CNN Attention-based Networks

+ Attention, CNN Review

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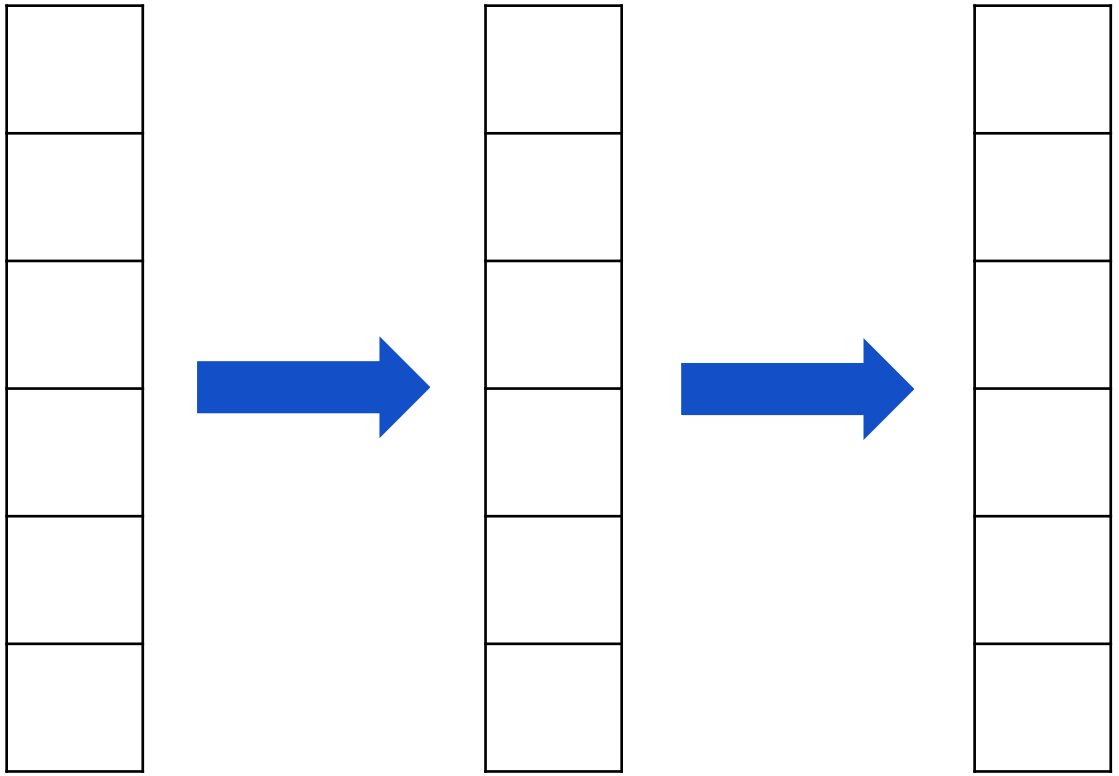
Contents

- ***Attention, Self-Attention in NLP***
- ***CNN-Review***
- ***CNN Attention Networks for Recognition***
- ***CNN Attention Networks for Other Vision Tasks***

Review 1: Attention

Neural Networks

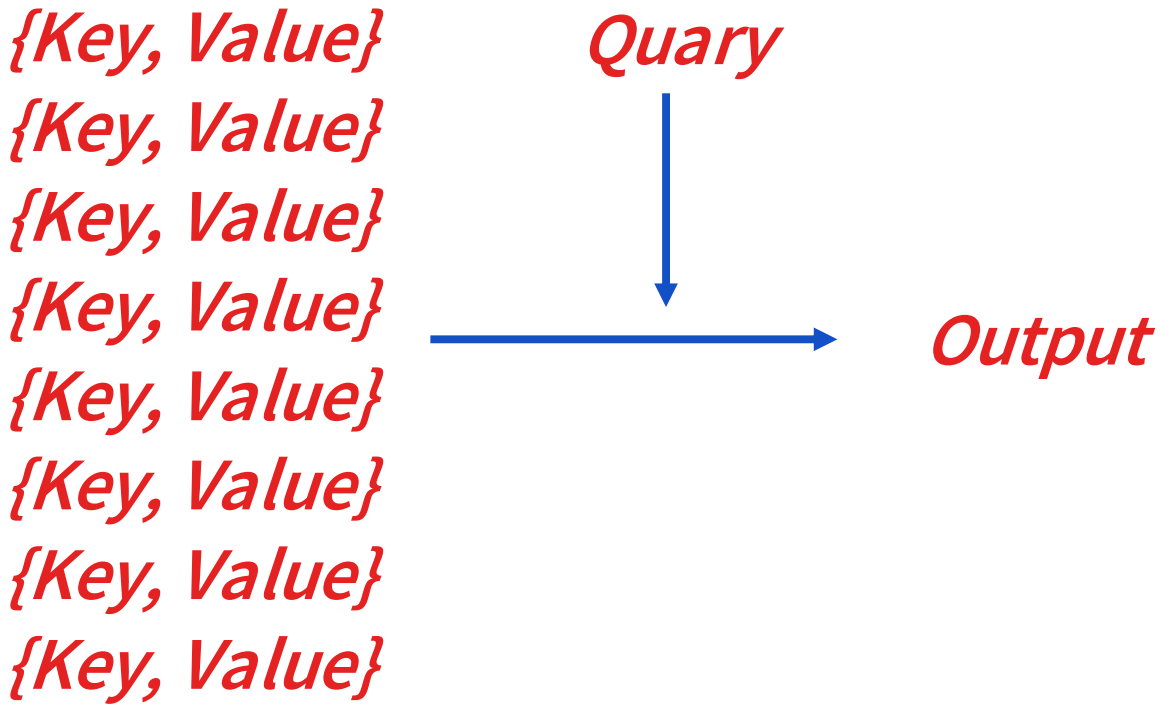


Input

Feature
Hidden State
Representation

Prediction

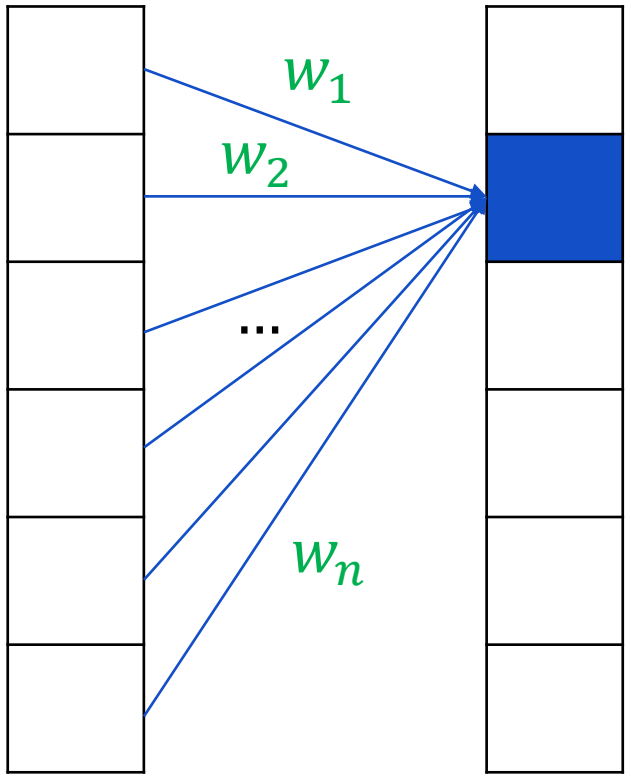
Attention



$$y = \sum_i w_i x_i$$

$$y = \sum_i f(Quary, Key) \times Value$$

Fully Connected Neural Network



Input

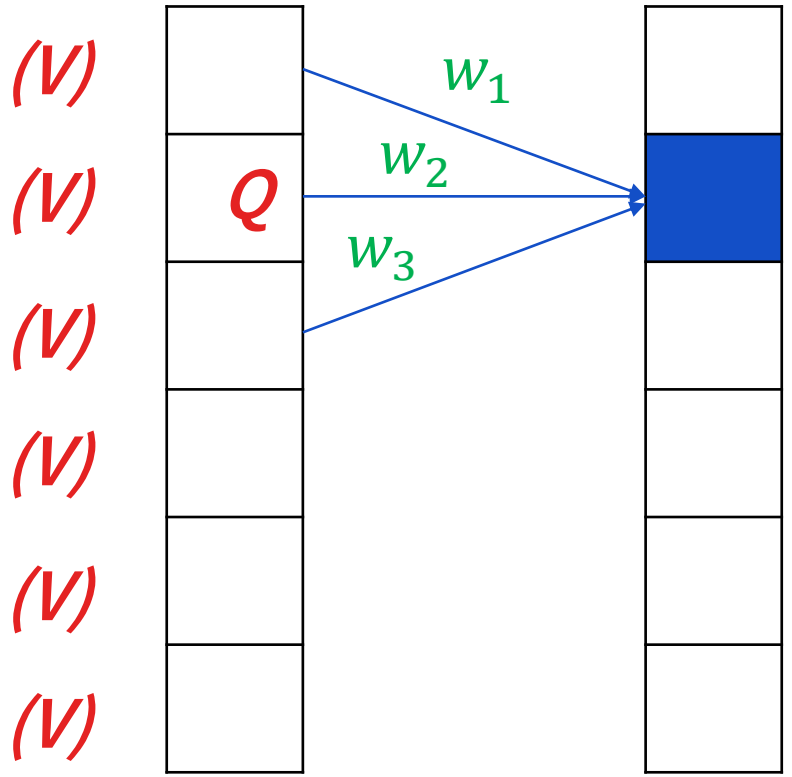
Feature
Hidden State
Representation

Fully Connected NN

Represent Blue
using Weighted Sum of Inputs

without Constraint

Convolutional Neural Network



Input

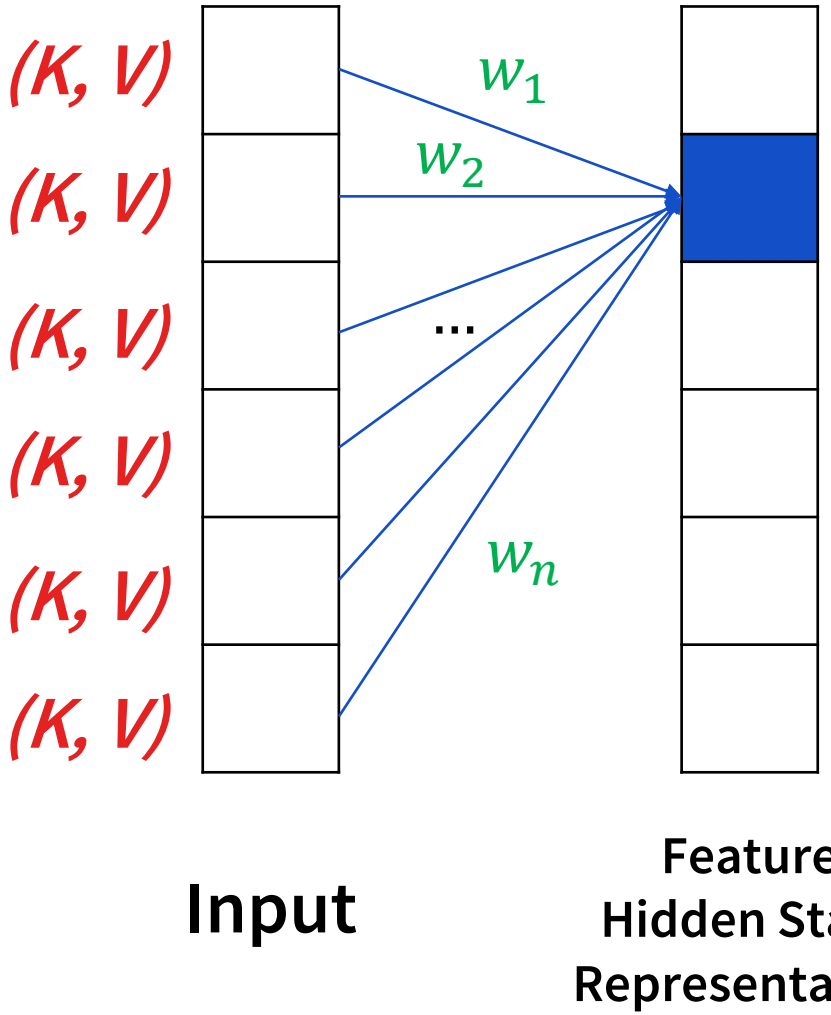
Feature
Hidden State
Representation

Convolutional NN

Represent Blue
using Weighted Sum of Inputs

from Current Position

Attention



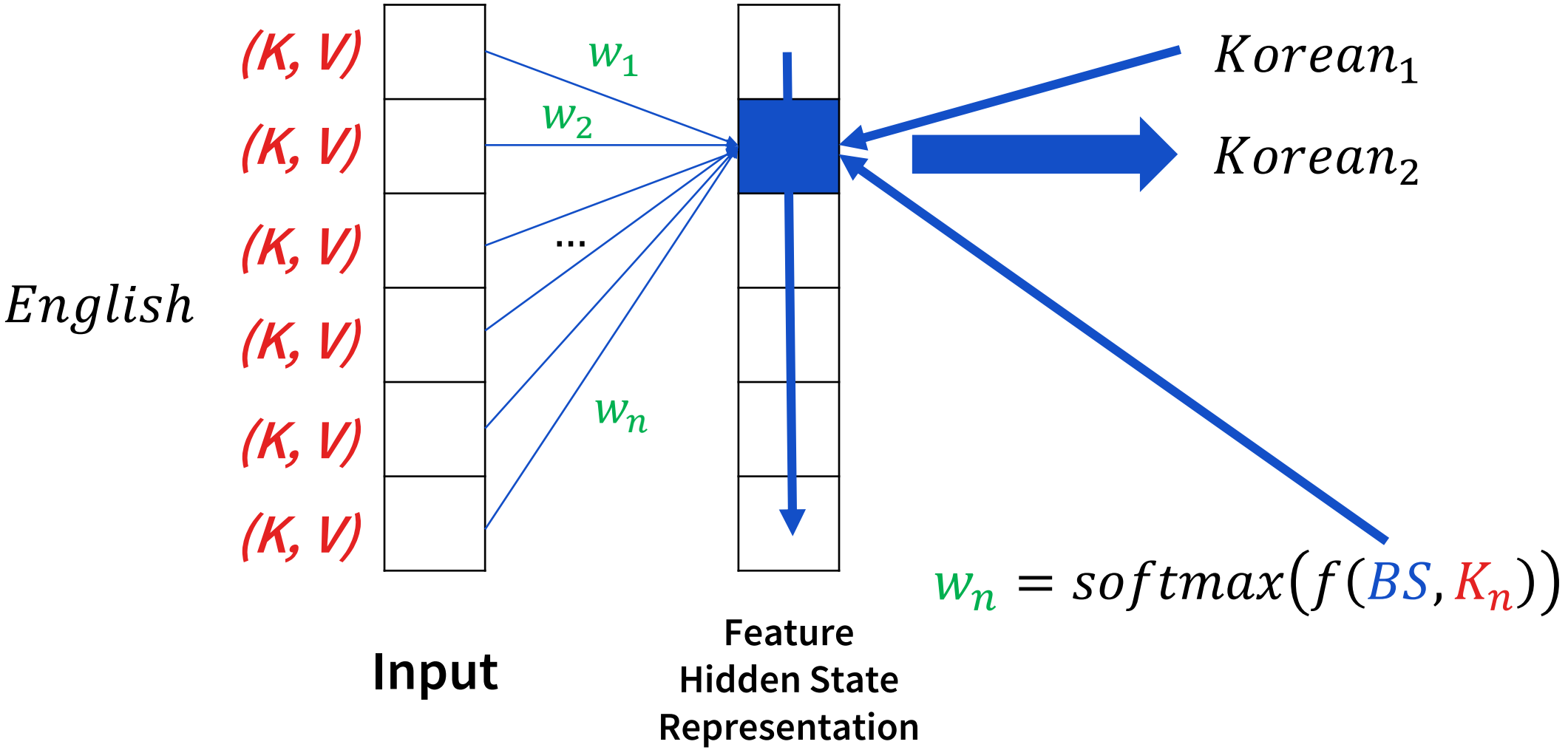
Attention

Represent Blue
using Weighted Sum of Inputs

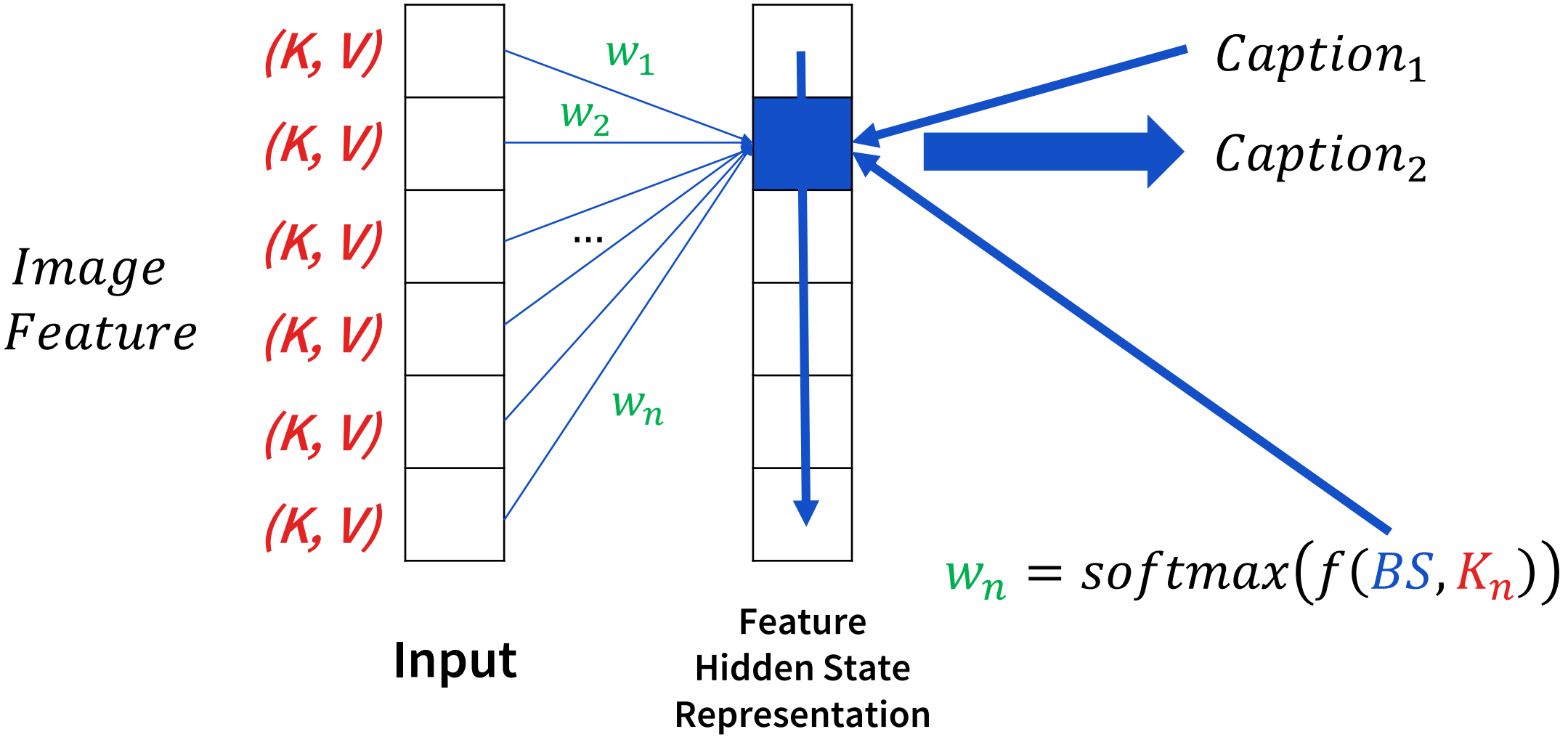
from Blue State and Inputs

$$w_n = softmax\big(f(BS, K_n)\big)$$

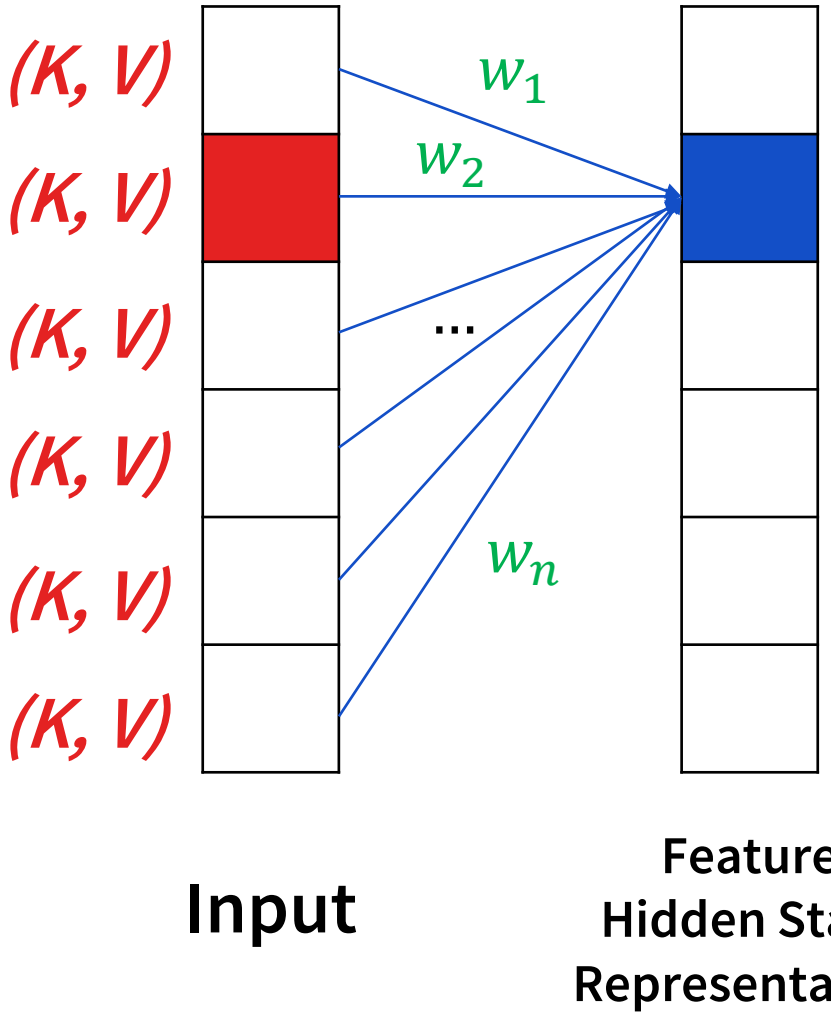
ex) Machine Translation (PR-055)



