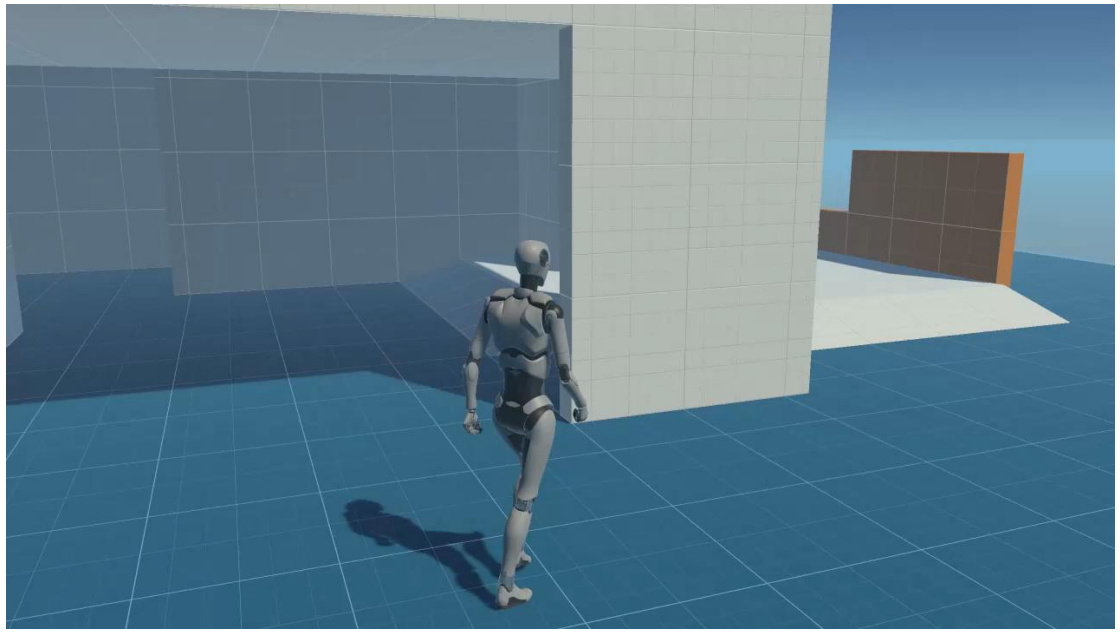
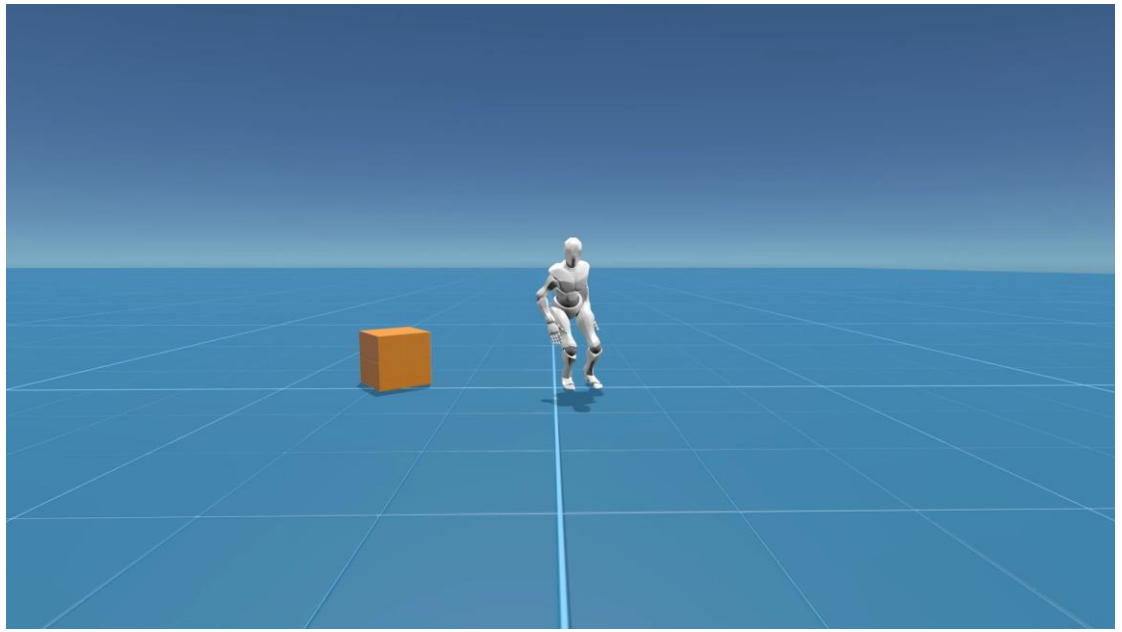
Physics-based Character Control with Model-based RL and Unified Motion Representations

Heyuan Yao
Peking University

Physics-based Character Animation



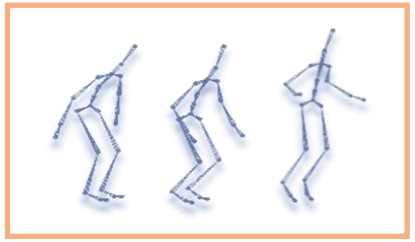
Kinematic motion generated with Unity Demo



Physics-based motion

Related Work

Demonstration Motion



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Control/Task

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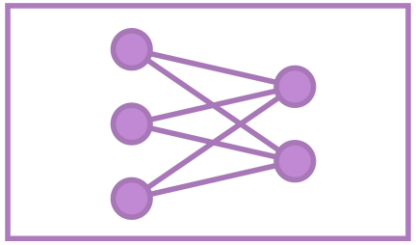
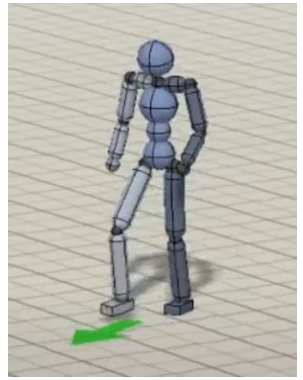
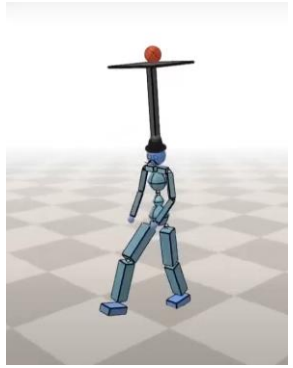
Control Policy



