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Development of a Lightweight Real-Time Application for Dynamic Hand Gesture Recognition

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Presentation Outline

- Background
- Literature Review & SOTA
- Proposed Framework & Application
- Evaluation Results & Comparison with SOTA
- Lightweight Application & Performance
- Conclusion & Future Work

Dynamic Hand Gesture Recognition

> Computer Vision
>> Perceptual Computing
>>> **Dynamic Hand Gesture Recognition (HGR)**

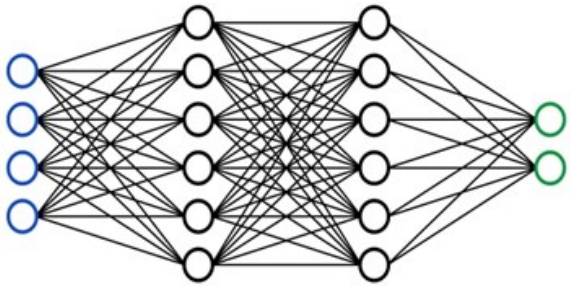
* **HGR Applications:**
  - Human-Machine Interactions
  - Human Behavior Analysis
  - Active & Assisted Living
  - Virtual & Augmented Reality
* **HGR Complexity:**
  - Human Hand
  - User Environment
  - Sensor Types

Existing HGR Frameworks

Input Modality

HGR Framework

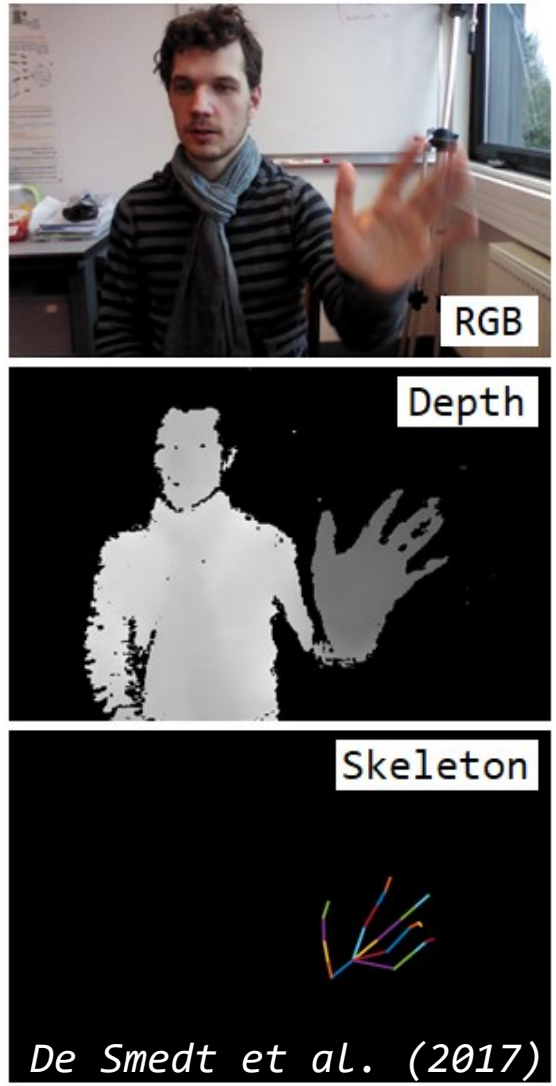
Gesture Classification



Network Architecture

State-Of-The-Art HGR Frameworks

- **Gesture Input Modalities:**
  - RGB [*Narayana et al. (2017), Köpüklü et al. (2019)*]
  - Depth [*Narayana et al. (2017), Köpüklü et al. (2019)*]
  - Skeleton [*Li et al. (2021), Shi et al. (2020), Sabater et al. (2021)*]
  - Optical Flow (RGB & Depth) [*Narayana et al. (2017)*]
- **Neural Network Architectures:**
  - Multi-Stream Fusion [*Li et al. (2021), Narayana et al. (2017)*]
  - Recurrent Neural Network [*Li et al. (2021)*]
  - (2D & 3D) Convolutional Neural Network [*Narayana et al. (2017), Köpüklü et al. (2019)*]
  - Graph Convolutional Network [*Li et al. (2021)*]
  - Attention Network [*Li et al. (2021), Shi et al. (2020)*]
  - Temporal Convolutional Network [*Sabater et al. (2021)*]



