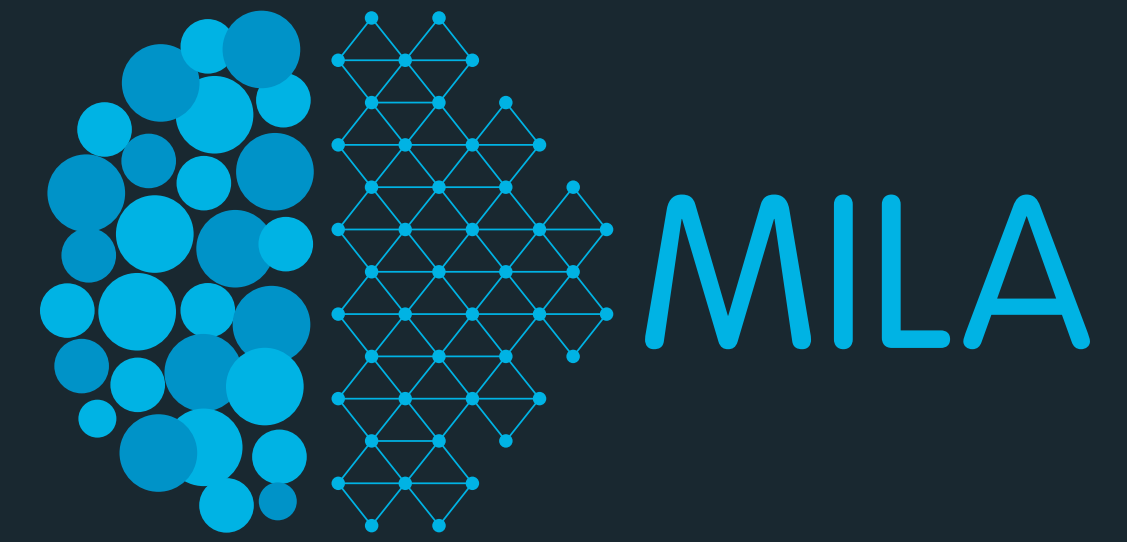


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Fully Convolutional DenseNets for Semantic Segmentation

Simon Jégou, Michal Drozdal, David Vazquez, [Adriana Romero](#), Yoshua Bengio

Outline



- Classical architectures and their extensions to FCN
- FC-DenseNets
- Results
- Wrap up

DL and Computer Vision



DL and Computer Vision



(Zhou et al., 2015)

DL and Computer Vision

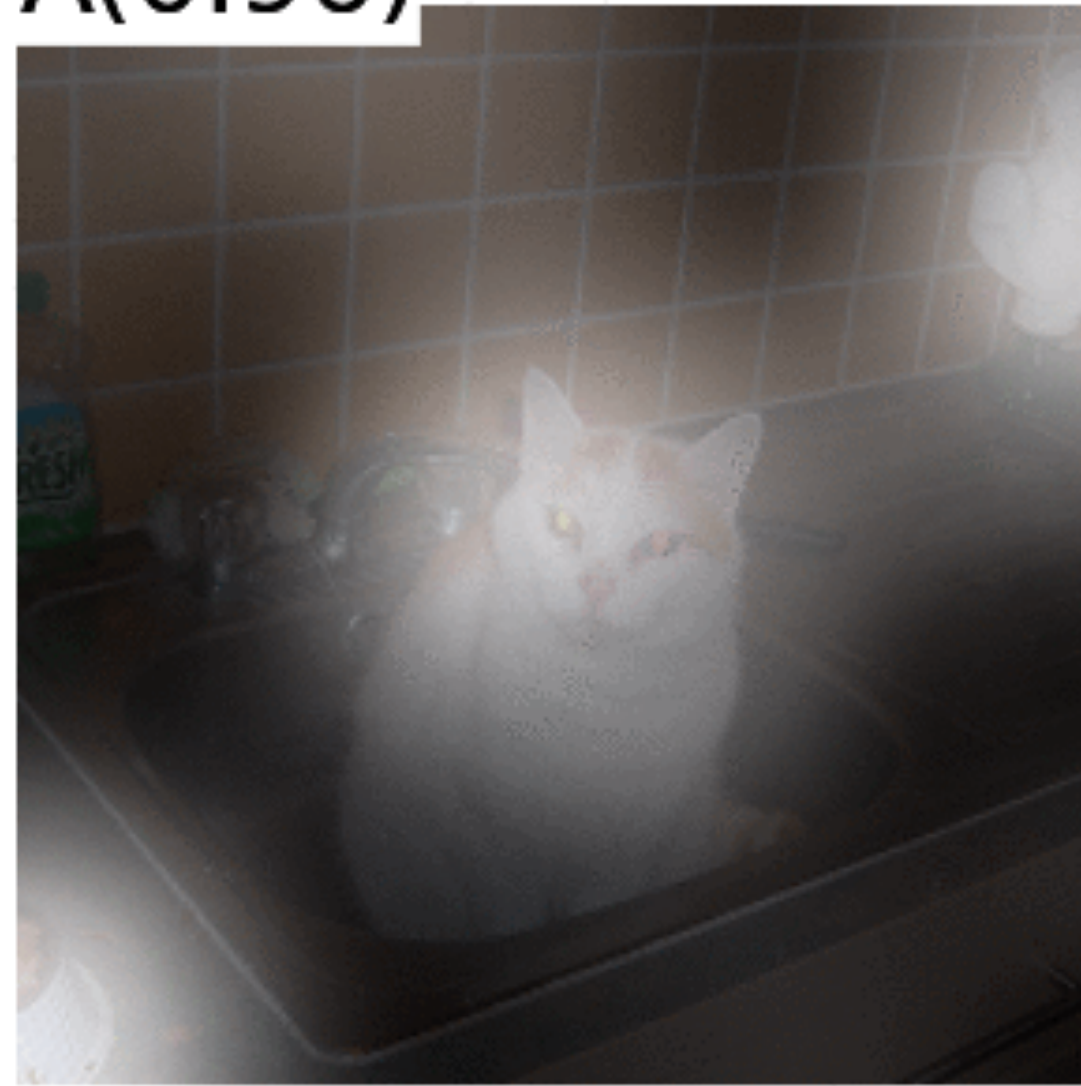


(Xu et al., 2015)

DL and Computer Vision



A(0.96)



(Xu et al., 2015)

DL and Computer Vision



A(0.96)



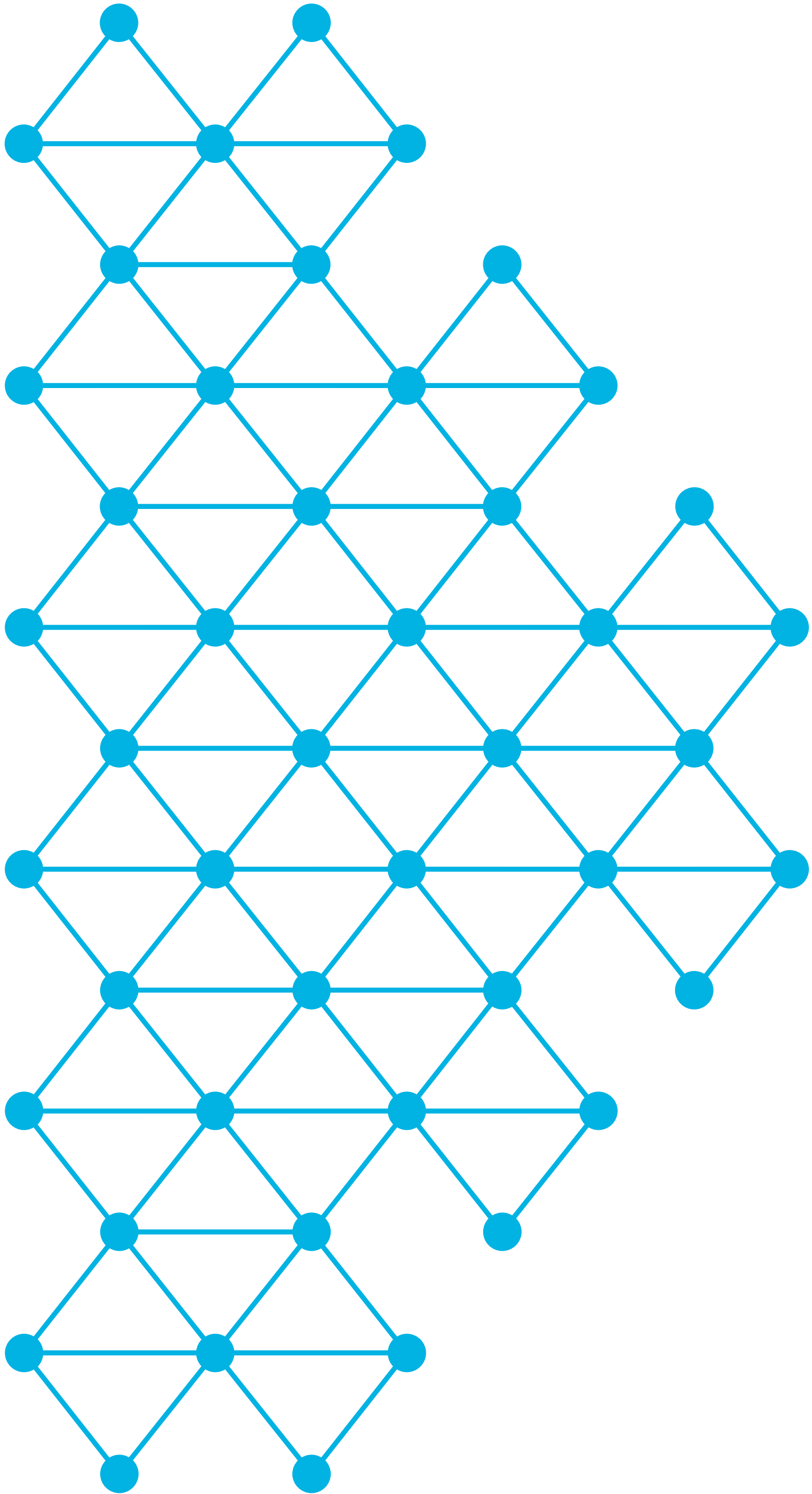
DL and Computer Vision



A(0.96)



(<https://www.youtube.com/watch?v=FroRjEejA30>, 2015)



Classical architectures and their extensions

CNN - classification

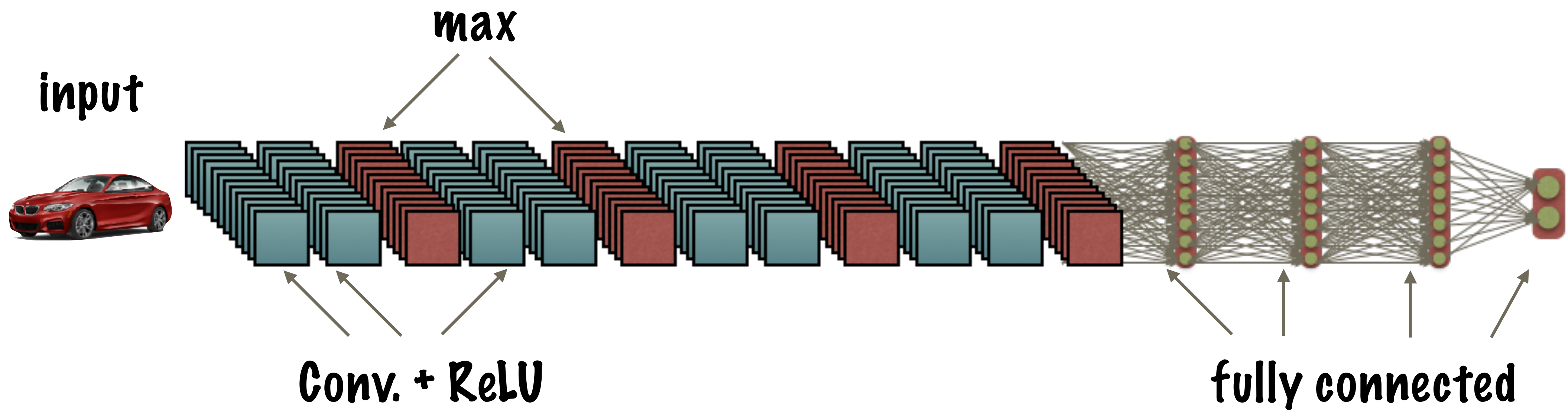
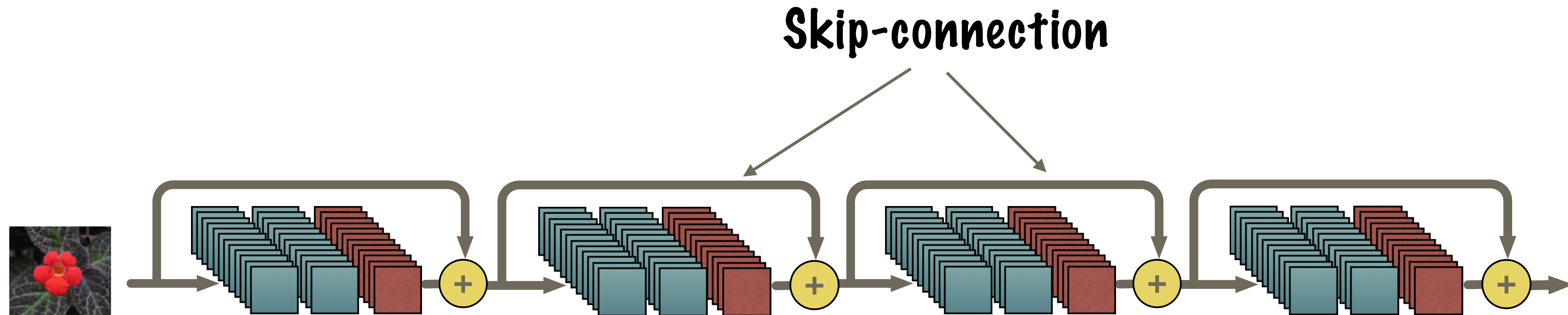


