Improving Tuberculosis(TB) Diagnostics using Deep Learning and Mobile Health Technologies among Resource-poor and Marginalized Communities

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Learning with Purpose

UMASS LOWELL

Tuberculosis(TB)

- A **chronic and infectious** disease
- Affects the **most disadvantaged populations** and involves complex treatment regimes
- More than **9 million** estimated new case and **1.5 million** deaths every year
- Over 80% were in South-East Asia, Western Pacific and African(2013)
- Majority of the infected populations was from **resource-poor** and **marginalized** communities.

Tuberculosis Diagnostics

Solution

Resource-poor Community

- Weak Healthcare Infrastructure

TB diagnosis Delay

- High infected Rate

mHealth System with Deep Learning

- Mobile-technique based data capturing and transmission
- Deep-learning-based analysis and detection
- User-centered
- Expedited TB diagnosis

Related Work

- mHealth in developing country for TB diagnosis
  - “Mobile health for public health in Peru: lessons learned”, 2015, E. F. Ruiz et al.
  - “Emerging technologies for monitoring drug-resistant tuberculosis at the point-of-care”, 2014,V. Mani et al.
- Develop Chest X-ray image database
  - Most of TB screen dataset have less than 200 images
  - ImageCLEF, JSRT Digital Image Database, ANODE Grand Challenge Database etc.. , but only contains one or two TB manifestation
- Computer-aided system to screen the chest radiography image for TB diagnosis
  - Computer-aided screening and scoring algorithms using chest radiographic features for TB diagnosis
  - X-ray image categorization on organ and pathology level

