Predicting ejection rate in cardiac MRI

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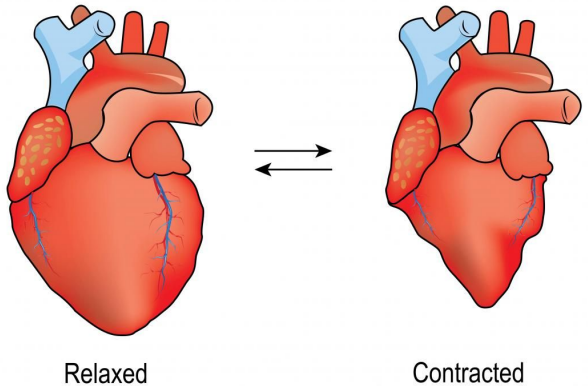
Motivation

Heart volume ratio is an indicator of cardiac disease

Left ventricle

- *Diastole volume* (relaxed, max volume)
- *Systole volume* (contracted, min volume)



Calculate *ejection rate*:

$$\text{Ejection rate: } ER = \frac{V_D - V_S}{V_D}$$

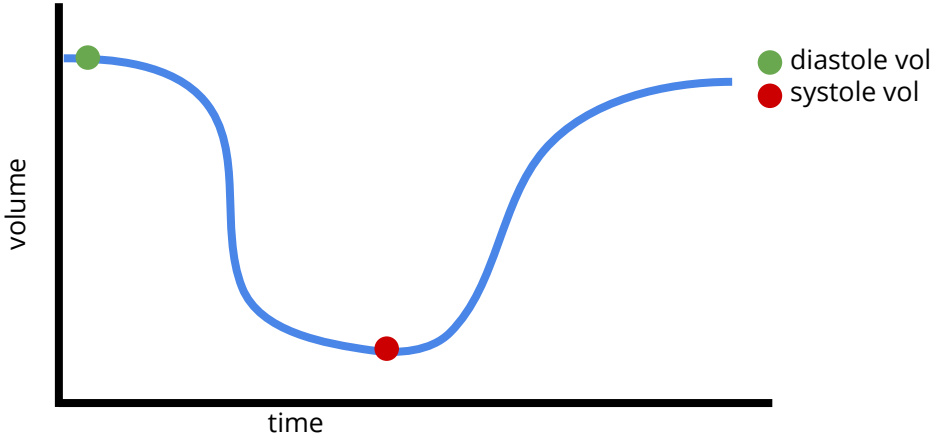
Figure source:
https://www.medicalnewstoday.com/articles/321447.php

Goal

Segment out left ventricle (ROI)

