

Deep Learning

Lecture 12

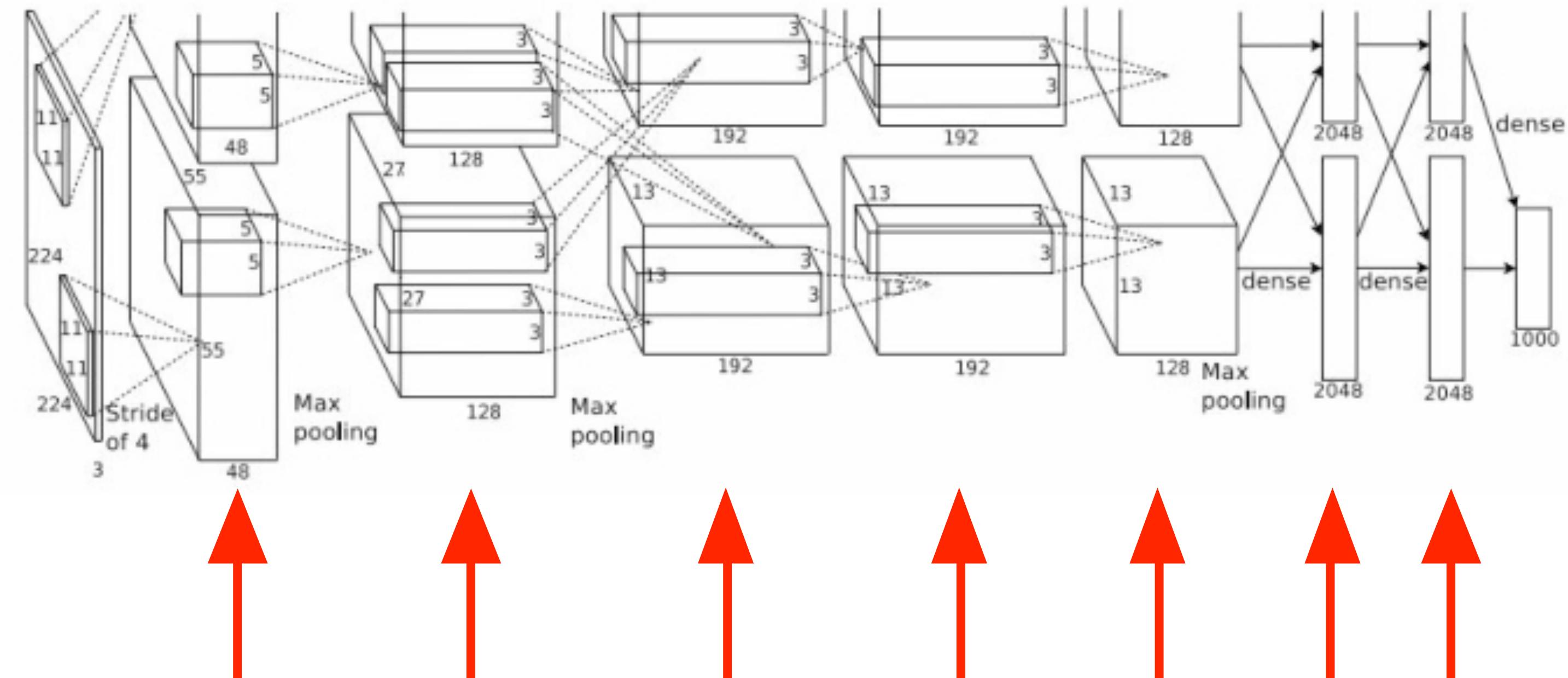
Visualizing CNNs

What's going on inside ConvNets?

This image is CC0 public domain



Input Image:
 $3 \times 224 \times 224$

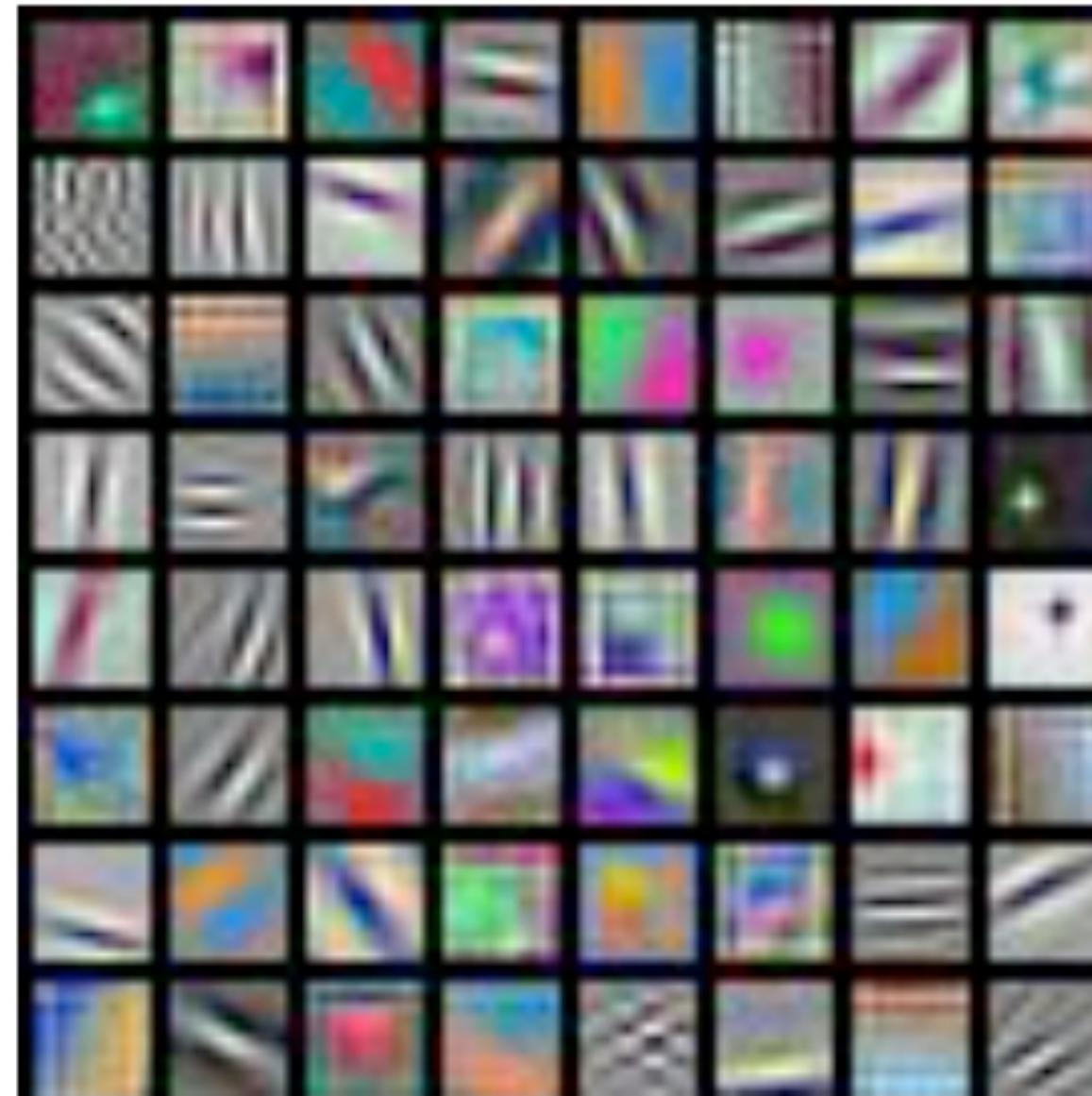


What are the intermediate features looking for?

Class Scores:
1000 numbers

Krizhevsky et al, “ImageNet Classification with Deep Convolutional Neural Networks”, NIPS 2012.
Figure reproduced with permission.

First Layer: Visualize Filters



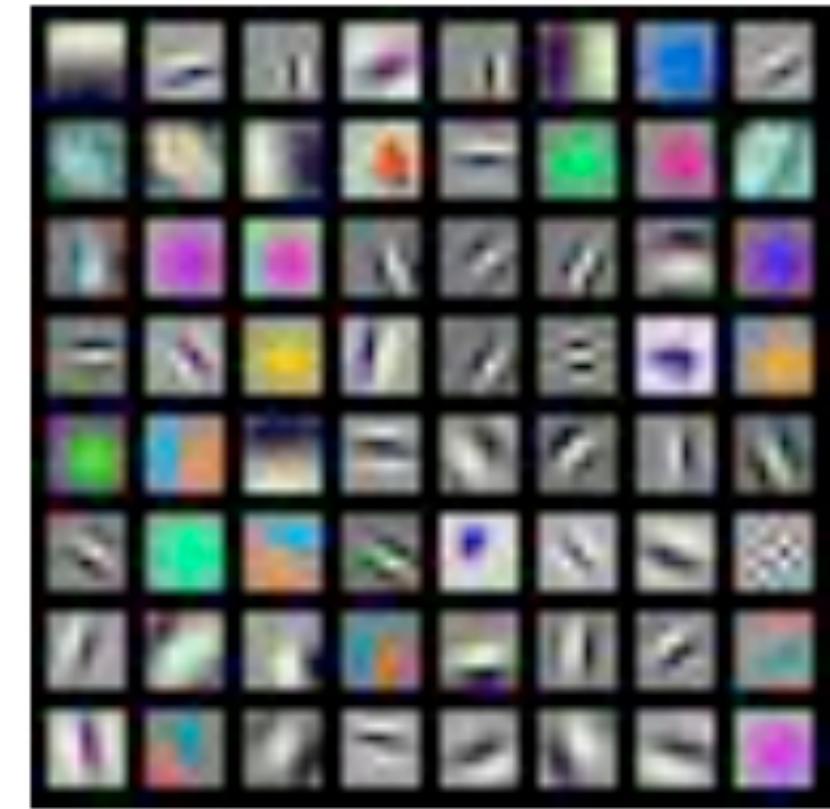
AlexNet:
 $64 \times 3 \times 11 \times 11$



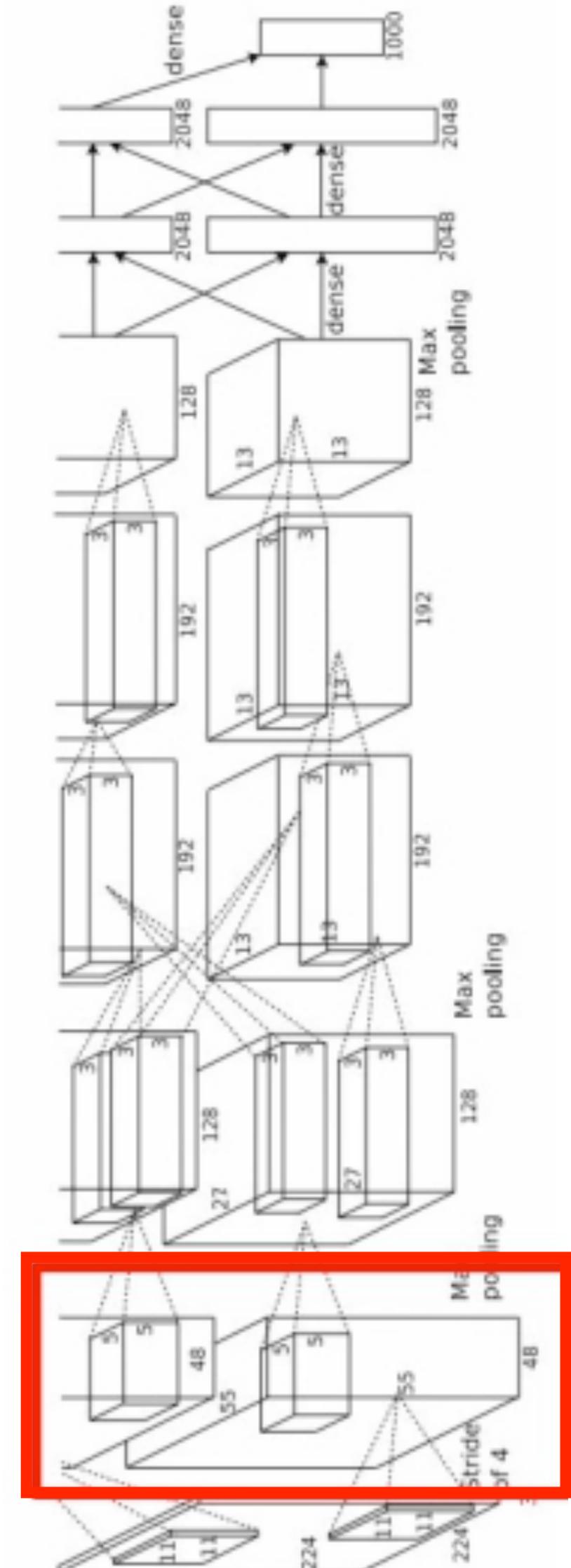
ResNet-18:
 $64 \times 3 \times 7 \times 7$



ResNet-101:
 $64 \times 3 \times 7 \times 7$



DenseNet-121:
 $64 \times 3 \times 7 \times 7$



Krizhevsky, "One weird trick for parallelizing convolutional neural networks", arXiv 2014
He et al, "Deep Residual Learning for Image Recognition", CVPR 2016
Huang et al, "Densely Connected Convolutional Networks", CVPR 2017

Visualize the filters/kernels (raw weights)

We can visualize filters at higher layers, but not that interesting

(these are taken from ConvNetJS CIFAR-10 demo)



layer 1 weights

$16 \times 3 \times 7 \times 7$



layer 2 weights

$20 \times 16 \times 7 \times 7$

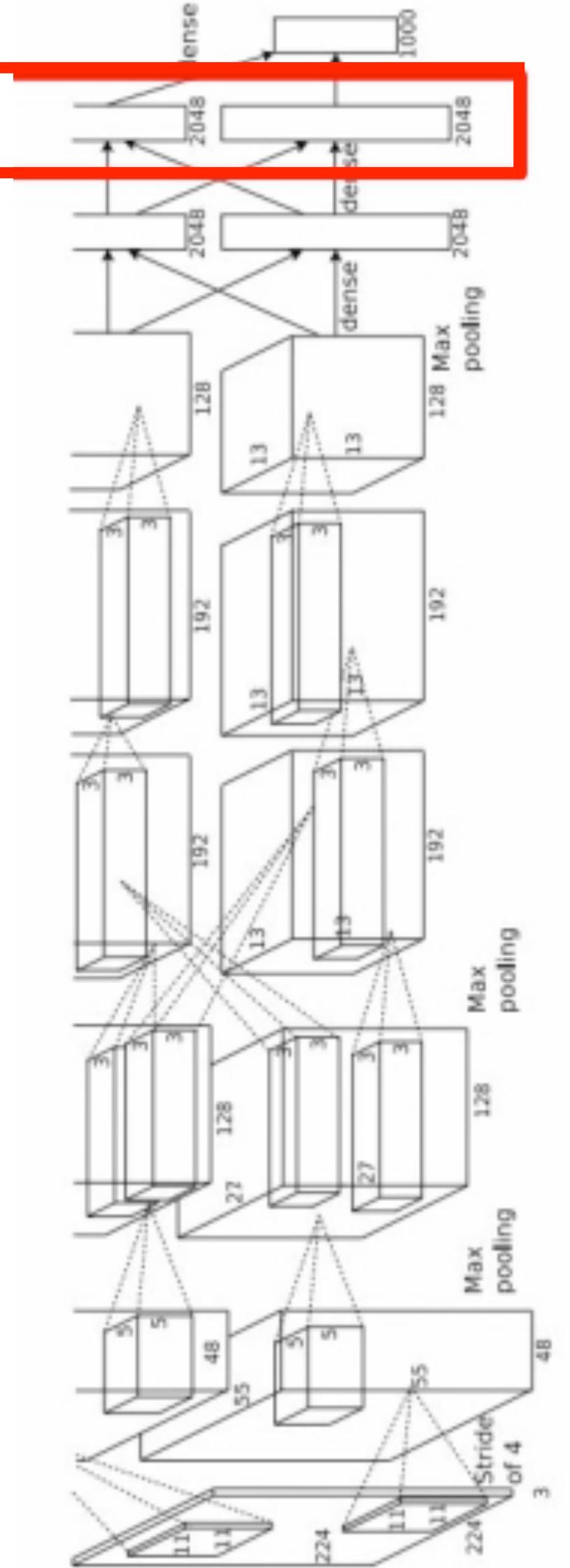


layer 3 weights

$20 \times 20 \times 7 \times 7$

Last Layer

FC7 layer

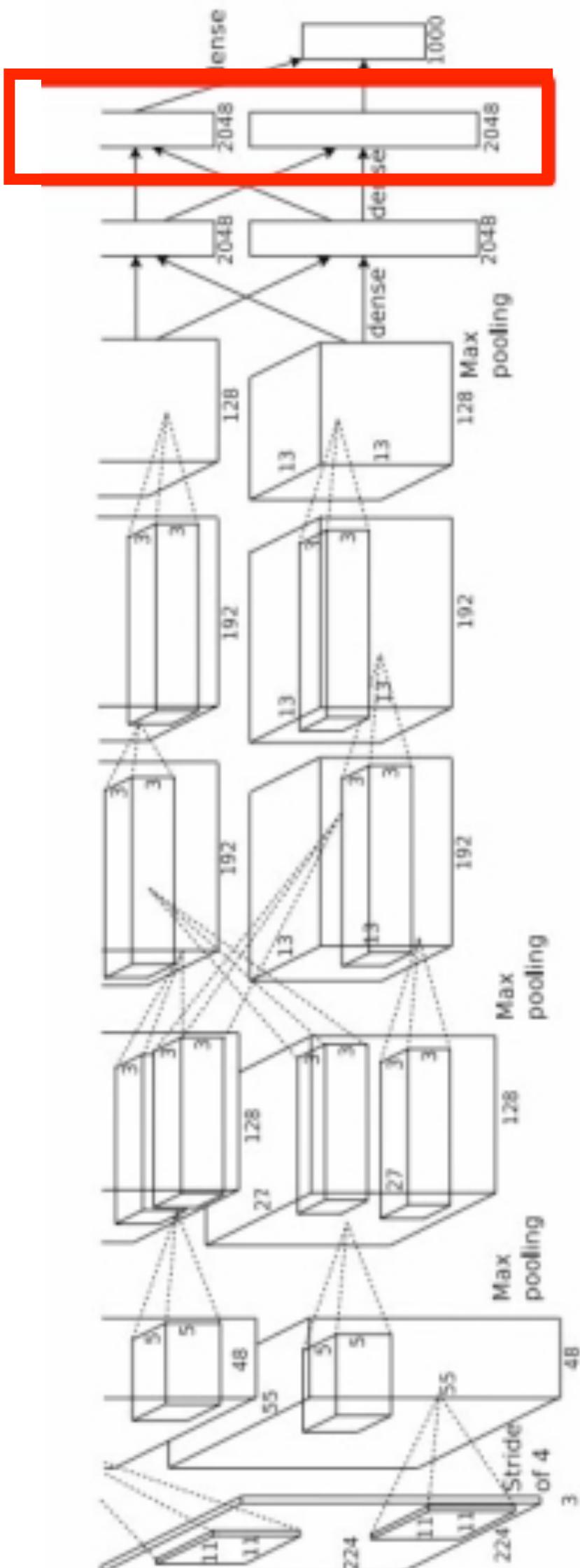


4096-dimensional feature vector for an image
(layer immediately before the classifier)

Run the network on many images, collect the
feature vectors

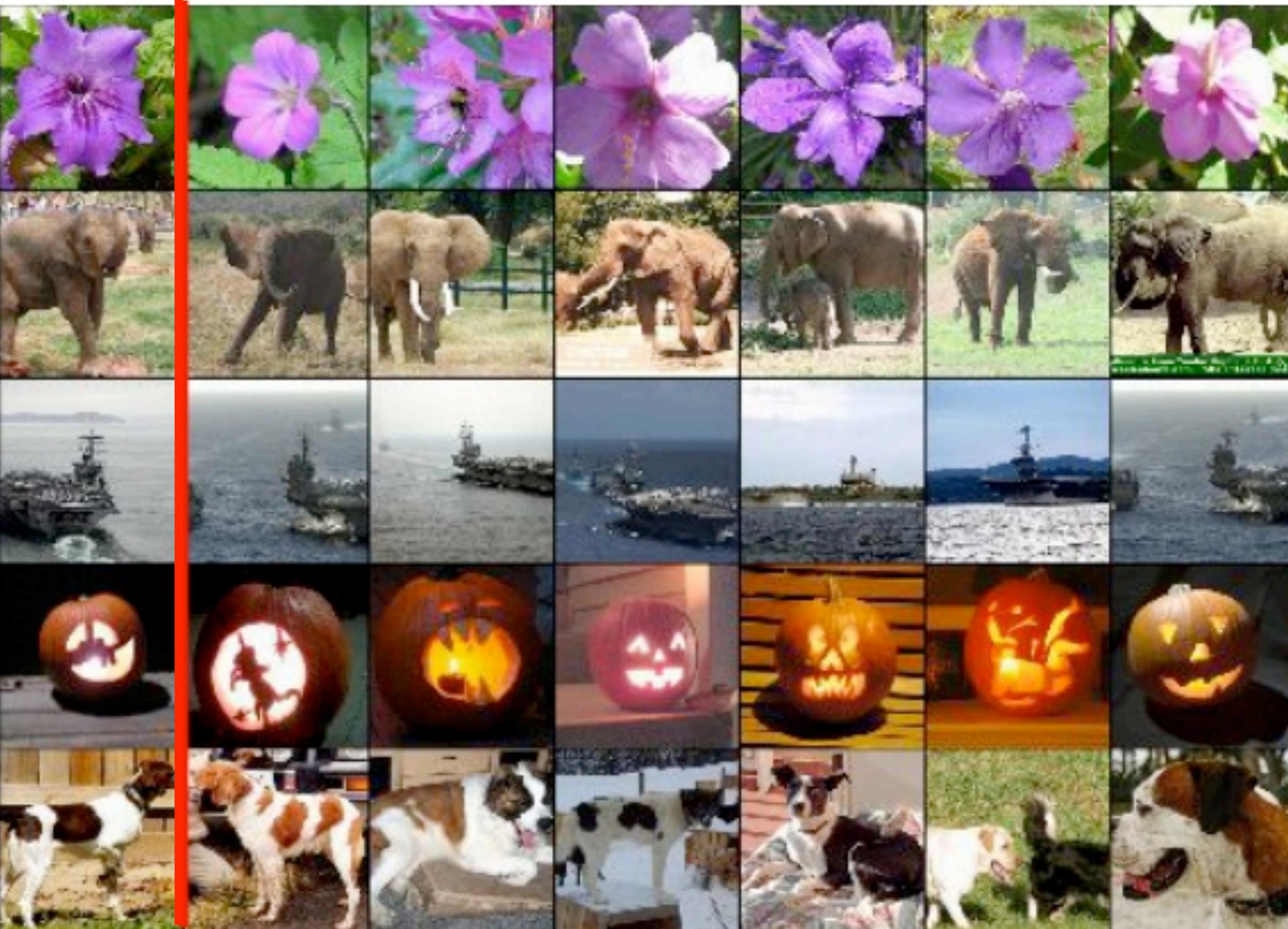
Last Layer: Nearest Neighbors

4096-dim vector



Test image L2 Nearest neighbors in feature space

Recall: Nearest neighbors in pixel space



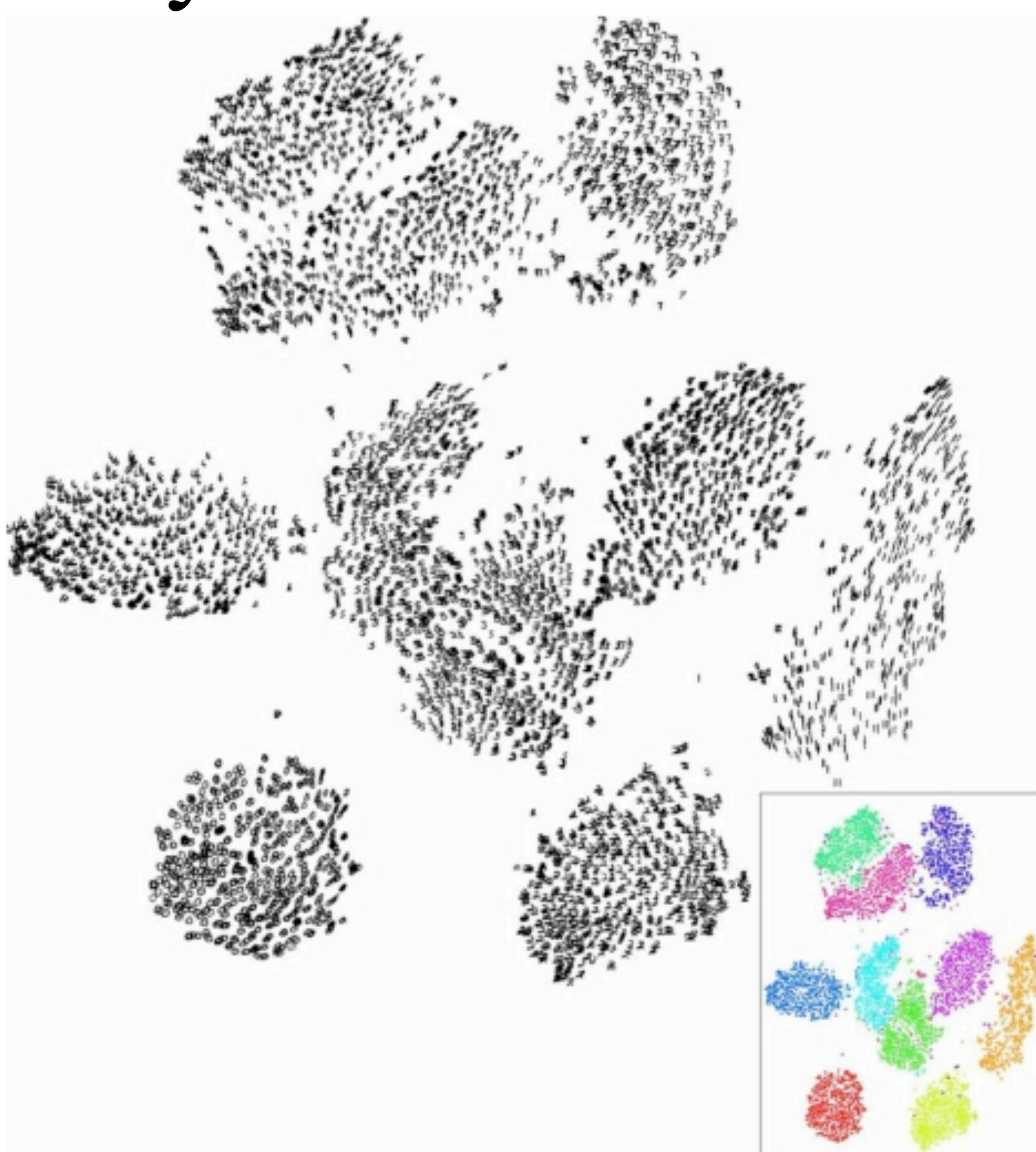
Krizhevsky et al, “ImageNet Classification with Deep Convolutional Neural Networks”, NIPS 2012.
Figures reproduced with permission.

Last Layer: Dimensionality Reduction

Visualize the “space” of FC7 feature vectors by reducing dimensionality of vectors from 4096 to 2 dimensions

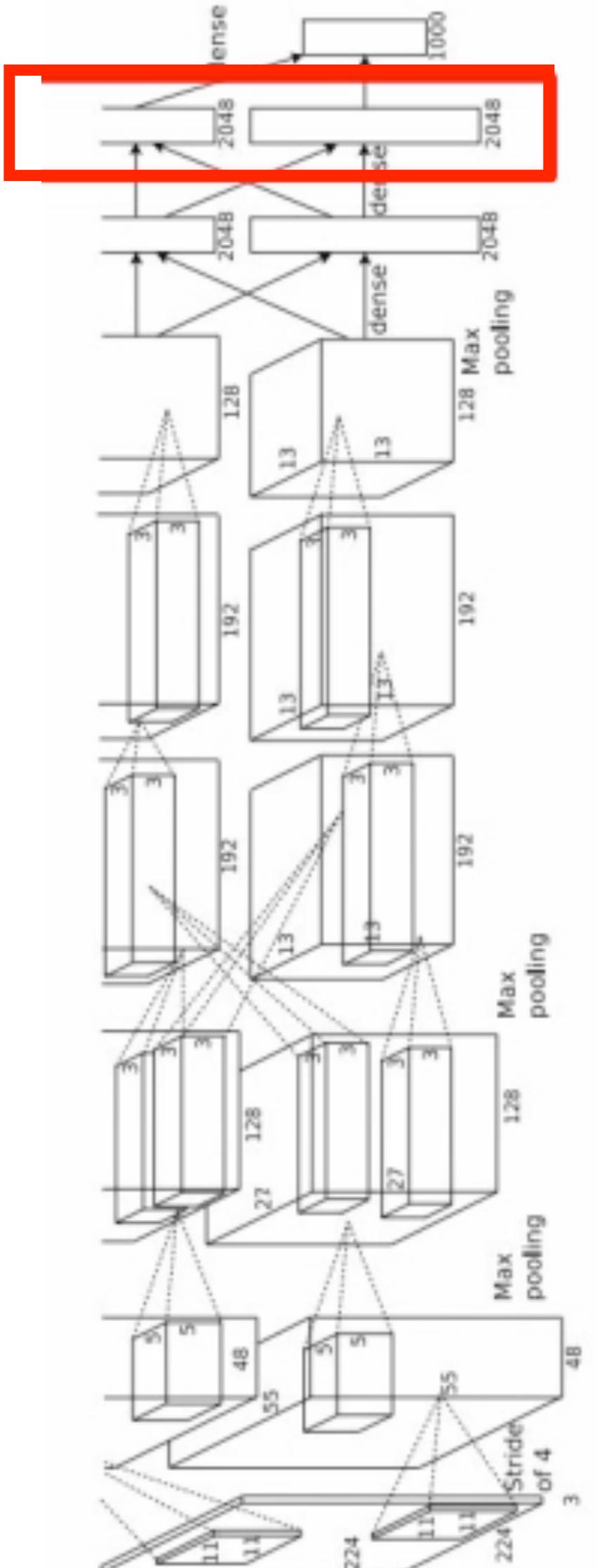
Simple algorithm: Principal Component Analysis (PCA)

More complex: t-SNE

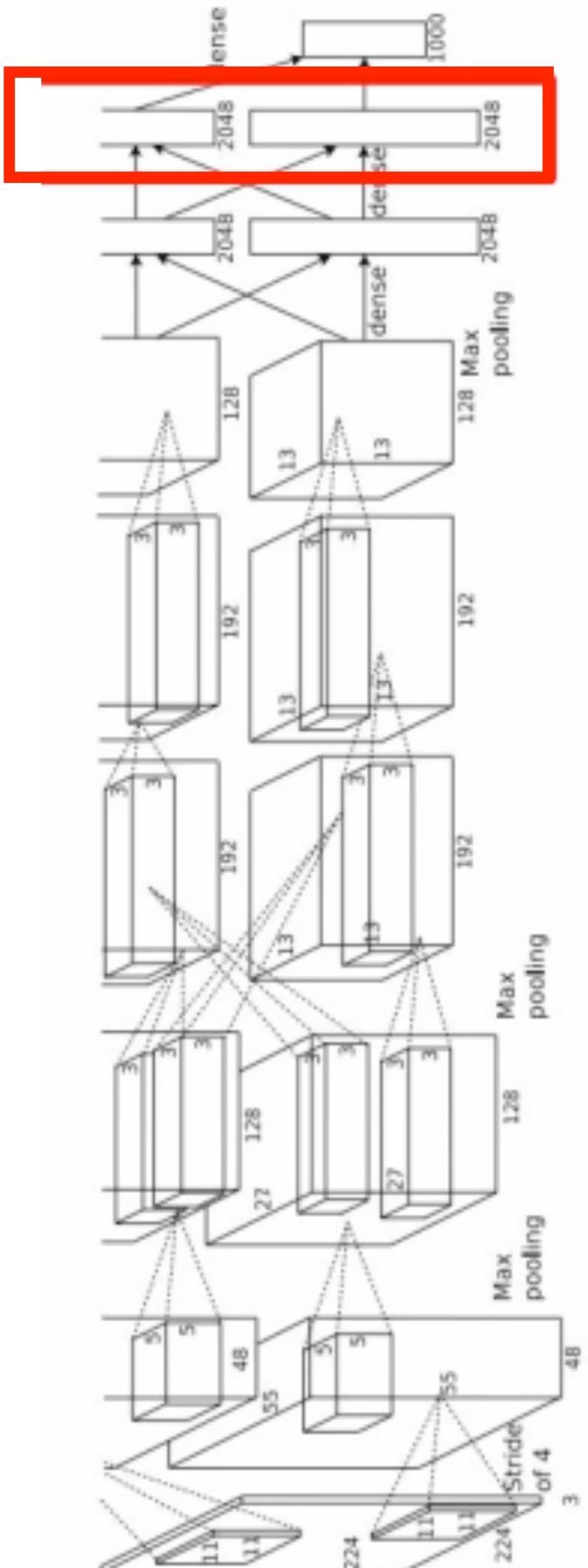


Van der Maaten and Hinton, “Visualizing Data using t-SNE”, JMLR 2008

Figure copyright Laurens van der Maaten and Geoff Hinton, 2008. Reproduced with permission.



Last Layer: Dimensionality Reduction

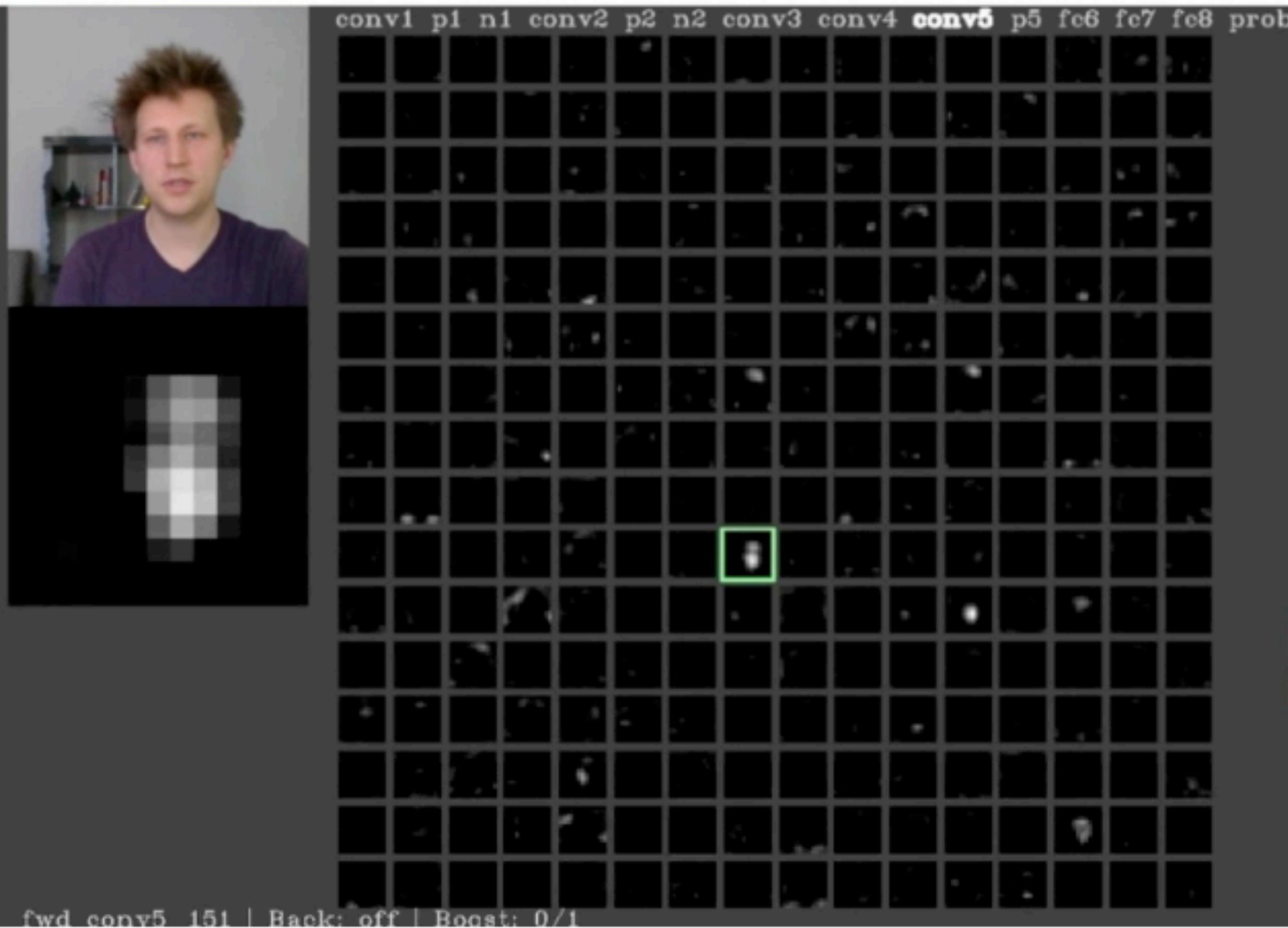


Van der Maaten and Hinton, “Visualizing Data using t-SNE”, JMLR 2008
Krizhevsky et al, “ImageNet Classification with Deep Convolutional Neural Networks”, NIPS 2012.
Figure reproduced with permission.