ex) Image Captioning



Self-Attention



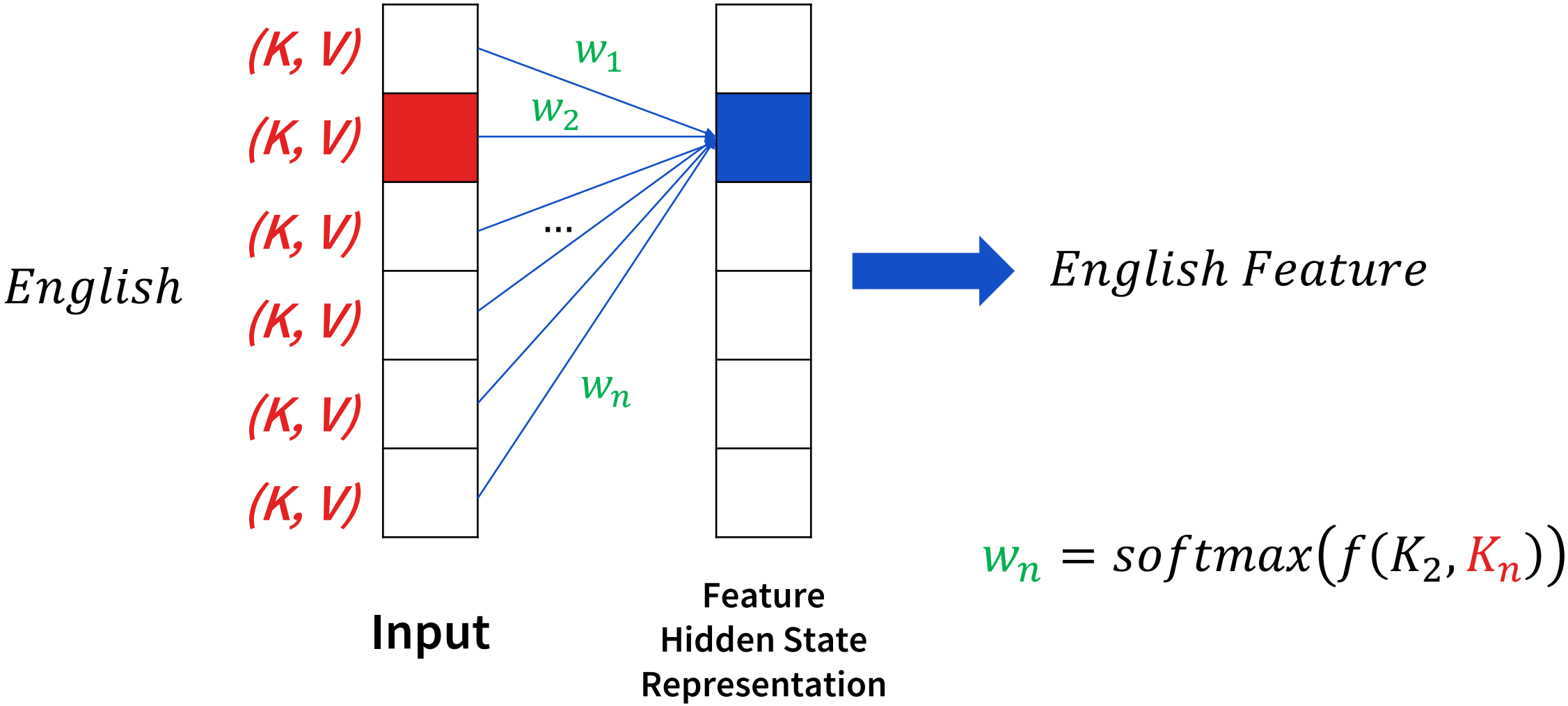
Self-Attention

Represent Blue
using Weighted Sum of Inputs

from Input and Inputs

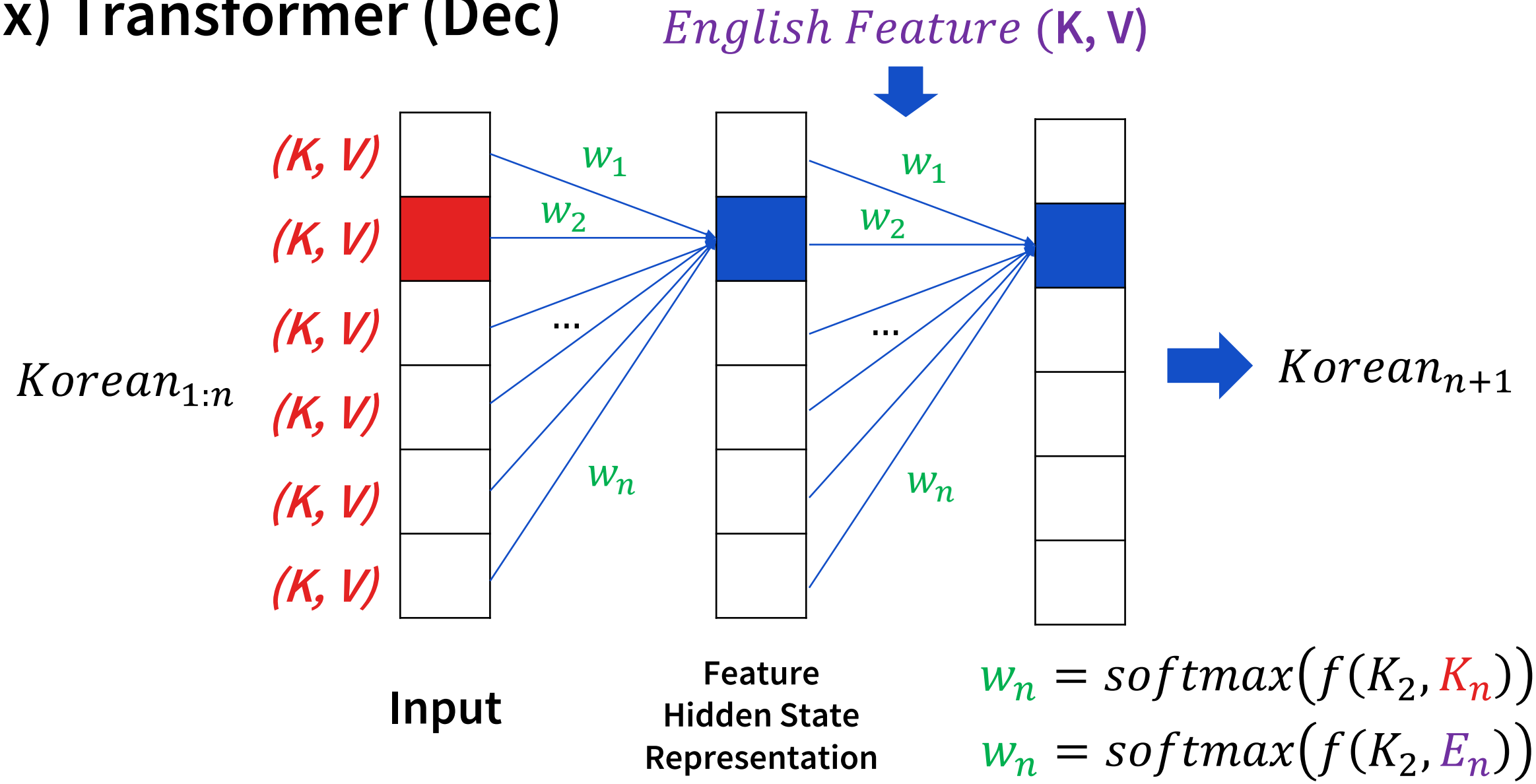
$$w_n = softmax\big(f(K_2, K_n)\big)$$

ex) Transformer (Enc) (PR-049, PR-161)

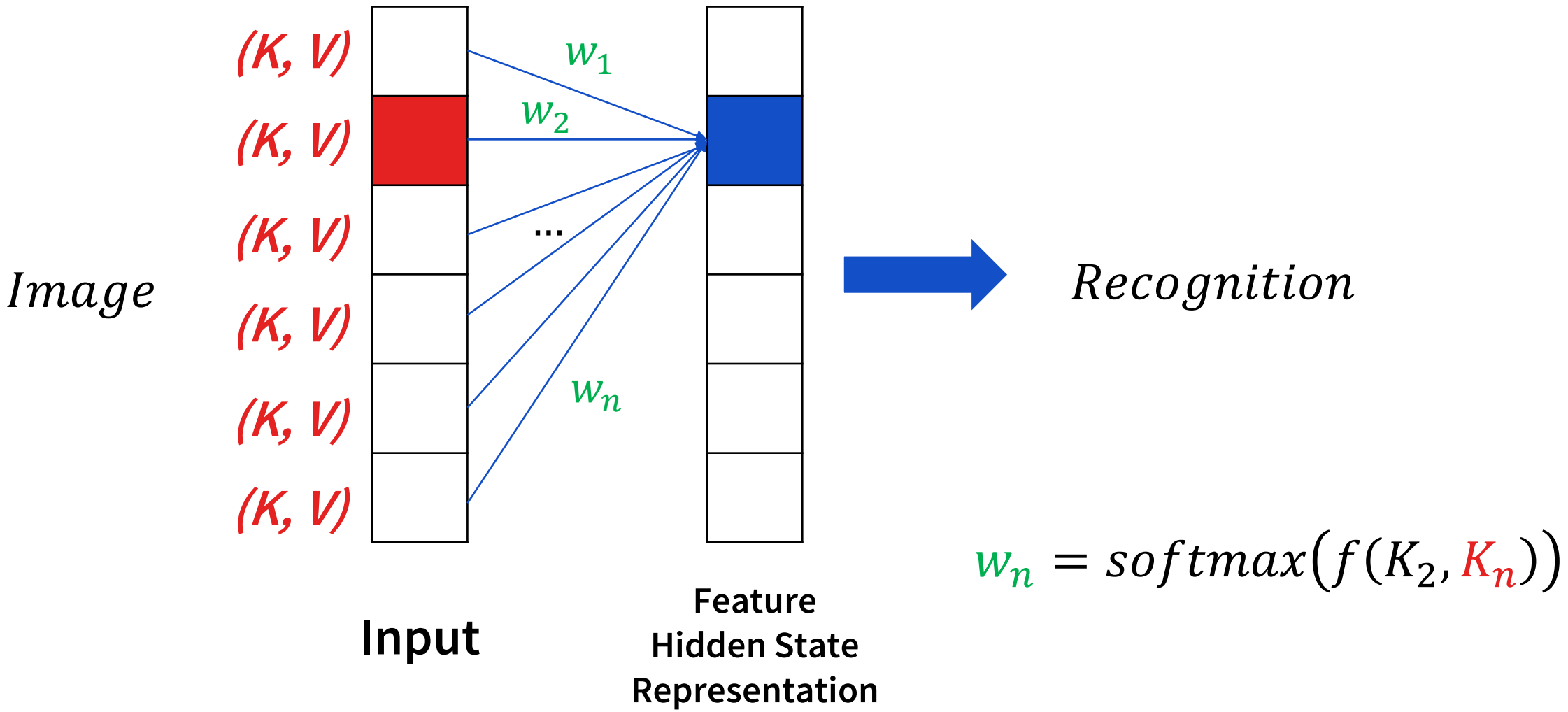


$$w_n = softmax\big(f(K_2, K_n)\big)$$

ex) Transformer (Dec)

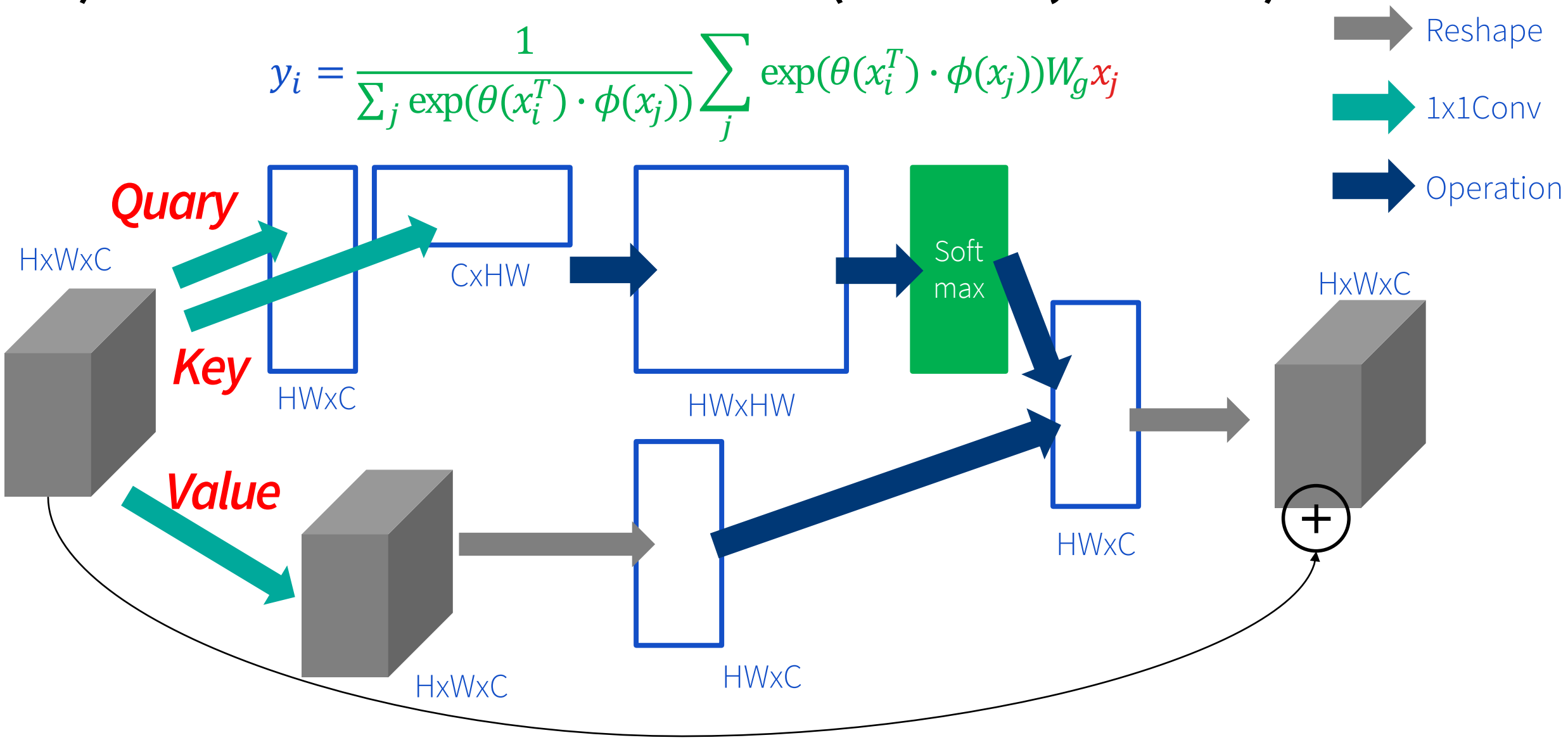


CNN Self-Attention for Image = Representation

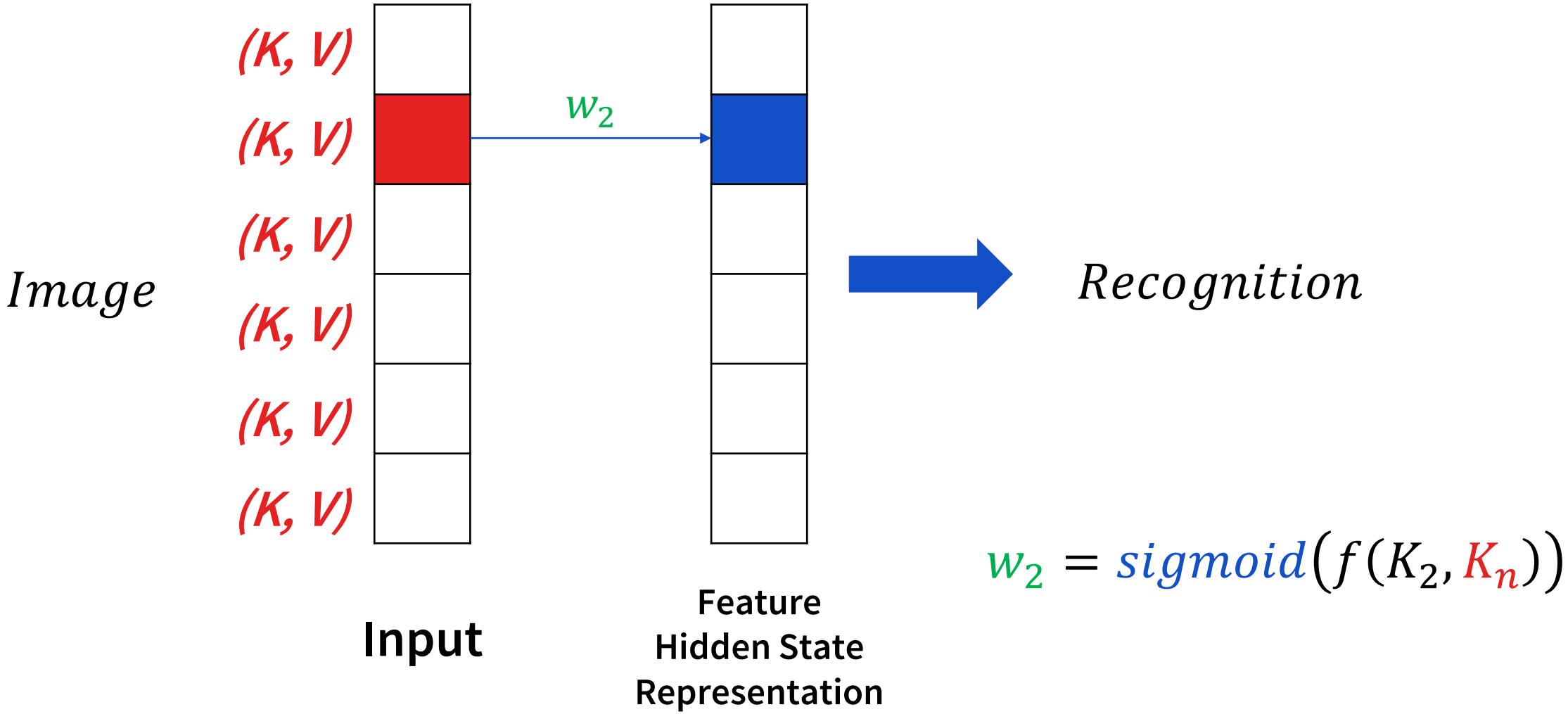


ex) Non-local Neural Networks (CVPR18, PR-083)

$$y_i = \frac{1}{\sum_j \exp(\theta(x_i^T) \cdot \phi(x_j))} \sum_j \exp(\theta(x_i^T) \cdot \phi(x_j)) W_g x_j$$

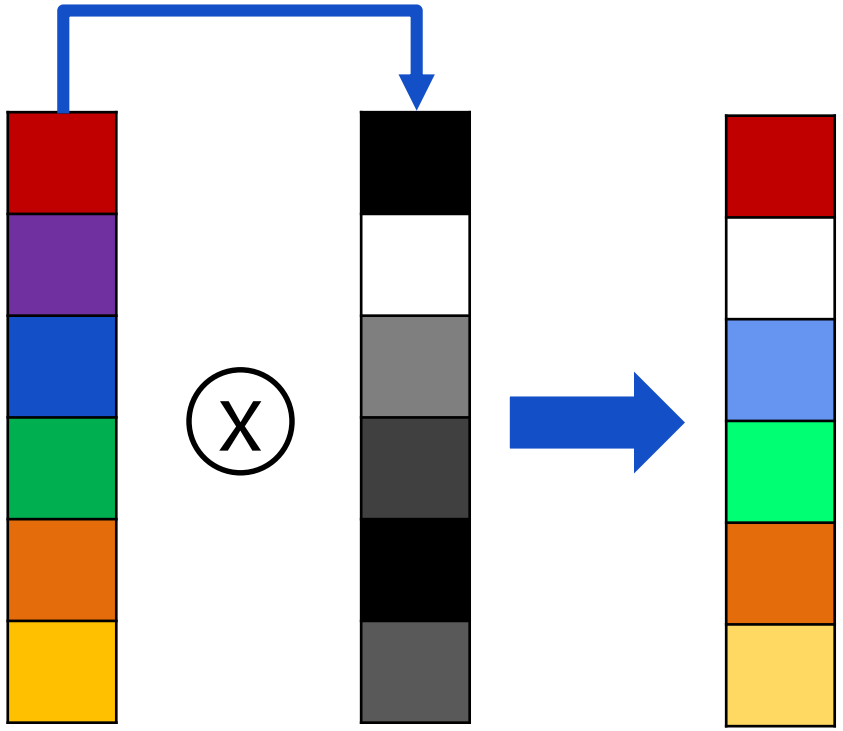


CNN Simplified-Attention for Image = Recalibration

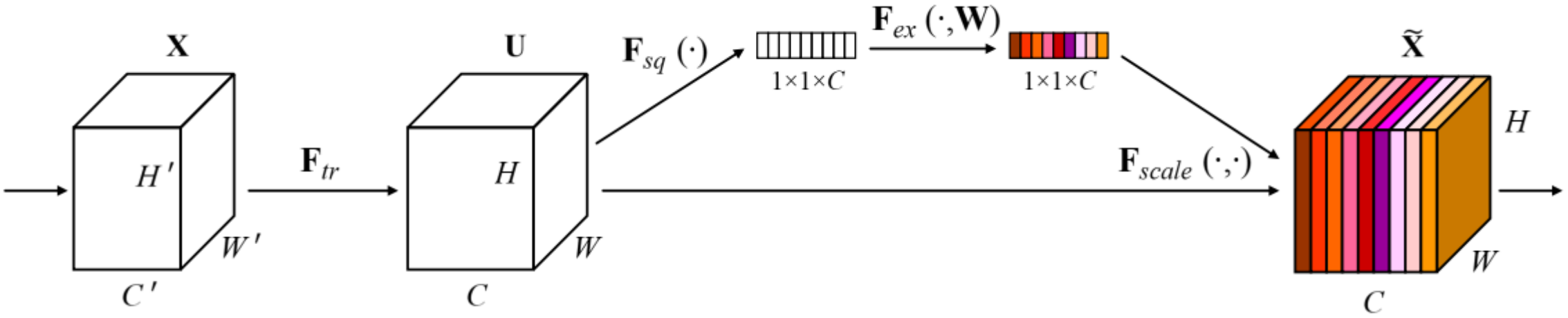


$$w_2 = sigmoid\big(f(K_2, K_n)\big)$$

CNN Simplified-Attention for Image = Recalibration



ex) Squeeze-and-Excitation Networks (CVPR18)

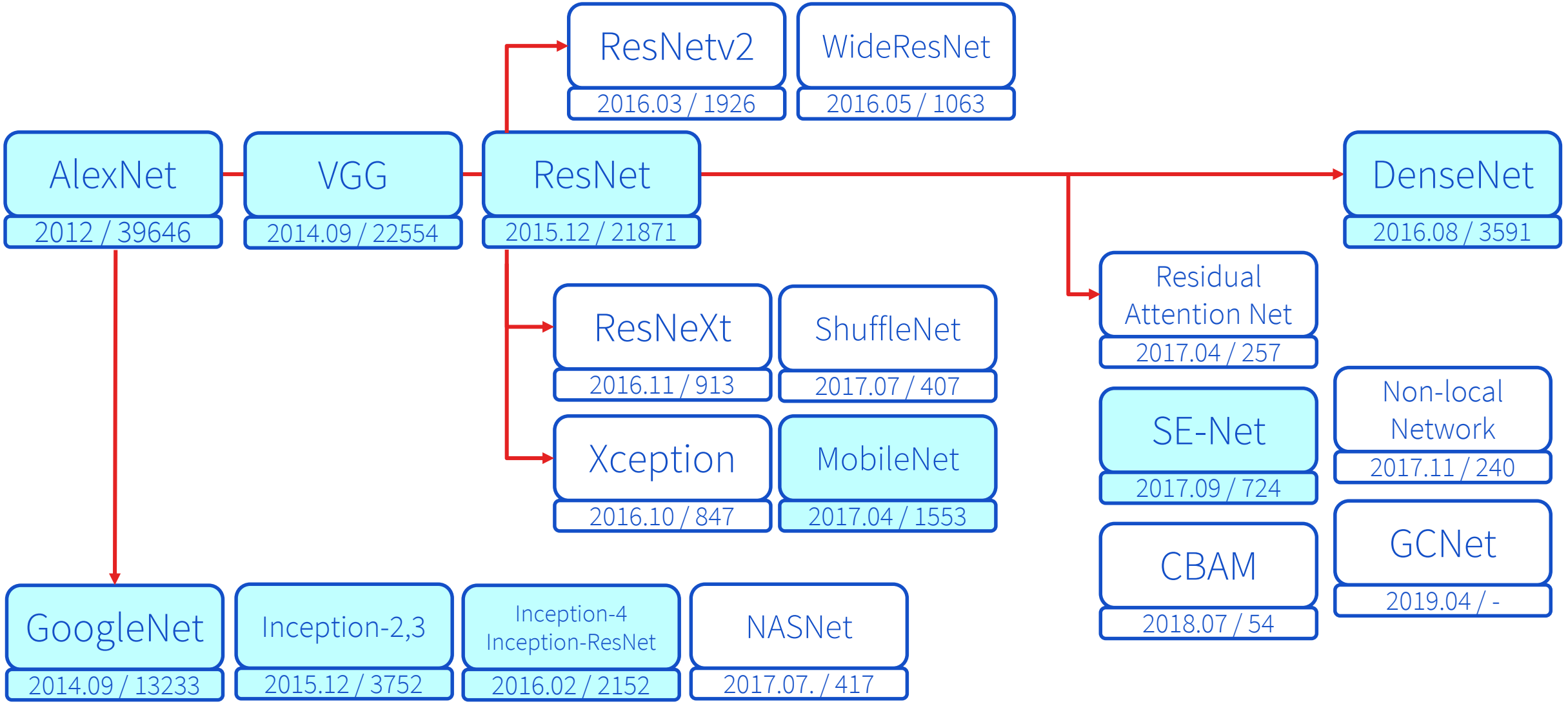


Summary

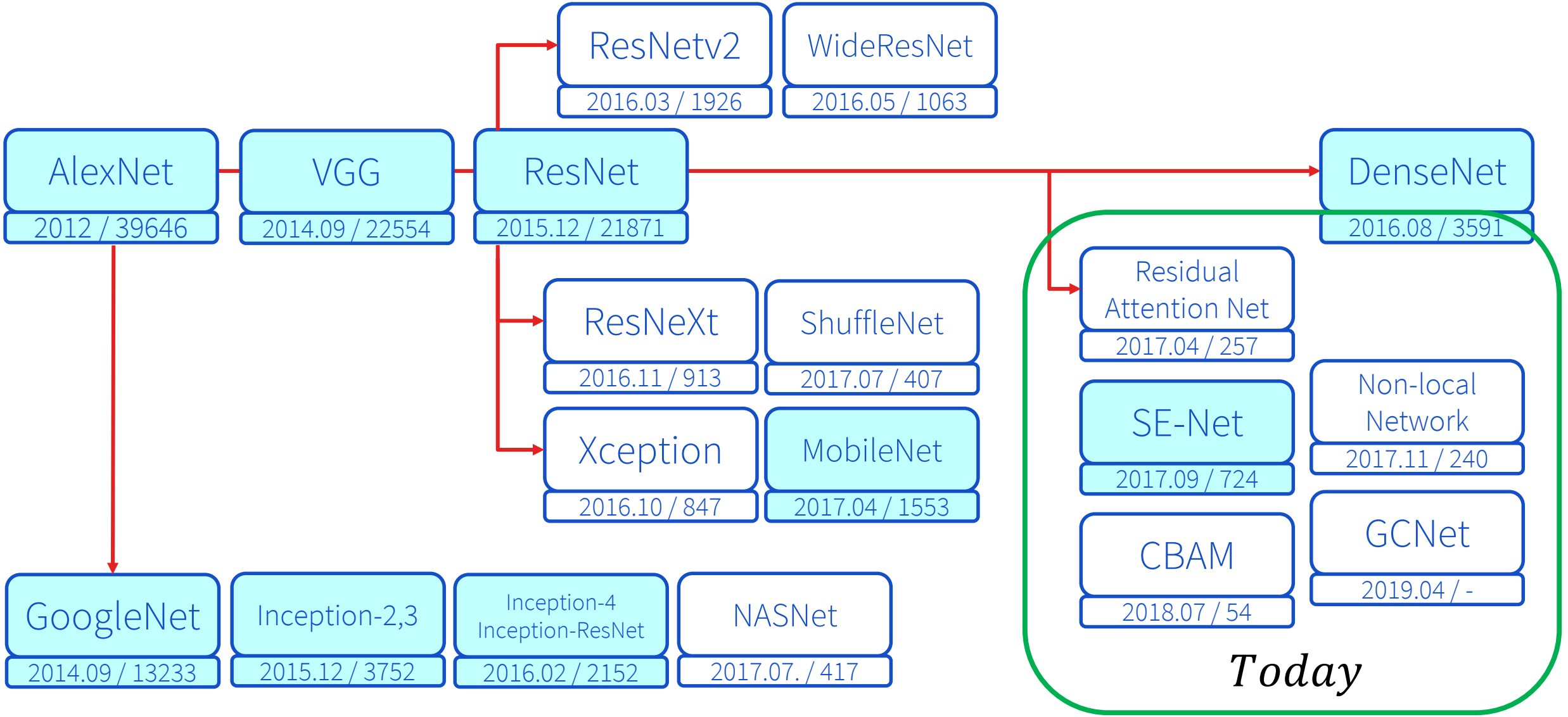
Attention	Quary	Structure	Objective	Examples
Attention	**Current** States	Recurrent	Representation	NMT, Captioning, VQA
Self-Attention	Input Itself	Feed-Forward	Representation	Transformer Non-local NN
	Input Itself	Feed-Forward	Recalibration	SE-Net, RAN, CBAM