Calculate volume for each timestep

Calculate ejection rate from systole- and diastole volume



Dataset

Source: Kaggle competition
Second Annual Data Science Bowl, 2017

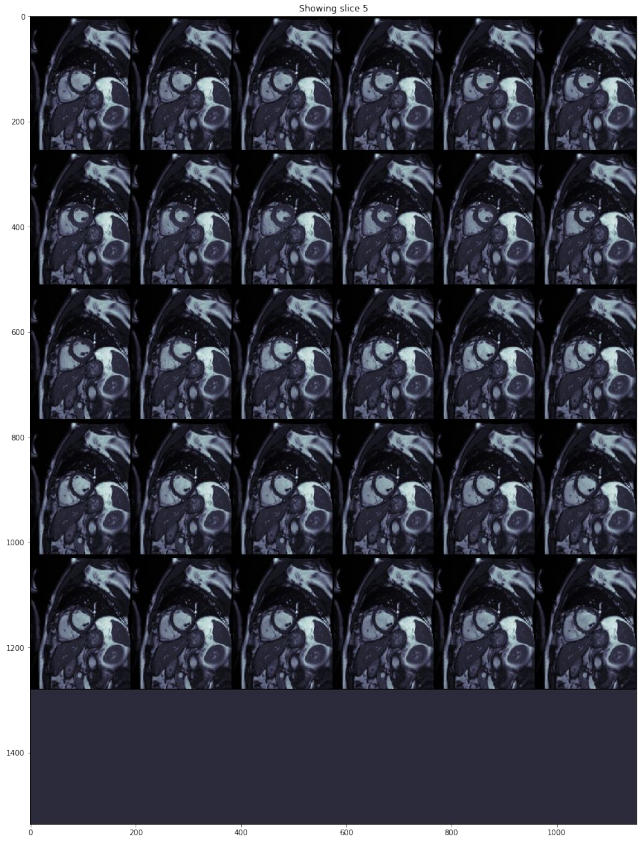
500 DICOM 4D cardiac images

- 3D images over a heartbeat cycle
- DICOM metadata

30 GB data (compressed)

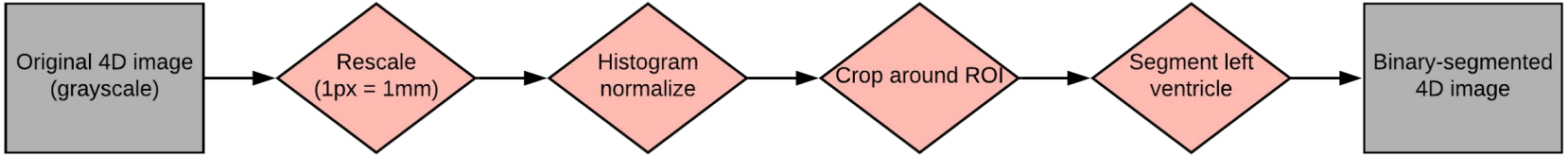
Non-standardized dataset
(different hospitals)

https://www.kaggle.com/c/second-annual-data-science-bowl

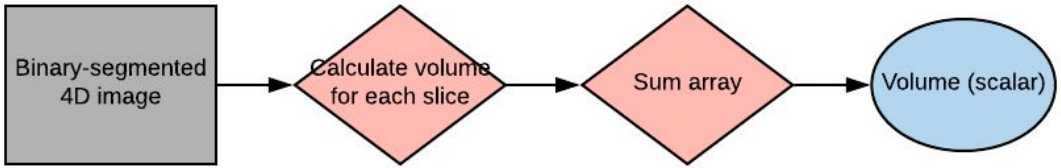


Pipeline overview

Preprocessing (streamline 4D images)



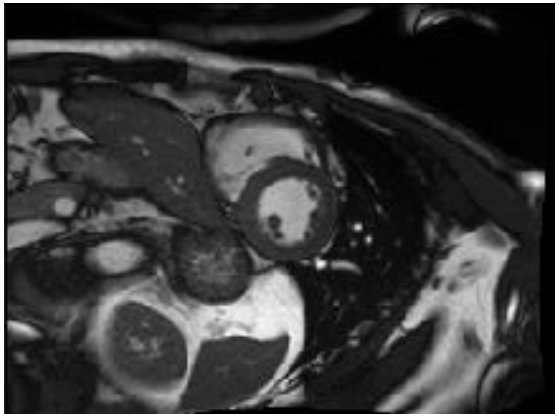
Volume calculation (calculate volume for each patient, no ML)