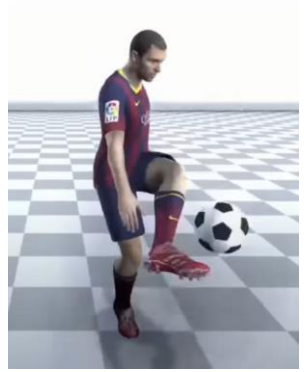
Liu et al.[2018]



Peng et al.[2018]



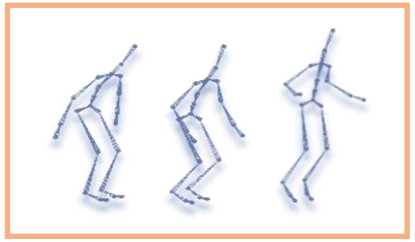
Park et al.[2022]



Xie et al.[2022]

Related Work

Demonstration Motion



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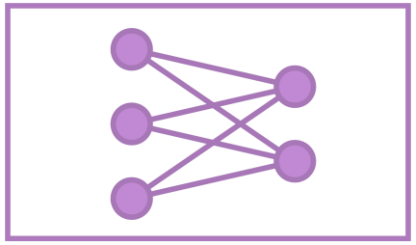
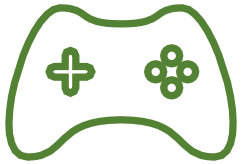
Task1

↓

Control Policy



Task2



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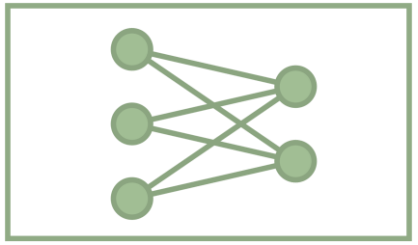
Control Policy



Dedicated **Reward**

...

Dedicated **Policy**

Learn **from Scratch**

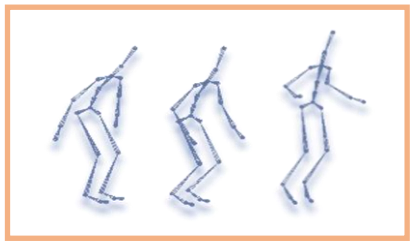
SIGGRAPH ASIA 2022 DAEGU

ControlVAE: Model-Based Learning of Generative Controllers for Physics-Based Characters

Heyuan Yao, Zhenhua Song, Baoquan Chen, Libin Liu

Motion Primitives

Demonstration Motion



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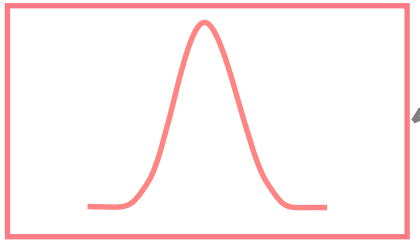
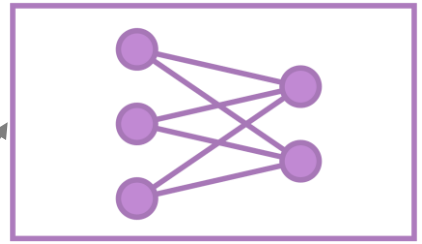
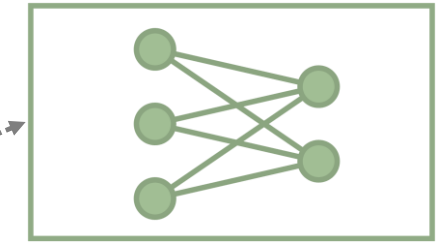
Motion Primitives



Control Policy





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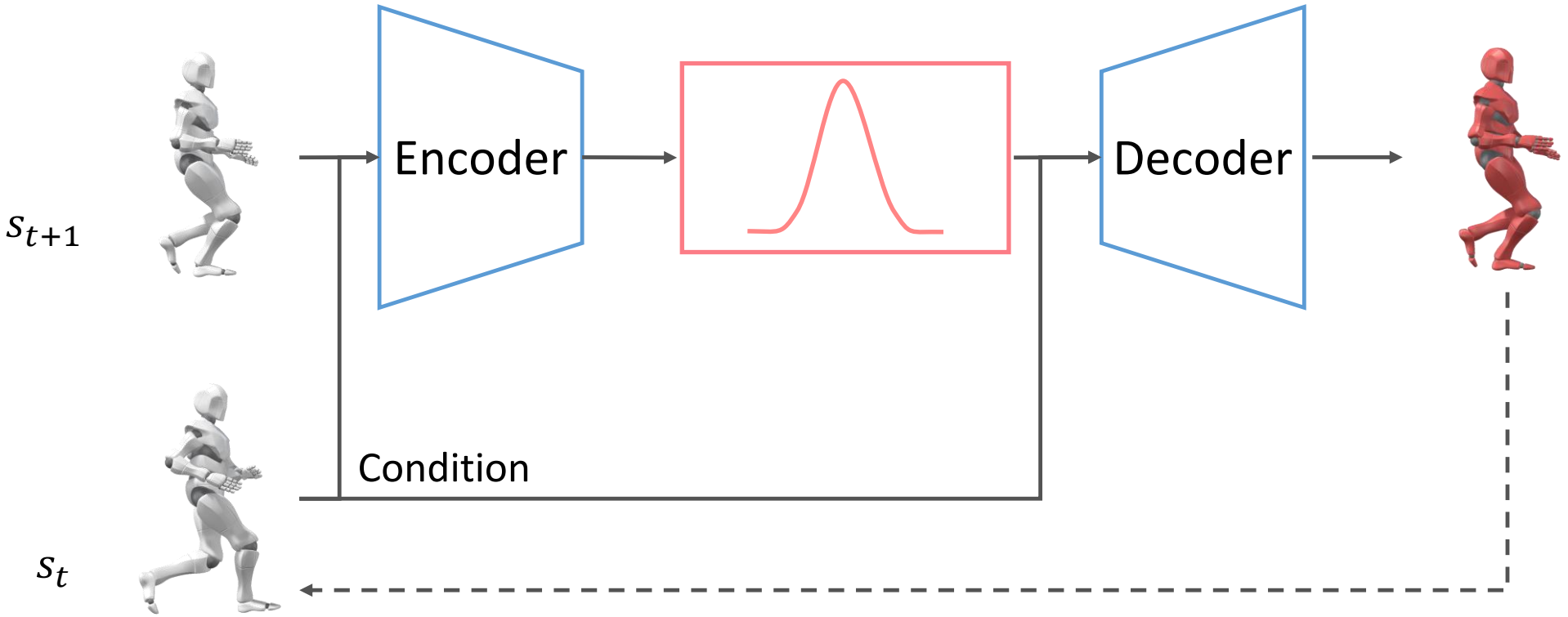
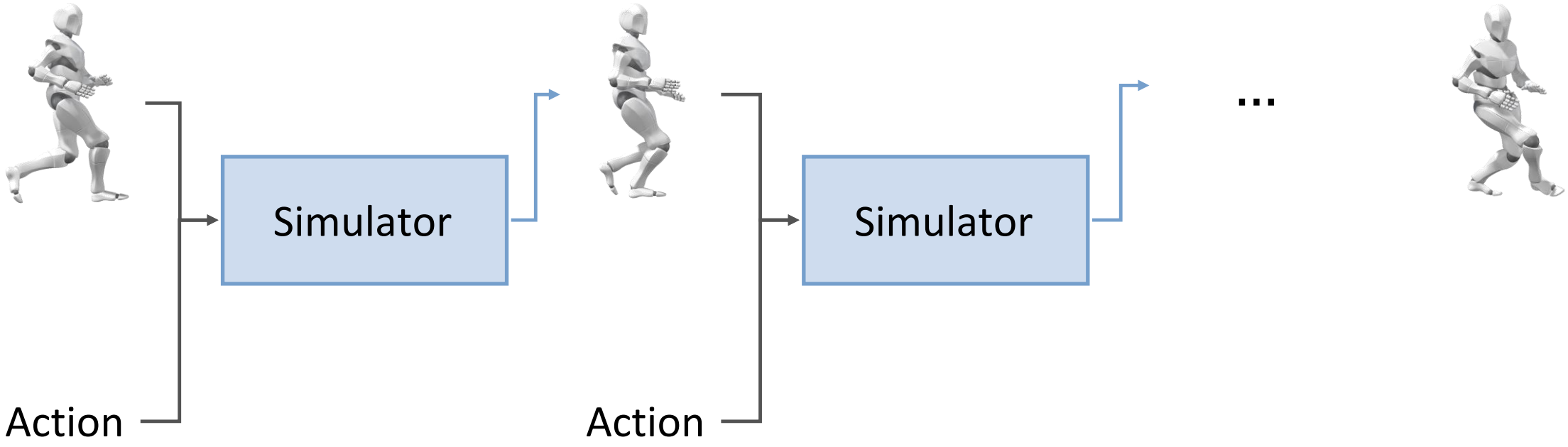
Motion Space Variational Autoencoder

