Medical image processing using Microsoft Deep Learning Framework (CNTK)

Naoto Usuyama
Jessica Lundin

Microsoft

We are hiring!
aka.ms/healthengineeringjobs
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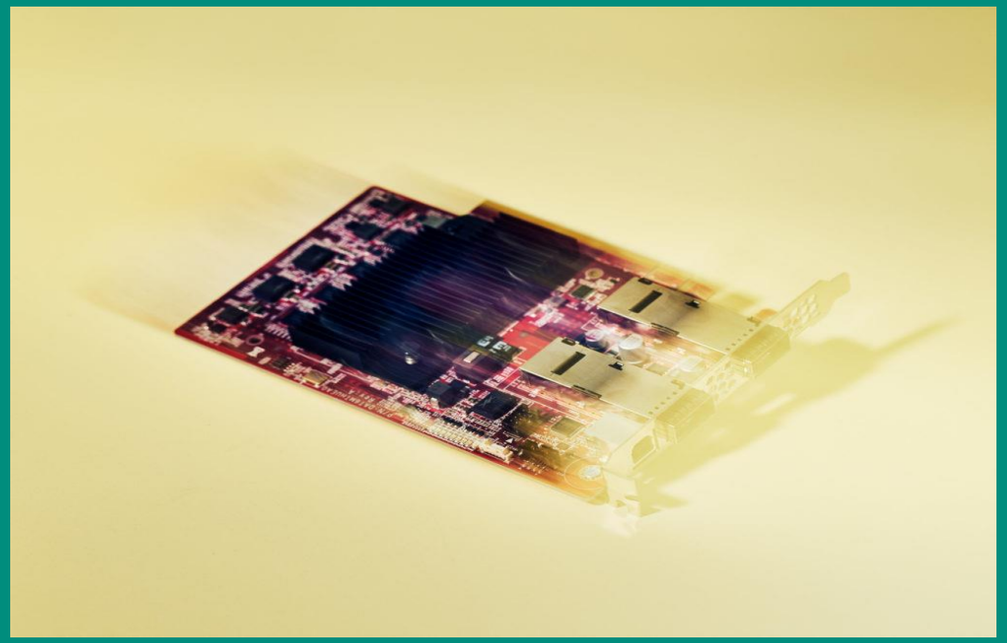
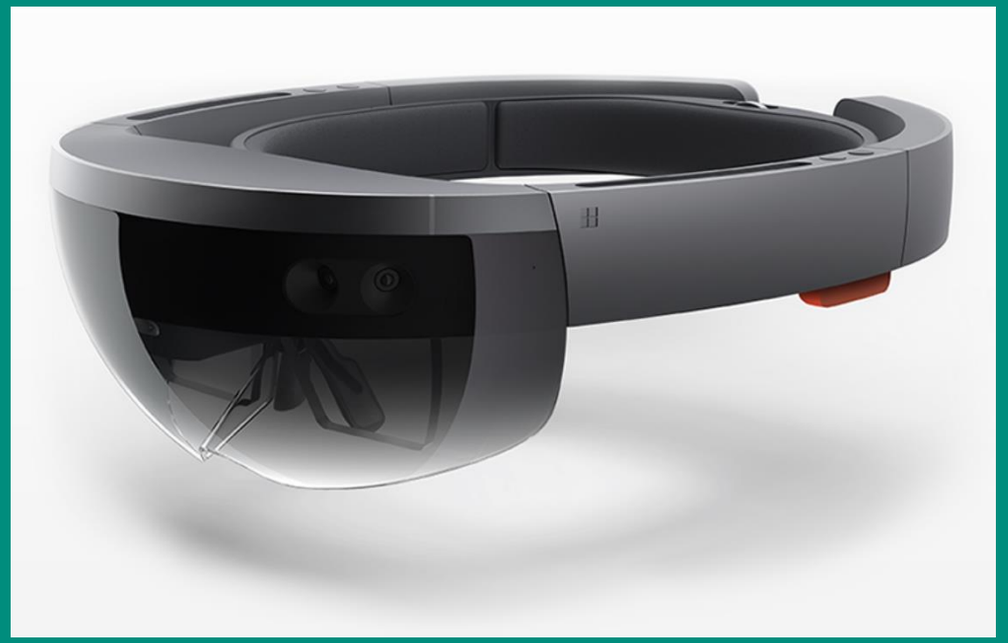




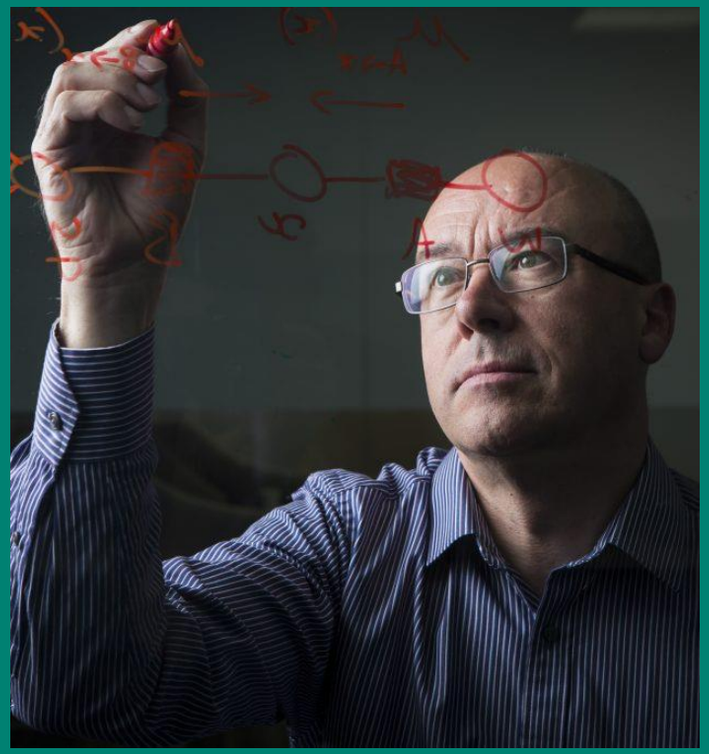
NExT

MSR Healthcare NExT

Microsoft Healthcare NExT

Hyperscale, secure cloud and AI services and platforms

Relationships with 168,000 healthcare organizations



Microsoft Research, with >75 projects in health/med/bio

MSR Healthcare NExT

Microsoft Research
Relevant moonshot projects

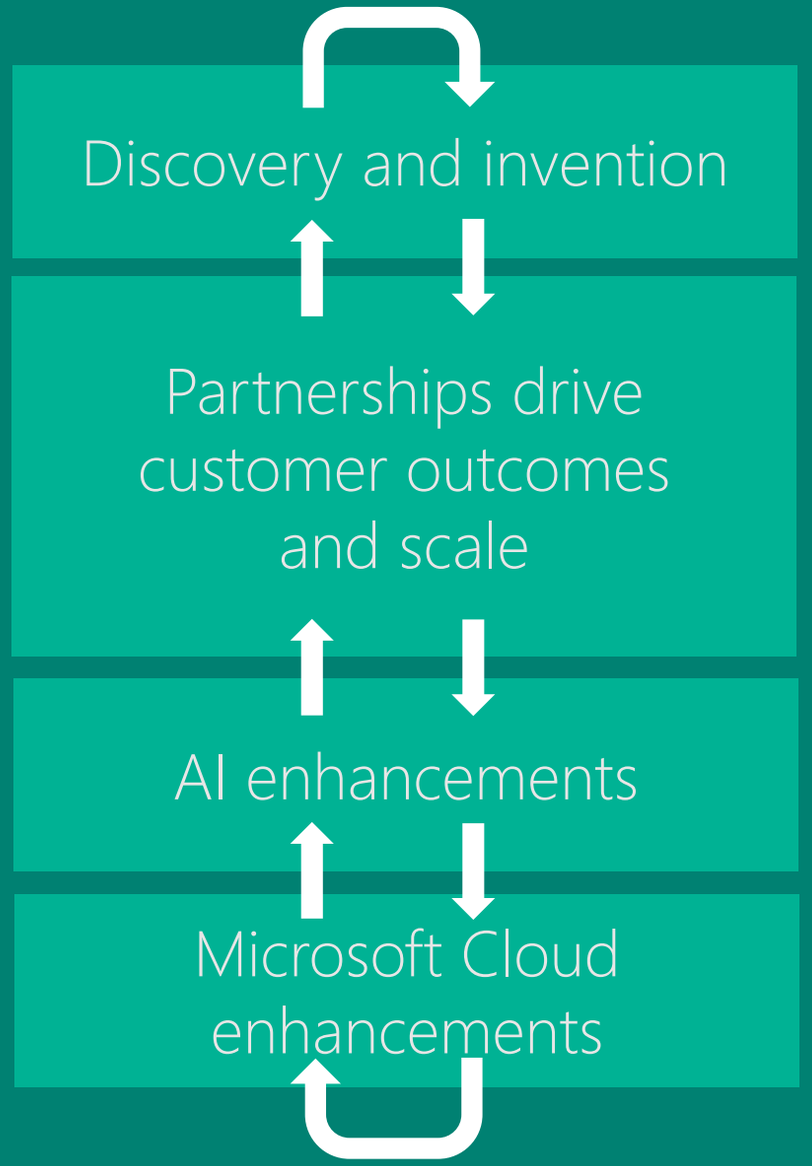
Strategic research partnerships

Clinician empowerment

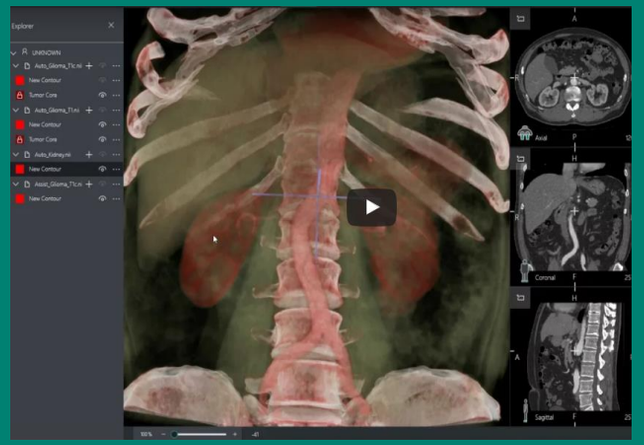
Patient engagement

Microsoft AI
Machine learning, speech, NLP, vision, search, reading, …

Microsoft Cloud
Secure and compliant data storage, sharing and analytics



Clinician empowerment



InnerEye

Assistive AI for oncologists and radiotherapists to spot and measure tumors automatically

Project Premonition

Detect pathogens before they cause outbreaks, via drones, robotic mosquito traps, genetic sequencing

Genomics

Perform “sample-to-answer” genomic processing – cheaper, easier, and up to 7X faster