Review 2: CNN Networks

CNN Review


AlexNet
2012 / 39646
VGG
2014.09 / 22554
ResNet
2015.12 / 21871
ResNetv2
2016.03 / 1926
WideResNet
2016.05 / 1063
DenseNet
2016.08 / 3591
ResNeXt
2016.11 / 913
ShuffleNet
2017.07 / 407
Xception
2016.10 / 847
MobileNet
2017.04 / 1553
Residual Attention Net
2017.04 / 257
SE-Net
2017.09 / 724
CBAM
2018.07 / 54
Non-local Network
2017.11 / 240
GCNet
2019.04 / -
GoogleNet
2014.09 / 13233
Inception-2,3
2015.12 / 3752
Inception-4
Inception-ResNet
2016.02 / 2152
NASNet
2017.07. / 417

CNN Review


ResNetv2
2016.03 / 1926
WideResNet
2016.05 / 1063
AlexNet
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2017.11 / 240
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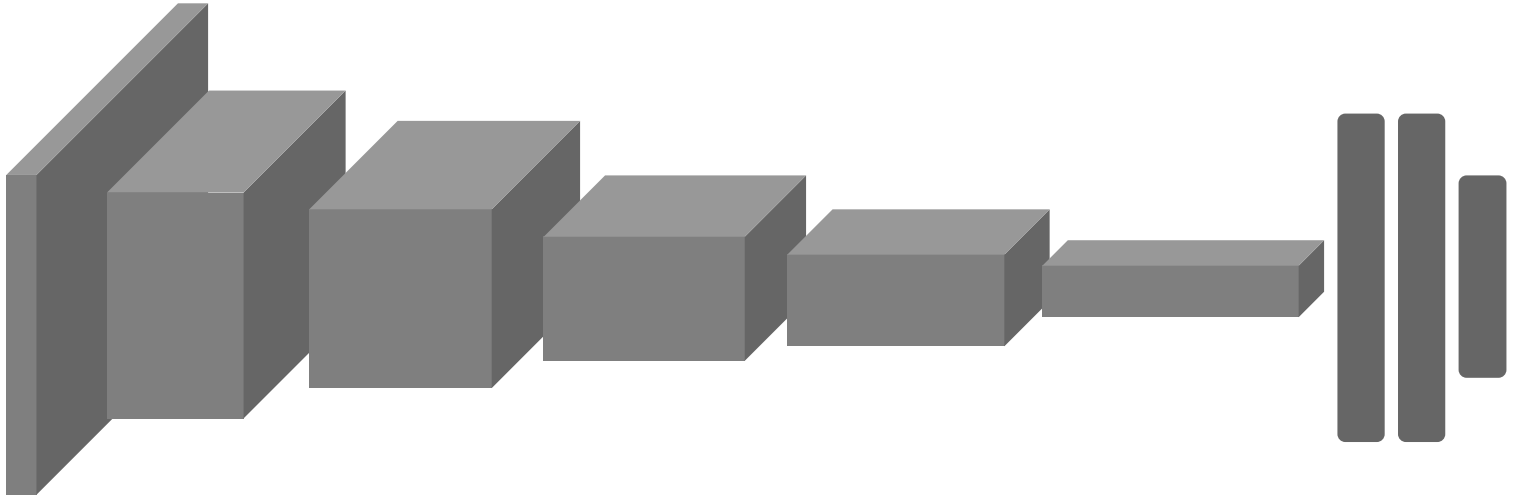
2014.09 / 13233
Inception-2,3
2015.12 / 3752
Inception-4
Inception-ResNet
2016.02 / 2152
NASNet
2017.07. / 417
Today

Plain Networks

ILSVRC12 **ILSVRC14**

AlexNet	VGG	ResNet
2012 / 39646	2014.09 / 22554	2015.12 / 21871

- ***Plain Networks using Max-Pooling***
- ***Low Performance / Large Parameters, Operations***

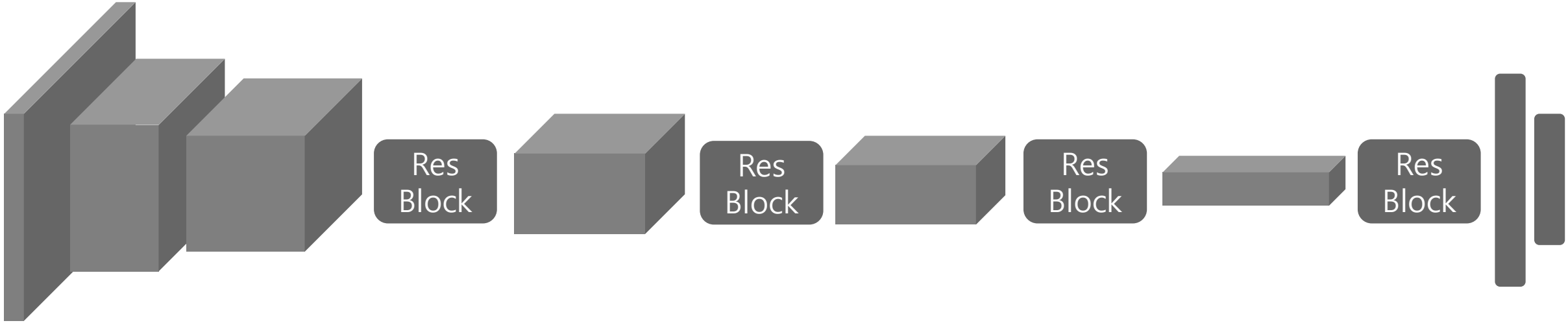


ResNet

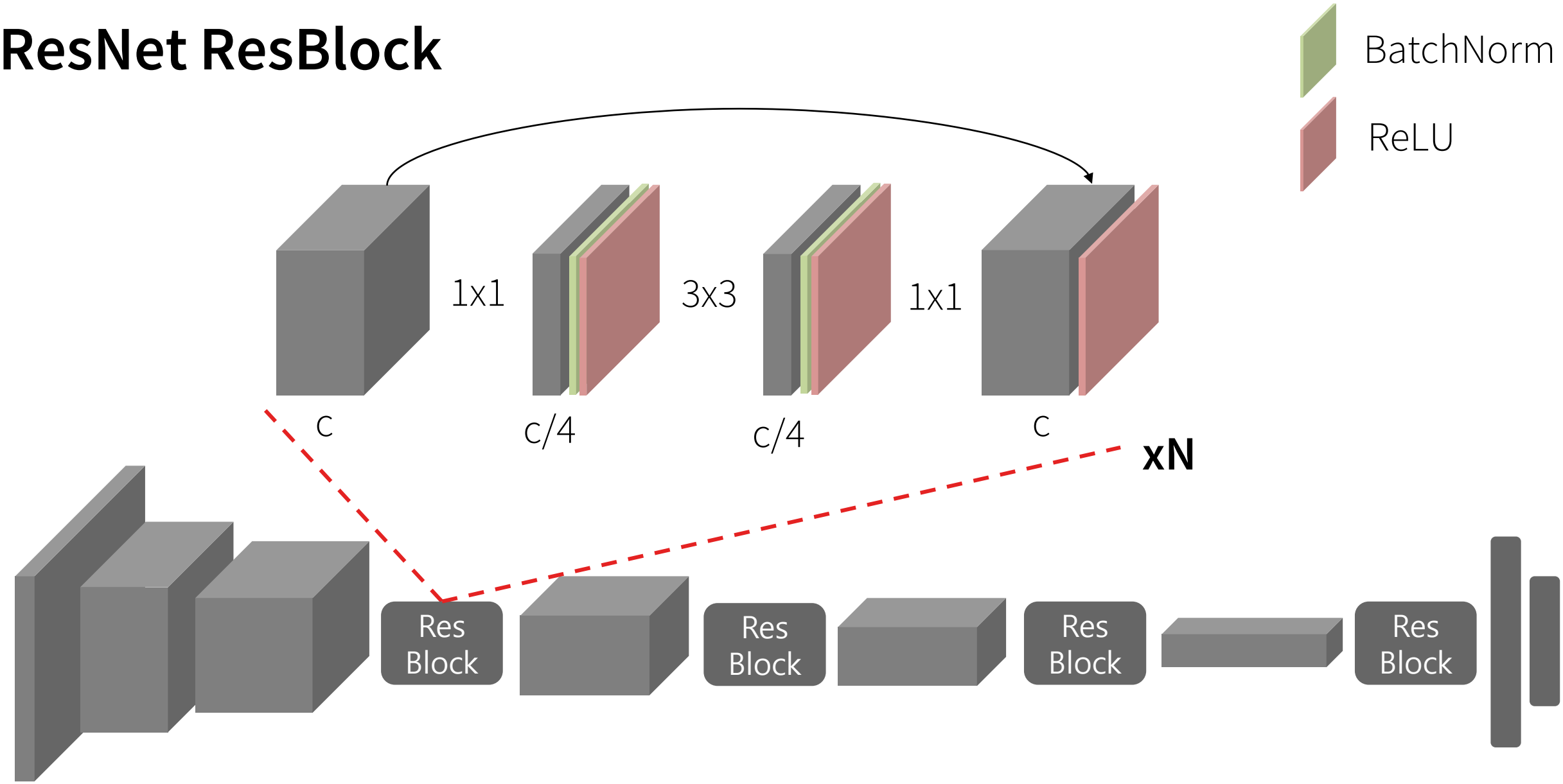
ILSVRC15

AlexNet	VGG	ResNet
2012 / 39646	2014.09 / 22554	2015.12 / 21871

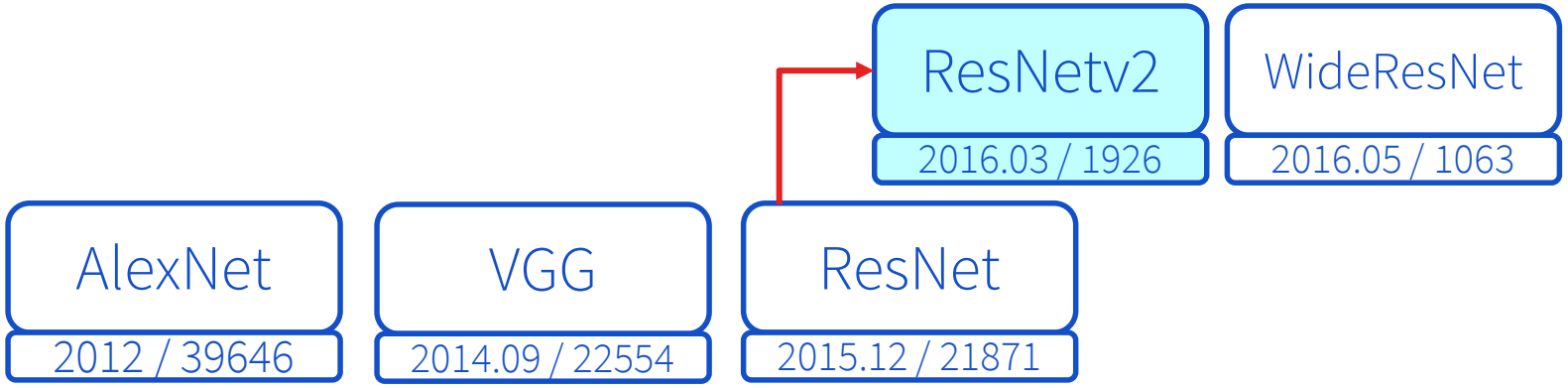
- ***Deeper Networks using Skip-Connection***



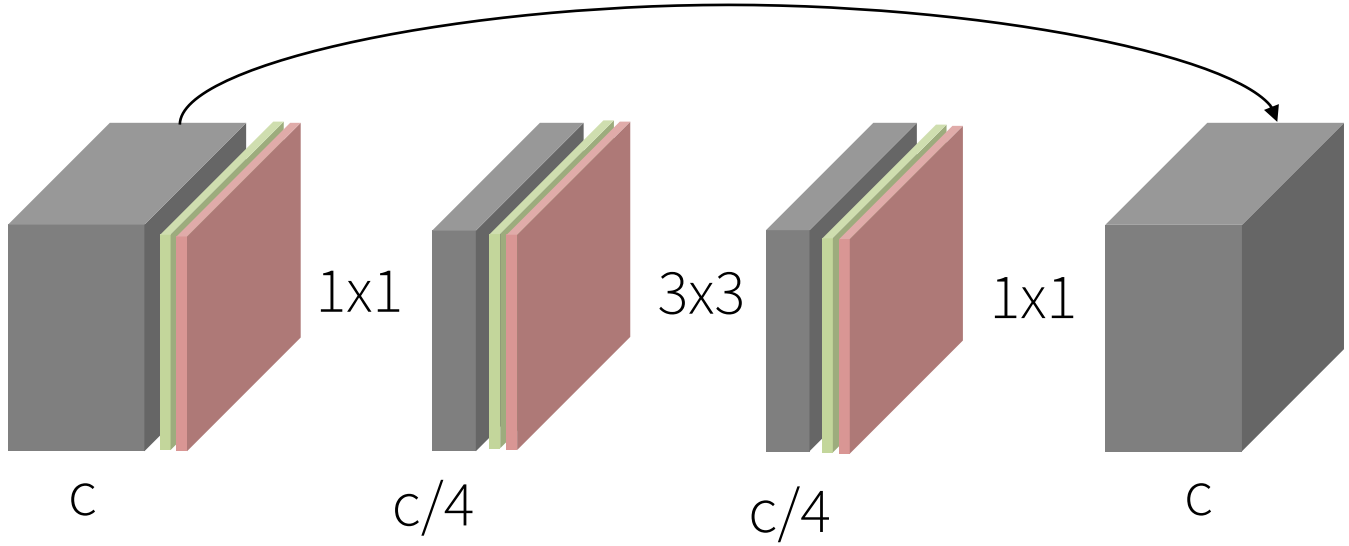
ResNet ResBlock



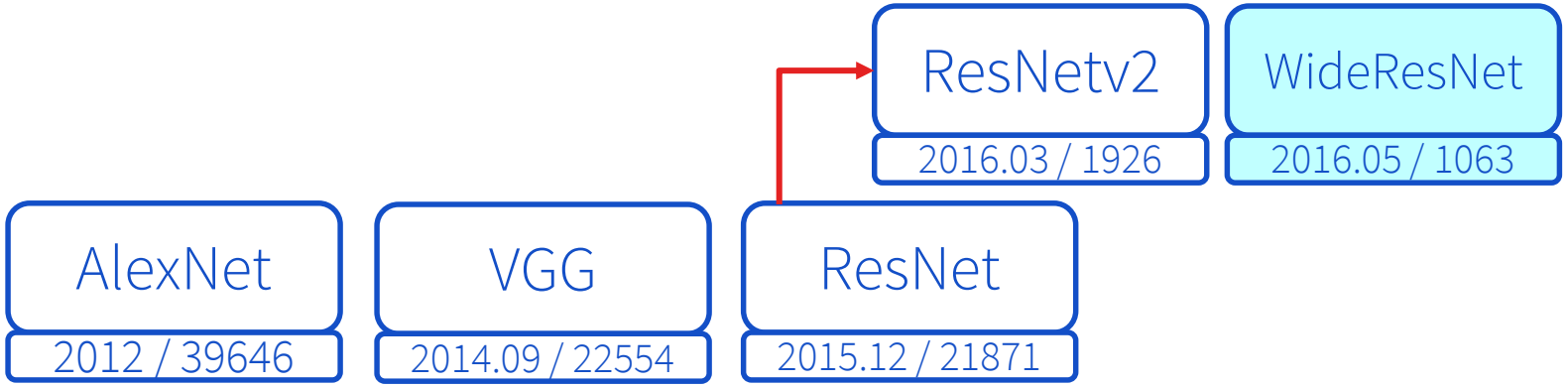
ResNet Variants



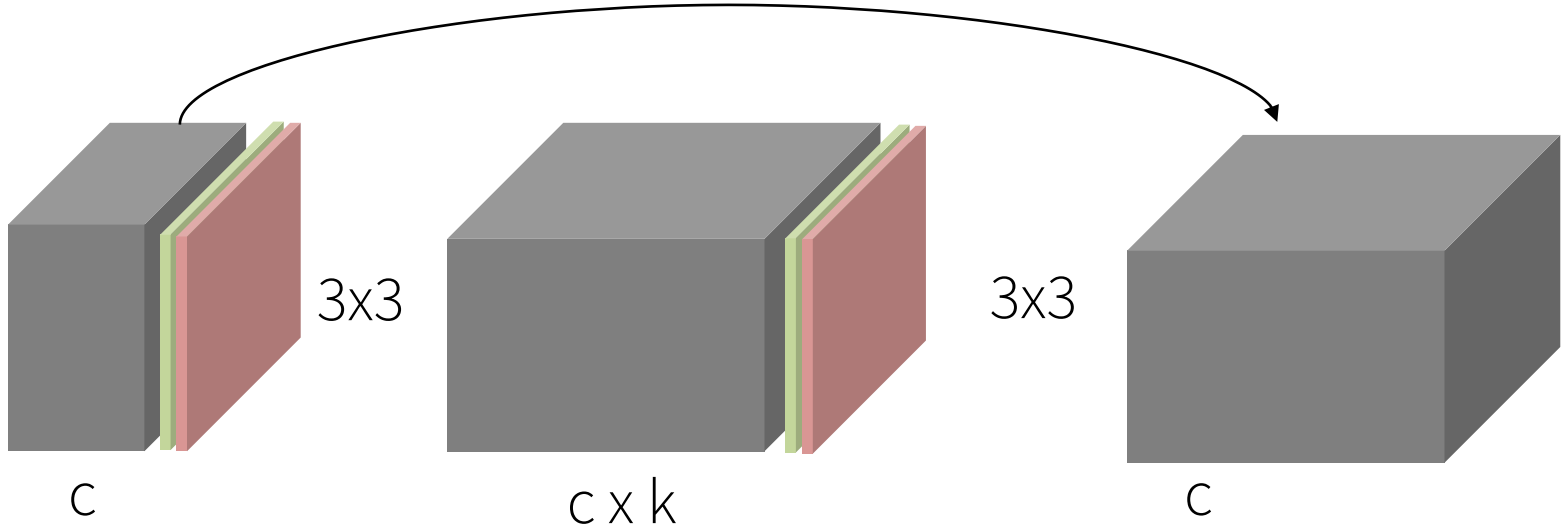
- ***Pre-activation ResNet***



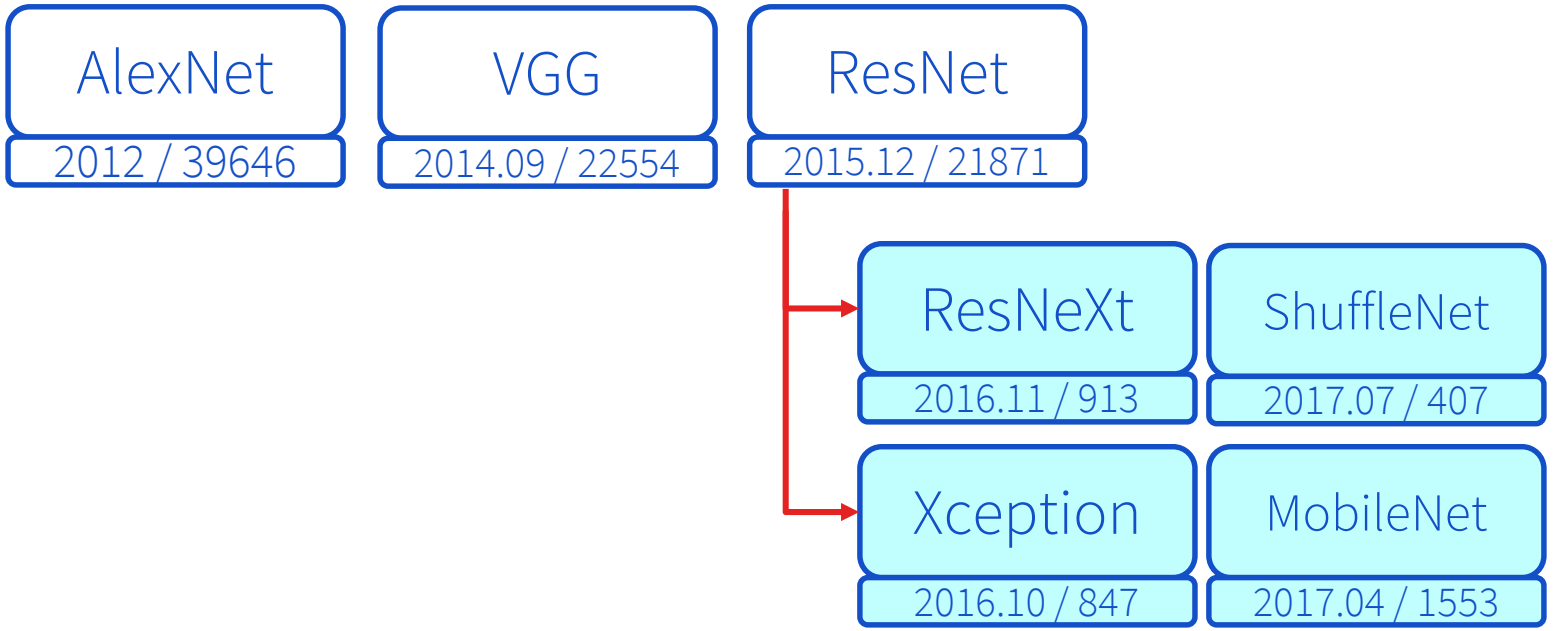
ResNet Variants



- ***Wider Channel ResNet***



ResNet with Cardinality

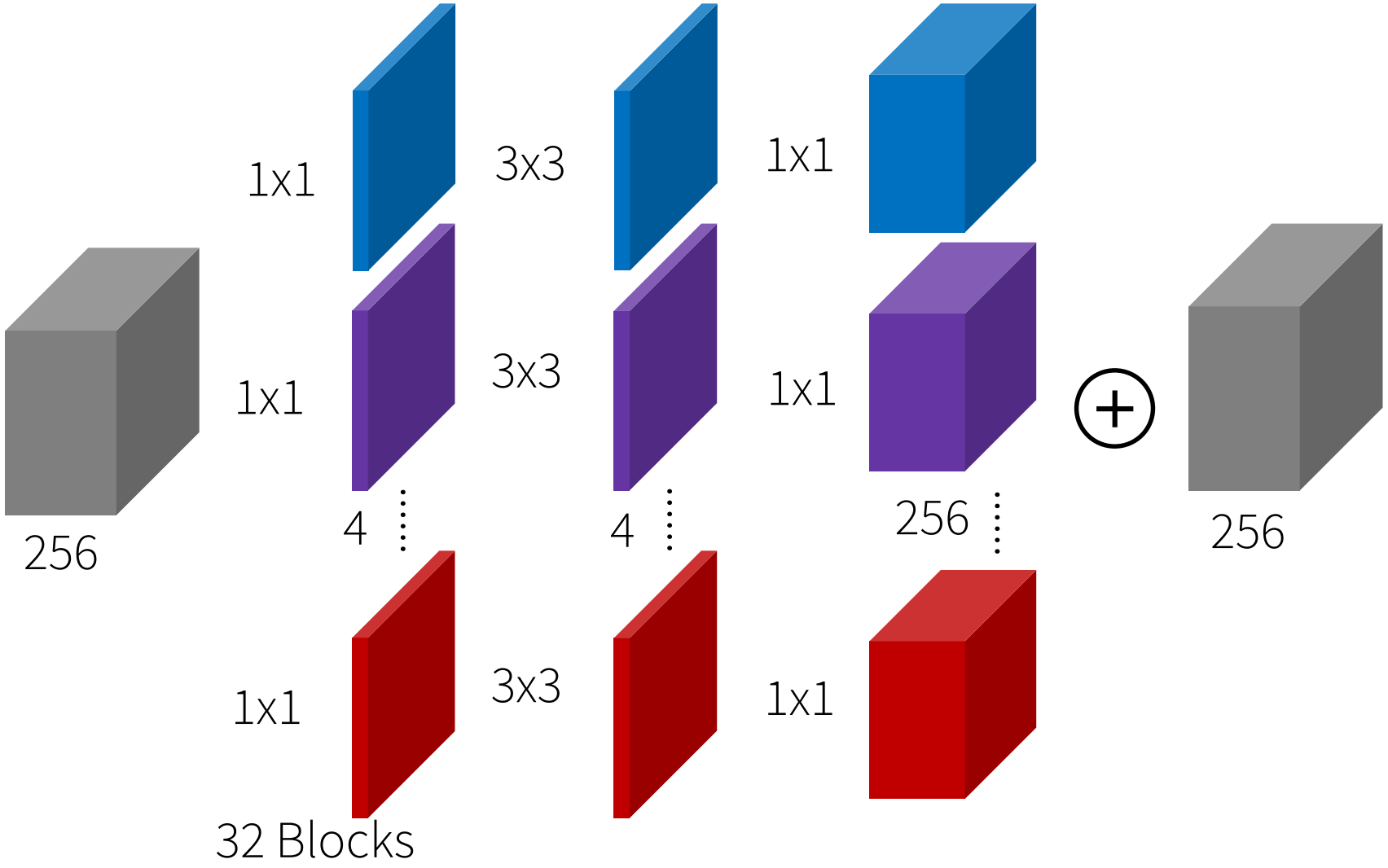


- ***Cardinality***
  = Group Conv

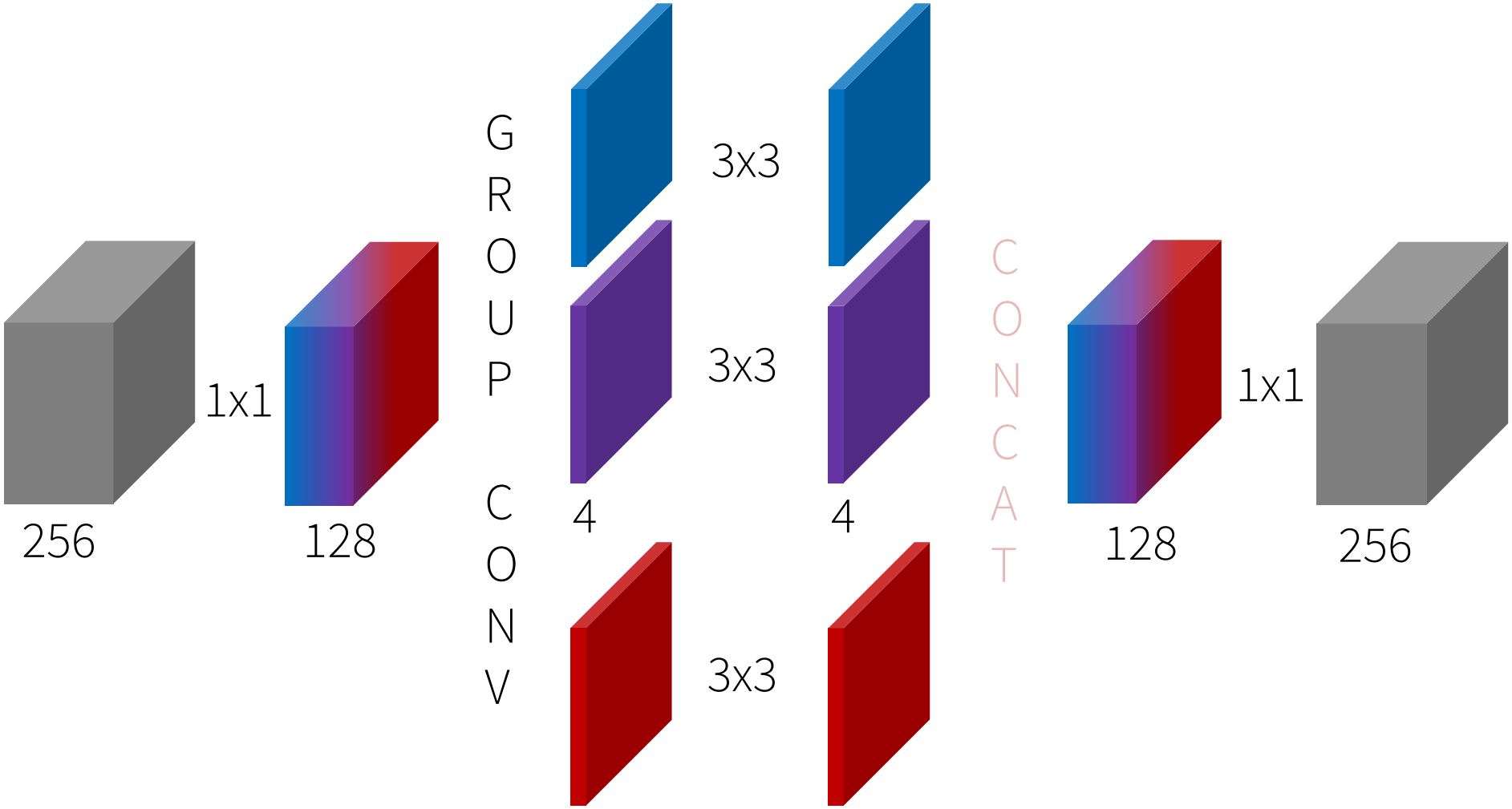
- ***Modify Convolution Operators***

- ***PR-034: Xception***
- ***PR-044: MobileNet***
- ***PR-054: SuffleNet / ResNeXt***