See high-resolution versions at
<http://cs.stanford.edu/people/karpathy/cnnembed/>

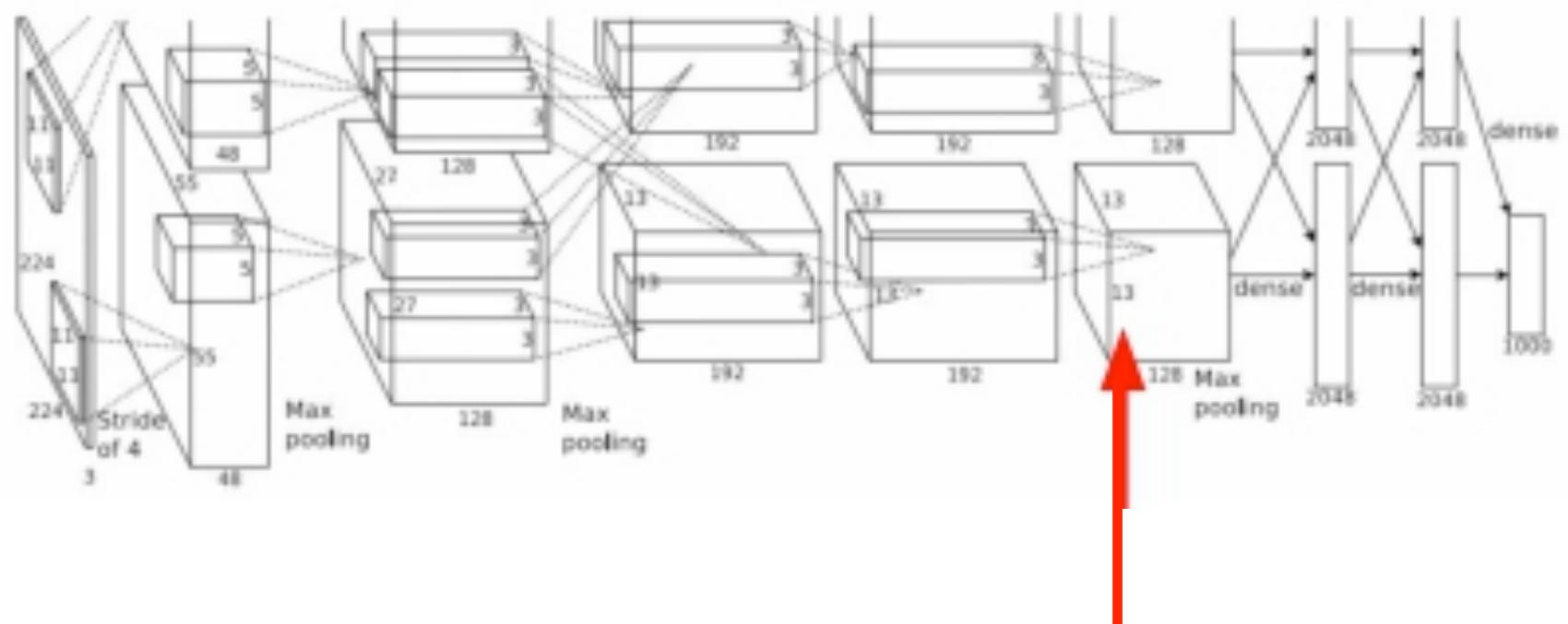
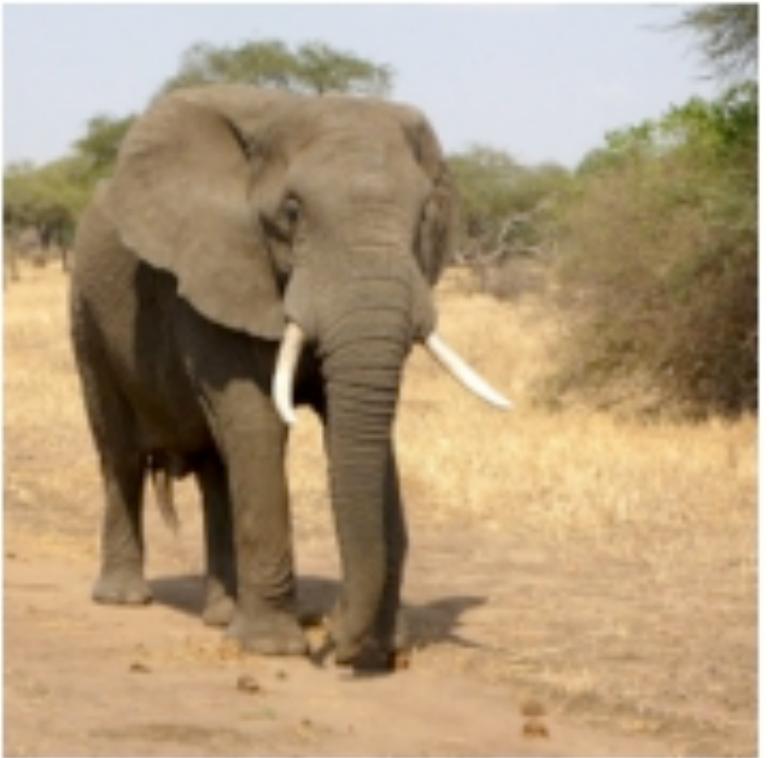
Visualizing Activations

conv5 feature map is
128x13x13; visualize
as 128 13x13
grayscale images



Yosinski et al, “Understanding Neural Networks Through Deep Visualization”, ICML DL Workshop 2014.
Figure copyright Jason Yosinski, 2014. Reproduced with permission.

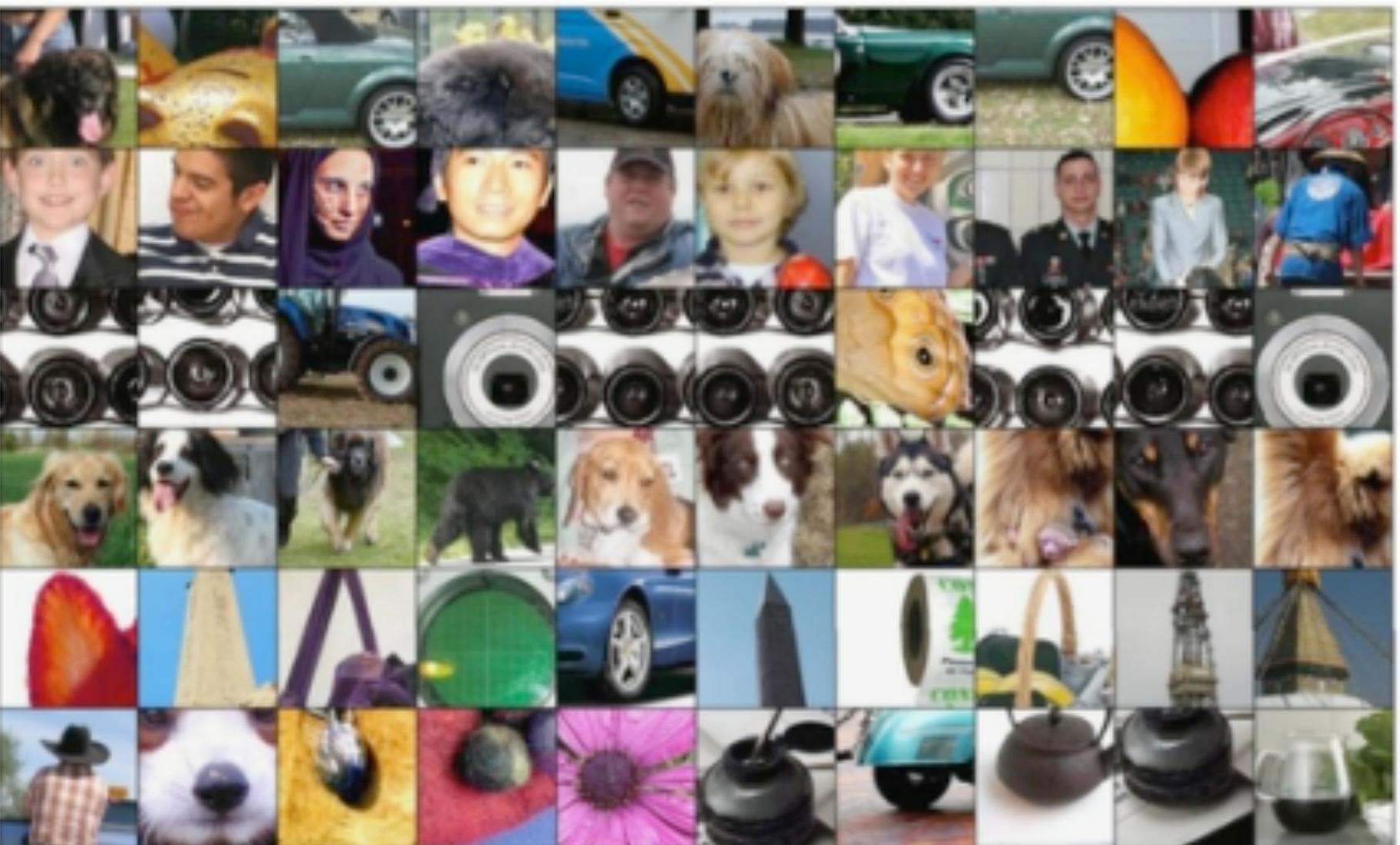
Maximally Activating Patches



Pick a layer and a channel; e.g. conv5 is $128 \times 13 \times 13$, pick channel 17/128

Run many images through the network,
record values of chosen channel

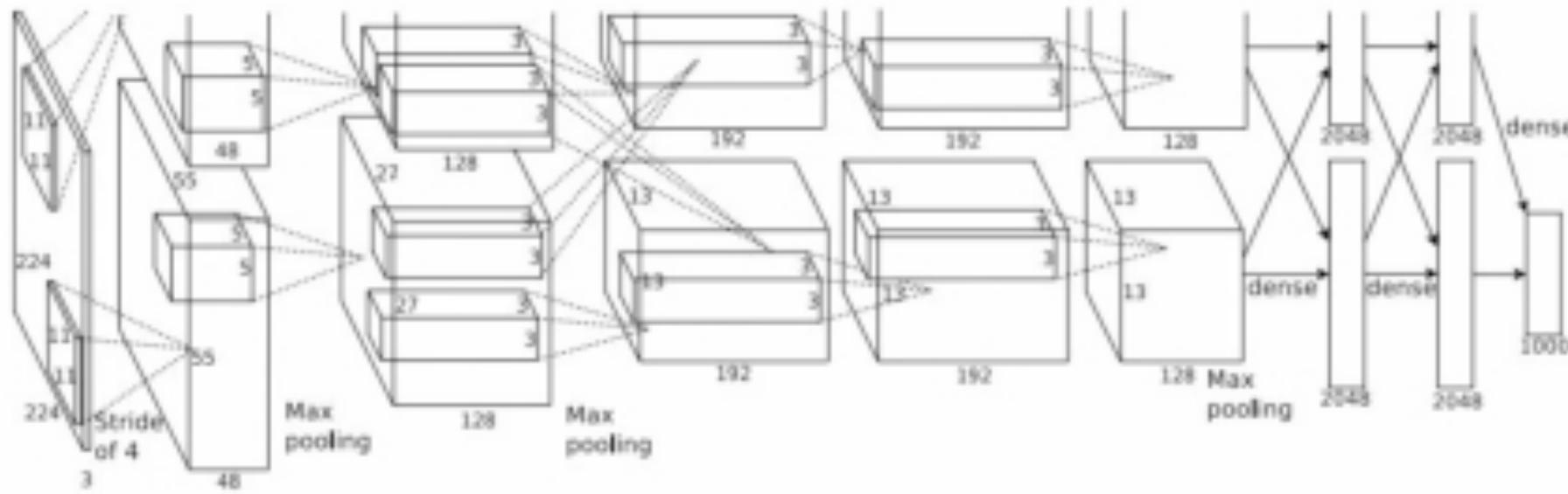
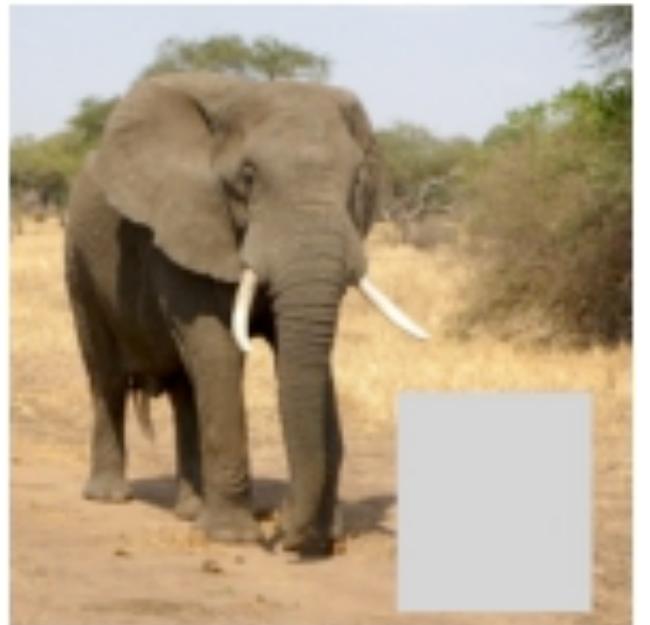
Visualize image patches that correspond
to maximal activations



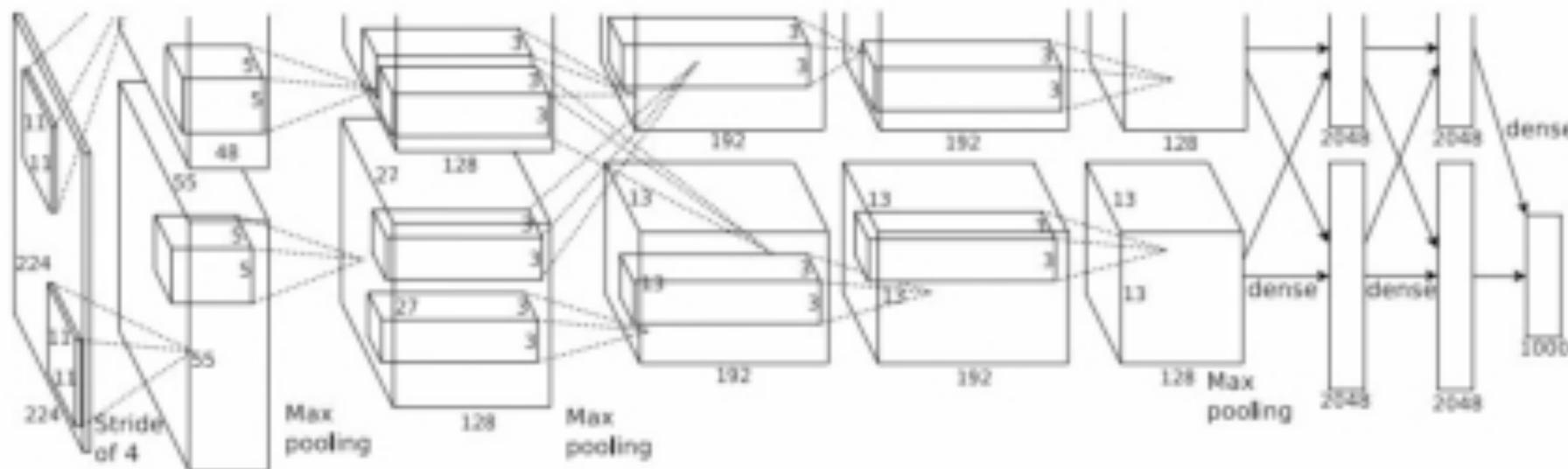
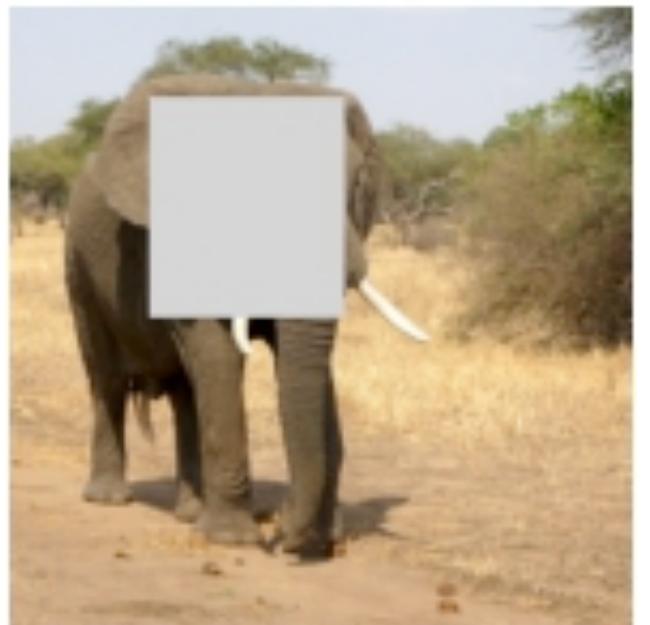
Springenberg et al, “Striving for Simplicity: The All Convolutional Net”, ICLR Workshop 2015
Figure copyright Jost Tobias Springenberg, Alexey Dosovitskiy, Thomas Brox, Martin Riedmiller, 2015;
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Which pixels matter: Saliency vs Occlusion

Mask part of the image before feeding to CNN,
check how much predicted probabilities change



$$P(\text{elephant}) = 0.95$$



$$P(\text{elephant}) = 0.75$$

Boat image is CC0 public domain

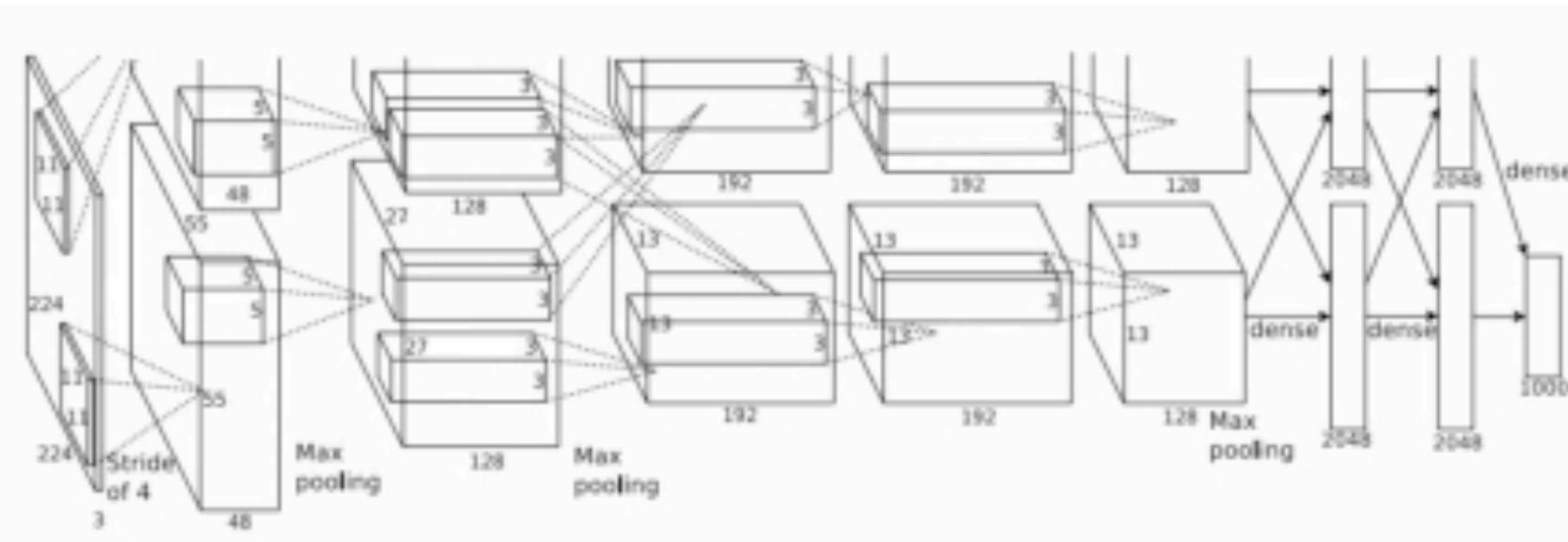
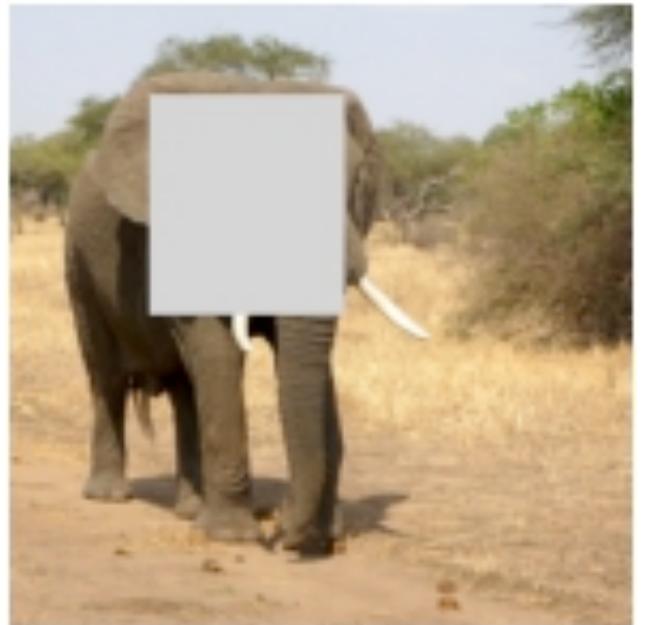
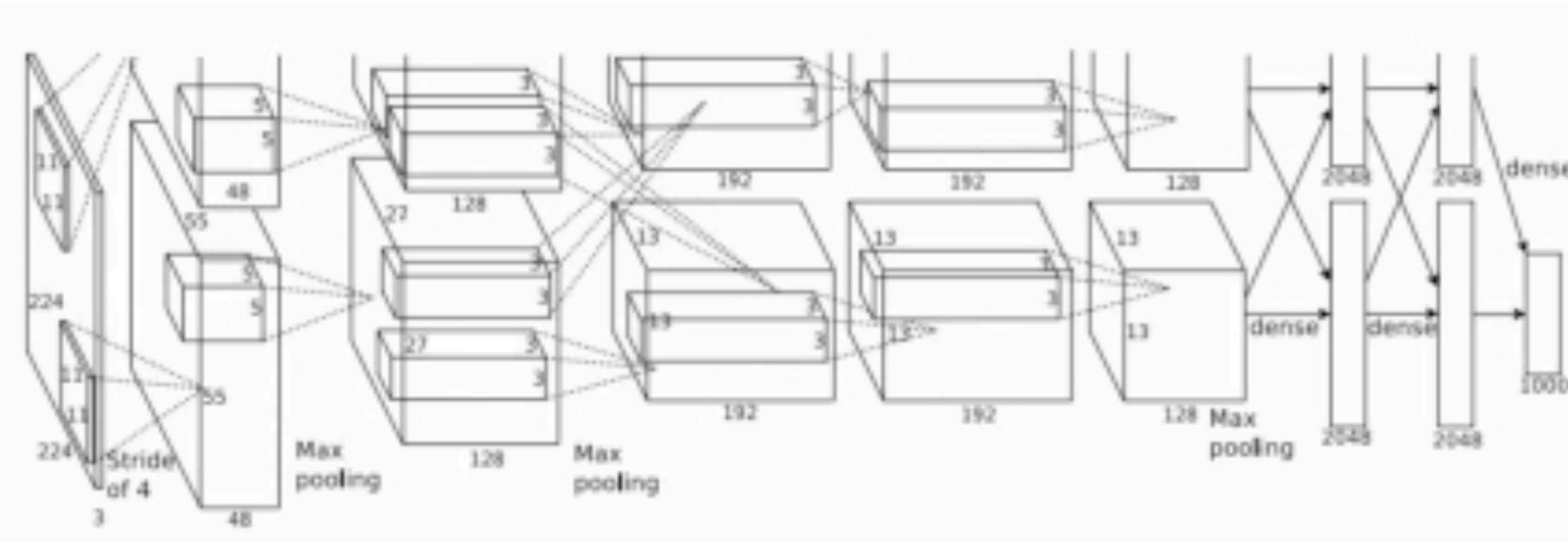
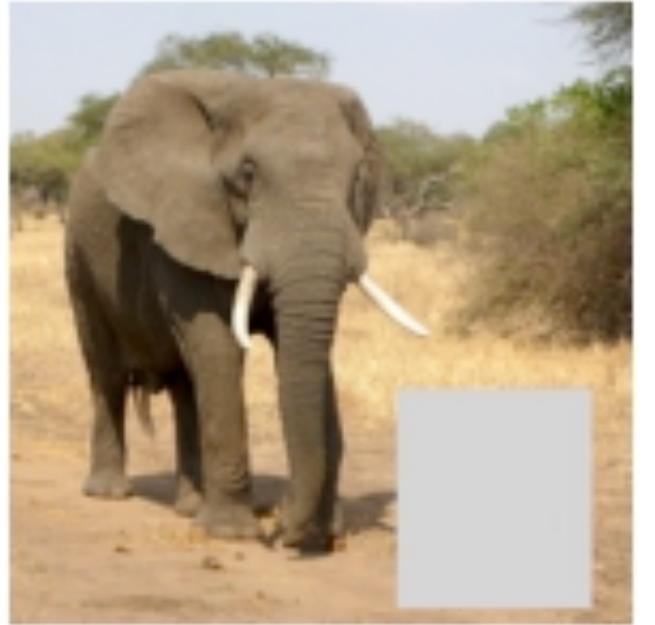
Elephant image is CC0 public domain

Go-Karts image is CC0 public domain

Zeiler and Fergus, "Visualizing and Understanding Convolutional Networks", ECCV 2014

Which pixels matter: Saliency vs Occlusion

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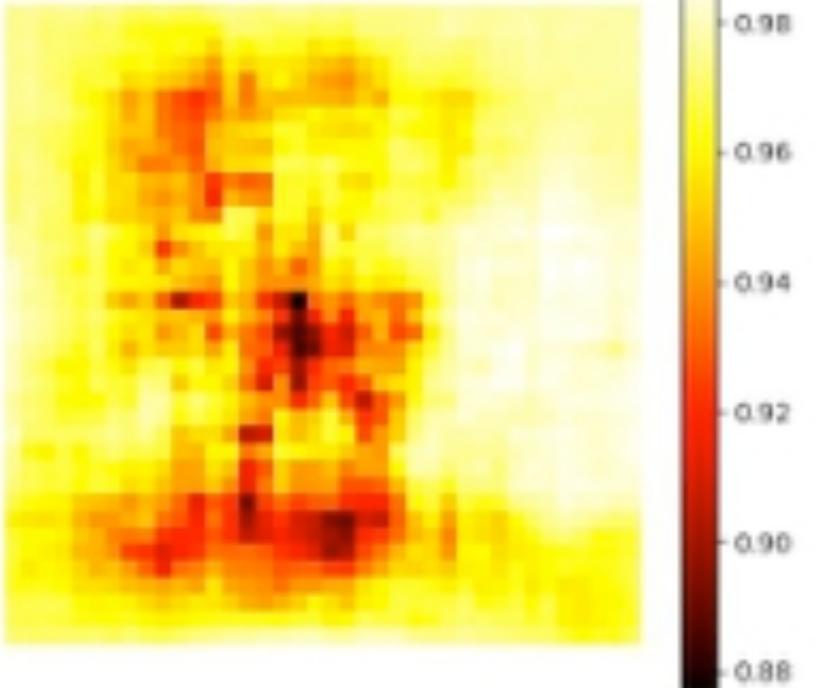


Zeiler and Fergus, "Visualizing and Understanding Convolutional Networks", ECCV 2014

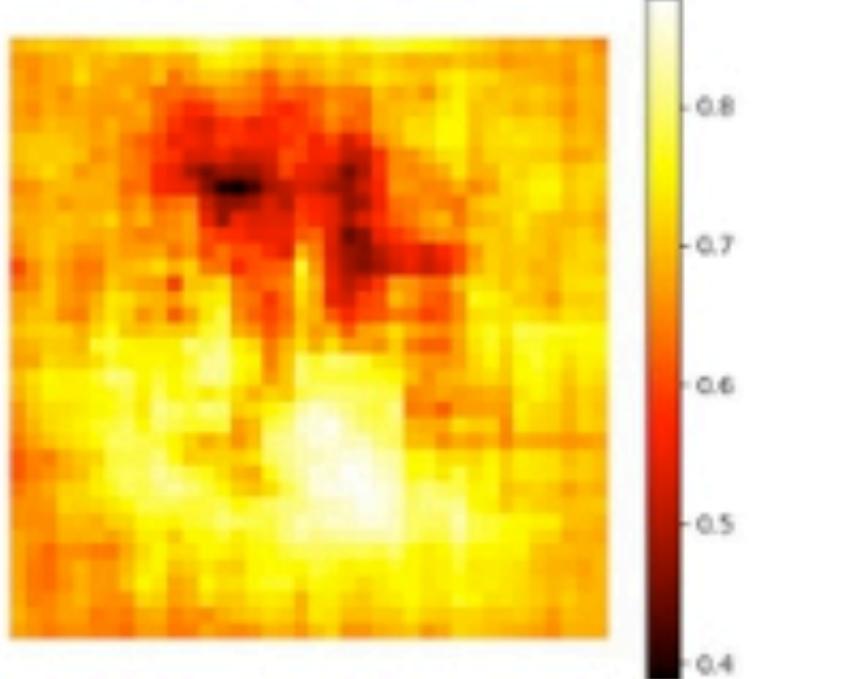
Boat image is CC0 public domain
Elephant image is CC0 public domain
Go-Karts image is CC0 public domain



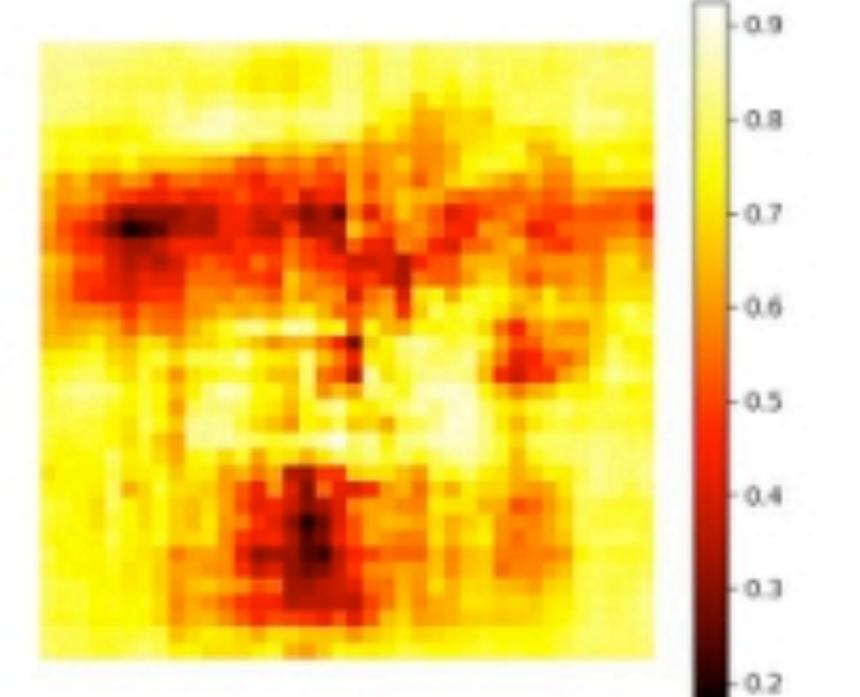
schooner



African elephant, *Loxodonta africana*

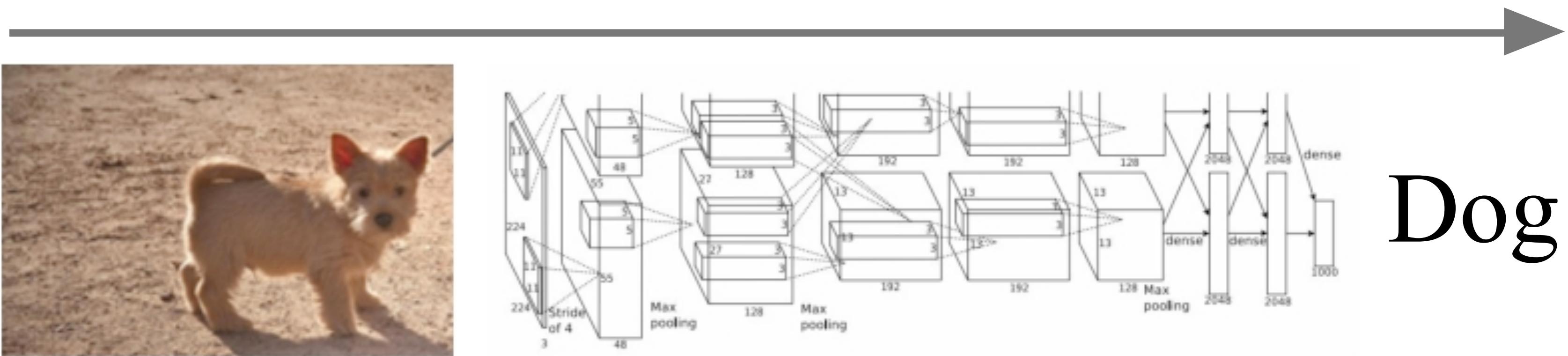


go-kart



Which pixels matter: Saliency via Backprop

Forward pass: Compute probabilities

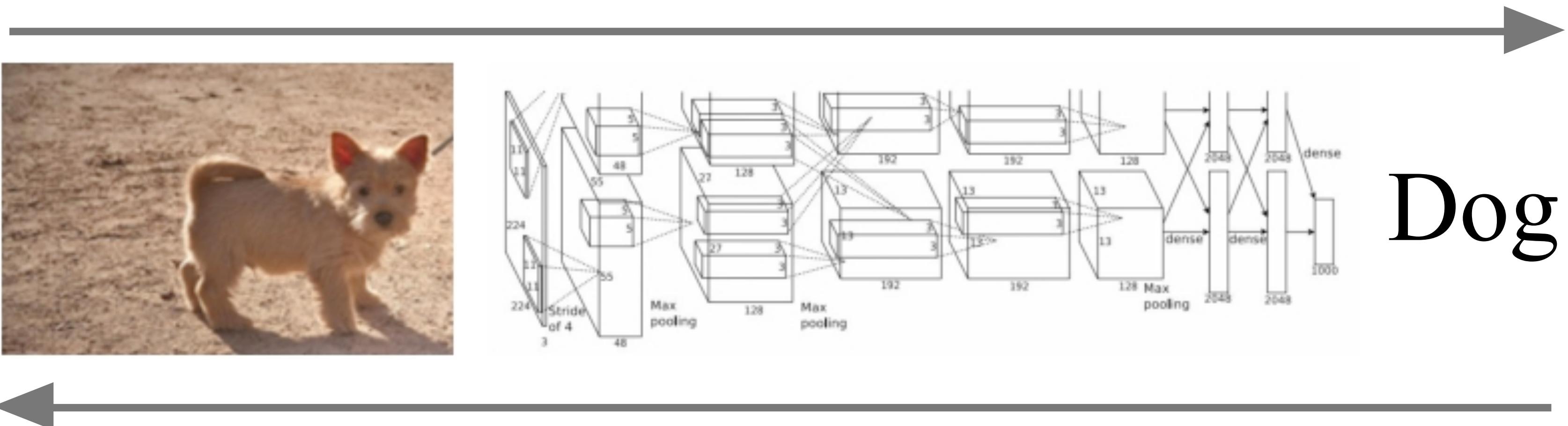


Simonyan, Vedaldi, and Zisserman, “Deep Inside Convolutional Networks: Visualising Image Classification Models and Saliency Maps”, ICLR Workshop 2014.