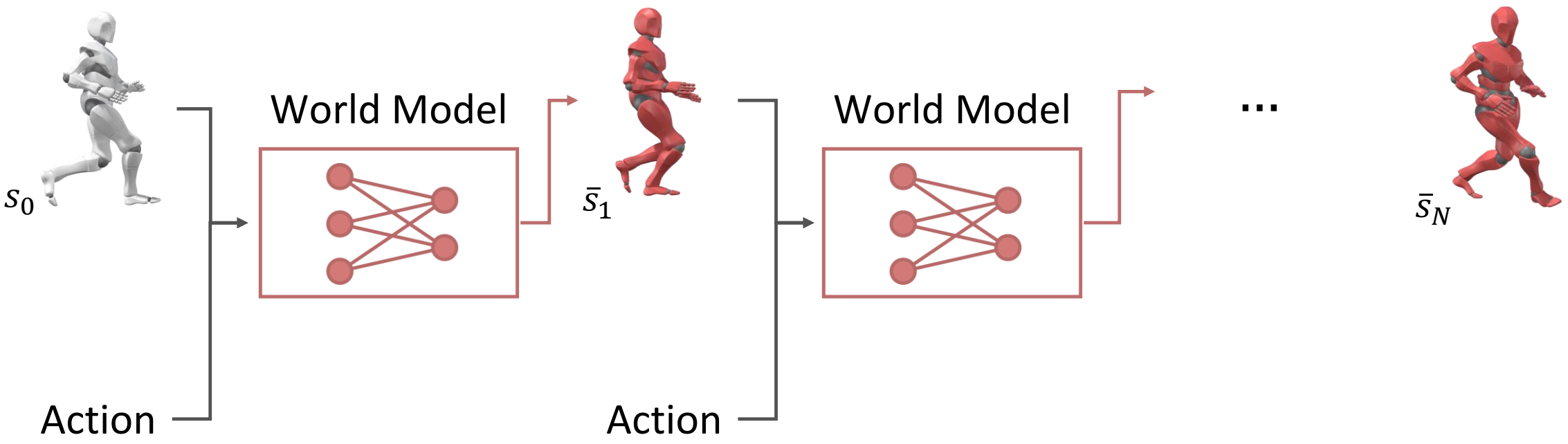


What is Decoder?



SuperTrack, Fussell et al.[2021]

