Evaluating an Autoencoder for Computing Muscle Synergies

Siddharth R. Nathella, Aaron J. Young, Lena H. Ting

George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology

Georgia Tech

Overview

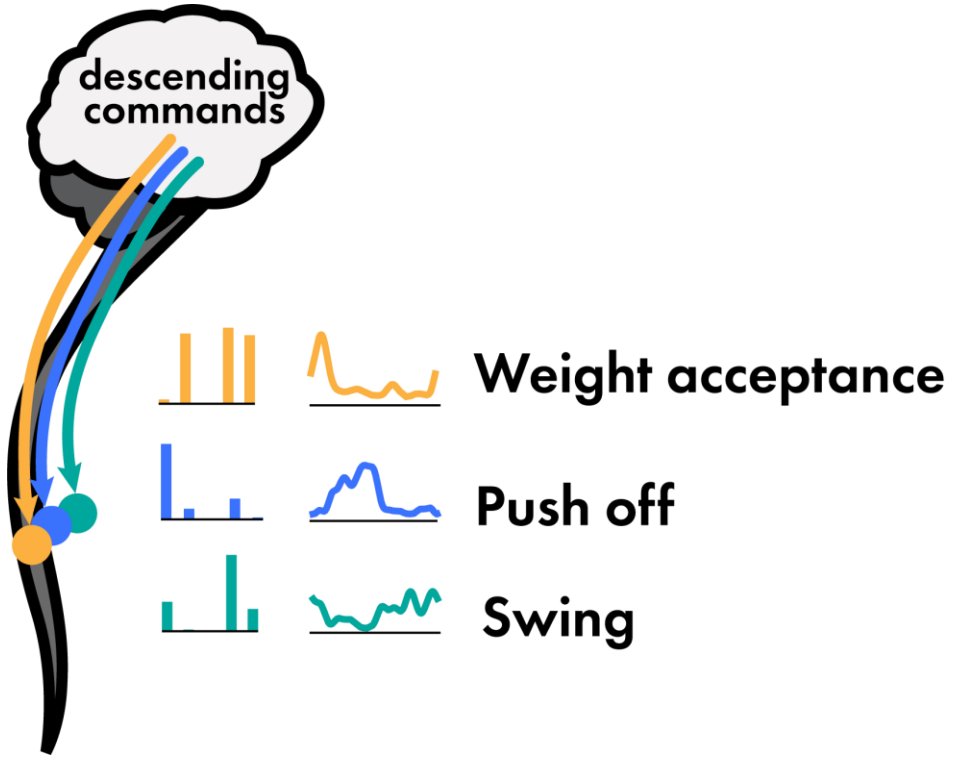
1. What are Muscle Synergies?
2. Current Technical Approach - NMF
3. What is an Autoencoder?
4. How well does an AE Compute Muscle Synergies?

What are Muscle Synergies?

Muscle synergies are sets of commonly recruited muscle coordination patterns which can be used to describe more complex patterns of motor control

Synergies have a specific biomechanical function[1,2]

A valuable tool in analysis of individuals with movement impairments[3,4]