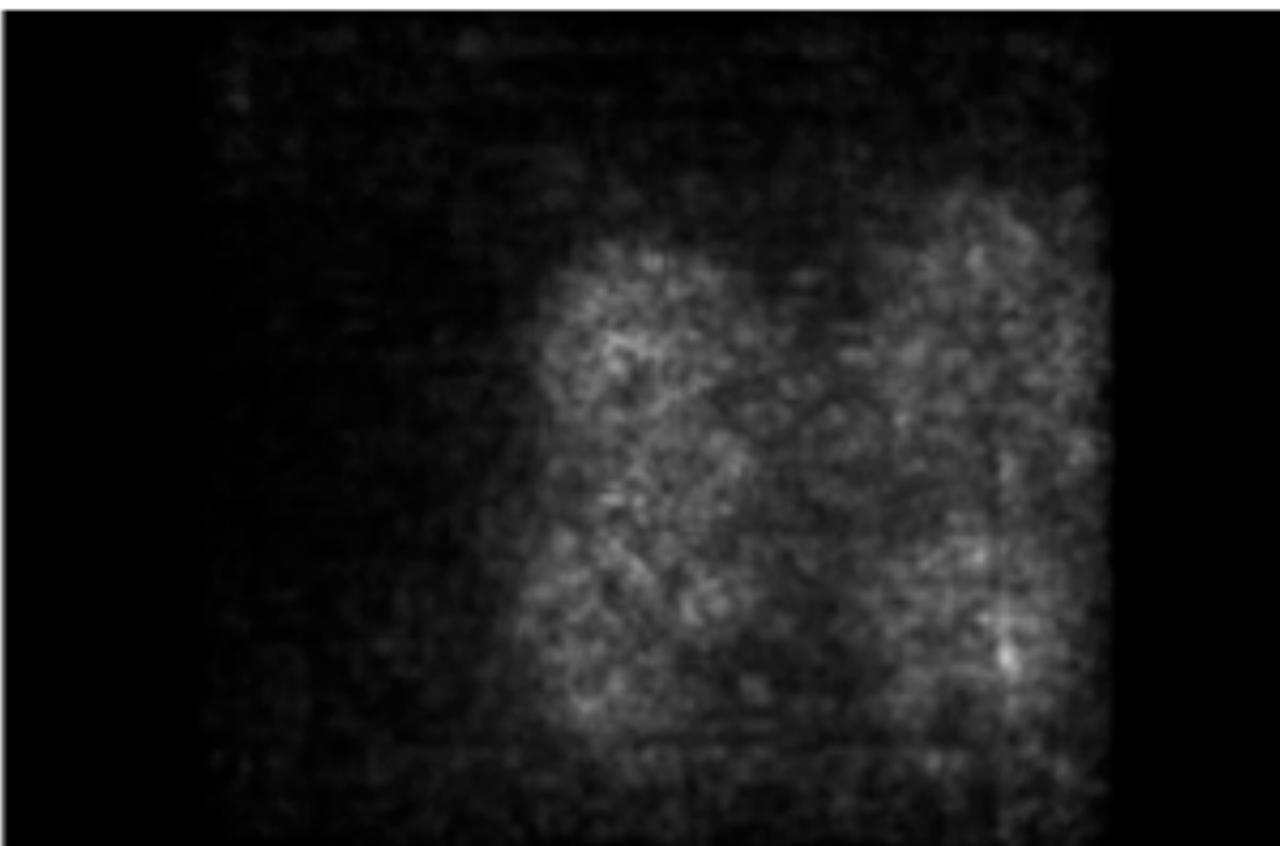
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Which pixels matter: Saliency via Backprop

Forward pass: Compute probabilities



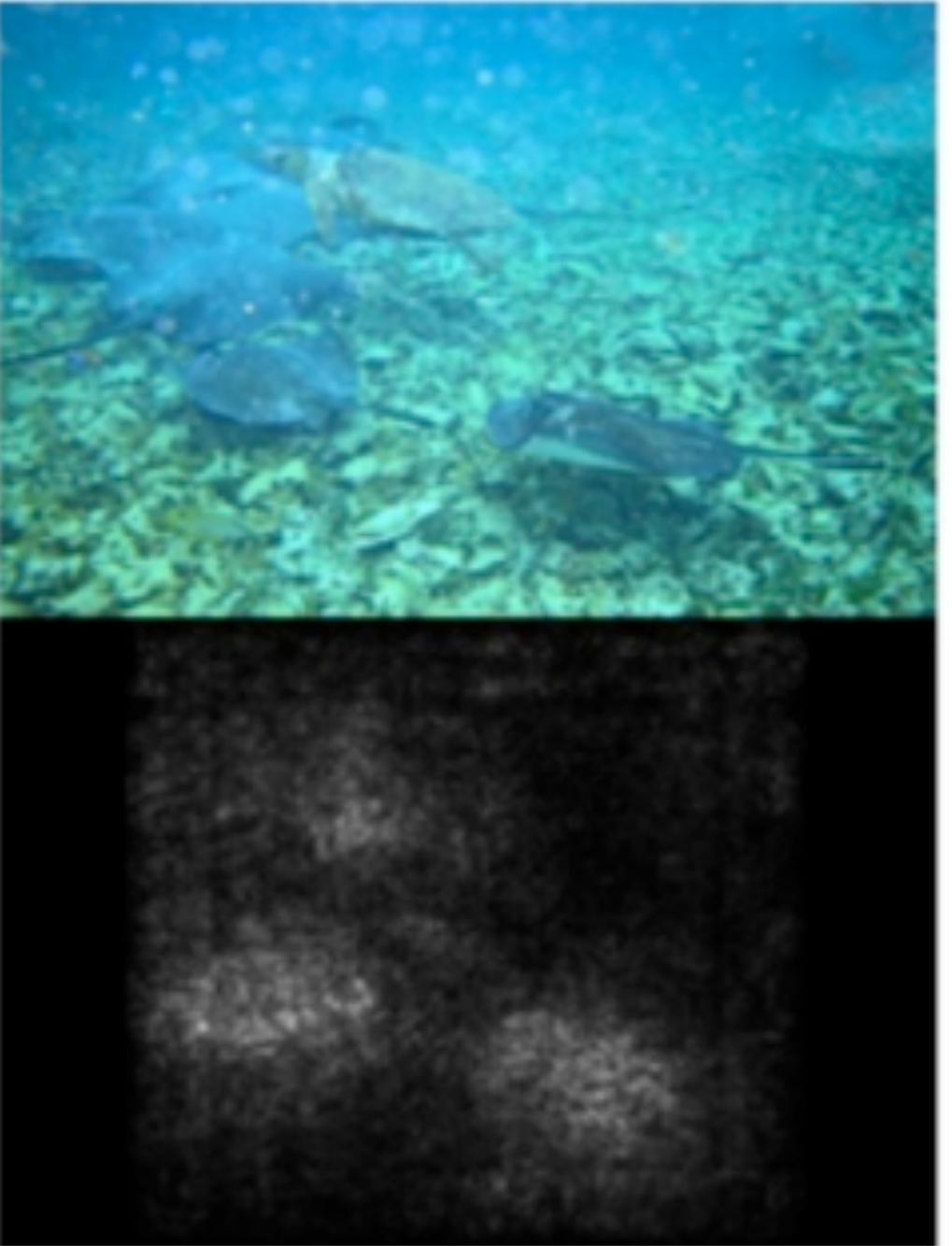
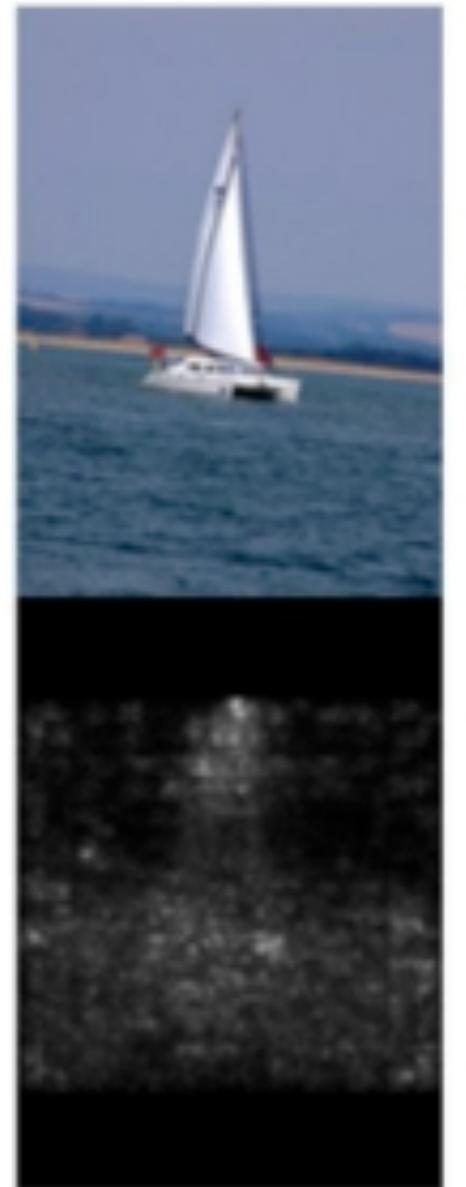
Compute gradient of (unnormalized) class score with respect to image pixels, take absolute value and max over RGB channels



Simonyan, Vedaldi, and Zisserman, “Deep Inside Convolutional Networks: Visualising Image Classification Models and Saliency Maps”, ICLR Workshop 2014.

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Saliency Maps

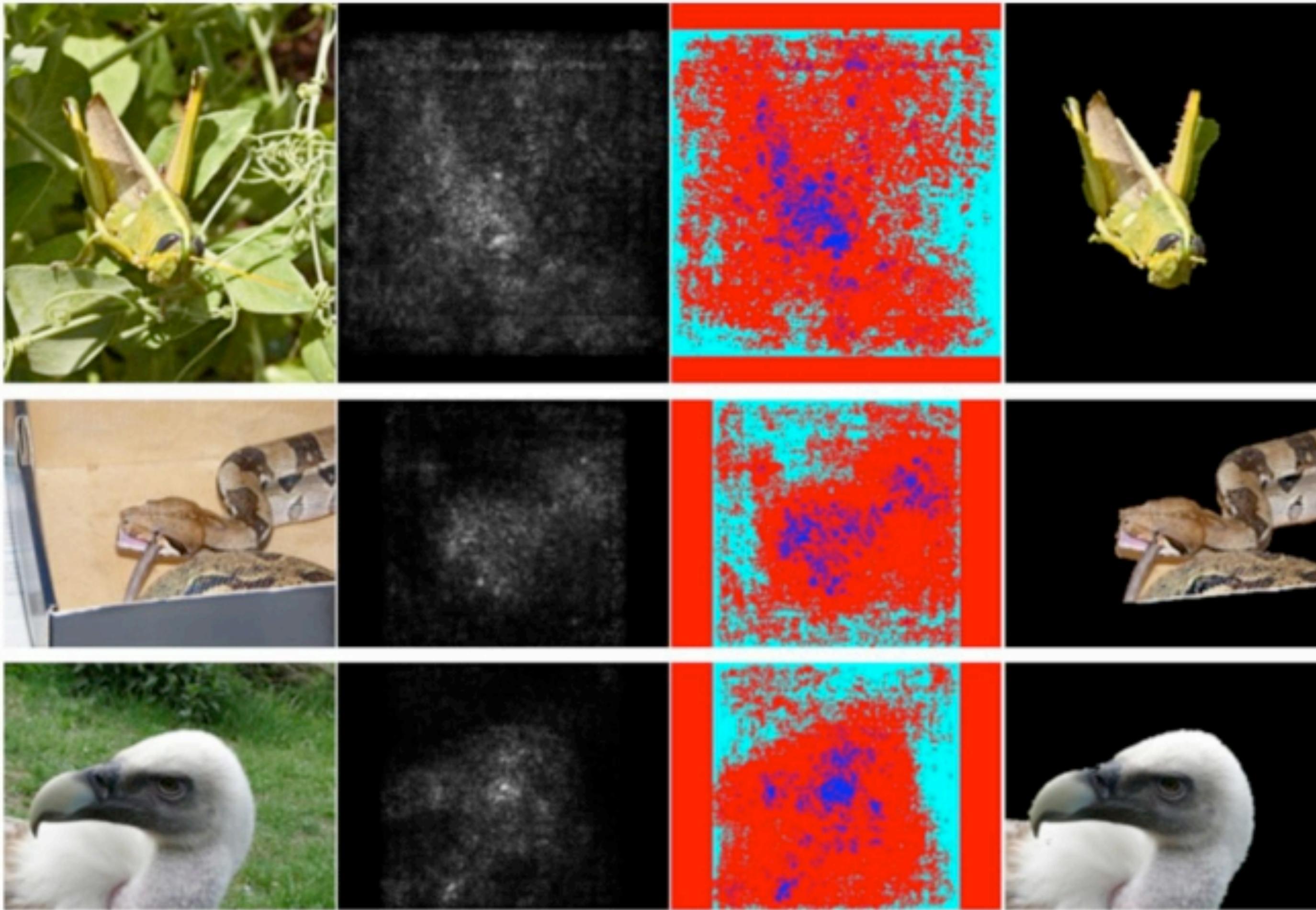


Simonyan, Vedaldi, and Zisserman, “Deep Inside Convolutional Networks: Visualising Image Classification Models and Saliency Maps”, ICLR Workshop 2014.

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Saliency Maps: Segmentation without supervision

Use GrabCut on
saliency map

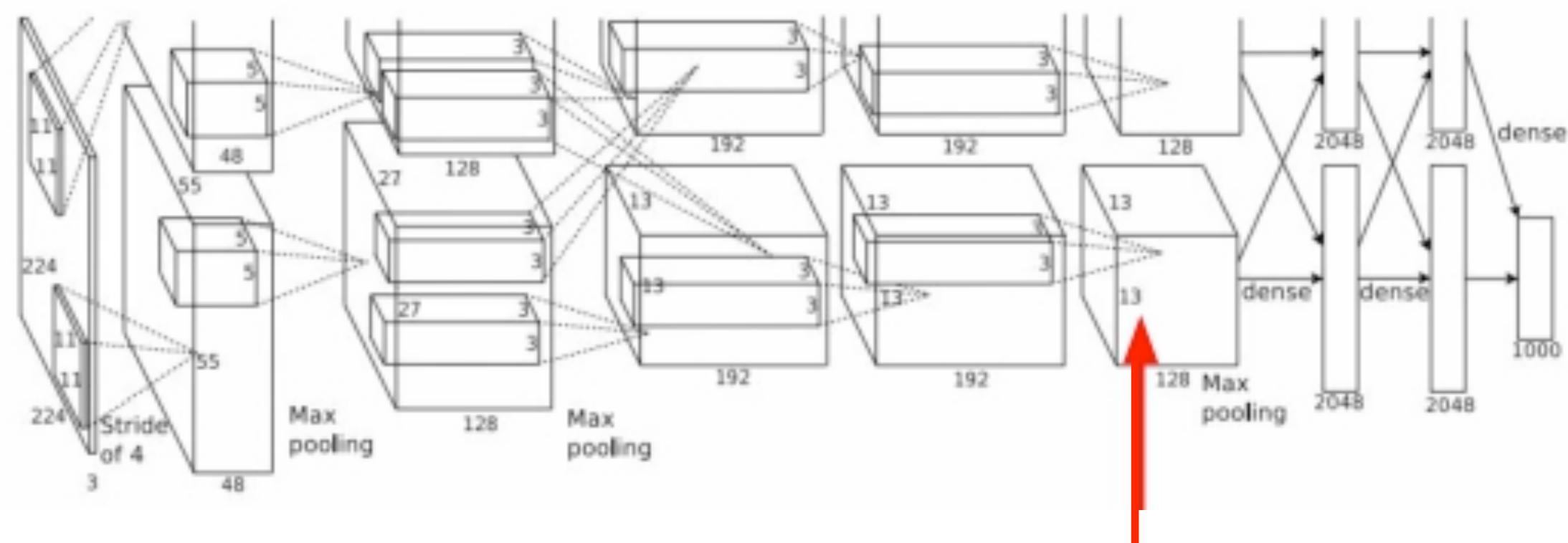


Simonyan, Vedaldi, and Zisserman, “Deep Inside Convolutional Networks: Visualising Image Classification Models and Saliency Maps”, ICLR Workshop 2014.

Figures copyright Karen Simonyan, Andrea Vedaldi, and Andrew Zisserman, 2014; reproduced with permission.

Rother et al, “Grabcut: Interactive foreground extraction using iterated graph cuts”, ACM TOG 2004

Intermediate Features via (guided) backprop

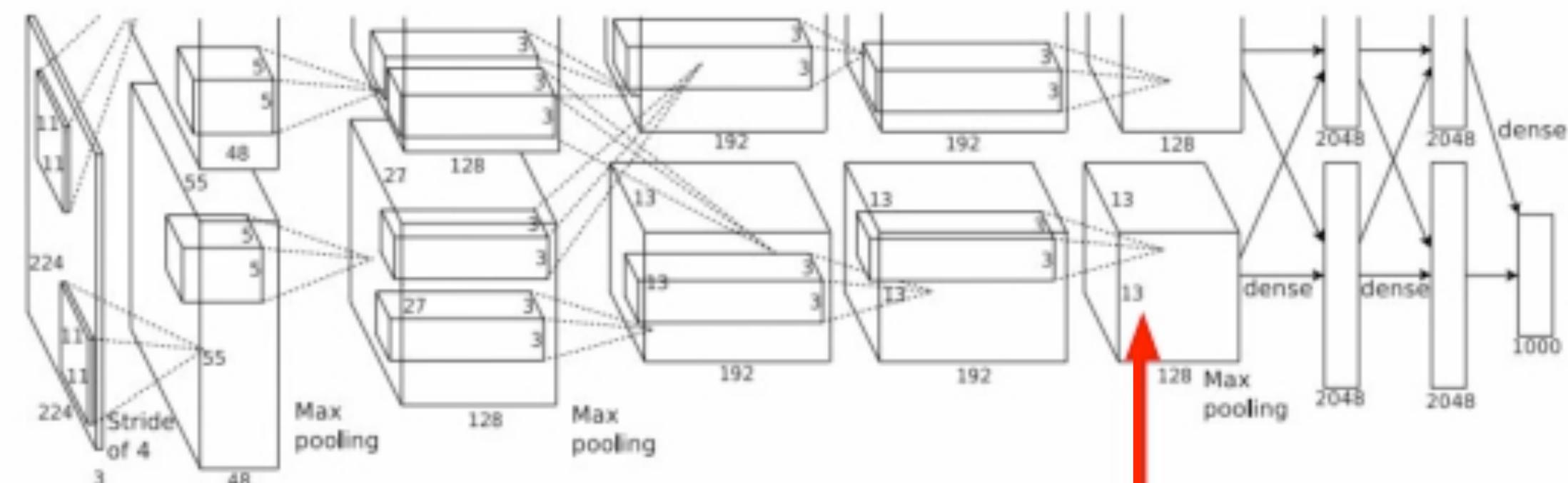


Pick a single intermediate neuron, e.g. one value in $128 \times 13 \times 13$ conv5 feature map

Compute gradient of neuron value with respect to image pixels

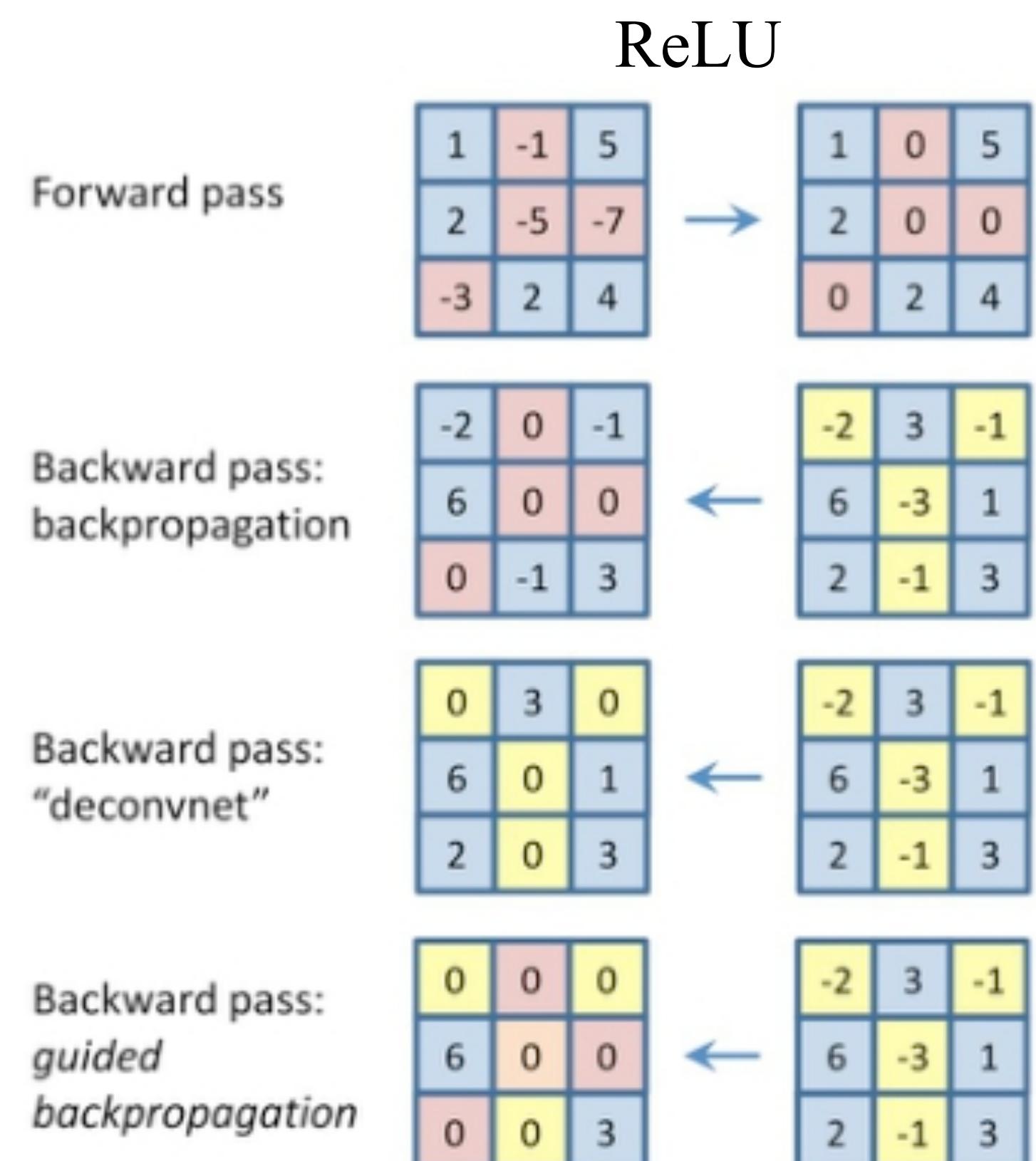
Zeiler and Fergus, "Visualizing and Understanding Convolutional Networks", ECCV 2014
Springenberg et al, "Striving for Simplicity: The All Convolutional Net", ICLR Workshop 2015

Intermediate Features via (guided) backprop



Pick a single intermediate neuron, e.g. one value in $128 \times 13 \times 13$ conv5 feature map

Compute gradient of neuron value with respect to image pixels



Images come out nicer if you only backprop positive gradients through each ReLU (guided backprop)

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Intermediate features via (guided) backprop



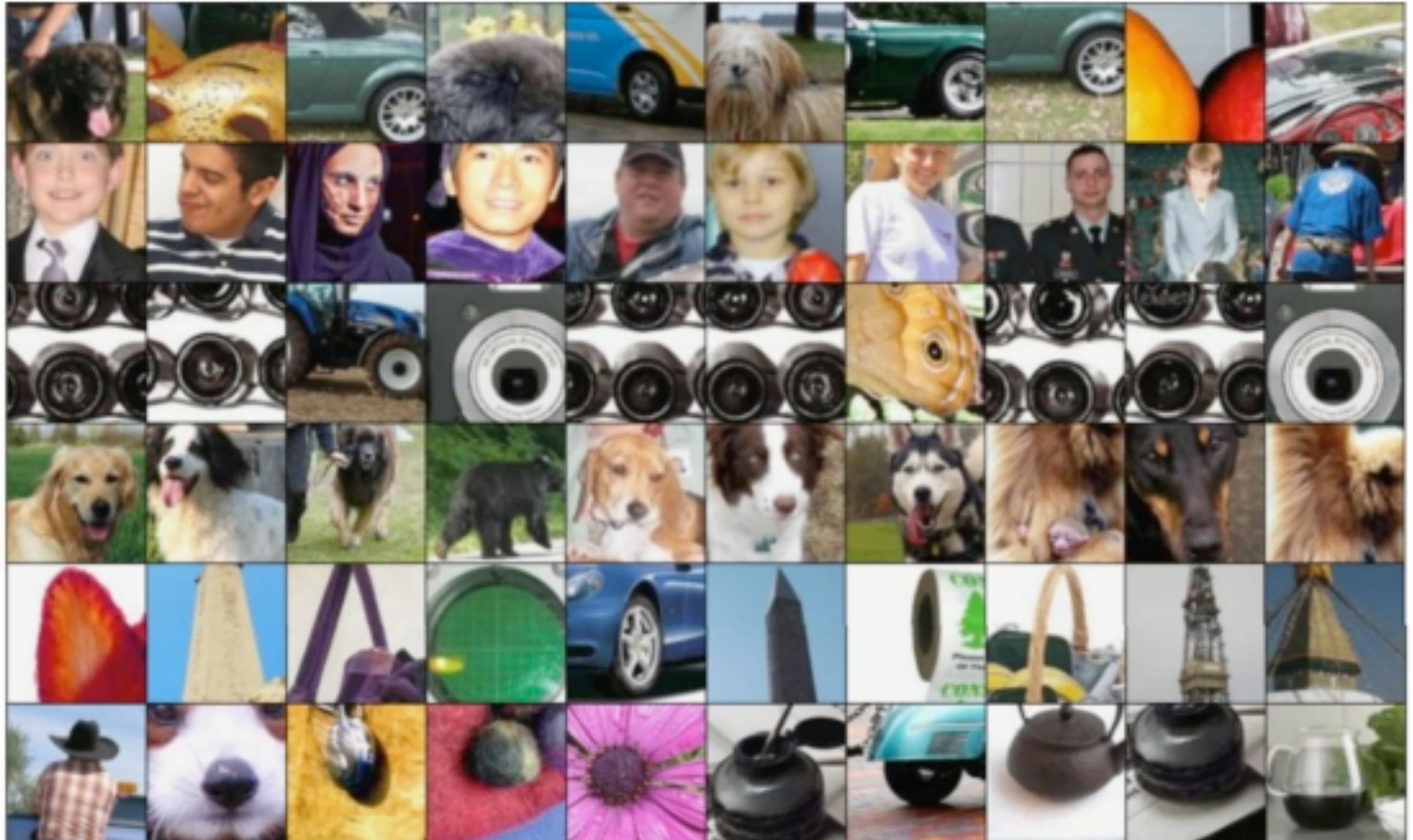
Maximally activating patches
(Each row is a different neuron)



Guided Backprop

Zeiler and Fergus, “Visualizing and Understanding Convolutional Networks”, ECCV 2014
Springenberg et al, “Striving for Simplicity: The All Convolutional Net”, ICLR Workshop 2015
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Intermediate features via (guided) backprop



Maximally activating patches
(Each row is a different neuron)



Guided Backprop

Zeiler and Fergus, “Visualizing and Understanding Convolutional Networks”, ECCV 2014
Springenberg et al, “Striving for Simplicity: The All Convolutional Net”, ICLR Workshop 2015
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Visualizing CNN features: Gradient Ascent

(Guided) backprop :

Find the part of an image that a neuron responds to

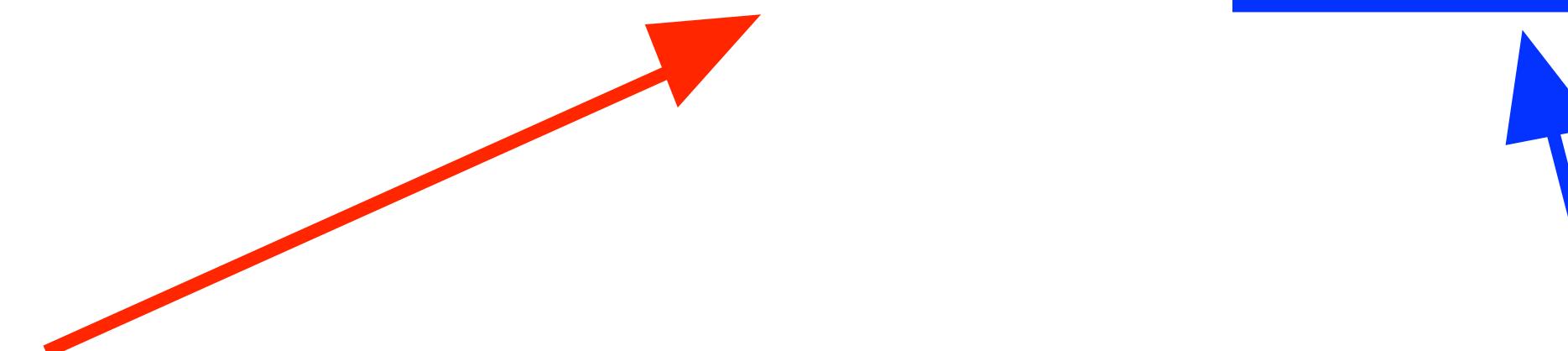
Gradient ascent :

Generate a synthetic image that maximally activates a neuron

$$I^* = \arg \max_I [f(I) + R(I)]$$

Neuron value

Natural image regularizer

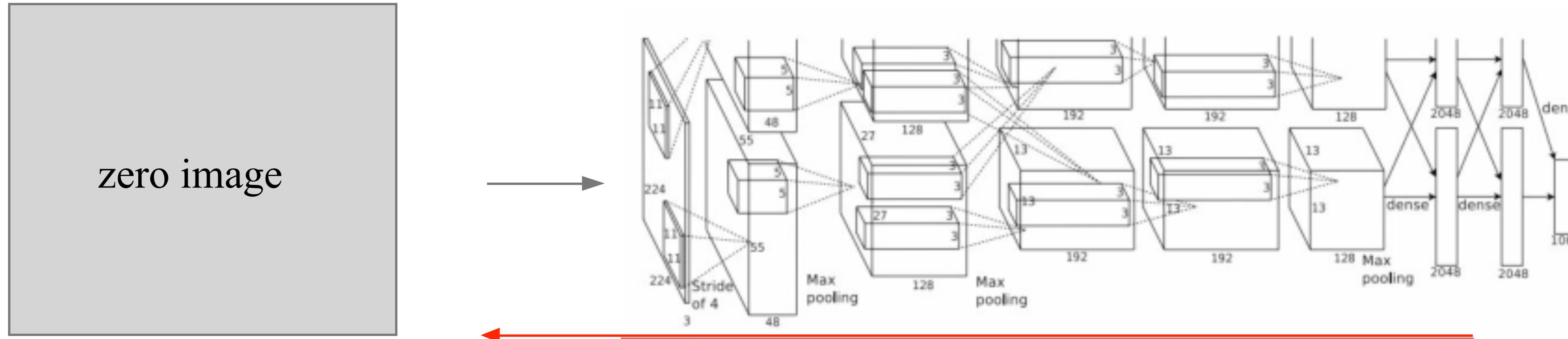


Visualizing CNN features: Gradient Ascent

1. Initialize image to zeros

$$\arg \max_I S_c(I) - \lambda \|I\|_2^2$$

score for class c (before Softmax)



Repeat:

2. Forward image to compute current scores
3. Backprop to get gradient of neuron value with respect to image pixels
4. Make a small update to the image

Visualizing CNN features: Gradient Ascent

$$\arg \max_I S_c(I) - \boxed{\lambda \|I\|_2^2}$$

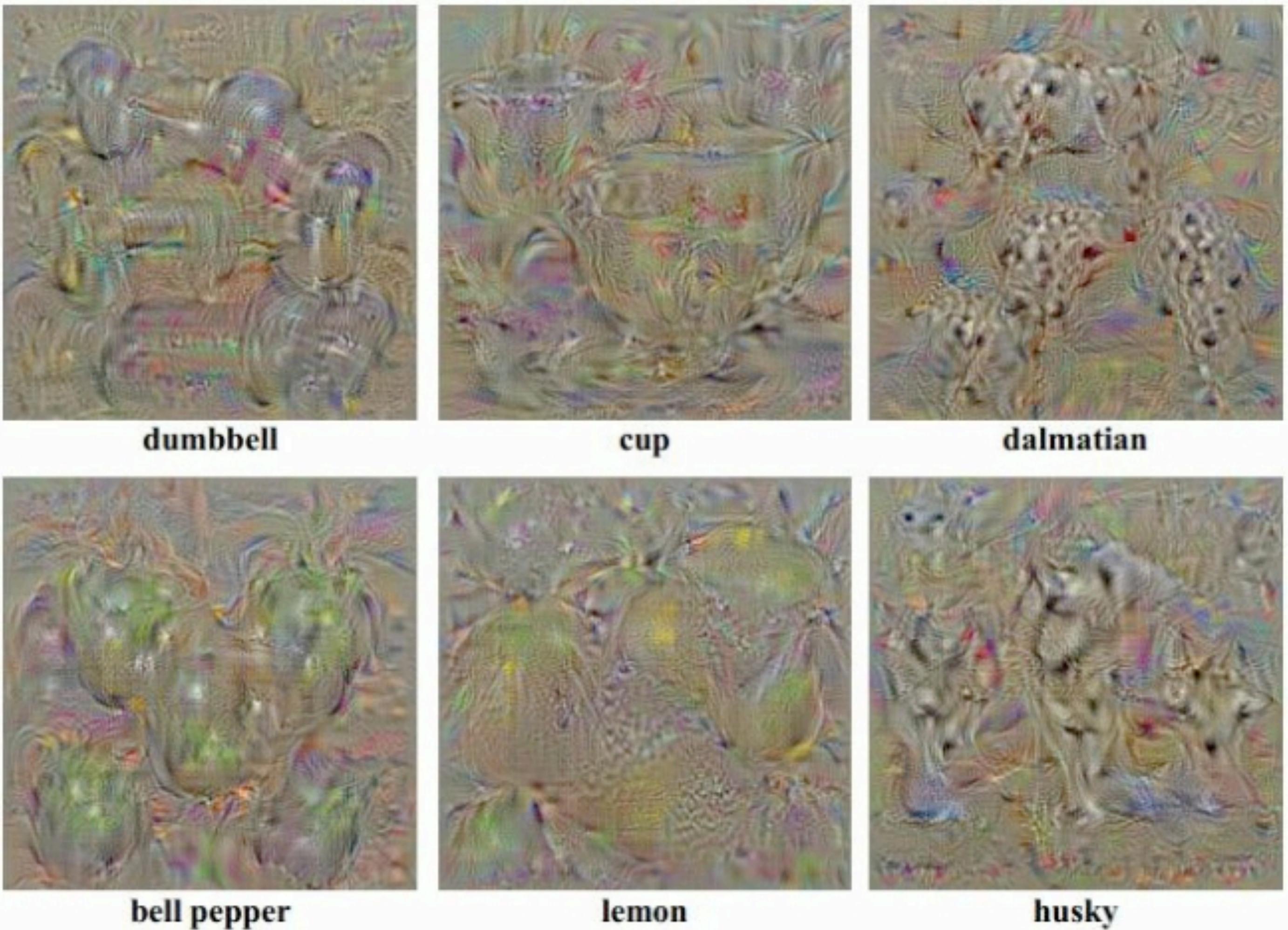
Simple regularizer: Penalize L2
norm of generated image

Simonyan, Vedaldi, and Zisserman, “Deep Inside Convolutional Networks: Visualising Image Classification Models and Saliency Maps”, ICLR Workshop 2014.
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Visualizing CNN features: Gradient Ascent

$$\arg \max_I S_c(I) - \boxed{\lambda \|I\|_2^2}$$

Simple regularizer: Penalize L2
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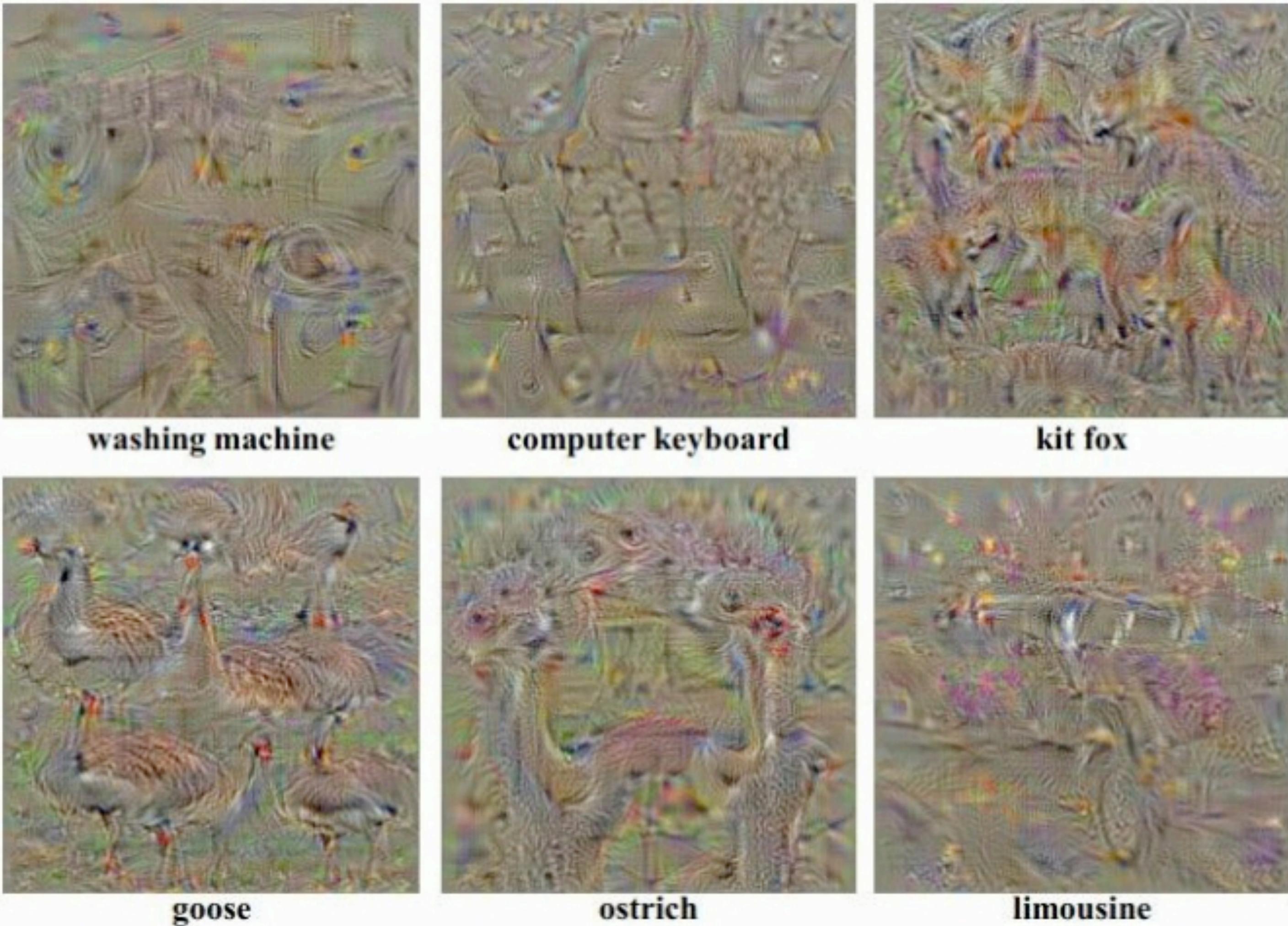
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Visualizing CNN features: Gradient Ascent

$$\arg \max_I S_c(I) - \boxed{\lambda \|I\|_2^2}$$

Simple regularizer: Penalize L2
norm of generated image



Yosinski et al, "Understanding Neural Networks Through Deep Visualization", ICML DL Workshop 2014.

