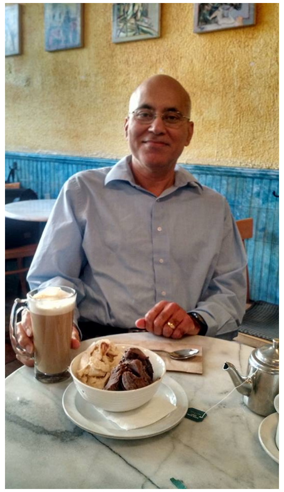
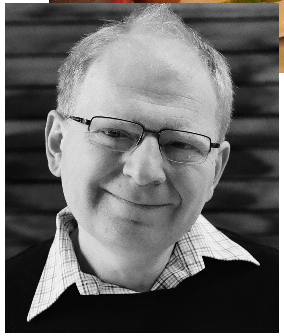
Self-Supervision

Saurabh Gupta

Is semantic supervision necessary to learn good representations?

- Manual labeling doesn't scale, suffers from biases
- Plenty of unlabeled visual data already, and growing really fast
- *And subject of the Gelato Bet:*
- *If, by the first day of autumn (Sept 23) of 2015, a method will exist that can match or beat the performance of R-CNN on Pascal VOC detection, without the use of any extra, human annotations (e.g. ImageNet) as pre-training, Mr. Malik promises to buy Mr. Efros one (1) gelato (2 scoops: one chocolate, one vanilla).*





[The Gelato Bet]

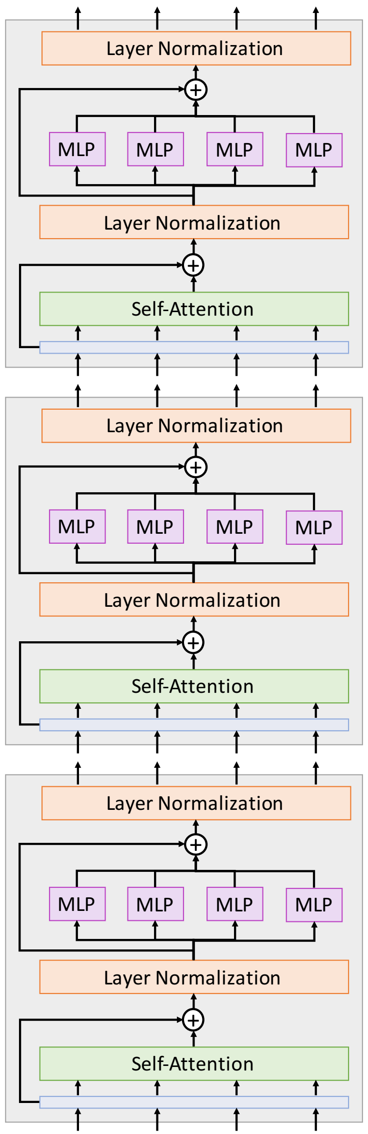
The Transformer: Transfer Learning

“ImageNet Moment for Natural Language Processing”

Pretraining:
Download a lot of text from the internet

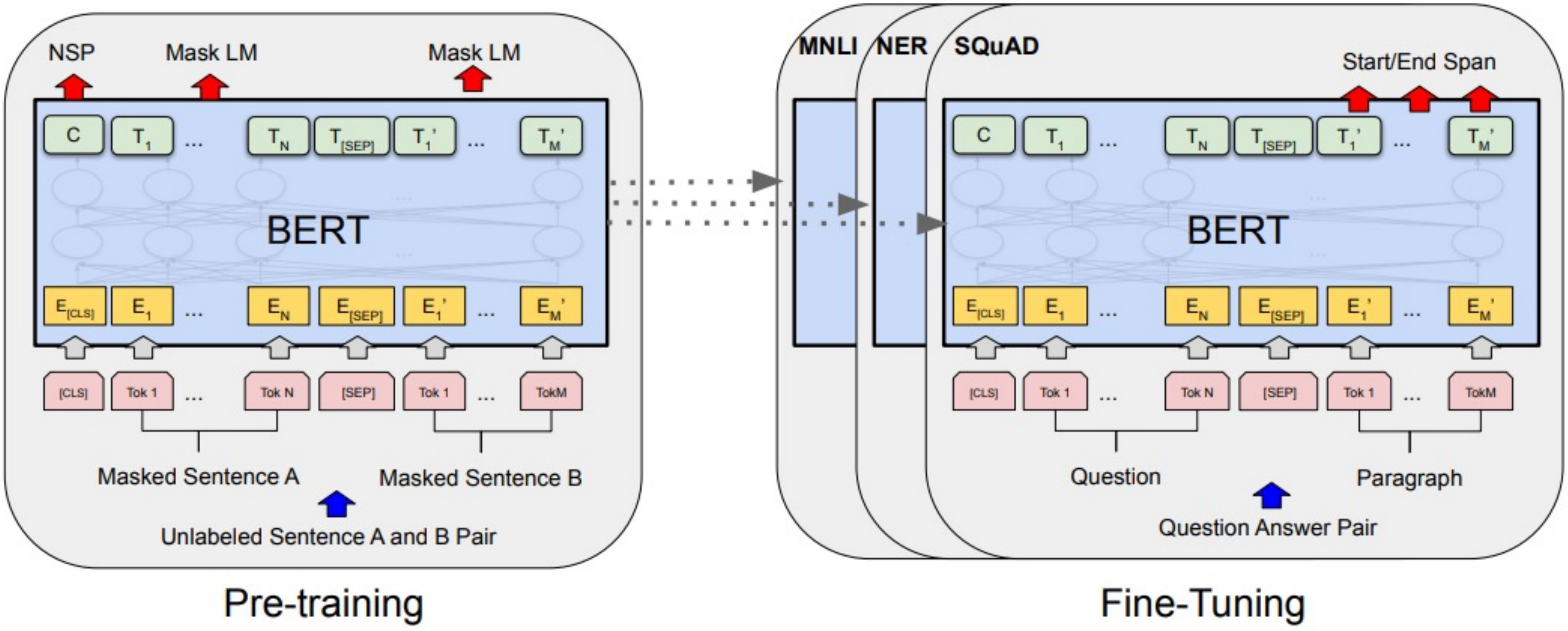
Train a giant Transformer model for language modeling

Finetuning:
Fine-tune the Transformer on your own NLP task



Devlin et al, "BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding", EMNLP 2018

The Transformer: Transfer Learning



Devlin et al, "BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding", EMNLP 2018

