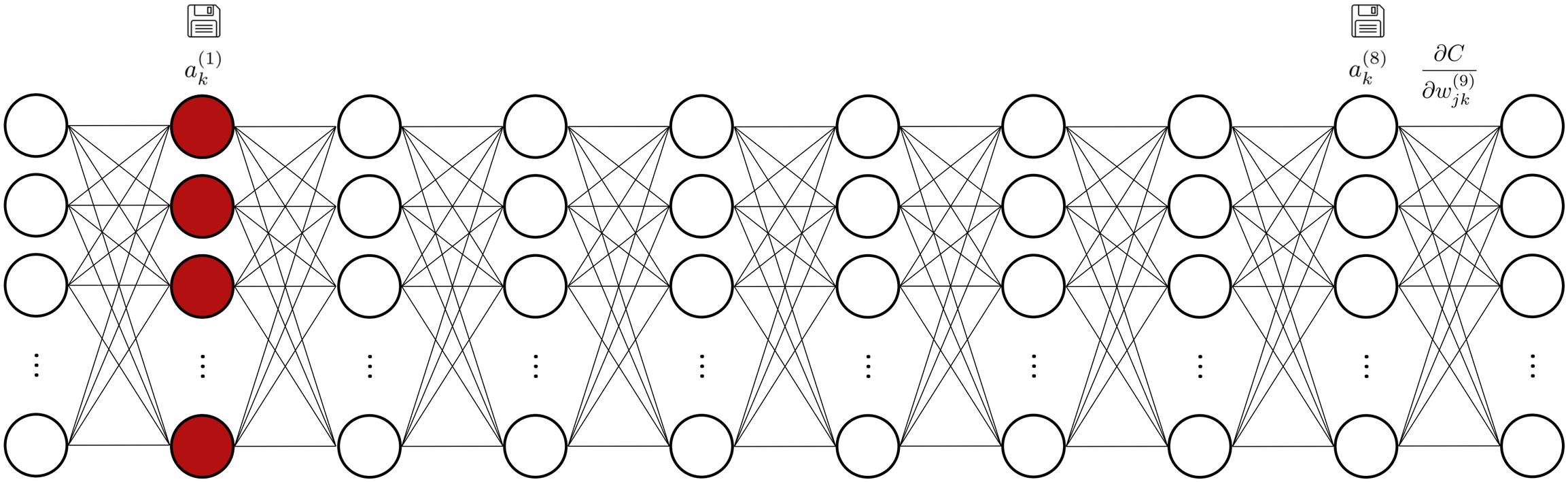

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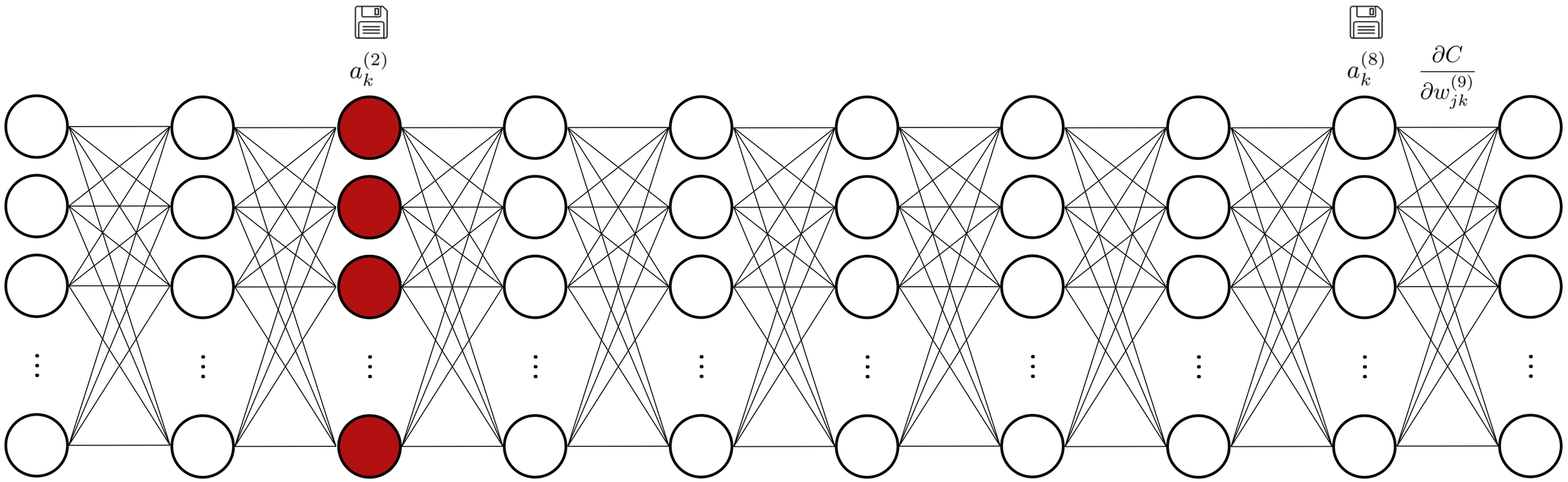

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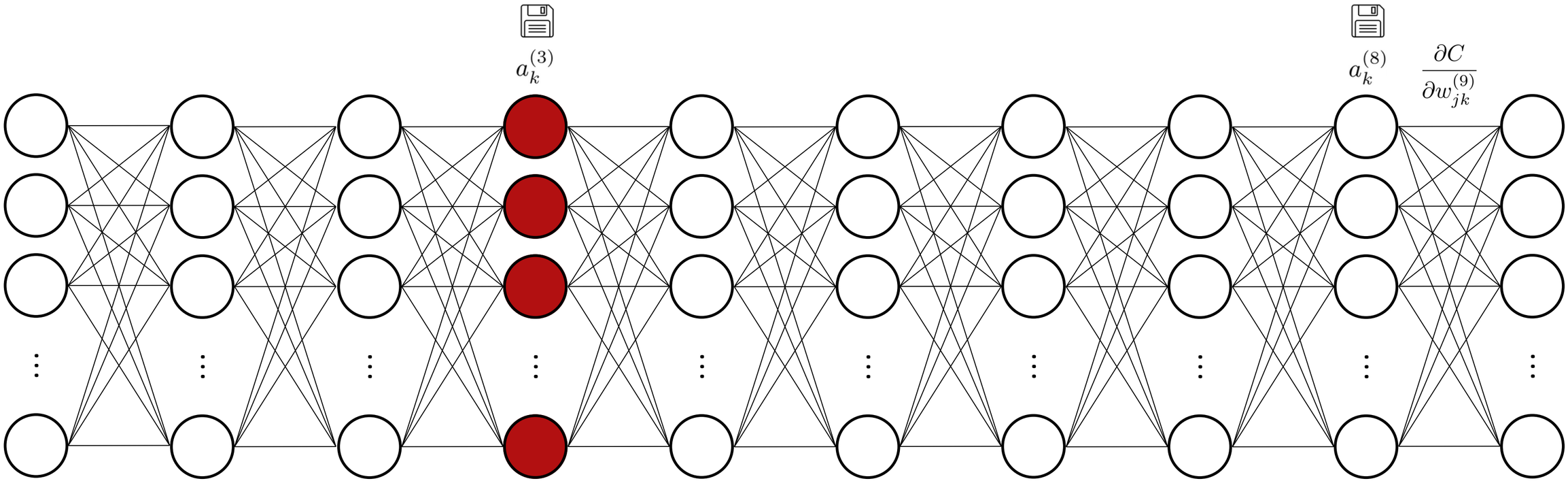

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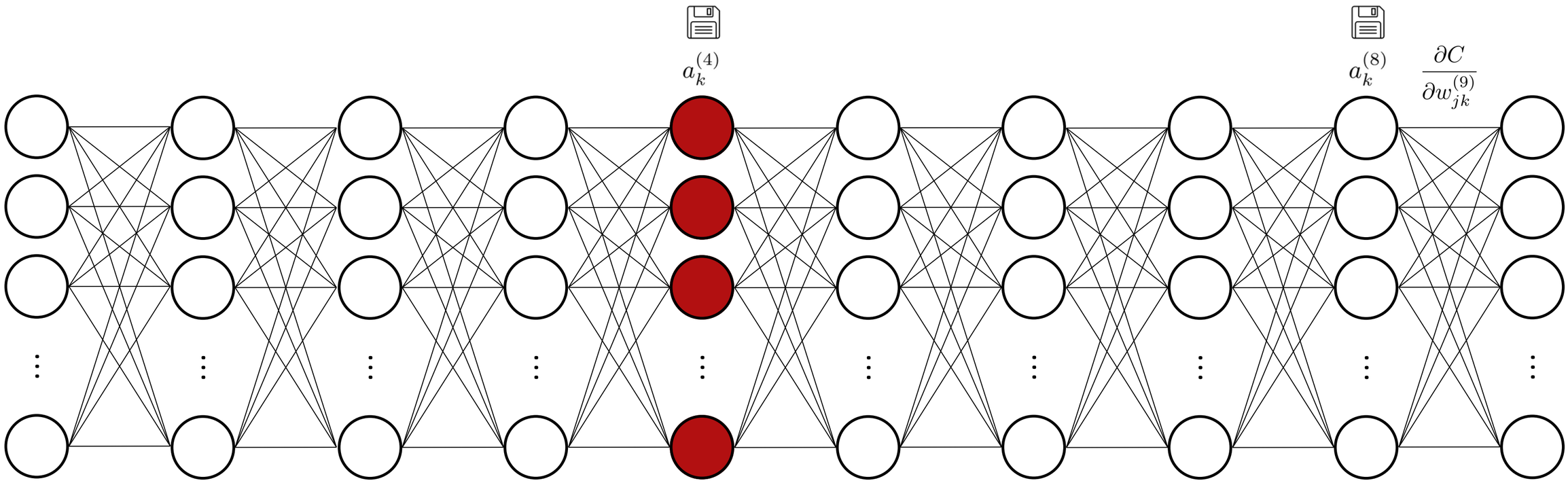
$$\delta_j^{(l)} = \sum_k \delta_k^{(l+1)}\, w_{kj}^{(l+1)}\, a_j^{(l)} \left(1 - a_j^{(l)}\right) \qquad \delta_j^{(L)} = 2\left(y_j - a_j^{(L)}\right) a_j^{(L)} \left(1 - a_j^{(L)}\right)$$



Optimization Stack

Gradient Checkpointing

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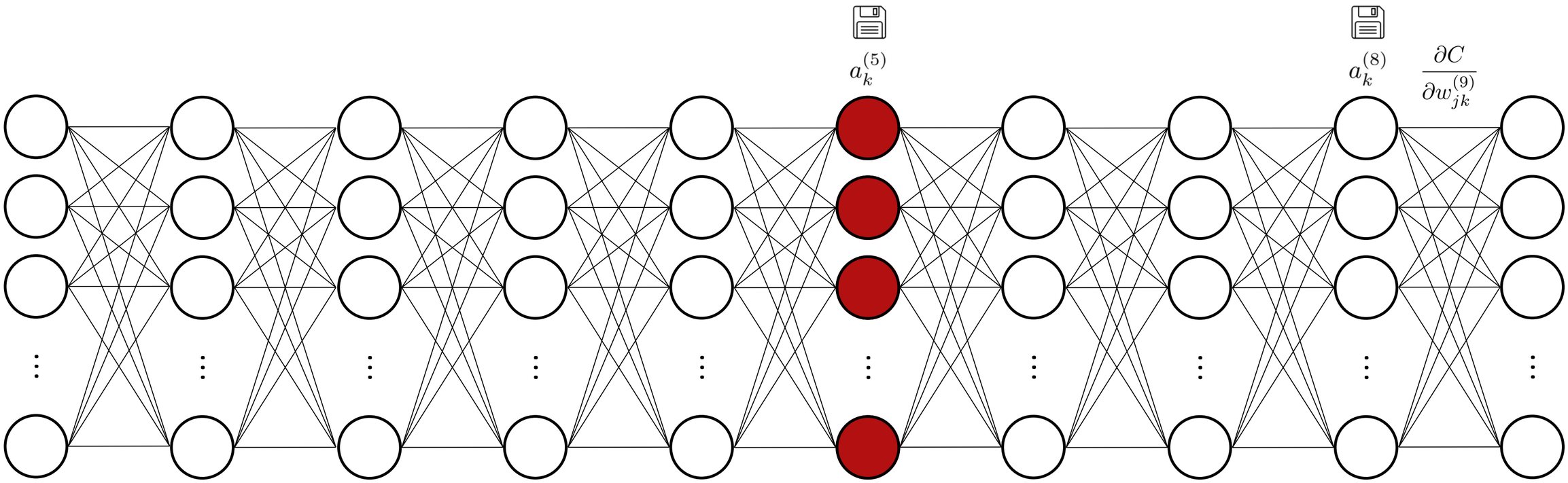