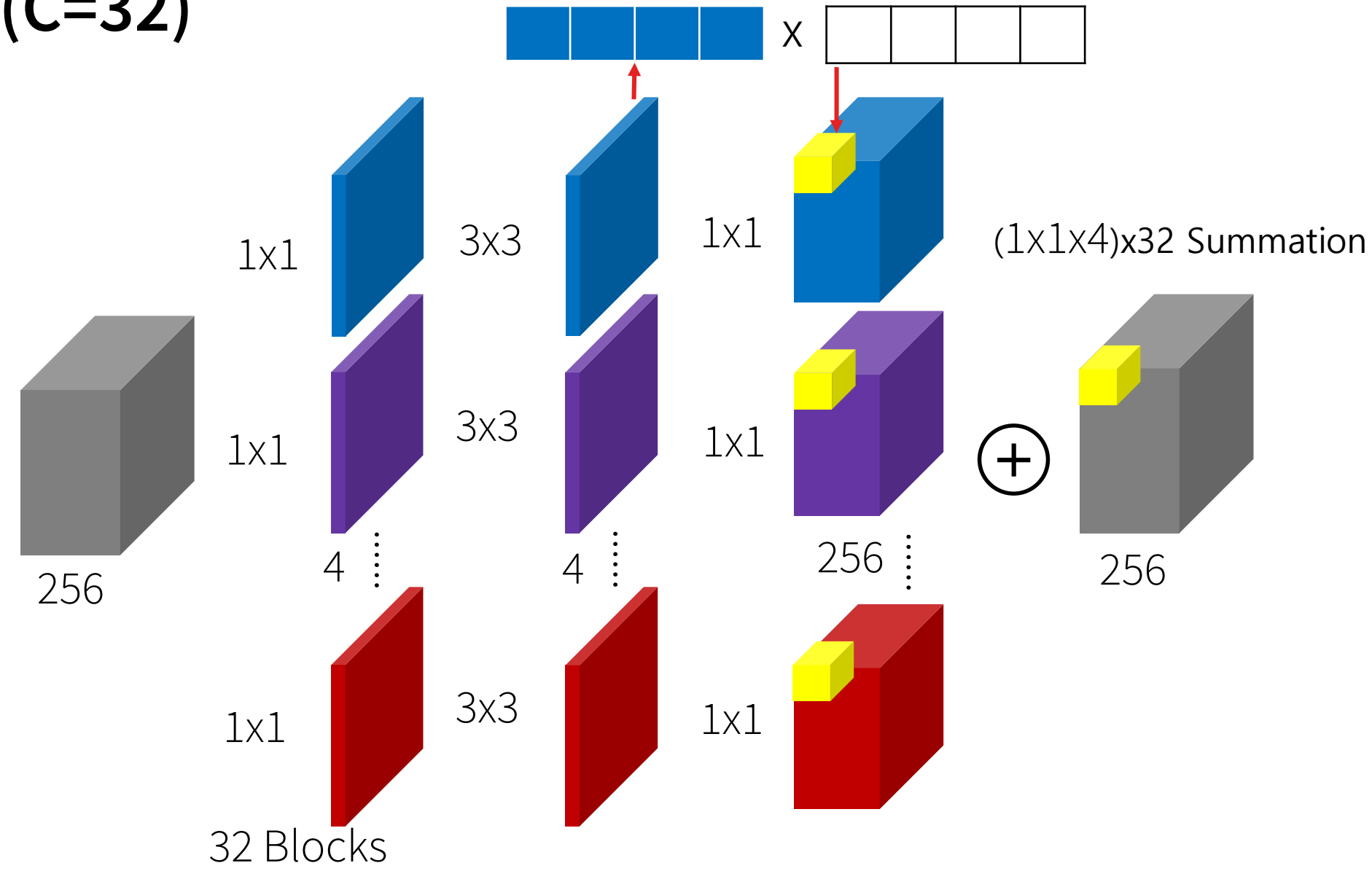
ResNeXt (C=32)



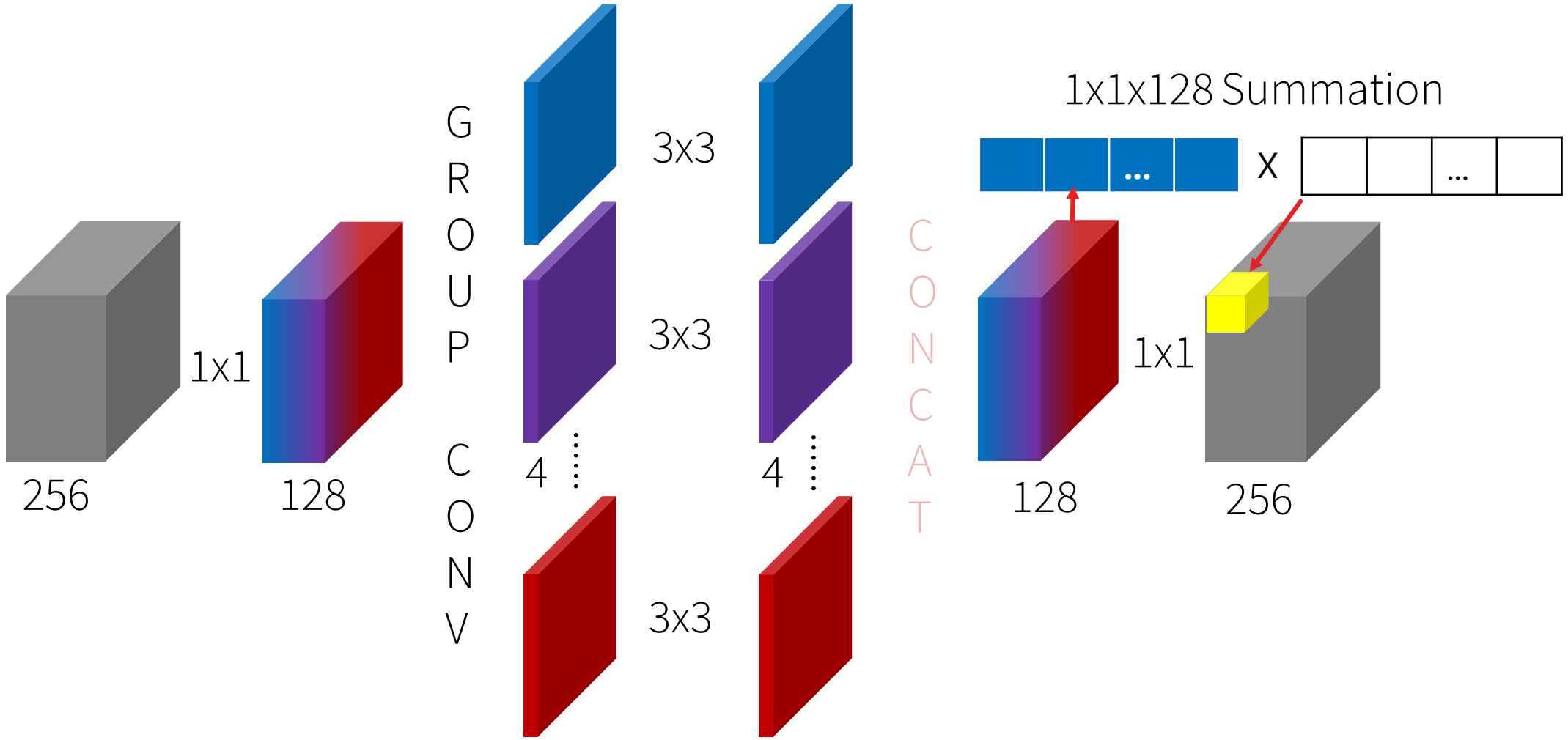
ResNeXt (C=32) with Group Conv.



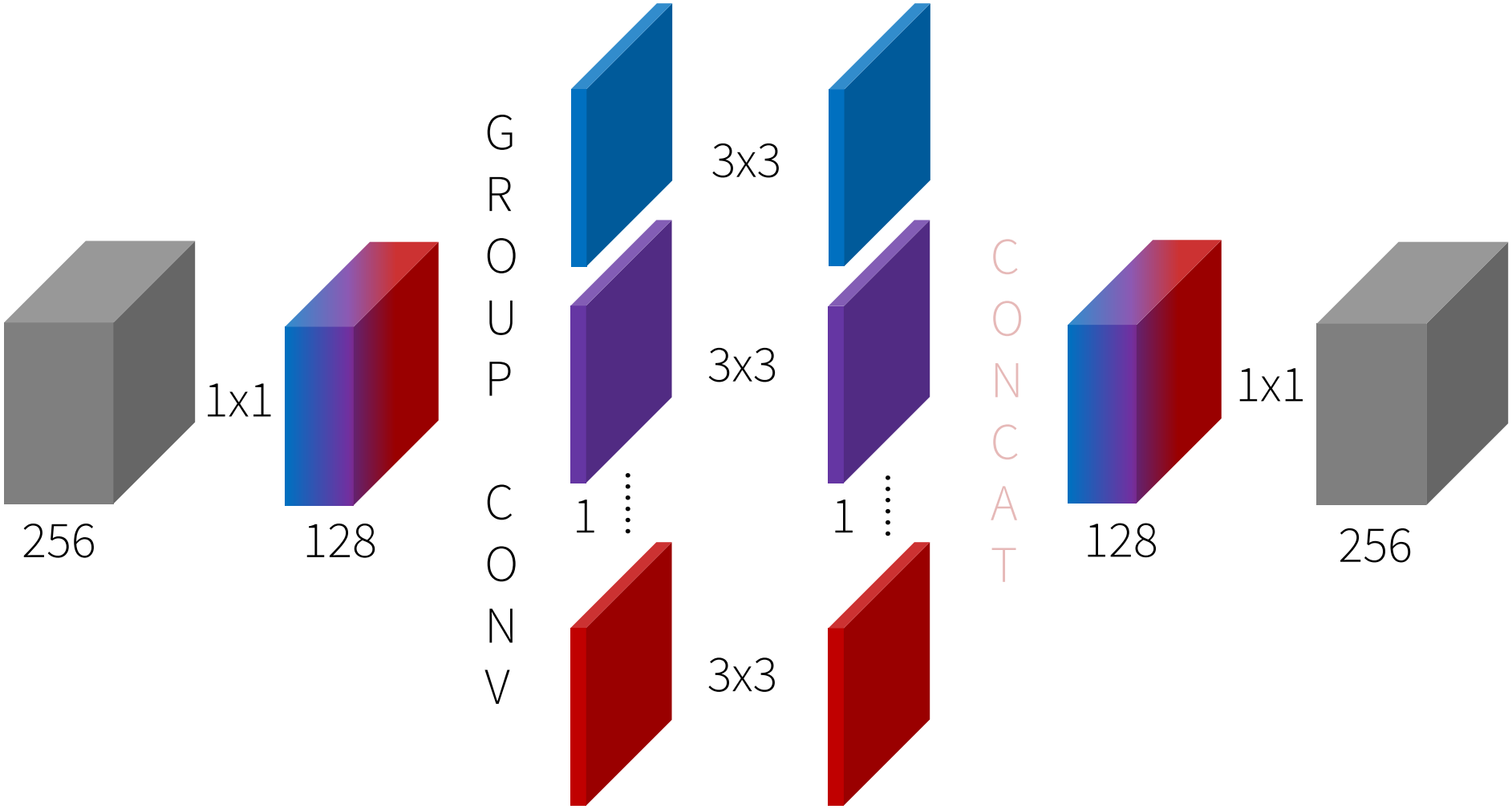
ResNeXt (C=32)


X
1x1
3x3
1x1
(1x1x4)x32 Summation
256
1x1
3x3
1x1
4
4
256
256
1x1
3x3
1x1
32 Blocks

ResNeXt (C=32) with Group Conv.



Xception (G=Channel)



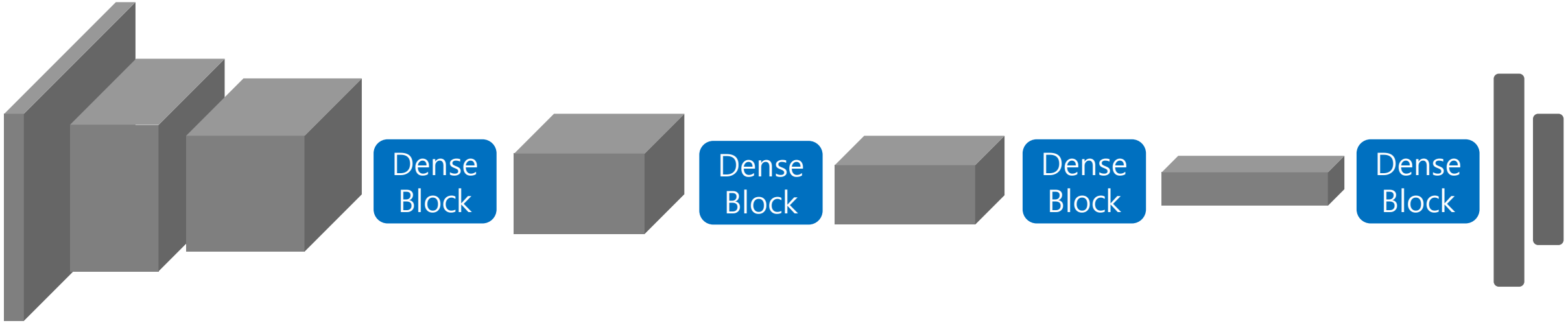
MobileNet / ShuffleNet

- *MobileNet: Lightweight Xception*
  - *Xception: 1x1 → 3x3 Depthwise*
  - *MobileNet: 3x3 Depthwise → 1x1*

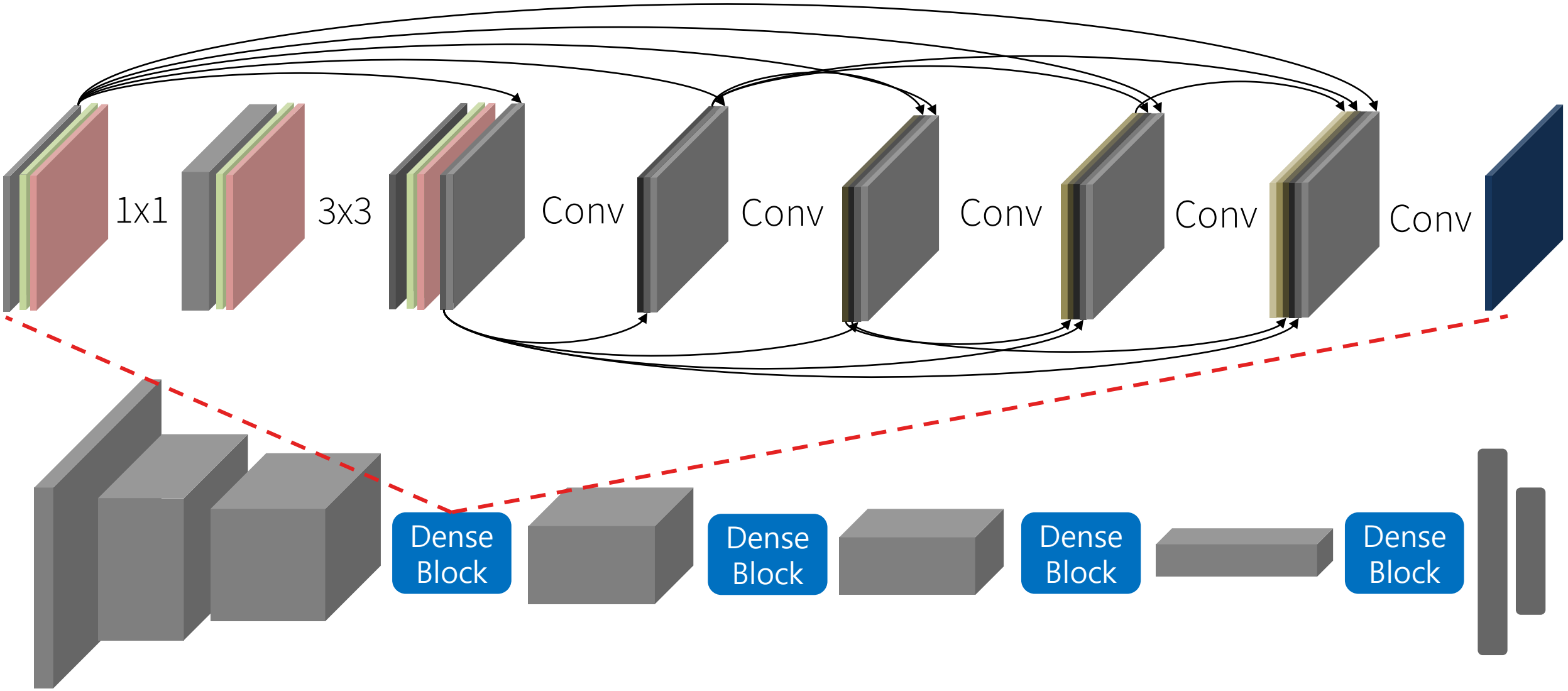
- *ShuffleNet: Lightweight ResNeXt + Channel Shuffle*

DenseNet

- ***DenseNet: Concat Previous Layers: PR-028***



DenseBlock


1x1
3x3
Conv
Conv
Conv
Conv
Conv
Dense Block
Dense Block
Dense Block
Dense Block

Inception / NASNet

AlexNet
2012 / 39646

VGG
2014.09 / 22554

ResNet
2015.12 / 21871

- ***Engineered Networks***
- ***PR-034: Inception***
- ***PR-069: NASNet***

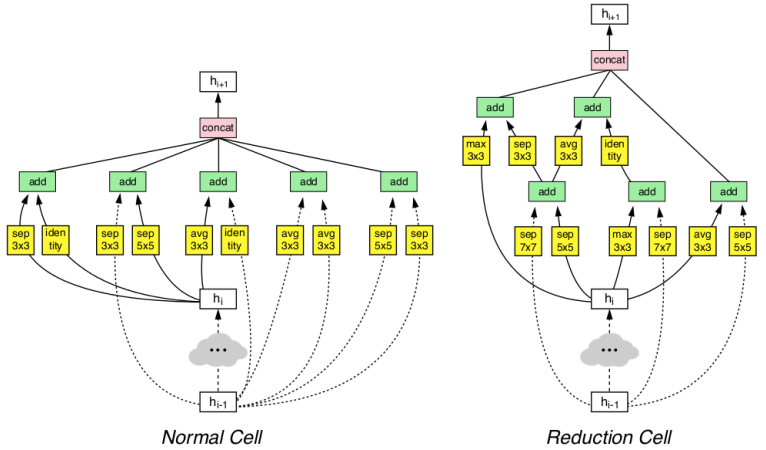
ILSVRC14

GoogleNet
2014.09 / 13233

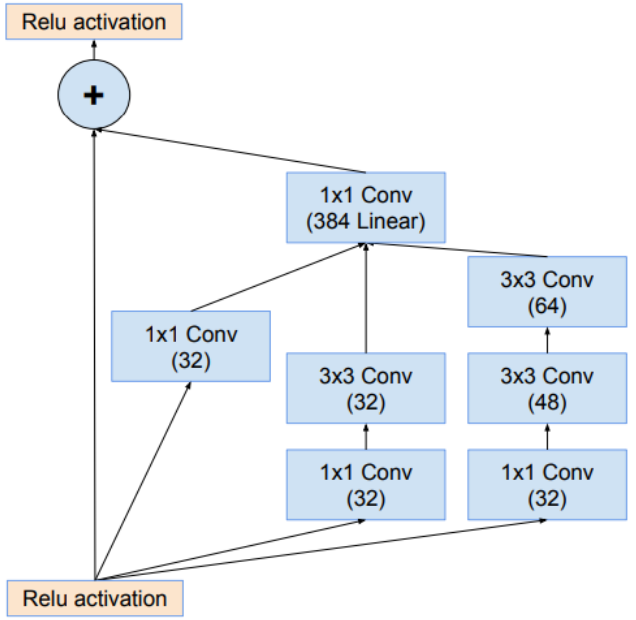
Inception-2,3
2015.12 / 3752

Inception-4
Inception-ResNet
2016.02 / 2152

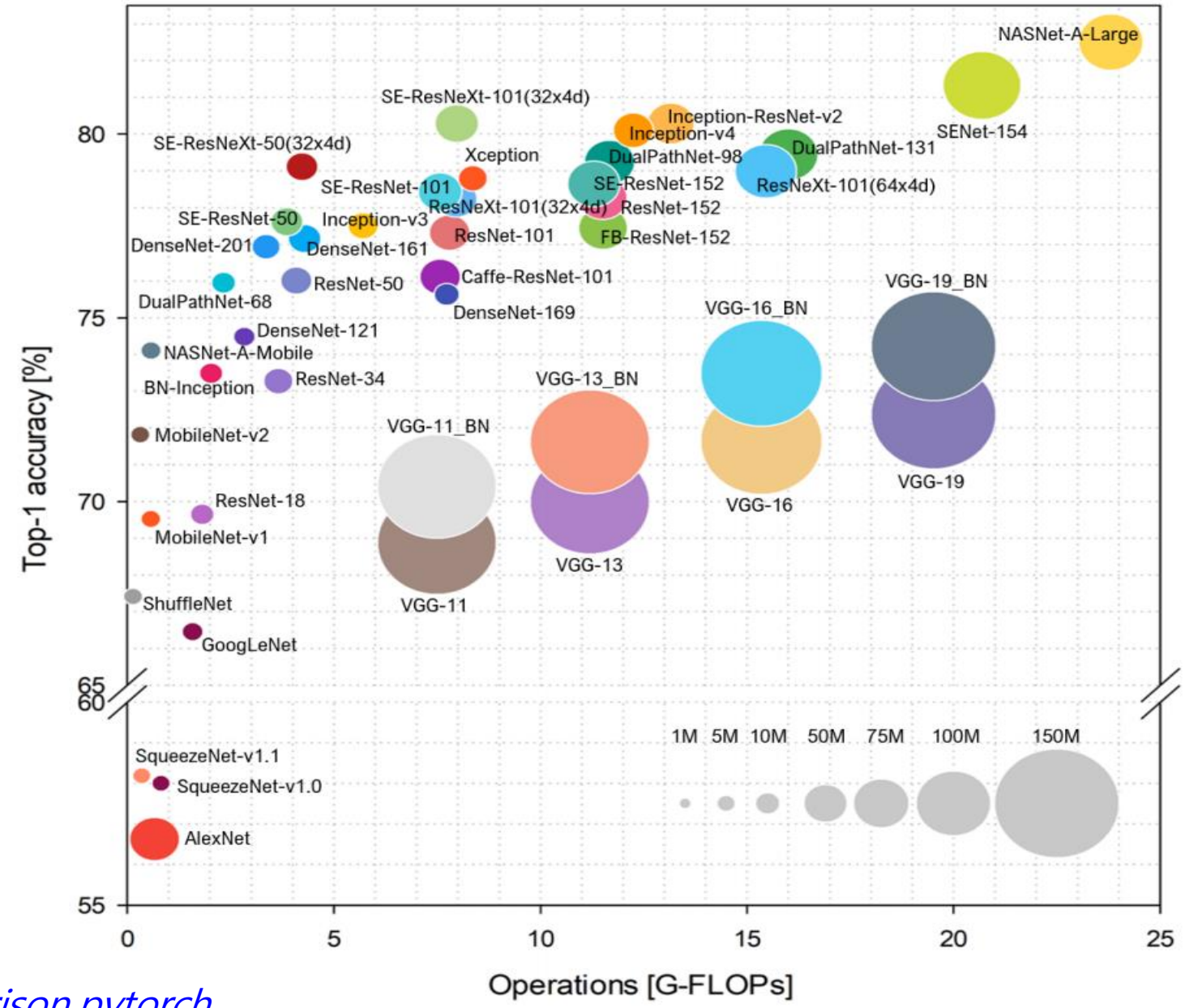
NASNet
2017.07. / 417



Normal Cell *Reduction Cell*



CNN Performances



https://github.com/CeLuigi/models-comparison.pytorch

CNN Review

Category	Networks	Pros	Cons
Plain	AlexNet, VGG	Simple Good Transfer	Low Performance
ResNet	ResNet	Simple	
Cardinality	ResNeXt/Xception MobileNet/ShuffleNet	Cost Efficient + Performance	Group Conv
DenseNet	DenseNet	Cost Efficient + Performance	Memory I/O
Engineering	Inception NASNet	SoTA	Complex

