What Helps Where – And Why? Semantic Relatedness for Knowledge Transfer

Marcus Rohrbach$^{1,2}$  Michael Stark$^{1,2}$  György Szarvas$^1$  Iryna Gurevych$^1$  Bernt Schiele$^{1,2}$

$^1$Department of Computer Science, TU Darmstadt  $^2$MPI Informatics, Saarbrücken
Knowledge transfer for zero-shot object class recognition

Unseen class
(no training images)

Giant panda?

Attributes for knowledge transfer

Describing using attributes
[Farhadi et al., CVPR `09 & `10]

• animal
• four legged
• mammal

Manual supervision:
Attribute labels

Group classes by attributes
[Lampert et al., CVPR `09]

white
paw

Manual supervision:
Object class-attribute associations

Knowledge transfer for zero-shot object class recognition

- Replace manual supervision by semantic relatedness mined from language resources

Attributes for knowledge transfer

- WordNet
- flickr
- Yahoo!
- Wikipedia

⇒ Unsupervised Transfer

Group classes by attributes

- [Lampert et al., CVPR `09]

Manual supervision:
Object class-attribute associations
Attribute-based model [Lampert et al., CVPR `09]

Known training classes

Class-attribute associations

Attributes classifiers

Class-attribute associations

Unseen test classes

Supervised: manual (human judges)
Attribute-based model [Lampert et al., CVPR `09]

Known training classes

Class-attribute associations

Attribute classifiers

Class-attribute associations

Unseen test classes

Supervised manual (human judges)

[Lampert et al., CVPR `09]
Direct similarity-based model

Known training classes

Class-attribute associations

Attribute classifiers
spots white ocean ...

Class-attribute associations

Unseen test classes

WordNet

Semantic relatedness from language
Direct similarity-based model

Known training classes

Classifier per class

Dalmatian  polar bear  killer whale

Unseen test classes

Class-attribute associations

semantic relatedness from language

WordNet

Direct similarity-based model

Known training classes

Classifier per class

Most similar classes

Unseen test classes

Figure:
- Known training classes: Dalmatian, polar bear, killer whale
- Unseen test classes: ... (more classes)
- Classifier per class:
  - Dalmatian
  - Polar bear
  - Killer whale

Semantic relatedness from language:
- WordNet
- Wikipedia
- Flickr

Legend:
- Direct similarity-based model
Outline

- Models for visual knowledge transfer
- **Semantic relatedness measures**
  - Language resources
    - WordNet
    - Wikipedia
    - WWW
    - Image search
  - Respective state-of-the-art measures
- Evaluation
- Conclusion
Semantic Relatedness Measures

- **WordNet**
- **Lin measure**
  [Budanitsky & Hirst, CL ’06]

![WordNet Diagram]

**WordNet**
[Fellbaum, MIT press ’98]

- entity
  - animal
    - mammal
      - horse
    - elephant
  - vehicle
    - car
    - bike
Semantic Relatedness Measures

- WordNet
- Lin measure  
[\(Budanitsky & Hirst, \text{CL `06}\)]

\[\text{WordNet} \]

\[\text{Lin measure} \]

\[\text{[Budanitsky & Hirst, CL `06]} \]

\[\text{Fellbaum, MIT press `98} \]

\[\text{entity} \]

\[\text{animal} \]

\[\text{mammal} \]

\[\text{vehicle} \]

\[\text{bike} \]
Semantic Relatedness Measures

- WordNet
- Lin measure
  [Budanitsky & Hirst, CL `06]
- Wikipedia
- Explicit Semantic Analysis
  [Gabrilovich & MarkovitchI, IJCAI `07]
Semantic Relatedness Measures

- WordNet
- Lin measure [Budanitsky & Hirst, CL '06]
- Wikipedia
- Explicit Semantic Analysis [Gabrilovich & Markovitchl, IJCAI '07]
Semantic Relatedness Measures

- WordNet
- Lin measure
  [Budanitsky & Hirst, CL '06]
- Wikipedia
- Explicit Semantic Analysis
  [Gabrilovich & Markovitch, IJCAI '07]
- Word Wide Web
- Hitcount (Dice coefficient)
  [Kilgarriff & Grefenstette, CL '03]
Semantic Relatedness Measures

- WordNet
- Lin measure  
  [Budanitsky & Hirst, CL `06]
- Wikipedia
- Explicit Semantic Analysis  
  [Gabrilovich & MarkovitchI, IJCAI `07]
- Word Wide Web
- Hitcount (Dice coeffient)  
  [Kilgarriff & Grefenstette, CL `03]
- Image search
- Visually more relevant
- Hitcount (Dice coeffient)

---

**web search**

*We watched a horse race yesterday. [..] Tomorrow we go in the zoo to look at the baby elephant.*

**image search**

*”the dance of the horse and elephant“*

Incidental co-occurence

Terms refer to same entity (the image)
Outline

- Models for visual knowledge transfer
- Semantic relatedness measures

**Evaluation**

- Attributes
  - Querying class-attribute associations
  - Mining attributes
- Direct similarity
- Attribute-based vs. direct similarity

**Conclusion**
Animals with attributes dataset
[Lampert et al., CVPR `09]
- 40 training, 10 test classes (disjoint)
- ≈ 30,000 images total
- Downsampled to 92 training images per class
- Manual associations to 85 attributes

Image classification
- SVM: Histogram intersection kernel
- Area under ROC curve (AUC) - chance level: 50%
- Mean over all 10 test classes
Performance of supervised approach