The Transformer: Transfer Learning

System	MNLI-(m/mm)	QQP	QNLI	SST-2	CoLA	STS-B	MRPC	RTE	**Average**
	392k	363k	108k	67k	8.5k	5.7k	3.5k	2.5k	-
Pre-OpenAI SOTA	80.6/80.1	66.1	82.3	93.2	35.0	81.0	86.0	61.7	74.0
BiLSTM+ELMo+Attn	76.4/76.1	64.8	79.8	90.4	36.0	73.3	84.9	56.8	71.0
OpenAI GPT	82.1/81.4	70.3	87.4	91.3	45.4	80.0	82.3	56.0	75.1
$\text{BERT}_{\text{BASE}}$	84.6/83.4	71.2	90.5	93.5	52.1	85.8	88.9	66.4	79.6
$\text{BERT}_{\text{LARGE}}$	**86.7/85.9**	**72.1**	**92.7**	**94.9**	**60.5**	**86.5**	**89.3**	**70.1**	**82.1**

Table 1: GLUE Test results, scored by the evaluation server (`https://gluebenchmark.com/leaderboard`). The number below each task denotes the number of training examples. The "Average" column is slightly different than the official GLUE score, since we exclude the problematic WNLI set.[8] BERT and OpenAI GPT are single-model, single task. F1 scores are reported for QQP and MRPC, Spearman correlations are reported for STS-B, and accuracy scores are reported for the other tasks. We exclude entries that use BERT as one of their components.

Devlin et al, "BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding", EMNLP 2018

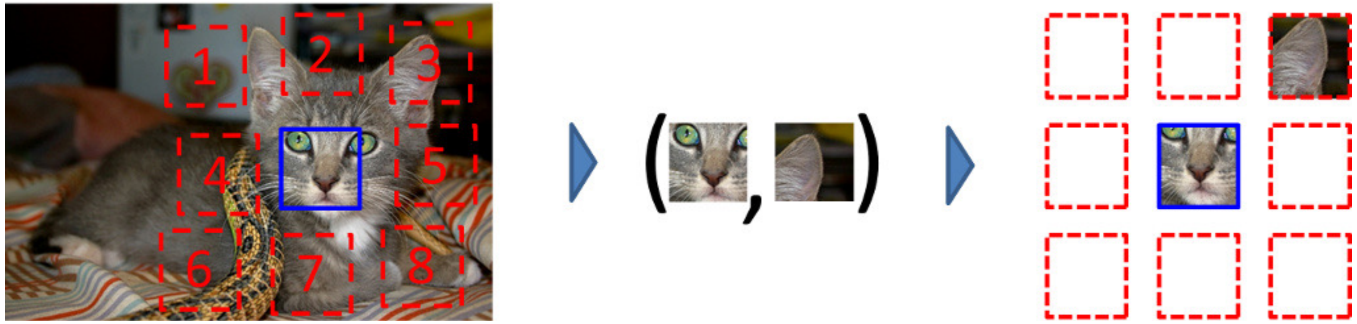
Pre-train representations on a pre-text task

E.g. Colorization

After pre-training, use representation for down-stream tasks.

Many other possibilities,

- Spatial relationship between pair of patches



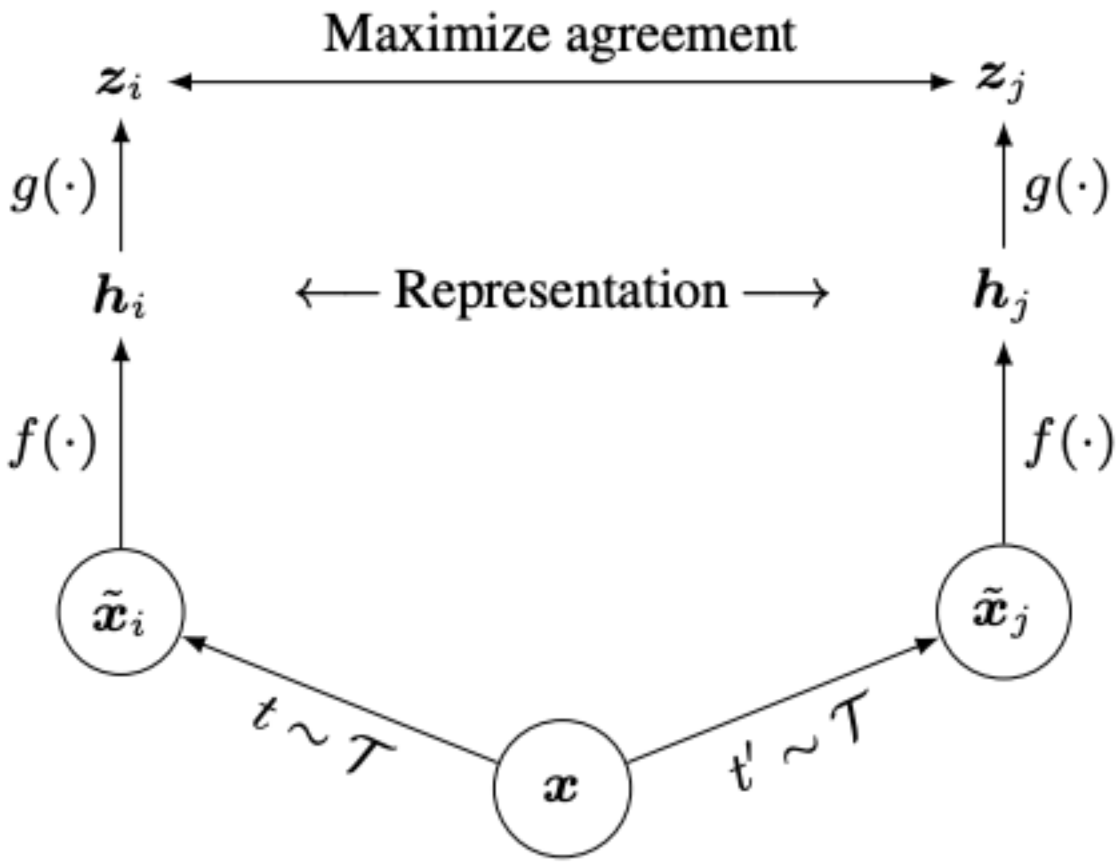
- Predict sound / frame ordering in a video
- Encourage two augmentations of same image to be closer to each other than to another image
- Predict hidden image patches from context

[Split-Brain Autoencoders: Unsupervised Learning by Cross-Channel Prediction](), Zhang et al. CVPR 2017
[Context as Supervisory Signal: Discovering Objects with Predictable Context](), Doersch et al. ICCV 2015

