Adapting to Continuously Shifting Domains

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Background: Domain Adaptation

• Adapting from one single source to one single target is limiting
• Incremental adaptation alone cannot recover good performance on past domains
• Goal: adapt between continuously shifting domains, while avoiding catastrophic forgetting

Standard domain adaptation

• Source domain $S$, with images $X_S$ and labels $Y_S$ drawn from $p_S(x,y)$
• Target domain $T$, with images $X_T$ unlabeled drawn from $p_T(x,y)$
• Source domain is similar to the target domain at time $t_0$
• Target domain is smoothly varying
• $p_{t_0}$ is more similar to $p_S$ than $p_{t_1}$ is to $p_S$

Solution: incrementally adapt to new domains with a replay loss to maintain performance on past domains

Continuous Unsupervised Adaptation

Continuous domain adaptation

• Source domain $S$, with images $X_S$ and labels $Y_S$ drawn from $p_S(x,y)$
• Target domains $T_t$, with images $X_{T_t}$ unlabeled drawn from $p_{T_t}(x,y)$
• Source domain is similar to the target domain at time $t_0$
• Target domain is smoothly varying
• $p_{t_0}$ is more similar to $p_S$ than $p_{t_1}$ is to $p_S$

Problem Statement

• Adapting from one single source to one single target is limiting
• Incremental adaptation alone cannot recover good performance on past domains
• Goal: adapt between continuously shifting domains, while avoiding catastrophic forgetting

CUA Framework

Iterative adaptation with subsampling

• Initialize $M$ like in the standard domain adaptation setting
• Subsample $\alpha$-fraction dataset $(X_p, Y_p)$ at every stage
• Optimize the sequential unsupervised adaptation update while matching sampled past data with the replay loss

$M \leftarrow M_{t-1}; (X_p, Y_p) \leftarrow \text{subsample}(X_p, Y_p, \alpha)$

$M_2 \leftarrow \arg\min_M d(M_2(X_S), M_1(T_1))$

MNIST Results

• 60000 training images of handwritten digits, 10000 test images
• Continuous shift represented by 45° rotations
• Source domain 0°, Target domains every 45° after

<table>
<thead>
<tr>
<th>Method</th>
<th>0°</th>
<th>45°</th>
<th>90°</th>
<th>135°</th>
<th>180°</th>
<th>225°</th>
<th>270°</th>
<th>315°</th>
<th>Average (%)</th>
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</thead>
<tbody>
<tr>
<td>Source</td>
<td>99.2</td>
<td>61.7</td>
<td>17.2</td>
<td>29.1</td>
<td>39.4</td>
<td>29.8</td>
<td>15.8</td>
<td>51.7</td>
<td>53.0 ± 0.8</td>
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<tr>
<td>ADDA</td>
<td>80.8</td>
<td>70.4</td>
<td>20.8</td>
<td>28.6</td>
<td>42.1</td>
<td>40.3</td>
<td>23.8</td>
<td>41.2</td>
<td>43.5 ± 1.2</td>
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<tr>
<td>DANN</td>
<td>96.6</td>
<td>64.7</td>
<td>19.9</td>
<td>28.4</td>
<td>41.4</td>
<td>32.9</td>
<td>24.2</td>
<td>67.3</td>
<td>47.2 ± 1.6</td>
</tr>
<tr>
<td>CUA (ours)</td>
<td>51.6</td>
<td>15.1</td>
<td>32.7</td>
<td>38.7</td>
<td>30.4</td>
<td>27.1</td>
<td>73.6</td>
<td>96.0</td>
<td>45.7 ± 1.4</td>
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<tr>
<td>CUA (Ours)</td>
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<td>82.0</td>
<td>77.3</td>
<td>85.8</td>
<td>88.2</td>
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<td>96.5</td>
<td>90.4 ± 1.6</td>
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<tr>
<td>Target Supervised (Oracle)</td>
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<td>96.7</td>
<td>96.8</td>
<td>97.4</td>
<td>96.6</td>
<td>96.5</td>
<td>96.8</td>
<td>96.4</td>
<td>97.0</td>
</tr>
</tbody>
</table>

Atari Results

• Atari game pong with base model ACKTR
• Continuous shift represented by color inversion $\Theta \in [0,1]$, where every pixel $x_{orig}$ is inverted into $x_{inv}$

$\Theta = (1 - \theta) \times x_{orig} + \theta \times (1 - x_{orig})$

Inversion factor $\Theta$

<table>
<thead>
<tr>
<th>Method</th>
<th>0.0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
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<tbody>
<tr>
<td>Source only</td>
<td>21.0</td>
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<td>2.28</td>
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<tr>
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<td>21.0</td>
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<tr>
<td>CUA (Ours)</td>
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<td>21.0</td>
<td>21.0</td>
<td>21.0</td>
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<tr>
<td>Target with reward</td>
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<td>21.0</td>
<td>21.0</td>
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