Figure courtesy of Kilian Weinberger

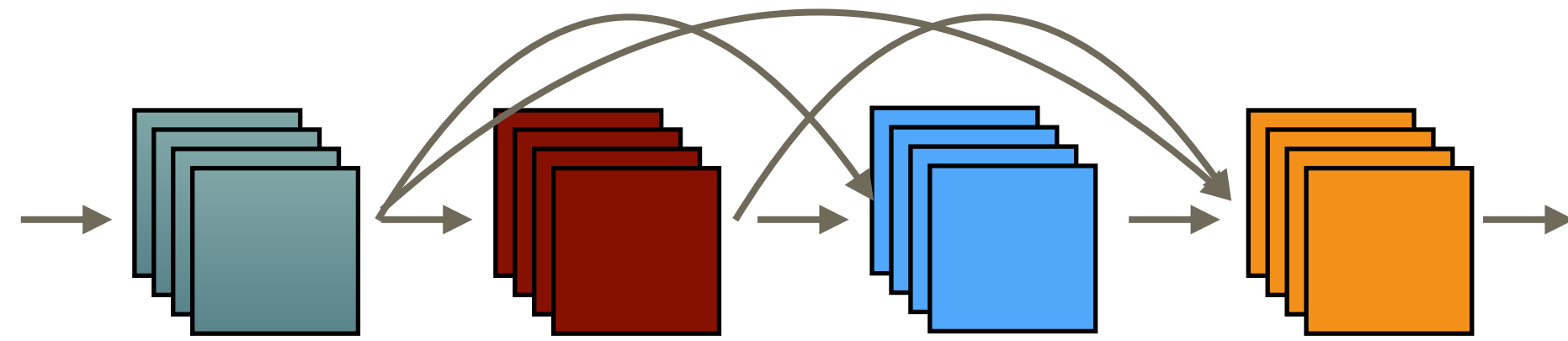
ResNet - classification



DenseNet - classification



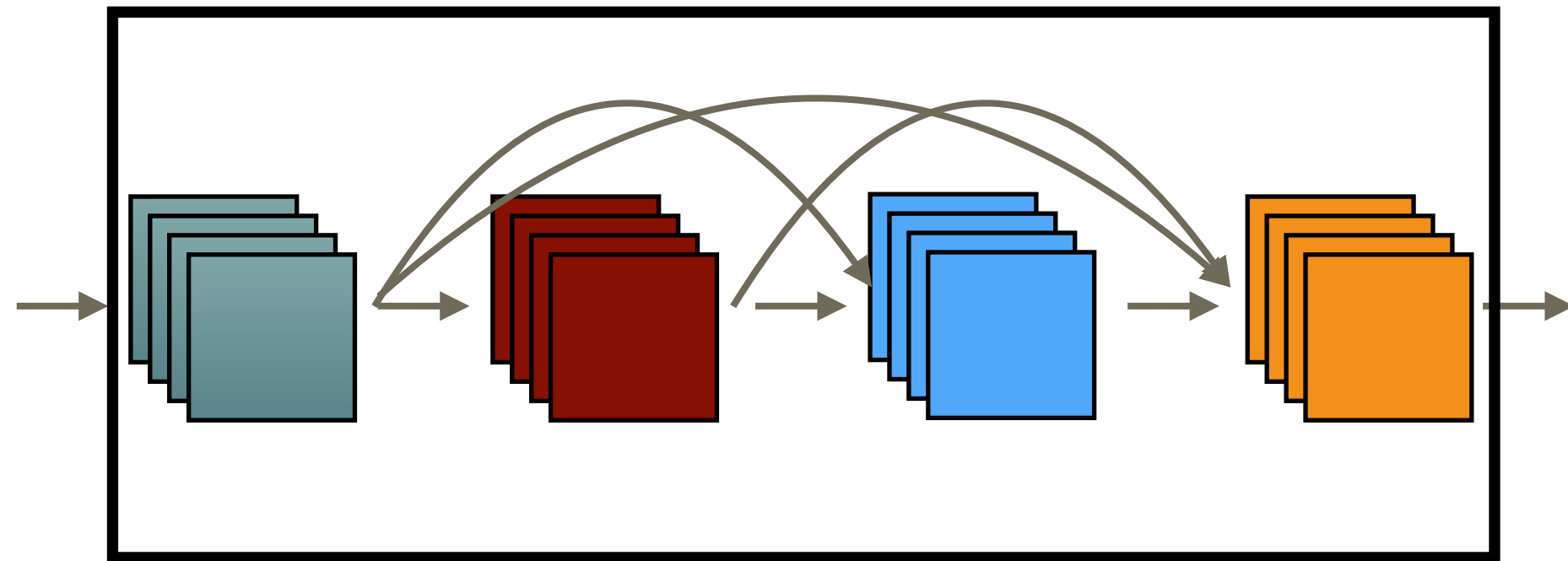
Connect every layer to every other layer of the same filter size (dense blocks).



DenseNet - classification

Connect every layer to every other layer of the same filter size (dense blocks).

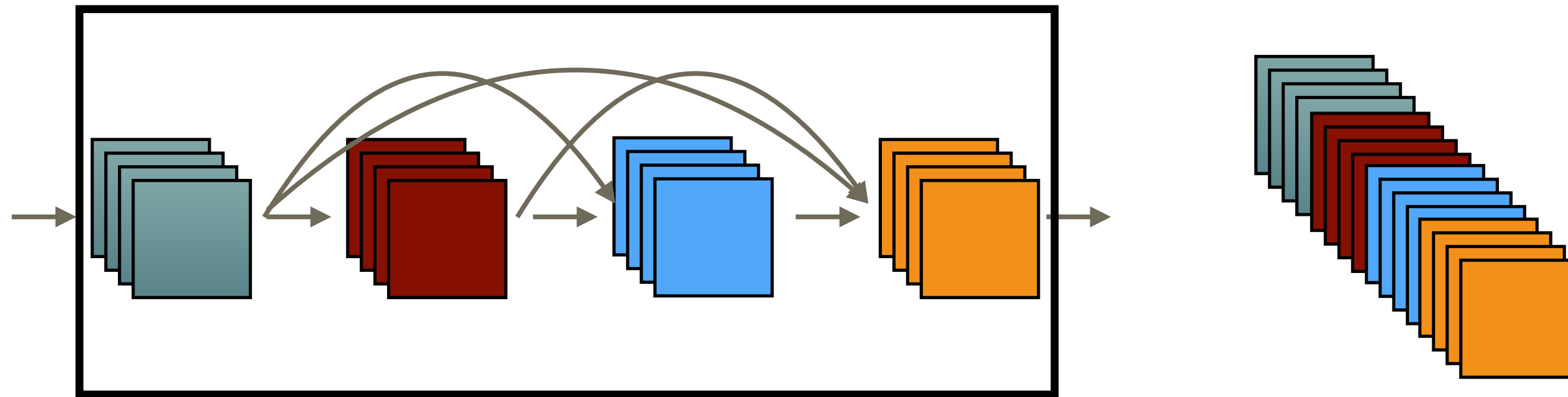
Dense Block (4 layers, growth rate 4)



DenseNet - classification

Connect every layer to every other layer of the same filter size (dense blocks).

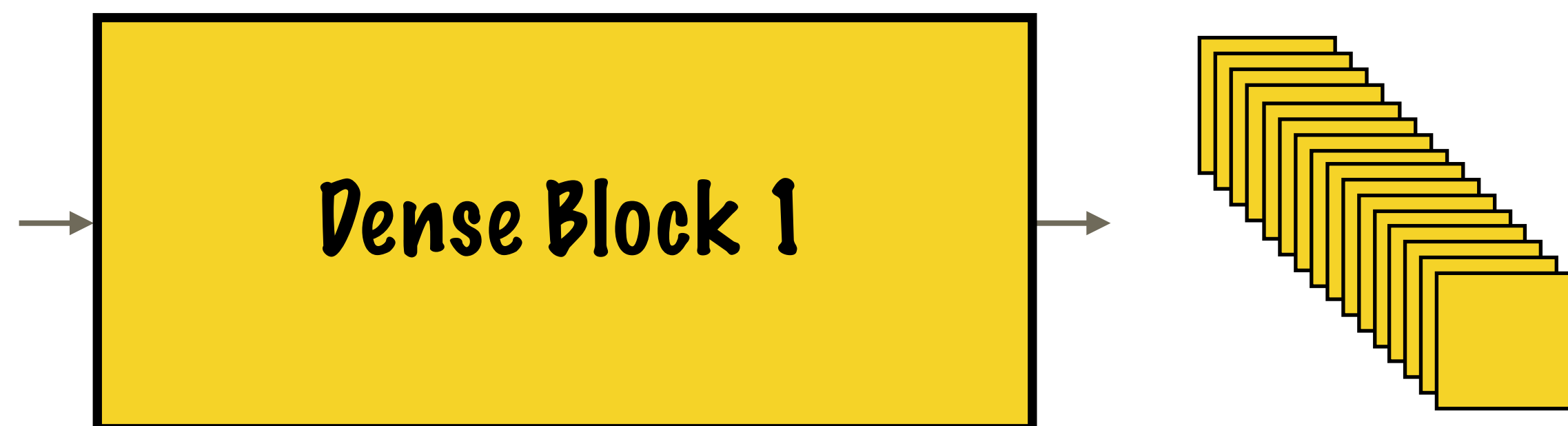
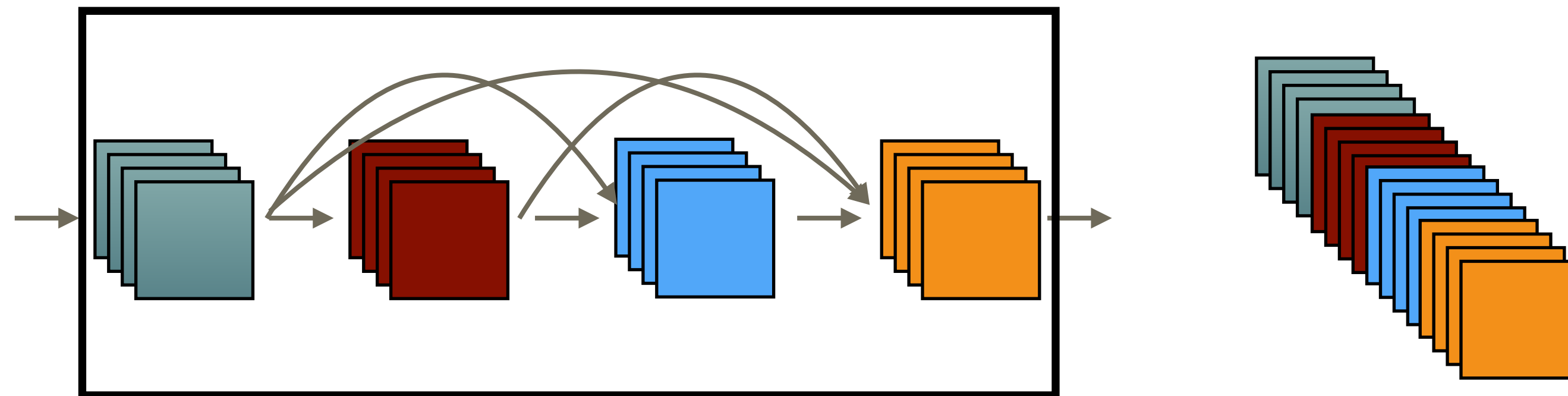
Dense Block (4 layers, growth rate 4)



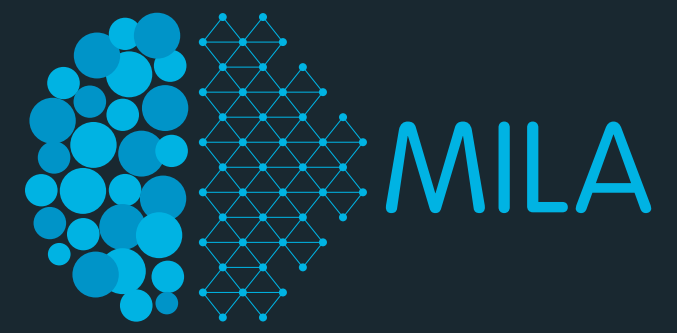
DenseNet - classification

Connect every layer to every other layer of the same filter size (dense blocks).