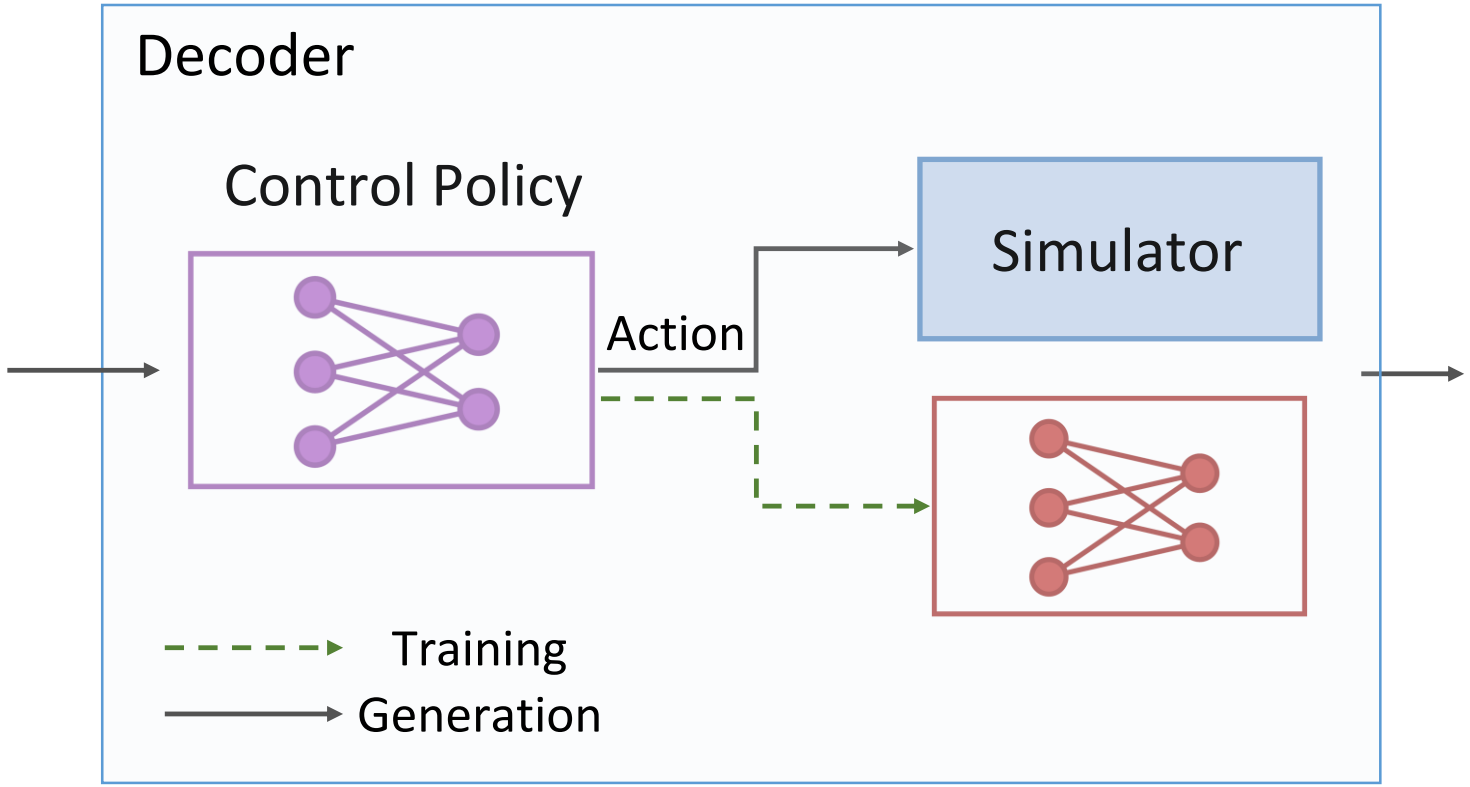
What is Decoder?



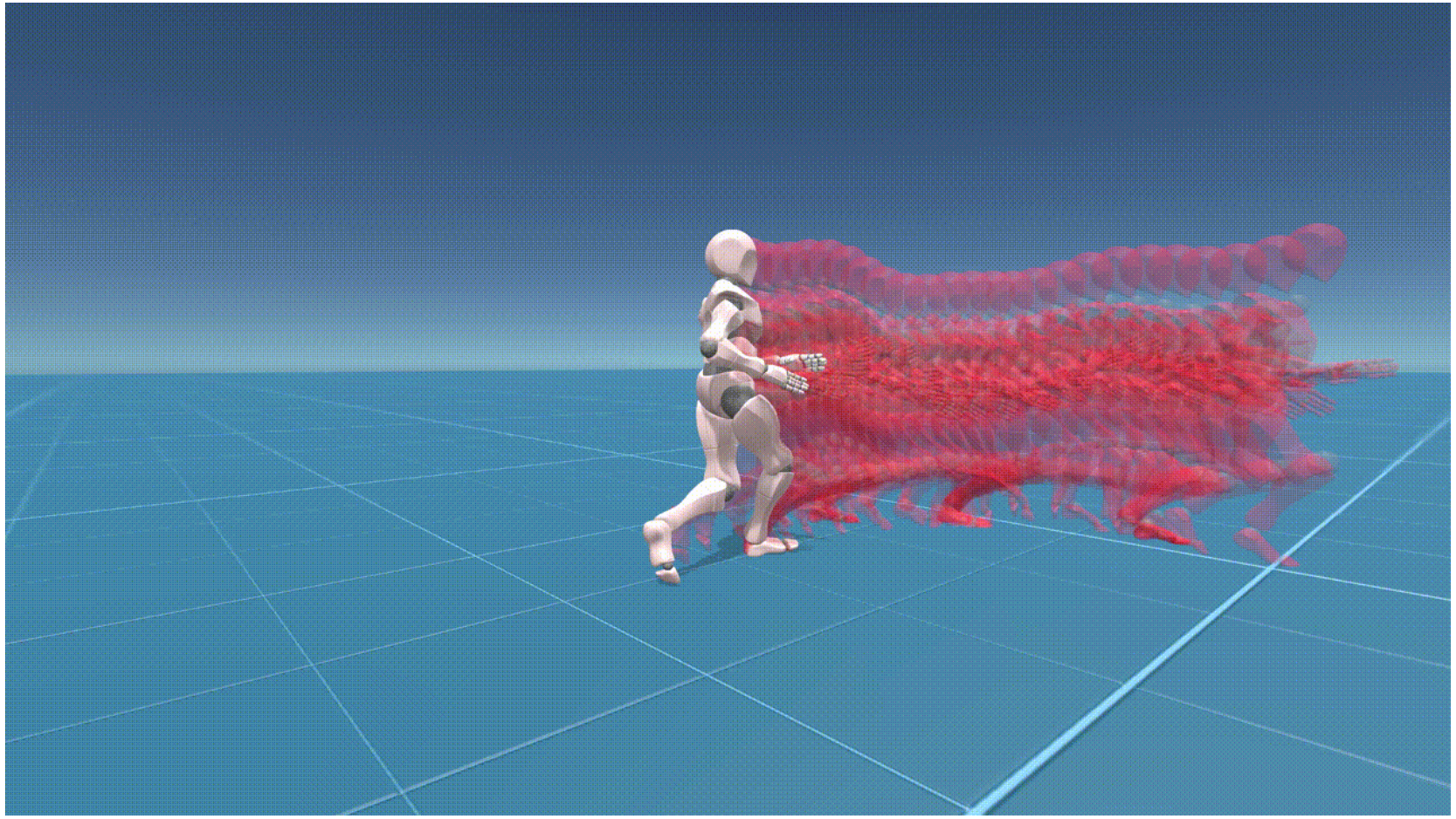
$$L = \sum_{t=1}^{N} \|s_i - \bar{s}_i\|$$

