FreeMusco: Motion-Free Learning of **Latent Control** for **Morphology-Adaptive** Locomotion in **Musculoskeletal** Characters

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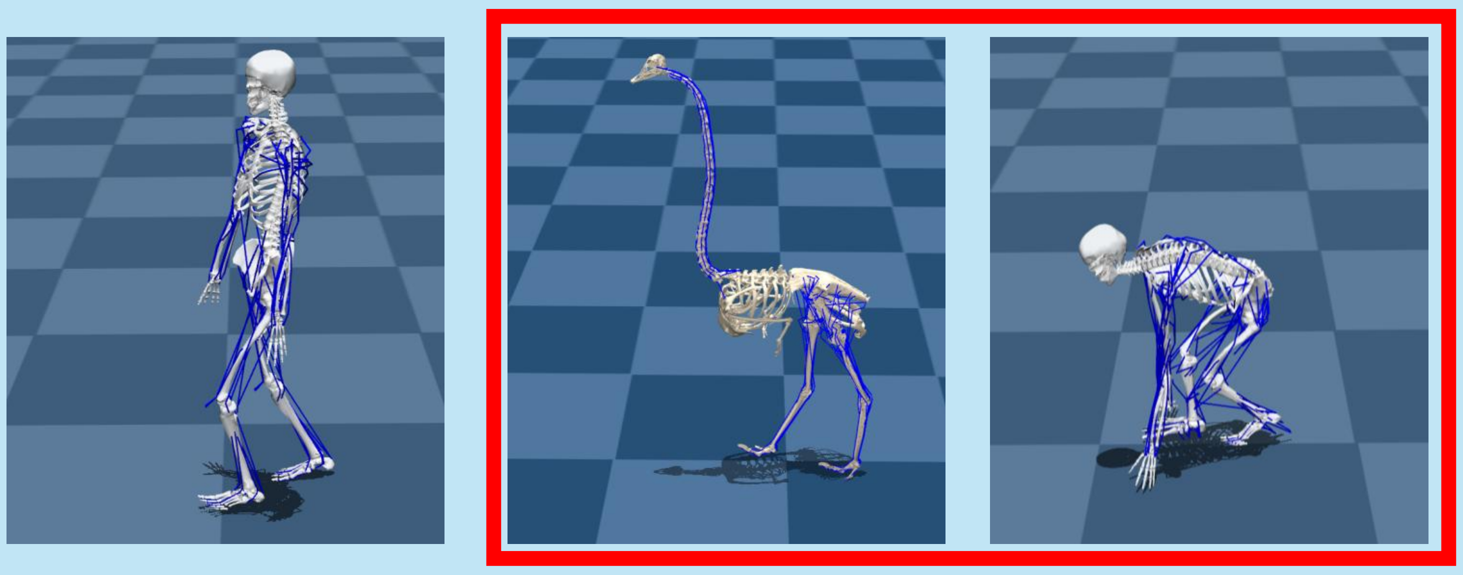
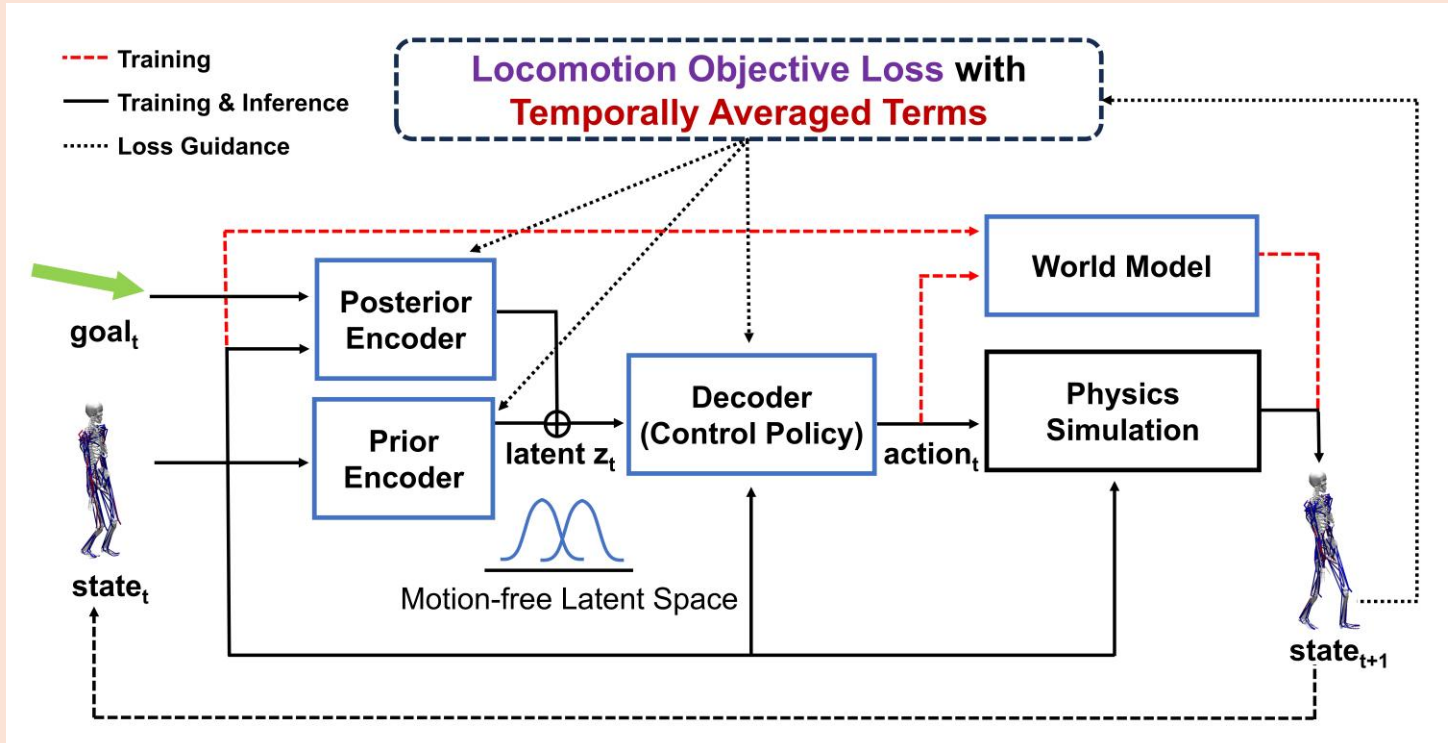
Motivation: How can we generate locomotion for the characters when **motion capture is infeasible?**