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Visualizing CNN features: Gradient Ascent

$$\arg \max_I S_c(I) - \lambda \|I\|_2^2$$

Better regularizer: Penalize L2 norm of image; also during optimization periodically

- (1) Gaussian blur image
- (2) Clip pixels with small values to 0
- (3) Clip pixels with small gradients to 0

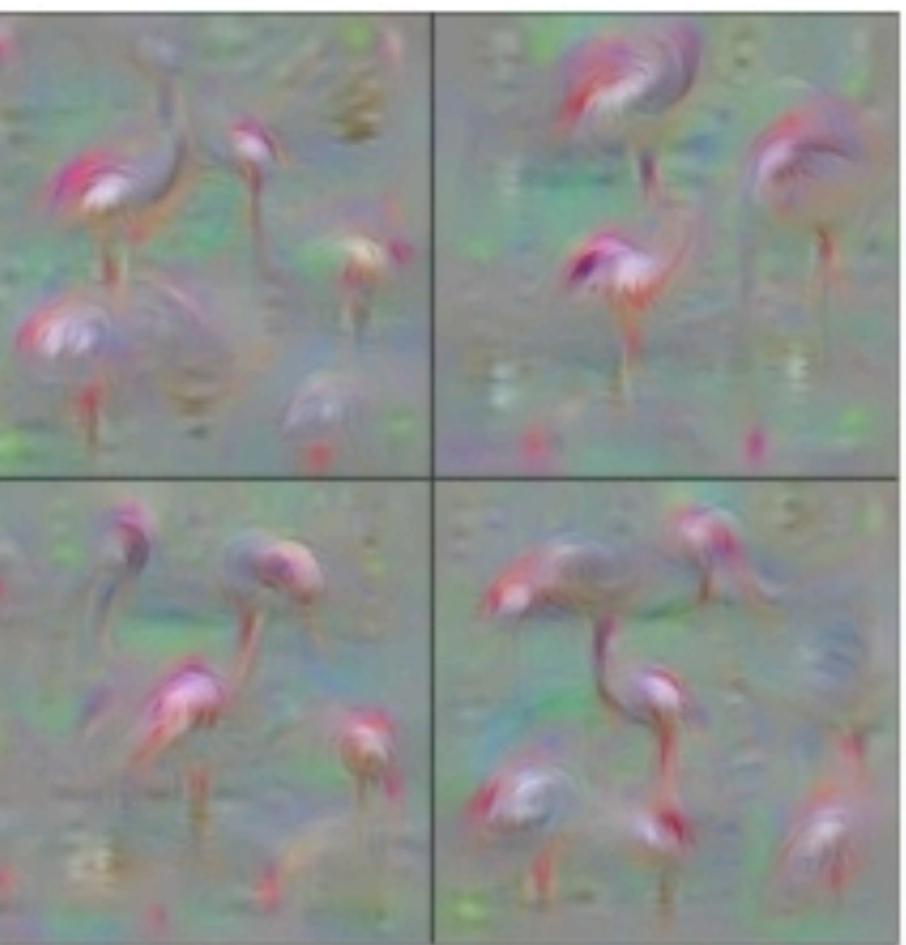
Yosinski et al, “Understanding Neural Networks Through Deep Visualization”, ICML DL Workshop 2014.

Visualizing CNN features: Gradient Ascent

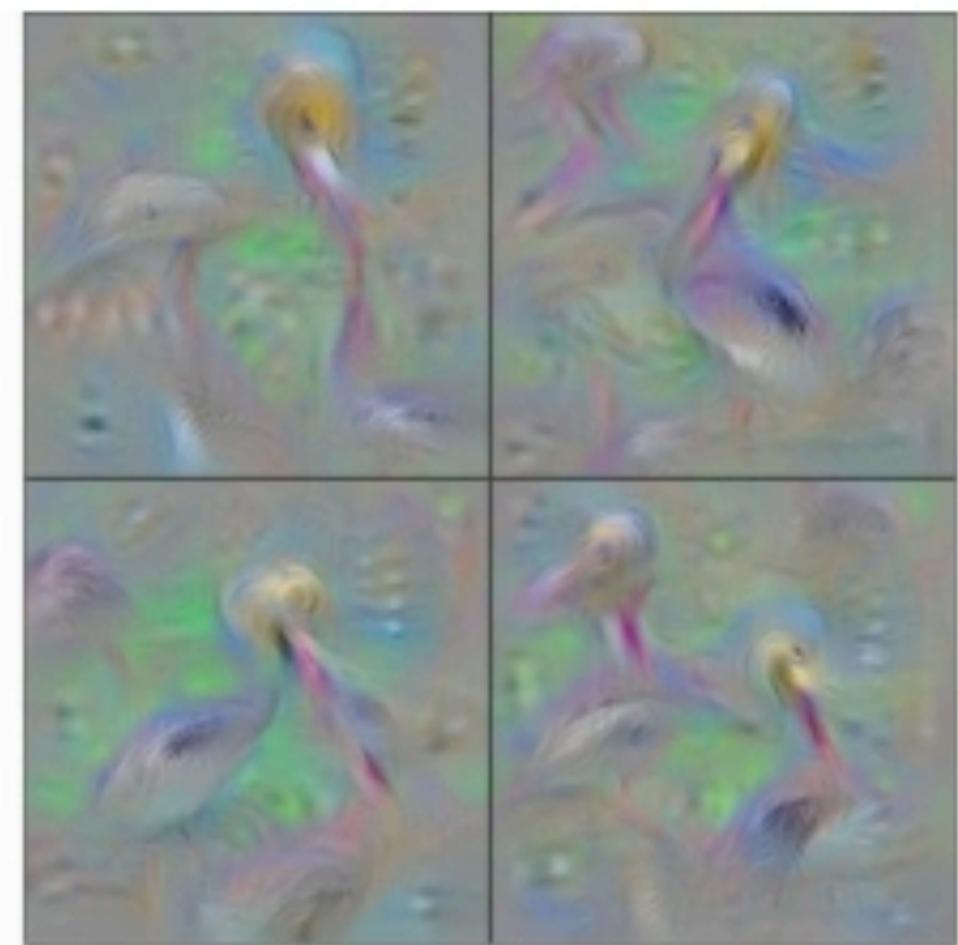
$$\arg \max_I S_c(I) - \lambda \|I\|_2^2$$

Better regularizer: Penalize L2 norm of image; also during optimization periodically

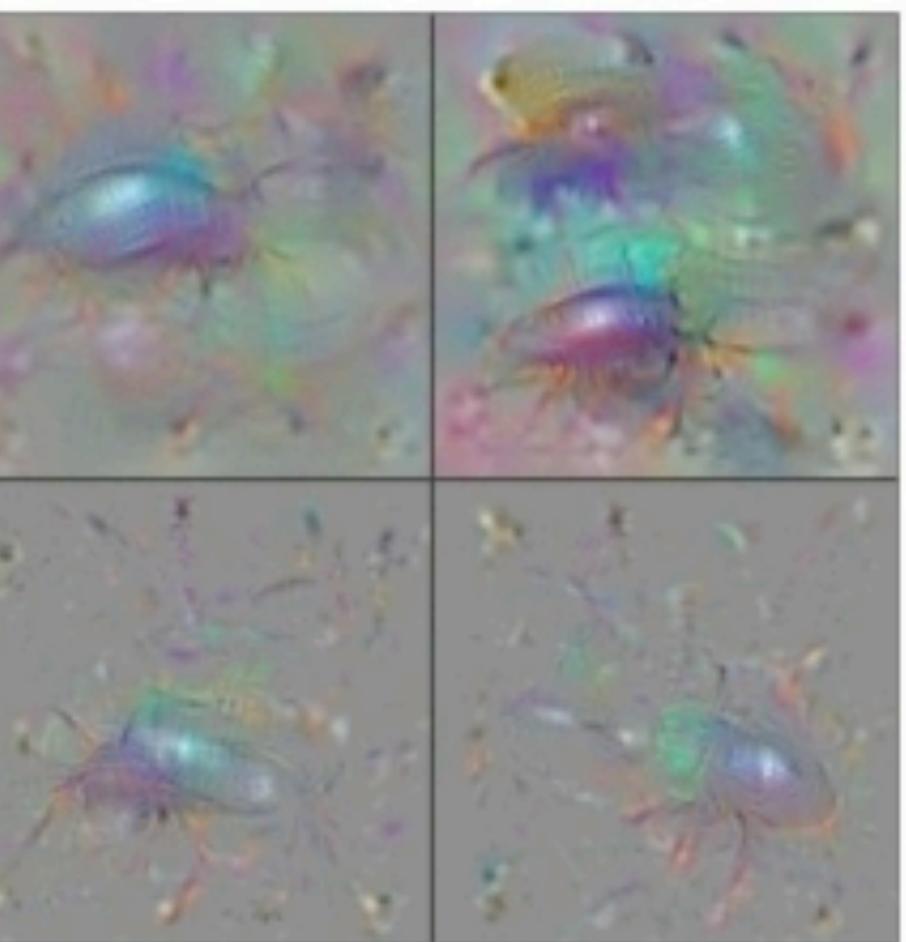
- (1) Gaussian blur image
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- (3) Clip pixels with small gradients to 0



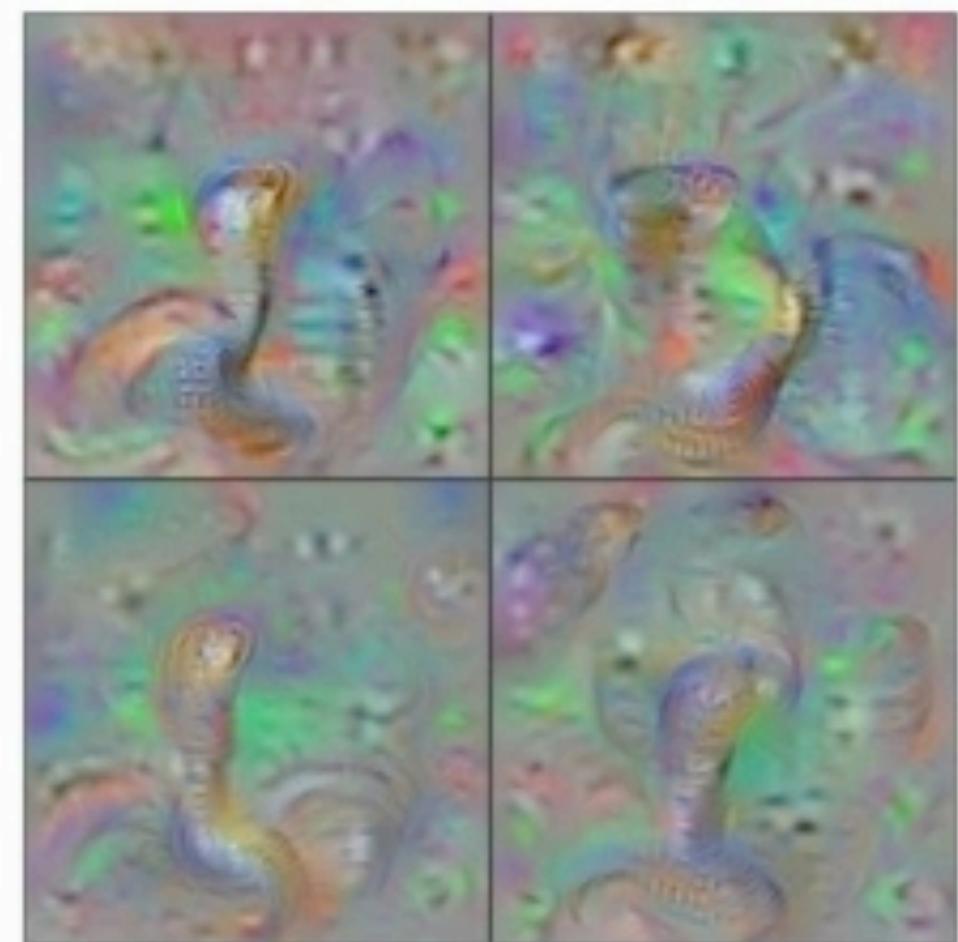
Flamingo



Pelican



Ground Beetle



Indian Cobra

Yosinski et al, “Understanding Neural Networks Through Deep Visualization”, ICML DL Workshop 2014.

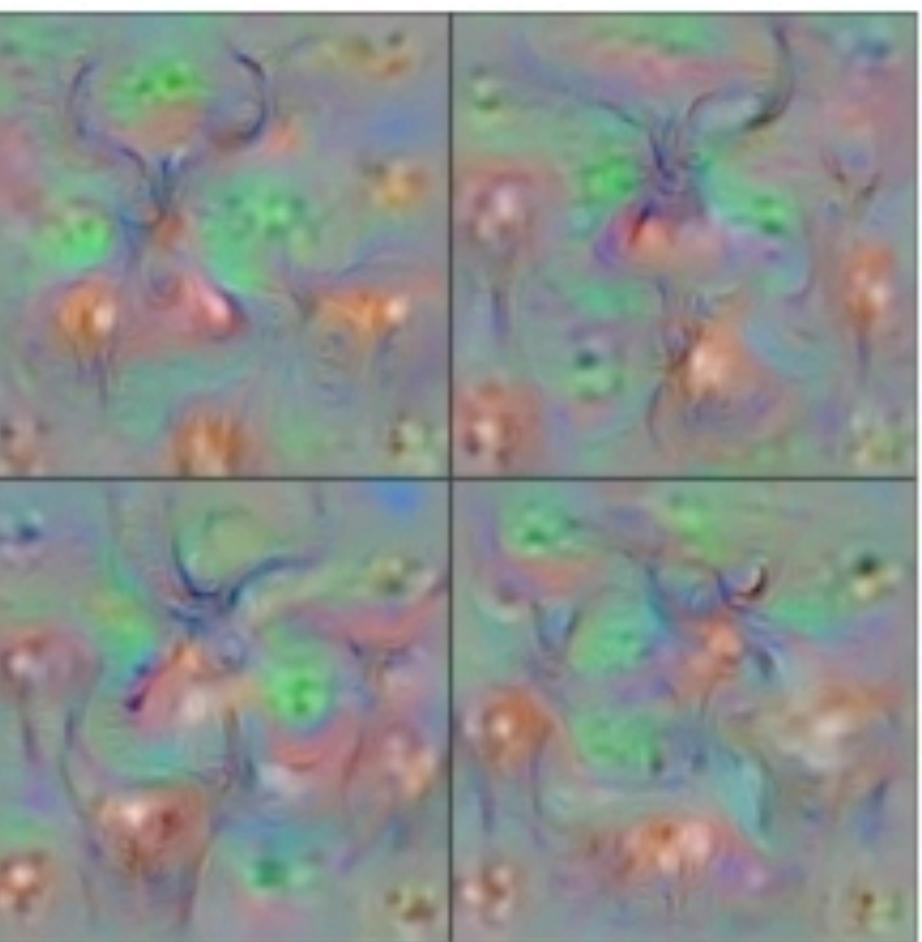
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Visualizing CNN features: Gradient Ascent

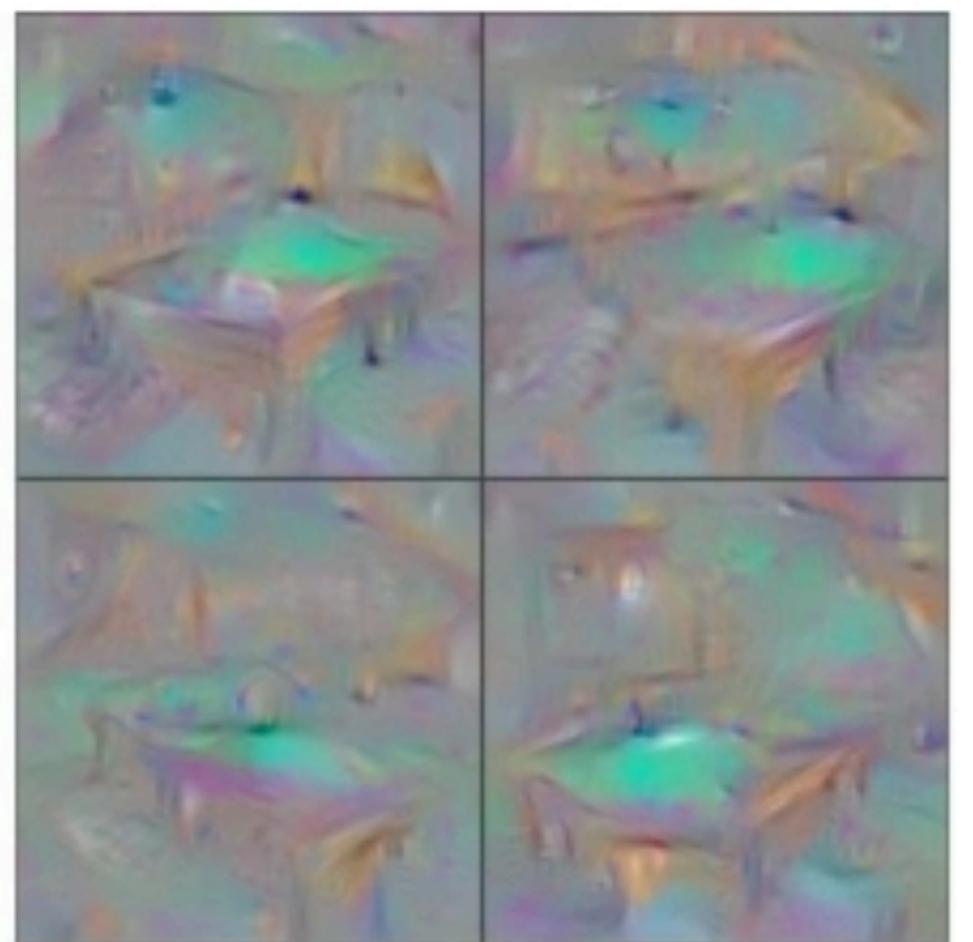
$$\arg \max_I S_c(I) - \lambda \|I\|_2^2$$

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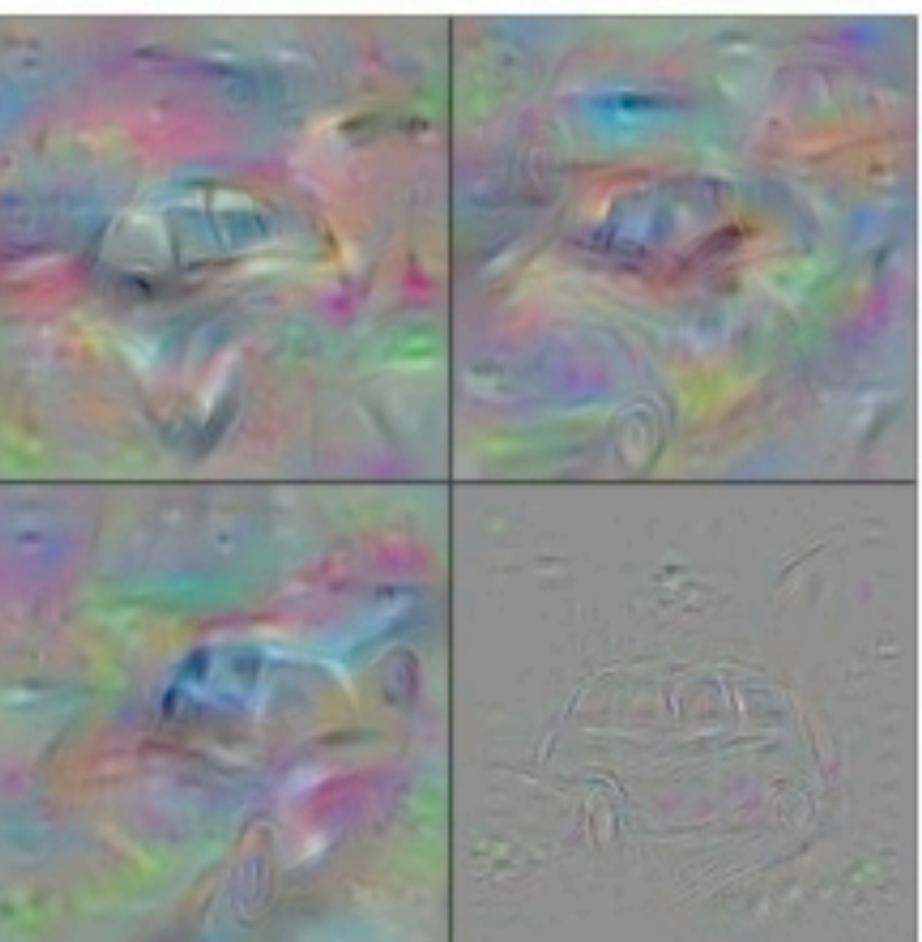
- (1) Gaussian blur image
- (2) Clip pixels with small values to 0
- (3) Clip pixels with small gradients to 0



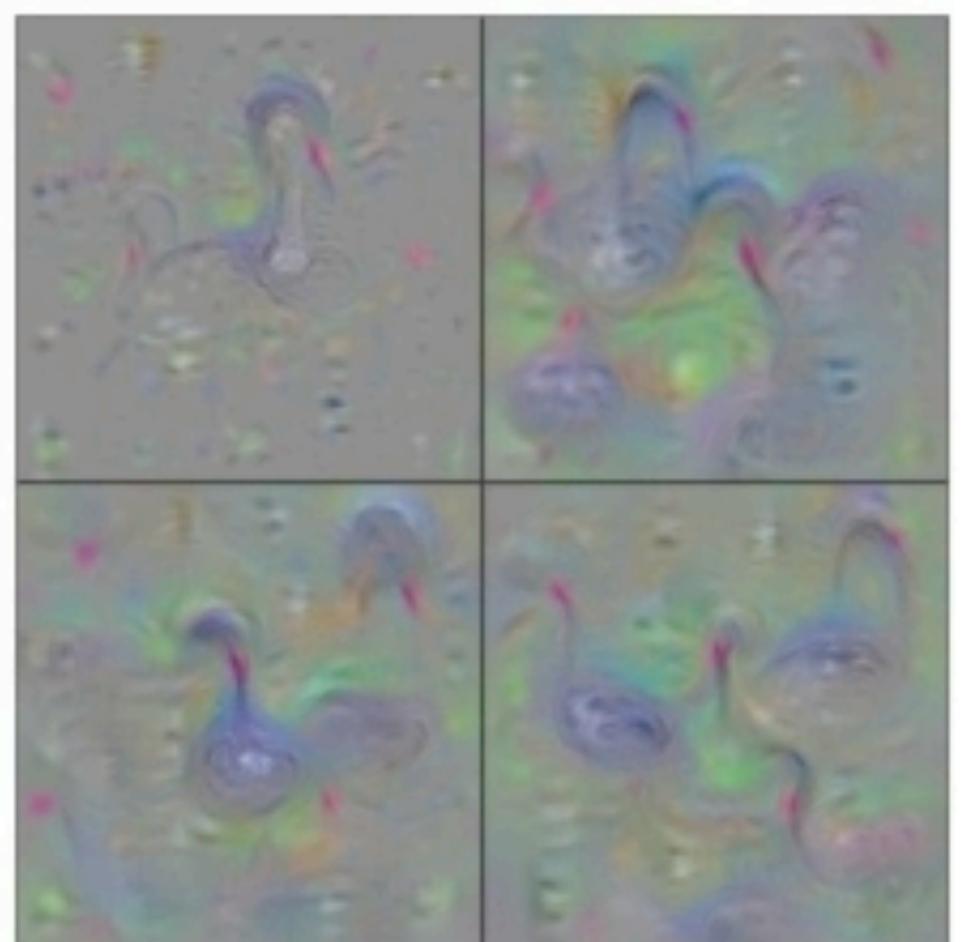
Hartebeest



Billiard Table



Station Wagon



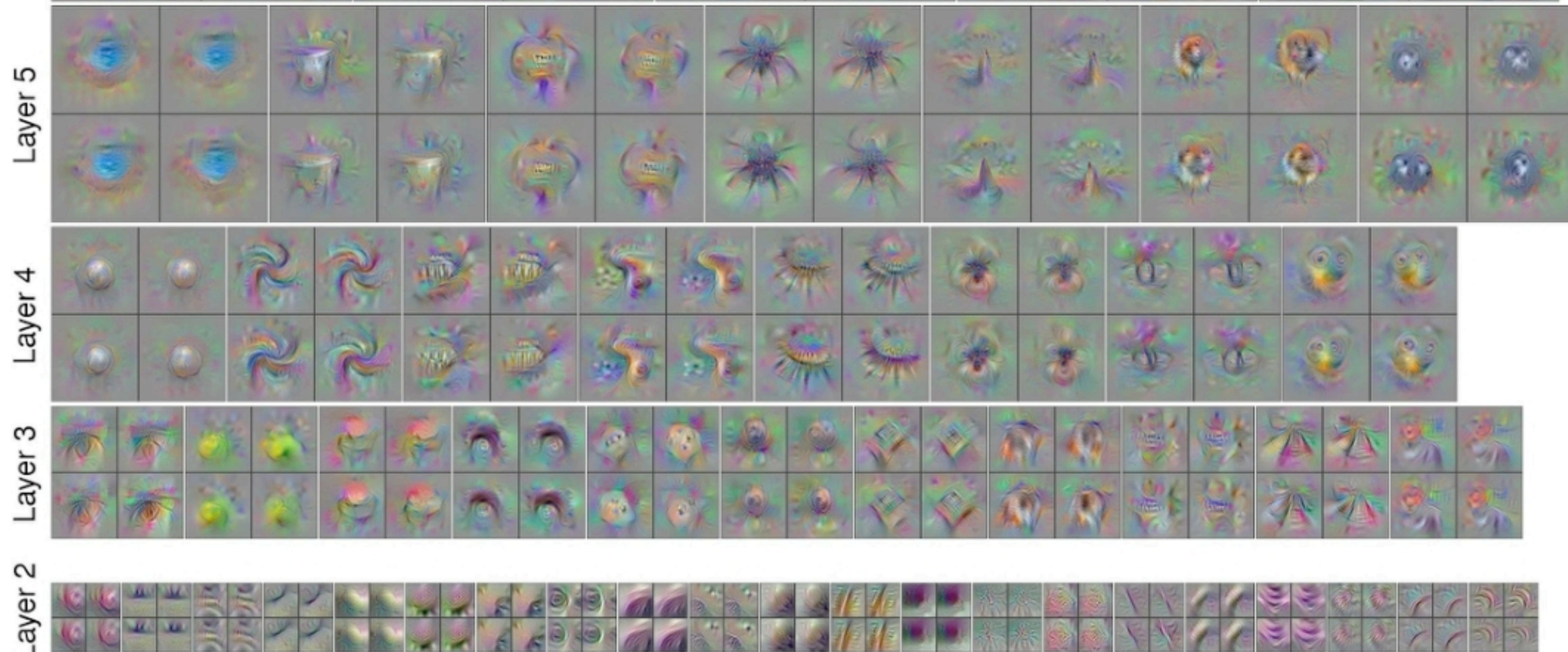
Black Swan

Yosinski et al, "Understanding Neural Networks Through Deep Visualization", ICML DL Workshop 2014.

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Visualizing CNN features: Gradient Ascent

Use the same approach to visualize intermediate features



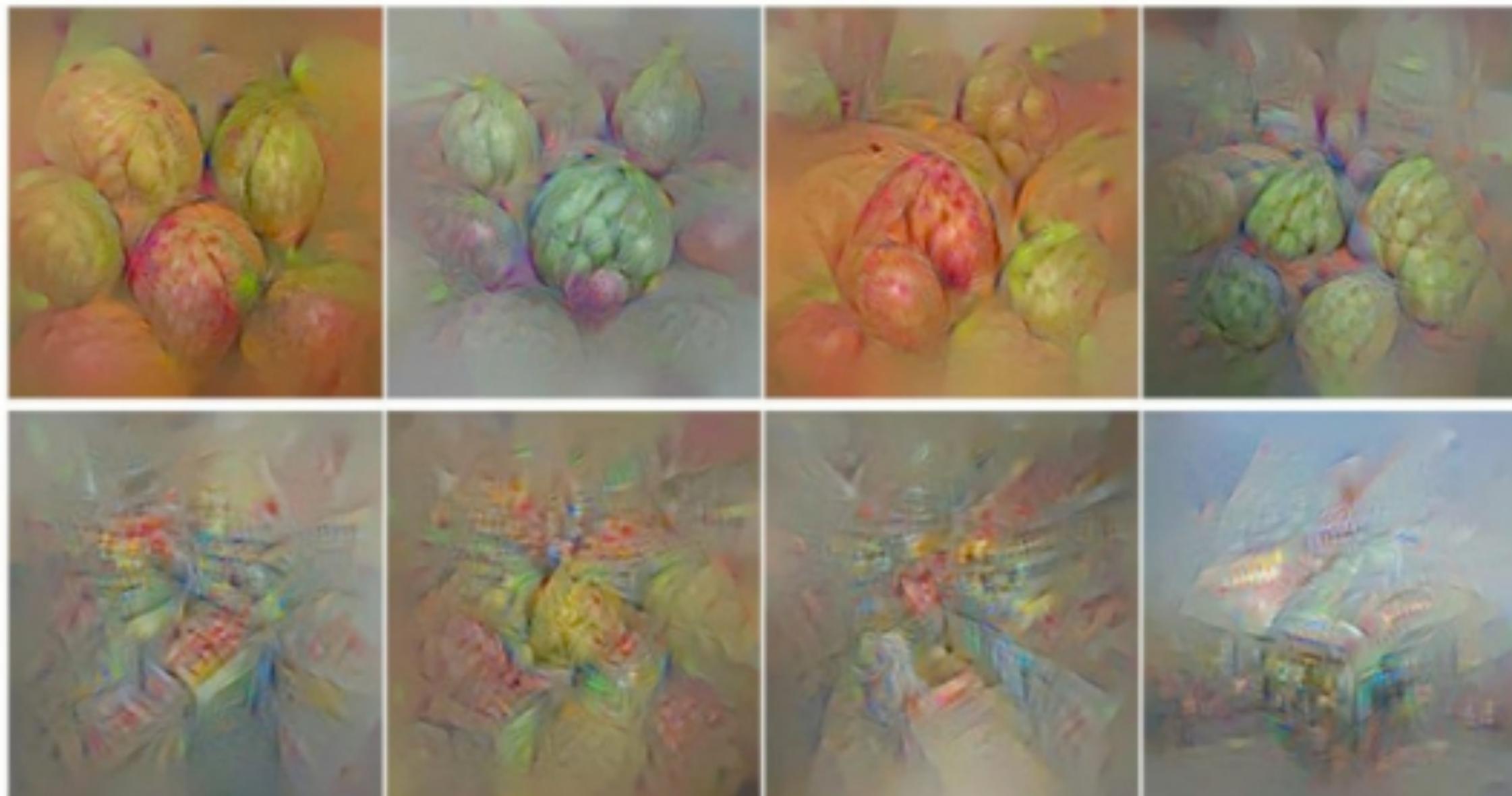
Yosinski et al, "Understanding Neural Networks Through Deep Visualization", ICML DL Workshop 2014.

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Visualizing CNN features: Gradient Ascent

Adding “multi-faceted” visualization gives even nicer results:
(Plus more careful regularization, center-bias)

Reconstructions of multiple feature types (facets) recognized by the same “grocery store” neuron



Corresponding example training set images recognized by the same neuron as in the “grocery store” class



Nguyen et al, “Multifaceted Feature Visualization: Uncovering the Different Types of Features Learned By Each Neuron in Deep Neural Networks”, ICML Visualization for Deep Learning Workshop 2016.
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Visualizing CNN features: Gradient Ascent

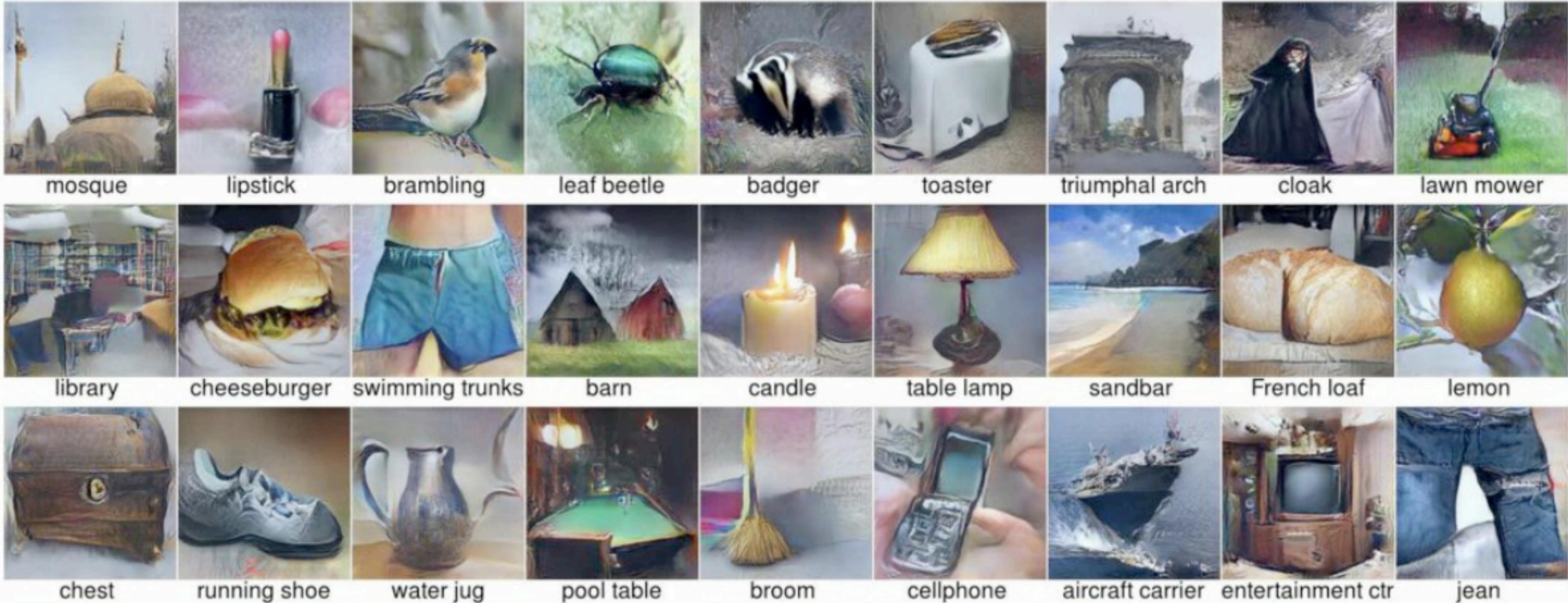


Nguyen et al, "Multifaceted Feature Visualization: Uncovering the Different Types of Features Learned By Each Neuron in Deep Neural Networks", ICML Visualization for Deep Learning Workshop 2016.

