Semantic Description of Objects in Images Based on Prototype Theory

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SIBGRAPI 2020 33rd Conference on Graphics, Patterns and Images
Workshop of Theses and Dissertations (WTD)

Abstract

This research aims to build a model for the semantic description of objects based on visual features extracted from images. Inspired by the human approach used to represent categories, we proposed a novel *Computational Prototype Model* (CPM) that encodes and stores the object's image category's central semantic meaning: the semantic prototype. Also, we proposed a *Prototype-based Description Model* that uses our CPM model to describe an object's image highlighting its most distinctive features within the category. Our description method uses the proposed Prototypical Similarity Layer (PS-Layer) to retrieve the category's semantics simulating the prototype-based concept of categorization of the Prototype Theory. Using different datasets, our experiments show that: *i)* the proposed CPM model successfully simulates the internal semantic structure of the categories; *ii)* the proposed semantic distance metric can be understood as the object typicality score within a category; *iii)* our semantic classification method based on prototypes can improve the performance and interpretation of CNN classification models; *iv)* our semantic descriptor encoding significantly outperforms other state-of-the-art image global encodings in clustering and classification tasks.

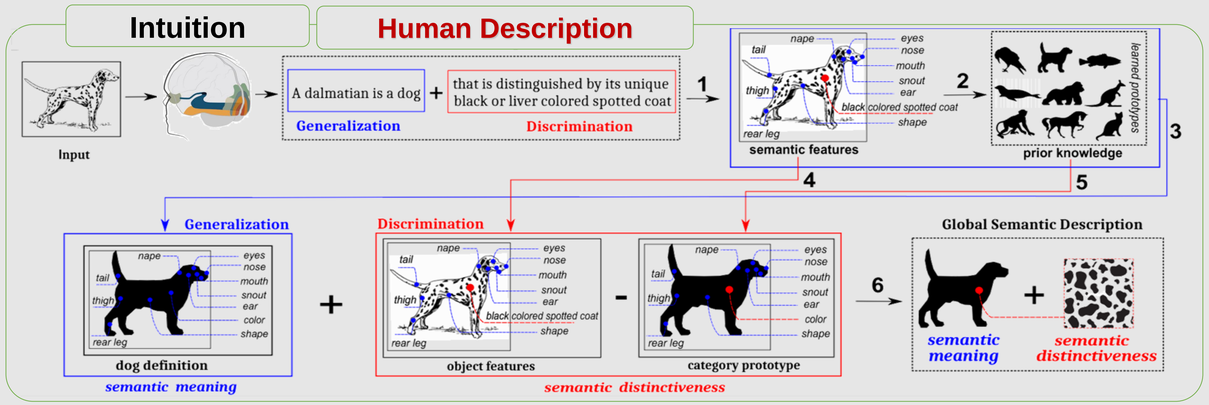
Introduction

Motivation

Although CNNs provide outstanding performance in image semantic processing tasks:

- CNN description models do not codify their image's representation based on the Cognitive Science foundations to represent the meaning.
- Is still unknown how to make an accurate interpretation of CNN classification models outputs.

As an attempt to overcome these, we bring into view the Prototype Theory as a framework to represent the semantic meaning of the visual information contained in an image.



Background

Prototype Theory Foundations

- The *prototype* stands for the *central semantic meaning* of the category [1,2].

- *Category internal semantic structure [1,2]:* category members are positioned around of the category prototype based on its degrees of typicity.

- *Object categorization* is made based on how similar a new exemplar is with the learned prototypes [3].
- Main characteristics (*prototypicality effects*) [1-5]:

	extensional	***intensional***
non-equality *(salience effect, core/periphery)*	Difference of typicality and membership salience	Clustering into family resemblances
non-discreteness *(demarcation problems, flexibly)*	Fuzziness at the edges, membership uncertainty	Absence of necessary-and-sufficient definitions

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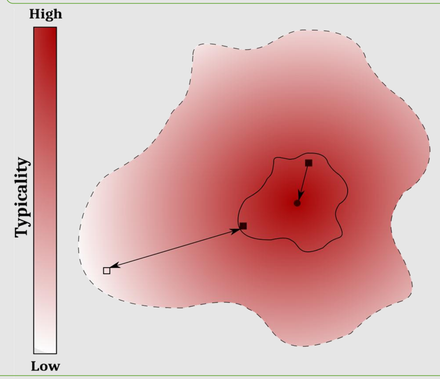
Methodology

