Predictive Pre-Training of Tennis Shot Embeddings

Final Project Presentation

Project/Team ID: TECO
George Tamer (gyt2107)
Flor Sanders (fps2116)
Tawab Safi (as7092)

EECS E6691 Advanced Deep Learning, 2024 Spring

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Introduction

Tennis = Skill + Strategy

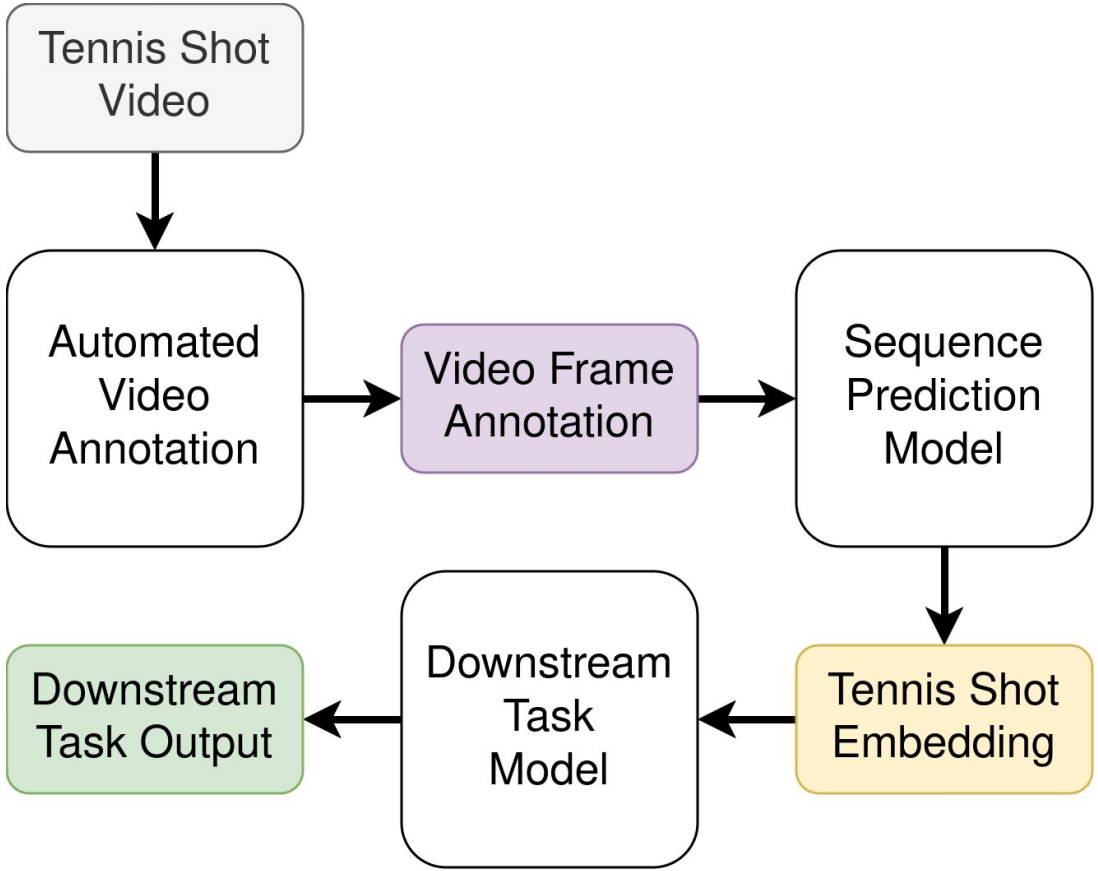
- Lots can be learned from:
  - player movements
  - ball trajectories
- Game analysis and coaching are big businesses
- Prohibitively expensive for most people

→ **Solve using Deep Learning**

- Predictive pre-training of shot embeddings
- Use embeddings as features in downstream tasks

Tennis Game [Wikipedia]