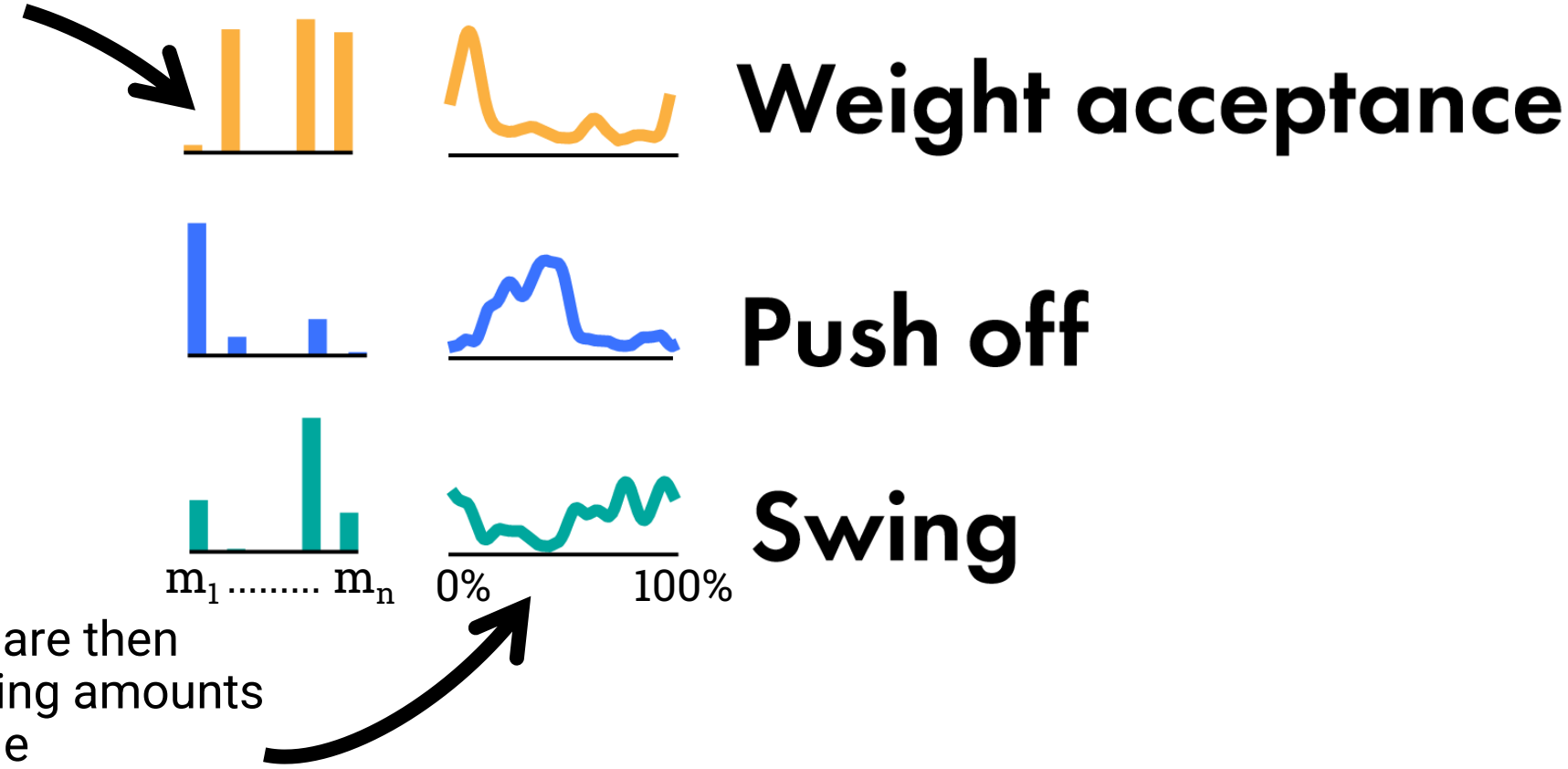


[1] Neptune et al., 2009 [2] Ting et al., 2015 [3] Clark et al, 2010 [4] Steele et al., 2015

Georgia Tech

Muscle Synergies as a Tool in Motor Control Analysis

Relative weightings of muscles compose synergy structure

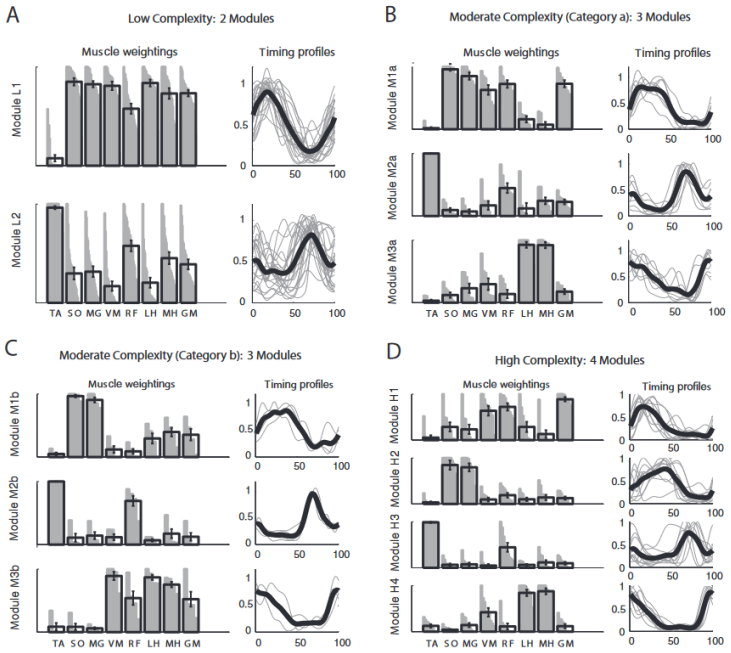


These synergies are then recruited by varying amounts over the gait cycle

Muscle Synergies as a Tool in Motor Control Analysis

Stroke survivors have fewer muscles synergies, present as *merged* forms of healthy synergies[3]

Variance accounted for by one synergy (VAF_1) is used as a metric for overall motor control complexity in children with Cerebral Palsy[5]



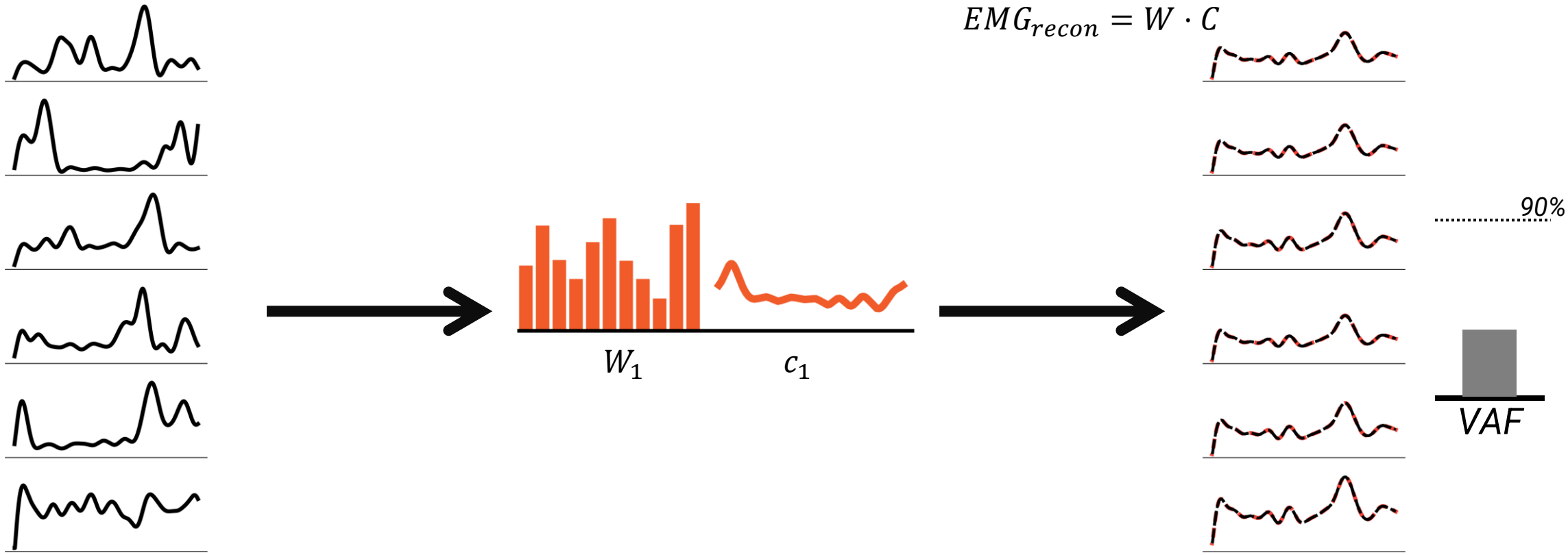
From Clark et al. *J. Neurophysiol*, 2010