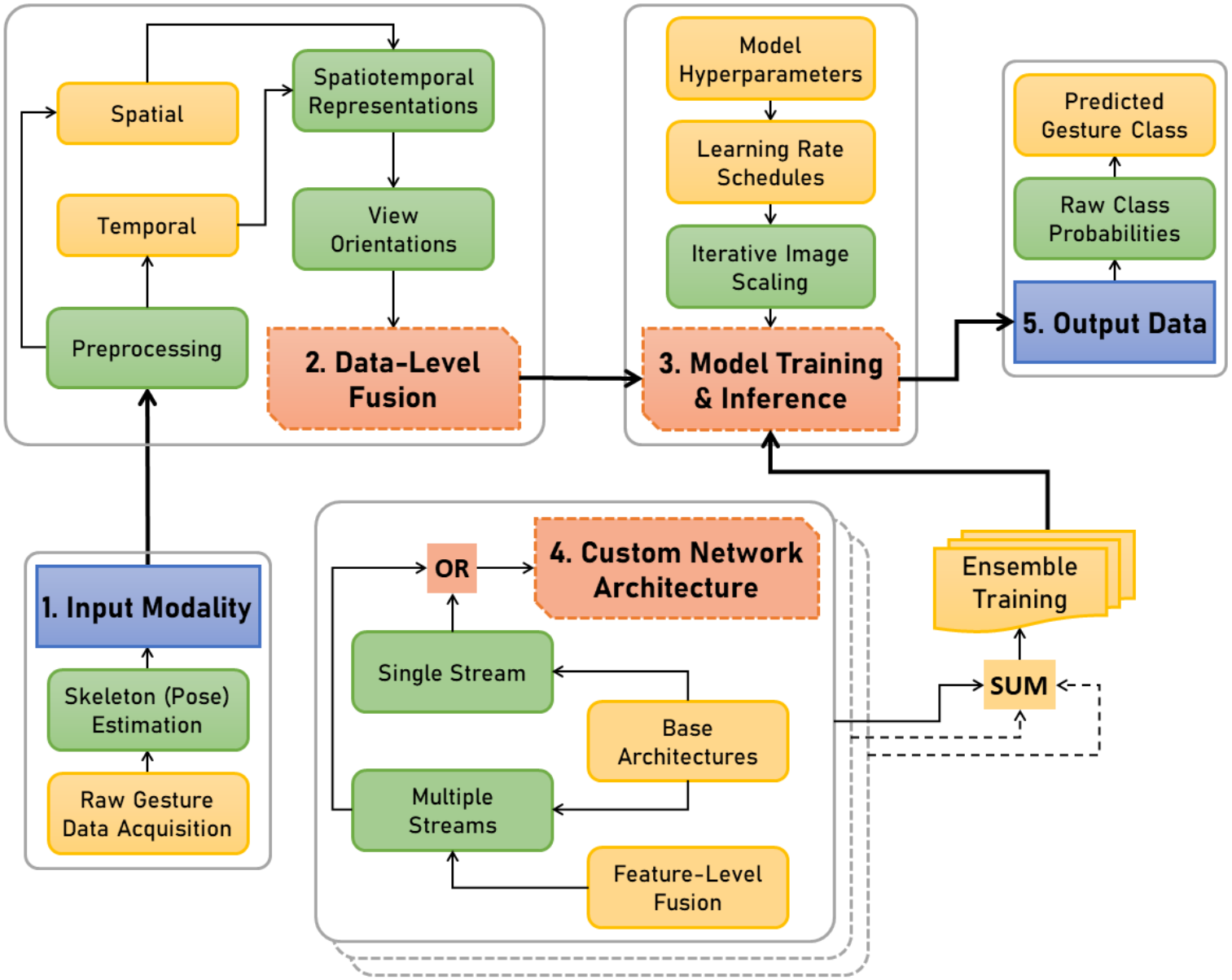
Constraints::

