Synthetic data for Visual Question Answering

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NLIP Seminar
18th May 2018
Overview

1. Visual Question Answering
2. Problems with the VQA Dataset
3. ShapeWorld
4. Other synthetic datasets
5. Experiments
Visual Question Answering
The VQA Dataset

Where is this cat laying?
Is the cat awake?
What color is the cat?

Is the cat facing the computer?
Is the cat typing?
Is the cat playing with the mouse?

What object is shining on the animal?
What objects is the cat sitting behind?
How many cats?

How many items are on the bookcase?
Are these two children related?
Is the dog begging for food?

Statistics: 205k MSCOCO images, 50k abstract scenes, 3 questions per image

Images: http://visualqa.org/browser/
Visual Question Answering

Motivation

- Multimodal grounded language task
- Generalisation of object recognition
- More specific and clearer evaluation than image captioning
- ‘Visual formal semantics’ in a natural setup
- Covers a wide variety of linguistic phenomena

Visual Turing Test?
Visual Question Answering

Basic CNN-LSTM model

Image: https://arxiv.org/abs/1505.00468
Visual Question Answering

Performance over time

Performance on the VQA Dataset v1.0

- Models
- LSTM-Q
- Human-Q-real
- Human-Q+I-real
Problems with the VQA Dataset

Examples revisited

Where is this cat laying?
Is the cat awake?
What color is the cat?

Is the cat facing the computer?
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Images: http://visualqa.org/browser/
Problems with the VQA Dataset

Crowd-sourced real-world datasets

- Natural or repurposed?
- ‘Zipfian’ tendency to simplicity
- Unintended biases/correlations
- Adversarial examples

Problems with the VQA Dataset

Remedies

**Improvements of the VQA Dataset**

- Making the V in VQA Matter: Elevating the Role of Image Understanding in Visual Question Answering (Goyal et al.)
- C-VQA: A Compositional Split of the Visual Question Answering (VQA) v1.0 Dataset (Agrawal et al.)

**Modification of existing datasets**

- Focused Evaluation for Image Description with Binary Forced-Choice Tasks (Hodosh & Hockenmaier)
- FOIL it! Find One mismatch between Image and Language caption (Shekhar et al.)
Problems with the VQA Dataset

Our proposal

▷ No single general evaluation benchmark, but investigation tailored to the model

▷ Dissimilar train/test distributions, requiring compositional generalisation

▷ Clean data with clear image/text relationship, instead of uncontrolled content

⇒ Synthetic data as targeted ‘unit-testing’ evaluation step, complementing general real-world benchmark datasets
ShapeWorld

Examples: Relations and quantifiers

- A magenta square is to the right of a green shape.
- A yellow shape is not in front of a square.
- A circle is farther from an ellipse than a gray cross.
- A cross is not the same color as a green rectangle.
- The lowermost green shape is a cross.
- A red shape is the same shape as a green shape.

- Less than one triangle is cyan.
- At least half the triangles are red.
- More than a third of the shapes are cyan squares.
- Exactly all the five squares are red.
- More than one of the seven cyan shapes is a square.
- Twice as many red shapes as yellow shapes are circles.
ShapeWorld
System overview

Sampled world model

{ size: 64, color: { name: black, shade: 0.0 }, noise-range: 0.1, entities:
  [ { shape: { name: cross, extent: { x: 0.10, y: 0.10 } }, rotation: 0.06, color: { name: yellow, shade: -0.24 }, center: { x: 0.47, y: 0.28 } },
    { shape: { name: cross, extent: { x: 0.08, y: 0.08 } }, rotation: 0.76, color: { name: red, shade: 0.26 }, center: { x: 0.49, y: 0.65 } },
    { shape: { name: pentagon, extent: { x: 0.09, y: 0.08 } }, rotation: 0.27, color: { name: yellow, shade: -0.16 }, center: { x: 0.15, y: 0.91 } },
    { shape: { name: circle, extent: { x: 0.12, y: 0.12 } }, rotation: 0.53, color: { name: red, shade: -0.12 }, center: { x: 0.80, y: 0.37 } },
    { shape: { name: cross, extent: { x: 0.09, y: 0.09 } }, rotation: 0.73, color: { name: yellow, shade: -0.42 }, center: { x: 0.92, y: 0.73 } } ] }

Linguistic representation

There is a blue circle.
Most crosses are yellow.
A pentagon is below a cross.

