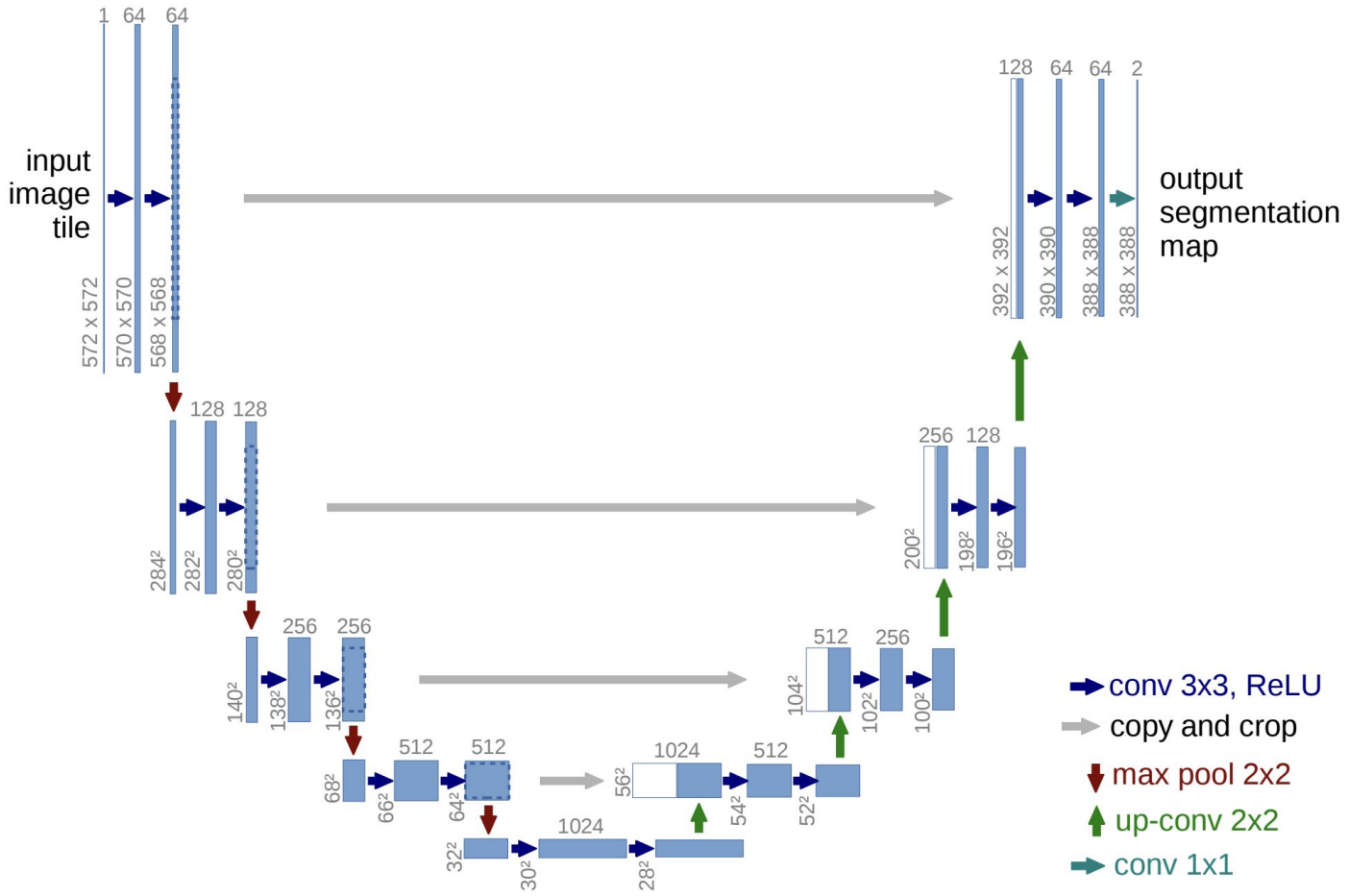
U-Net

Larissa Heinrich, HHMI Janelia

AI@MBL 2025

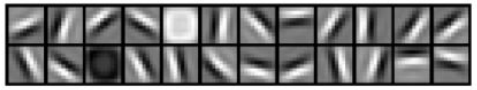
[slides adapted from Shalin Mehta and Anna Kreshuk]

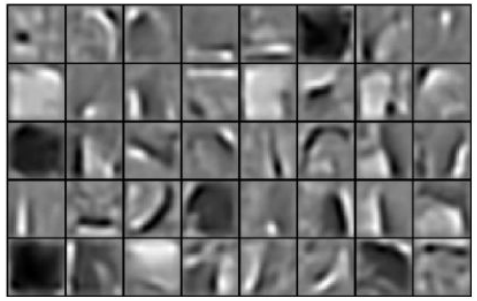
does this look familiar?

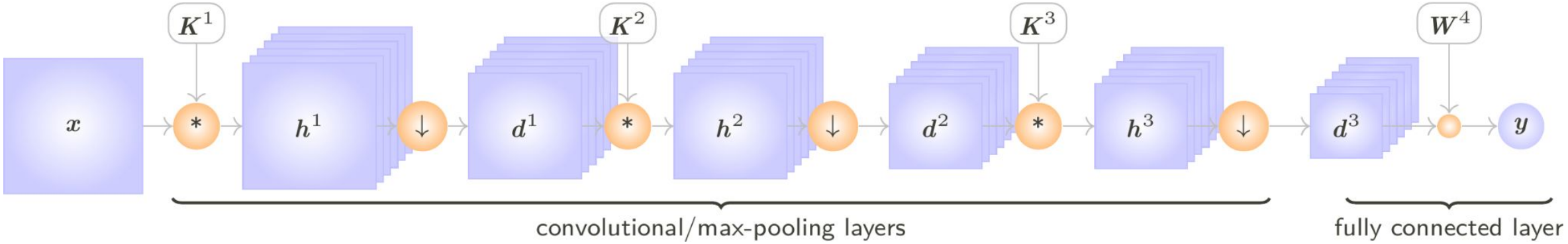


[Ronneberger et al., 2015]

remember yesterday?