Contrastive Learning

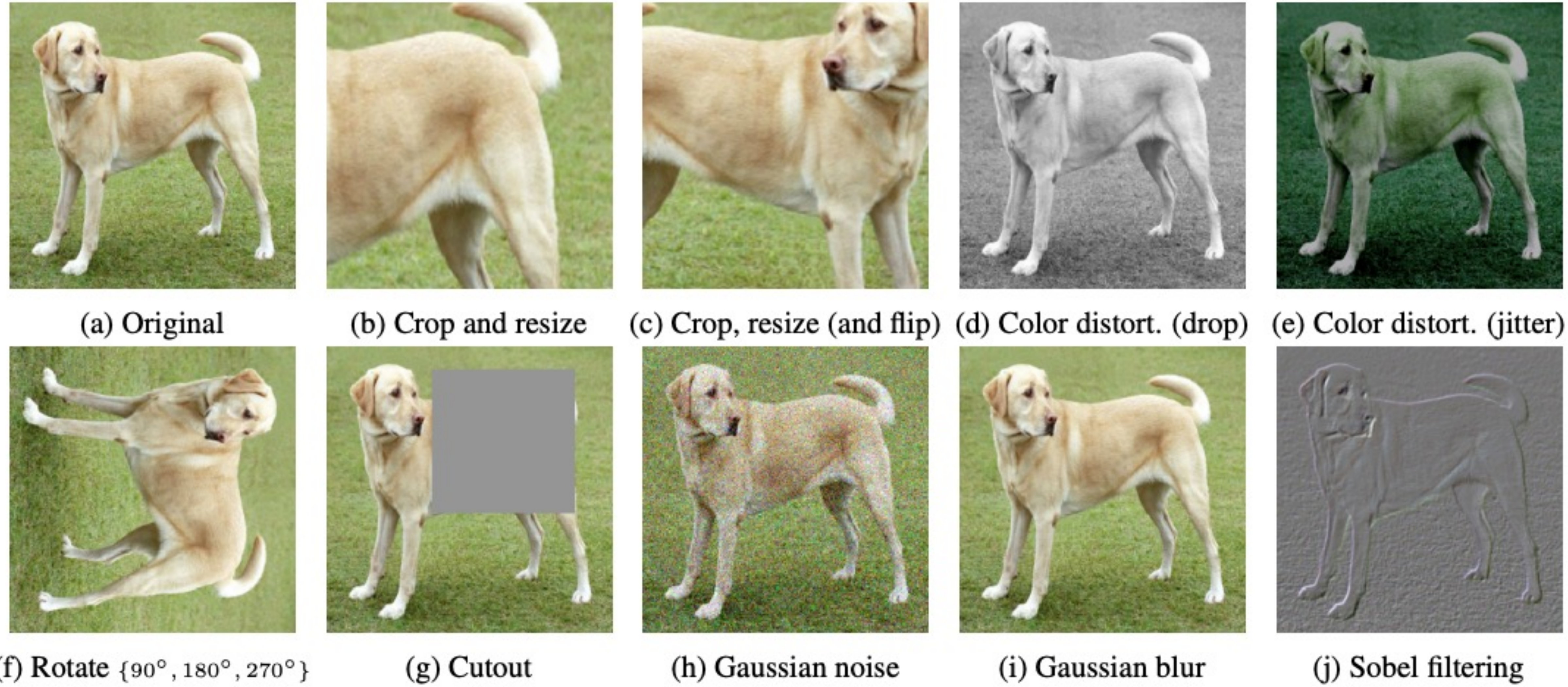
- Encourage two augmentations of an image to be close.
- Using a contrastive loss:

$$\ell_{i,j} = -\log \frac{\exp(\mathrm{sim}(\boldsymbol{z}_i, \boldsymbol{z}_j)/\tau)}{\sum_{k=1}^{2N} \mathbb{1}_{[k \neq i]} \exp(\mathrm{sim}(\boldsymbol{z}_i, \boldsymbol{z}_k)/\tau)}$$



A Simple Framework for Contrastive Learning of Visual Representations, Chen et al. ICML 2020
See also: Momentum Contrast for Unsupervised Visual Representation Learning, He et al. CVPR 2020

Augmentations

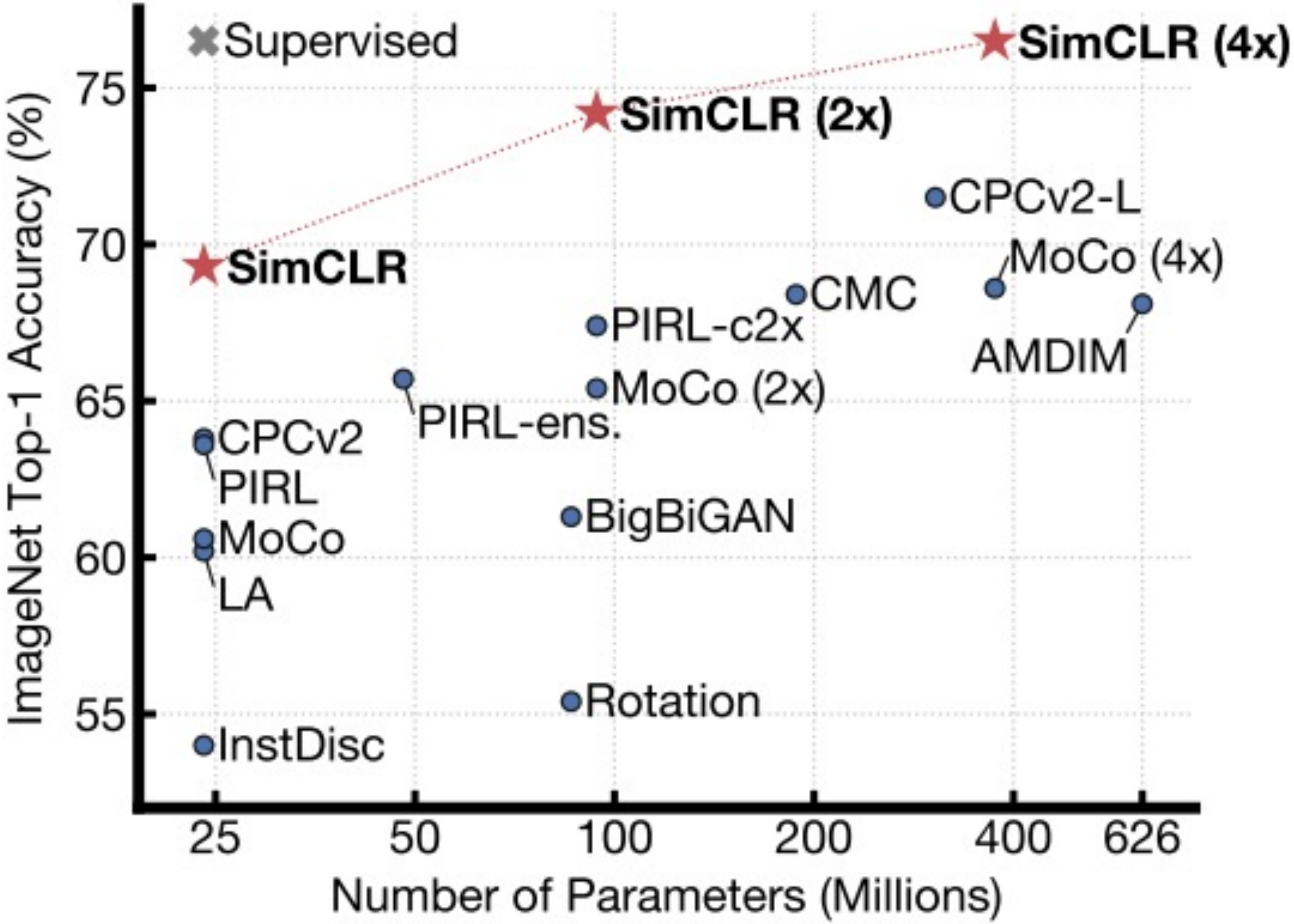


(a) Original (b) Crop and resize (c) Crop, resize (and flip) (d) Color distort. (drop) (e) Color distort. (jitter)