Care team productivity

AI tools to empower clinicians to focus on patients, not IT systems

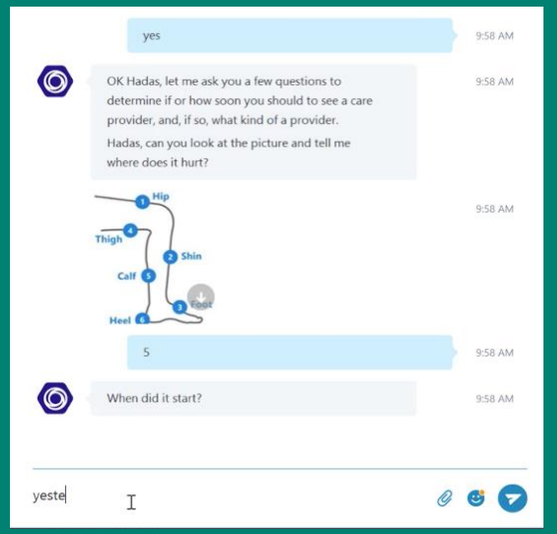
Patient engagement

HealthVault

Secure and compliant platform for health data

HealthVault Insights

ML-driven adherence to care plans



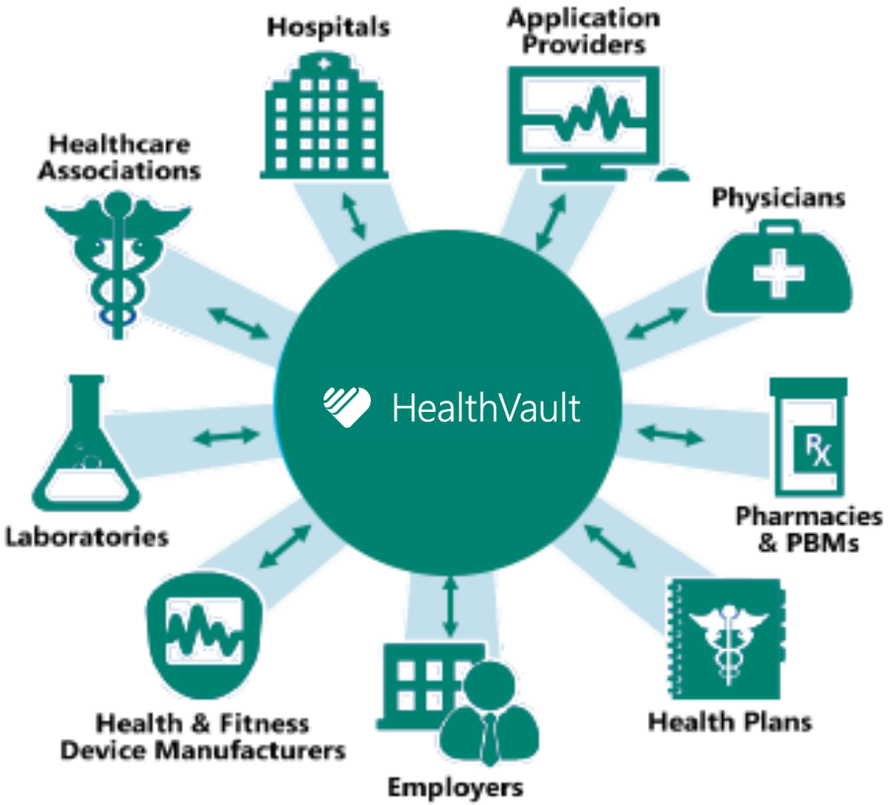
Health bot

AI-driven agent for medical& insurance triage

Research collaborations

Focus on data science, hard problems

HealthVault

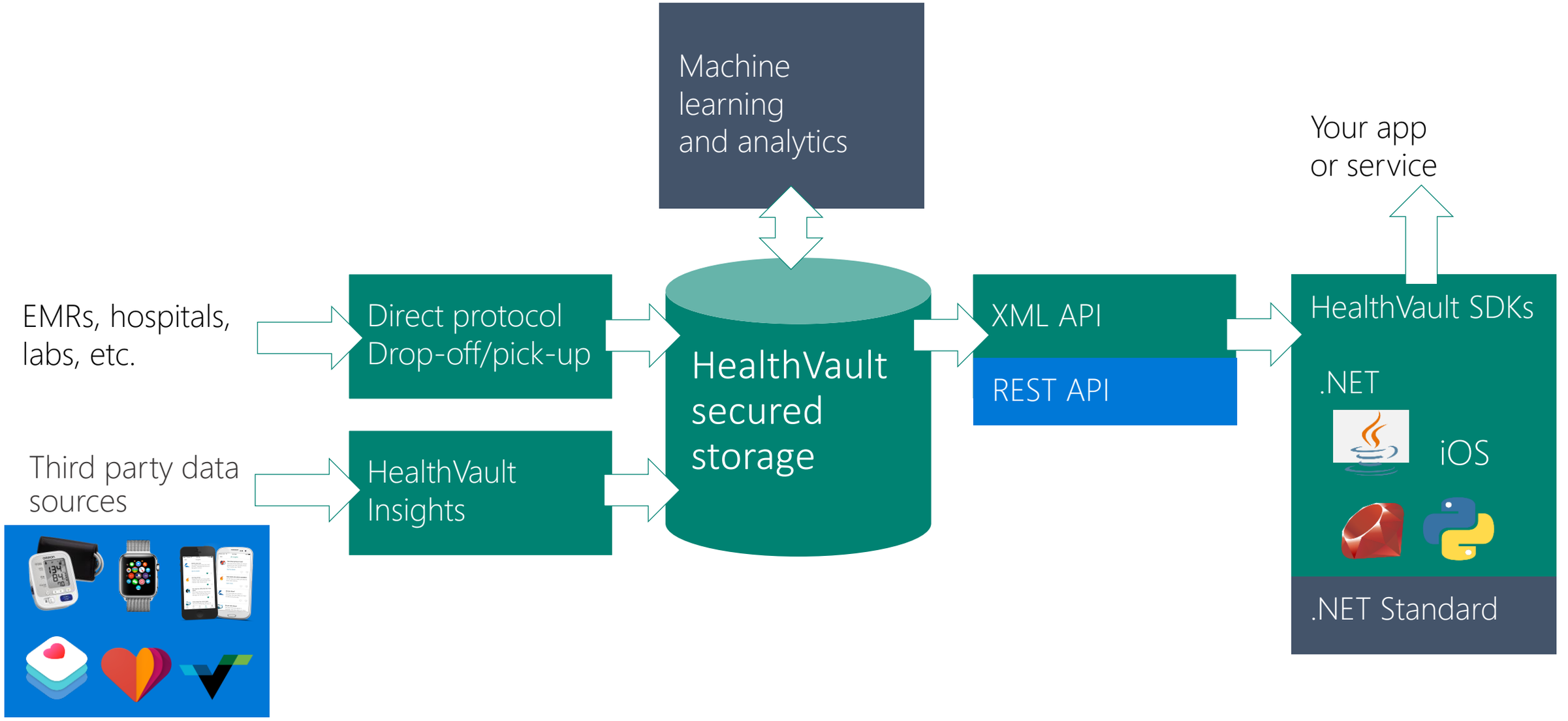


- HIPAA compliant service for PHI
- Secure web service for reading and writing data
- Supports hundreds of apps and devices via HealthKit and Google Fit
- Built-in privacy, security and user control sharing
- Secure messaging
- CCD data exchange
- DICOM medical image storage
- Meaningful Use 2 reporting
- Event notifications

HealthVault key features

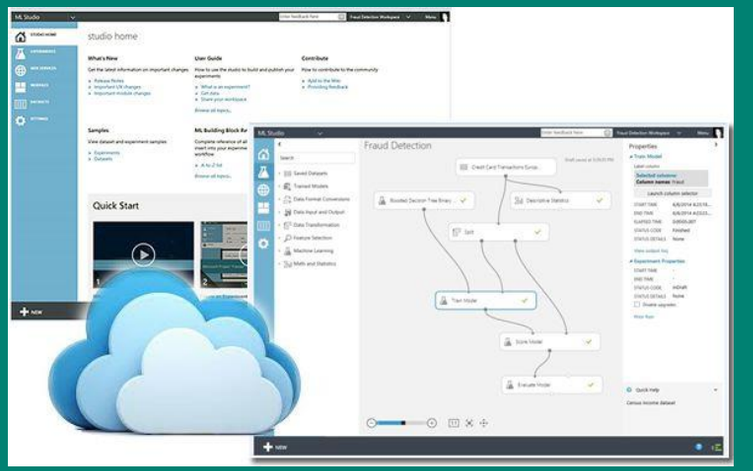
Security	Industry standard HTTPS, encryption-at-rest, rich authorization, auditing
Platform	Rich XML and REST APIs with interoperable datatypes for healthcare data
Client SDKs	.NET, .NET Standard, Java, Objective-C, Ruby and more
Industry standards	Direct Messaging, HL7 (CCD/CCDA)
Healthcare vocabularies built-in	ICD-9, RxNorm, HL7, Snomed
Industry program support	Certified for U.S. HITECH Act Meaningful Use 2 reporting

Technical overview

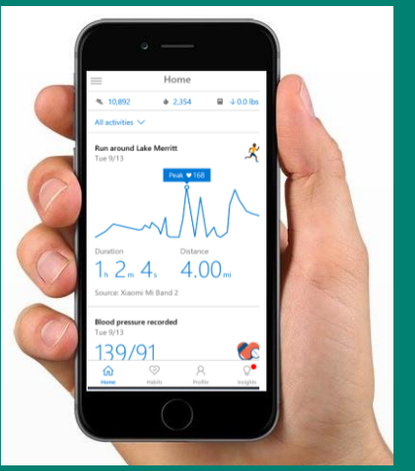


Driving adherence to care plans

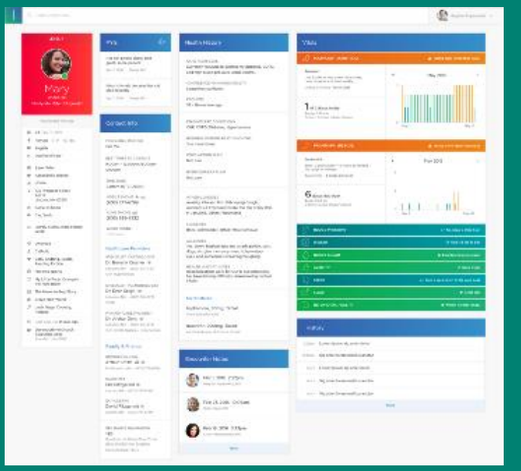
Baseline health monitoring via hundreds of activity trackers and medical sensors. Secure storage via on Azure.



AI runs on Azure to create insights Individual data from wearables, Office, Cortana.



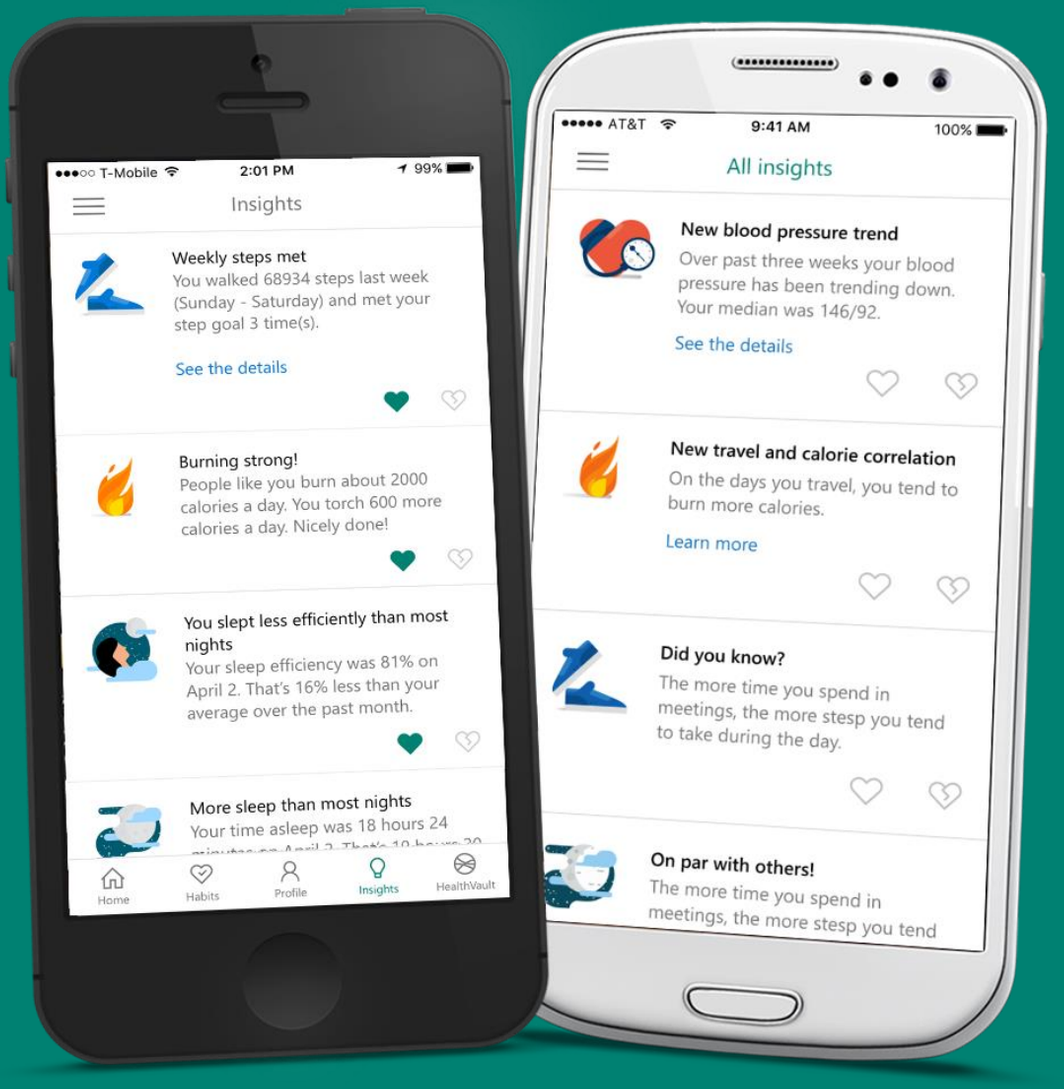
Personalized care plans via app or API to help drive engagement and adherence to care plans.



Care plans continuously evolve with machine learning for personalized coaching and insights.

Personalized insights to drive adherence

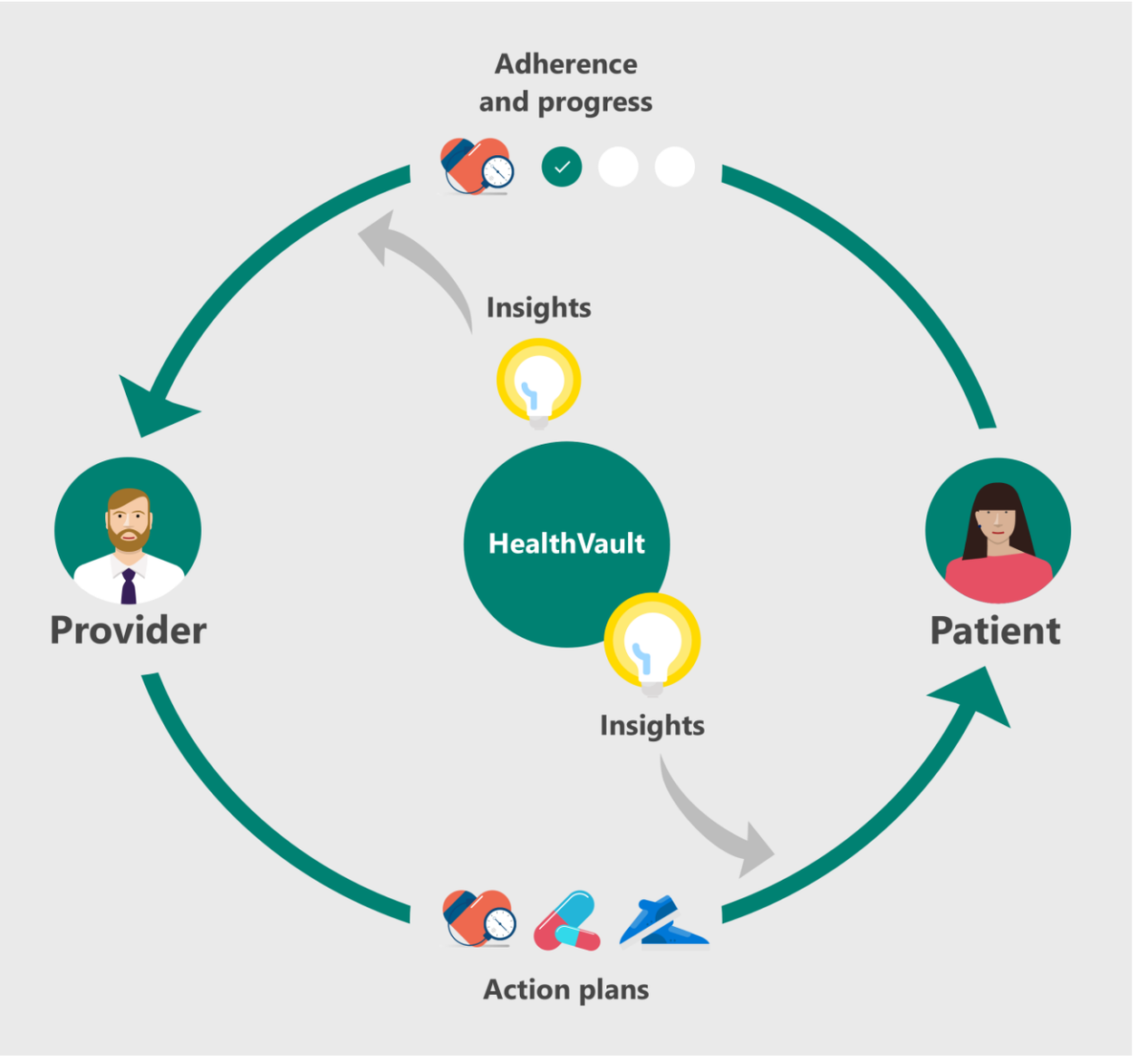
- Azure Machine Learning platform
- 200+ insights (and growing)
- ML trained to spot trends, anomalies, correlations
- Based on population models, personalized with individual health data and sensors



Action plans framework

Drive virtuous cycle of provider/patient communications

- Patients log adherence through client app or automatically
- Providers tweak plans over time to personalize care



Action plan developer offering

Resources

- Samples: https://github.com/Microsoft/healthvault-samples/
- Documentation: https://go.microsoft.com/fwlink/?linkid=846927

