Can geodesic information help convolutional neural networks?

Application to the segmentation of Fontana Masson histological images of pigmented reconstructed epidermis
Introduction

- State-of-the-art for most segmentation applications: deep learning, especially convolutional neural networks (CNNs)
- However: these networks only use local information to classify pixels
- What about global information, such as topology?
Contents

- Context and objectives
- Database
- Methods
  - using conventional CNNs
  - injecting topological information:
    - topological map
    - morphological reconstruction
- Results
- Conclusion and integration
Context and objectives
Skin Imaging and Characterization

- **Histological images:**
  - Fontana Masson staining
  - Pigmented reconstructed epidermis

- **Objectives:**
  - **1: Skin morphology:**
    - 3 limits to be detected:
      - Surface
      - *SC-LED* junction
      - Basal layer (or DEJ)
  - **2: Skin pigmentation:**
    - Melanin detection:
      - Dark pixels
Database
Database

- 117 images of Fontana Masson stained pigmented reconstructed epidermis histological samples
  - variable sizes, around 4000 x 3000 pixels
- Resolution: 0.45 µm / pixel
- All images coming from the same slide go to the same database

<table>
<thead>
<tr>
<th>Database</th>
<th>Train / Validation</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>117 images</td>
<td>94 images</td>
<td>23 images</td>
</tr>
<tr>
<td>100%</td>
<td>80%</td>
<td>20%</td>
</tr>
</tbody>
</table>
Generation of ground truth images

- The ground truth has been obtained by an automatic method developed by the ADCIS company, whose results were manually edited and modified by L’Oréal experts, when needed
Image example with ground-truth
Image example with ground-truth
Methods

Conventional CNNs
Train and validation

- Build 512x512 crops from train and validation database
- Only keep crops containing at least some *stratum corneum* or living epidermis → 1458 crops
- 80% are used for training; 20% for validation
- Labels coded as 3 separate binary channels
  - 1: background
  - 2: *stratum corneum*
  - 3: living epidermis
Using neural networks – main choices

- We consider only fully CNNs
- Jaccard-based loss:

\[ J(X,Y) = 1 - \frac{XY + \varepsilon}{X^2 + Y^2 - XY + \varepsilon} \]

- Network’s output: 3 channels. Segmentation obtained by assigning to each pixel the label corresponding to the highest value among the 3 channels
Chosen architecture: U-Net

We used 16 instead of 64

Receptive field: 92 pixel radius

[From Ronneberger et al., 2015]
UNet's receptive field (185 x 185 pixels)
Comments

- Validation loss: **0.060**
- The frontiers between *stratum corneum* and living epidermis and between living epidermis and background are correctly segmented
- The definition of the frontier between *stratum corneum* and background causes difficulties
- How can the CNN use topology information?
Methods

Method 1: Adding a topological map
Adding topology information

- Add an extra input layer containing the connected components of the background that touch the top and bottom of the image
- Empirically selected threshold to define the background: 220 (condition on the three color channels)
Comments: topological mask method

- The network now uses global information
- Validation loss: **0.027** (was 0.060 with standard method)
- The extra added channel requires more memory, and the threshold value has to be manually chosen
Methods

Method 2: Adding a Morphological Reconstruction
Using a morphological reconstruction

- Reconstruction by dilation from top and bottom borders: fills background tissue holes (and erases some light textures)
- Mean between result and original image: recovers erased textures
Comments: reconstruction

- The network uses global information
- Validation loss: **0.027** (same as before)
- We do not need an extra input channel
Results
Application to test database

- Purely convolutional neural network ➔ we can apply it directly to a whole image (provided its dimensions are multiples of $2^n$)
Post-processing

- For *stratum corneum* and living epidermis: keep the largest connected component
- For background: keep the components that touch the image top and bottom
- Interpolation: closest component
  - implemented using a watershed from markers
Post-processing illustration
Post-processing (topology map)

Without post-processing

With post-processing
Post-processing (reconstruction method)

Without post-processing

With post-processing
### Accuracy

<table>
<thead>
<tr>
<th>Method</th>
<th>No post-processing</th>
<th>Post processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard method</td>
<td>97.98 %</td>
<td>98.83%</td>
</tr>
<tr>
<td>Topological map</td>
<td>99.25%</td>
<td>99.46%</td>
</tr>
<tr>
<td>Morphological reconstruction</td>
<td>99.21 %</td>
<td>99.49%</td>
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Jaccard (IoU) of the living epidermis
<table>
<thead>
<tr>
<th>Method</th>
<th>No post-processing</th>
<th>Post processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard method</td>
<td>94.09 %</td>
<td>94.24%</td>
</tr>
<tr>
<td>Topological map</td>
<td>94.20%</td>
<td>94.67%</td>
</tr>
<tr>
<td>Morphological reconstruction</td>
<td>94.61 %</td>
<td>94.82%</td>
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Jaccard (IoU) of the stratum corneum
### Jaccard (IoU) of the *stratum corneum*

<table>
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<tr>
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<th>Post processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard method</td>
<td>83.70 %</td>
<td>91.46%</td>
</tr>
<tr>
<td>Topological map</td>
<td>94.87%</td>
<td>96.99%</td>
</tr>
<tr>
<td>Morphological reconstruction</td>
<td>91.46 %</td>
<td>97.43%</td>
</tr>
</tbody>
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Background / *stratum corneum*

- Mean distance (in pixels) to ground-truth contour

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<th>Post-processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard method</td>
<td>829</td>
<td>18</td>
</tr>
<tr>
<td>Topological map</td>
<td>285</td>
<td>5</td>
</tr>
<tr>
<td>Morphological reconstruction</td>
<td>367</td>
<td>4</td>
</tr>
</tbody>
</table>
With the reconstruction method, only two images from the test database contained errors visible at first sight.
Visual analysis: other errors
Visual analysis: correct results
Visual analysis: correct results
Visual analysis: correct results
Conclusion
Two geodesic methods to allow a CNN to use topological information are proposed based on:
- a topology map
- a morphological reconstruction

Their application to Fontana Masson histological images of pigmented reconstructed epidermis is successful.

They give similar results. The second one uses less memory and does not need any thresholding.
Ongoing work

- Application to a larger database (2000 images)
- Industrial integration by ADCIS
Perspectives

- Integration of the pre-processing step inside the network
- Use mathematical morphology to help CNNs to enforce structure
Thank you for your attention

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