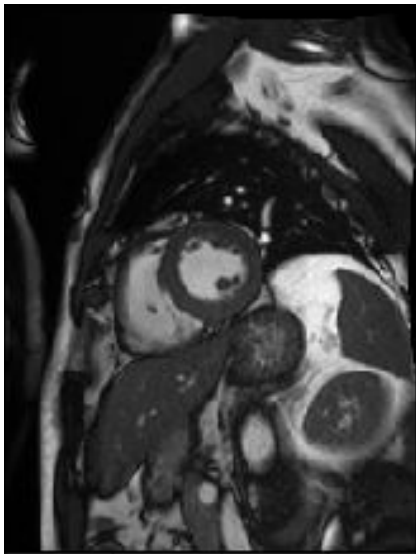


Preprocessing - scale and orientation

Using DICOM metadata

- Scale (ensure 1 pixel = 1 sq. mm)
- Rotation axis

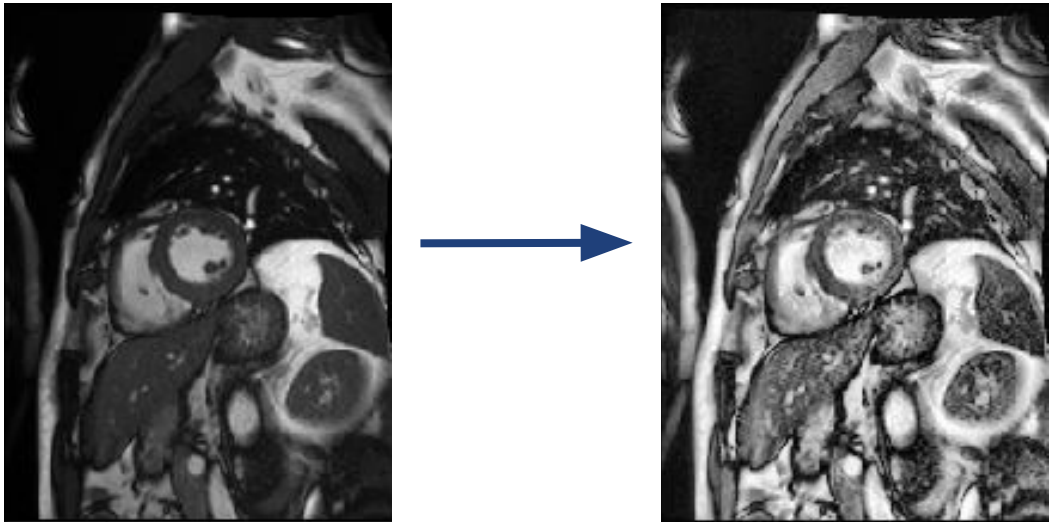




Preprocessing - intensity normalization

Apply histogram normalization

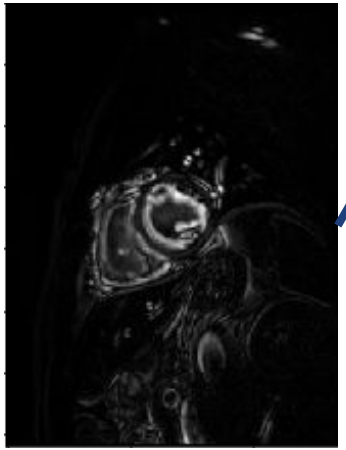
Ensures ROI will look similar across patients



