

딥러닝 세미나 Season #7

Zero-Shot Learning

by Convex Combination of Semantic Embeddings

2014, *ICLR*, M. Norouzi et al.

<https://arxiv.org/pdf/1312.5650.pdf>

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조건희

〈 Classic Machine Learning Approach 〉

10가지 클래스를 분류하는 image classifier 에 대해 생각해보자

Zero-shot
learning by
convex
combination of
semantic
embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

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이미지를 처리해야 하므로

ResNet, VGG, Inception 등을 이용하면 되겠지?

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

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학습에 이용할 데이터셋은

10가지 클래스에 대한 이미지를 각각 준비하면 되겠다

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

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이제 학습을 돌려보자!

〈 Classic Machine Learning Approach 〉

이제 클래스를 좀더 세분화해서

10,000가지 클래스를 분류하는 image classifier에 대해 생각해보자

Zero-shot
learning by
convex
combination of
semantic
embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

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Zero-shot
learning by
convex
combination of
semantic
embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

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10,000가지 클래스의 이미지 데이터는 어떻게 구하지?

Zero-shot
learning by
convex
combination of
semantic
embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

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10,000가지 클래스의 이미지 데이터는 어떻게 구하지?

게다가 열심히 학습했던 10가지 클래스 분류 모델은

재활용이 안되네 $\pi\pi$

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

정리하자면,
n-way classification 문제에서 n 이 아주 클 경우에는
기존 기계학습 방법을 그대로 적용하기 어려움

Zero-shot
learning by
convex
combination of
semantic
embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

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그래서

이미지의 semantic embedding을 이용하는 방법이 나옴
바로 Zero-Shot Learning

Zero-Shot Learning



$$\mathcal{D}_0 \equiv \{(\mathbb{X}_i, y_i)\}_{i=1}^m$$

데이터셋 크기: m

$$\mathbb{X}_i \in \mathbb{R}^p$$

p 차원 벡터

$$y_i \in \mathcal{Y}_0 \equiv \{1, \dots, n_0\}$$

클래스: n_0 개

Zero-shot learning by convex combination of semantic embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

Zero-Shot Learning

Zero-shot learning by convex combination of semantic embeddings

– Introduction

– Zero-Shot Learning

– ConSE: Convex combination of semantic embeddings

– Result



$$\mathcal{D}_0 \equiv \{(\mathbb{X}_i, y_i)\}_{i=1}^m \quad \text{데이터셋 크기: } m$$
$$\mathbb{X}_i \in \mathbb{R}^p \quad p \text{ 차원 벡터}$$
$$y_i \in \mathcal{Y}_0 \equiv \{1, \dots, n_0\}$$

클래스: n_0 개



$$\mathcal{D}_1 \equiv \{(\mathbb{X}'_j, y'_j)\}_{j=1}^{m'} \quad \text{데이터셋 크기: } m'$$
$$\mathbb{X}'_j \in \mathbb{R}^p \quad p \text{ 차원 벡터}$$
$$y'_j \in \mathcal{Y}_1 \equiv \{n_0 + 1, \dots, n_0 + n_1\}$$

클래스: n_1 개

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result



〈제로샷 러닝의 목적〉

\mathcal{D}_0 으로 학습한 *classifier*가
 \mathcal{D}_1 에도 잘 적용되도록 하는 것

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result



〈제로샷 러닝의 목적〉

\mathcal{D}_0 으로 학습한 *classifier*가
 \mathcal{D}_1 에도 잘 적용되도록 하는 것

$\mathcal{Y}_0 \cap \mathcal{Y}_1 = \emptyset$ 이므로
다른 정보가 주어지지 않으면 불가능

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result



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$$\mathcal{Y}_0 \cap \mathcal{Y}_1 = \emptyset \text{ 이므로}$$