* **Hardware Requirements:**
  - Inbuilt PC Webcam
* **Computational Complexity:**
  - Minimize CPU & RAM Utilization

Requirements::

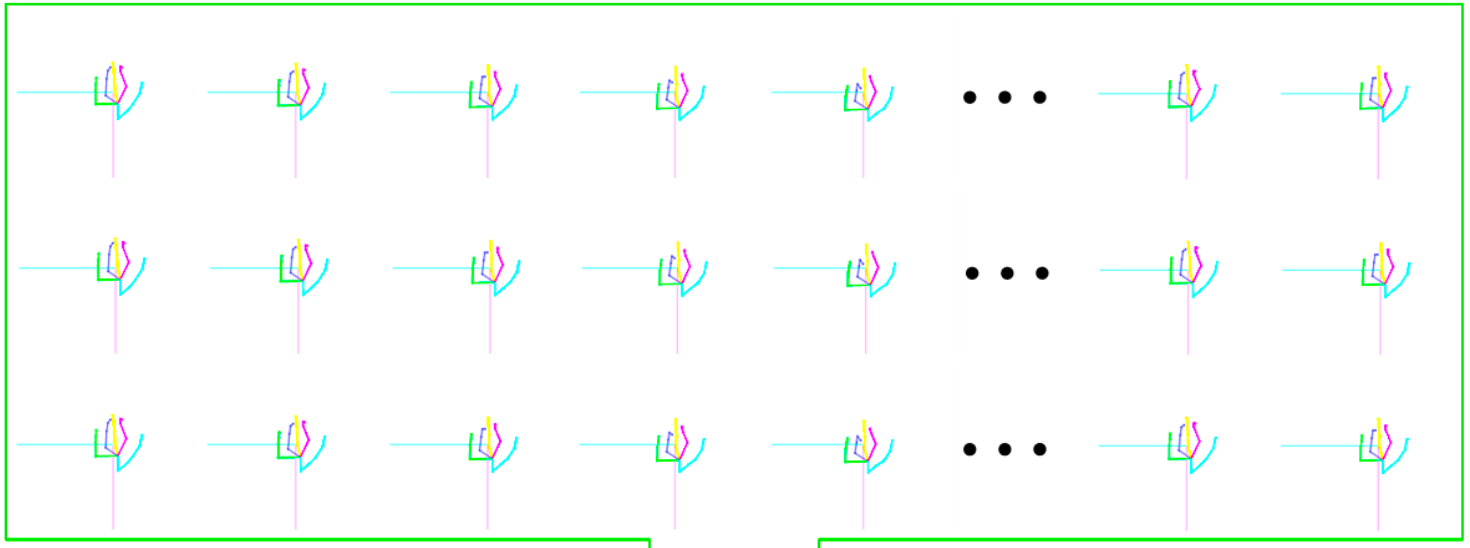
* **Classification Accuracy:**
  - Maintain SOTA Evaluation Performance
* **Real-Time Performance:**
  - Maximize FPS
  - Minimize Latency

