Momentum Contrast for Unsupervised Visual Representation Learning

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MoCo (2020, CVPR)

❖ Momentum Contrast for Unsupervised Visual Representation Learning

- 2020년에 CVPR에 게재되었으며, 2023년 05월 18일 기준 7033회 인용됨
- Dynamic dictionary와 Momentum update를 사용한 contrastive learning 방법론
- CV 분야에서 지도 학습과 비지도 학습으로 표현 학습을 했을 때의 성능의 차이를 줄여주는 방법론

Momentum Contrast for Unsupervised Visual Representation Learning

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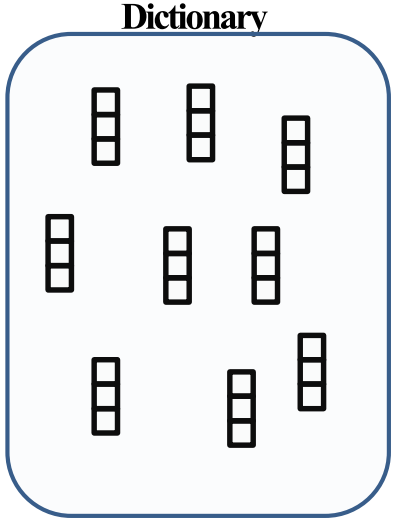
Background

❖ Natural Language Processing (NLP) vs Computer vision (CV)

- **NLP: 비지도 표현 학습을 사용해 레이블을 사용하지 않고도 좋은 표현 학습을 가능하게 한 사례가 있음**
  - ➢ Discrete symbol (ex: word, character…)이 연속으로 구성된 데이터를 사용하기 때문
  - ➢ 자연어 처리에서 사용되는 모델이 텍스트 데이터 자체의 내재적인 구조, 순차적인 특성을 활용해서 좋은 표현 학습 가능
- **CV: 비지도 표현 학습을 사용해 레이블 없이 좋은 표현 학습을 하는 것보다 지도 학습을 사용하는 것이 더 우세**
  - ➢ 이미지 데이터는 연속적이고 고차원 데이터이며 텍스트 데이터처럼 순차적인 특성을 갖고 있지 않음
  - ➢ 따라서, 레이블이 없는 경우 → Pretext task, Contrastive Learning 등장



