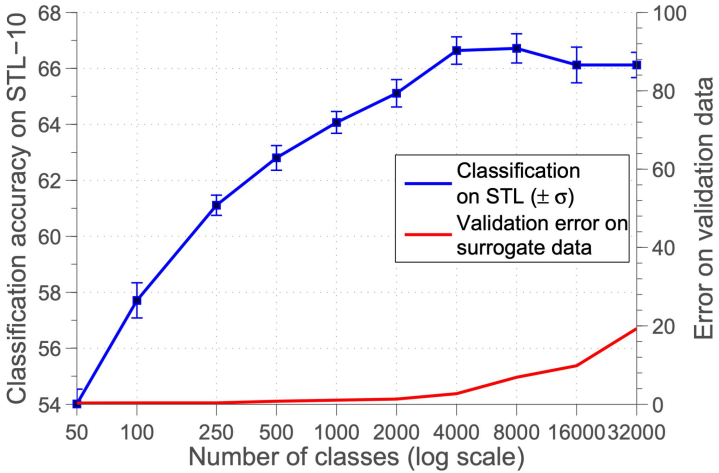
Pre-text Learning for CNNs

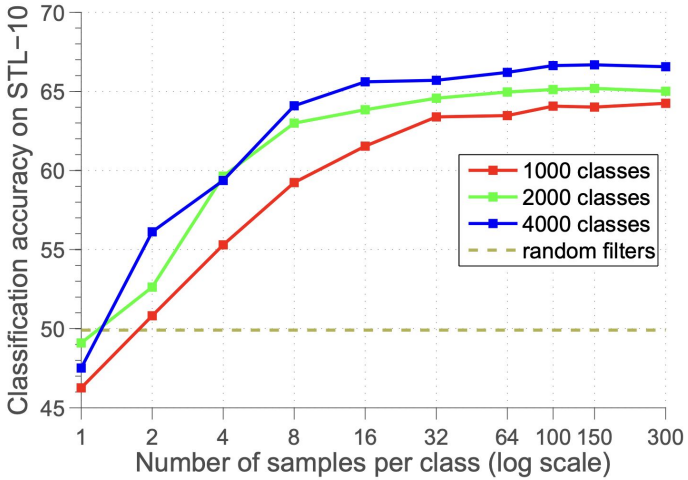
Large Scale Deep Learning

Exemplar, 2014, Dosovitskiy et al.

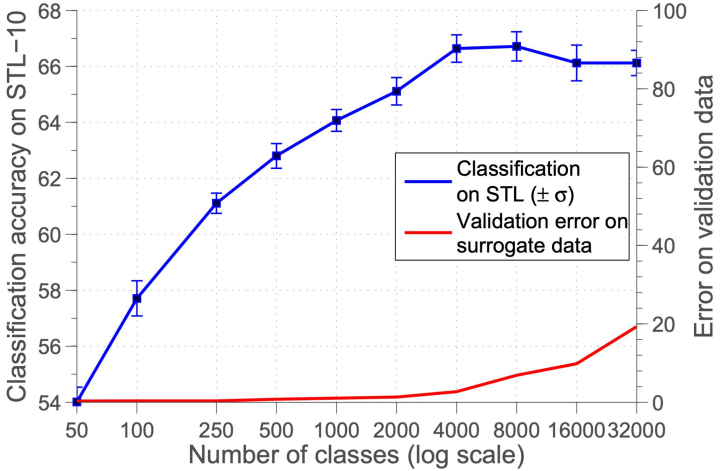
https://arxiv.org/abs/1406.6909

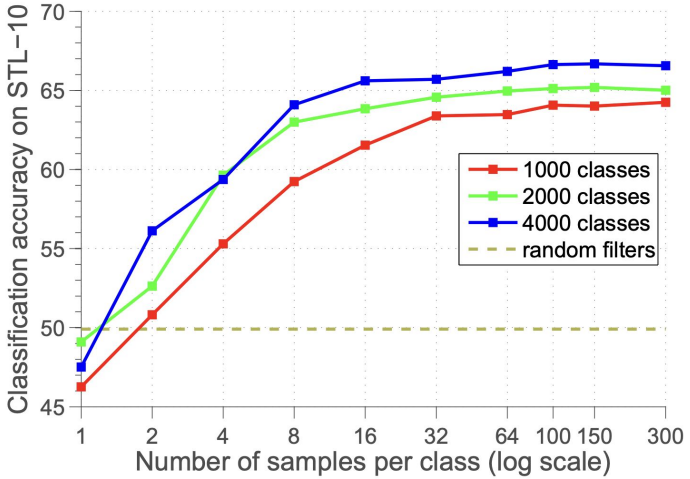
Exemplar


Classification accuracy on STL−10
Error on validation data
Number of classes (log scale)
Classification on STL (± σ)
Validation error on surrogate data
68
66
64
62
60
58
56
54
100
80
60
40
20
0
50
100
250
500
1000
2000
4000
8000
16000
32000


Classification accuracy on STL−10
Number of samples per class (log scale)
1000 classes
2000 classes
4000 classes
random filters
70
65
60
55
50
45
1
2
4
8
16
32
64
100
150
300

