Deep Learning Research on Knee Osteoarthritis

Introduction

- **According to WHO →** KOA is degradation of joints in knee with **loss of cartilage, joint space narrowing, osteophytes,** and sometimes **joint inflammation**, resulting in **pain** and **decreased function** with **w**orldwide **Prevalence** in **2024: 364.58 million.**

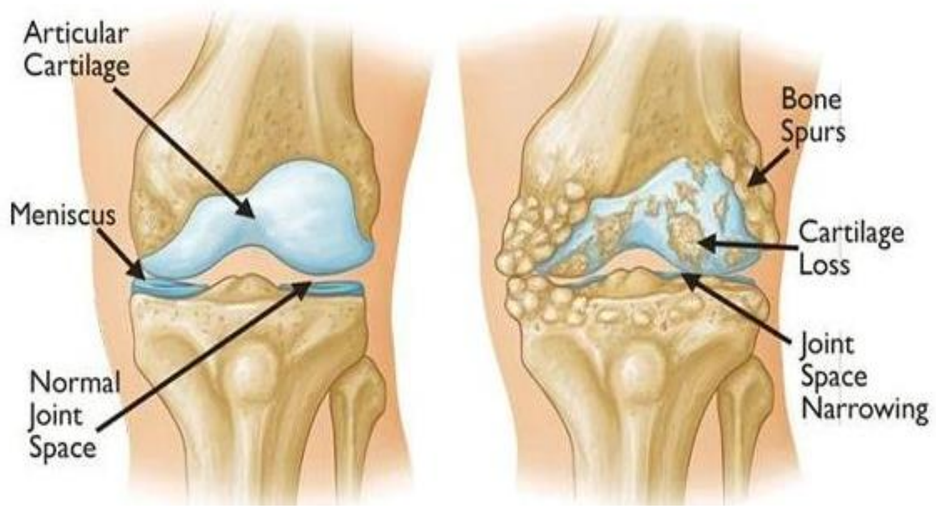

Figure: Schematic of Knee Anatomy(source-internet)

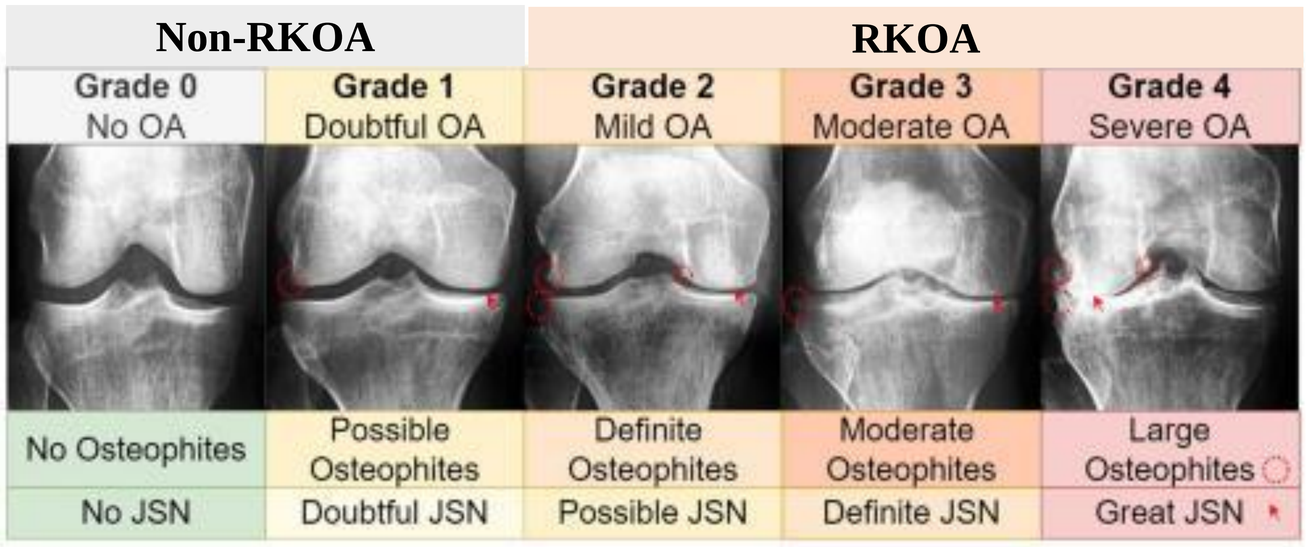

Figure:Pictorial Representation of KL grades in KOA (Kellergen et al., 1957)

Current Research Direction of Our Team

Diffusion based Shape-aware Learning with Multi-resolution Context for Segmentation of Tibiofemoral Knee Joint Tissues: An End-to-end Approach (Accepted in ICIP-25)

Challenges: **High variability in knee tissues, information dilution, heterogeneous scanning parameters, low signal-to-noise ratio (SNR), and motion artifacts.**