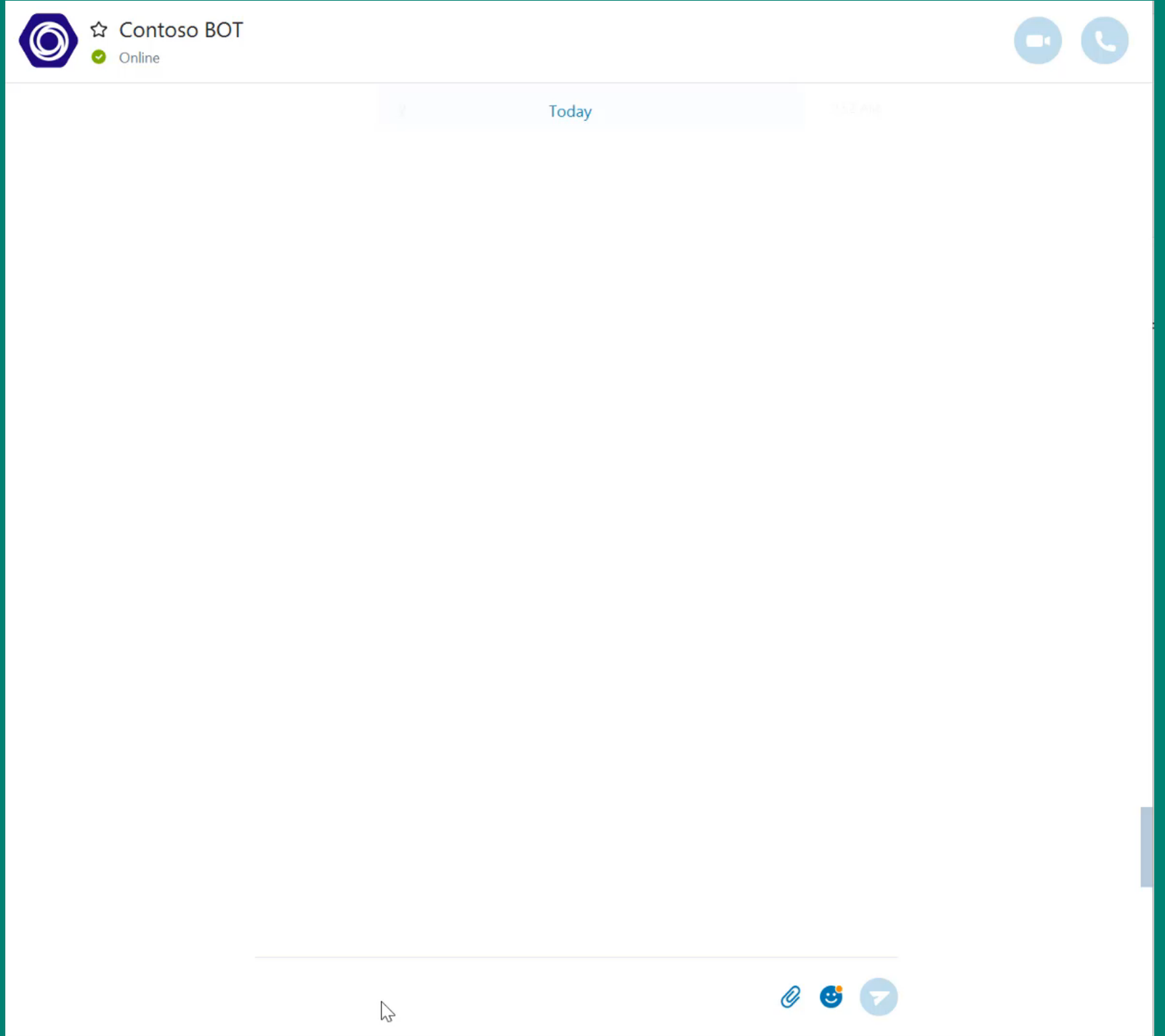
HealthVault supports common healthcare standards including

- HL7 Clinical Document Architecture/Continuity of Care Documents
- The Direct Project
- HealthVault XML API released under Microsoft Community Promise

Health and wearable aggregators: Apple Health, Google Fit, Validic
Phone motion sensors: iOS, Android, Windows 10 Mobile

Health Bot

Smarter triage and information through conversational intelligence



Contoso BOT

Online

Today

From your **Microsoft Health** wearable device data I see you have ***12 workout minutes last week***, that's an anomaly for you. Your usual average is ***125 workout minutes per week***. Is this correct? 9:59 AM

y 9:59 AM

OK Hadas, this would reduce the chance of a new orthopedic problem.

Cortana says you have been traveling ***long distance*** to ***Orlando*** this week. Is that correct?. 9:59 AM

y 9:59 AM

Are you experiencing new shortness of breath? 9:59 AM

n 9:59 AM

Contact Contoso 24h Nurse Line

Please use reference #87654

Call Nurse Line 9:59 AM

Contoso BOT

Online

Today

Derek Christopher Shepherd, M.D.

Mercy West Hospital. 1234 Denny St. 98013
Seattle WA

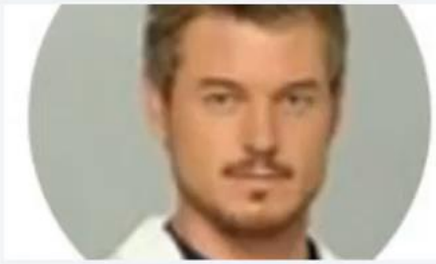
yes

10:10 AM

derek shephred , M.D., is not in your provider network. You can see dr . derek shephred but your insurance will only cover 50% rather than 90% for providers that are in network.

Dr. Sloan is in your network, has a five-star quality rating, and his office is about 3 miles from your home. Click on the card below to connect with his appointment desk and schedule a visit.

10:10 AM



Mark Everett Sloan, M.D.

Seattle Grace hospital 3421 Main St. 98028
Seattle WA

Call clinic

Health bot for triage and inquiries

Bot framework

- Natural language processing
- Multi-turn conversations
- Any end point
- Any API

Cortana

- World knowledge
- Location
- Calendar
- Travel

HealthVault

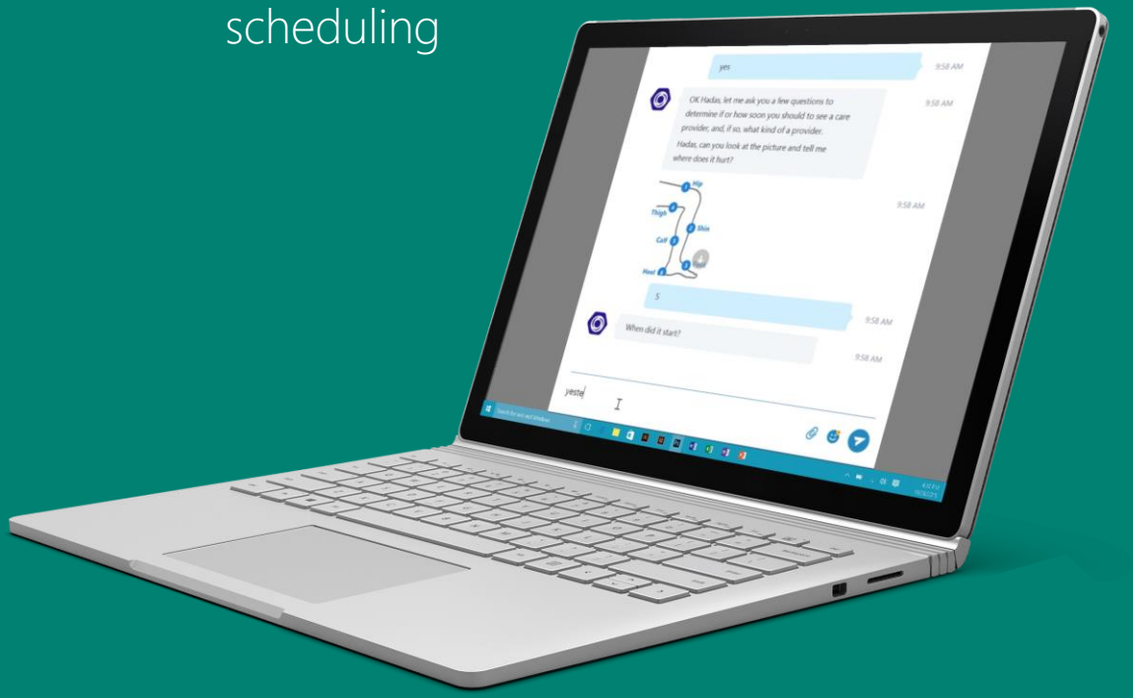
- Personal health records
- Prescriptions
- Wearable data

Third party data

- Authoritative medical protocols
- Service provider lookup and scheduling

Customer systems

- Payer
- Provider



- Bot framework API to develop your own health bot
- Scenario editor
- HIPAA compliance
- Licensed medical triage protocols
- Voice support
- HealthVault and Cortana integration

Medical Image Analysis

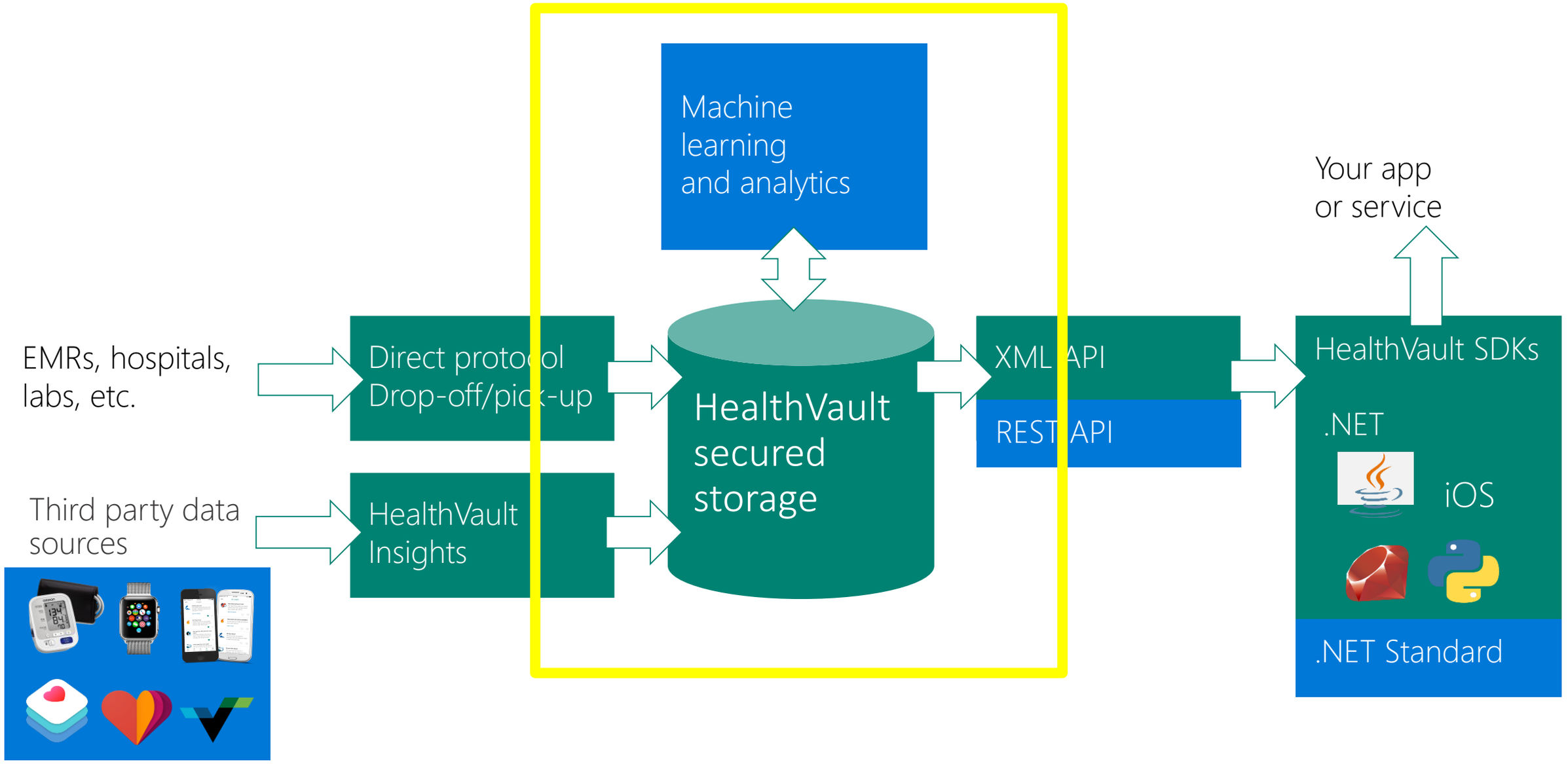
Medical images on HealthVault

- Support DICOM
  - DICOM: **D**igital **I**maging and **Co**mmunications in **M**edicine
- Web-based platform API
- .NET client SDK/Sample App

Ref:

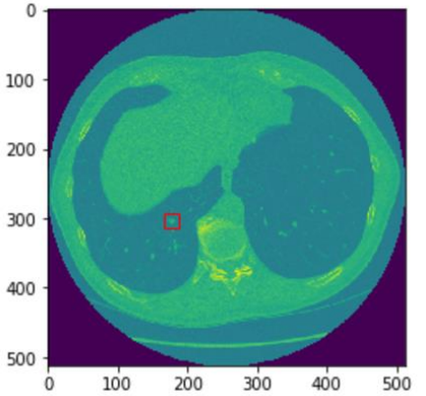
- Medical imaging on HealthVault
  - https://aka.ms/hv_medical_image
- List of Data Types on HealthVault
  - https://developer.healthvault.com/DataTypes

HealthVault data pipeline



Tutorial

- Public datasets
  - Retina images: Diabetic Retinopathy Classification
  - Lung CT: Lung Nodule Detection
- CNTK/Keras
  - Train deep learning models
- Preprocessing for medical images



https://aka.ms/pydata-medical-image

Target Audience

- Interested in medical image analysis
- Interested in deep learning

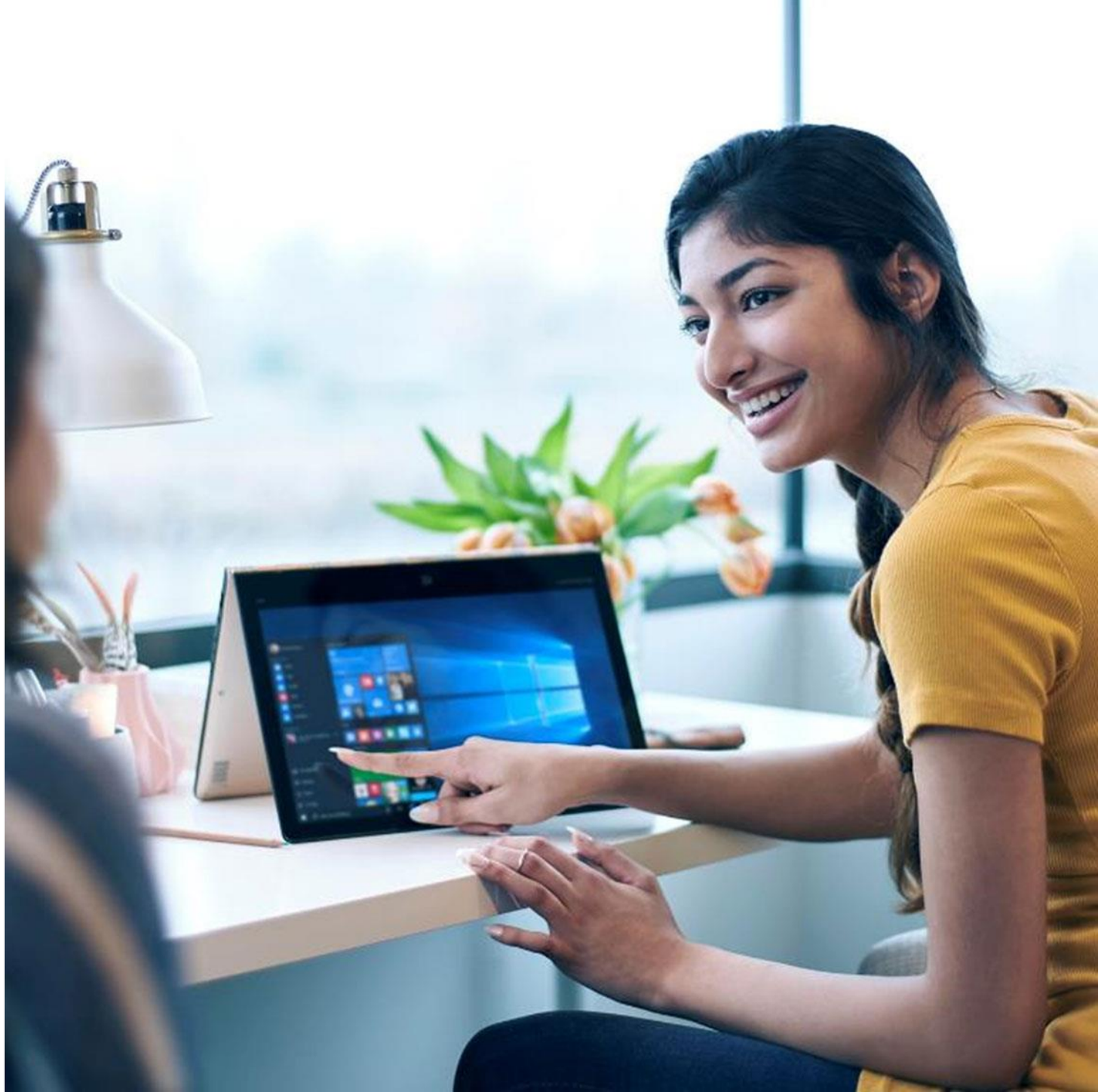
Goal

- Provide good starting point for deep learning medical image processing
- End-to-end deep learning using CNTK and Keras

