Comparison of deep learning and handcrafted features for mining simulation data

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Introduction

Computational Fluid Dynamics (CFD) Simulations:

- Heavily used in engineering design
- Complex and large outputs (flow fields)
- Hard to interpret manually

Approach:

- Construct large scale CFD dataset
- Train CNN on 2D flow fields
- Compare deep learning with hand crafted feature approaches
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CFD Simulations/Dataset
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**CFD Simulations/Dataset**

- Velocity Vector Field ($\vec{U}$)
- Pressure Field ($p$)
- Turbulent Viscosity ($\nu_t$)
- ~ 16K Simulations of air flow around randomly deformed airfoils
- Predict drag and lift forces applied on the shape
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Hand Crafted Features (RMSE)

- Tested a number of detectors and descriptors
- Tested two approaches of combining different modalities (Single & Multiple dictionaries) - (SD & MD)
- Tested dense sampling with best performing descriptors
- Regression is done with a Random Forest (RF)
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**Hand Crafted Features (RMSE)**

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- Dense sampling outperforms all detectors tested
- ORB & SIFT best performing descriptors
- SIFT slightly outperforms ORB descriptor
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Deep learning approaches

- one network for all velocity component (VC)
- one network for each velocity component (DS)
- vector field kernels and activations (RotEqNet)
- Train Random forests with VC activations (VC-RF)
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### Comparison

<table>
<thead>
<tr>
<th>Approach</th>
<th>Drag (*1e-3)</th>
<th>Lift (*1e-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE-SIFT-MD</td>
<td>6.28</td>
<td>2.33</td>
</tr>
<tr>
<td>VC</td>
<td>5.32</td>
<td>2.18</td>
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<tr>
<td>VC-RF</td>
<td><strong>2.83</strong></td>
<td><strong>0.92</strong></td>
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<table>
<thead>
<tr>
<th>Approach</th>
<th>Drag</th>
<th>Lift</th>
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<tbody>
<tr>
<td>DE-SIFT-MD</td>
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<td>VC</td>
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<td>VC-RF</td>
<td><strong>0.981</strong></td>
<td><strong>0.994</strong></td>
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Per test example lift absolute error

![Graph showing comparison of deep learning and handcrafted features](chart.png)
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**Varying training set size**

<table>
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<th>train set size</th>
<th>1K</th>
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<th>4K</th>
<th>8K</th>
<th>14K</th>
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<tr>
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<td><strong>Lift regression</strong></td>
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<tr>
<td>DE-SIFT-MD</td>
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<td>6.16</td>
<td>5.19</td>
<td>2.33</td>
</tr>
</tbody>
</table>
Conclusions

- Construct big scale CFD simulation dataset
- Compare deep learning and hand crafted based approaches
- In terms of RMSE, deep learning approaches outperform hand crafted based approaches, but not in terms of $R^2$
- Combination of VC and RF has the best performance (RMSE & $R^2$)
- As the train set size reduces, deep learning approaches manage to better maintain their performance over the hand crafted feature based approaches
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Thank you!