B.Sc. in Computer Science and Engineering Thesis
Bangladesh University of Engineering and Technology

A Quantitative Analysis of Severity Grading of Knee Osteoarthritis

Presented by

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Overview

- Problem Definition
- Motivation
- Challenges
- Literature Review
- Methodology
- Results
- Performance
- Our Contribution
- Future Direction

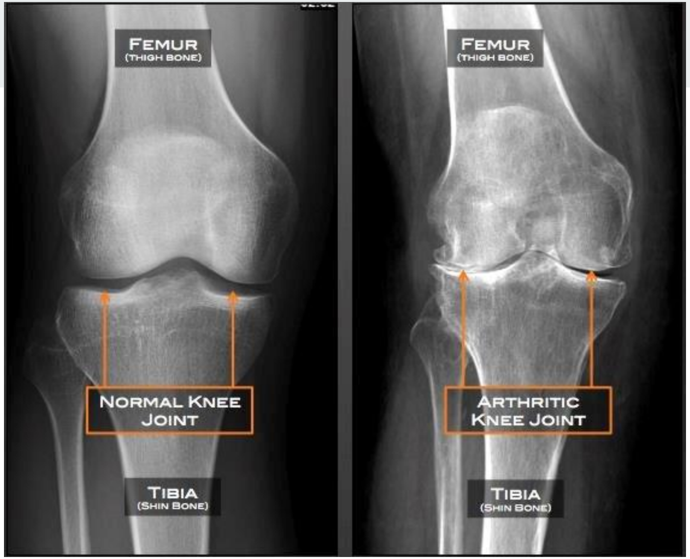
Problem Definition

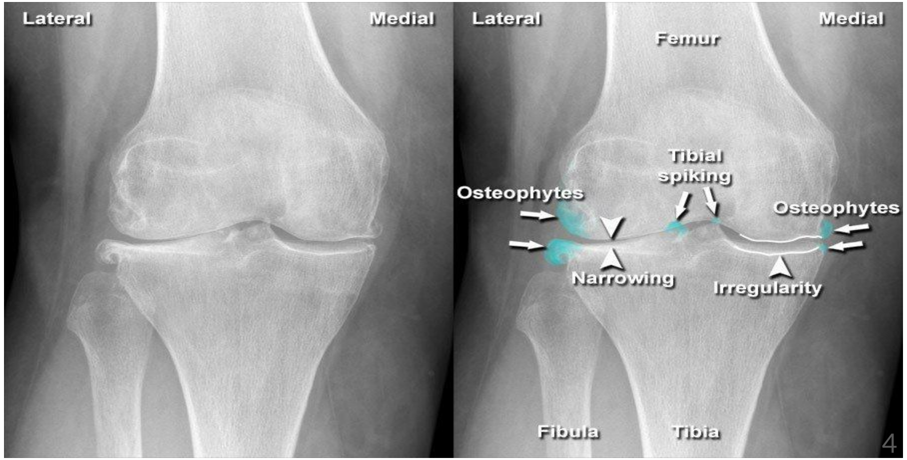
- Knee osteoarthritis (OA) is a degenerative joint disease that affects the cartilage and bones within the knee joint, leading to pain, stiffness, and decreased mobility.

- One of the most common causes of disability in adults.

Problem Definition (Contd.)

- Typically detected through X-rays.
- Most common symptom: *Joint Space Narrowing*
- Another common symptom: Presence of *Osteophytes*





Motivation

Motivation

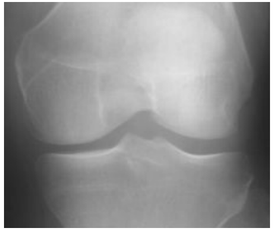
- In 2020, estimated 654.1 million individuals (aged 40 years and older) were affected globally.

- Significantly impacts individuals' quality of life.

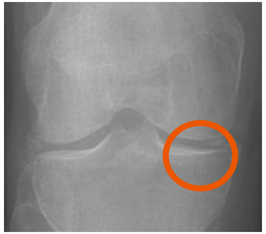
- Traditionally, ***Knee OA (KOA)*** has been assessed using qualitative methods such as the ***Kellgren-Lawrence (KL)*** grading system.

What is KL Grading System?

Categorizes the current state of the disease, based on the *Joint Space Narrowing*, *Osteophyte count* etc.

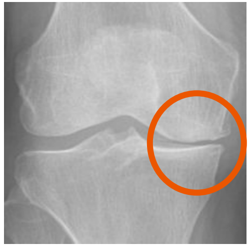


Grade 0: No OA features.



Grade 1: Doubtful narrowing, possible osteophytes.

Grade 2: Definite osteophytes, possible narrowing.



Grade 3: Multiple osteophytes, definite narrowing, possible deformity.

Grade 4: Large osteophytes, marked narrowing, severe sclerosis, definite deformity.

Limitations of KL Grading

- **Variability in Diagnosis** : Different clinicians' interpretations can vary, leading to inconsistent KL grades and unreliable diagnoses.
- **Potential Inaccuracies** : Subjective interpretation can lead to inaccurate grades.
- **Inconsistent Treatment Plans** : Diagnostic variability causes inconsistent treatment plans.
- **Lack of Precision** : Lacks precision, offering broad categorization but not detailed assessment or progression monitoring.

Challenges

Challenges

- **Lack of Labelled Data** : Absence of ground truth labels complicates the validation of edge detection and gap measurement techniques.
- **Low-Quality X-ray Images** : Low-resolution and poor-contrast X-ray images create difficulties in accurately processing anatomical structures.
- **Inaccurate Detection with FastSAM** : Lacks precision for X-ray images due to its generic nature, smoothing out critical necessary details.
- **Reliance on Opinion-Based KL Grading** : Subjective KL grading introduces variability and potential bias, affecting the reliability of decisions.

Literature Review

Literature Review

Kondal et al. [1]: Used a two-stage CNN model for KL grading; highly dependent on dataset quality and lacks generalizability.

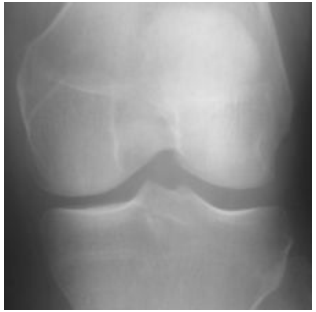
Antony et al. [2]: Proposed FCN for knee joint localization and CNN for severity quantification; requires significant computational resources.

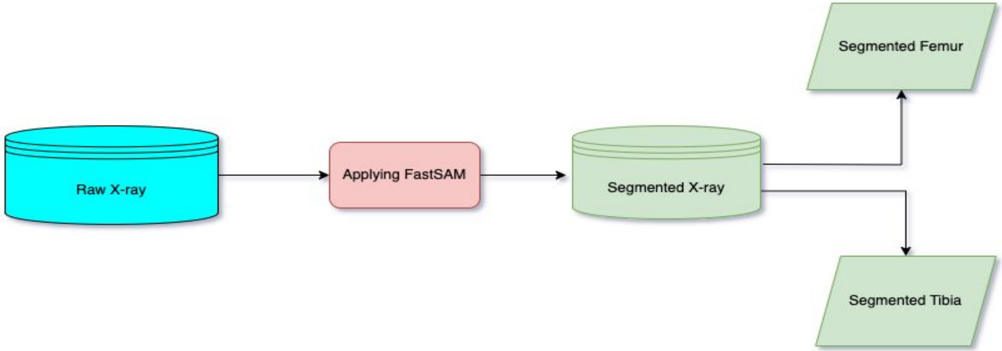
Brahim et al. [4]: Combined image pre-processing with machine learning for early OA detection; relied on manual feature engineering and showed inconsistent performance across datasets.