Non-Goal

- Not ready for self-diagnosis or production-use

Machine Environment



Prerequisite: Machine Setup

- Setting up an environment for Deep Learning is not easy…
- A machine with GPU(s)
  - CUDA, cuDNN, NVIDIA Driver
- Deep Learning libraries
  - CNTK, Keras
- Data science libraries
  - pandas, numpy, scipy, matplot
- Image processing libraries
  - opencv
  - SimpleITK

Azure N-Series: VM with GPU

Size	CPU-Core	Memory	Disk	RDMA	GPU
NV6	6	56 GB	380 GB	-	M60 ×1
NV12	12	112 GB	680 GB	-	M60 ×2
NV24	24	224 GB	1.5 TB	-	M60 ×4
NC6	6	56 GB	340 GB	-	K80 ×1
NC12	12	112 GB	680 GB	-	K80 ×2
NC24	24	224 GB	1.5 TB	-	K80 ×4
NC24r	24	224 GB	1.5 TB	InfiniBand	K80 ×4

Linux and Windows

http://aka.ms/azure_gpu

Azure Data Science VM

- Azure Data Science VM come with popular data science libraries preinstalled
  - CUDA/CUDNN/NVIDIA DRIVER
  - CNTK/Tensorflow/Keras
  - Anaconda
  - pandas/numpy/scipy
- Easy to setup
  - Choose N-Series as backend for GPU
- Linux and Windows

https://aka.ms/azure_dsvm_gpu

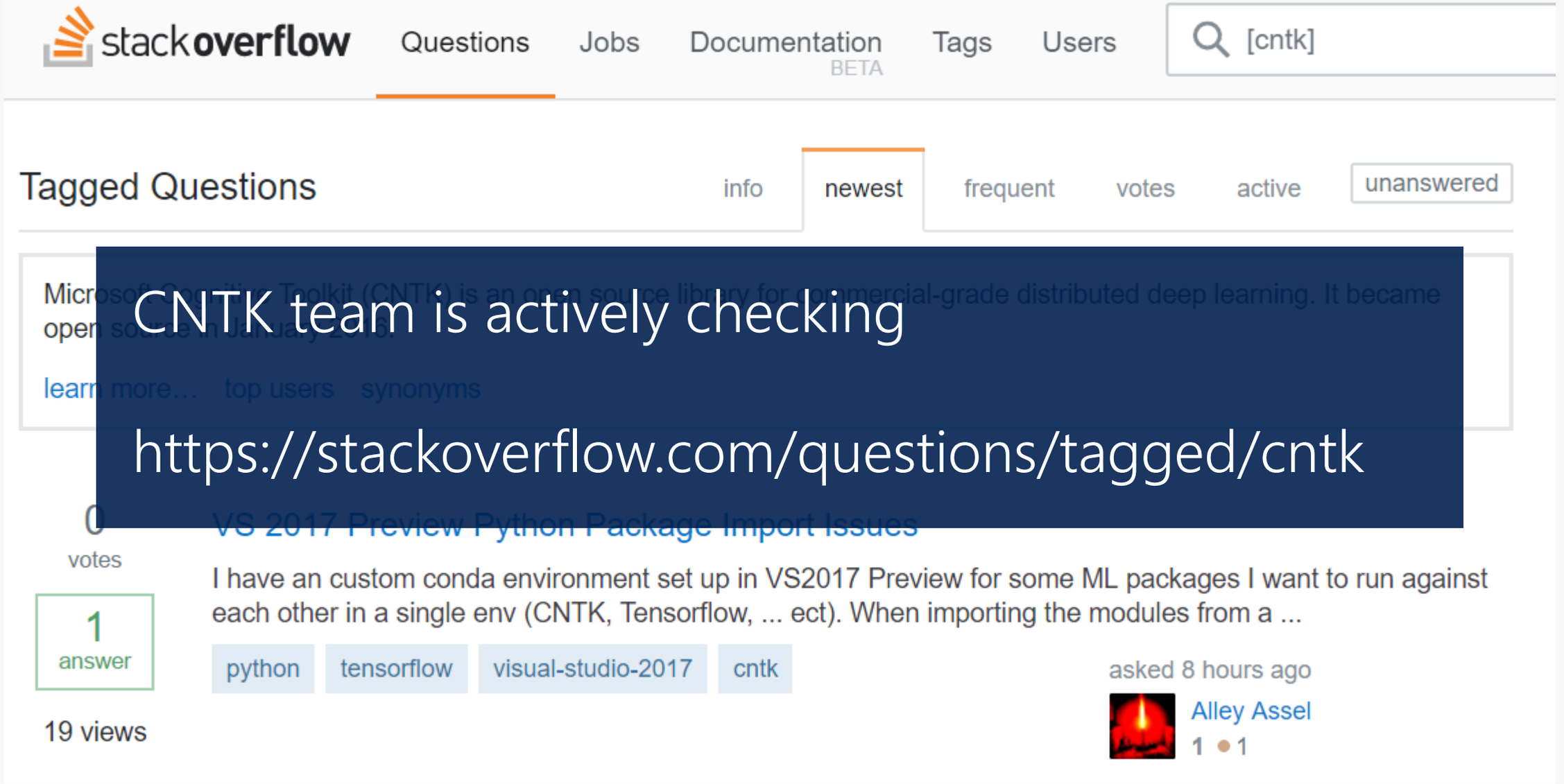
CNTK

CNTK

- Microsoft's open-source deep-learning toolkit
- 1st-class with Python
- 1st-class on Linux and Windows
- Internal = External version

https://github.com/Microsoft/CNTK

Post questions to Stack Overflow!



CNTK v2: Keras support (Beta)

- **Keras** is a popular frontend for deep learning frameworks
  - Python
  - Can define deep learning models in a friendly syntax
  - Support CNTK/tensorflow/theano backends
- **NOTE**: CNTK Keras support is just released and still beta. CNTK team is actively working on for improvements.

https://aka.ms/keras_cntk

Keras: Switching backend

- Environment variable
  - KERAS_BACKEND=CNTK
  - KERAS_BACKEND=tensorflow
  - KERAS_BACKEND=theano
- Or, ~/.keras/keras.json
  - { "image_data_format": "channels_last", "epsilon": 1e-07, "floatx": "float32", "backend": “cntk" }

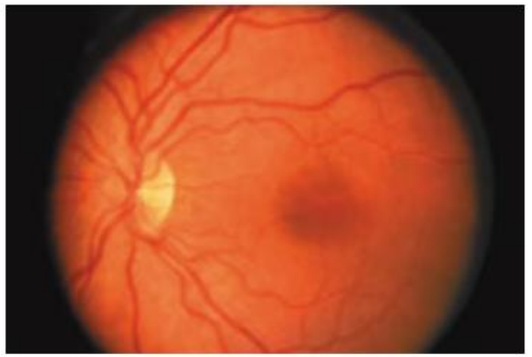
No need to change frontend codes

https://keras.io/backend/

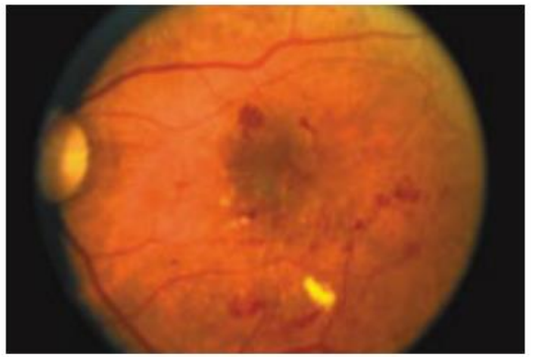
Example 1: Diabetic Retinopathy

Diabetic Retinopathy (DR)

- Common eye disease for diabetes patients
- High blood sugar levels cause damage to blood vessels in the retina.
- Causes blurry vision and vision loss



A normal retina.

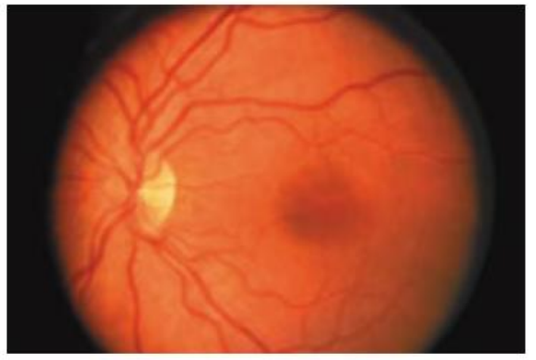


A retina showing signs of diabetic retinopathy.

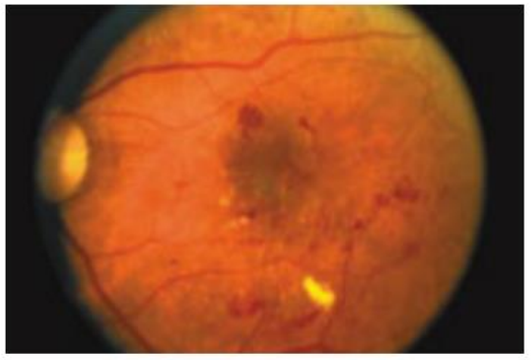
https://www.aao.org/eye-health/diseases/what-is-diabetic-retinopathy

DR: Severity Scale

- 0: No Diabetic Retinopathy
- 1: Mild
- 2: Moderate
- 3: Severe
- 4: Proliferative Diabetic Retinopathy



A normal retina.



A retina showing signs of diabetic retinopathy.

http://www.icoph.org/downloads/Diabetic-Retinopathy-Scale.pdf

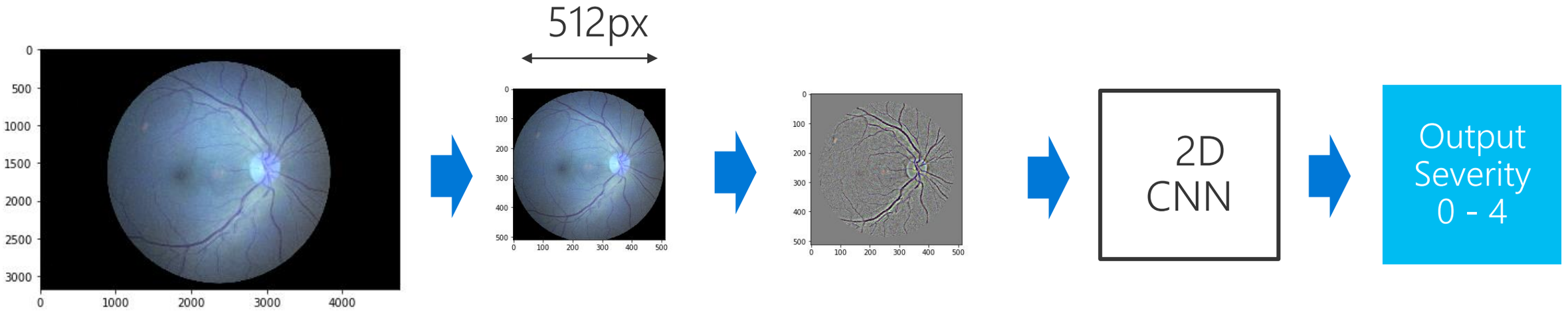
Explore data sets

- See Jupyter notebook
- https://github.com/usuyama/pydata-medical-image/blob/master/diabetic_retinopathy/notebooks/0_DR_explore.ipynb

Example 1: Diabetic Retinopathy Detection

- Input
  - Retina Image (Fundus Photography)
  - JPEG, no metadata
- Output
  - Severity
    - 0 - No DR
      1 - Mild
      2 - Moderate
      3 - Severe
      4 - Proliferative DR
- Data set
  - Kaggle Competition (Feb, 2015)
  - https://www.kaggle.com/c/diabetic-retinopathy-detection/data

Method overview



Raw Image
~ 3000px x 4000px

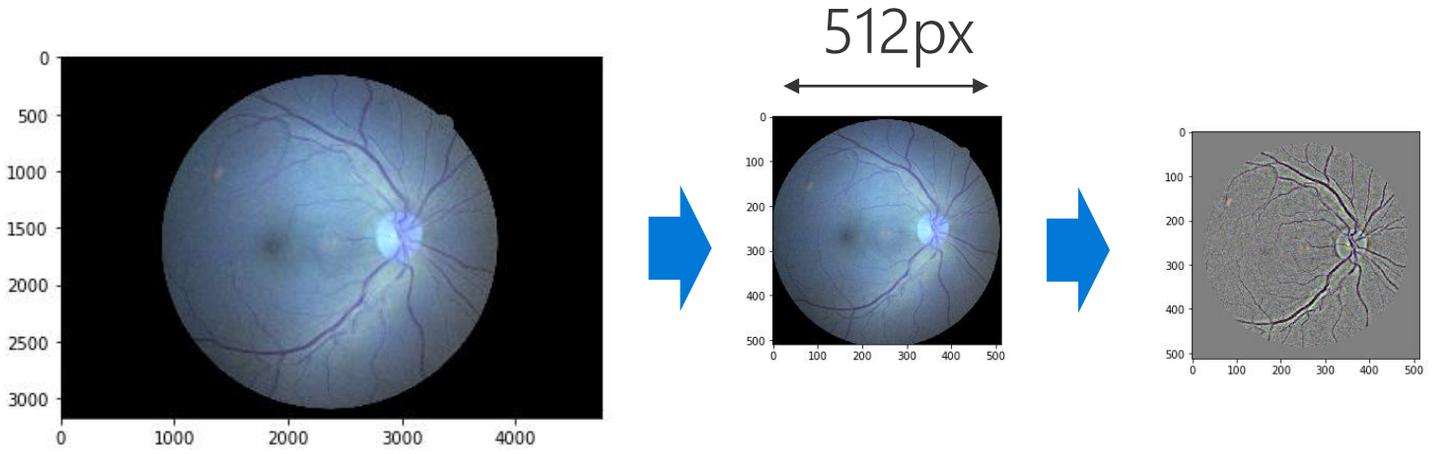
Resize and crop

Standardization

DR: Preprocess

https://github.com/usuyama/pydata-medical-image/blob/master/diabetic_retinopathy/notebooks/1_preprocess.ipynb

- Crop and resize to 512x512 (**`cv2.resize`**)
- Subtract local average
  - **`cv2.GaussianBlur`** and **`cv2.addWeighted`**