mHealth

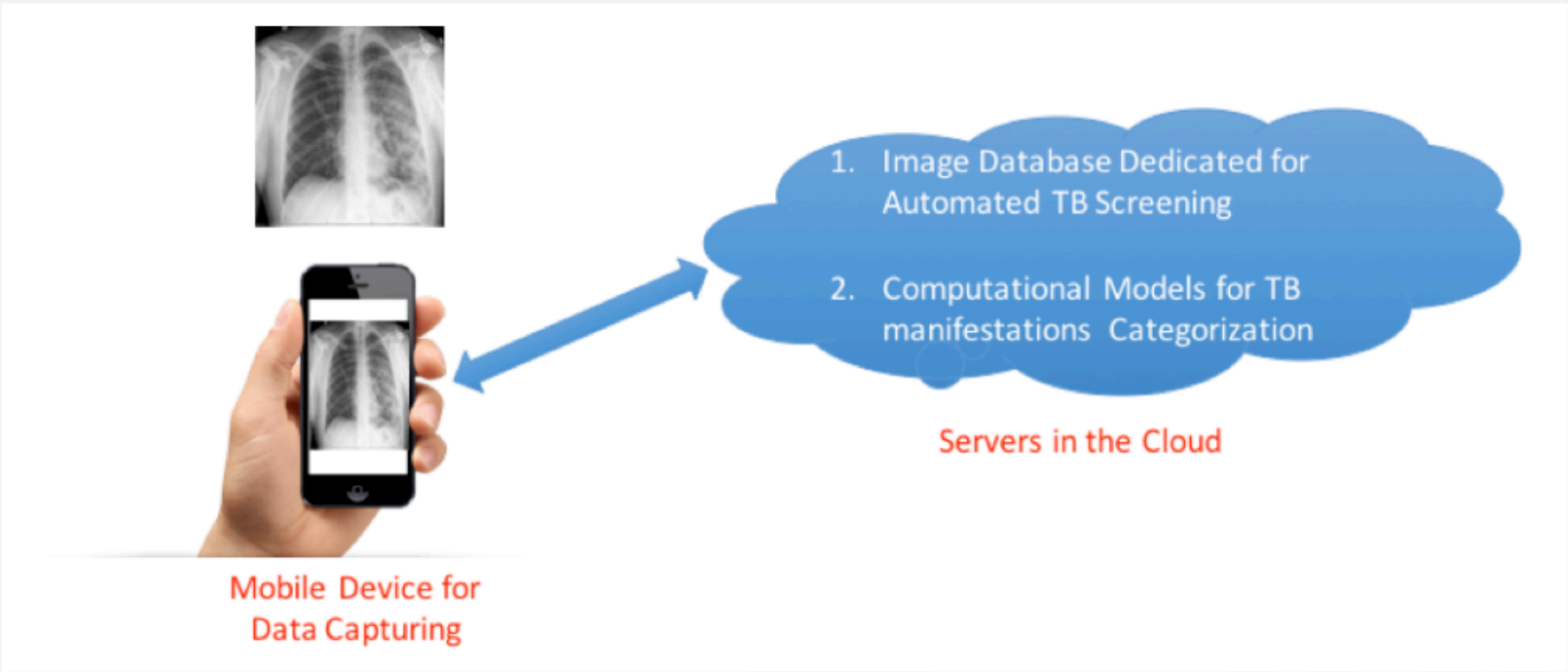
Challenge

- Lack of large scale, well-annotated, real-world X-ray Image Dataset
- Lack of mobile device-based computing system

Solution!

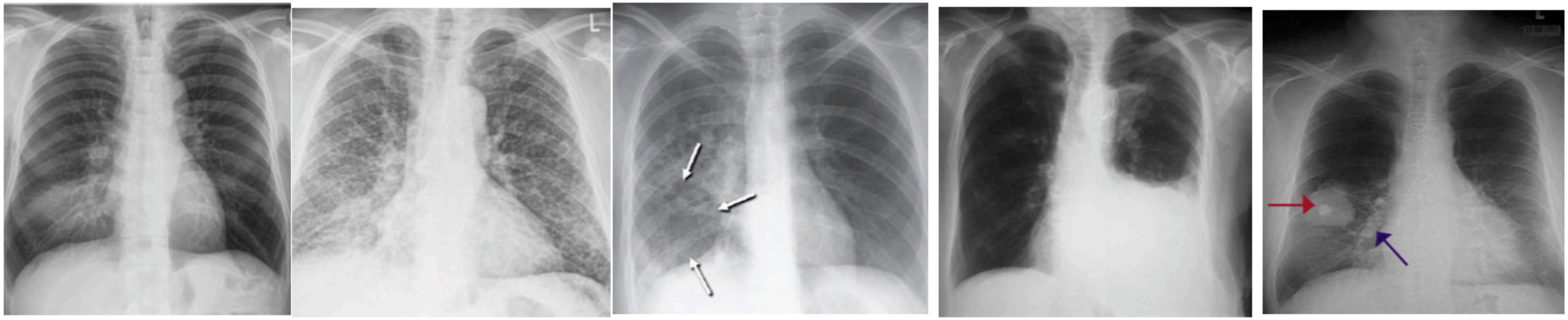
- * International research team
  * Clinical and research collaborators
  * Develop Annotation software
- * Develop a Mobile-cloud system
  * Deep learning model Training in cloud server

System Overview



- **Mobile Application**
  - Image Capturing and Data Transmission
- **Cloud Server**
  - X-ray Image Annotation
  - Deep Learning(CNN)-based Data Analytics