Methodology



Video Annotation - Dataset

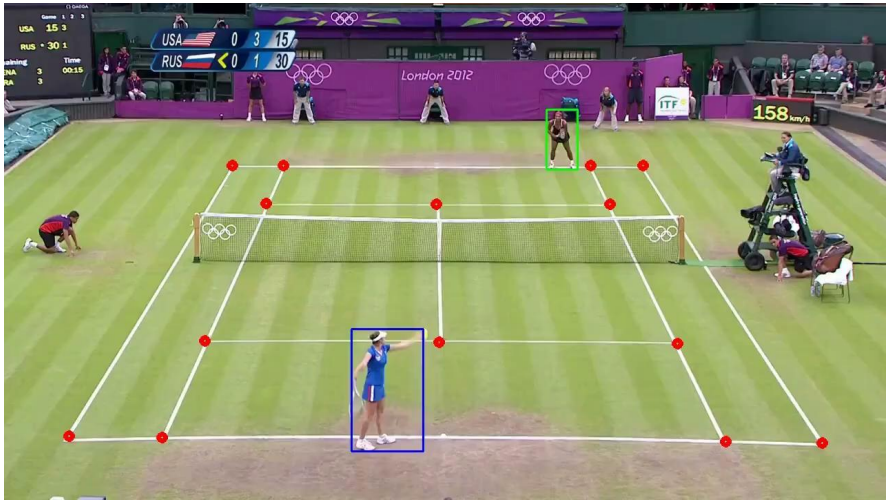
Tenniset

- 2012 London Olympic Games
- Five full-length tennis matches
  - (V006 - V010)
- Start/end frame annotations
- Serve in/out annotations
- Hit type annotations
  - flat/topspin/slice/unsure
  - forehand/backhand

Video Annotation - Ball, Court & Player Detection

TennisProject

- Ball Detection
  - Tracknet
- Court Detection
  - Modified Tracknet
  - 14 Court Points
- Player Detection
  - Faster R-CNN trained on COCO
  - Heuristics to identify playes



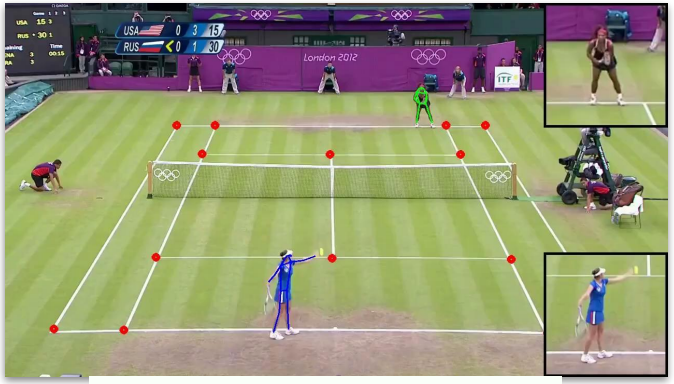
→ **Extract 2D player position on court using homography.**

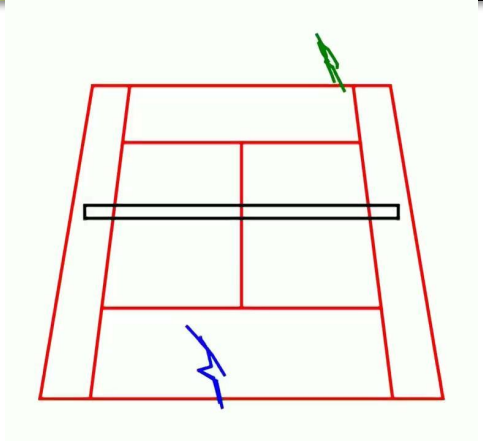
Video Annotation - 2D & 3D Player Pose Detection