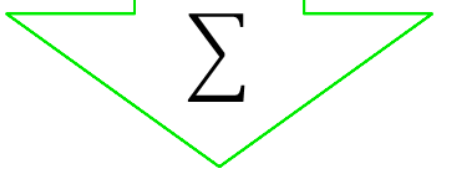
Application Constraints & Requirements

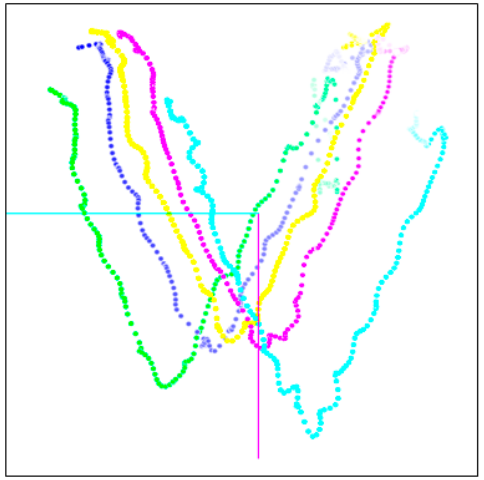


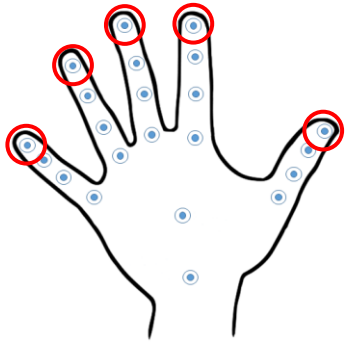
Proposed Dynamic HGR Framework

Temporal Trails Data-Level Fusion



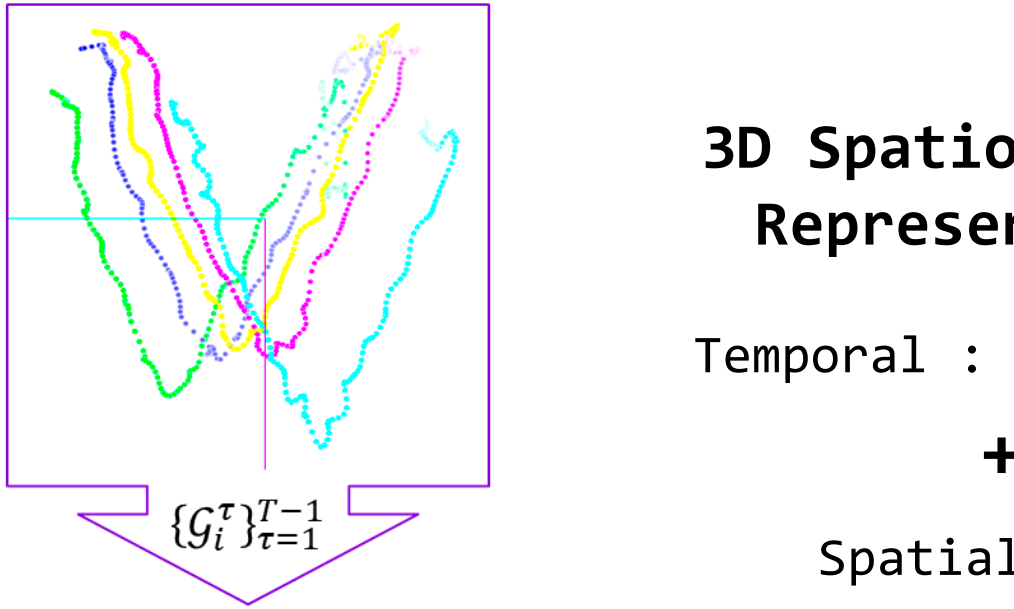






Temporal Information Condensation::

- $\sum\{\mathcal{G}_i^{\tau}\}_{\tau=1}^{T-1}$
  - Five Fingertips
  - Dynamic Gesture, i
  - Temporal Window, T