Dense Block (4 layers, growth rate 4)

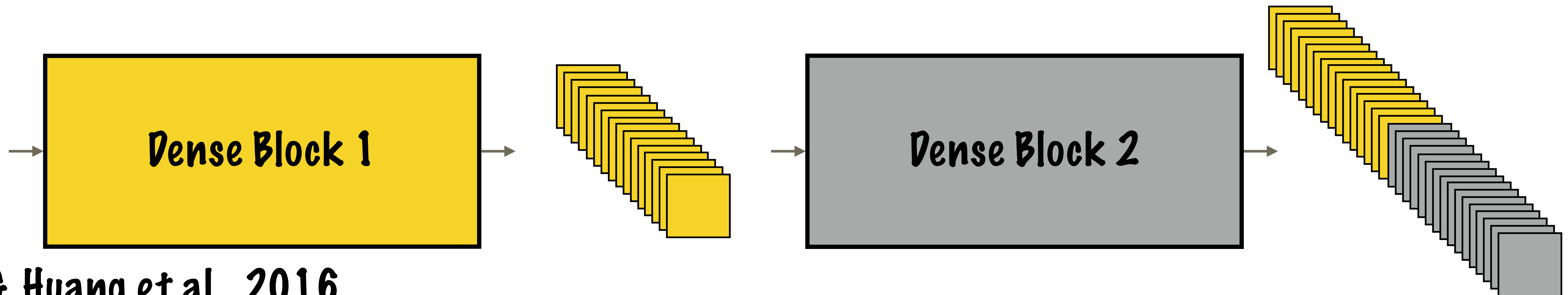
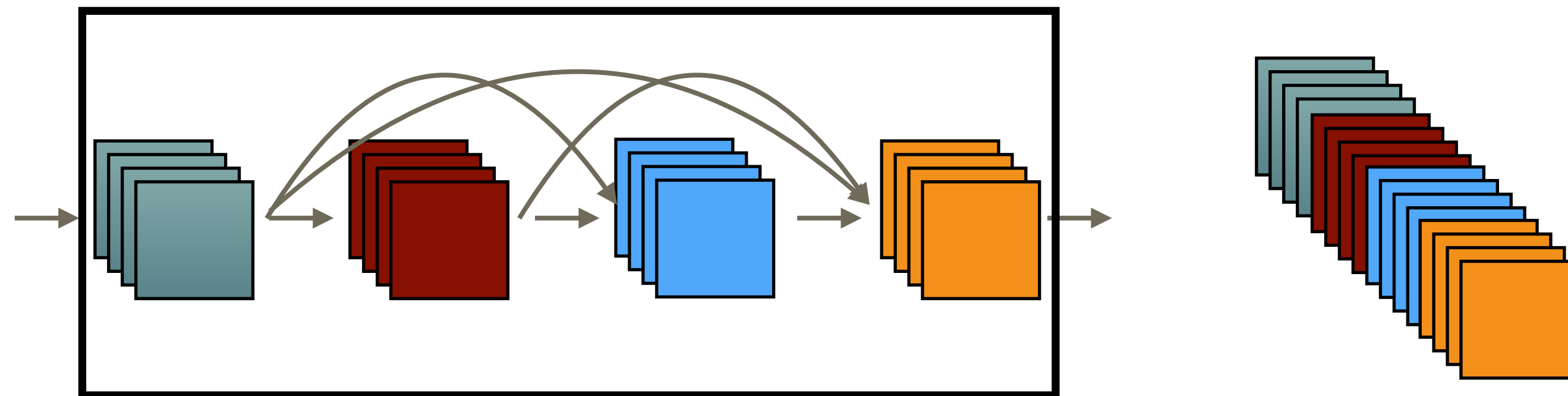


DenseNet - classification



Connect every layer to every other layer of the same filter size (dense blocks).

Dense Block (4 layers, growth rate 4)

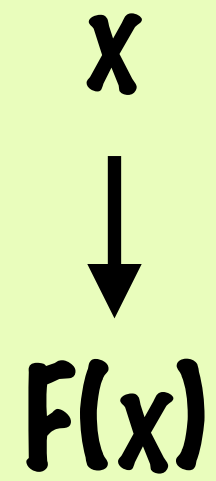


G. Huang et al., 2016

CNNs vs ResNets vs DenseNets



CNNs



CNNs vs ResNets vs DenseNets

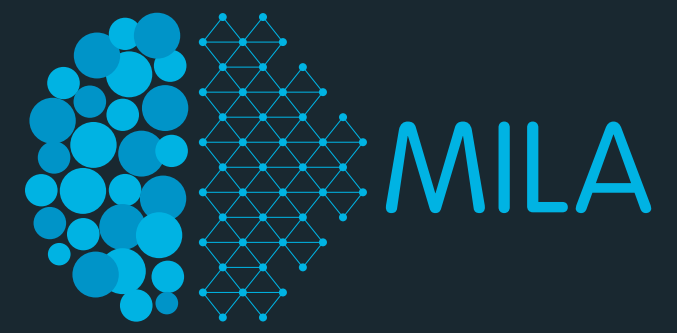


CNNs

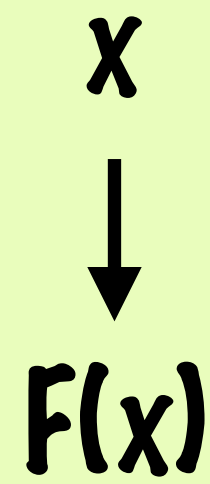
x
↓
 $F(x)$

$$F(x) = \left(\begin{array}{c} \text{Conv.} \\ + \\ \text{ReLU} \end{array} \right) \times n$$

CNNs vs ResNets vs DenseNets

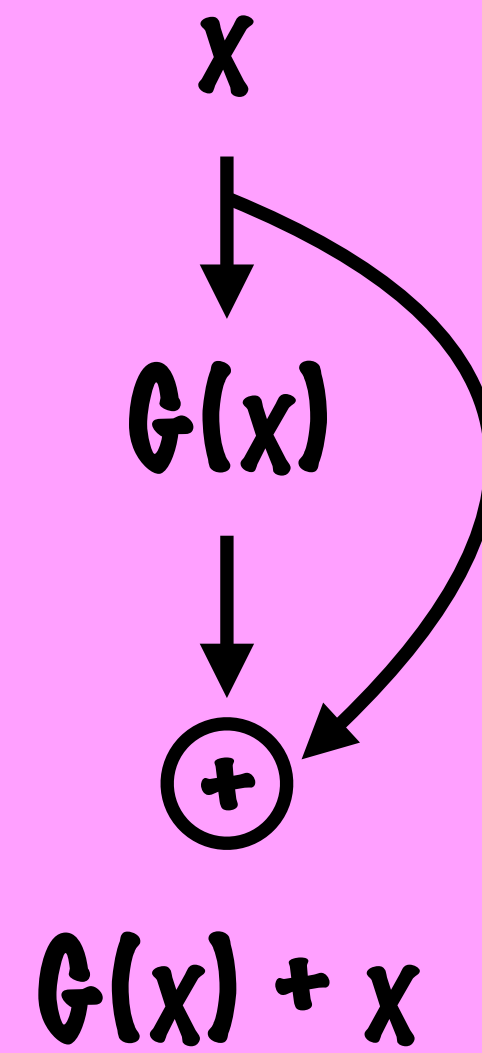


CNNs



$$F(x) = \left(\begin{array}{c} \text{Conv.} \\ + \\ \text{ReLU} \end{array} \right) \times n$$

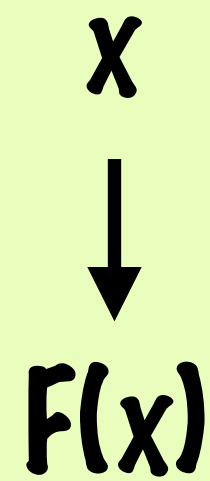
ResNets



CNNs vs ResNets vs DenseNets

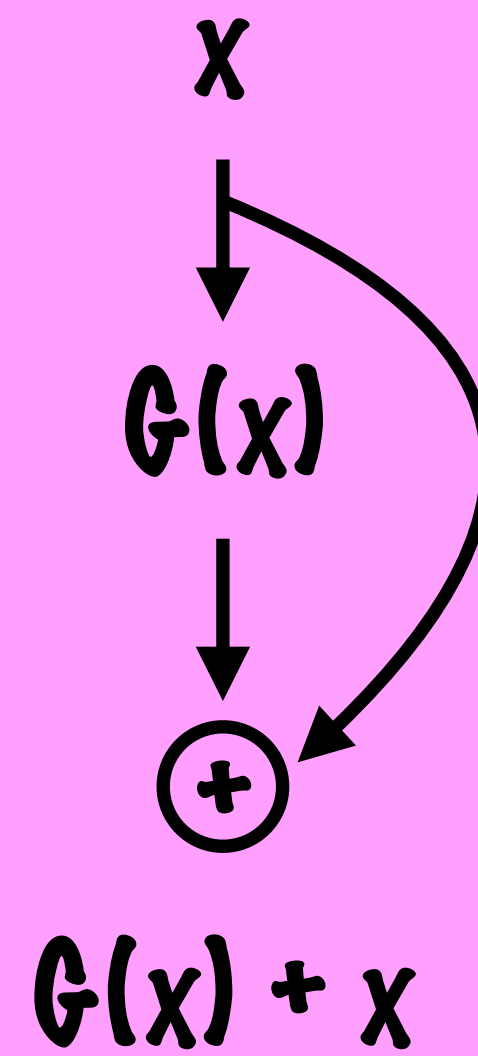


CNNs



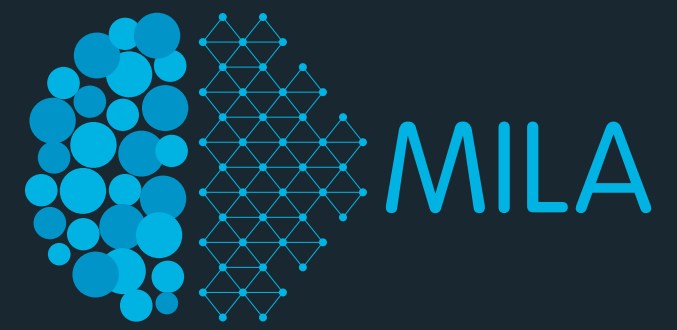
$$F(x) = \left(\begin{array}{c} \text{Conv.} \\ + \\ \text{ReLU} \end{array} \right) \times n$$

ResNets

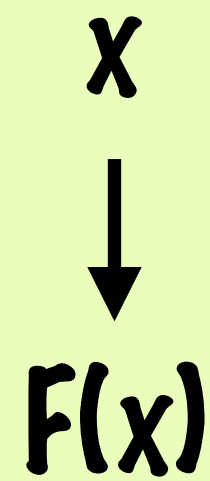


$$G(x) = \left(\begin{array}{c} \text{BN} \\ + \\ \text{ReLU} \\ + \\ \text{Conv.} \end{array} \right) \times n$$