Problem Formulation

Dataset 1 : Original X-ray

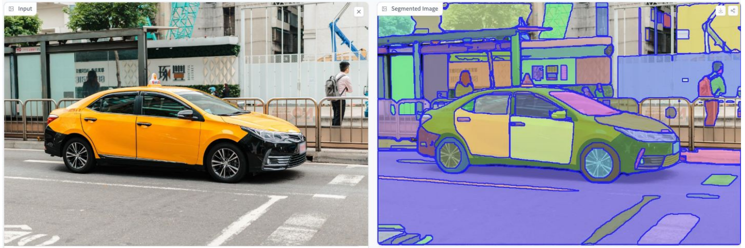
- Contains knee X-ray images labeled with the severity of osteoarthritis (KL grading).
- **Grade 0-2** : Each contains 1000 images.
- **Grade 3** : Contains 750 images.
- **Grade 4** : Contains 150 images.
- **Resolution** : 224 x 224 pixels, grayscale.
- Source: [Knee Osteoarthritis KL graded dataset]

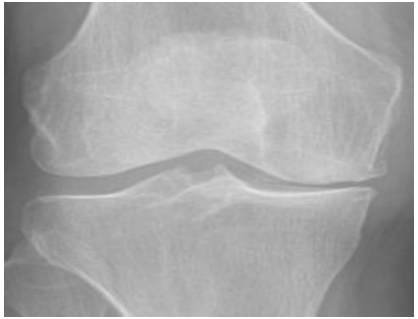




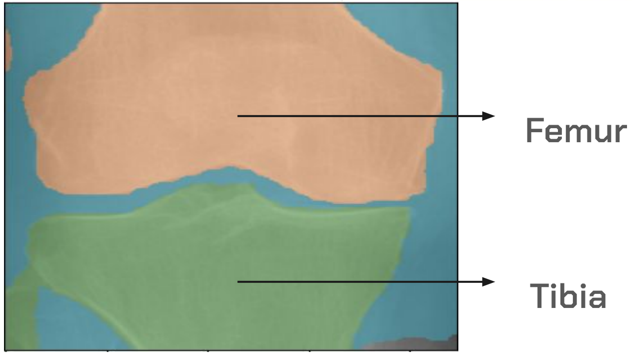
Dataset 2 : Fast Segmented Knee X-ray Images

- FastSAM : CNN Segment Anything Model trained using only 2% of the SA-1B dataset.
- Segmented X-rays are produced by applying FastSAM model on each original X-ray.
- Source: [Fast segmented Knee X-ray dataset]





Applying FastSAM



Methodology

Initial Approach Using Sobel Operator

- Sobel creates an intensity gradient which helps detect edges.
- However, there is little isolating factor between the inside of a bone and the knee gap.

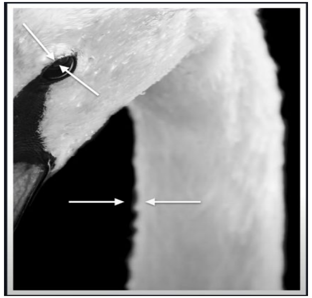
14	51	46	201	172	183
21	67	3	194	164	191
12	35	38	196	175	229
39	25	23	152	156	216
39	10	62	167	144	167
69	35	20	162	186	219

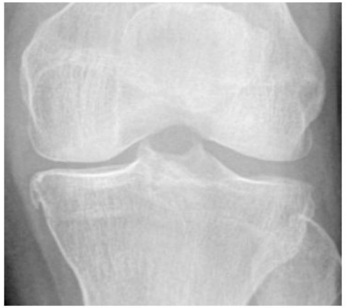
*

-1	0	1
-2	0	2
-1	0	1

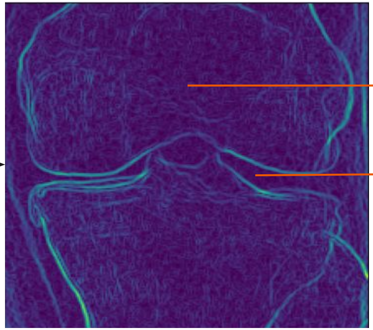
=

14	51	46	201	172	183
21	67	3	194	164	191
12	35	38	196	175	229
39	25	23	152	156	216
39	10	62	167	144	167
69	35	20	162	186	219





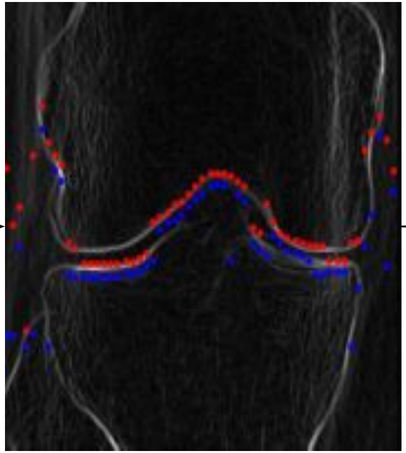
Applying Sobel



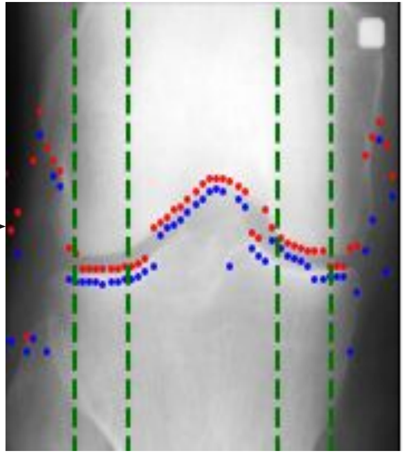
Findings from Sobel Operator

- The colored dots cross over the knee gap and fail to detect edges on ROI.