Proposed Method

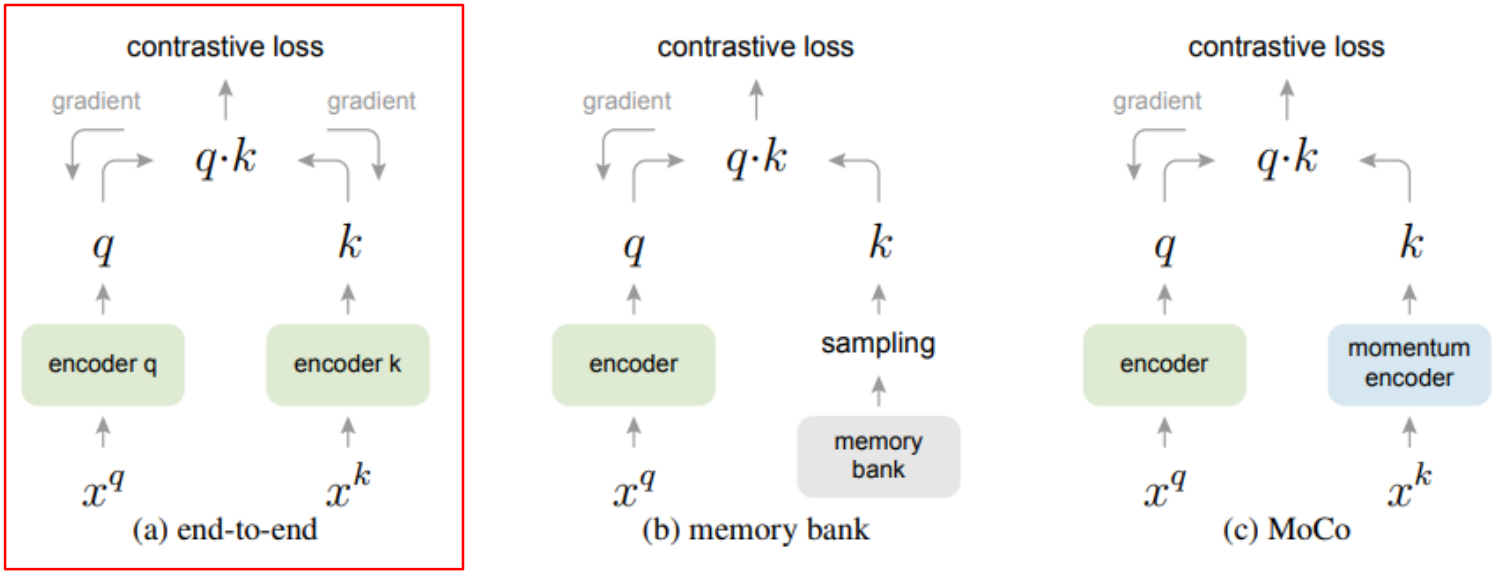
❖ Overall Architecture

- Contrastive loss를 사용한 컨셉이 비슷한 세 가지의 방법론 비교 설명

1. end-to-end

   ✓ 동일한 encoder를 사용해서 query와 key representation vector 추출 → inconsistency

   ✓ Mini batch size 만큼의 dictionary 사용 → dictionary 사이즈가 GPU 메모리 사이즈에 제한 받음



Proposed Method

❖ Overall Architecture

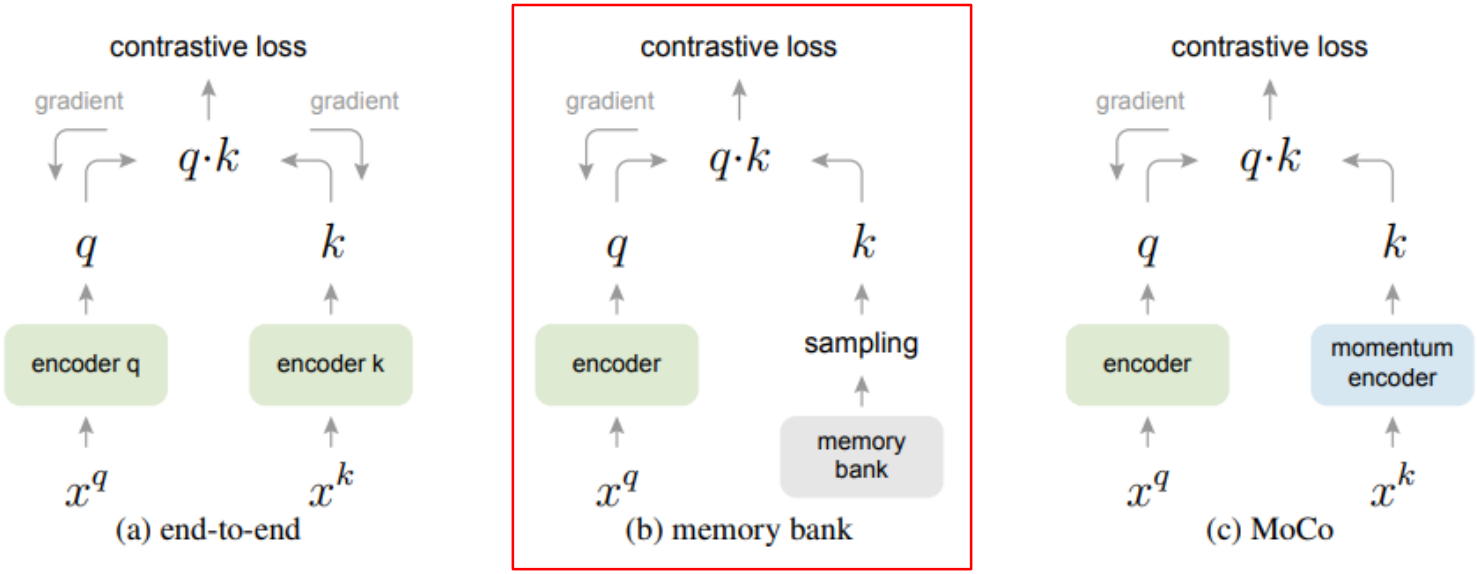
- Contrastive loss를 사용한 컨셉이 비슷한 세 가지의 방법론 비교 설명

1. memory bank

✓ MoCo와 동일하게 momory bank에서 샘플링한 key 값 사용

✓ 모든 데이터 셋에 대한 representation memory bank에 저장

✓ Momentum update를 하는데, encoder에 해당 방법을 적용하는 것이 momory bank 내에 새로운 샘플을 업데이트하는데 적용 → less consistent



Proposed Method

$$\mathcal{L}_q = -\log \frac{\exp(q \cdot k_+ / \tau)}{\sum_{i=0}^{K} \exp(q \cdot k_i / \tau)}$$