SuperTrack, Fussell et al.[2021]

Physics-based Decoder



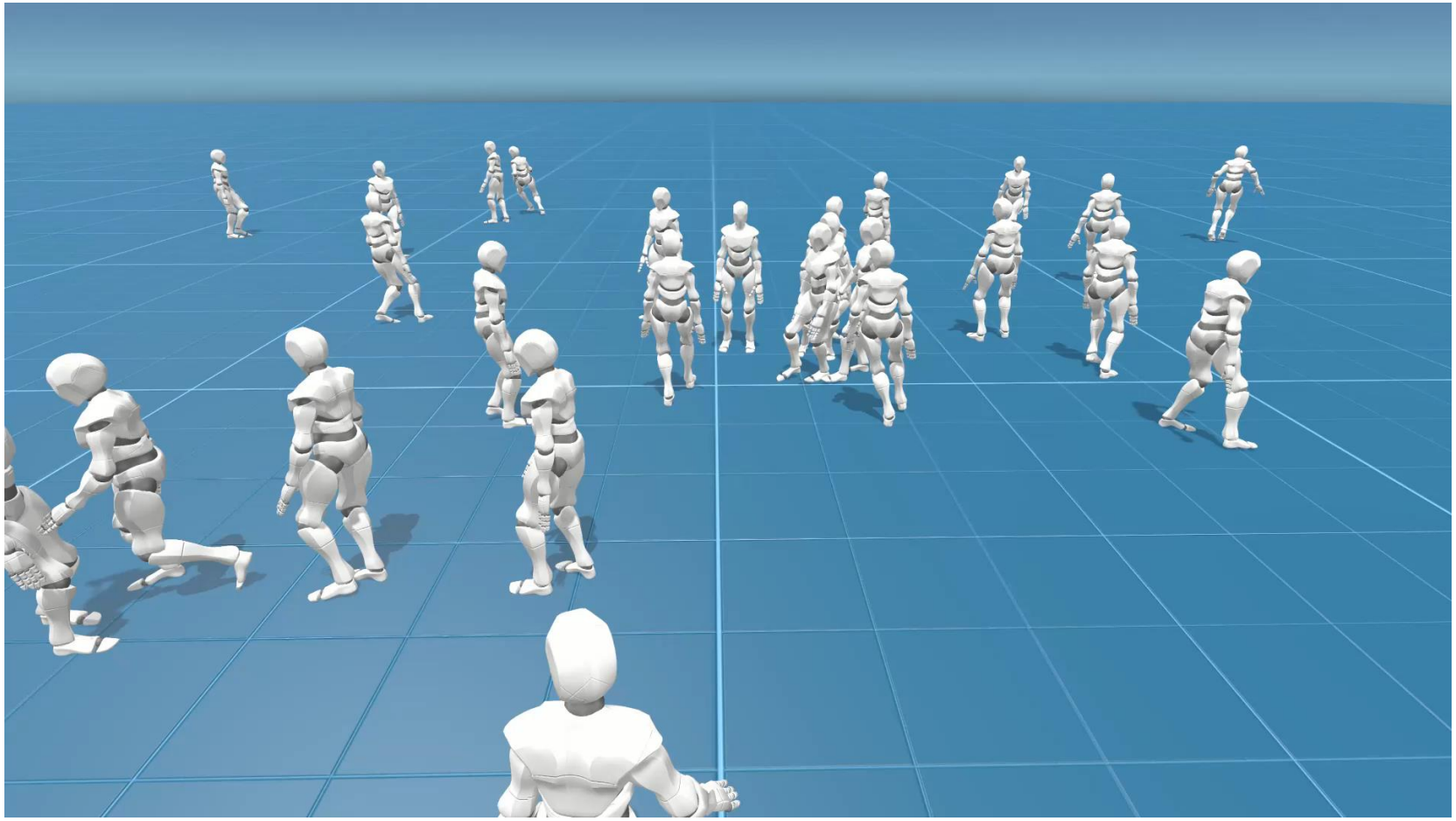
Learning a World Model



Red: prediction