Optimization Stack

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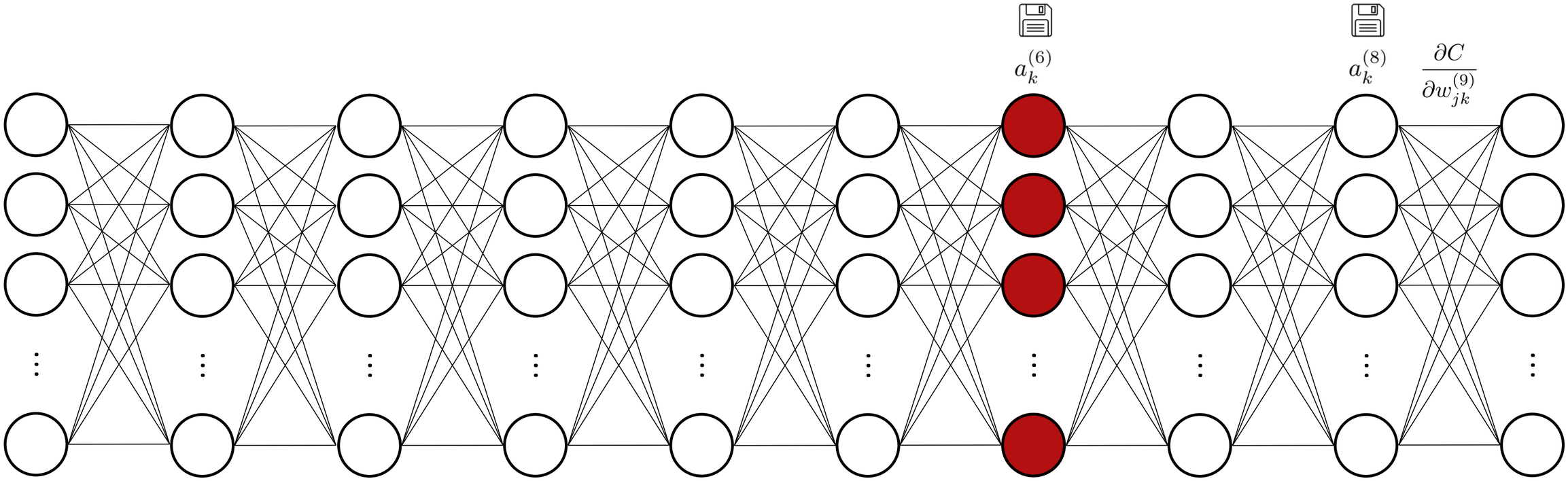

Optimization Stack

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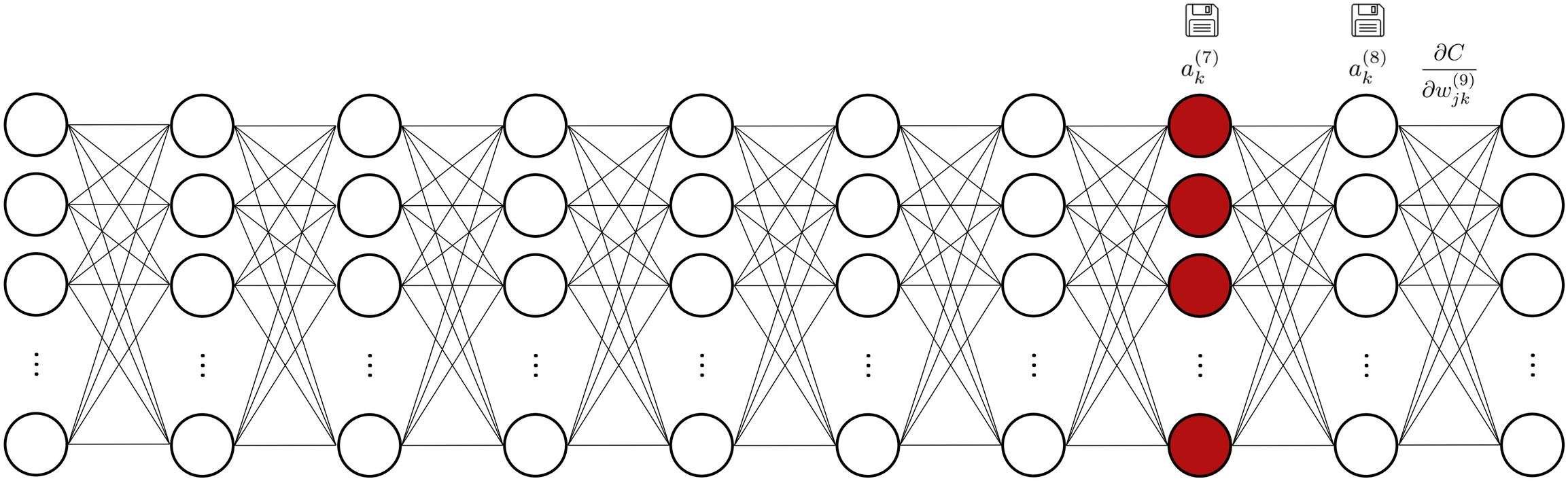

Optimization Stack

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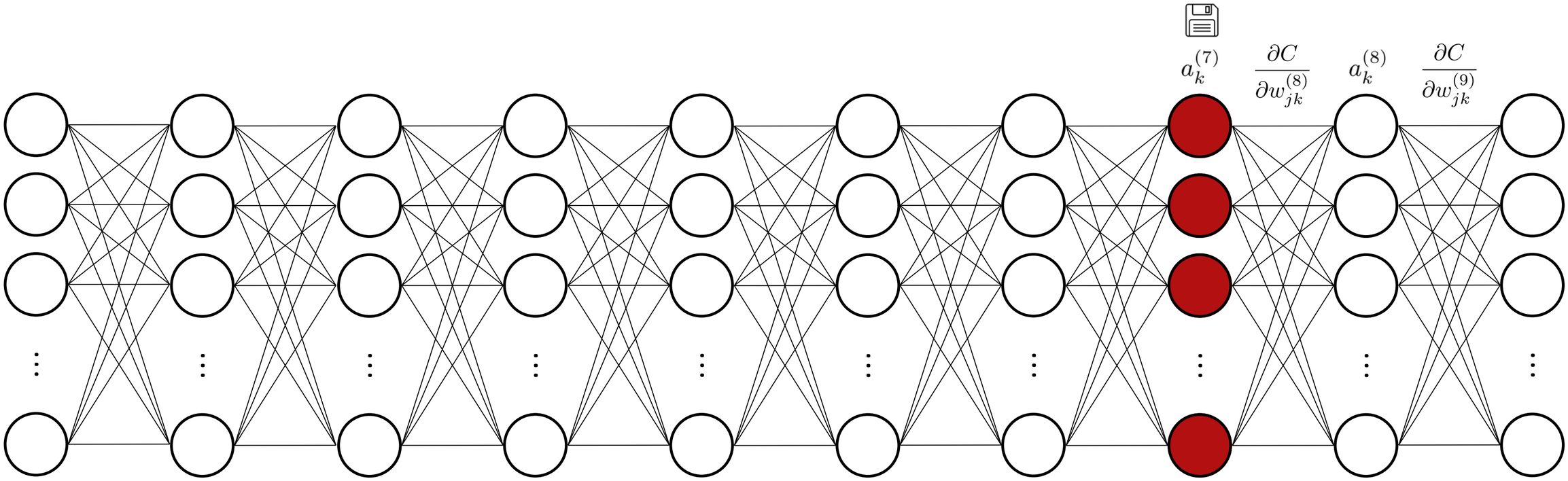

Optimization Stack

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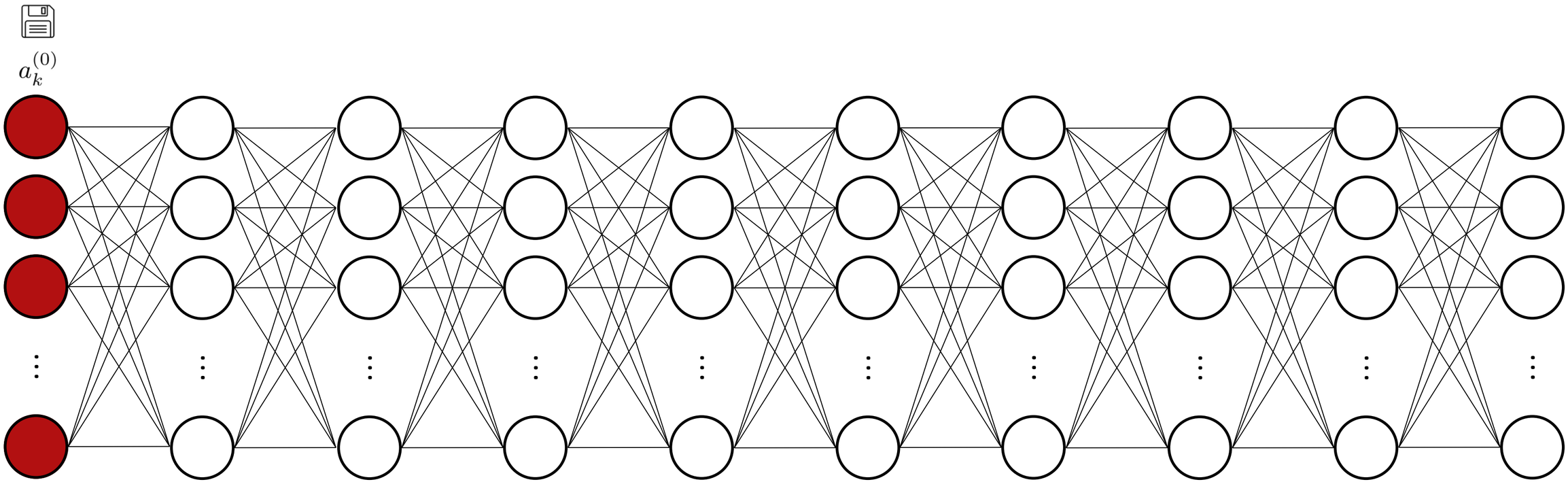

Optimization Stack

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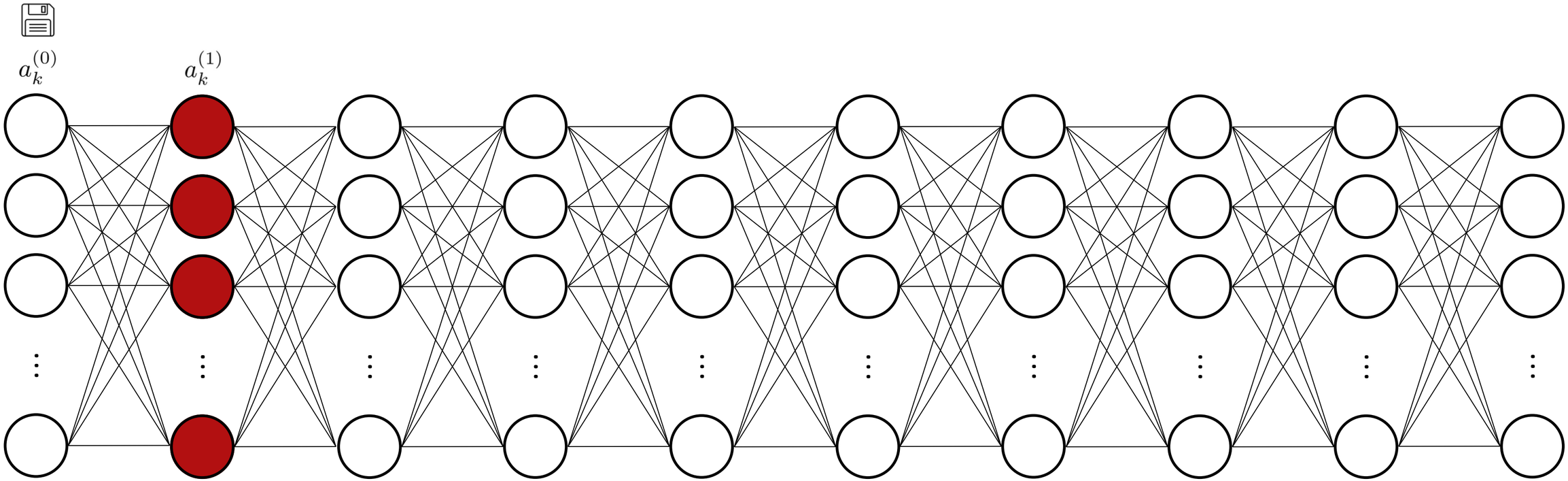