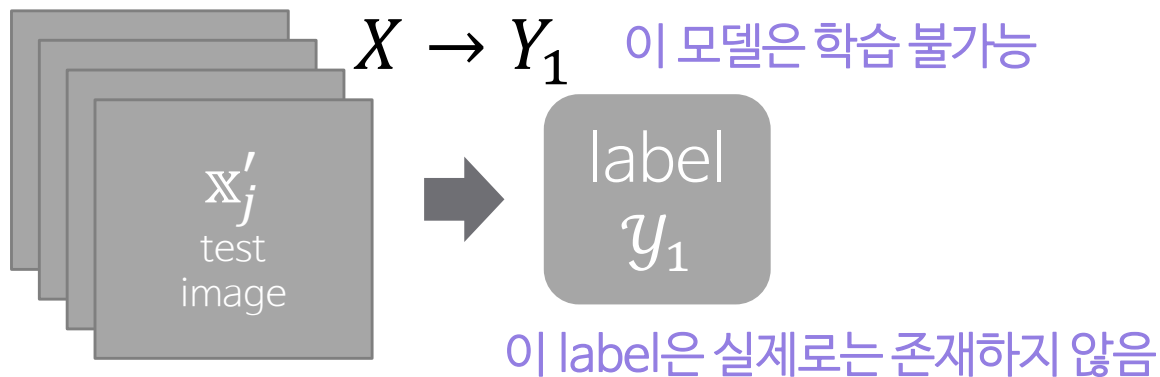
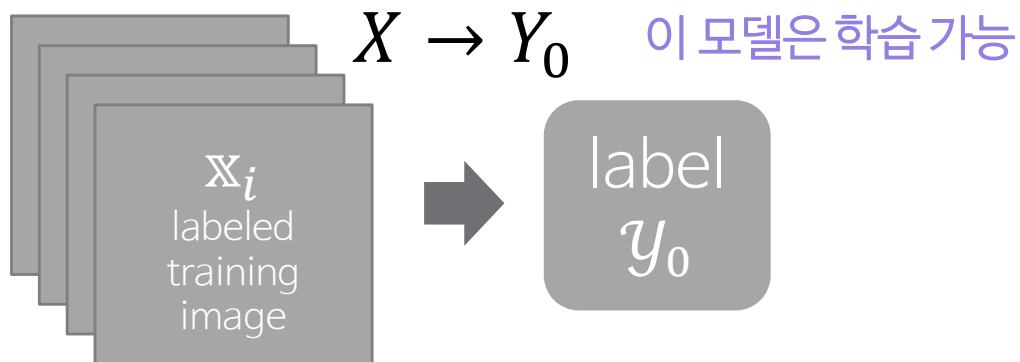
다른 정보가 주어지지 않으면 불가능

모든 label y ($1 \leq y \leq n_0 + n_1$) 에 대해서
semantic embedding

$$s(y) \in \mathcal{S} \equiv \mathbb{R}^q \text{ } q \text{ 차원 벡터}$$

가 존재하면 가능

Zero-Shot Learning



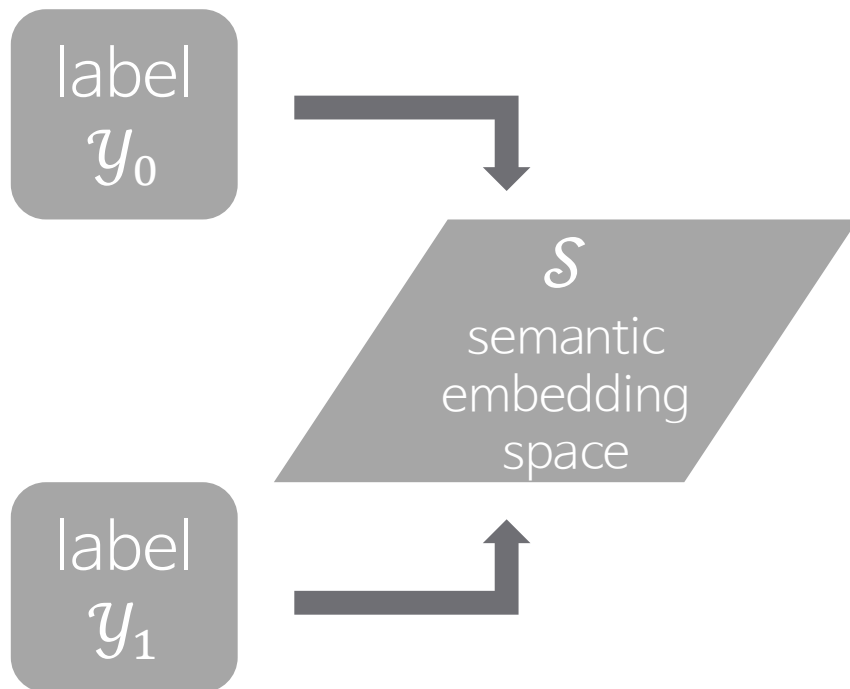
Zero-shot learning by convex combination of semantic embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