[3] Clark et al., 2010 [5] Schwartz et al., 2016

Georgia Tech

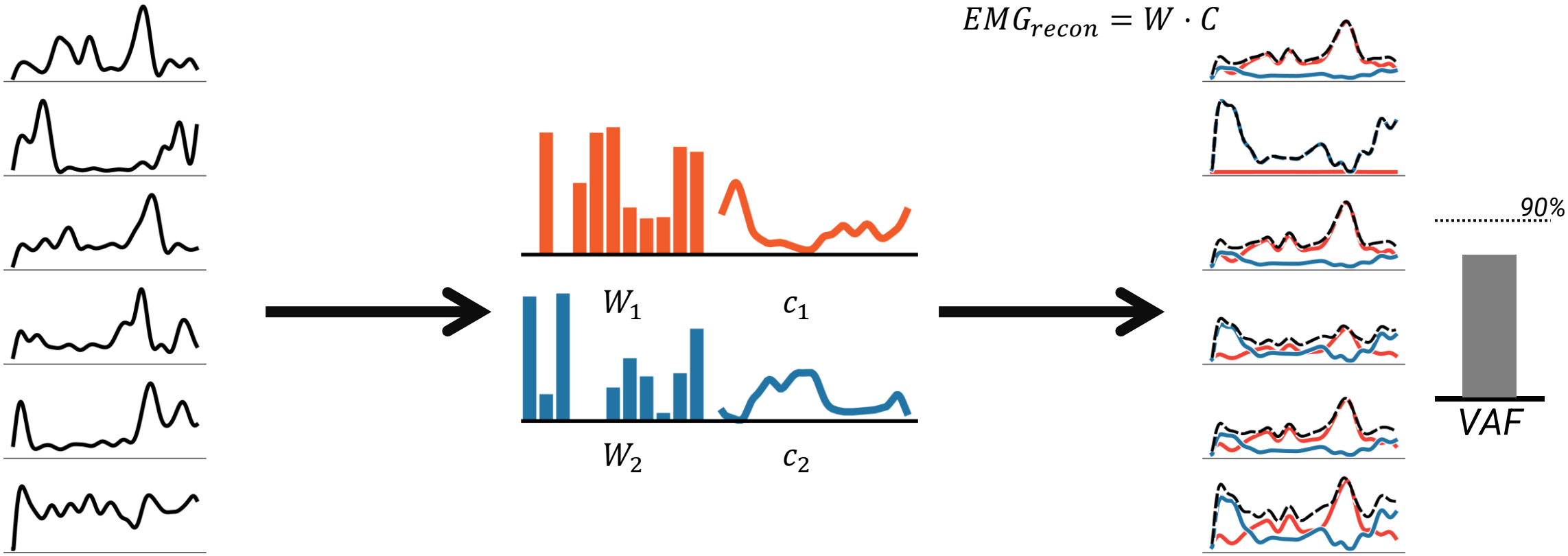
Current State of the Art – NMF

Non-Negative Matrix Factorization (NMF) is a matrix decomposition algorithm which is iteratively used to compute muscle synergy structures



Current State of the Art – NMF

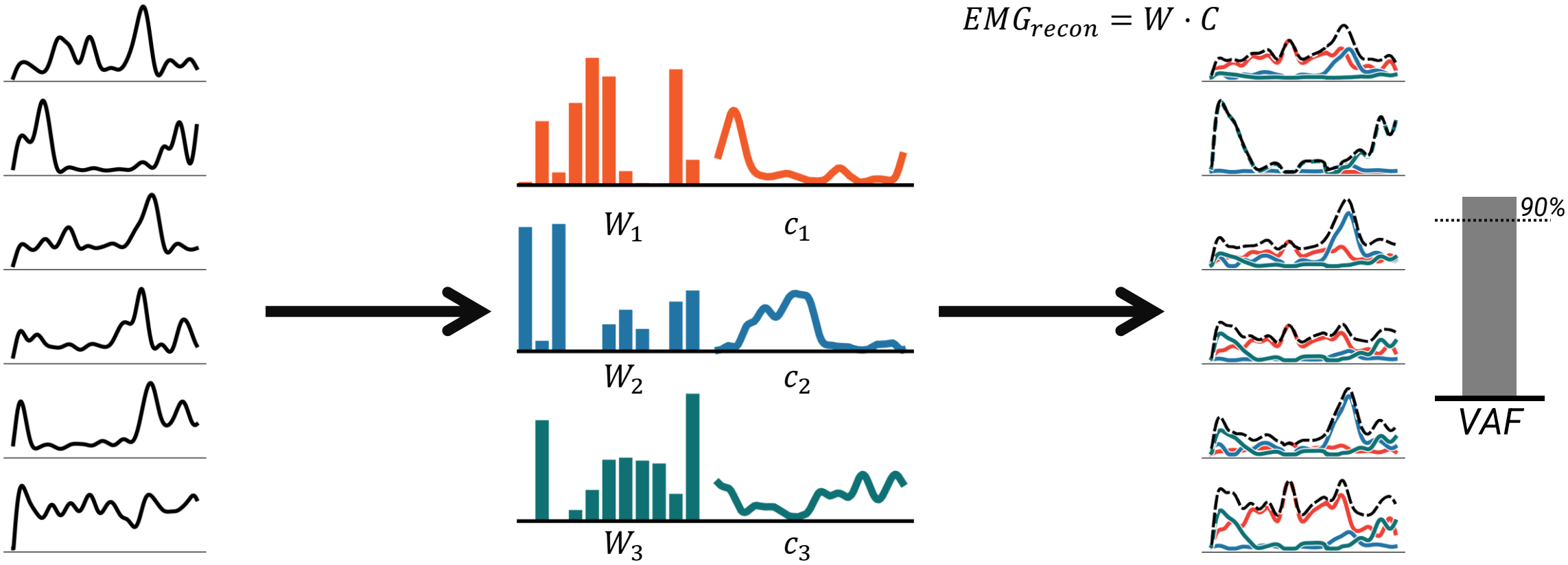
Number of synergies is iteratively increased until a reconstruction threshold is achieved