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Visualizing CNN features: Gradient Ascent

Optimize in FC6 latent space instead of pixel space:



Nguyen et al., "Synthesizing the preferred inputs for neurons in neural networks via deep generator networks," NIPS 2016

Figure copyright Nguyen et al, 2016; reproduced with permission.

Fooling Images / Adversarial Examples

- (1) Start from an arbitrary image
- (2) Pick an arbitrary class
- (3) Modify the image to maximize the class
- (4) Repeat until network is fooled

Fooling Images / Adversarial Examples

African elephant



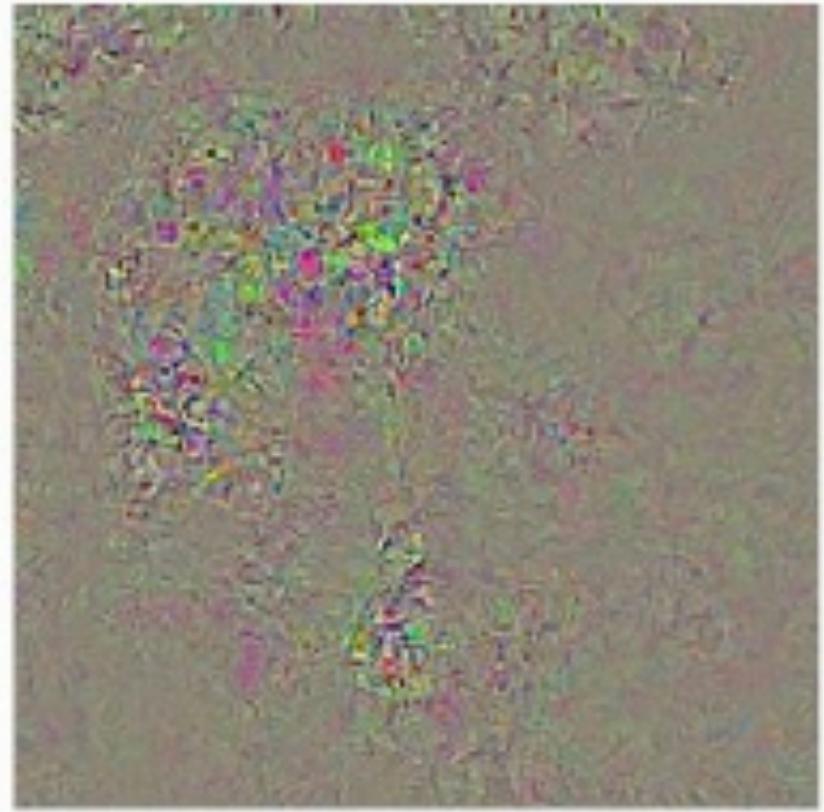
koala



Difference



10x Difference



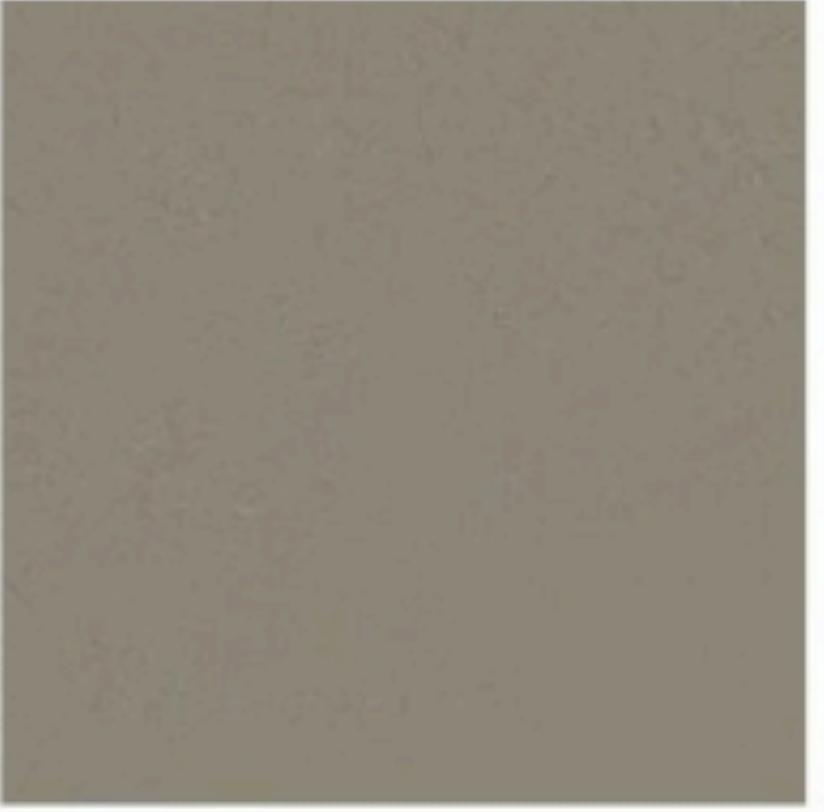
schooner



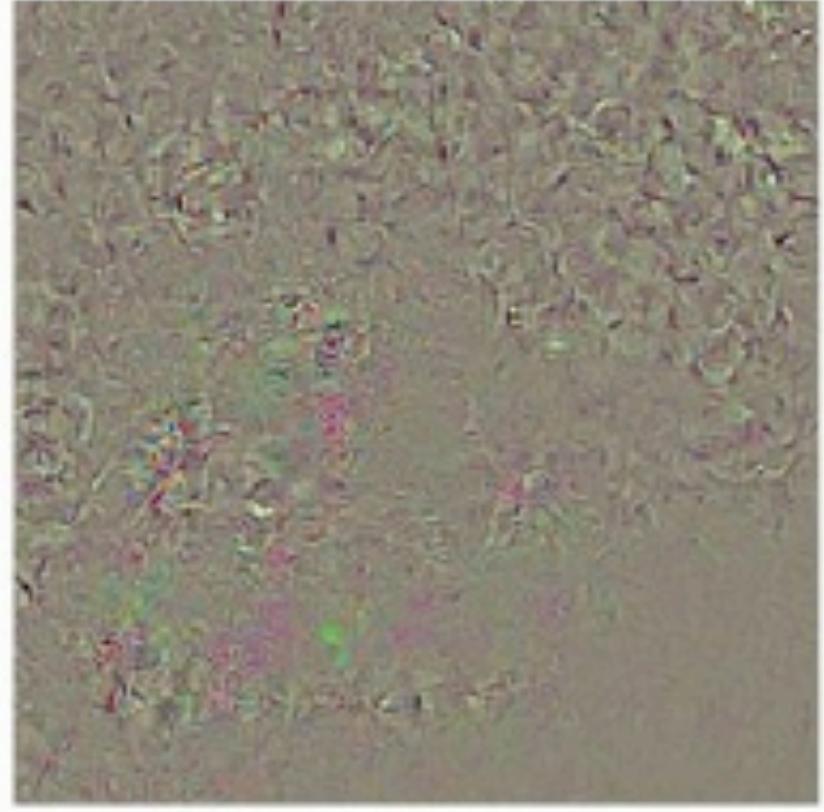
iPod



Difference



10x Difference



Boat image is CC0 public domain
Elephant image is CC0 public domain

Fooling Images / Adversarial Examples

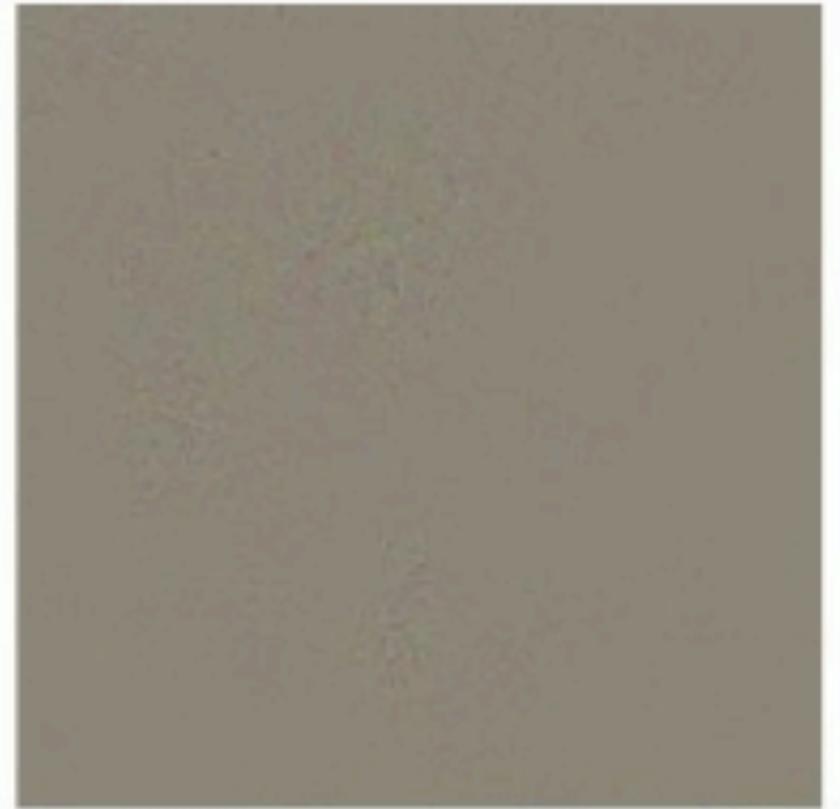
African elephant



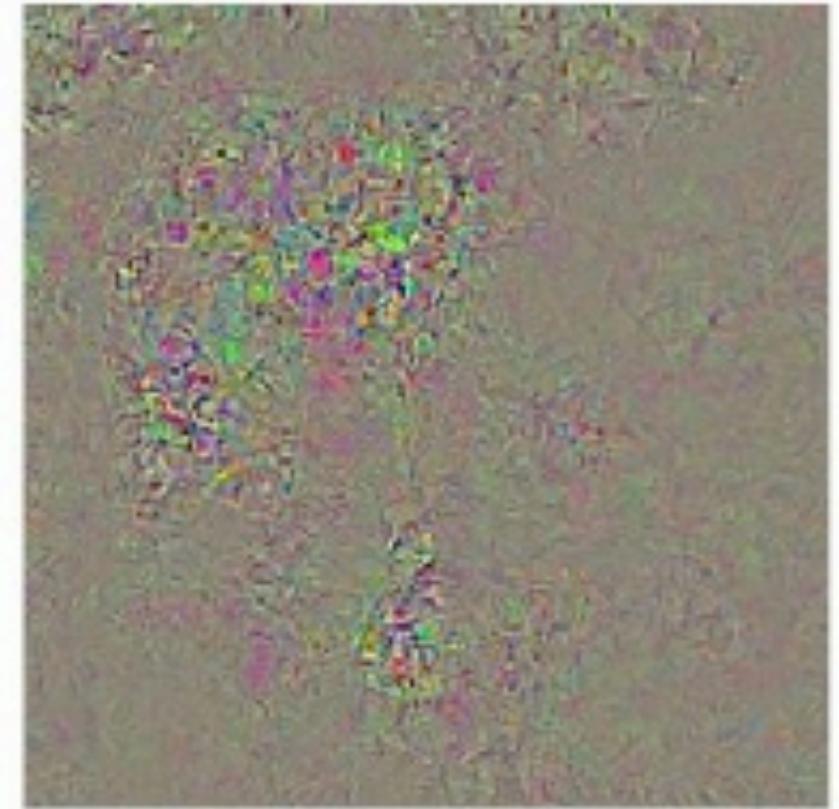
koala



Difference



10x Difference



schooner



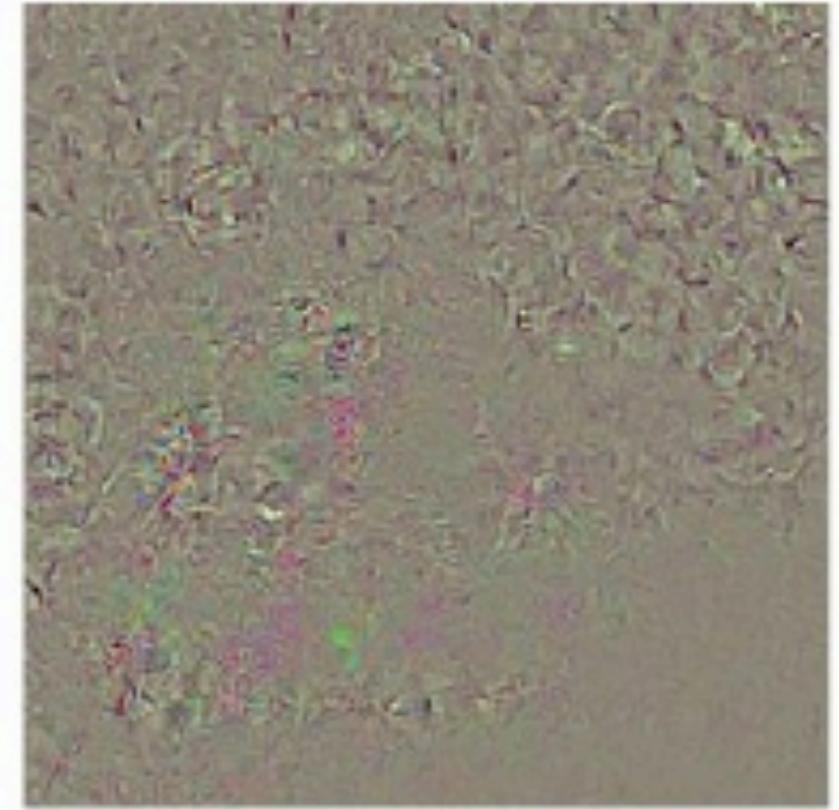
iPod



Difference



10x Difference

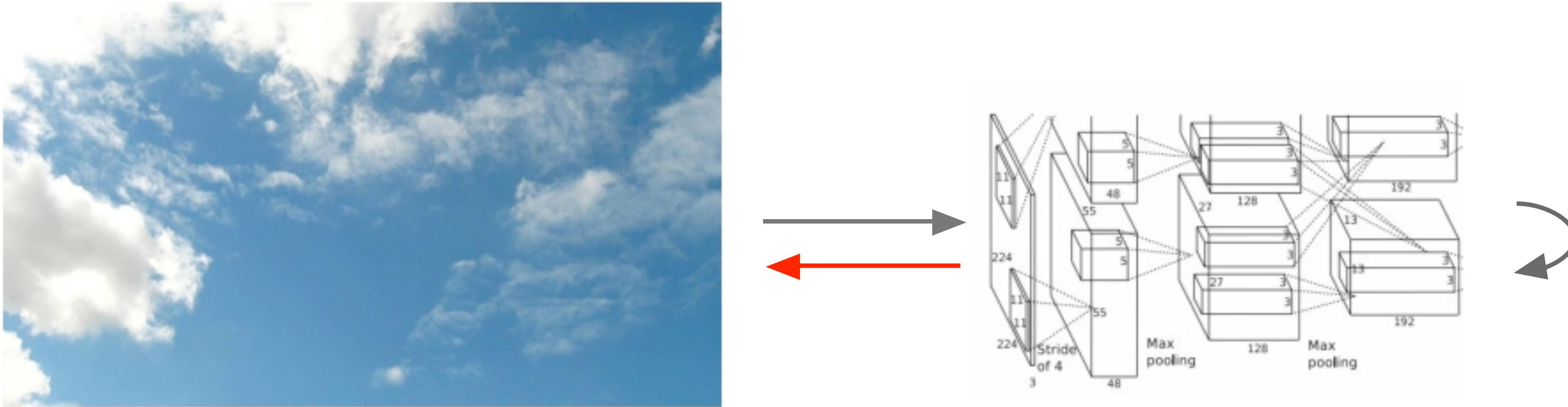


Check out [Ian Goodfellow's lecture from last year](#)

Boat image is CC0 public domain
Elephant image is CC0 public domain

DeepDream: Amplify existing features

Rather than synthesizing an image to maximize a specific neuron, instead try to **amplify** the neuron activations at some layer in the network



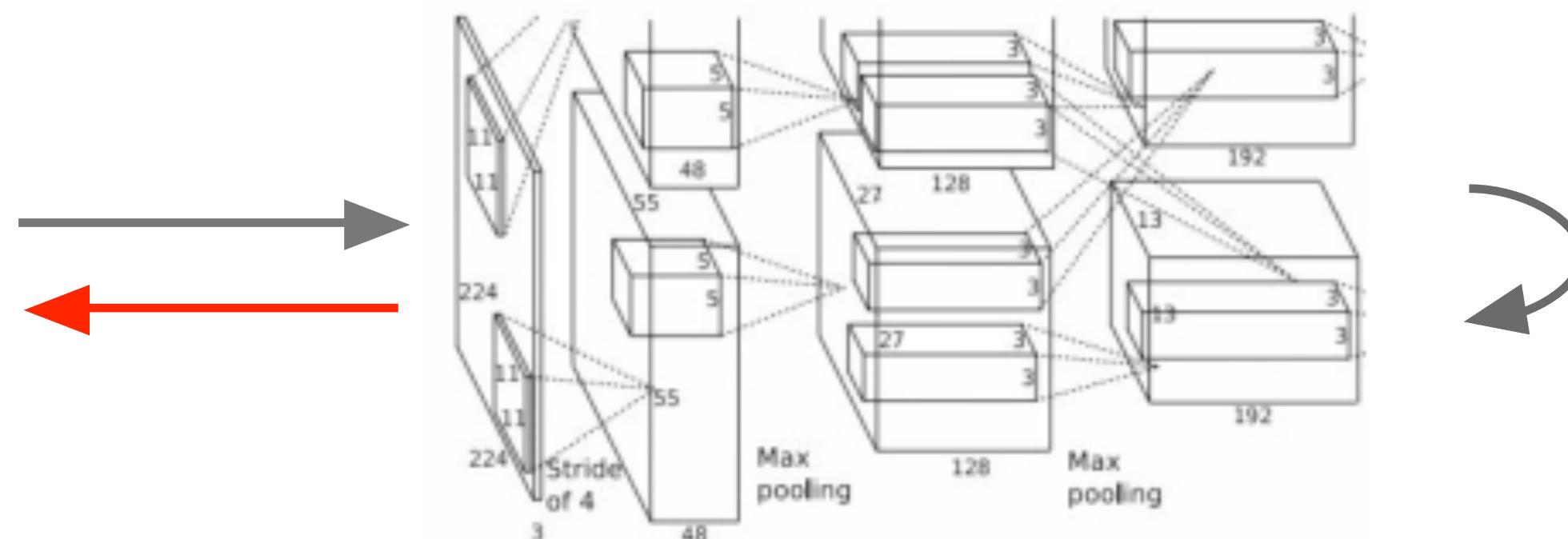
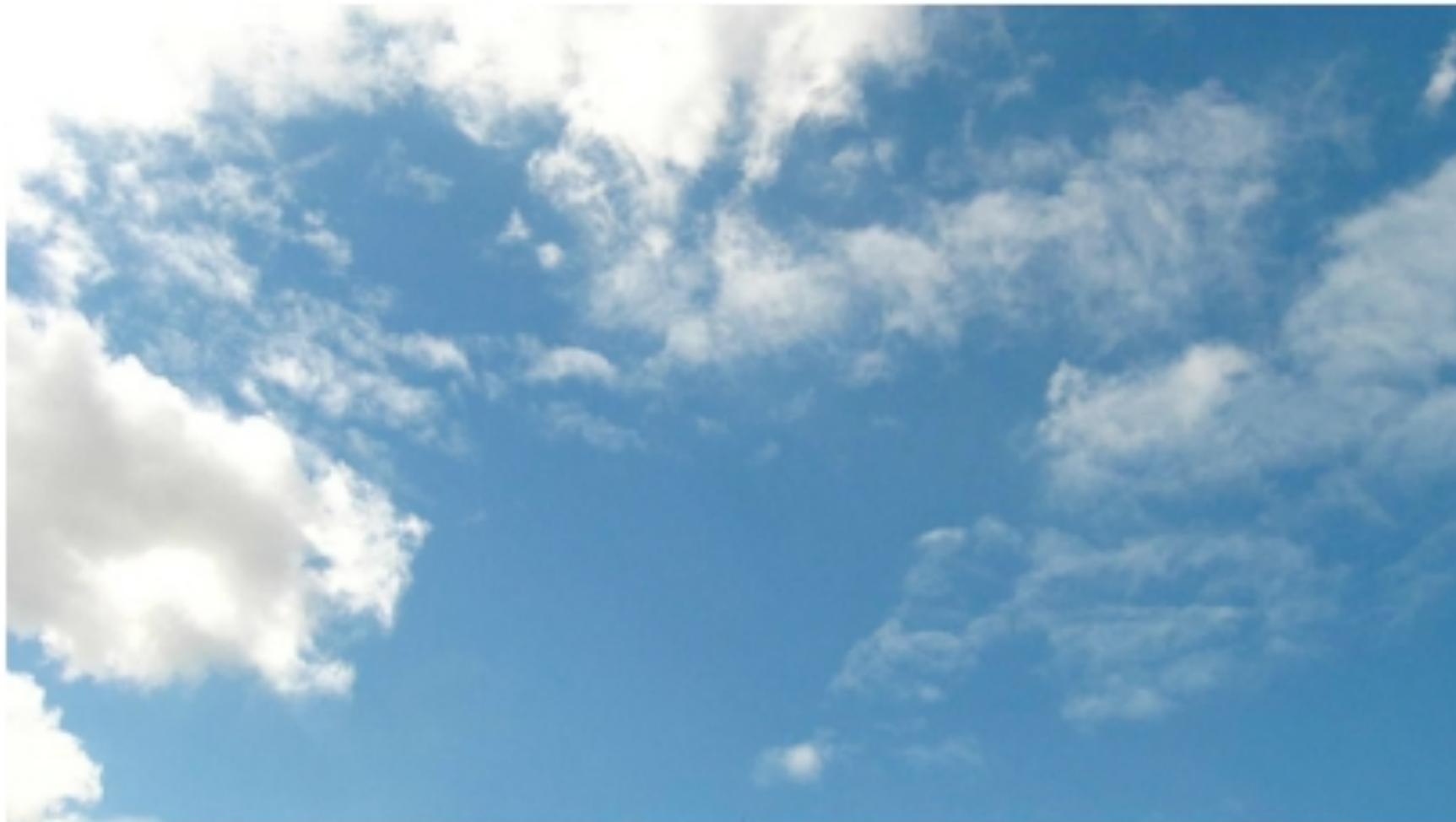
Choose an image and a layer in a CNN; repeat:

1. Forward: compute activations at chosen layer
2. Set gradient of chosen layer *equal to its activation*
3. Backward: Compute gradient on image
4. Update image

Mordvintsev, Olah, and Tyka, “Inceptionism: Going Deeper into Neural Networks”, [Google Research Blog](#). Images are licensed under [CC-BY 4.0](#).

DeepDream: Amplify existing features

Rather than synthesizing an image to maximize a specific neuron, instead try to **amplify** the neuron activations at some layer in the network



Choose an image and a layer in a CNN; repeat:

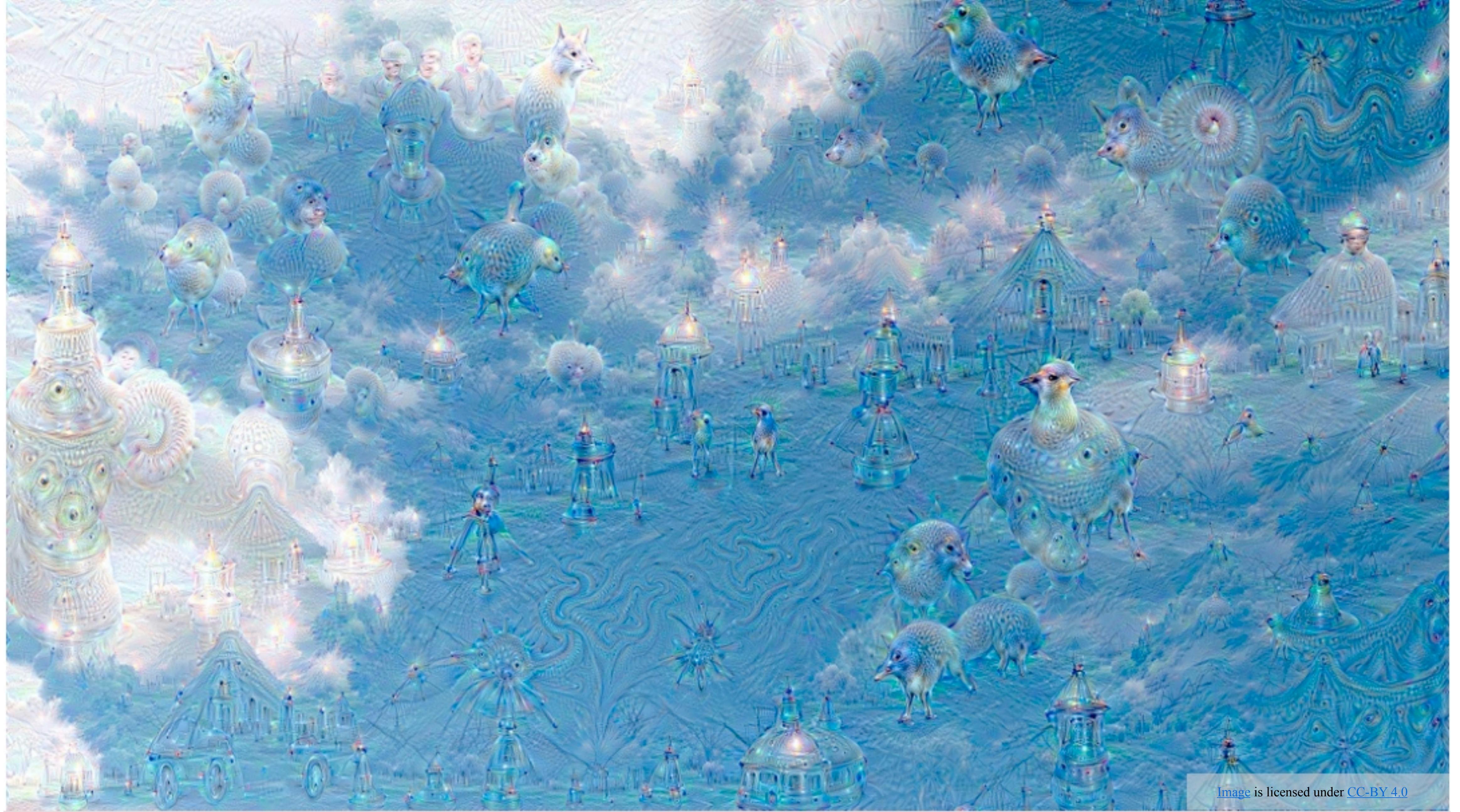
1. Forward: compute activations at chosen layer
2. Set gradient of chosen layer *equal to its activation*
3. Backward: Compute gradient on image
4. Update image

Equivalent to:
 $I^* = \arg \max_I \sum_i f_i(I)^2$

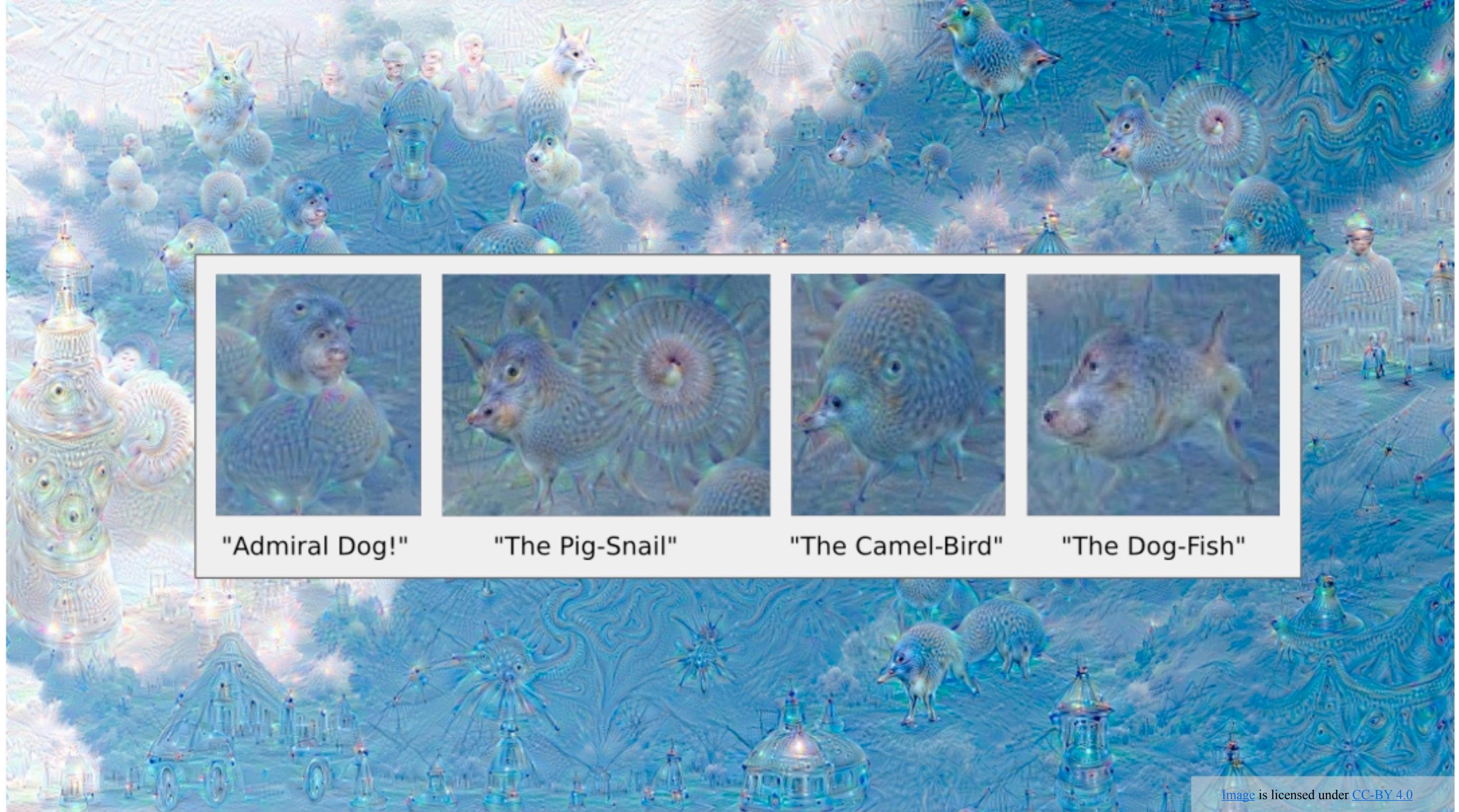
Mordvintsev, Olah, and Tyka, “Inceptionism: Going Deeper into Neural Networks”, [Google Research Blog](#). Images are licensed under [CC-BY 4.0](#)



[Sky image](#) is licensed under [CC-BY SA 3.0](#)



[Image](#) is licensed under [CC-BY 4.0](#)



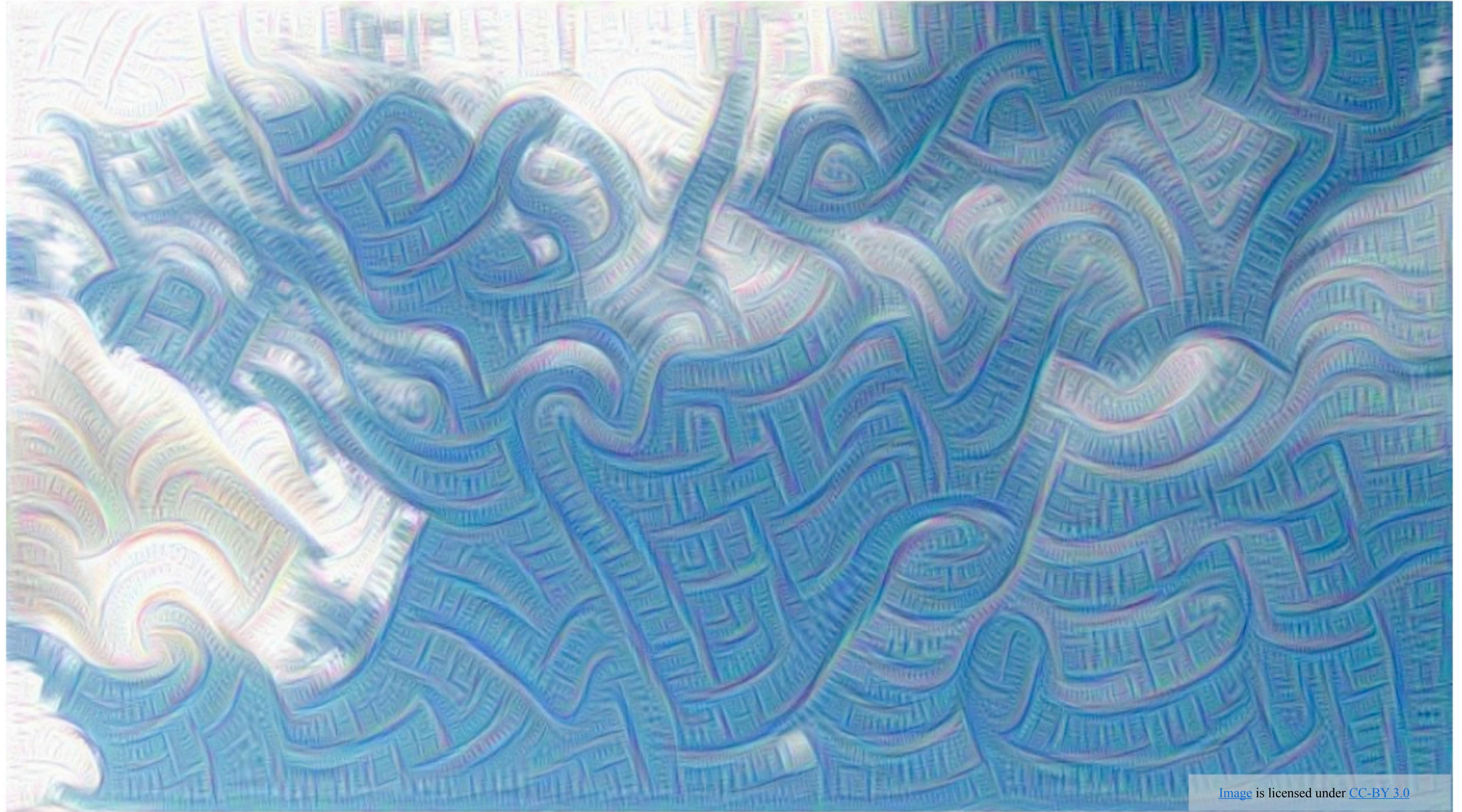
"Admiral Dog!"

