CNVLUTIN: Ineffectual-neuron-free DNN computing

J. Albericio, P. Judd, T. Hetherington*,
T. Aamodt*, N. E. Jerger, A. Moshovos

UNIVERSITY OF TORONTO

UBC *

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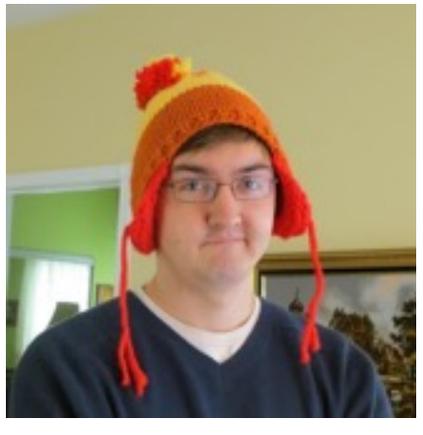
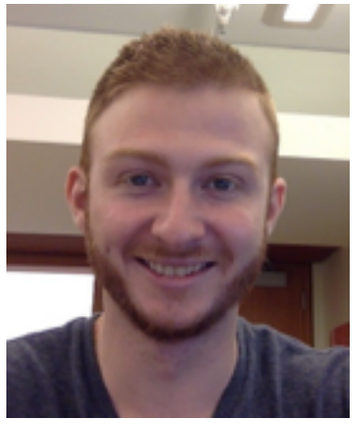
J. Albericio



P. Judd



T. Hetherington*

T. Aamodt*

N. Enright Jerger

A. Moshovos

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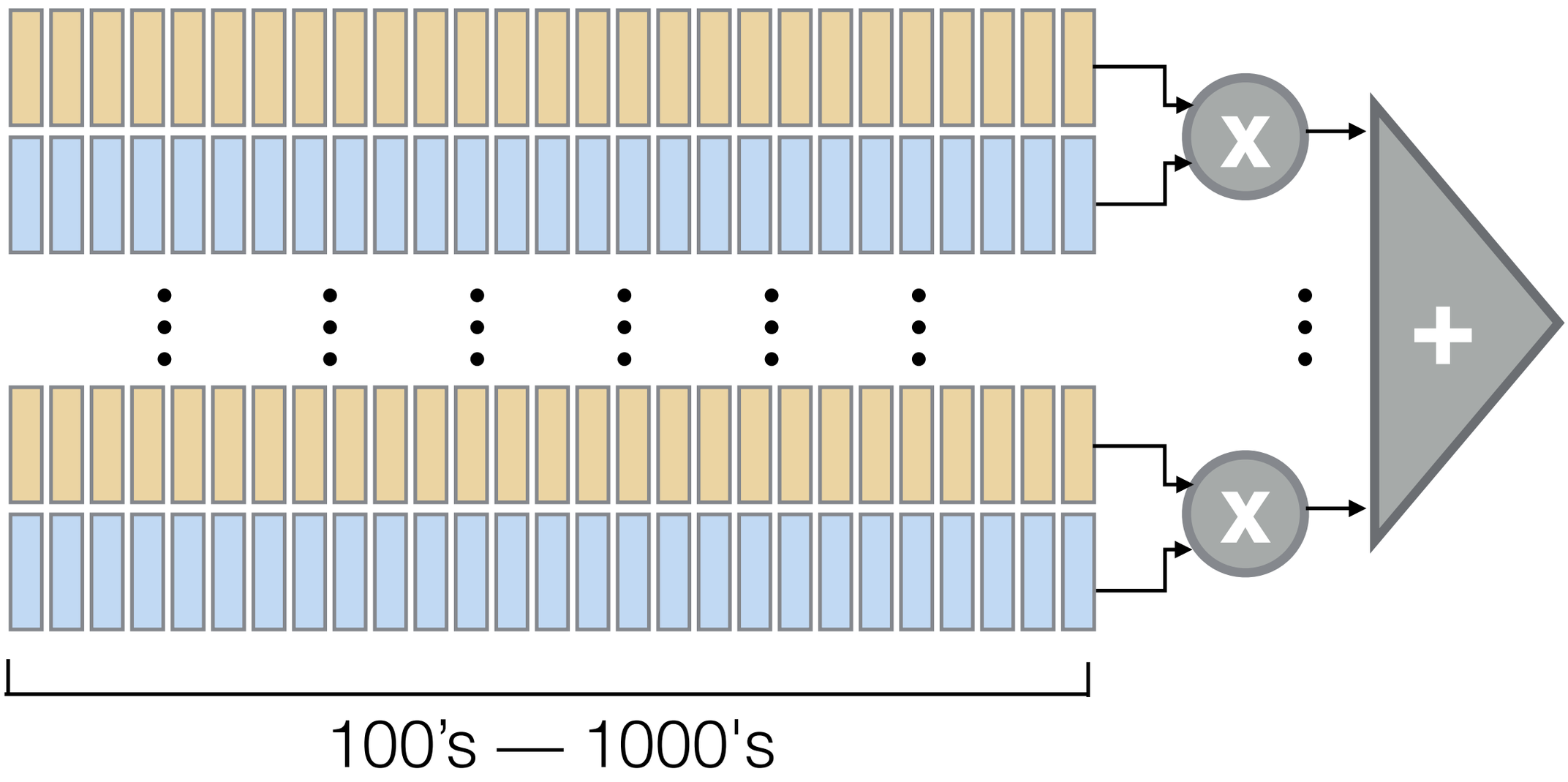
DNNs = SIMD Heaven



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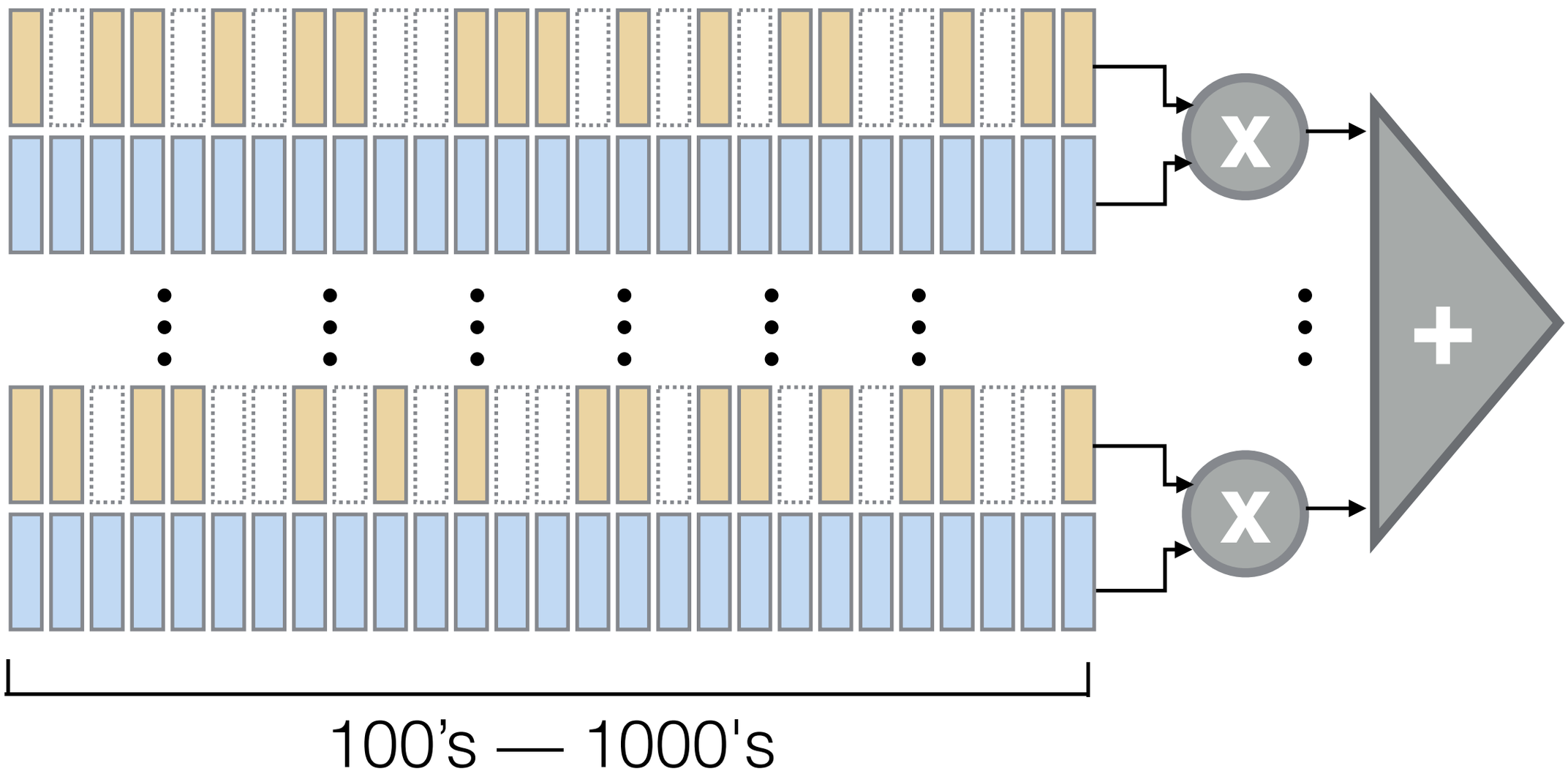

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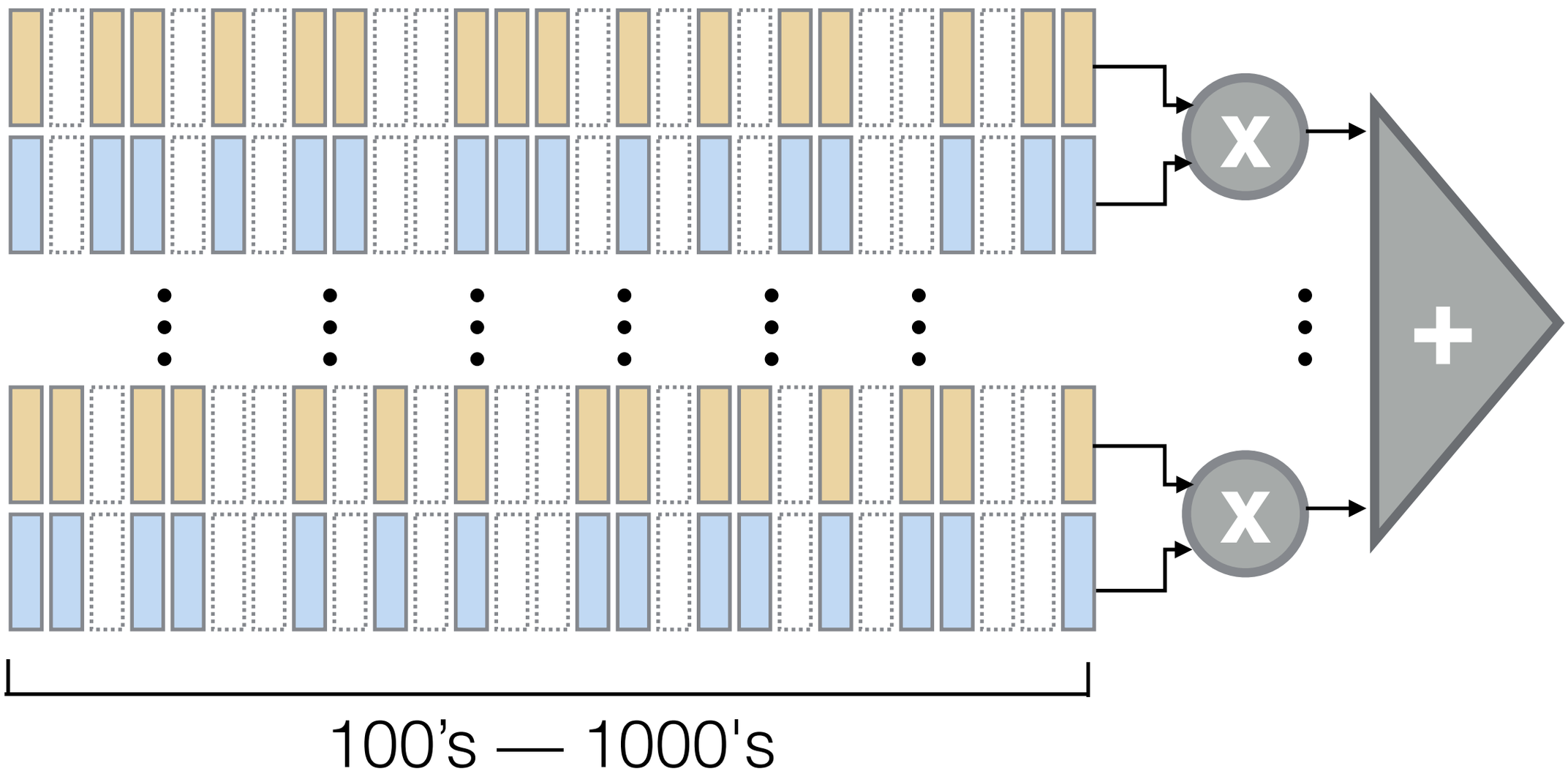

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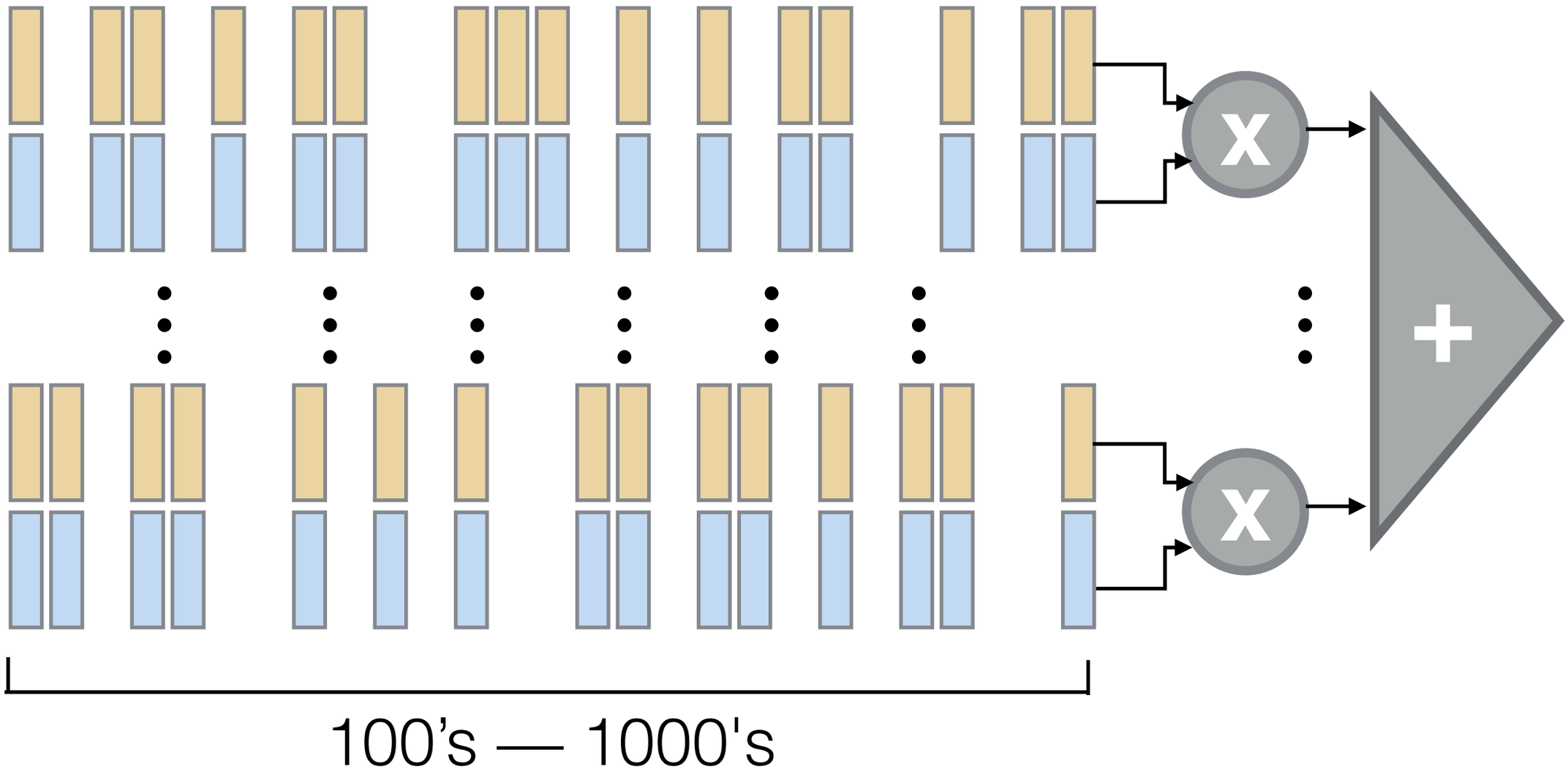

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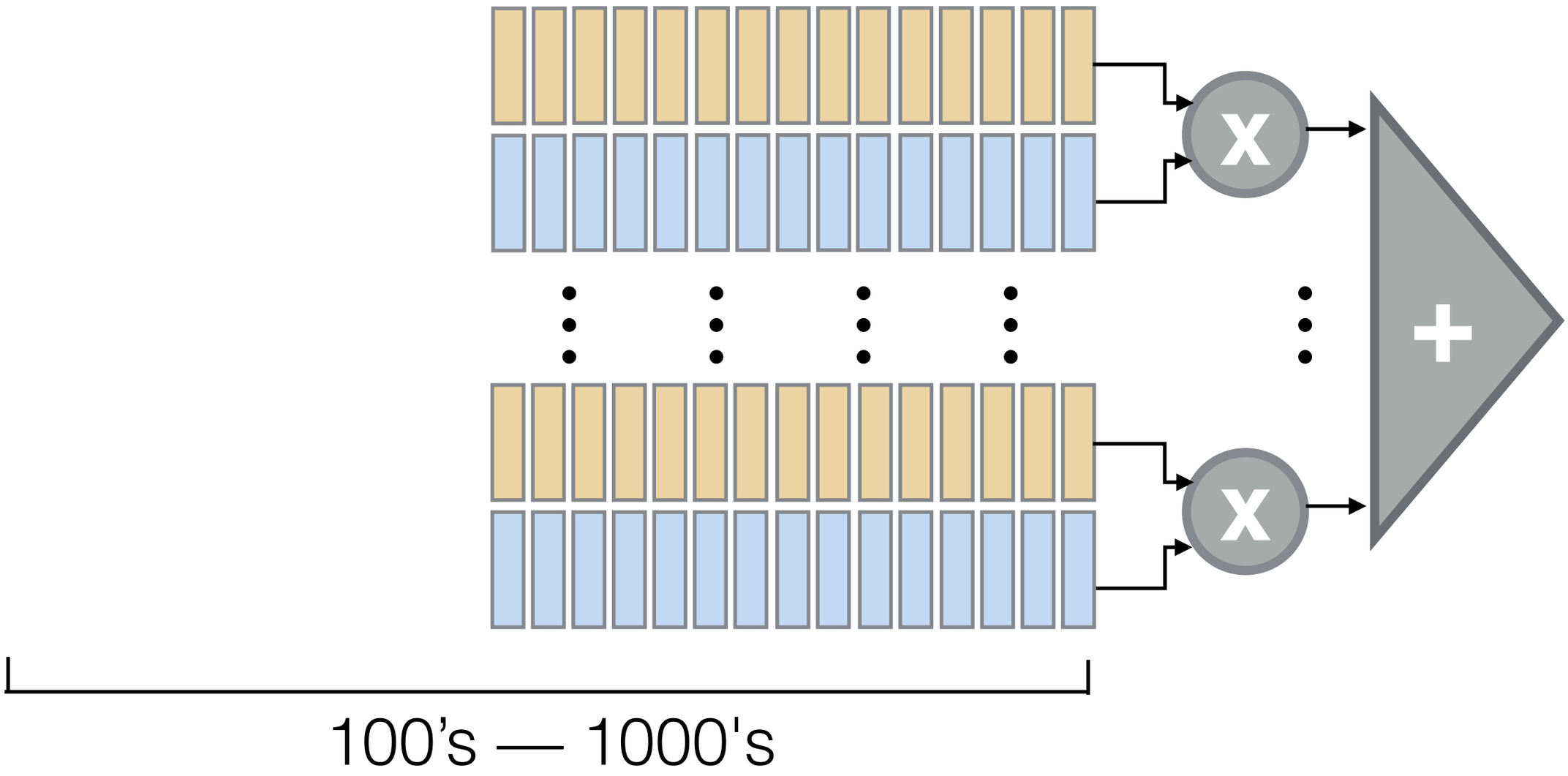


CNVLUTIN: Smarter SIMD

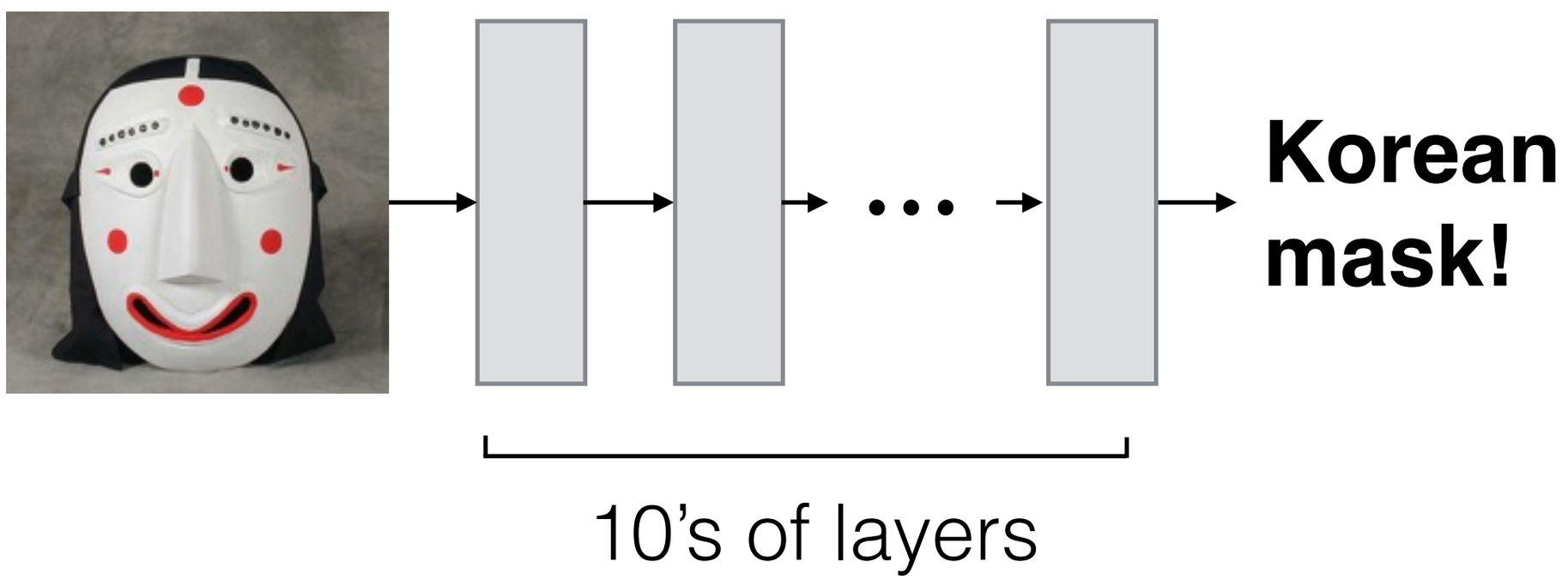
52% Performance — 2x ED²P

Out-of-the-box networks

Outline

1. What's a CNN?
2. A wide SIMD design
3. CNVLUTIN: Skipping neurons in a wide SIMD design
4. Evaluation
5. Our approach

What's a CNN?