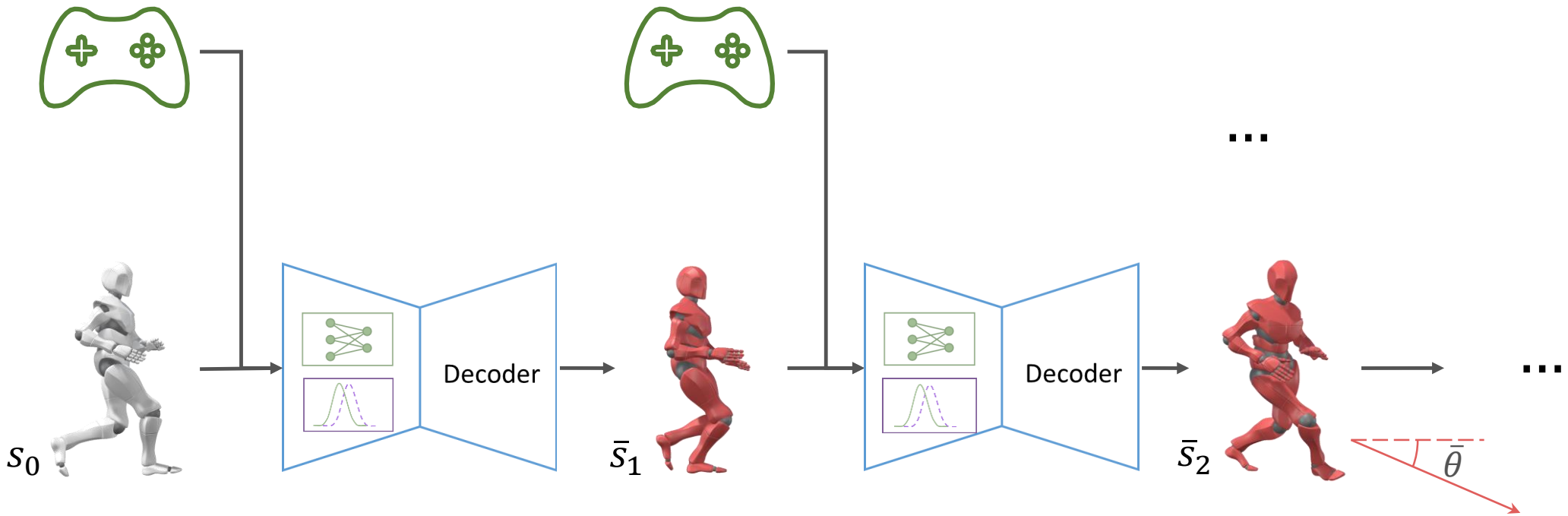
White: simulation

Sampling with ControlVAE



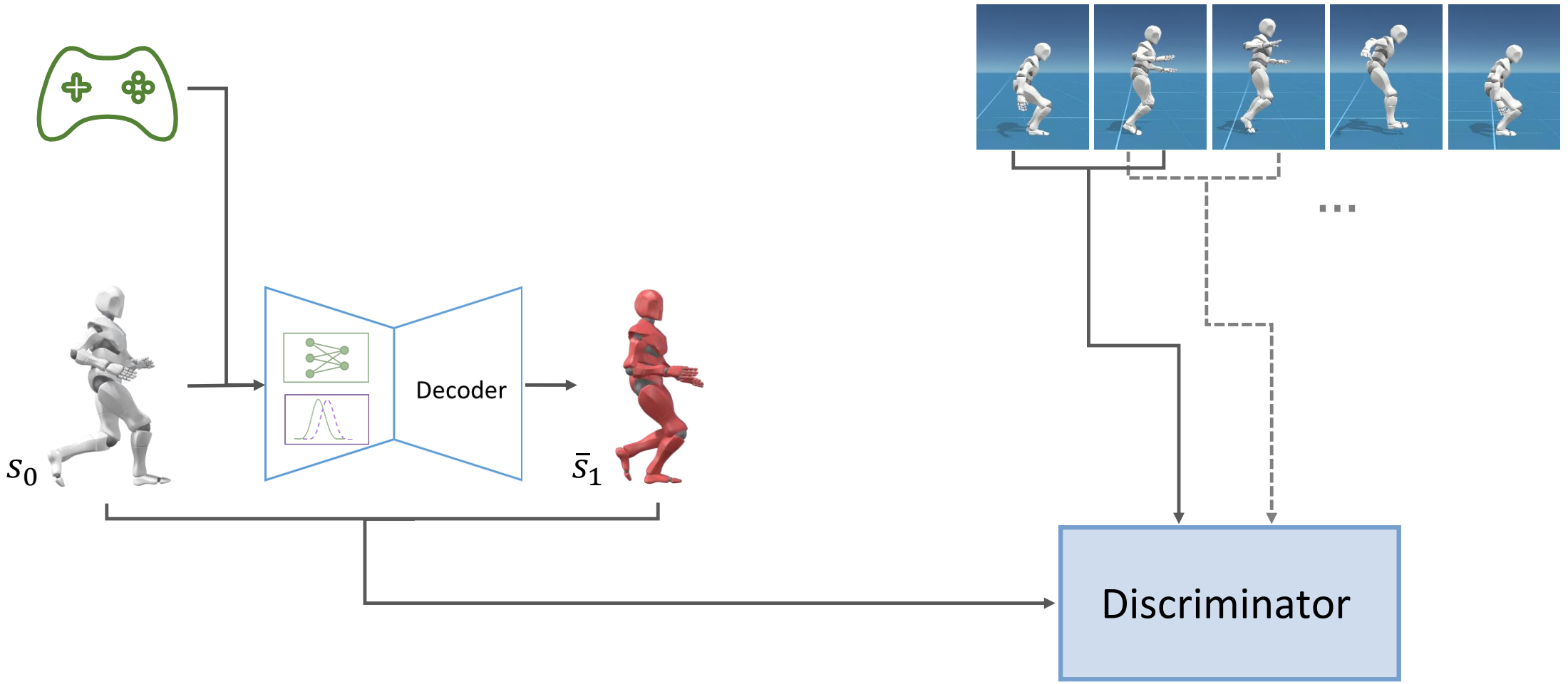
Random samples in the latent skill space