Georgia Tech

Current State of the Art – NMF

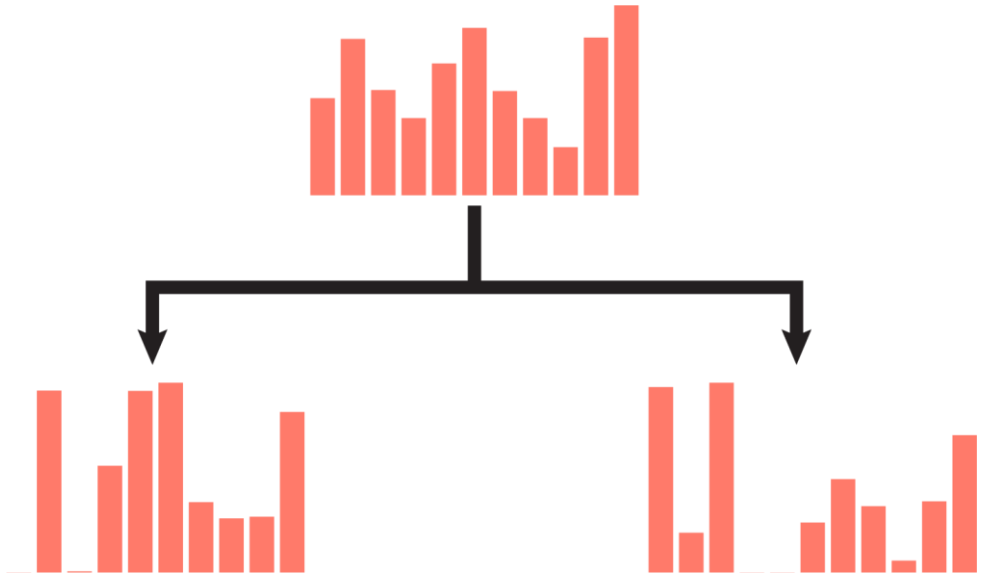
Number of synergies is iteratively increased until a reconstruction threshold is achieved



Current State of the Art – NMF - Limitations

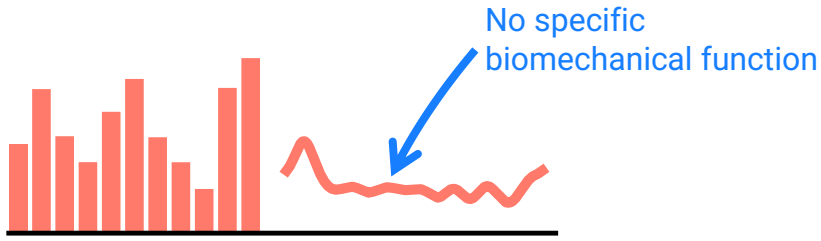
Changes in the number of synergies selected influences the structures of the synergies

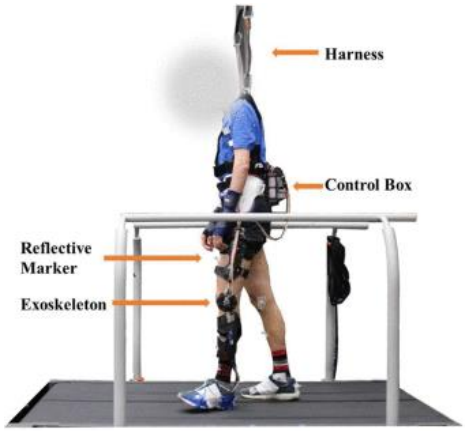
- As synergy count increases, synergies appear to “split”
- “True” structure is difficult to determine



Synergies at lower synergy counts have little functional relevance

- VAF_1 doesn’t reflect a specific synergy





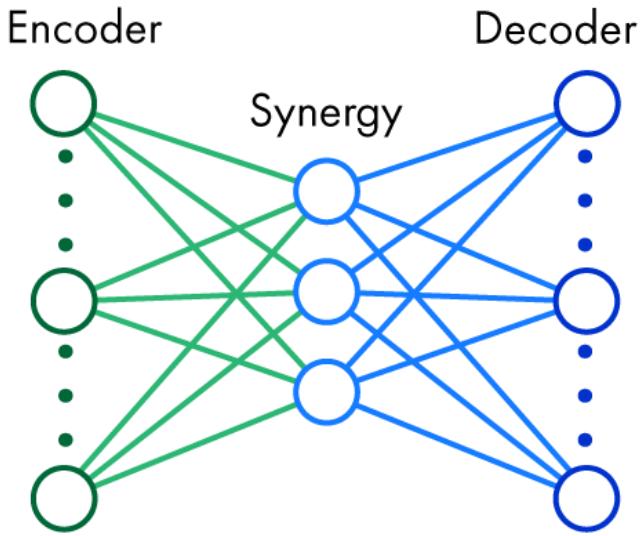
From Lee et al. *IEEE Transact Biomed*, 2023