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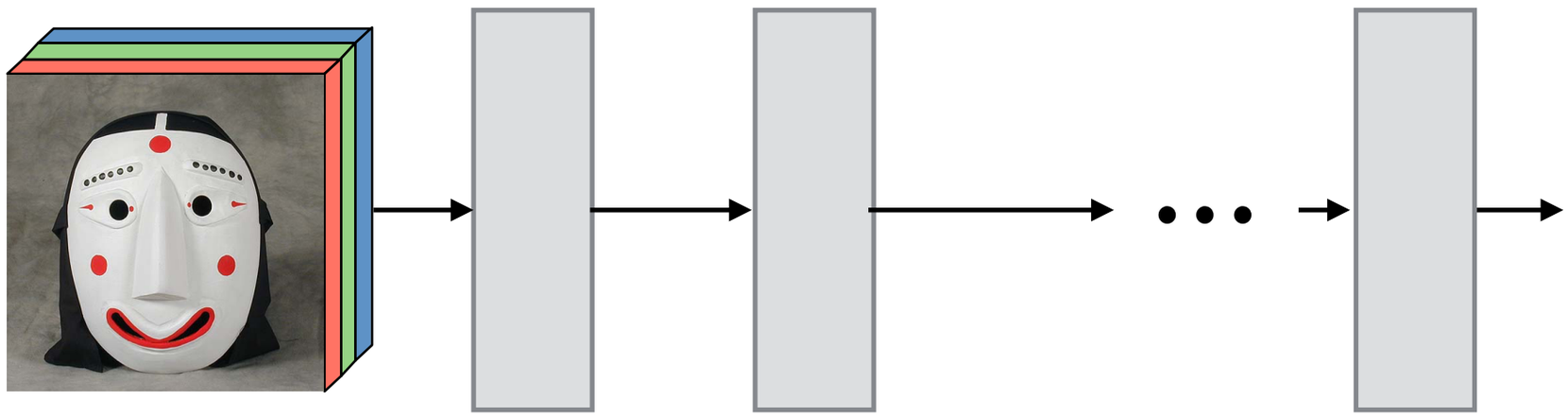

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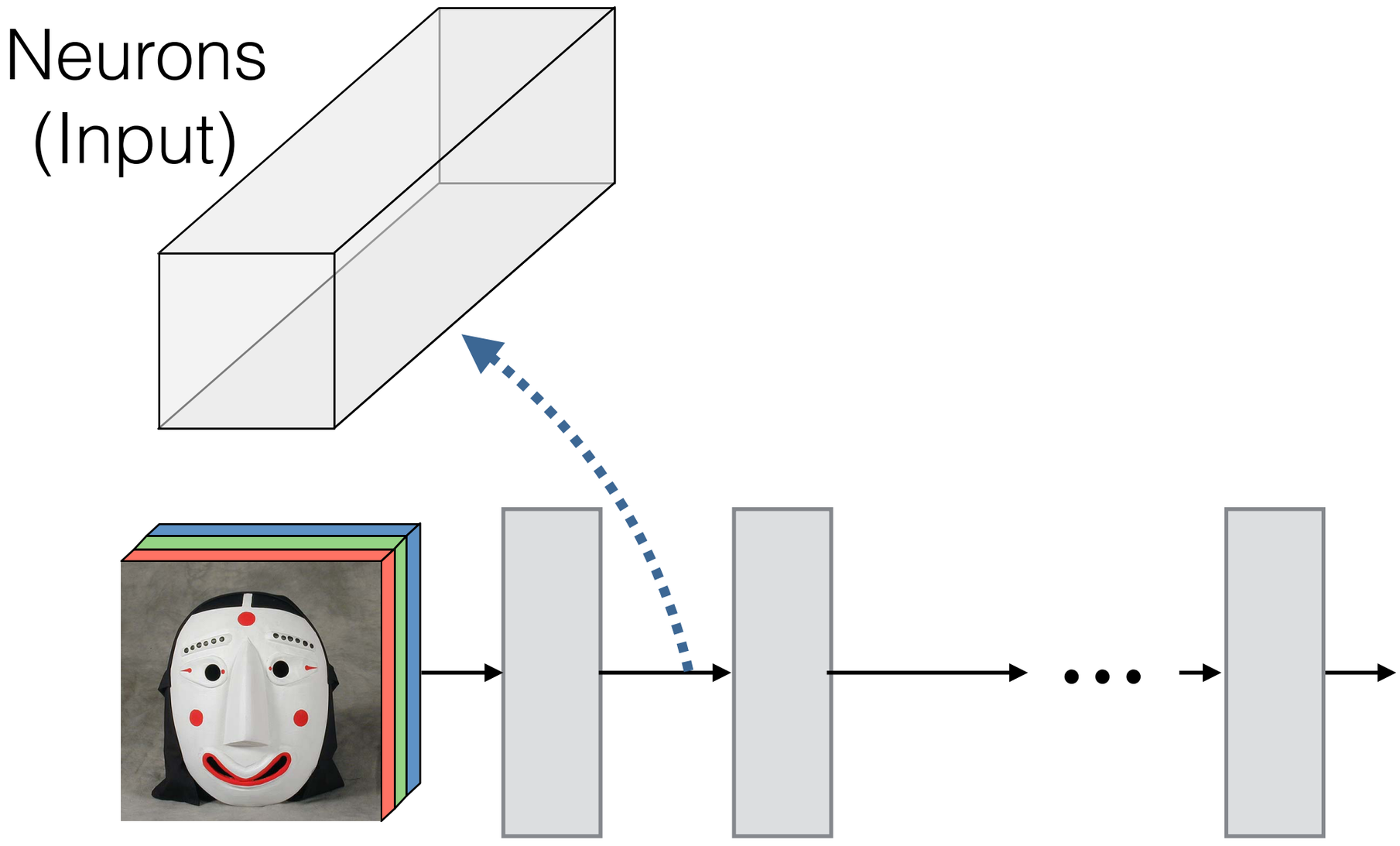

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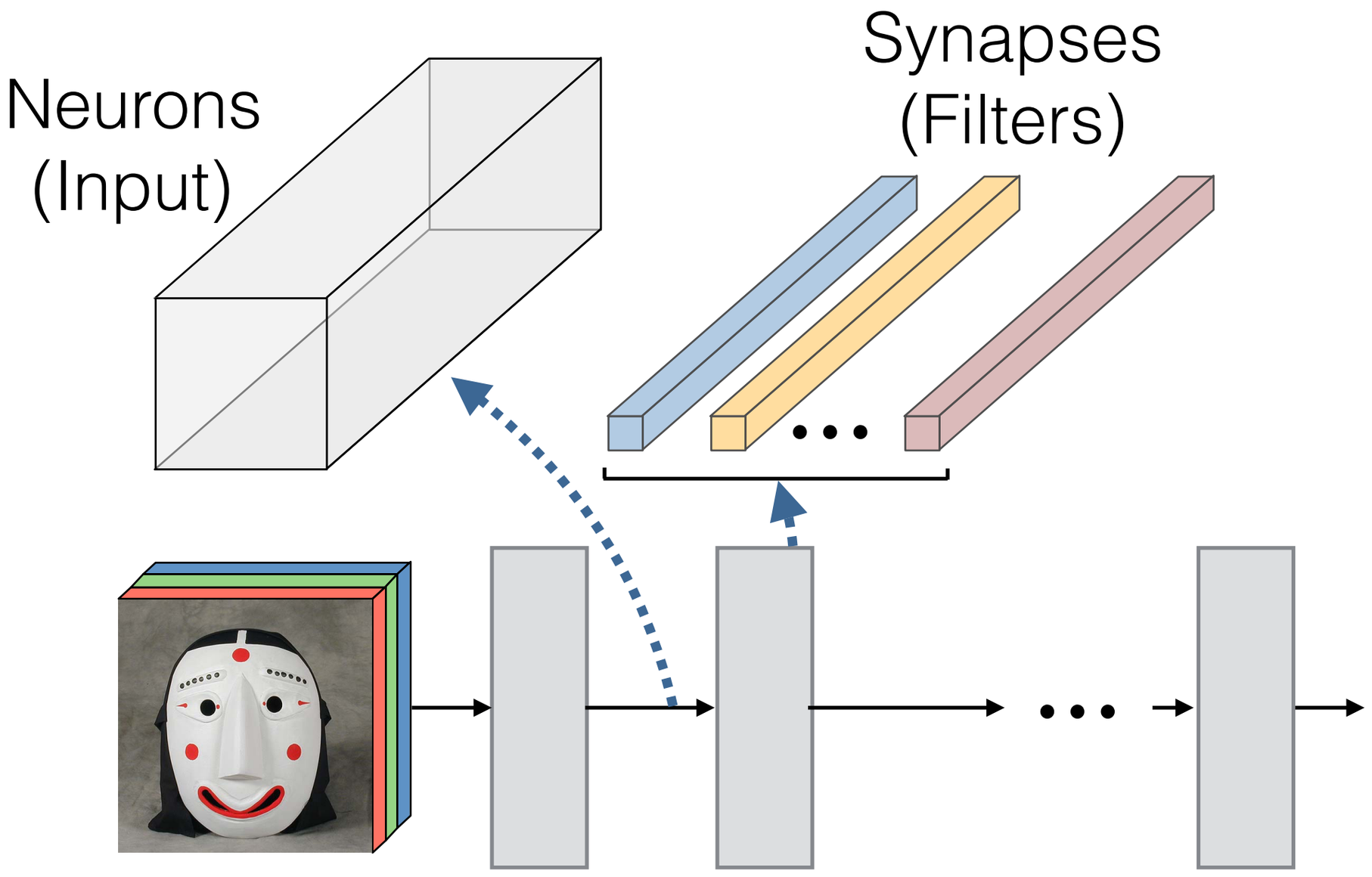

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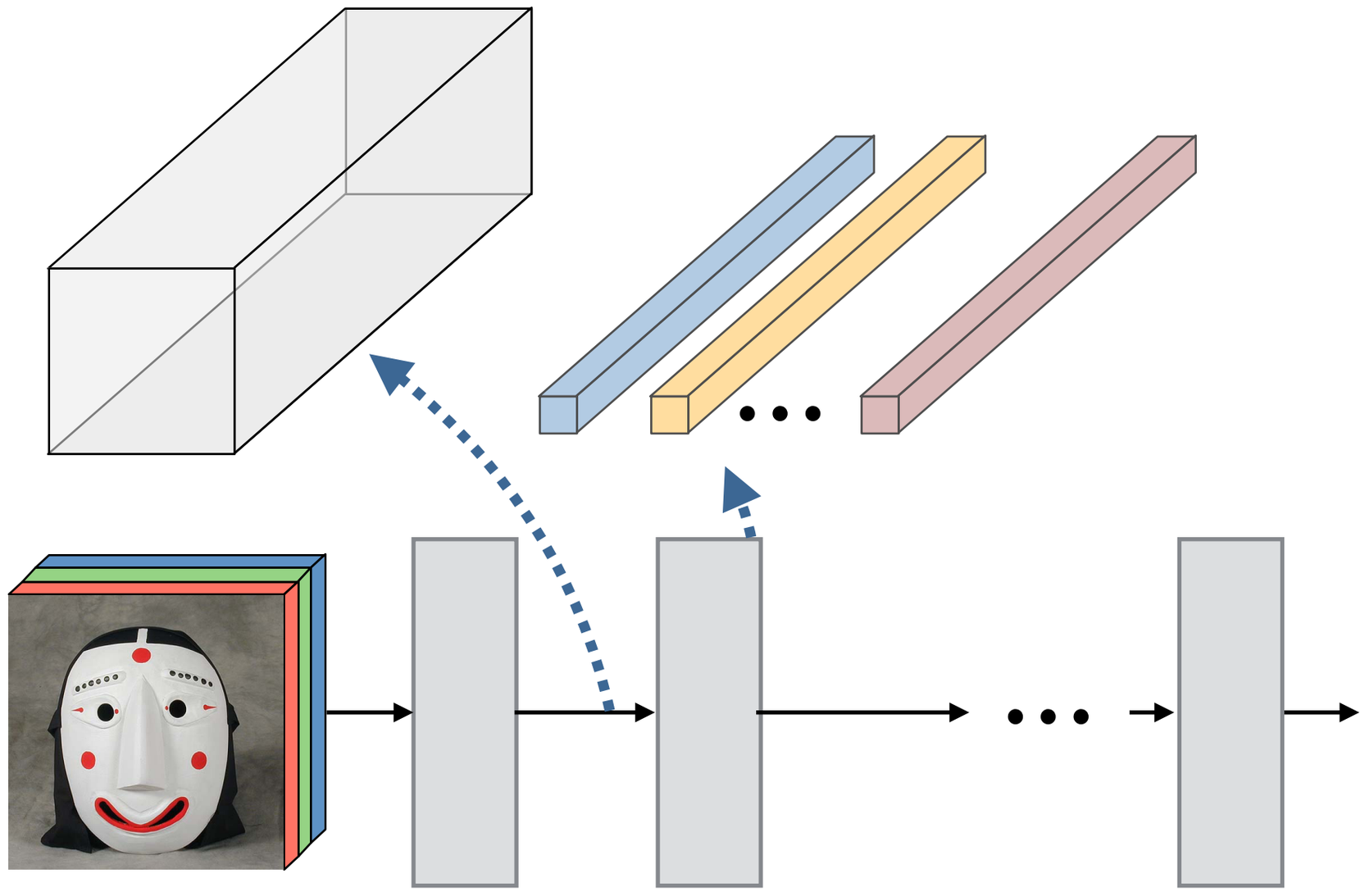

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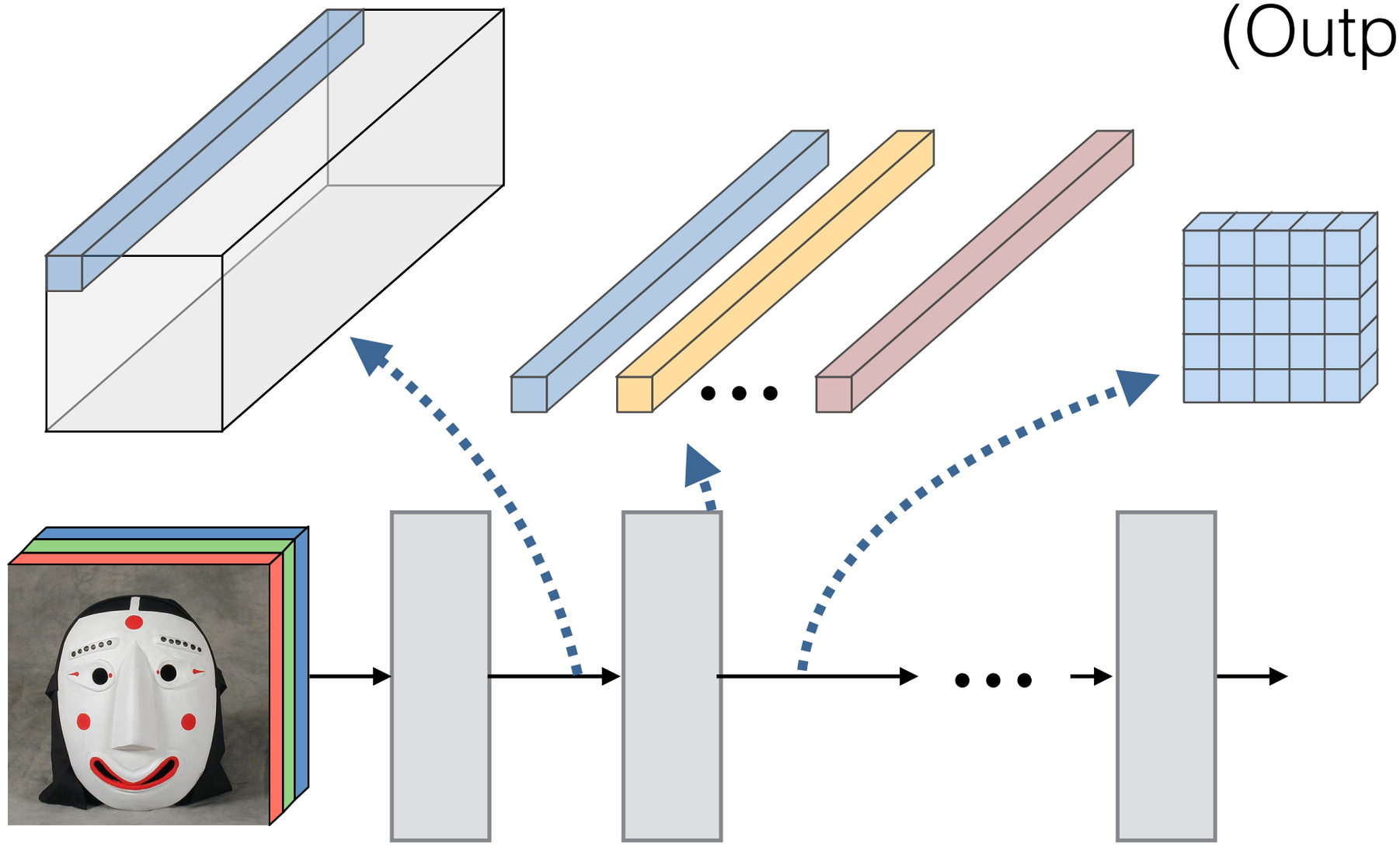

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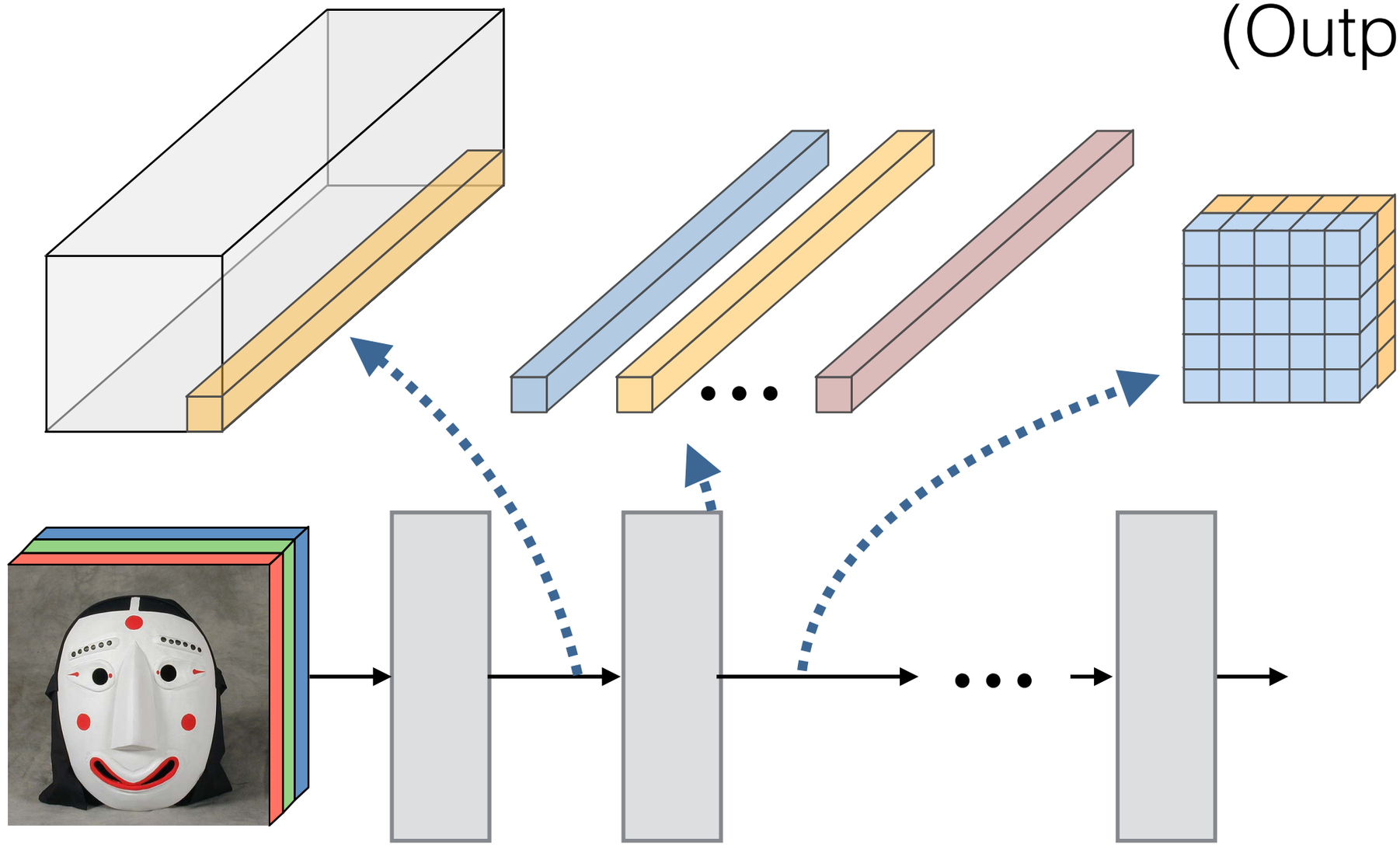

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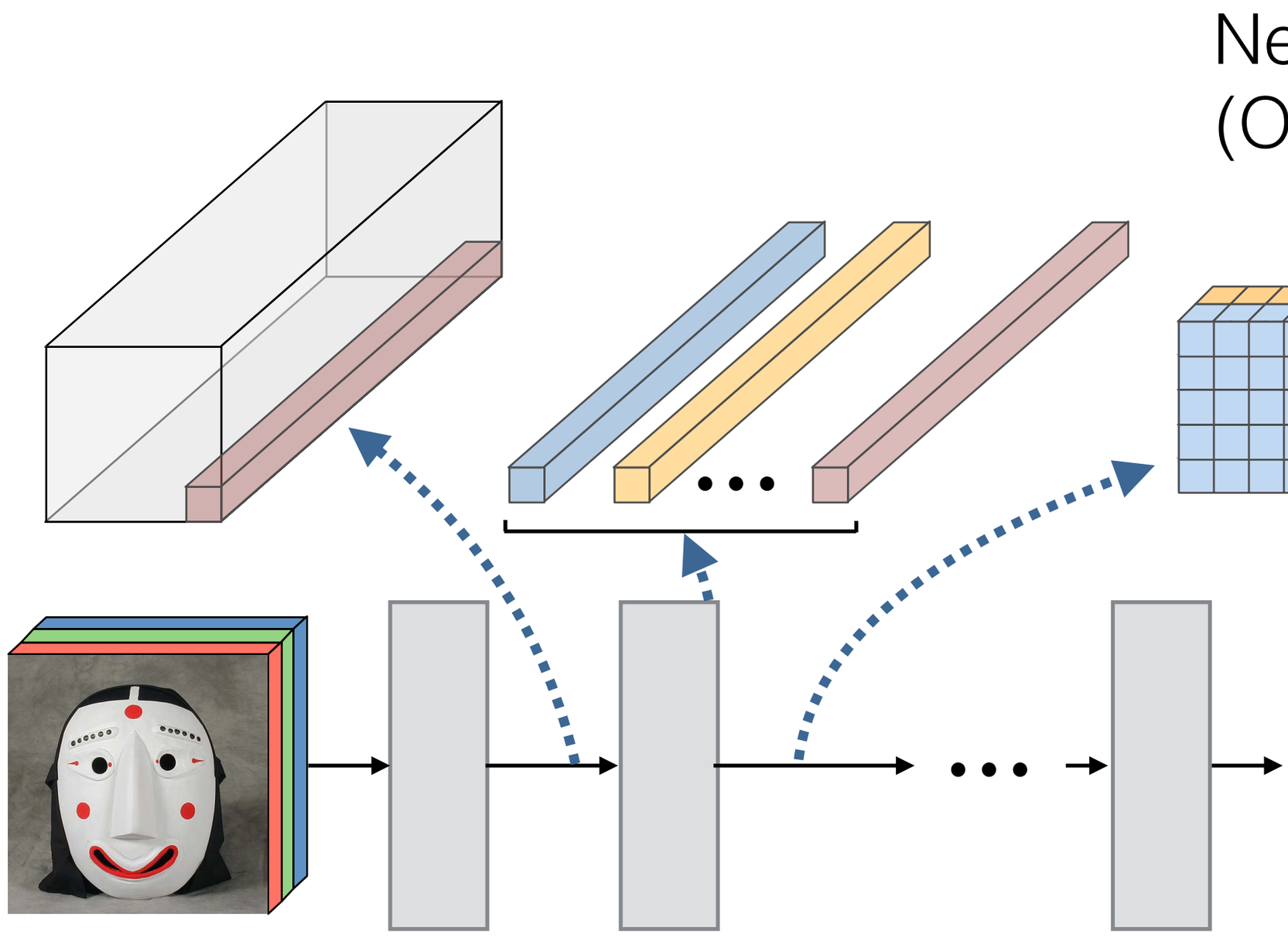

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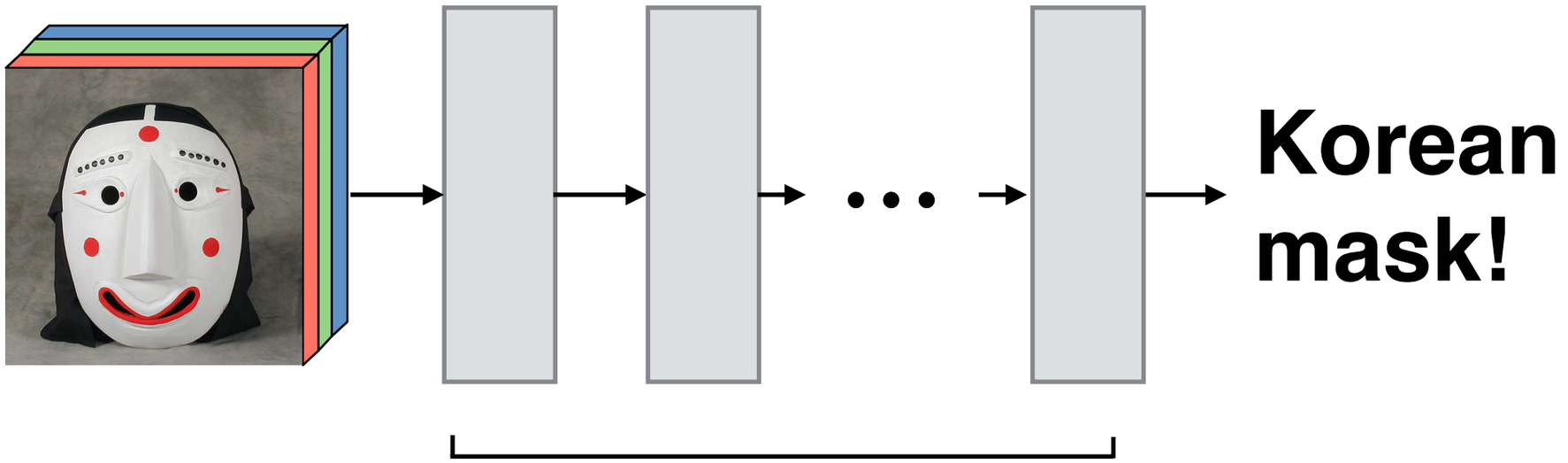

