Automatically Quantifying Radiographic Knee OA Severity

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Objectives

Develop a machine learning model to **automatically quantify knee osteoarthritis (OA) severity**, labeled using the Kellgren and Lawrence (KL) grading system

Motivation

- **Knee OA** is most common cause of **limited mobility** in adults
- **Radiographic (X-ray)** and **symptomatic OA** status **do not correlate**
- Identifying **predictors of pain** from radiographic images could be used as **targets for drug development**

Osteoarthristis Staging

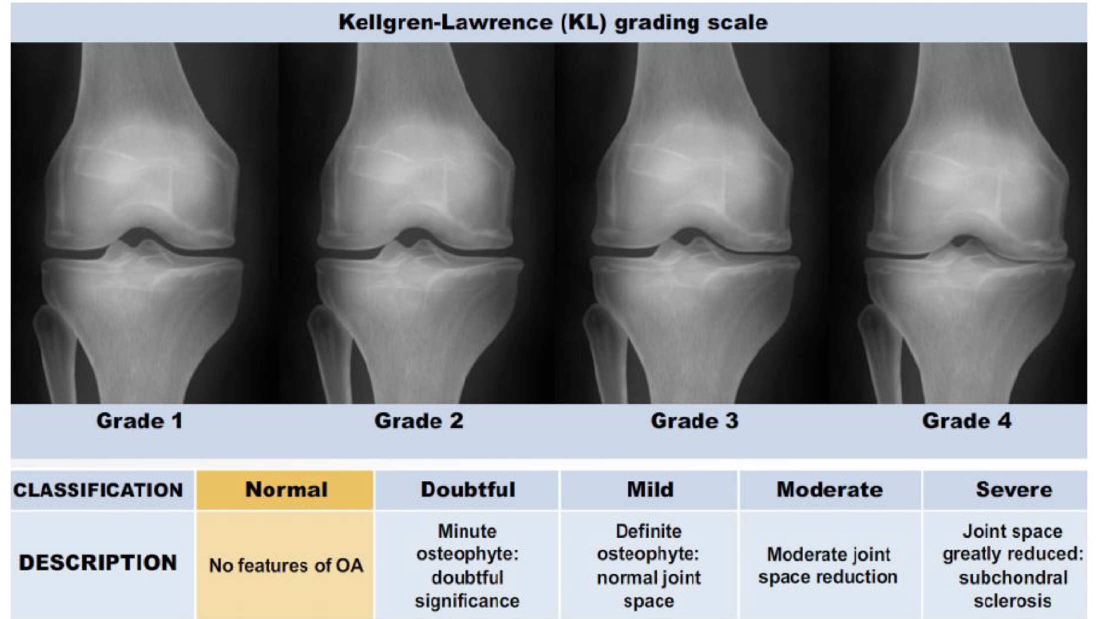

Figure: **Kellgren and Lawrence (KL)** grading system

Dataset

Knee X-ray images were obtained from the **Osteoarthritis Initiative (OAI) dataset** courtesy of the Mobilize lab at Stanford University

Stage	Number of Images	% of total
0	3054	40.45
1	1384	18.34
2	1978	26.20
3	960	12.71
4	173	2.29

Methodology 1

Feature Extraction

- Pre-process images to have a fixed size **(1280x768)** such that change in resolution and aspect ratio is minimal
- Extract features from final **pooling layer** (pool-5) of the raw images using a ImageNet **pre-trained VGG-16 network**
- Generate activation map by **convolving a 224x224 window** (fixed input size for VGG-16 net) over the pre-processed image
- Apply **max pooling** to down-sample activation feature size

Methodology 2

Faster Region-CNN : Train a faster R-CNN to first **extract the knee joint region** from the X-ray images and then **classify** them based on KL score. It has the following steps :

- **Labeling :** Label a **bounding box** for each image containing the **knee-joint region**
- **Training :** It has a 4-step training procedure:
  - **Step 1 :** Train a **region proposal network** with weights initialized from pre-trained ZF network
  - **Step 2 :** Train the **object classification network** using proposals from step 1
  - **Step 3 :** Re-train **region proposal network** with initialized weights learnt in step 2
  - **Step 4 :** Re-train **object classification network** using proposals from step 3