(f) Rotate $\{90^\circ, 180^\circ, 270^\circ\}$ (g) Cutout (h) Gaussian noise (i) Gaussian blur (j) Sobel filtering

[A Simple Framework for Contrastive Learning of Visual Representations](), Chen et al. ICML 2020

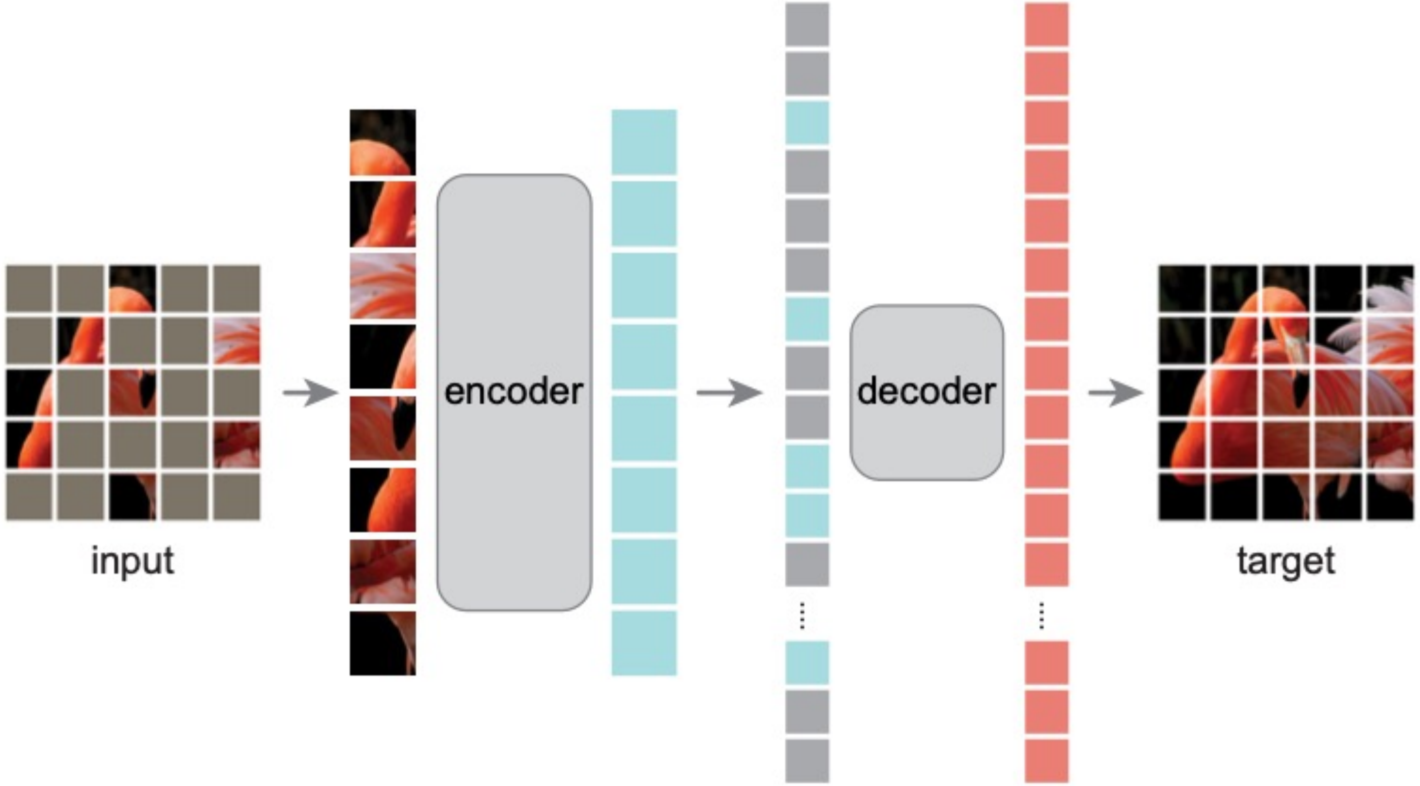
Results



A Simple Framework for Contrastive Learning of Visual Representations, Chen et al. ICML 2020

Masked Auto-Encoders

- Mask out image patches, predict masked patches from visible patches.
- Pre-train encoder & decoder.
- Use encoder as an image representation.



Masked Autoencoders Are Scalable Vision Learners, He et al. CVPR 2022

Better than semantic supervision on ImageNet 1K!

method	pre-train data	AP^{box} ViT-B	AP^{box} ViT-L	AP^{mask} ViT-B	AP^{mask} ViT-L
supervised	IN1K w/ labels	47.9	49.3	42.9	43.9
MoCo v3	IN1K	47.9	49.3	42.7	44.0
BEiT	IN1K+DALLE	49.8	**53.3**	44.4	47.1
MAE	IN1K	**50.3**	**53.3**	**44.9**	**47.2**

Table 4. **COCO object detection and segmentation** using a ViT Mask R-CNN baseline. All entries are based on our implementation. Self-supervised entries use IN1K data *without* labels. Mask AP follows a similar trend as box AP.

method	pre-train data	ViT-B	ViT-L
supervised	IN1K w/ labels	47.4	49.9
MoCo v3	IN1K	47.3	49.1
BEiT	IN1K+DALLE	47.1	53.3
MAE	IN1K	**48.1**	**53.6**

Table 5. **ADE20K semantic segmentation** (mIoU) using UperNet. BEiT results are reproduced using the official code. Other entries are based on our implementation. Self-supervised entries use IN1K data *without* labels.

dataset	ViT-B	ViT-L	ViT-H	ViT-H_{448}	prev best
iNat 2017	70.5	75.7	79.3	**83.4**	75.4 [55]
iNat 2018	75.4	80.1	83.0	**86.8**	81.2 [54]
iNat 2019	80.5	83.4	85.7	**88.3**	84.1 [54]
Places205	63.9	65.8	65.9	**66.8**	66.0 [19]†
Places365	57.9	59.4	59.8	**60.3**	58.0 [40]‡

Table 6. **Transfer learning accuracy on classification datasets**, using MAE pre-trained on IN1K and then fine-tuned. We provide system-level comparisons with the previous best results.
†: pre-trained on 1 billion images. ‡: pre-trained on 3.5 billion images.