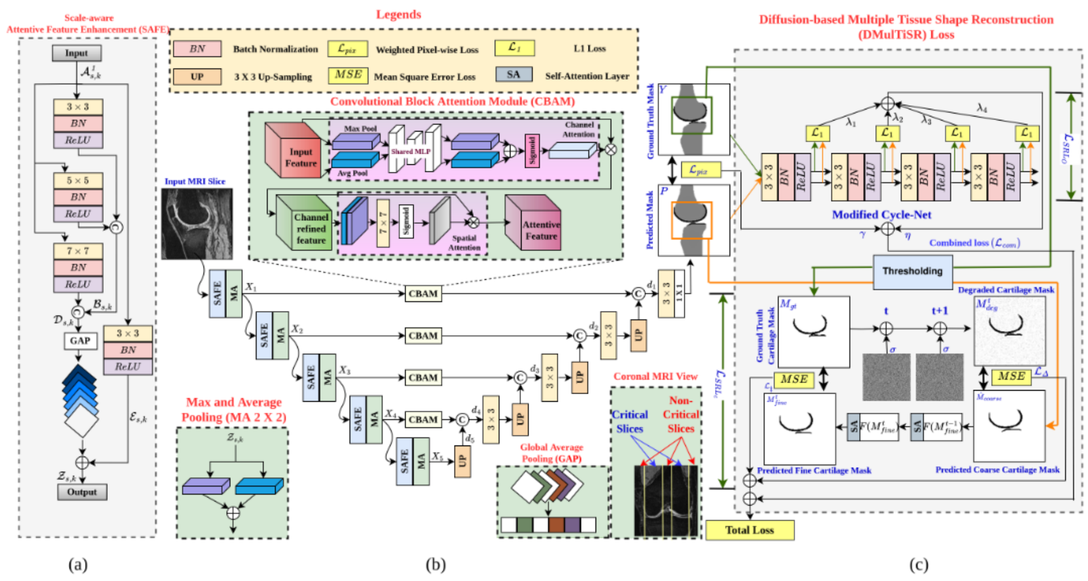

Fig: Schematic of the proposed Multi Scale-Attentive Unet (MiSA-Unet) model

Figure: Quantitative comparison of the proposed MtSA-Unet with SOTA

Architecture	Metrics	FC	TC	FB	TB
Knee MRI Segmentation					
2D and 3D CNN + SSM [2]	DSC (%) ↑	89.9	85.6	98.5	98.5
	VOE (%) ↓	18.1	24.9	2.8	2.9
	HD (mm) ↓	5.35	6.35	2.93	3.16
*Modified cGAN [3]	DSC (%)	89.5	83.9	98.5	98.5
	VOE (%)	18.92	27.55	–	–
2D-3D ensemble Unet [4]	DSC (%)	90.3	86.5	98.6	98.8
	VOE (%)	17.5	23.6	2.8	2.4
*Modified Unet++ [1]	DSC (%)	90.9	85.8	99.1	98.2
nnUnet + Entropy	DSC (%)	89.8	86.4	98.6	98.6
Distance Maps [5]	HD (mm)	5.22	4.70	11.82	5.30
Unet-S [7]	DSC (%)	89.7	89.8	98.7	98.7
	HD(mm)	5.58	4.74	4.05	3.82
*Modified Source-free UDA [8]	DSC (%)	74.7	59.4	93.7	94.7
Other Network Architectures					
Unet [14]	DSC (%)	88.6	87.0	98.3	98.3
	VOE (%)	20.06	22.41	3.34	3.29
	HD (mm)	6.69	5.23	6.12	4.05
Attention Unet [22]	DSC (%)	88.7	87.1	98.3	98.2
	VOE (%)	19.62	22.16	3.33	3.24
	HD (mm)	6.88	5.56	6.00	6.46
HRnet [23]	DSC (%)	88.9	86.5	98.2	98.2
	VOE (%)	18.67	22.11	3.19	3.78
	HD (mm)	6.28	5.94	7.10	6.99
SAMed [24]	DSC (%)	89.0	87.1	98.6	98.5
	VOE (%)	17.89	22.89	2.12	2.90
	HD (mm)	5.28	3.94	5.90	3.64
Proposed MiSA-Unet (Critical slices only)	DSC (%)	89.8	88.0	98.5	98.5
	VOE (%)	18.76	20.94	2.76	3.08
	HD (mm)	6.41	4.95	5.47	3.89
Proposed MiSA-Unet$^{\Theta}$ (All slices)	DSC (%)	90.4	90.1	98.7	98.6
	VOE (%)	17.22	18.97	4.09	2.9
	HD (mm)	4.74	3.11	2.54	4.32

• The best and second best results are denoted in red and blue colors, respectively. The * indicates the architectures specifically modified for the knee MRI segmentation task, and The Θ indicates the model's testing on both critical and non-critical slices with the post-processing stage (similar to Deng et al.[1]).