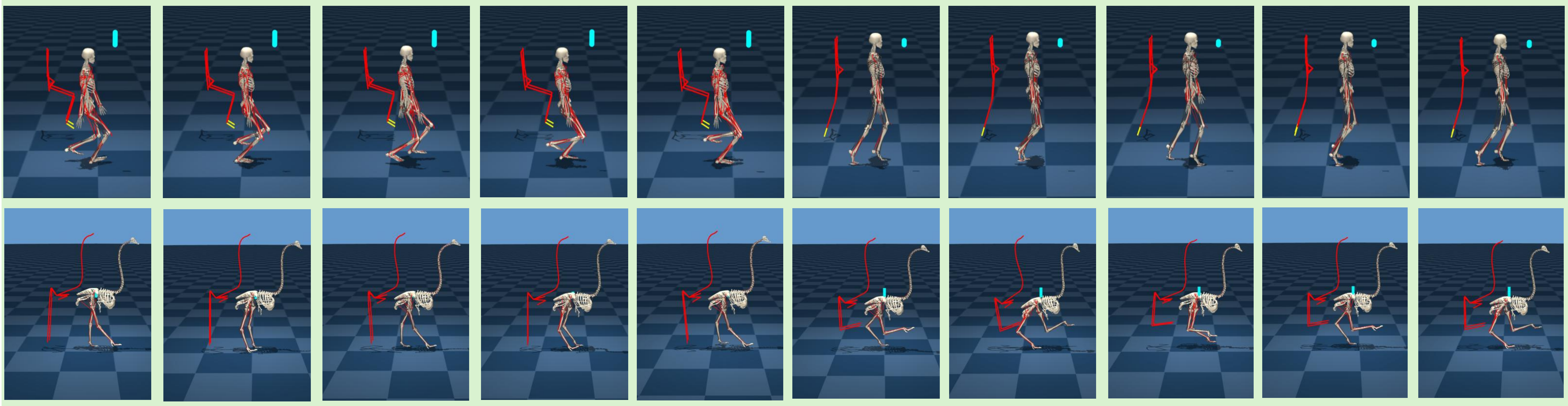
We propose a **motion-free framework** that learns a latent space of **morphology-adaptive locomotion,** leveraging only **musculoskeletal simulation.**