Zero-Shot Learning

Word2Vec

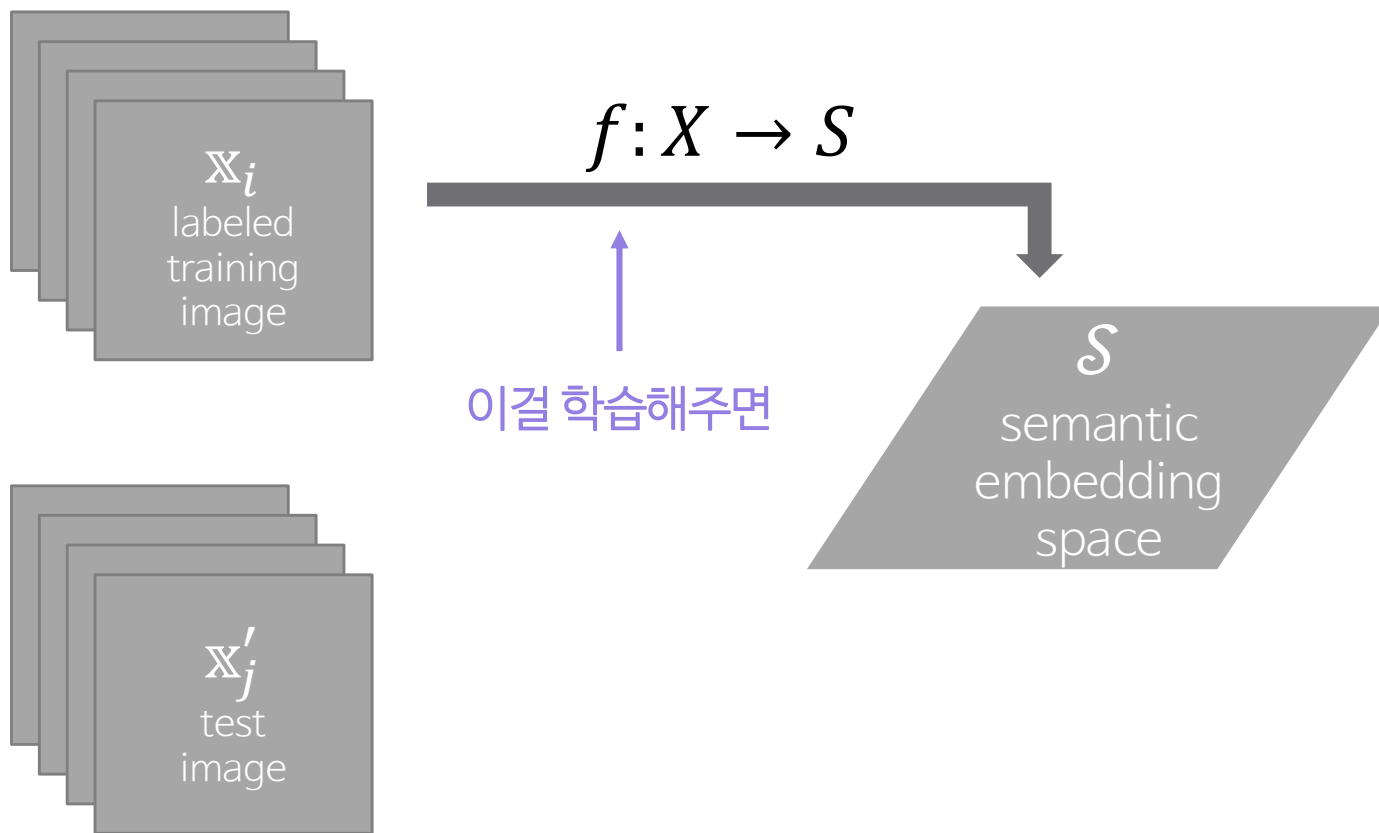
단어의 의미가 비슷하면
semantic embedding space 상의
벡터 좌표도 비슷하도록 학습함



Zero-shot learning by convex combination of semantic embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