Optimization Stack

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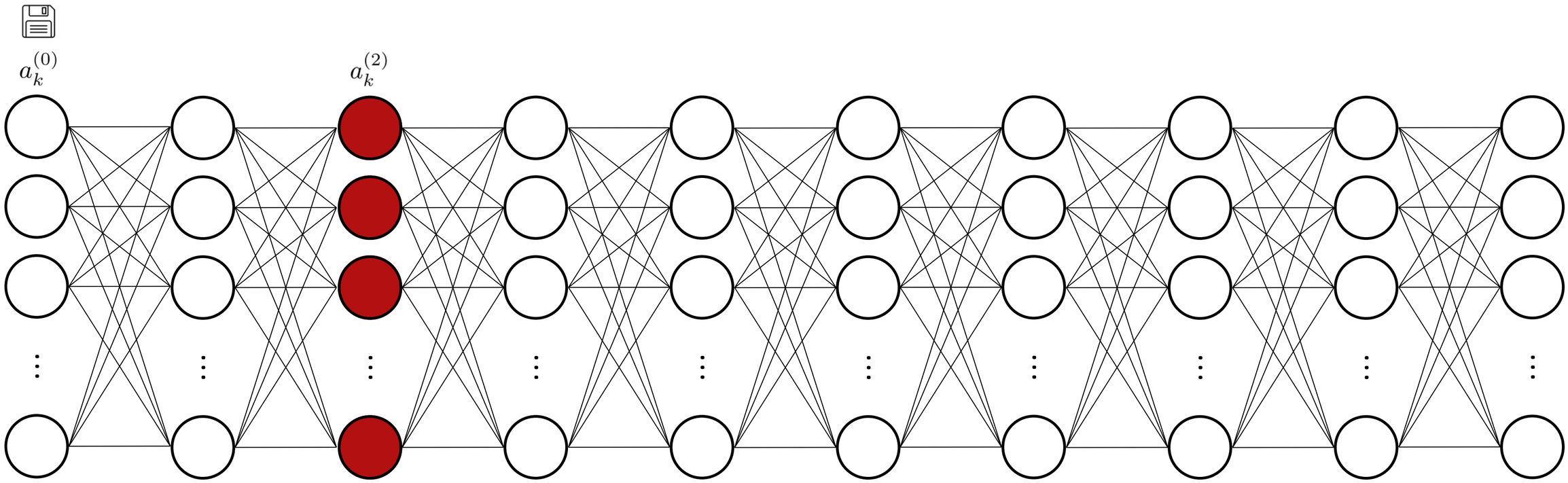

Optimization Stack

Gradient Checkpointing

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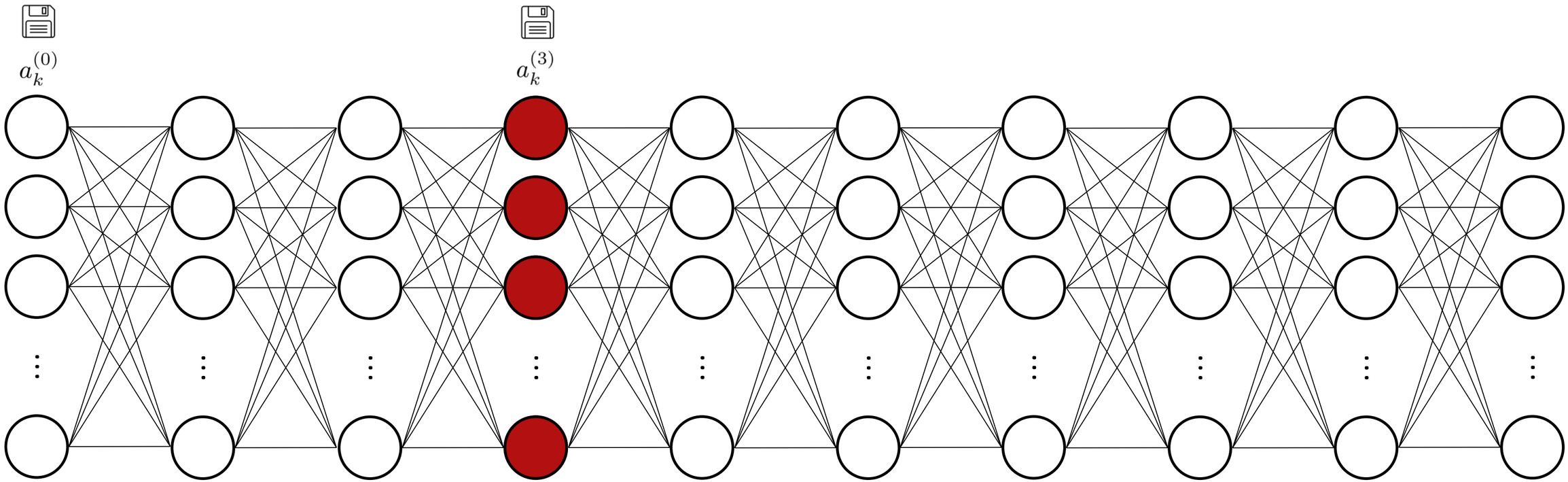

Optimization Stack

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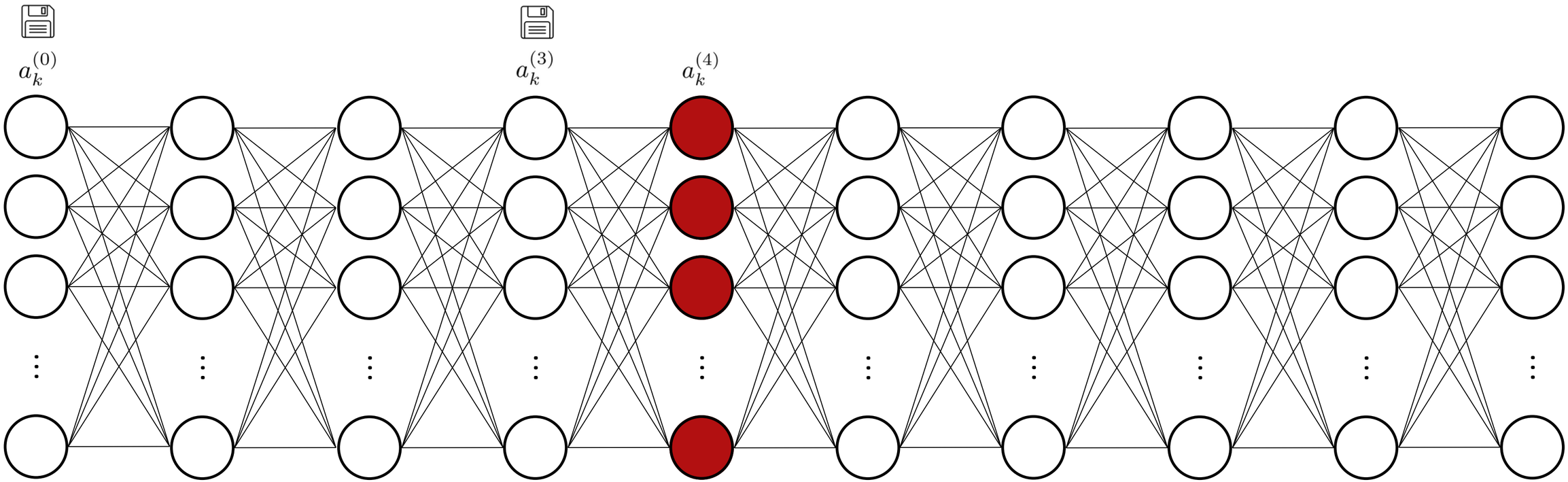

Optimization Stack

Gradient Checkpointing

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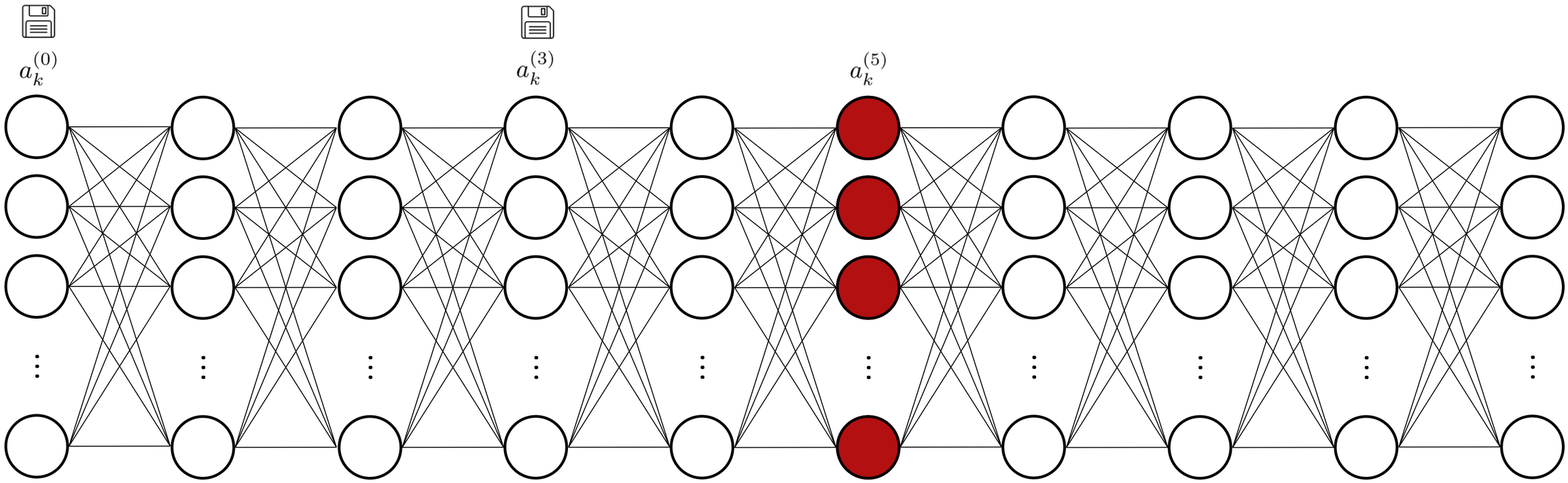

Optimization Stack

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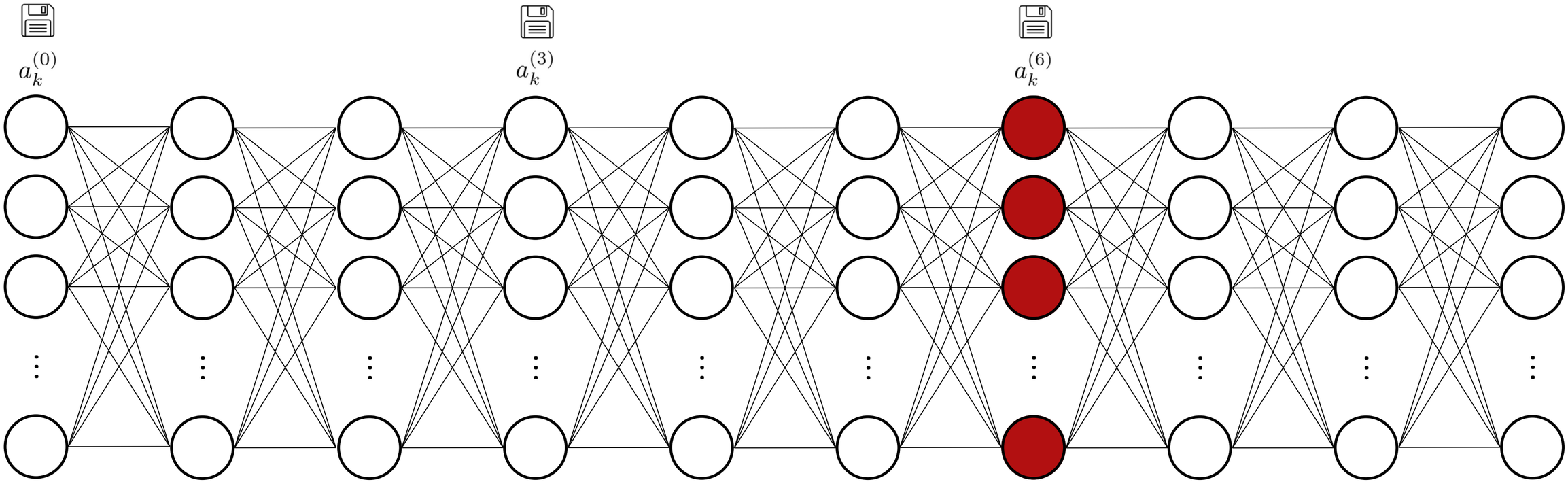