Preprocessing - identifying ROI

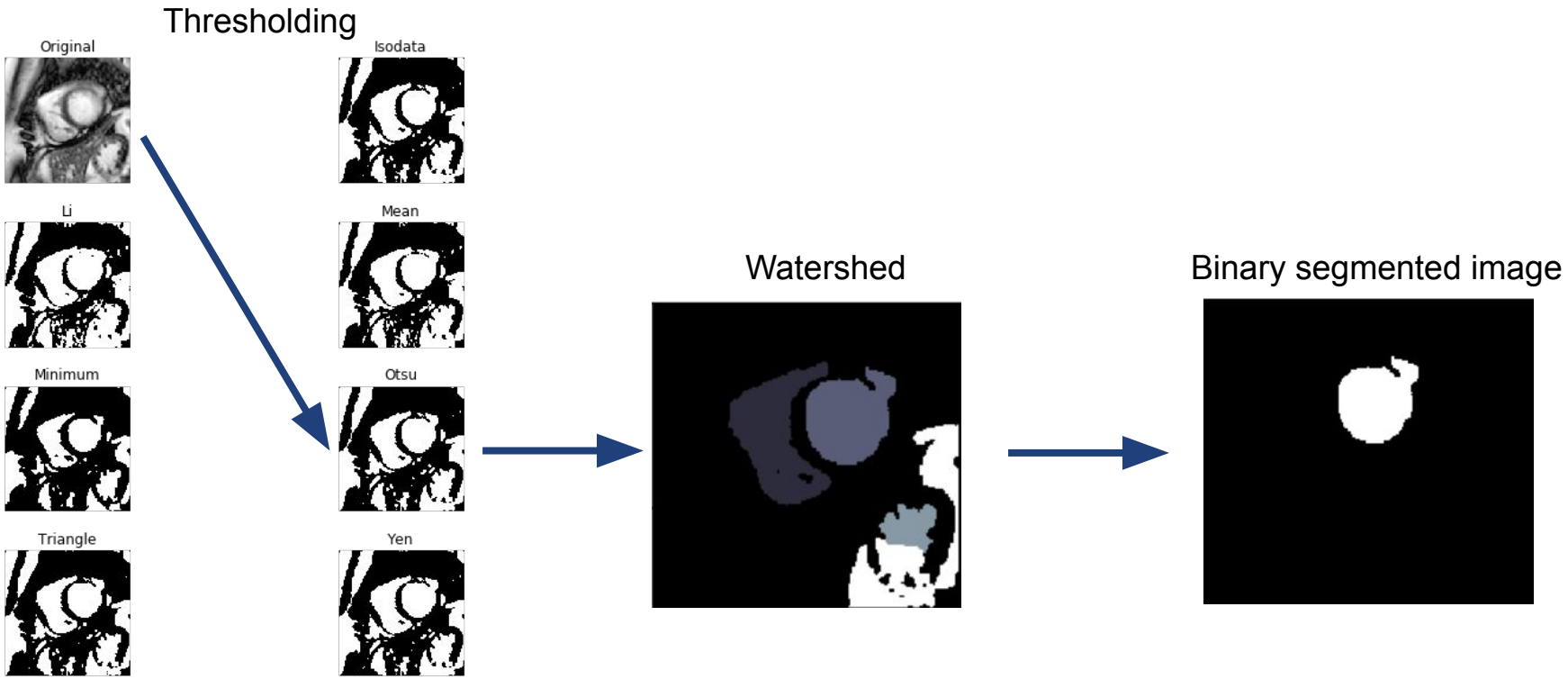
Normalized img

Coords of ROI
(using FFT)

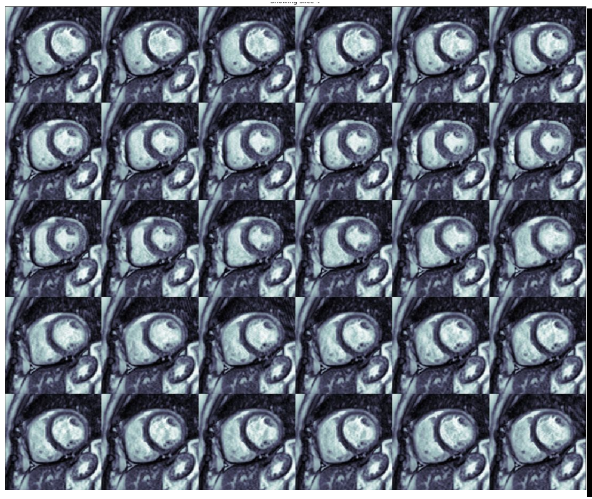


Cropped, squared image

Preprocessing - segmentation

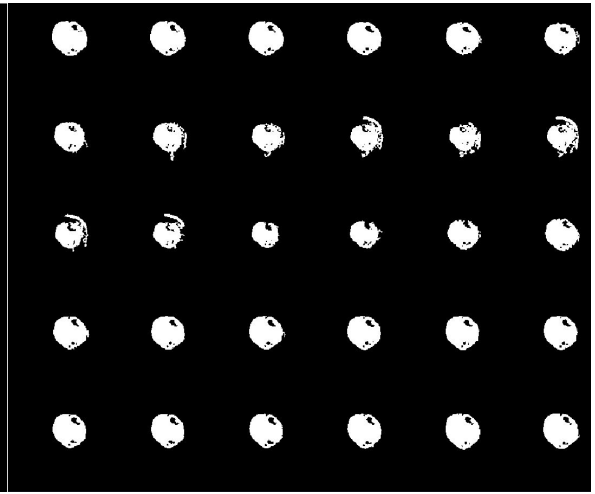


Preprocessing - segmentation example



Histogram-normalized img

Watershed



Binary-segmented img
(left ventricle)