"The Pig-Snail"

"The Camel-Bird"

"The Dog-Fish"

[Image](#) is licensed under [CC-BY 4.0](#)



[Image](#) is licensed under [CC-BY 3.0](#)



[Image](#) is licensed under [CC-BY 3.0](#)

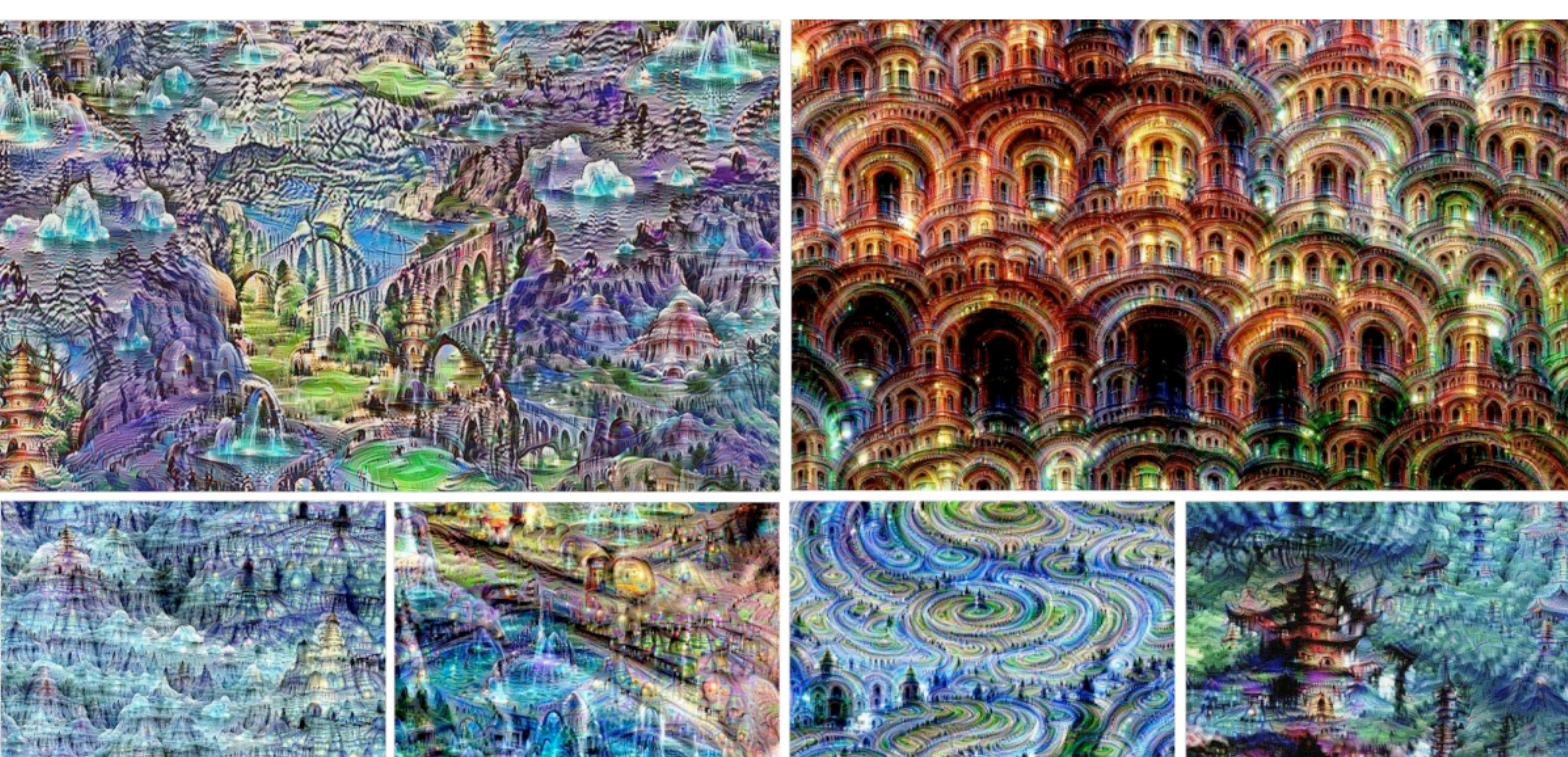


Image is licensed under CC-BY 4.0

Feature Inversion

Given a CNN feature vector for an image, find a new image that:

- Matches the given feature vector
- “looks natural” (image prior regularization)

$$\mathbf{x}^* = \underset{\mathbf{x} \in \mathbb{R}^{H \times W \times C}}{\operatorname{argmin}} \ell(\Phi(\mathbf{x}), \Phi_0) + \lambda \mathcal{R}(\mathbf{x})$$

Given feature vector

Features of new image

$$\ell(\Phi(\mathbf{x}), \Phi_0) = \|\Phi(\mathbf{x}) - \Phi_0\|^2$$

$$\mathcal{R}_{V^\beta}(\mathbf{x}) = \sum_{i,j} \left((x_{i,j+1} - x_{ij})^2 + (x_{i+1,j} - x_{ij})^2 \right)^{\frac{\beta}{2}}$$

Total Variation regularizer
(encourages spatial smoothness)

Mahendran and Vedaldi, “Understanding Deep Image Representations by Inverting Them”, CVPR 2015

Feature Inversion

Reconstructing from different layers of VGG-16

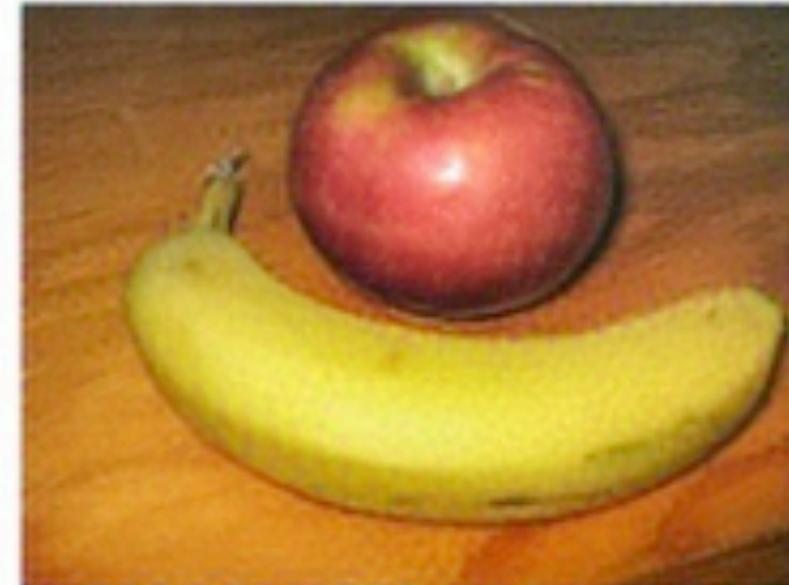
y



relu2_2



relu3_3



relu4_3



relu5_1



relu5_3



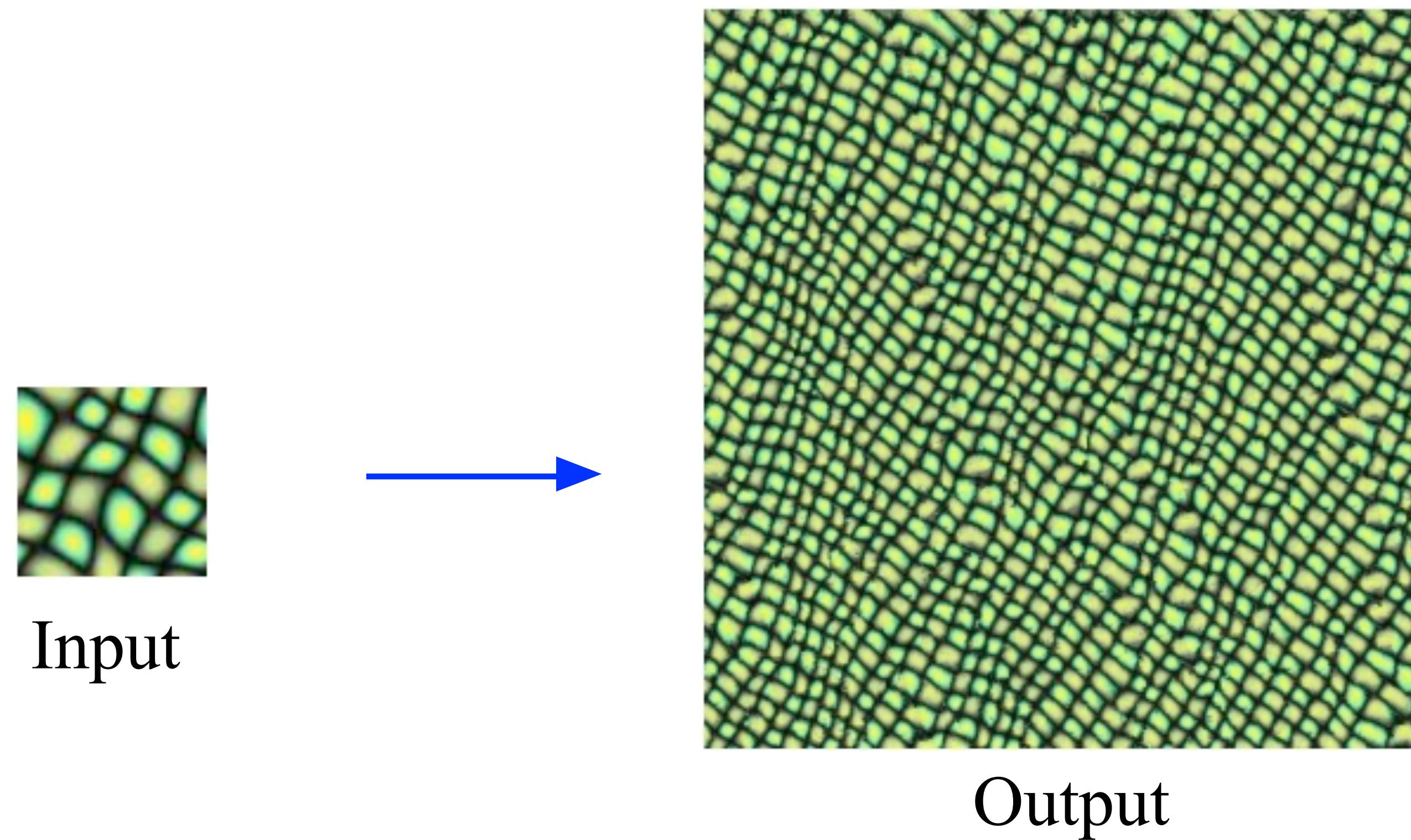
Mahendran and Vedaldi, "Understanding Deep Image Representations by Inverting Them", CVPR 2015

Figure from Johnson, Alahi, and Fei-Fei, "Perceptual Losses for Real-Time Style Transfer and Super-Resolution", ECCV 2016. Copyright Springer, 2016.

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Texture Synthesis

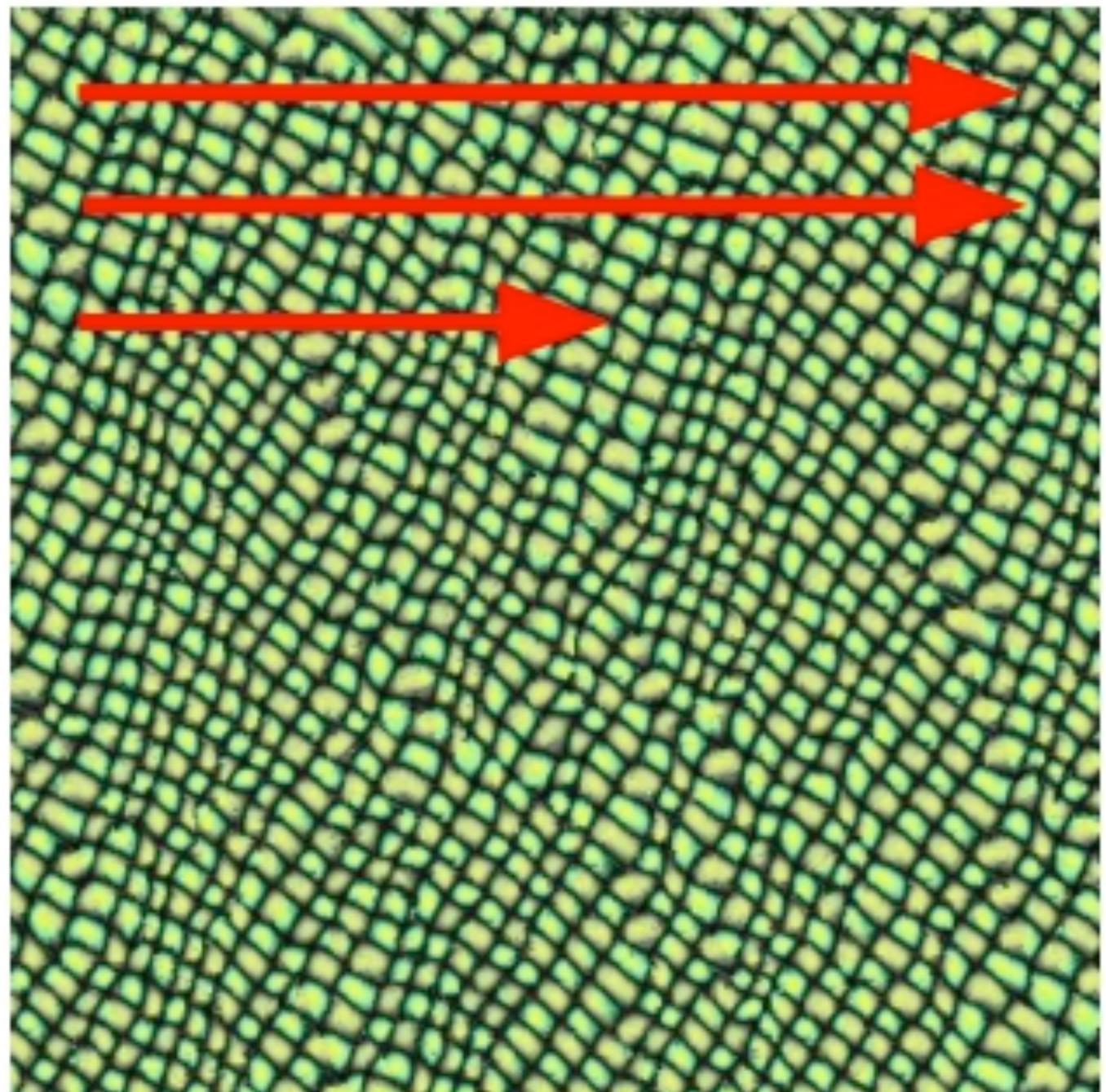
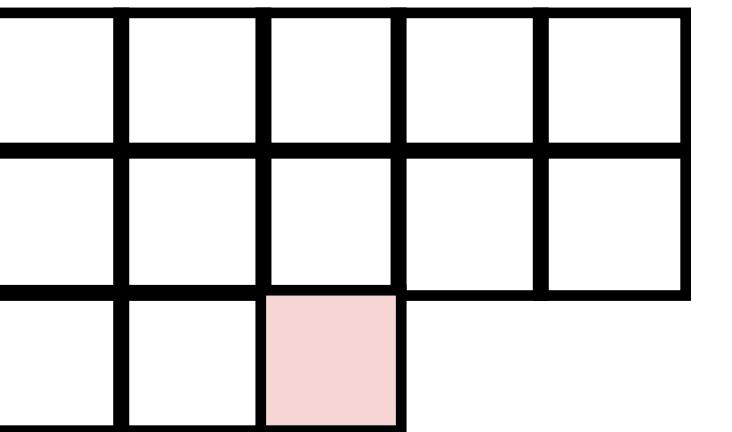
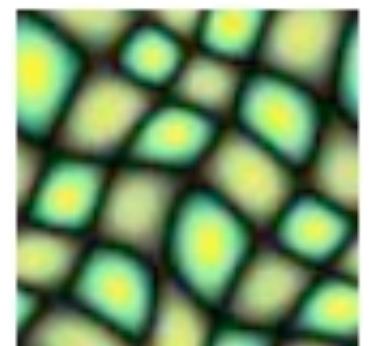
Given a sample patch of some texture, can we generate a bigger image of the same texture?



[Output image](#) is licensed under the [MIT license](#)

Texture Synthesis: Nearest Neighbor

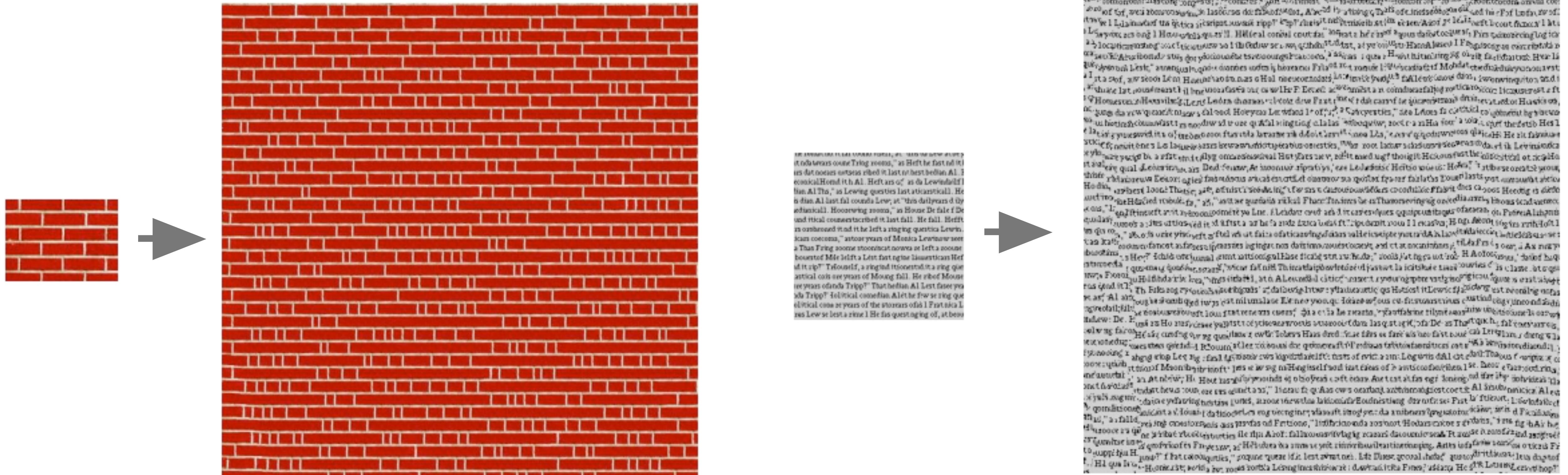
Generate pixels one at a time in scanline order; form neighborhood of already generated pixels and copy nearest neighbor from input



Wei and Levoy, “Fast Texture Synthesis using Tree-structured Vector Quantization”, SIGGRAPH 2000

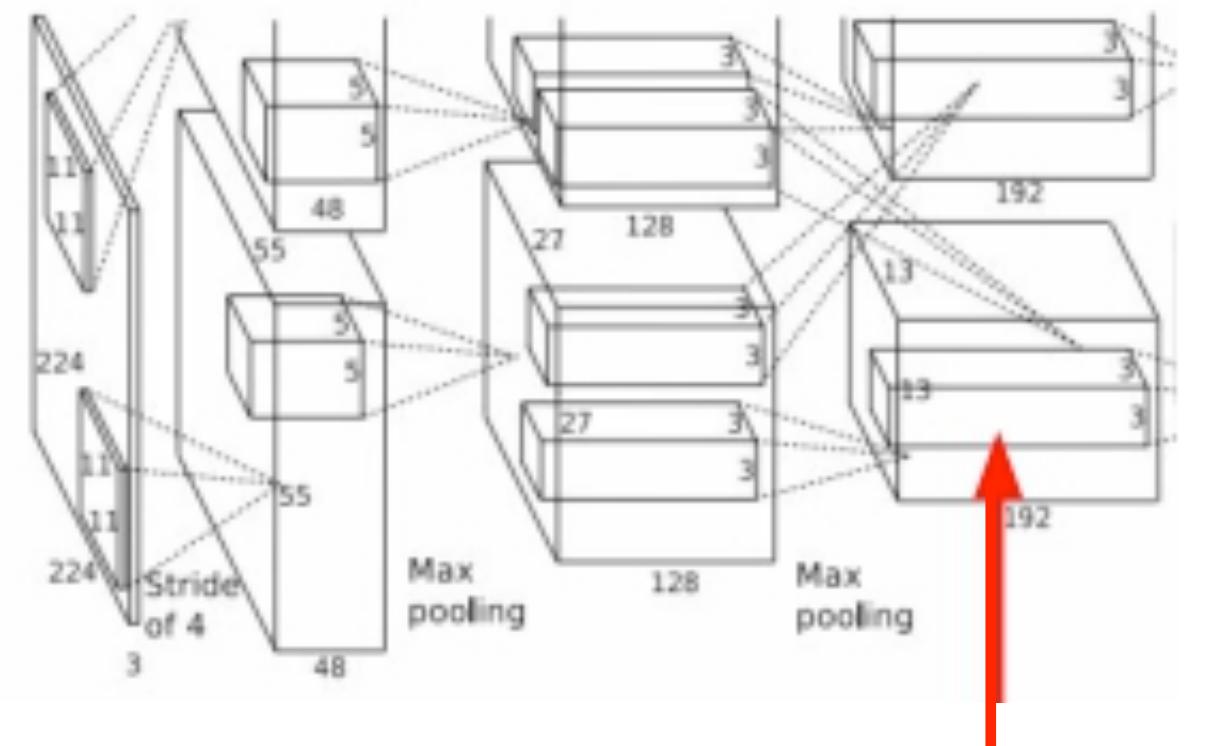
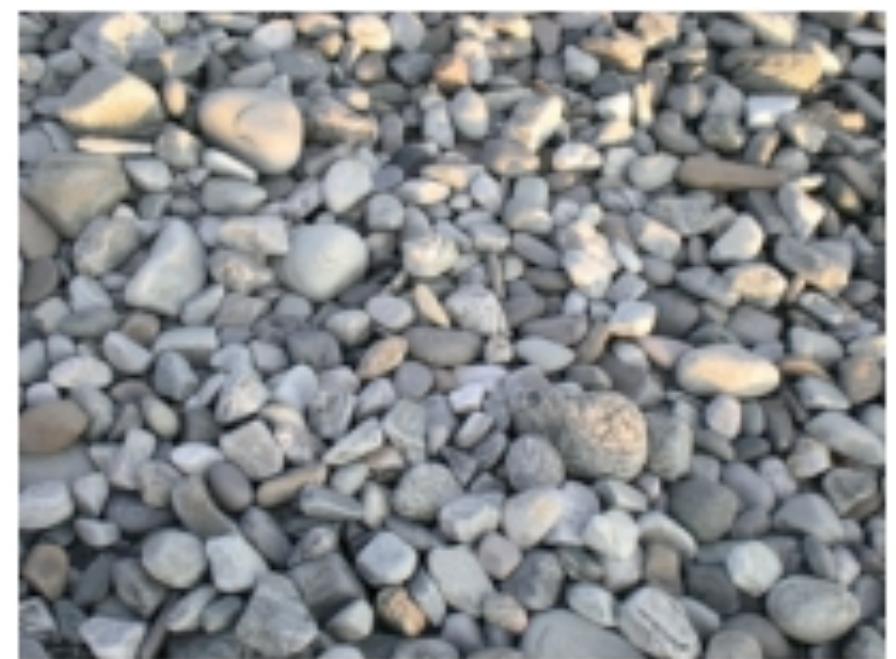
Efros and Leung, “Texture Synthesis by Non-parametric Sampling”, ICCV 1999

Texture Synthesis: Nearest Neighbor

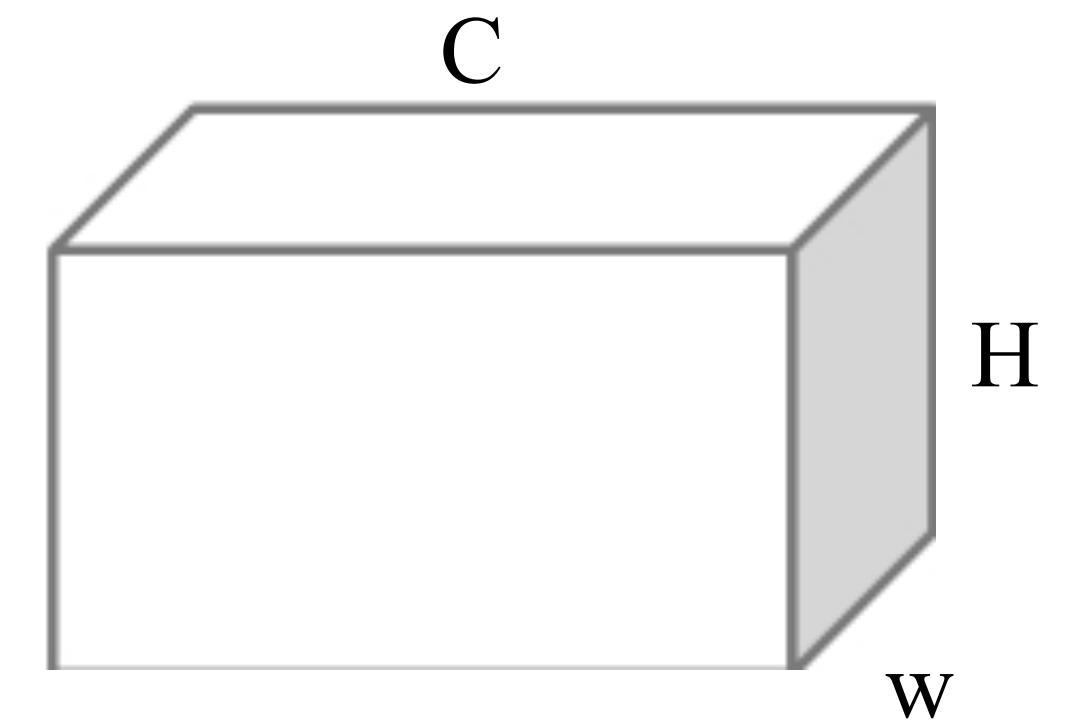


Images licensed under the [MIT license](#)

Neural Texture Synthesis: Gram Matrix

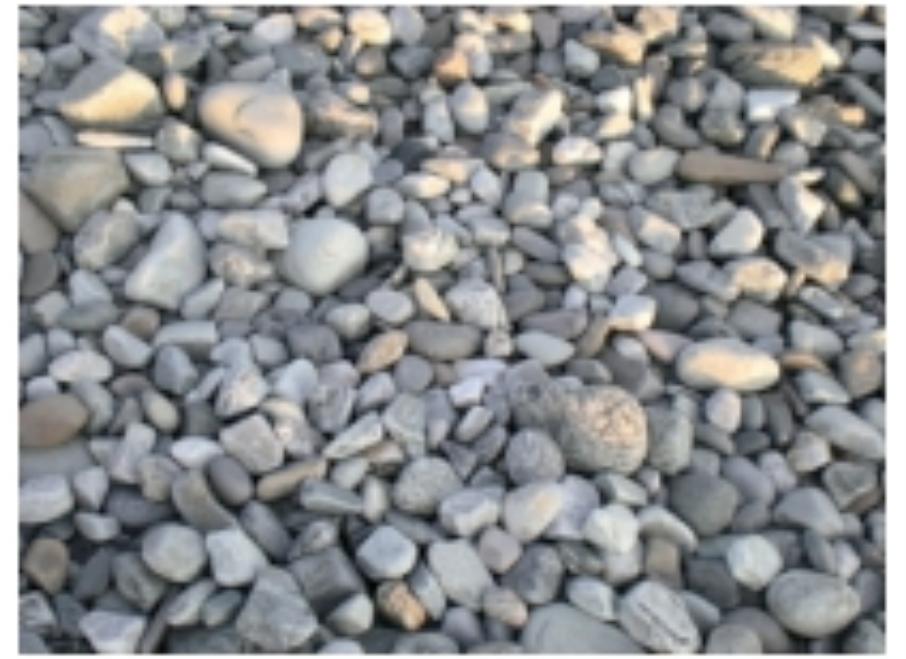


[This image is in the public domain.](#)

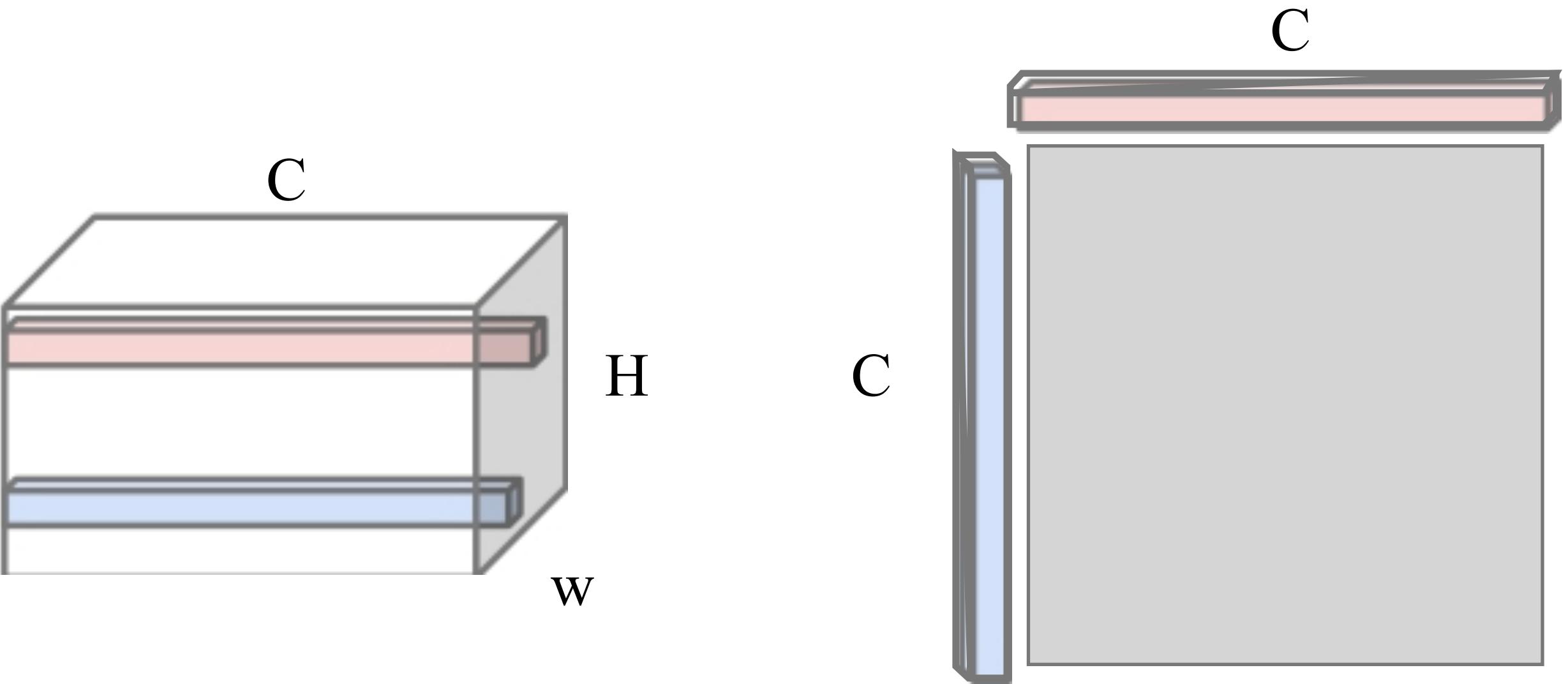
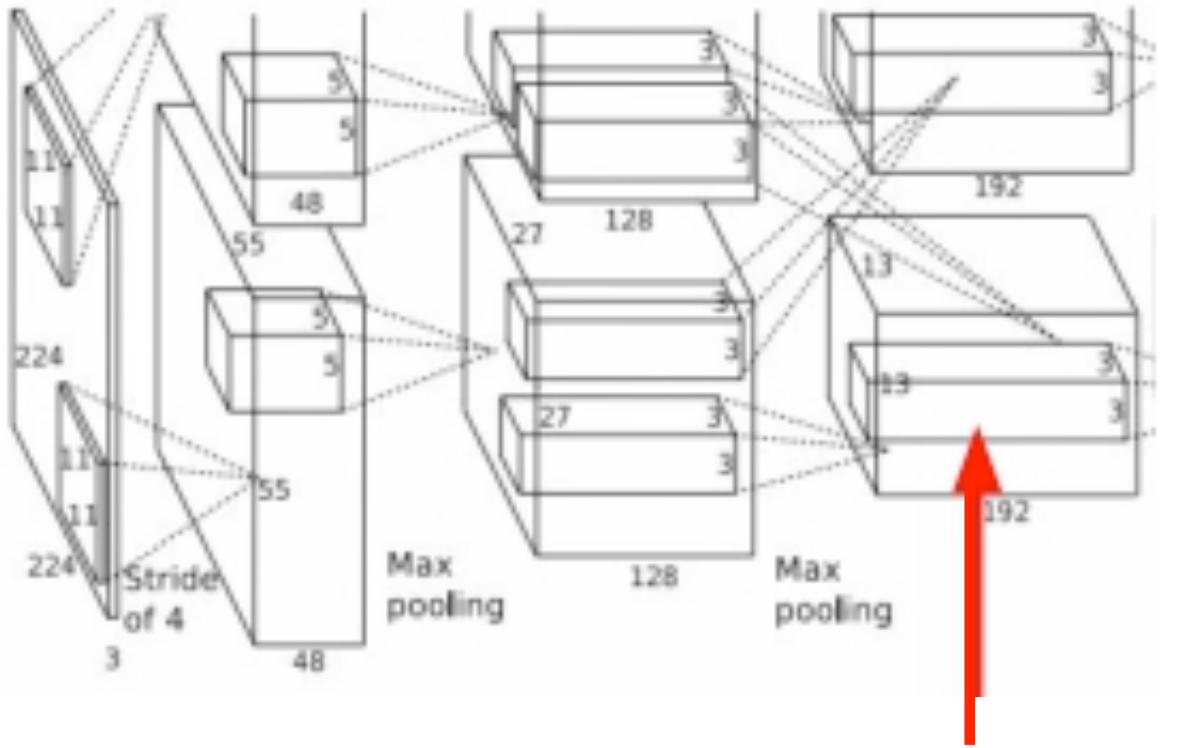


Each layer of CNN gives $C \times H \times W$ tensor of features; $H \times W$ grid of C -dimensional vectors

Neural Texture Synthesis: Gram Matrix



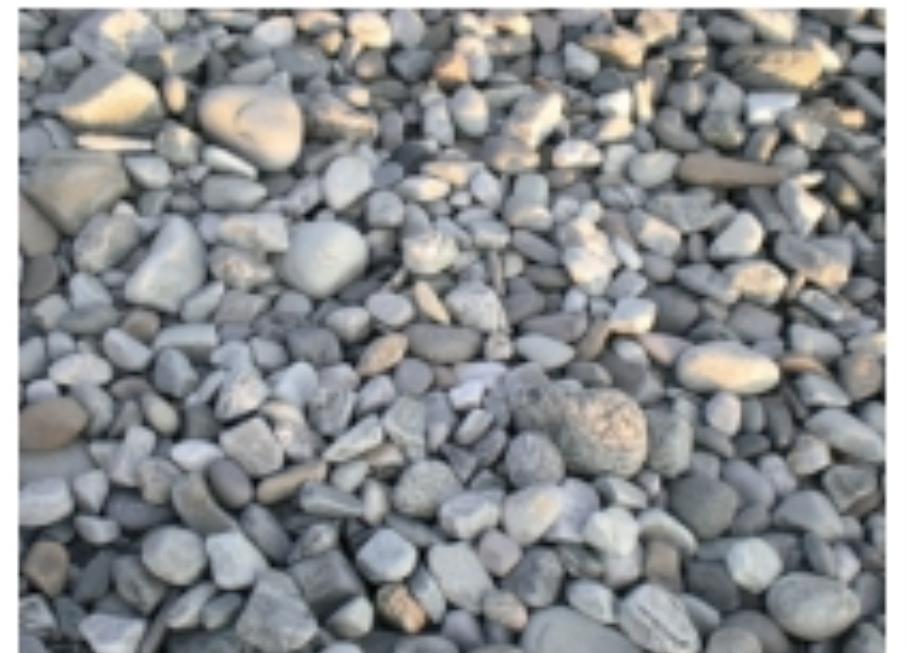
This image is in the public domain.