Optimization Stack

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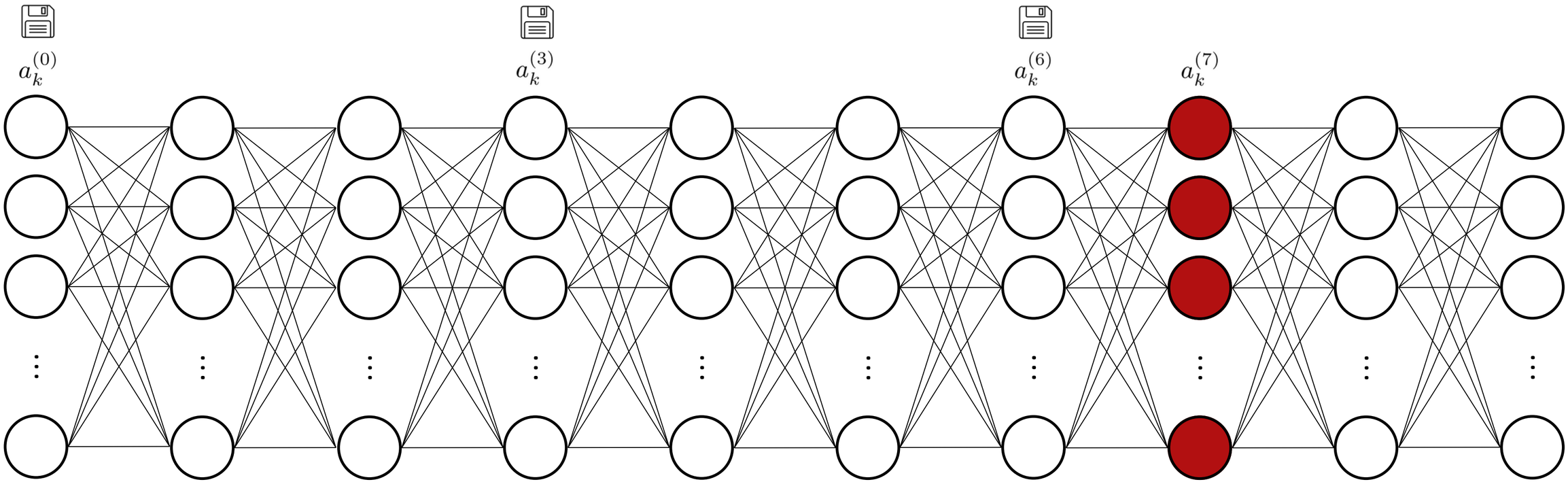

Optimization Stack

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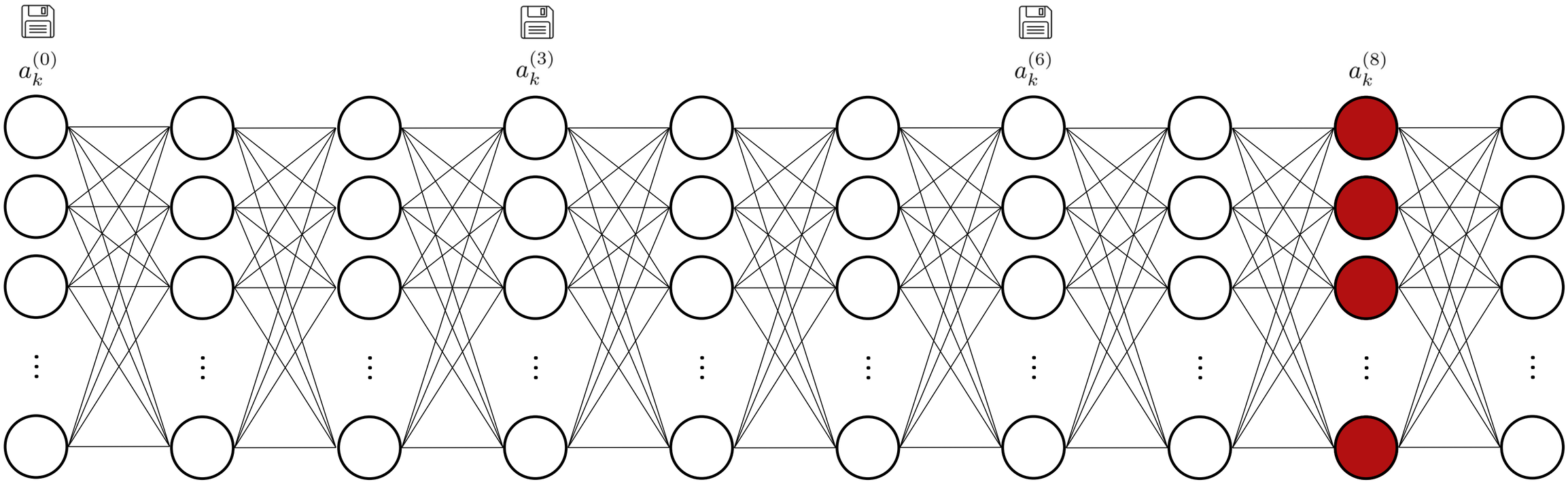

Optimization Stack

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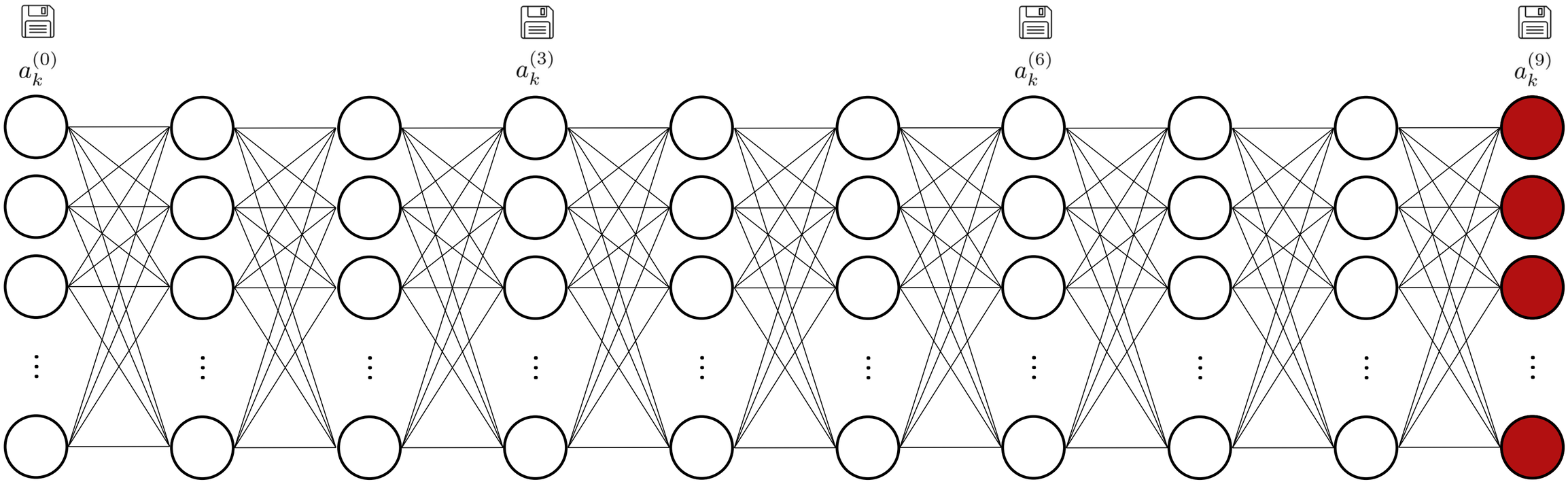

Optimization Stack

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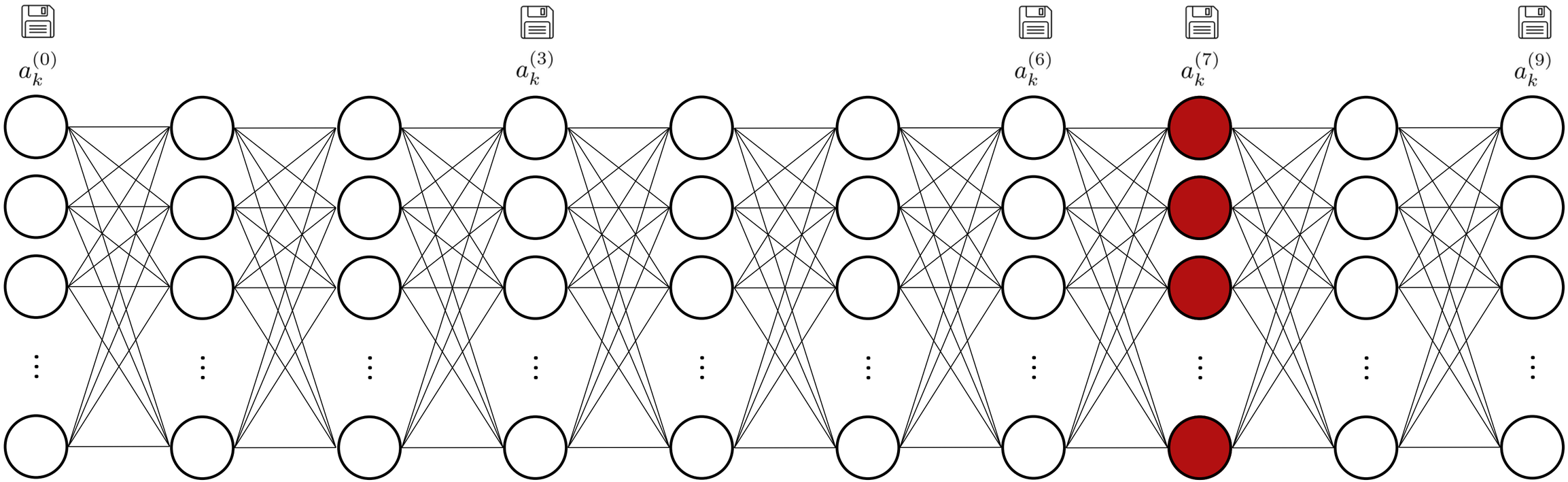

Optimization Stack

Gradient Checkpointing

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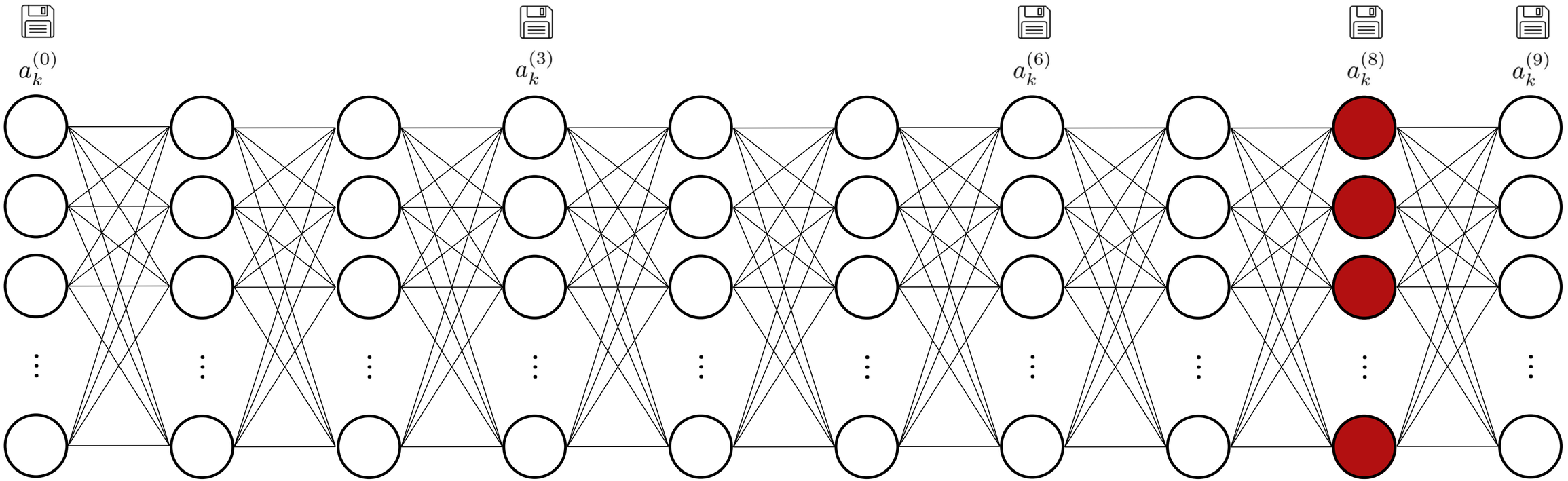