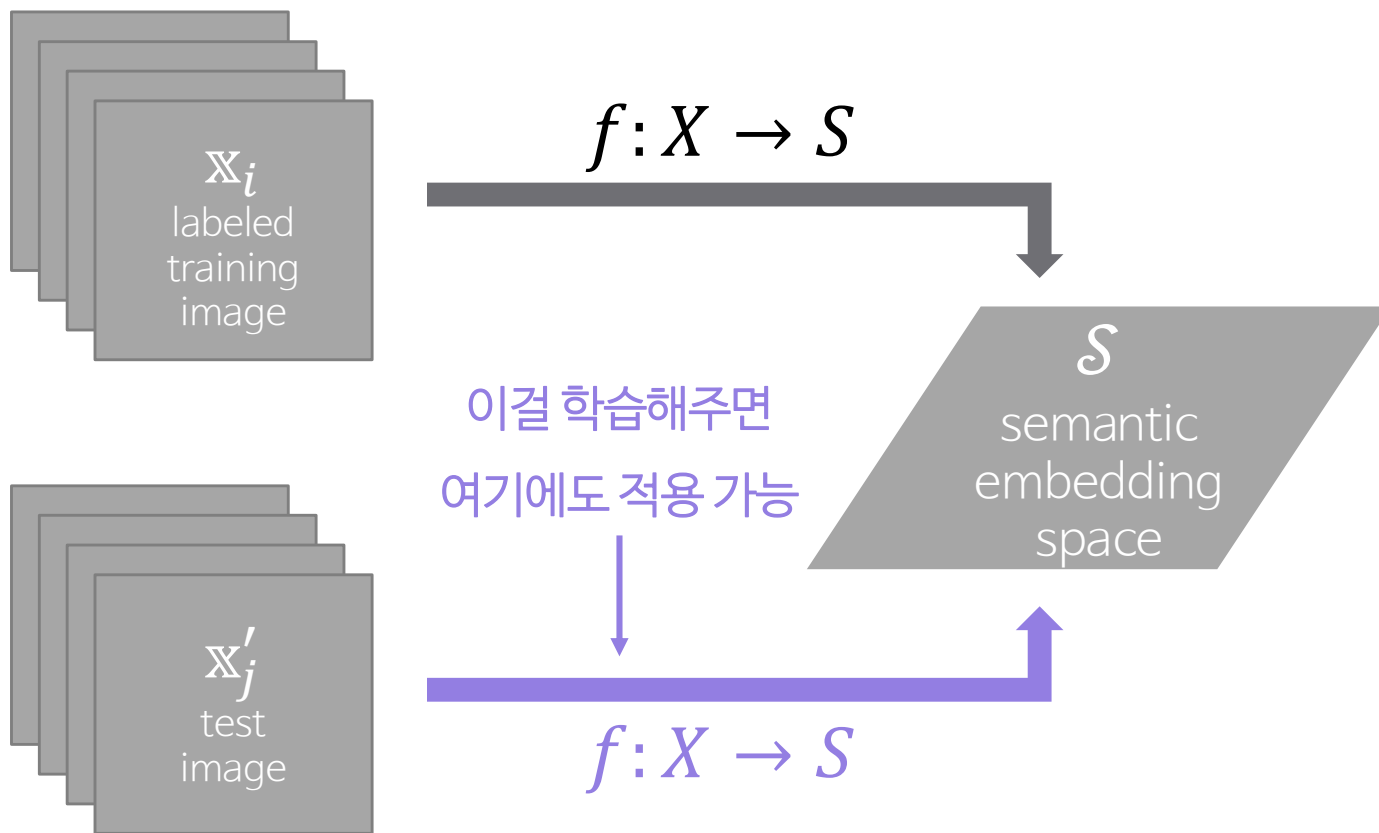
Zero-Shot Learning



Zero-shot learning by convex combination of semantic embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

Zero-Shot Learning

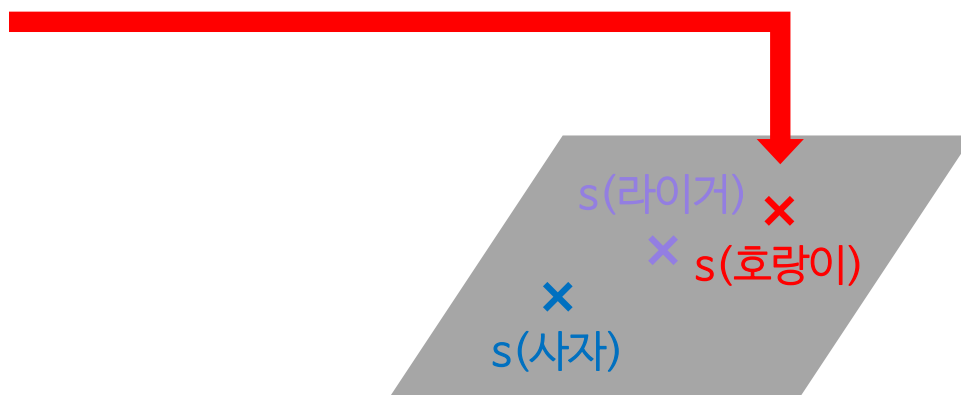


Zero-shot learning by convex combination of semantic embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