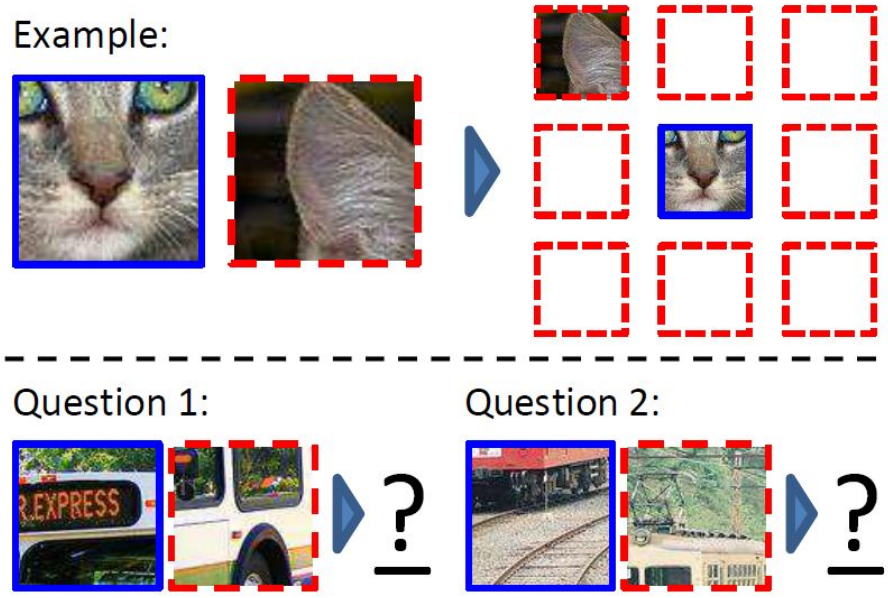
Exemplar

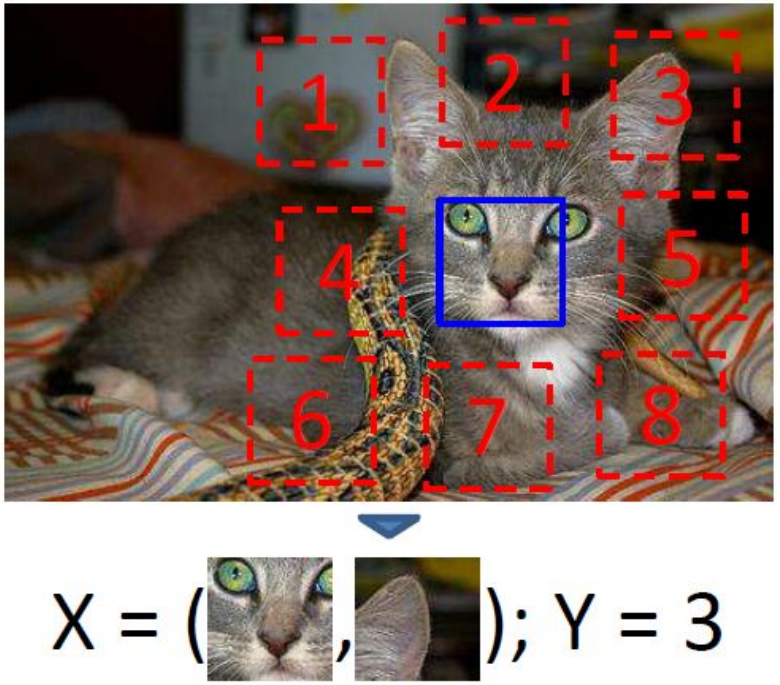




Algorithm	STL-10	CIFAR-10(400)	CIFAR-10	Caltech-101	Caltech-256(30)	#features
Convolutional K-means Network [32]	60.1 ± 1	70.7 ± 0.7	82.0	—	—	8000
Multi-way local pooling [33]	—	—	—	77.3 ± 0.6	41.7	1024×64
Slowness on videos [14]	61.0	—	—	74.6	—	556
Hierarchical Matching Pursuit (HMP) [34]	64.5 ± 1	—	—	—	—	1000
Multipath HMP [35]	—	—	—	82.5 ± 0.5	50.7	5000
View-Invariant K-means [16]	63.7	72.6 ± 0.7	81.9	—	—	6400
Exemplar-CNN (64c5-64c5-128f)	67.1 ± 0.2	69.7 ± 0.3	76.5	$79.8 \pm 0.5^{*}$	42.4 ± 0.3	256
Exemplar-CNN (64c5-128c5-256c5-512f)	72.8 ± 0.4	75.4 ± 0.2	82.2	$86.1 \pm 0.5^{\dagger}$	51.2 ± 0.2	960
Exemplar-CNN (92c5-256c5-512c5-1024f)	$\mathbf{74.2 \pm 0.4}$	$\mathbf{76.6 \pm 0.2}$	**84.3**	$\mathbf{87.1 \pm 0.7}^{\ddagger}$	$\mathbf{53.6 \pm 0.2}$	1884
Supervised state of the art	70.1[36]	—	92.0 [37]	91.44 [38]	70.6 [2]	—

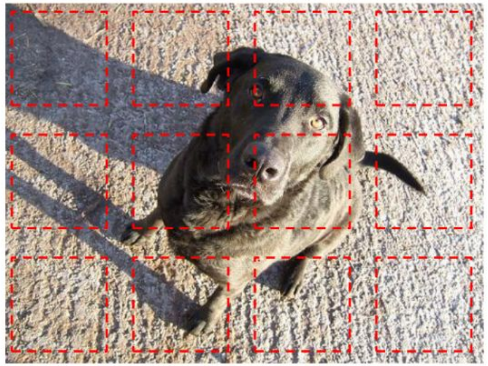
Context Prediction, 2015, Doersch et al.





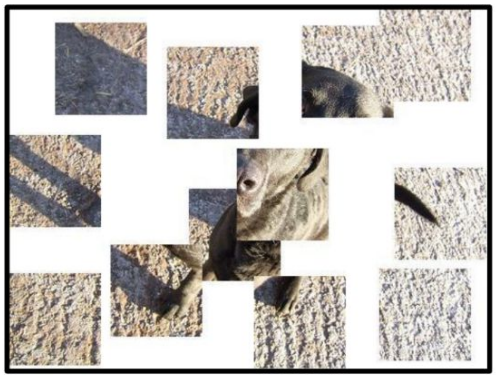
https://arxiv.org/abs/1505.05192

Context Prediction

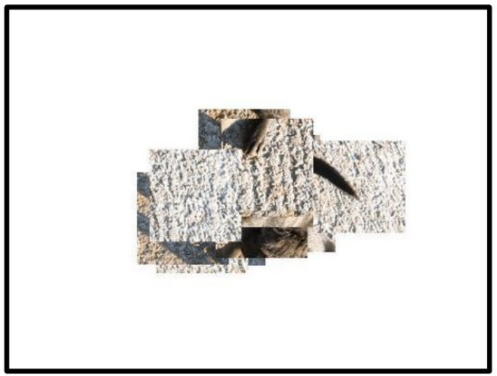


Initial layout, with sampled patches in red

Image layout is discarded



We can recover image layout automatically



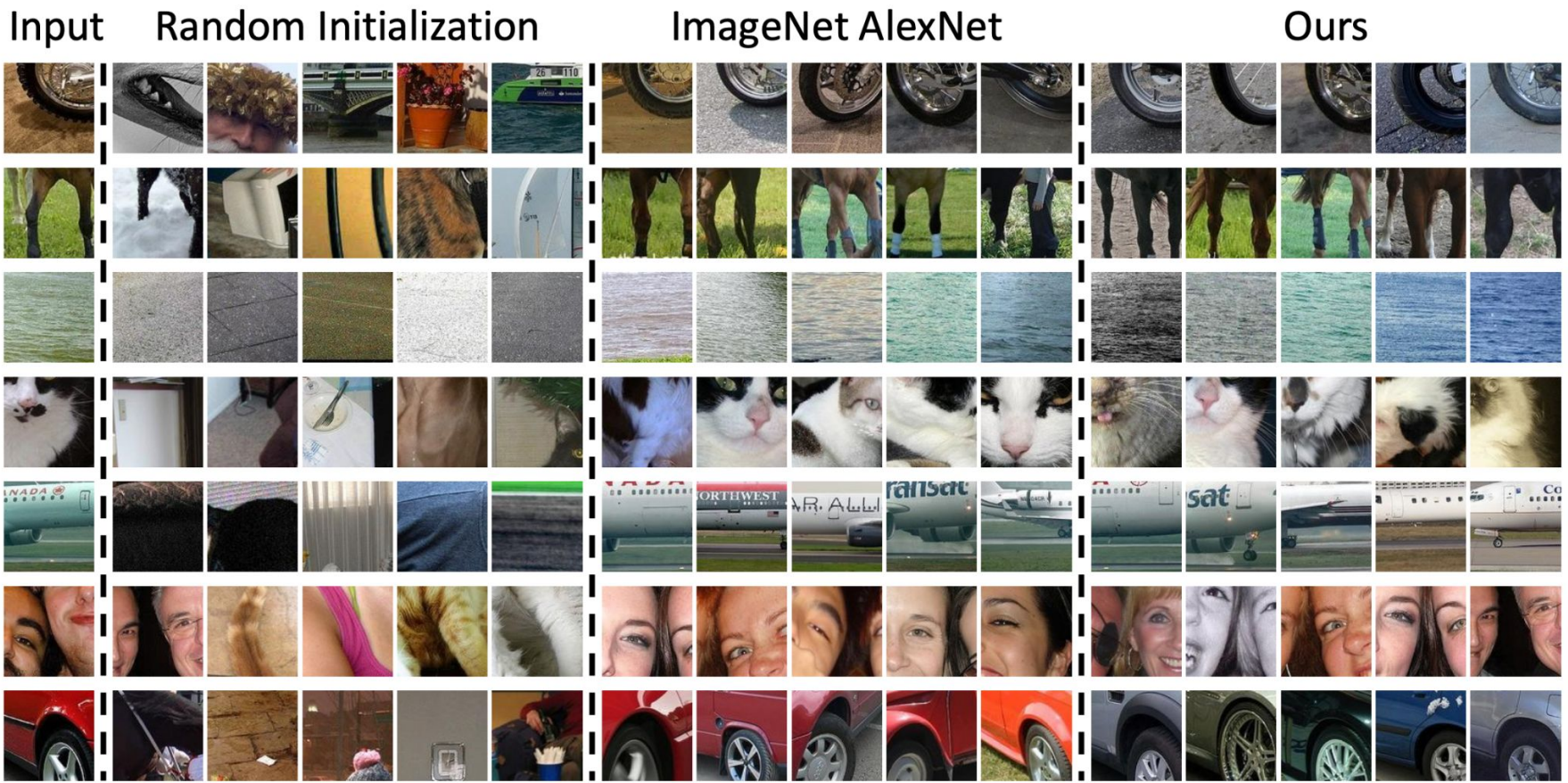
Cannot recover layout with color removed