Optimization Stack

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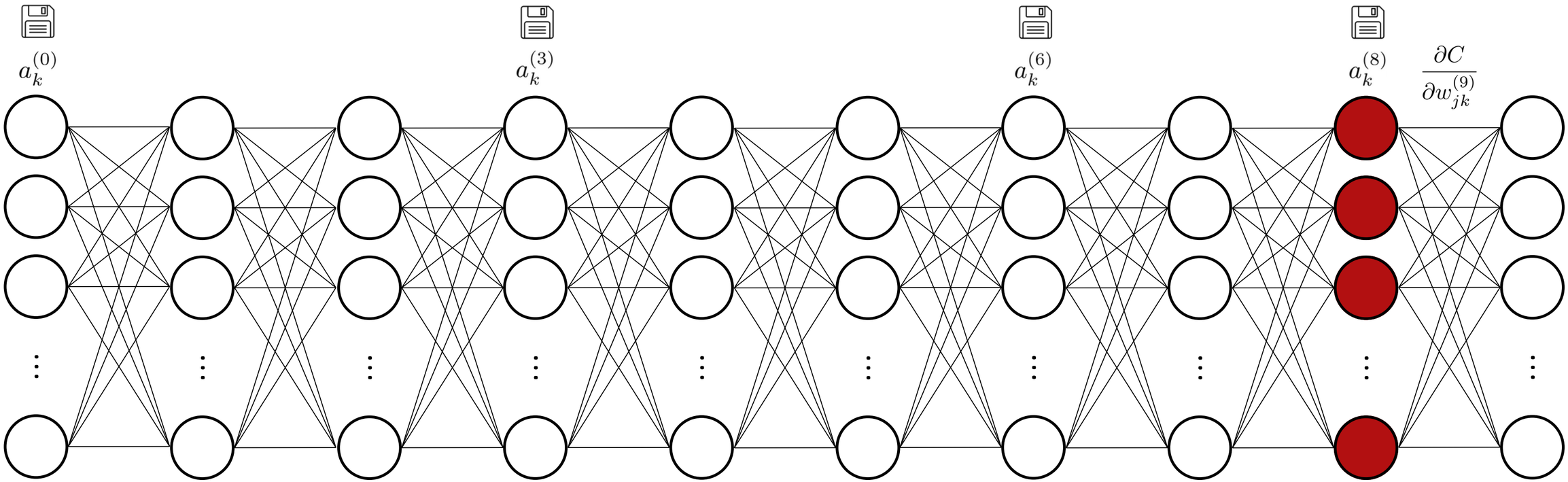

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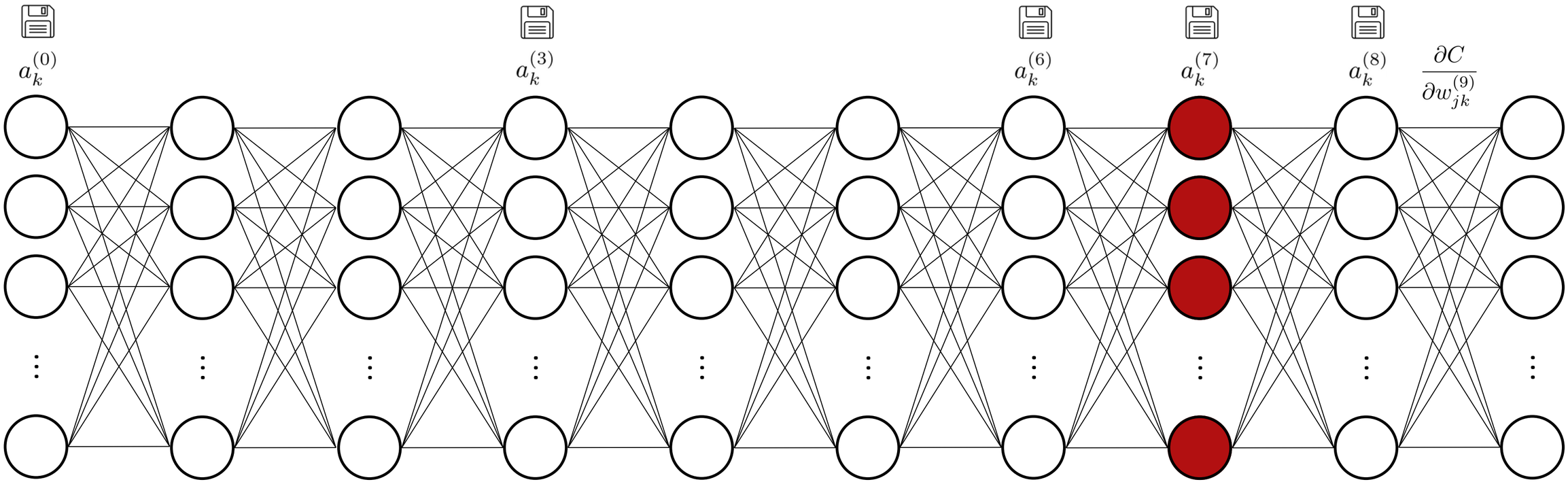

Optimization Stack

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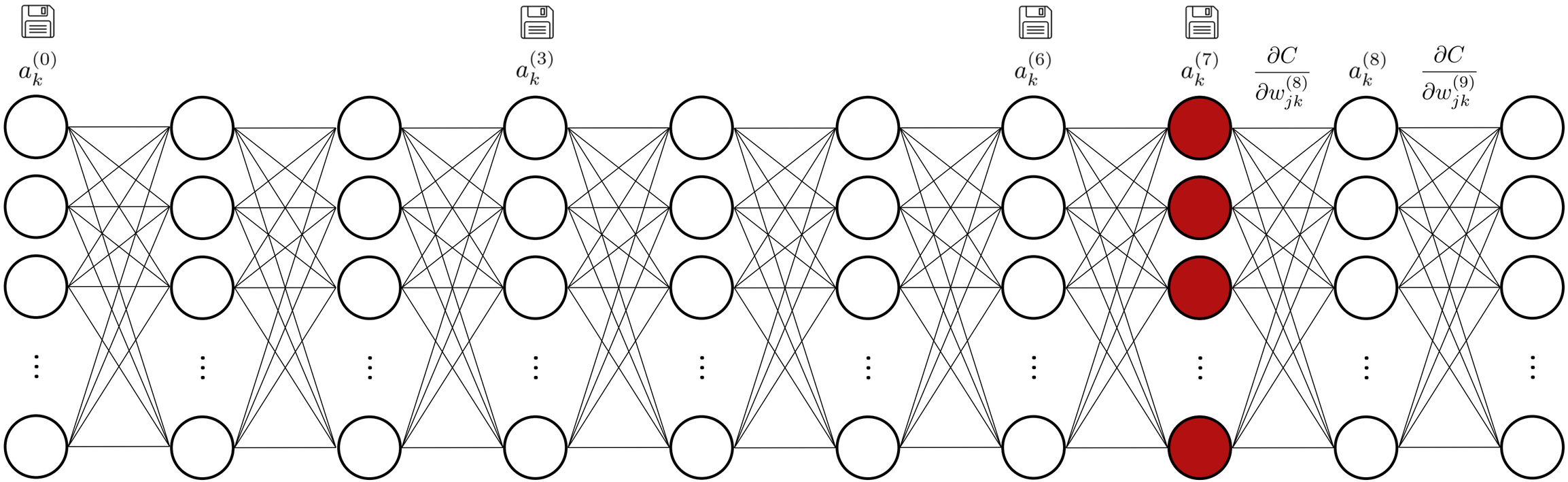

Optimization Stack

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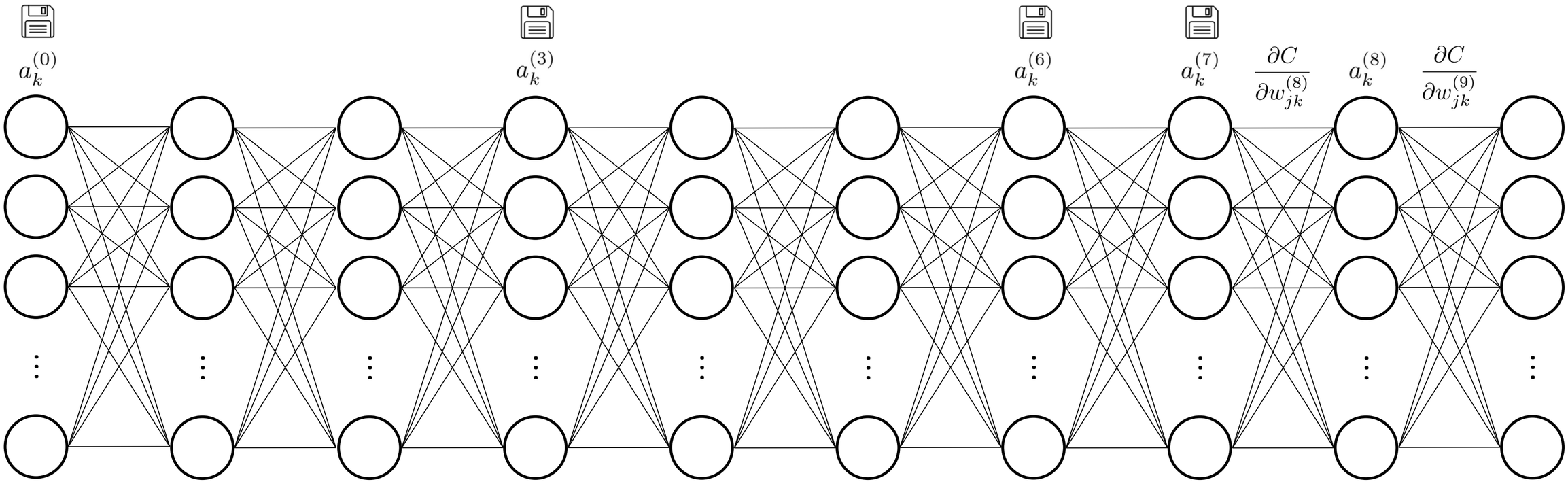

Optimization Stack

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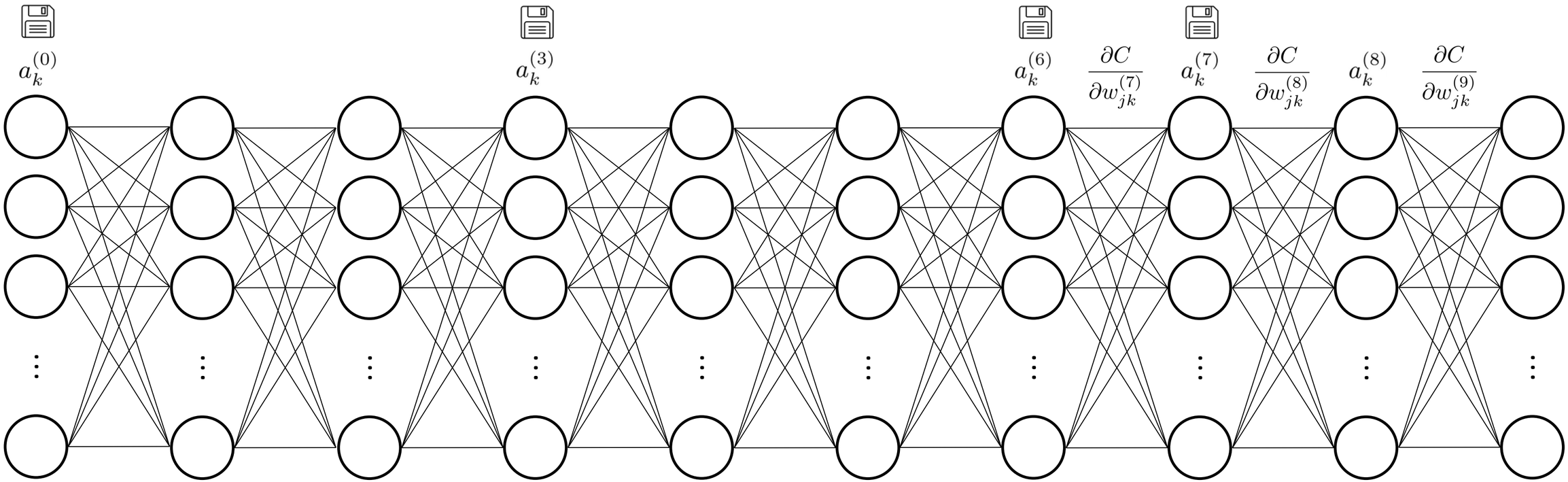