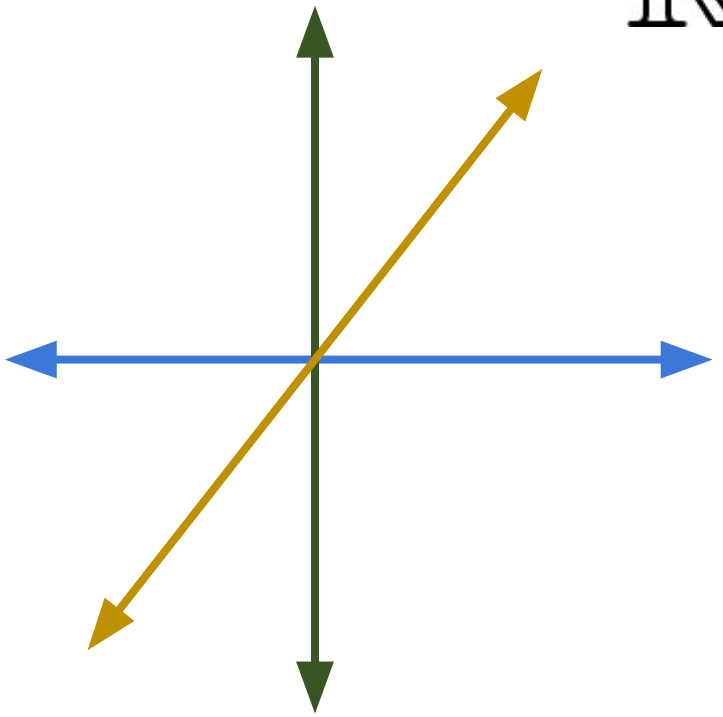






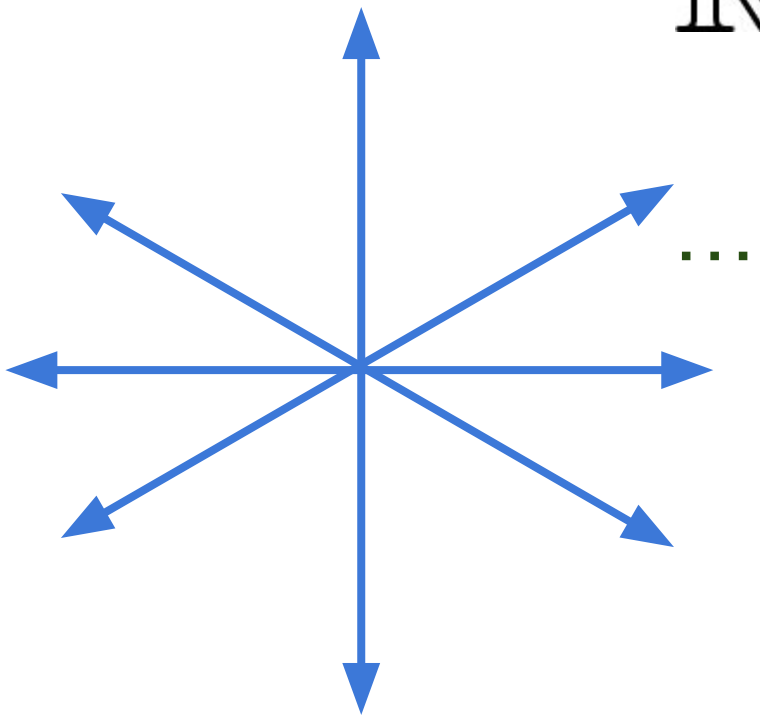
images

$\mathbb{R}^3$



images

$$\mathbb{R}^{H \times W}$$



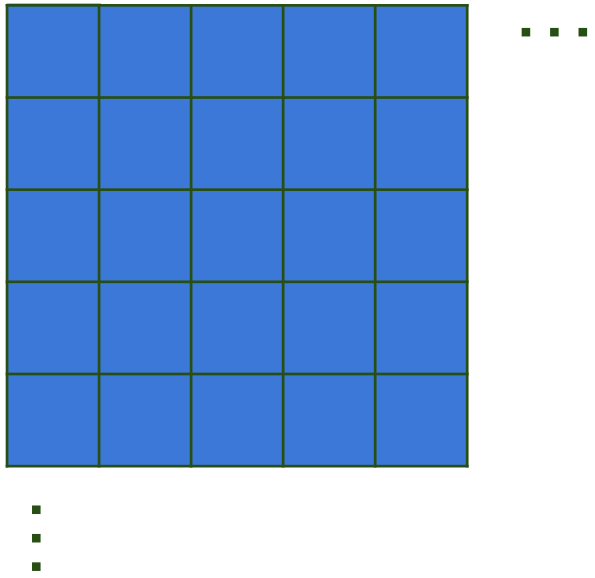


image classification

$$\mathbb{R}^{H \times W}$$

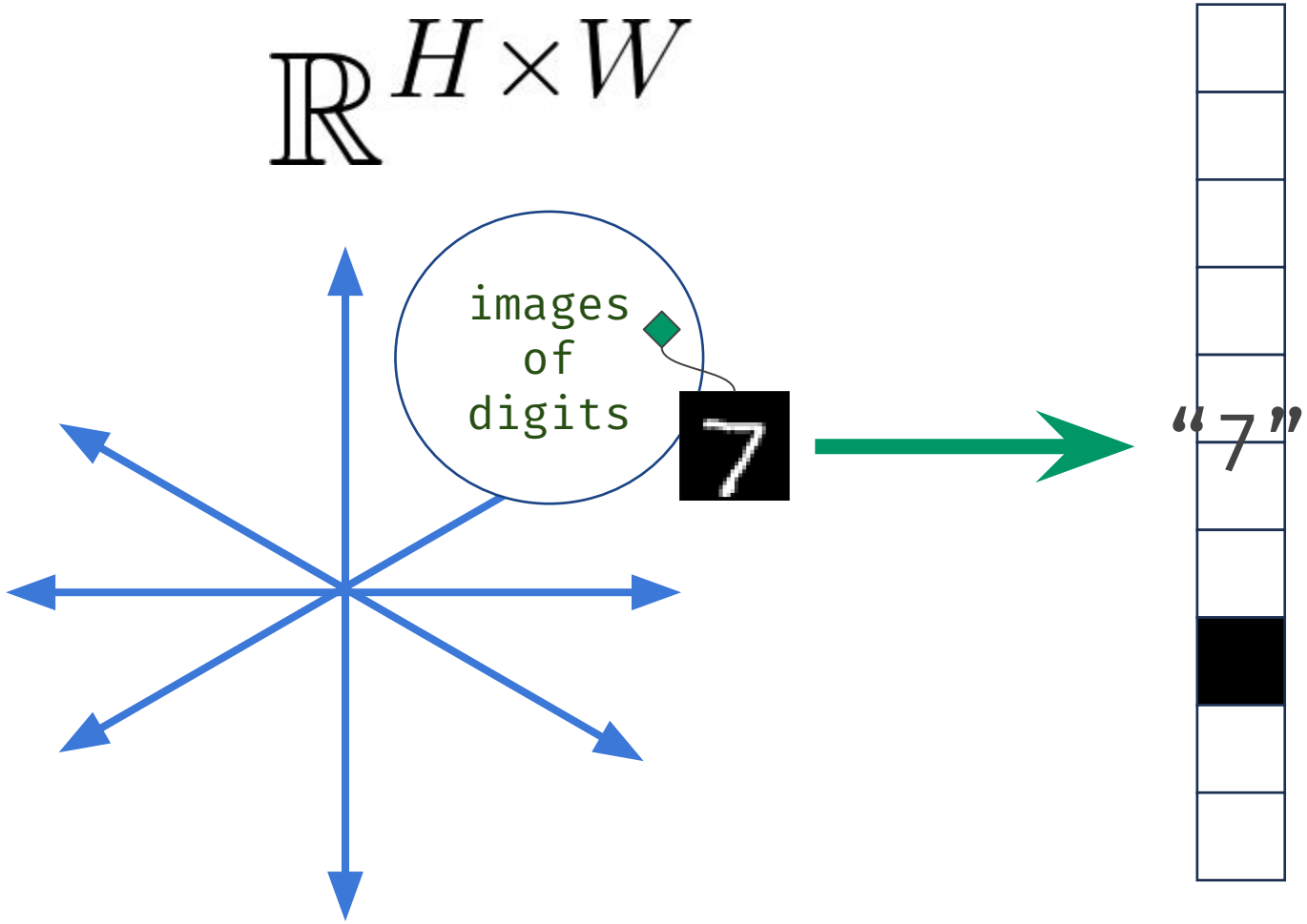
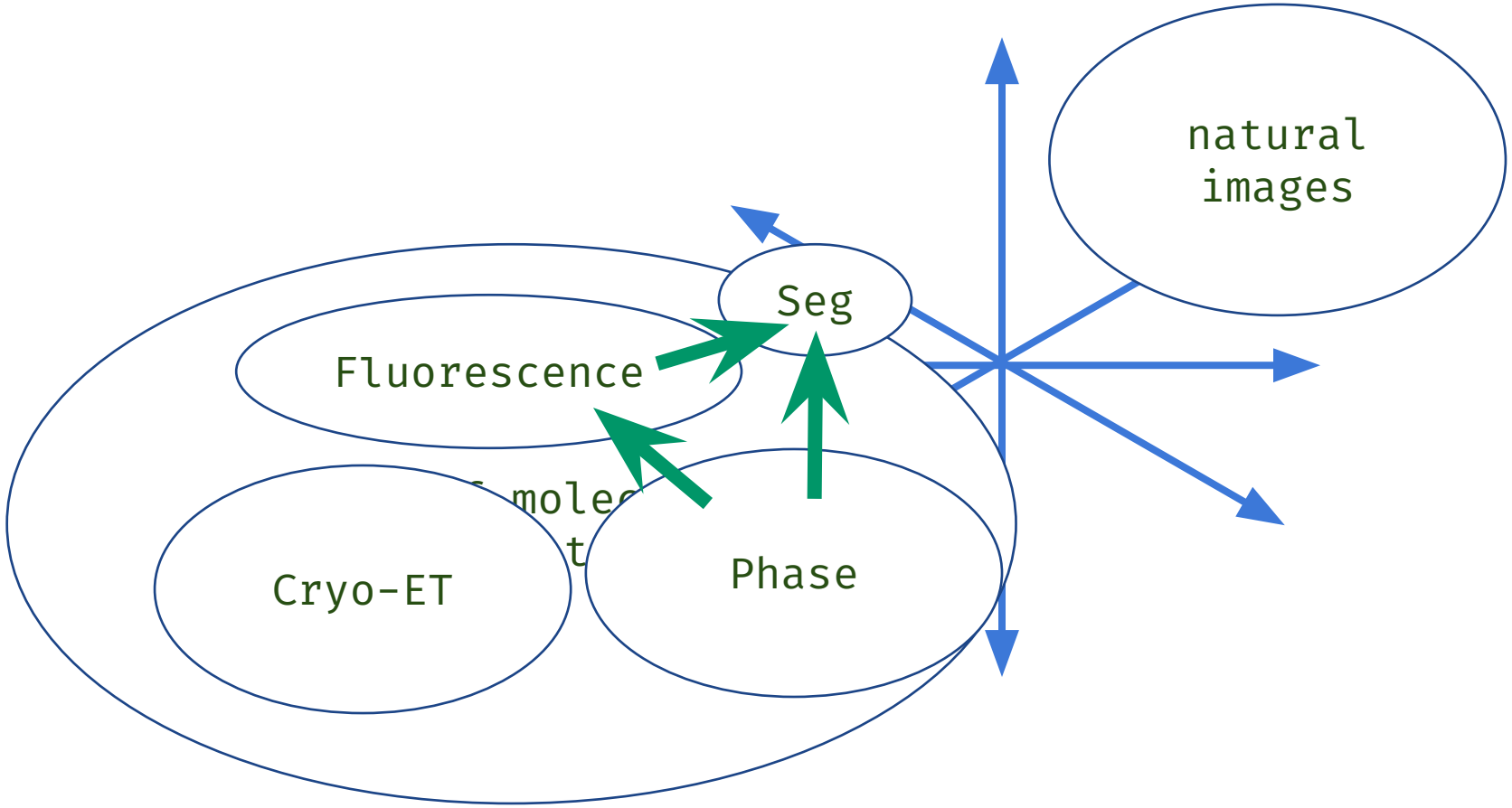
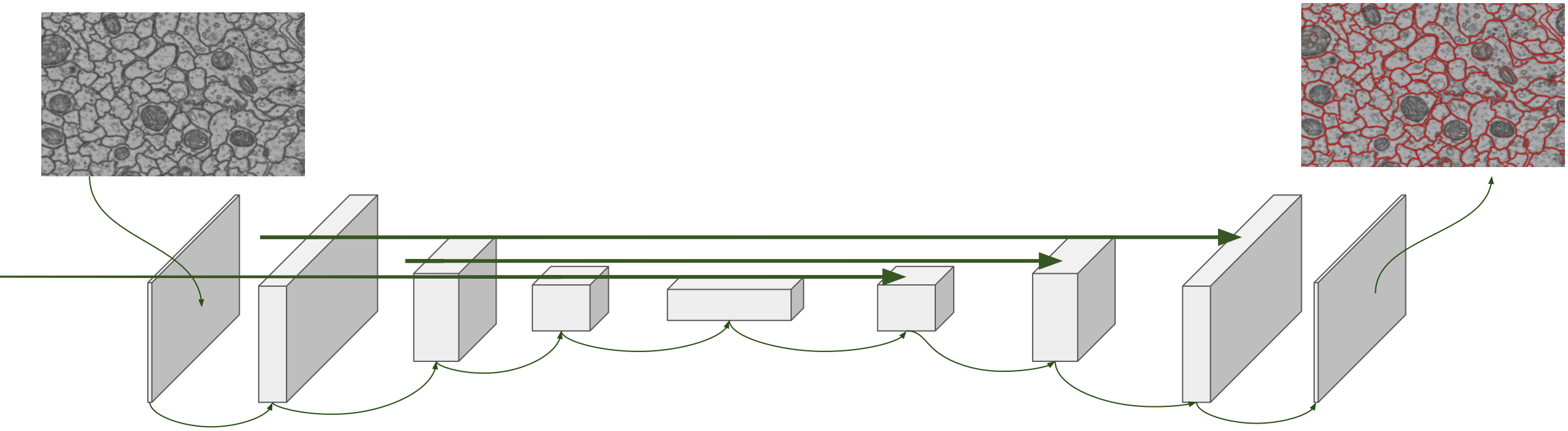


image-to-image transforms

$$\mathbb{R}^{H \times W}$$

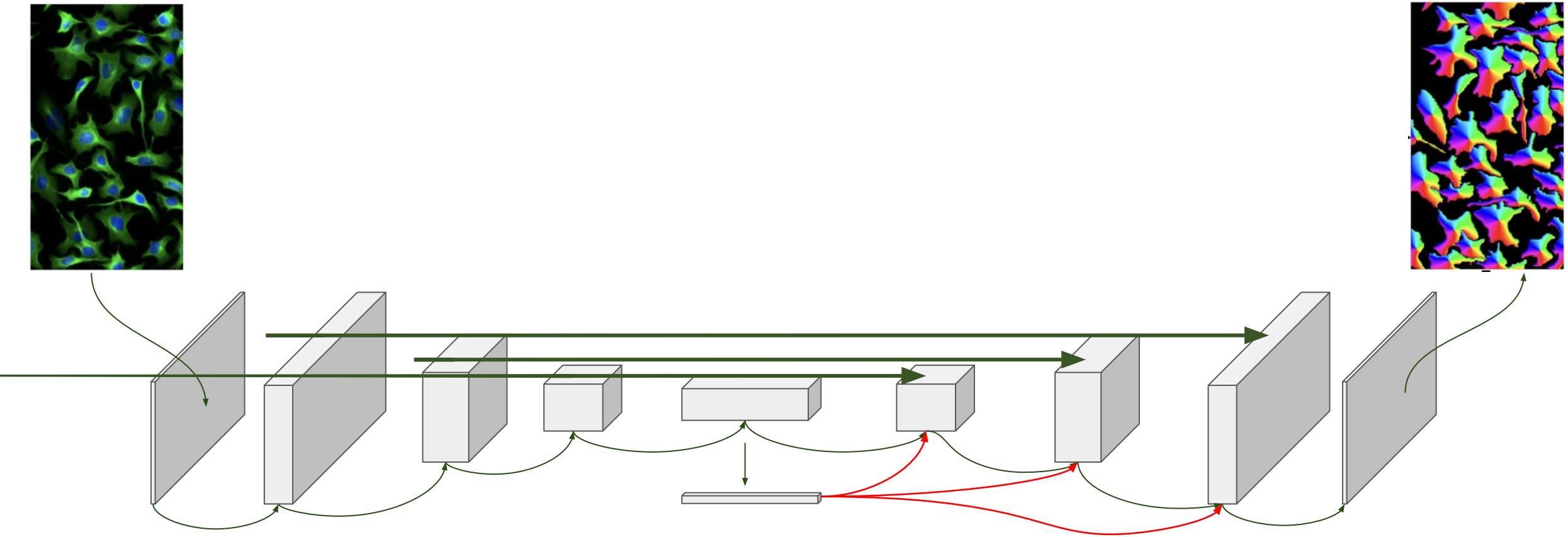


U-Net in bioimage analysis



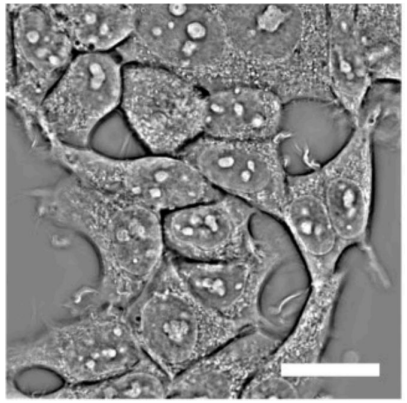
[Ronneberger et al., 2015]

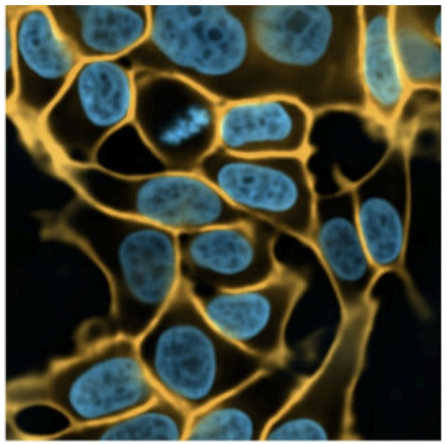
U-Net in bioimage analysis

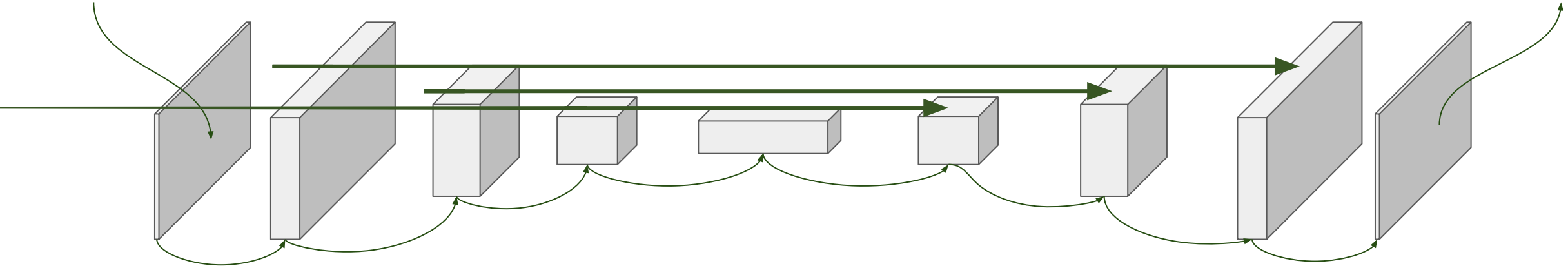


[Stringer et al., 2021]