Context Prediction

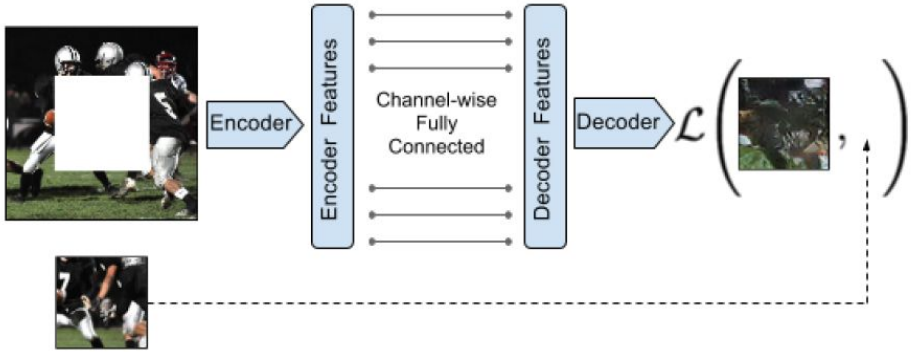
VOC-2007 Test	aero	bike	bird	boat	bottle	bus	car	cat	chair	cow	table	dog	horse	mbike	person	plant	sheep	sofa	train	tv	mAP
DPM-v5[17]	33.2	60.3	10.2	16.1	27.3	54.3	58.2	23.0	20.0	24.1	26.7	12.7	58.1	48.2	43.2	12.0	21.1	36.1	46.0	43.5	33.7
[8] w/o context	52.6	52.6	19.2	25.4	18.7	47.3	56.9	42.1	16.6	41.4	41.9	27.7	47.9	51.5	29.9	20.0	41.1	36.4	48.6	53.2	38.5
Regionlets[58]	54.2	52.0	20.3	24.0	20.1	55.5	68.7	42.6	19.2	44.2	49.1	26.6	57.0	54.5	43.4	16.4	36.6	37.7	59.4	52.3	41.7
Scratch-R-CNN[2]	49.9	60.6	24.7	23.7	20.3	52.5	64.8	32.9	20.4	43.5	34.2	29.9	49.0	60.4	47.5	28.0	42.3	28.6	51.2	50.0	40.7
Scratch-Ours	52.6	60.5	23.8	24.3	18.1	50.6	65.9	29.2	19.5	43.5	35.2	27.6	46.5	59.4	46.5	25.6	42.4	23.5	50.0	50.6	39.8
Ours-projection	58.4	62.8	33.5	27.7	24.4	58.5	68.5	41.2	26.3	49.5	42.6	37.3	55.7	62.5	49.4	29.0	47.5	28.4	54.7	56.8	45.7
Ours-color-dropping	60.5	66.5	29.6	28.5	26.3	56.1	70.4	44.8	24.6	45.5	45.4	35.1	52.2	60.2	50.0	28.1	46.7	42.6	54.8	58.6	46.3
Ours-Yahoo100m	56.2	63.9	29.8	27.8	23.9	57.4	69.8	35.6	23.7	47.4	43.0	29.5	52.9	62.0	48.7	28.4	45.1	33.6	49.0	55.5	44.2
ImageNet-R-CNN[21]	64.2	69.7	50	41.9	32.0	62.6	71.0	60.7	32.7	58.5	46.5	56.1	60.6	66.8	54.2	31.5	52.8	48.9	57.9	64.7	54.2
K-means-rescale [31]	55.7	60.9	27.9	30.9	12.0	59.1	63.7	47.0	21.4	45.2	55.8	40.3	67.5	61.2	48.3	21.9	32.8	46.9	61.6	51.7	45.6
Ours-rescale [31]	61.9	63.3	35.8	32.6	17.2	68.0	67.9	54.8	29.6	52.4	62.9	51.3	67.1	64.3	50.5	24.4	43.7	54.9	67.1	52.7	51.1
ImageNet-rescale [31]	64.0	69.6	53.2	44.4	24.9	65.7	69.6	69.2	28.9	63.6	62.8	63.9	73.3	64.6	55.8	25.7	50.5	55.4	69.3	56.4	56.5
VGG-K-means-rescale	56.1	58.6	23.3	25.7	12.8	57.8	61.2	45.2	21.4	47.1	39.5	35.6	60.1	61.4	44.9	17.3	37.7	33.2	57.9	51.2	42.4
VGG-Ours-rescale	71.1	72.4	54.1	48.2	29.9	75.2	78.0	71.9	38.3	60.5	62.3	68.1	74.3	74.2	64.8	32.6	56.5	66.4	74.0	60.3	61.7
VGG-ImageNet-rescale	76.6	79.6	68.5	57.4	40.8	79.9	78.4	85.4	41.7	77.0	69.3	80.1	78.6	74.6	70.1	37.5	66.0	67.5	77.4	64.9	68.6

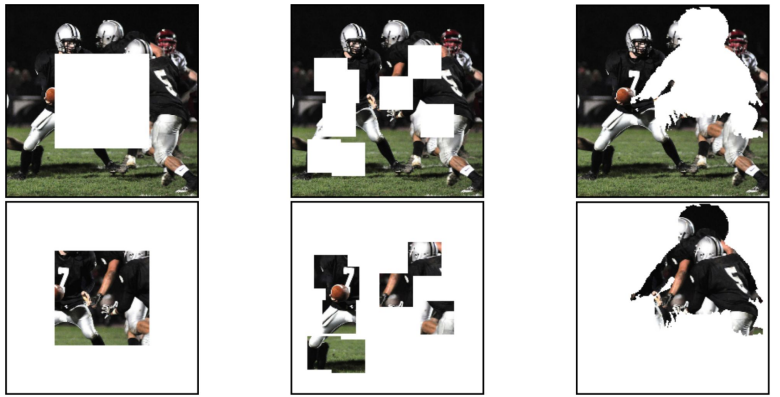
Table 1. Mean Average Precision on VOC-2007.