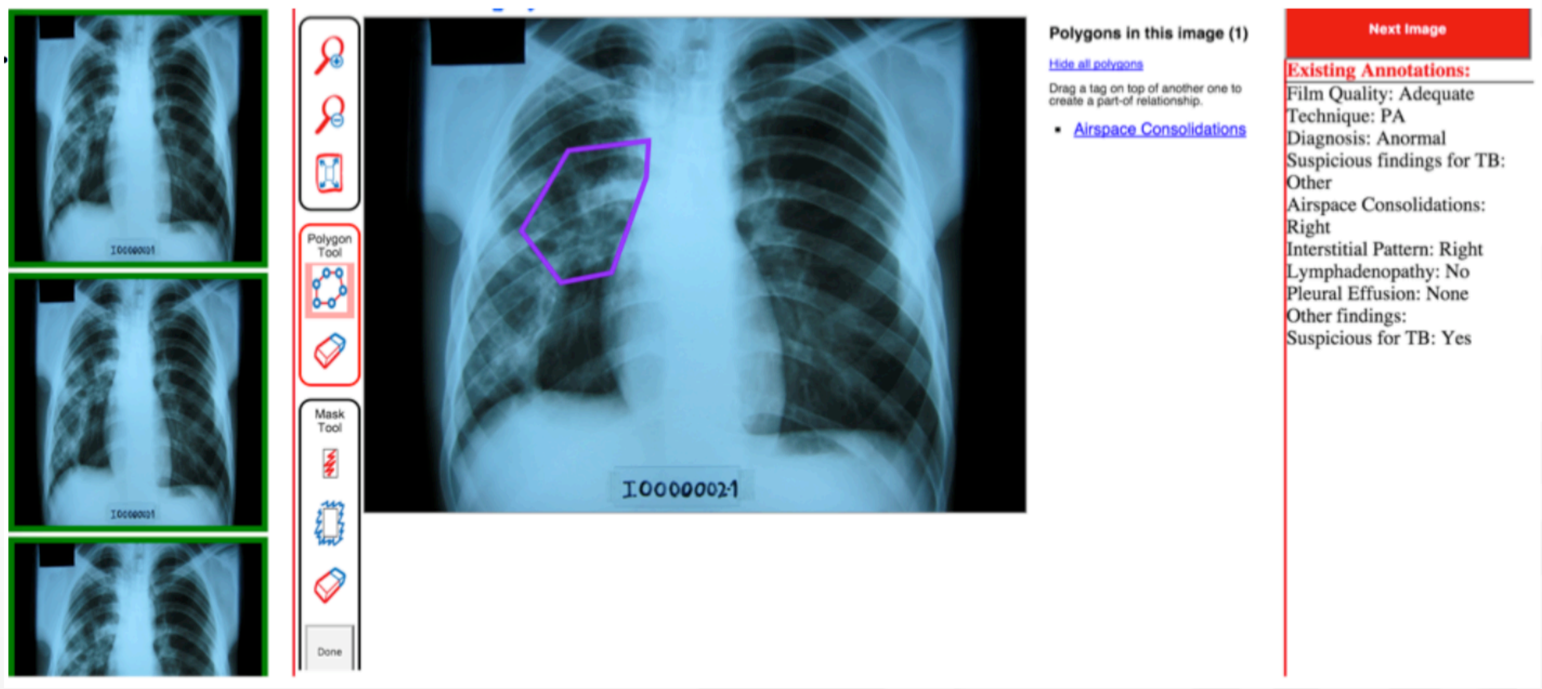
TB Manifestation



(a) (b) (c) (d) (e)

- (a) Air space consolidation which showing glass opacity with consolidation in the right middle lobe;
- (b) Miliary pattern with seed-like appearance;
- (c) Cavity located at the lower lobe (annotated by arrows);
- (d) Pleural effusion, which is excess fluid that accumulates in the pleural cavity;
- (e) Calcified granulomata: The red arrow indicates a large 5 cm diameter squamous cell carcinoma of the right lower lobe and there is 1.5 cm bright opacity in the middle of the mass (which is a calcified granuloma). Additional calcified granulomatous areas are medial to the mass, as indicated by blue arrow.