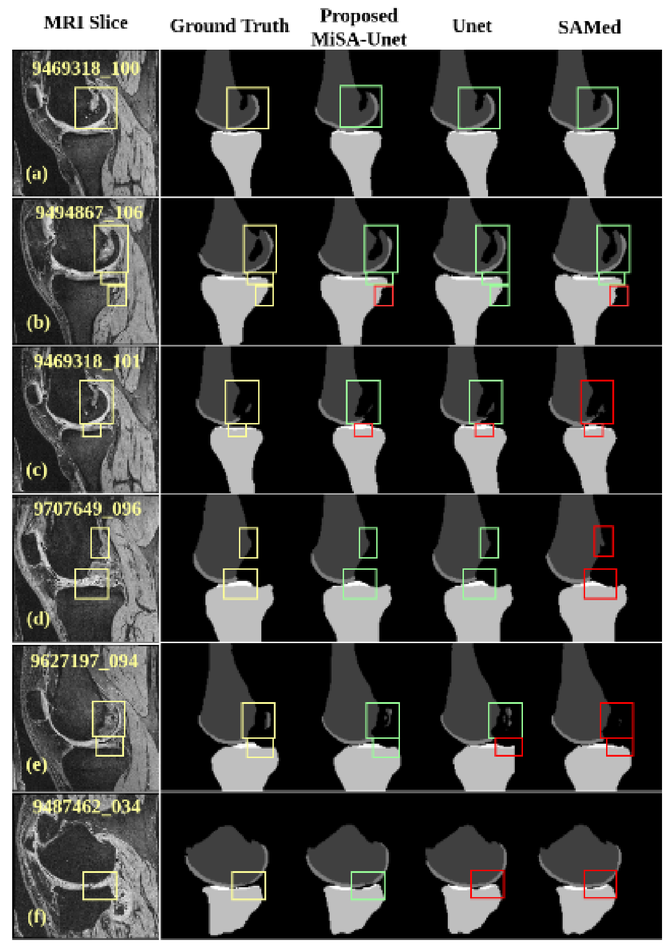

Figure: Qualitative comparison of proposed with MtSA-Unet

Key Findings

- **A Single-stage and end-to-end segmentation network with a focus only on critical slices with time reduction.**
- **Improvement of average DSC by 2.33% (on critical slices) with post-processing it further improved by 1% for all slices.**

MedCAM-OsteoCls: Medical Context Aware Multimodal Classification of Knee Osteoarthritis (Accepted at ICASSP-25)