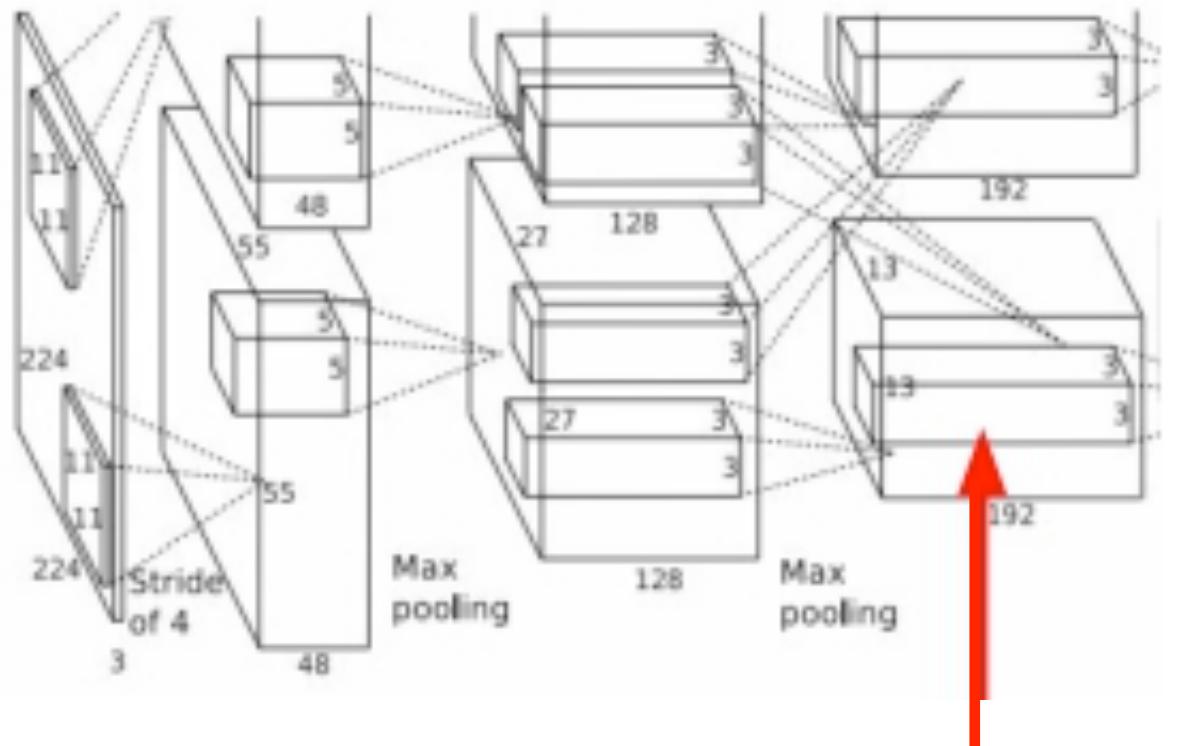
Each layer of CNN gives $C \times H \times W$ tensor of features; $H \times W$ grid of C -dimensional vectors

Outer product of two C -dimensional vectors gives $C \times C$ matrix measuring co-occurrence

Neural Texture Synthesis: Gram Matrix



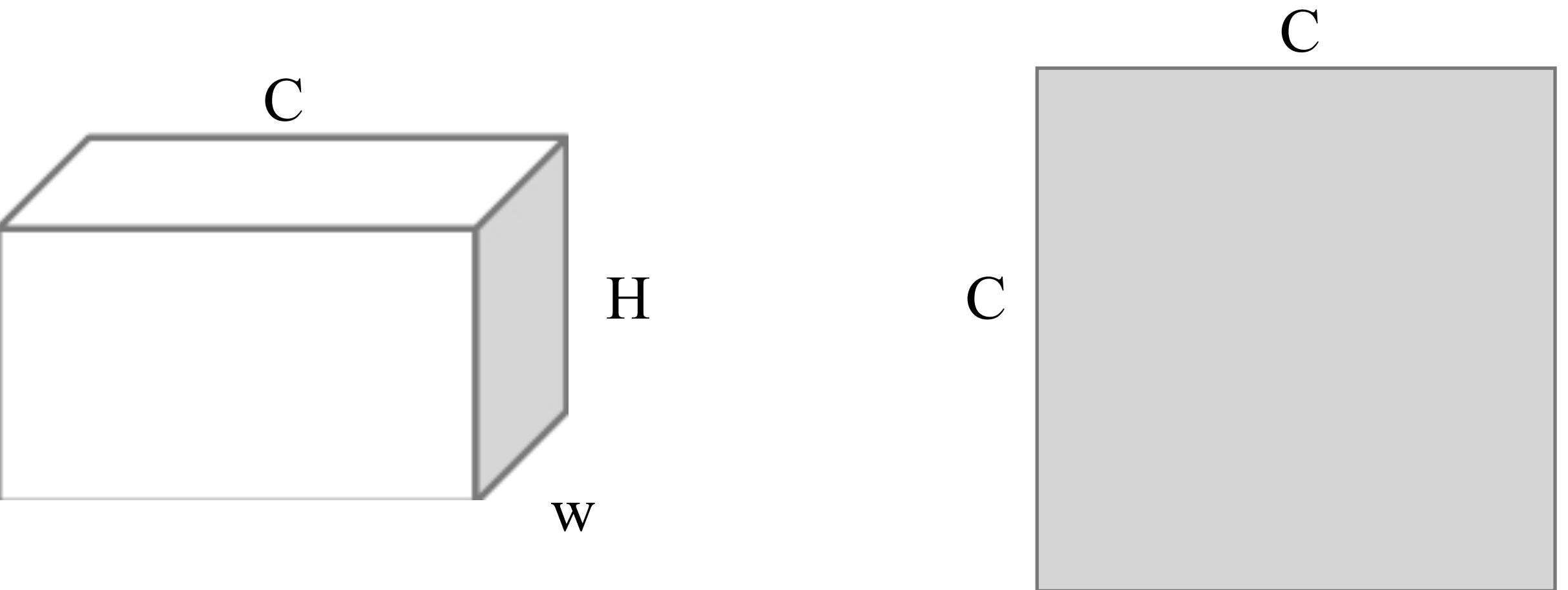
This image is in the public domain.



Each layer of CNN gives $C \times H \times W$ tensor of features; $H \times W$ grid of C -dimensional vectors

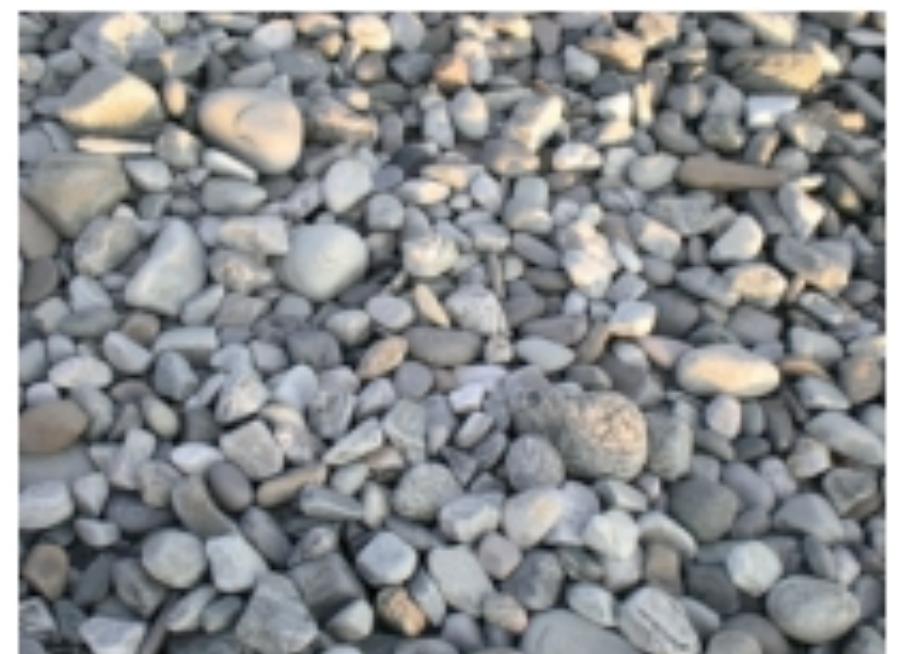
Outer product of two C -dimensional vectors gives $C \times C$ matrix measuring co-occurrence

Average over all HW pairs of vectors, giving **Gram matrix** of shape $C \times C$

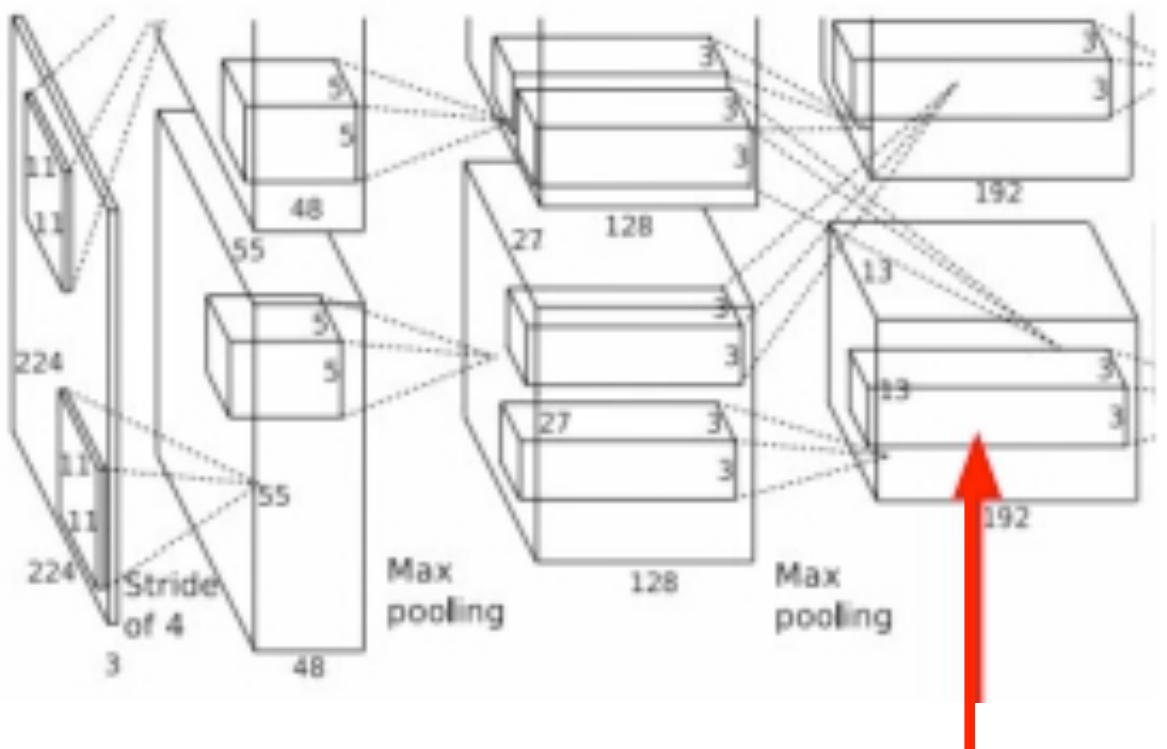


Gram Matrix

Neural Texture Synthesis: Gram Matrix



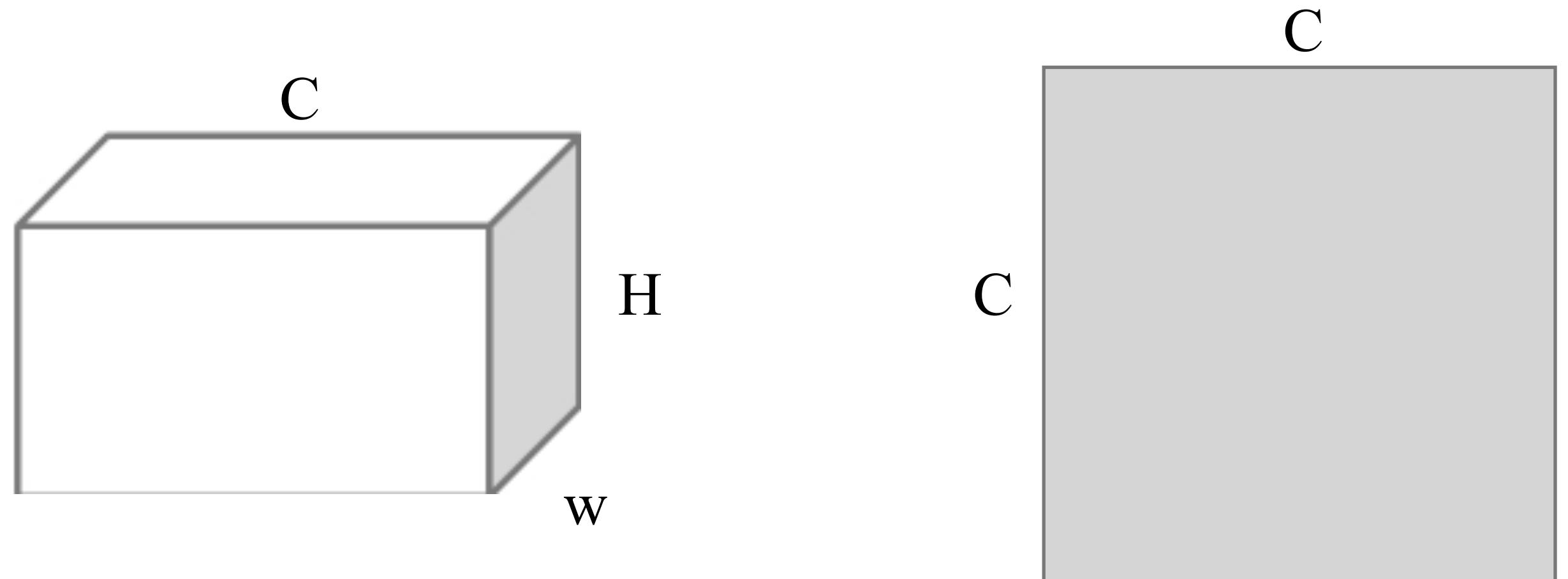
This image is in the public domain.



Each layer of CNN gives $C \times H \times W$ tensor of features; $H \times W$ grid of C -dimensional vectors

Outer product of two C -dimensional vectors gives $C \times C$ matrix measuring co-occurrence

Average over all HW pairs of vectors, giving **Gram matrix** of shape $C \times C$



Efficient to compute; reshape features from

$C \times H \times W$ to $=C \times HW$

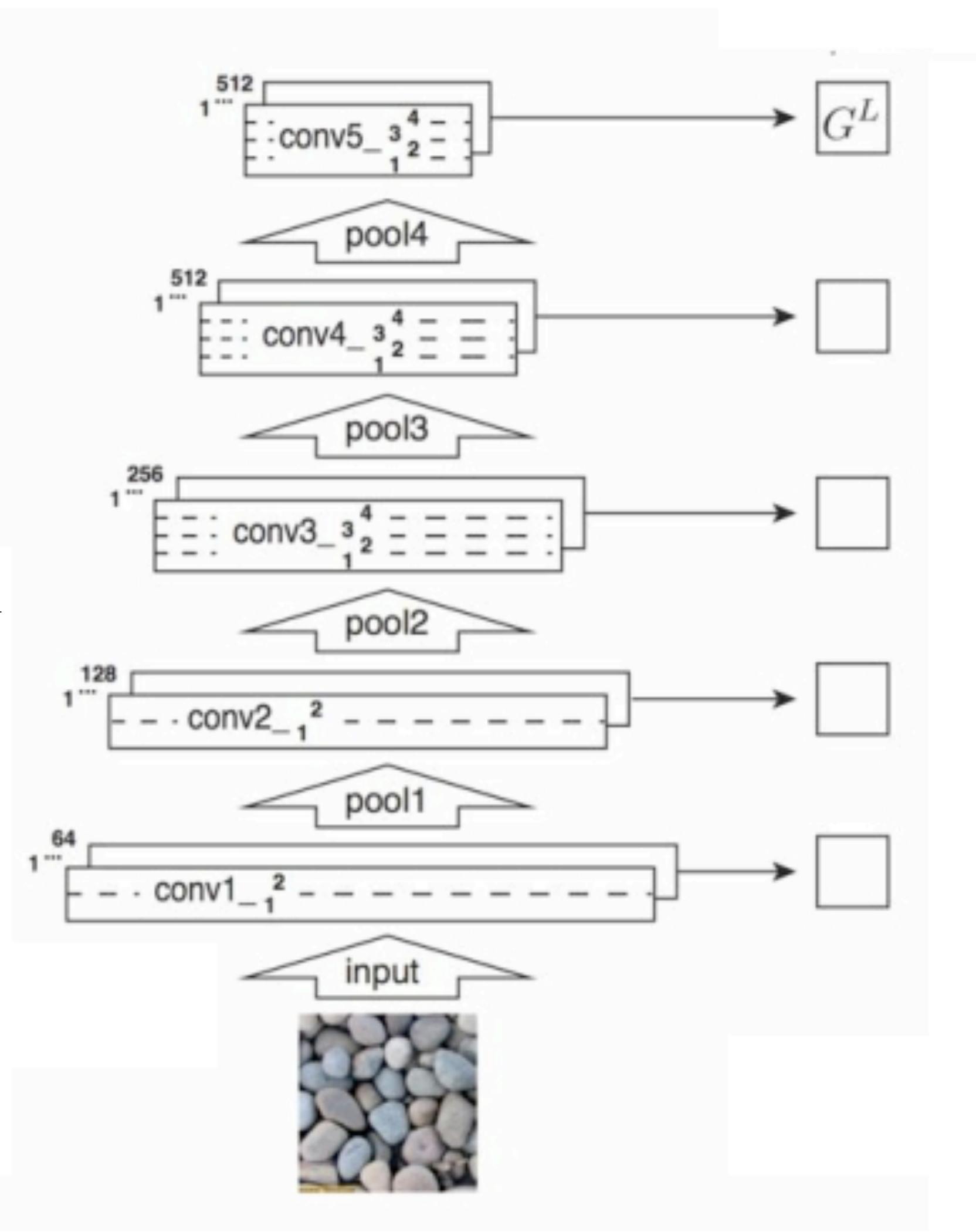
then compute $G = FF^T$

Neural Texture Synthesis

1. Pretrain a CNN on ImageNet (VGG-19)
2. Run input texture forward through CNN, record activations on every layer; layer i gives feature map of shape $C_i \times H_i \times W_i$
3. At each layer compute the *Gram matrix* giving outer product of features:

$$G_{ij}^l = \sum_k F_{ik}^l F_{jk}^l \text{ (shape } C_i \times C_i\text{)}$$

random

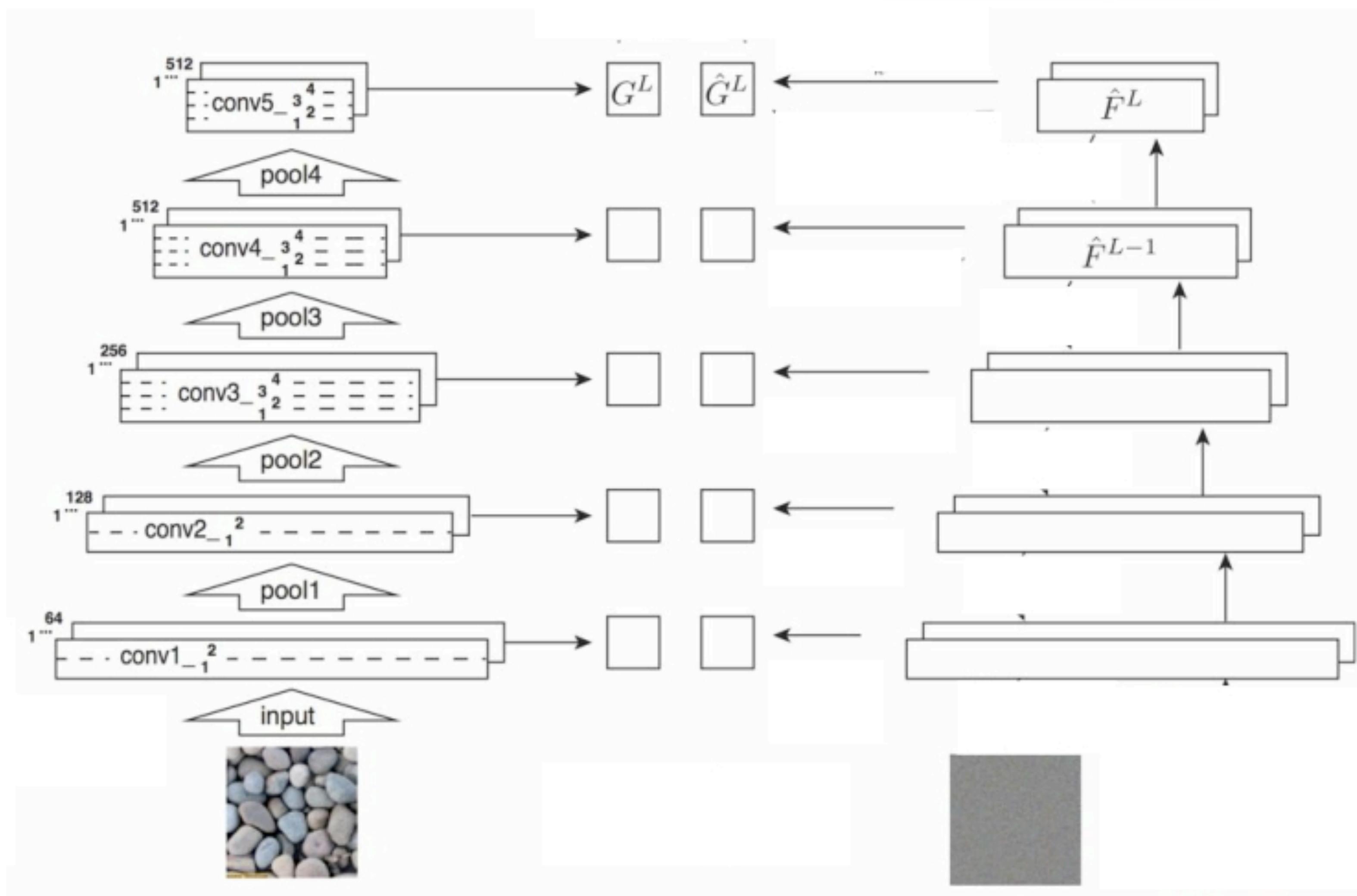


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4. Initialize generated image from random noise
5. Pass generated image through CNN, compute Gram matrix on each layer

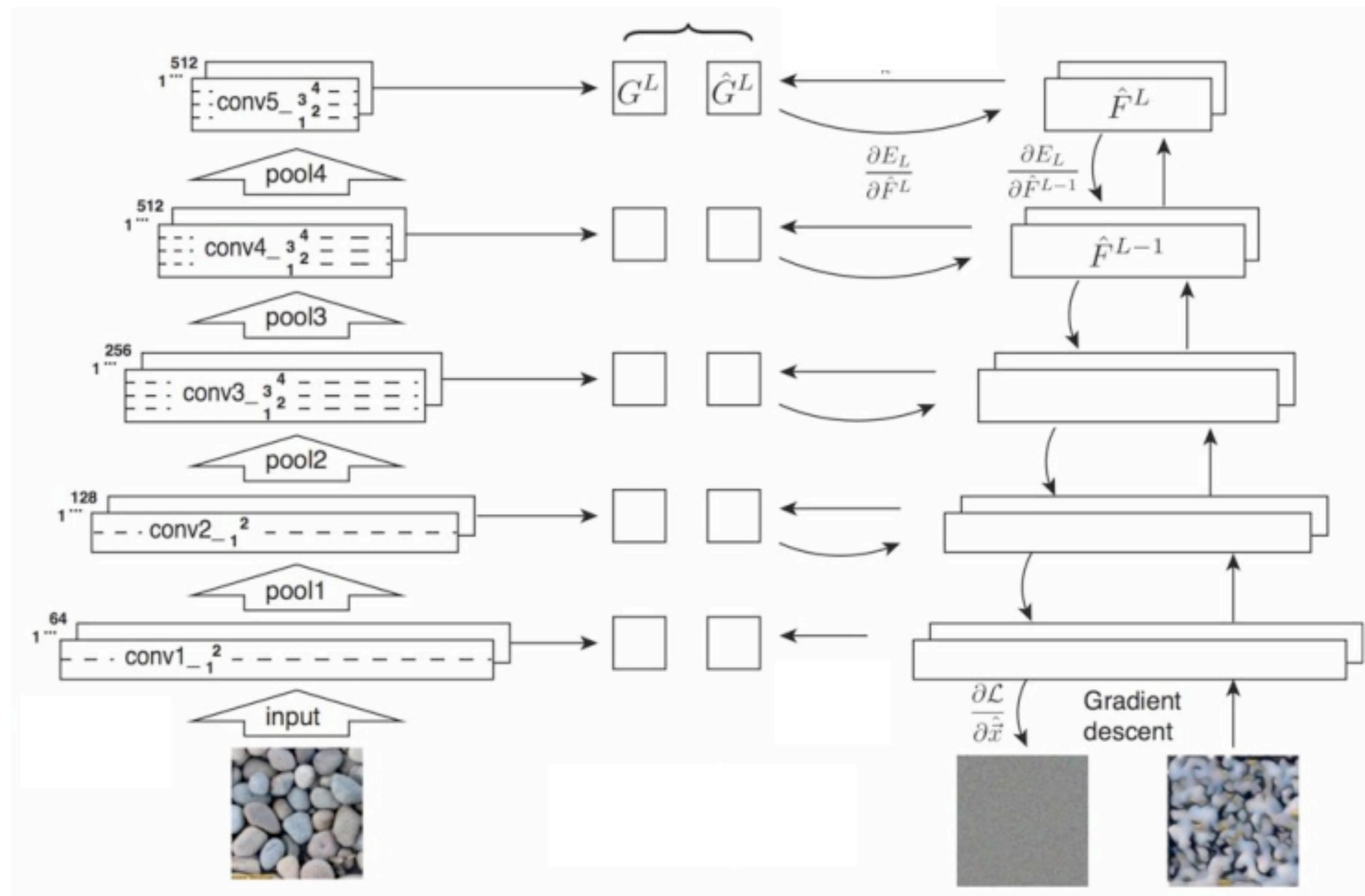


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$$G_{ij}^l = \sum_k F_{ik}^l F_{jk}^l \text{ (shape } C_i \times C_i\text{)}$$
4. Initialize generated image from random noise
5. Pass generated image through CNN, compute Gram matrix on each layer
6. Compute loss: weighted sum of L2 distance between Gram matrices
7. Backprop to get gradient on image
8. Make gradient step on image
9. GOTO 5

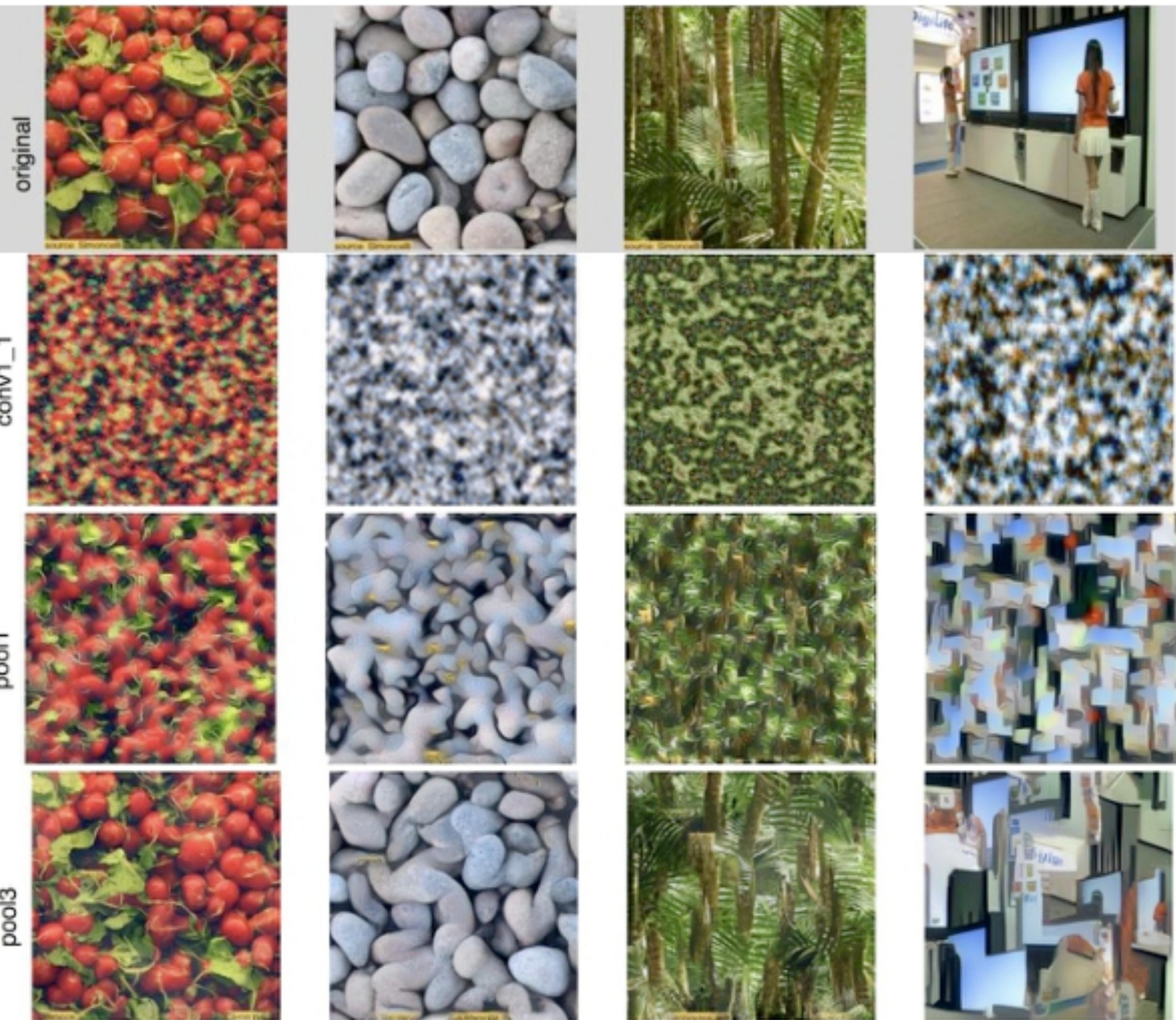
$$E_l = \frac{1}{4N_l^2 M_l^2} \sum_{i,j} (G_{ij}^l - \hat{G}_{ij}^l)^2$$

$$\mathcal{L}(\vec{x}, \hat{\vec{x}}) = \sum_{l=0}^L w_l E_l$$



Neural Texture Synthesis

Reconstructing texture from higher layers recovers larger features from the input texture



Gatys, Ecker, and Bethge, “Texture Synthesis Using Convolutional Neural Networks”, NIPS 2015
Figure copyright Leon Gatys, Alexander S. Ecker, and Matthias Bethge, 2015. Reproduced with permission.

Neural Texture Synthesis: Texture = Artwork

Texture synthesis
(Gram
reconstruction)

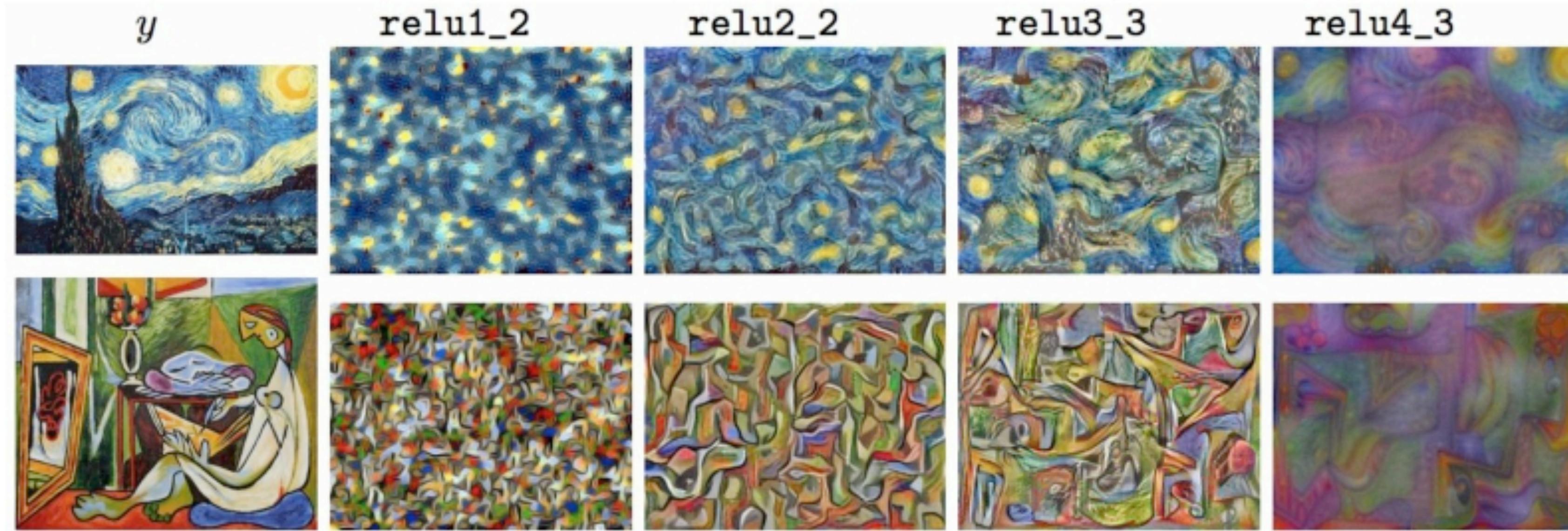
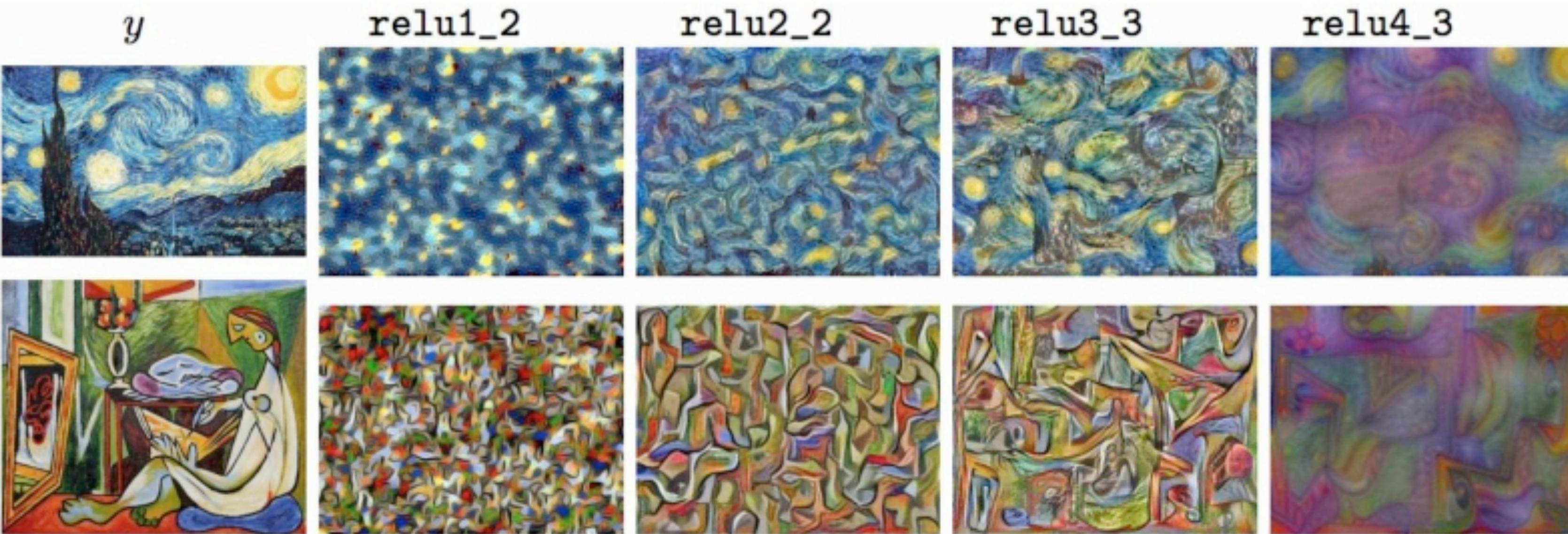


Figure from Johnson, Alahi, and Fei-Fei, "Perceptual Losses for Real-Time Style Transfer and Super-Resolution", ECCV 2016. Copyright Springer, 2016.
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Neural Style Transfer: Feature + Gram Reconstruction

Texture synthesis
(Gram
reconstruction)



Feature
reconstruction

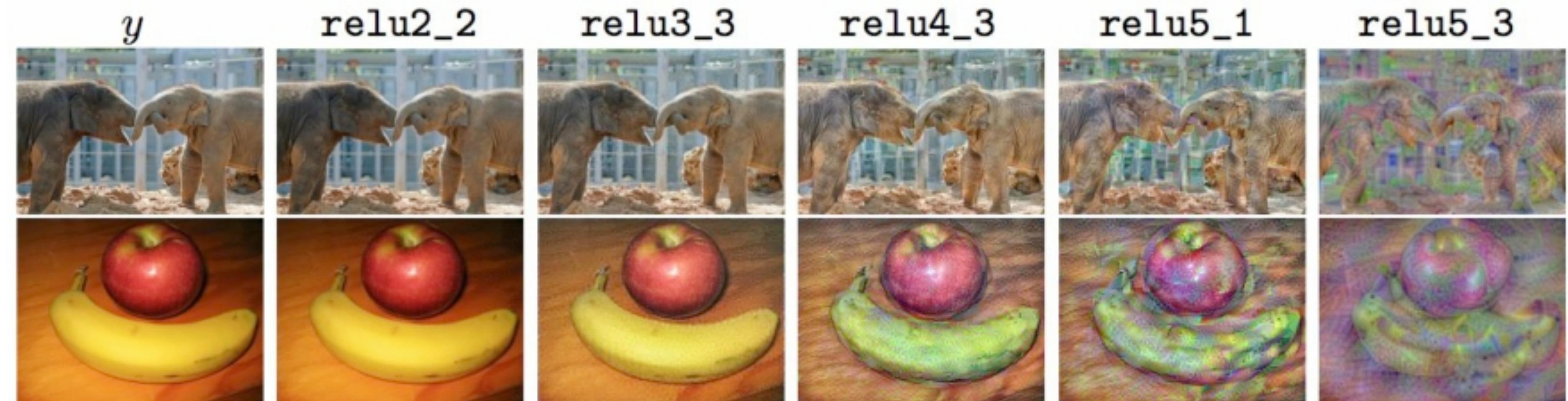


Figure from Johnson, Alahi, and Fei-Fei, "Perceptual Losses for Real-Time Style Transfer and Super-Resolution", ECCV 2016. Copyright Springer, 2016.
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Neural Style Transfer

Content Image



Style Image



This image is licensed under CC-BY 3.0

[Starry Night](#) by Van Gogh is in the public domain

Gatys, Ecker, and Bethge, "Texture Synthesis Using Convolutional Neural Networks", NIPS 2015

Neural Style Transfer

Content Image



+

Style Image



=

Style Transfer!