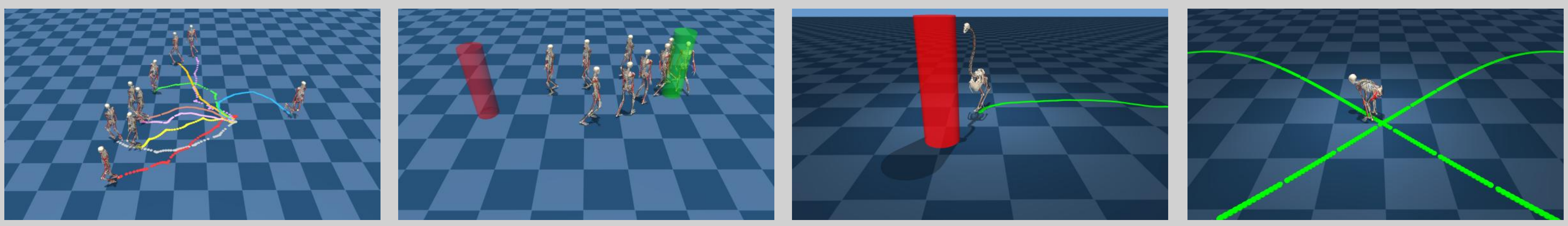
Based on **conditional VAE and model-based RL,** characters are guided by proposed **locomotion objective loss** with **temporally averaged terms.**

Energy-efficient strategies depend on morphology and can naturally emerge in our motion-free system.

Various locomotion styles (form & intensity control)



Latent Space and Downstream Tasks



$$L_{objective} = \underbrace{L_{vel} + L_{dir}}_{\text{Control Objective}} + \underbrace{L_{height} + L_{up}}_{\text{Balancing Objective}} + \underbrace{L_{pose} + L_{energy}}_{\text{Biomechanical Objective}}$$

- We introduce the **temporally averaged loss** to promote biologically plausible locomotion by accounting for **natural oscillations in movement,** comparing averages of the **simulated** and **target** states over a **short temporal windows.**

$$L_{avg}(\{\bar{x}_t\},\{x_t\}) = \left\| \frac{1}{T_p} \cdot \sum_{t=0}^{T_p-1} \gamma^t \cdot \bar{x}_t - \frac{1}{T_p} \cdot \sum_{t=0}^{T_p-1} \gamma^t \cdot x_t \right\|_1 \qquad L_{step}(\{\bar{x}_t\},\{x_t\}) = \frac{1}{T_p} \cdot \sum_{t=0}^{T_p-1} \gamma^t \cdot \|\bar{x}_t - x_t\|$$

- $L_{vel}, L_{up}, L_{pose}$
- $L_{dir}, L_{height}, L_{energy}$

Temporally-Averaged (Ours) vs Per-step