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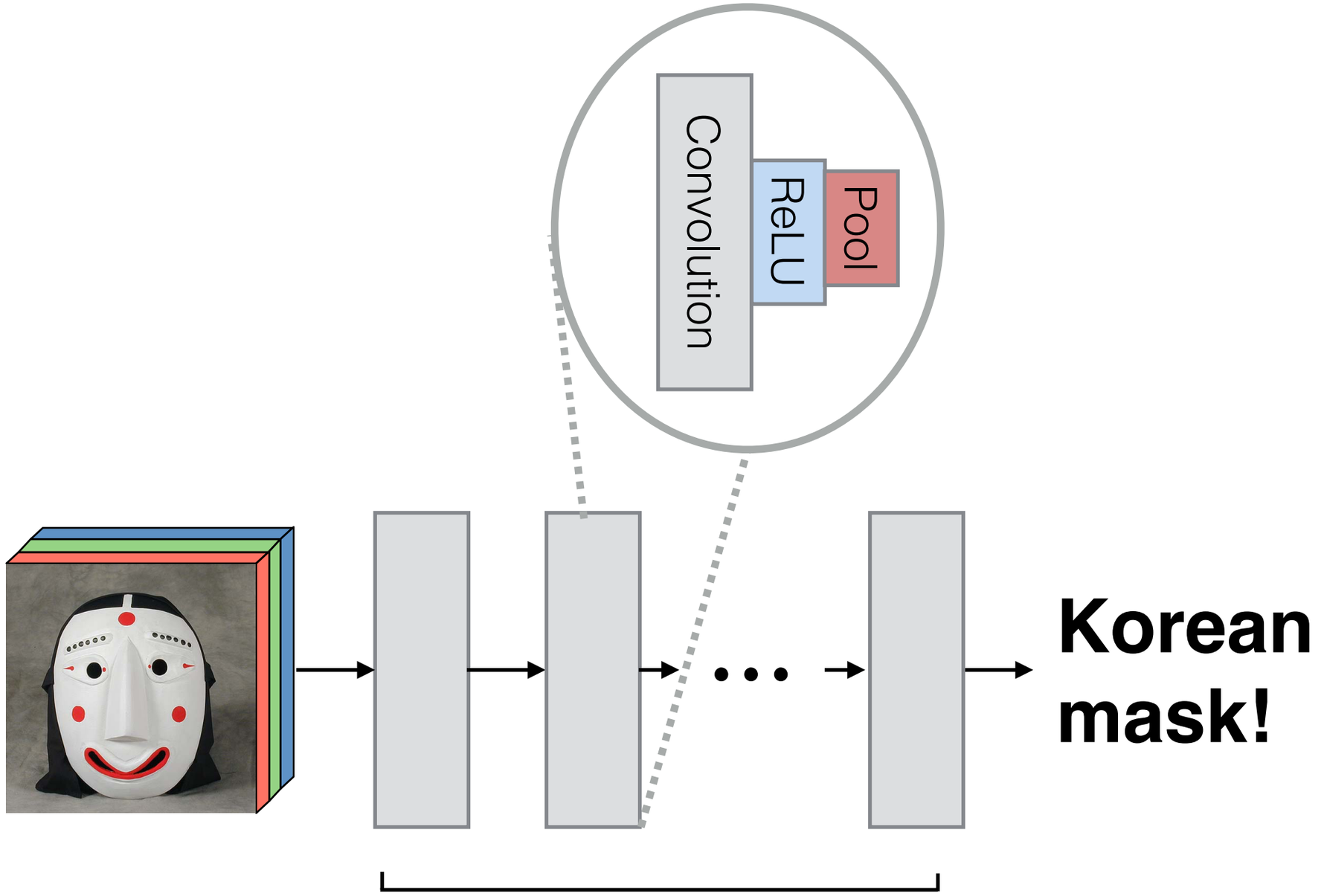

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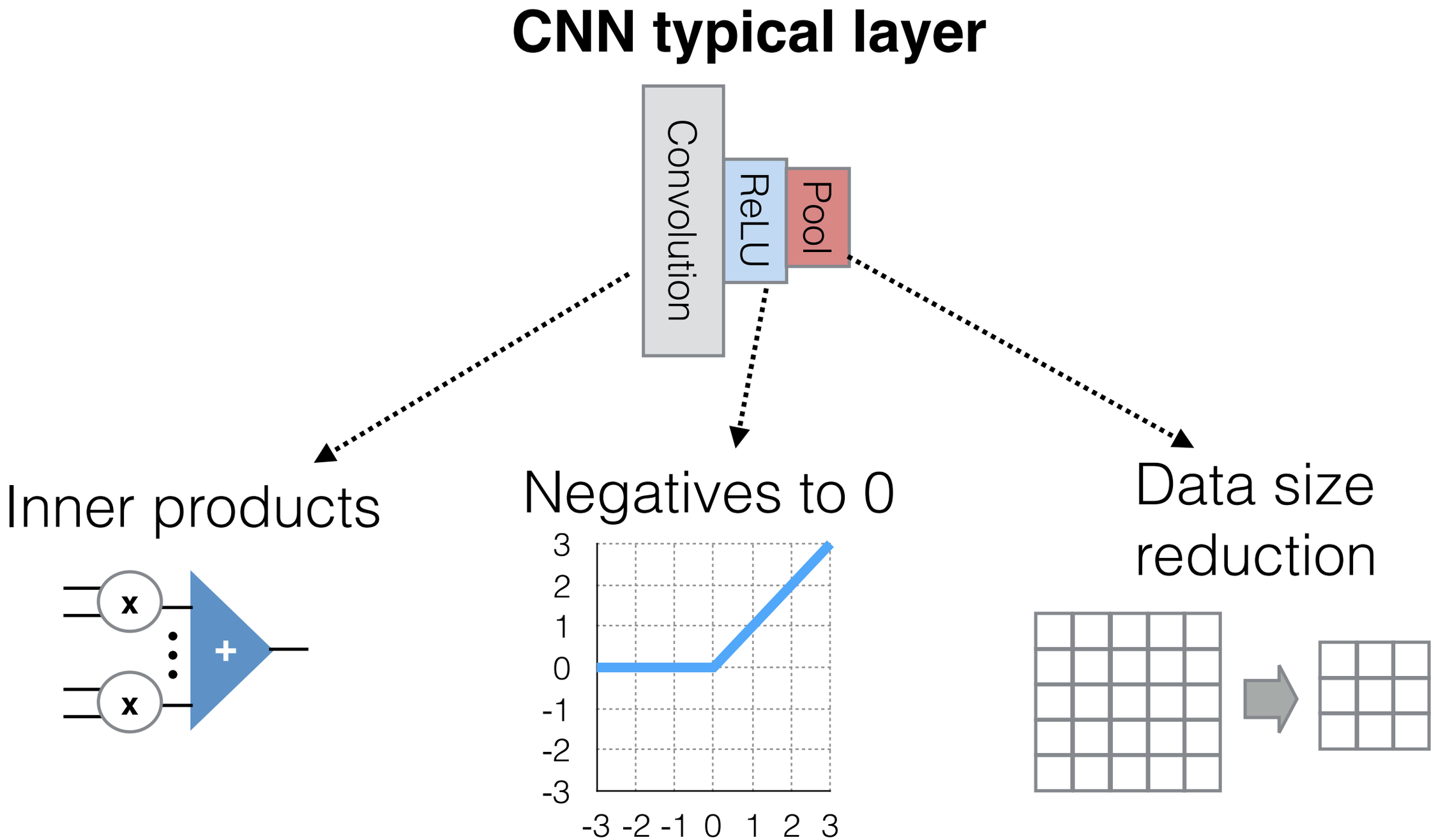
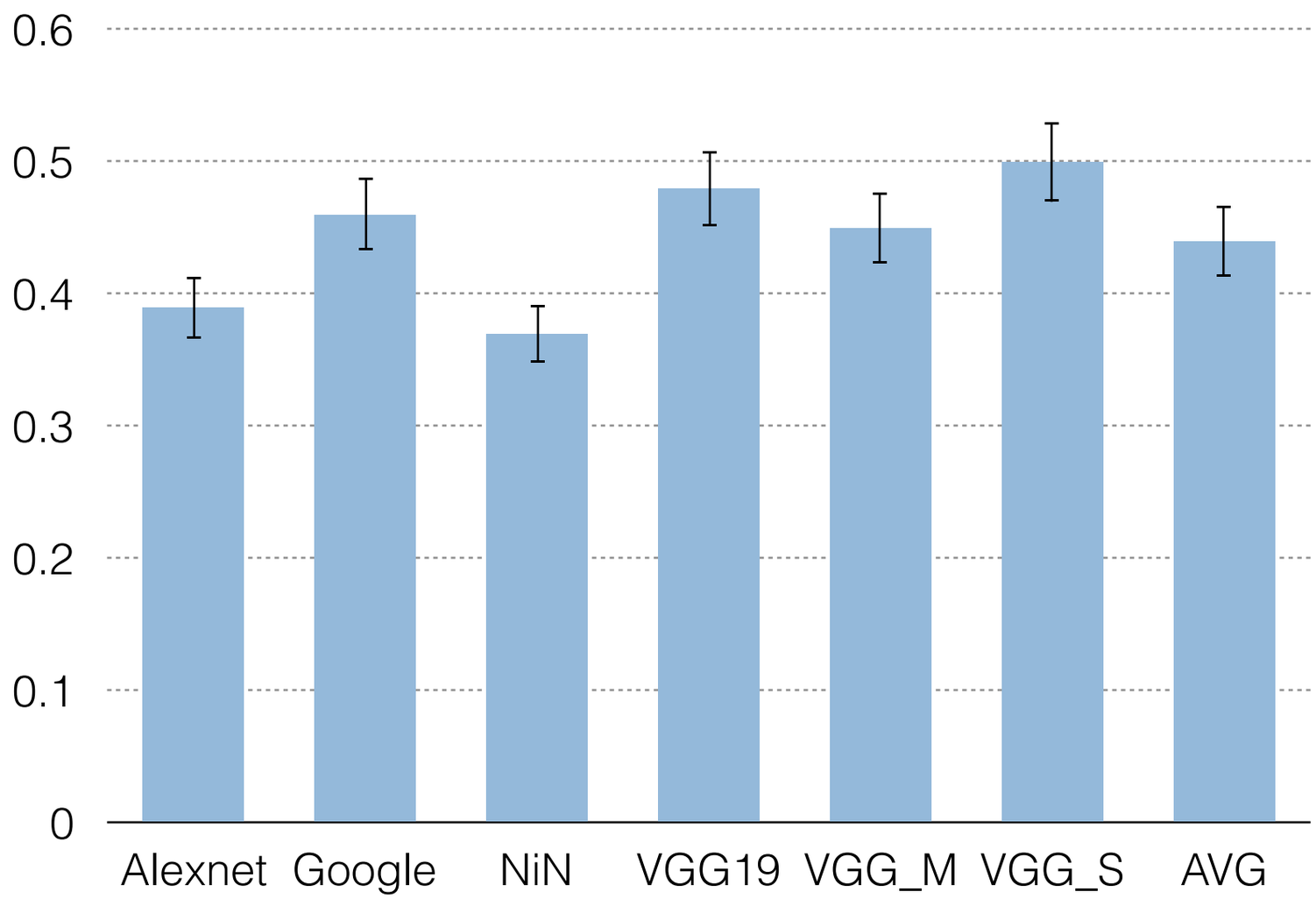

CNN typical layer
Convolution
ReLU
Pool
Inner products
x
x
+
Negatives to 0
3
2
1
0
-1
-2
-3
-3 -2 -1 0 1 2 3
Data size reduction

~90%

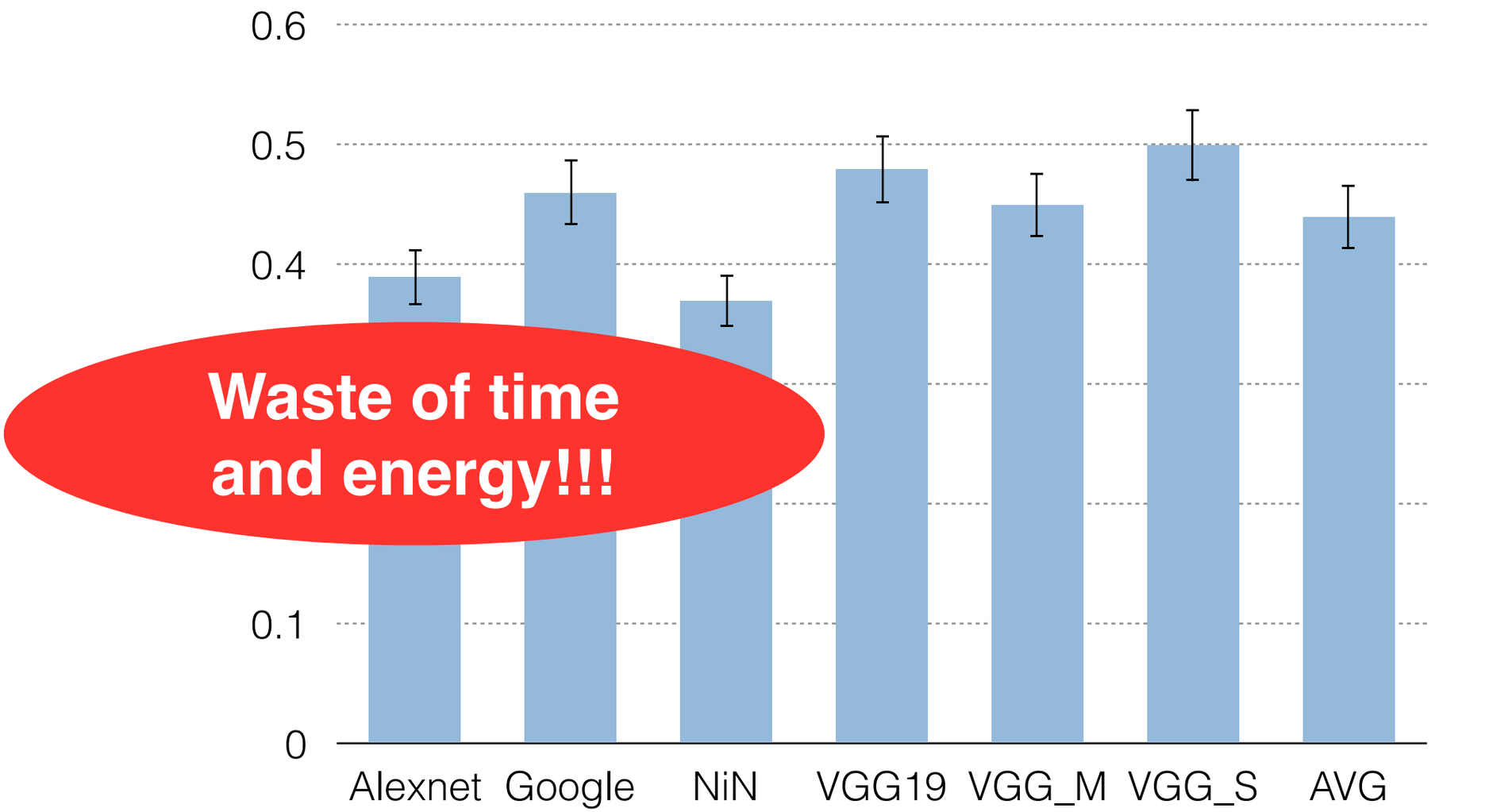
Time spent in convolutions

Lots of Runtime Zeroes



Fraction of zero neurons in multiplications

Lots of Runtime Zeroes



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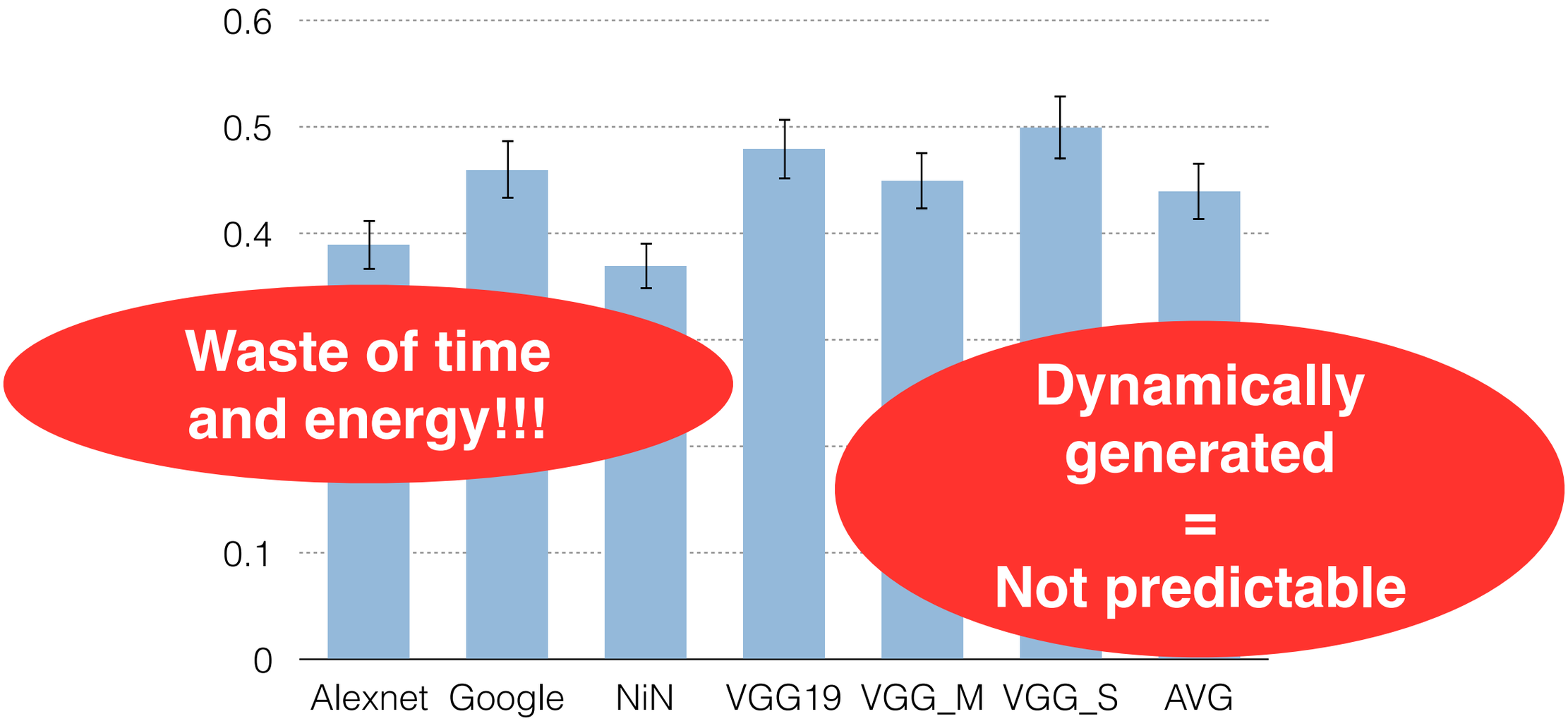
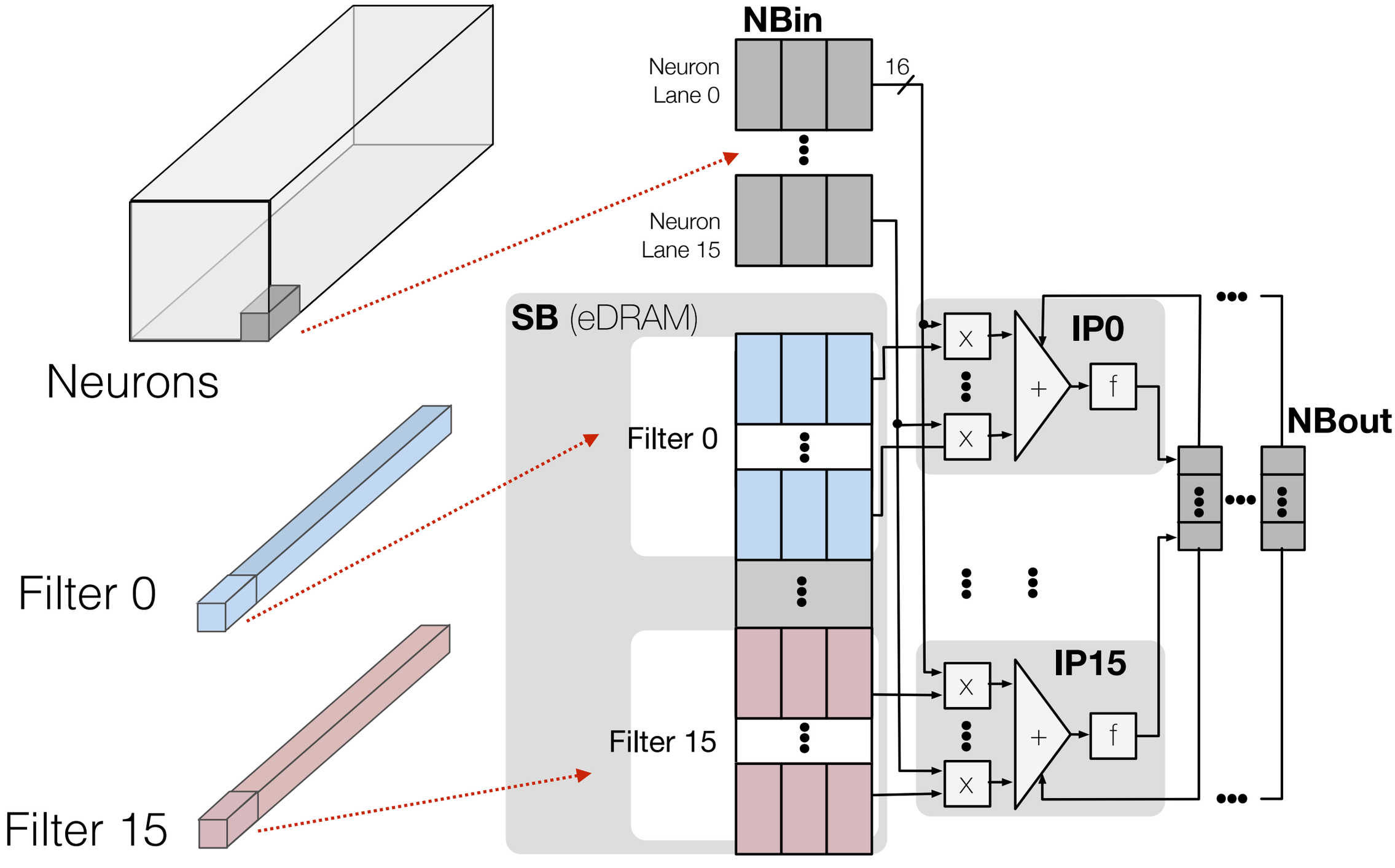


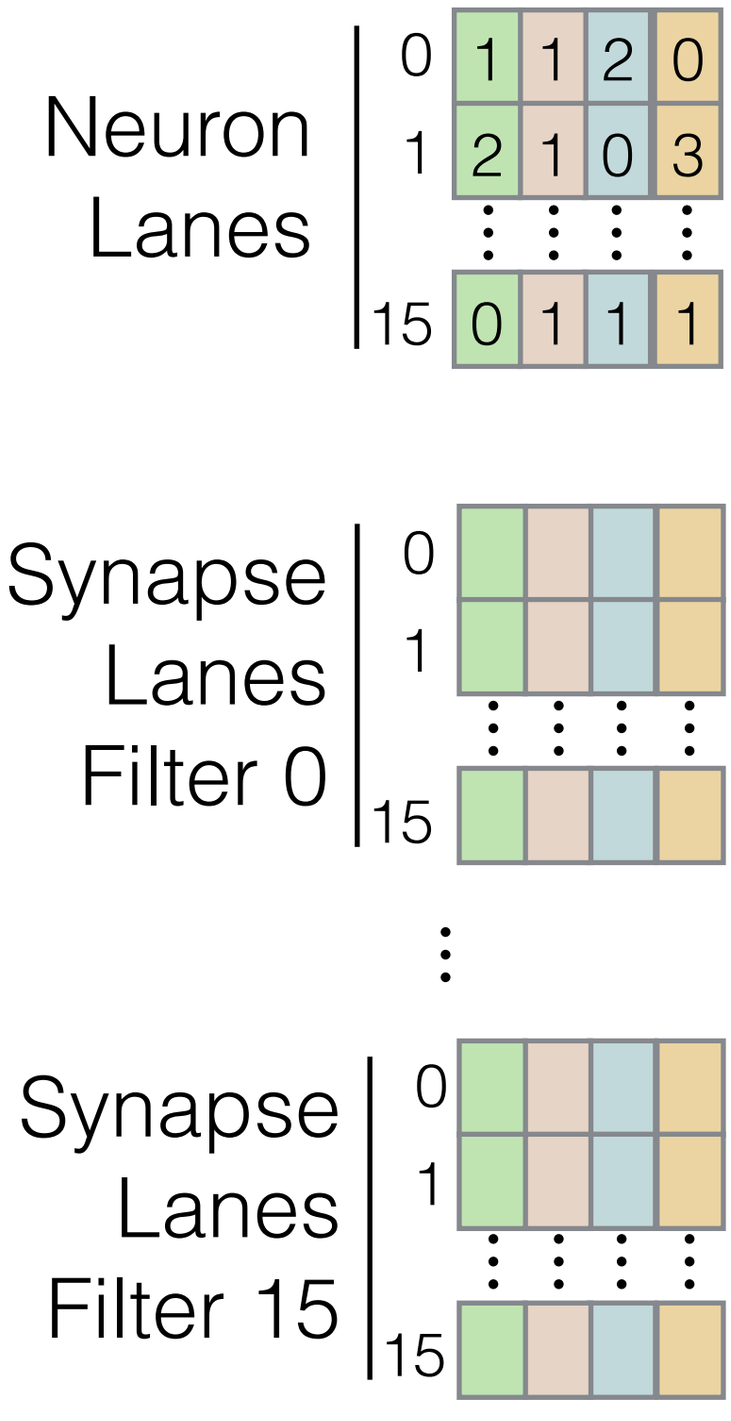
Fraction of zero neurons in multiplications