Georgia Tech

Our Approach - Autoencoder

An Autoencoder (AE) is a neural network structure used to transform data into lower dimensional representations

- Can perform non-linear operations
- Incorporates an additional “bias” term



Our Approach - Autoencoder

The AE compresses EMG data into a muscle synergy representation

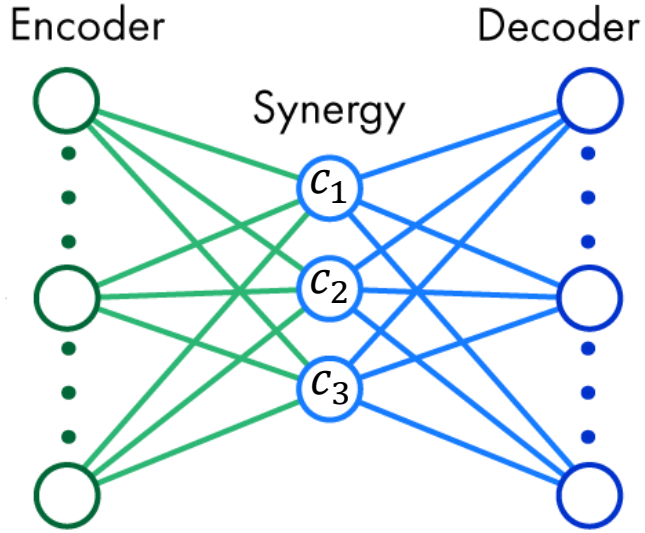
$$EMG_{recon} = g(W \cdot C + b)$$

One hidden layer

Hidden size reflects number of synergies

Walking data from Open-Source Dataset[6]

(n=21, 1.3m/s, 11 muscles)

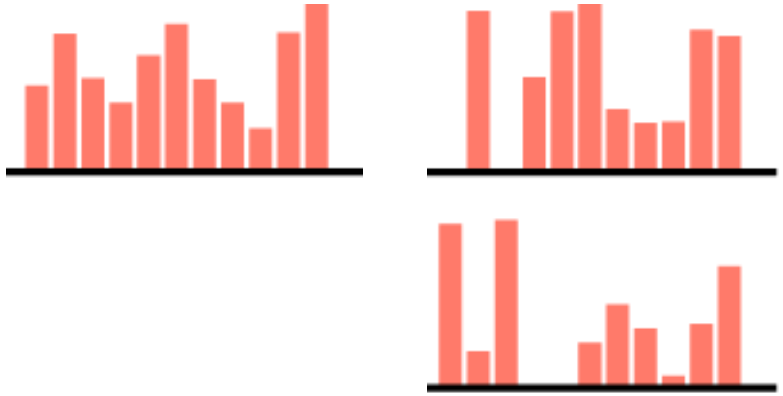


[6] Camargo et al., 2021

Georgia Tech

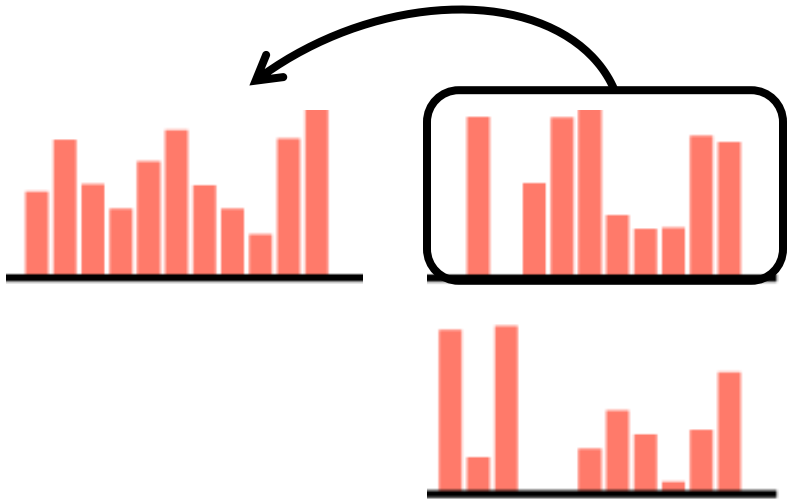
Comparison of Synergy Structure - Process

- For each method (NMF & AE), we iteratively computed 1 – 5 synergies
- Agreement between corresponding synergies by Pearsons's correlation coefficient