CNNs vs ResNets vs DenseNets

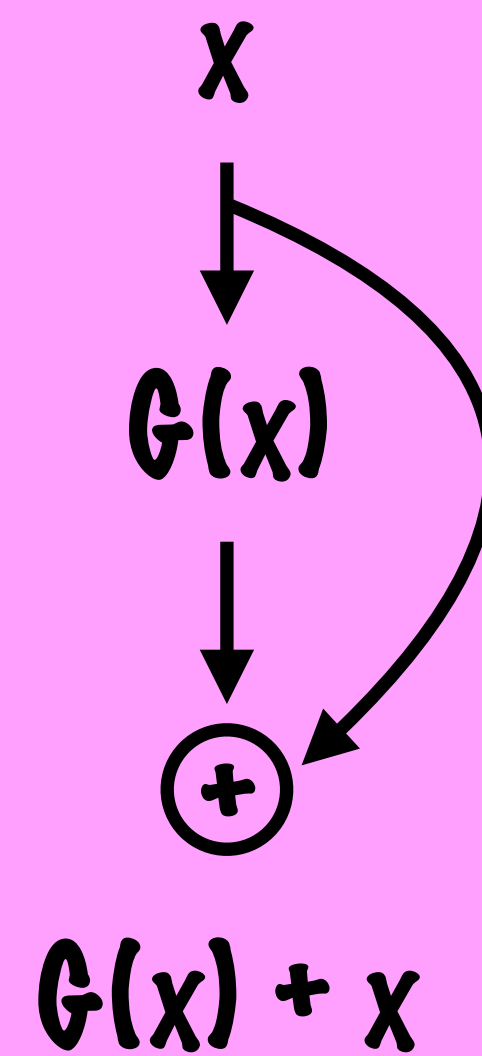


CNNs



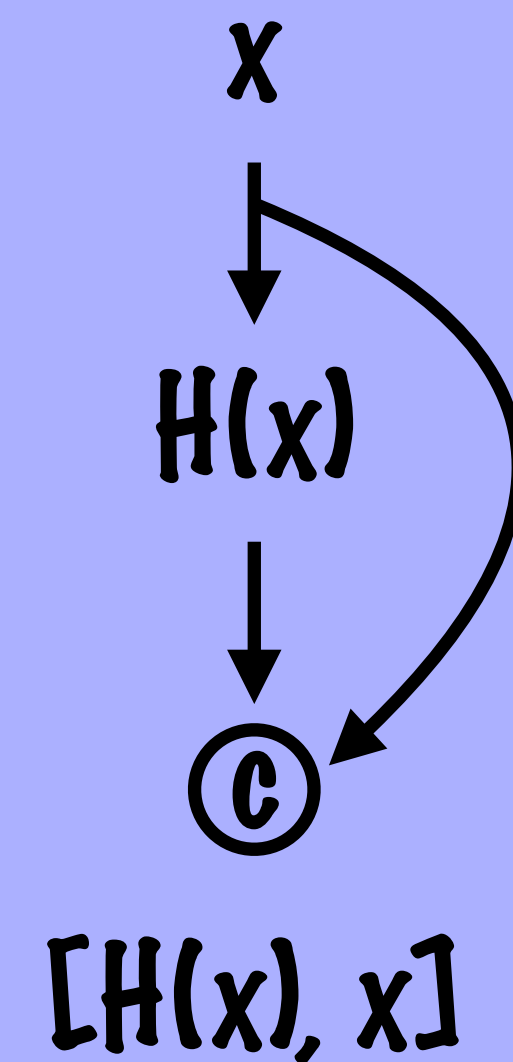
$$F(x) = \left(\begin{array}{c} \text{Conv.} \\ + \\ \text{ReLU} \end{array} \right) \times n$$

ResNets

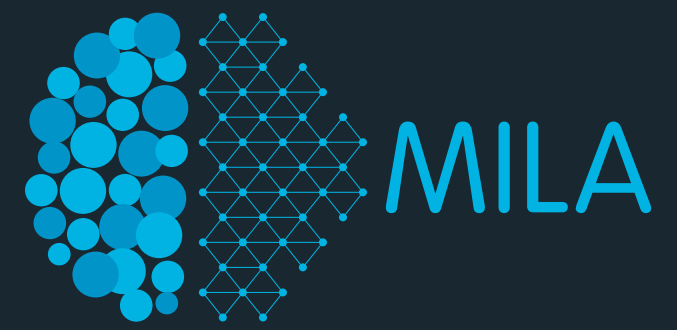


$$G(x) = \left(\begin{array}{c} \text{BN} \\ + \\ \text{ReLU} \\ + \\ \text{Conv.} \end{array} \right) \times n$$

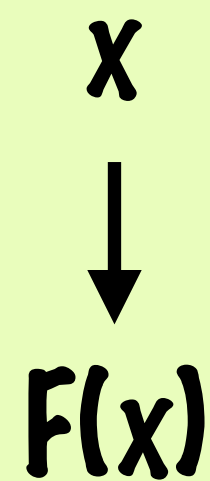
DenseNets



CNNs vs ResNets vs DenseNets

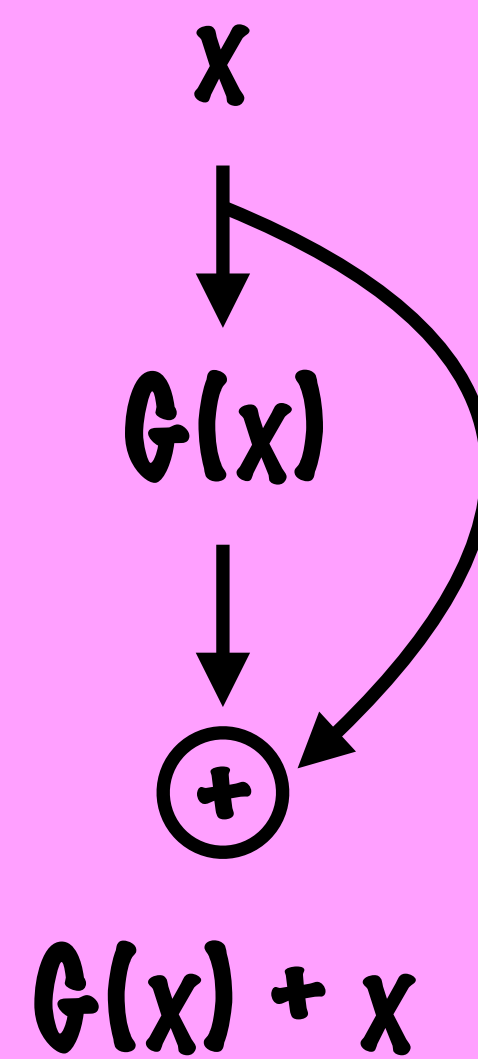


CNNs



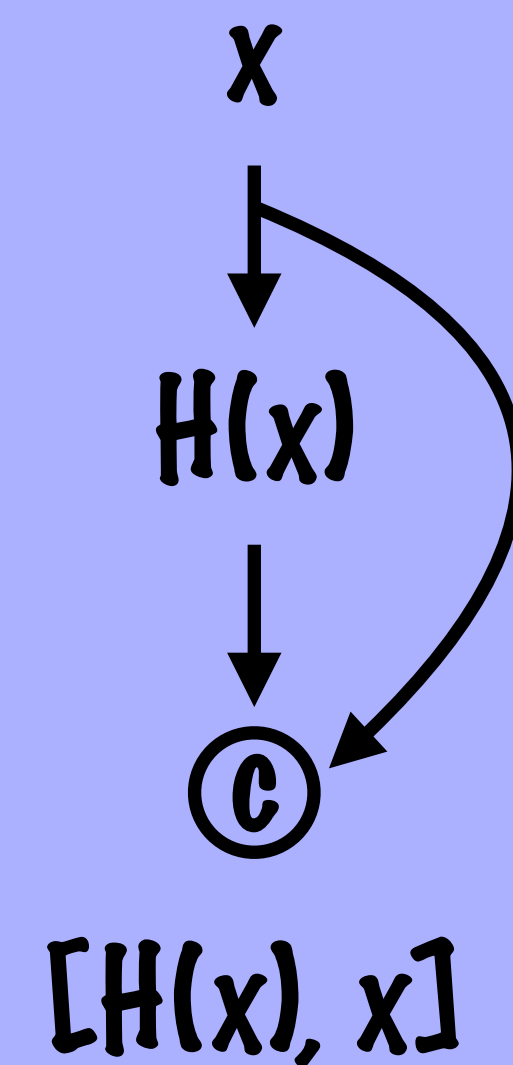
$$F(x) = \left(\begin{array}{c} \text{Conv.} \\ + \\ \text{ReLU} \end{array} \right) \times n$$

ResNets



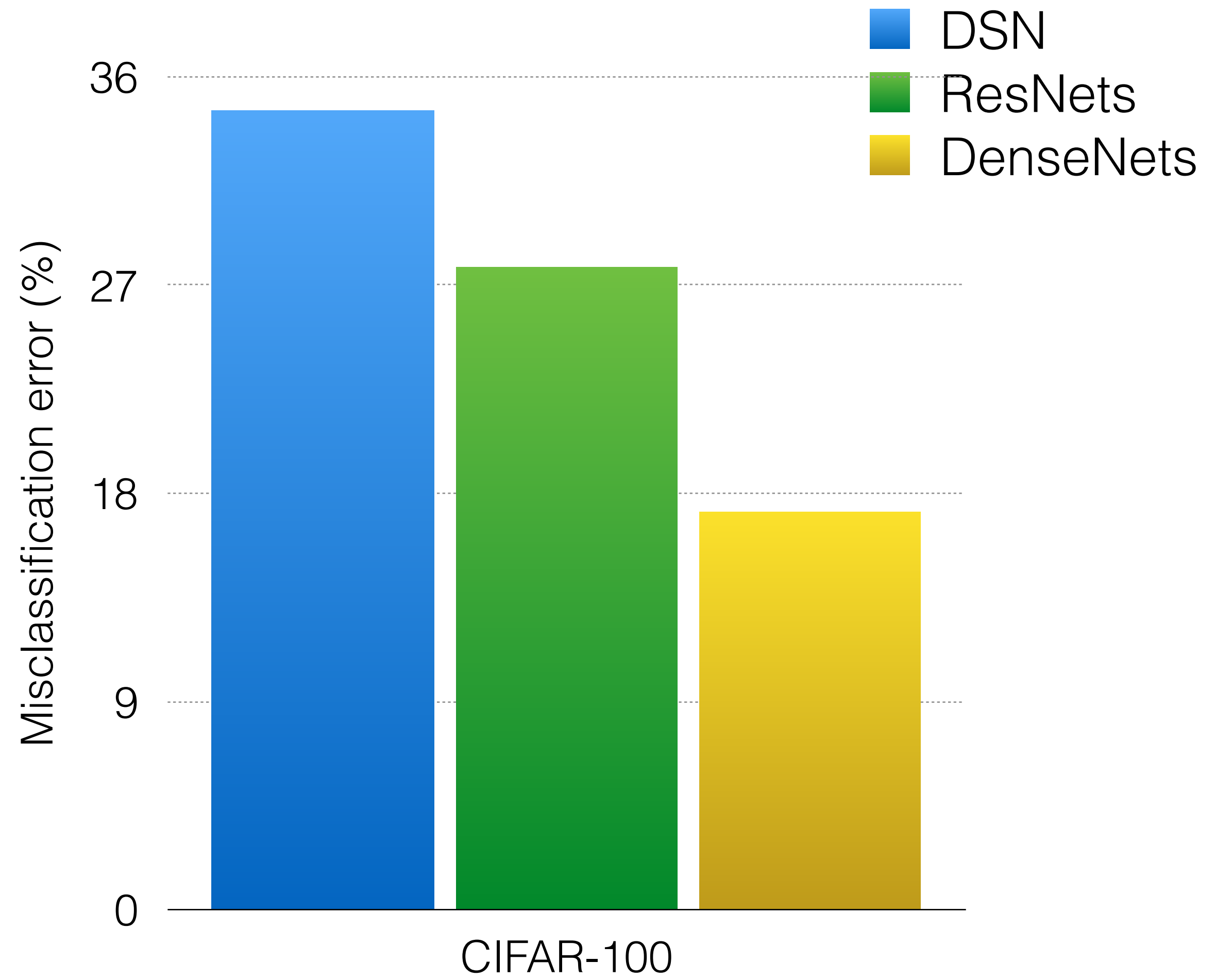
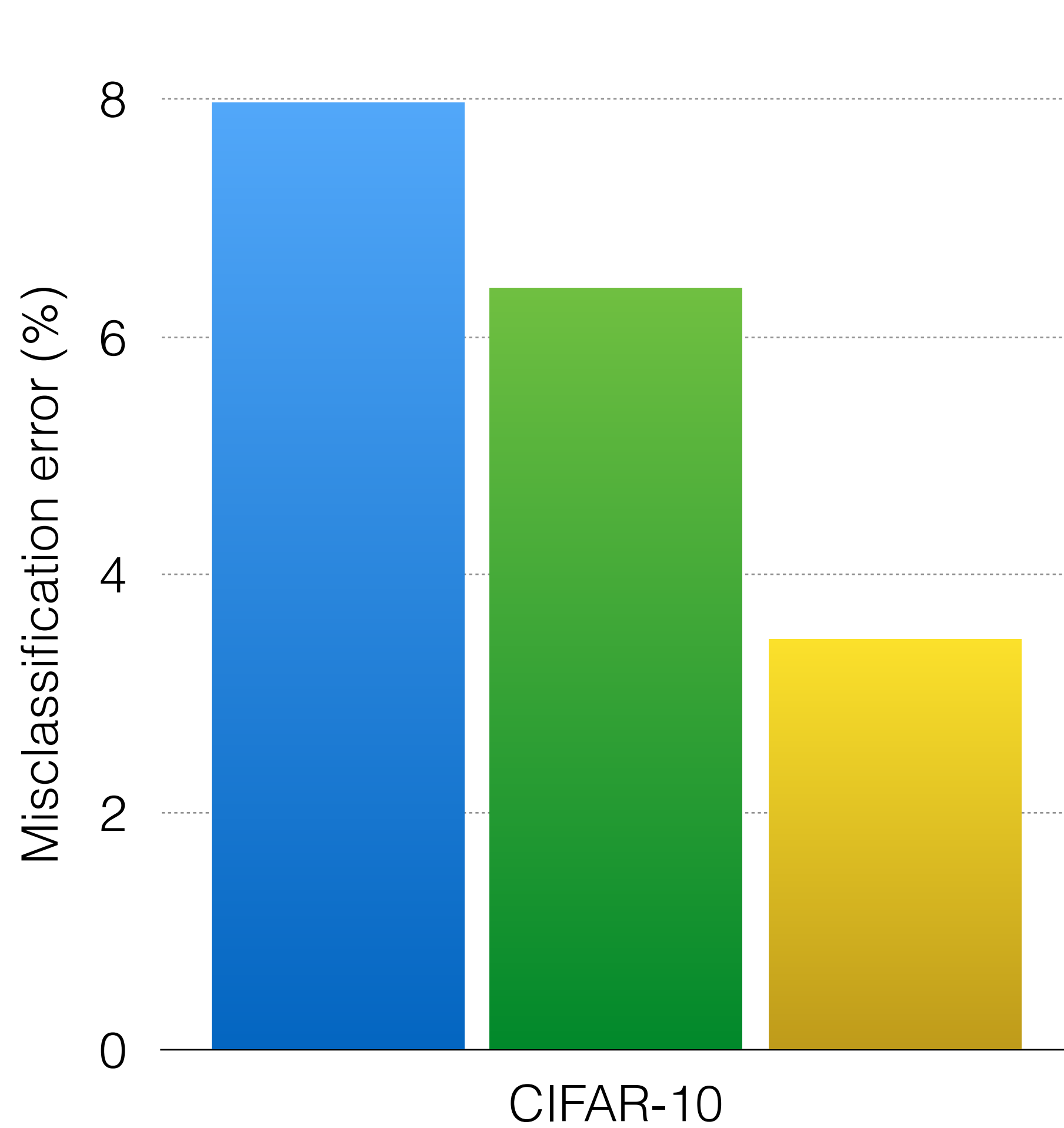
$$G(x) = \left(\begin{array}{c} \text{BN} \\ + \\ \text{ReLU} \\ + \\ \text{Conv.} \end{array} \right) \times n$$