How to compute DNNs: DaDianNao*

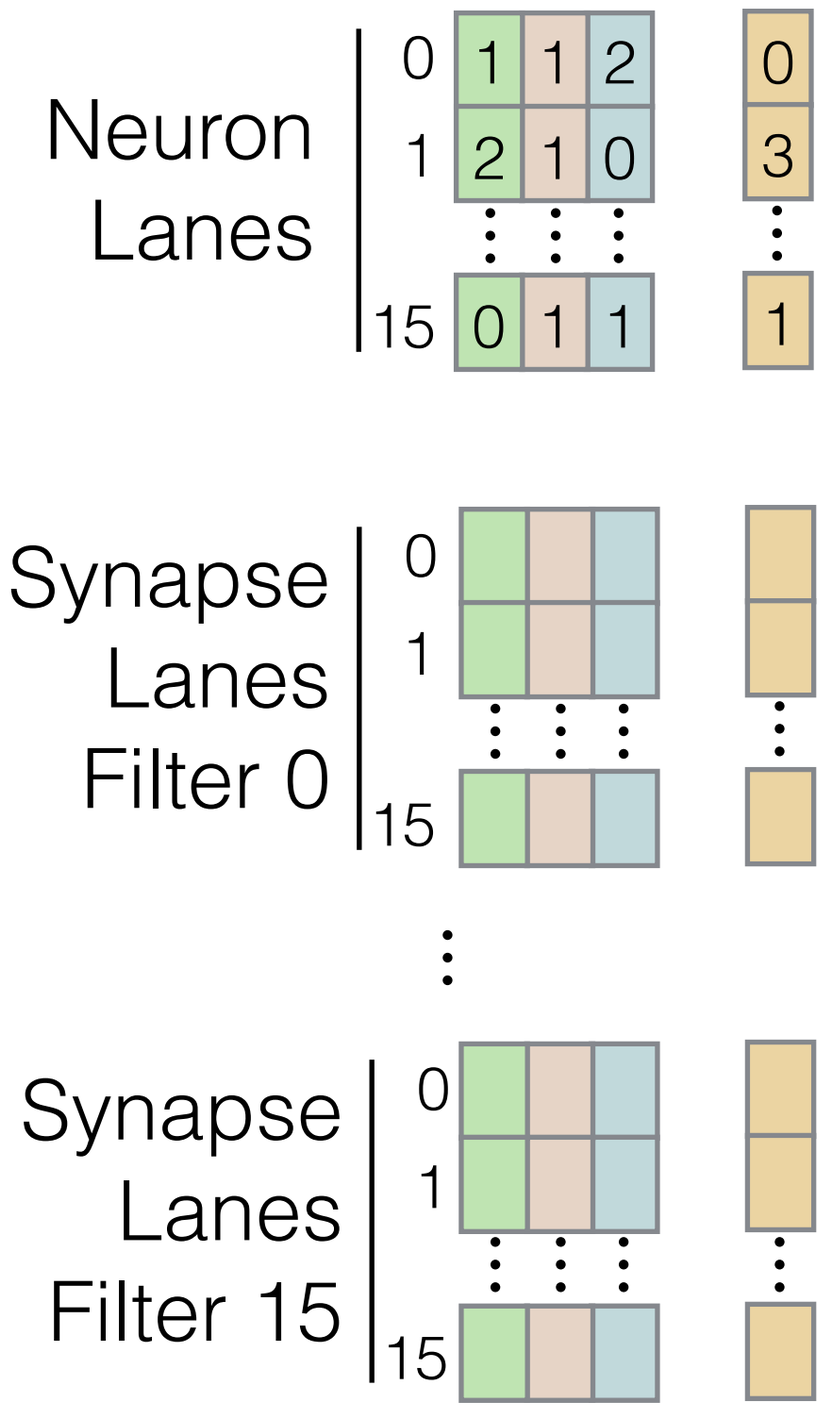


*Chen et al. MICRO 2014

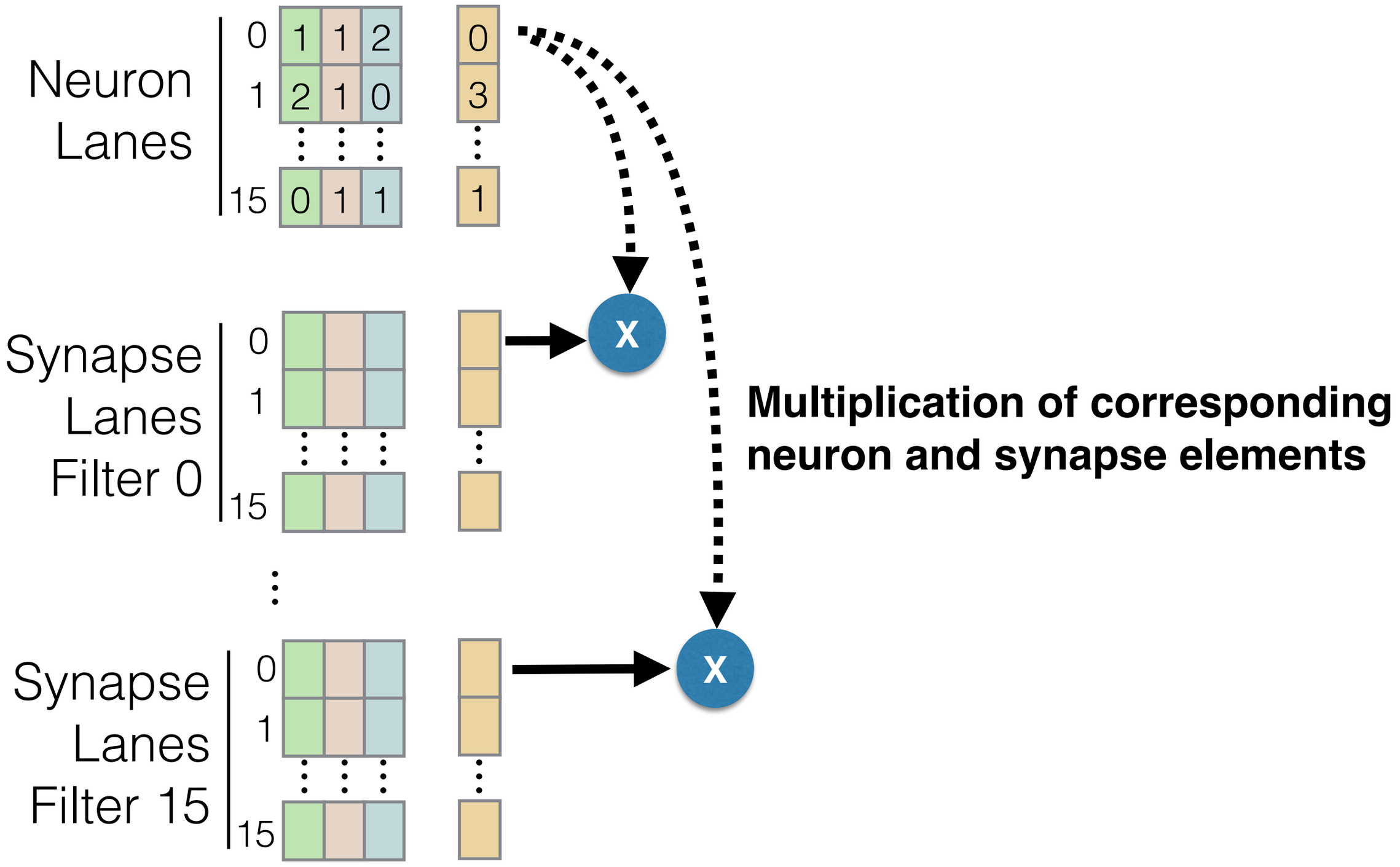
Processing in DaDianNao



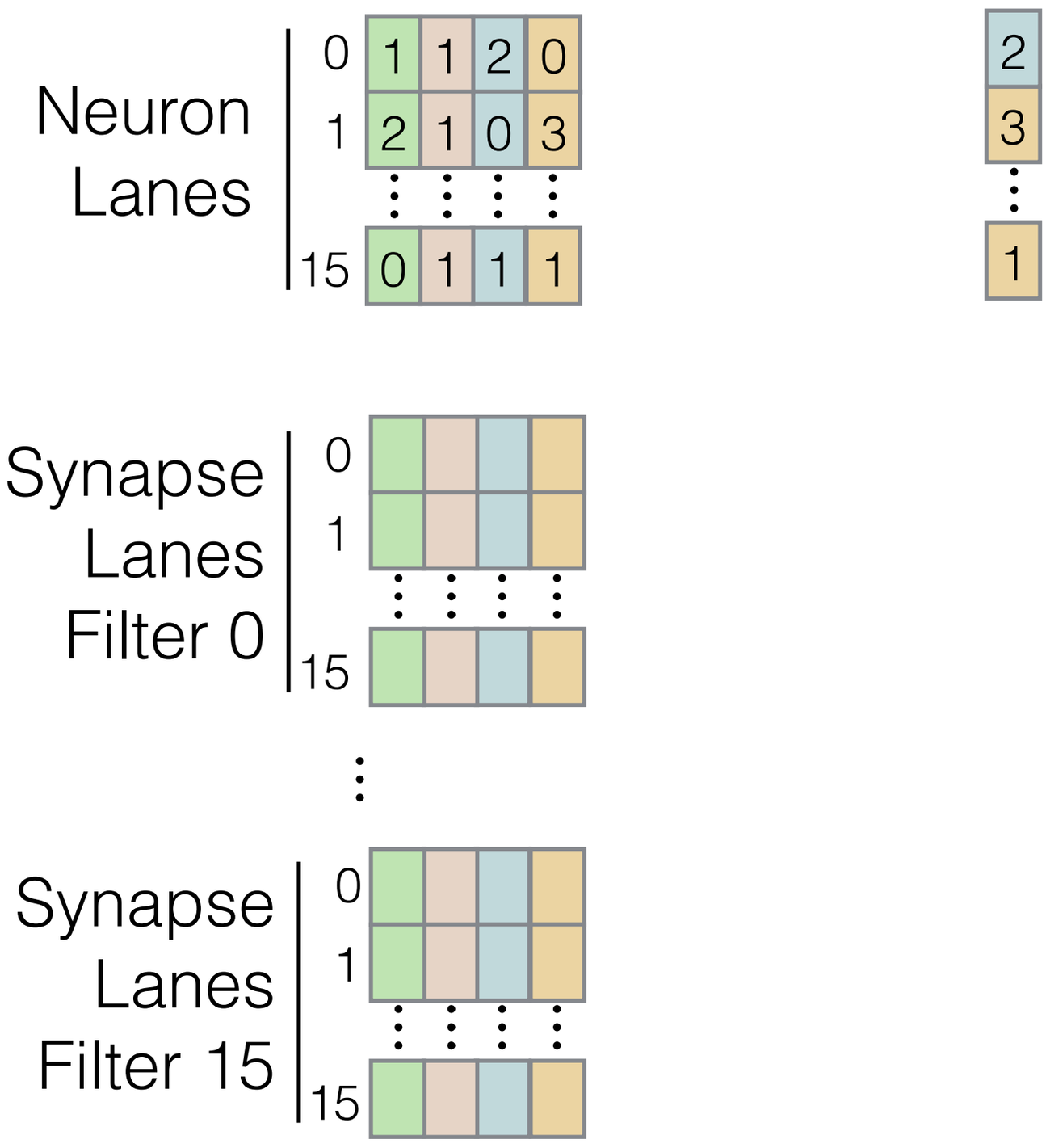
Processing in DaDianNao



Processing in DaDianNao



Zero-skipping in DaDianNao?



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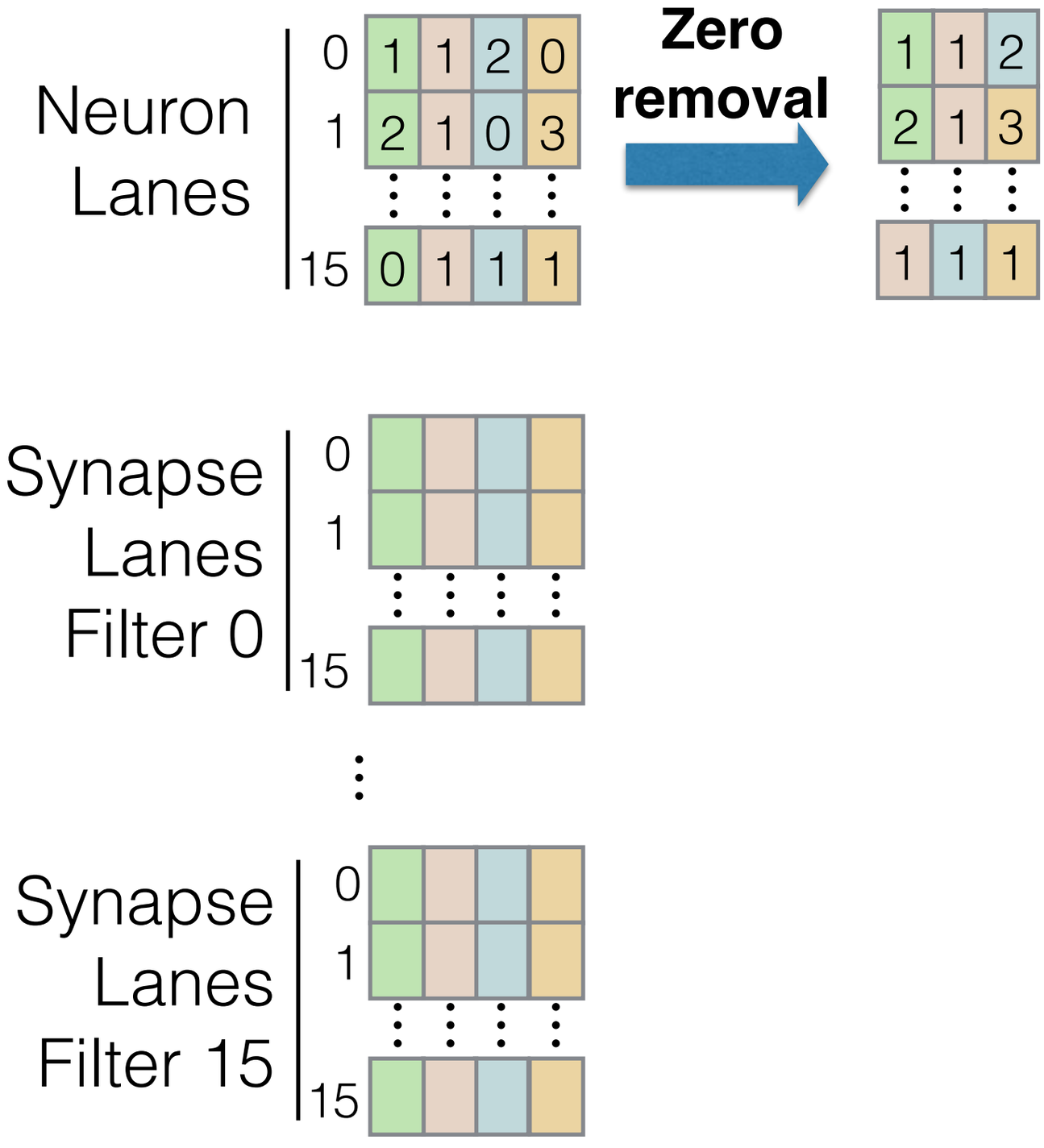

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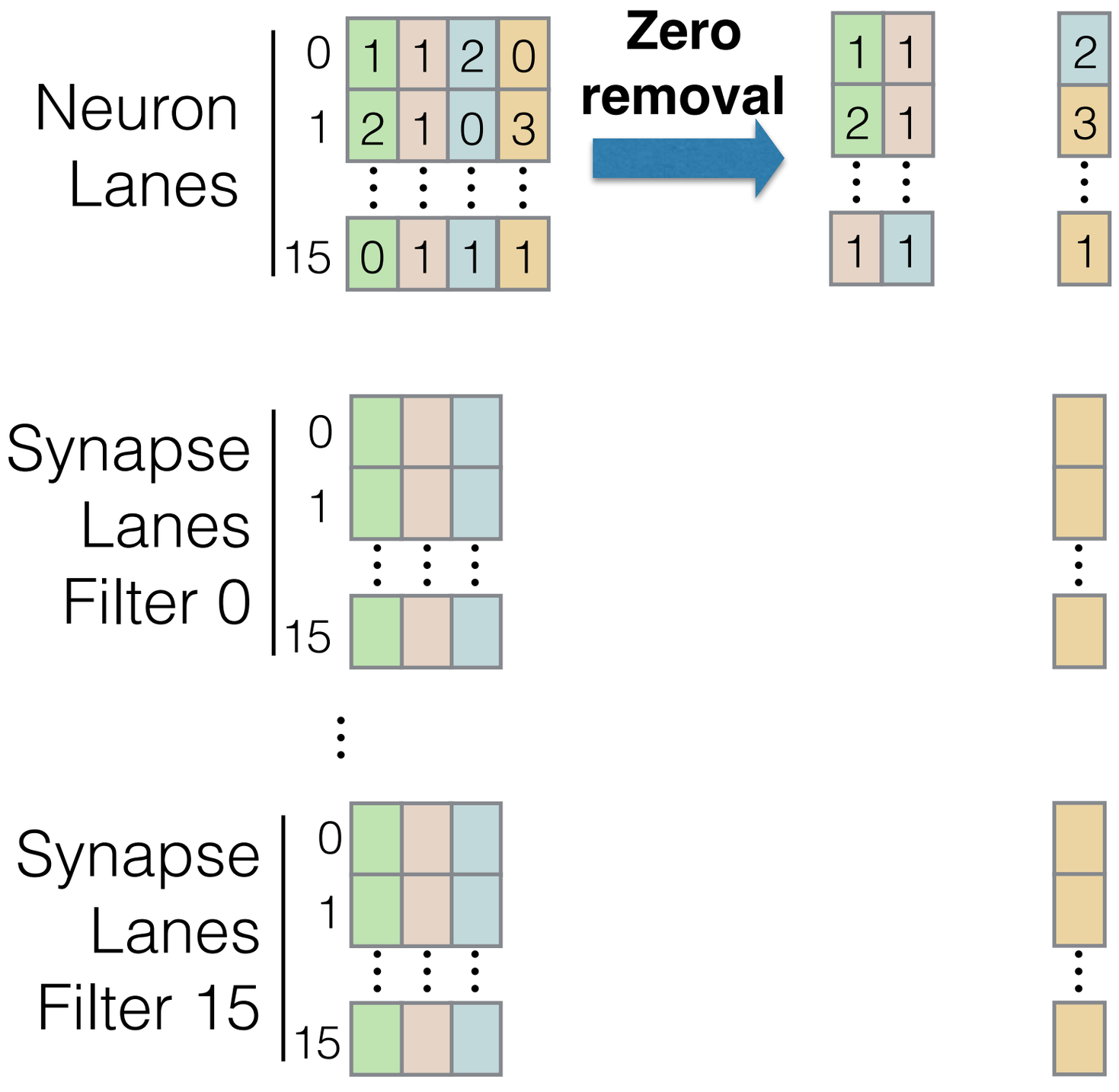

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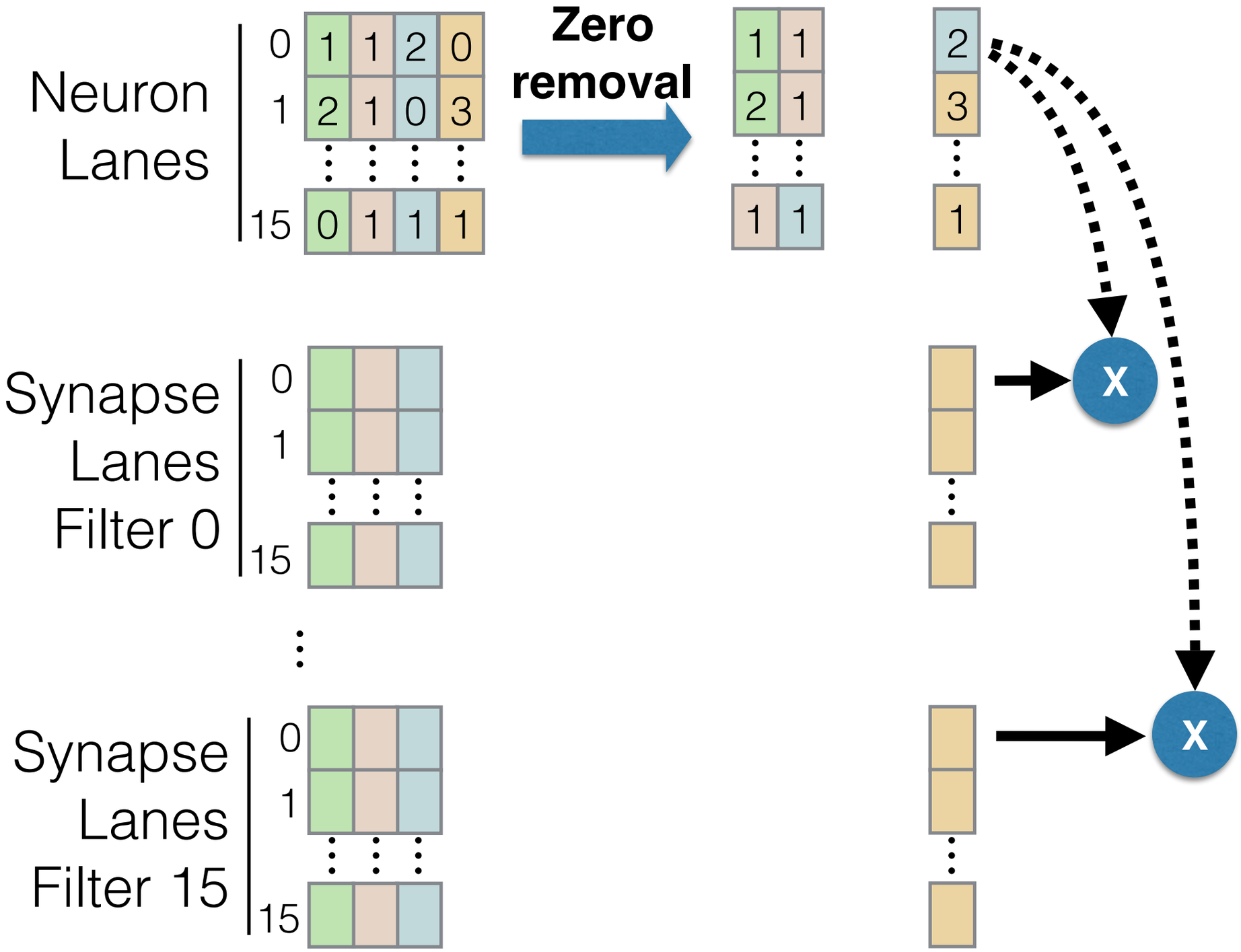

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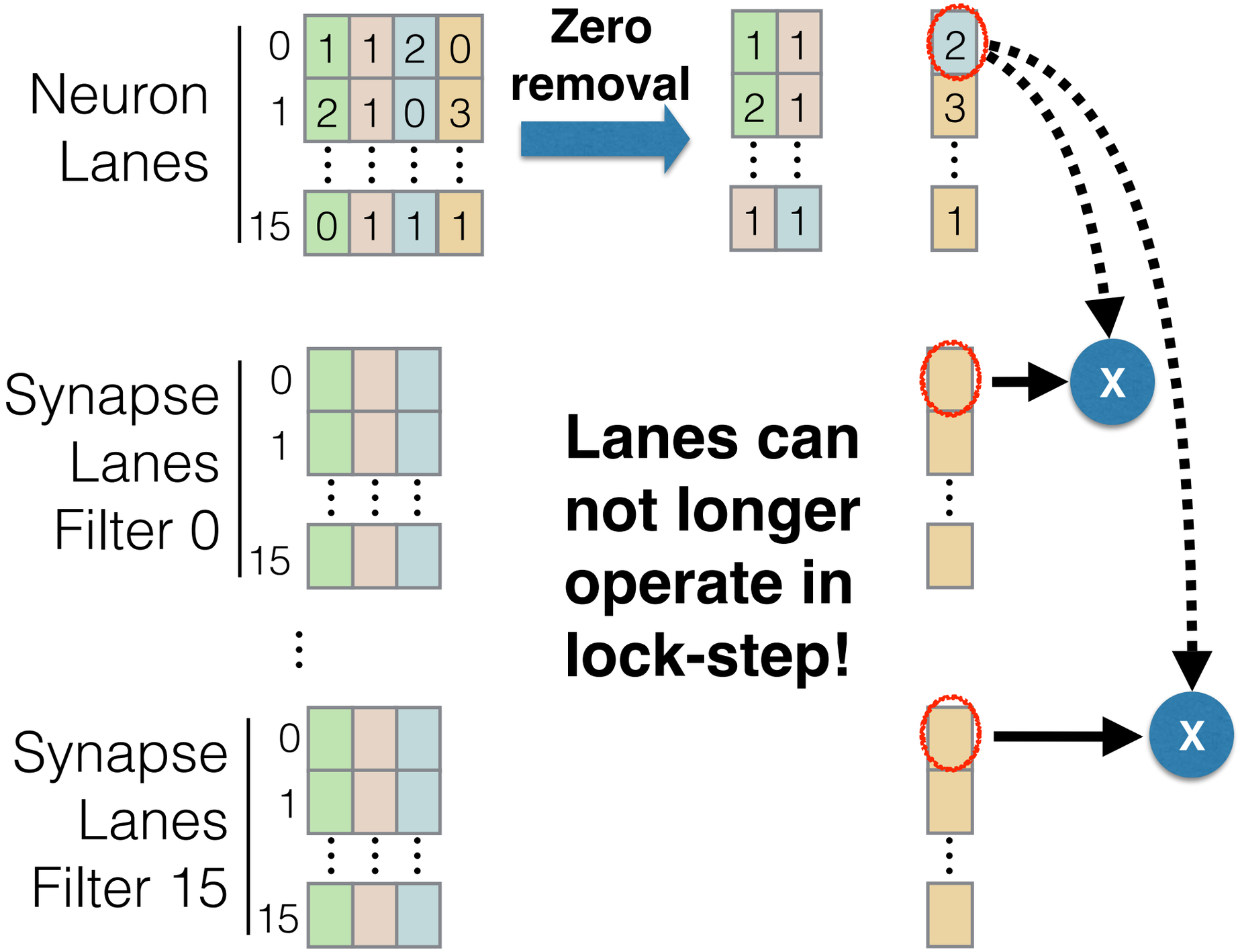
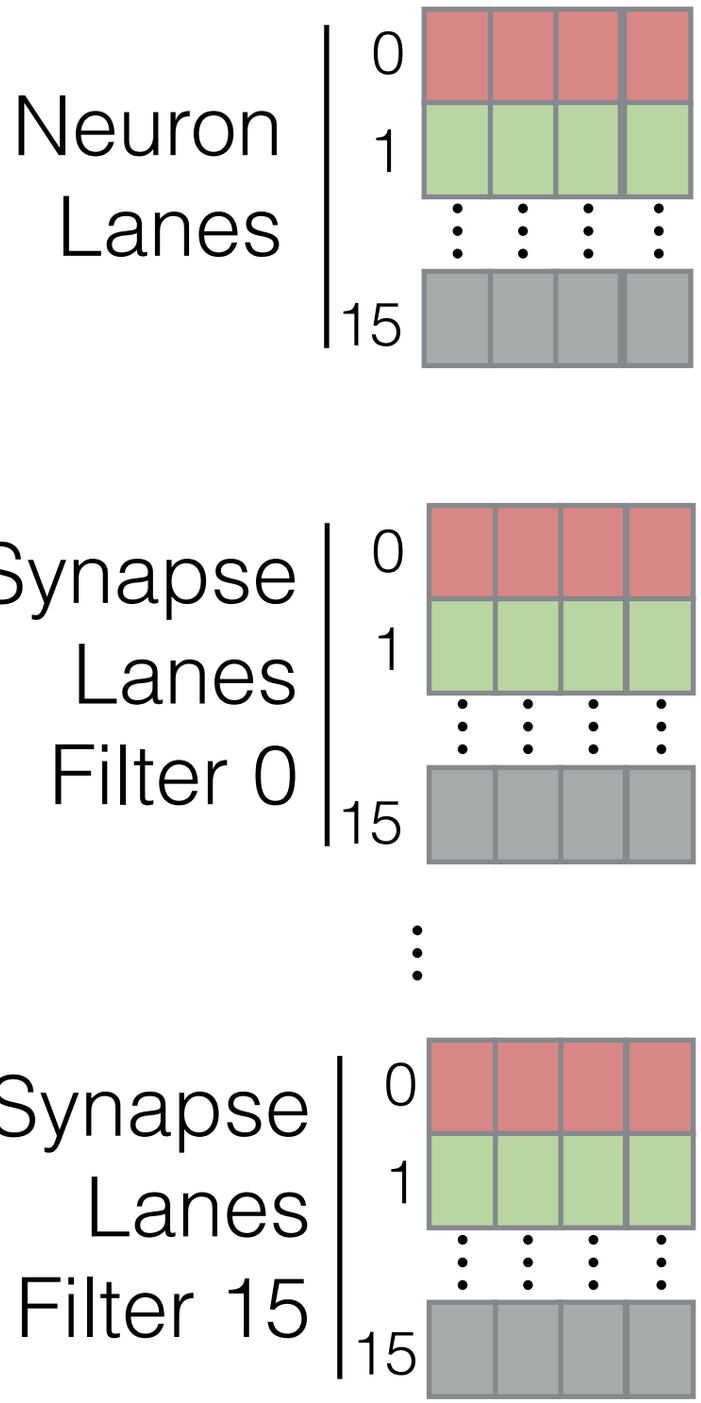
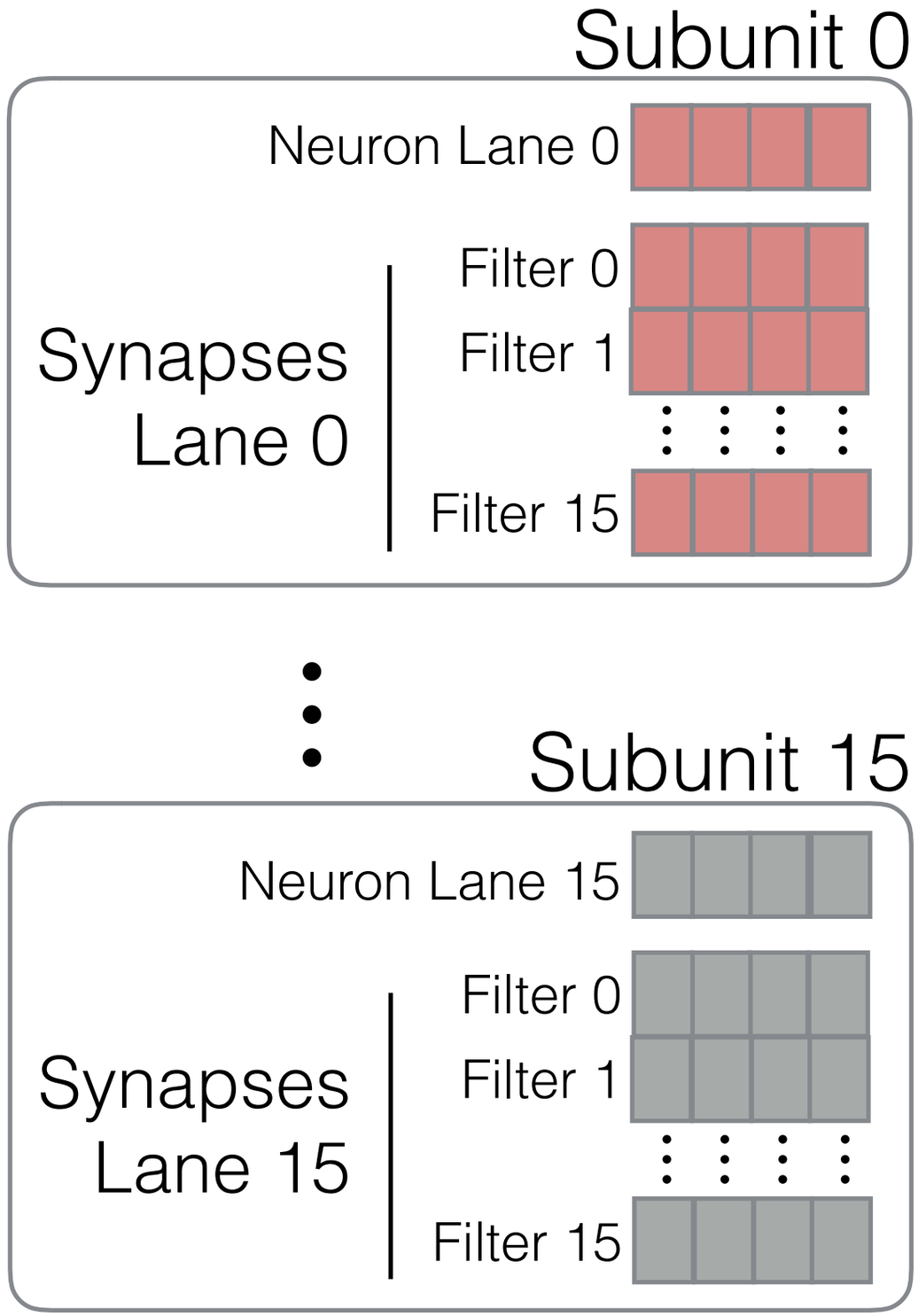