Computational Prototype Model (CPM)

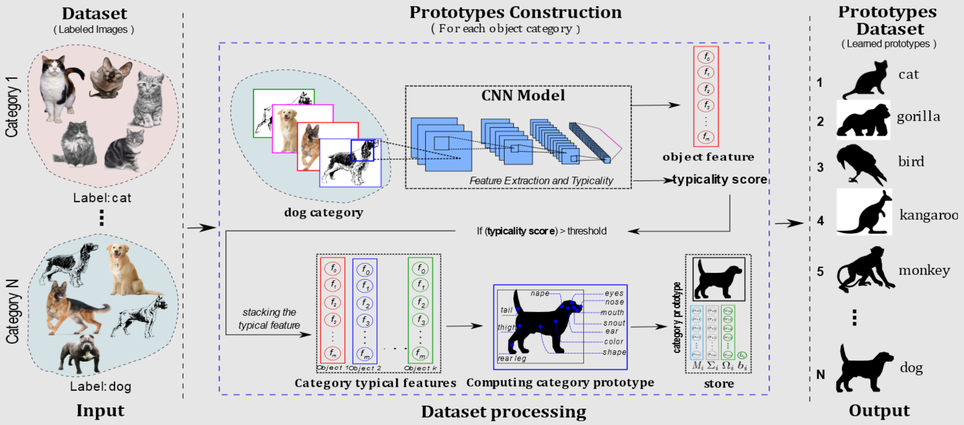


Legend

- Typical members
- Non-typical members
- Semantic Prototype
- Abstract Prototype
- Category edges (*undefined*)
- Semantic Prototype edges (*defined*)
- Prototypical distance
- Distance between objects

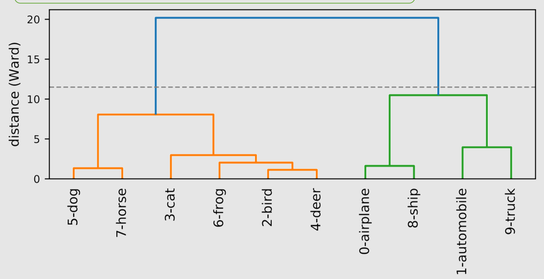
Category internal structure. The figure shows our expected semantic representation of the category internal structure. We show the key definitions, the advantages and the constraints of our CPM Model.

Off-line construction of the semantic prototypes dataset



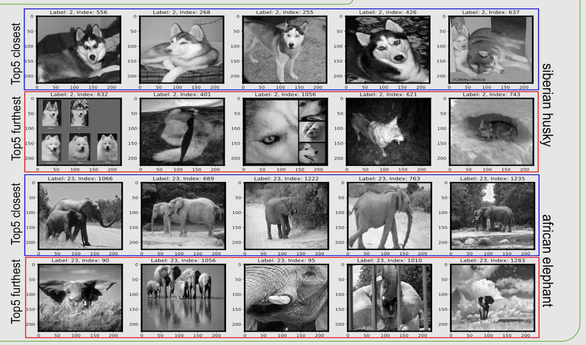
Results

Semantic prototype encoding

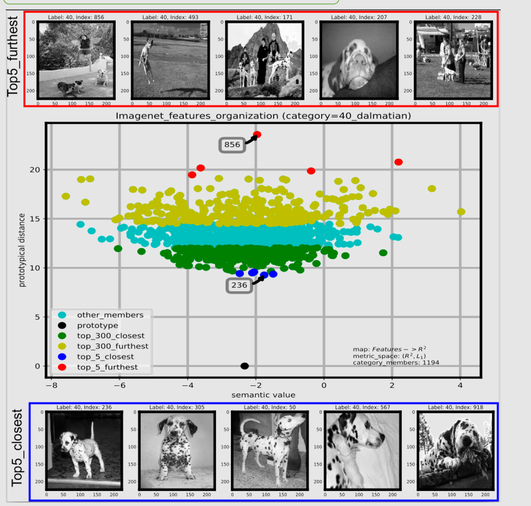


Hierarchical clustering of CIFAR10 semantic prototypes.