Zero-Shot Learning

예를 들어 '호랑이'와 '사자' 이미지를 학습했을 경우

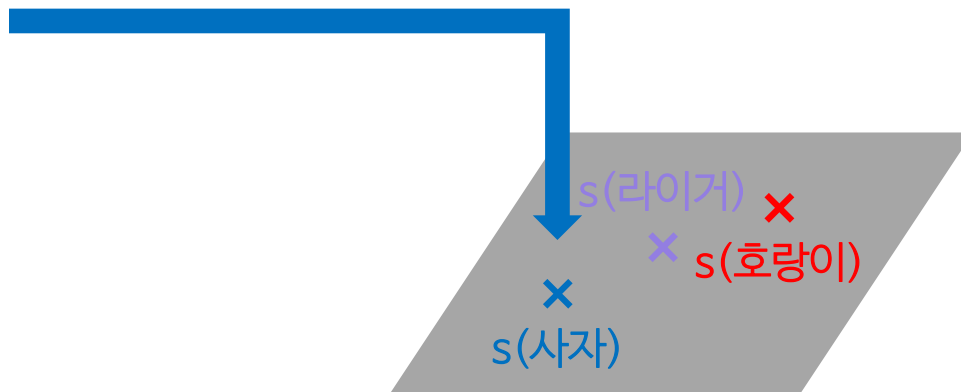


Zero-shot learning by convex combination of semantic embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

Zero-Shot Learning

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Zero-shot learning by convex combination of semantic embeddings

– Introduction

– Zero-Shot Learning

– ConSE: Convex combination of semantic embeddings

– Result

Zero-Shot Learning

Zero-shot learning by convex combination of semantic embeddings

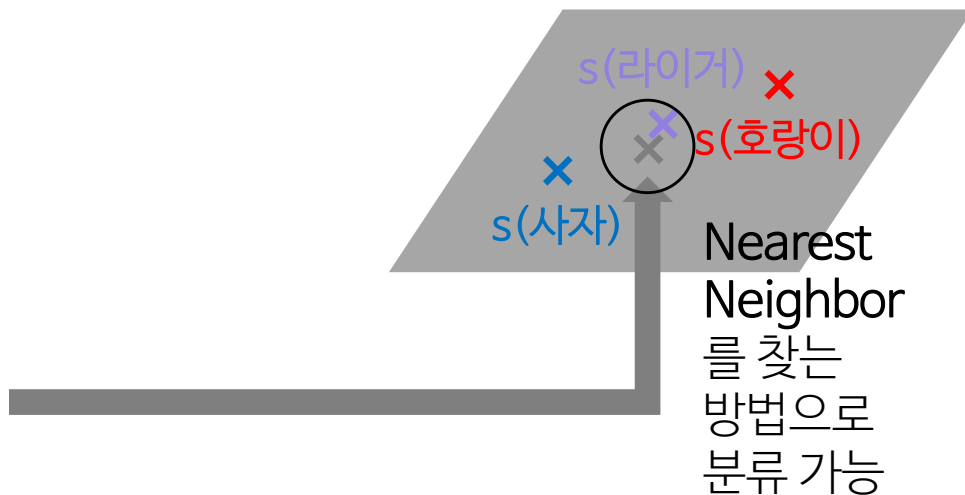
- Introduction

- Zero-Shot Learning

- ConSE: Convex combination of semantic embeddings

- Result

예를 들어 ‘호랑이’와 ‘사자’ 이미지를 학습했을 경우
‘라이거’라는 label은 학습되지 않았지만
분류할 수 있게 됨



기존 제로샷은

$f: X \rightarrow S$ 를 직접 학습하지만

이 논문에서 제안하는 모델(ConSE)은

$f: X \rightarrow S$ 를 간접적으로 학습함

오히려 classic machine learning 처럼

기존 classifier를 그대로 가져다 이용

ConSE: Convex combination of semantic embeddings



classifier 학습

$$p_0(y|\mathbb{X})$$

이미지 x 의 label이 y 일 확률

$$\sum_{y=1}^{n_0} p_0(y|\mathbb{X}) = 1$$

Zero-shot
learning by
convex
combination of
semantic
embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