MMPose

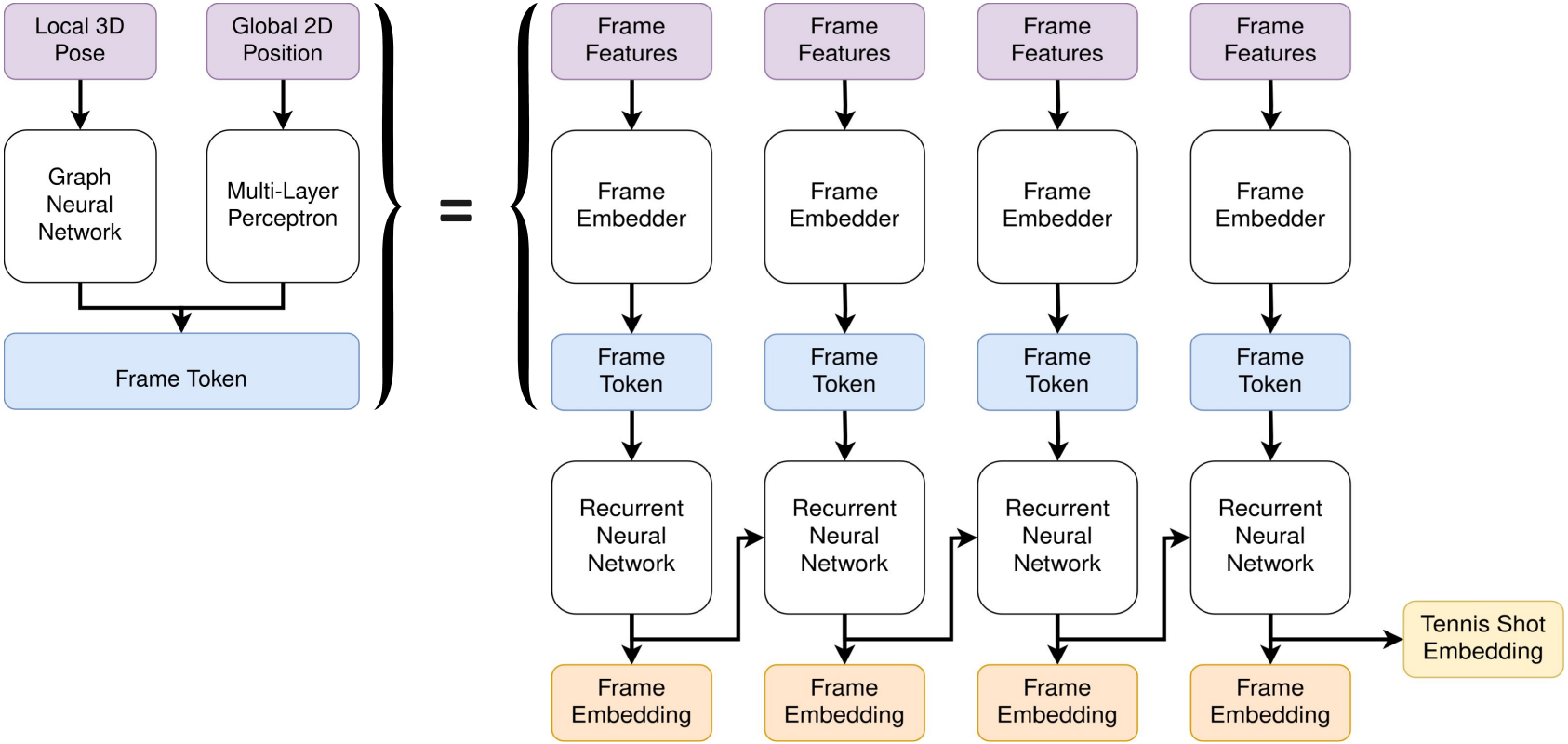
- Framework for pose detection models
- 2D Pose Detection
  - RTMDet + RTMPose
  - Refine bounding box estimates
- 3D Pose Detection
  - MotionBERT
  - Fix orientation by matching 3D to 2D poses
- Total of 3,183 processed shot segments

→ **Reduced frame dimensionality from 1280x720x3 pixels to 2x17x3 coordinates**



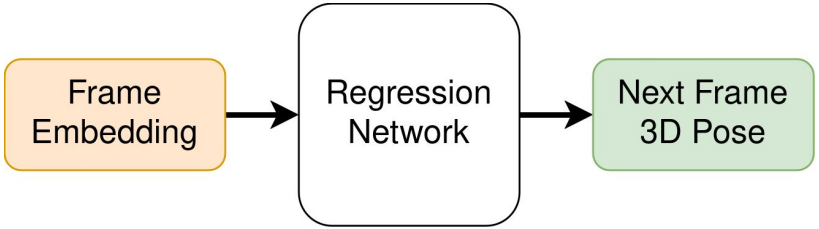


Deep Learning Model Architecture



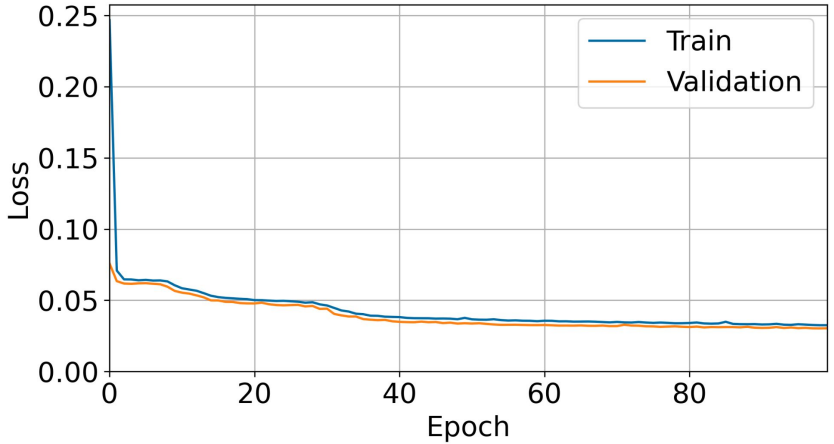
Model Pre-Training

Pre-Training Task



- Goal: Learn meaningful embedding
- Task: Predict next 3D pose
  - Inspired by ELMo
- Train model end-to-end
- Test Loss: 0.0331