Agreement?
ShapeWorld
Language generation

Diagram:
- **World model**
  - **JSON spec**
    - `[attr]::blue_a_sw e? =1=> [type]:node`
  - **DMRS snippets**
  - **DMRS graph**
    - **convert (+ post-processing)**
      - **MRS structure**
        - **generate**
          - **Surface string**
            - "There is a blue shape."
- **Captioner**
  - **sample**
  - **Caption objects**
    - **map**
  - **RegularTypeCaptioner**
    - ** ARG1/EQ **
      - `_blue_a_sw` `predsort(?)`
"A pentagon is above a green ellipse, and no blue shape is an ellipse."

↑ ERG + ACE realization ↑

↑ Internal DMRS mapping ↑

<table>
<thead>
<tr>
<th>a</th>
<th>a.shape=pg</th>
<th>a.y&gt;b.y</th>
<th>bcolor=gr</th>
<th>b.shape=el</th>
<th>∧</th>
<th>¬∃c</th>
<th>c.color=bl</th>
<th>true</th>
<th>c=d</th>
<th>∃d</th>
<th>d.shape=el</th>
</tr>
</thead>
<tbody>
<tr>
<td>a:</td>
<td>a.shape=pg</td>
<td>a.y&gt;b.y</td>
<td>b: color=gr ∧ b.shape=el</td>
<td>∧</td>
<td>¬∃c: c.color=bl</td>
<td>c=d</td>
<td>∃d: d.shape=el</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>a:</td>
<td>a.shape=pg ∧ [∃b: b.color=gr ∧ b.shape=el ∧ a.y&gt;b.y]</td>
<td>∧</td>
<td>¬∃c: c.color=bl ∧ [∃d: d.shape=el ∧ c=d]</td>
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</tr>
<tr>
<td>(a:</td>
<td>a.shape=pg ∧ [∃b: b.color=gr ∧ b.shape=el ∧ a.y&gt;b.y]) ∧ (¬∃c: c.color=bl ∧ [∃d: d.shape=el ∧ c=d])</td>
<td></td>
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</tr>
</tbody>
</table>

ShapeWorld
Compositionality
ShapeWorld
Design choices

- Caption is extracted from image, i.e. world model
- Incorrect caption via minimal modification of correct one
- Three agreement values to avoid ambiguous cases
- Initialize generator/captioner values before sampling
- Various tautology/contradiction checks
Other synthetic datasets
Comparison to other VQA datasets

**CLEVR**
(Compositional Language and Elementary Visual Reasoning)

**NLVR**
(Natural Language Visual Reasoning)

**SHAPES**

**Sort-of-CLEVR**

**COG**
(“visual reasoning in time, in parallel with human cognitive experiments”)

Other synthetic datasets
Artificial text-only datasets

**bAbI Tasks**

**Task 13: Compound Coreference**
1. Daniel and Sandra journeyed to the office.
2. Then they went to the garden.
3. Sandra and John travelled to the kitchen.
4. After that they moved to the hallway.

Q: *Where is Daniel?*
⇒ garden

**FraCaS Test Suite**

**Monotonicity (upwards on second argument)**
1. Every European has the right to live in Europe.
2. Every European is a person.
3. Every person who has the right to live in Europe can travel freely within Europe.

Q: *Can every European travel freely within Europe?*
⇒ yes

Other synthetic datasets

Performance on CLEVR
Other synthetic datasets
CLEVR-inspired systems

Seq2Seq Module Network

FiLM Model
(Feature-wise Linear Modulation)

Images: https://arxiv.org/abs/1705.03633,
https://arxiv.org/abs/1709.07871
# Experiments