❖ Overall Architecture

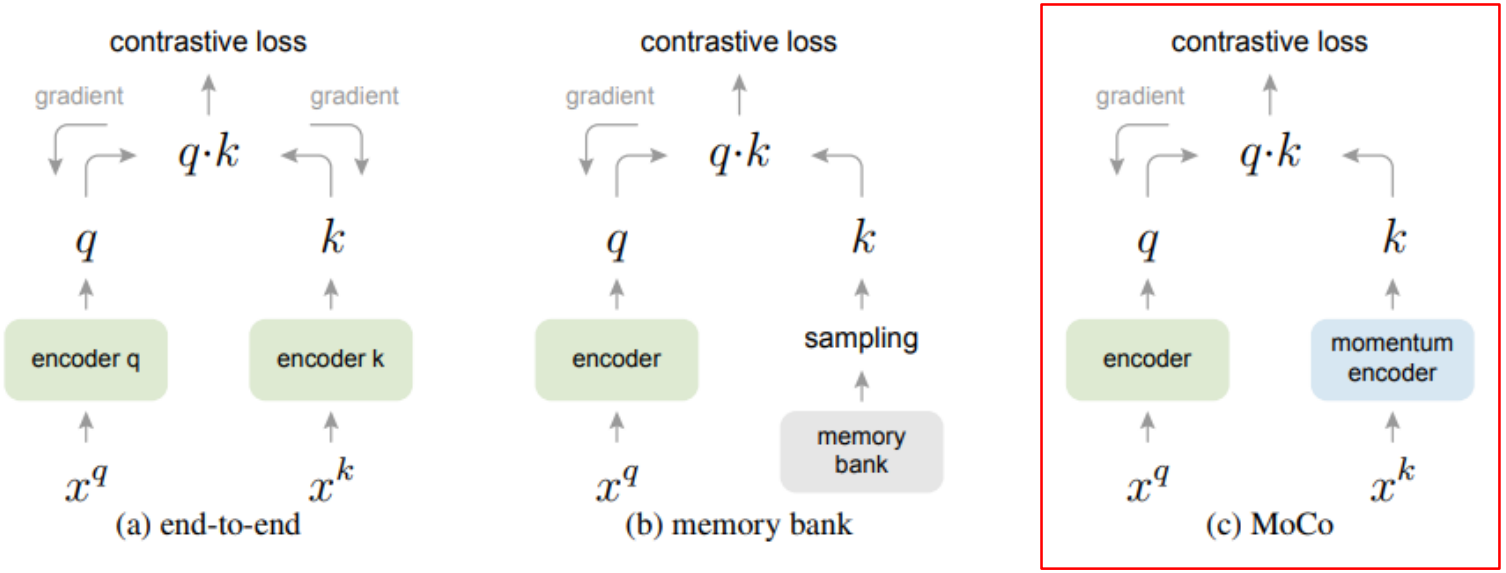
- Contrastive loss를 사용한 컨셉이 비슷한 세 가지의 방법론 비교 설명

1. MoCo

✓ Query encoder에만 gradient update 적용, key encoder에는 momentum update 적용 $\theta_k \leftarrow m\theta_k + (1-m)\theta_q$.

✓ Queue 형태의 dictionary를 사용함으로써 batch size에 영향을 받지 않고 거대한 negative sample 보유 가능

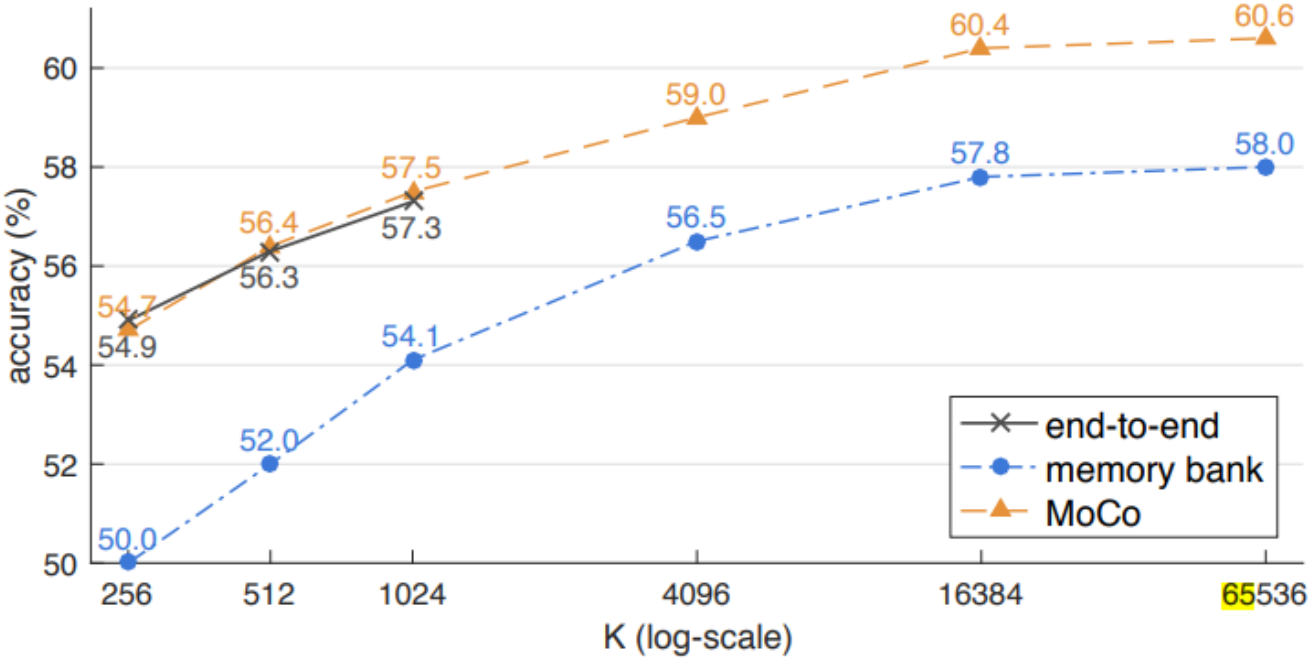
✓ Momentum encoder에서 나온 key가 새로운 sample로 들어가고 오래된 sample 제거