Optimization Stack

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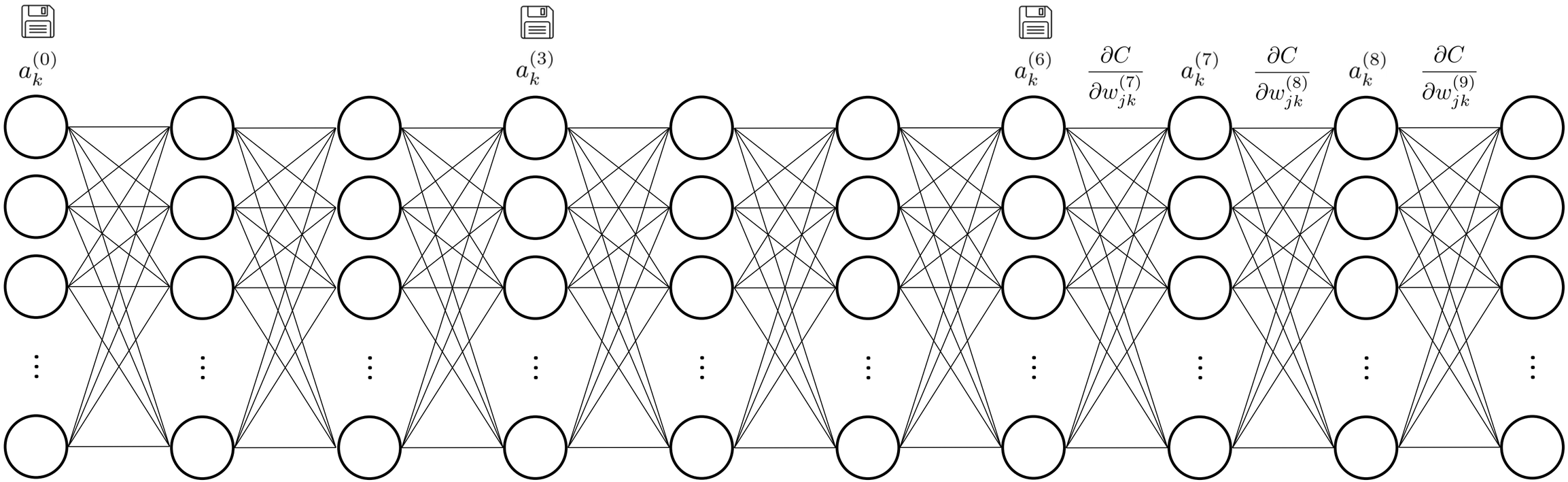
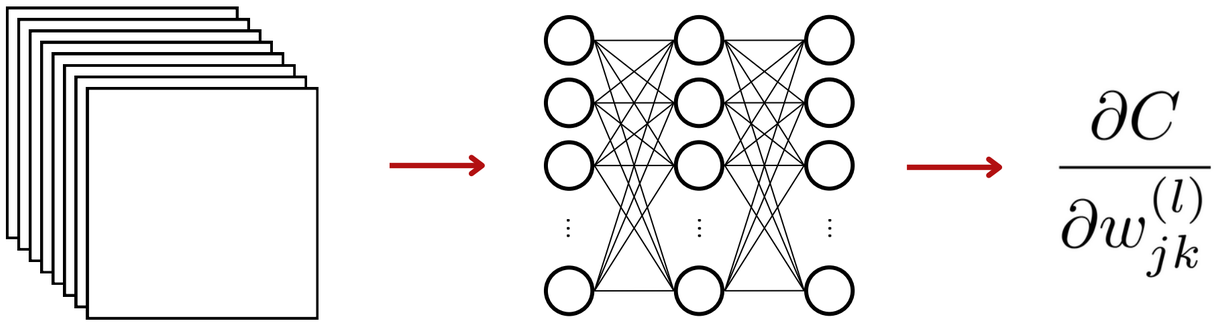