CNVLUTIN: Decoupling Lanes





DaDianNao **CNVLUTIN**

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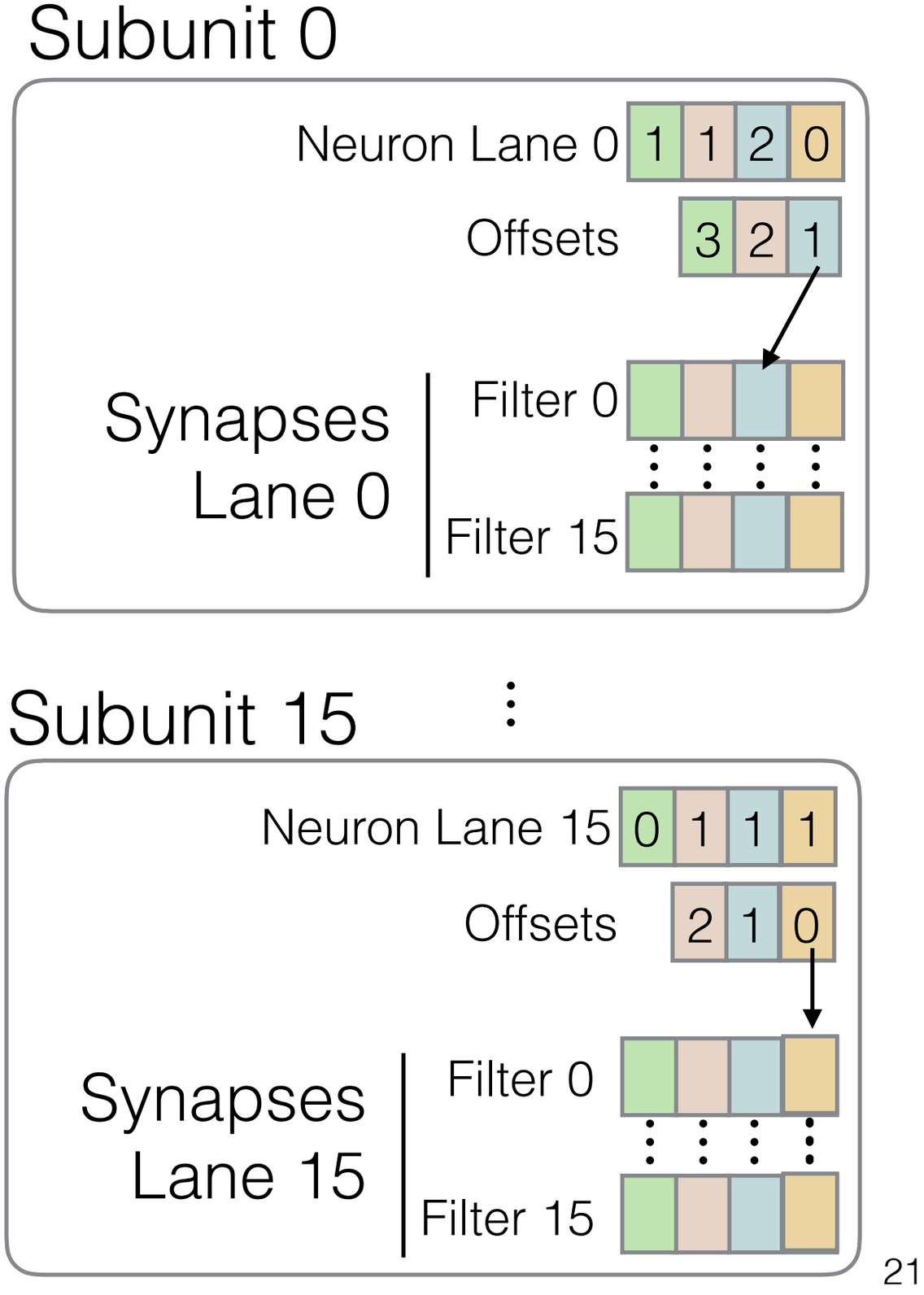

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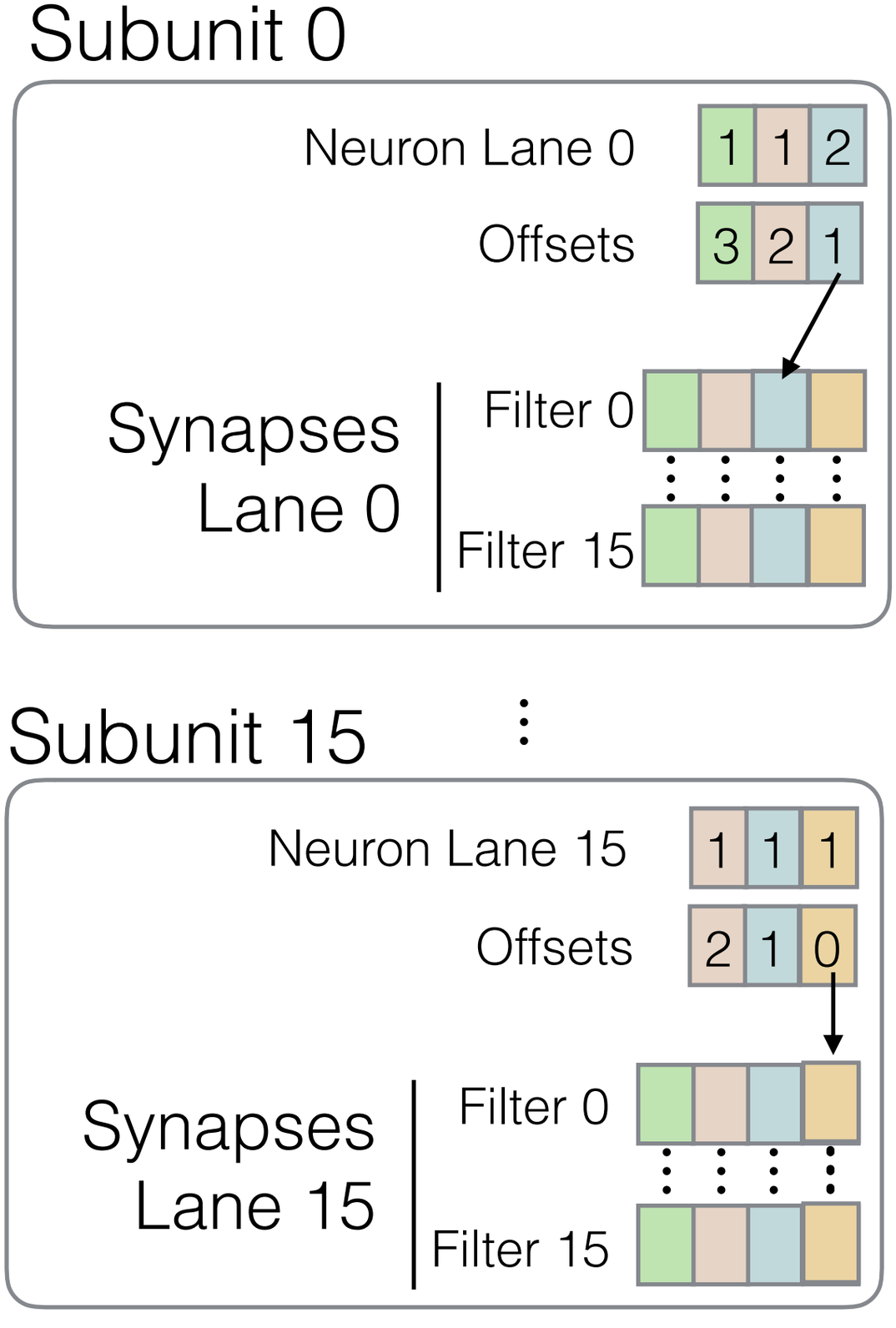

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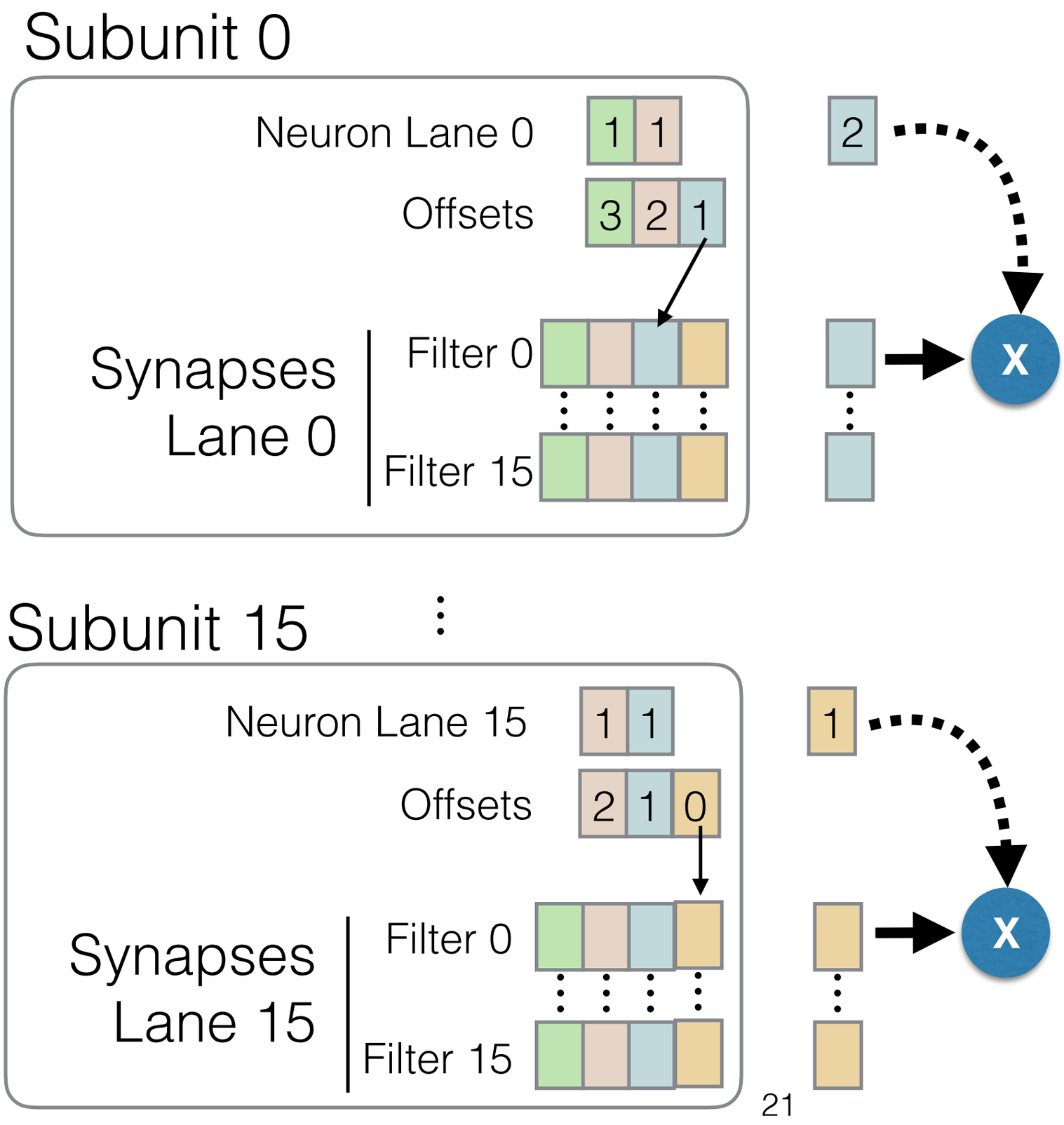
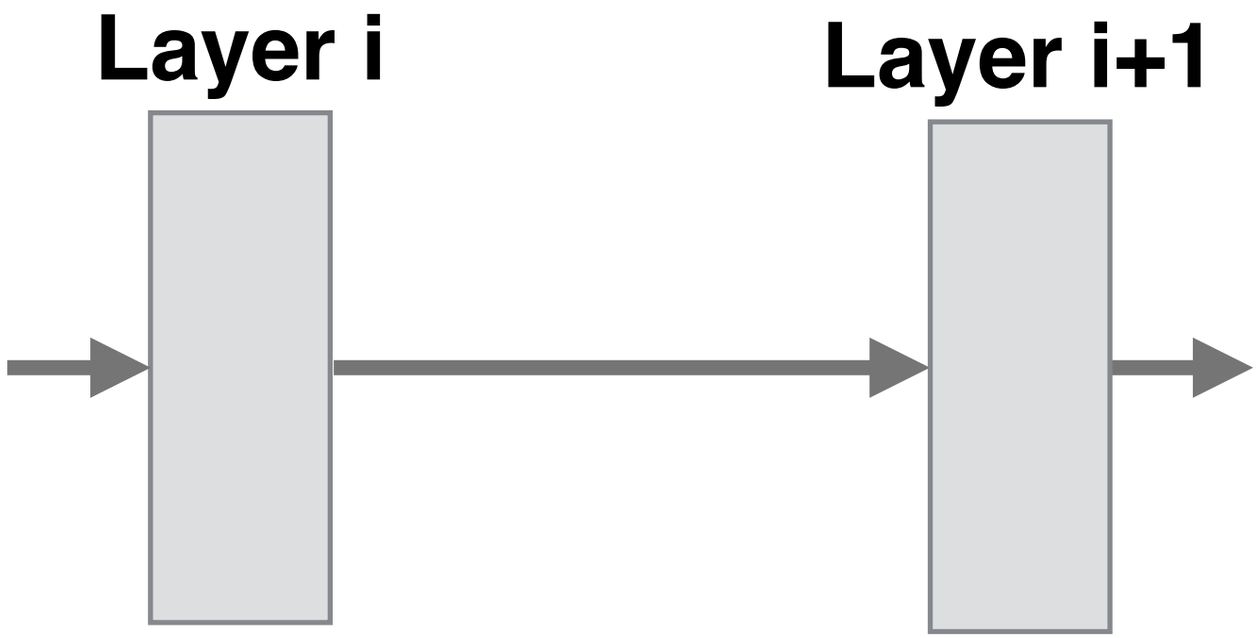


CNVLUTIN: Ineffectual-neuron Filtering



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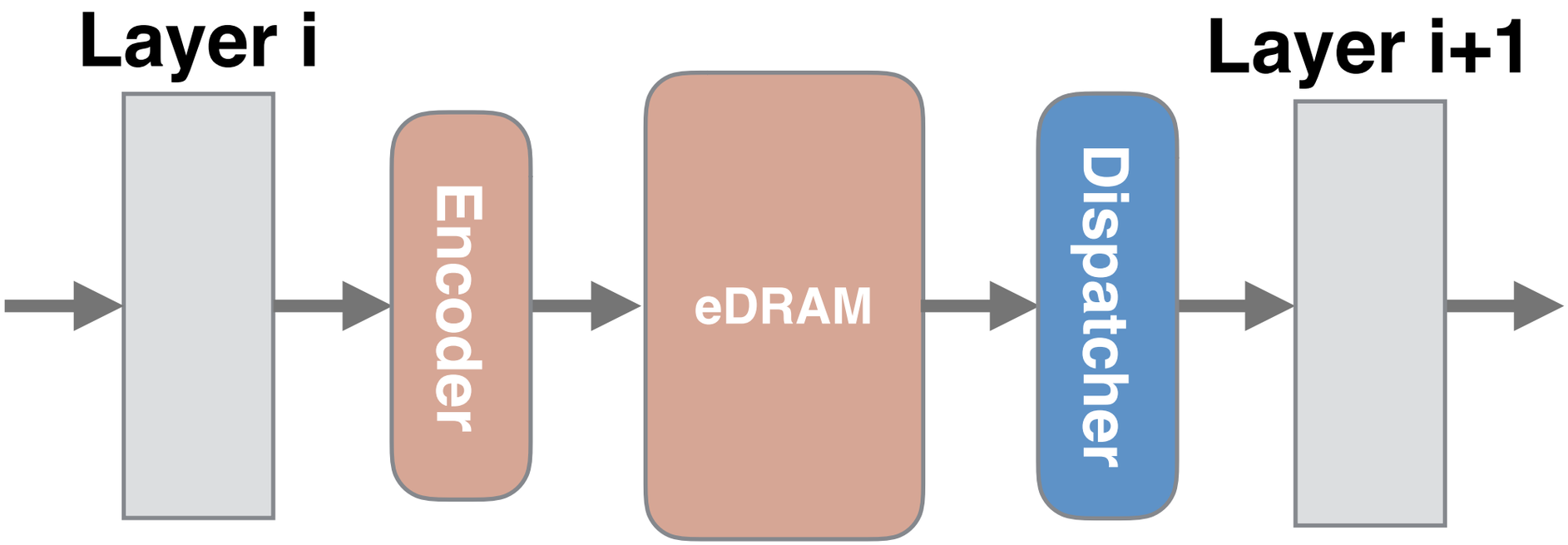

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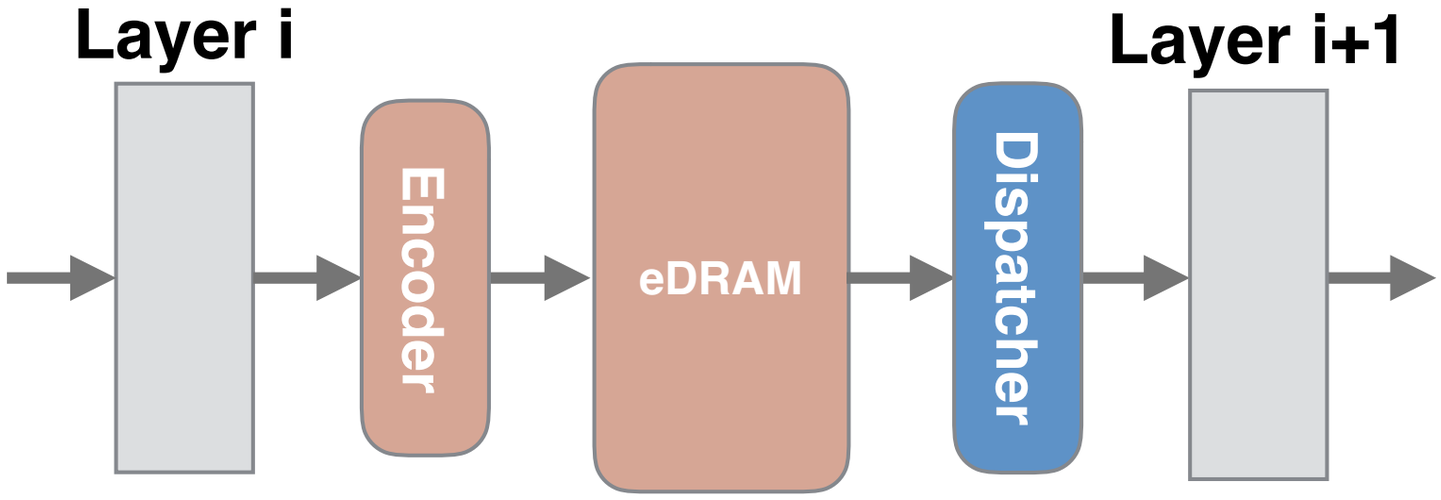

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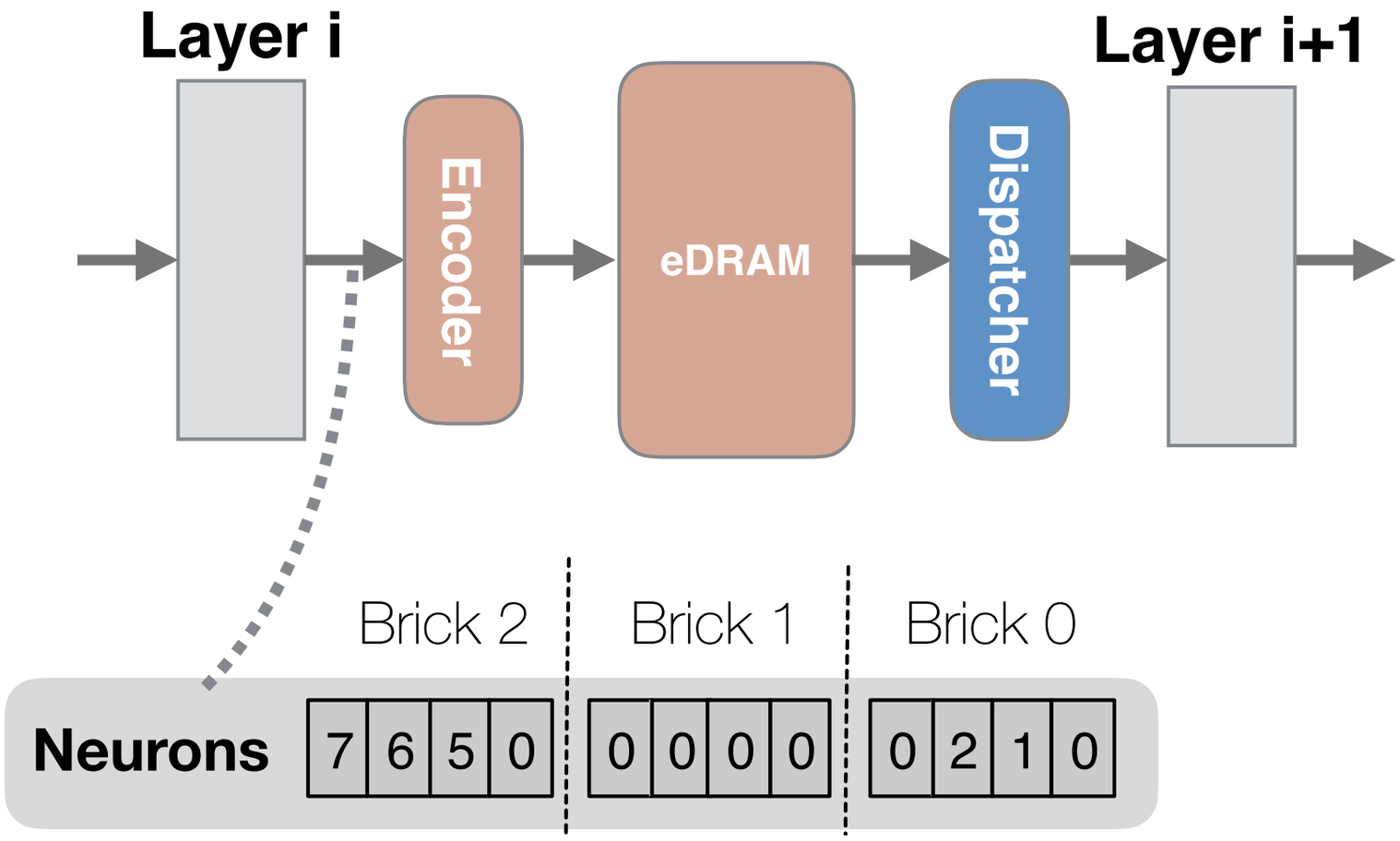