Masked Autoencoders Are Scalable Vision Learners, He et al. CVPR 2022

Improves performance on ImageNet itself

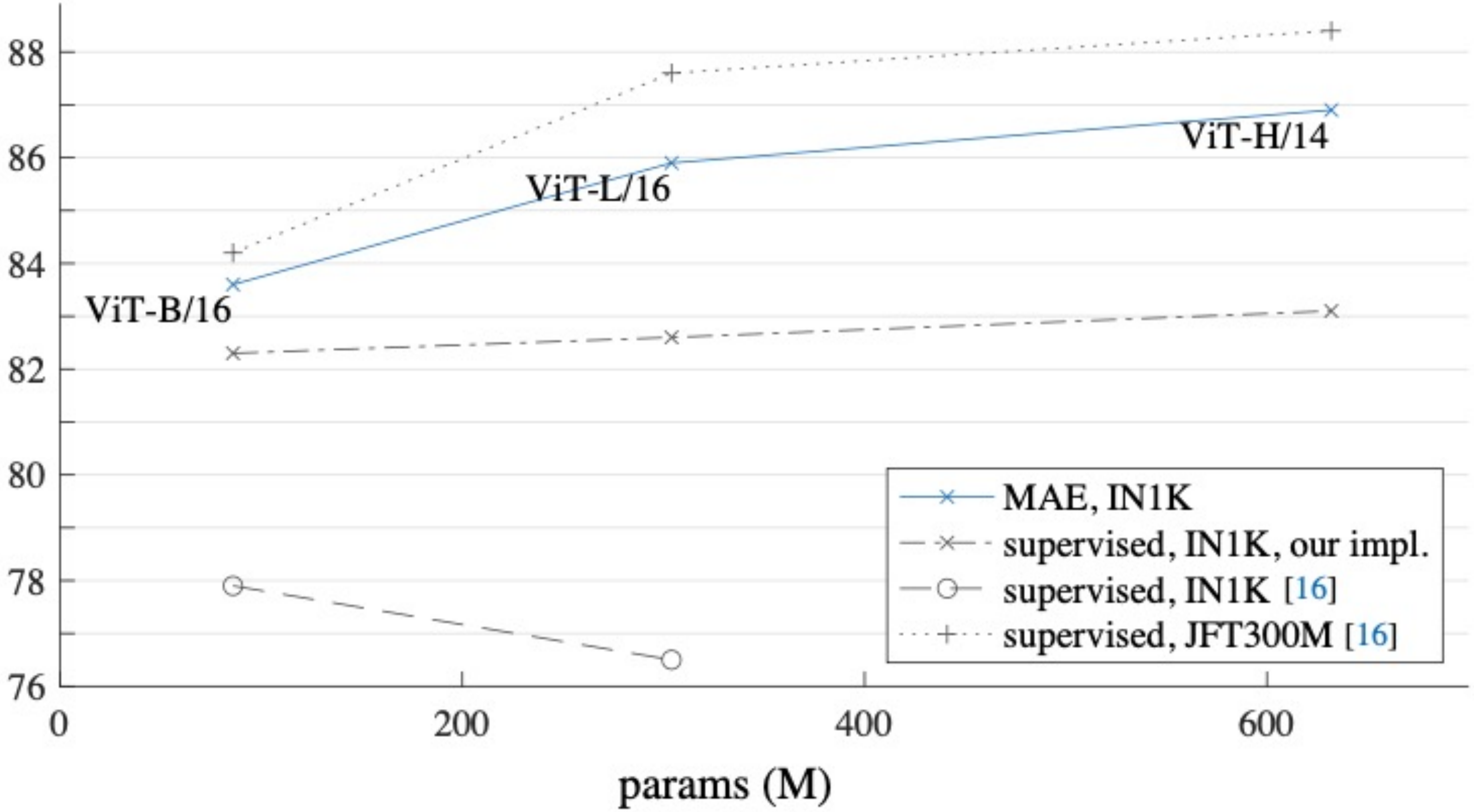


Figure 8. **MAE pre-training *vs*. supervised pre-training**, evaluated by fine-tuning in ImageNet-1K (224 size). We compare with the original ViT results [16] trained in IN1K or JFT300M.

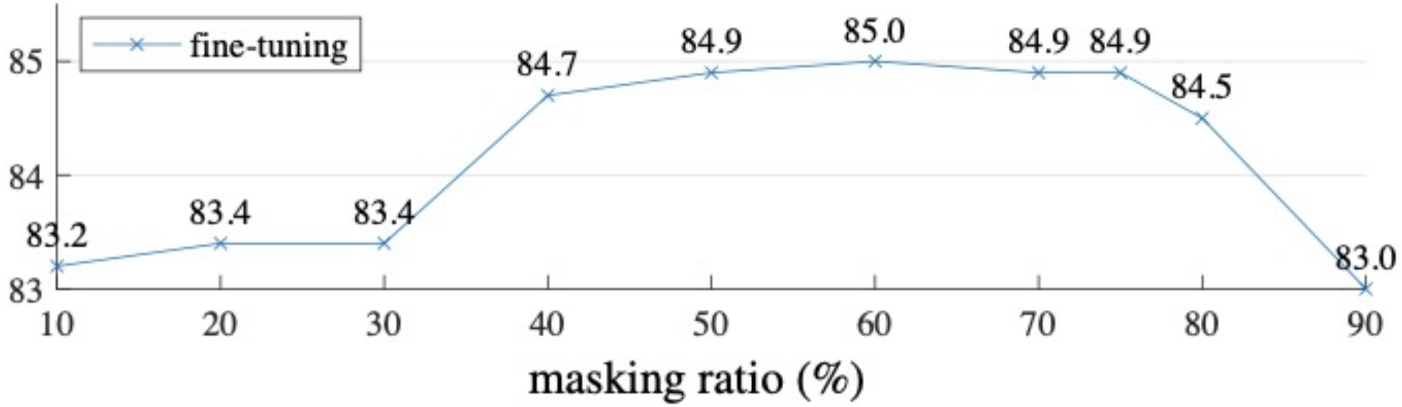
[Masked Autoencoders Are Scalable Vision Learners](), He et al. CVPR 2022