DenseNets

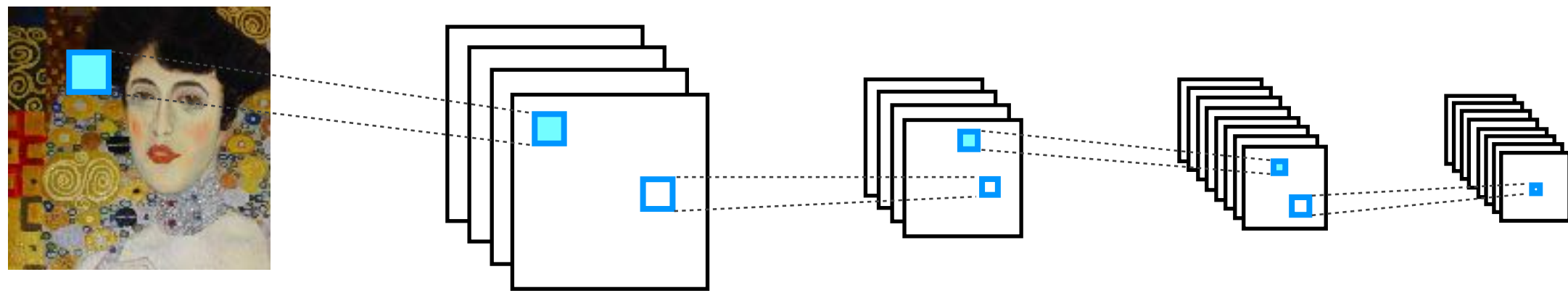


$$H(x) = \left(\begin{array}{c} \text{BN} \\ + \\ \text{ReLU} \\ + \\ \text{Conv.} \\ + \\ \text{Dropout} \end{array} \right)$$

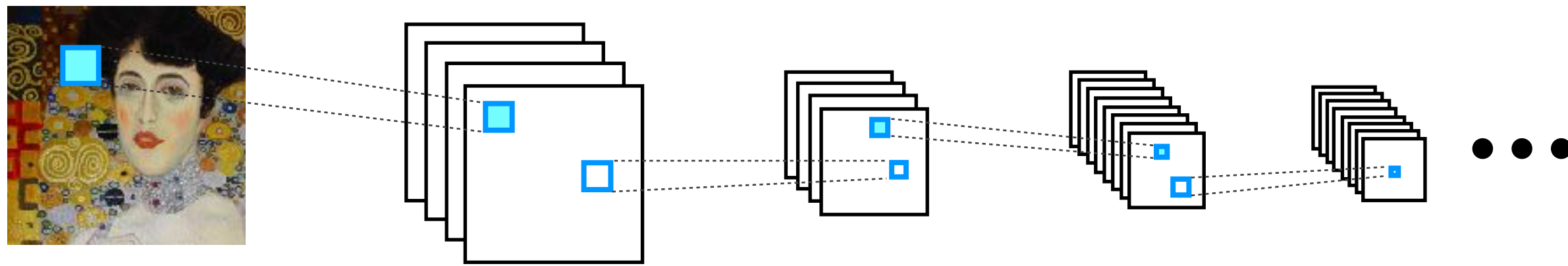
Classification results



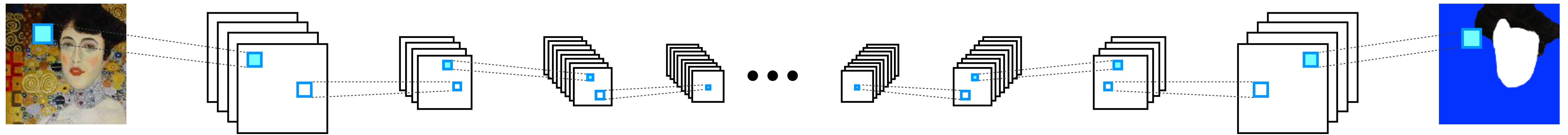
FCN - semantic segmentation



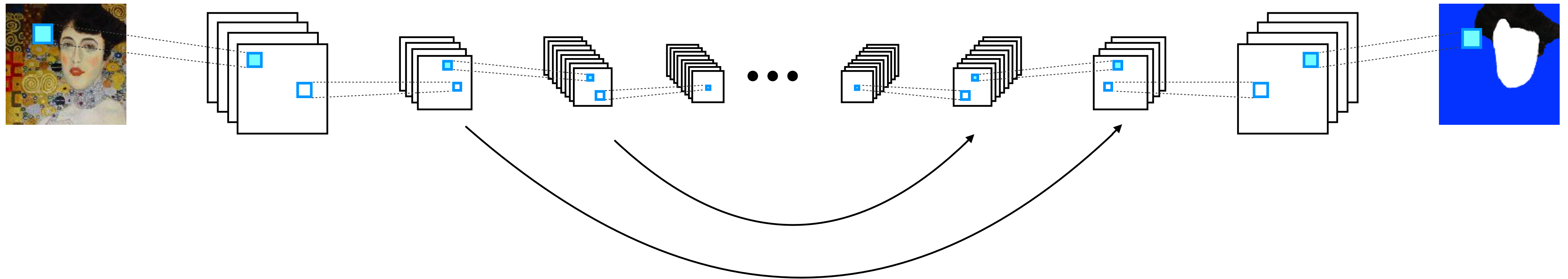
FCN - semantic segmentation



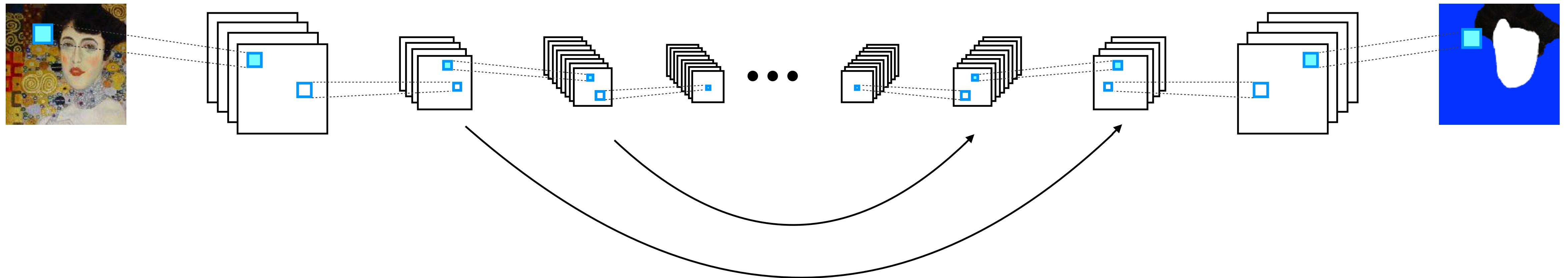
FCN - semantic segmentation



FCN - semantic segmentation



FCN - semantic segmentation

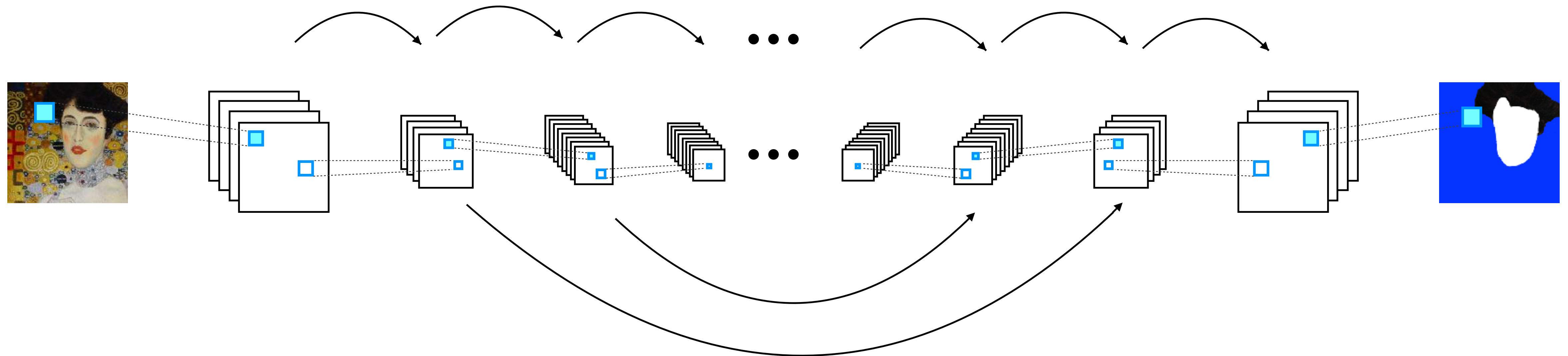


- * **Sum** (J. Long et al., 2015)
- * **Concat** (O. Ronneberger et al., 2015)
- * **Index tracking** (V. Badrinarayanan et al., 2015)