Challenges: **Overlap between KOA stages, and progression heterogeneity.**

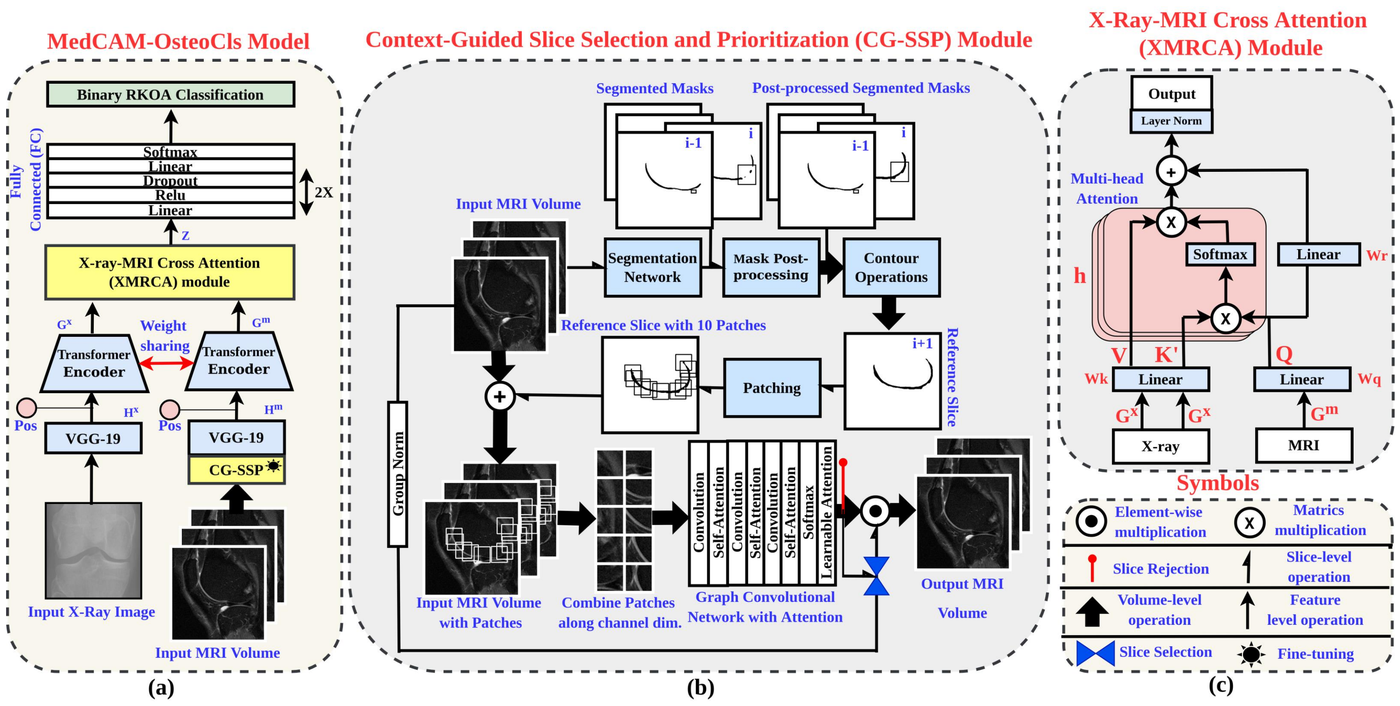

Figure: Overall schematic of the proposed MedCAM-OsteoCls model with (a) VGG-19-TE +Fully Connected (FC) Network, (b) the CG-SSP, (c) the XMRCA module.

Integrating critical MRI slice features with X-ray features enhanced recall, thus reducing the risk of missing treatment for RKOA patients.

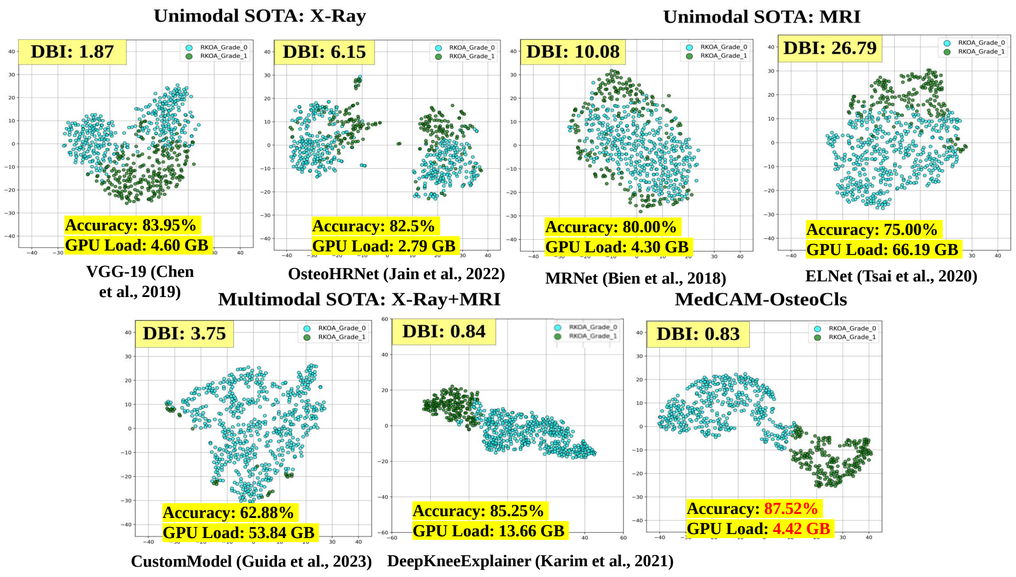

Figure: Visualization of tSNE plots for Unimodal and Multimodal schemes with the MedCAM-OsteoCls model.

Key Findings

- **Proposed model is computationally efficient in terms of GPU utilization by 64.64% compared to SOTA.**
- **The improved performance is achieved by cross-attending critical MRI slice features with the X-ray as a query vector.**

Our Team

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Selected References

- Kellgren, J. H., & Lawrence, J. S. (1957). Radiological assessment of osteo-arthrosis. *Ann Rheum Dis*, *16*(4), 494-502.
- Ambellan, F., Tack, A., Ehlke, M., & Zachow, S. (2019). Automated segmentation of knee bone and cartilage combining statistical shape knowledge and convolutional neural networks: Data from the Osteoarthritis Initiative. *Medical image analysis*, *52*, 109-118.
- Daydar, A., Pramanick, A., Sur, A., & Kanagaraj, S. (2024). Segmentation of tibiofemoral joint tissues from knee MRI using MtRA-Unet and incorporating shape information: Data from the Osteoarthritis Initiative. *arXiv preprint arXiv:2401.12932*..
- Bien, N., Rajpurkar, P., Ball, R. L., Irvin, J., Park, A., Jones, E., ... & Lungren, M. P. (2018). Deep-learning-assisted diagnosis for knee magnetic resonance imaging: development and retrospective validation of MRNet. *PLoS medicine*, *15*(11), e1002699.