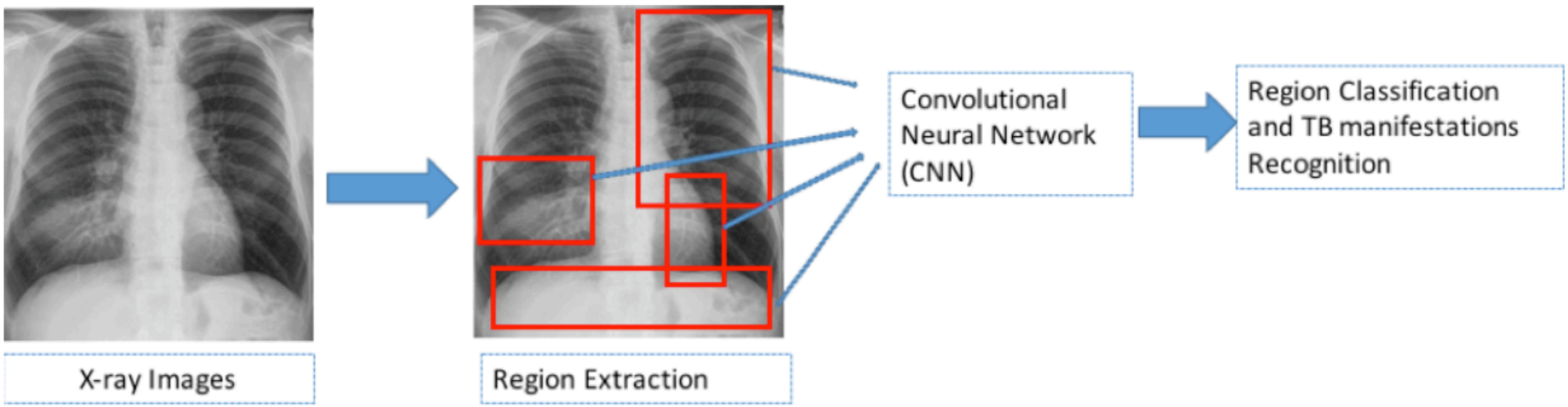
Annotation Software



* Modified from open source software

- Left Panel: Lists of Images
- Middle Panel: Annotation tools
- Right Panel: existing annotation details