Original X-Ray Image



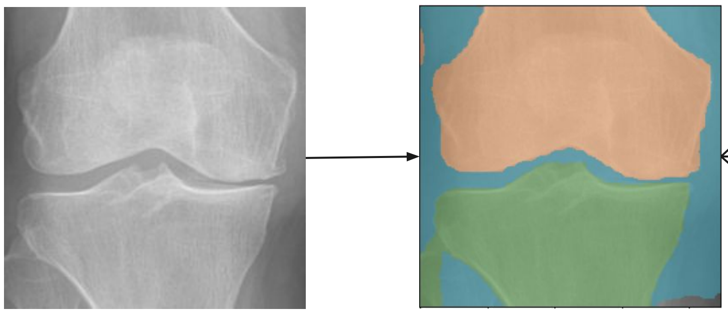
Sobel Image with plotting

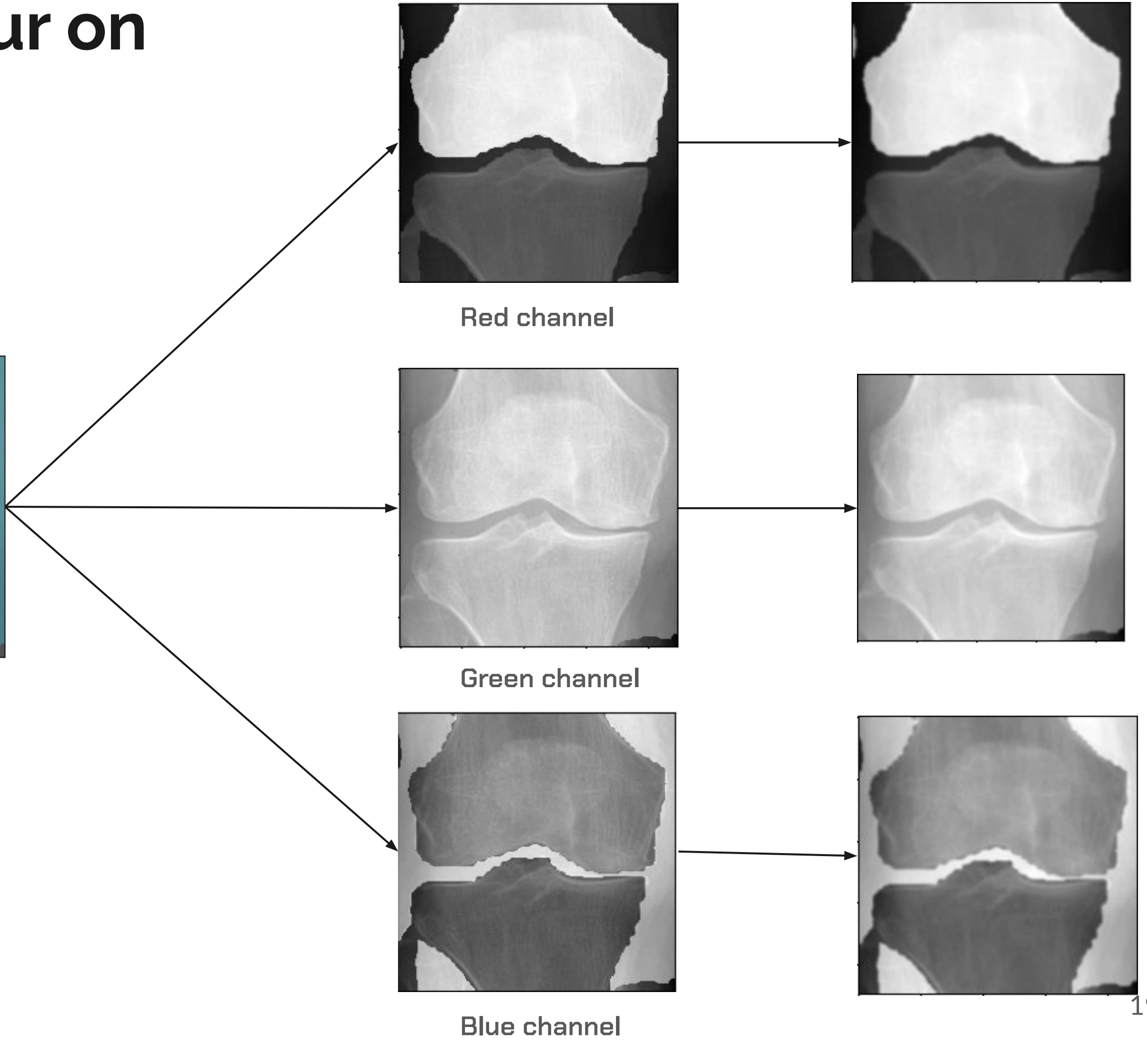


Superimposed plotting on original X-ray image with ROI selected

Applying Gaussian Blur on Segmented X-ray

- Reduces noise
- Kernel Size: 5 X 5





Adaptive Thresholding

- Converts the blurred image into a binary image to highlight edges.
- Adjusts the threshold value dynamically across the image to account for varying lighting conditions.
- Pixels > Threshold $\longrightarrow$ 0 (black)
  Pixels < Threshold $\longrightarrow$ 255 (white).

Morphological Operations (Closing and Opening)

Closing:

- Morphological closing is applied using a small kernel (3x3).
- Closing helps to fill small holes or gaps in the binary image, connecting disjointed edges.
- Performed twice to ensure better connectivity.

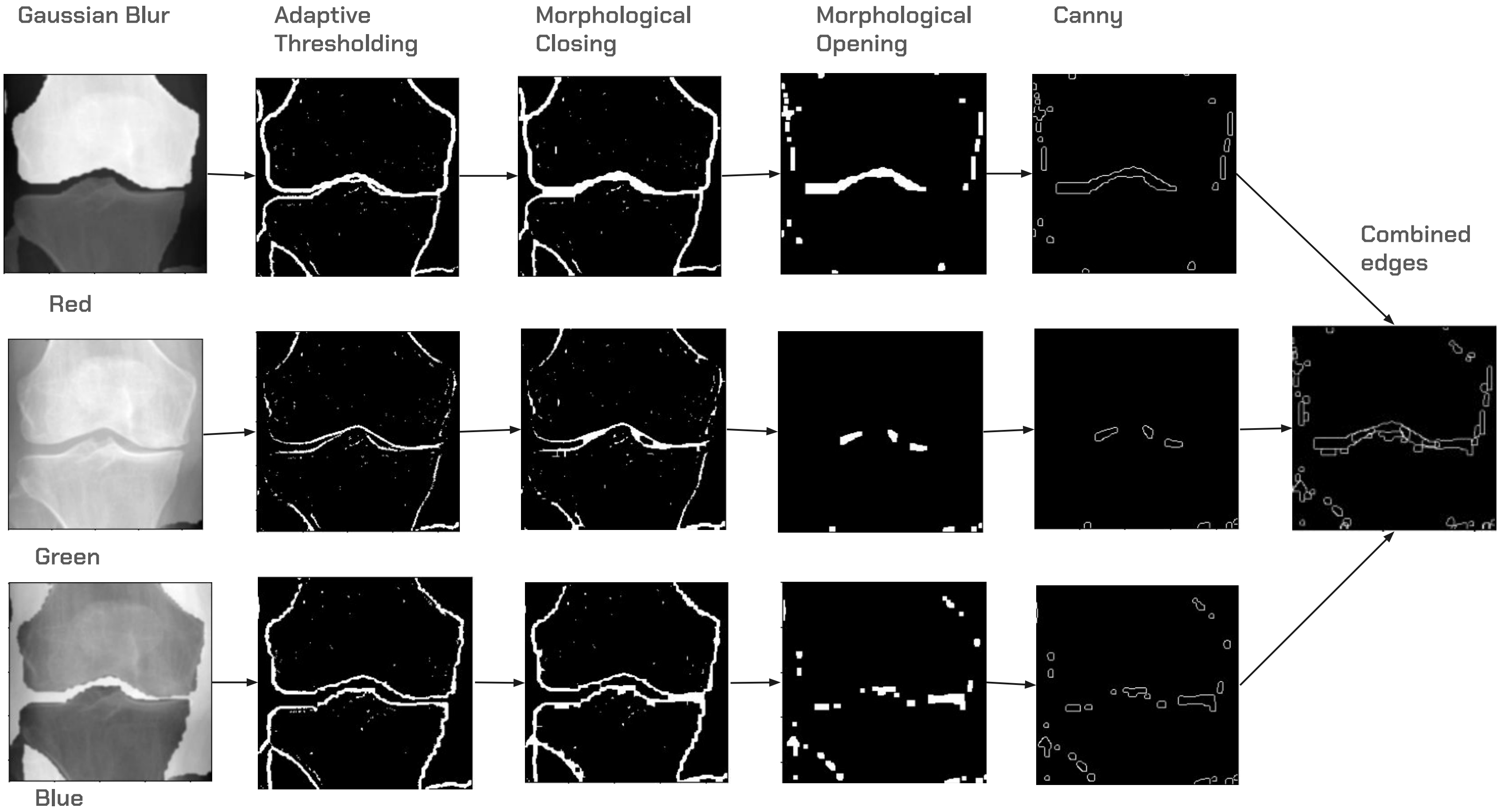
Opening:

- Morphological opening is applied next to remove small noise and irrelevant details from the binary image.
- Opening helps to clean up the image by removing isolated noise points.

Canny Edge Detection

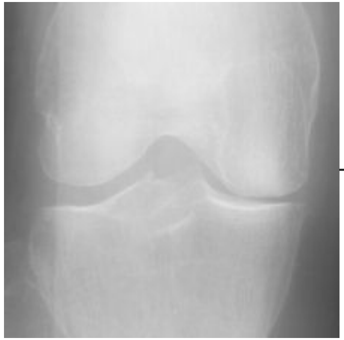
- Identifies and highlights the edges with pixel intensity changes.
- Creates a clear outline of the structures in the image.
- Add all 3 outputs of the channels so far through bitwise or.