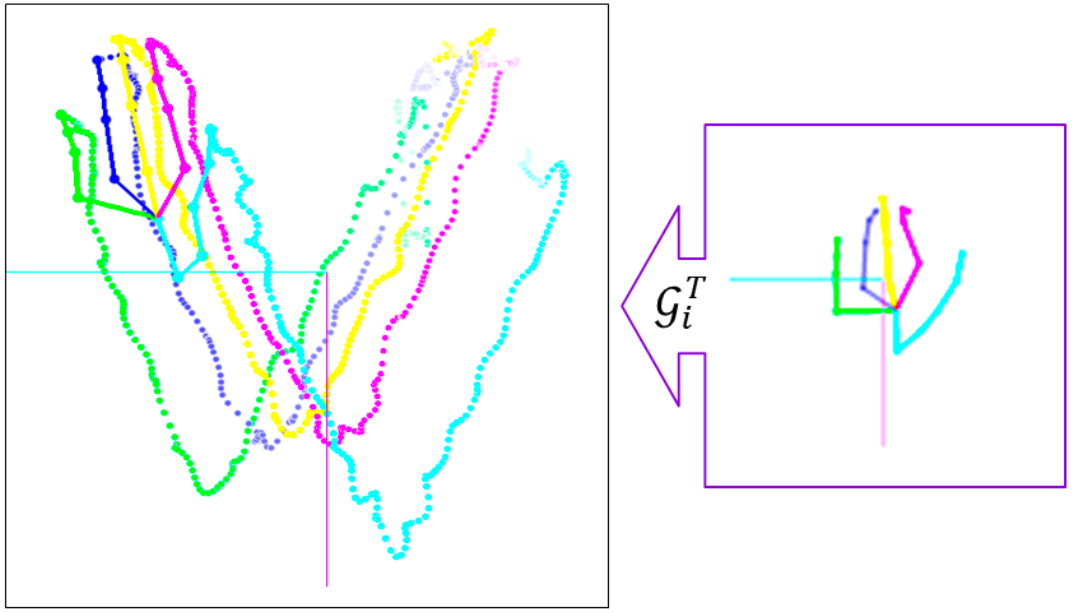


3D Spatiotemporal Representation

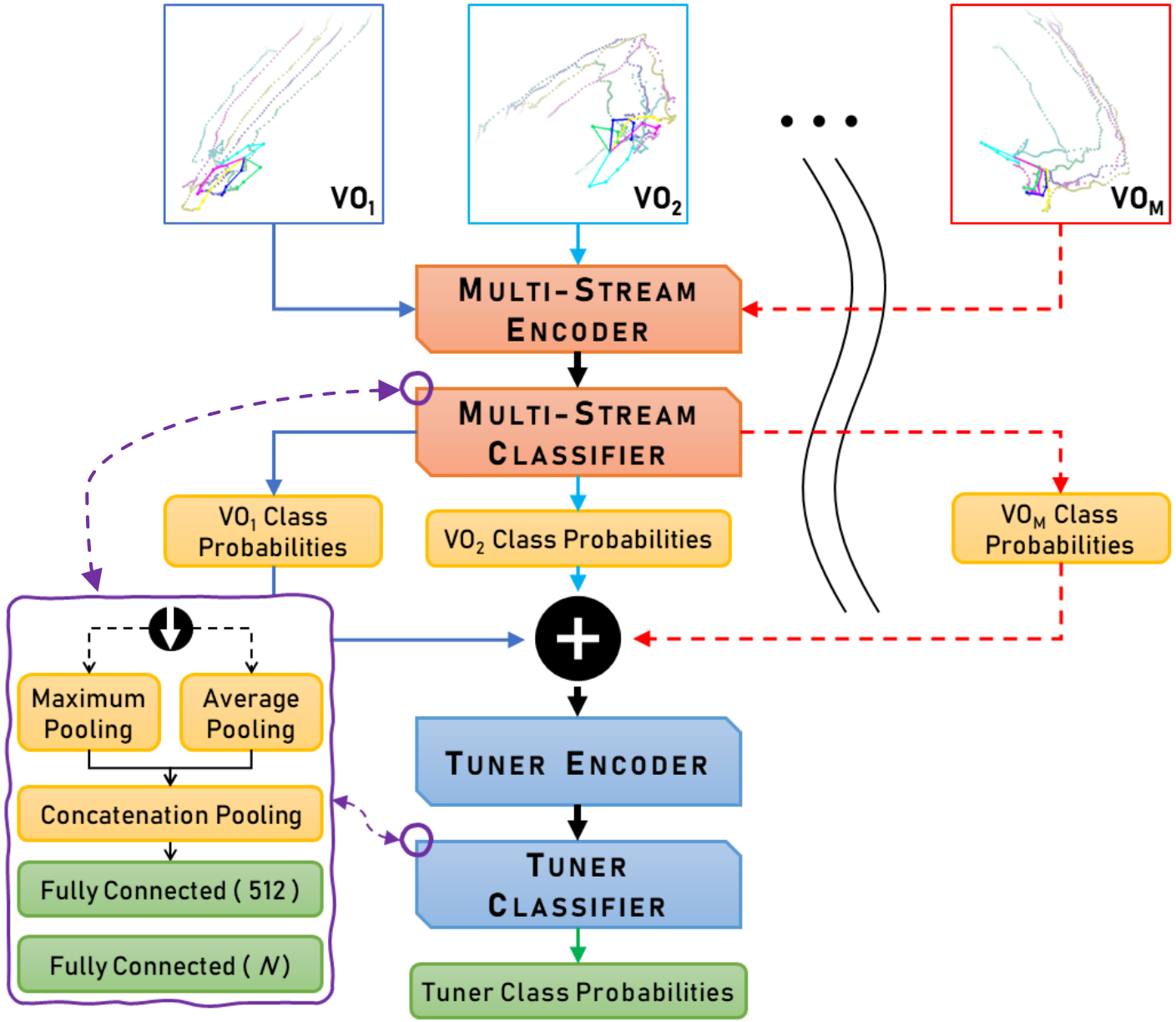
Temporal : $\sum\{\mathcal{G}_i^{\tau}\}_{\tau=1}^{T-1}$