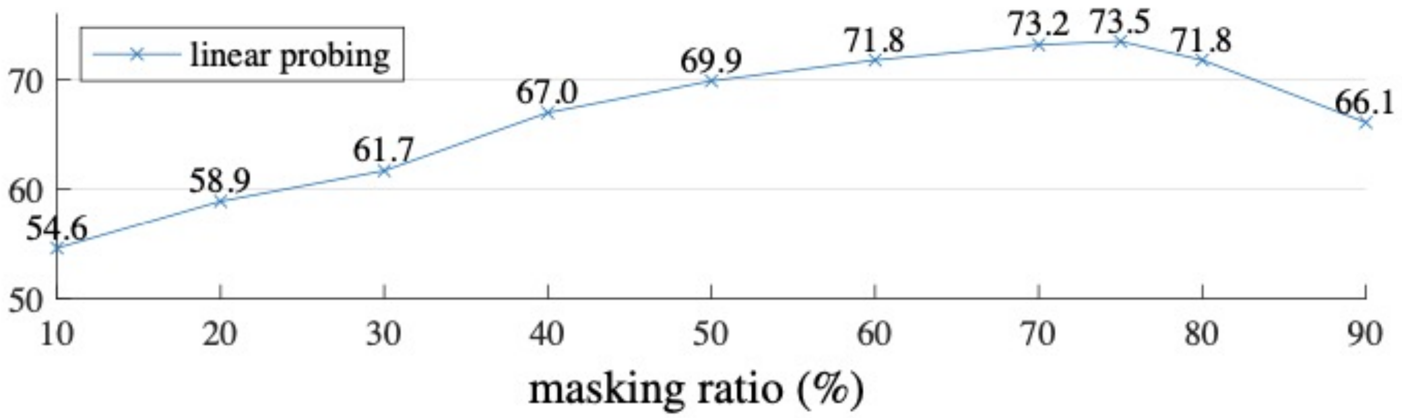
Better than past self-supervision approaches

method	pre-train data	ViT-B	ViT-L	ViT-H	ViT-H_{448}
scratch, our impl.	-	82.3	82.6	83.1	-
DINO [5]	IN1K	82.8	-	-	-
MoCo v3 [9]	IN1K	83.2	84.1	-	-
BEiT [2]	IN1K+DALLE	83.2	85.2	-	-
MAE	IN1K	<u>83.6</u>	<u>85.9</u>	<u>86.9</u>	**87.8**

[Masked Autoencoders Are Scalable Vision Learners](), He et al. CVPR 2022

Ablations





Need high masking ratio for good learning.
NLP models use 15-20% masking ratio.

case	ft	lin	FLOPs
encoder w/ [M]	84.2	59.6	3.3×
encoder w/o [M]	**84.9**	**73.5**	**1**×

Faster and better to not input masked out patches to encoder

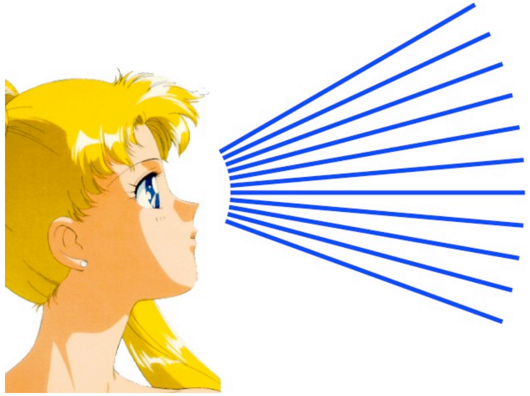
case	ft	lin
pixel (w/o norm)	84.9	73.5
pixel (w/ norm)	**85.4**	**73.9**
PCA	84.6	72.3
dVAE token	85.3	71.6

Normalized pixels are a better target than discrete tokens / PCA coefficients

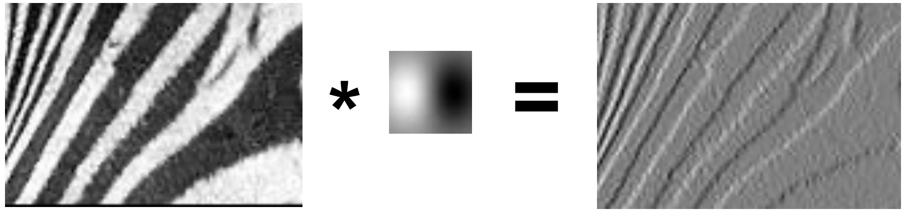
Masked Autoencoders Are Scalable Vision Learners, He et al. CVPR 2022