Central - Peripheral meaning

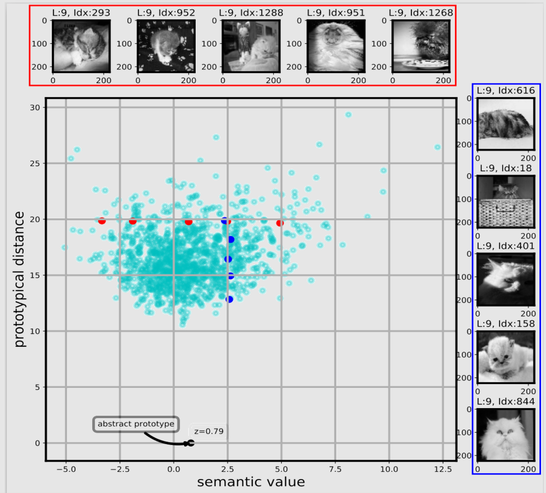


Prototypical organization



Dalmatian category of ImageNet dataset.

Image Typicality Score [6]



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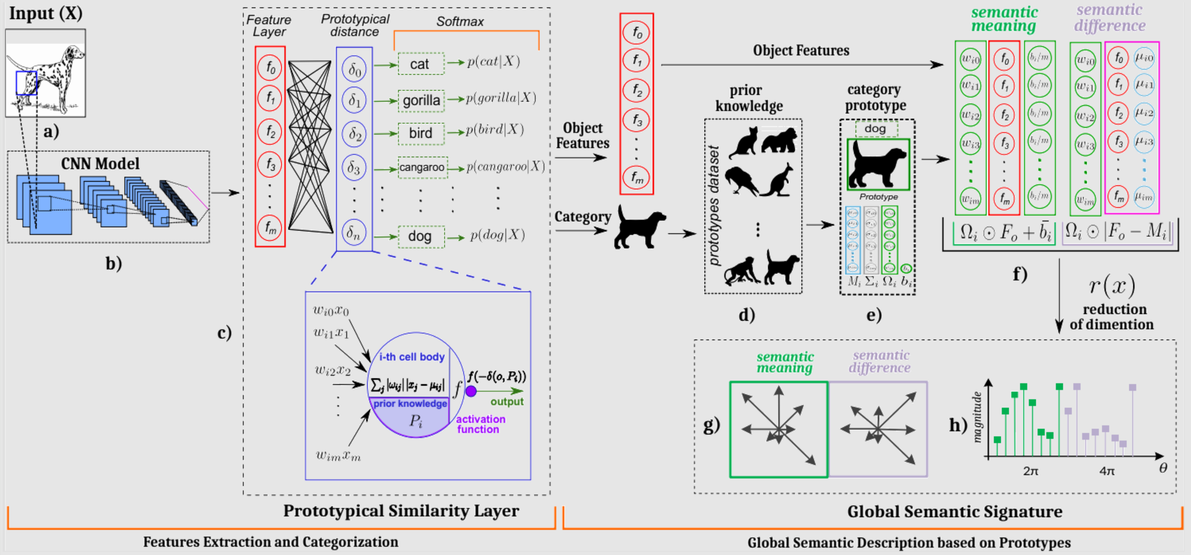
Methodology

Prototype-based description model (GSDP)



Set of steps to transform the visual information received as input into a Global Semantic Descriptor signature. The methodology workflow can be divided into two main stages: **1)** Feature extraction and Categorization and **2)** transformation of CNN-object features into our Global Semantic Signature. *a)* input image; *b)-c)* features extraction and classification using a pre-trained CNN-classification model. Our Prototypical Similarity Layer (PS-Layer) is used to convert a common CNN-model into a prototype-based CNN-classification model; *d)* prototype dataset; *e)* category prototype selection; *f)* global semantic description of object using category prototype; *g)* graphic representation of our descriptor signature resulting from the dimensionality reduction function (r(x)); and *h)* Global Semantic Signature.