Raw Image

~ 3000px x 4000px

Standardization

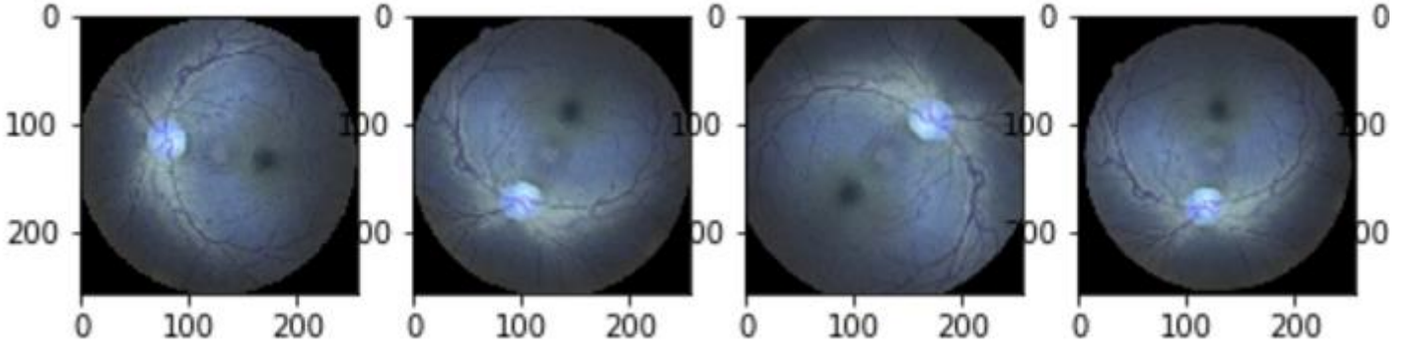
Dr. Graham's Report: https://kaggle2.blob.core.windows.net/forum-message-attachments/88655/2795/competitionreport.pdf

DR: Data Augmentation

- Deep learning requires large datasets for generalization ability
- "Augment" images by random transformation
  - Ex: Rotate, Flip, Scale (Zoom), etc.
  - Can be more creative!
- The model will be invariant to these transformations

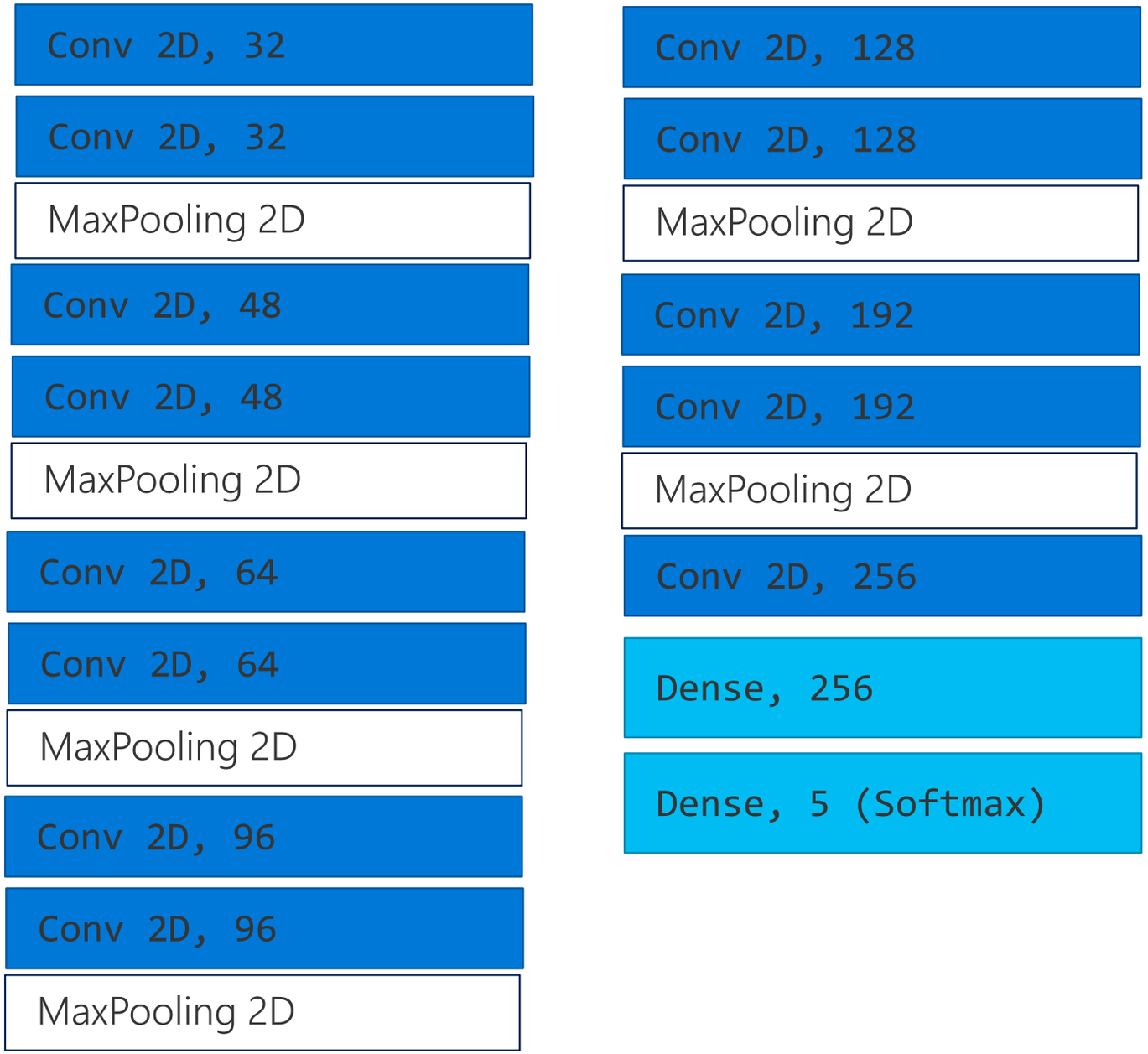
https://github.com/aleju/imgaug

Keras: ImageDataGenerator



2D CNN

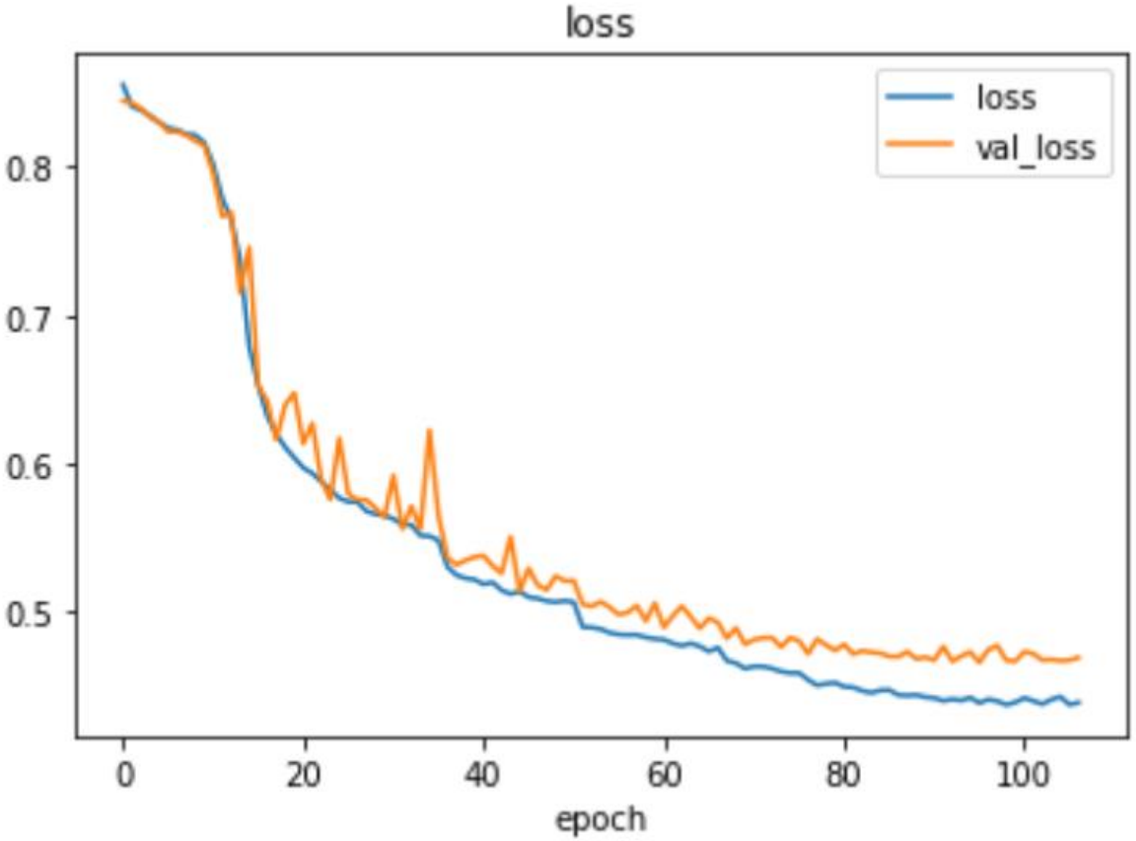
- VGG-like
- Input Shape=(512, 512, 3)
- Conv2D
  - Kernel = (3, 3)
- MaxPooling2D
  - Stride= (2, 2)

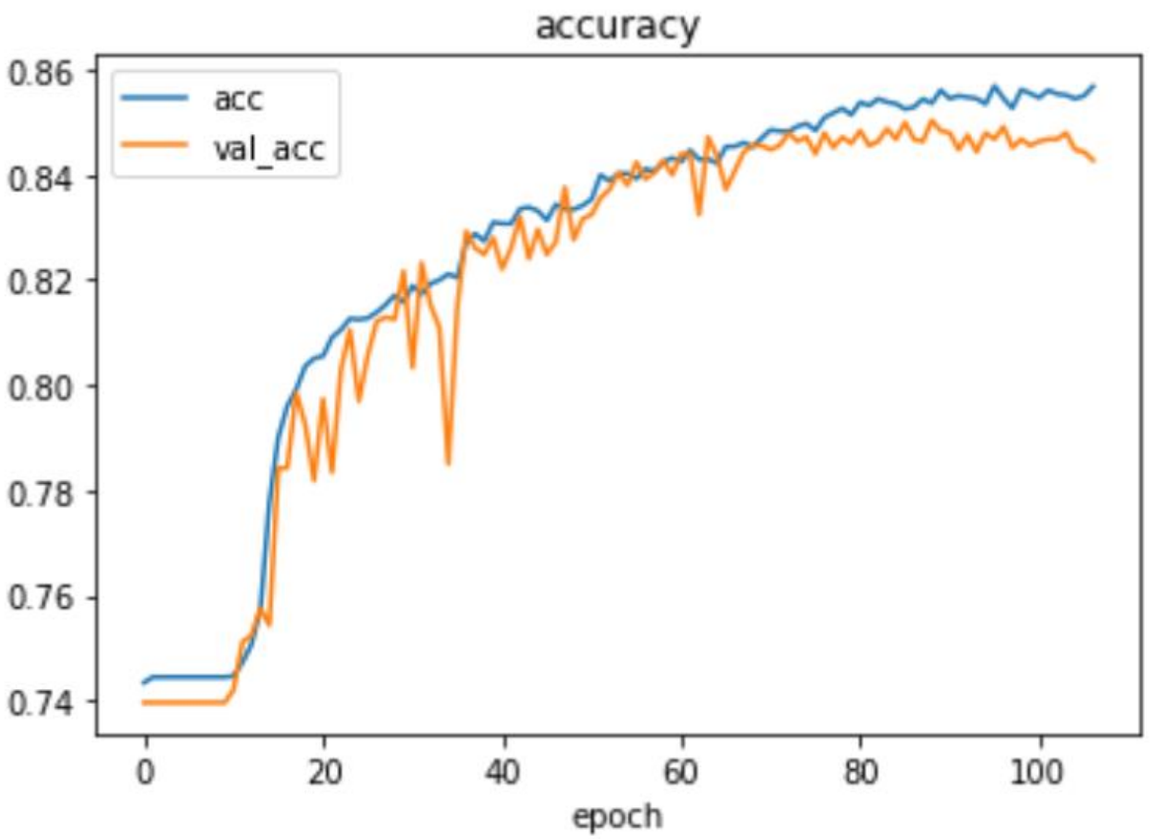


Training

- https://github.com/usuyama/pydata-medical-image/blob/master/diabetic_retinopathy/notebooks/2_Train-Predict-2D-CNN.ipynb