CNN Review

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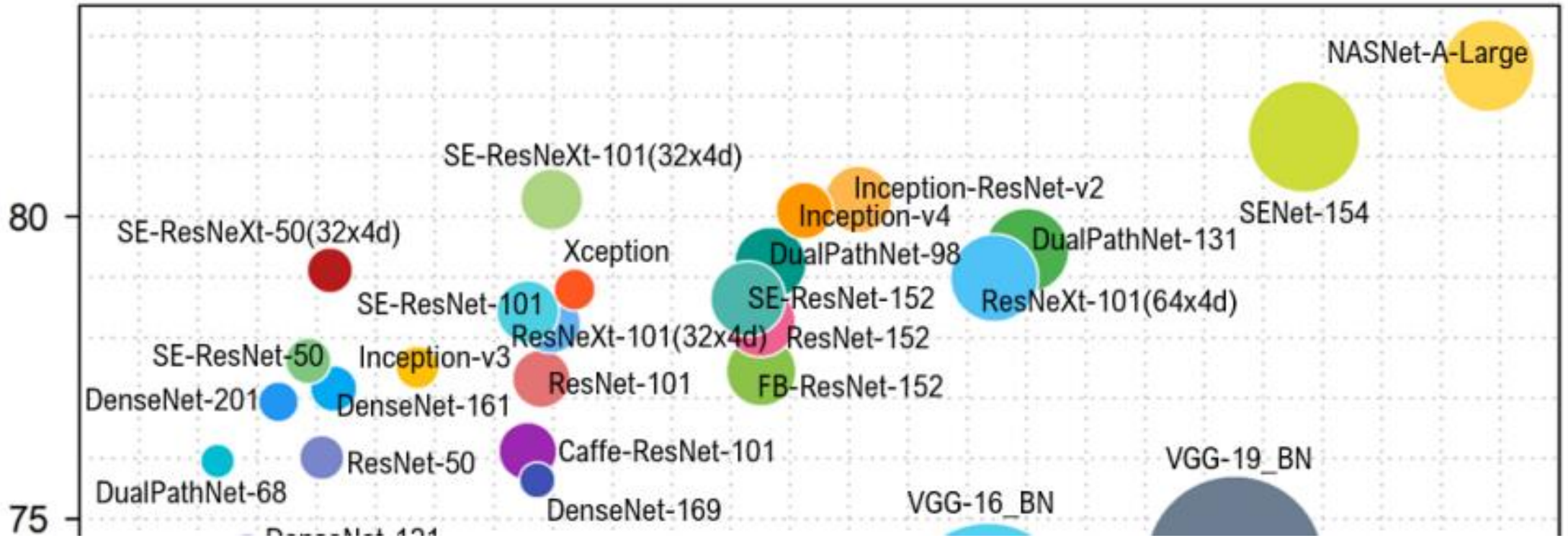
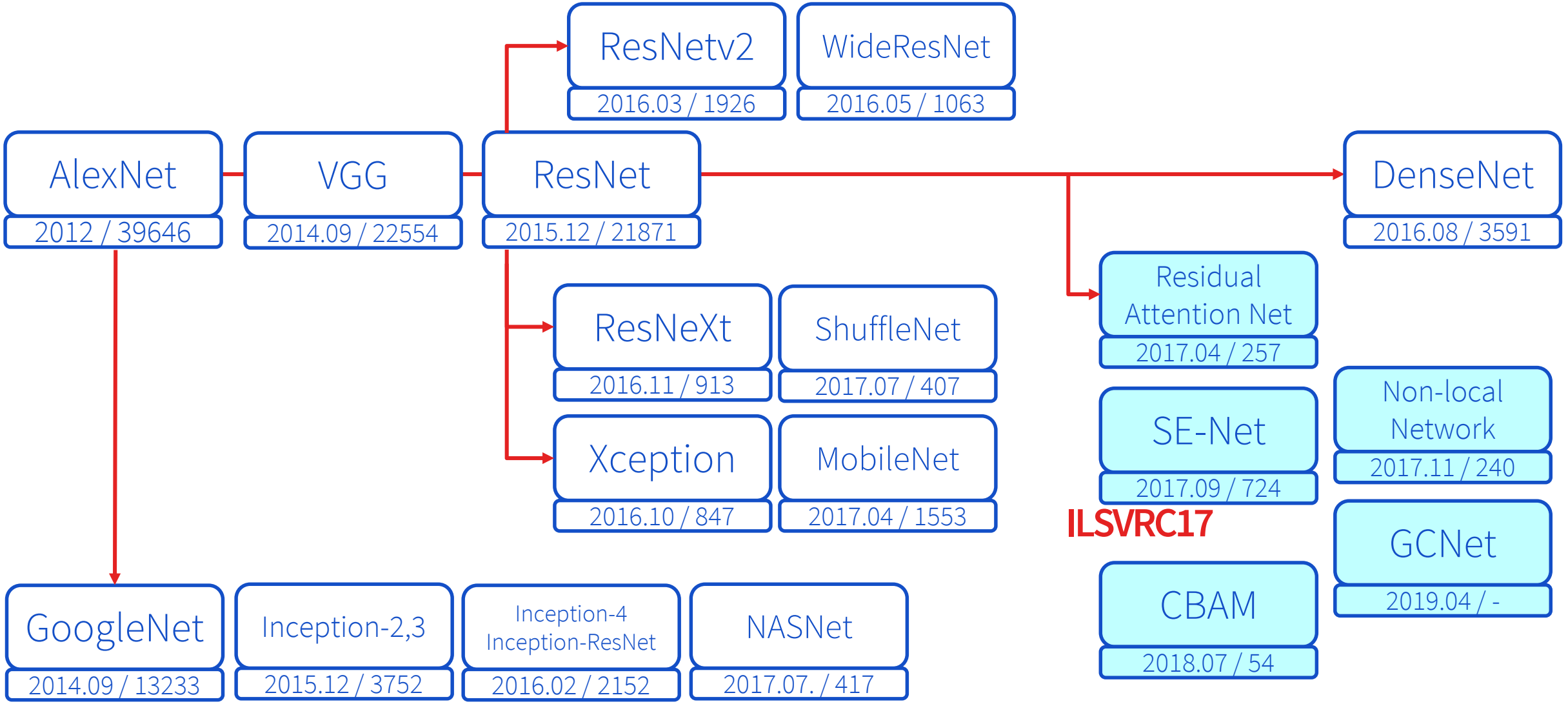
DenseNet	DenseNet	Cost Efficient + Performance	Memory I/O
Engineering	Inception NASNet	SoTA	Complex
Attention Module	SENet, CBAM, GCNet	Simple + Performance	

CNN Review


NASNet-A-Large
SE-ResNeXt-101(32x4d)
Inception-ResNet-v2
Inception-v4
SENet-154
80
SE-ResNeXt-50(32x4d)
Xception
DualPathNet-98
DualPathNet-131
SE-ResNet-101
SE-ResNet-152
ResNeXt-101(64x4d)
ResNeXt-101(32x4d)
ResNet-152
SE-ResNet-50
Inception-v3
ResNet-101
FB-ResNet-152
DenseNet-201
DenseNet-161
Caffe-ResNet-101
VGG-19_BN
ResNet-50
DualPathNet-68
DenseNet-169
VGG-16_BN
75

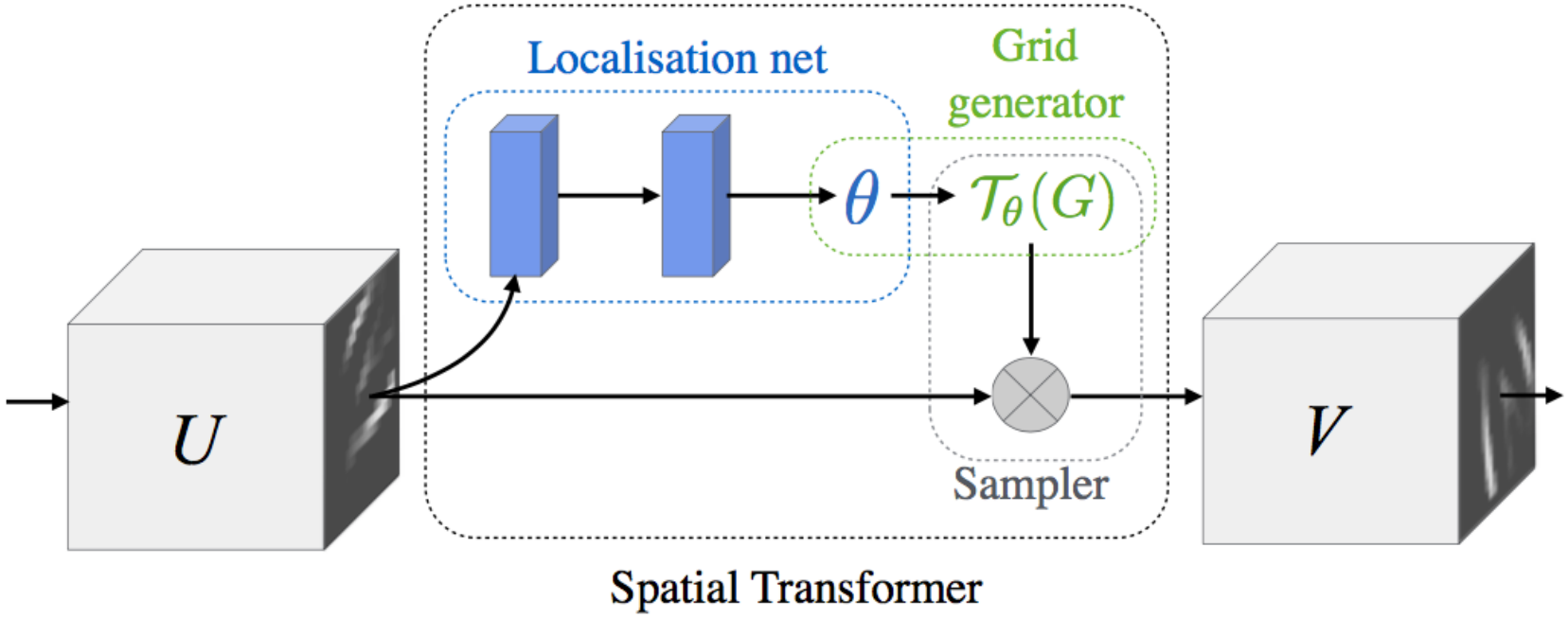
CNN x Attention

CNN Attention-Networks

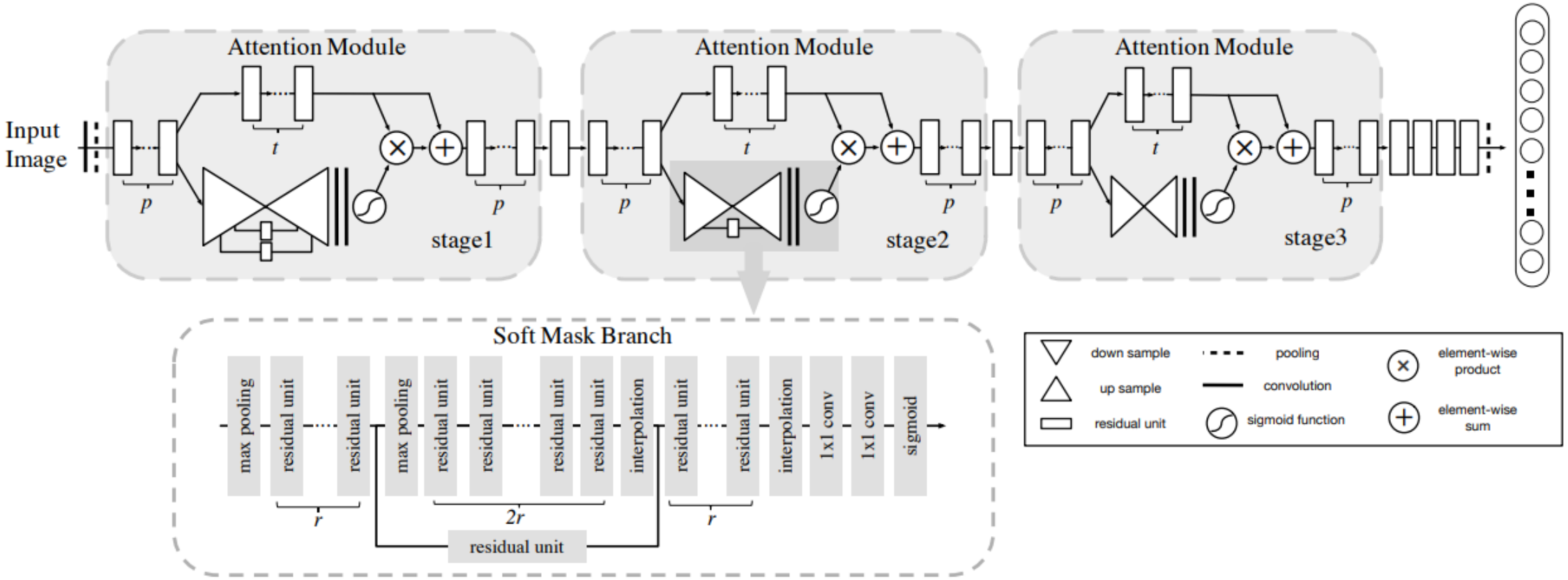


Spatial Transformer Networks (NIPS15, PR-011)

- *Recalibration (with Transform)*

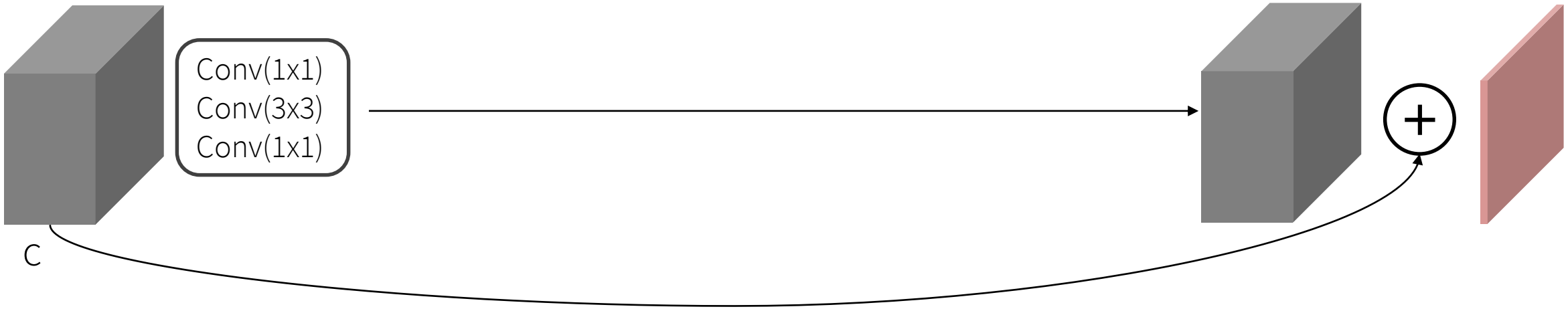


Residual Attention Network (CVPR17)



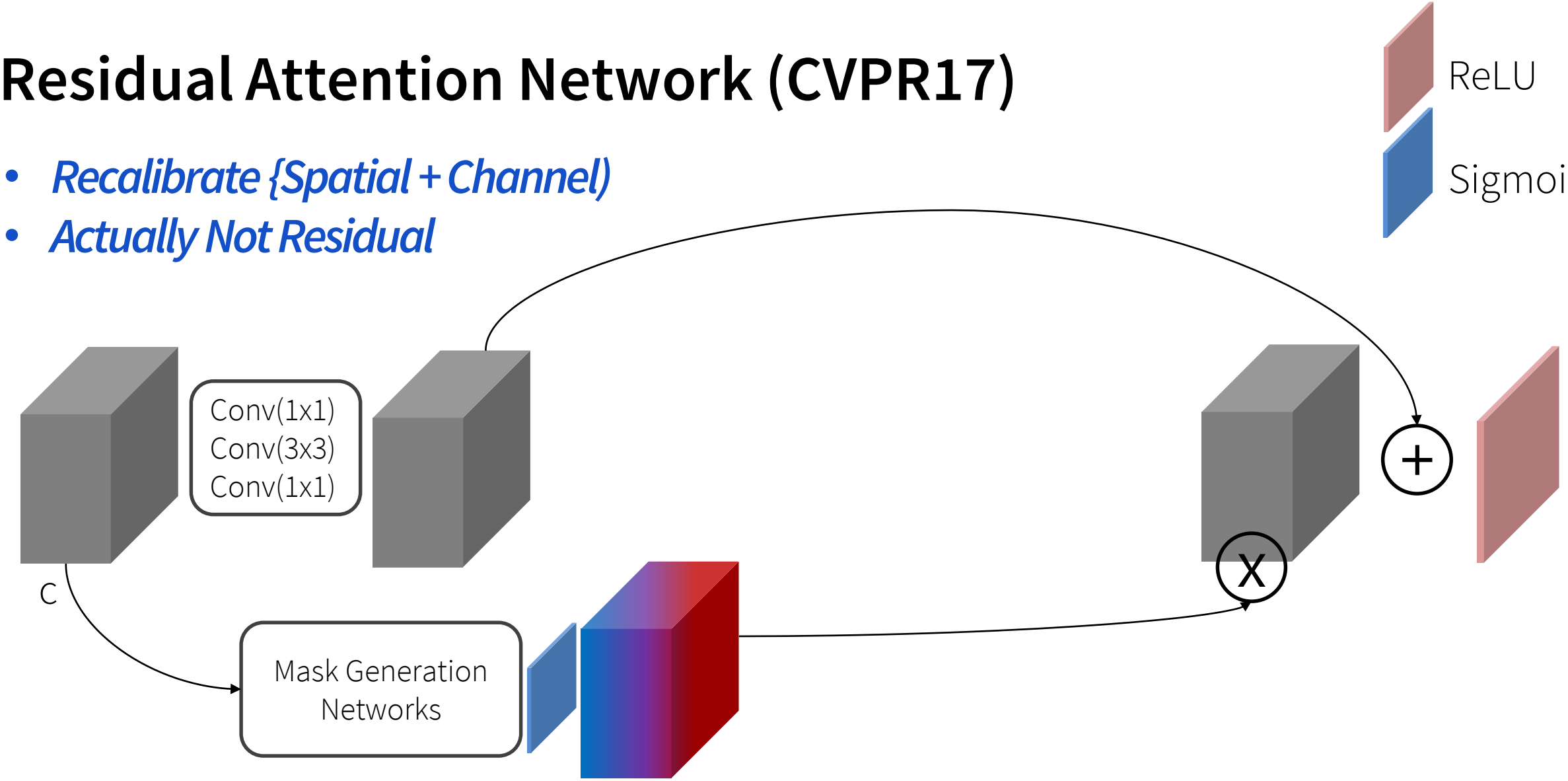
Residual Attention Network (CVPR17)

- *Original ResNet (BottleNeck Block)*



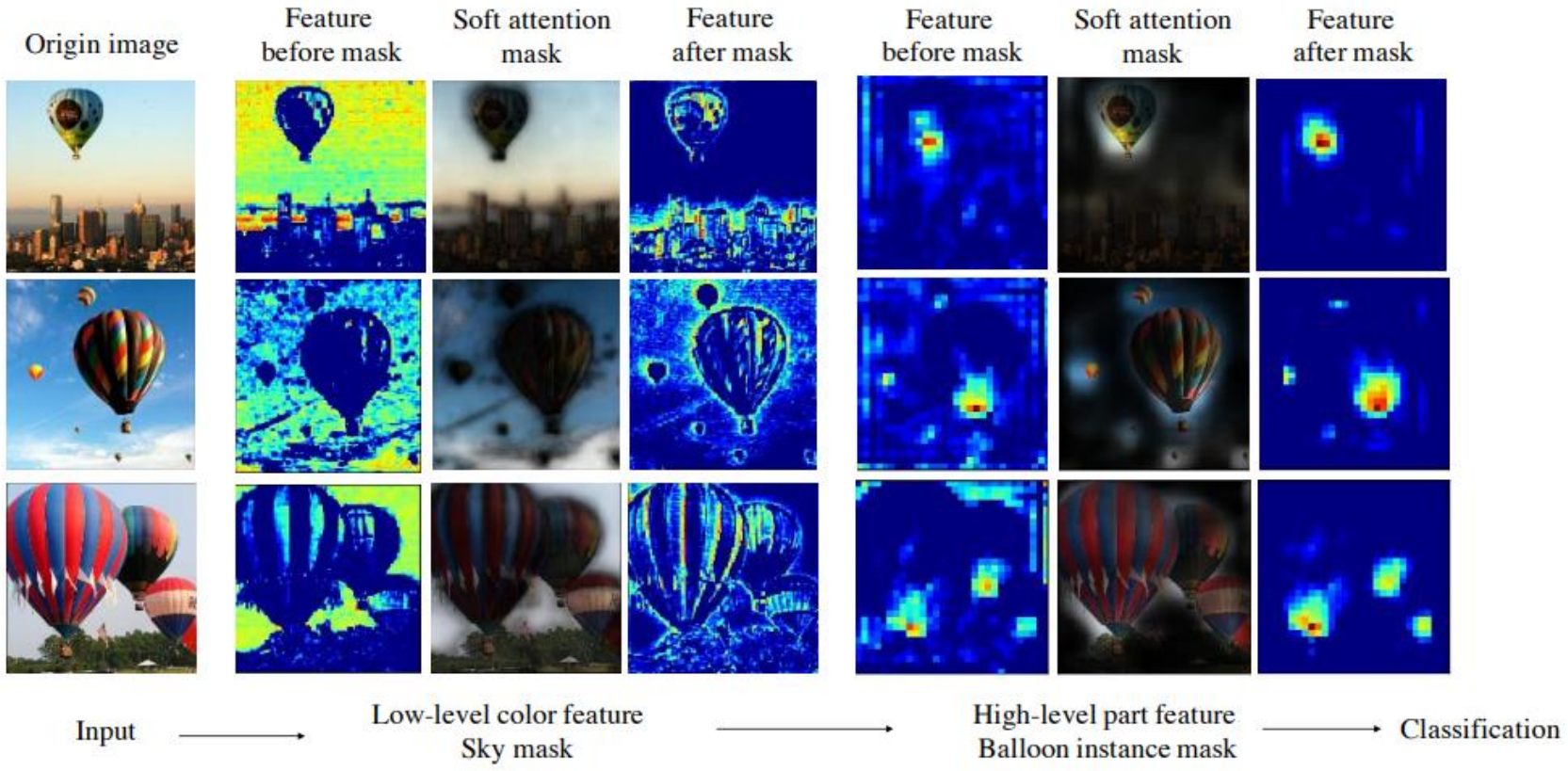
Residual Attention Network (CVPR17)

- *Recalibrate {Spatial + Channel)*
- *Actually Not Residual*



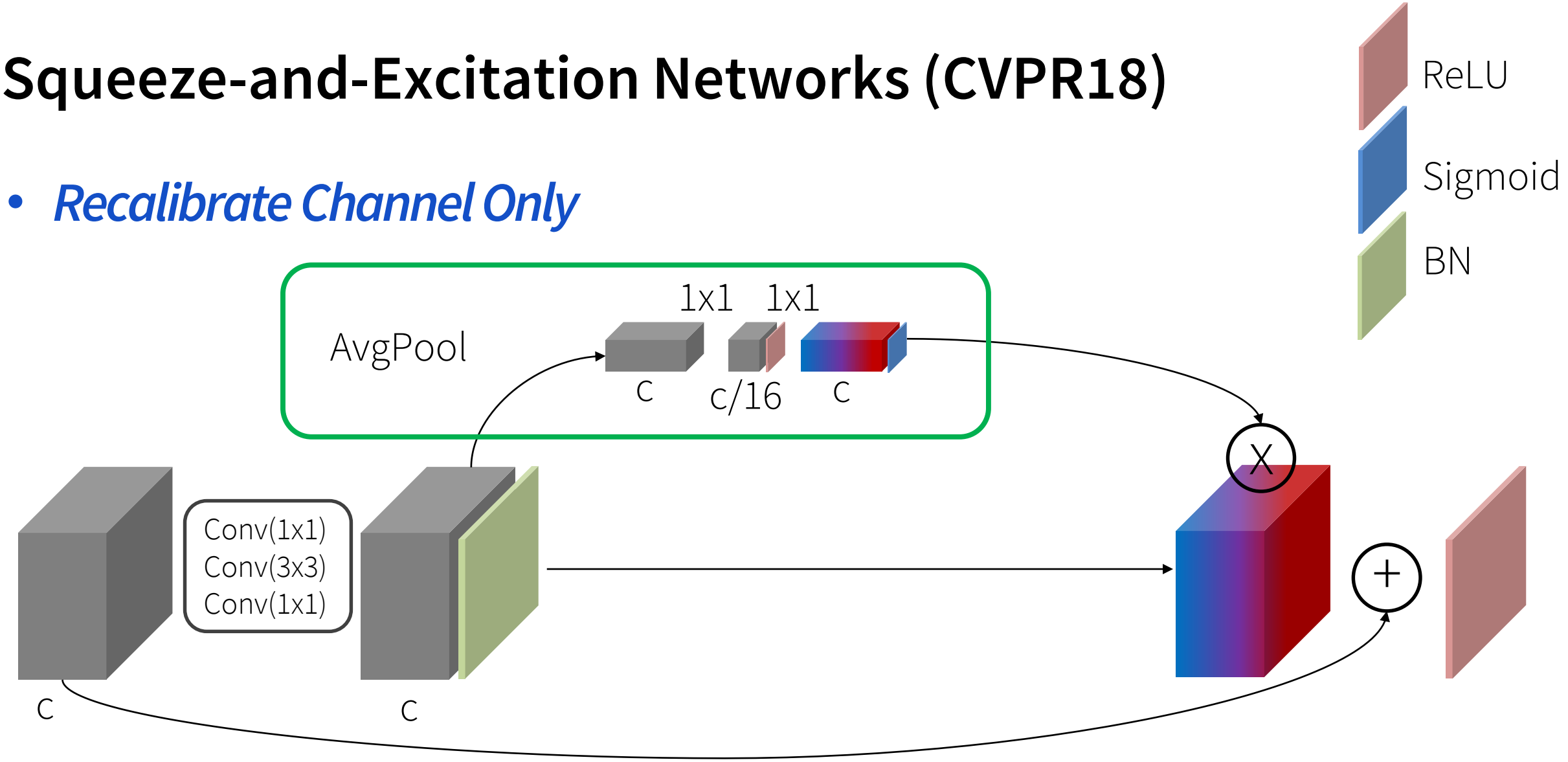
Residual Attention Network (CVPR17)