Context Prediction



Inpainting, 2016, Pathak et al.

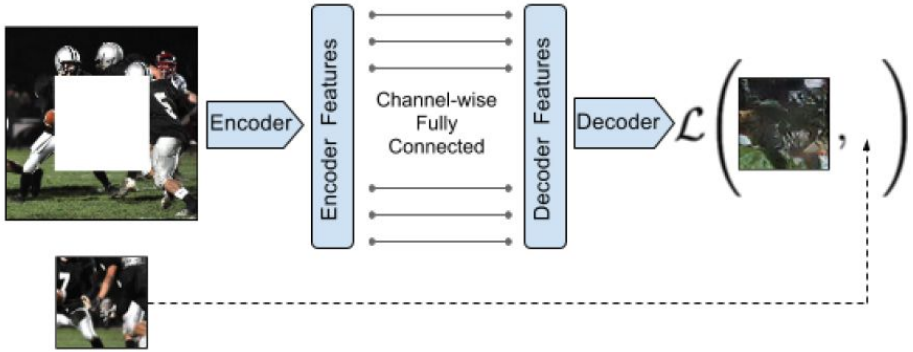


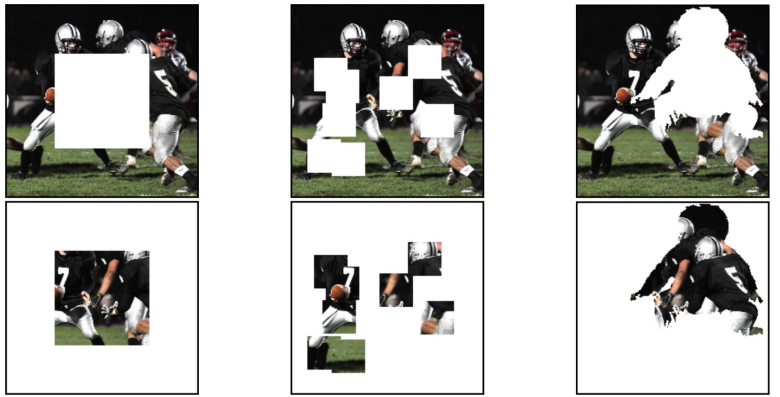


(a) Central region (b) Random block (c) Random region

https://arxiv.org/abs/1604.07379

Inpainting, 2016, Pathak et al.





(a) Central region (b) Random block (c) Random region

$$\mathcal{L}_{rec}(x) = \|\hat{M} \odot (x - F((1 - \hat{M}) \odot x))\|_2^2$$

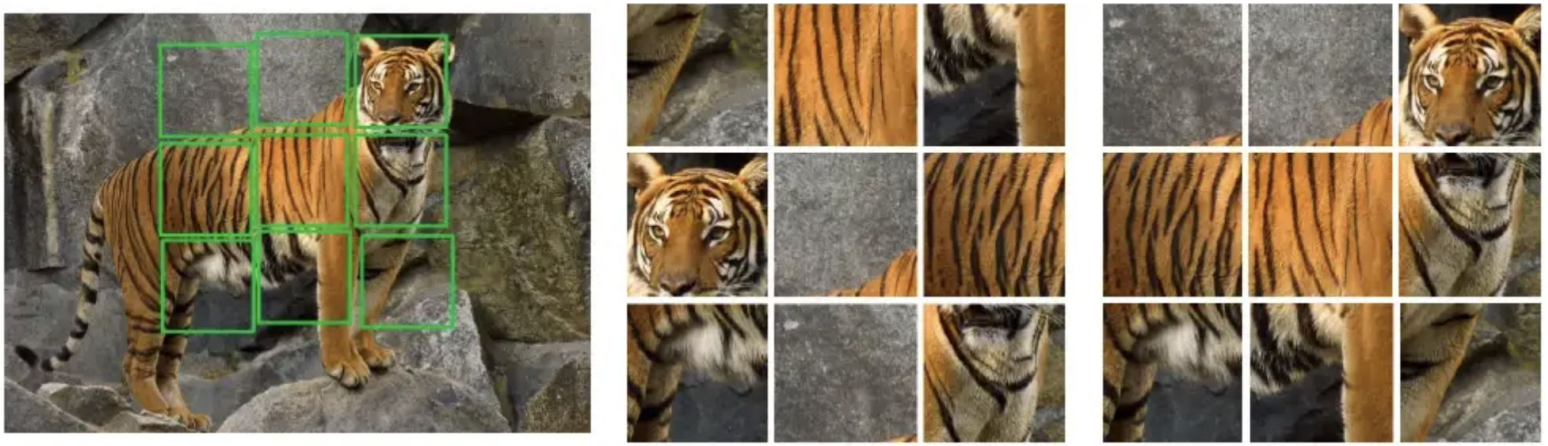
$$\mathcal{L}_{adv} = \max_D \quad \mathbb{E}_{x \in \mathcal{X}}[\log(D(x)) + \log(1 - D(F((1 - \hat{M}) \odot x)))]$$

Inpainting, 2016

Pretraining Method	Supervision	Pretraining time	Classification	Detection	Segmentation
ImageNet [26]	1000 class labels	3 days	78.2%	56.8%	48.0%
Random Gaussian	initialization	< 1 minute	53.3%	43.4%	19.8%
Autoencoder	-	14 hours	53.8%	41.9%	25.2%
Agrawal *et al.* [1]	egomotion	10 hours	52.9%	41.8%	-
Wang *et al.* [39]	motion	1 week	58.7%	47.4%	-
Doersch *et al.* [7]	relative context	4 weeks	55.3%	46.6%	-
Ours	context	14 hours	56.5%	44.5%	30.0%

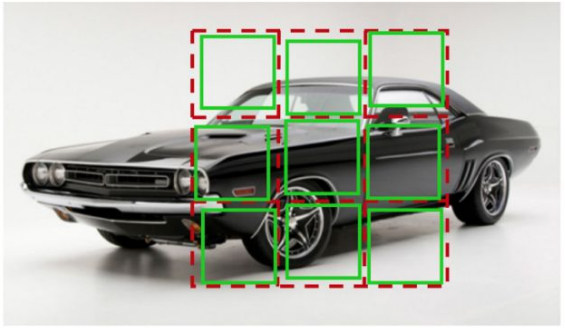
https://arxiv.org/abs/1604.07379

Jigsaw Puzzles, 2016, Noroozi et al.