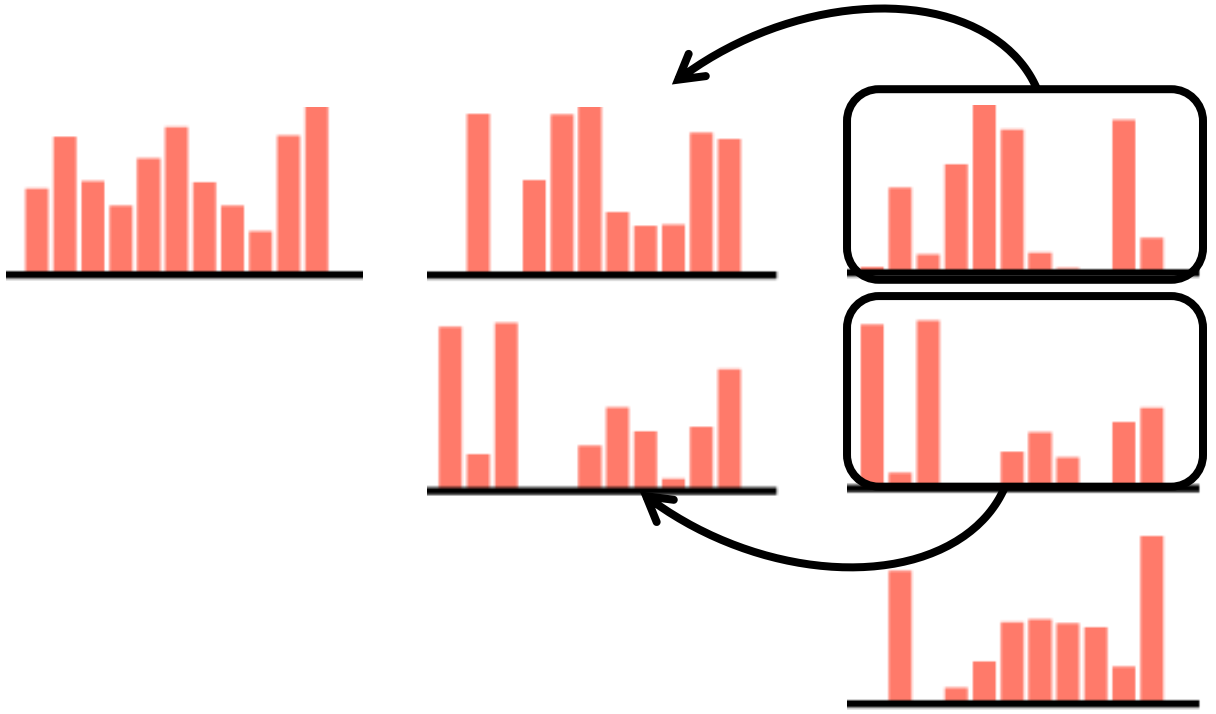
Comparison of Synergy Structure - Process

- For each method (NMF & AE), we iteratively computed 1 – 5 synergies
- Agreement between corresponding synergies by Pearsons's correlation coefficient

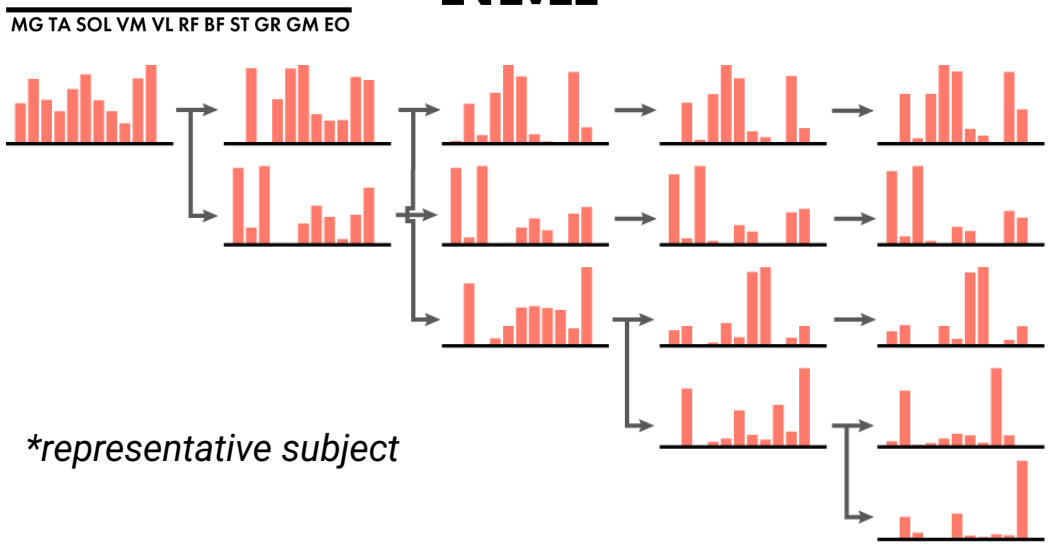


Comparison of Synergy Structure - Process

- For each method (NMF & AE), we iteratively computed 1 – 5 synergies
- Agreement between corresponding synergies by Pearsons's correlation coefficient