Optimization Stack

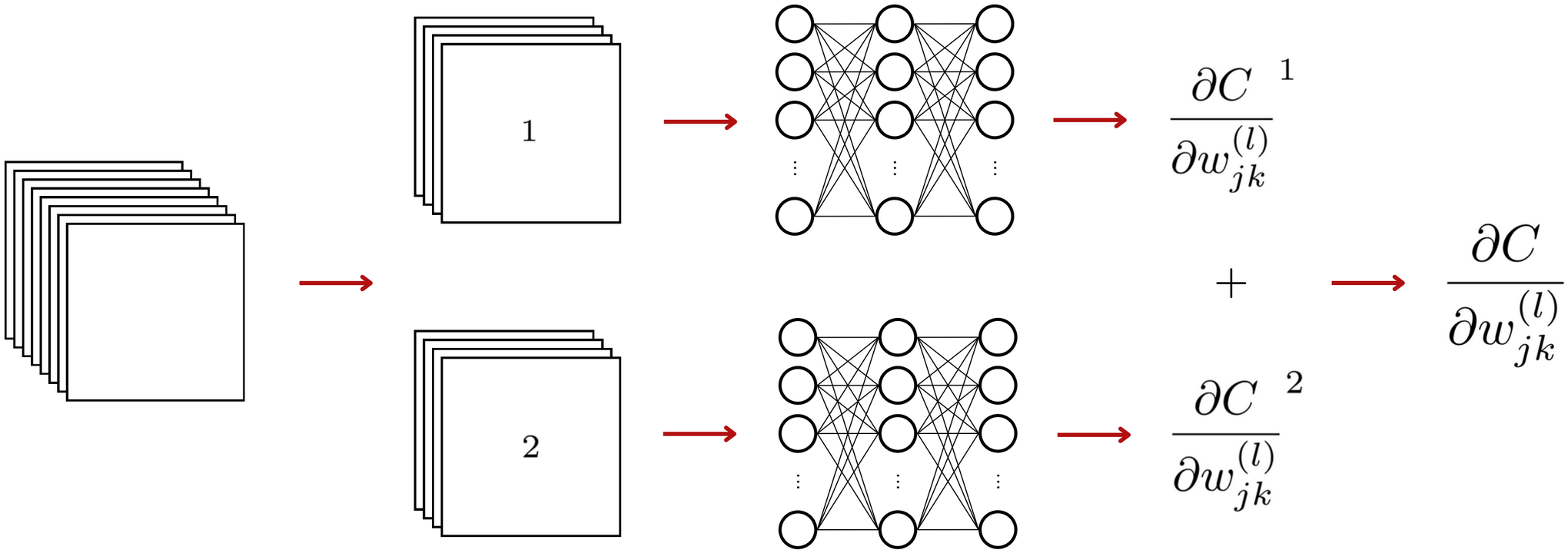
Microbatching



$$\frac{\partial C}{\partial w_{jk}^{(l)}}$$

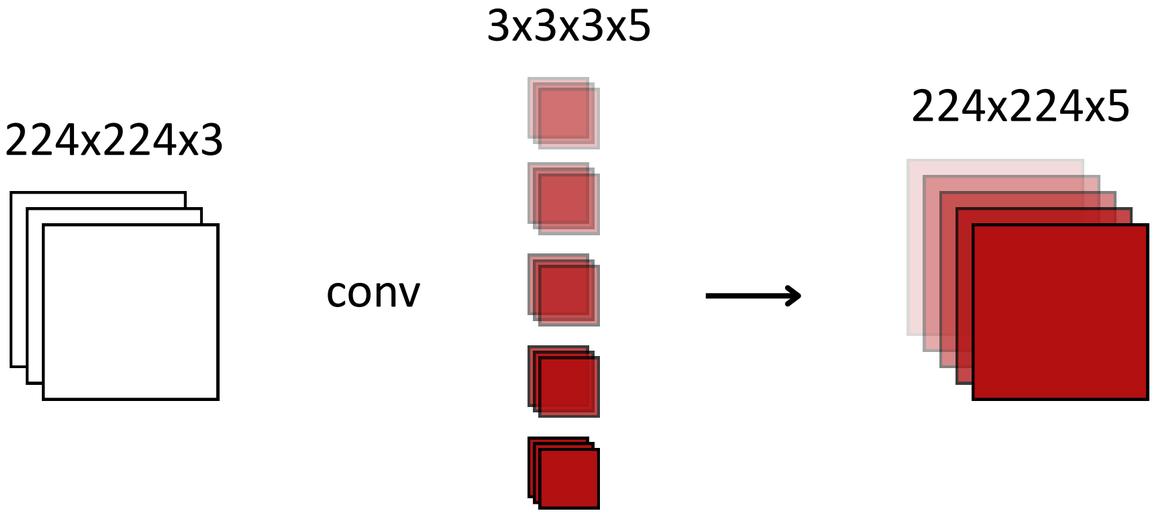
Optimization Stack

Microbatching



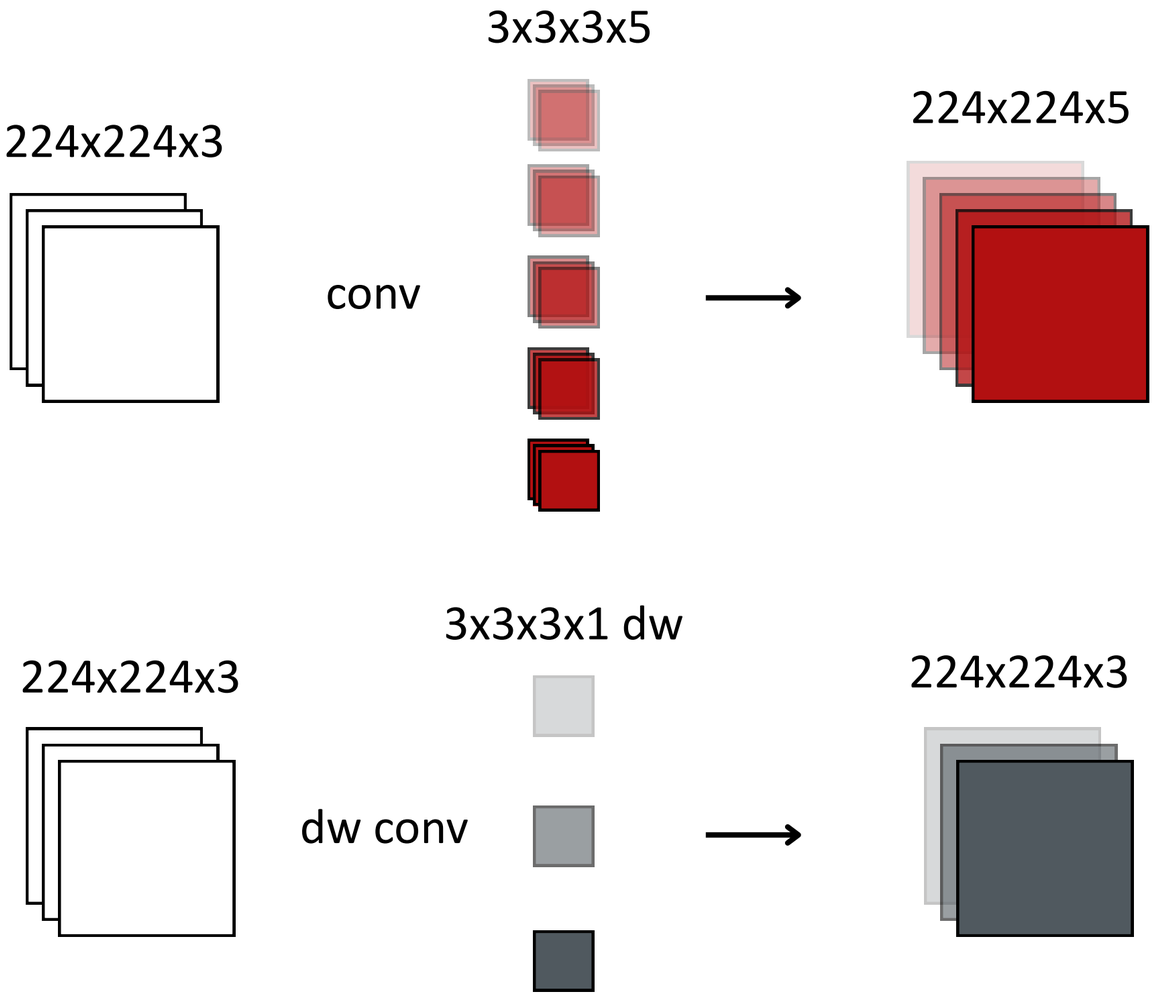
Optimization Stack

MobileNet



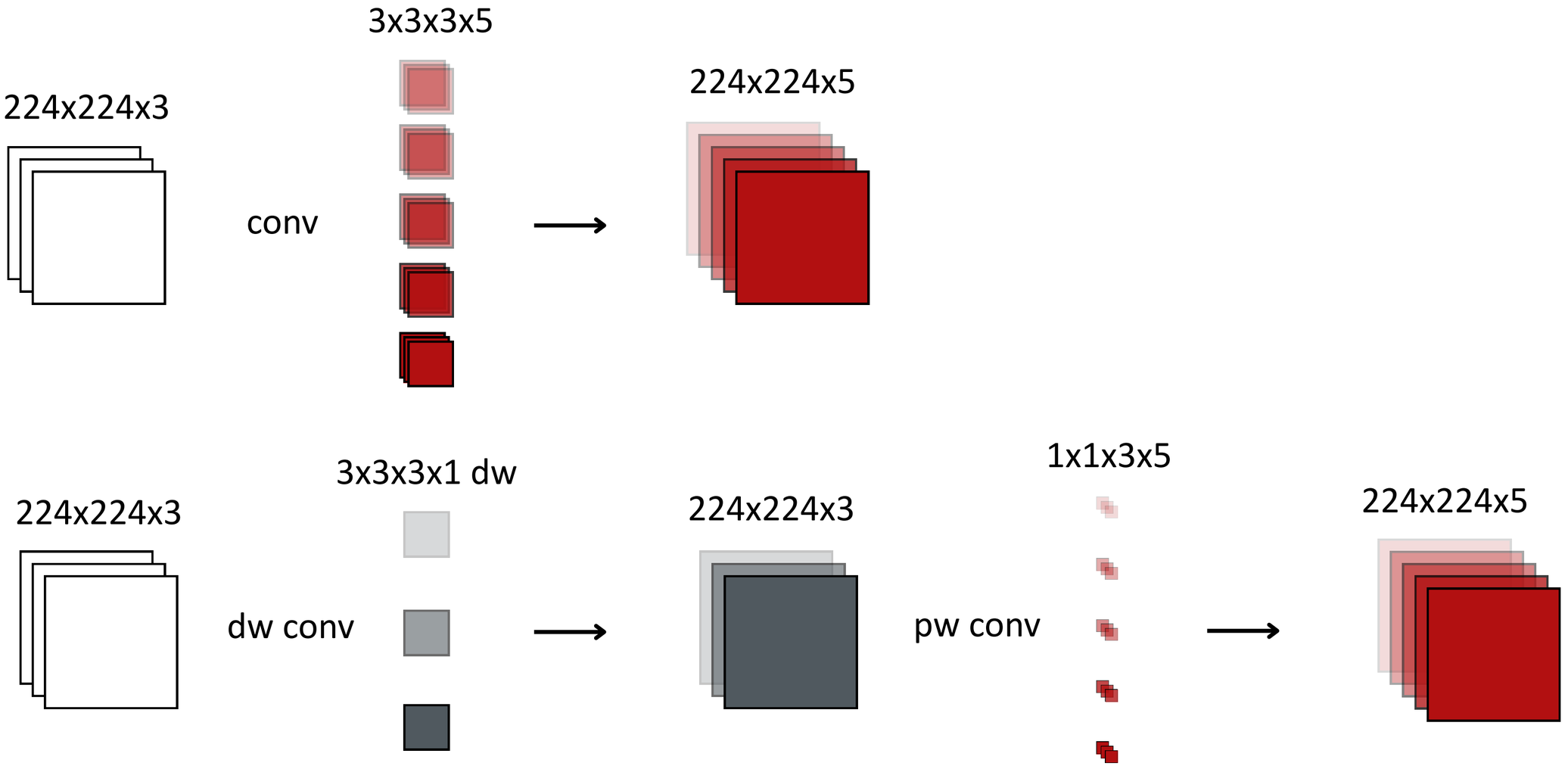
Optimization Stack

MobileNet



Optimization Stack

MobileNet



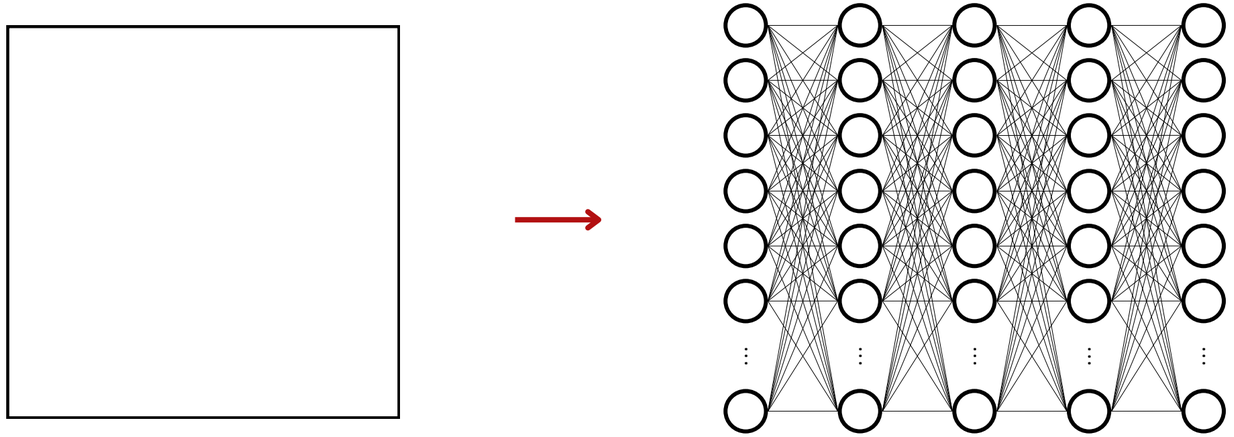
Optimization Stack

MobileNet

Layer	Input Size	Output Size	Filter Shape; Stride
Convolution	$224 \times 224 \times 3$	$112 \times 112 \times 32$	$3, 3, 3, 32; 2$
Depthwise Separable 1	$112 \times 112 \times 32$	$112 \times 112 \times 64$	$3, 3, 32, 1$ dw; 1 $1, 1, 32, 64; 1$
Depthwise Separable 2	$112 \times 112 \times 64$	$56 \times 56 \times 128$	$3, 3, 64, 1$ dw; 2 $1, 1, 64, 128; 1$
Depthwise Separable 3	$56 \times 56 \times 128$	$56 \times 56 \times 128$	$3, 3, 128, 1$ dw; 1 $1, 1, 128, 128; 1$
Depthwise Separable 4	$56 \times 56 \times 128$	$28 \times 28 \times 256$	$3, 3, 128, 1$ dw; 2 $1, 1, 128, 256; 1$
Depthwise Separable 5	$28 \times 28 \times 256$	$28 \times 28 \times 256$	$3, 3, 256, 1$ dw; 1 $1, 1, 256, 256; 1$
Depthwise Separable 6	$28 \times 28 \times 256$	$14 \times 14 \times 512$	$3, 3, 256, 1$ dw; 2 $1, 1, 256, 512; 1$
Depthwise Separable 7–11	$14 \times 14 \times 512$	$14 \times 14 \times 512$	[$3, 3, 512, 1$ dw; 1 $1, 1, 512, 512; 1$] $\times 5$
Depthwise Separable 12	$14 \times 14 \times 512$	$7 \times 7 \times 1024$	$3, 3, 512, 1$ dw; 2 $1, 1, 512, 1024; 1$
Depthwise Separable 13	$7 \times 7 \times 1024$	$7 \times 7 \times 1024$	$3, 3, 1024, 1,$ dw; 1 $1, 1, 1024, 1024; 1$
Average Pool	$7 \times 7 \times 1024$	1024	$7, 7$
Fully Connected	1024	8	$1024, 8$