- *Results: Interpretable Features*



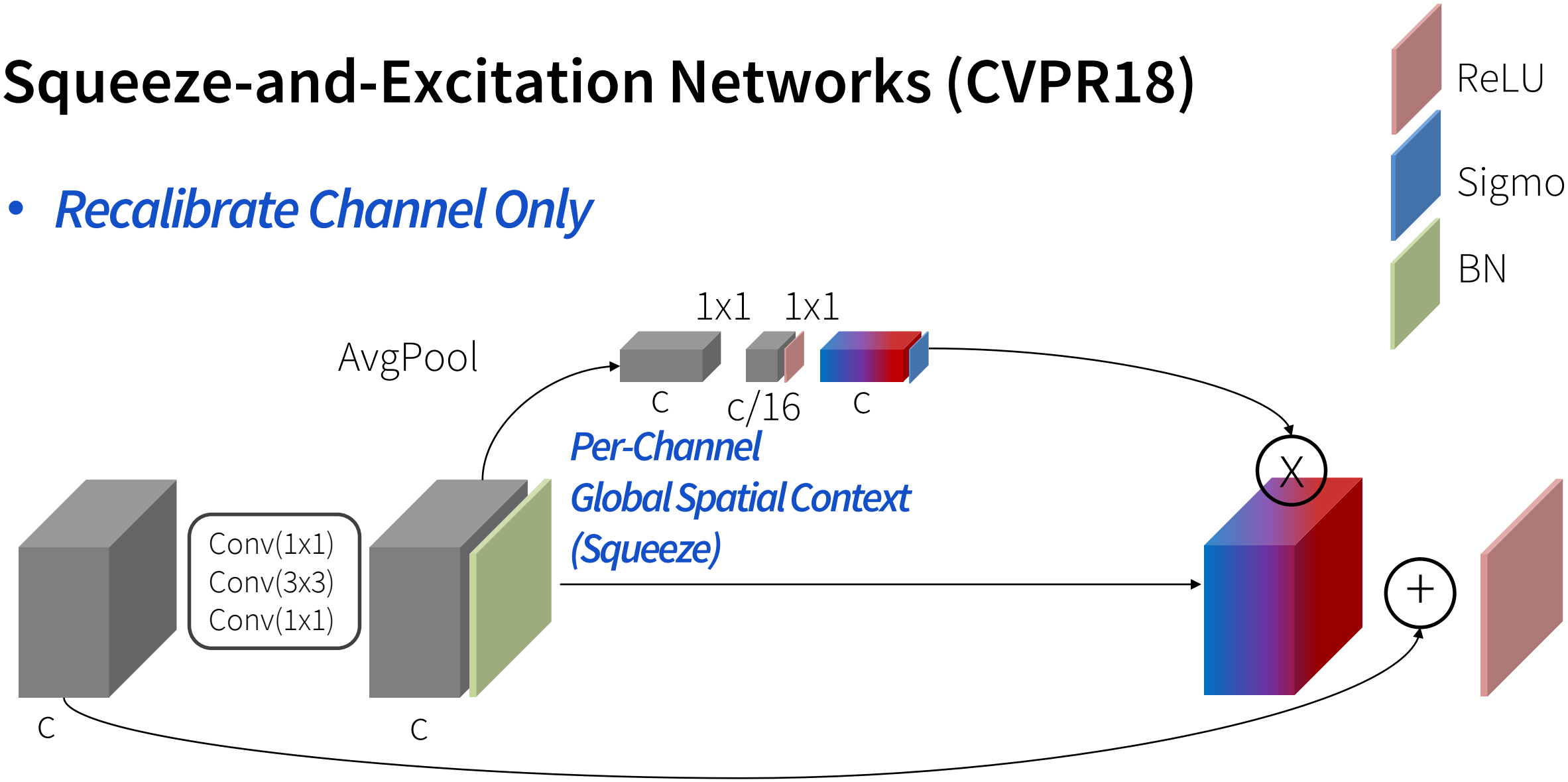
Squeeze-and-Excitation Networks (CVPR18)

- ***Recalibrate Channel Only***



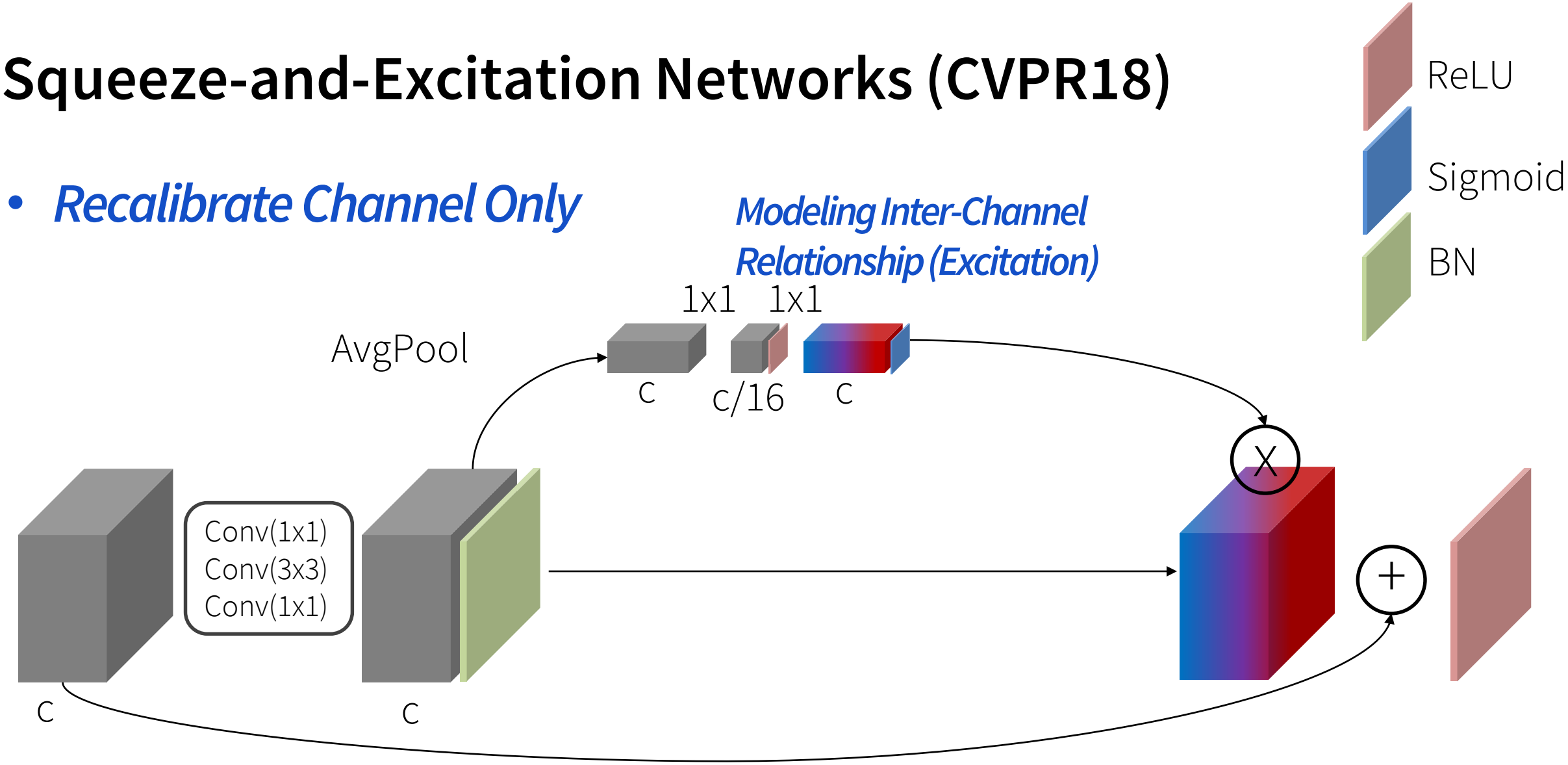
Squeeze-and-Excitation Networks (CVPR18)

- ***Recalibrate Channel Only***



Squeeze-and-Excitation Networks (CVPR18)

- ***Recalibrate Channel Only***



Squeeze-and-Excitation Networks (CVPR18)

	original		re-implementation			SENet		
	top-1 err.	top-5 err.	top-1 err.	top-5 err.	GFLOPs	top-1 err.	top-5 err.	GFLOPs
ResNet-50 [13]	24.7	7.8	24.80	7.48	3.86	$23.29_{(1.51)}$	$6.62_{(0.86)}$	3.87
ResNet-101 [13]	23.6	7.1	23.17	6.52	7.58	$22.38_{(0.79)}$	$6.07_{(0.45)}$	7.60
ResNet-152 [13]	23.0	6.7	22.42	6.34	11.30	$21.57_{(0.85)}$	$5.73_{(0.61)}$	11.32
ResNeXt-50 [19]	22.2	-	22.11	5.90	4.24	$21.10_{(1.01)}$	$5.49_{(0.41)}$	4.25
ResNeXt-101 [19]	21.2	5.6	21.18	5.57	7.99	$20.70_{(0.48)}$	$5.01_{(0.56)}$	8.00
VGG-16 [11]	-	-	27.02	8.81	15.47	$25.22_{(1.80)}$	$7.70_{(1.11)}$	15.48
BN-Inception [6]	25.2	7.82	25.38	7.89	2.03	$24.23_{(1.15)}$	$7.14_{(0.75)}$	2.04
Inception-ResNet-v2 [21]	$19.9^{\dagger}$	$4.9^{\dagger}$	20.37	5.21	11.75	$19.80_{(0.57)}$	$4.79_{(0.42)}$	11.76

Squeeze-and-Excitation Networks (CVPR18)

Ratio r	top-1 err.	top-5 err.	Params
2	22.29	6.00	45.7M
4	22.25	6.09	35.7M
8	22.26	5.99	30.7M
16	22.28	6.03	28.1M
32	22.72	6.20	26.9M
original	23.30	6.55	25.6M

Excitation	top-1 err.	top-5 err.
ReLU	23.47	6.98
Tanh	23.00	6.38
Sigmoid	**22.28**	**6.03**

Squeeze	top-1 err.	top-5 err.
Max	22.57	6.09
Avg	**22.28**	**6.03**

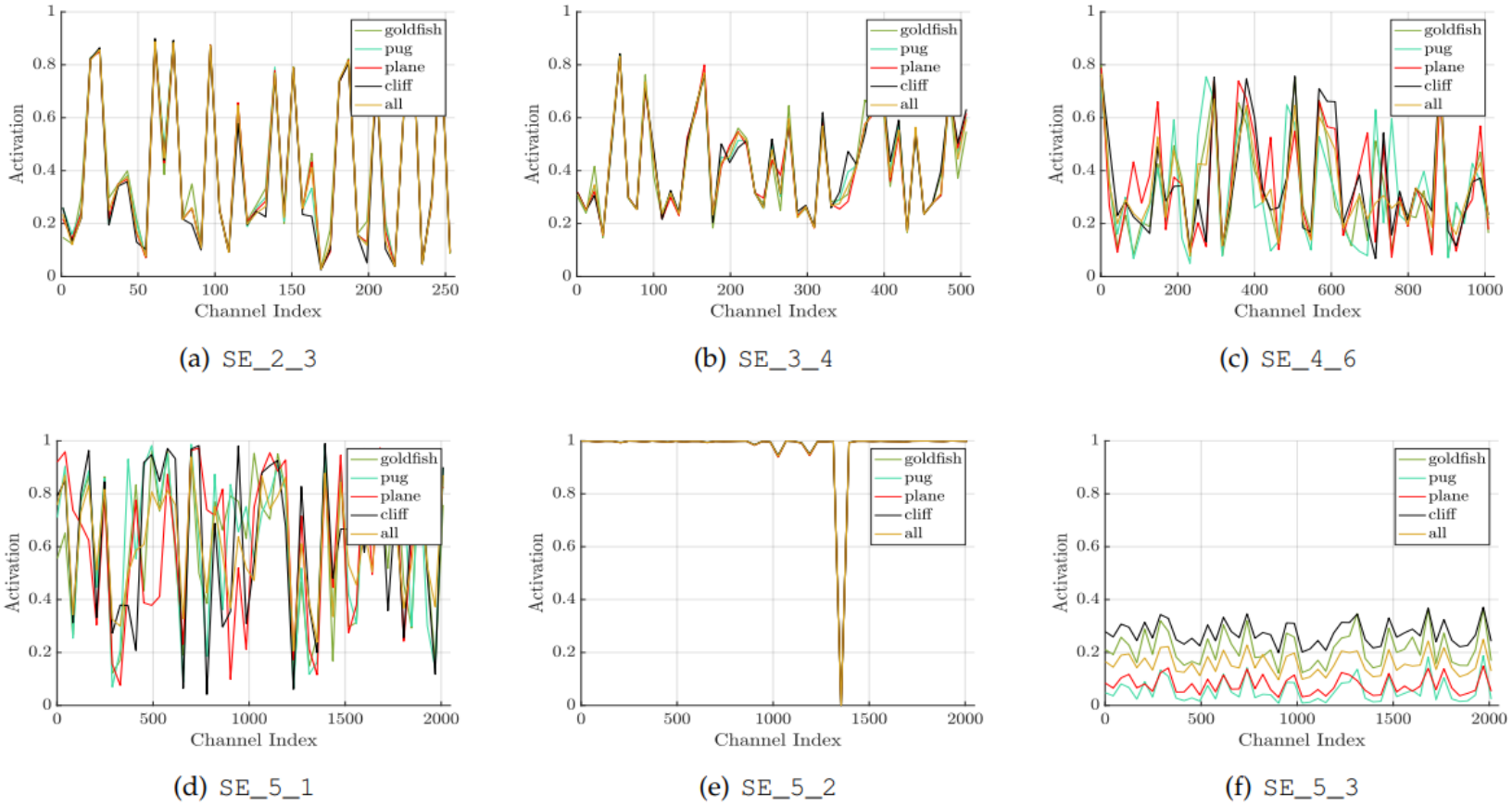
Design	top-1 err.	top-5 err.
SE	22.28	6.03
SE-PRE	22.23	6.00
SE-POST	22.78	6.35
SE-Identity	22.20	6.15

Stage	top-1 err.	top-5 err.	GFLOPs	Params
ResNet-50	23.30	6.55	3.86	25.6M
SE_Stage_2	23.03	6.48	3.86	25.6M
SE_Stage_3	23.04	6.32	3.86	25.7M
SE_Stage_4	22.68	6.22	3.86	26.4M
SE_All	22.28	6.03	3.87	28.1M

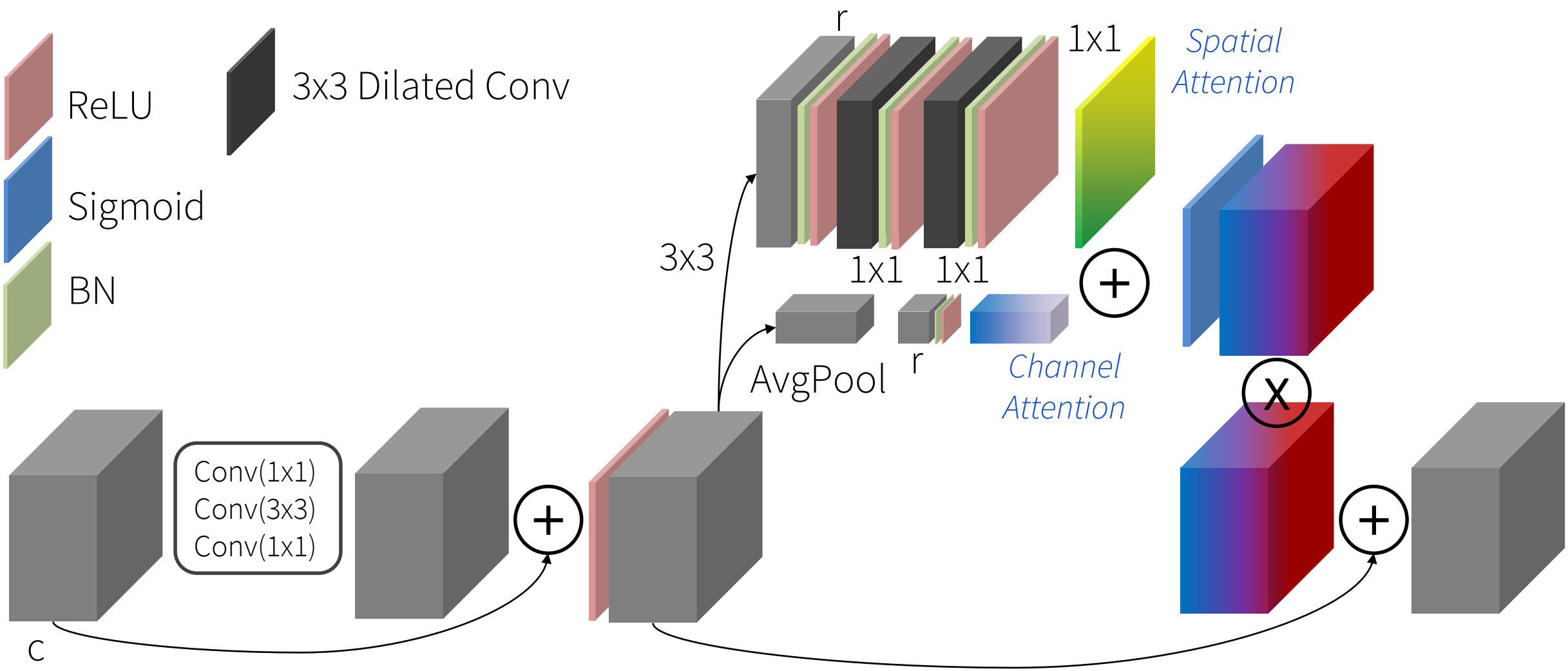
Design	top-1 err.	top-5 err.	GFLOPs	Params
SE	22.28	6.03	3.87	28.1M
SE_3×3	22.48	6.02	3.86	25.8M

Squeeze-and-Excitation Networks (CVPR18)

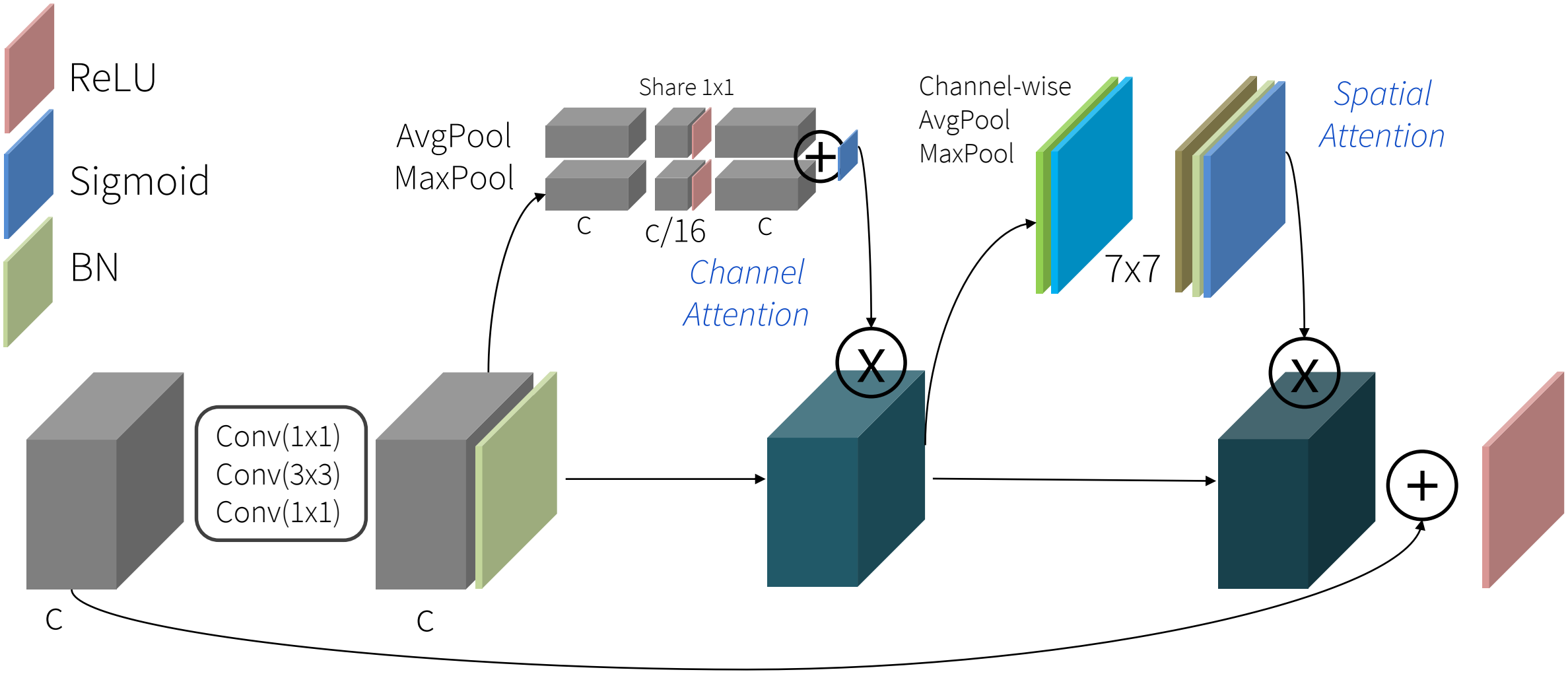
- *Channel Recalibration Stats.*



Bottleneck Attention Networks (BMVC18)



Convolutional Block Attention Networks (ECCV18)



BAM / CBAM Results

Architecture	Parameters	GFLOPs	Top-1(%)	Top-5(%)
ResNet18 [15]	11.69M	1.81	29.60	10.55
ResNet18 [15] + BAM	11.71M$_{(+0.02)}$	1.82$_{(+0.01)}$	**28.88**	**10.01**
ResNet50 [15]	25.56M	3.86	24.56	7.50
ResNet50 [15] + BAM	25.92M$_{(+0.36)}$	3.94$_{(+0.08)}$	**24.02**	**7.18**
ResNet101 [15]	44.55M	7.57	23.38	6.88
ResNet101 [15] + BAM	44.91M$_{(+0.36)}$	7.65$_{(+0.08)}$	**22.44**	**6.29**
WideResNet18 [47] (widen=1.5)	25.88M	3.87	26.85	8.88
WideResNet18 [47] (widen=1.5) + BAM	25.93M$_{(+0.05)}$	3.88$_{(+0.01)}$	**26.67**	**8.69**
WideResNet18 [47] (widen=2.0)	45.62M	6.70	25.63	8.20
WideResNet18 [47] (widen=2.0) + BAM	45.71M$_{(+0.09)}$	6.72$_{(+0.02)}$	**25.00**	**7.81**
ResNeXt50 [43] (32x4d)	25.03M	3.77	22.85	6.48
ResNeXt50 [43] (32x4d) + BAM	25.39M$_{(+0.36)}$	3.85$_{(+0.08)}$	**22.56**	**6.40**
MobileNet[18]	4.23M	0.569	31.39	11.51
MobileNet[18] + BAM	4.32M$_{(+0.09)}$	0.589$_{(+0.02)}$	**30.58**	**10.90**
MobileNet[18] $\alpha = 0.7$	2.30M	0.283	34.86	13.69
MobileNet[18] $\alpha = 0.7$ + BAM	2.34M$_{(+0.04)}$	0.292$_{(+0.009)}$	**33.09**	**12.69**
MobileNet[18] $\rho = 192/224$	4.23M	0.439	32.89	12.33
MobileNet[18] $\rho = 192/224$ + BAM	4.32M$_{(+0.09)}$	0.456$_{(+0.017)}$	**31.56**	**11.60**
SqueezeNet v1.1 [22]	1.24M	0.290	43.09	20.48
SqueezeNet v1.1 [22] + BAM	1.26M$_{(+0.02)}$	0.304$_{(+0.014)}$	**41.83**	**19.58**