Processing Segmented X-ray



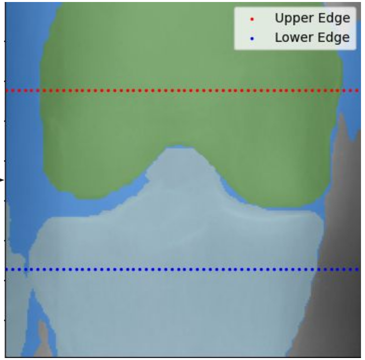
Initializing the Points

- We try to find edges with the help of points or markers.
- Red for upper edge, blue for lower edge.
- Initial row index for starting the search for the upper edge (red), 1/4th from the top of the image.
- Initial row index for starting the search for the lower edge (blue), 3/4th from the top of the image.



KL Grade 3
original X-ray

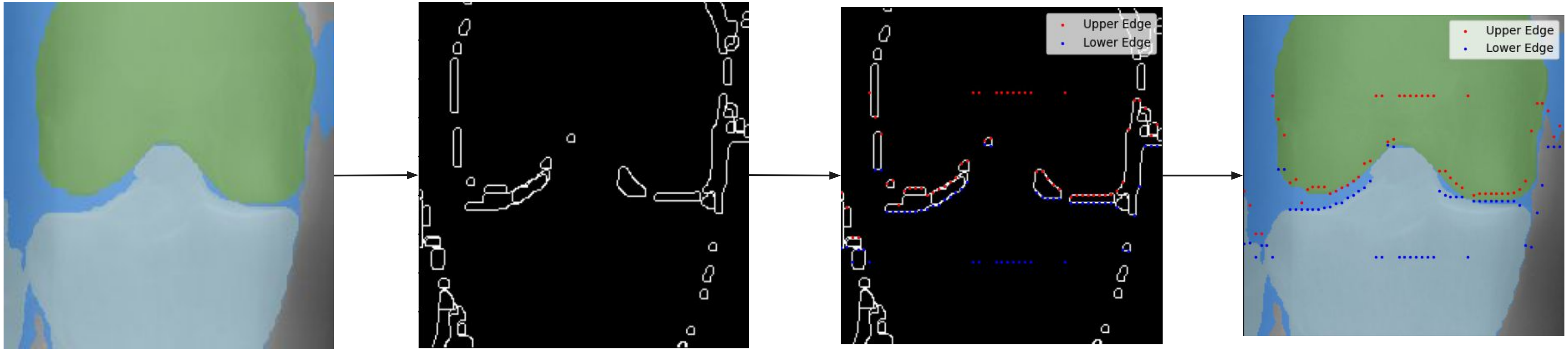
FastSAM X-ray



Points initialized

Aligning Points on Edges Using Preprocessed Image

- For each column, searches from top to bottom within the specified range to find the upper edge.
- Similarly, searches from bottom to top to find the lower edge.



FastSAM X-ray

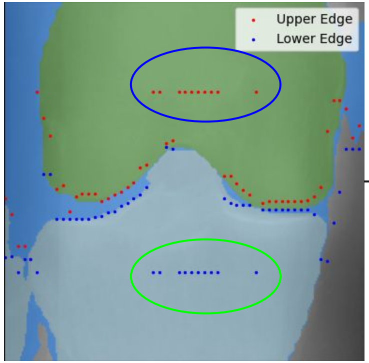
Preprocessed image

Points on Preprocessed image

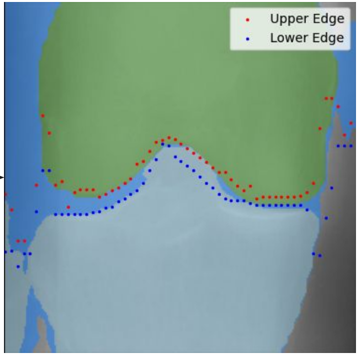
Points on FastSAM image

Applying Simulated Annealing

- Only refine points that were untouched before.
- Cost is based on the distance from the neighbouring points in the same row.
- 1000 iterations, 0.99 cooling rate.
- Newer cost < current cost : improves the solution.
- Newer cost > current cost: accepts but with a probability that decreases with temperature.



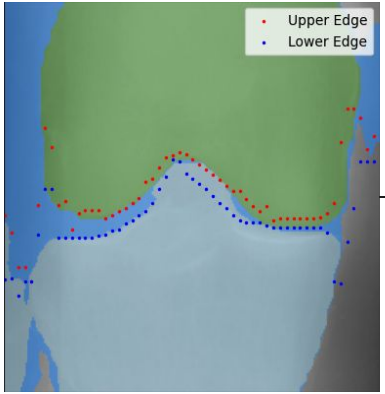
Before Simulated Annealing



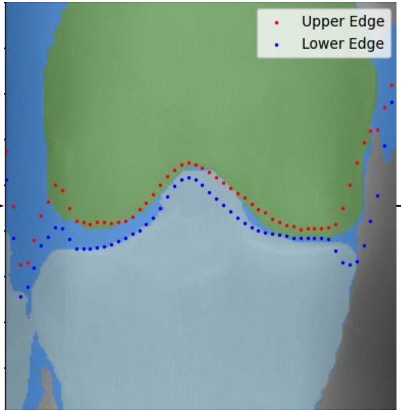
After Simulated Annealing

Applying Local Smoothing

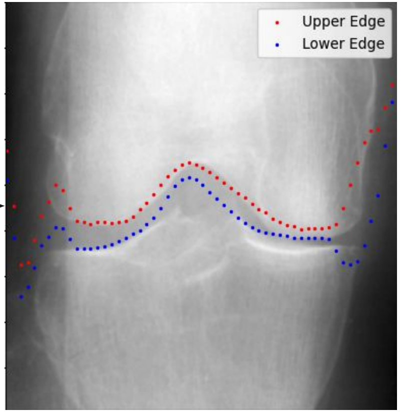
- 1D convolution of window size=5.
- Essentially slides the kernel over the input array of points and computes the weighted sum of the elements within the window.
- Produces a smoothed output.



Before Local Smoothing



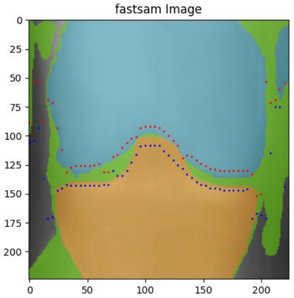
After Local Smoothing



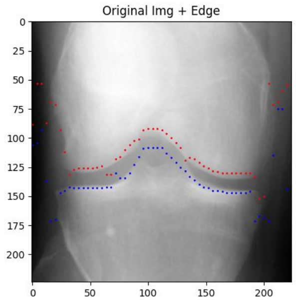
Superimposing the points on original x-ray

Results

Results : Edge Detection



superimpose



56 points along upper edge

Joint space width

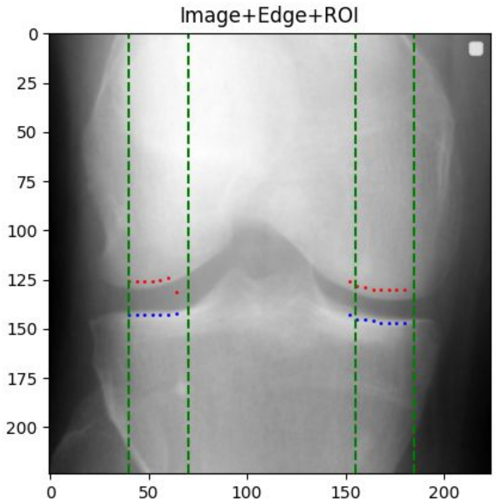
56 points along lower edge

Width = 224
Interval = 4

40 : 70

Region of interest

155 : 185



Results : Edge Detection (Contd.)