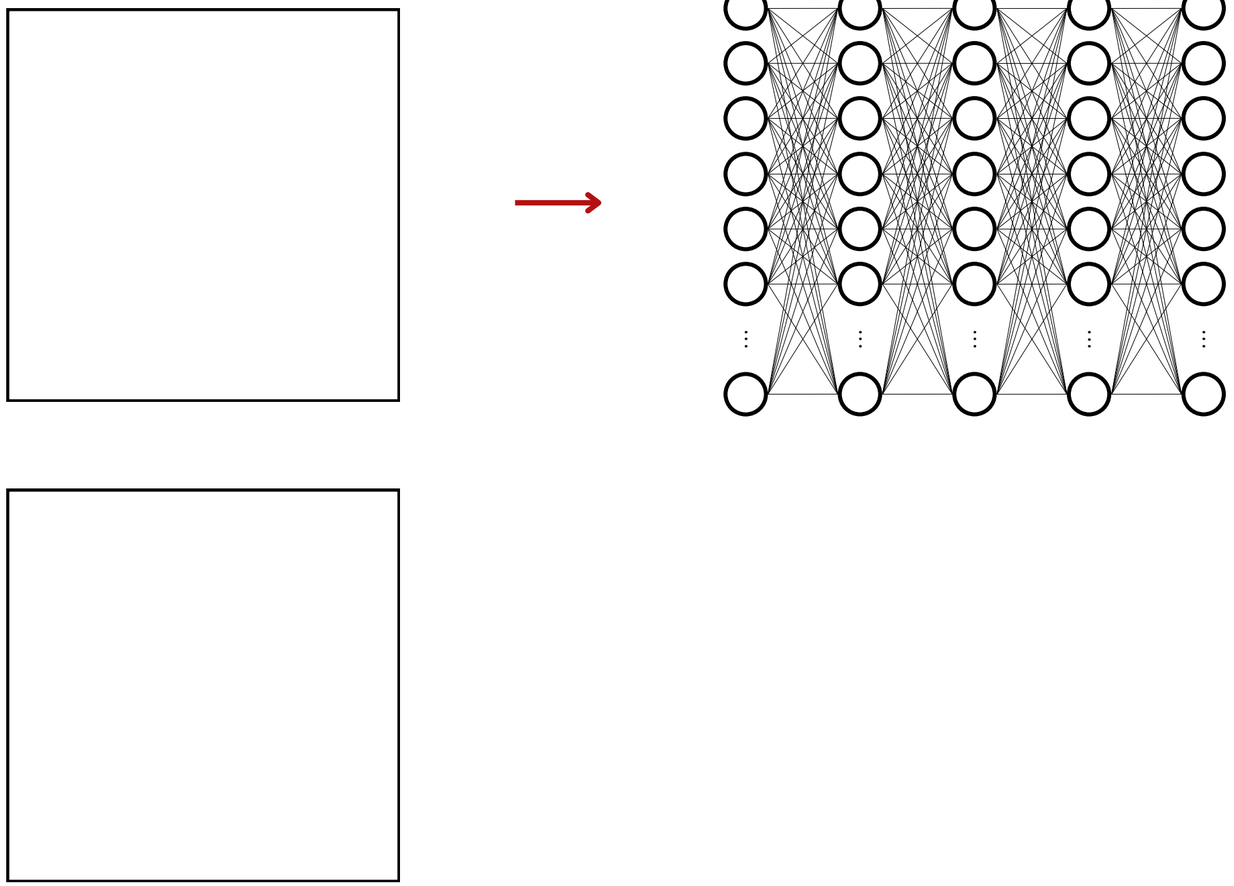
Optimization Stack

Patching



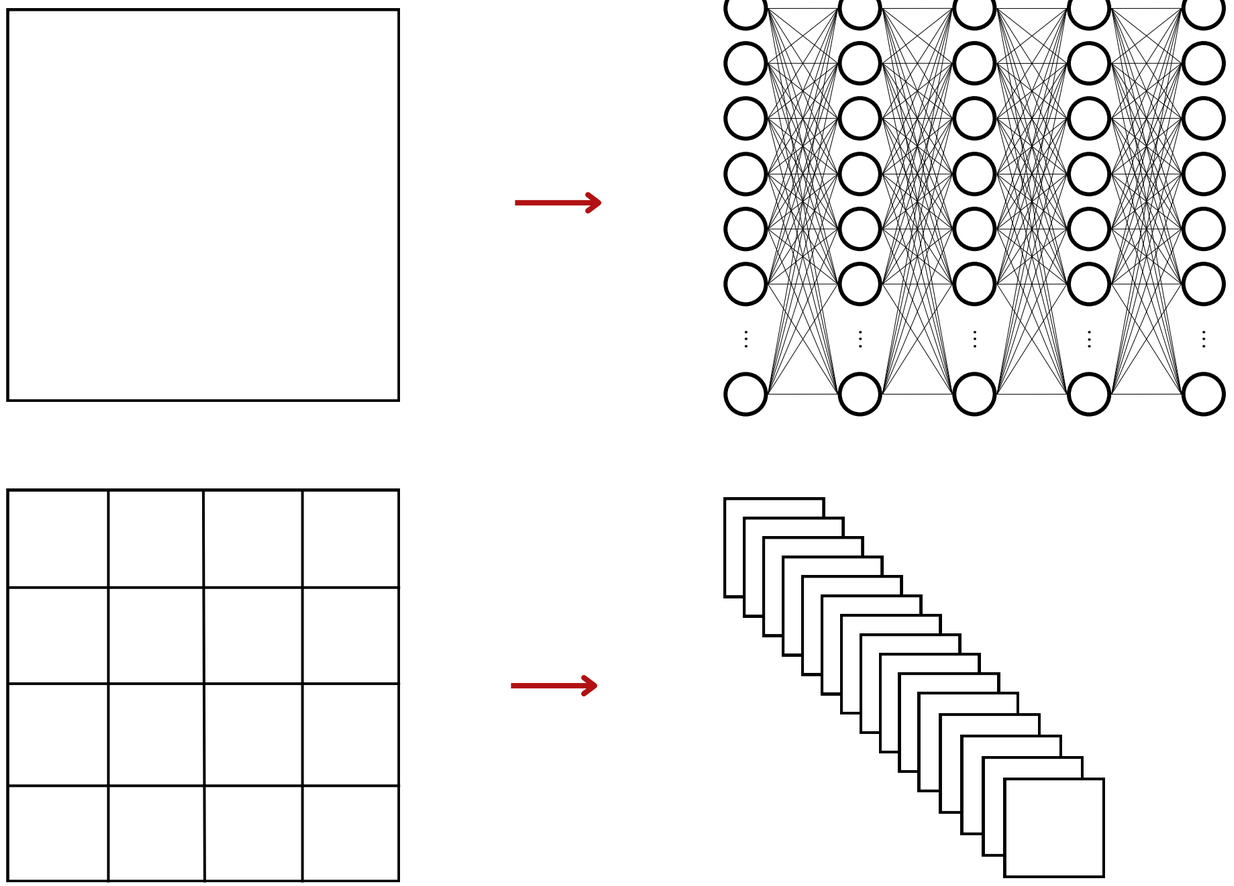
Optimization Stack

Patching



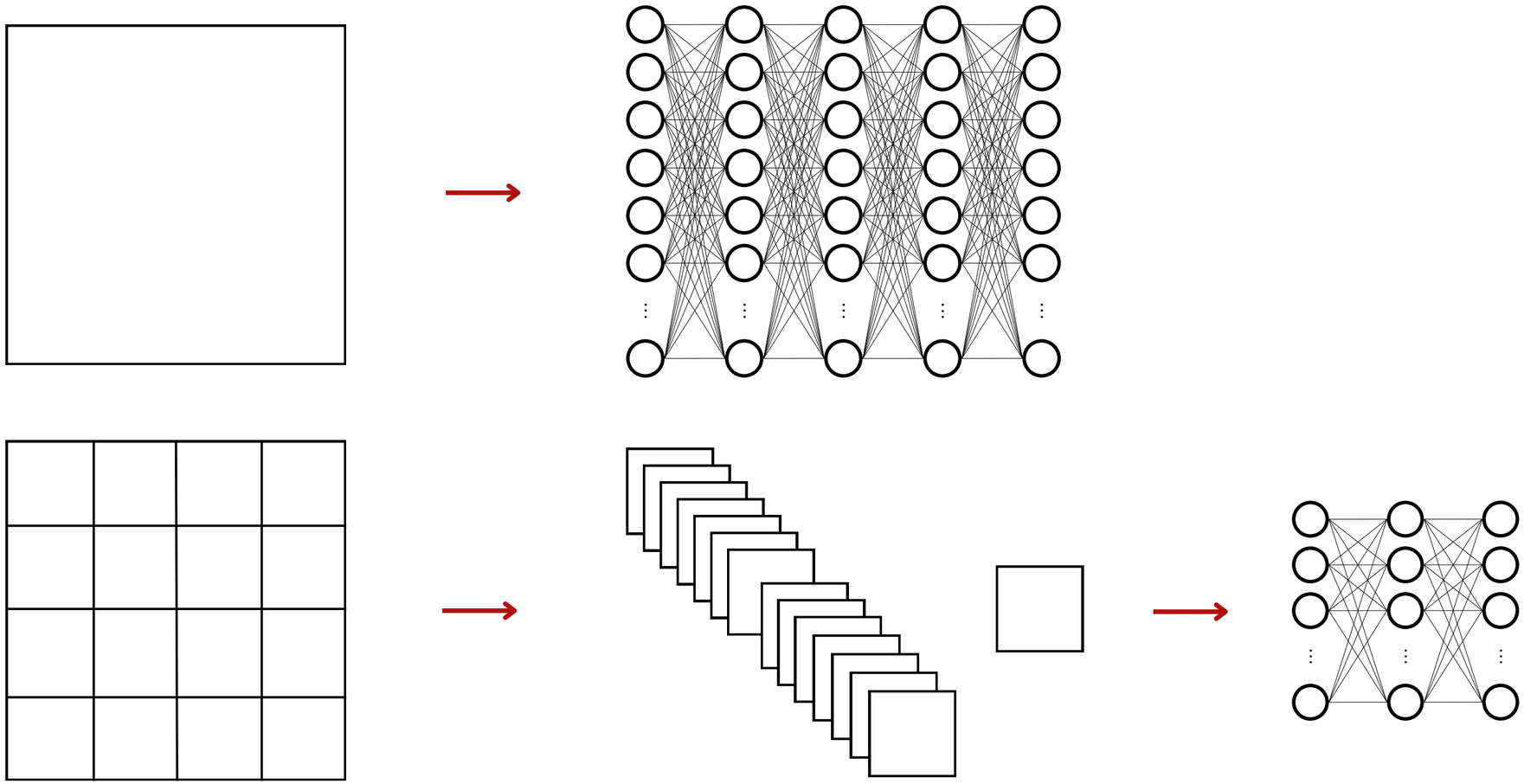
Optimization Stack

Patching



Optimization Stack

Patching

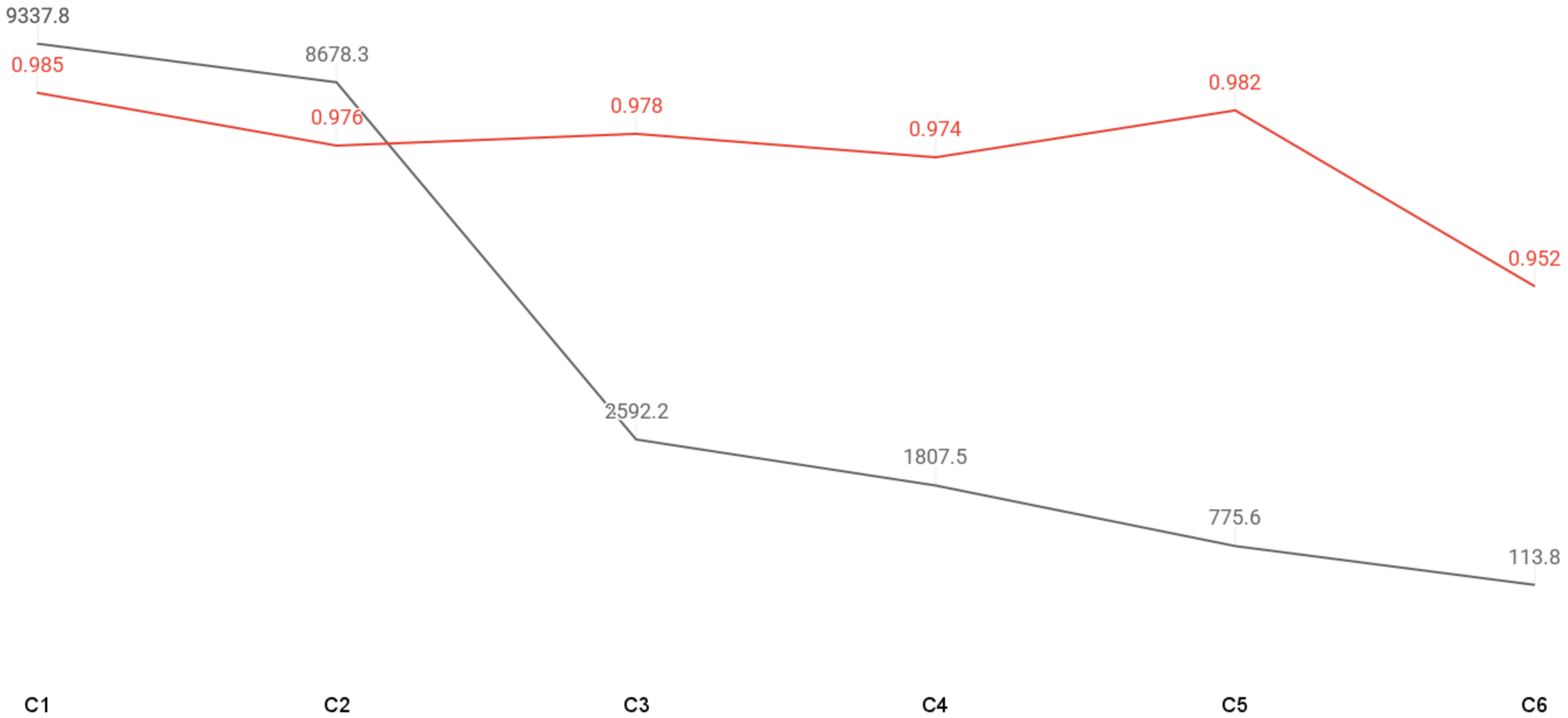


Optimization Stack

Patching

Layer	Input Size	Output Size	Filter Shape; Stride
Convolution	$32 \times 32 \times 3$	$32 \times 32 \times 32$	$3, 3, 3, 32; 1$
Depthwise Separable 1	$32 \times 32 \times 32$	$32 \times 32 \times 64$	$3, 3, 32, 1$ dw; 1 $1, 1, 32, 64; 1$
Depthwise Separable 2	$32 \times 32 \times 64$	$16 \times 16 \times 128$	$3, 3, 64, 1$ dw; 2 $1, 1, 64, 128; 1$
Depthwise Separable 3	$16 \times 16 \times 128$	$16 \times 16 \times 128$	$3, 3, 128, 1$ dw; 1 $1, 1, 128, 128; 1$
Depthwise Separable 4	$16 \times 16 \times 128$	$8 \times 8 \times 256$	$3, 3, 128, 1$ dw; 2 $1, 1, 128, 256; 1$
Depthwise Separable 5	$8 \times 8 \times 256$	$8 \times 8 \times 256$	$3, 3, 256, 1$ dw; 1 $1, 1, 256, 256; 1$
Depthwise Separable 6	$8 \times 8 \times 256$	$4 \times 4 \times 512$	$3, 3, 256, 1$ dw; 2 $1, 1, 256, 512; 1$
Depthwise Separable 7	$4 \times 4 \times 512$	$4 \times 4 \times 1024$	$3, 3, 512, 1$ dw; 1 $1, 1, 512, 1024; 1$
Depthwise Separable 8	$4 \times 4 \times 1024$	$4 \times 4 \times 1024$	$3, 3, 1024, 1$ dw; 1 $1, 1, 1024, 1024; 1$
Average Pool	$4 \times 4 \times 1024$	1024	$4, 4$
Fully Connected	1024	8	$1024, 8$

Results


9337.8
8678.3
2592.2
1807.5
775.6
113.8
0.985
0.976
0.978
0.974
0.982
0.952
C1
C2
C3
C4
C5
C6

Thank You