https://arxiv.org/abs/1603.09246

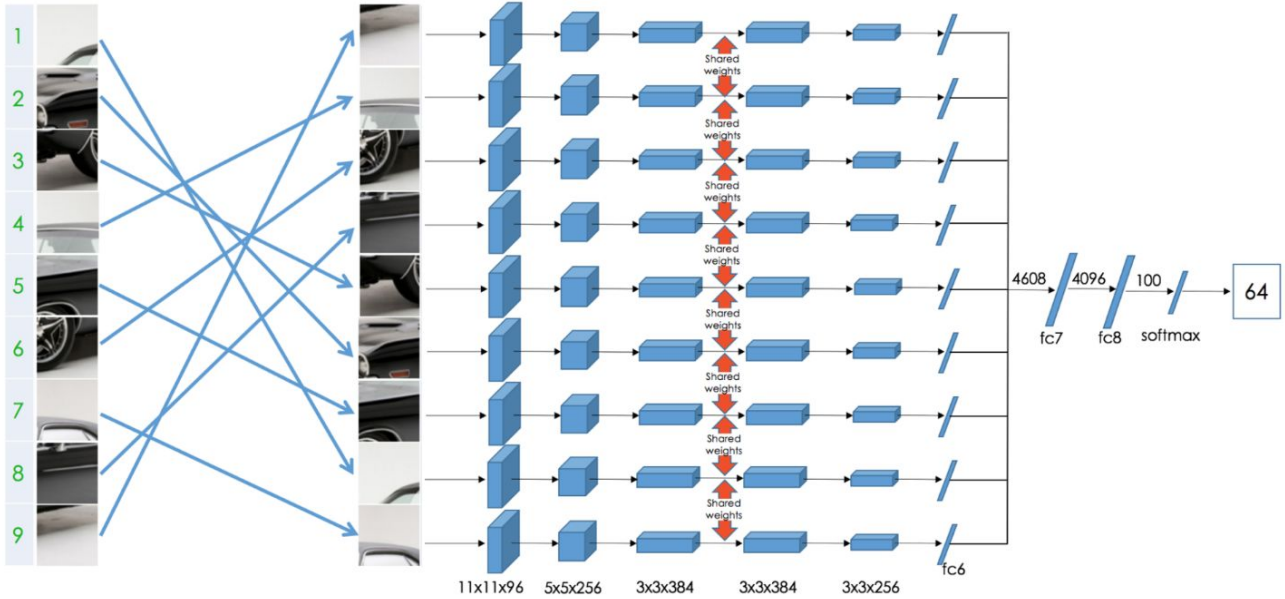
Jigsaw Puzzles



Permutation Set

index	permutation
64	9,4,6,8,3,2,5,1,7

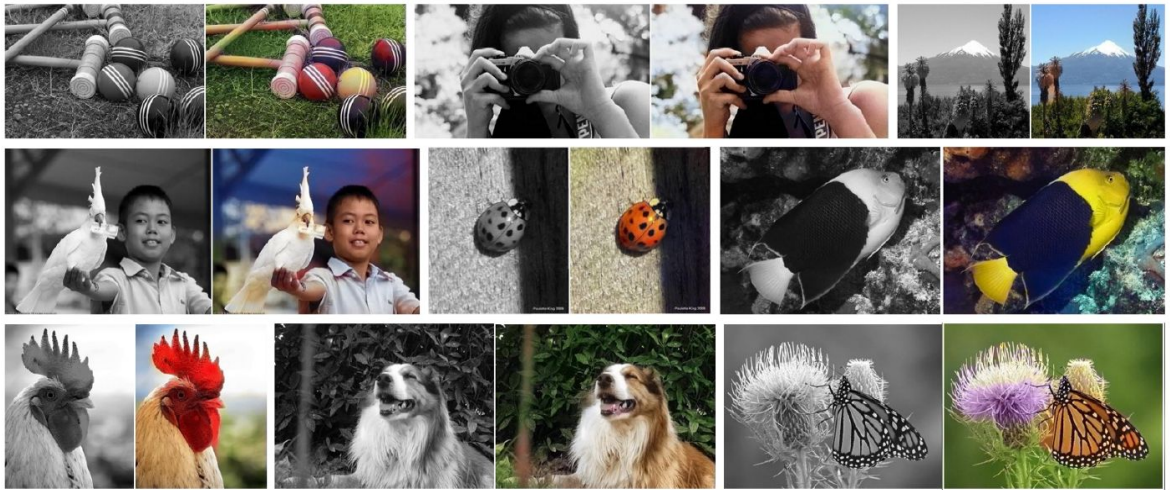
Reorder patches according to the selected permutation



Jigsaw Puzzles

Method	Pretraining time	Supervision	Classification	Detection	Segmentation
Krizhevsky*et al.* [25]	3 days	1000 class labels	**78.2%**	**56.8%**	**48.0%**
Wang and Gupta[39]	1 week	motion	58.4%	44.0%	-
Doersch *et al.* [10]	4 weeks	context	55.3%	46.6%	-
Pathak *et al.* [30]	14 hours	context	56.5%	44.5%	29.7%
Ours	2.5 days	context	**67.6%**	**53.2%**	**37.6%**

Colorization, 2016, Zhang et. al.



https://arxiv.org/abs/1603.08511

Colorization

L2 Loss is **NOT** Robust!

$$\mathrm{L}_2(\widehat{\mathbf{Y}}, \mathbf{Y}) = \frac{1}{2} \sum_{h,w} \|\mathbf{Y}_{h,w} - \widehat{\mathbf{Y}}_{h,w}\|_2^2$$

Colorization

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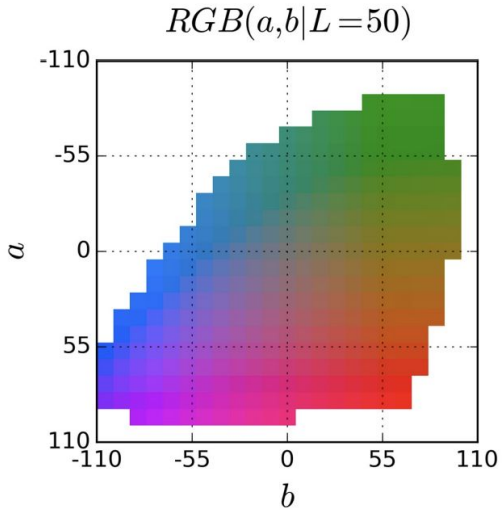

$$Q = 313$$

Colorization

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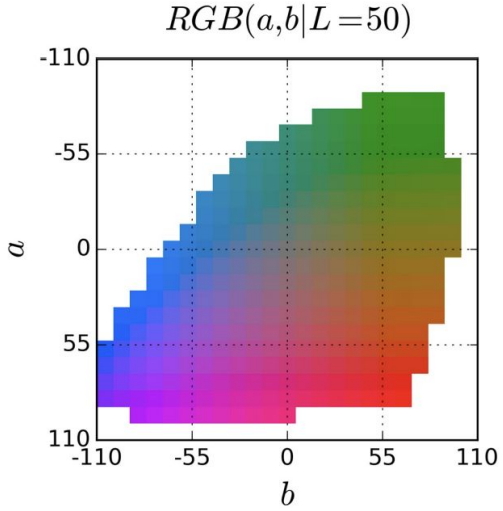

$$Q = 313$$

$$\widehat{\mathbf{Z}} \in [0,1]^{H\times W\times Q}$$

$$\mathbf{Z} = \mathcal{H}_{gt}^{-1}(\mathbf{Y})$$

$$\mathrm{L}_{cl}(\widehat{\mathbf{Z}}, \mathbf{Z}) = -\sum_{h,w} v(\mathbf{Z}_{h,w}) \sum_{q} \mathbf{Z}_{h,w,q} \log(\widehat{\mathbf{Z}}_{h,w,q})$$