ConSE: Convex combination of semantic embeddings

Zero-shot
learning by
convex
combination of
semantic
embeddings

– Introduction

– Zero-Shot
Learning

– ConSE:
Convex
combination
of semantic
embeddings

– Result



$$p_0(y|\mathbb{X})$$

이미지 x 의 label이 y 일 확률

$$\widehat{y}_0(\mathbb{X}, 1) \equiv \operatorname{argmax}_{y \in \mathcal{Y}_0} p_0(y|\mathbb{X})$$

most likely training label

(즉, 이 classifier는 x 의 label을 이 label로 판단할 것이다)

ConSE: Convex combination of semantic embeddings

Zero-shot learning by convex combination of semantic embeddings

– Introduction

– Zero-Shot Learning

– ConSE: Convex combination of semantic embeddings

– Result



$$p_0(y|\mathbb{X})$$

이미지 x 의 라벨이 y 일 확률

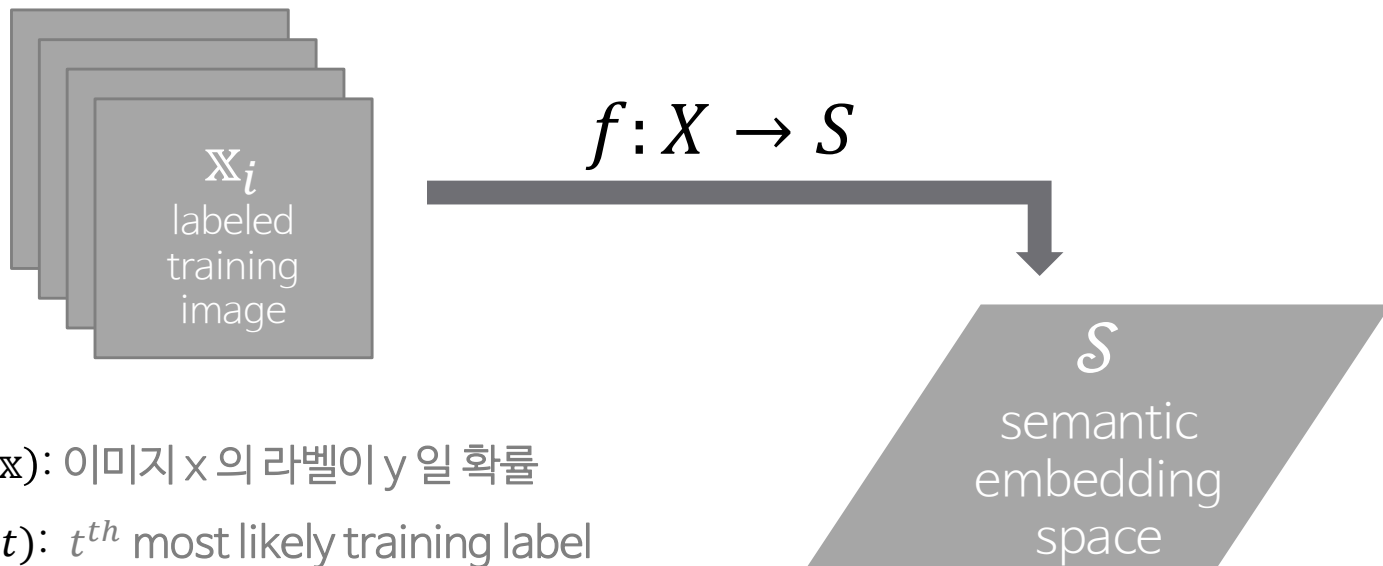
$$\widehat{y_0}(\mathbb{X}, t)$$

t^{th} most likely training label

ConSE: Convex combination of semantic embeddings

Zero-shot learning by convex combination of semantic embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result



$p_0(y|\mathbb{x})$: 이미지 \mathbb{x} 의 라벨이 y 일 확률

$\widehat{y}_0(\mathbb{x}, t)$: t^{th} most likely training label

$$f(\mathbb{x}) = \frac{1}{Z} \sum_{t=1}^T p(\widehat{y}_0(\mathbb{x}, t) | \mathbb{x}) \cdot s(\widehat{y}_0(\mathbb{x}, t))$$