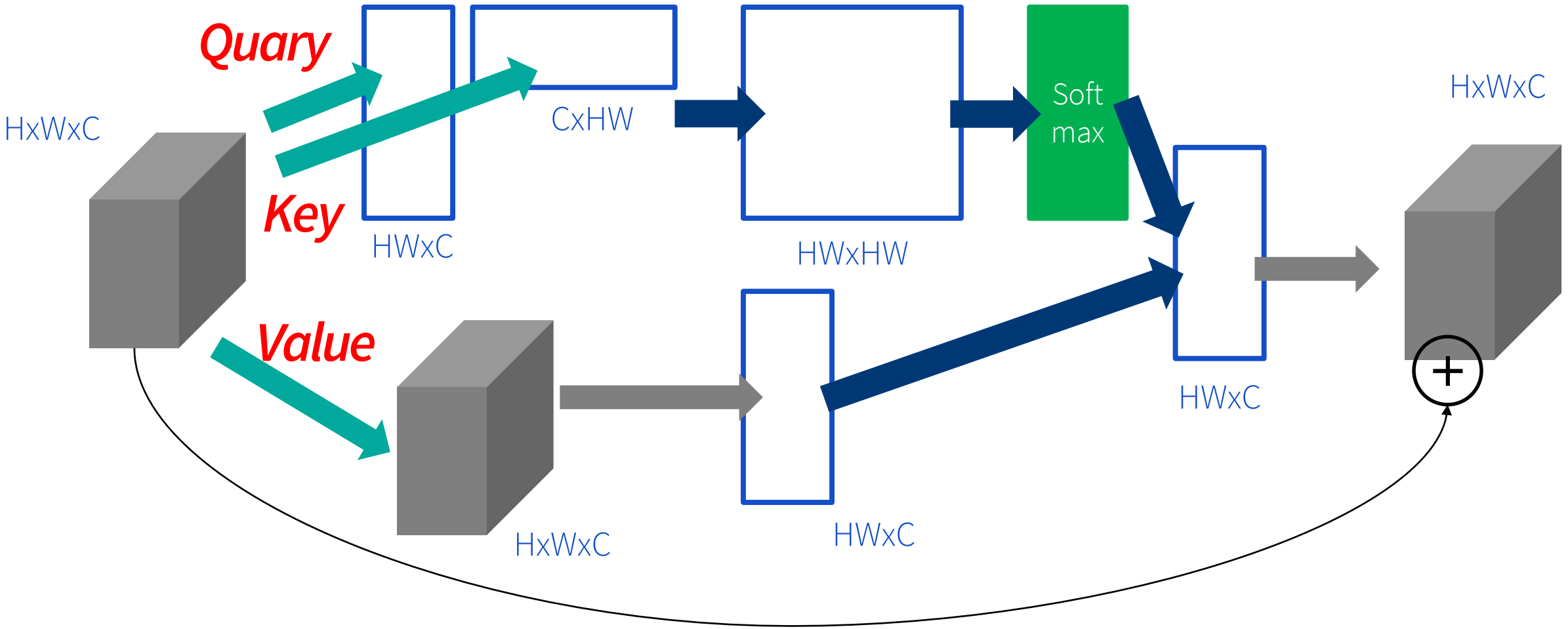
Architecture	Param.	GFLOPs	Top-1 Error (%)	Top-5 Error (%)
ResNet18 [5]	11.69M	1.814	29.60	10.55
ResNet18 [5] + SE [28]	11.78M	1.814	29.41	10.22
ResNet18 [5] + CBAM	11.78M	1.815	**29.27**	**10.09**
ResNet34 [5]	21.80M	3.664	26.69	8.60
ResNet34 [5] + SE [28]	21.96M	3.664	26.13	8.35
ResNet34 [5] + CBAM	21.96M	3.665	**25.99**	**8.24**
ResNet50 [5]	25.56M	3.858	24.56	7.50
ResNet50 [5] + SE [28]	28.09M	3.860	23.14	6.70
ResNet50 [5] + CBAM	28.09M	3.864	**22.66**	**6.31**
ResNet101 [5]	44.55M	7.570	23.38	6.88
ResNet101 [5] + SE [28]	49.33M	7.575	22.35	6.19
ResNet101 [5] + CBAM	49.33M	7.581	**21.51**	**5.69**
WideResNet18 [6] (widen=1.5)	25.88M	3.866	26.85	8.88
WideResNet18 [6] (widen=1.5) + SE [28]	26.07M	3.867	26.21	8.47
WideResNet18 [6] (widen=1.5) + CBAM	26.08M	3.868	**26.10**	**8.43**
WideResNet18 [6] (widen=2.0)	45.62M	6.696	25.63	8.20
WideResNet18 [6] (widen=2.0) + SE [28]	45.97M	6.696	24.93	7.65
WideResNet18 [6] (widen=2.0) + CBAM	45.97M	6.697	**24.84**	**7.63**
ResNeXt50 [7] (32x4d)	25.03M	3.768	22.85	6.48
ResNeXt50 [7] (32x4d) + SE [28]	27.56M	3.771	**21.91**	6.04
ResNeXt50 [7] (32x4d) + CBAM	27.56M	3.774	21.92	**5.91**
ResNeXt101 [7] (32x4d)	44.18M	7.508	21.54	5.75
ResNeXt101 [7] (32x4d) + SE [28]	48.96M	7.512	21.17	5.66
ResNeXt101 [7] (32x4d) + CBAM	48.96M	7.519	**21.07**	**5.59**

RAN / SE / BAM / CBAM Comparison

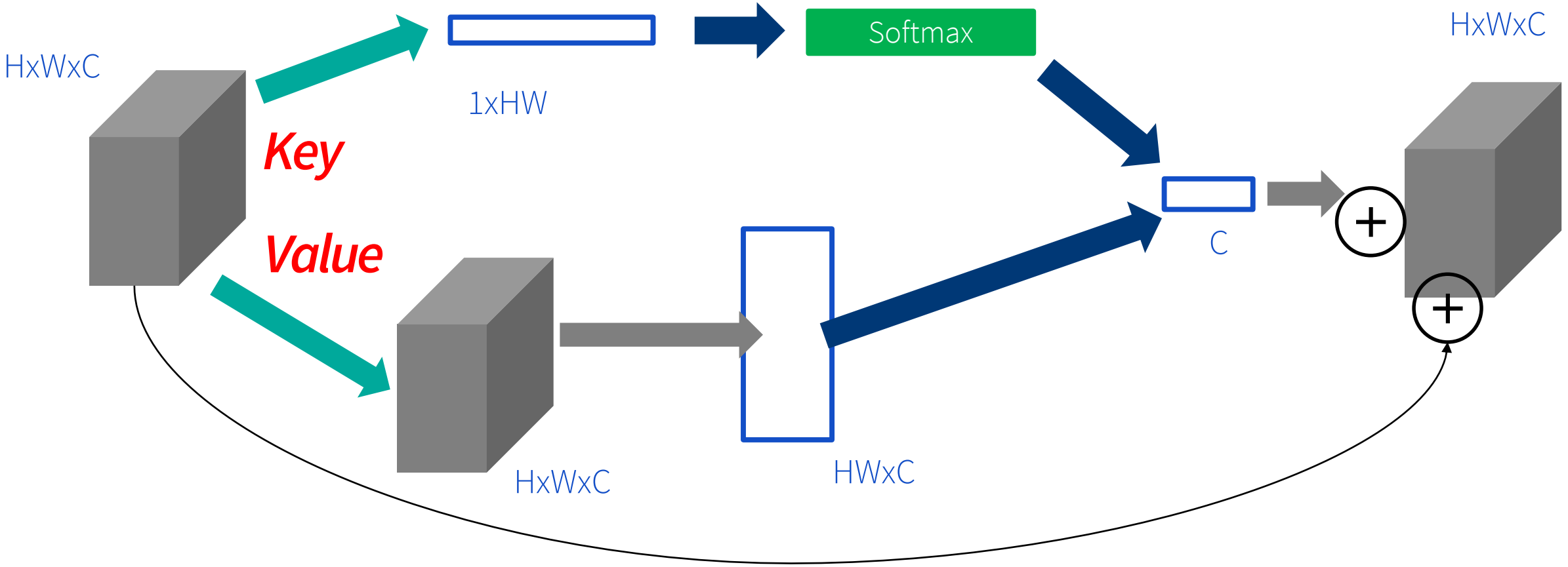
Network	Module Position	Attention
RAN (CVPR17)	Modified	ChannelxSpatial 3D
SE (CVPR18)	In the ResBlock	Channel
BAM (BMVC18)	Before the Stride=2 ResBlock	Channel, Spatial Parallel
CBAM (ECCV18)	In the ResBlock	Channel, Spatial Sequential

Non-local Networks

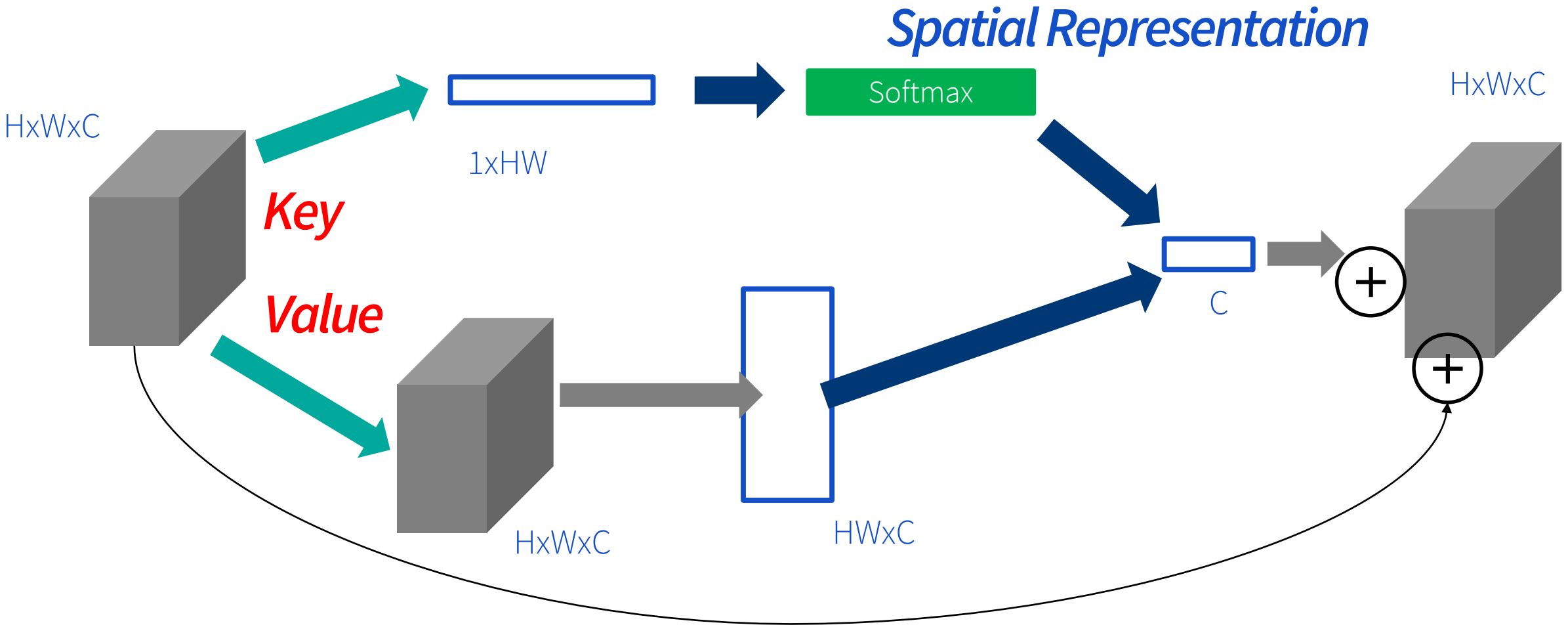
- *Represent Spatial-Only*



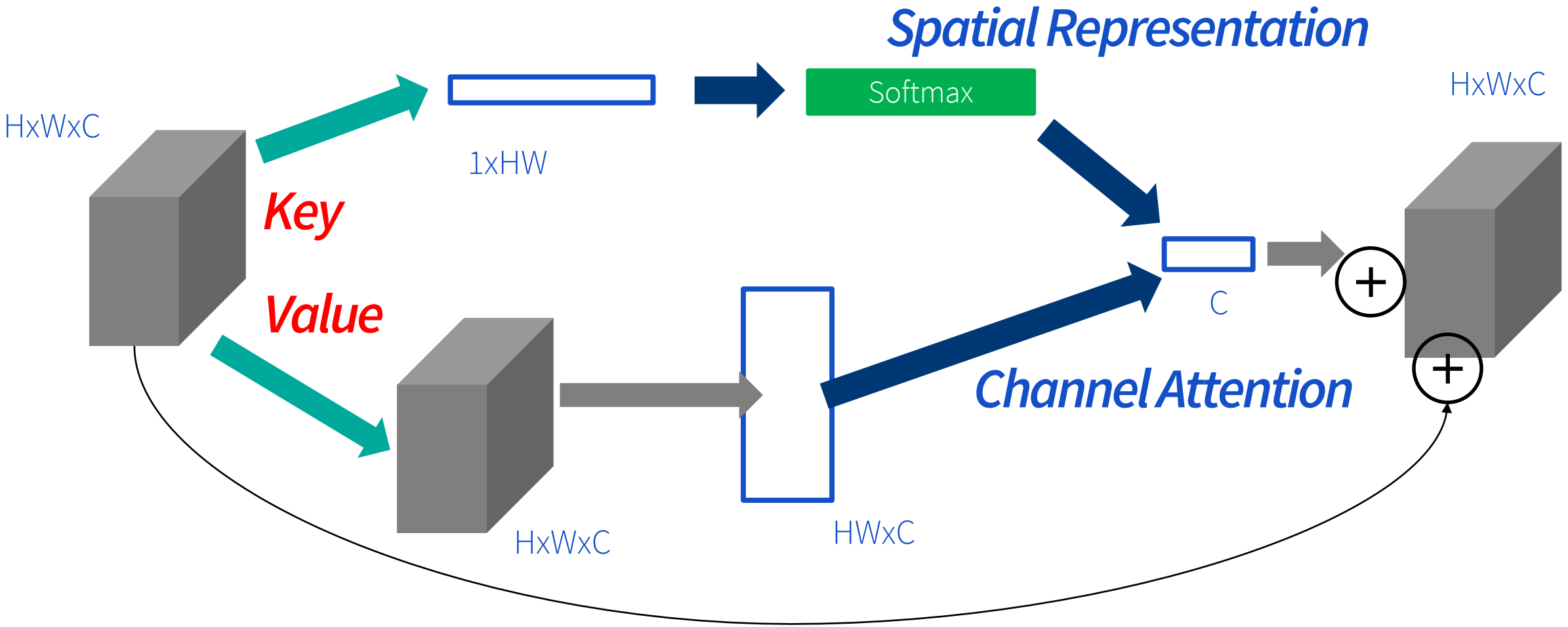
Global-Context Attention Networks



Global-Context Attention Networks



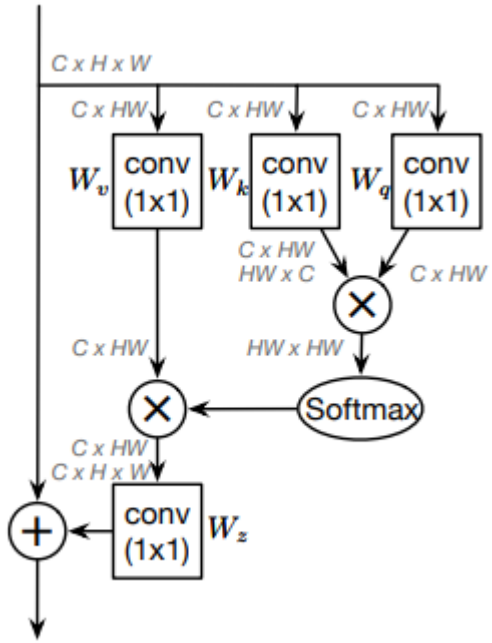
Global-Context Attention Networks



Global-Context Attention Networks

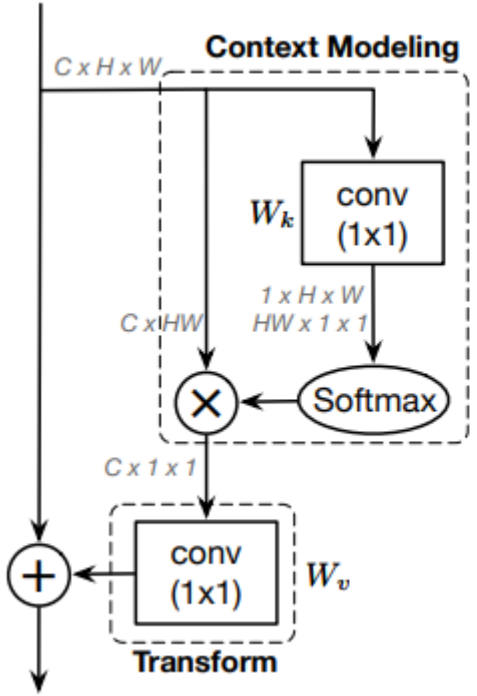
Quary Independent Representation → Recalibration

Global-Context Attention Networks



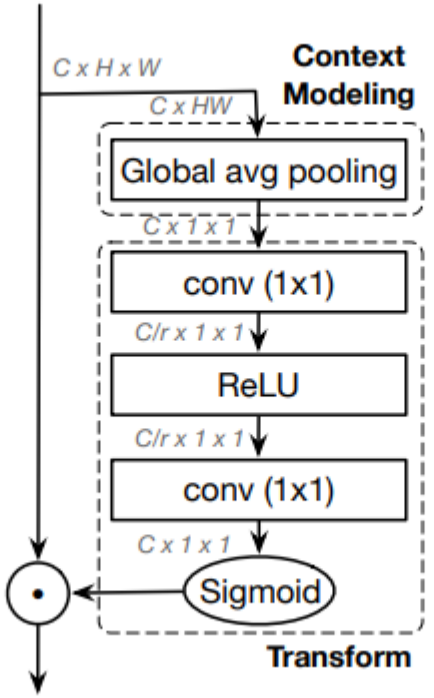
NLNet

Spatial Weighted Sum
Per Pixel
(HxW)



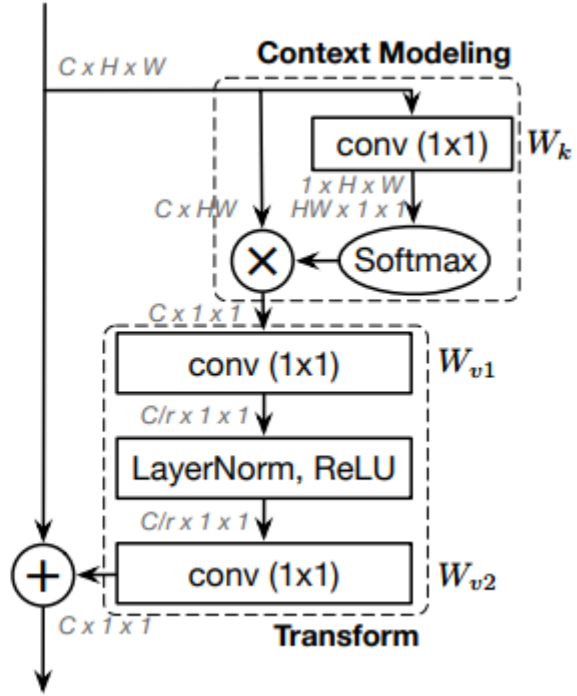
Simplified NLNet

Spatial Weighted Sum
Shared
(Scalar)



SENet

Spatial Aggregation
(Global Avg Pool)
→ for Channel Recalibration



GCNet

Spatial Weighted Sum
→ for Channel Recalibration

Global-Context Attention Networks

Quary Independent Representation → Recalibration

Non-local Networks Meet Squeeze-Excitation Networks and Beyond (GCNet)

Global-Context Attention Networks

backbone		AP^{bbox}	AP^{bbox}_{50}	AP^{bbox}_{75}	AP^{mask}	AP^{mask}_{50}	AP^{mask}_{75}	FLOPS
(a) **test on validation set**								
R50	baseline	37.2	59.0	40.1	33.8	55.4	35.9	279.4G
	+GC r16	39.4	61.6	42.4	35.7	58.4	37.6	279.6G
	+GC r4	**39.9**	**62.2**	**42.9**	**36.2**	**58.7**	**38.3**	279.6G
R101	baseline	39.8	61.3	42.9	36.0	57.9	38.3	354.0G
	+GC r16	41.1	63.6	45.0	37.4	60.1	39.6	354.3G
	+GC r4	**41.7**	**63.7**	**45.5**	**37.6**	**60.5**	**39.8**	354.3G
X101	baseline	41.2	63.0	45.1	37.3	59.7	39.9	357.9G
	+GC r16	42.4	64.6	46.5	38.0	60.9	40.5	358.2G
	+GC r4	**42.9**	**65.2**	**47.0**	**38.5**	**61.8**	**40.9**	358.2G
X101 +Cascade	baseline	44.7	63.0	48.5	38.3	59.9	41.3	536.9G
	+GC r16	45.9	64.8	50.0	39.3	61.8	42.1	537.2G
	+GC r4	**46.5**	**65.4**	**50.7**	**39.7**	**62.5**	**42.7**	537.3G
X101+DCN +Cascade	baseline	47.1	66.1	51.3	40.4	63.1	43.7	547.5G
	+GC r16	**47.9**	**66.9**	**52.2**	**40.9**	63.7	**44.1**	547.8G
	+GC r4	**47.9**	**66.9**	51.9	40.8	**64.0**	44.0	547.8G
(b) **test on test-dev set**								
X101 +Cascade	baseline	45.0	63.7	49.1	38.7	60.8	41.8	536.9G
	+GC r16	46.5	65.7	50.7	40.0	62.9	43.1	537.2G
	+GC r4	**46.6**	**65.9**	**50.7**	**40.1**	**62.9**	**43.3**	537.3G
X101+DCN +Cascade	baseline	47.7	66.7	52.0	41.0	63.9	44.3	547.5G
	+GC r16	48.3	67.5	**52.7**	**41.5**	**64.6**	**45.0**	547.8G
	+GC r4	**48.4**	**67.6**	**52.7**	**41.5**	**64.6**	**45.0**	547.8G

	Top-1 Acc	Top-5 Acc	#params(M)	FLOPs(G)
(a) **Block Design**				
baseline	76.88	93.16	25.56	3.86
+1NL	77.20	93.51	27.66	4.11
+1SNL	77.28	93.60	26.61	3.86
+1GC	77.34	93.52	25.69	3.86
+all GC	**77.70**	**93.66**	28.08	3.87
(b) **Pooling and fusion**				
	Top-1 Acc	Top-5 Acc	#params(M)	FLOPs(G)
baseline	76.88	93.16	25.56	3.86
avg+scale (SENet)	77.26	93.55	28.07	3.87
avg+add	77.40	93.60	28.07	3.87
att+scale	77.34	93.48	28.08	3.87
att+add	**77.70**	**93.66**	28.08	3.87

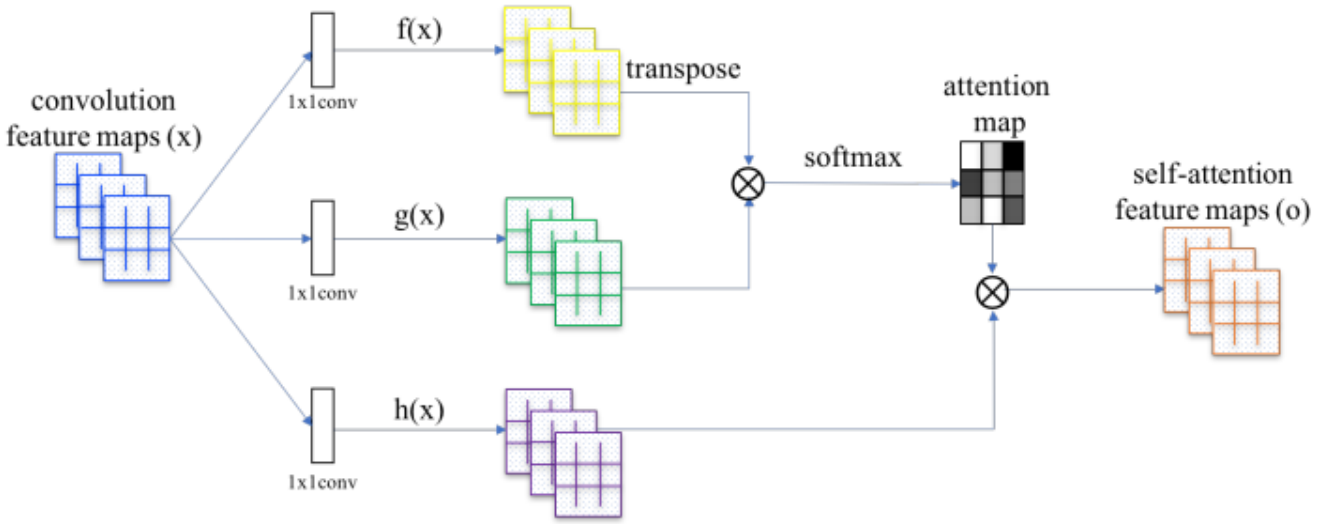
Table 4: **Ablation study** of GCNet with ResNet-50 on **image classification** on ImageNet validation set.