U-Net in bioimage analysis

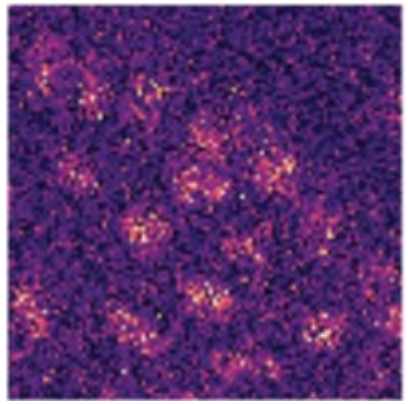


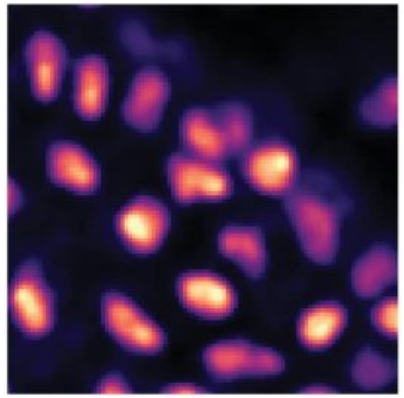


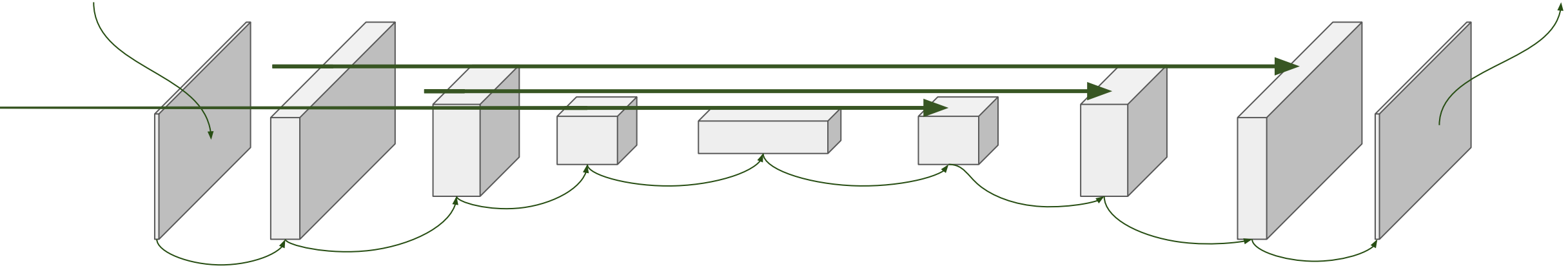


[Liu et al., 2024]

U-Net in bioimage analysis







[Weigert et al., 2018]

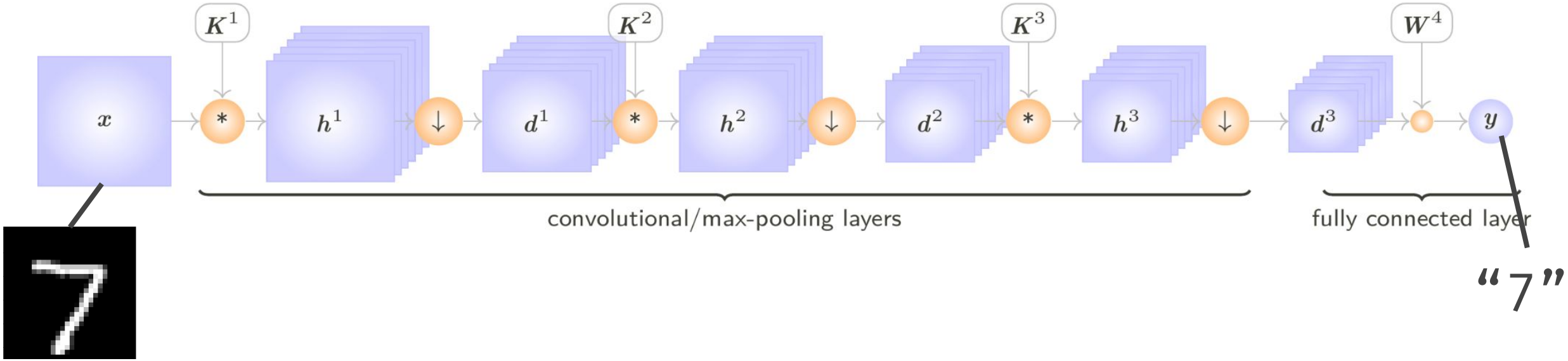
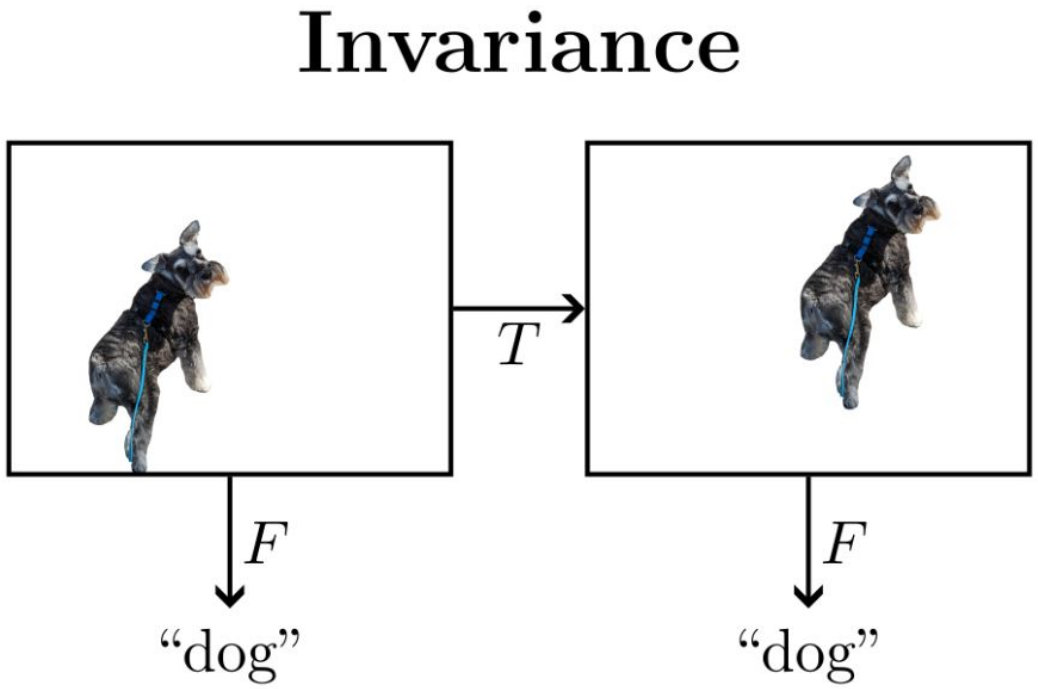
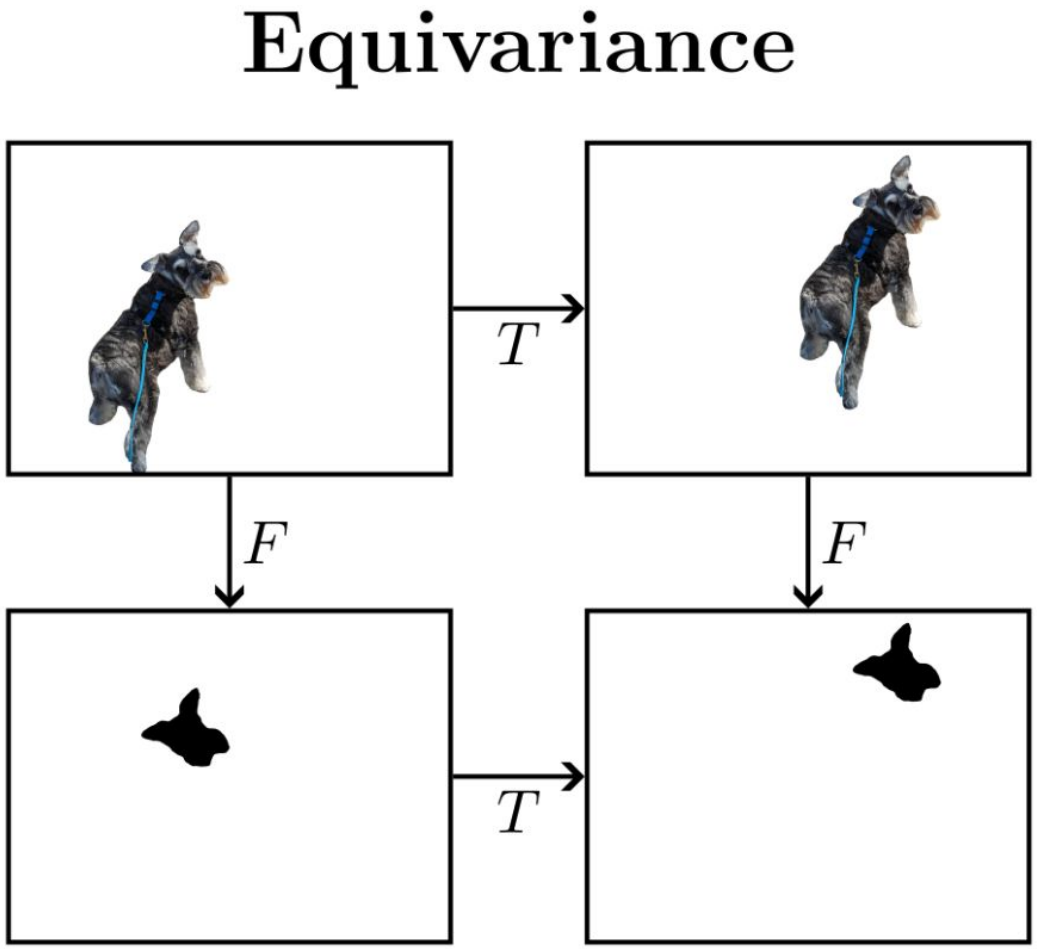


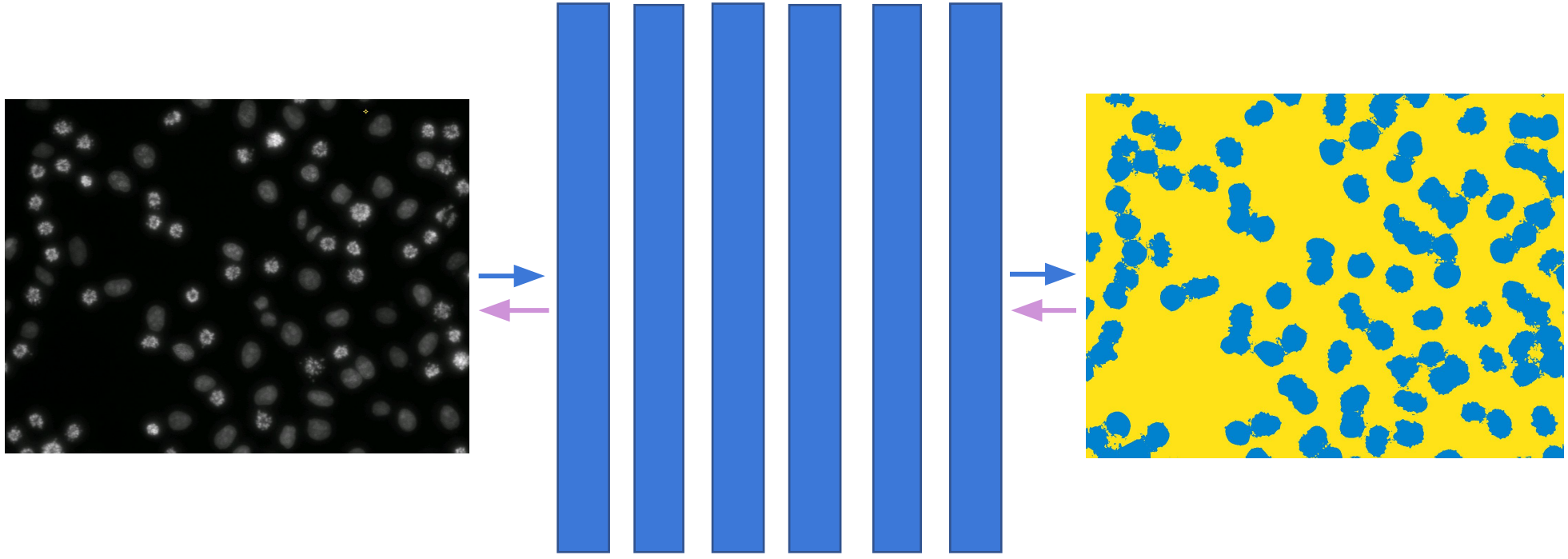
image-to-image: what’s missing?