Training: Learning Curve



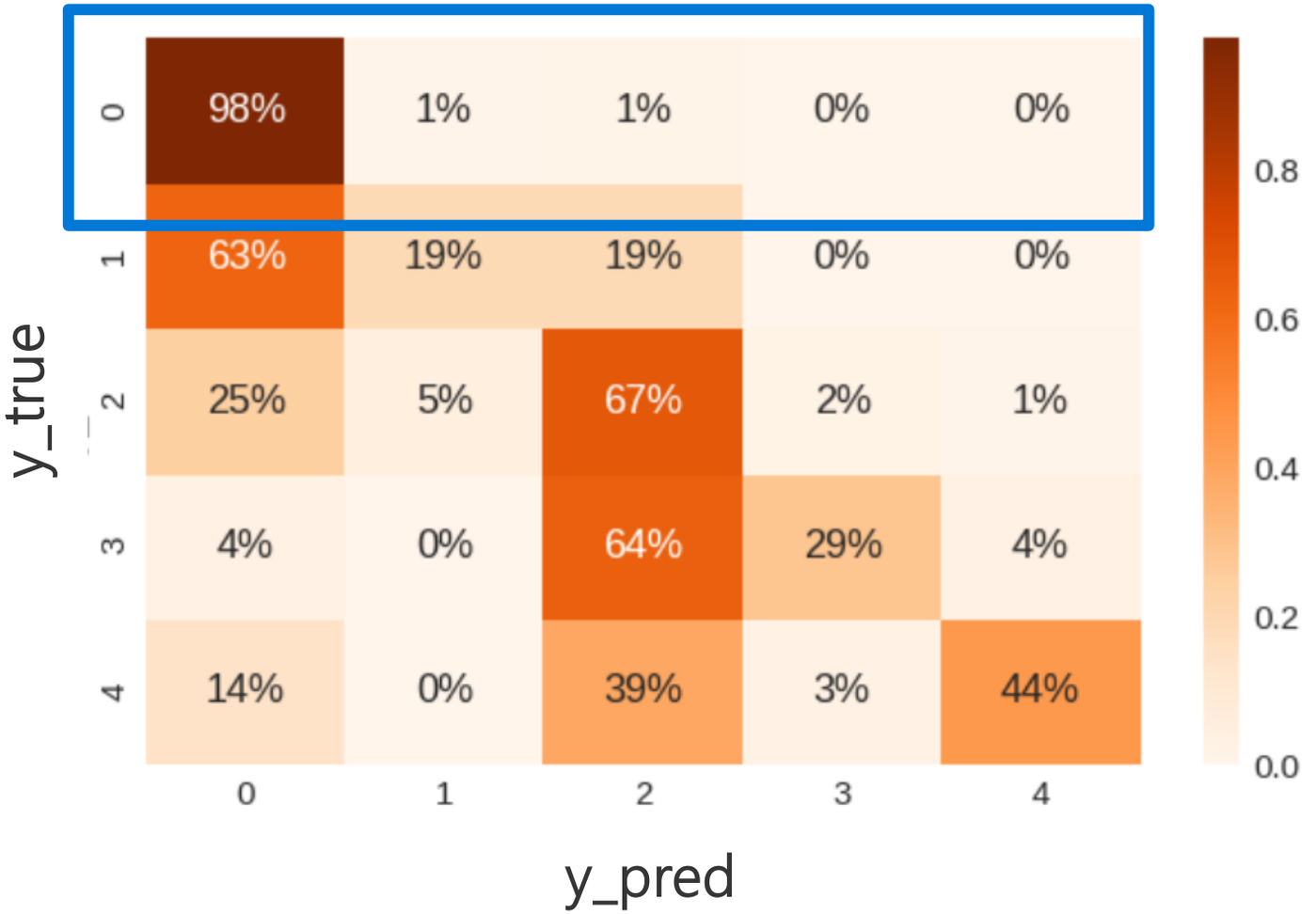


Training took ~1.5 days using GTX 1080 Ti

Epoch: 1 pass of training set

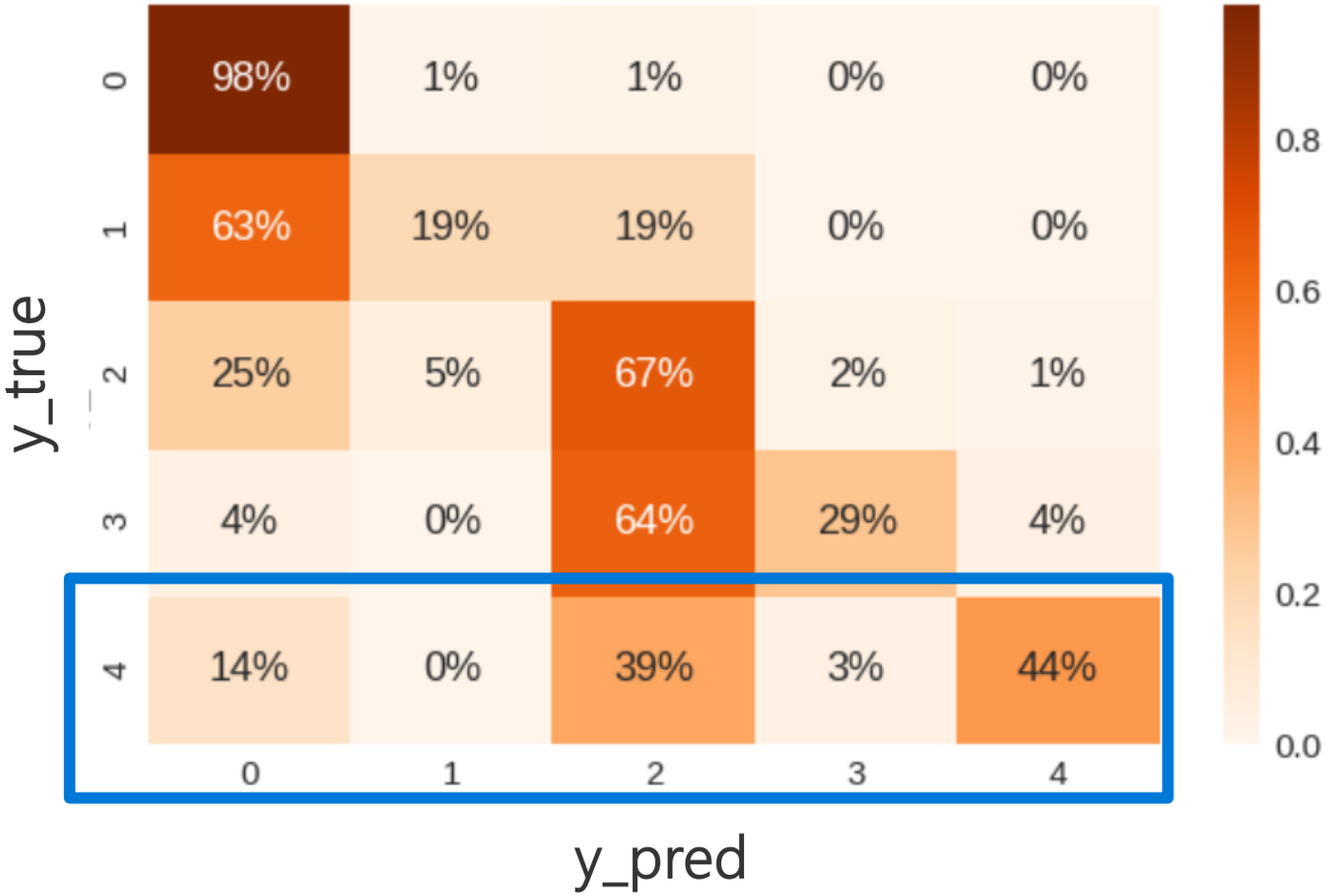
Result: Confusion Matrix

- Correct answer rate
- Many misclassifications in the lower left:
  - Predicted less severe than actual



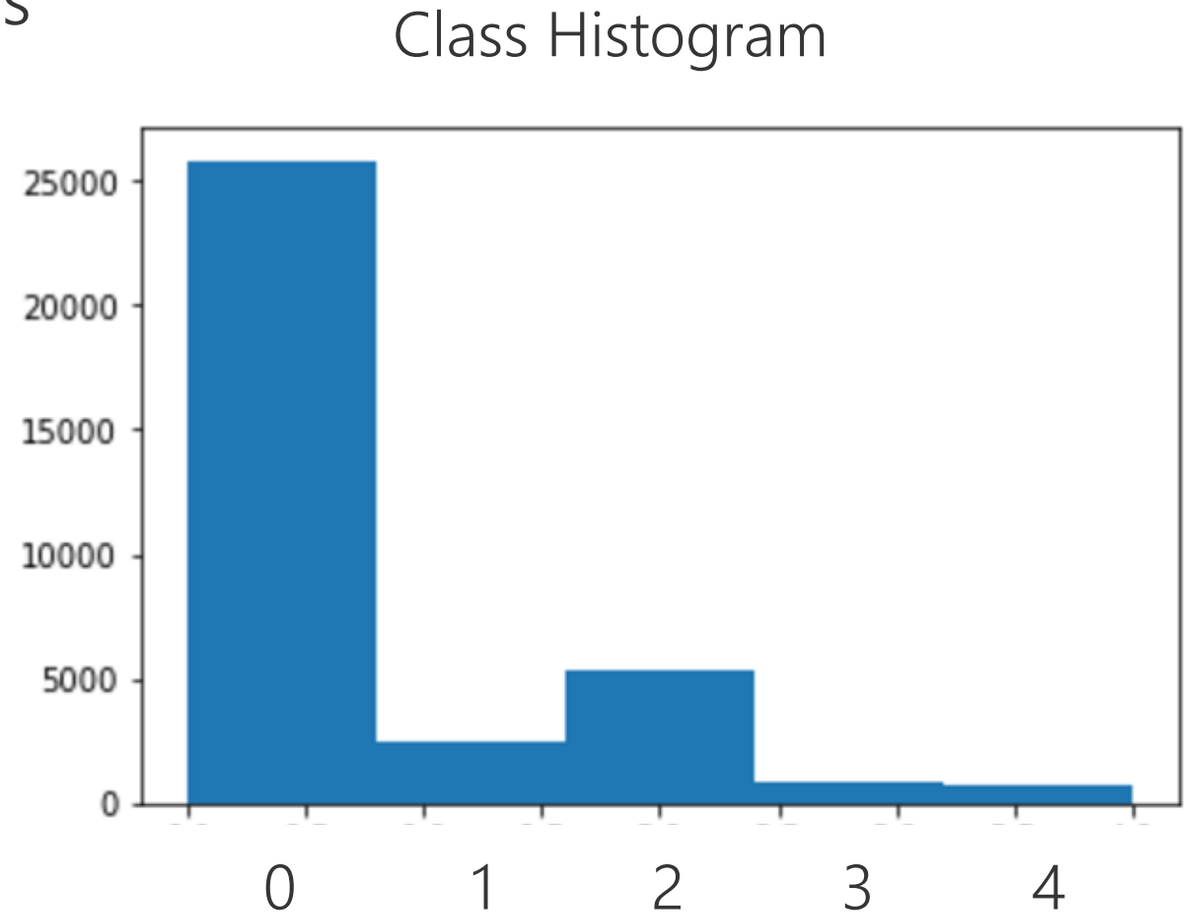
Result: Confusion Matrix

- Correct answer rate per class
- Many misclassifications in the lower left:
  - Predicted less severe than actual



Next Step: Tackling Class Imbalance

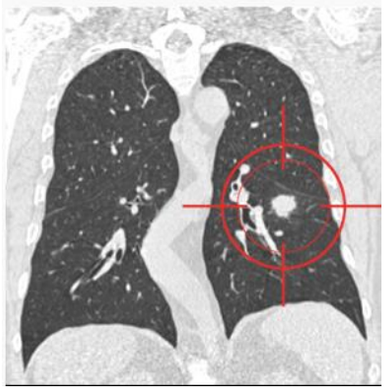
- Resampling
  - Oversample from less frequent classes
- Weighted loss function
  - Higher penalty for rare classes
  - Higher penalty for severe classes
- Create ‘0 vs other’ classifier
  - Then, create 2nd classifier for 1-4



Example 2: Lung Nodule

Lung Nodule

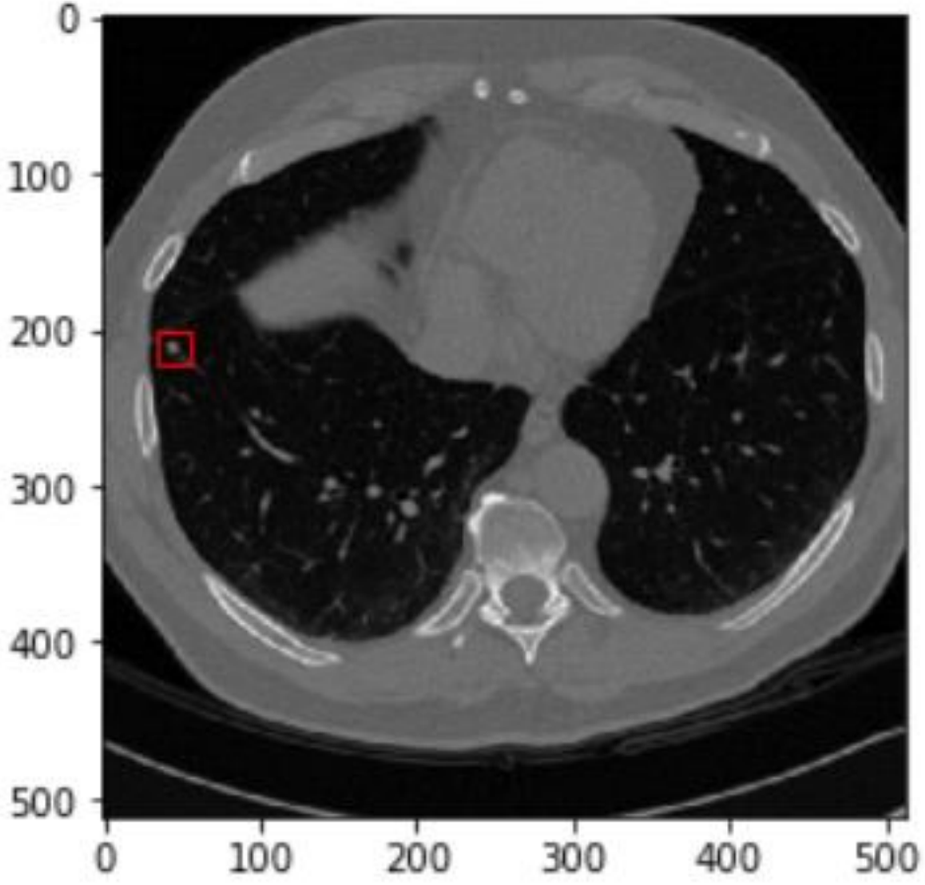
- Lung nodules are small masses of tissue in the lung
- They appear as round, white shadows on CT Scan
- About 0.2 inch (5 millimeters) to 1.2 inches (30 millimeters)
- Not always malignant, but needs monitoring for growth

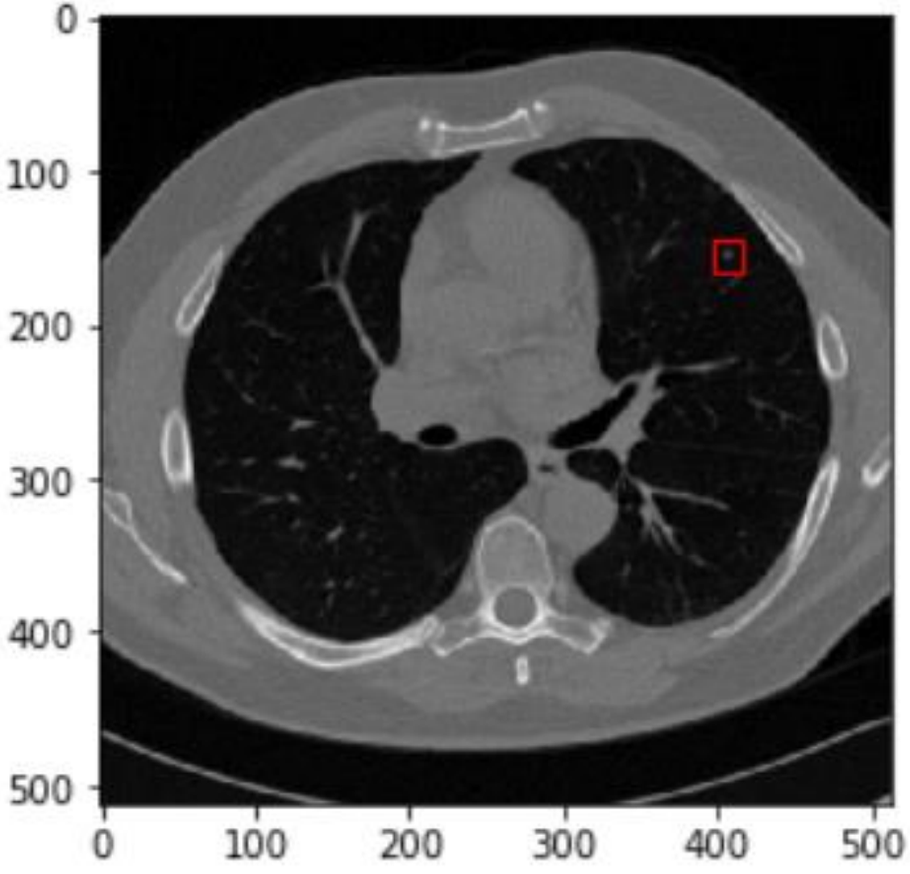


http://www.mayoclinic.org/diseases-conditions/lung-cancer/expert-answers/lung-nodules/faq-20058445

