Subcortical brain structure segmentation using FCNNs

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Diseases and their relation to subcortical structures

**Alzheimer's:** structure degeneration

**Schizophrenia:** volume abnormalities
[Shenton M.E. et al., Psychiatry Res. 2002]

**Tumors:** avoid radiation on sensitive regions
[Hoehn D. et al., Journal of Medical Cases, 2012]
3D Segmentation

Our results

Groundtruth
Why automatic segmentation?

Visualization and inspection

No need for manual annotation
(time consuming, need experts, limited reproducibility)

Non-invasive diagnosis and treatment
Segmentation using MRI

- Intensity is not enough
- Spatial arrangement patterns

white matter?
thalamus?
Goal

- Classify *every pixel* as one of $L$ possible structures.
- Exploit context.
- Enforce volumetric homogeneity.

*Fully convolutional neural networks (FCNNs) + Graphical models (MRFs)*
Semantic segmentation of MRI slices

2D slice $\xrightarrow{\text{FCNN}^{[1]}}$ Softmax

$P(\text{thalamus})$

$P(\text{putamen})$

$P(\text{caudate})$

$P(\text{white matter})$

Segmentation

[1] Long et al., CVPR 2015
Our CNN architecture

- 16 layers including max-pooling and dropout.
- Compact architecture (~4GB GPU RAM).
MRF for volume homogeneity

\[ S^* = \arg \min_E(S) = \sum_{i \in V} V_i(l_i) + \lambda \sum_{(i,j) \in E} V_{ij}(l_i, l_j) \]

\[ f(P_i^{\text{CNN}}(l_i)) \]

\[ d(I_i, I_j)[l_i \neq l_j] \]
Experiments

- Two datasets:
  - Internet Brain Segmentation Repository (IBSR).
  - Roland Epilepsy (RE).
- Train CNN on 2D slices from *axial* view.
- Data augmentation: ~100K training images.
Results (Dice coefficient)

Dice: 1 = perfect overlap with ground truth.

Average Dice (IBSR)

- Thalamus: 0.87
- Putamen: 0.83
- Caudate: 0.78
- Pallidum: 0.75
## Comparison with other methods

<table>
<thead>
<tr>
<th></th>
<th>Freesurfer(^1)</th>
<th>FSL(^2)</th>
<th>Ours</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBSR - Thalamus</td>
<td>0.86</td>
<td>0.85</td>
<td><strong>0.87</strong></td>
</tr>
<tr>
<td>IBSR - Caudate</td>
<td><strong>0.82</strong></td>
<td>0.68</td>
<td>0.78</td>
</tr>
<tr>
<td>IBSR - Putamen</td>
<td>0.81</td>
<td>0.81</td>
<td><strong>0.83</strong></td>
</tr>
<tr>
<td>IBSR - Pallidum</td>
<td>0.71</td>
<td>0.73</td>
<td><strong>0.75</strong></td>
</tr>
<tr>
<td>RE - Putamen</td>
<td>0.74</td>
<td>0.88</td>
<td><strong>0.89</strong></td>
</tr>
<tr>
<td>Running time (1 vol.)</td>
<td>~hours</td>
<td>~minutes</td>
<td>~1 minute</td>
</tr>
</tbody>
</table>

\(^1\) Fischl et al., Neuron 2002.
\(^2\) Patenaude et al., NeuroImage 2011.
The type of unaries matters

Dice coefficient (IBSR dataset)

1. Thalamus left
2. Caudate left
3. Putamen left
4. Pallidum left
5. Thalamus right
6. Caudate right
7. Putamen right
8. Pallidum right

- Random forest unaries
- CNN unaries
The type of unaries matters

Dice coefficient (RE dataset)

- Putamen L.
- Putamen R.

Random forest unaries

CNN unaries
MRF removes spurious responses

CNN

CNN+MRF
Limitations and future directions

Small structures are challenging

1-2 pixels wide

Left hemisphere  Right hemisphere

Does not work for sagittal view because of symmetry

3D CNNs
Summary

- **FCNNs + MRFs:**
  - accurate, *dense* labelling using 2D image data.
  - volumetric homogeneity
- Efficient segmentation of 3D volumes: (~1 min)
- No need for expensive GPUs (~4GB GPU RAM)

Code, **CNN probability maps:**
[https://github.com/tsogkas/brainseg](https://github.com/tsogkas/brainseg)
IBSR dataset: Hausdorff distance

1. Thalamus left
2. Caudate left
3. Putamen left
4. Pallidum left
5. Thalamus right
6. Caudate right
7. Putamen right
8. Pallidum right
IBSR dataset: contour mean distance

1. Thalamus left
2. Caudate left
3. Putamen left
4. Pallidum left
5. Thalamus right
6. Caudate right
7. Putamen right
8. Pallidum right

Random forest unaries
CNN unaries
RE dataset: HD and CMD

Hausdorff distance

Contour mean distance

Putamen L.                    Putamen R.
CNN unaries

Random forest unaries

CNN unaries