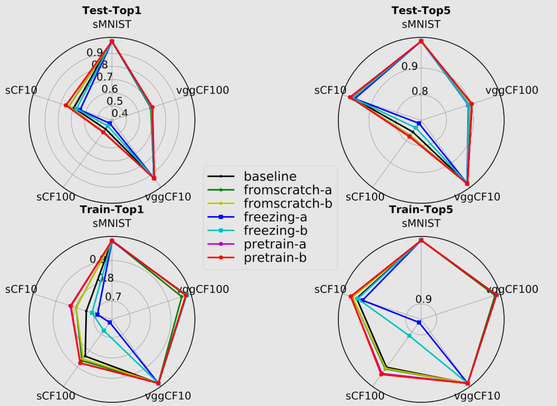
Results

GSDP - Signature Information Analysis

t-SNE visualization of VGG16 based features

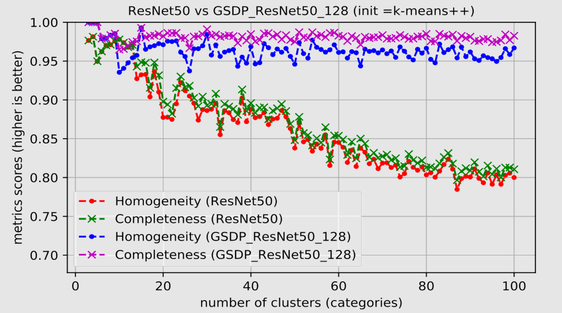
t-SNE visualization of ResNet50 based features

Prototype-based Semantic Classification (PS-Layer Performance Summary)



GSDP Performance Evaluation

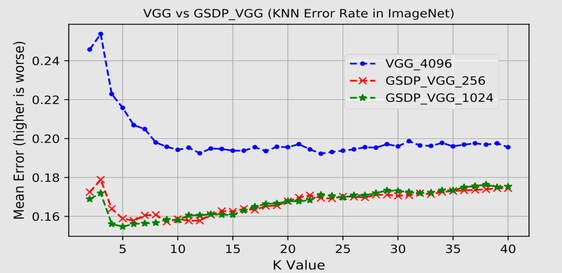
Cluster Metrics Score History [7] (ImageNet Dataset)



Cross-Dataset Cluster Metrics Score (Coco Dataset)

Descriptor	Size	FPS	Metrics Scores				
			H	C	V	ARI	AMI
Deep Features Performance on Coco [38](CrossDataset)							
ResNet50 [6]	2048	10.6	0.29	0.36	0.32	0.17	0.31
ResNet50_PCA_128	128	12.5	0.32	0.34	0.33	0.17	0.31
ResNet50_PCA_512	512	12.5	0.34	0.35	0.34	0.20	0.33
GSDP_RNet_128 (our)	128	9.6	**0.43**	**0.69**	**0.53**	**0.16**	**0.52**
GSDP_RNet_512 (our)	512	9	0.34	0.47	0.40	0.09	0.39

Classification Error Rate (ImageNet Dataset)



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Conclusion

In this Ph.D. dissertation we introduced and evaluated three models based on the foundations of Prototype Theory to propose semantic representations of object's categories and object's images:

i. A Computational Prototype Model (CPM),
ii. A novel Prototype-based Description Model (GSDP) and,
iii. A Prototype-based Classification Model (PS-Layer).

Experiments showed that our CPM model can capture the object's visual typicality and the central and peripheral meaning of objects' categories. Our novel GSDP representation introduces a new approach to the semantic description of object's images; and experiments in large image dataset shows that it is discriminative, small dimensioned and encodes the semantic information of category members. Our PS-Layer introduces the image typicality property in semantic category learning process and experiments conducted showed that it can outperform some CNN-Models architecture.

Our prototype-based description model proposes a starting point to introduce the theoretical foundation related *to the representation of semantic meaning and the learning of visual concepts* of the Prototype Theory in the CNN-Descriptors family.

Acknowledgment

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CAPES FAPEMIG
UFMG Universidade Federal de Minas Gerais
Programa de Pós-Graduação Ciência da Computação UFMG

References

Publications & Awards

- Part of this work was published in:
  - 2019 IEEE Winter Conference on Applications of Computer Vision (WACV 2019)[8].
- An extension journal paper is under review in the Transactions on Image Processing (TIP).
- The Ph.D. dissertation of this work was also selected to be presented at the WACV 2019 Doctoral Consortium.

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