Experiment

❖ Comparison of three contrastive loss mechanisms

- MoCo가 가장 우수한 성능을 보임
- end-to-end의 경우, mini-batch size만큼 dictionary를 갖고 있다 보니, GPU 메모리 제한으로 인해 1024 이후로는 진행 불가능



Experiment

❖ Comparison under the linear classification protocol in ImageNet

method	architecture	#params (M)	accuracy (%)
Exemplar [17]	R50w3×	211	46.0 [38]
RelativePosition [13]	R50w2×	94	51.4 [38]
Jigsaw [45]	R50w2×	94	44.6 [38]
Rotation [19]	Rv50w4×	86	55.4 [38]
Colorization [64]	R101*	28	39.6 [14]
DeepCluster [3]	VGG [53]	15	48.4 [4]
BigBiGAN [16]	R50	24	56.6
	Rv50w4×	86	61.3
methods based on contrastive learning follow:			
InstDisc [61]	R50	24	54.0
LocalAgg [66]	R50	24	58.8
CPC v1 [46]	R101*	28	48.7
CPC v2 [35]	$R170^{*}_{wider}$	303	65.9
CMC [56]	$R50_{L+ab}$	47	$64.1^{\dagger}$
	$R50w2\times_{L+ab}$	188	$68.4^{\dagger}$
AMDIM [2]	$AMDIM_{small}$	194	$63.5^{\dagger}$
	$AMDIM_{large}$	626	$68.1^{\dagger}$
MoCo	R50	24	60.6
	RX50	46	63.9
	R50w2×	94	65.4
	R50w4×	375	**68.6**

Experiment

❖ Comparison with previous methods on object detection fine-tuned on PASCAL VOC

ImageNet-1M

pre-train	Default VOC metric: AP_{50} RelPos, by [14]	Multi-task [14]	Jigsaw, by [26]	LocalAgg [66]	MoCo	COCO style: AP MoCo	Averaged over 5 trials: AP_{75} Multi-task [14]	MoCo
super. IN-1M	74.2	74.2	70.5	74.6	74.4	42.4	44.3	42.7
unsup. IN-1M	66.8 (−7.4)	70.5 (−3.7)	61.4 (−9.1)	69.1 (−5.5)	74.9 (+0.5)	46.6 (+4.2)	43.9 (−0.4)	50.1 (+7.4)
unsup. IN-14M	-	-	69.2 (−1.3)	-	75.2 (+0.8)	46.9 (+4.5)	-	50.2 (+7.5)
unsup. YFCC-100M	-	-	66.6 (−3.9)	-	74.7 (+0.3)	45.9 (+3.5)	-	49.0 (+6.3)
unsup. IG-1B	-	-	-	-	75.6 (+1.2)	47.6 (+5.2)	-	51.7 (+9.0)