Training History

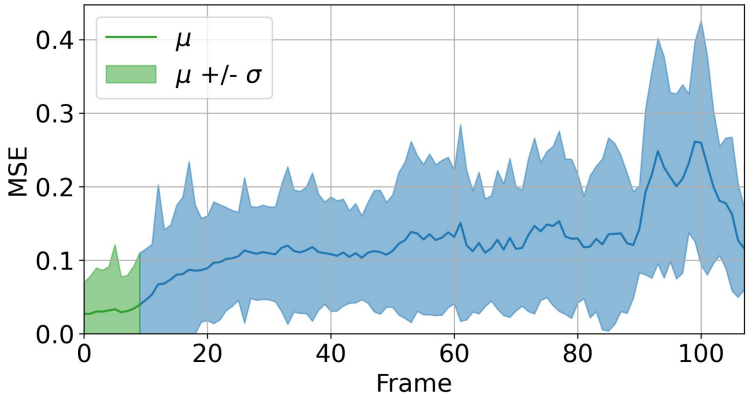


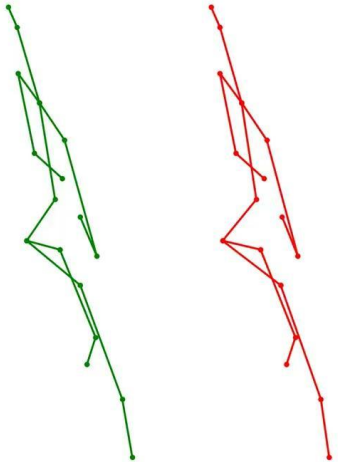
Model Pre-Training Results

Pretrained Model Evaluation

From the first 3D pose and 2D position, predict all subsequent 3D poses iteratively.

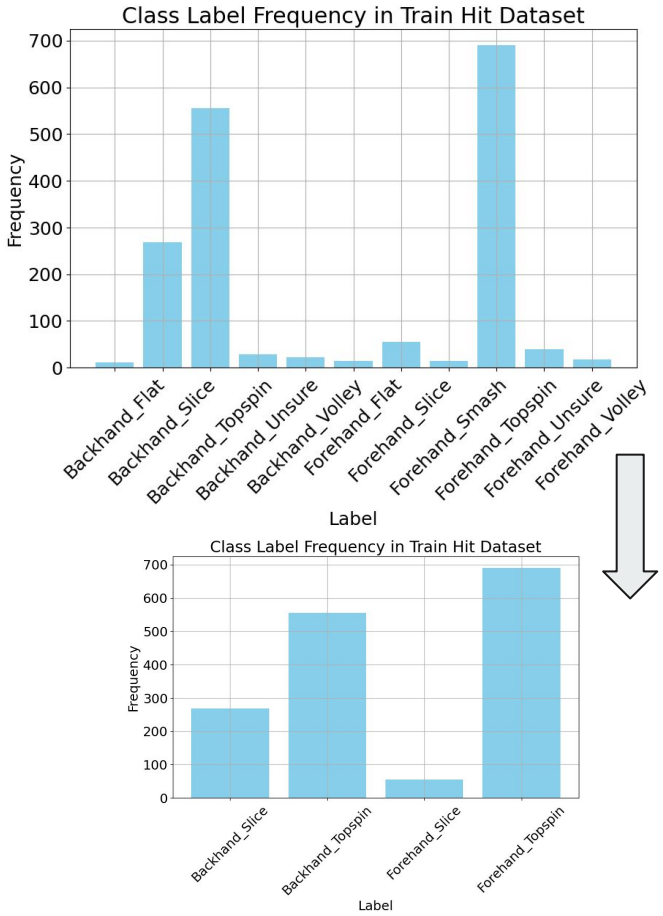
→ **Record quality drift over time**





Downstream Task - Shot Classification

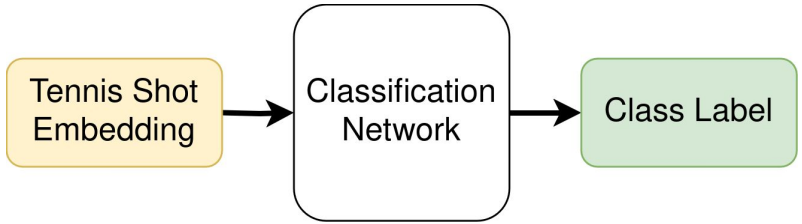
- Task: given an embedding of the shot, predict the shot type
- 11 classes in original test dataset
- Kept top 4 classes due to extreme shot imbalance