UPPER EDGE

```
Grade,ImageID,Point_1,Point_2,Point_3,Point_4,Point_5,Point_6,Point_7,Point_8,Point_9,Point_10,Point_11,Point_12,Po
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0,s_9372030L.png,
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0,s_9754907R.png,
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```

Results : Edge Detection (Contd.)

LOWER EDGE

```
ade,ImageID,Point_1,Point_2,Point_3,Point_4,Point_5,Point_6,Point_7,Point_8,Point_9,Point_10,Point_11,Point_
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8,168,137,151,159,167,154,155,167,133,133,133,133,133,133,132,131,131,129,128,126,123,121,118,117,117,117,11
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,92,94,158,159,164,168,136,132,132,132,132,136,136,136,136,136,135,135,134,128,125,126,124,123,124,124,121,1
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s_9526432L.png,
,153,136,147,153,154,166,168,145,146,146,146,146,146,146,146,146,145,144,142,139,137,128,126,127,128,128,128
```

Results : Joint Space Width per Image

CORRESPONDING POINT DISTANCES

```
0,s_9551114L.png,
23,0,35,99,58,42,45,11,10,10,10,10,14,14,13,13,11,12,12,14,14,14,16,16,17,16,17,3,19,21,14,20,17,15,29,28,21,22,
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0,s_9526432L.png,
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```

LEFT ROI [10:17]

RIGHT ROI [39:46]

Results : Joint Space Width per Image (Contd.)

```
Image_ID,Left,Right
9865771R.png,18,15
9112976L.png,18,15
9381081L.png,18,18
9307892R.png,18,18
9258662R.png,69,18
9528886L.png,18,18
9305113L.png,120,15
9844581L.png,21,18
9781555R.png,12,24
9714958L.png,36,114
9794849R.png,21,18
9240515L.png,12,18
9293349R.png,12,12
9743577L.png,21,12
9771624R.png,33,21
9950320L.png,18,18
9805234L.png,21,18
9040944L.png,15,21
9403165R.png,117,48
9160026L.png,21,30
9246995R.png,15,21
9641901R.png,18,18
```

ROI GAPS : 0

```
9028418R.png,15,15
9314341L.png,12,9
9043894R.png,21,15
9251736L.png,12,60
9392241L.png,18,9
9421088L.png,12,15
9418547L.png,12,15
9035449L.png,15,15
9471143L.png,15,33
9169022L.png,12,24
9638612R.png,15,12
9766202R.png,15,18
9589798L.png,12,15
9979265R.png,15,18
9226021L.png,15,15
9135752R.png,12,12
9682254R.png,15,12
9621650L.png,9,21
9372194L.png,24,114
9382772R.png,9,12
9902772L.png,12,15
9556608L.png,12,24
9480968R.png,12,12
```

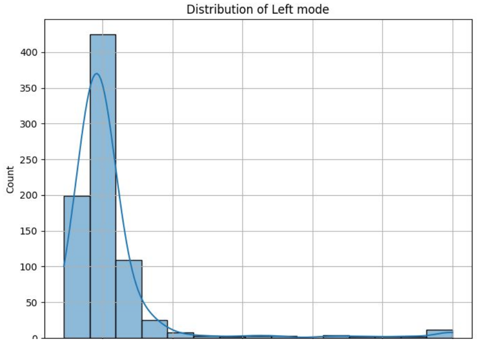
ROI GAPS : 2

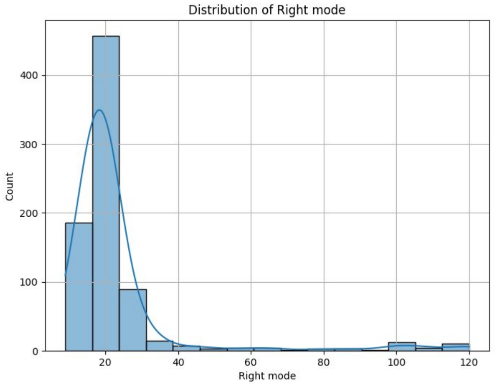
```
9742871R.png,12,21
9323079R.png,12,12
9820479L.png,12,12
9049507L.png,12,15
9326657R.png,6,9
9761503L.png,12,12
9156694R.png,6,6
9453626L.png,6,12
9755634R.png,12,12
9317124L.png,48,48
9680800R.png,6,12
9208400R.png,57,12
9810432R.png,12,6
9900761R.png,12,12
9439428R.png,6,12
9843822R.png,6,9
9851309L.png,15,6
9613488L.png,111,111
9604541R.png,6,12
9645683L.png,12,12
9555061L.png,9,12
```