Manual supervision

Mean AUC
Querying class-attribute association

- Performance of queried association
  - Encouraging
  - Below manual supervision

Manual supervision: detailed description
“having a high degree of physical coordination”
Querying class-attribute association

- Performance of queried association
  - Encouraging
  - Below manual supervision
- Image search (Yahoo Img, Flickr)
  - Based on image related text
- Wikipedia
  - Robust resource (definition texts)

![image search](image)

the dance of the **horse** and **elephant**
Querying class-attribute association

- Performance of queried association
  - Encouraging
  - Below manual supervision
- Image search (Yahoo Img, Flickr)
  - Based on image related text
- Wikipedia
  - Robust resource (definition text)
- Yahoo Web
  - Very noisy resource

Noise:
While he watched a horse race the leg of his chair broke.
Querying class-attribute association

- Performance of queried association
  - Encouraging
  - Below manual supervision
- Image search (Yahoo Img, Flickr)
  - Based on image related text
- Wikipedia
  - Robust resource (definition text)
- Yahoo Web
  - Very noisy resource
- WordNet
  - Path length poor indicator of class-attribute associations
Mining attributes

Known training classes

Class-attribute associations

Attribute terms

Spots
White
Ocean
...

Class-attribute associations

Unseen test classes

semantic relatedness from language

WordNet

Mining attributes

Known training classes

Class-attribute associations

Attribute terms

Class-attribute associations

Unseen test classes

WordNet

semantic relatedness from language

Mining attributes

Known training classes

Attribute classifiers

Class-attribute associations

Word Net

Unseen test classes

Class-attribute associations
Mining attributes

- Additional measure: Holonym patterns
  - Only part attributes
  - Hit Counts of Patterns
    [Berland & Charniak, ACL 1999]
      - “cow’s leg”
      - “leg of a cow”
      - Dice coefficient

<table>
<thead>
<tr>
<th>web search</th>
<th>holonym patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>While he watched a horse race the leg of his chair broke.</td>
<td>Leg of the horse</td>
</tr>
</tbody>
</table>

Incidental co-occurrence

One term likely part of other term
Mining attributes

- Best: Yahoo Holonymys
  - Close to manual attributes
  - Tailored towards part attributes

Mean AUC

- fully supervised
- Yahoo Img
- Flickr Img
- Wikipedia
- Yahoo Web
- WordNet

Mining attributes

- **Best: Yahoo Holonymys**
  - Close to manual attributes
  - Tailored towards part attributes

- **Performance drop**
  - Reduced diversity
    - Only part attributes
  - Specialized terms
    - E.g. pilus (=hair)
  - Coverage problem:
    Image search, Wikipedia

---

<table>
<thead>
<tr>
<th></th>
<th>50%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>fully supervised</td>
<td>🟦</td>
<td>🟦</td>
</tr>
<tr>
<td>Yahoo Img</td>
<td>🟦</td>
<td>🟦</td>
</tr>
<tr>
<td>Flickr Img</td>
<td>🟦</td>
<td>🟦</td>
</tr>
<tr>
<td>Wikipedia</td>
<td>🟦</td>
<td>🟦</td>
</tr>
<tr>
<td>Yahoo Web</td>
<td>🟦</td>
<td>🟦</td>
</tr>
<tr>
<td>WordNet</td>
<td>🟦</td>
<td>🟦</td>
</tr>
<tr>
<td>Yahoo Holonymys</td>
<td>🟦</td>
<td>🟦</td>
</tr>
</tbody>
</table>

Mean AUC
- manual attributes
- mined attributes
Outline

- Models for visual knowledge transfer
- Semantic relatedness measures
- Evaluation
  - Attributes
    - Querying class-attribute associations
    - Mining attributes
  - Direct similarity
  - Attribute-based vs. direct similarity
- Conclusion
Direct similarity-based model

Known training classes

Classifier per class

Dalmatian  polar bear  killer whale

most similar classes

Unseen test classes

Semantic relatedness from language

WordNet

Unseen test classes

Direct Similarity

- Nearly all very good
  - On par with manual supervision attribute model (black)
  - Clearly better than any mined attribute-associations result

- Why?
  - Five most related classes
    - Ranking of semantic relatedness reliable
  - Similar between methods
Attributes vs. direct similarity

- Extending the test set
  - Add images
    - From known classes
    - As negatives
  - More realistic setting

- Results
  - Direct similarity drop in performance (orange curve)
  - Attribute models generalize well
Outline

- Models for visual knowledge transfer
- Semantic relatedness measures
- Evaluation

**Conclusion**
Conclusion

- Supervision replaced with **semantic relatedness**
  - Direct similarity
    - better than attributes
    - **on par with supervised approach**
Conclusion

- Supervision replaced with semantic relatedness
  - Direct similarity
    - better than attributes
    - on par with supervised approach
- Attributes: generalize better
Conclusion

- Supervision replaced with semantic relatedness
  - Direct similarity
    - better than attributes
    - on par with supervised approach

- Attributes: generalize better

- Semantic relatedness measures
  - Overall best
    - Yahoo image with hit count
    - Holonym patterns for web search
      - Improvement
      - Limited to part attributes
    - WordNet poor for object-attributes associations
Thank you!

Knowledge Transfer

Further supervision for closing the semantic gap? See us at our poster (A2, Atrium)!

Software?

www.mis.tu-darmstadt.de/nlp4vision