Calculating volume

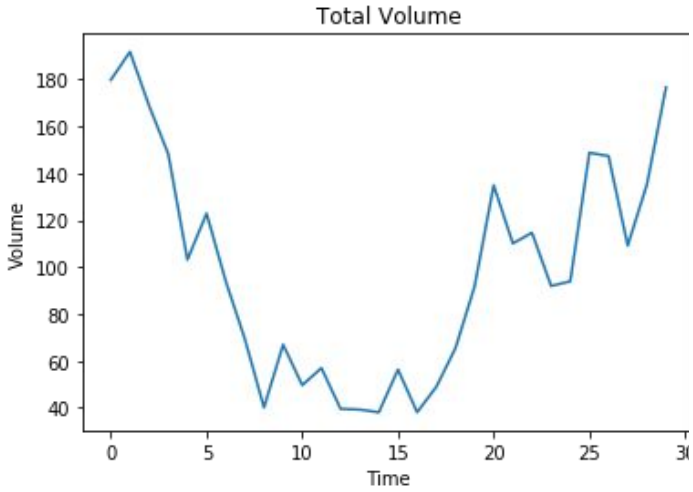
Left ventricle is segmented as foreground

Area: count foreground pixels

Distance between slices (d): given by DICOM

$$Area(s) = \sum_{p \in s} p, \text{ where } p \in \{0, 1\}$$

$$V(I(t)) = \sum_{s \in I(t)} Area(s) \cdot d$$



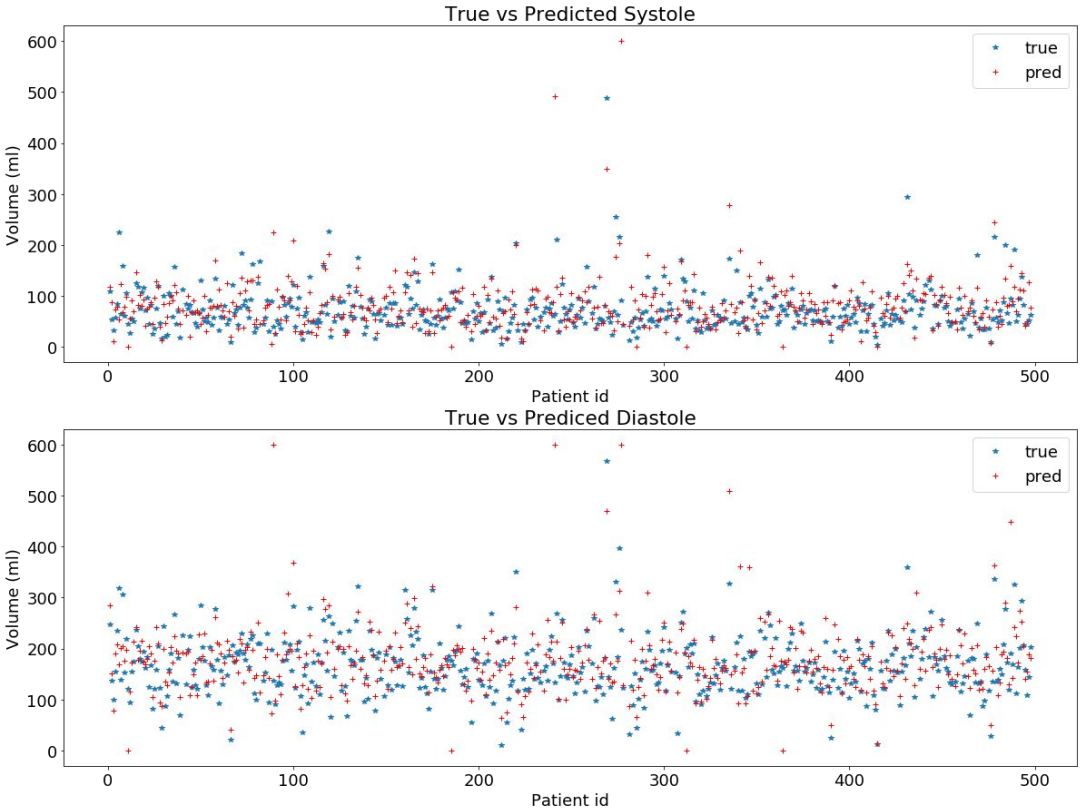
Volume predictions - comparison

RMSE systole = 46.1 ml

RMSE diastole = 56.2 ml

$$V_S = \underset{t}{\operatorname{argmin}}\, V(I(t))$$

$$V_D = \underset{t}{\operatorname{argmax}}\, V(I(t))$$

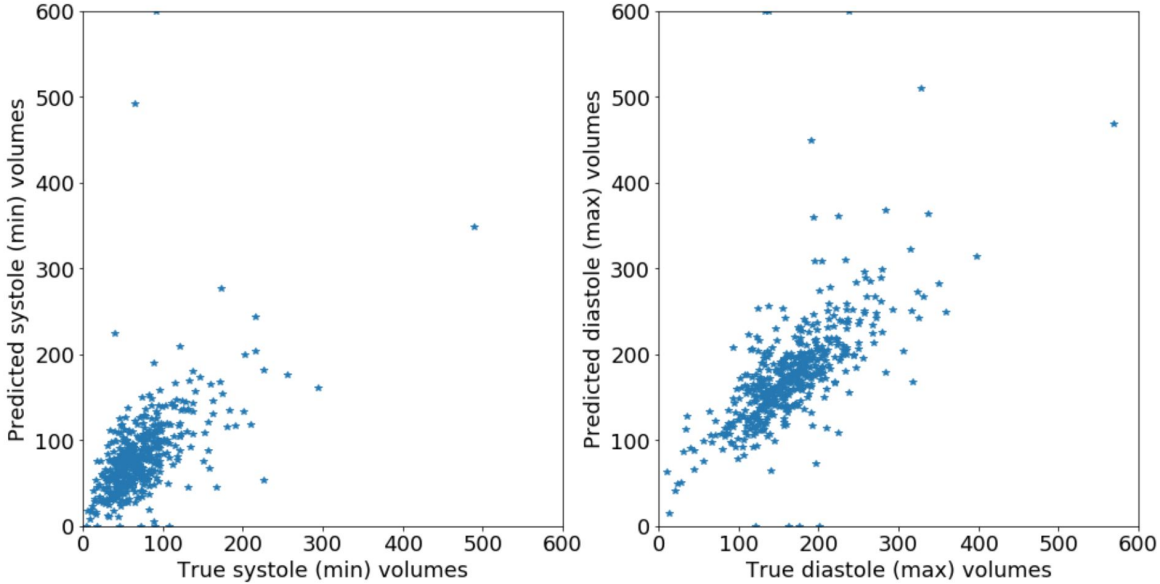


Volume predictions - correlation with GT

Correlation between observed and predicted volumes

Corr systole = 0.548

Corr diastole = 0.626

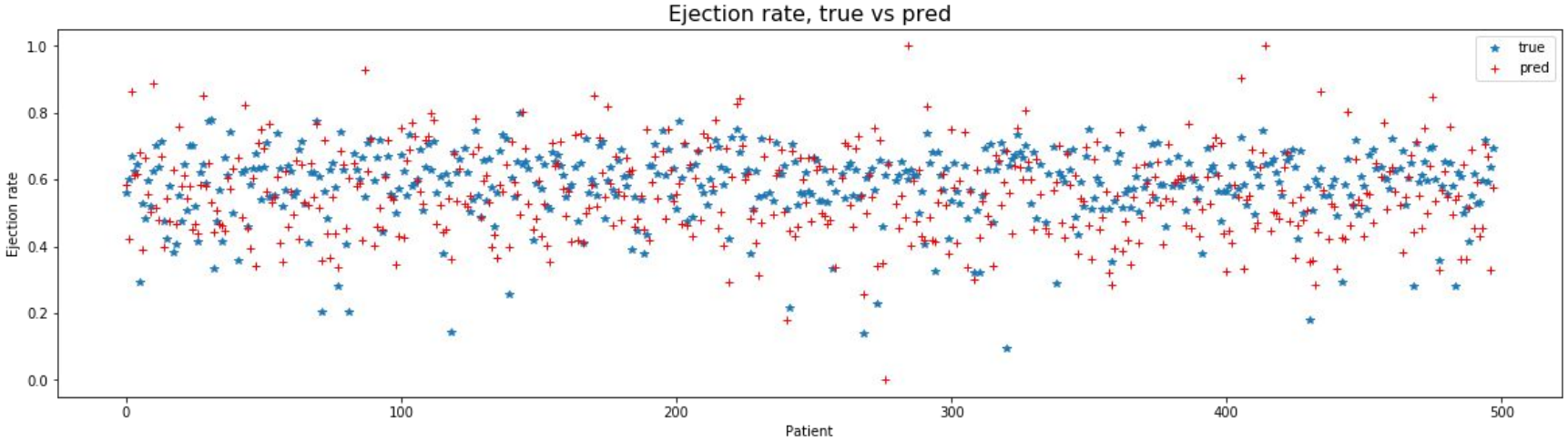