ConSE: Convex combination of semantic embeddings

Zero-shot learning by convex combination of semantic embeddings

- Introduction

- Zero-Shot Learning

- ConSE: Convex combination of semantic embeddings

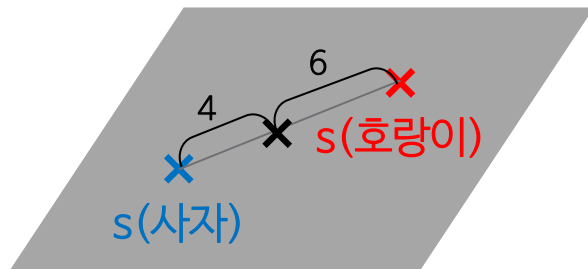
- Result

‘라이거’ 이미지를 classifier에 넣었을 때 각 label일 확률



y		$p_0(y \mathbb{x})$
$\hat{y}_0(\mathbb{x}, 1)$	사자	0.6
$\hat{y}_0(\mathbb{x}, 2)$	호랑이	0.4

$$f(\mathbb{x}) = 0.6 \cdot s('사자') + 0.4 \cdot s('호랑이') \\ \approx s('라이거')$$



$$f(\mathbb{x}) = \frac{1}{Z} \sum_{t=1}^T p(\hat{y}_0(\mathbb{x}, t) | \mathbb{x}) \cdot s(\hat{y}_0(\mathbb{x}, t))$$

ConSE: Convex combination of semantic embeddings

Zero-shot learning by convex combination of semantic embeddings

- Introduction

- Zero-Shot Learning

- ConSE: Convex combination of semantic embeddings

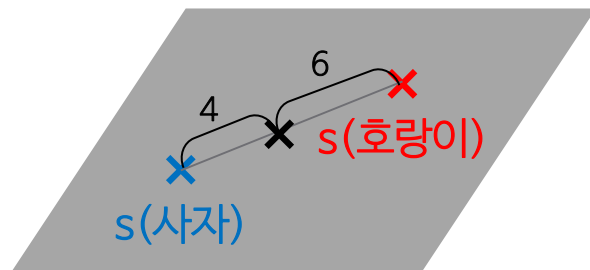
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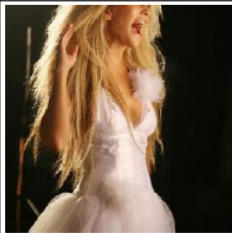
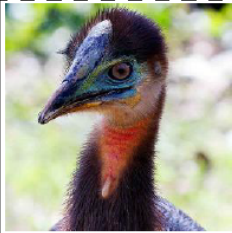


$$f(\mathbf{x}) = 0.6 \cdot s(\text{'사자'}) + 0.4 \cdot s(\text{'호랑이'}) \\ \approx s(\text{'라이거'})$$



cosine similarity

$$\hat{y}_1(\mathbf{x}, 1) \equiv \operatorname{argmax}_{y' \in \mathcal{Y}_1} \cos(f(\mathbf{x}), s(y'))$$

Result

Test Image	Softmax Baseline [7]	DeViSE [6]	ConSE (10)
	wig fur coat Saluki, gazelle hound Afghan hound, Afghan stole	water spaniel tea gown bridal gown, wedding gown spaniel tights, leotards	business suit dress, frock hairpiece, false hair, postiche swimsuit, swimwear, bathing suit kit, outfit
	ostrich, Struthio camelus black stork, Ciconia nigra vulture crane peacock	heron owl, bird of Minerva, bird of night hawk bird of prey, raptor, raptorial bird finch	ratite, ratite bird, flightless bird peafowl, bird of Juno common spoonbill New World vulture, cathartid Greek partridge, rock partridge
	sea lion plane, carpenter's plane cowboy boot loggerhead, loggerhead turtle goose	elephant turtle turtleneck, turtle, polo-neck <u>flip-flop, thong</u> handcart, pushcart, cart, go-cart	California sea lion Steller sea lion Australian sea lion South American sea lion eared seal
	hamster broccoli Pomeranian capuchin, ringtail weasel	golden hamster, Syrian hamster rhesus, rhesus monkey <u>pipe</u> <u>shaker</u> American mink, Mustela vison	golden hamster, Syrian hamster rodent, gnawer Eurasian hamster rhesus, rhesus monkey rabbit, coney, cony

Zero-shot
learning by
convex
combination of
semantic
embeddings

- Introduction
- Zero-Shot Learning
- ConSE:
Convex
combination
of semantic
embeddings
- Result