+

Spatial : $\mathcal{G}_i^{T}$



Temporal Trails Data-Level Fusion

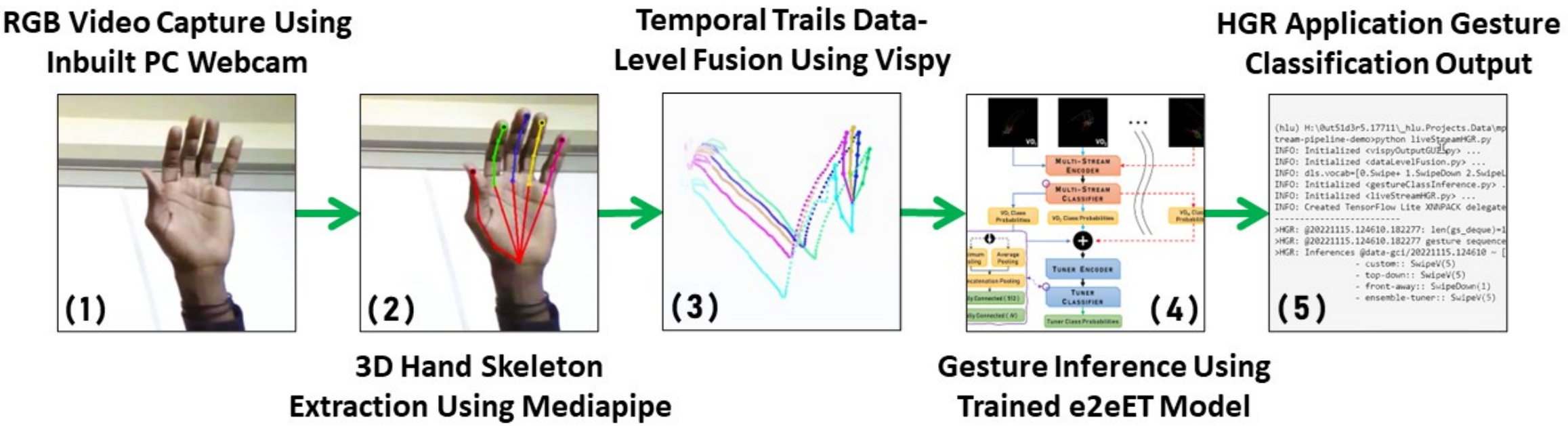


End-to-end Ensemble Tuner [e2eET] Multi-Stream CNN Architecture

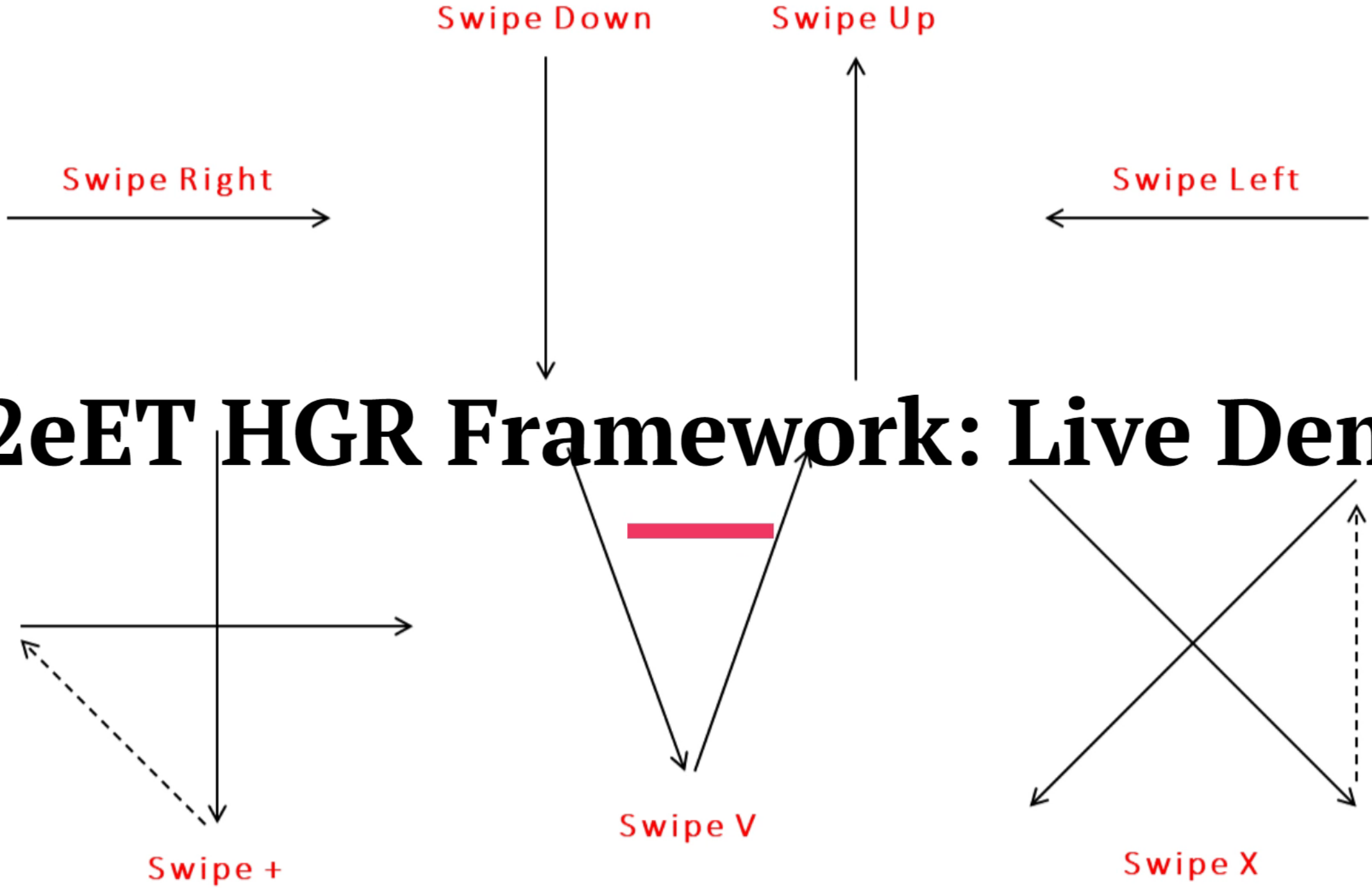
HGR Framework Accuracy Comparison w/SOTA

Datasets / SOTA Frameworks	Classification Accuracy	
	SOTA	Ours
1. Dynamic Hand Gesture 14/28 Dataset (DHG1428) – n=2800 ; c=14/28		
Li et al. (2021)	95.18%	94.11% [-1.07%]
2. 3D Hand Gesture Recognition....Dataset (SHREC2017) – n=2800 ; c=14/28		
Shi et al. (2020)	95.45%	96.61% [+1.16%]
3. Consiglio Nazionale delle Ricerche....Dataset (CNR) – n=1925 | c=16		
Lupinetti et al. (2020)	98.78%	97.05% [-1.73%]
4. Leap Motion Dynamic Hand Gesture Benchmark (LMDHG) – n=608 ; c=13		
SOTA: Lupinetti et al. (2020)	92.11%	98.97% [+6.86%]
5. First-Person Hand Action Benchmark (FPHA) – n=1175 ; c=45		
SOTA: Sabater et al. (2021)	92.93%	91.83% [-4.10%]