ROI GAPS : 4

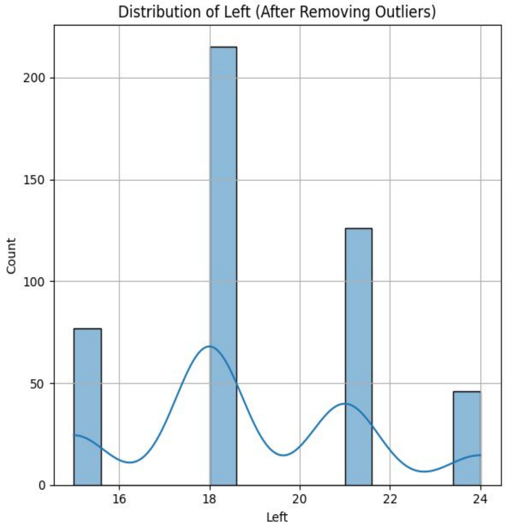
Results : Distribution Plots per Grade

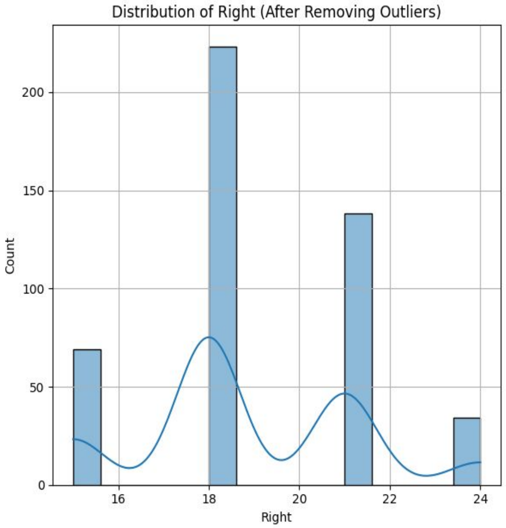
Grade 0



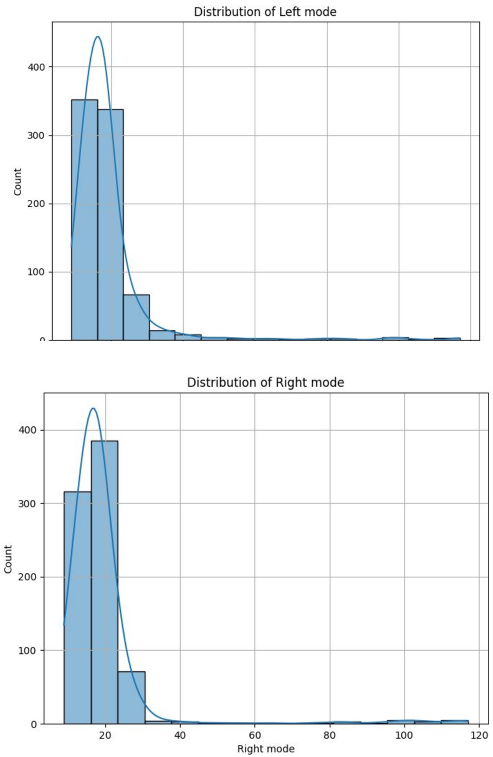


Denoising



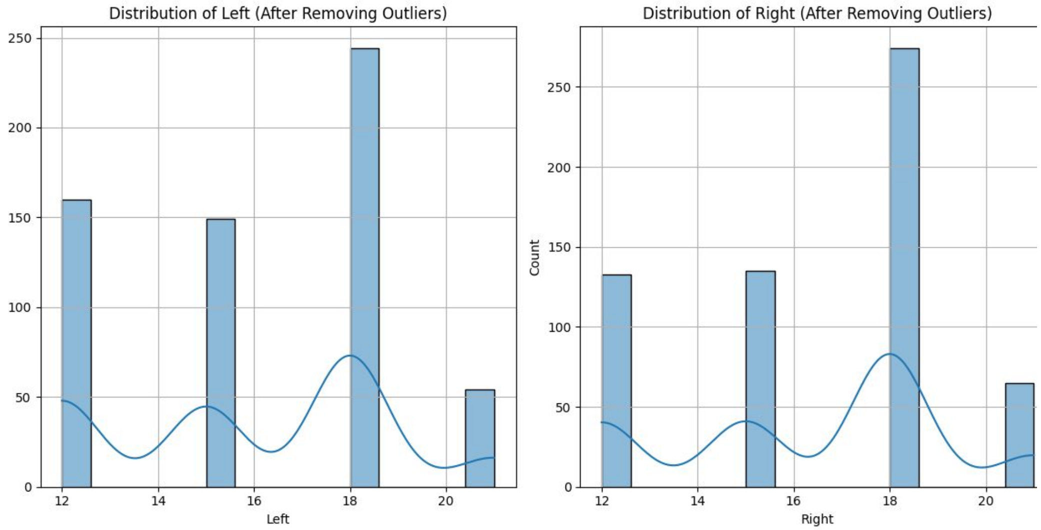


Results : Distribution Plots per Grade (Contd.)



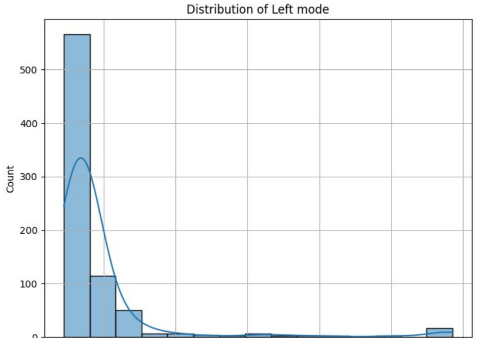
Denoising

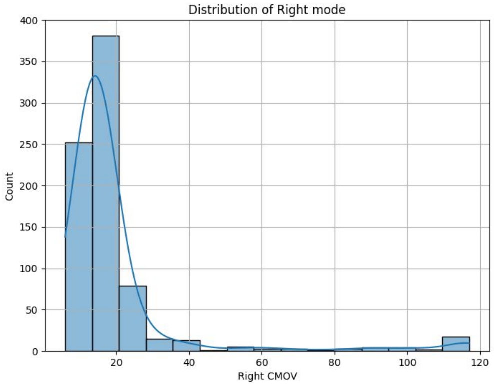
Grade 1



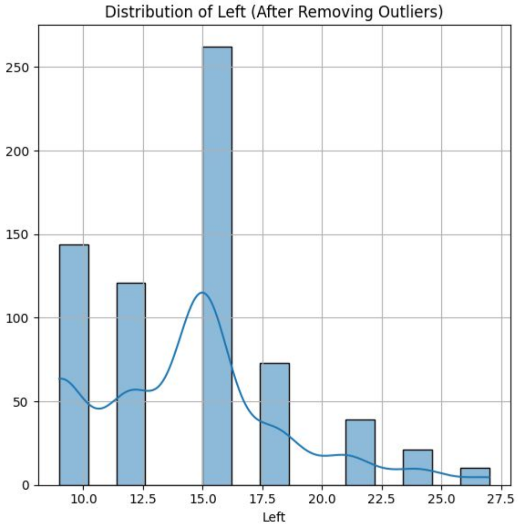
Results : Distribution Plots per Grade (Contd.)

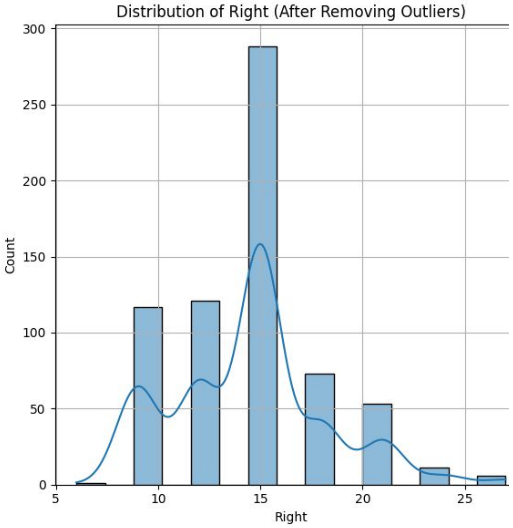
Grade 2



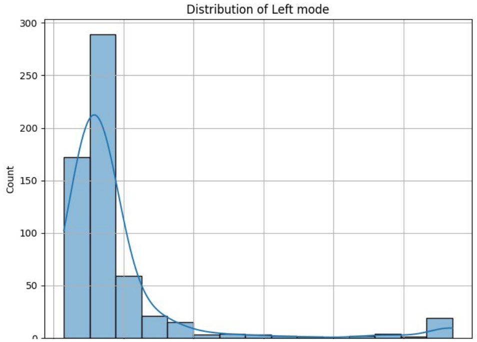


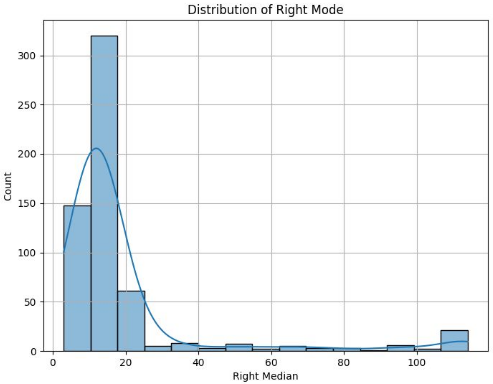
Denoising





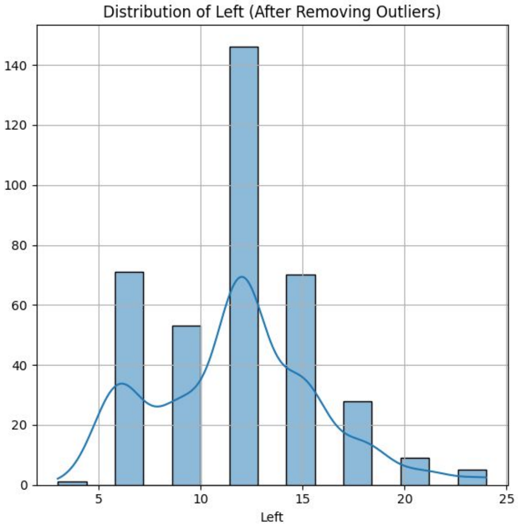
Results : Distribution Plots per Grade (Contd.)