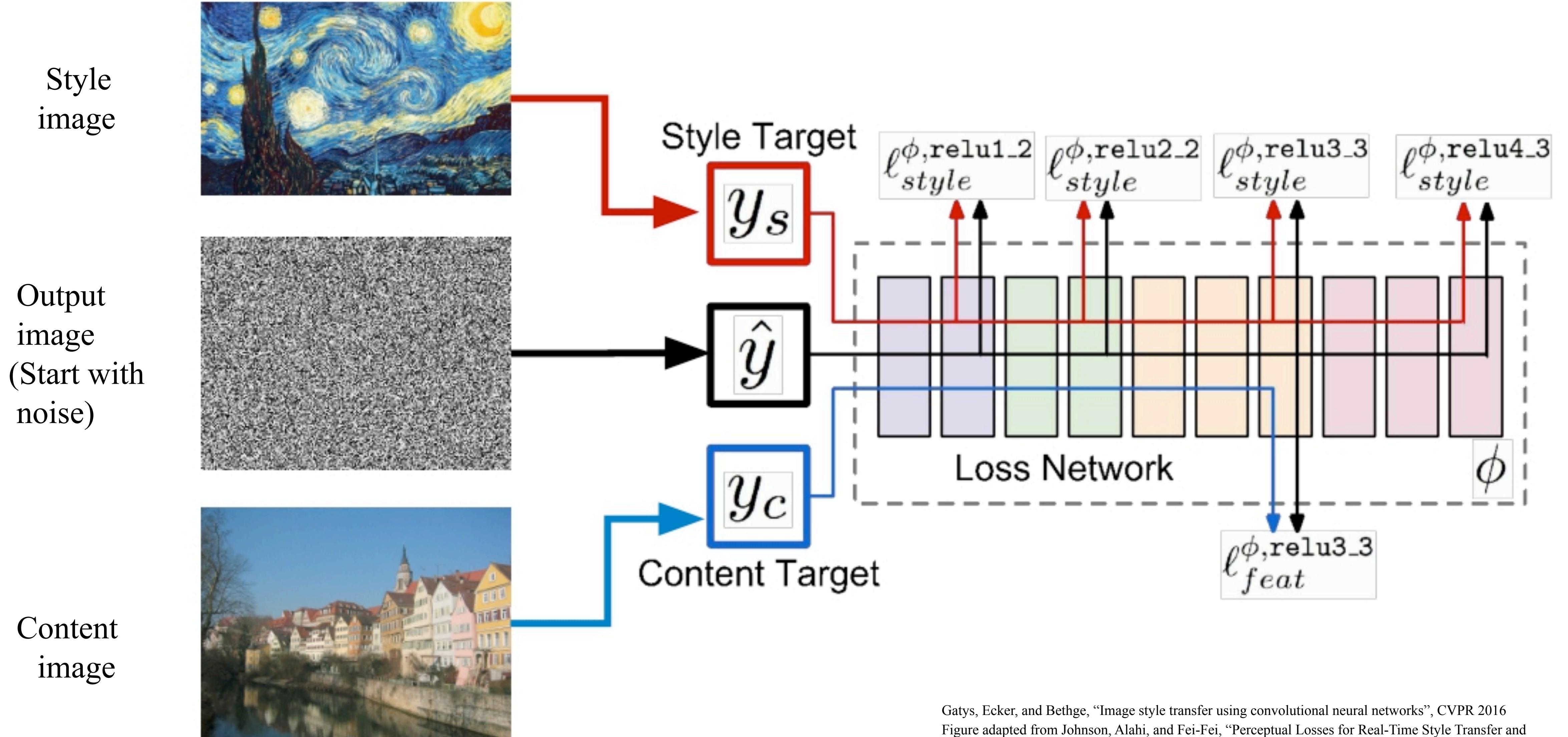


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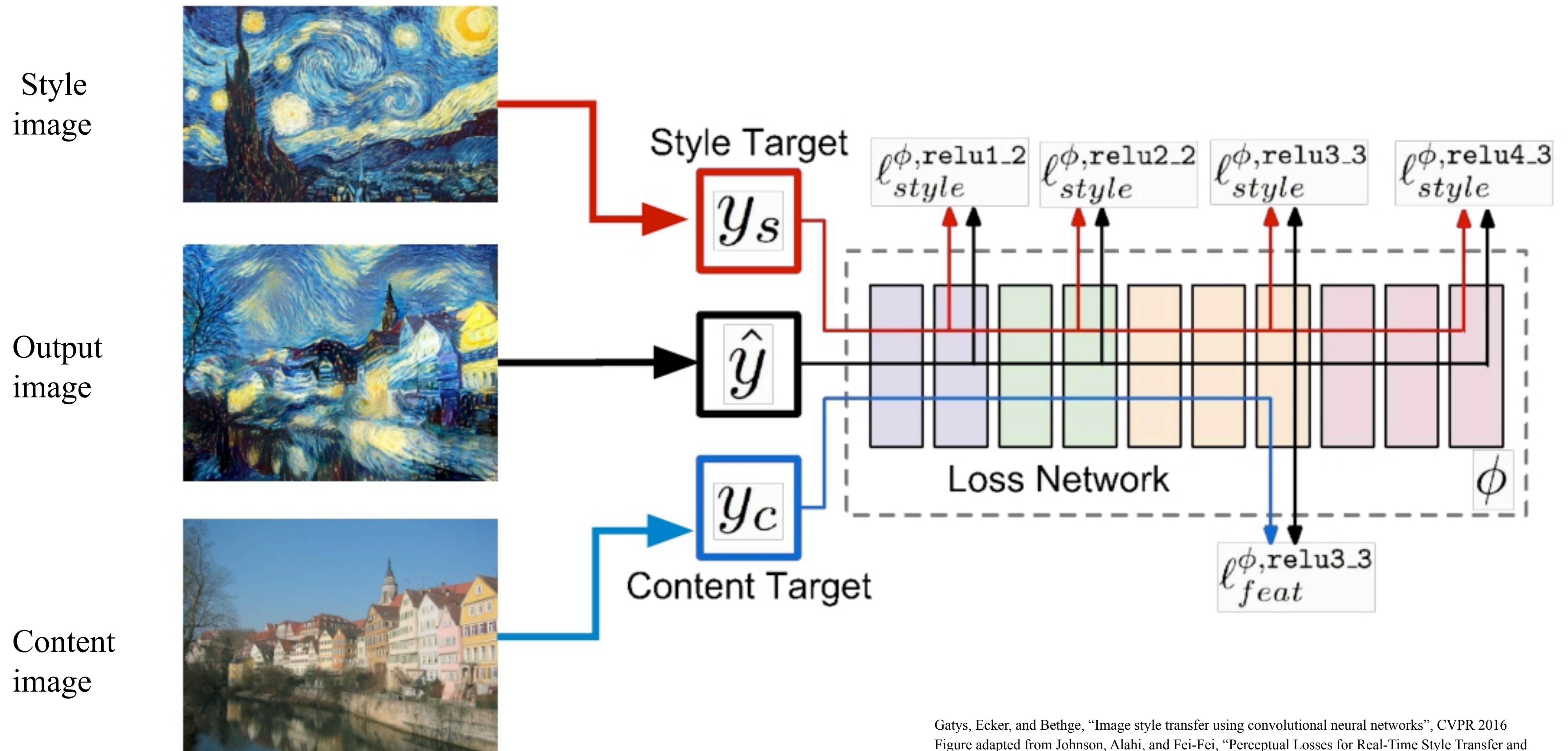
[Starry Night](#) by Van Gogh is in the public domain

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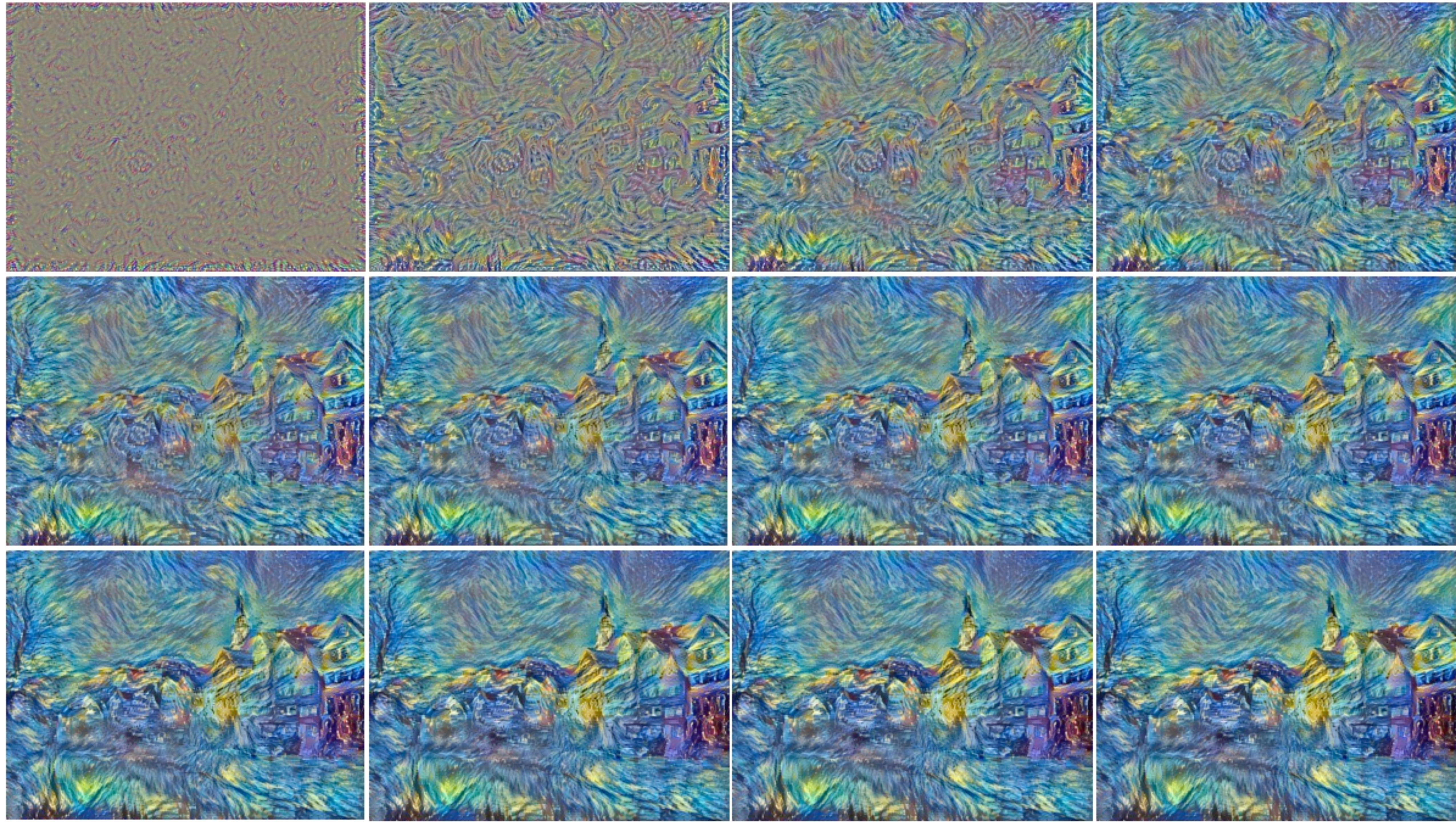
Gatys, Ecker, and Bethge, “Image style transfer using convolutional neural networks”, CVPR 2016



Gatys, Ecker, and Bethge, “Image style transfer using convolutional neural networks”, CVPR 2016
 Figure adapted from Johnson, Alahi, and Fei-Fei, “Perceptual Losses for Real-Time Style Transfer and Super-Resolution”, ECCV 2016. Copyright Springer, 2016. Reproduced for educational purposes.



Gatys, Ecker, and Bethge, “Image style transfer using convolutional neural networks”, CVPR 2016
 Figure adapted from Johnson, Alahi, and Fei-Fei, “Perceptual Losses for Real-Time Style Transfer and Super-Resolution”, ECCV 2016. Copyright Springer, 2016. Reproduced for educational purposes.



Neural Style Transfer

Example outputs from
[my implementation](#)
(in Torch)



Gatys, Ecker, and Bethge, “Image style transfer using convolutional neural networks”, CVPR 2016
Figure copyright Justin Johnson, 2015.

Neural Style Transfer



More weight to
content loss



More weight to
style loss

Neural Style Transfer

Resizing style image before running style transfer algorithm can transfer different types of features



Larger style
image

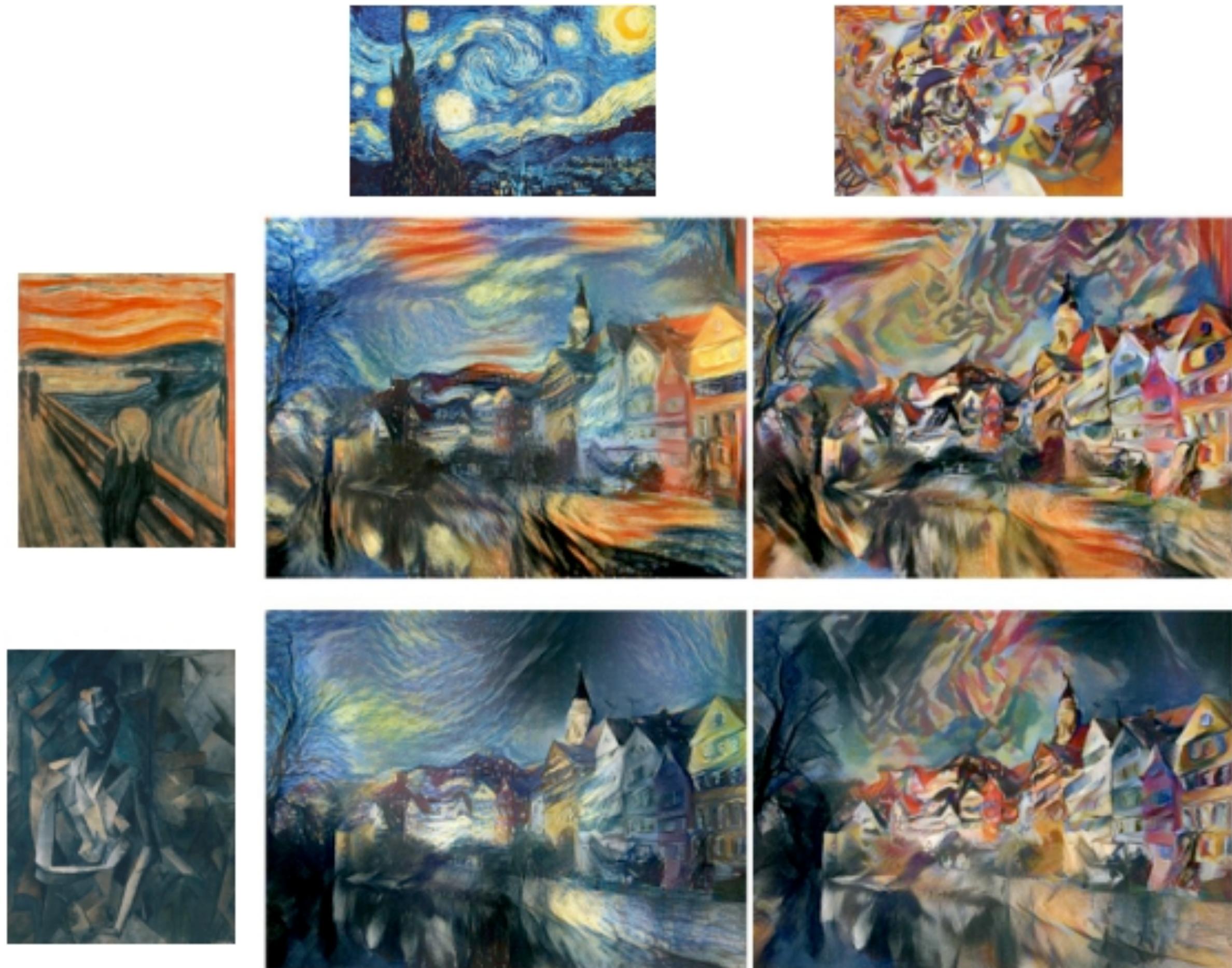


Smaller style
image

Gatys, Ecker, and Bethge, "Image style transfer using convolutional neural networks", CVPR 2016
Figure copyright Justin Johnson, 2015.

Neural Style Transfer: Multiple Style Images

Mix style from multiple images by taking a weighted average of Gram matrices



Gatys, Ecker, and Bethge, "Image style transfer using convolutional neural networks", CVPR 2016
Figure copyright Justin Johnson, 2015.

Neural Style Transfer

Problem: Style transfer requires many forward / backward passes through VGG; very slow!

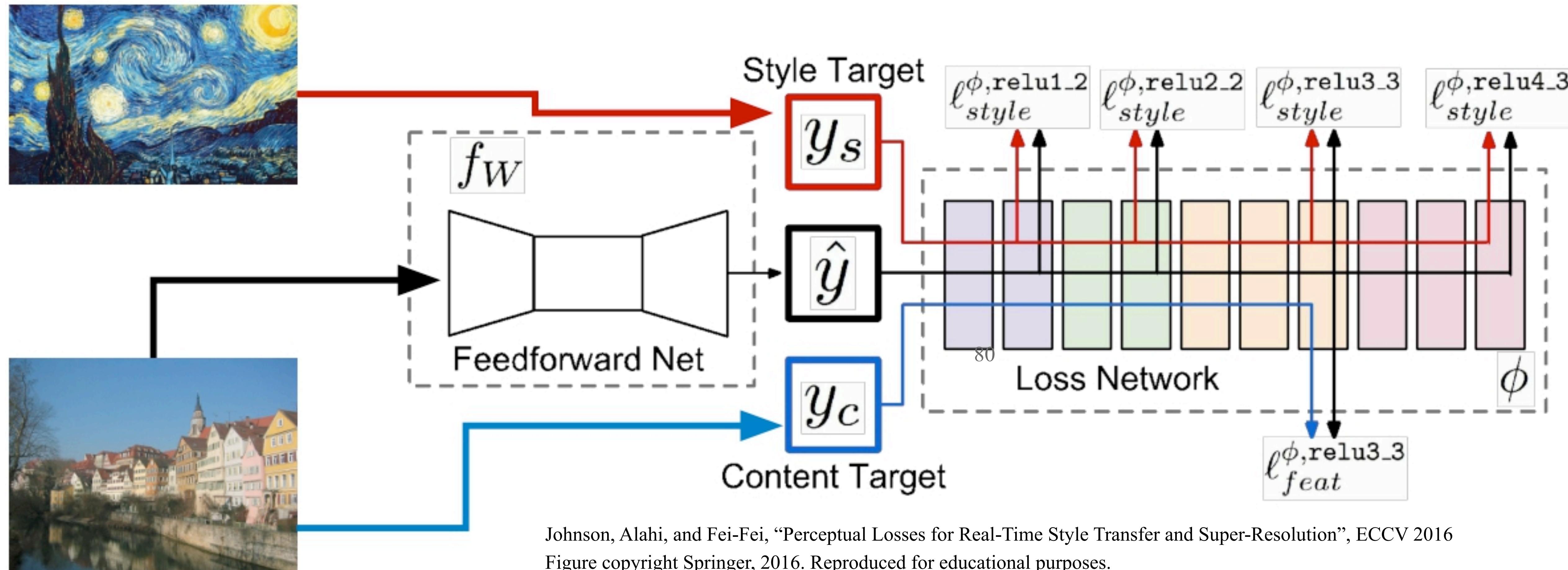
Neural Style Transfer

Problem: Style transfer requires many forward / backward passes through VGG; very slow!

Solution : Train another neural network to perform style transfer for us!

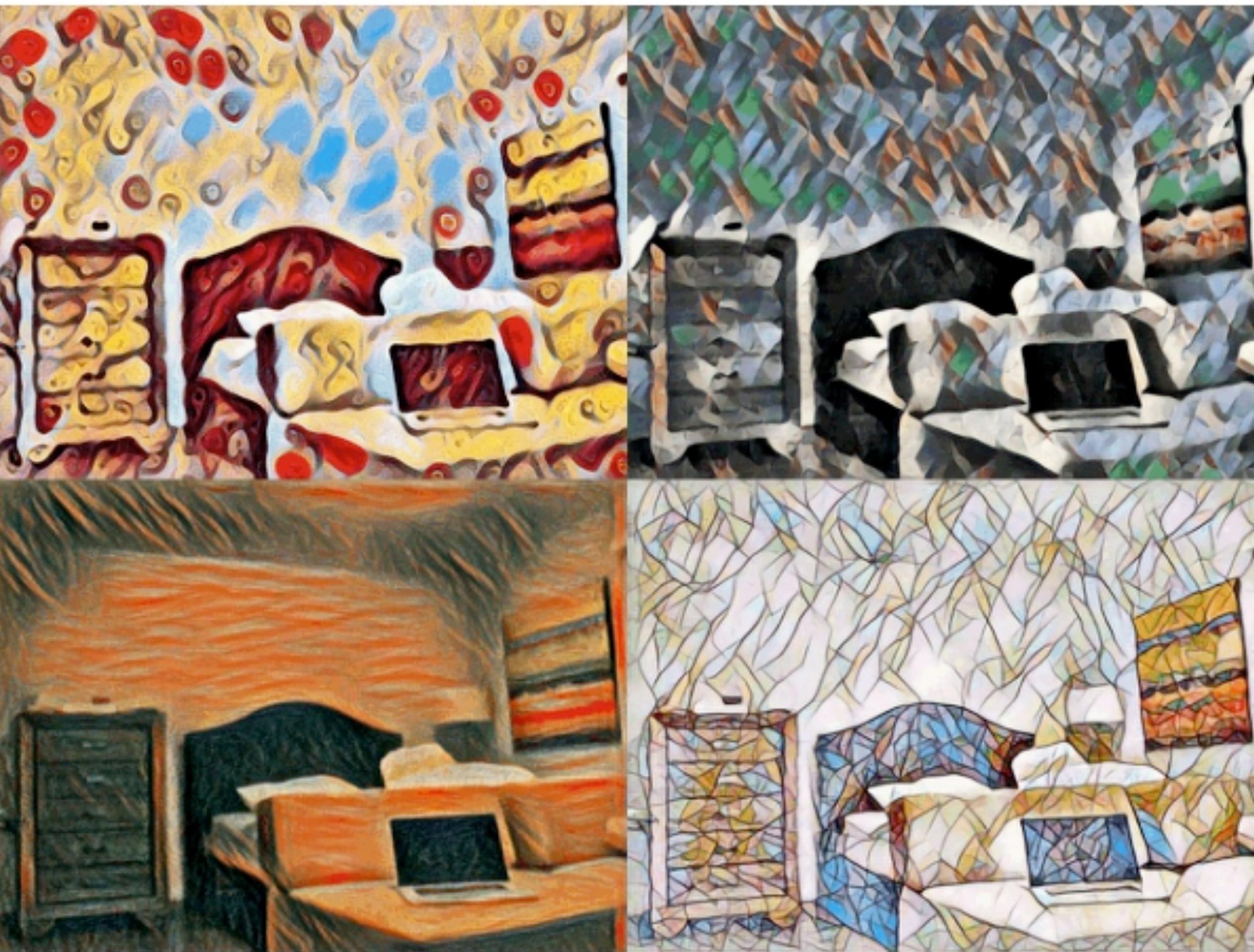
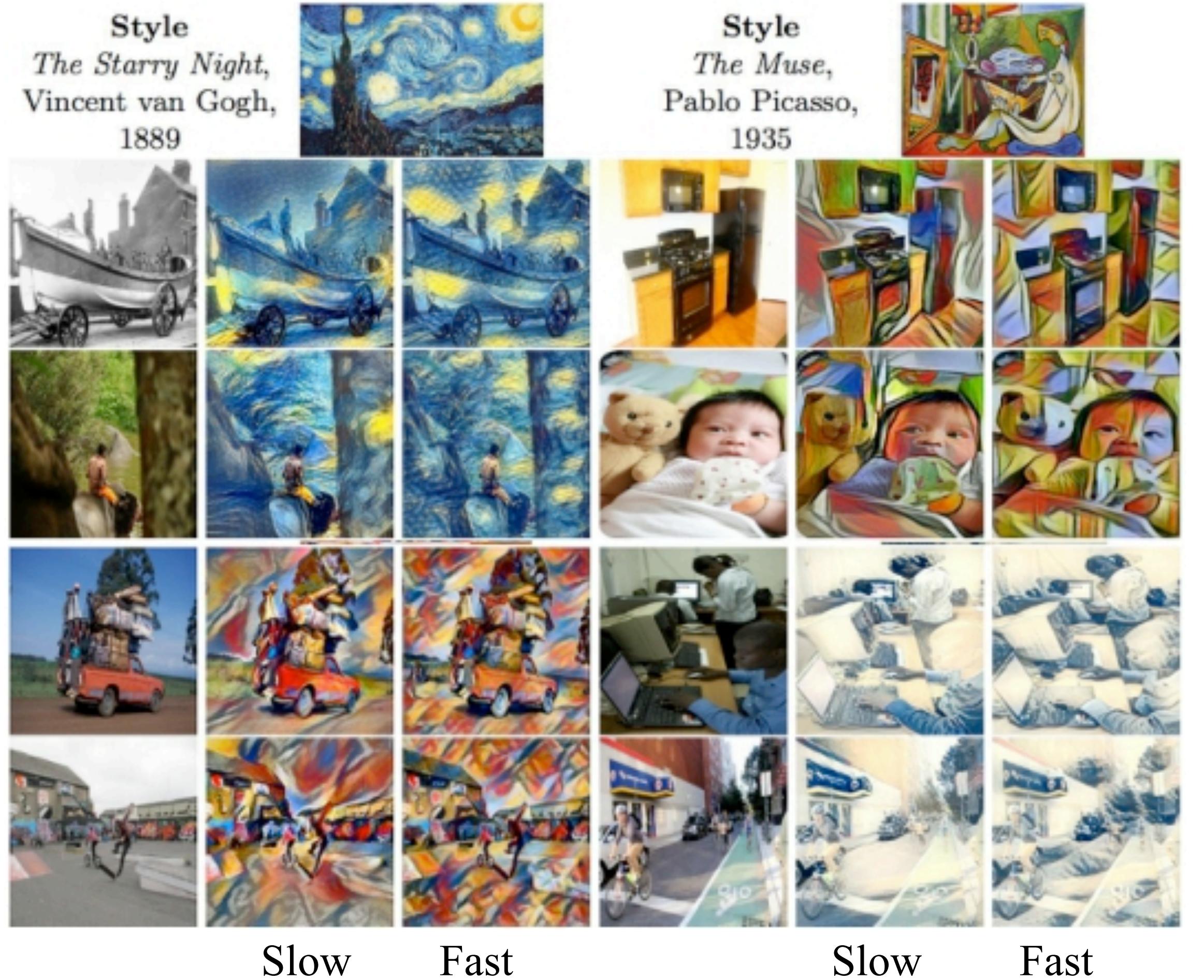
Fast Style Transfer

- (1) Train a feedforward network for each style
- (2) Use pretrained CNN to compute same losses as before
- (3) After training, stylize images using a single forward pass



Johnson, Alahi, and Fei-Fei, “Perceptual Losses for Real-Time Style Transfer and Super-Resolution”, ECCV 2016
Figure copyright Springer, 2016. Reproduced for educational purposes.

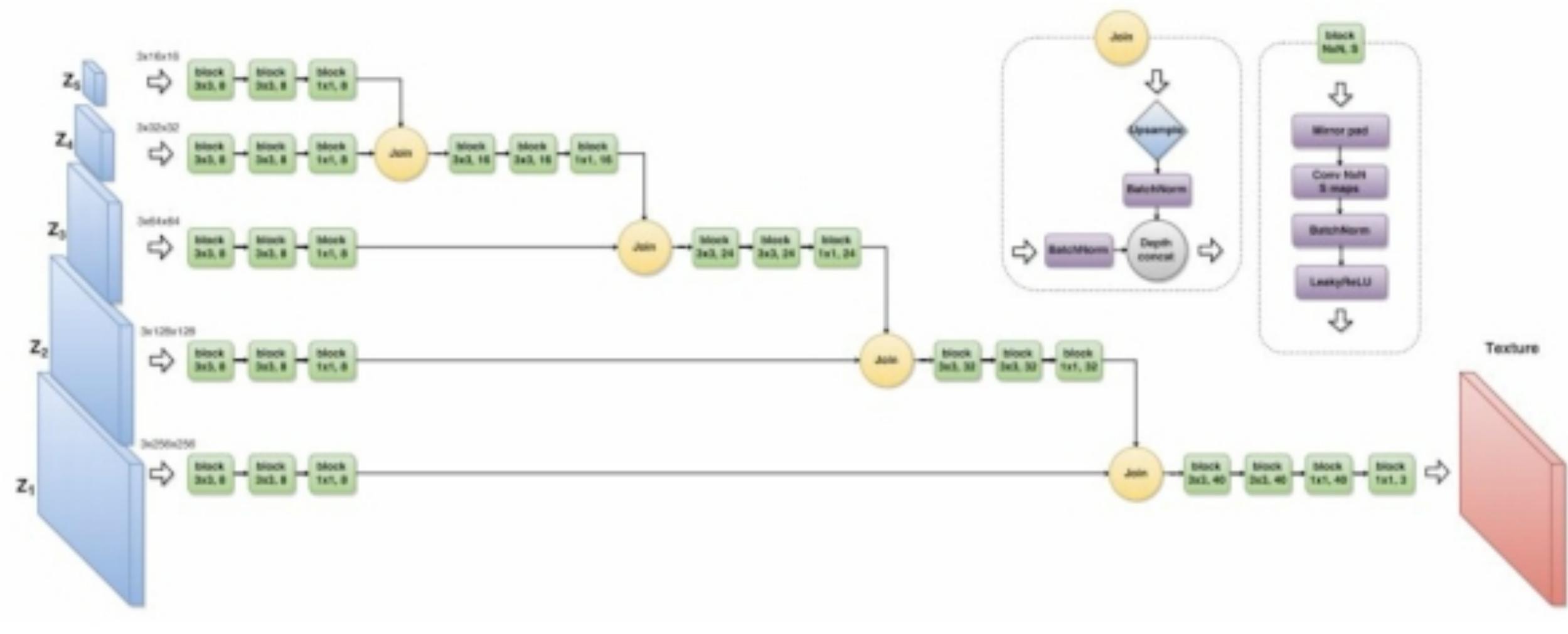
Fast Style Transfer



Johnson, Alahi, and Fei-Fei, “Perceptual Losses for Real-Time Style Transfer and Super-Resolution”, ECCV 2016
Figure copyright Springer, 2016. Reproduced for educational purposes.

<https://github.com/jcjohnson/fast-neural-style>

Fast Style Transfer



Concurrent work from Ulyanov et al, comparable results

Ulyanov et al, “Texture Networks: Feed-forward Synthesis of Textures and Stylized Images”, ICML 2016

Ulyanov et al, "Instance Normalization: The Missing Ingredient for Fast Stylization", arXiv 2016

Figures copyright Dmitry Ulyanov, Vadim Lebedev, Andrea Vedaldi, and Victor Lempitsky, 2016. Reproduced with permission.

Fast Style Transfer



Replacing batch normalization with Instance Normalization improves results

Ulyanov et al, “Texture Networks: Feed-forward Synthesis of Textures and Stylized Images”, ICML 2016

Ulyanov et al, “Instance Normalization: The Missing Ingredient for Fast Stylization”, arXiv 2016

Figures copyright Dmitry Ulyanov, Vadim Lebedev, Andrea Vedaldi, and Victor Lempitsky, 2016. Reproduced with permission.

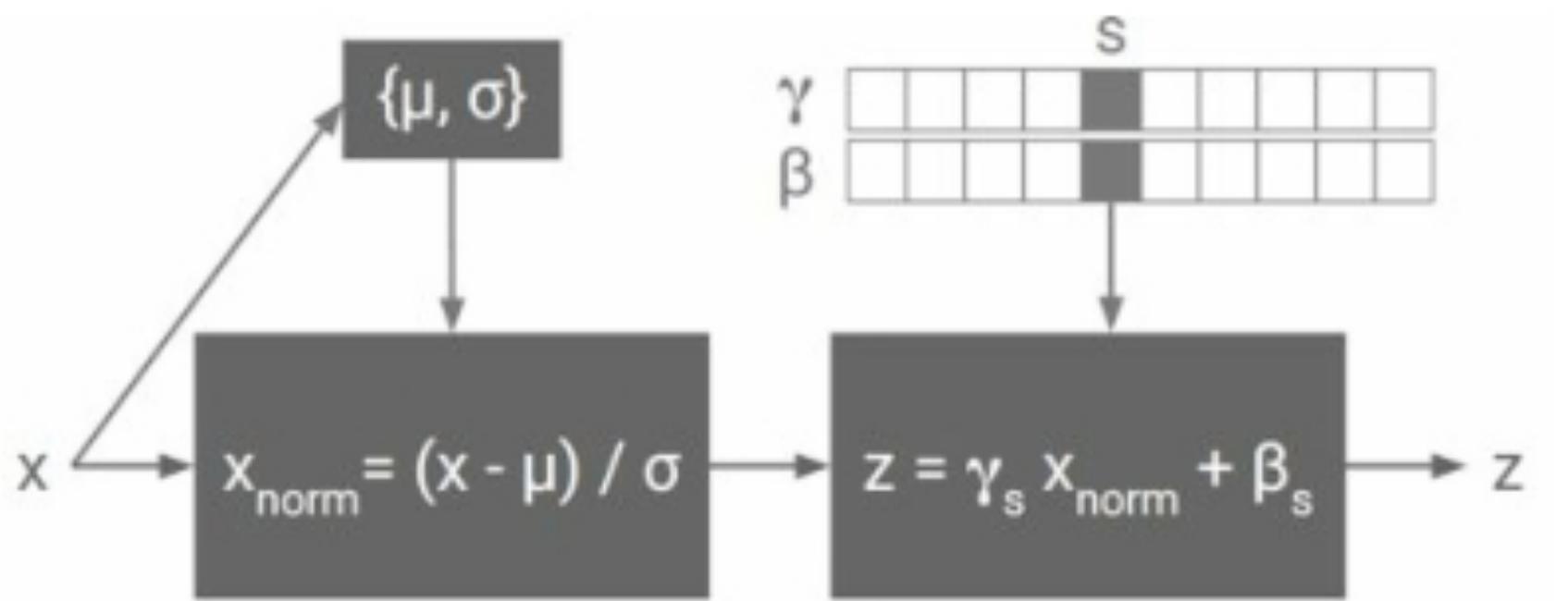
One Network, Many Styles



Dumoulin, Shlens, and Kudlur, “A Learned Representation for Artistic Style”, ICLR 2017.
Figure copyright Vincent Dumoulin, Jonathon Shlens, and Manjunath Kudlur, 2016; reproduced with permission.

One Network, Many Styles

Use the same network for multiple styles using conditional instance normalization: learn separate scale and shift parameters per style



Single network can blend styles after training

Dumoulin, Shlens, and Kudlur, “A Learned Representation for Artistic Style”, ICLR 2017.
Figure copyright Vincent Dumoulin, Jonathon Shlens, and Manjunath Kudlur, 2016; reproduced with permission.

Summary

Many methods for understanding CNN representations

Activations : Nearest neighbors, Dimensionality reduction, maximal patches, occlusion

Gradients : Saliency maps, class visualization, fooling images, feature inversion

Fun : DeepDream, Style Transfer.