## Early experimental results

<table>
<thead>
<tr>
<th>Dataset configuration</th>
<th>LSTM-only</th>
<th>CNN-LSTM</th>
<th>HCA-par</th>
<th>HCA-alt</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OneShape</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C: no hypernyms</td>
<td>90 / 70 / 100</td>
<td>95 / 64 / 57</td>
<td>98 / 71 / 73</td>
<td>97 / 68 / 66</td>
</tr>
<tr>
<td>C: only hypernyms</td>
<td>100 / 100 / 100</td>
<td>52 / 34 / 30</td>
<td>96 / 78 / 82</td>
<td>95 / 75 / 73</td>
</tr>
<tr>
<td>I: changed shape</td>
<td>6 / 5 / 7</td>
<td>70 / 81 / 82</td>
<td>60 / 63 / 58</td>
<td>73 / 78 / 78</td>
</tr>
<tr>
<td>I: changed color</td>
<td>8 / 15 / 0</td>
<td>100 / 100 / 99</td>
<td>100 / 92 / 96</td>
<td>100 / 97 / 89</td>
</tr>
<tr>
<td>I: changed both</td>
<td>7 / 5 / 6</td>
<td>96 / 97 / 98</td>
<td>87 / 85 / 84</td>
<td>93 / 92 / 89</td>
</tr>
<tr>
<td><strong>MultiShape</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>correct instances</td>
<td>48 / 49 / 50</td>
<td>76 / 64 / 54</td>
<td>81 / 68 / 65</td>
<td>71 / 59 / 53</td>
</tr>
<tr>
<td>I: random attr.</td>
<td>58 / 63 / 68</td>
<td>67 / 74 / 79</td>
<td>64 / 67 / 68</td>
<td>70 / 73 / 78</td>
</tr>
<tr>
<td>I: random existing attr.</td>
<td>100 / 100 / 100</td>
<td>78 / 86 / 95</td>
<td>55 / 71 / 79</td>
<td>72 / 87 / 95</td>
</tr>
<tr>
<td><strong>Spatial</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C: no hypernyms</td>
<td>85 / 85 / 69</td>
<td>45 / 44 / 41</td>
<td>83 / 83 / 86</td>
<td>92 / 62 / 100</td>
</tr>
<tr>
<td>C: only hypernyms</td>
<td>95 / 95 / 97</td>
<td>4 / 6 / 4</td>
<td>60 / 59 / 65</td>
<td>49 / 40 / 52</td>
</tr>
<tr>
<td>I: swapped direction</td>
<td>11 / 13 / 16</td>
<td>98 / 97 / 98</td>
<td>36 / 39 / 30</td>
<td>50 / 61 / 47</td>
</tr>
<tr>
<td>I: object random attr.</td>
<td>15 / 12 / 16</td>
<td>88 / 88 / 91</td>
<td>69 / 68 / 68</td>
<td>63 / 66 / 60</td>
</tr>
<tr>
<td>I: subject random attr.</td>
<td>13 / 12 / 17</td>
<td>87 / 88 / 89</td>
<td>69 / 71 / 70</td>
<td>61 / 64 / 56</td>
</tr>
<tr>
<td><strong>Quantification</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>correct instances</td>
<td>23 / 22 / 18</td>
<td>25 / 30 / 26</td>
<td>74 / 71 / 72</td>
<td>70 / 71 / 75</td>
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<tr>
<td>incorrect instances</td>
<td>94 / 93 / 93</td>
<td>88 / 90 / 88</td>
<td>81 / 83 / 88</td>
<td>78 / 82 / 82</td>
</tr>
<tr>
<td>instances with “no”</td>
<td>52 / 51 / 48</td>
<td>61 / 60 / 61</td>
<td>56 / 56 / 51</td>
<td>55 / 55 / 58</td>
</tr>
<tr>
<td>instances with “the” (=1)</td>
<td>53 / 58 / 61</td>
<td>55 / 59 / 58</td>
<td>59 / 59 / 55</td>
<td>63 / 63 / 63</td>
</tr>
<tr>
<td>instances with “a” (≥1)</td>
<td>34 / 35 / 36</td>
<td>34 / 36 / 37</td>
<td>49 / 50 / 51</td>
<td>48 / 52 / 50</td>
</tr>
<tr>
<td>instances with “two” (≥2)</td>
<td>53 / 48 / 48</td>
<td>50 / 50 / 49</td>
<td>70 / 69 / 62</td>
<td>72 / 67 / 58</td>
</tr>
<tr>
<td>instances with “most”</td>
<td>49 / 50 / 49</td>
<td>48 / 48 / 49</td>
<td>69 / 68 / 60</td>
<td>60 / 52 / 51</td>
</tr>
<tr>
<td>instances with “all”</td>
<td>52 / 54 / 50</td>
<td>48 / 50 / 51</td>
<td>47 / 52 / 51</td>
<td>49 / 50 / 51</td>
</tr>
</tbody>
</table>
Experiments
The meaning of “most” (Pietroski et al., 2009)

Cardinality-based mechanism

\[ \text{most}(A, B) \iff |S_A \cap S_B| > \frac{1}{2}|A| \iff |S_A \cap S_B| > |S_A - S_B| \]

Pairing-based mechanism

\[ \text{most}(A, B) \iff \exists S: S \subset B \text{ and OneToOne}(A, S) \]

Images: https://doi.org/10.1111/j.1468-0017.2009.01374.x
Experiments
Replication with ShapeWorld data

Random  Paired  Partitioned

+ “More/less than half the shapes are X.”
Conclusion

Synthetic data...

- can be generated in arbitrary quantities
- avoids biases found in real-world data
- provides challenging test data
- can be tailored to the evaluation goals
- is configurable, flexible and reusable
- makes unit-testing deep learning models possible
Thank you for your attention!

Questions?