Ejection rate prediction

RMSE ER = 0.138

Model is 14% off (on average)

$$\text{Ejection rate: } ER = \frac{V_D - V_S}{V_D}$$



Improvements

Compare with expert segmentations

More sophisticated segmentation

Output probability distribution rather than scalar

Machine learning/Deep learning approaches

- UNet (*Ronneberger et al. 2015*)
- Augment with smaller dataset with ground truth segmentation

Appendix

Kaggle kernel(s) link

https://www.kaggle.com/tnilsson/bigimaging-complete
https://www.kaggle.com/tnilsson/bigimaging-analysis

Image indexing

4D image: [slice, time, height, width]

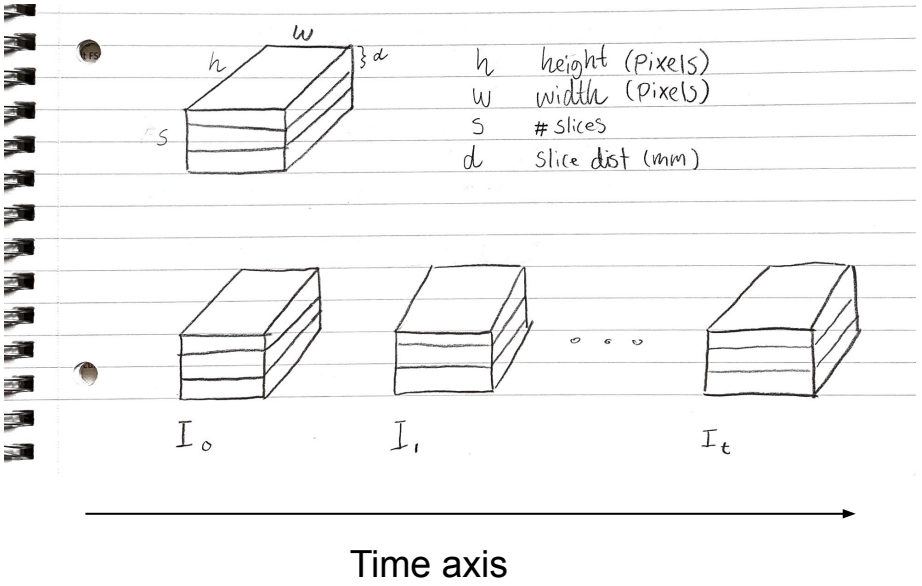
Slice: z-coordinate

Time: voxel-number

- first: start of heartbeat
- last: end of heartbeat

Height: number of rows

Width: number of columns



Dataset issues

Main issue: images come from different MRI scanners and different hospitals

- None of the 4 dimensions are constant across all images
- Pixels are not standardized to SI units
- Varying brightness levels across patients
- 2D pictures taken from different center locations
- Some DICOM metadata missing (distance between slices ex)

Solution: preprocessing

- Rectify above issues

Sunnybrook

Sunnybook Cardiac Dataset

- Cardiac images dataset
- Annotation dataset (coordinate vectors)

Problem:

- Inconsistent naming between image- and annotation dataset
- Would require more time to investigate.

https://www.cardiacatlas.org/studies/sunnybrook-cardiac-data/