shift equivariance

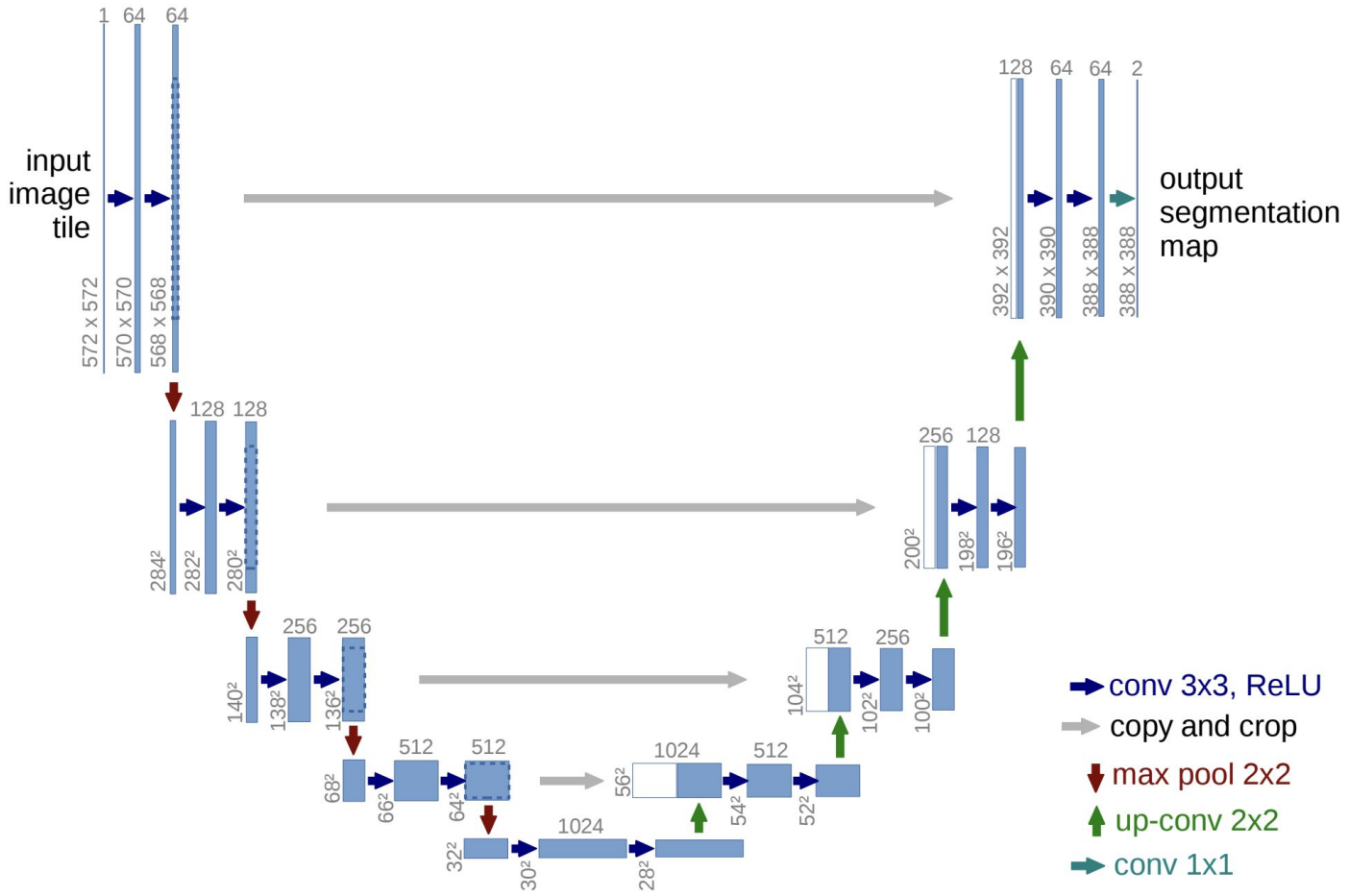




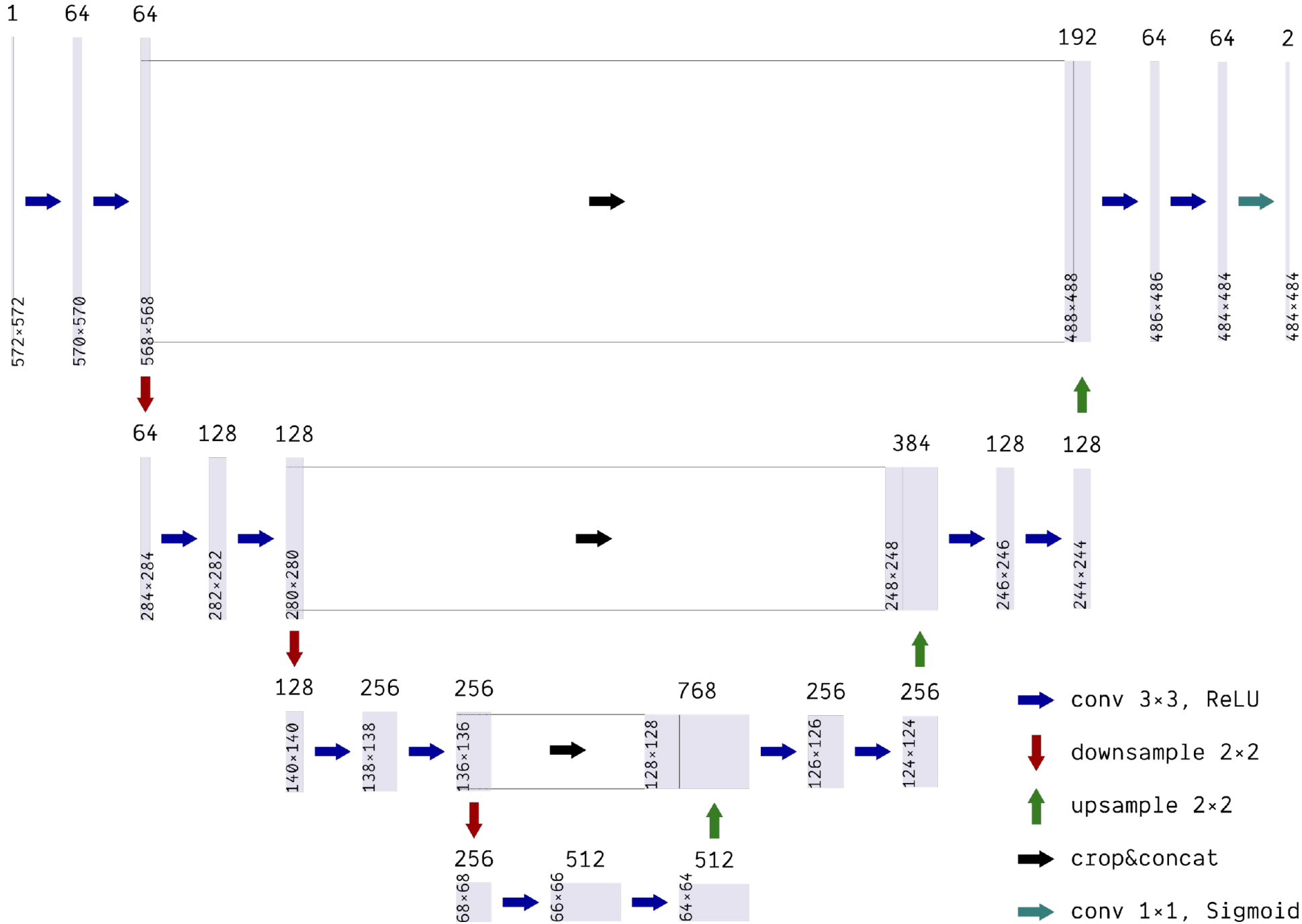
stacking convolutions



the U-Net



[Ronneberger et al., 2015]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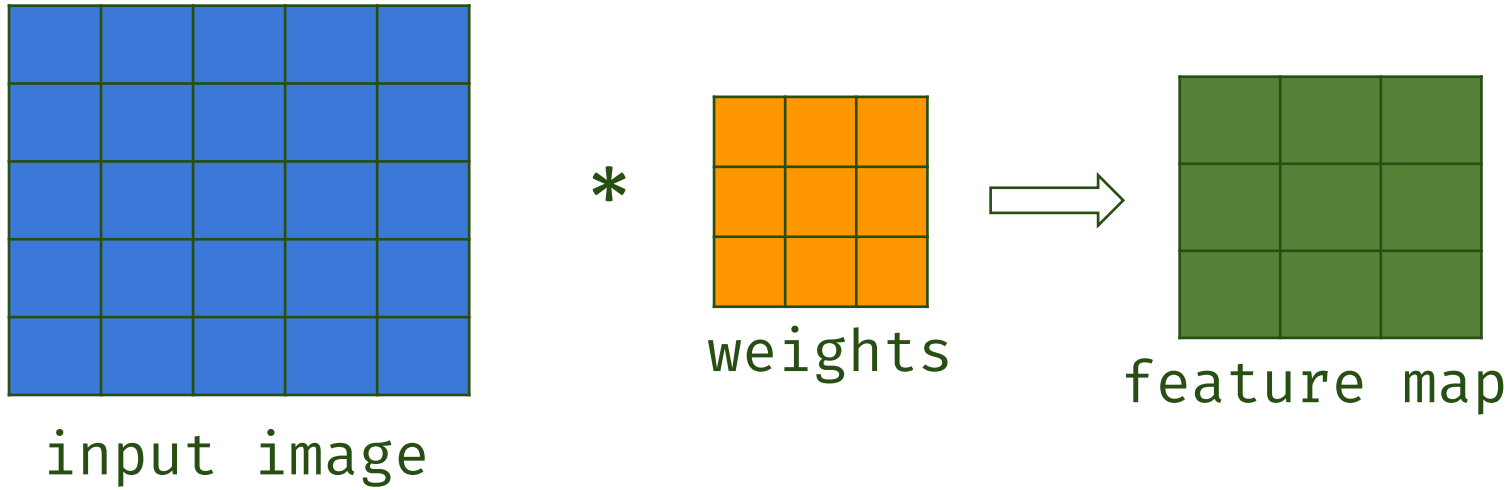
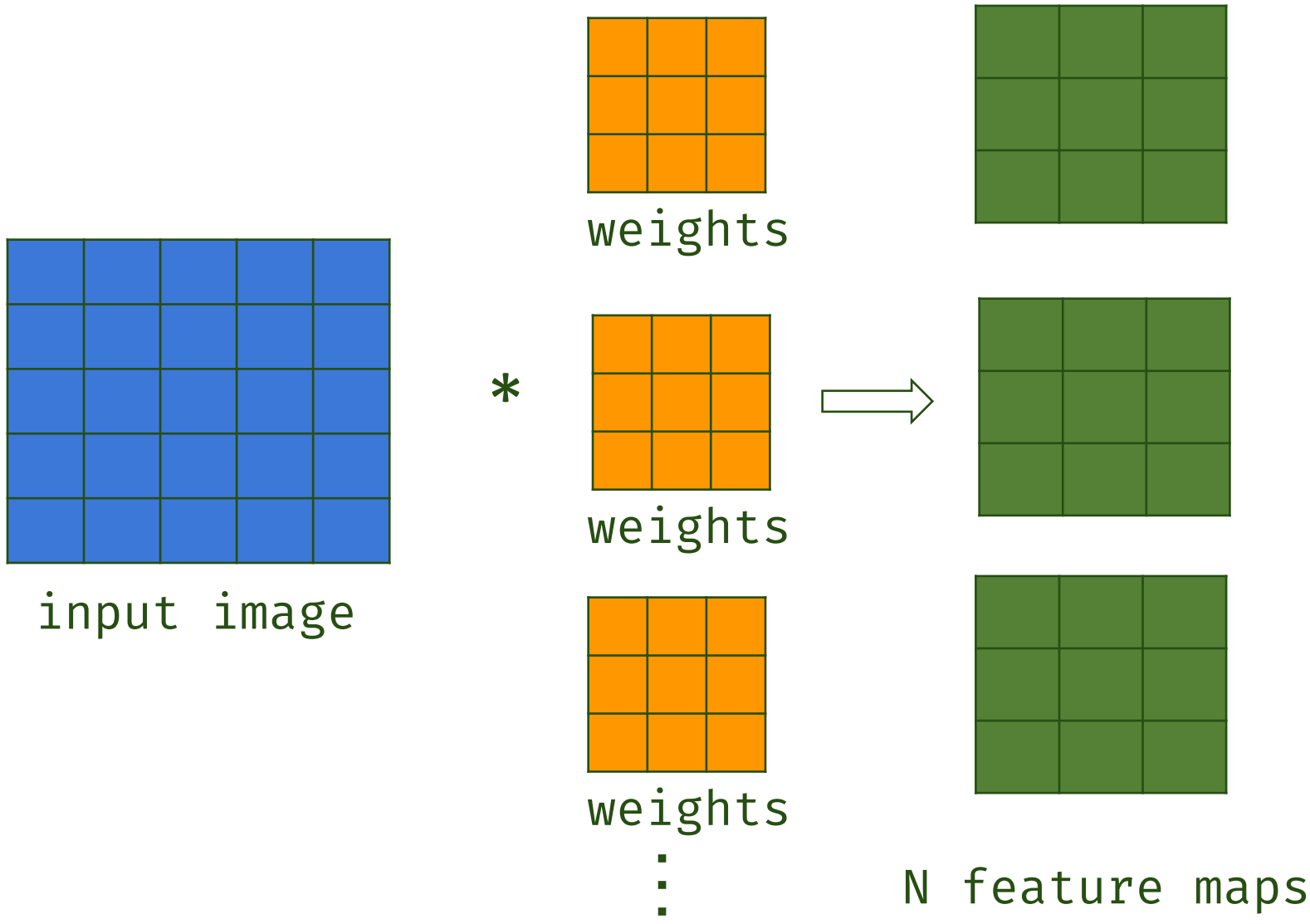
64×64
conv 3×3, ReLU
downsample 2×2
upsample 2×2
crop&concat
conv 1×1, Sigmoid