Downstream Tasks

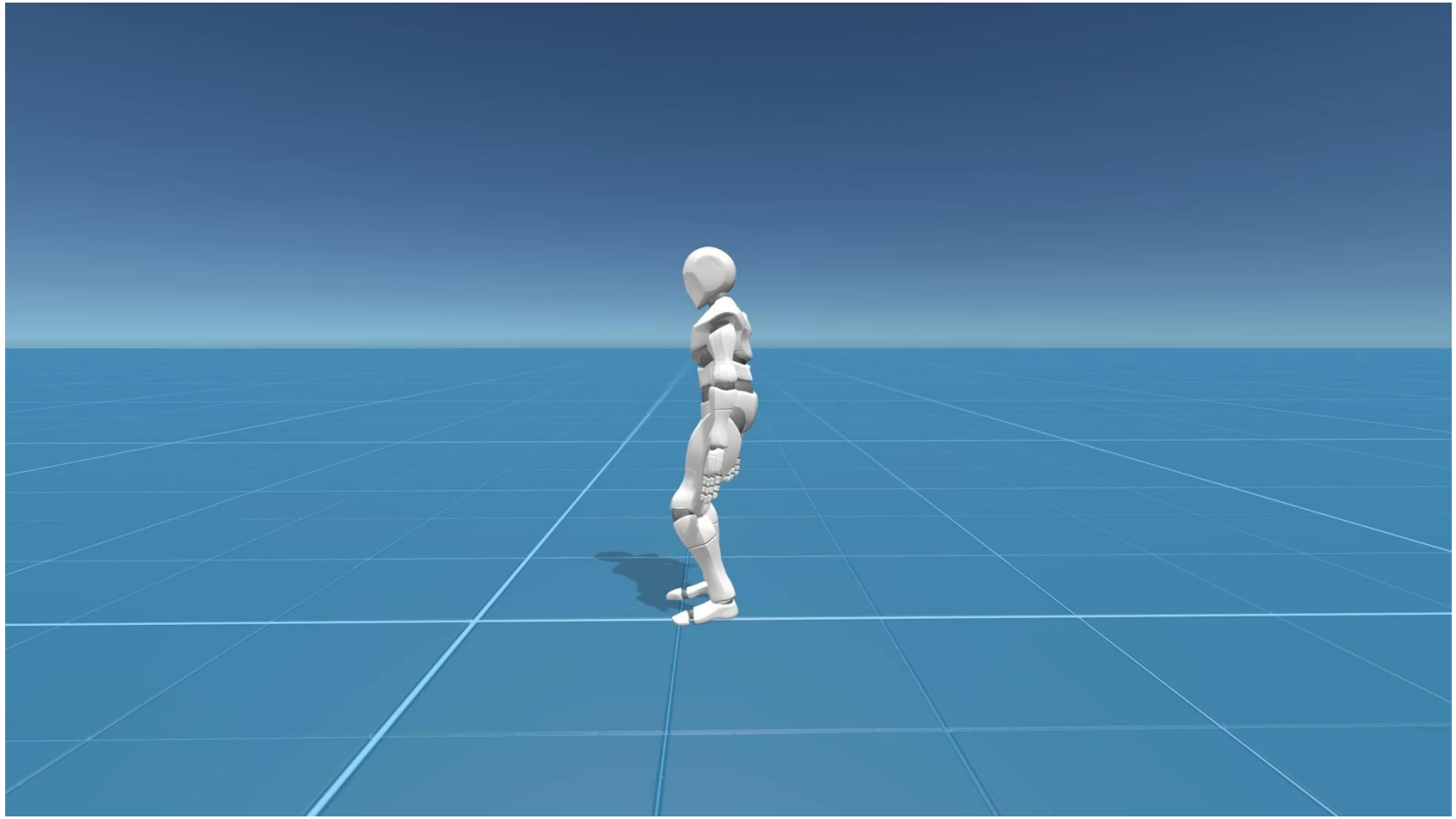


$$L_{task} = \sum_{t=1}^{N} \|\bar{\theta}_i - \tilde{\theta}_i\| + \cdots$$

Downstream Tasks

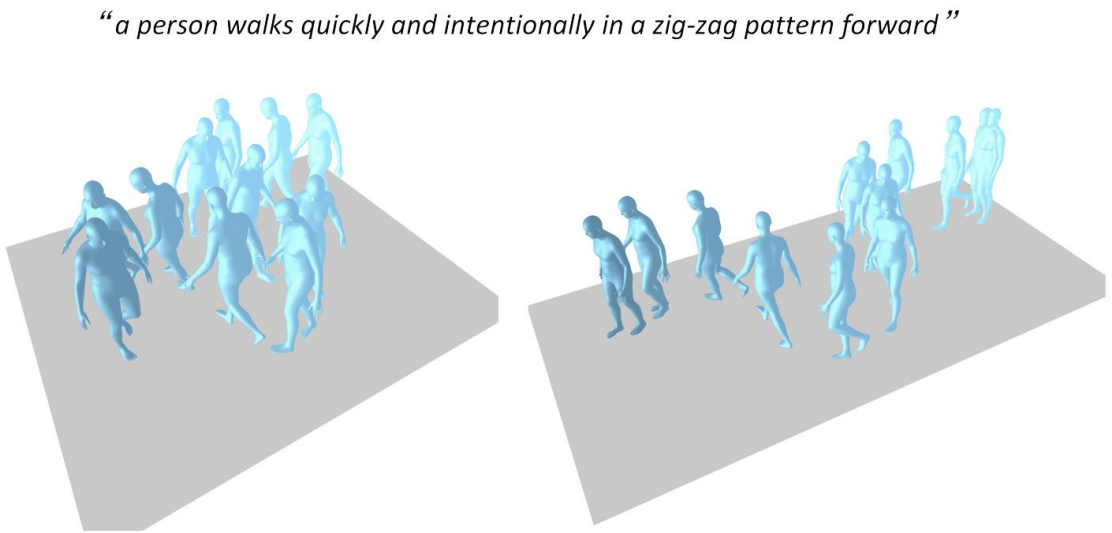


Downstream Tasks



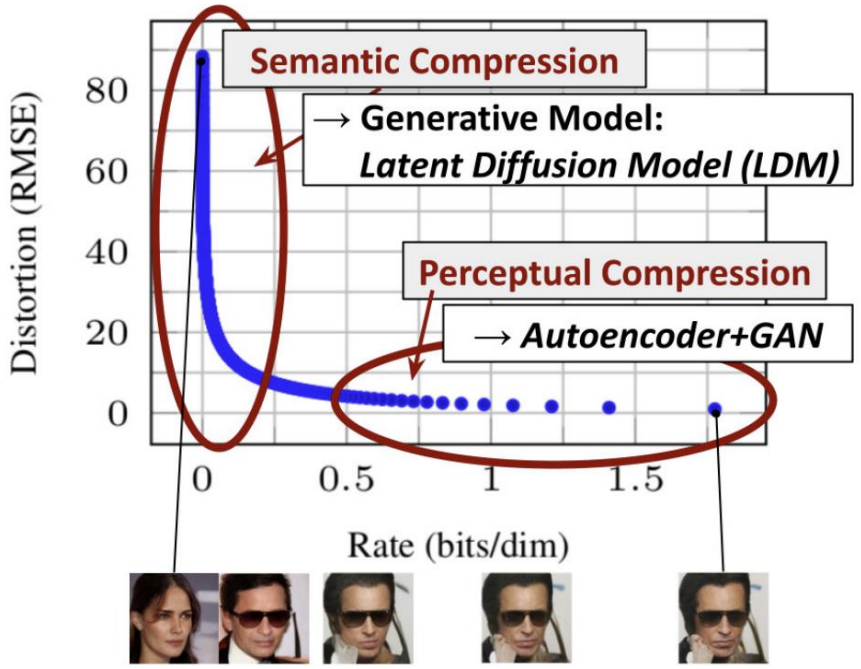
Some Motivations

Stable Diffusion(140M images)