Colorization

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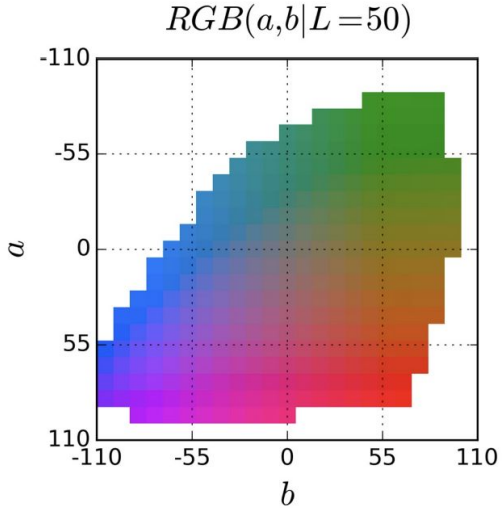
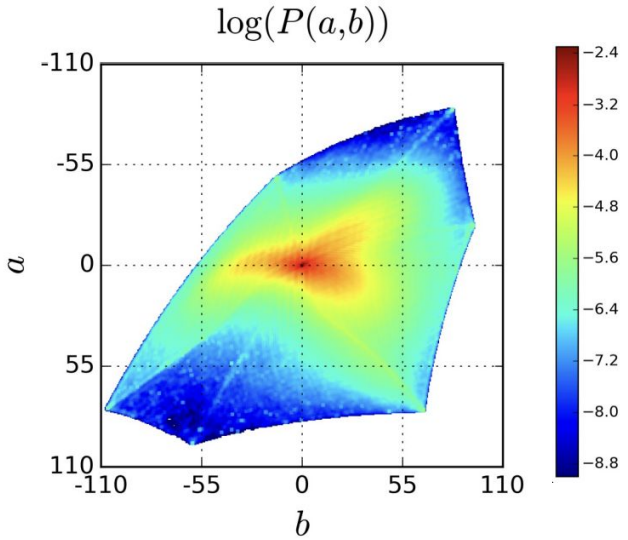


$$Q = 313$$



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Colorization

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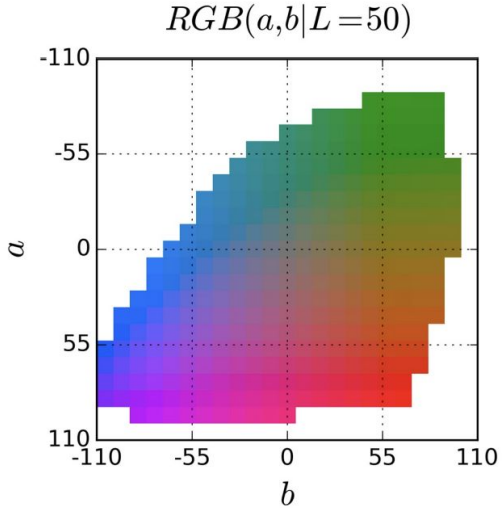
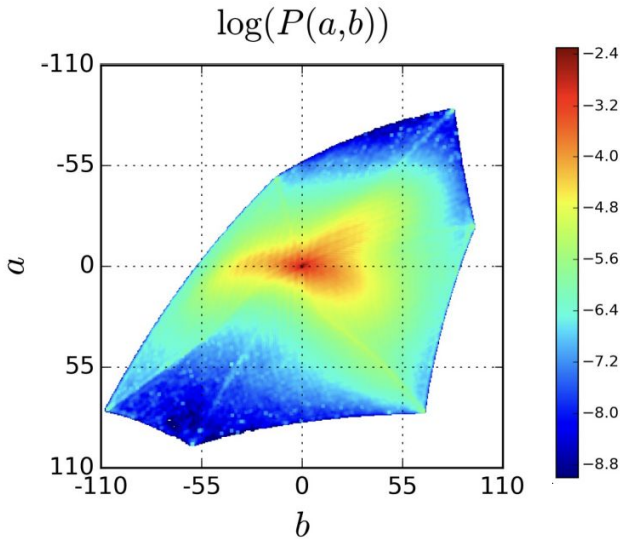


$$Q = 313$$



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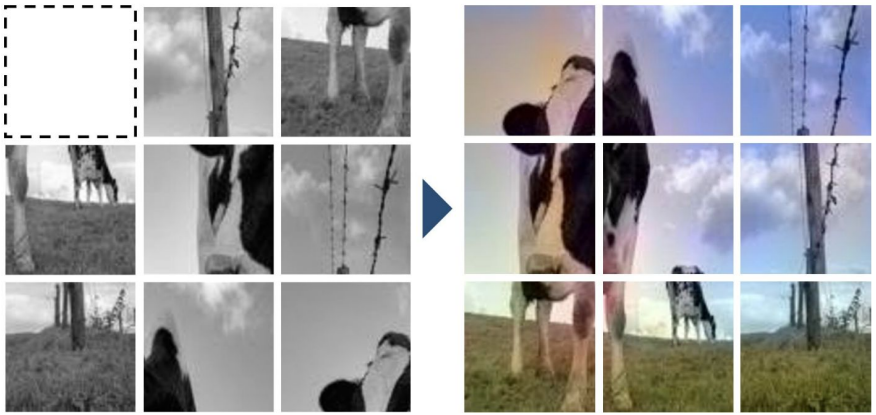
$$\mathcal{H}(\mathbf{Z}_{h,w}) = \mathbb{E}\big[f_T(\mathbf{Z}_{h,w})\big], \quad f_T(\mathbf{z}) = \frac{\exp(\log(\mathbf{z})/T)}{\sum_q \exp(\log(\mathbf{z}_q)/T)}$$

Colorization

		Class. (%mAP)			Det. (%mAP)		Seg. (%mIU)	
fine-tune layers	**[Ref]**	**fc8**	**fc6-8**	**all**	**[Ref]**	**all**	**[Ref]**	**all**
ImageNet [38]	-	76.8	78.9	79.9	[36]	56.8	[42]	48.0
Gaussian	[10]	–	–	53.3	[10]	43.4	[10]	19.8
Autoencoder	[16]	24.8	16.0	53.8	[10]	41.9	[10]	25.2
k-means [36]	[16]	32.0	39.2	56.6	[36]	45.6	[16]	32.6
Agrawal et al. [8]	[16]	31.2	31.0	54.2	[36]	43.9	–	–
Wang & Gupta [15]	–	28.1	52.2	58.7	[36]	47.4	–	–
*Doersch et al. [14]	[16]	44.7	55.1	**65.3**	[36]	**51.1**	–	–
*Pathak et al. [10]	[10]	–	–	56.5	[10]	44.5	[10]	29.7
*Donahue et al. [16]	–	38.2	50.2	58.6	[16]	46.2	[16]	34.9
Ours (gray)	–	**52.4**	**61.5**	**65.9**	–	46.1	–	35.0
Ours (color)	–	**52.4**	**61.5**	**65.6**	–	46.9	–	**35.6**

