Le basi dell’Intelligenza Artificiale

Deep Learning applicato al medical imaging

Dissemination event, 10 marzo 2023, Pinerolo
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Detection from CXR: dataset, trust and explainability
AI primer

Introduction to Deep Learning in medical imaging
Actors in the play

Methods & tools

Challenges
Feature Engineering

Challenge

- Problem understanding and method mapping
- Tool/model selection based on target features
- Development and validation

Data samples
Learning based approach

Challenge

- Problem understanding and method mapping
- Dataset
- Model selection & training
- Development and validation

Data

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Magic and Threats

- Deep learning is
  ○ Powerful and **general method**
  ○ Maps **knowledge** on complex model **through data**
  ○ Can **tackle ill-posed problem** (missing data, noise, high dimensionality, etc.)
The Co.R.S.A. Challenge

- Challenge: can we detect Covid-19 from simple CXR imaging?
- Supervised learning approach

Large labeled image dataset

Deep Learning:
Convolutional layers + neural classifier
Deep Learning for dummies (supervised)

Test the model

Data & labels

Improve the model

Target output & Loss function
What it is

- **IS powerful**: allows one to train huge models (billions of parameters)
- **IS general**: can extract knowledge directly from examples
- **IS getting momentum in** medical imaging (unsupervised learning, generative models, multimodal)
and what it is not

- is NOT intelligent: dataset shall be balanced, learn by examples (with random sampling)
- is NOT guaranteed to be explainable (trust)
- is NOT guaranteed to generalize well (robust): biases and collateral learning can limit the learning, new data can cause catastrophic forgetting
A receipt

- Spend as much time as needed to define/understand the challenge
- Data collection
  - consider all possible correlated/potentially useful information
  - beware biases (age, gender, acquisition method, etc.)
- Importance of preprocessing/quality of data (especially on small dataset)
- Discuss and refine obtained metrics
- Inspect (try to understand, to constrain) extracted features
- Exploit learning complexity to unveil unexpected phenomena challenging prior assumptions
- Public dataset & GDPR and ethical issues
Deep learning for lung nodules segmentation in CT scans
DeepHealth UC4: A successful collaboration

https://zenodo.org/record/5797912#.Y_yoztLMJhE
# UniToChest

## UnitoChest Nodules Distribution

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Category</th>
<th>Number of Nodules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodule Diameter</td>
<td>&lt; 0.3mm</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>&lt; 10mm</td>
<td>4,321</td>
</tr>
<tr>
<td></td>
<td>&lt; 30mm</td>
<td>6,031</td>
</tr>
<tr>
<td></td>
<td>&gt; 30mm</td>
<td>847</td>
</tr>
<tr>
<td>Splits</td>
<td>Training</td>
<td>9,823</td>
</tr>
<tr>
<td></td>
<td>Validation</td>
<td>483</td>
</tr>
<tr>
<td></td>
<td>Test</td>
<td>990</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>11,295</td>
</tr>
</tbody>
</table>

![UnitoChest Nodules Distribution Diagram](diagram.png)
UniToChest

<table>
<thead>
<tr>
<th>Splits</th>
<th>Number of Patients</th>
<th>Male</th>
<th>Female</th>
<th>Average Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training</td>
<td>498</td>
<td>303</td>
<td>195</td>
<td>66</td>
</tr>
<tr>
<td>Validation</td>
<td>62</td>
<td>39</td>
<td>23</td>
<td>68</td>
</tr>
<tr>
<td>Test</td>
<td>63</td>
<td>35</td>
<td>28</td>
<td>65</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>623</td>
</tr>
</tbody>
</table>

UnitoChest dataset population
UniToChest

Robustness to the biases of CT acquisition machines
Model presented in 2015 [pdf] for biomedical image segmentation (UNet-2D).
Results

Ground truth

Prediction
## Results

<table>
<thead>
<tr>
<th>Trained</th>
<th>Input size</th>
<th>Dice Score</th>
<th>IoU</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNet-2D from scratch</td>
<td>512x512</td>
<td>0.70</td>
<td>0.59</td>
</tr>
<tr>
<td>UNet-2D pretrained on LIDC</td>
<td>512x512</td>
<td>0.73</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Paper: [https://link.springer.com/chapter/10.1007/978-3-031-06427-2_16](https://link.springer.com/chapter/10.1007/978-3-031-06427-2_16)
How AI can help radiologists?