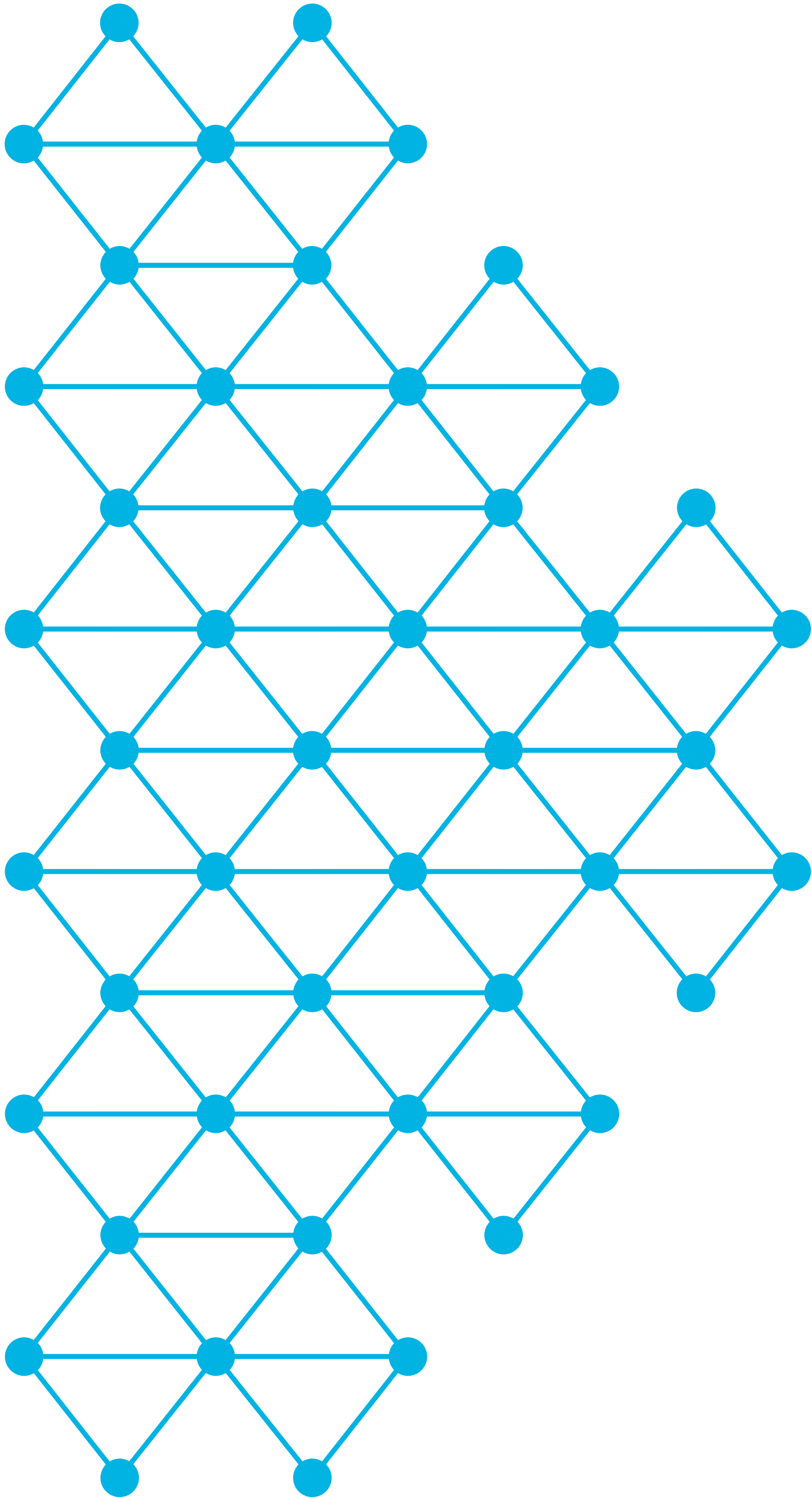
FCN - semantic segmentation



* **ResUnet (M. Drozdal et al., 2016)**

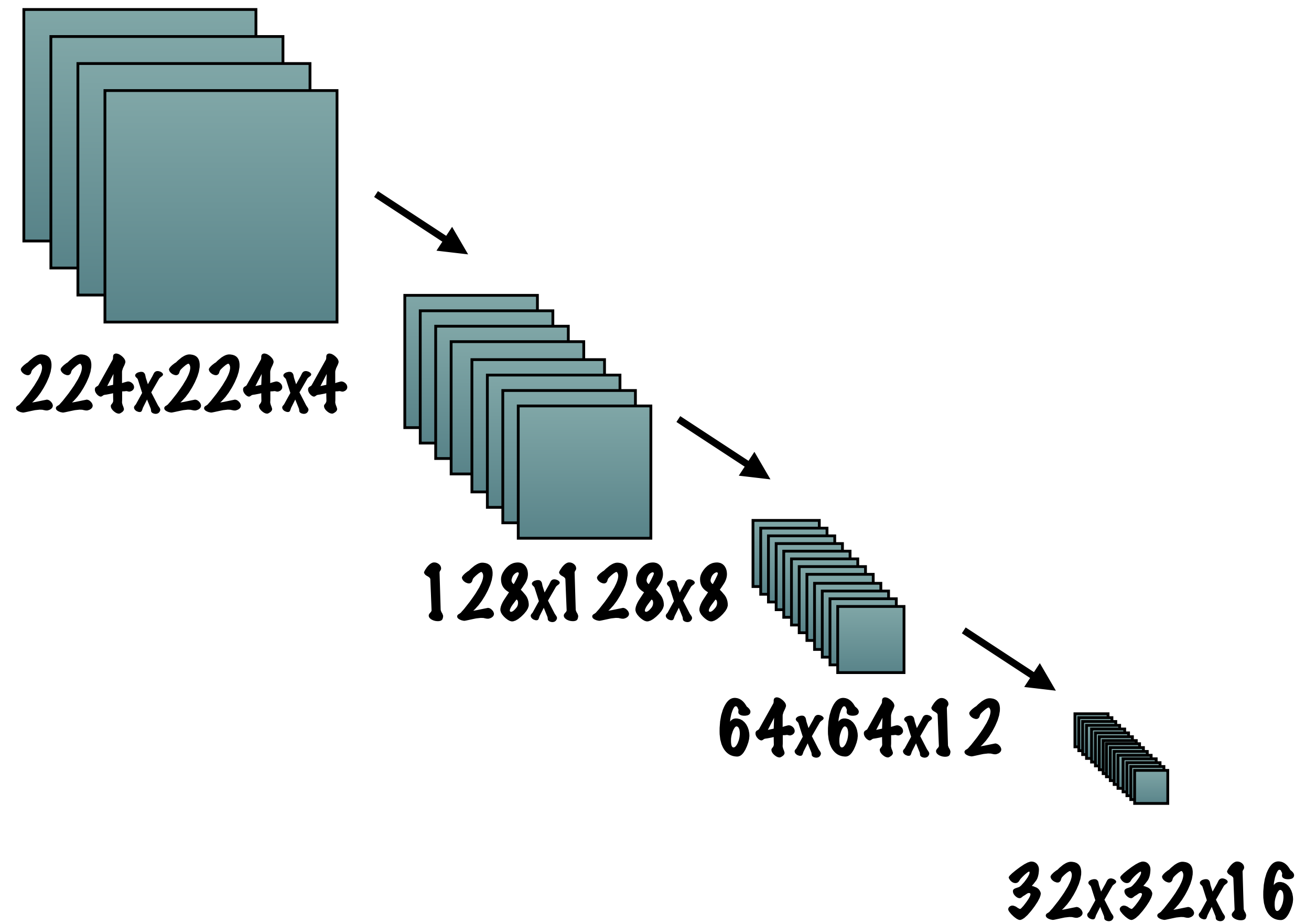


- * **Sum (J. Long et al., 2015)**
- * **Concat (O. Ronneberger et al., 2015)**
- * **Index tracking (V. Badrinarayanan et al., 2015)**