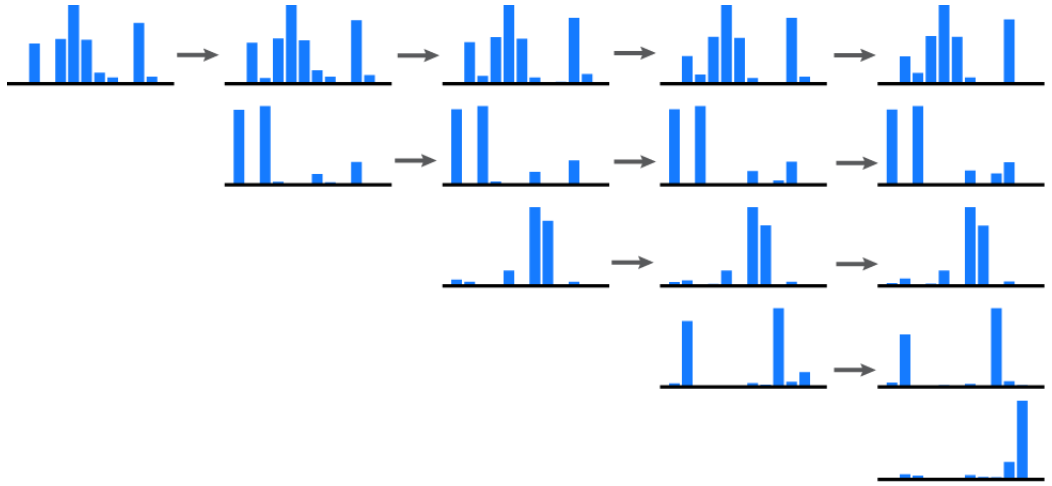


NMF

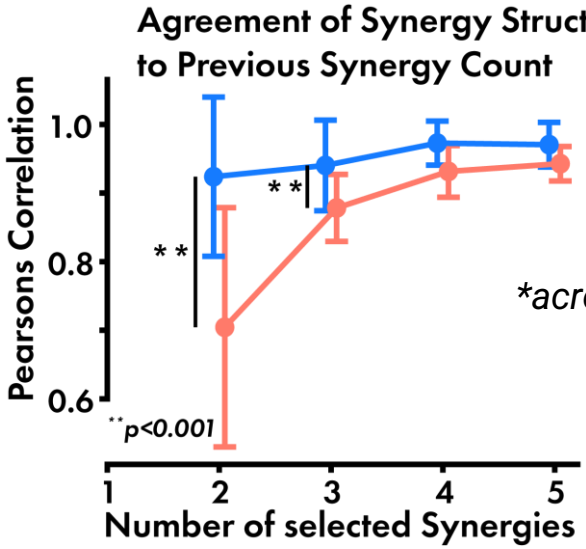


*representative subject

AE



- The Autoencoder shows stronger agreement in synergy structure across synergy counts
- NMF shows characteristic “splitting” of synergies as synergy count is incremented
- AE gives same information at synergy count of 1 & 5

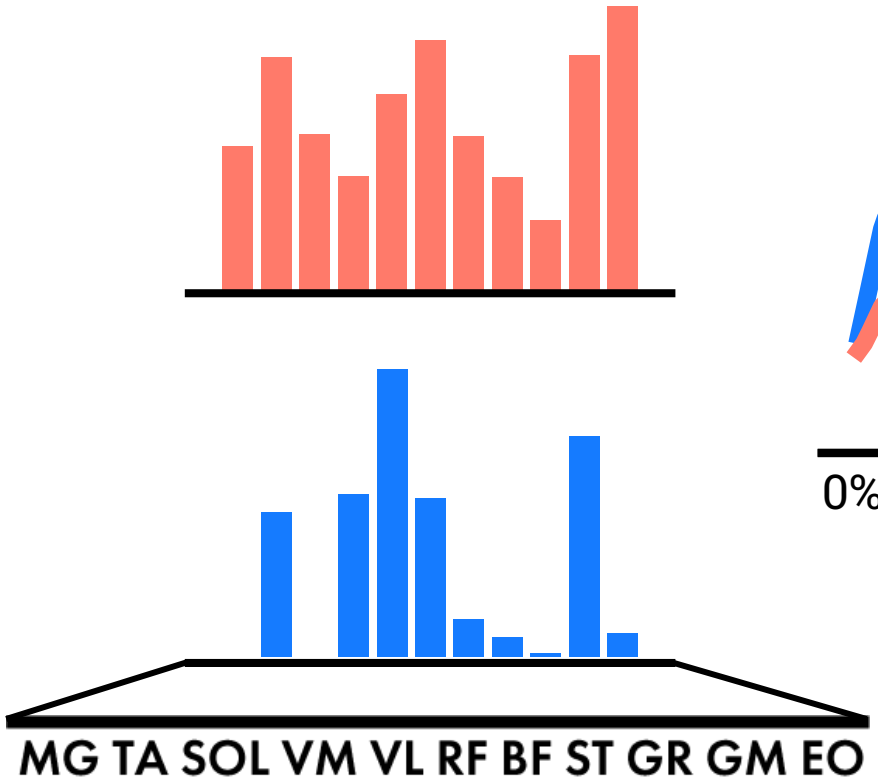


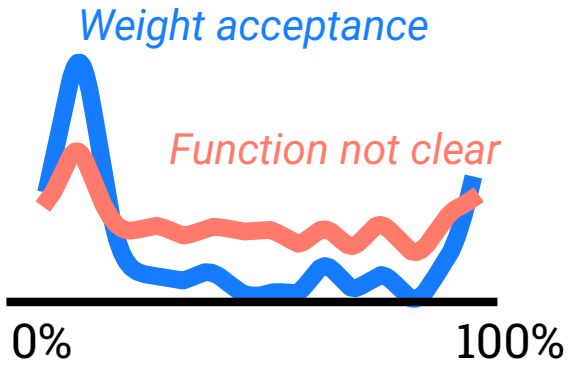
*across all subjects

Georgia Tech

Functional Relevance

Synergies @ 1 selected synergy





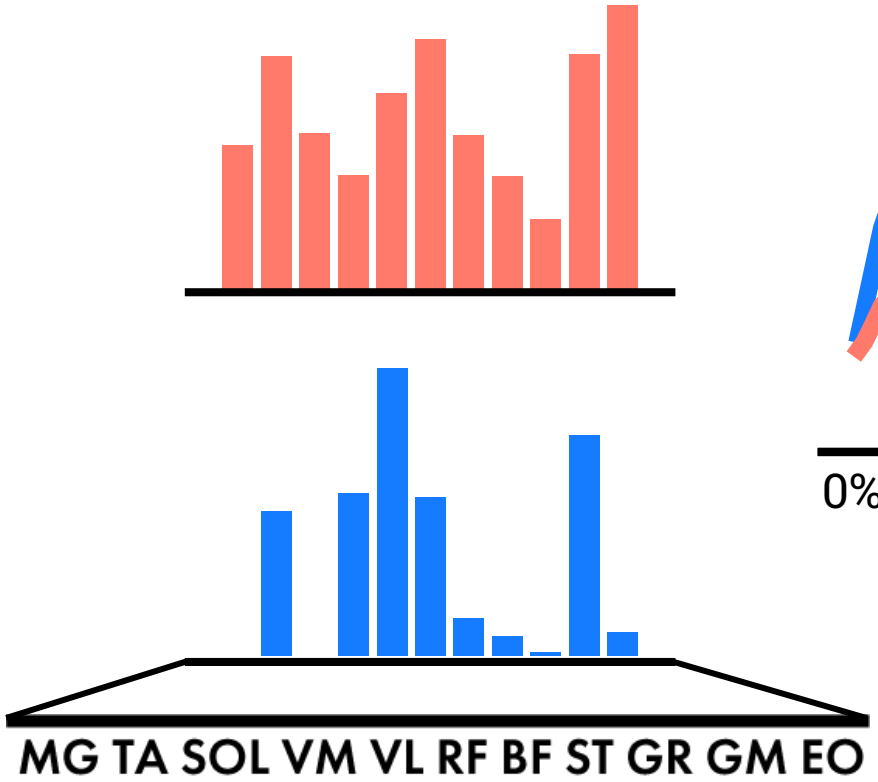
NMF activation and synergy arrangement does not indicate specific biomechanical function