1. User chooses a CT scan
2. Upload file to server
3. Server processes the image with already trained deep learning model
4. The output mask with lung nodules segmented is returned to the user
COVID detection

The Co.R.S.A. challenge: dataset, trust, interpretability
Imaging, AI and COVID-19

A step back in time ...to ~Sept. 2020

- 28M+ cases worldwide
- RT-PCR as golden standard
- Chest X-Ray (CXR) less sensitive than CT, but easier to deploy
- CXR often used in practice for preliminary screening
Early efforts to build datasets (< 2020)

**COVID-19 Image Data Collection**

A chest X-ray image dataset of viral and bacterial pneumonias (mostly COVID-19)

**Covid19-CXR:** Around 100 images at the time (public); gathered from research articles and public sources - Cohen et al. 
[https://github.com/ieee8023/covid-chestxray-dataset](https://github.com/ieee8023/covid-chestxray-dataset)

**CORDA (1st iteration):** Largest dataset at the time ~900 CXRs; gathered directly from hospitals in Piedmont; however private at the time

**CORDA:** Covid Radiographic images Data-set for AI 
Collaboration with Città della Salute e della Scienza and San Luigi Gonzaga
- 898 CXRs on patients with fever or respiratory symptoms
- Virus testing to determine COVID infection
- Collected in March and April 2020 (peak of the epidemic in Italy)
AI Pipeline

**Preprocessing**

Preprocessing ensures that all images are coherent with each other (e.g. histogram normalization). This helps the neural network to converge faster.

Preprocessing helps in removing noise in the data

Data anonymization is also usually performed as first step

Other operations such as **lungs segmentation** can be used to partially remove polarizing features from the image (e.g. biases such as medical devices and text)
The problem with small datasets - Biases

New data (>= 2020)

- Mostly covid-19 positives

Previously available data (< 2020)

- All negatives
The problem with small datasets - Biases

New data (>= 2020)

Previously available data (< 2020)

Montgomery County X-ray Set

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The problem with small datasets - Biases

The two datasets (e.g. CORDA vs ChestXRay) are very different, for two reasons:

- Covid19+ vs Covid19- **GOOD**
- Other reasons such as populations (i.e. children vs adults) **BAD**

Deep Learning models are naive: they take the **simplest** solution to the problem
The problem with small datasets

Despite many works initially claimed detection accuracy of >90%, the real accuracy (BA) is around 67% at max, and the sensitivity is low.

<table>
<thead>
<tr>
<th>Method</th>
<th>Baseline [20]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backbone</td>
<td>RN-18 RN-18 RN-18</td>
</tr>
<tr>
<td>Classifier</td>
<td>FC FC FC</td>
</tr>
<tr>
<td>Pretrain</td>
<td>- RSNA CXR</td>
</tr>
<tr>
<td>Train</td>
<td>CDSS</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.56 0.54 0.54</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.58 0.80 0.58</td>
</tr>
<tr>
<td>BA</td>
<td>0.57 0.67 0.56</td>
</tr>
<tr>
<td>AUC</td>
<td>0.59 0.72 0.67</td>
</tr>
</tbody>
</table>
Takeaway

Direct COVID-19 diagnosis from CXR is hard with limited data

- Differences in negative vs positive population have a major impact
- Together with the limited number of images, this prevents the model from learning any useful clinical features (e.g. lung pathologies, appearance, etc.)
Mimicking the radiologist workflow

The direct approach fails to learn relevant features due to lack of sufficient data.

…but if we first explicitly focus on diagnosis objective radiological findings, we might obtain features also relevant for covid-19.
How to deal with limited data

Some large non-covid dataset exist, e.g. CheXpert, with more than 200k CXR images.

CheXpert is well suited for learning objective radiological findings (e.g. opacity, consolidation, etc.).

The learned knowledge can then be transferred to the smaller covid datasets (transfer learning).
AI Radiological Report

This part extracts lower dimensional features from the image

This part predicts the probability of each possible observation

- no finding: 1%
- fracture: 2%
- lung opacity: 80%
- edema: 60%
- consolidation: 70%
- pneumonia: 70%
- lesion: 60%
- atelectasis: 65%
- pleural effusion: 55%
- pneumothorax: 35%
- pleural other: 20%
- enlarged cardiom.: 40%
- cardiomegaly: 20%
Covid-19 diagnosis from report

The AI radiological report can be used to predict the presence of Covid-19. For full explainability, a decision tree (a type AI model) can be employed.
Covid-19 diagnosis from report

With this approach, we are able to improve the results significantly

- Previous accuracy 67%, sensitivity 56%
- Improved accuracy 75% sensitivity 77%

*With slightly more sophisticated models we achieve:*

- **Accuracy 81% sensitivity 79%**
Interpreting AI predictions

- Other than the final covid diagnosis, with this approach we provide the **AI radiological report** which can explain the final decision (at least partially), and provide useful information to the clinician.

- We can also visualize which region of the image influenced the most the decision process.
The CORDA data release

The CORDA dataset has since been publicly released, and is now available on Zenodo!
https://zenodo.org/record/7501816#.ZAeAv9LMJhE

The kept growing in size and now contains:

- 3000+ images (both CXRs and CTs)
- 4 participating hospitals (mauriziano, molinette, san luigi, monzino)

!! IMPORTANT: All images have been anonymized before sharing !!

More information can be found on the CoRSA website: https://corsa.di.unito.it/
Thanks

Do you have any questions?

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https://github.com/EIDOSLab