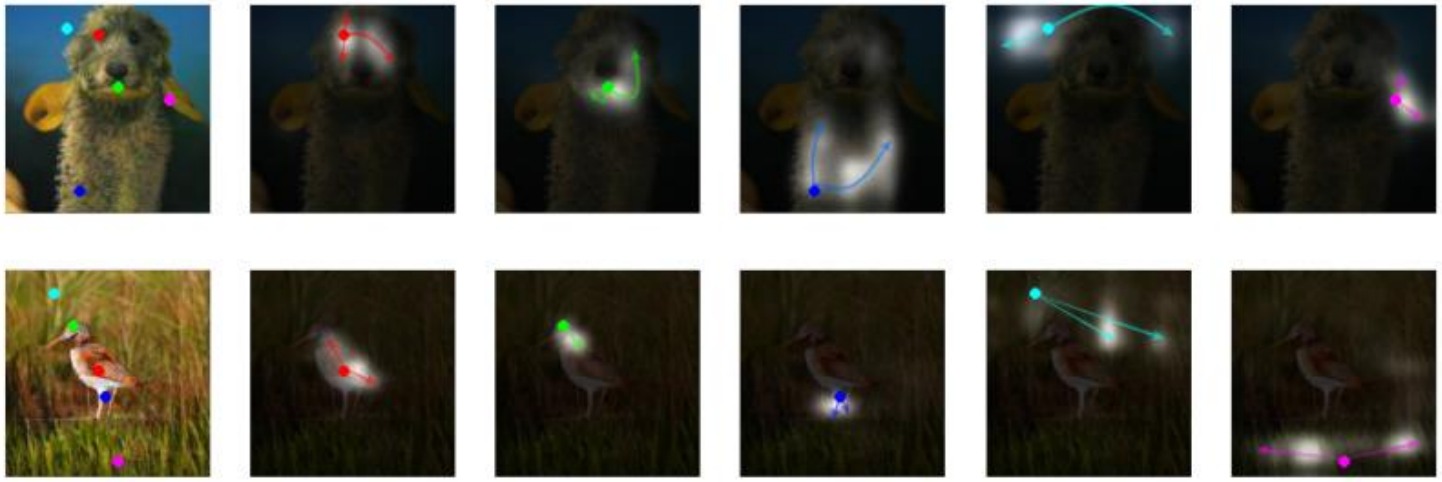
Summary

Network	Attention	Spatial Modeling
RAN (CVPR17)	ChannelxSpatial 3D	Network
SE (CVPR18)	Channel	Avg Pool
BAM (BMVC18)	Channel, Spatial Parallel	Avg Pool
CBAM (ECCV18)	Channel, Spatial Sequential	Avg Pool + Max Pool
NLNet (CVPR18)	Spatial (Representation)	Non-local Representation
GCNet (Preprint19)	Channel	Non-local Representation

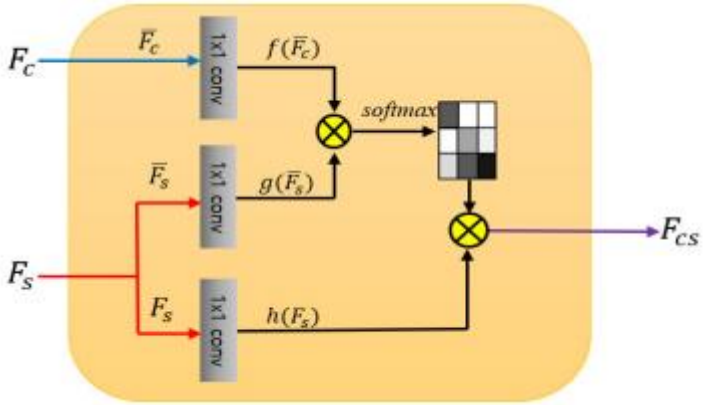
CNN x Attention: Other Vision Tasks

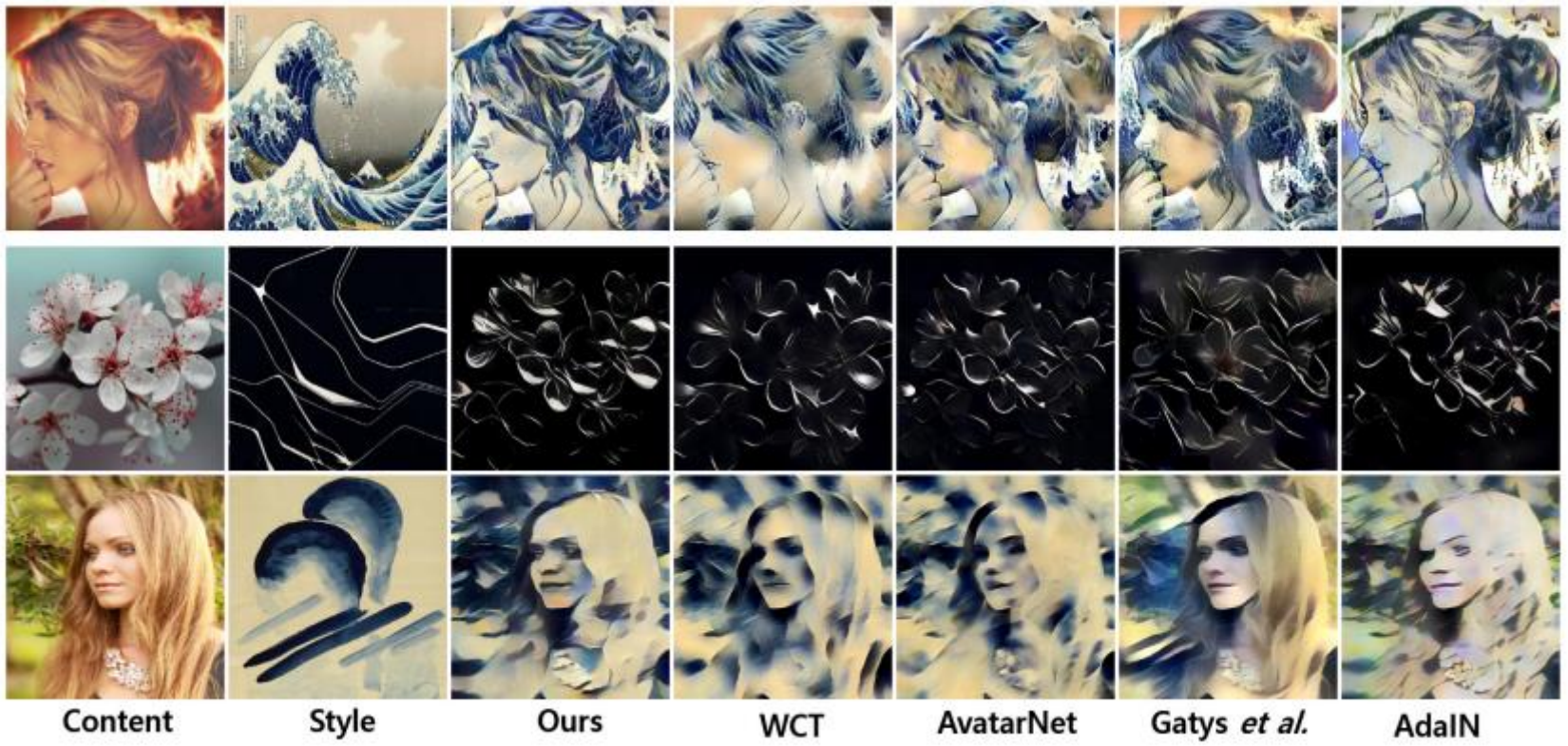
Self-Attention GAN





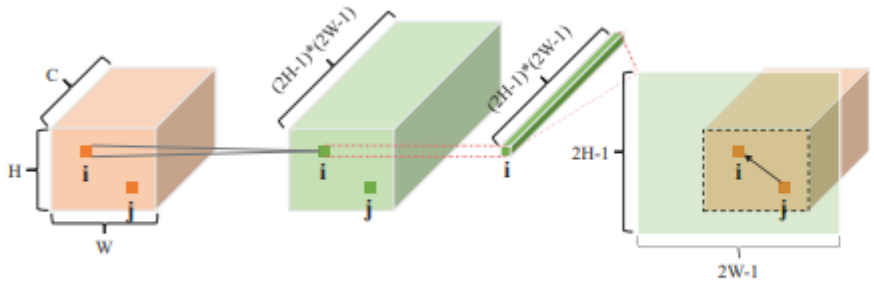
Style Transfer (CVPR19)



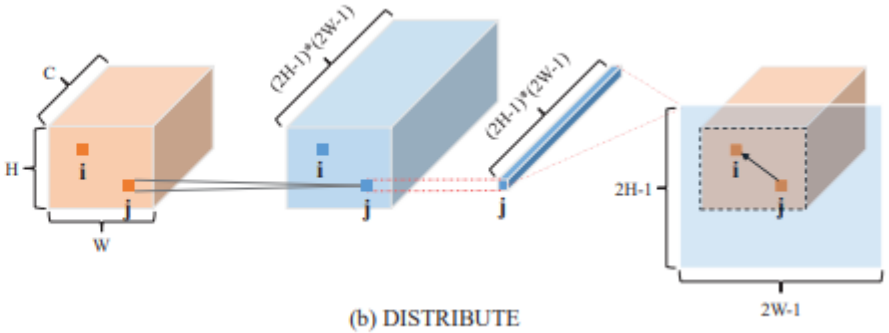


Arbitrary Style Transfer with Style-Attentional Networks

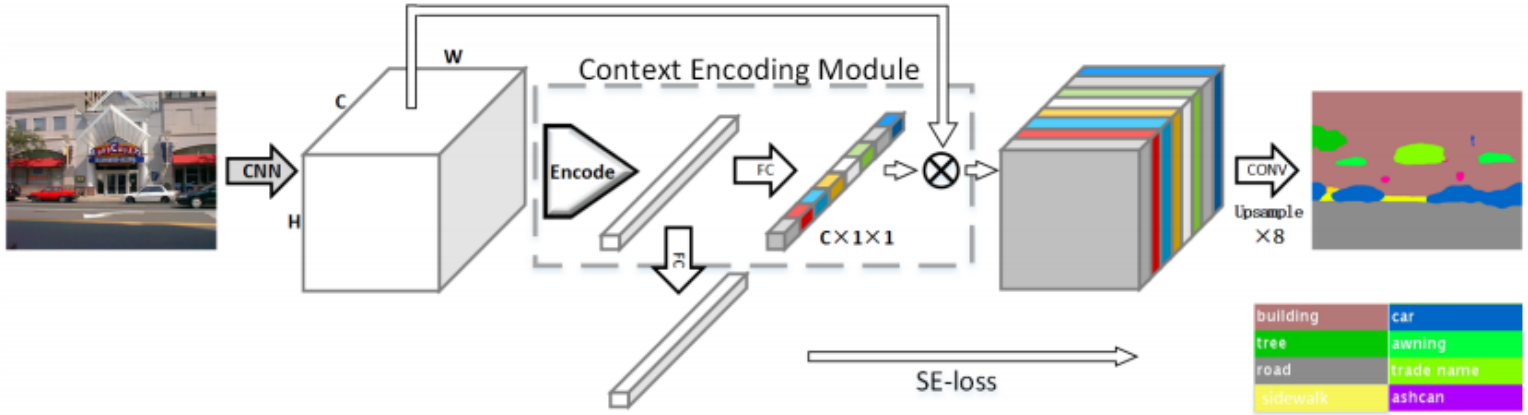
PSANet (ECCV18) / Context Encoding (CVPR18) / OCNet (2018)



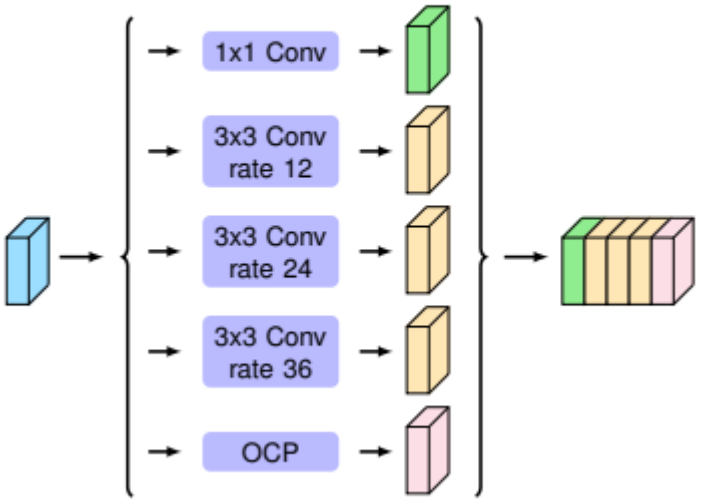
(a) COLLECT



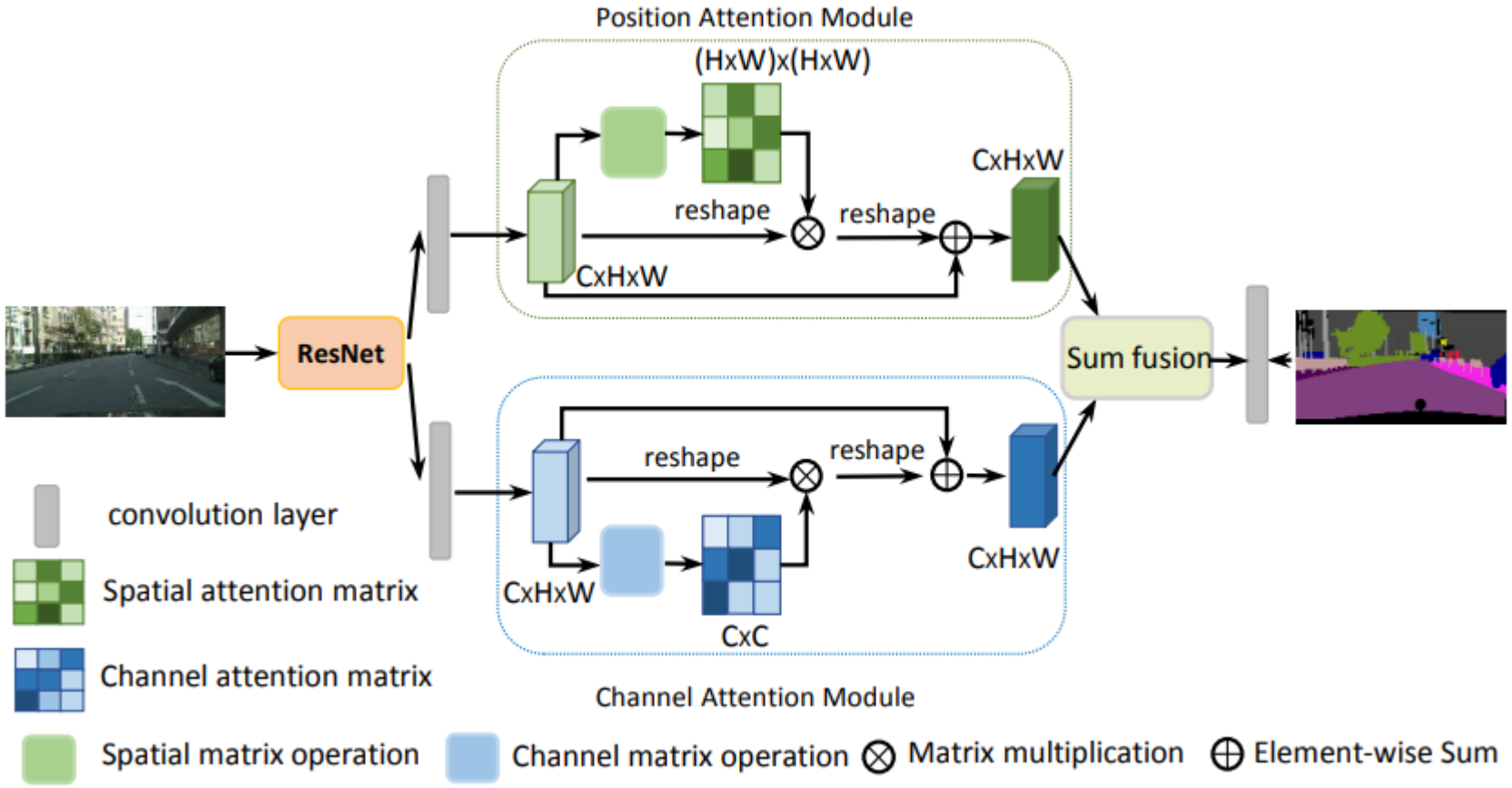
(b) DISTRIBUTE



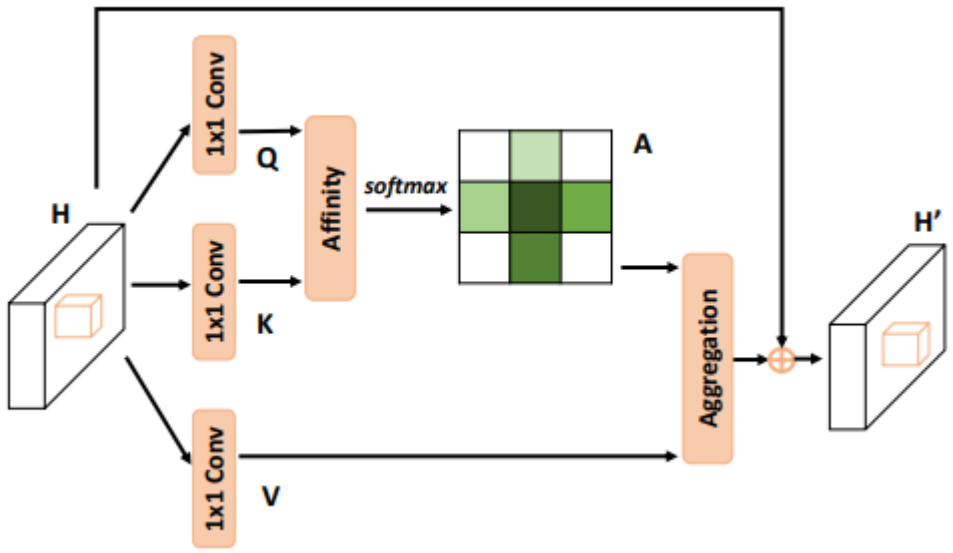
(d) ASP-OC



Dual Attention Network (CVPR19)



Criss-Cross Non-local Attention Networks (2019)



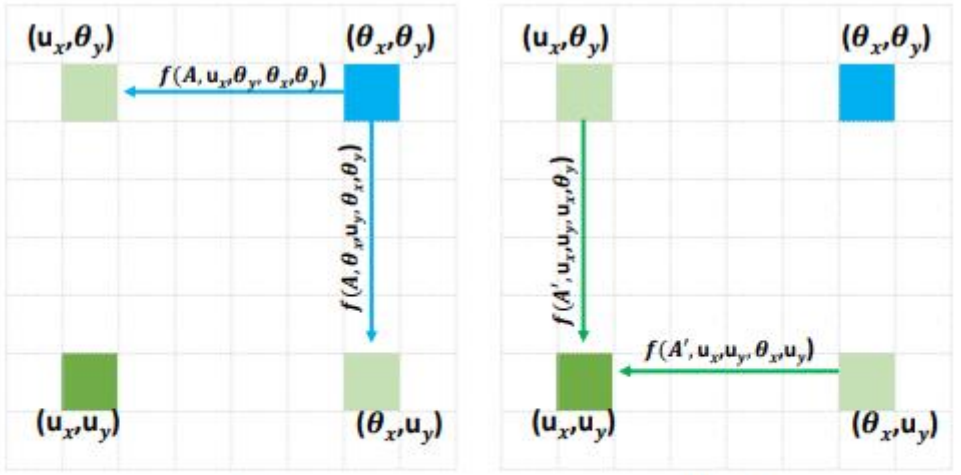


Figure 4. An example of information propagation when the loop number is 2.

Semantic Segmentation

Network	Performance (Cityscape) mIoU	Structure
DenseASPP (CVPR18)	80.6	DenseNet
PSANet (ECCV18)	80.1	Spatial Attention
Context Encoding (CVPR18)	-	Channel Attention
CCNet (Arxiv19)	81.4	Fast NL-Net
DANet (CVPR19)	81.5	NL-Net (Spatial + Channel)
OCNet (Arxiv18)	81.7	NL-Net + PSP

Non-local in SISR

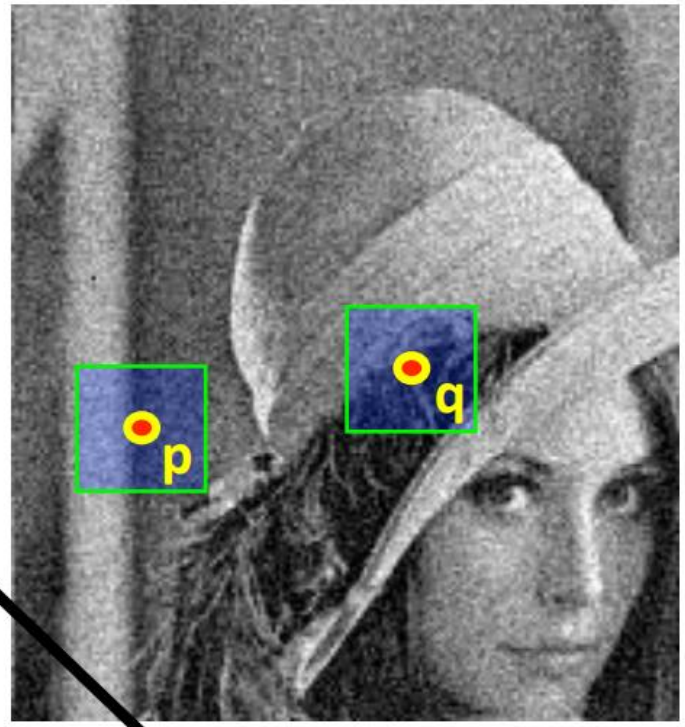
NL-Means Method:
Buades (2005)

p, q neighbors define a vector distance;

$$|| V_p - V_q ||^2$$

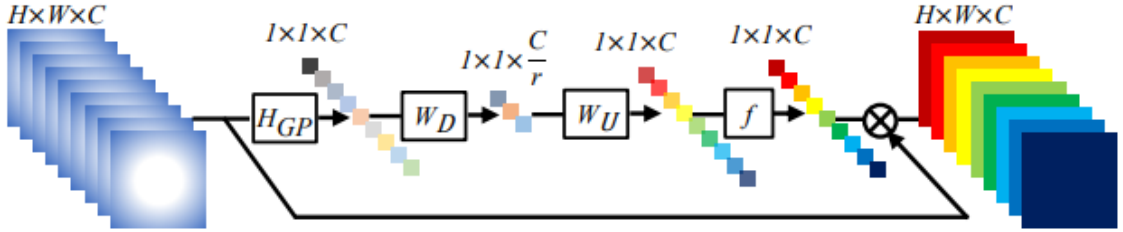
Filter with this:

No spatial term!



$$NLMF[I]_{\mathbf{p}} = \frac{1}{W_{\mathbf{p}}} \sum_{\mathbf{q} \in S} G_{\sigma_s}(\| \mathbf{p} - \mathbf{q} \|) G_{\sigma_r}\left(\| \vec{V}_{\mathbf{p}} - \vec{V}_{\mathbf{q}} \|^2\right) I_{\mathbf{q}}$$

Single Image Super-Resolution



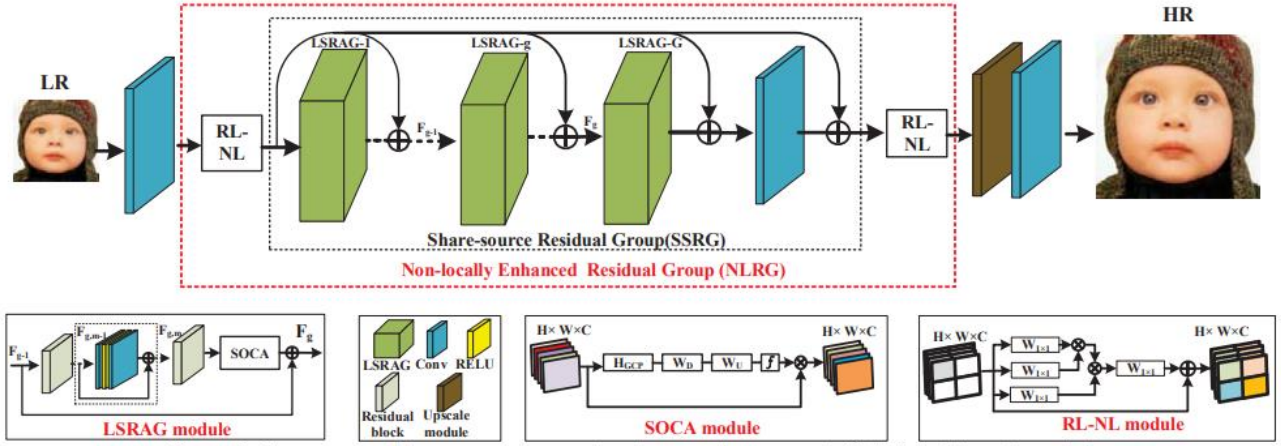
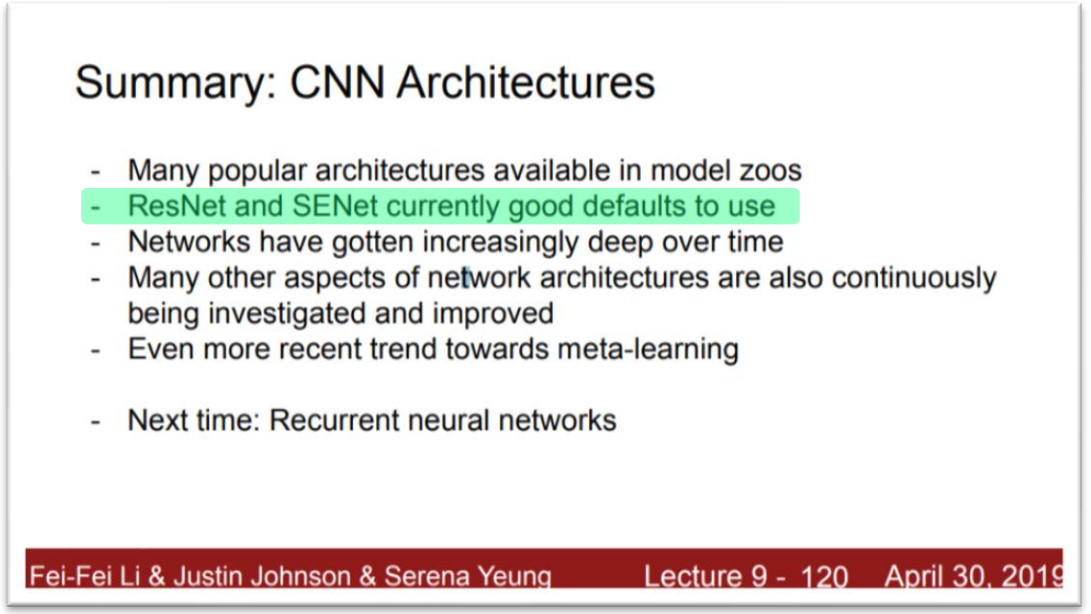


Figure 2. Framework of the proposed second-order attention network (SAN) and its sub-modules.

Network	Performance (set5, PSNR)	Structure
RDN (CVPR18)	38.24 / 32.47 (x2, x4)	DenseNet
RNRN (ICLR19)	38.17 / 32.49	NL-Net
RCAN (ECCV18)	38.27 / 32.63	Channel Attention
SAN (CVPR19)	38.31 / 32.64	Channel Attention + NL-Net

Conclusion

- *Attention (Recurrent) vs Self-Attention (Feed-Forward)*
- *Representation vs Recalibration*
- *Channel Attention: Simple*
- *Spatial Attention: Global Information*



Thank You
Q&A?