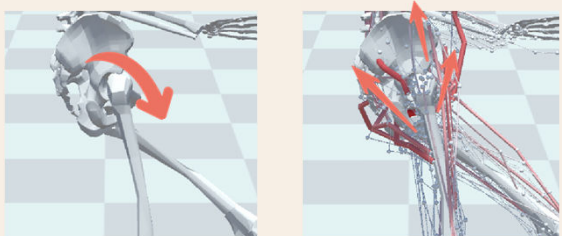


## Motivation

Muscle-driven characters have a biomechanically accurate structure, but the increased degrees of freedom make them hard to control.



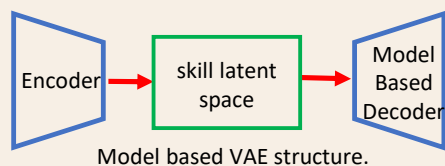
Actuation with joint torques and muscle forces

Accumulative phenomena, such as muscle fatigue, commonly exist in real life but are not well-explored in animation.



Marathon's struggle and Collapse  
Image Credit: <https://www.youtube.com/watch?v=jrZH35yx78g>

Recent research (e.g. [2]) learns versatile skill embeddings using model-based RL and VAE, supporting various downstream tasks.



Model based VAE structure.

## Method

We propose a novel muscle force model, allowing effective learning of complex motion control

- \* Compute proportional derivative (PD) muscle control  
**Target muscle length** is calculated by the control policy.

$$f_{pd} = k_p \cdot ( \text{Target Length} - \text{Current Length} ) - k_d \cdot \dot{\text{Current Length}}$$

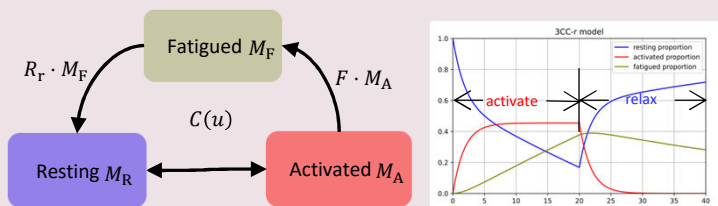
- \* Apply force limits:

$$f_{pd} = \max(0, f_{pd}) \quad \leftarrow \text{contractile force only}$$

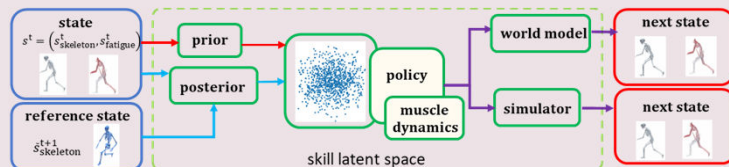
$$f = \text{clip}(f_{lb}, f_{pd}, f_{ub}) \quad \leftarrow \text{force limit determined by activation and fatigue dynamics}$$

$$f_{lb}, f_{ub} = [a_{lb}, a_{ub}] \cdot f_{CE}^l(l) f_{CE}^v(i) + f_{PE}^l(l) \quad \leftarrow \text{Hill-type model}$$

- \* Simulate muscle fatigue using the 3CC-r model [1]



We augment the model-based method, ControlVAE [2], with muscle dynamics to learn various skills.

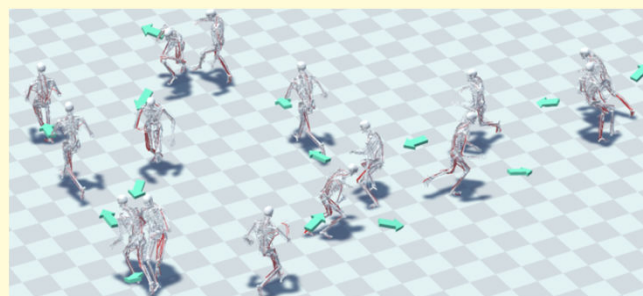


[1] John M Looft, Nicole Herkert, and Laura Frey-Law. 2018. Modification of a threecompartment muscle fatigue model to predict peak torque decline during intermittent tasks. Journal of biomechanics 77 (2018), 16–25.  
[2] Heyuan Yao, Zhenhua Song, Baoquan Chen, and Libin Liu. 2022. ControlVAE. ACM Transactions on Graphics 41, 6 (nov 2022), 1–16. <https://doi.org/10.1145/3550454.3555434>

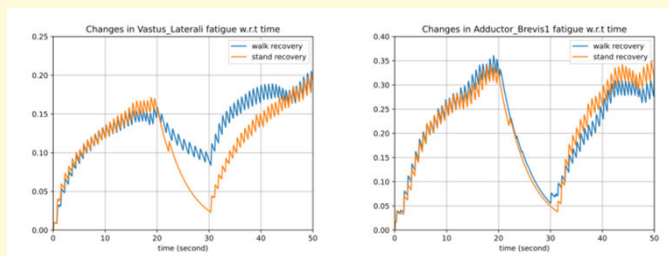
## Results



The character tracks a diverse range of motions.



Trajectories generated by random sampling.



Curve of fatigue accumulation and recovery in the run-walk/idle test.