Instagram-1B

❖ Object detection and instance segmentation fine-tuned on COCO

pre-train	AP^{bb}	AP^{bb}_{50}	AP^{bb}_{75}	AP^{mk}	AP^{mk}_{50}	AP^{mk}_{75}
random init.	31.0	49.5	33.2	28.5	46.8	30.4
super. IN-1M	38.9	59.6	42.7	35.4	56.5	38.1
MoCo IN-1M	38.5 (−0.4)	58.9 (−0.7)	42.0 (−0.7)	35.1 (−0.3)	55.9 (−0.6)	37.7 (−0.4)
MoCo IG-1B	38.9 (0.0)	59.4 (−0.2)	42.3 (−0.4)	35.4 (0.0)	56.5 (0.0)	37.9 (−0.2)

(a) Mask R-CNN, R50-**FPN**, **1**× schedule

pre-train	AP^{bb}	AP^{bb}_{50}	AP^{bb}_{75}	AP^{mk}	AP^{mk}_{50}	AP^{mk}_{75}
random init.	36.7	56.7	40.0	33.7	53.8	35.9
super. IN-1M	40.6	61.3	44.4	36.8	58.1	39.5
MoCo IN-1M	40.8 (+0.2)	61.6 (+0.3)	44.7 (+0.3)	36.9 (+0.1)	58.4 (+0.3)	39.7 (+0.2)
MoCo IG-1B	41.1 (+0.5)	61.8 (+0.5)	45.1 (+0.7)	37.4 (+0.6)	59.1 (+1.0)	40.2 (+0.7)

(b) Mask R-CNN, R50-**FPN**, **2**× schedule

pre-train	AP^{bb}	AP^{bb}_{50}	AP^{bb}_{75}	AP^{mk}	AP^{mk}_{50}	AP^{mk}_{75}
random init.	26.4	44.0	27.8	29.3	46.9	30.8
super. IN-1M	38.2	58.2	41.2	33.3	54.7	35.2
MoCo IN-1M	38.5 (+0.3)	58.3 (+0.1)	41.6 (+0.4)	33.6 (+0.3)	54.8 (+0.1)	35.6 (+0.4)
MoCo IG-1B	39.1 (+0.9)	58.7 (+0.5)	42.2 (+1.0)	34.1 (+0.8)	55.4 (+0.7)	36.4 (+1.2)

pre-train	AP^{bb}	AP^{bb}_{50}	AP^{bb}_{75}	AP^{mk}	AP^{mk}_{50}	AP^{mk}_{75}
random init.	35.6	54.6	38.2	31.4	51.5	33.5
super. IN-1M	40.0	59.9	43.1	34.7	56.5	36.9
MoCo IN-1M	40.7 (+0.7)	60.5 (+0.6)	44.1 (+1.0)	35.4 (+0.7)	57.3 (+0.8)	37.6 (+0.7)
MoCo IG-1B	41.1 (+1.1)	60.7 (+0.8)	44.8 (+1.7)	35.6 (+0.9)	57.4 (+0.9)	38.1 (+1.2)

Experiment

- MoCo vs. ImageNet supervised pre-training, fine-tuned on various tasks

pre-train	COCO keypoint detection AP^{kp}	AP^{kp}_{50}	AP^{kp}_{75}
random init.	65.9	86.5	71.7
super. IN-1M	65.8	86.9	71.9
MoCo IN-1M	66.8 (+1.0)	87.4 (+0.5)	72.5 (+0.6)
MoCo IG-1B	66.9 (+1.1)	87.8 (+0.9)	73.0 (+1.1)

pre-train	COCO dense pose estimation AP^{dp}	AP^{dp}_{50}	AP^{dp}_{75}
random init.	39.4	78.5	35.1
super. IN-1M	48.3	85.6	50.6
MoCo IN-1M	50.1 (+1.8)	86.8 (+1.2)	53.9 (+3.3)
MoCo IG-1B	50.6 (+2.3)	87.0 (+1.4)	54.3 (+3.7)

pre-train	LVIS v0.5 instance segmentation AP^{mk}	AP^{mk}_{50}	AP^{mk}_{75}
random init.	22.5	34.8	23.8
super. IN-1M†	24.4	37.8	25.8
MoCo IN-1M	24.1 (−0.3)	37.4 (−0.4)	25.5 (−0.3)
MoCo IG-1B	24.9 (+0.5)	38.2 (+0.4)	26.4 (+0.6)

pre-train	Cityscapes instance seg. AP^{mk}	AP^{mk}_{50}	Semantic seg. (mIoU) Cityscapes	VOC
random init.	25.4	51.1	65.3	39.5
super. IN-1M	32.9	59.6	74.6	74.4
MoCo IN-1M	32.3 (−0.6)	59.3 (−0.3)	75.3 (+0.7)	72.5 (−1.9)
MoCo IG-1B	32.9 (0.0)	60.3 (+0.7)	75.5 (+0.9)	73.6 (−0.8)