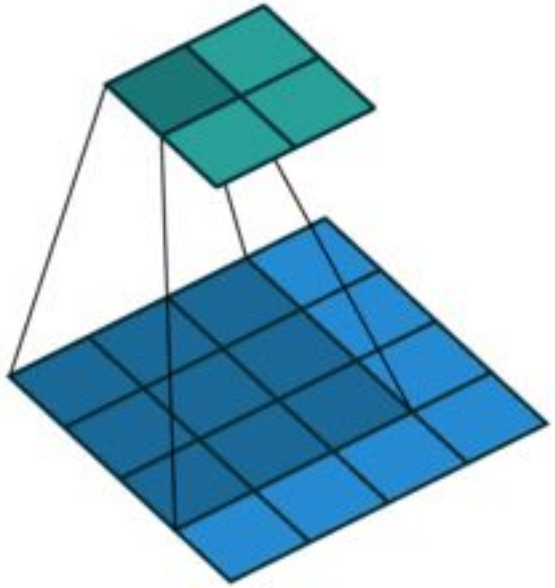
convolutional layer



convolutional layer



hyperparameters of convolution



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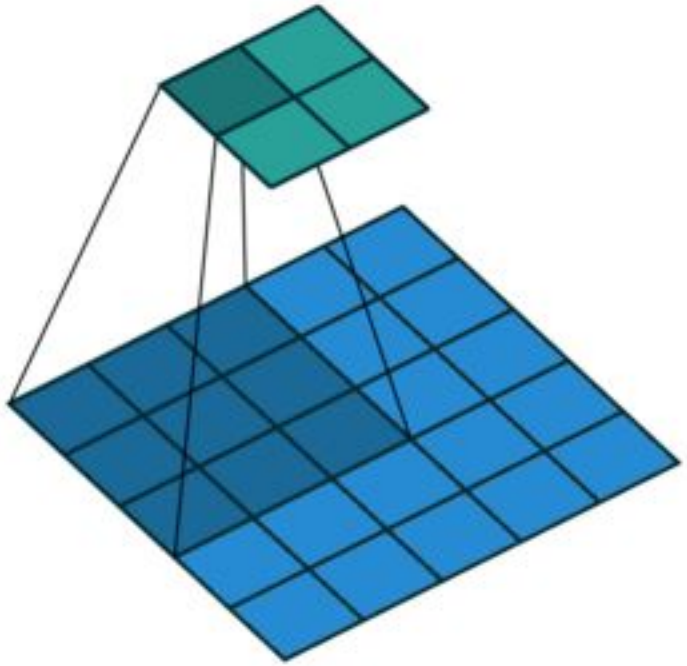

padding = 0,
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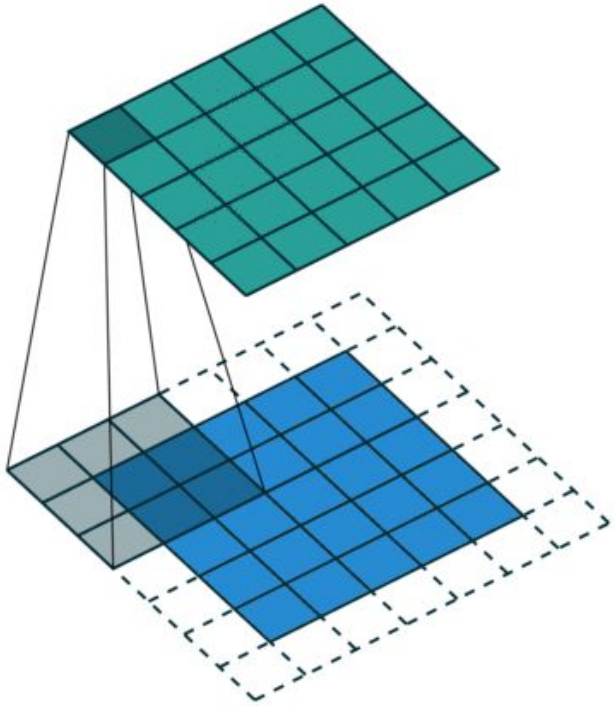
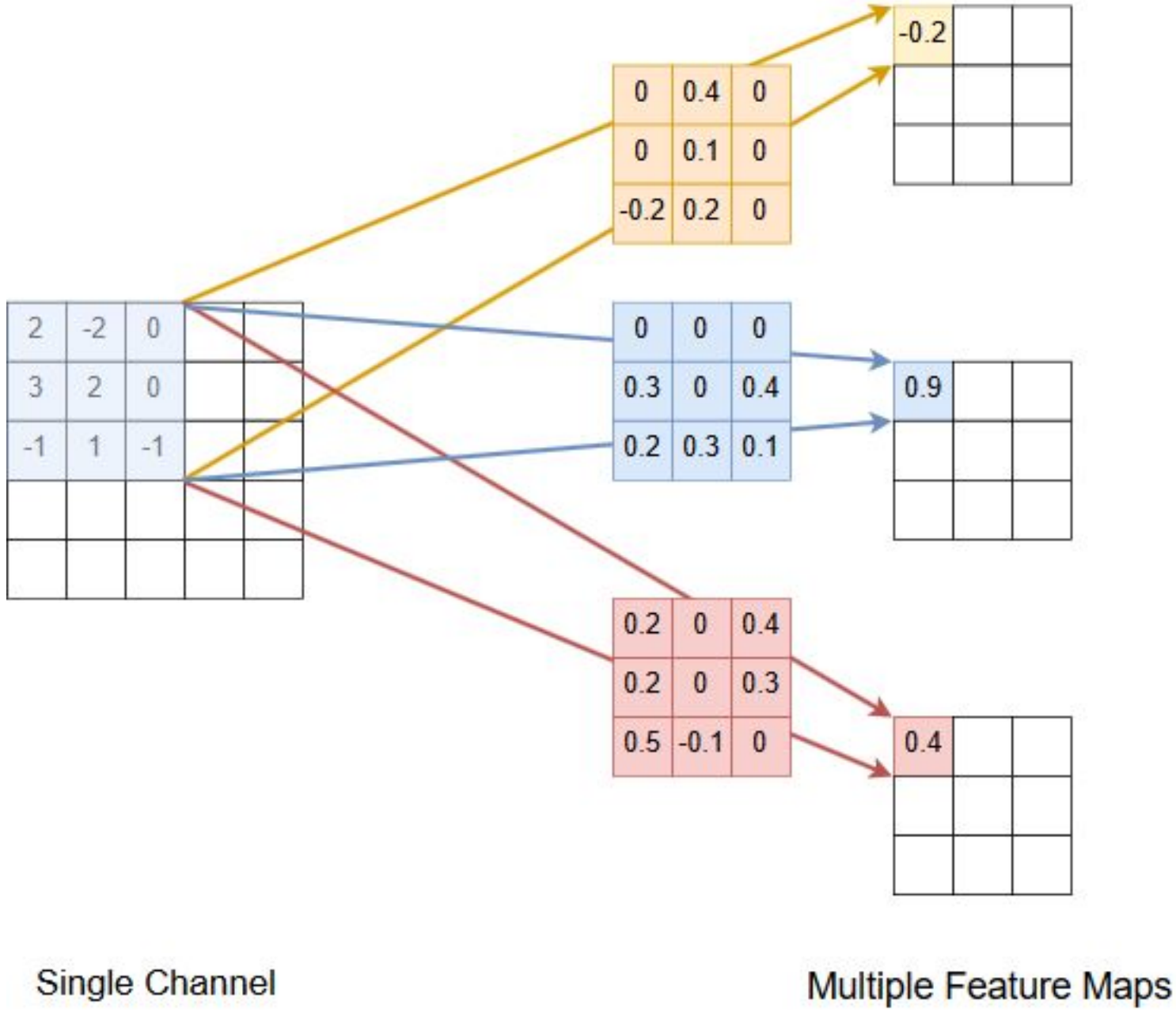