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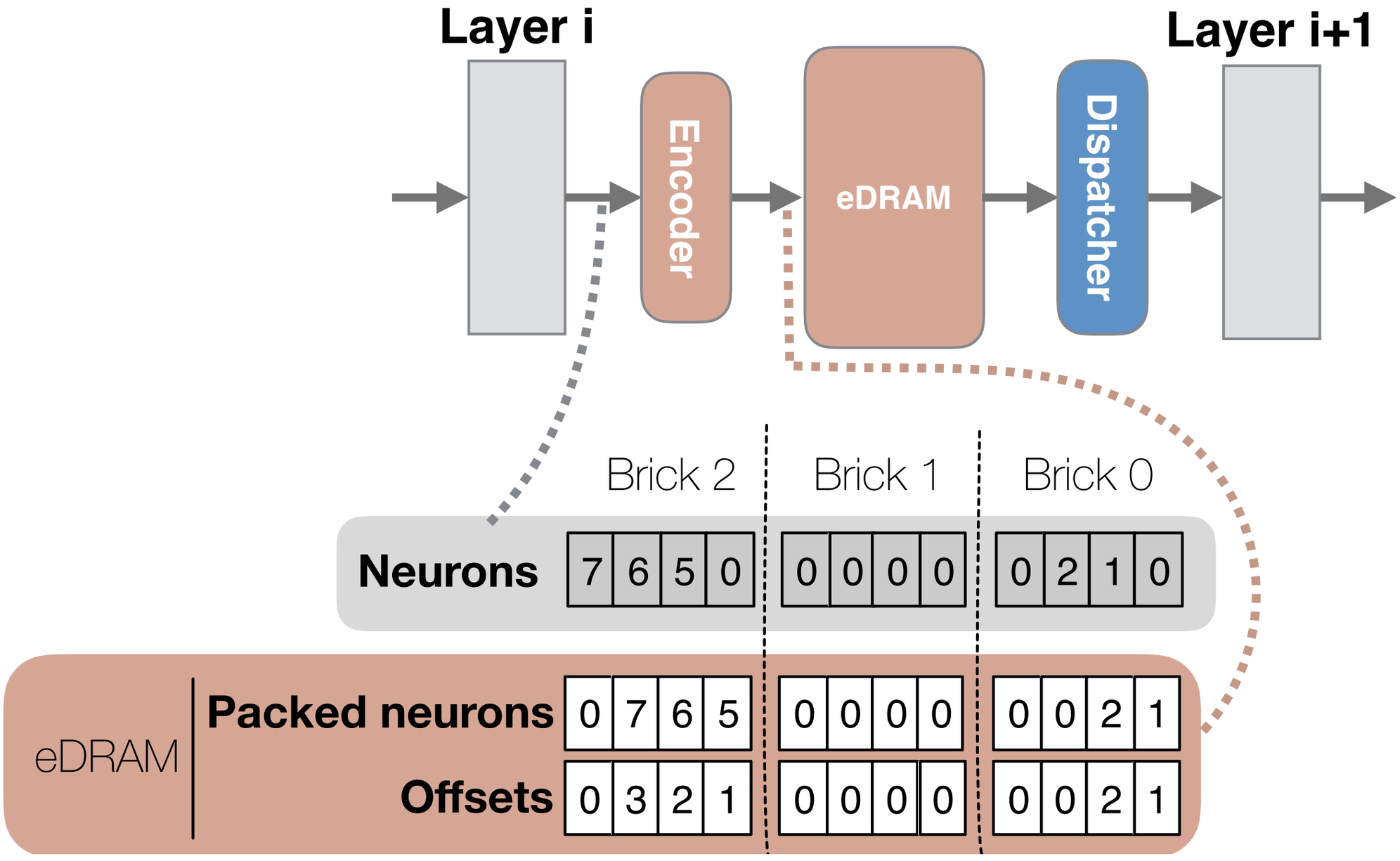

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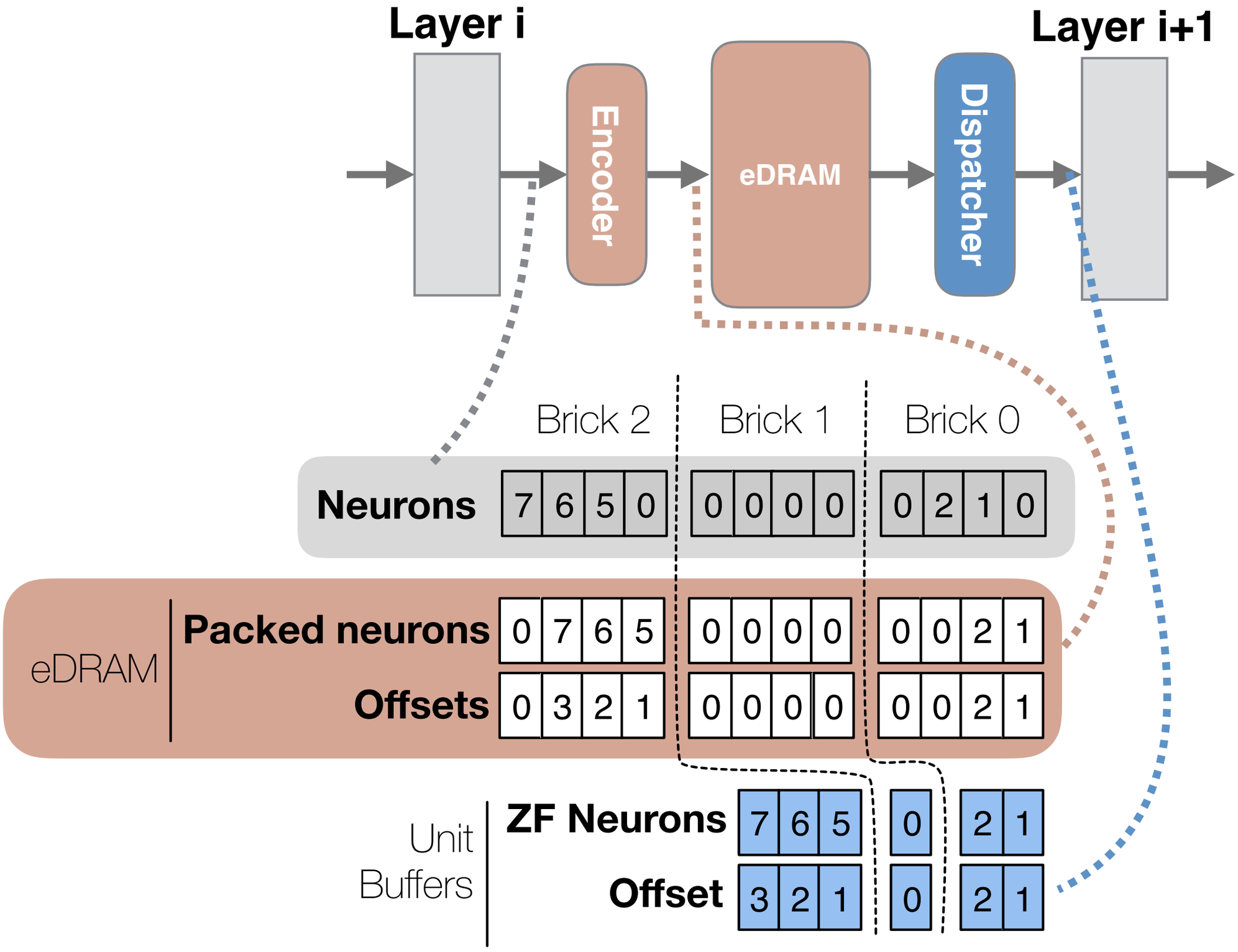
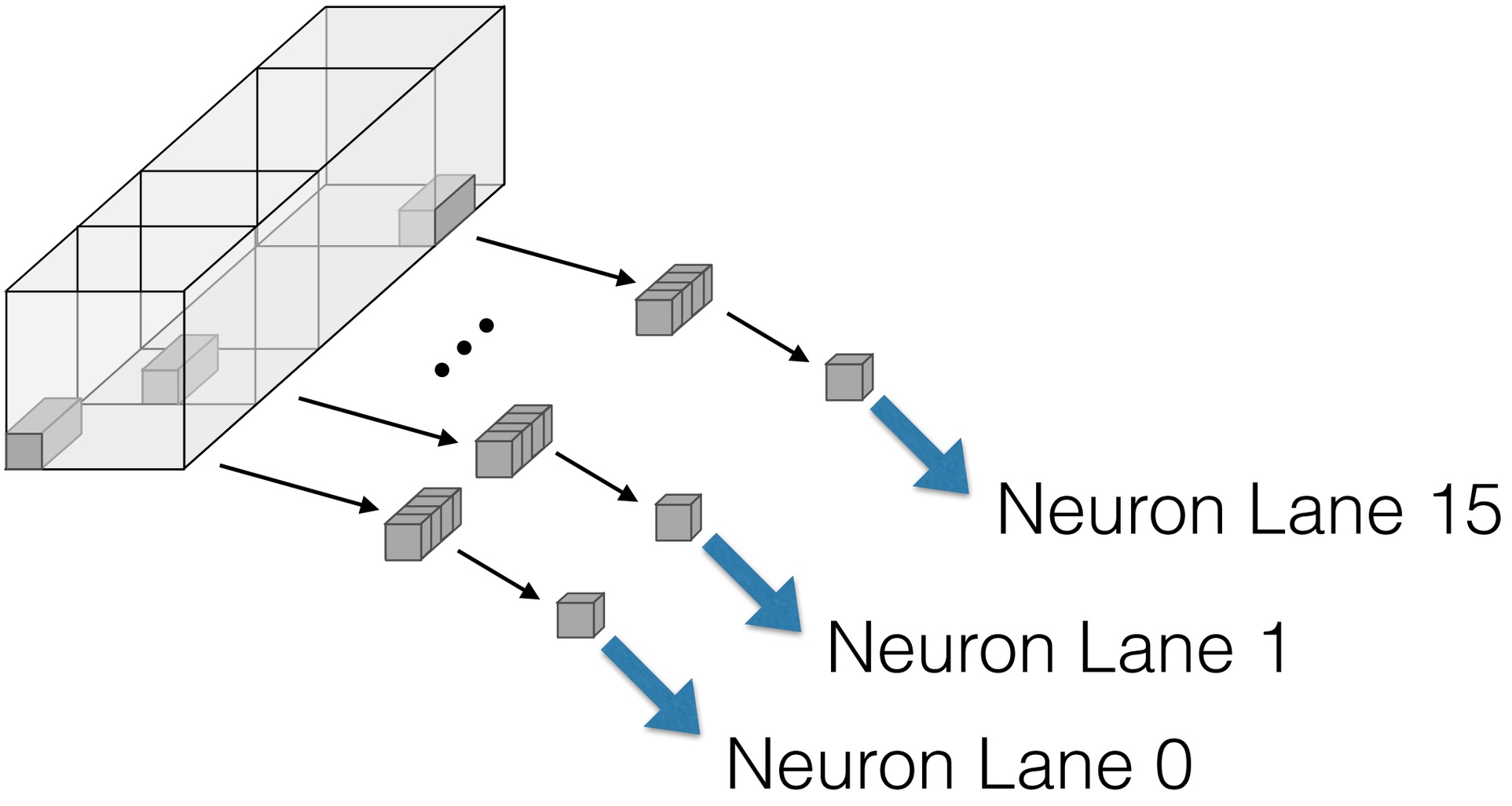


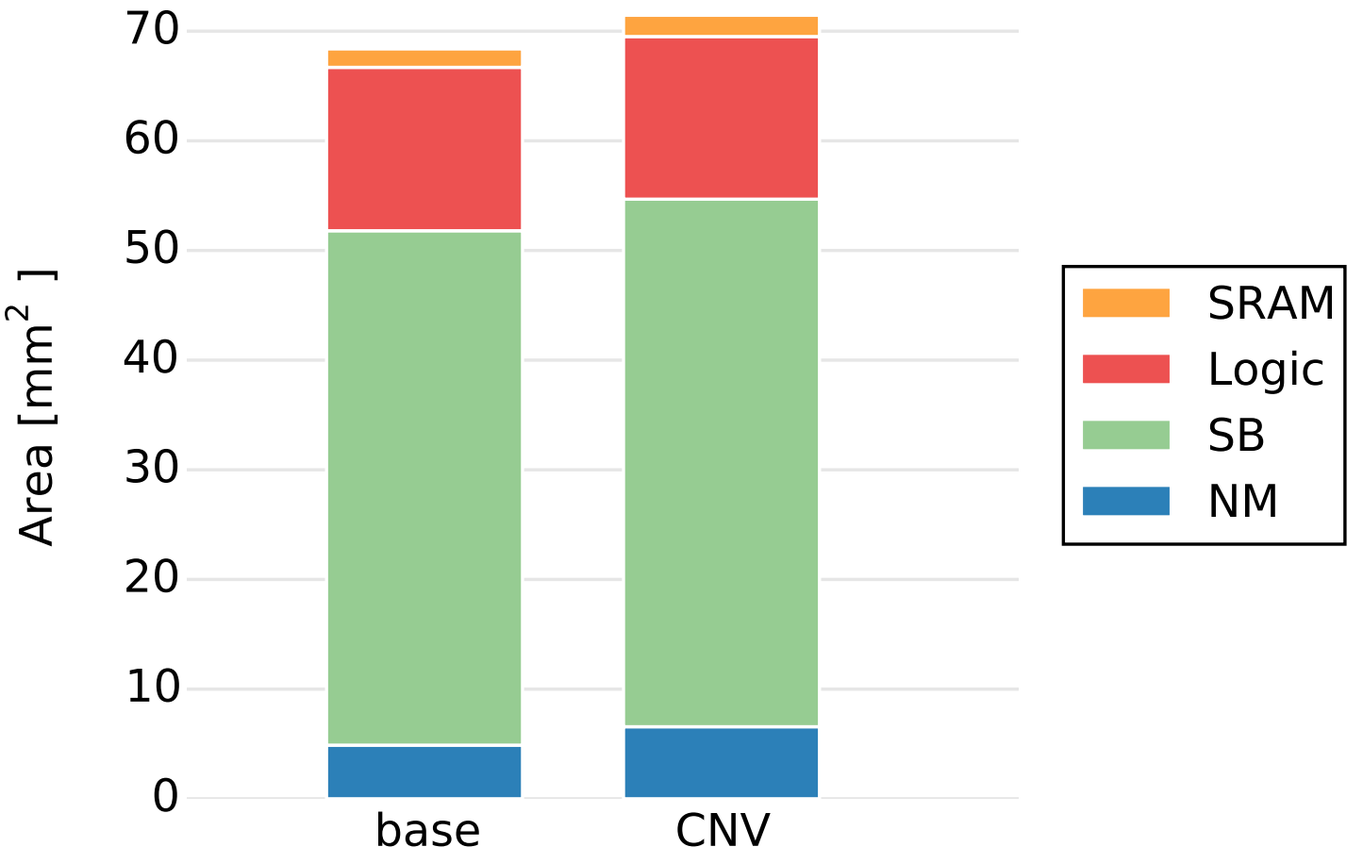
CNVLUTIN: Computation Slicing



Methodology

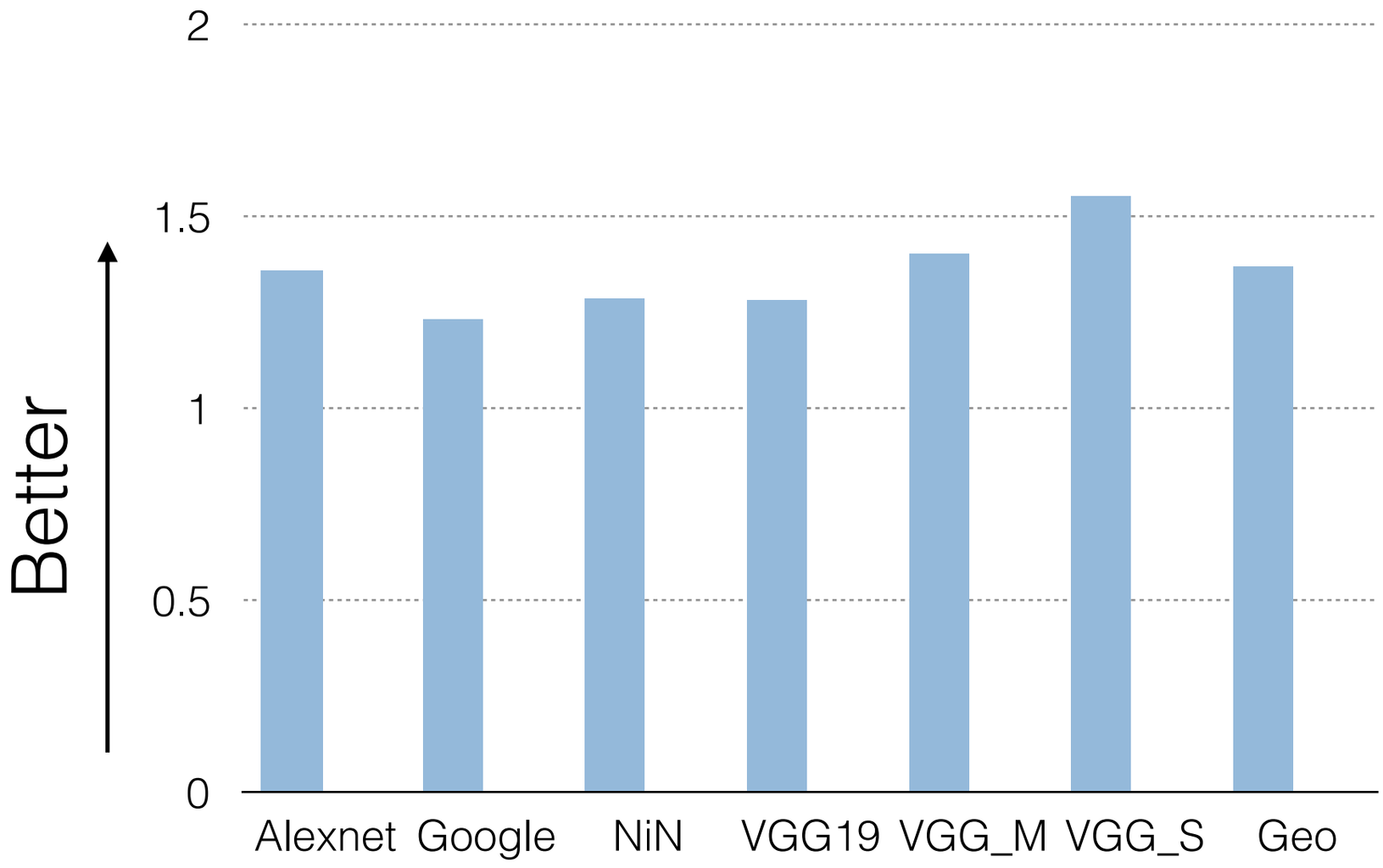
- In-house timing simulator: baseline + CNVLUTIN
- Logic + SRAM: Synthesis on 65nm TSMC
- eDRAM model: Destiny
- DNNs: Trained models from Caffe model zoo

Area

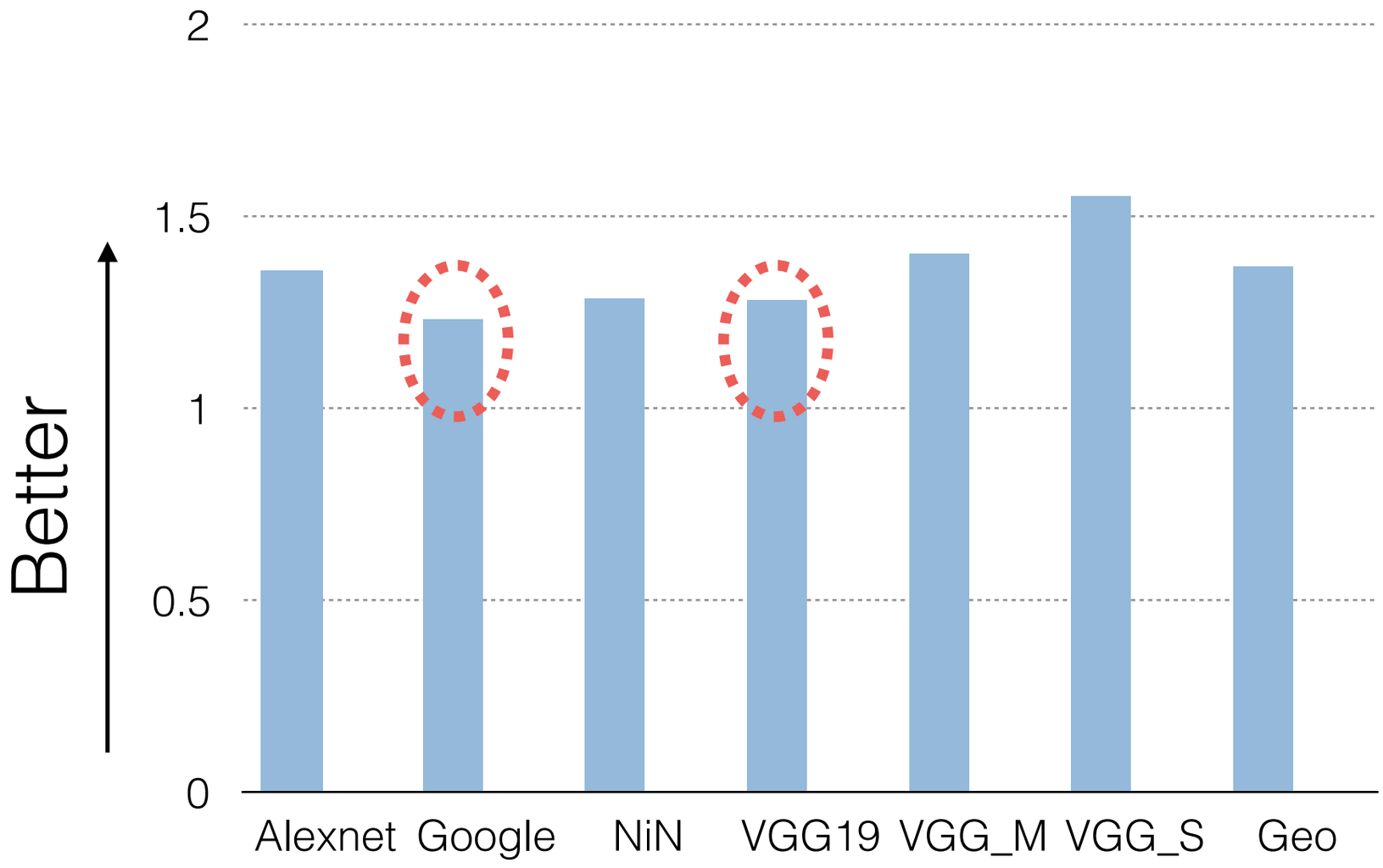


Only +4.5% in area overhead

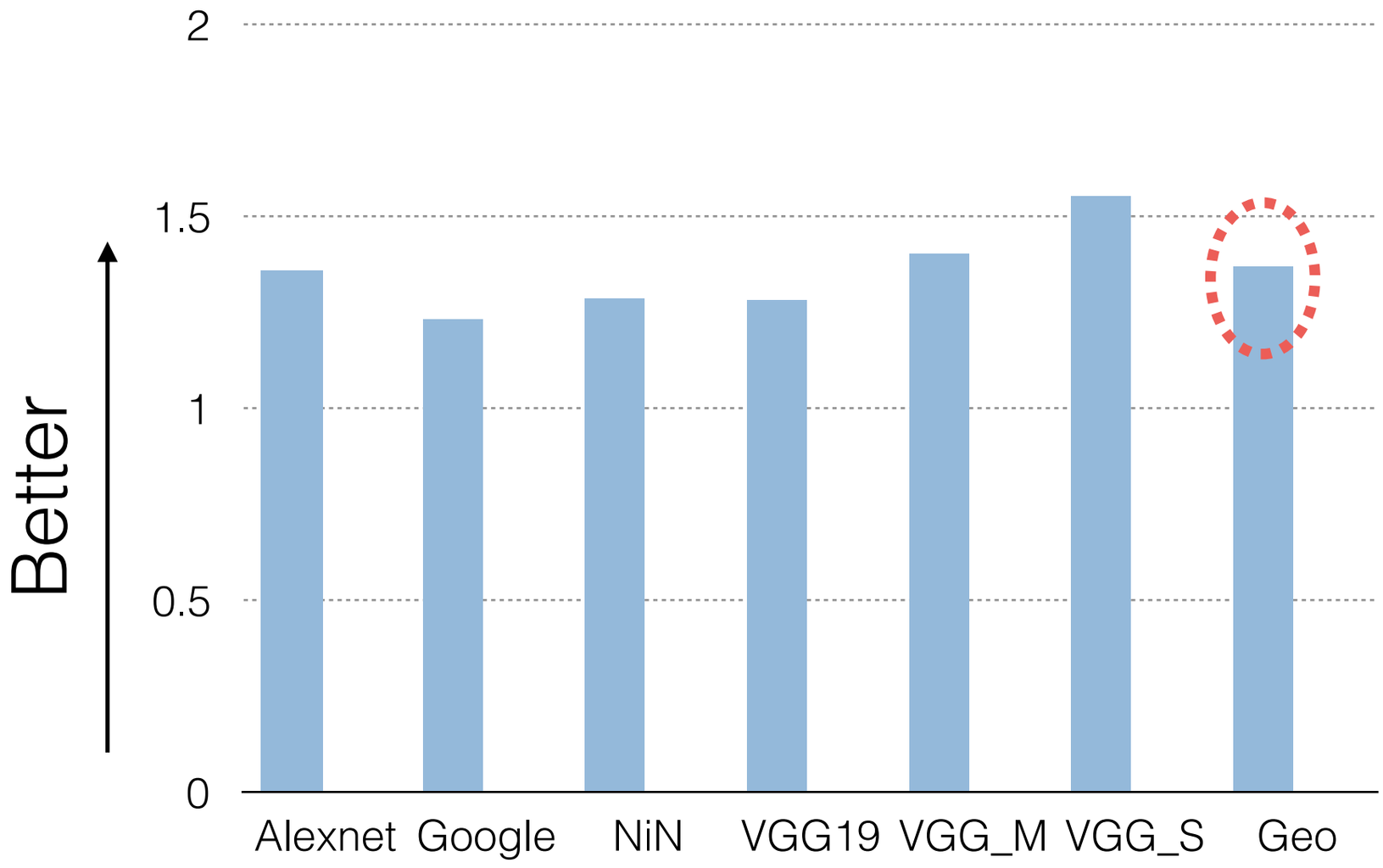
Speedup: ineffectual = 0



Speedup: ineffectual = 0



Speedup: ineffectual = 0



1.37x Performance on average

Loosening the Ineffectual Neuron Criterion

CNVLUTIN **zero**

“If all you have is ~~a hammer~~, everything looks like a ~~nail~~”

