Using Explanations to Improve Ensembling of Visual Question Answering Systems

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Abstract
We present results on using explanations as auxiliary features to improve stacked ensembles for Visual Question Answering (VQA). VQA is a challenging task that requires systems to jointly reason about natural language and vision. We present results applying a recent ensembling approach to VQA, Stacking with Auxiliary Features (SWAF), which learns to combine the results of multiple systems. We propose using features based on explanations to improve SWAF. Using explanations we are able to improve ensembling of three recent VQA systems.

1 Introduction
In recent years, deep-learning has led to unprecedented breakthroughs in many avenues of Artificial Intelligence and most notably in computer vision. Even though the results produced by these deep networks have been groundbreaking, they lack transparency, making them hard to understand and interpret [Lipton, 2016]. Consequently, when such intelligent models that provide no explanation for their decisions fail, it becomes very difficult to do any root cause analysis. Transparency is also important in order to build human trust in systems. Recently, there has been some work by the deep learning community on generating explanations as a way to better understand and interpret the decisions made by deep neural networks [Hendricks et al., 2016; Goyal et al., 2016; Selvaraju et al., 2016].

Visual Question Answering (VQA) is a challenging task that requires systems to attend to regions of an image or question or both for producing an output. VQA addresses open-ended questions about images [Antol et al., 2015] and has attracted significant attention in the past year [Andreas et al., 2016; Goyal et al., 2016; Agrawal et al., 2016]. It requires visual and linguistic comprehension, language grounding as well as commonsense knowledge. A variety of methods to address these challenges have been developed in recent years [Fukui et al., 2016; Xu and Saenko, 2016; Lu et al., 2016; Chen et al., 2015]. The vision component of a typical VQA system extracts visual features using a deep convolutional neural network (CNN), and the linguistic component encodes the question into a semantic vector using a recurrent neural network (RNN). An answer is then generated conditioned on the visual features and the question vector. Some VQA models have an explicit attention component in the architecture [Fukui et al., 2016; Lu et al., 2016], whereas systems that use CNNs without attention [Antol et al., 2015], the gradient for the desired class is backpropagated through the convolutional feature maps to obtain a visualization of the focus regions in an image.

Explanation can be helpful in not just understanding and interpreting systems’ output but also leveraging systems for improving performance. For example, a system that generates an explanation that is not coherent with its output is not reliable. For VQA, explanation can be of two types – visual or textual. The regions in an image that a model attends to while generating an output can be considered a visual explanation. The words in the question that a model attends to while generating an output can be considered a visual explanation. The words in the question that a model attends to while generating an output can be considered a visual explanation. Most VQA systems use visual attention, however there are some that use both visual and textual attention while generating an output. The visual explanation is generally represented using heat-maps that use color intensities to highlight the regions in that image that a model attends to. In this paper, we use visual explanation for improving the accuracy of VQA systems.

Most VQA systems have a single underlying method that optimizes a specific loss function and do not leverage the advantage of using multiple diverse models. Ensembling
systems intelligently is crucial to optimizing overall performance. In this paper, we use Stacking with Auxiliary Features (SWAF) [Rajani and Mooney, 2017] to more effectively combine diverse VQA models. The key idea is that we trust systems’ agreement on an answer more if they also agree on its explanation. Traditional stacking [Wolpert, 1992] trains a supervised meta-classifier to appropriately combine multiple system outputs. SWAF further enables the stacker to exploit additional relevant knowledge of both the component systems and the problem by providing “auxiliary features” to the meta-classifier. Our key contribution is using visual explanations to create additional useful auxiliary features for SWAF applied to VQA. We demonstrate that ensembling three leading VQA systems using this approach outperforms a variety of baselines and ablations.

2 Background and Related Work

VQA is the task of answering a natural language question about the content of an image by returning an appropriate word or phrase. Figure 1 shows a sample of images and questions from the VQA 2016 challenge. The dataset consists of images taken from the MS COCO dataset [Lin et al., 2014] and three questions per image obtained through Mechanical Turk. Table 1 gives some statistics on the dataset.

