This Looks Like That: Deep Learning for Interpretable Image Recognition

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A new form of interpretability...
A new form of interpretability...
A new form of interpretability...
...with richer explanations

(a) Object attention (class activation map)  (b) Part attention (attention-based models)
...with richer explanations

(a) Object attention (class activation map)
(b) Part attention (attention-based models)
(c) Part attention + comparison with learned prototypical parts (our model)

Previous methods
ProtoPNet Architecture
ProtoPNet Architecture
ProtoPNet Architecture
ProtoPNet Architecture
ProtoPNet Architecture

Convolutional layers $f$

Prototype layer $g_p$

max pool

3.954

1.447

2.617

Similarity score
ProtoPNet Architecture
ProtoPNet as Scoring Sheets

<table>
<thead>
<tr>
<th>Original image (box showing part that looks like prototype)</th>
<th>Prototype</th>
<th>Training image where prototype comes from</th>
<th>Activation map</th>
<th>Similarity Score</th>
<th>Class</th>
<th>Points Connection Contributed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.499</td>
<td>1.180</td>
<td>7.669</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.392</td>
<td>1.127</td>
<td>4.950</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.890</td>
<td>1.108</td>
<td>4.310</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total points to red-bellied woodpecker: 32.736</td>
</tr>
</tbody>
</table>
Training Algorithm

Stage 1: stochastic gradient descent (SGD) of layers before last layer

\[
\min_{\mathbf{p}, \mathbf{w}_{\text{com}}} \frac{1}{n} \sum_{i=1}^{n} \text{CrsEnt}(h \circ g_p \circ f(x_i), y_i) + \lambda_1 \text{Clst} + \lambda_2 \text{Sep}, \quad \text{where}
\]

\[
\text{Clst} = \frac{1}{n} \sum_{i=1}^{n} \min_{j, \mathbf{p}_j \in \mathbf{P}_g, \mathbf{z} \in \text{patches}(f(x_i))} \| \mathbf{z} - \mathbf{p}_j \|_2^2; \quad \text{Sep} = -\frac{1}{n} \sum_{i=1}^{n} \min_{j, \mathbf{p}_j \in \mathbf{P}_g, \mathbf{z} \in \text{patches}(f(x_i))} \| \mathbf{z} - \mathbf{p}_j \|_2^2.
\]

Stage 2: projection of prototypes

\[
\mathbf{p}_j \leftarrow \arg \min_{\mathbf{z} \in \mathcal{Z}_j} \| \mathbf{z} - \mathbf{p}_j \|_2, \quad \text{where} \quad \mathcal{Z}_j = \{ \hat{\mathbf{z}} : \hat{\mathbf{z}} \in \text{patches}(f(x_i)) \forall i \text{ s.t. } y_i = k \}.
\]

Stage 3: Convex optimization of last layer

\[
\min_{\mathbf{w}_h} \frac{1}{n} \sum_{i=1}^{n} \text{CrsEnt}(h \circ g_p \circ f(x_i), y_i) + \lambda \sum_{k=1}^{K} \sum_{j, \mathbf{p}_j \notin \mathbf{P}_k} |w_h^{(k,j)}|.
\]
## Accuracy Comparison

<table>
<thead>
<tr>
<th>Model</th>
<th>VGG16</th>
<th>VGG19</th>
<th>Res34</th>
<th>Res152</th>
<th>Dense121</th>
<th>Dense161</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>76.1 ± 0.2</td>
<td>76.0 ± 0.2</td>
<td>79.2 ± 0.1</td>
<td>82.3 ± 0.3</td>
<td>80.2 ± 0.2</td>
<td>80.1 ± 0.3</td>
</tr>
<tr>
<td>ProtoPNet</td>
<td>74.6 ± 0.2</td>
<td>78.0 ± 0.2</td>
<td>82.3 ± 0.3</td>
<td>81.5 ± 0.4</td>
<td>82.2 ± 0.2</td>
<td>82.2 ± 0.2</td>
</tr>
</tbody>
</table>

### Interpretability

<table>
<thead>
<tr>
<th>Model</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td><strong>B-CNN</strong>: 85.1 (bb), 84.1 (full)</td>
</tr>
<tr>
<td>Object-level attn.</td>
<td><strong>CAM</strong>: 70.5 (bb), 63.0 (full)</td>
</tr>
<tr>
<td>Part-level attention</td>
<td><strong>Part R-CNN</strong>: 76.4 (bb+anno.), <strong>PS-CNN</strong>: 76.2 (bb+anno.), <strong>PN-CNN</strong>: 85.4 (bb+anno.), <strong>DeepLAC</strong>: 80.3 (anno.), <strong>SPDA-CNN</strong>: 85.1 (bb+anno.), <strong>PA-CNN</strong>: 82.8 (bb), <strong>MG-CNN</strong>: 83.0 (bb), 81.7 (full), <strong>ST-CNN</strong>: 84.1 (full), <strong>2-level attn.</strong>: 77.9 (full), <strong>FCAN</strong>: 82.0 (full), <strong>Neural const.</strong>: 81.0 (full), <strong>MA-CNN</strong>: 86.5 (full), <strong>RA-CNN</strong>: 85.3 (full)</td>
</tr>
<tr>
<td>Part-level attn. + prototypical cases</td>
<td><strong>ProtoPNet</strong> (ours): 80.8 (full, VGG19+Dense121+Dense161-based), 84.8 (bb, VGG19+ResNet34+DenseNet121-based)</td>
</tr>
</tbody>
</table>
Analysis of Latent Space

(a) nearest prototypes of two test images
left: original test image
right: top: three nearest prototypes of the image, with prototypical parts shown in box
below: test image with patch closest to each prototype shown in box

(b) nearest image patches to prototypes
left: prototype, with prototypical parts in box
middle: nearest training images to prototype, with patch closest to prototype in box
right: nearest test images to prototype, with patch closest to prototype in box
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