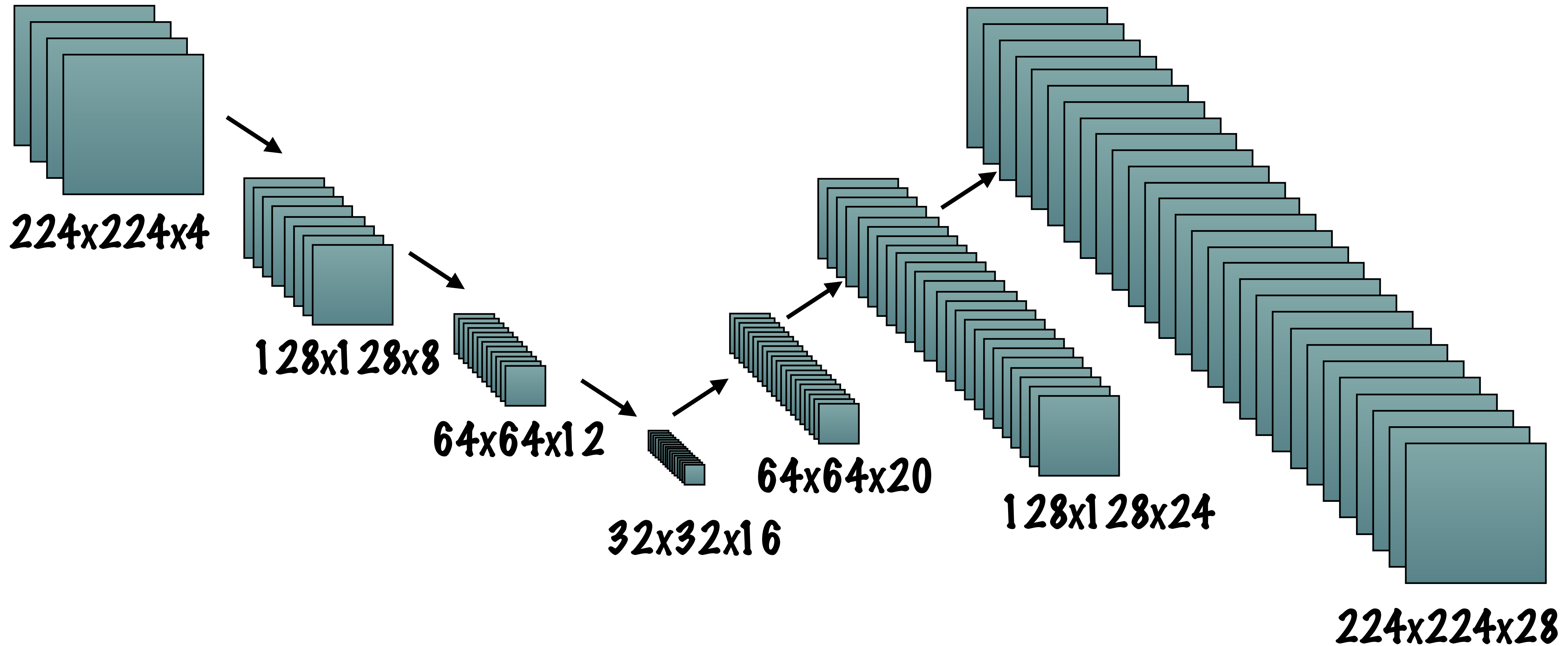


FC-DenseNets

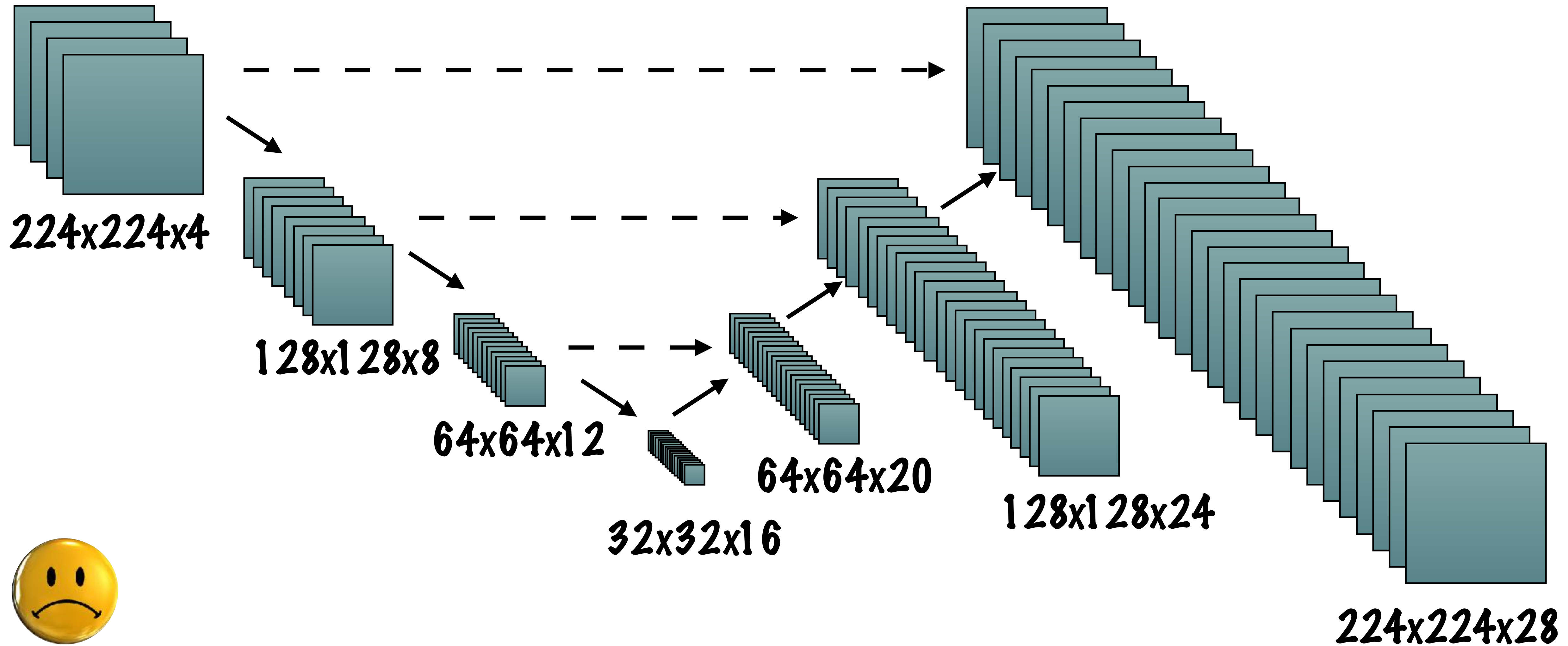
Naive extension of DenseNets



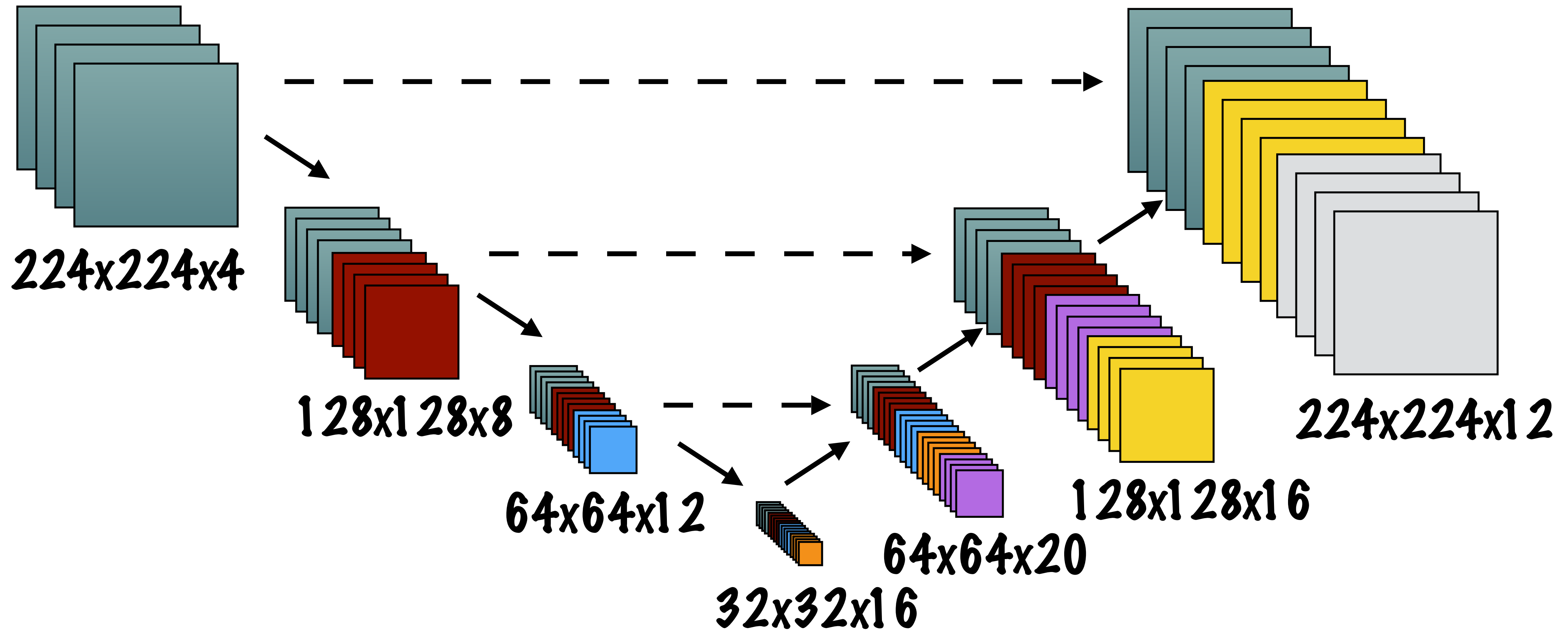
Naive extension of DenseNets



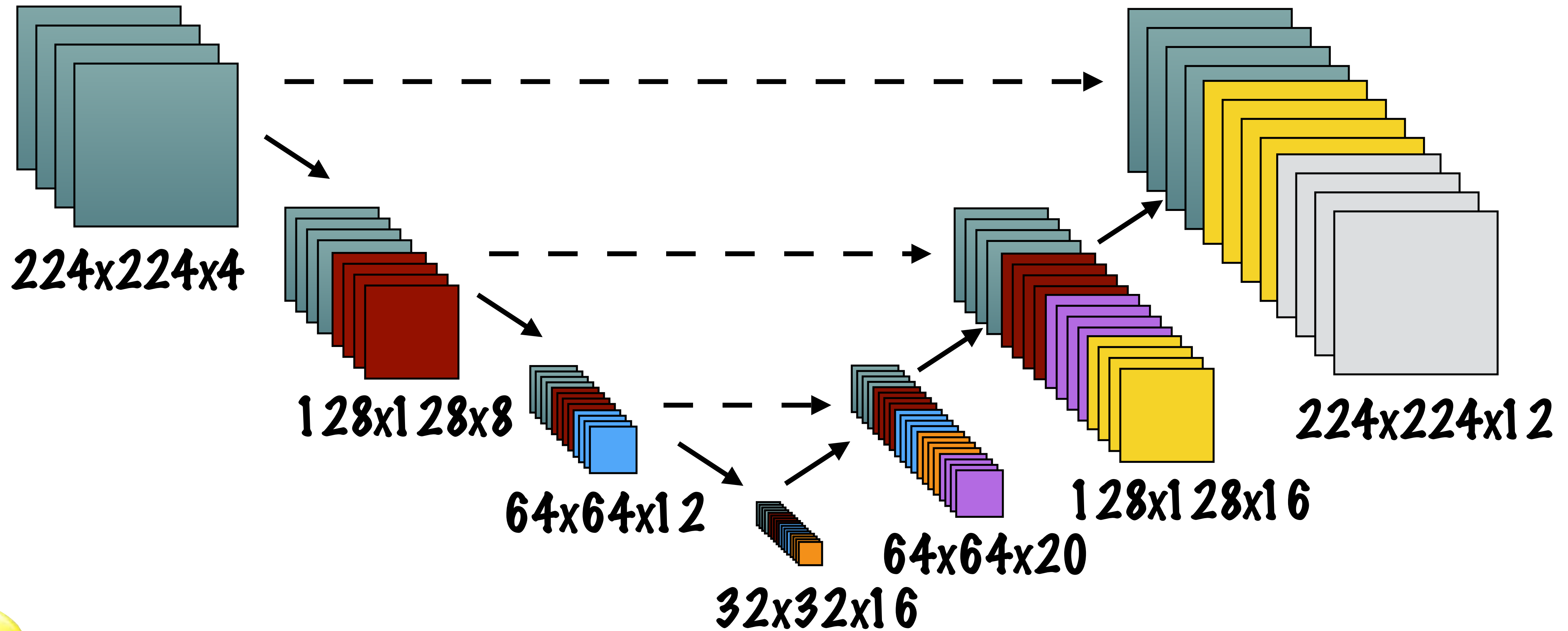
Naive extension of DenseNets

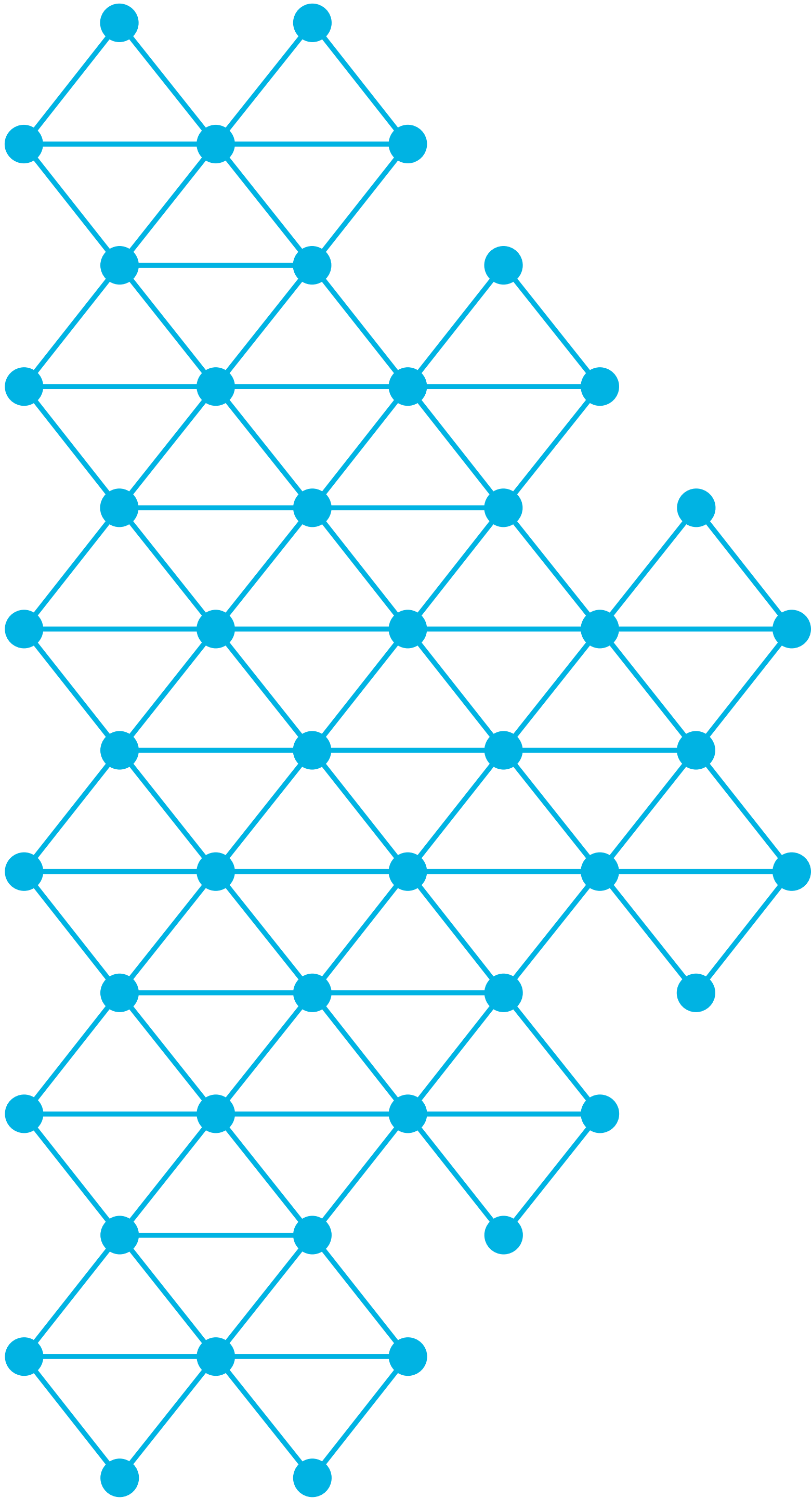


Fully Convolutional DenseNets



Fully Convolutional DenseNets





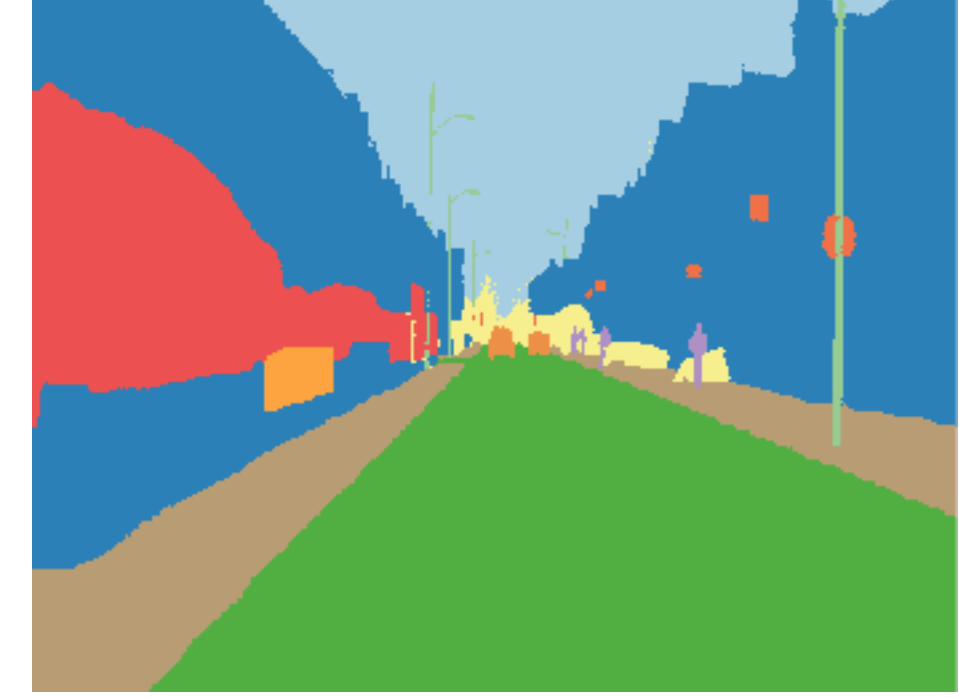
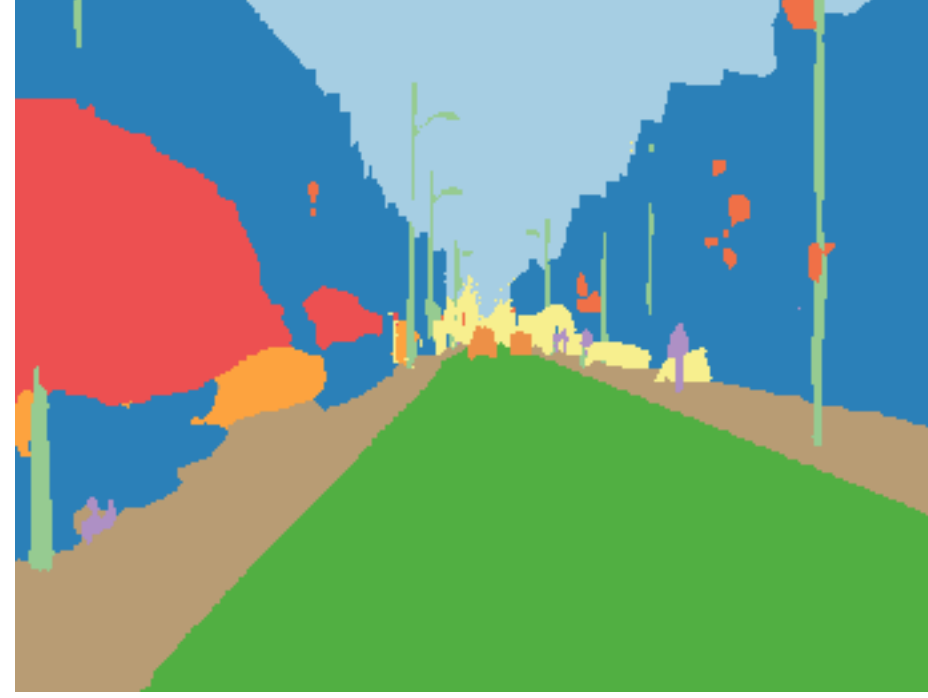
Results