I. Early vision

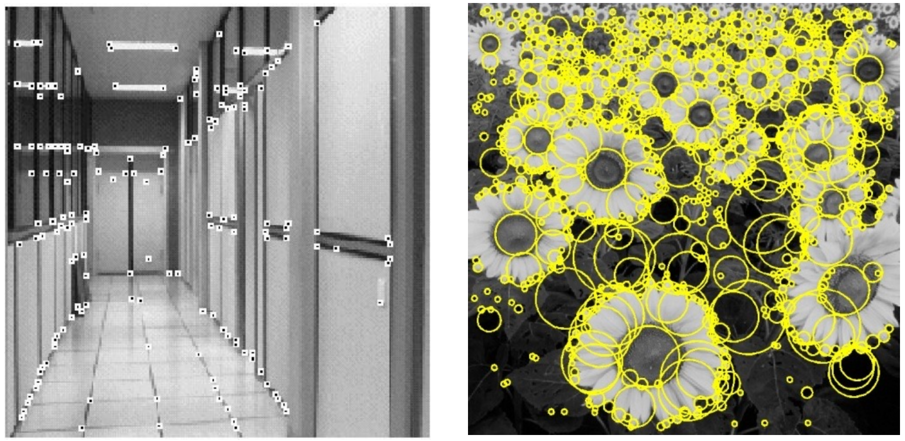
Basic image formation and processing



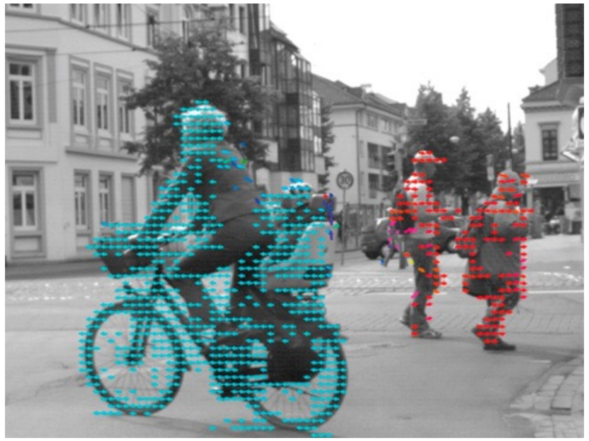
Cameras and sensors
Light and color



Linear filtering
Edge detection



Feature extraction

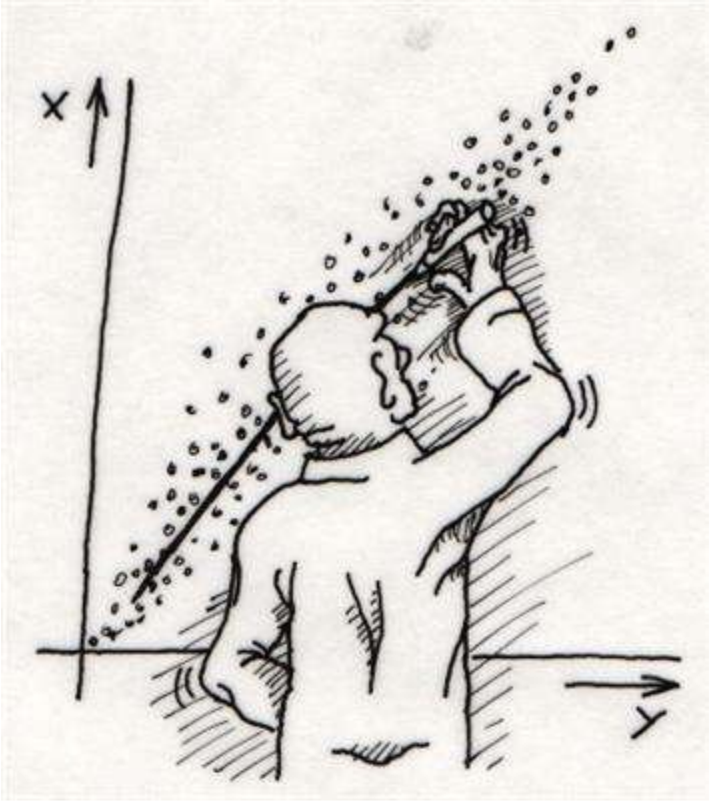


Optical flow

Source: L. Lazebnik

II. “Mid-level vision”

Fitting and grouping

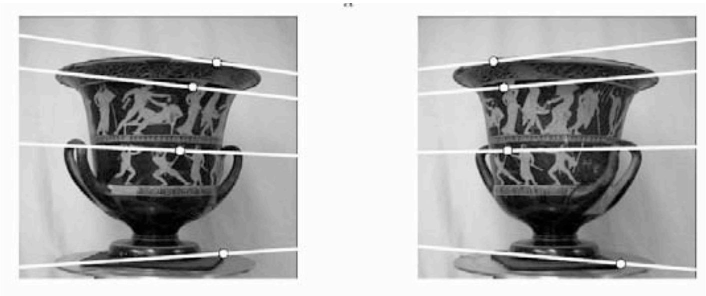


Fitting: Least squares
Voting methods

Alignment

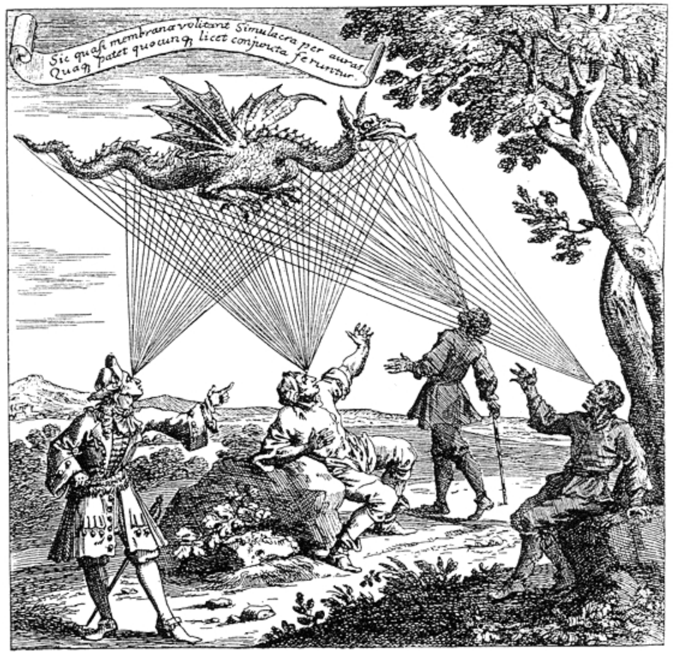
Source: L. Lazebnik

III. Multi-view geometry



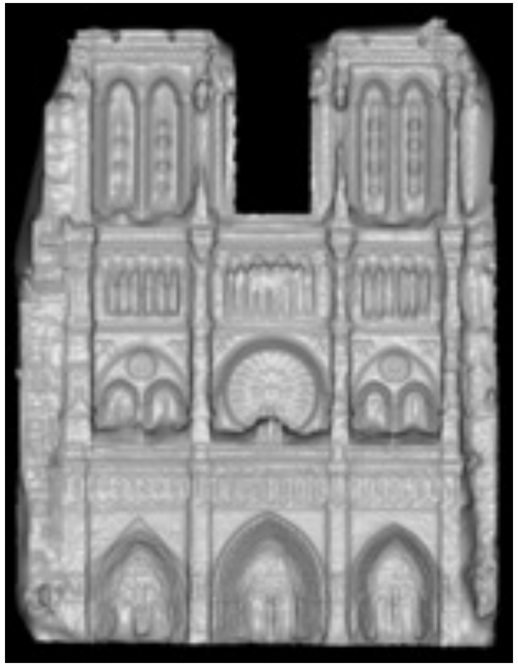
Epipolar geometry

Two-view stereo



Драконъ, видимый подъ различными углами зрѣнія
По гравюрѣ на мѣди изъ „Oculus artificialis teledioptricus“ Цана. 1702 года.