Lung Nodule

a needle in a haystack



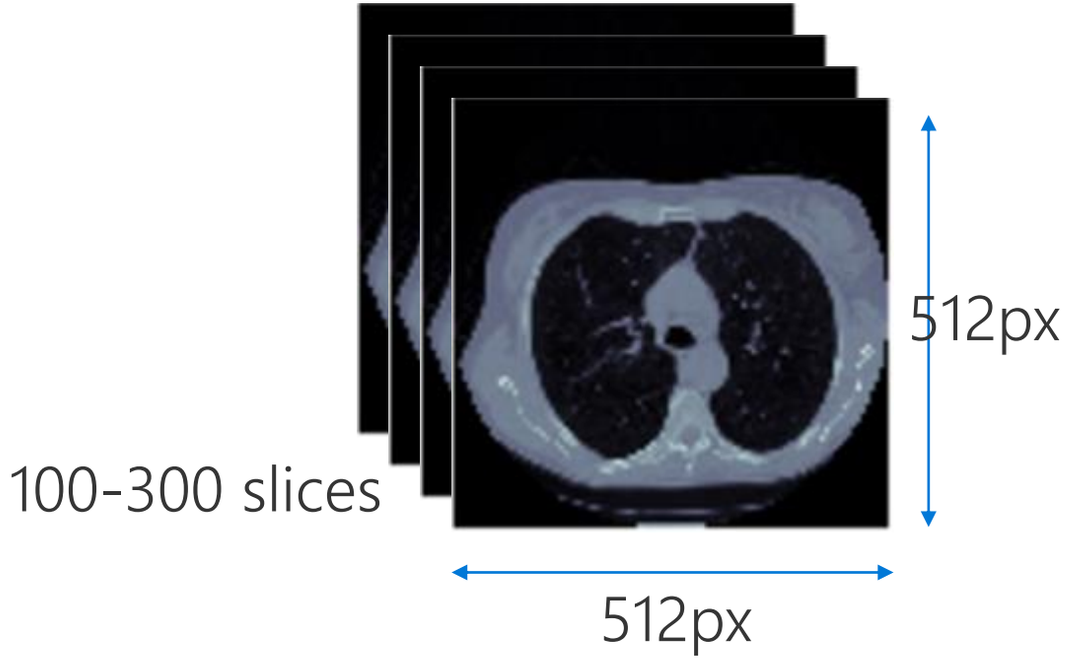


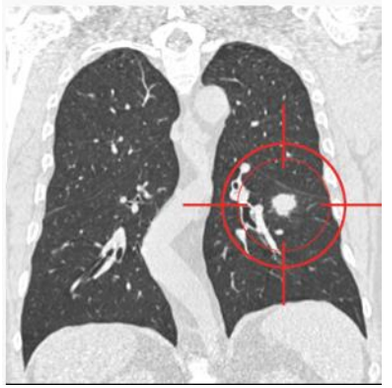
Explore

- See Jupyter Notebook
- https://github.com/usuyama/pydata-medical-image/blob/master/lung_nodule/notebooks/0_LUNA_explore.ipynb

Example 2: Lung Nodule Detection

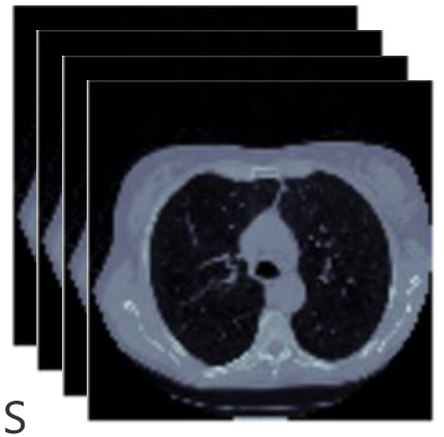
- Input
  - Lung CT Scan
    - 100-300 Slices per patient
    - Slice: (512px, 512px)
- Output
  - Detect lung nodule location
- Dataset
  - LUNA16 (https://luna16.grand-challenge.org/)





Method Overview

CT Scan

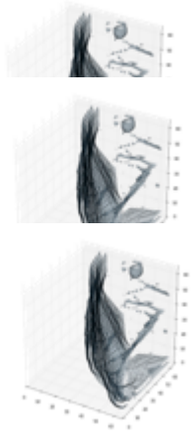


100-300 slices

512

512

Small 3D Cube (48mm x 48mm x 48mm)



3D CNN

Probability of containing a lung nodule

Prediction

Sliding Window over the CT Scan

3D Probability Map

Preprocess: Rescale to 1mm resolution

- Slice thickness and resolution vary from sample to sample
- New slice thickness and spacing
  - (1mm, 1mm, 1mm)
- Nodule size matters

```
voxel_spacing = SimpleITK.ReadImage(img_file) # spacing of voxels in mm
# […] calculate resize factor from spacing to (1mm, 1mm, 1mm)
resized_img = scipy.ndimage.interpolation.zoom(img, resize_factor, mode='nearest')
```

https://github.com/usuyama/pydata-medical-image/blob/master/lung_nodule/scripts/preprocess.py

Normalize: Hounsfield Scale

- The values in LIDC data are Hounsfield Scale
  - https://en.wikipedia.org/wiki/Hounsfield_scale
- Normalize the values to 0 – 1

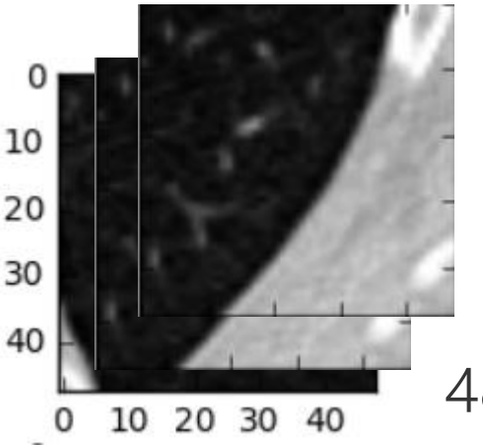
```
MIN_BOUND = -1000.0
MAX_BOUND = 400.0

mage = (image - MIN_BOUND) / (MAX_BOUND - MIN_BOUND)
image[image > 1.0] = 1.0
image[image < 0.0] = 0.0
```

Substance	HU
Air	−1000
Lung	-700 to −600[2]
Fat	−120 to −90[3]
Chyle	−30[4]
Water	0
Urine	-5 to +15[3]
Bile	-5 to +15[3]
CSF	+15
Kidney	+20 to +45[3]
Lymph nodes	+10 to +20[5]
Blood	+30 to +45
Muscle	+35 to +55[3]
White matter	+20 to +30
Grey matter	+37 to +45
Liver	+40 to +60
Soft Tissue, Contrast	+100 to +300
Bone	+700 (cancellous bone) to +3000 (cortical bone)

Extracting Small 3D cube

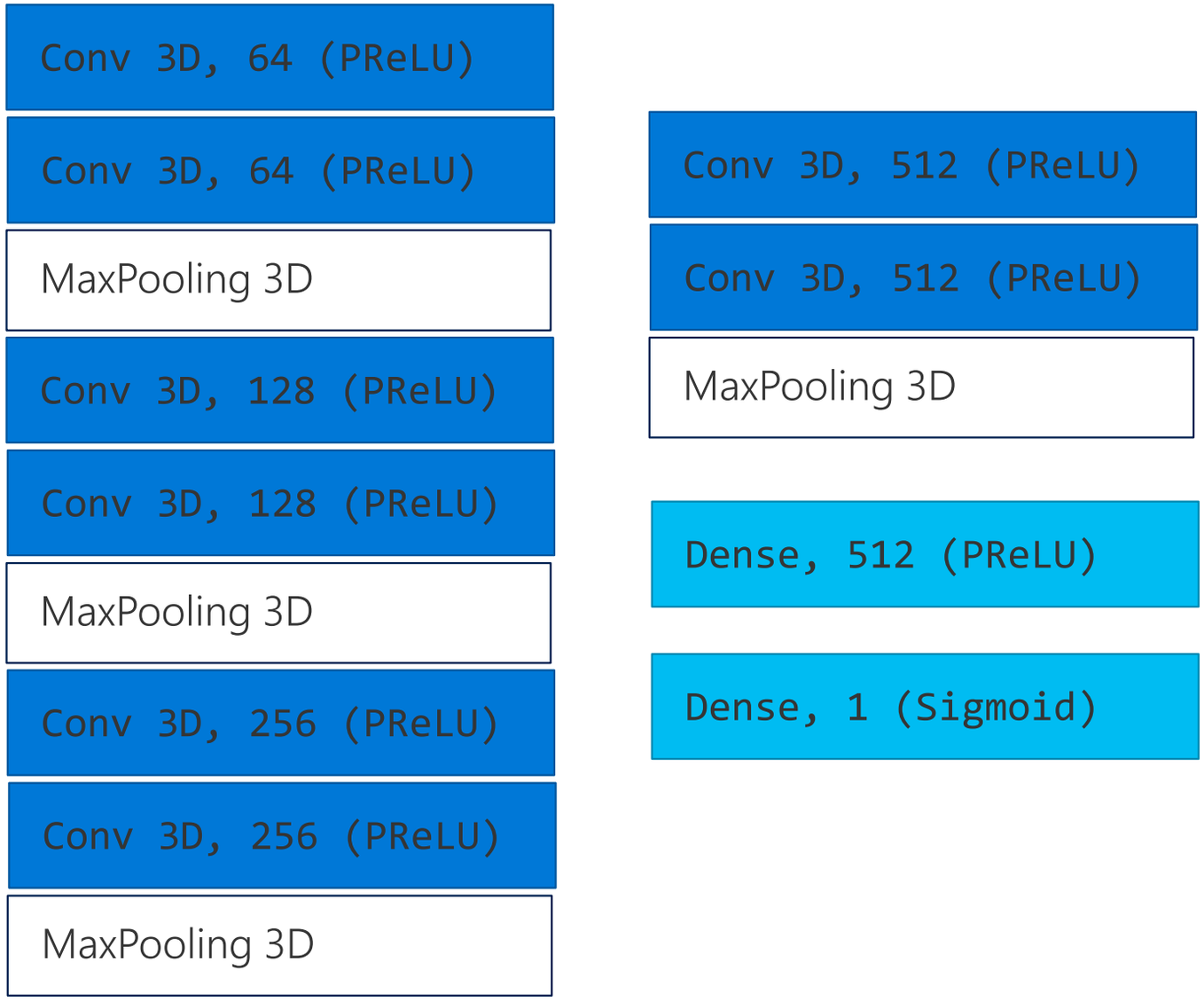
- The whole CT scan is too large for GPU memory
- Small 3D Cube as 3D-CNN input
  - (48mm, 48mm, 48mm)
- Positive samples around annotated lung nodules
- Negative samples
  - Pick positions randomly
  - Avoid annotated lung nodules



48 slices

3D-CNN

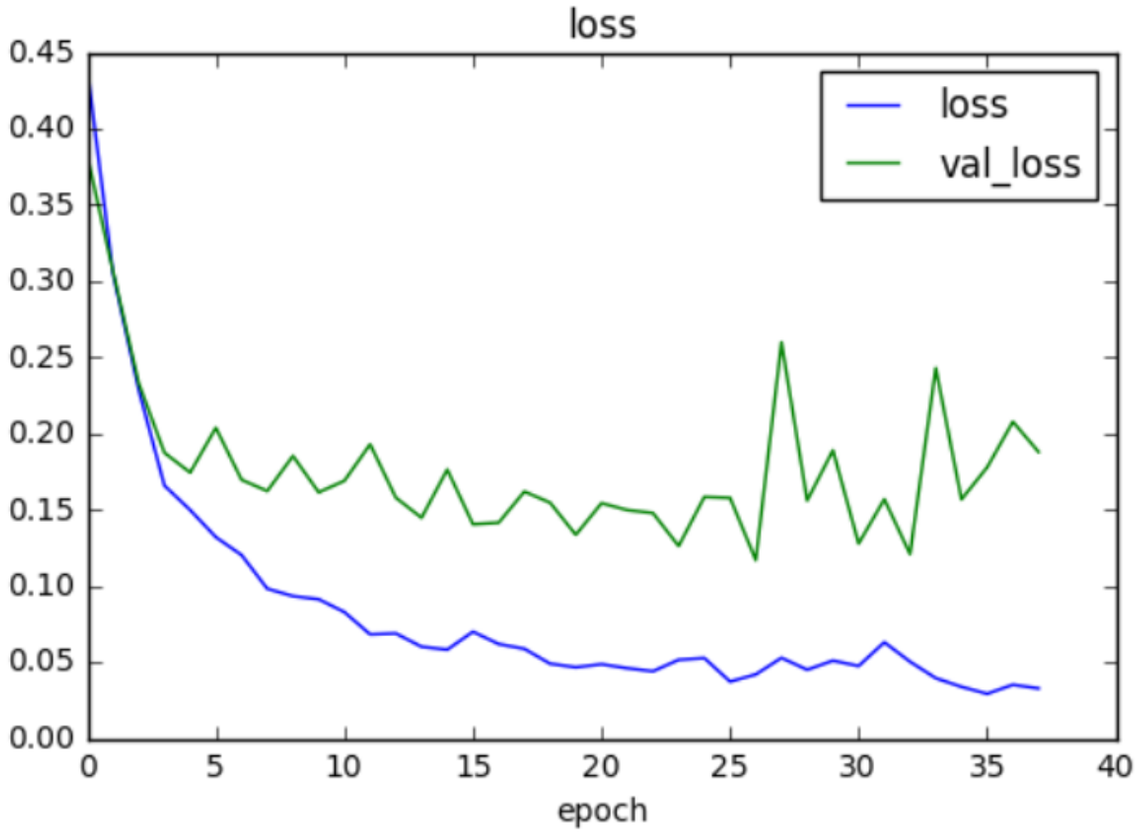
- VGG-like
- Conv3D
  - kernel = (3, 3, 3)
- MaxPooling3D
  - Stride= (2, 2, 2)

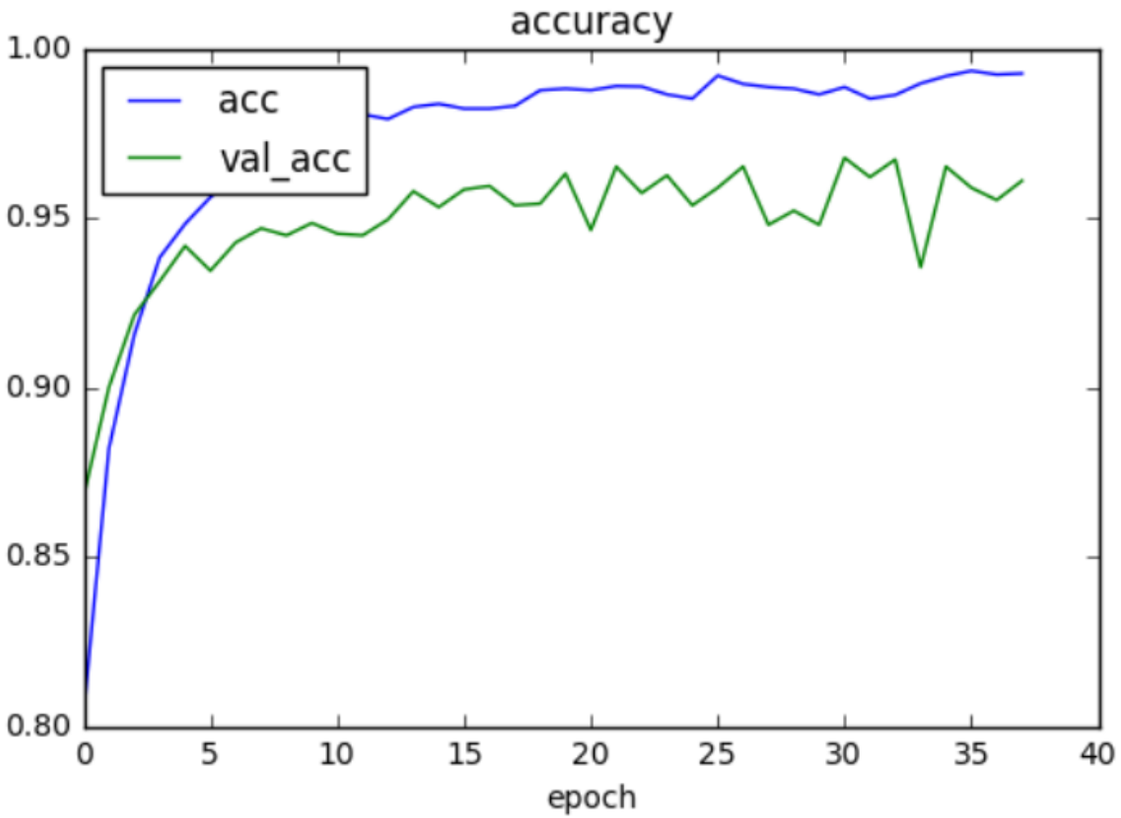


Training

- https://github.com/usuyama/pydata-medical-image/blob/master/lung_nodule/notebooks/1_train_3D-CNN.ipynb