Damaged Jigsaw Puzzles, 2018

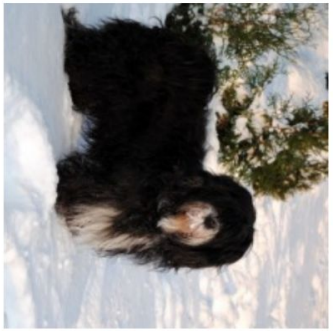


Method	Class.	Det.	Segm.
ImageNet [20]	79.9	56.8	48.0
Random	53.3	43.4	19.8
RelativePosition [4]	65.3	51.1	-
Jigsaw [25]	67.6	**53.2**	37.6
Ego-motion [36]	54.2	43.9	-
Adversarial [6]	58.6	46.2	34.9
Inpainting [30]	56.5	44.5	29.7
Colorization [38]	65.9	46.9	35.6
Split-Brain [39]	67.1	46.7	36.0
ColorProxy [21]	65.9	-	<u>38.4</u>
WatchingObjectMove [29]	61.0	52.2	-
Counting [26]	<u>67.7</u>	51.4	36.6
CDJP	**69.2**	<u>52.4</u>	**39.3**

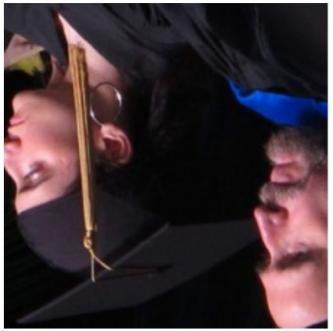
https://arxiv.org/abs/1802.01880

Rotations, 2018, Gidaris et. al.

90° rotation



270° rotation



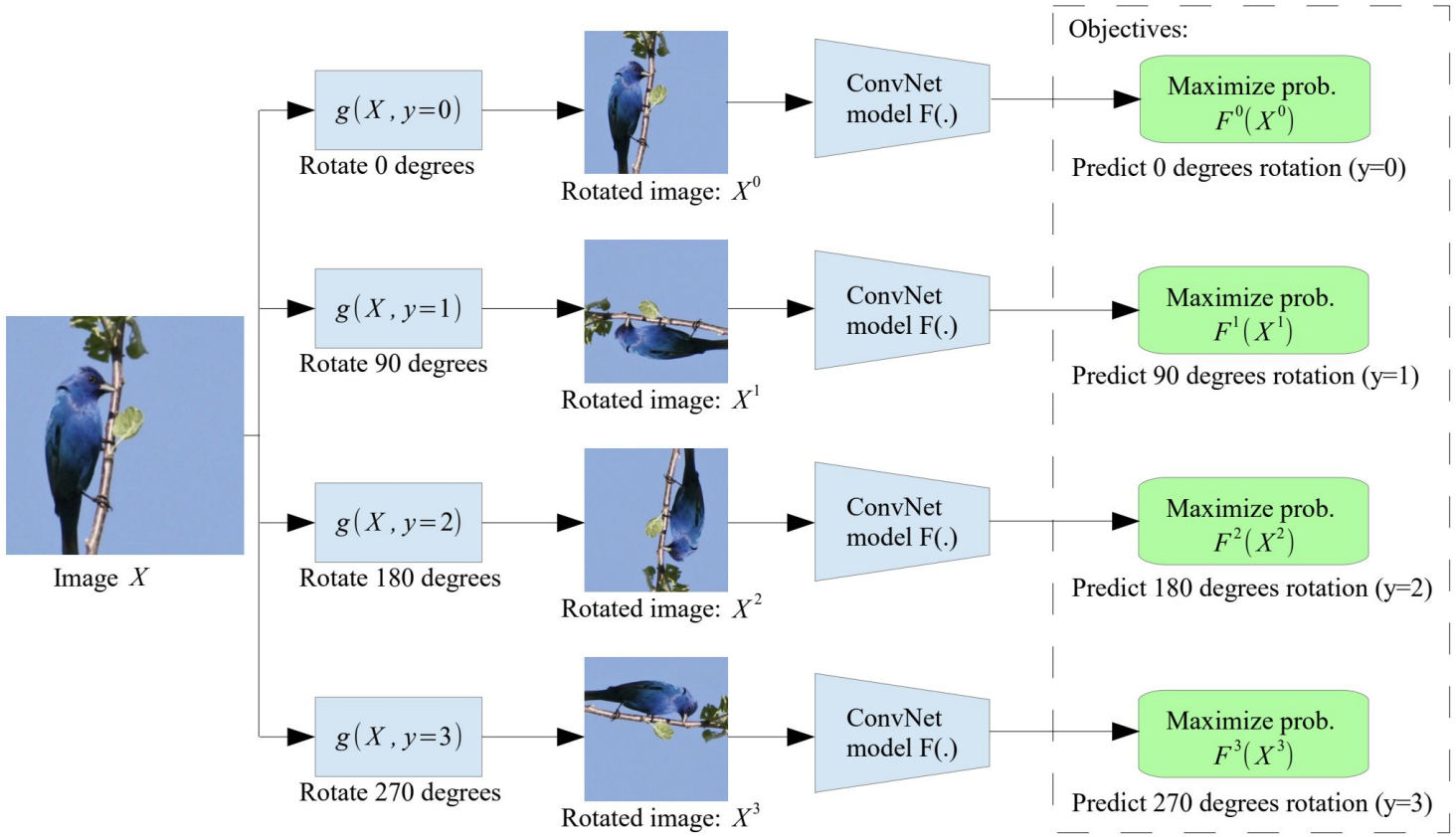
180° rotation

0° rotation

270° rotation

https://arxiv.org/abs/1803.07728

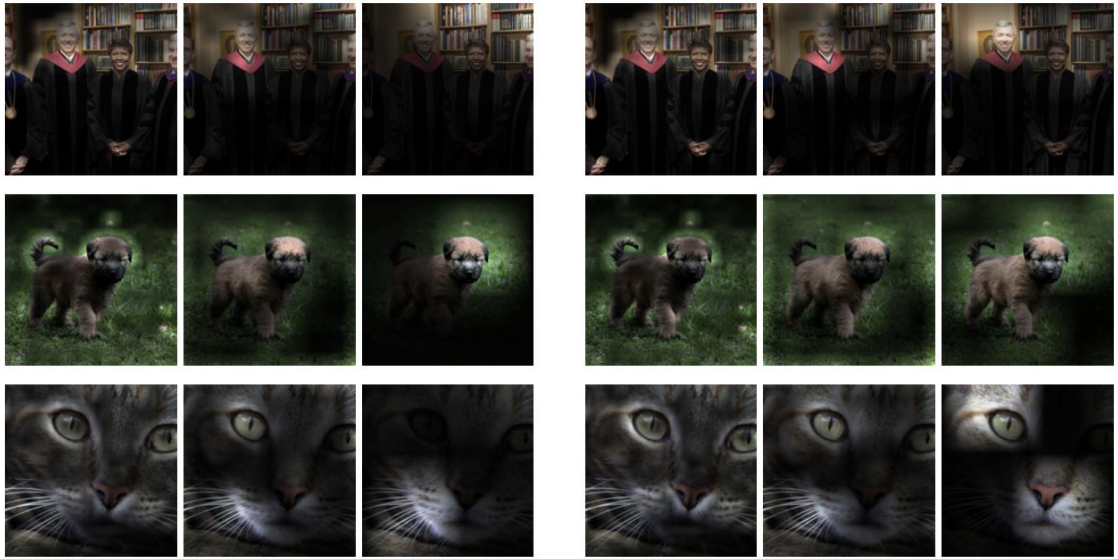
Rotations, 2018, Gidaris et. al.