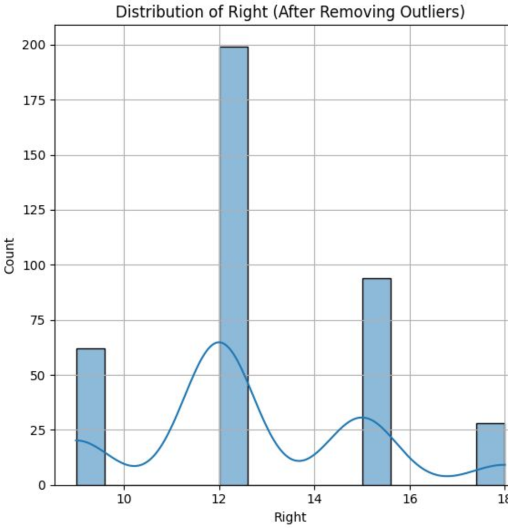




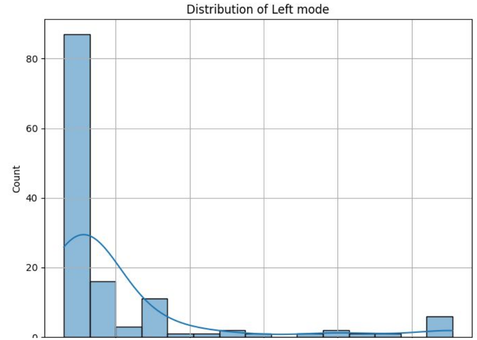
Denoising

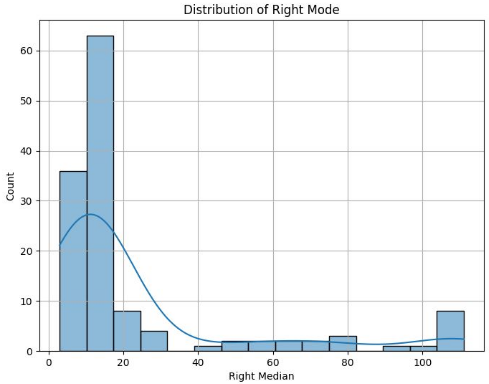
Grade 3





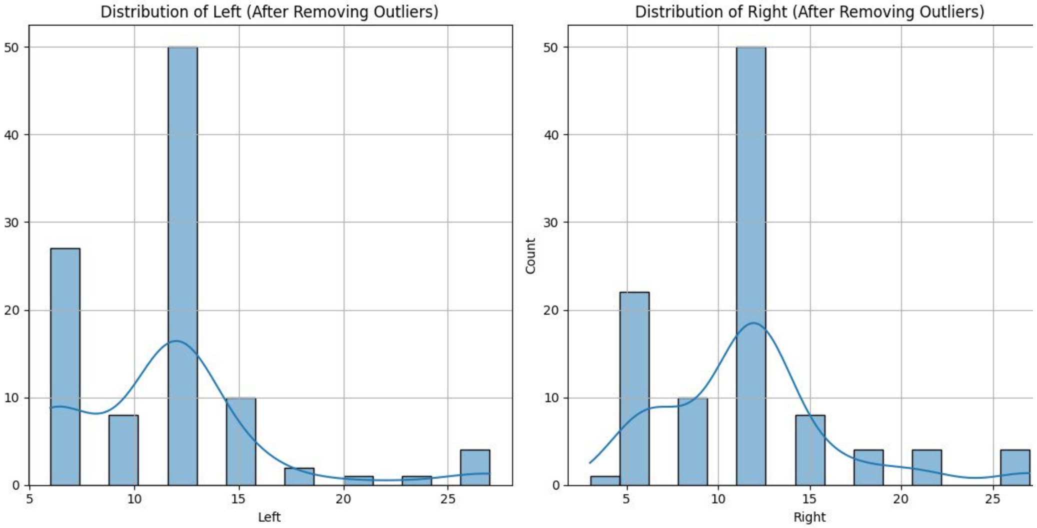
Results : Distribution Plots per Grade (Contd.)





Denoising

Grade 4



Results : Joint Space Width per Grade

Grade	Left Joint Space			Right Joint Space		
	Mode	Mean	Std. Dev.	Mode	Mean	Std. Dev
0	18	18.91	2.58	18	18.88	2.42
1	18	15.94	2.87	18	16.32	2.84
2	15	14.30	4.07	15	14.45	3.76
3	12	11.80	4.01	12	12.68	2.41
4	12	11.38	4.71	12	11.73	4.82

Results : Joint Space Width per Grade (Contd.)

Grade	Left Joint Space		Right Joint Space	
	px	%	px	%
0	19	8.00	19	8.00
1	16	7.00	16	7.00
2	14	6.00	14	6.00
3	11	5.00	12	5.00
4	11	5.00	11	5.00

Pixel values taken from Mean and Mode

$$\frac{16}{224} \times 100 = 7.14 \approx 7.00$$

Image height

Optimum Range for Osteoarthritis

- Images from grade 3 and 4 are definitely having Osteoarthritis.
- Those from 2 having narrowed joint space are Osteoarthritic.
- It is observed that, Joint Space Width for all of these are **below 7%**.
- Therefore, if a knee joint under diagnosis, have joint space width less than 7%, we can say that, it is affected by Osteoarthritis.

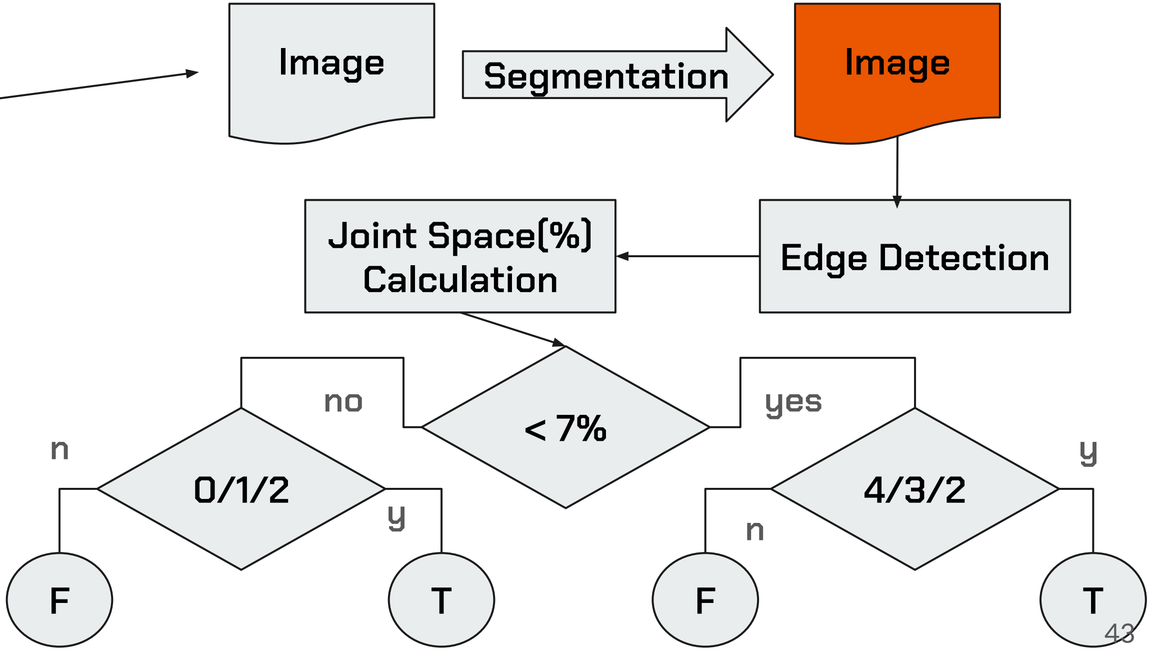
Joint Space Width < 7% => Osteoarthritis ⚠️