<table>
<thead>
<tr>
<th></th>
<th>Images</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training</td>
<td>82,783</td>
<td>248,349</td>
</tr>
<tr>
<td>Validation</td>
<td>40,504</td>
<td>121,512</td>
</tr>
<tr>
<td>Test</td>
<td>81,43</td>
<td>244,302</td>
</tr>
</tbody>
</table>

Table 1: VQA dataset size

In stacking, a meta-classifier is learned to combine the outputs of multiple underlying systems. The stacker learns a classification boundary based on the confidence scores provided by individual systems for each possible output. Stacking With Auxiliary Features (SWAF) provides the meta-classifier additional information, such as features of the current problem and provenance information for the output from individual systems. We use visual explanation that provides information about regions in an image that are crucial for generating the output. This allows SWAF to learn which systems are reliable based on what regions of the image they attend to, on which types of problems and when to trust agreements between specific systems. It has previously been applied effectively to information extraction and entity linking [Viswanathan et al., 2015; Rajani and Mooney, 2016; 2017]. To the best of our knowledge, there has been no prior work on using explanation for improving ensembles. Figure 2 gives an overview of the SWAF approach.

We use SWAF to combine three diverse VQA systems such that the final ensemble performs better than any individual component model even on questions with low agreement. The three component models are trained on the VQA training set and the stacker is trained on the validation data.

![Figure 2: Ensemble Architecture using Stacking with Auxiliary Features. Given an input, the ensemble judges every possible question-answer pair produced by the component systems and determines the final output answer.](image)

2.1 Long Short Term Memory (LSTM)

The LSTM model is one of the original baseline models used to establish a benchmark for the VQA dataset [Antol et al., 2015]. It combines an LSTM [Hochreiter and Schmidhuber, 1997] for the question and a CNN for the image to generate an answer and uses one-hot encoding for the words in the question and the penultimate layer of the VGGNet [Simonyan and Zisserman, 2015] as image features fused together using element-wise multiplication. We note that this model does not have an explicit attention.

2.2 Multimodal Compact Bilinear pooling (MCB)

Traditionally, systems that combine vision and language vector representations use concatenation or element-wise product or sum. [Fukui et al., 2016] argue that such methods are not as effective as an outer product of the visual and textual vectors. To overcome the challenge of high dimensionality due to the outer product, the authors propose using Multimodal Compact Bilinear pooling (MCB) to efficiently and expressively combine multimodal features. The MCB model extracts representations for the image using the 152-layer Residual Network [He et al., 2015] and an LSTM embedding of the question. The two vectors are pooled using MCB and the answer is obtained by treating the problem as a multi-class classification problem with 3,000 possible answers.

2.3 Hierarchical Question-Image Co-Attention (HieCoAtt)

The idea behind the HieCoAtt model is that in addition to using visual attention to focus on where to look, it is equally important to model what words to attend to in the question (question attention) [Lu et al., 2016]. The model jointly reasons about the visual and language components using “co-attention.” Question attention is modeled using a hierarchical architecture including word, phrase, and question levels. HieCoAtt uses two types of co-attention – parallel and sequential at all three levels of the question hierarchy.
3 Auxiliary Features for SWAF

For stacking the VQA systems, we first form unique question-answer pairs across all outputs before passing them through the stacker. If a system generates a given I/O pair, then we use its probability estimate for that output, otherwise the confidence is considered zero. If a question-answer pair is classified as correct by the stacker, but there is also another answer that is classified correct for the same question, the pair with higher classifier confidence is chosen. For questions that did not have any answer classified as correct by the stacker, we choose the answer with lowest classifier confidence, which means it is least likely to be incorrect.

The confidence scores along with explanation as auxiliary features are used by the stacker, as shown in Figure 2, to classify each question-answer pair. The auxiliary features are the backbone of the SWAF approach, enabling the stacker to intelligently learn to rely on systems’ outputs conditioned on the supporting evidence. Along with explanation, we also use three other types of features that enable the stacker to get more context while making a decision.

3.1 Explanation

Recently, there has been work on analyzing regions of the image that VQA models focus on while answering the question [Goyal et al., 2016]. The authors concluded that deep learning models attend to relevant parts of the image while answering the question. The parts of images that the models focus on can be thought of as visual explanations for the question. We use these visual explanations to construct auxiliary features for SWAF.

The part of image to which the model attends can be visualized using a heat-map. Figure 3 shows an image and its heat-map for a given question. The idea is to trust the agreement between systems when they also agree on the heat-map explanation. The heat-map of a given system is compared to every other system’s heat-map using the rank correlation protocol described in [Das et al., 2016]. This generates $n$ choose 2 “explanation agreement” auxiliary features for SWAF. The idea behind using such features is that it enables the stacker to learn to rely on systems that “look” at the right region of the image when generating an answer.