https://arxiv.org/abs/1803.07728

Rotations

Input images on the models



Conv1 27 × 27 Conv3 13 × 13 Conv5 6 × 6

(a) **Attention maps of supervised model**

Conv1 27 × 27 Conv3 13 × 13 Conv5 6 × 6

(b) **Attention maps of our self-supervised model**

Rotations

Model	ConvB1	ConvB2	ConvB3	ConvB4	ConvB5
RotNet with 3 conv. blocks	85.45	88.26	62.09	-	-
RotNet with 4 conv. blocks	85.07	89.06	86.21	61.73	-
RotNet with 5 conv. blocks	85.04	**89.76**	86.82	74.50	50.37

Rotations

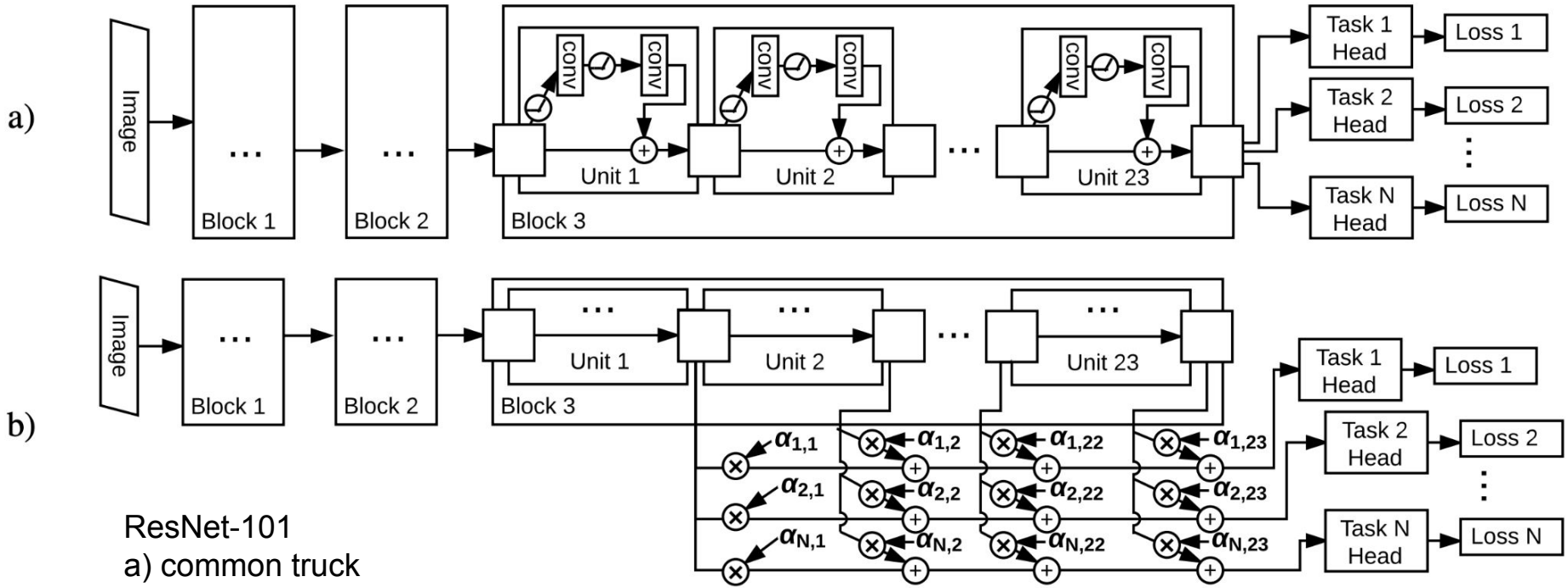
Model	ConvB1	ConvB2	ConvB3	ConvB4	ConvB5
RotNet with 3 conv. blocks	85.45	88.26	62.09	-	-
RotNet with 4 conv. blocks	85.07	89.06	86.21	61.73	-
RotNet with 5 conv. blocks	85.04	**89.76**	86.82	74.50	50.37

Method	Conv1	Conv2	Conv3	Conv4	Conv5
ImageNet labels	19.3	36.3	44.2	48.3	50.5
Random	11.6	17.1	16.9	16.3	14.1
Random rescaled Krähenbühl et al. (2015)	17.5	23.0	24.5	23.2	20.6
Context (Doersch et al., 2015)	16.2	23.3	30.2	31.7	29.6
Context Encoders (Pathak et al., 2016b)	14.1	20.7	21.0	19.8	15.5
Colorization (Zhang et al., 2016a)	12.5	24.5	30.4	31.5	30.3
Jigsaw Puzzles (Noroozi & Favaro, 2016)	18.2	28.8	34.0	33.9	27.1
BIGAN (Donahue et al., 2016)	17.7	24.5	31.0	29.9	28.0
Split-Brain (Zhang et al., 2016b)	17.7	29.3	35.4	35.2	32.8
Counting (Noroozi et al., 2017)	18.0	30.6	34.3	32.5	25.7
(Ours) RotNet	**18.8**	**31.7**	**38.7**	**38.2**	**36.5**

Rotations

	Classification (%mAP)		Detection (%mAP)	Segmentation (%mIoU)
Trained layers	fc6-8	all	all	all
ImageNet labels	78.9	79.9	56.8	48.0
Random		53.3	43.4	19.8
Random rescaled Krähenbühl et al. (2015)	39.2	56.6	45.6	32.6
Egomotion (Agrawal et al., 2015)	31.0	54.2	43.9	
Context Encoders (Pathak et al., 2016b)	34.6	56.5	44.5	29.7
Tracking (Wang & Gupta, 2015)	55.6	63.1	47.4	
Context (Doersch et al., 2015)	55.1	65.3	51.1	
Colorization (Zhang et al., 2016a)	61.5	65.6	46.9	35.6
BIGAN (Donahue et al., 2016)	52.3	60.1	46.9	34.9
Jigsaw Puzzles (Noroozi & Favaro, 2016)	-	67.6	53.2	37.6
NAT (Bojanowski & Joulin, 2017)	56.7	65.3	49.4	
Split-Brain (Zhang et al., 2016b)	63.0	67.1	46.7	36.0
ColorProxy (Larsson et al., 2017)		65.9		38.4
Counting (Noroozi et al., 2017)	-	67.7	51.4	36.6
(Ours) RotNet	**70.87**	**72.97**	**54.4**	**39.1**

Task Ensemble, 2017, Doersch et al.



ResNet-101
a) common truck
b) lasso architecture

https://arxiv.org/abs/1708.07860

Task Ensemble

Net structure	ImageNet	PASCAL	NYU
No Lasso	69.30	**70.53**	79.25
Eval Only Lasso	**70.18**	68.86	79.41
Pre-train Only Lasso	68.09	68.49	78.96
Pre-train & Eval Lasso	69.44	68.98	79.45

Pre-training	ImageNet	PASCAL	NYU
RP	59.21	66.75	**80.54**
RP+Col	66.64	68.75	79.87
RP+Ex	65.24	69.44	78.70
RP+MS	63.73	68.81	78.72
RP+Col+Ex	68.65	69.48	80.17
RP+Col+Ex+MS	**69.30**	**70.53**	79.25
INet Labels	85.10	74.17	80.06