Performance

Test for Validity of Osteoarthritis Detection

Test Dataset

Grade	Images
0	92
1	95
2	97
3	93
4	24

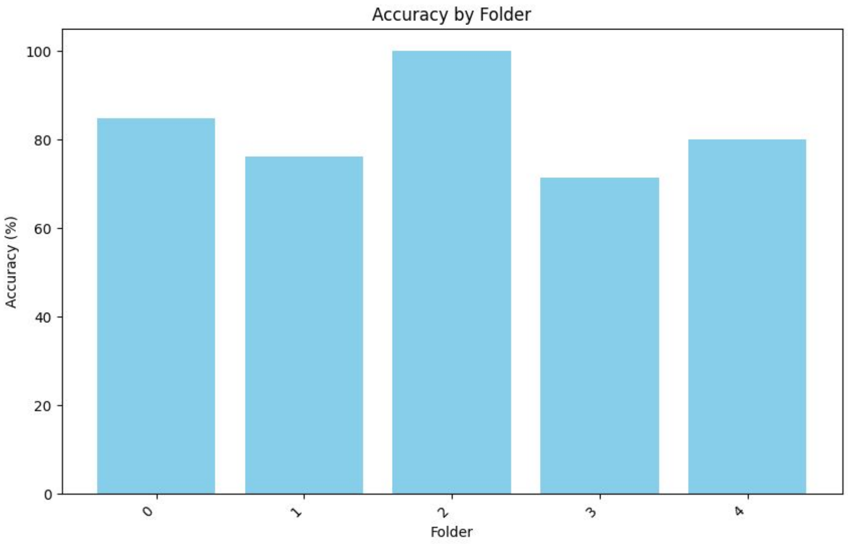


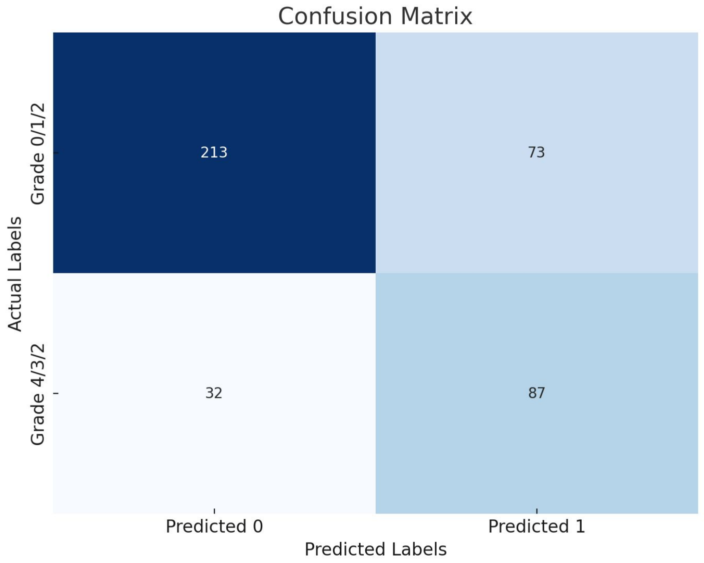
Detection Validity Test : Outputs

1	Folder	Image	Result	Correct
2	0	9891187R.png	0	True
3	0	9597737L.png	1	False
4	0	9208055L.png	0	True
5	0	9117692R.png	1	False
6	0	9541651R.png	0	True
7	0	9543679R.png	0	True
8	0	9301641L.png	0	True
9	0	9313715R.png	0	True
10	0	9903777L.png	1	False
11	0	9316069R.png	0	True

Folder	Total	Correct	Accuracy (%)
0	92	78	84.78260869565217
1	96	73	76.04166666666666
2	98	98	100.0
3	94	67	71.27659574468085
4	25	20	80.0

Performance Metrics





Overall Accuracy = 82.96%

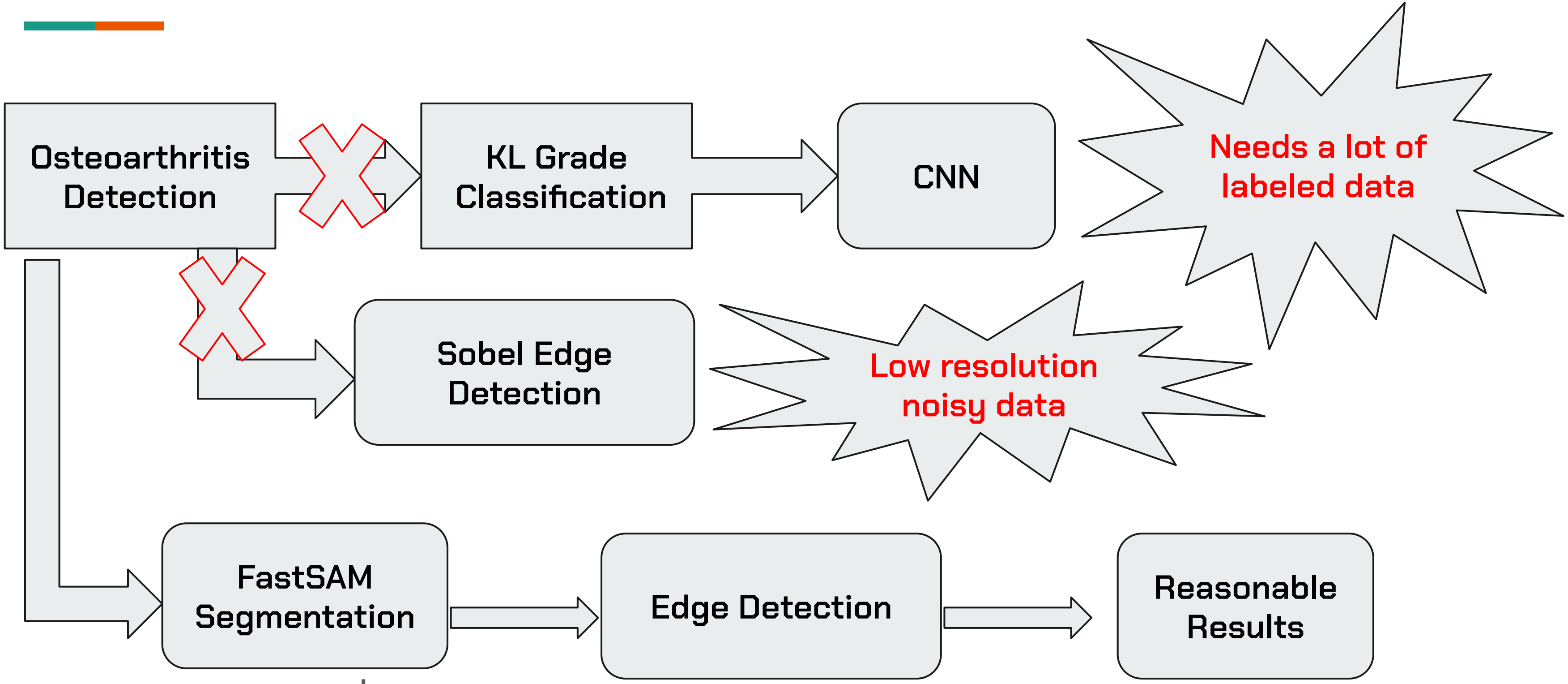
Performance Metrics (Contd.)

Average Precision	:	$\sum_{c \in classes} \frac{TP}{TP+FP}$	0.54
Sensitivity / Recall	:	$\frac{TP}{TP+FN}$	0.73
Specificity	:	$\frac{TN}{TN+FP}$	0.74
F1 Score	:	$\frac{2 \times TP}{2 \times TP+FP+FN}$	0.62

Overall Accuracy = 82.96%

Our Contribution

Our Contribution : Efficient Low Resource System



Low resource
Computationally efficient

Our Contribution : Pre-Diagnosis

It may save valuable time and money by utilising very low resources and computation in a very short time

Advanced diagnostics → No Osteoarthritis

This may cause Significant waste of time and money

Test with our system

NO → May have mild Osteoarthritis. Go for Advanced Diagnostics to confirm.

YES → Sure to have Osteoarthritis. Go for treatment.

Conclusion

- Accurate joint space measurement aids in advanced diagnosis and treatment decisions.
- Achieved 82.96% accuracy in osteoarthritis detection.
- Suitable for low-resource settings and easy to use clinically.
- Demonstrated efficiency and clinical utility of the proposed framework.

Future Directions

- ❖ Incorporate **osteophyte detection** for improved accuracy.
- ❖ Detecting presence and level of Subchondral **sclerosis**.
- ❖ Conduct extensive clinical validation.
- ❖ Optimize edge detection and statistical analysis algorithms.
- ❖ Explore broader applications in joint assessments.
- ❖ Develop software tools for **integration into diagnostic workflows**.

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Thank you!