(Maslow’s hammer)

37	0	13	10
15	1	123	0
0	7	1	3
0	1	20	0
18	31	0	33

Loosening the Ineffectual Neuron Criterion

CNVLUTIN **zero**

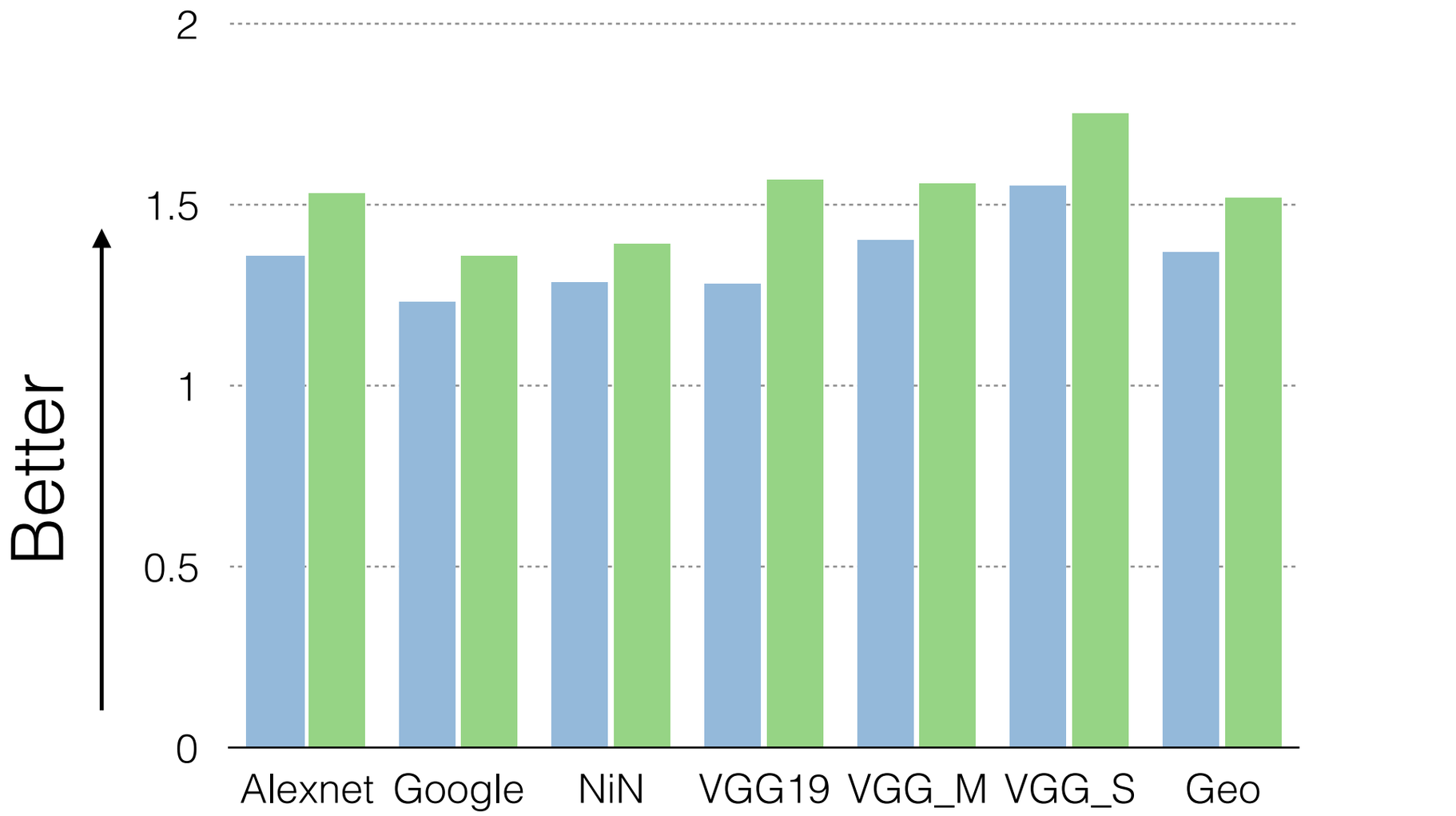
“If all you have is ~~a hammer~~, everything looks like a ~~nail~~”

(Maslow’s hammer)

37	0	13	10
15	1	123	0
0	7	1	3
0	1	20	0
18	31	0	33

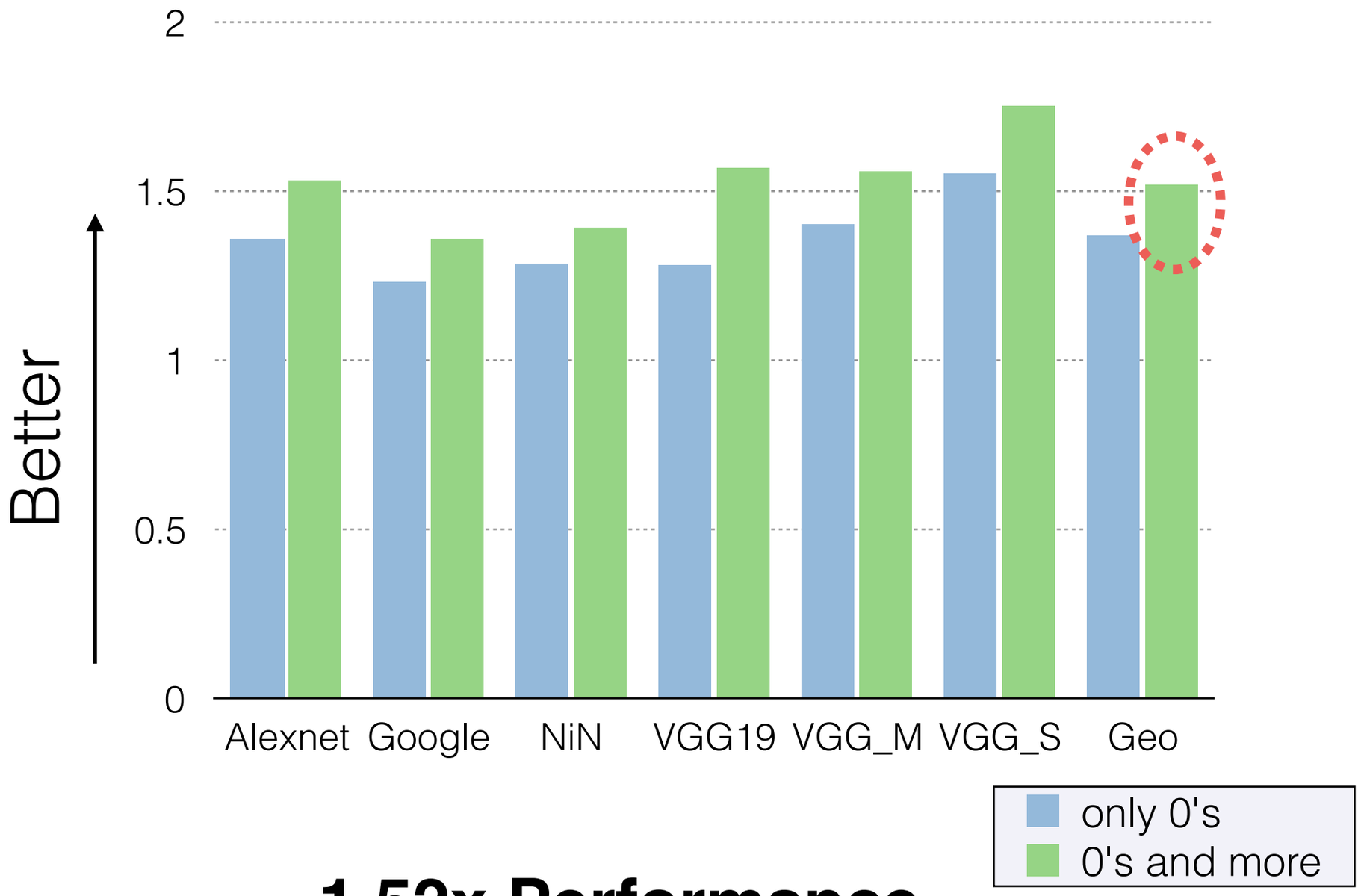
Example: consider ineffectual if value<2

Speedup: ineffectual >= 0



1.52x Performance
No accuracy lost

Speedup: ineffectual >= 0



1.52x Performance
No accuracy lost

Loosening the Ineffectual Neuron Criterion

CNVLUTIN **zero**

“If all you have is ~~a hammer~~, everything looks like a ~~nail~~”

(Maslow’s hammer)

37	0	13	10
15	1	123	0
0	7	1	3
0	1	20	0
18	31	0	33

Example: consider ineffectual if value<2

Loosening the Ineffectual Neuron Criterion

CNVLUTIN **zero**

“If all you have is ~~a hammer~~, everything looks like a ~~nail~~”

(Maslow’s hammer)

37	0	13	10
15	1	123	0
0	7	1	3
0	1	20	0
18	31	0	33

Example: consider ineffectual if value<8

Loosening the Ineffectual Neuron Criterion

CNVLUTIN **zero**

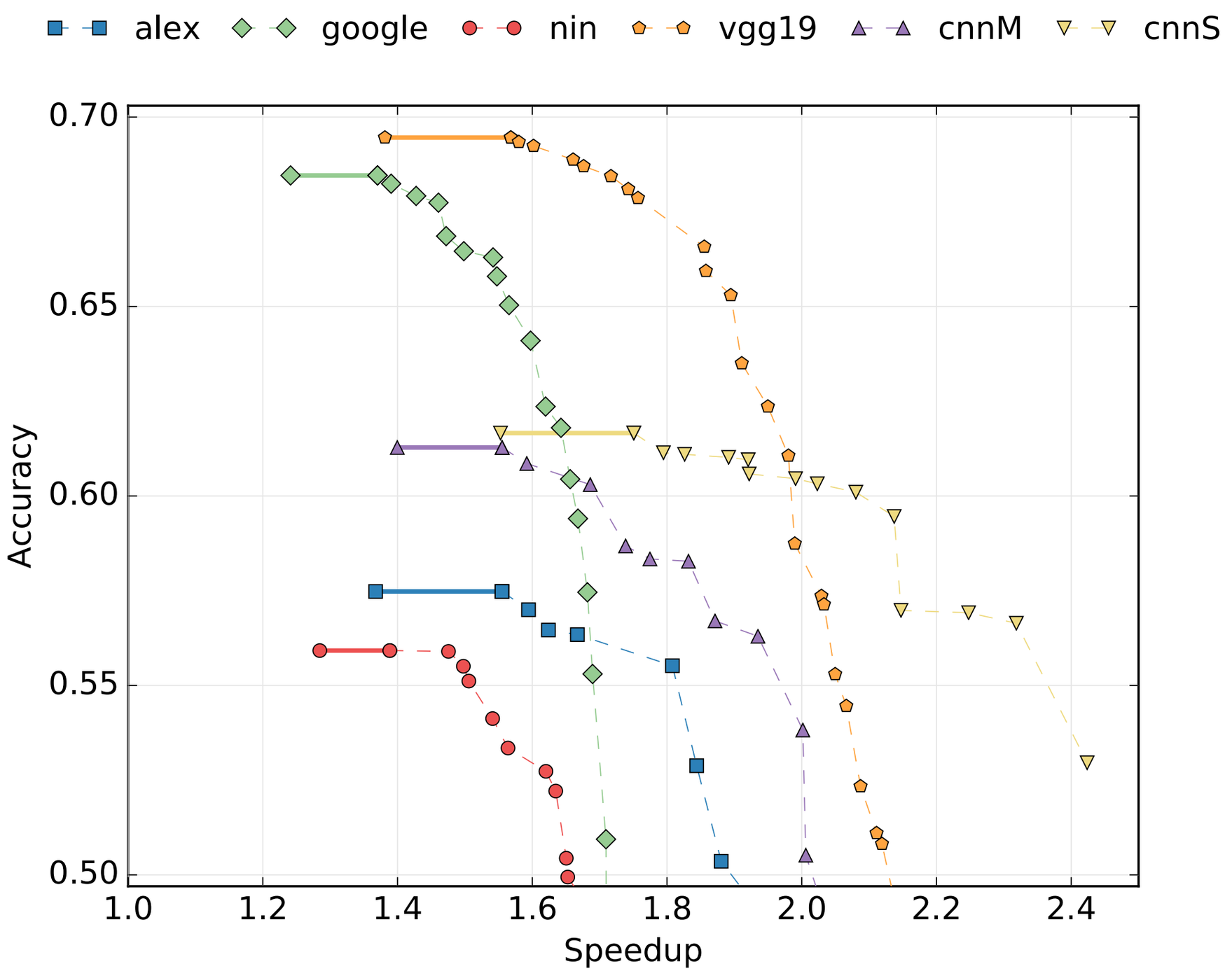
“If all you have is ~~a hammer~~, everything looks like a ~~nail~~”

(Maslow’s hammer)

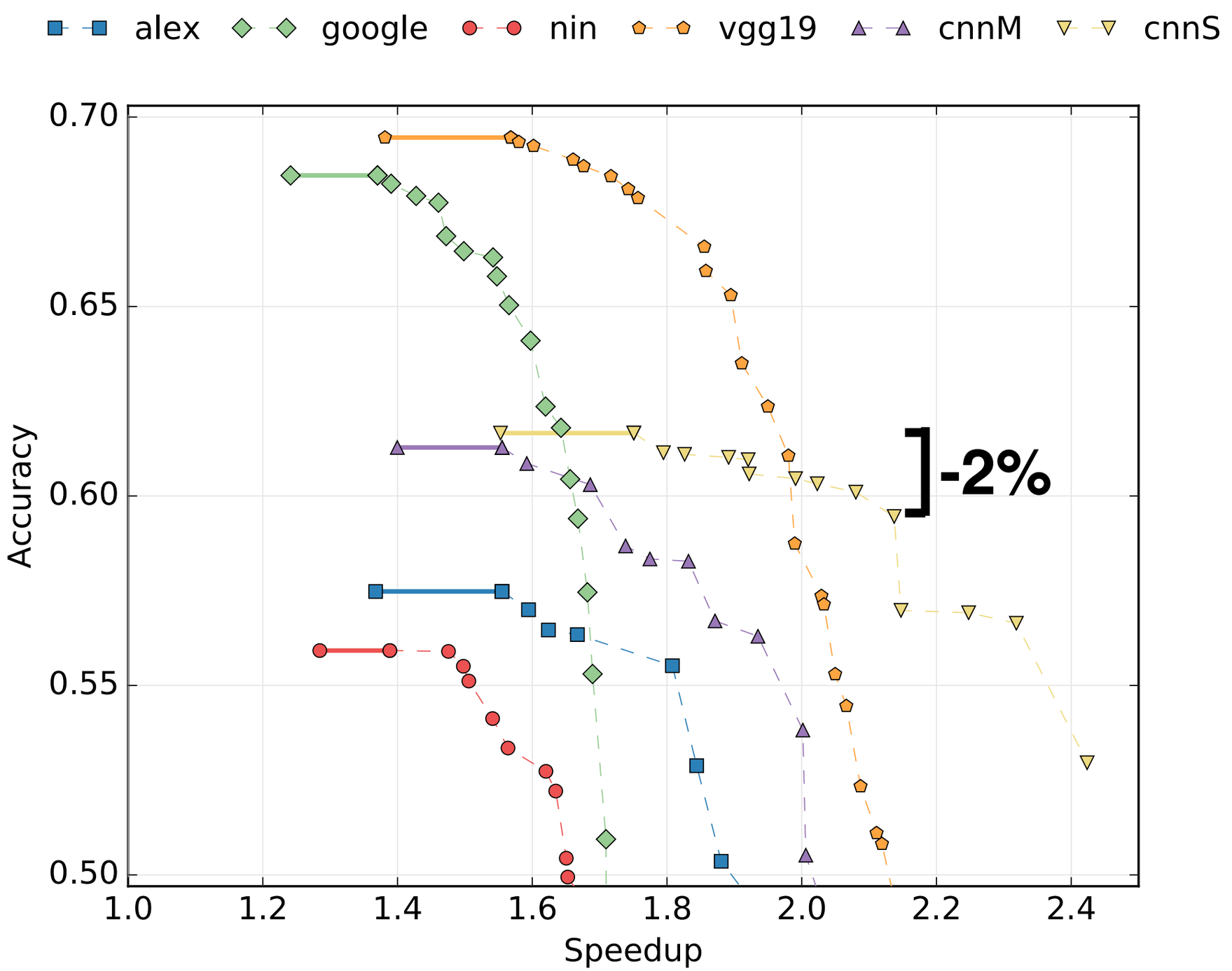
37	0	13	10
15	1	123	0
0	7	1	3
0	1	20	0
18	31	0	33

Example: consider ineffectual if value<32

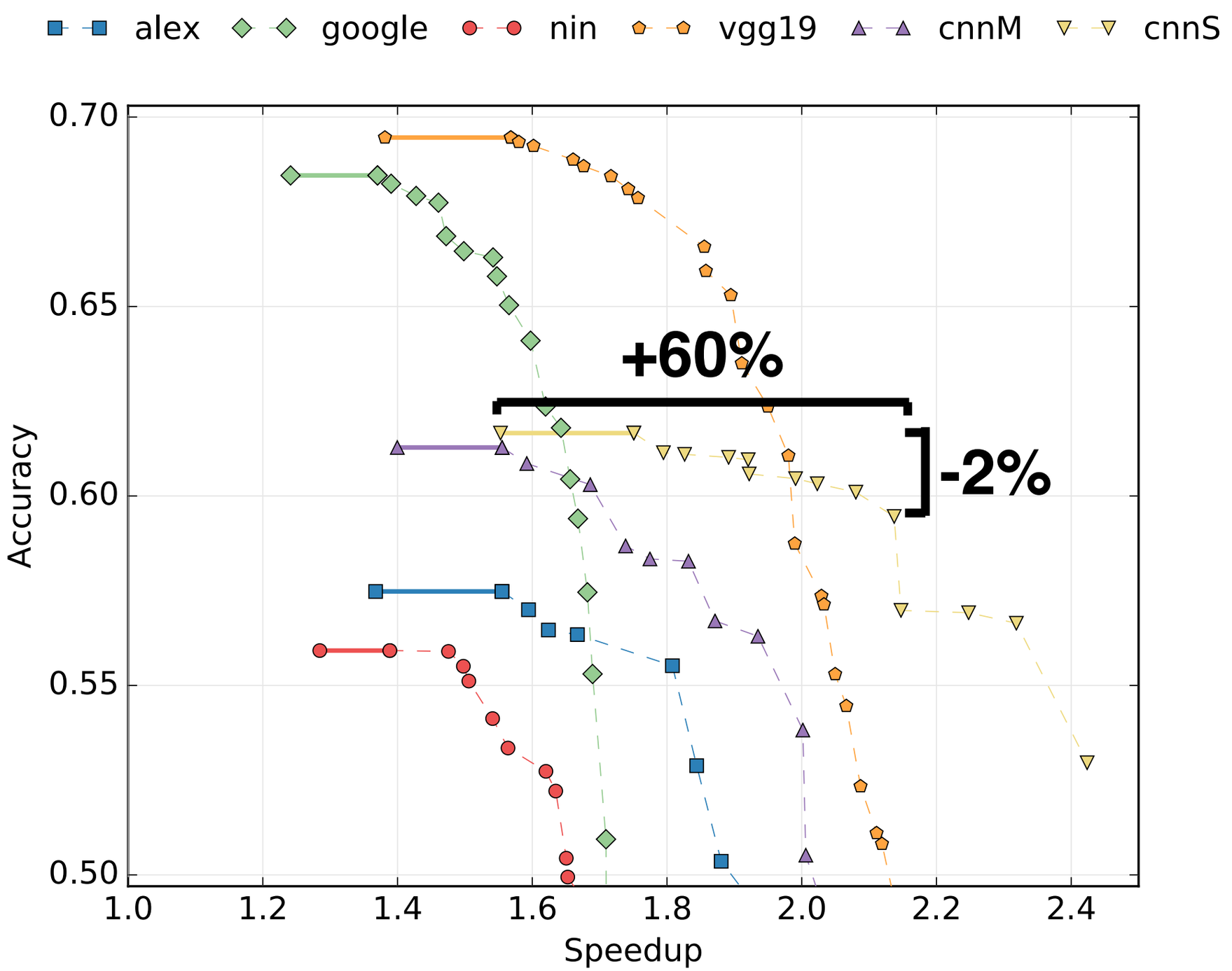
Trading accuracy for performance



Trading accuracy for performance



Trading accuracy for performance



CNVLUTIN: Smarter SIMD

52% Performance — 2x ED²P
No accuracy lost

out-of-the-box networks

Our Approach

Value-Aware Deep Learning Acceleration

arXiv, a while ago:

Reduced-Precision Strategies for Bounded Memory in DNNs

ICS 2016

Proteus: Exploiting Numerical Precision Variability in DNNs

Today

CNVLUTIN: Ineffectual-Neuron-Free DNN Computing

CAL (to appear)

How to offer performance that scales linearly with required numerical precision

More things coming soon :-)

Additional Material

CNVLUTIN: Ineffectual-neuron-free DNN computing

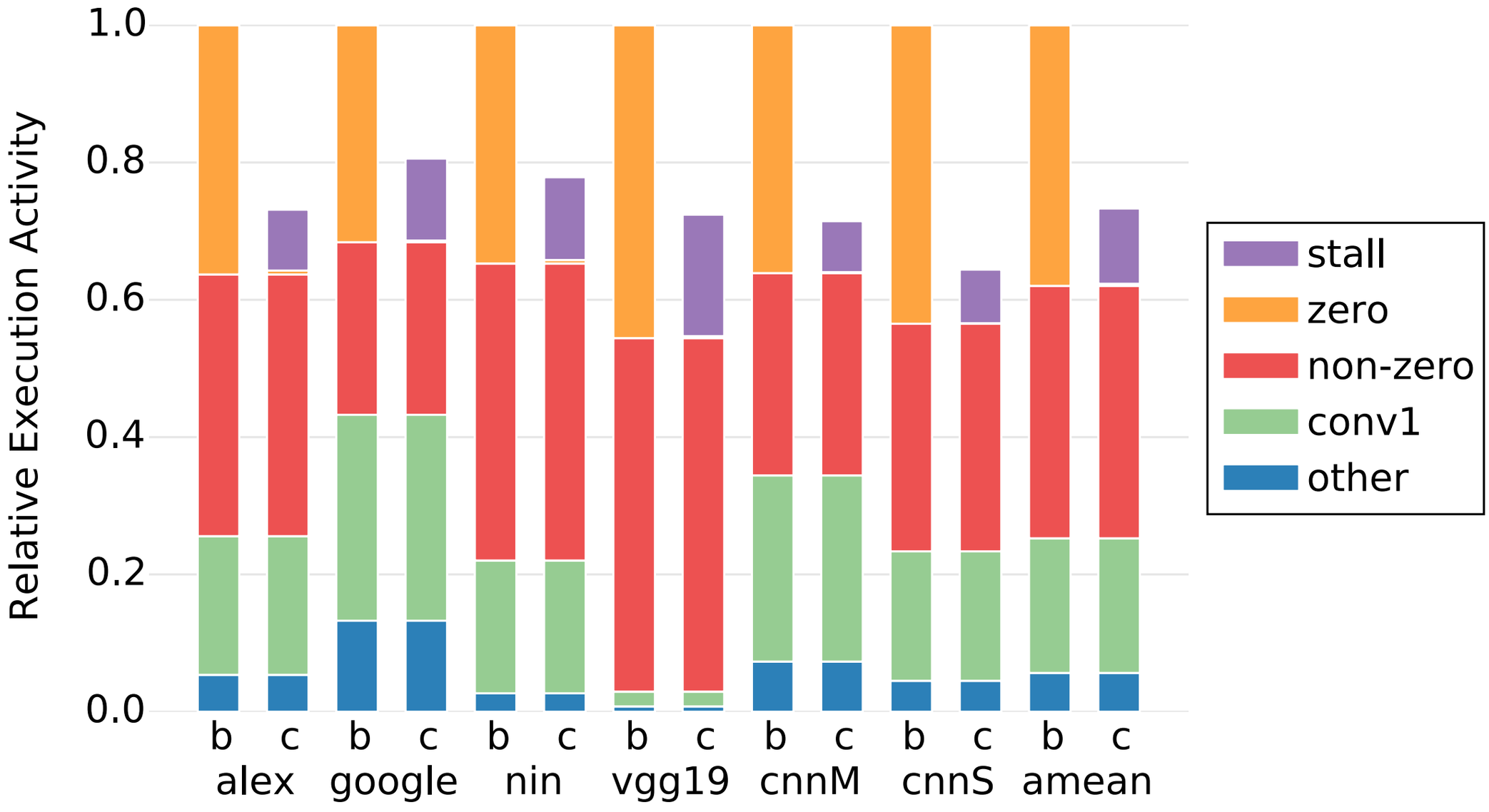
J. Albericio, P. Judd, T. Hetherington*,
T. Aamodt*, N. E. Jerger, A. Moshovos

UNIVERSITY OF TORONTO

UBC*

Please cite the original source.