Training: Learning Curve

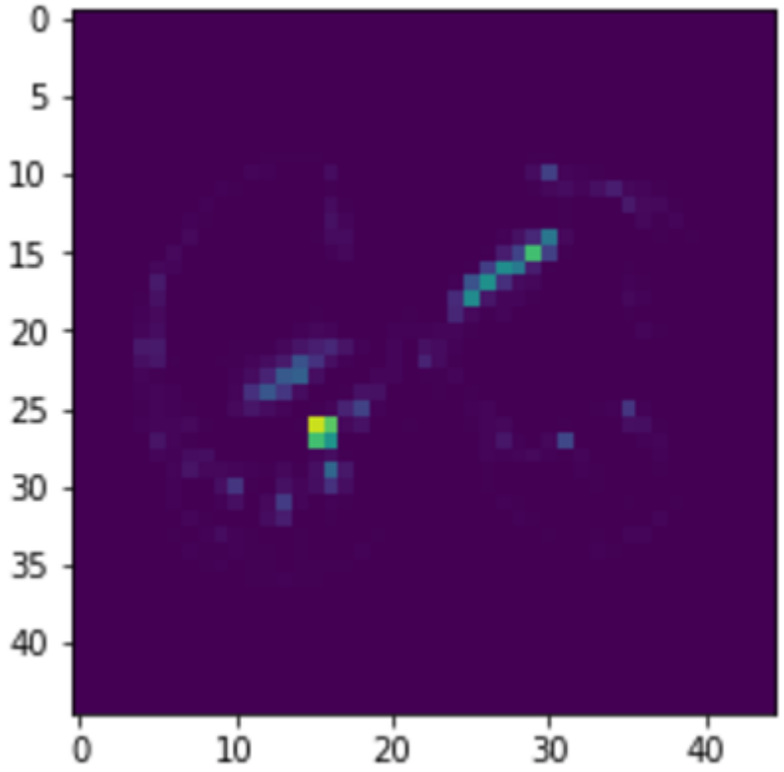




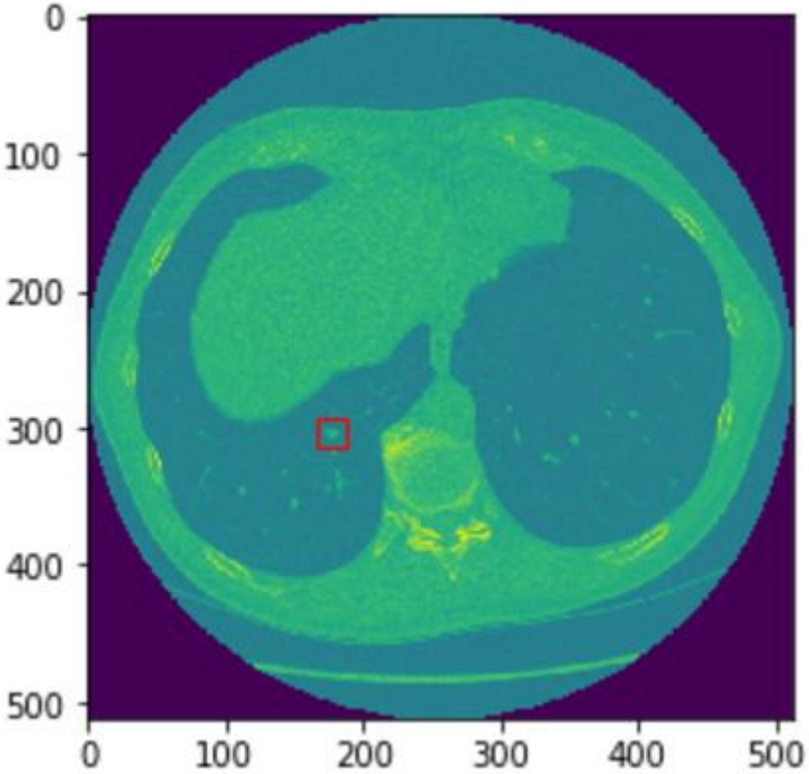
Training took ~12 hours using Tesla K80
Epoch: 1 pass of training set

Prediction

- Sliding Window over the CT scan images



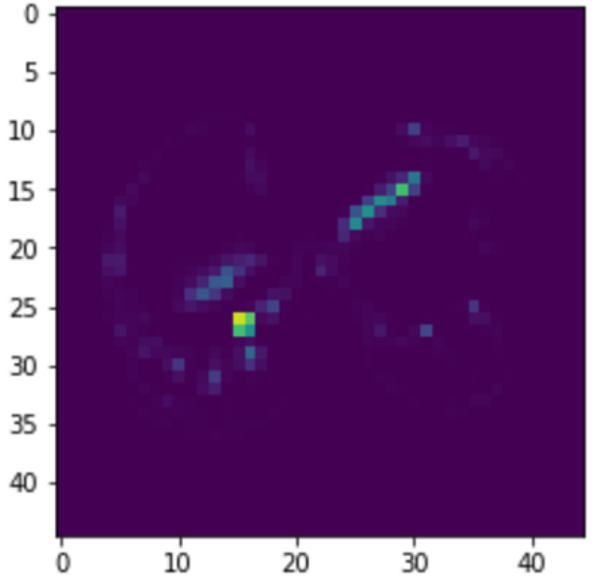
Prediction (Probability Map)



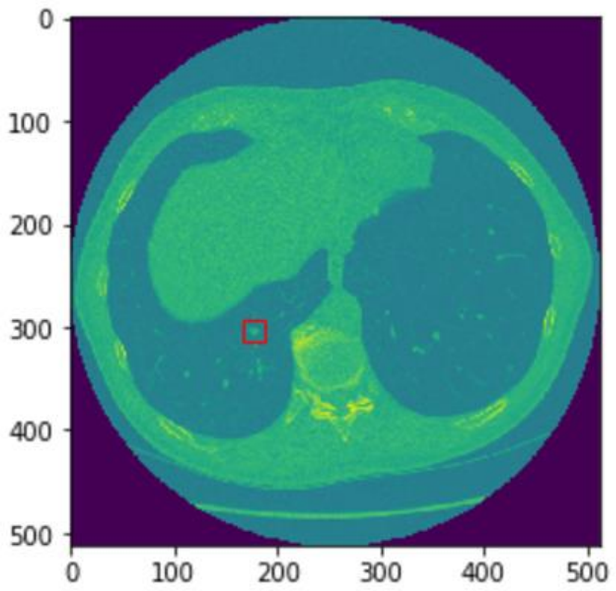
Ground Truth

Next Step: Hard negative mining

- Collect false positives
- Restart the training with the collected false positives



Prediction



Ground Truth

Summary

- MSR Healthcare team and HealthVault
- CNTK with Keras (Beta)
- Tutorials: Medical Image Processing
  - Diabetic retinopathy classification using 2D CNN
  - Lung nodule detection using 3D CNN

https://aka.ms/pydata-medical-image

MSR Healthcare Team is hiring!
https://aka.ms/msr_health_jobs

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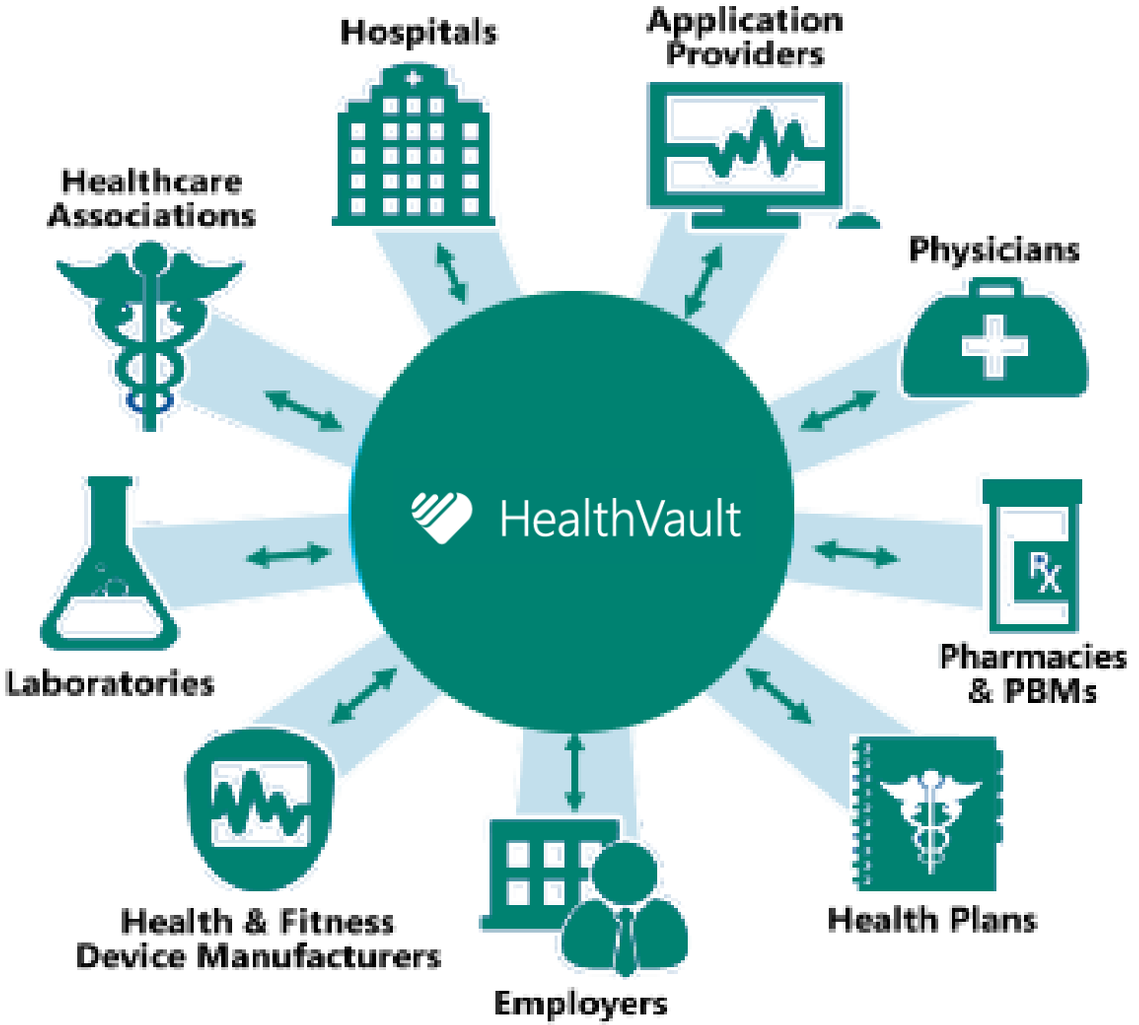
https://aka.ms/msr_health_jobs



Microsoft

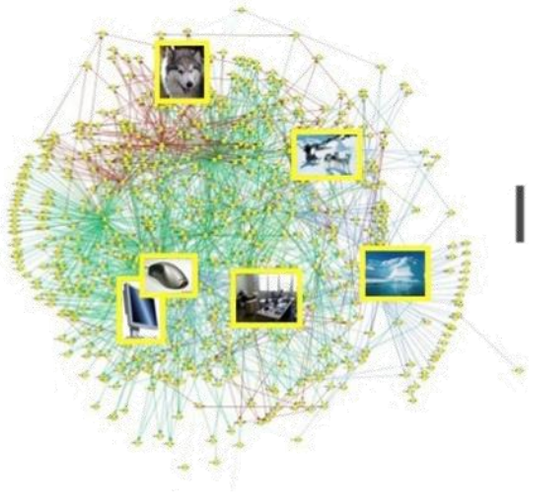
Deep Learning Courses

- Deep Learning Explained
  - https://www.edx.org/course/deep-learning-explained-microsoft-dat236x
- Stanford cs231n by Fei-Fei Li
  - http://cs231n.stanford.edu/
- Deep Learning (book)
  - http://www.deeplearningbook.org/

NVIDIA GPU Overview

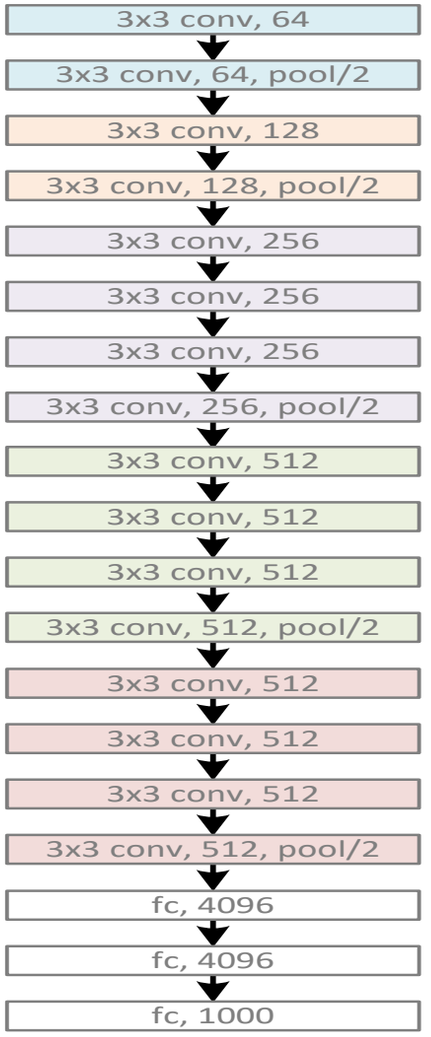
Very Deep Network (2014)

VGG, 19 layers
(ImageNet 2014)



IMAGENET

http://www.robots.ox.ac.uk/~vgg/practicals/cnn/



Ideas for improvements

- Test time augmentation
- Model averaging
- For Diabetic Retinopathy example, frame the problem as regression problem because the output is ordinal
  - Mean Squared Error for loss function
- Debug the model
  - Check the false positives and false negatives
  - Visualize the parameters/filters

Ideas for improvements

- Hyper parameter tuning
  - Learning rate
  - # of layers
  - Kernel size
  - Other optimizers
  - Etc.
  - Other layers
    - Dropout Layer
    - Batch Normalization Layer
    - Advanced activations like LeakyReLU and PReLU

Keras backend benchmark

Non-official benchmarks

Accuracy

Validation accuracy after 20 epochs

Backend	K80	Titan X	1080 Ti
Theano		**0.9843**	**0.9843**
TensorFlow	**0.9839**	0.9804	0.9840
CNTK	0.9796	0.9835	0.9830

Speed

Average time in seconds for 20 epochs

Backend	K80	Titan X	1080 Ti
Theano		20.0 (14.3x)	3.6 (2.8x)
TensorFlow	3.4 (1.2x)	2.8 (2.0x)	1.9 (1.5x)
CNTK	**2.8**	**1.4**	**1.3**

NOTE: CNTK Keras support is just released and still beta. CNTK team is actively working on for improvements.

- http://minimaxir.com/2017/06/keras-cntk/
- https://github.com/szilard/benchm-dl/blob/master/keras_backend.md