Result

Test Label Set	# Candidate Labels	Model	Flat hit@k (%)				
			1	2	5	10	20
<u>2-hops</u>	1, 589	DeViSE	6.0	10.0	18.1	26.4	36.4
		ConSE(1)	9.3	14.4	23.7	30.8	38.7
		ConSE(10)	9.4	15.1	24.7	32.7	41.8
		ConSE(1000)	9.2	14.8	24.1	32.1	41.1
2-hops <u>(+1K)</u>	1, 589 +1000	DeViSE	0.8	2.7	7.9	14.2	22.7
		ConSE(1)	0.2	7.1	17.2	24.0	31.8
		ConSE(10)	0.3	6.2	17.0	24.9	33.5
		ConSE(1000)	0.3	6.2	16.7	24.5	32.9
3-hops	7, 860	DeViSE	1.7	2.9	5.3	8.2	12.5
		ConSE(1)	2.6	4.2	7.3	10.8	14.8
		ConSE(10)	2.7	4.4	7.8	11.5	16.1
		ConSE(1000)	2.6	4.3	7.6	11.3	15.7
3-hops (+1K)	7, 860 +1000	DeViSE	0.5	1.4	3.4	5.9	9.7
		ConSE(1)	0.2	2.4	5.9	9.3	13.4
		ConSE(10)	0.2	2.2	5.9	9.7	14.3
		ConSE(1000)	0.2	2.2	5.8	9.5	14.0
ImageNet 2011 21K	20, 841	DeViSE	0.8	1.4	2.5	3.9	6.0
		ConSE(1)	1.3	2.1	3.6	5.4	7.6
		ConSE(10)	1.4	2.2	3.9	5.8	8.3
		ConSE(1000)	1.3	2.1	3.8	5.6	8.1
ImageNet 2011 21K (+1K)	20, 841 +1000	DeViSE	0.3	0.8	1.9	3.2	5.3
		ConSE(1)	0.1	1.2	3.0	4.8	7.0
		ConSE(10)	0.2	1.2	3.0	5.0	7.5
		ConSE(1000)	0.2	1.2	3.0	4.9	7.3

Zero-shot learning by convex combination of semantic embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

Result

Zero-shot
learning by
convex
combination of
semantic
embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings
- Result

Test Label Set	Model	<u>Hierarchical precision@k</u>				
		1	2	5	10	20
2-hops	DeViSE	0.06	0.152	0.192	0.217	0.233
	ConSE(10)	0.094	0.214	0.247	0.269	0.284
2-hops (+1K)	Softmax baseline	0	0.236	0.181	0.174	0.179
	DeViSE	0.008	0.204	0.196	0.201	0.214
	ConSE(10)	0.003	0.234	0.254	0.260	0.271
3-hops	DeViSE	0.017	0.037	0.191	0.214	0.236
	ConSE(10)	0.027	0.053	0.202	0.224	0.247
3-hops (+1K)	Softmax baseline	0	0.053	0.157	0.143	0.130
	DeViSE	0.005	0.053	0.192	0.201	0.214
	ConSE(10)	0.002	0.061	0.211	0.225	0.240
ImageNet 2011 21K	DeViSE	0.008	0.017	0.072	0.085	0.096
	ConSE(10)	0.014	0.025	0.078	0.092	0.104
ImageNet 2011 21K (+1K)	Softmax baseline	0	0.023	0.071	0.069	0.065
	DeViSE	0.003	0.025	0.083	0.092	0.101
	ConSE(10)	0.002	0.029	0.086	0.097	0.105

Result

Zero-shot learning by convex combination of semantic embeddings

- Introduction
- Zero-Shot Learning
- ConSE: Convex combination of semantic embeddings

- Result

Test Label Set	Model	Hierarchical precision@ k				
		1	2	5	10	20
ImageNet 2011 1K	Softmax baseline	0.556	0.452	0.342	0.313	0.319
	DeViSE	0.532	0.447	0.352	0.331	0.341
	ConSE (1)	0.551	0.422	0.32	0.297	0.313
	ConSE (10)	0.543	0.447	0.348	0.322	0.337
	ConSE (1000)	0.539	0.442	0.344	0.319	0.335

Test Label Set	Model	Flat hit@ k (%)			
		1	2	5	10
ImageNet 2011 1K	Softmax baseline	55.6	67.4	78.5	85.0
	DeViSE	53.2	65.2	76.7	83.3
	ConSE (1)	55.1	57.7	60.9	63.5
	ConSE (10)	54.3	61.9	68.0	71.6
	ConSE (1000)	53.9	61.1	67.0	70.6

감사합니다