Quantitative results - CamVid

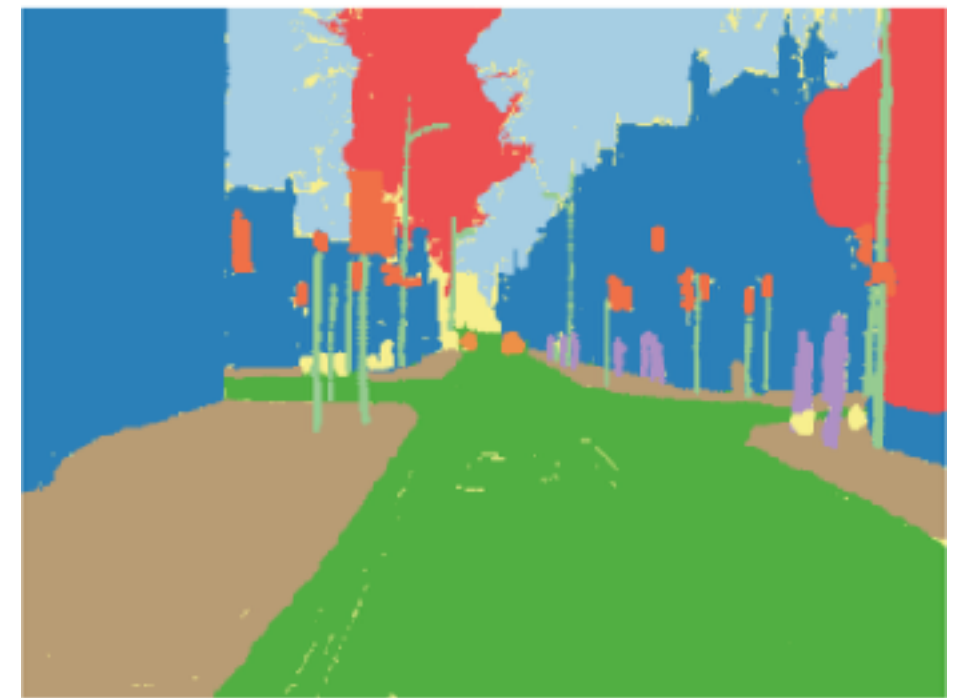
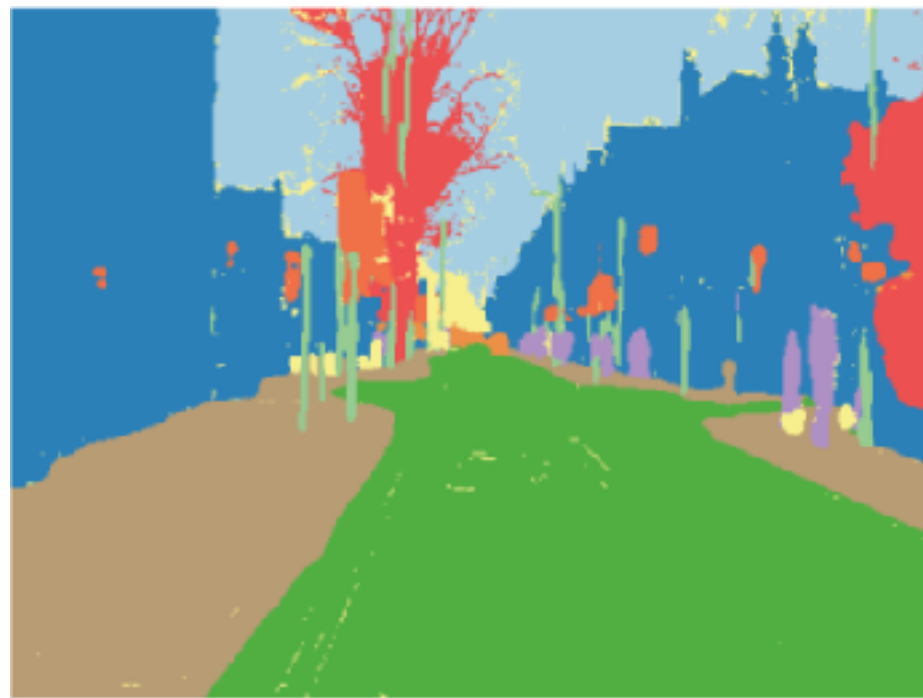


Model	Pretrained	# parameters (M)	Building	Tree	Sky	Car	Sign	Road	Pedestrian	Fence	Pole	Sidewalk	Cyclist	Mean IoU	Global accuracy
SegNet [1]	✓	29.5	68.7	52.0	87.0	58.5	13.4	86.2	25.3	17.9	16.0	60.5	24.8	46.4	62.5
Bayesian SegNet [14]	✓	29.5	n/a											63.1	86.9
DeconvNet [20]	✓	252	n/a											48.9	85.9
Visin et al. [35]	✓	32.3	n/a											58.8	88.7
FCN8 [19]	✗	134.5	77.8	71.0	88.7	76.1	32.7	91.2	41.7	24.4	19.9	72.7	31.0	57.0	88.0
DeepLab-LFOV [5]	✓	37.3	81.5	74.6	89.0	82.2	42.3	92.2	48.4	27.2	14.3	75.4	50.1	61.6	—
Dilation8 [36]	✓	140.8	82.6	76.2	89.0	84.0	46.9	92.2	56.3	35.8	23.4	75.3	55.5	65.3	79.0
Dilation8 + FSO [16]	✓	140.8	84.0	77.2	91.3	85.6	49.9	92.5	59.1	37.6	16.9	76.0	57.2	66.1	88.3
Classic Upsampling	✗	20	73.5	72.2	92.4	66.2	26.9	90.0	37.7	22.7	30.8	69.6	25.1	55.2	86.8
FC-DenseNet56 (k=12)	✗	1.5	77.6	72.0	92.4	73.2	31.8	92.8	37.9	26.2	32.6	79.9	31.1	58.9	88.9
FC-DenseNet67 (k=16)	✗	3.5	80.2	75.4	93.0	78.2	40.9	94.7	58.4	30.7	38.4	81.9	52.1	65.8	90.8
FC-DenseNet103 (k=16)	✗	9.4	83.0	77.3	93.0	77.3	43.9	94.5	59.6	37.1	37.8	82.2	50.5	66.9	91.5

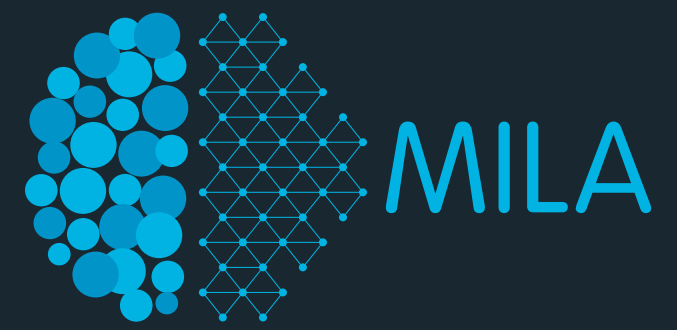
Qualitative results - good



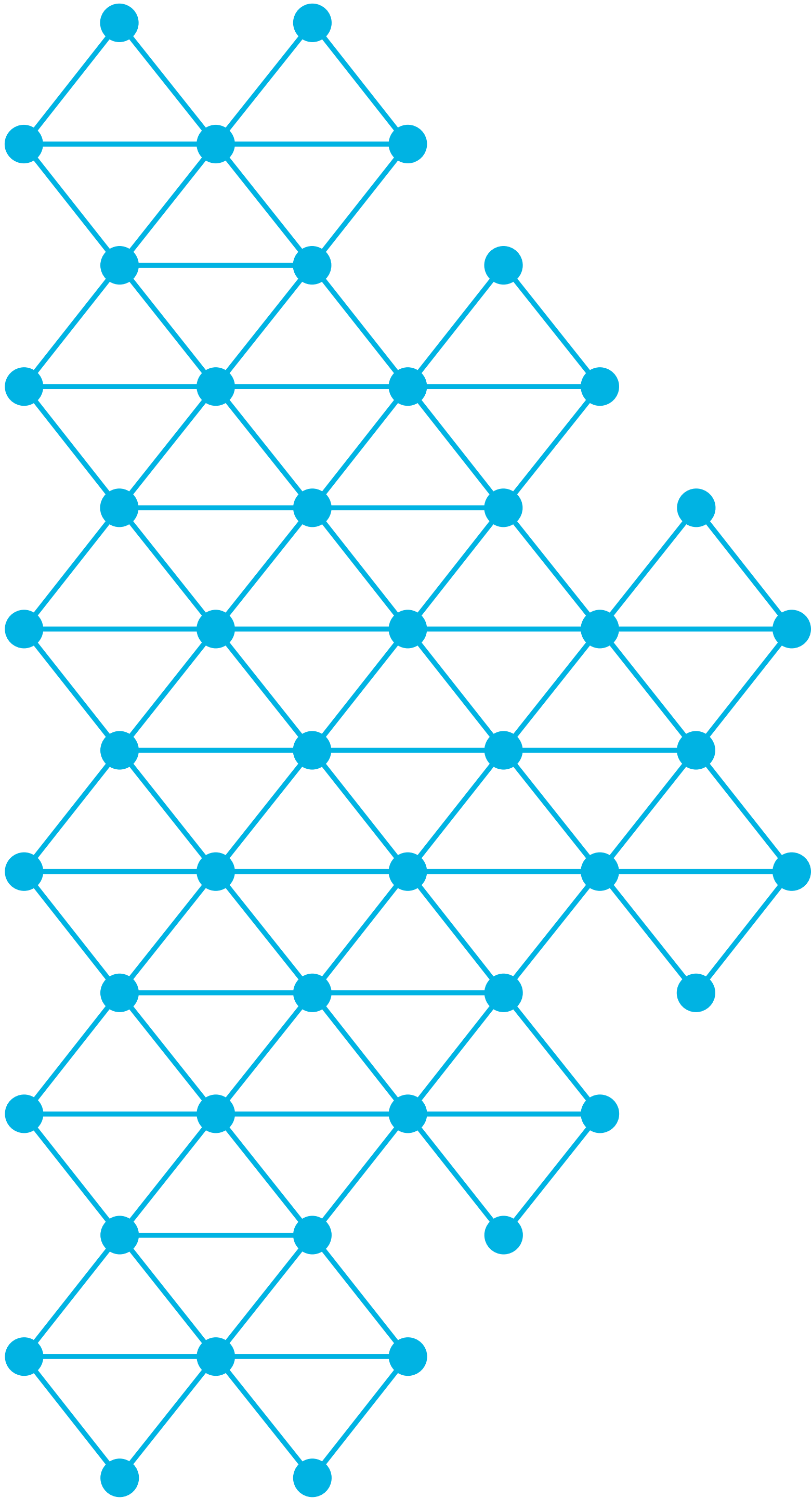
Qualitative results - fail



Quantitative results - Gatech



Model	Acc.
<i>2D models (no time)</i>	
2D-V2V-from scratch [33]	55.7
FC-DenseNet103	79.4
<i>3D models (incorporate time)</i>	
3D-V2V-from scratch [33]	66.7
3D-V2V-pretrained [33]	76.0



Wrap up

Wrap up



- We presented an extension of DenseNets for semantic segmentation.
- FC-DenseNets encourage deep supervision and feature reuse, while mitigating the feature explosion.
- FC-DenseNets as an ensemble of variable depth networks.

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Thank you!