Proposed Computational Model

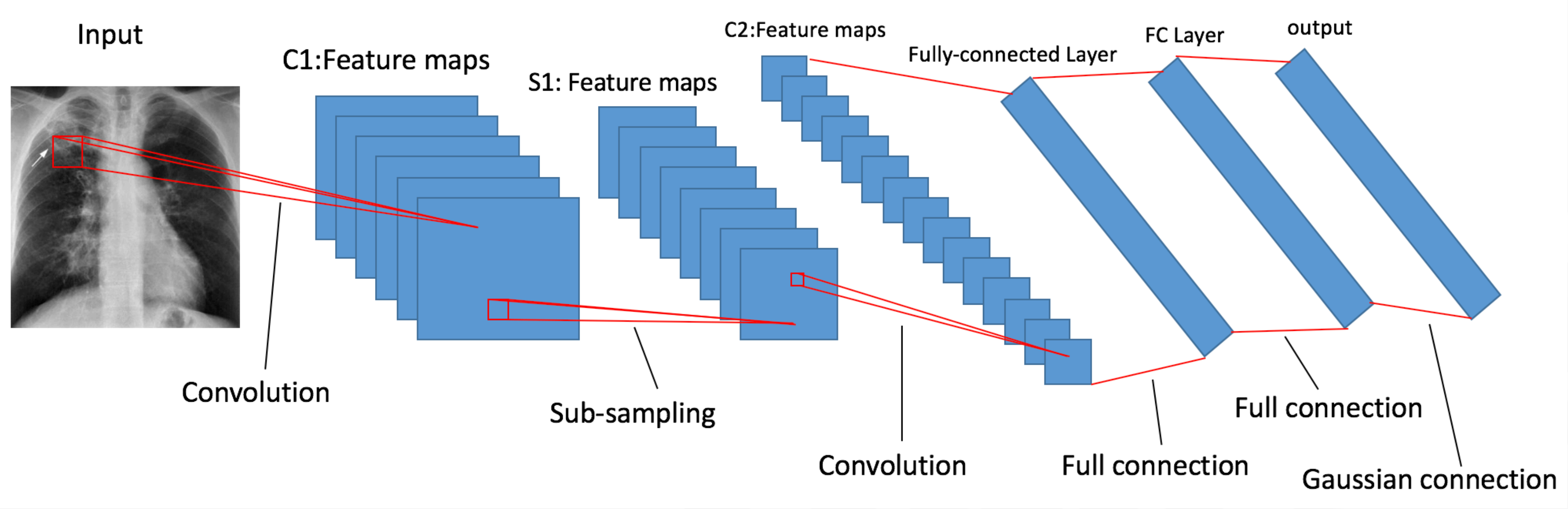


- Extraction of region proposal
- Compute CNN features
- Region Classification
- TB manifestation recognition

Proposed Approach: Deep Learning

- A branch of *machine learning*
- Attempts to model *high-level abstractions* in data by using *model architectures*
- Multiple layers of *nonlinear* processing units
- The unsupervised or supervised learns ***feature representations*** in each layer, with the layers forming a hierarchy from *low-level to high-level* features
- Among various techniques, **Convolutional Neural Network(CNN)** has achieved most promising result in *classification* and *object detection* for images.

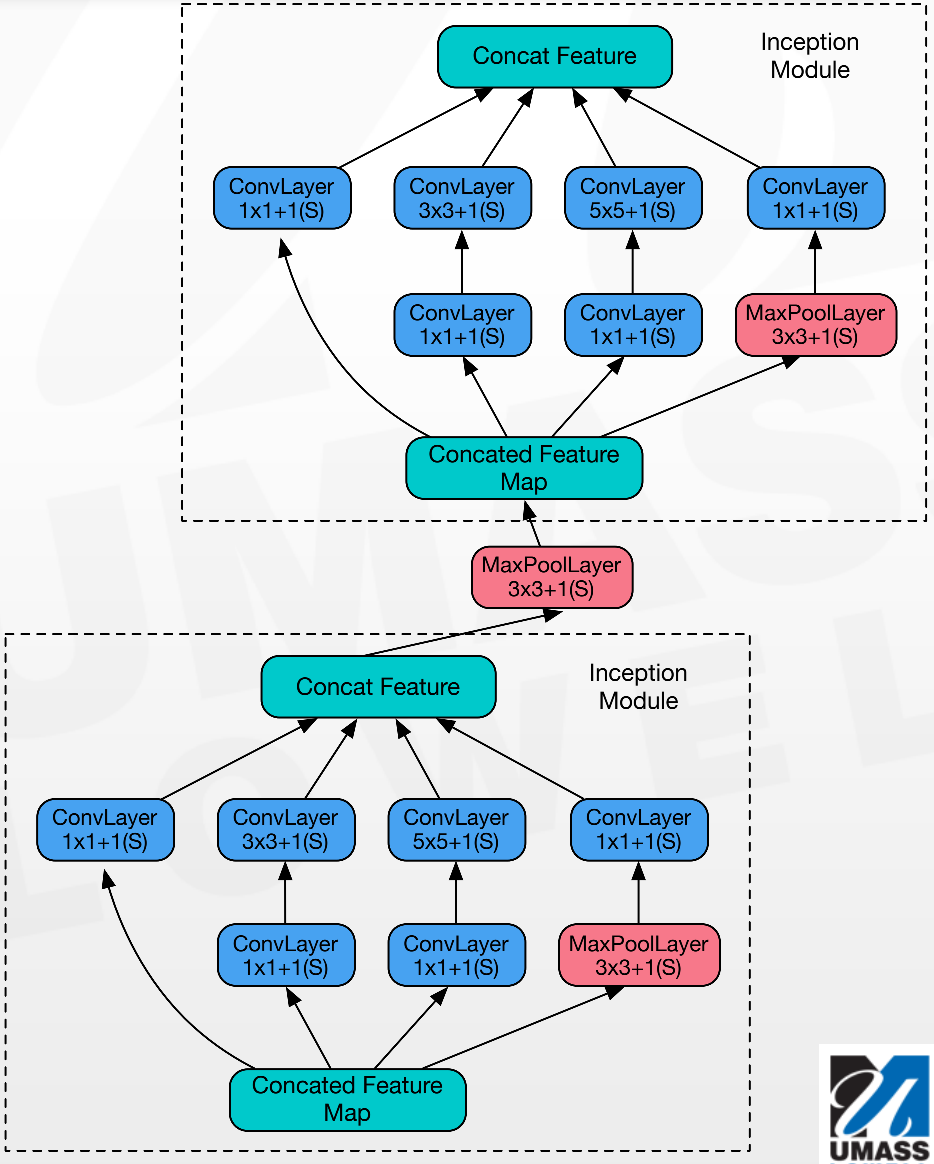
Proposed Approach: Deep Learning (CNN) Model Structure