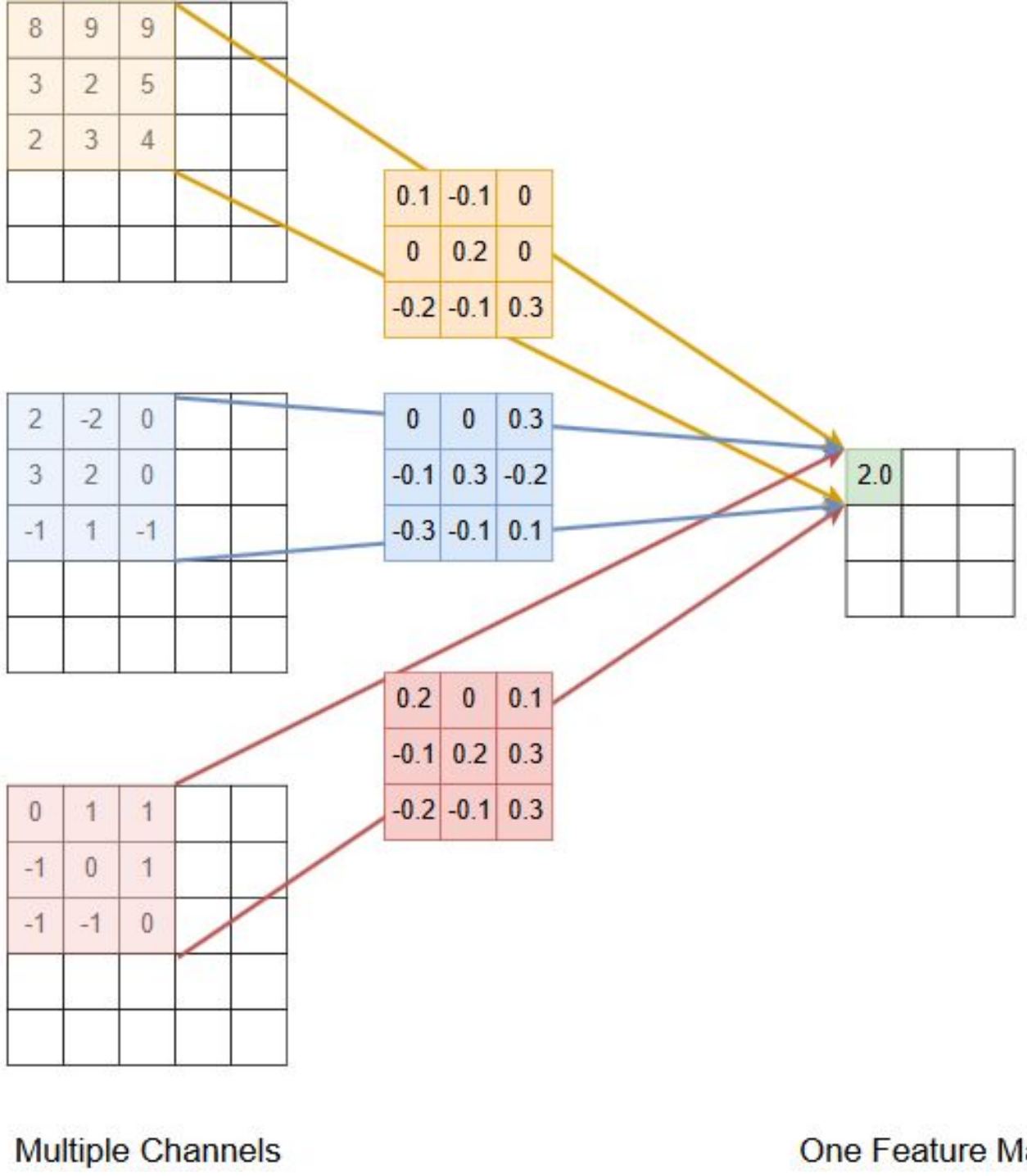
padding = 1,
stride = 1

https://hannibunny.github.io/mlbook/neuralnetworks/convolutionDemos.html

multi-channel output

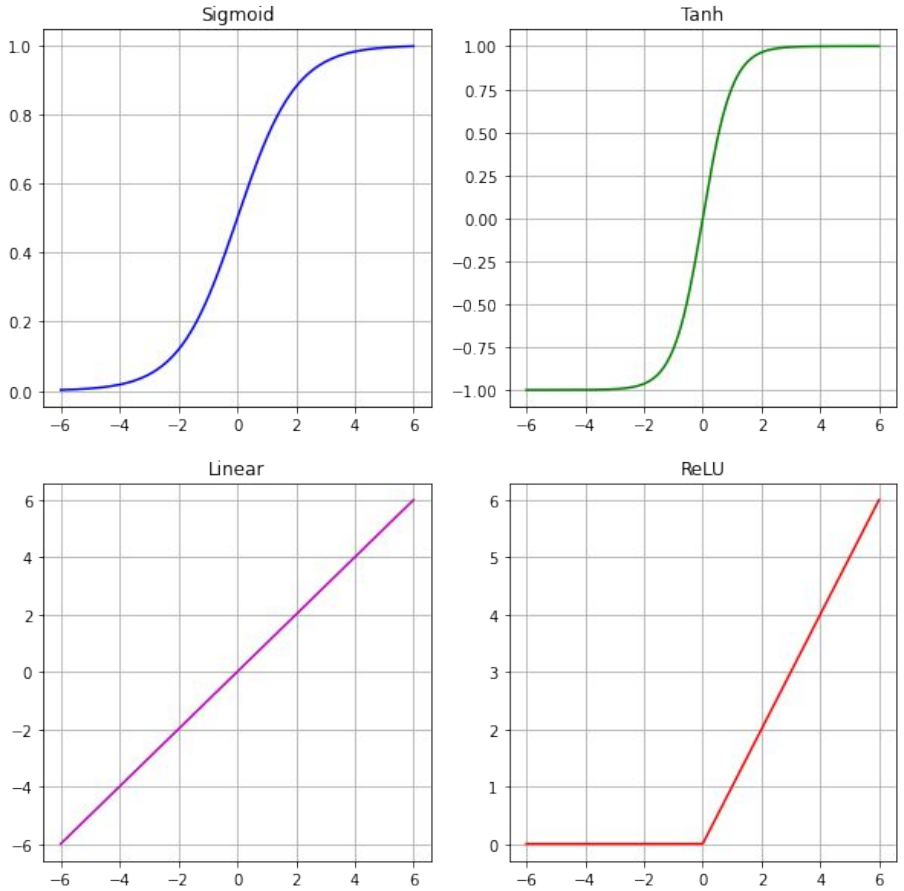


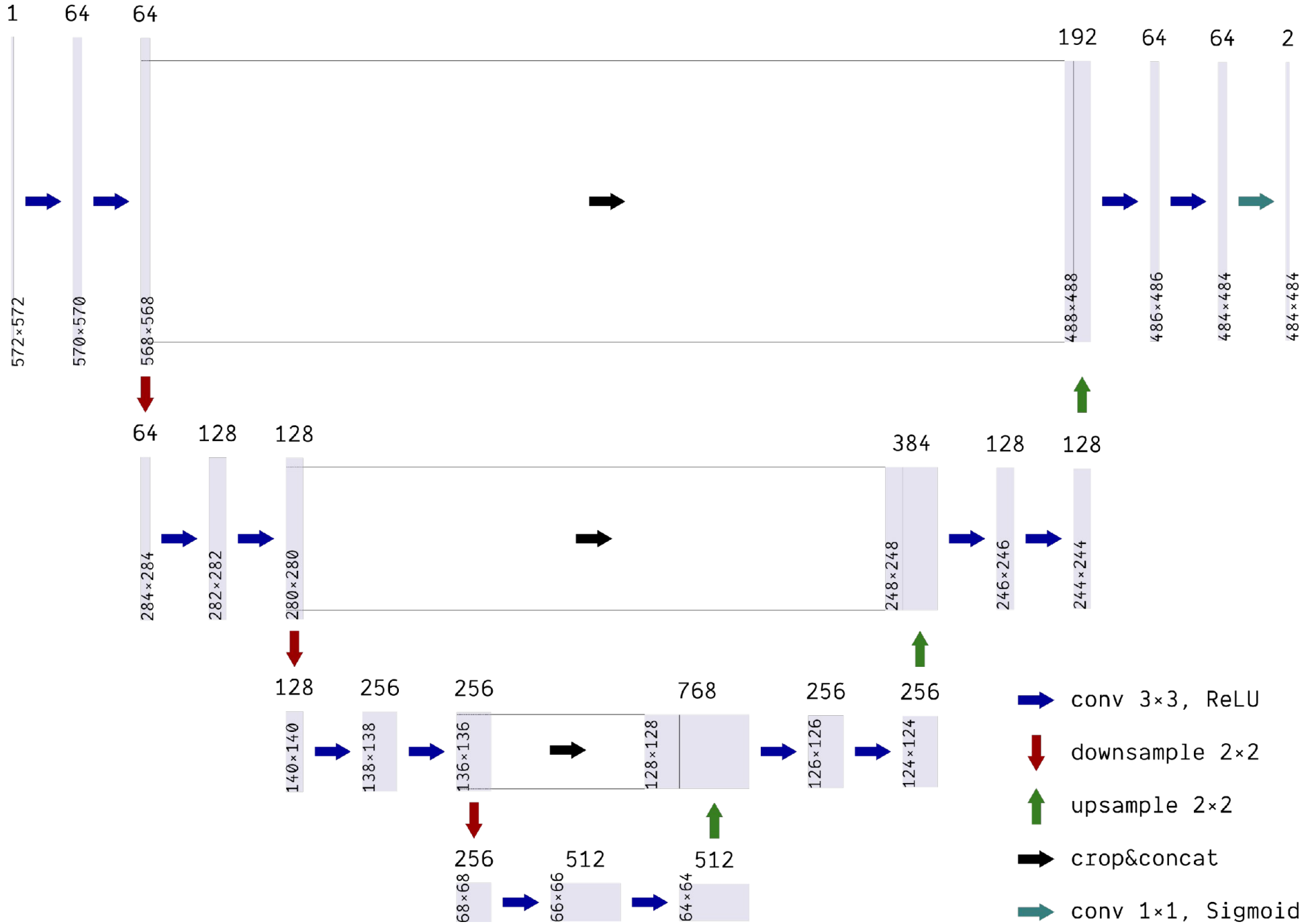
multi-channel input



activation functions

update feature-maps element-wise

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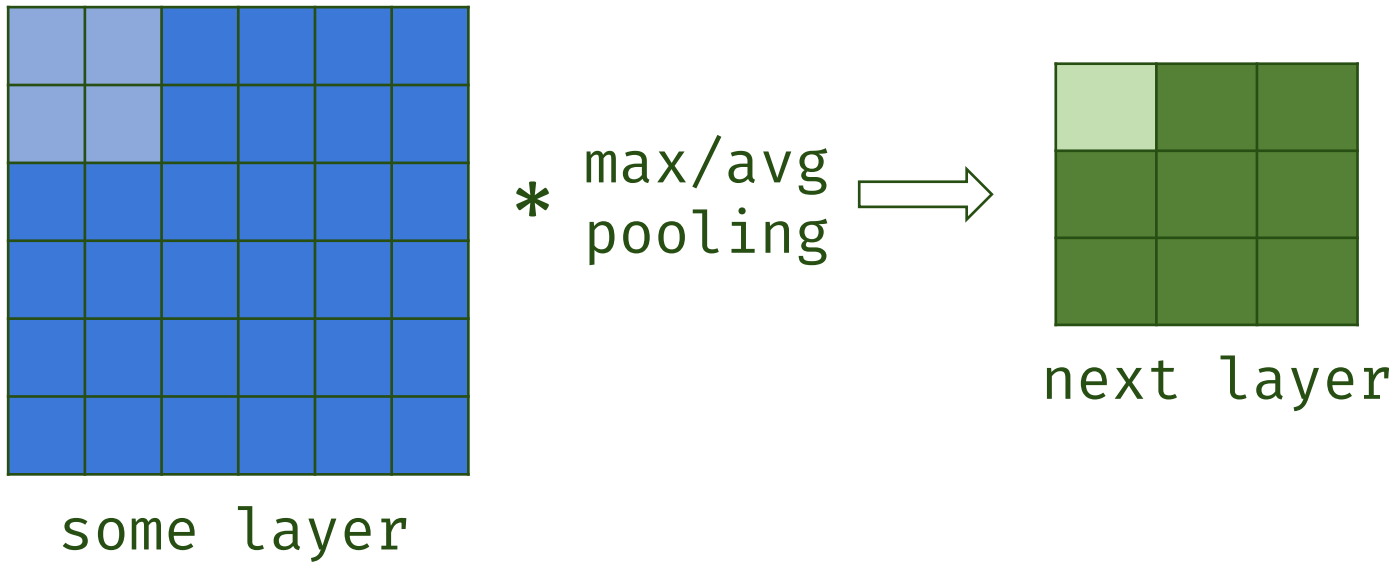
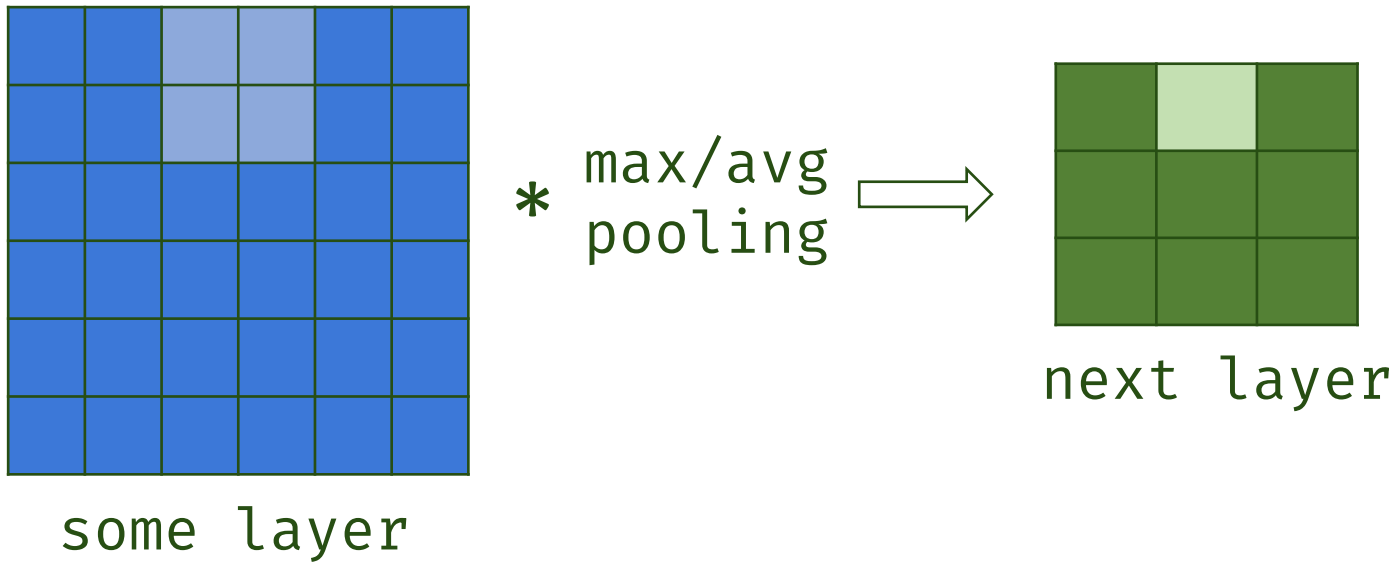
conv 3×3, ReLU
downsample 2×2
upsample 2×2
crop&concat
conv 1×1, Sigmoid