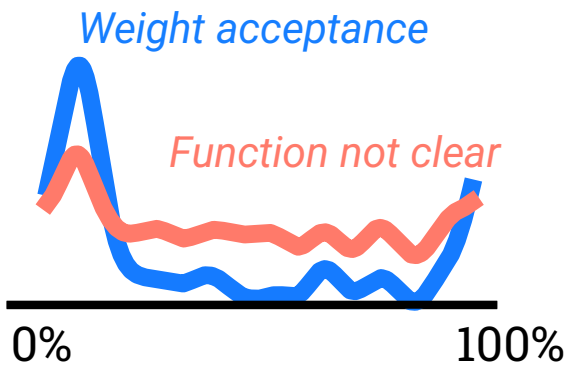
AE has very clear synergy arrangement and activation timing

Georgia Tech

VAF_1

Synergies @ 1 selected synergy





VAF_1 is used as an overall metric of motor control complexity →

Schwartz et al., 2016
Steele et al., 2015
Conner et al., 2021
Conner et al., 2022
Goudriaan et al., 2021
Shuman et al., 2018
Shuman et al., 2019
Spomer et al., 2023

*Including similarly derived measures (Walk-DMC)

VAF_1 with AE describes how much a person utilizes a *specific synergy*

Georgia Tech

Takeaways

Autoencoder Advantages

- Gives interpretable synergies much like NMF
- **Consistent synergy structure** regardless of the number of synergies selected
- Synergies **at lower selected count** have **stronger functional relevance** than NMF
- A step towards consistency & automation

Next Steps:

- More complex models for subject independence
- Evaluate previously published data with autoencoder method

Thanks!

EPIC LAB
Exoskeleton & Prosthetic Intelligent Controls

Neuromechanics Lab
Wallace H. Coulter Department of Biomedical Engineering
Georgia Tech College of Engineering and Emory School of Medicine

Aaron Young
co-advisor

Lena Ting
co-advisor

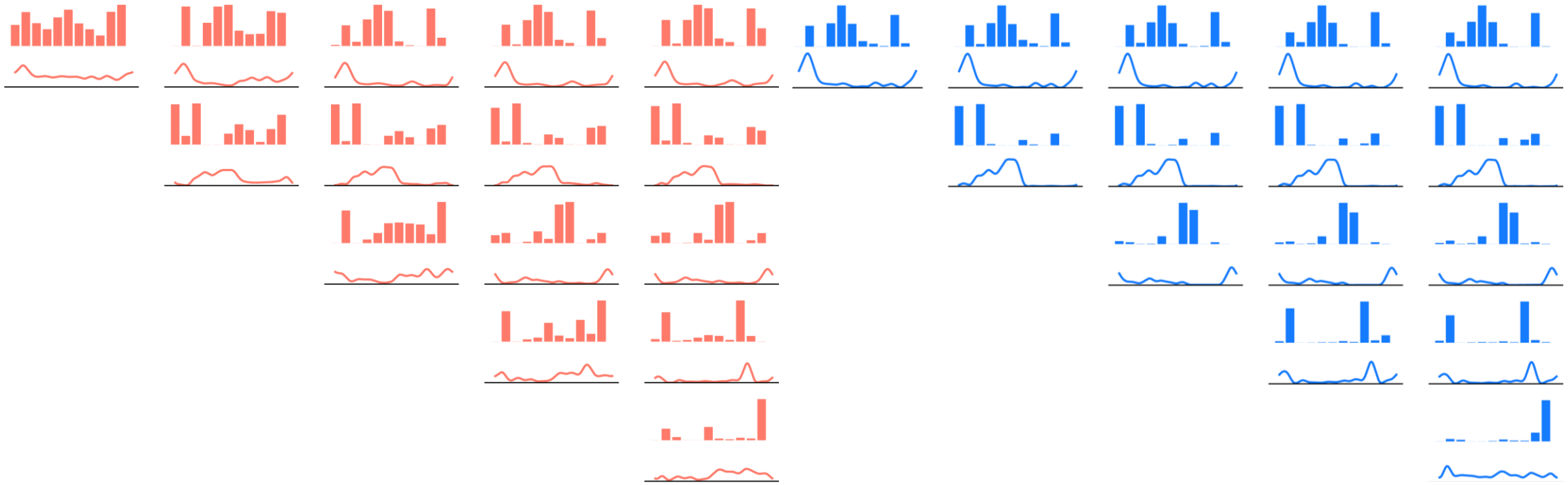
Funding – Georgia Tech Woodruff School of Mechanical Engineering Interdisciplinary Research Fellowship

Georgia Tech

Questions ???

Backup Slides

Synergies & Activation Profiles



Reconstruction Accuracy