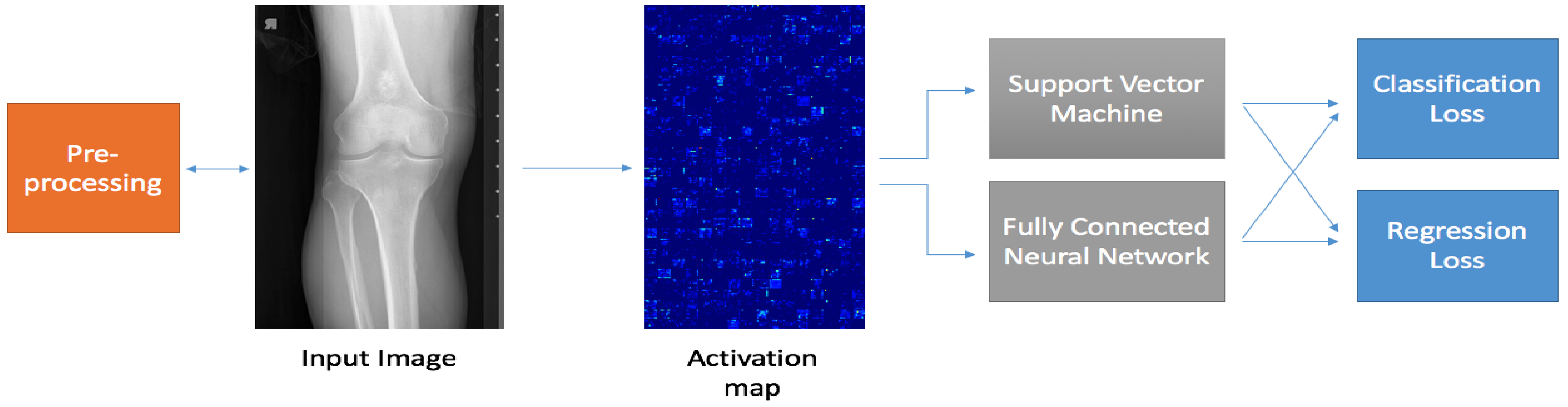

Figure: Training pipeline for Methodology 1

Methodology 1

Model Selection

- **Support Vector Machine :** Train a **linear kernel** support vector machine on extracted features
- **Fully Connected Neural Network :** Train a **2-layer** fully connected neural network on extracted features

Loss Function

- **Classification Loss :** Use a **categorical cross-entropy** loss function
- **Regression Loss :** Use a **mean-squared error** loss function

Results - Methodology 1

Linear SVM

- **Training = 4200 images**
- **Validation = 1400 images**
- **Test = 700 images**

Regression Loss							
	0	1	2	3	4	Precision	Recall
0	160	34	44	33	4	0.58	0.58
1	66	14	30	32	2	0.17	0.12
2	38	29	58	38	3	0.34	0.35
3	13	5	34	44	3	0.28	0.34
4	0	0	3	10	3	0.20	0.19
					Mean	0.39	0.40

Results - Methodology 1

Linear SVM

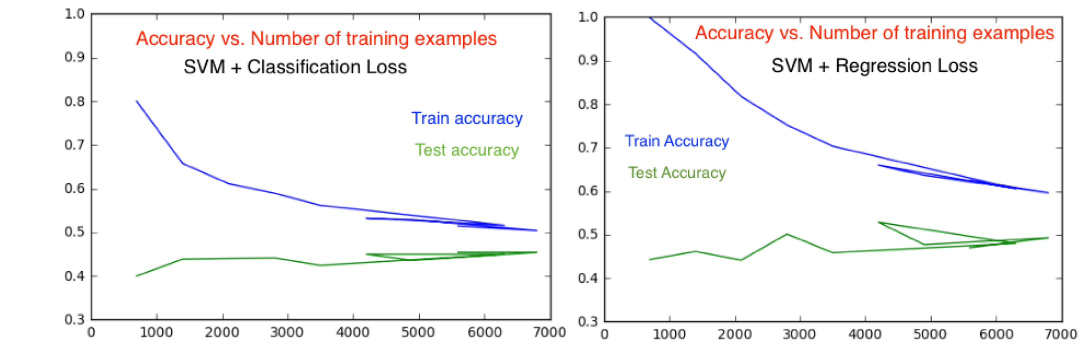

Figure: Accuracy vs. Training size for linear SVM

Fully Connected Neural Net

Classification Loss							
	0	1	2	3	4	Precision	Recall
0	200	26	42	7	0	0.54	0.73
1	84	17	34	9	0	0.24	0.12
2	66	20	70	10	0	0.38	0.42
3	20	7	36	36	0	0.49	0.36
4	2	0	2	12	0	0.00	0.00
					Mean	0.42	0.46

Regression Loss							
	0	1	2	3	4	Precision	Recall
0	100	149	23	2	0	0.72	0.36
1	28	85	29	2	0	0.24	0.59
2	10	90	58	8	0	0.33	0.35
3	1	22	60	15	1	0.43	0.15
4	0	1	6	8	1	0.50	0.06
					Mean	0.48	0.37

Results - Methodology 2

- **Training + Validation = 700 images**
- **Validation = 200 images**
- **Test = 300 images**

Predicting the knee-joint region has an accuracy of **98 %** when the Intersection over Union (IoU) threshold is fixed at 0.7.

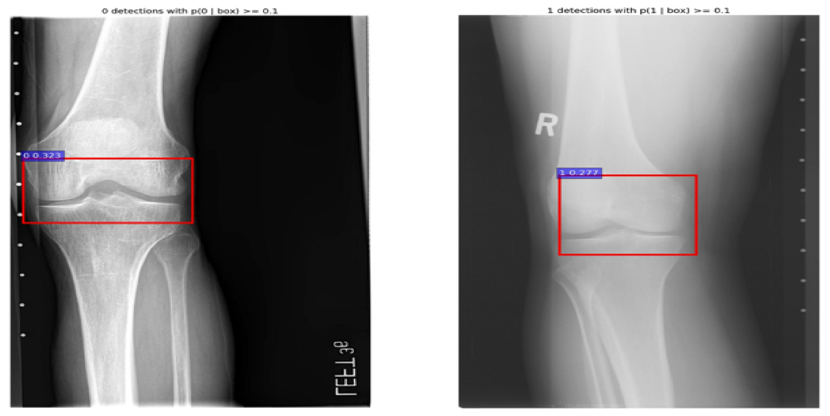

Figure: Examples of correctly classified X-ray images (with knee joint region extracted) using faster R-CNN