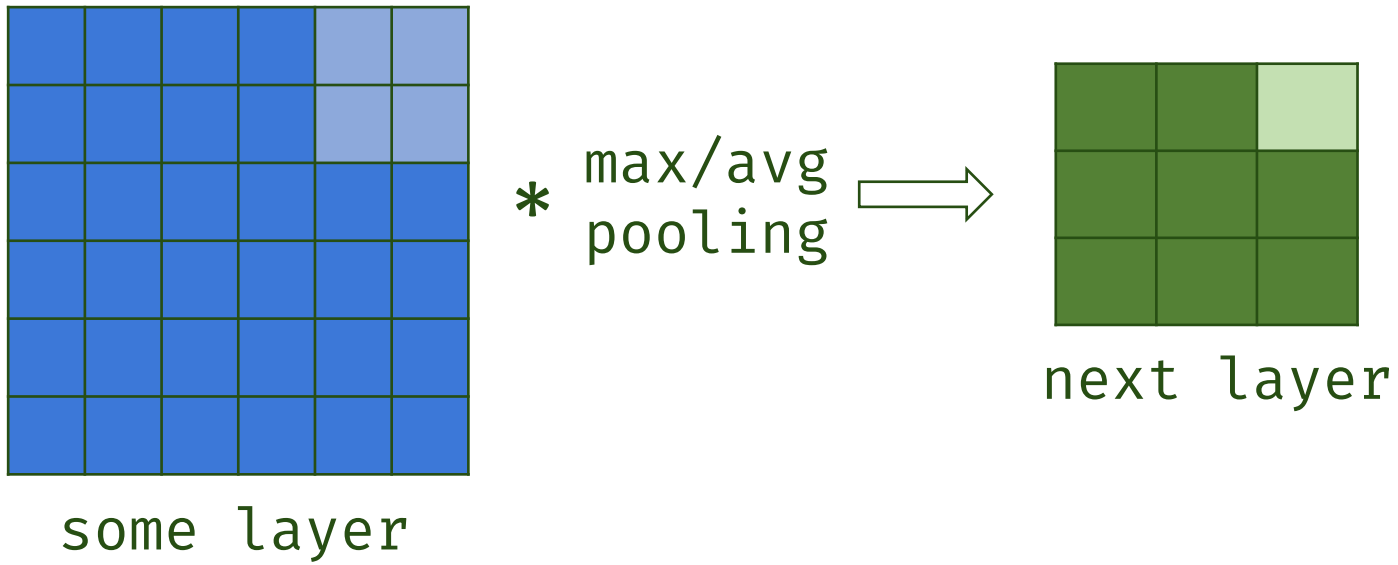
downsampling



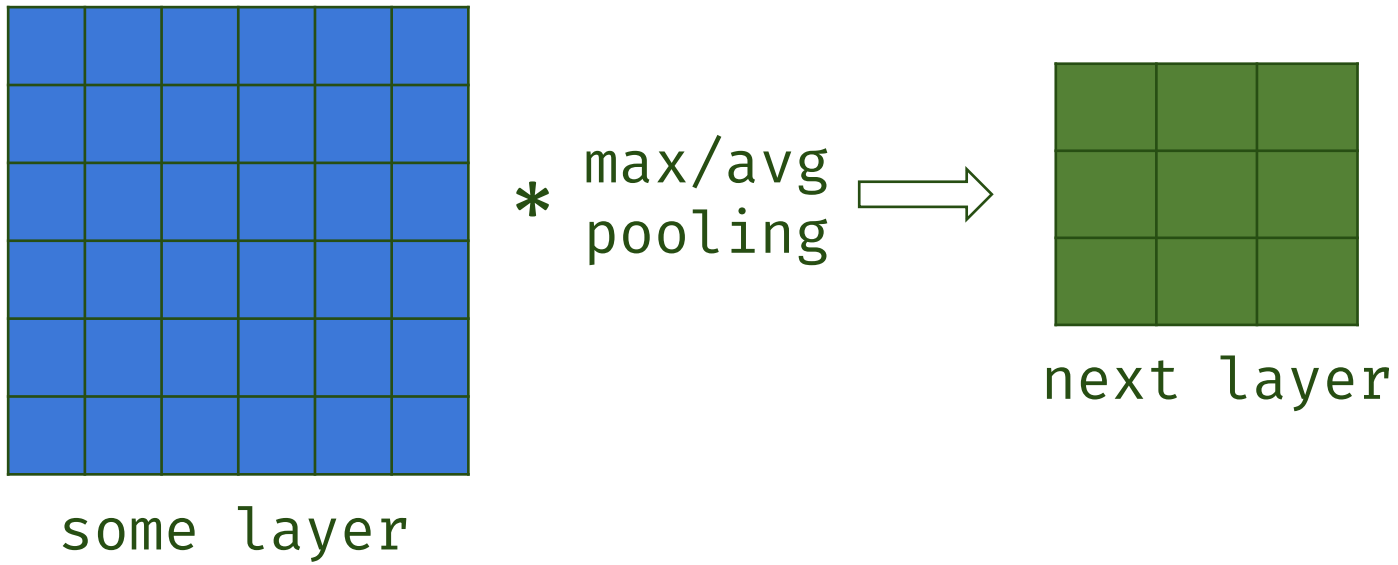
downsampling

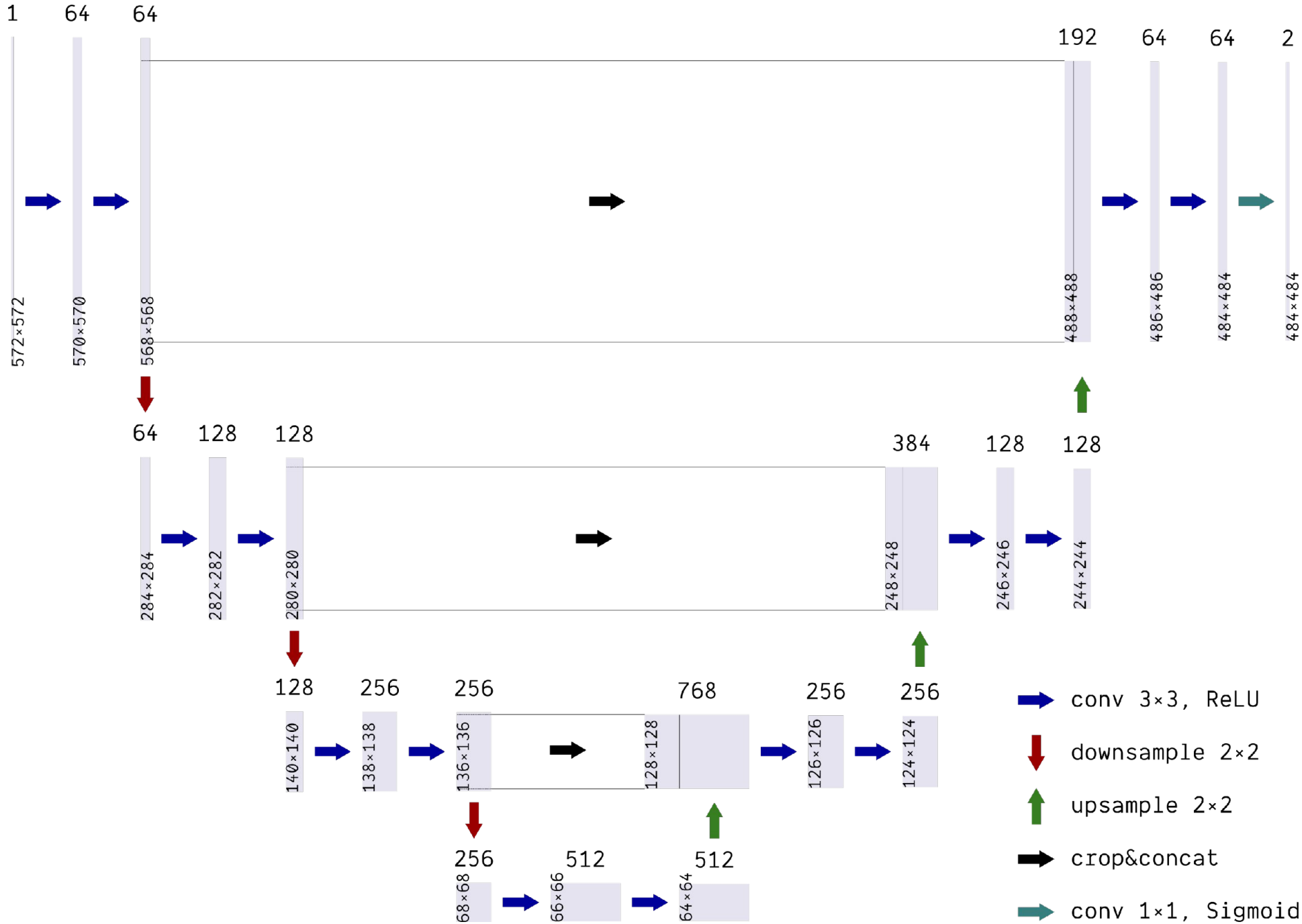


downsampling



downsampling

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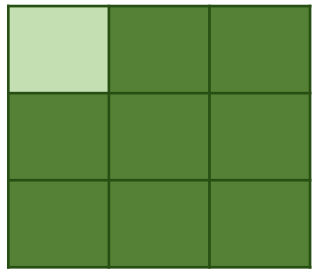
conv 3×3, ReLU
downsample 2×2
upsample 2×2
crop&concat
conv 1×1, Sigmoid

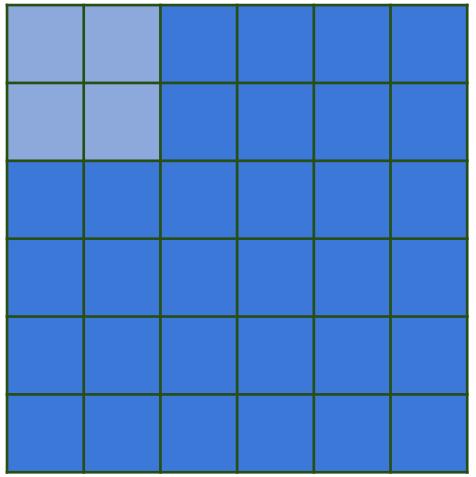
upsampling

upsampling



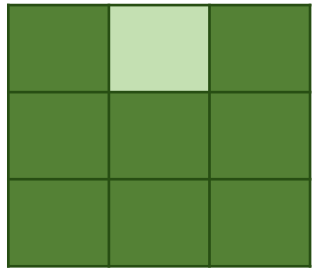
some layer

* nearest-neighbor/
bilinear



next layer

upsampling



some layer

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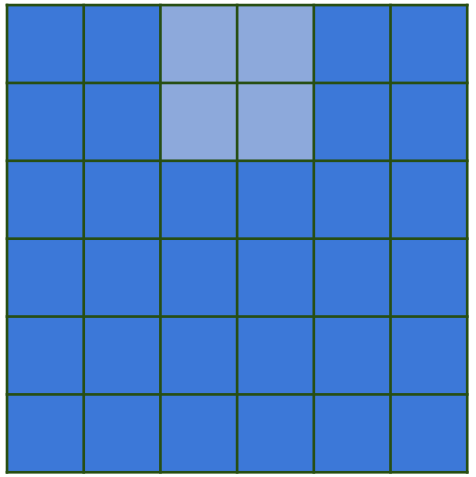
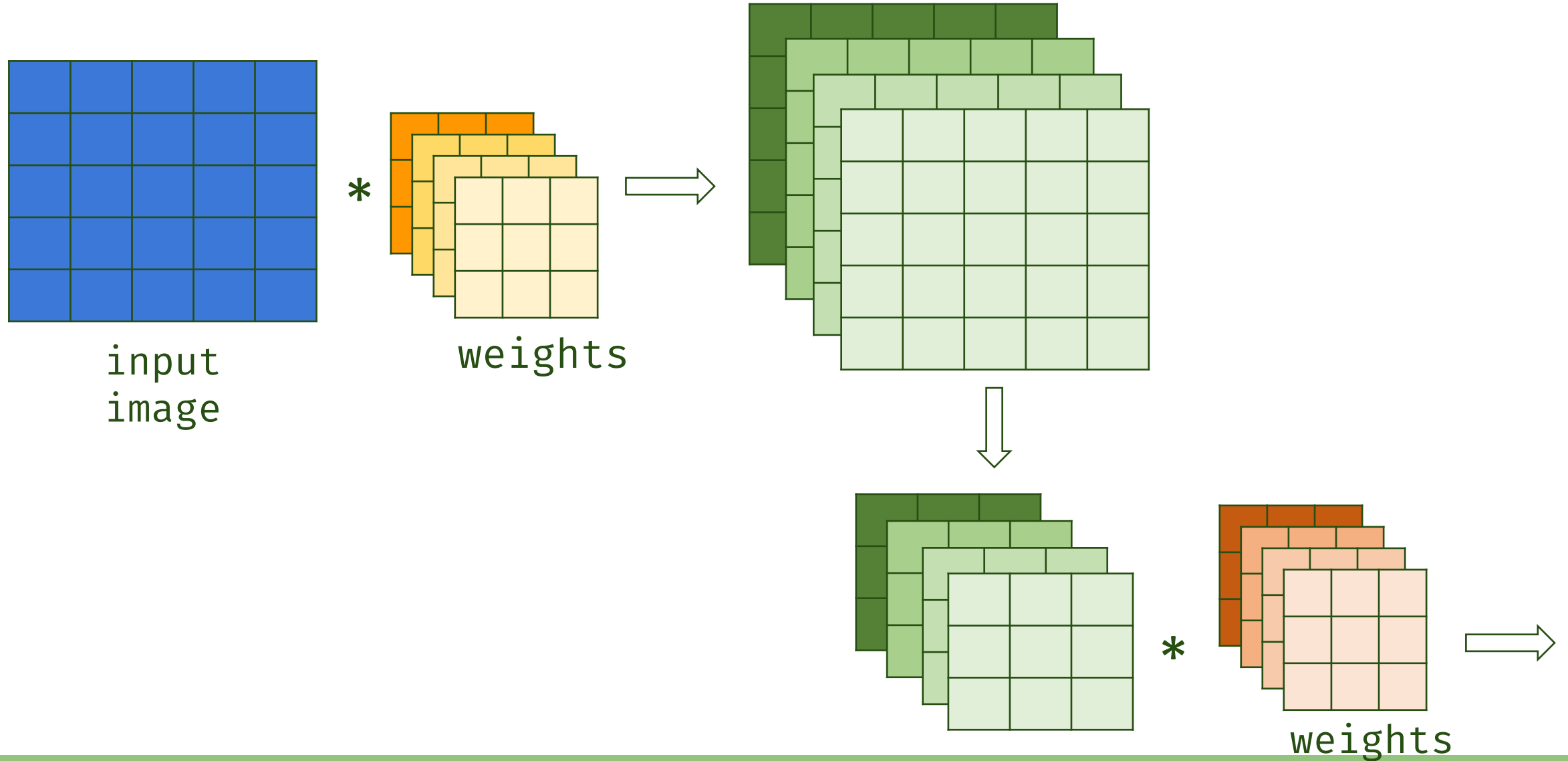


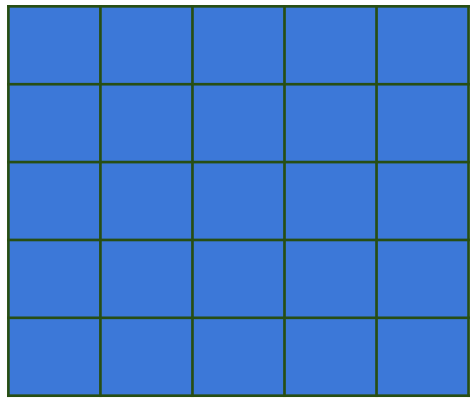
next layer

upsampling

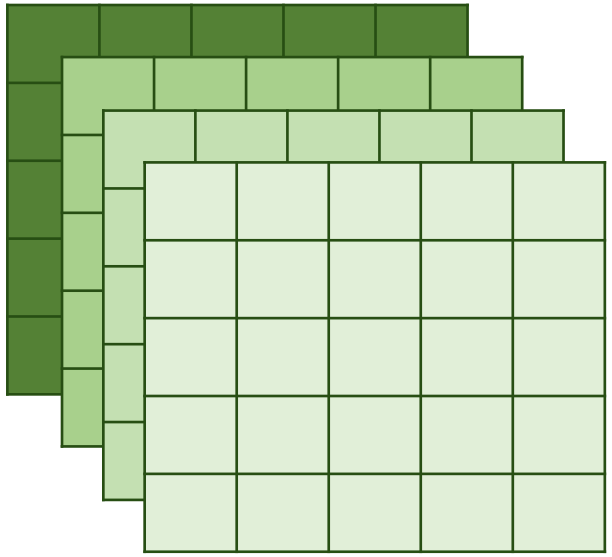
building an encoder



building a decoder



output
image



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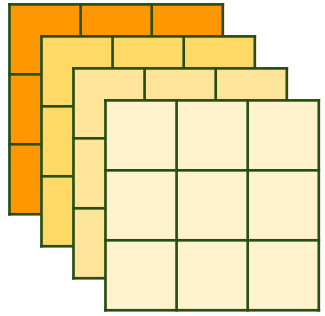
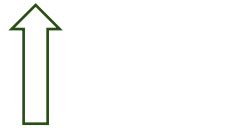
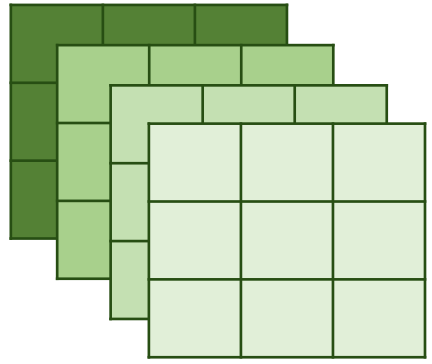


weights





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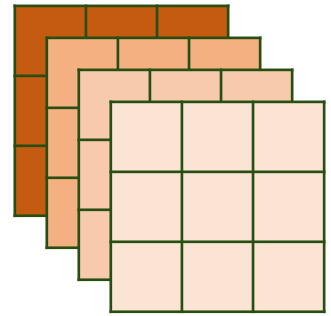