Downstream Task - Network Surgery and Fine-Tuning

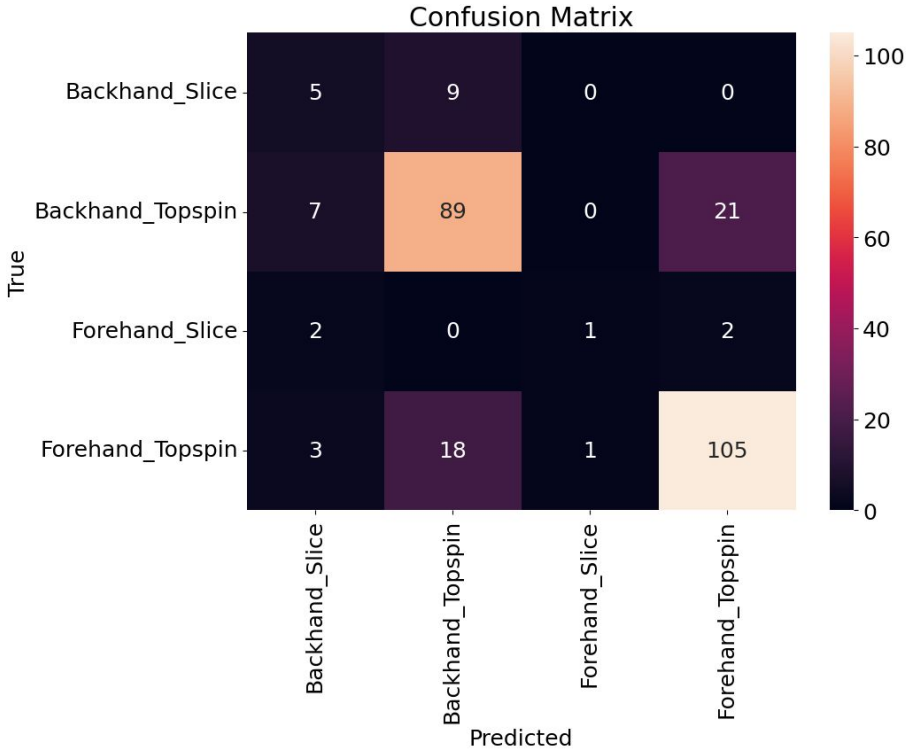
Procedure

- Add a simple MLP head to the model
- Freeze all weights except for the MLP
- Train for N epochs
- Unfreeze all weights
- Continue training



Downstream Task - Results

- Accuracy: 0.7605
- Precision: 0.7626
- Recall: 0.7605
- F1 Score: 0.7601



Conclusion

- Learning representations of sports shots through video -> 3d workspace -> graph construction is a promising direction for future research.

- Performing sequence modelling over continuous action spaces is a challenging task, and requires careful data curation and network architecting.

- The learnt representations are capable enough to serve as inputs to downstream tasks.

Future Work

Data Collection

- Quantity
  - Process more tennis matches
- Quality
  - Hand-keypoint extraction
  - Track ball and racket in 3d
- Modality
  - Collect { shot-video , caption } data samples to enable novel downstream tasks such as searching and coaching

Model Improvements

- Graph Construction
  - Use a temporal graph
  - Multiplayer graphs
- Encoder Variants
  - Try pre-training with BERT-style masking & reconstruction
- Multimodal
  - Contrastive learning on graph and text modalities
- Learning player style

References

- **Our Github:** https://github.com/ecbme6040/e6691-2024spring-project-TECO-as7092-gyt2107-fps2116
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- TennisProject: https://github.com/yastrebksv/TennisProject
  - TrackNet: https://arxiv.org/abs/1907.03698
  - TennisCourtDetector: https://github.com/yastrebksv/TennisCourtDetector
  - Faster R-CNN: https://arxiv.org/abs/1506.01497
- MMPose: https://github.com/open-mmlab/mmpose
  - RTMDet: https://arxiv.org/abs/2212.07784
  - RTMPose: https://arxiv.org/abs/2303.07399
  - MotionBERT: https://arxiv.org/abs/2210.06551
- RNN Literature Review: https://arxiv.org/abs/1912.05911
- Graph Attention Network: https://arxiv.org/abs/1710.10903
- BERT: https://arxiv.org/abs/1810.04805
- CLIP multimodal embeddings: https://arxiv.org/abs/2103.00020
- V-JEPA:https://ai.meta.com/research/publications/revisiting-feature-prediction-for-learning-visual-representations-from-video/