- Input
- Convolutional Layer
- Sub-sampling/Pooling Layer
- Fully-connected Layer
- Output

Proposed Approach: Model Optimization

- Proposed approach for model optimization
  - Hinted by two recent advances
    - Network in Network
    - GoogLeNet
  - 22 Layers
  - Inception Model
  - Repeated inceptions
  - Smaller convolution size



* Liu, Cao. et al. DeepFood

Proposed Approach: Training Strategy

- Dataset
  - ImageNet (millions of images)
  - X-ray TB image datasets(~4700 images)
- Caffe + Cuda 6.5
  - Model Zoo(publicly released)
  - GPU accelerating, Nvidia K80
- Pretrain + finetune
  - GoogLeNet Model on ImageNet
  - Finetune on our TB datasets

Experimental Result(1)

- Dataset: 4701 images from Peru
- Two categories: Abnormal(4248 images) vs Normal (453 images)
- Convolutional Neural Network(CNN)
  - GoogLeNet Model
  - Pre-trained on ImageNet, fine-tuned on our X-ray dataset
  - Binary classification: 4/5 of the images for training, 1/5 of the images for testing

# of iteration	10,000	30,000	50,000	80,000	100,000
Average precision	82.8%	88.6%	89.0%	89.5%	89.6%

Table1: Average Precision for binary classification

Experimental Result(2)

- Dataset: 4701 images from Peru
- Four categories, Same training strategy

Category(TB Manifestation)	Total Image #	Image # Used for Training	Image # Used for Testing
Cavitation	1182	946	246
Lymphadenopathy	202	162	40
Infiltration	2252	1802	450
Pleural Effusion	560	448	112

Table2: Data distribution for different TB manifestation

# of iteration	10,000	30,000	50,000	80,000	100,000
Average precision	43.48%	61.68%	61.92%	62.05%	62.07%

Table3: Average Precision for multi-class classification

Conclusion

- Mobile technologies have the potential to reduce the burden of TB for better diagnosis.
- Deep learning technology, especially CNN, can further improve the classification accuracy of X-ray images.
- Our integrated system can reduce the diagnosis time, within resource-poor and marginalized communities.

Future Work

- Continue to develop the large scale, real-world X-ray TB database.
- Improve the classification accuracy for the deep learning computational models.
- Implement a scalable solution by making the mobile device based system available as an open source platform
- Conduct field-testing in tuberculosis clinics in Peru.

Acknowledgement

- *This project is supported in partial by*
  - *NSF/NIH Smart and Connected Health Program:* SCH:INT:A Sociotechnical Systems approach for Improving Tuberculosis Diagnostics Using Mobile Health Technologies, $1.29M, 2015-2019, PIs: Prof. Yu Cao, Benyuan Liu, and Maria Brunette

Q&A

Thank you!