Lightweight Real-Time Application



Code available at:: https://github.com/Outsiders17711/e2eET-Skeleton-Based-HGR-Using-Data-Level-Fusion



e2eET HGR Framework: Live Demo

HGR Application Performance Analysis

* **Test Platform::**
  - Lenovo PC @ Windows 10
  - Intel Core i7-9750H CPU
  - 16GB RAM
* **HGR Application Stats::**
  - 4 Python Modules
  - 3 UI Windows
  - ~2s Latency @ 15FPS
  - 93.46% Classification Accuracy

PC Software	RAM Utilized
HGR Application Modules	648.9 MB
RGB Video Capture + Mediapipe Skeleton Estimation	*90.0 MB*
Vispy Data-Level Fusion	*86.6 MB*
e2eET Model Inference	*358.8 MB*
Vispy Output GUI	*82.6 MB*
Terminal	*30.8 MB*
Google Chrome [9 Tabs]	821.7 MB
Adobe Acrobat DC [3 Documents]	228.7 MB
Microsoft Word [3 Documents]	199.8 MB
Windows Explorer [3 Windows]	166.7 MB

Conclusion

+ Demonstrated the viability of Data-Level Fusion in HGR domain.
+ Leveraged advances in deep, data-driven ML algorithms and architectures.
+ Using a custom end-to-end Ensemble Tuner Multi-stream CNN Architecture.

↪ **HGR Framework & Application::**

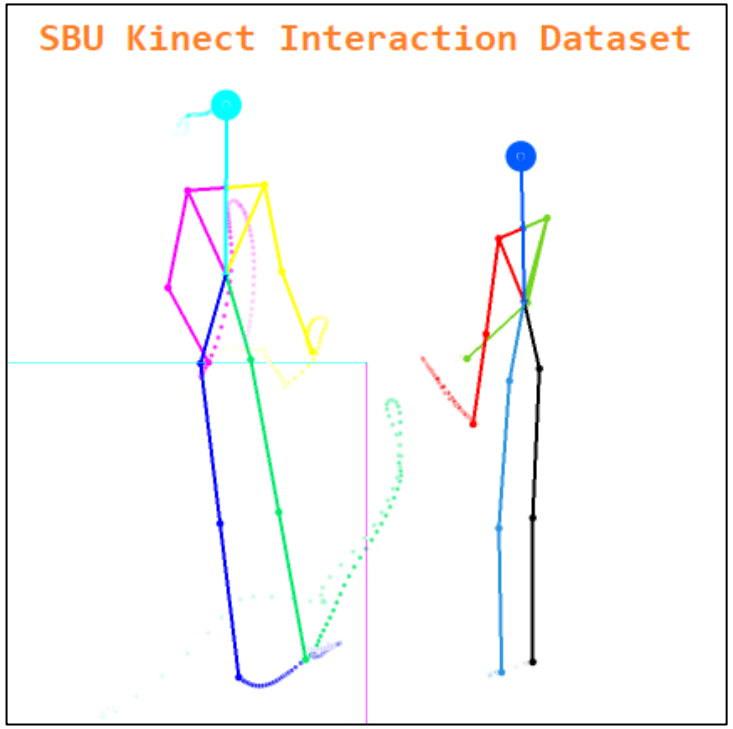
3D Hand Gesture Recognition ⟶ 2D Image Classification

☑ Obtained classification accuracies between -4.10% and +6.86% of SOTA.
☑ Minimized hardware requirements and computational complexity.

Future Work

Data-level Fusion::

- Gesture Visualization
- Image Generation



e2eET Architecture::

- Loss Function
- Ensemble Tuning Method

HGR Framework & Application::

- Unsegmented Data Streams
- Skeleton-based Human Action Recognition

References

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Thank You!
Questions?