Execution Activity Breakdown

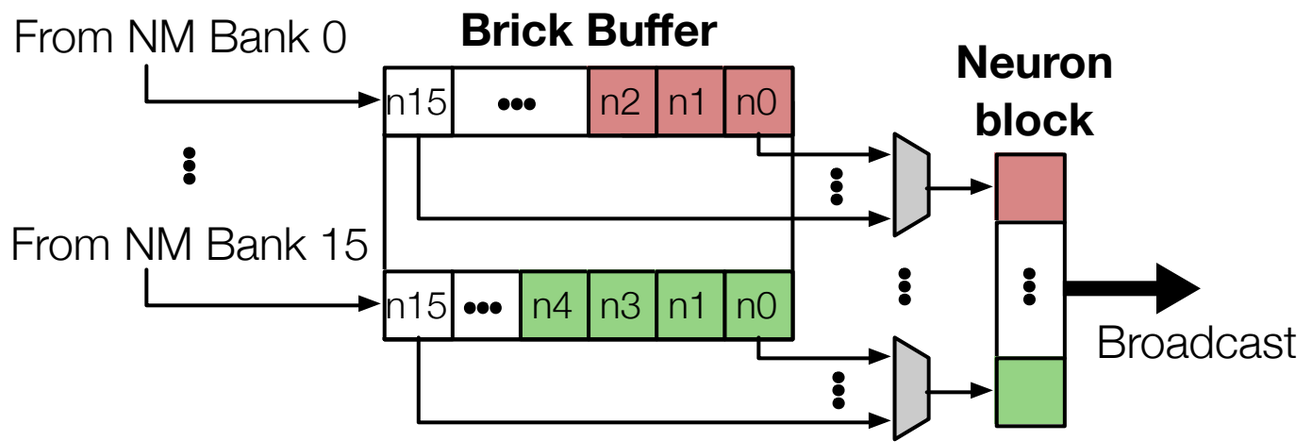


Cnvlutin: Maintaining Wide NM accesses

Dispatcher:

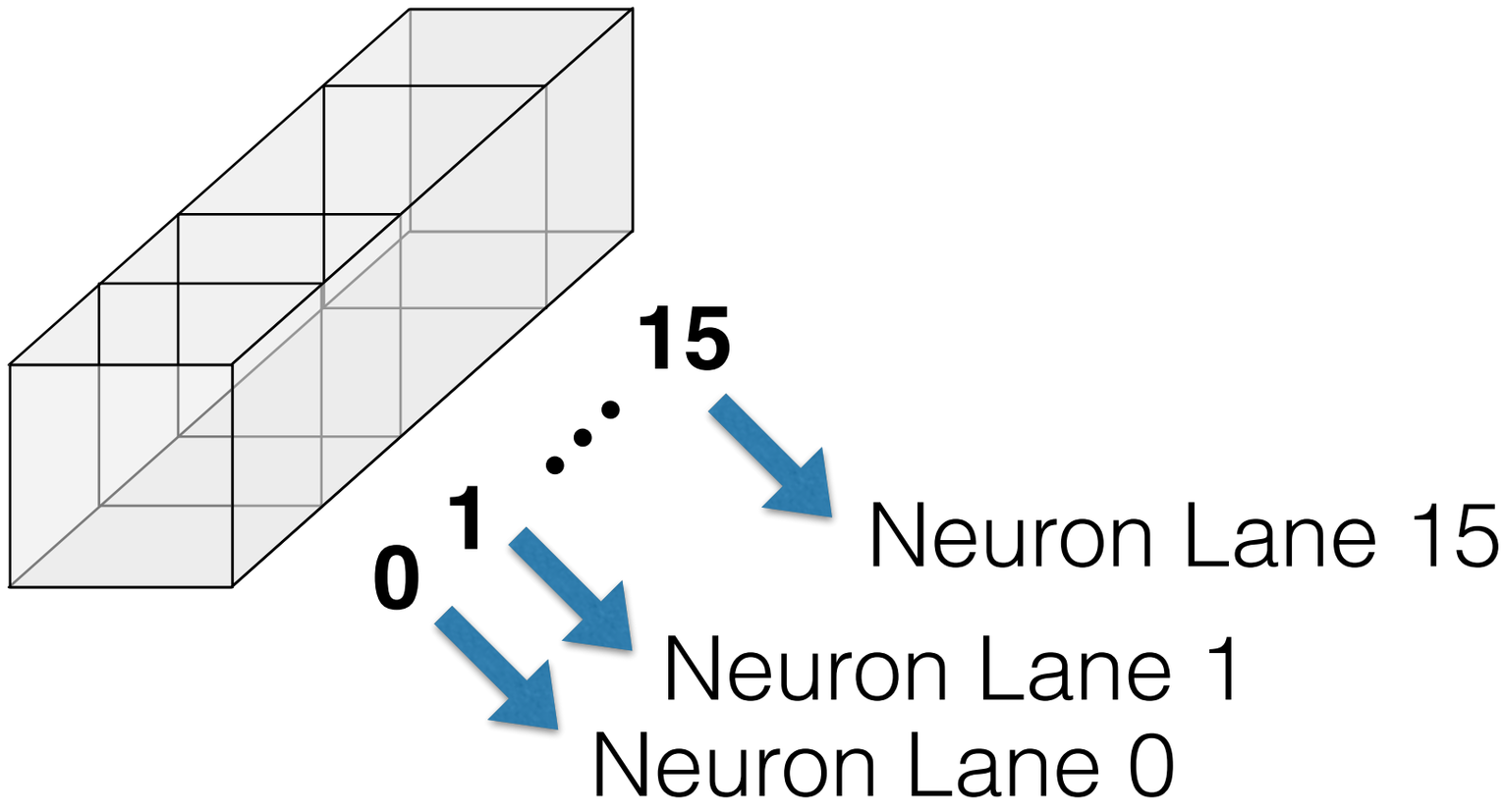
Reads Neuron Bricks - up to 16 neuron

Maintain one per Neuron Lane



Cnvlutin: Maintaining Wide NM accesses

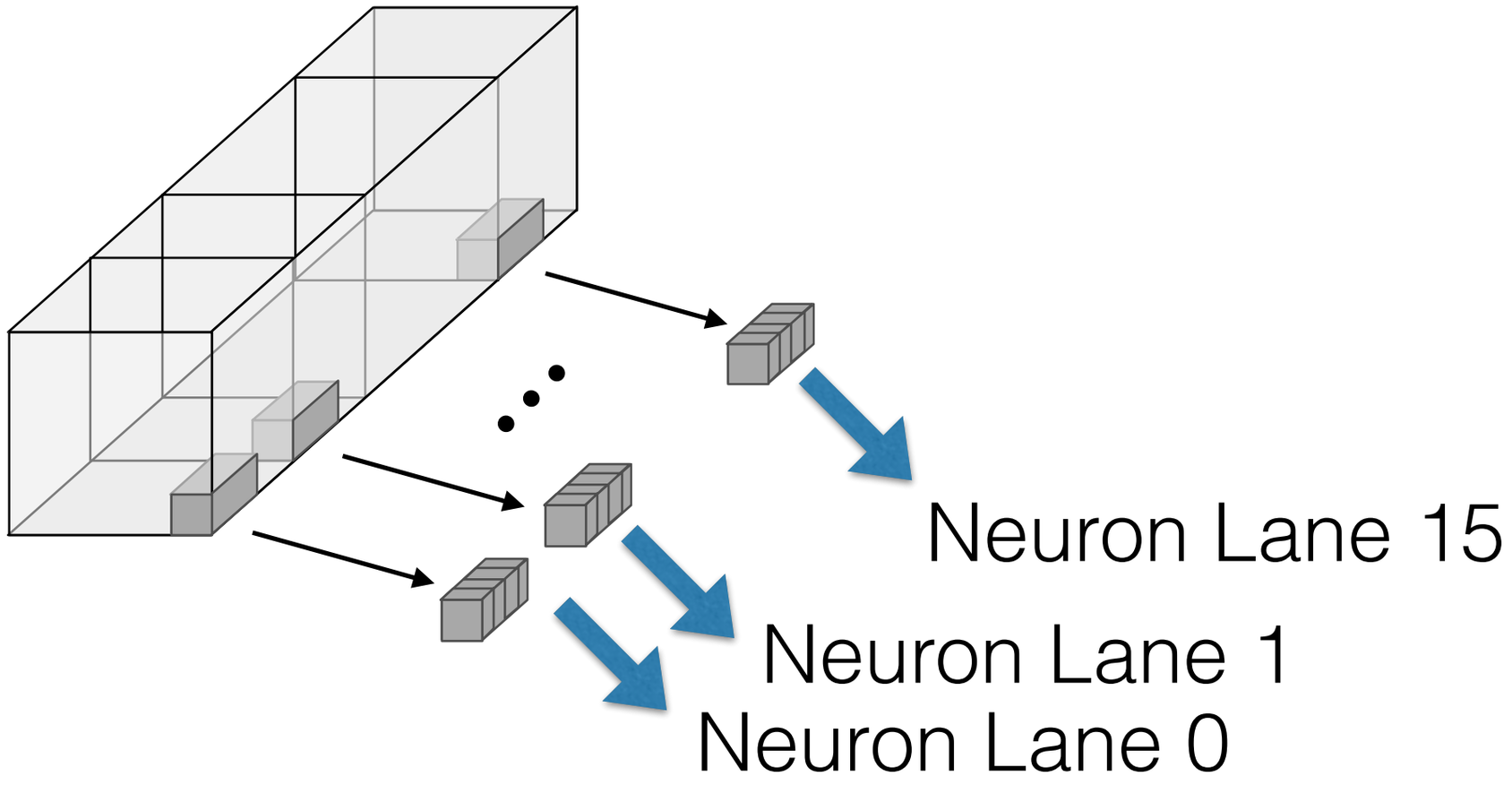
#1: Partition NM in 16 Slices over 16 banks



Cnvlutin: Maintaining Wide NM accesses

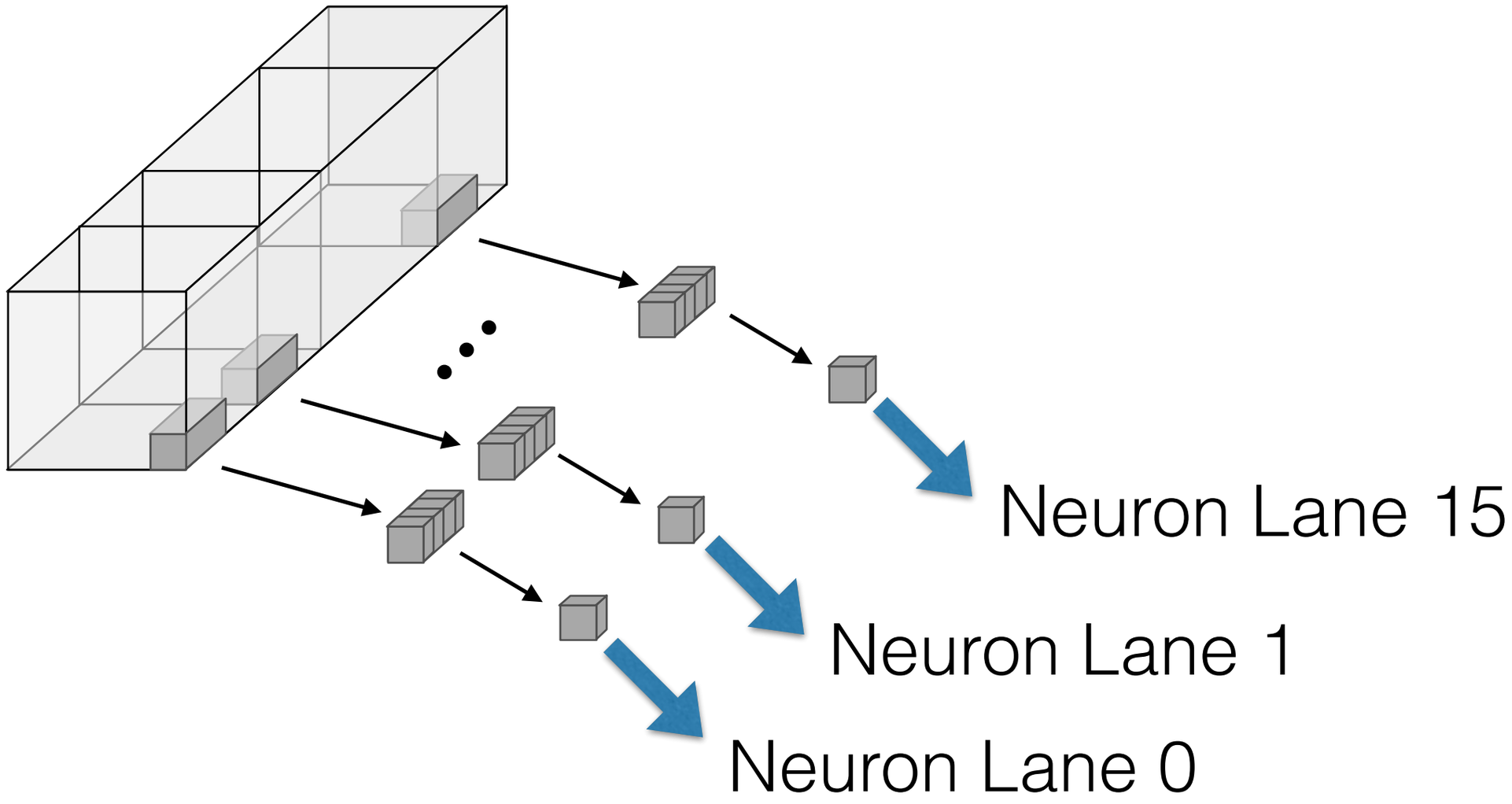
#2: Fetch and Maintain One Container per Slice

Container: up to 16 non-zero neurons

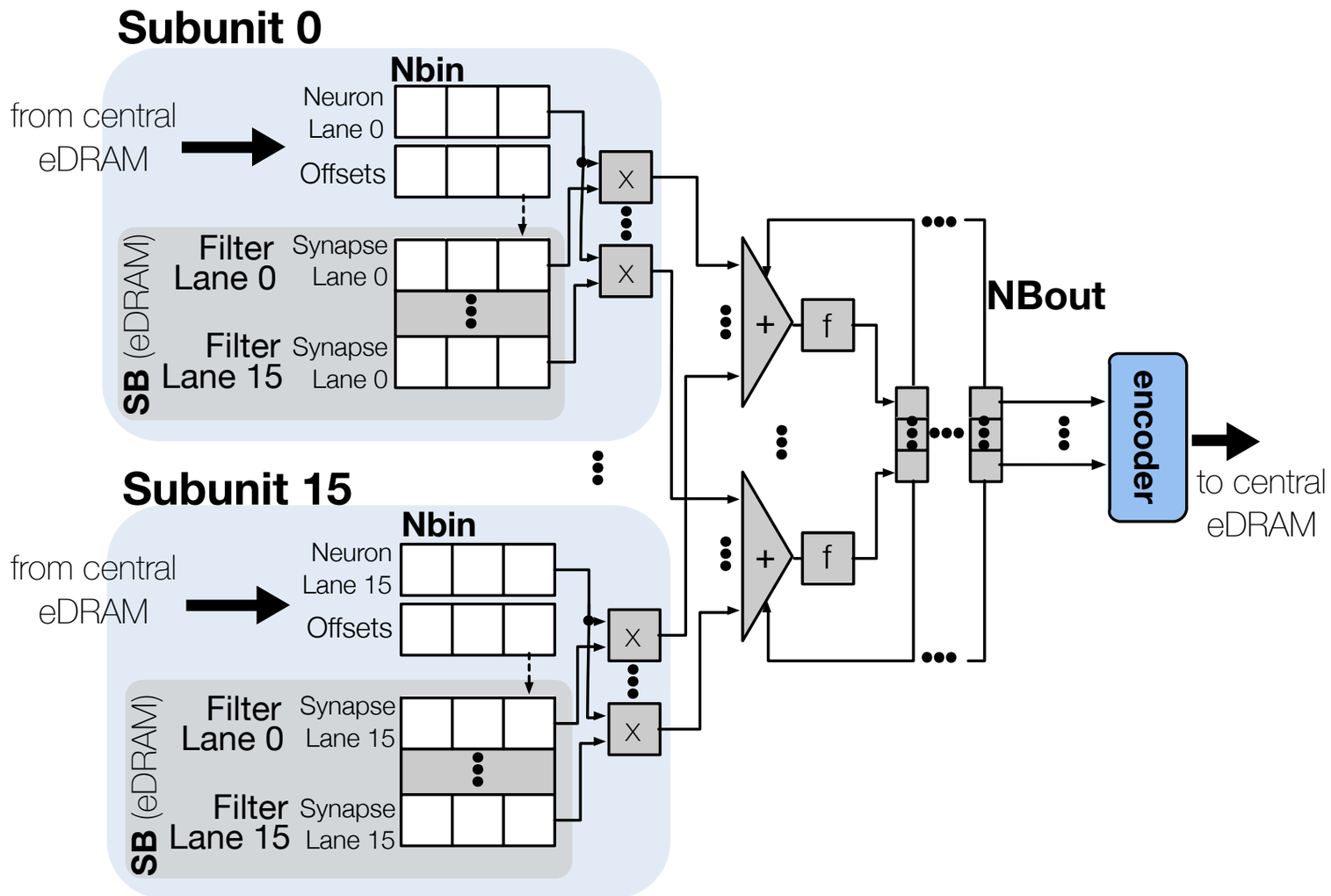


Cnvlutin: Maintaining Wide NM accesses

#3: Keep neuron lanes supplied with one neuron per cycle



Cnvlutin: Summary



Decoupled Neuron Lanes:

Neuron + coordinate

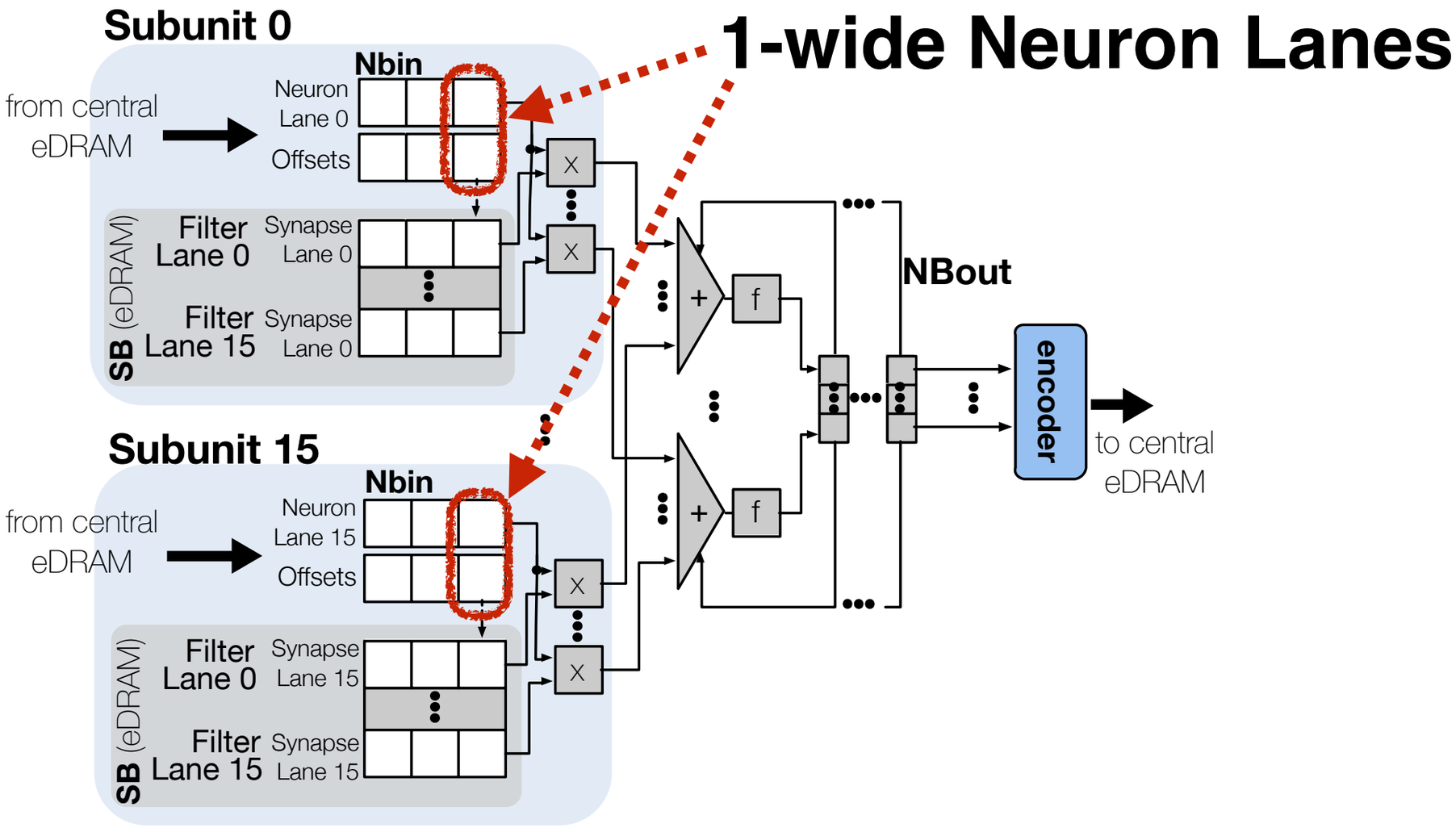
Proceed independently

Partitioned SB:

16-wide accesses

1 synapse per filter

Cnvlutin: Summary



Decoupled Neuron Lanes:

Neuron + coordinate

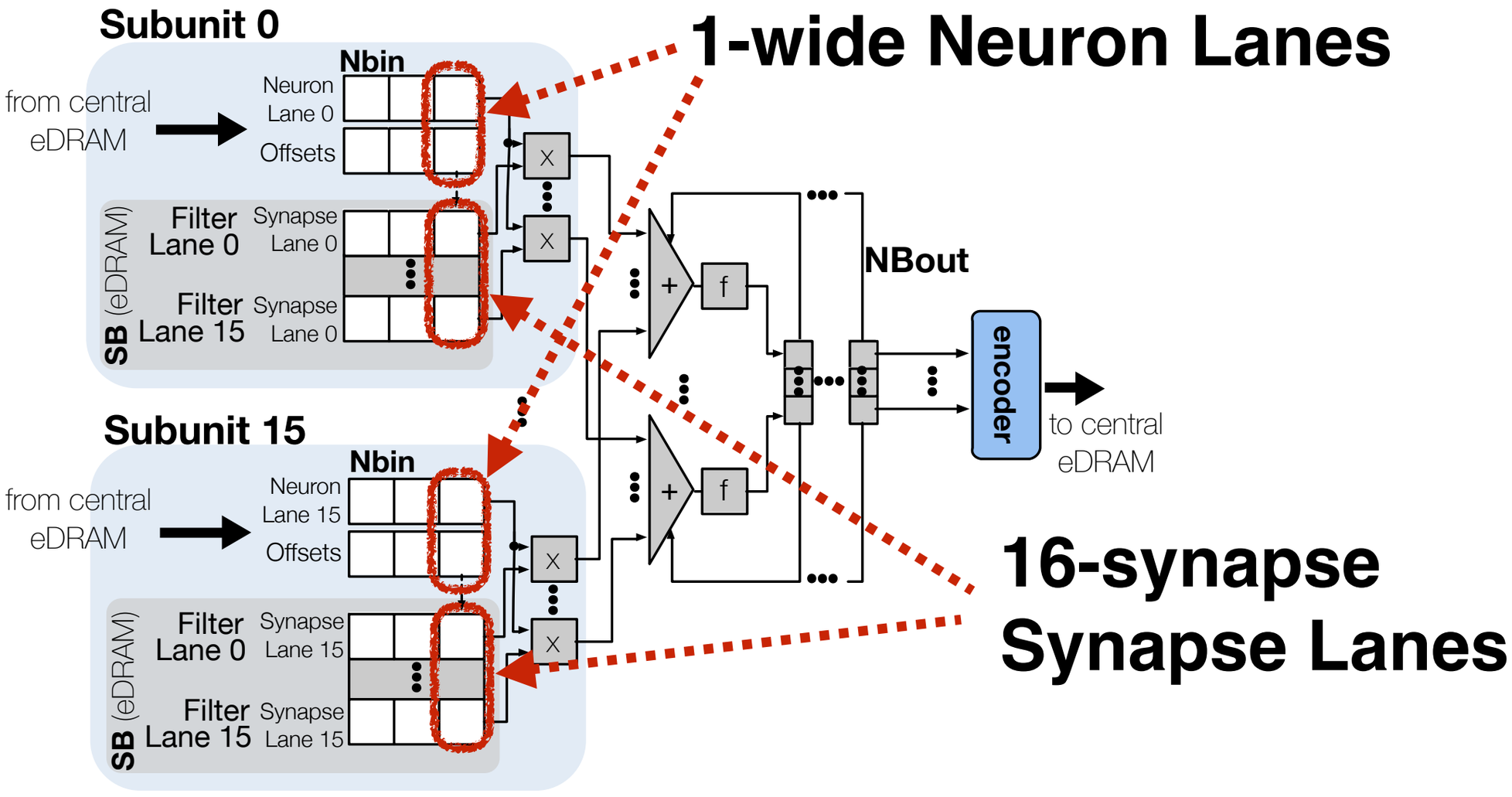
Proceed independently

Partitioned SB:

16-wide accesses

1 synapse per filter

Cnvlutin: Summary



Decoupled Neuron Lanes:

Neuron + coordinate

Proceed independently

Partitioned SB:

16-wide accesses

1 synapse per filter