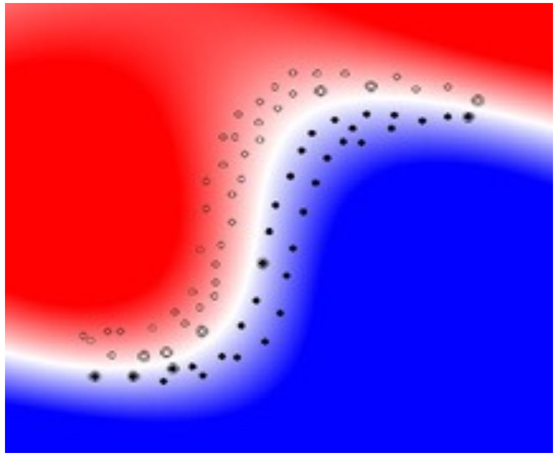
Structure from motion



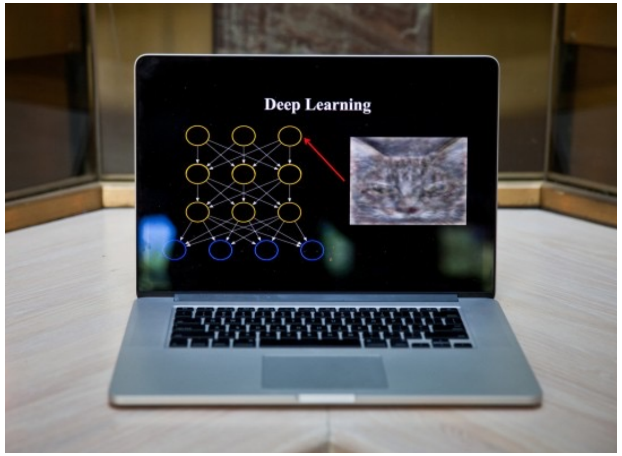
Multi-view stereo

Source: L. Lazebnik

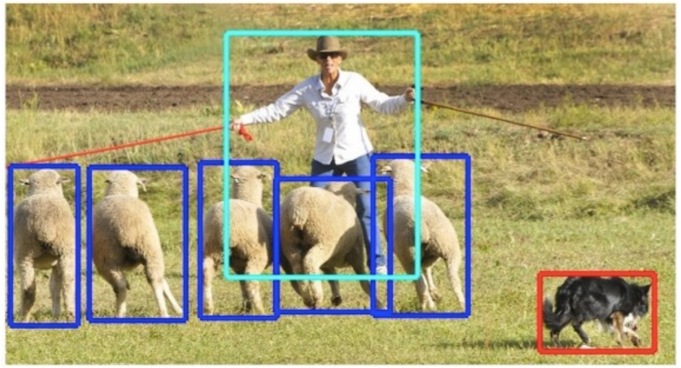
IV. Recognition



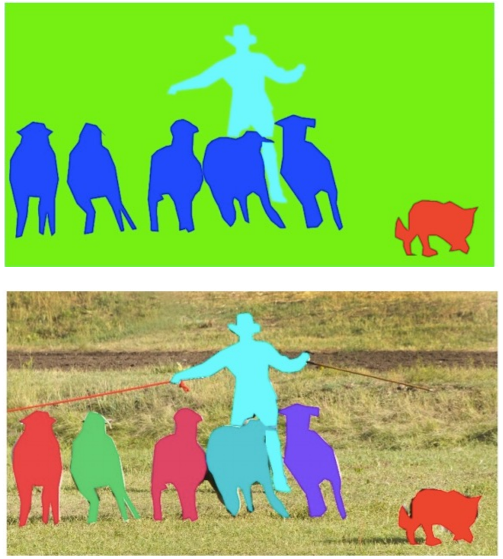
Basic classification



Deep learning



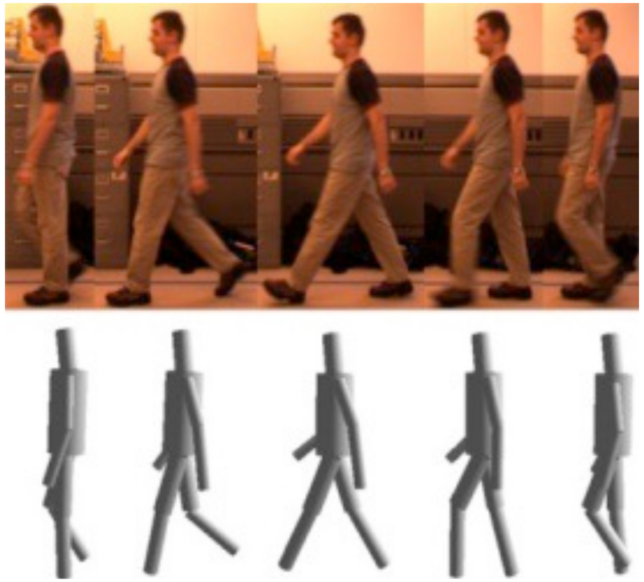
Object detection



Segmentation

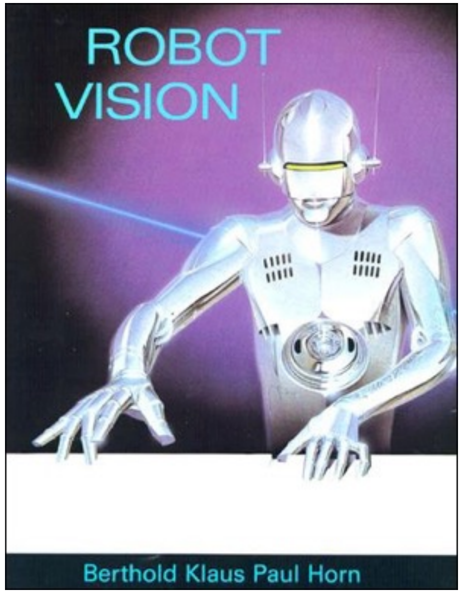
Source: L. Lazebnik

V. Additional Topics (time permitting)

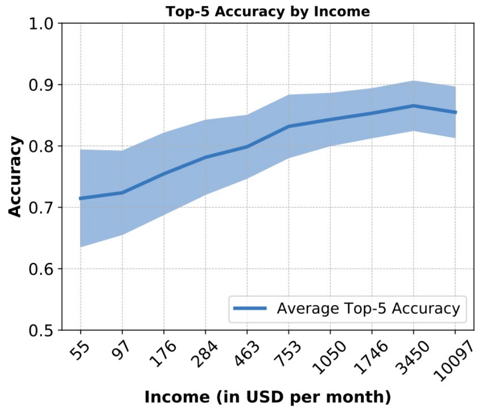


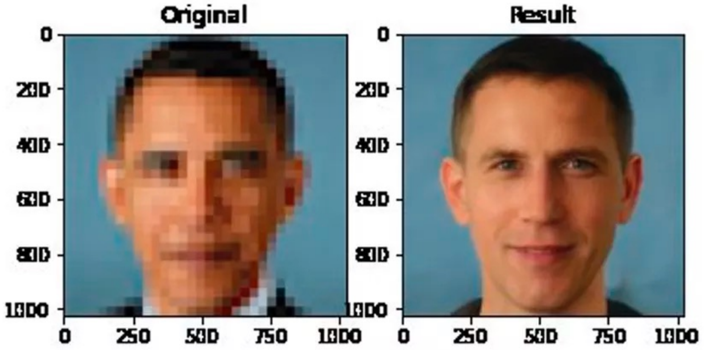
Video

Generation



Vision and Robotics





Bias and Ethical Considerations

Source: L. Lazebnik

What’s next?

- Machine Learning (CS 446)
- Applied Machine Learning (CS 441)
- Deep Learning for Computer Vision (CS 444)
- Advanced Classes:
  - Robot Perception (Shenlong)
  - 3D Vision (Derek)
  - Robot Learning (Saurabh, Yunzhu)
  - Autonomous Vehicles (DAF)
  - Learning to Learn (Yuxiong)
  - Efficient & Predictive Vision (Lynna)
  - Meta-Vision (Lana)
  - Deep Generative and Dynamical Models (Arindam)
  - Generative AI Models (Lav)