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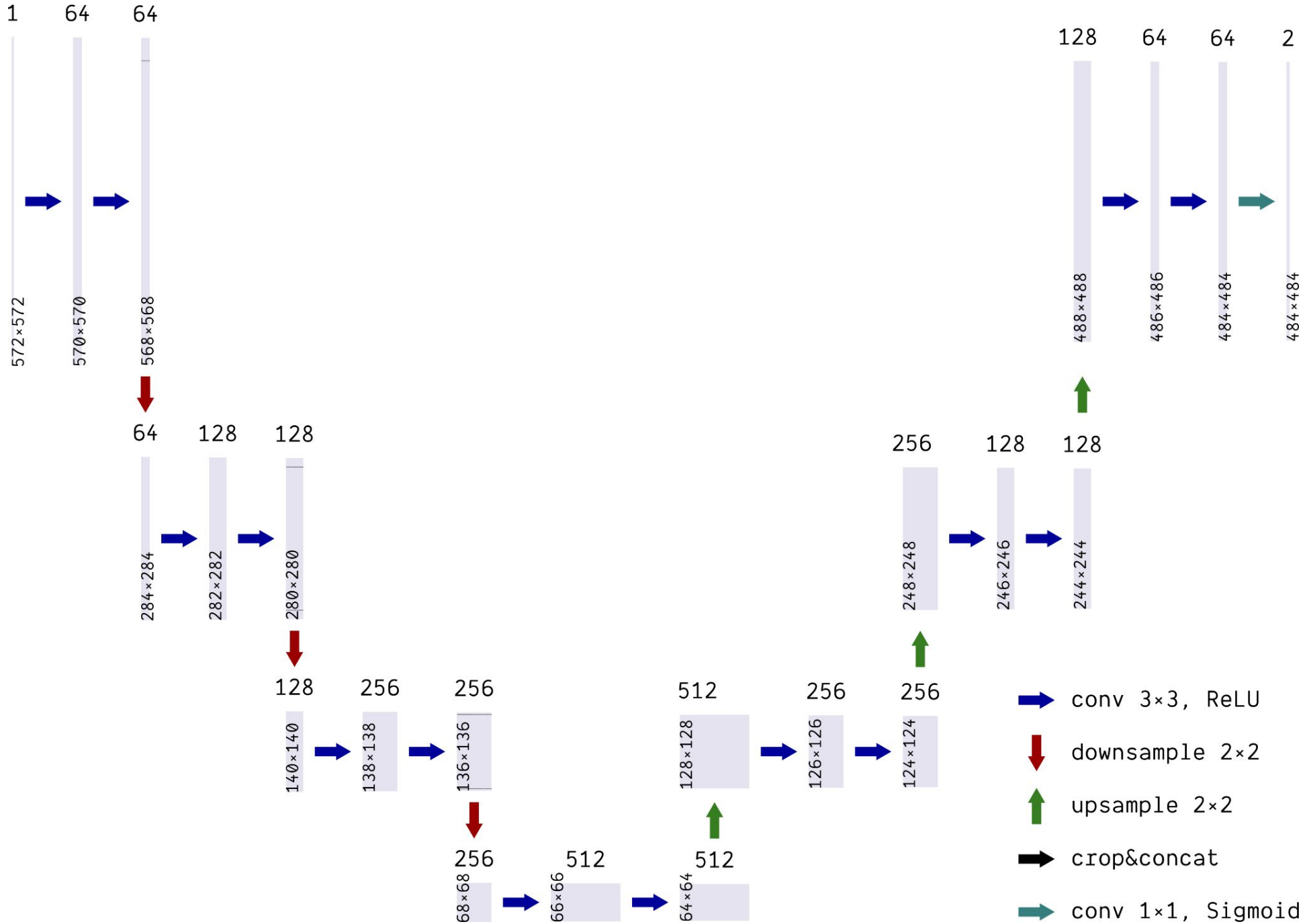
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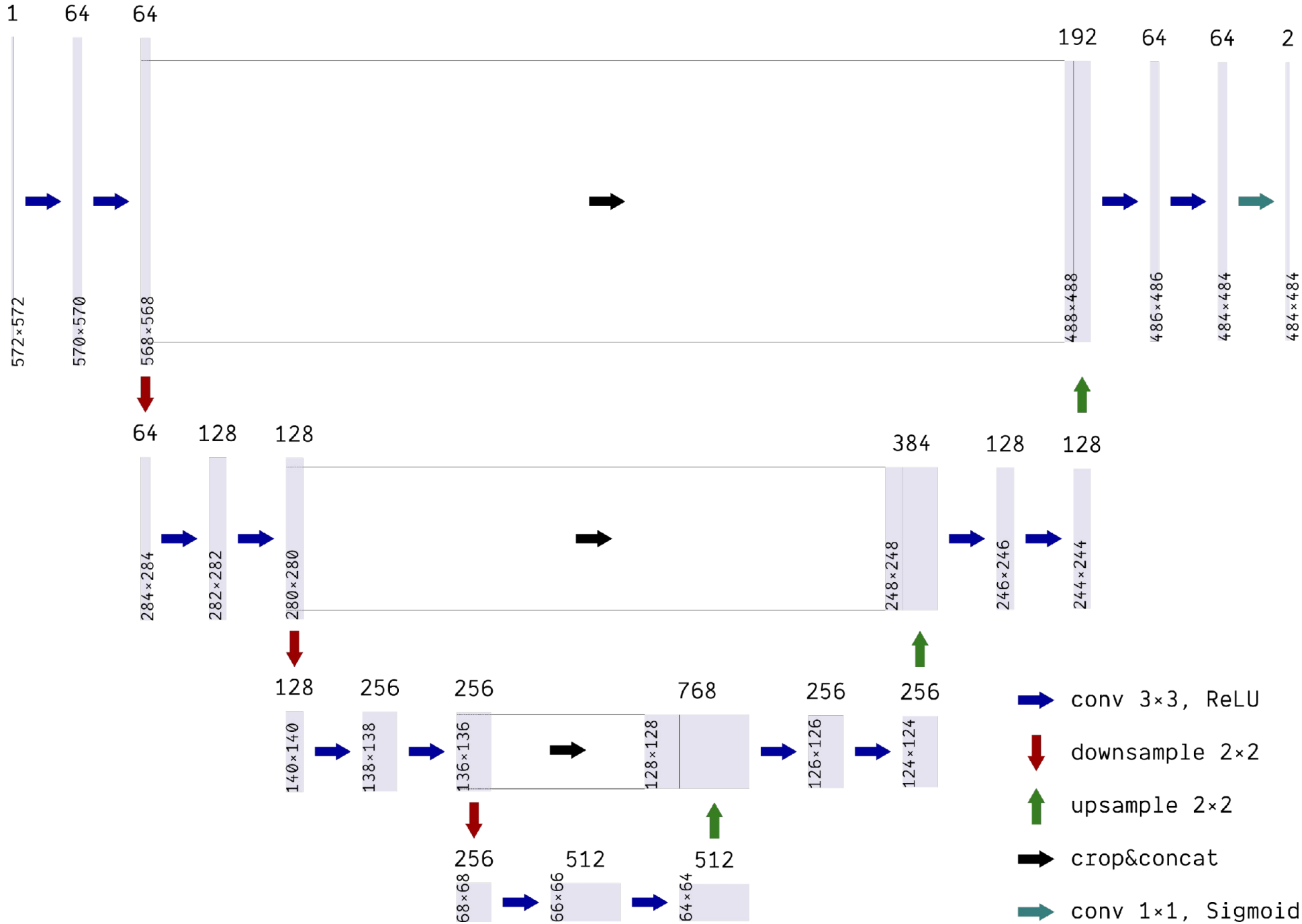
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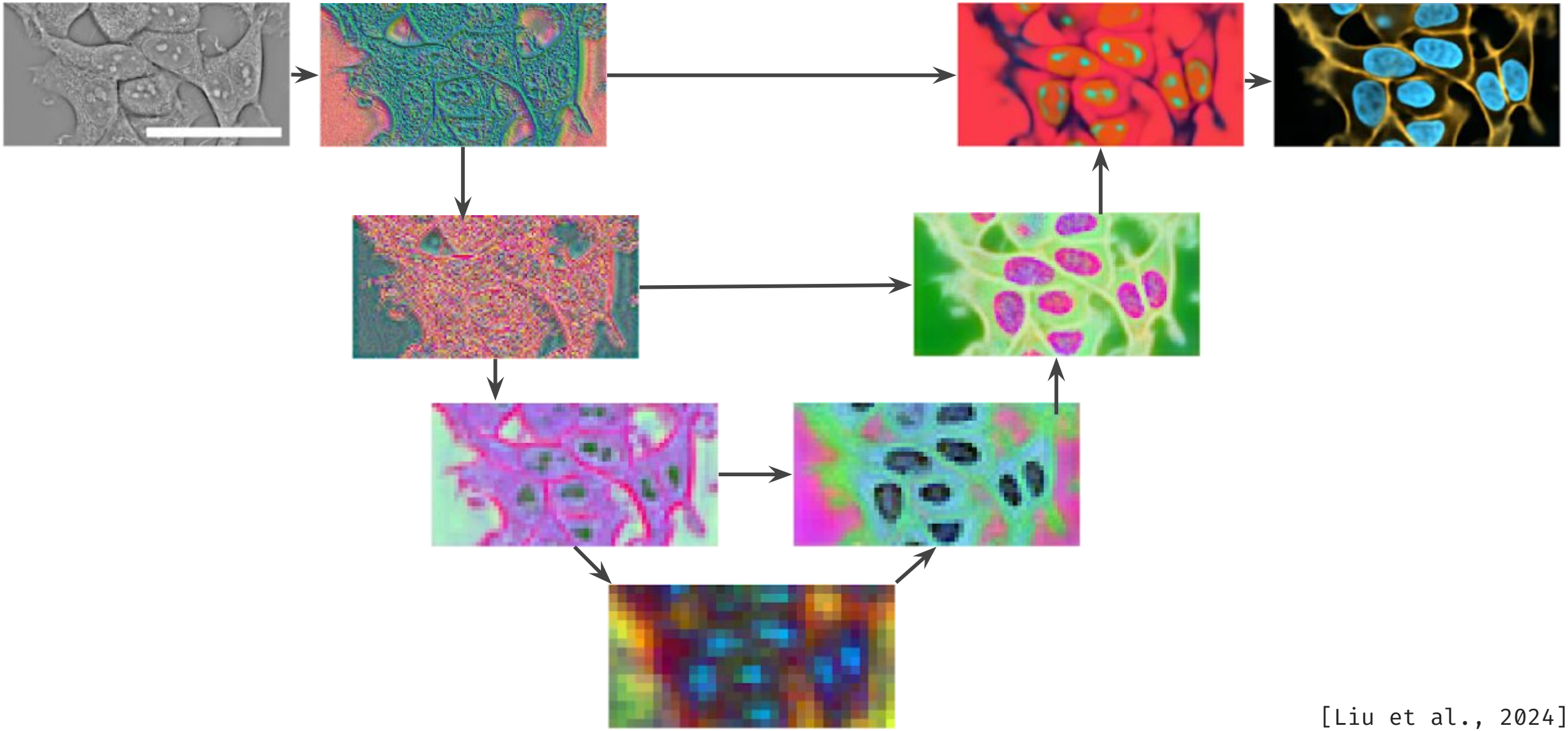
conv 3×3, ReLU
downsample 2×2
upsample 2×2
crop&concat
conv 1×1, Sigmoid

multi-scale representation

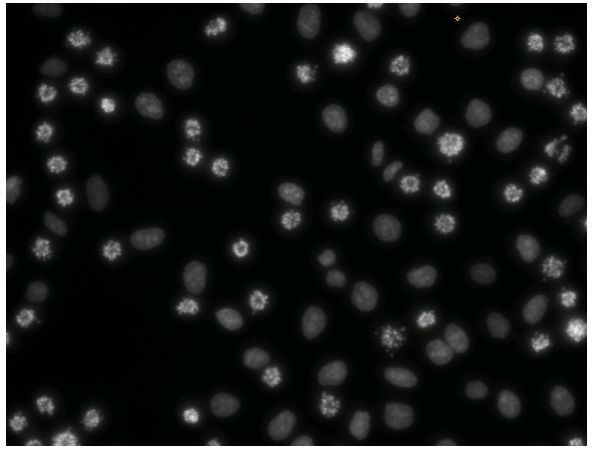


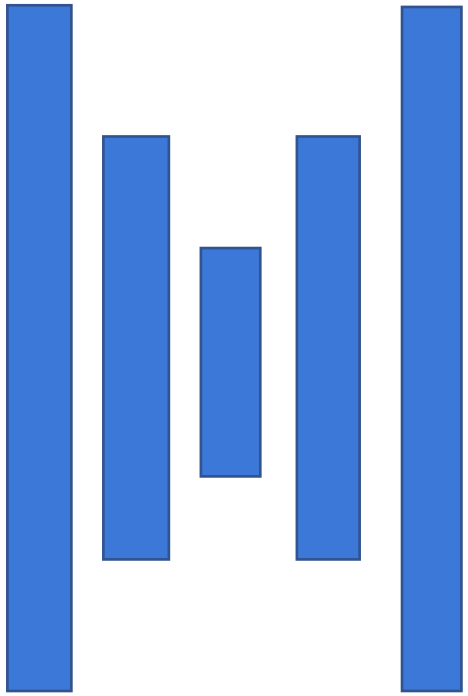
[Liu et al., 2024]

training

Forward pass

Backpropagation





Groundtruth

Some other image

Loss for training

Trying to become some other image

Current output: transformed image

Metric for validation

Go build your own U-Net!