We use the GradCAM algorithm [Goyal et al., 2016] to generate explanatory heat-maps for each answer. Given an image and category, the image is forward propagated through the CNN part of the model. The gradients are set to zero for all categories except the one under consideration, which is set to 1. This signal is then backpropagated to the convolutional feature maps of interest and is combined to compute the heat-map.

3.2 Question and Answer Types

[Antol et al., 2015] analyzed the VQA data and found that most questions fall into several types based on the first few words. For example, questions beginning with “What is...”, “Is there...”, “How many...”, or “Does the...”. Using the validation data, we discover such lexical patterns that define a set of question types. The questions were tokenized and a question type was formed by adding one token at a time, up to a maximum of 5, to the current substring. The question “What is the color of the vase?” has the following types “What”, “What is”, “What is the”, “What is the color”, “What is the color of”. The prefixes that contain at least 500 questions were then retained as types. We added a final type “other” for questions that do not fall into any of the predefined types, resulting in a total of 70 question types. A 70-bit vector is used to encode the question type as a set of auxiliary features.

The original analysis of VQA answers found that they are 38% “yes/no” and 12% numbers. There is clearly a pattern in the VQA answers as well and we use the questions to infer some of these patterns. We considered three answer types – “yes/no”, “number” and “other”. The answer-type auxiliary features are encoded using a one-hot vector. We classify all questions beginning with “Does”, “Is”, “Was”, “Are”, and “Has” as “yes/no”. Ones beginning with “How many”, “What time”, “What number” are assigned “number” type. These inferred answer types are not exhaustive but have good coverage.

3.3 Question Features

We also use a bag-of-words (BOW) representation of the question as auxiliary features. Words that occur at least five or more times in the validation set were included. The final sparse vector of dimension 3, 391 representing a question was normalized by the number of unique words in the question. [Goyal et al., 2016] showed that attending to specific words in the question is important in VQA. Including a BOW in the auxiliary features equips the stacker to efficiently learn which words are important to classifying answers.

3.4 Image Features

Along with the aforementioned features, we also use “deep visual features” of the image as additional auxiliary features. Specifically, we use the 4, 096 features from VGGNet’s fc7 layer [Simonyan and Zisserman, 2015]. Using such image features enables the stacker to learn to rely on systems that are good at identifying answers for particular types of images.
Table 2: Accuracy results on the VQA open-ended test-standard set (except for the explanation features)

<table>
<thead>
<tr>
<th>Method</th>
<th>All</th>
<th>Yes/No</th>
<th>Number</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voting (MCB + HieCoAtt + LSTM)</td>
<td>60.31</td>
<td>80.22</td>
<td>34.92</td>
<td>48.83</td>
</tr>
<tr>
<td>iBOWIMG [Zhou et al., 2015]</td>
<td>55.72</td>
<td>76.55</td>
<td>35.03</td>
<td>42.62</td>
</tr>
<tr>
<td>DPPNet [Noh et al., 2016]</td>
<td>57.36</td>
<td>80.28</td>
<td>36.92</td>
<td>42.24</td>
</tr>
<tr>
<td>LSTM [Antol et al., 2015]</td>
<td>58.20</td>
<td>80.60</td>
<td>36.50</td>
<td>43.70</td>
</tr>
<tr>
<td>HieCoAtt [Lu et al., 2016]</td>
<td>61.80</td>
<td>79.70</td>
<td>38.70</td>
<td>51.70</td>
</tr>
<tr>
<td>MCB [Fukui et al., 2016]</td>
<td>62.56</td>
<td>80.68</td>
<td>35.59</td>
<td>52.93</td>
</tr>
<tr>
<td>Stacking</td>
<td>62.59</td>
<td>81.79</td>
<td>34.58</td>
<td>51.72</td>
</tr>
<tr>
<td>+ Q/A types</td>
<td>62.73</td>
<td>82.09</td>
<td>35.47</td>
<td>52.10</td>
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<tr>
<td>+ Question Features</td>
<td>63.12</td>
<td>81.61</td>
<td>36.07</td>
<td>53.77</td>
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<tr>
<td>+ Image Features</td>
<td>65.44</td>
<td>82.08</td>
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<td>57.15</td>
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<tr>
<td>+ Explanation*</td>
<td>65.54</td>
<td>82.28</td>
<td>38.63</td>
<td>57.32</td>
</tr>
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Table 4: Accuracy results on the VQA open-ended test-dev set

<table>
<thead>
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