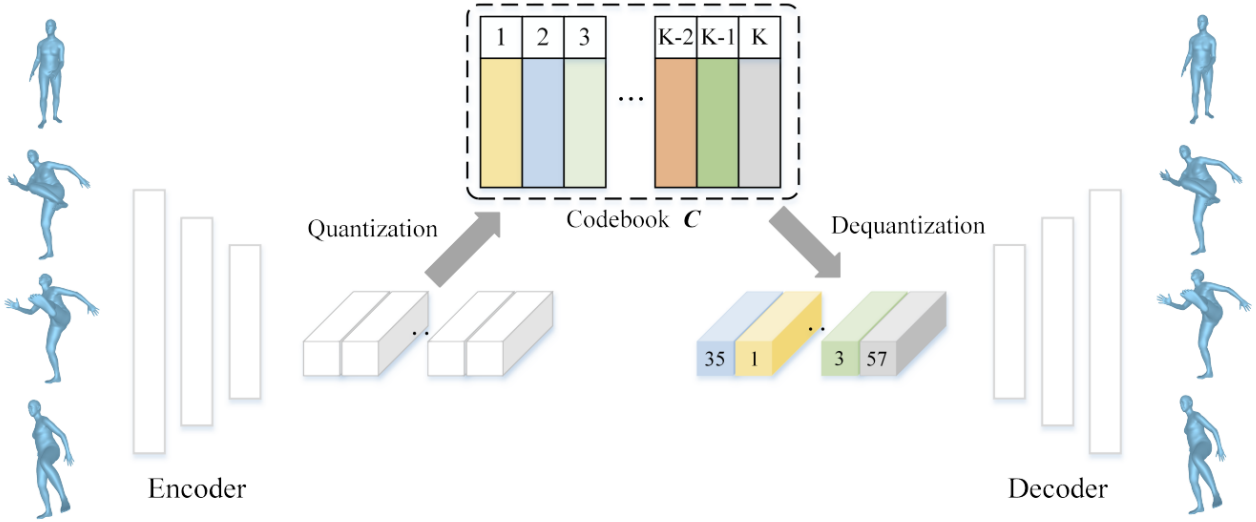


T2M-GPT(14K motions)

Some Motivations

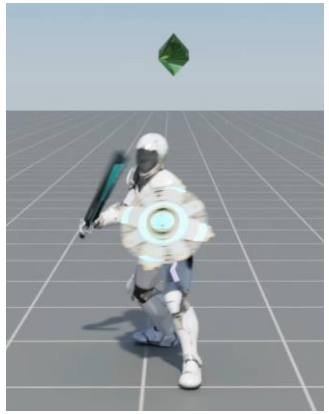


Stable Diffusion(VQ-VAE+Diffusion)

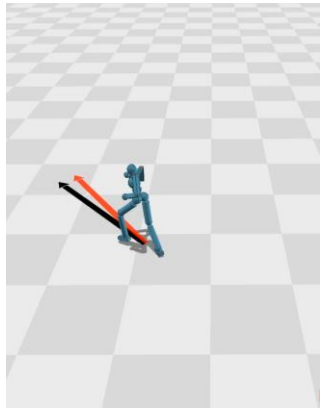


T2M-GPT(VQ-VAE+GPT)

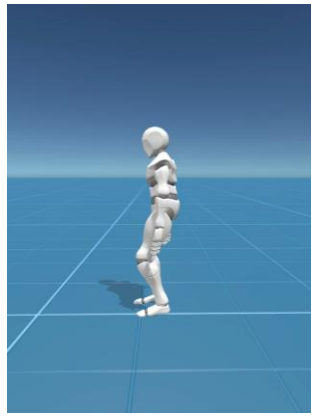
Some Motivations



Peng et al.[2022]



Won et al.[2022]

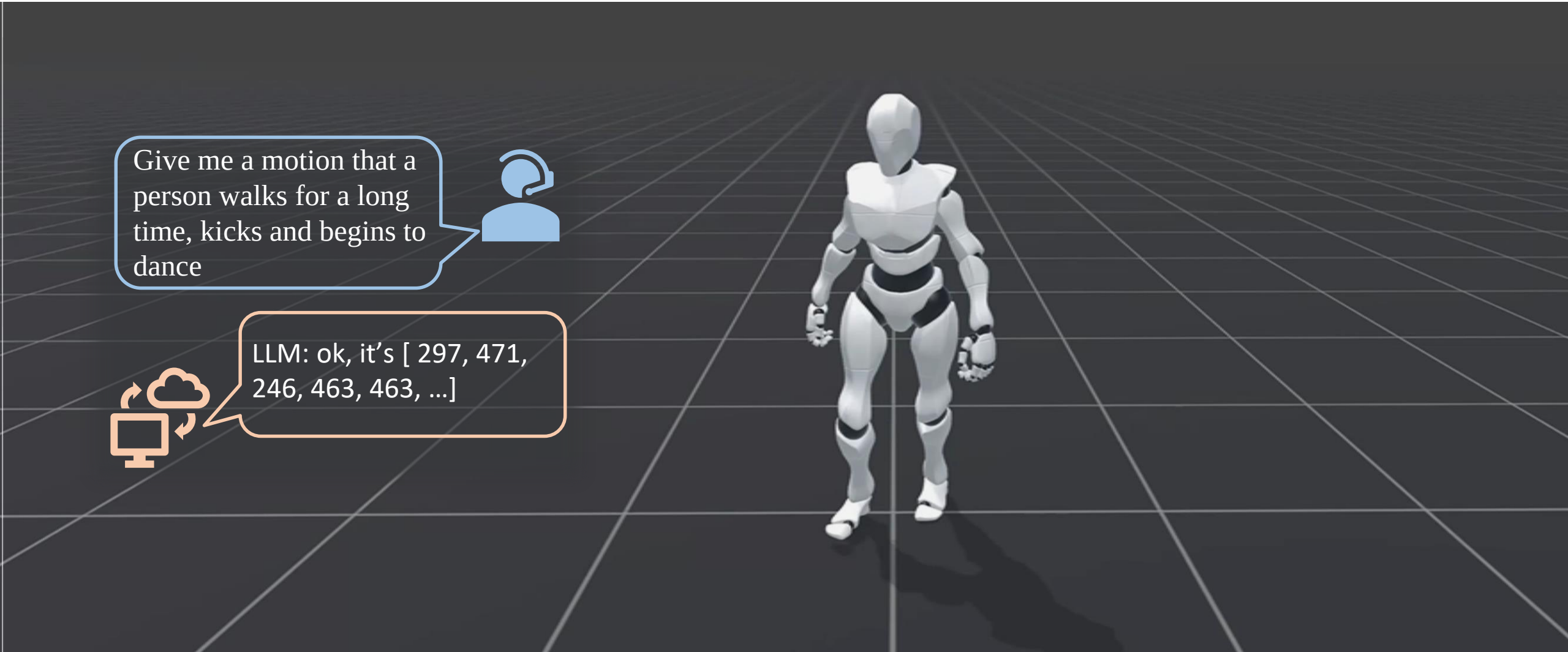


Yao et al.[2022]

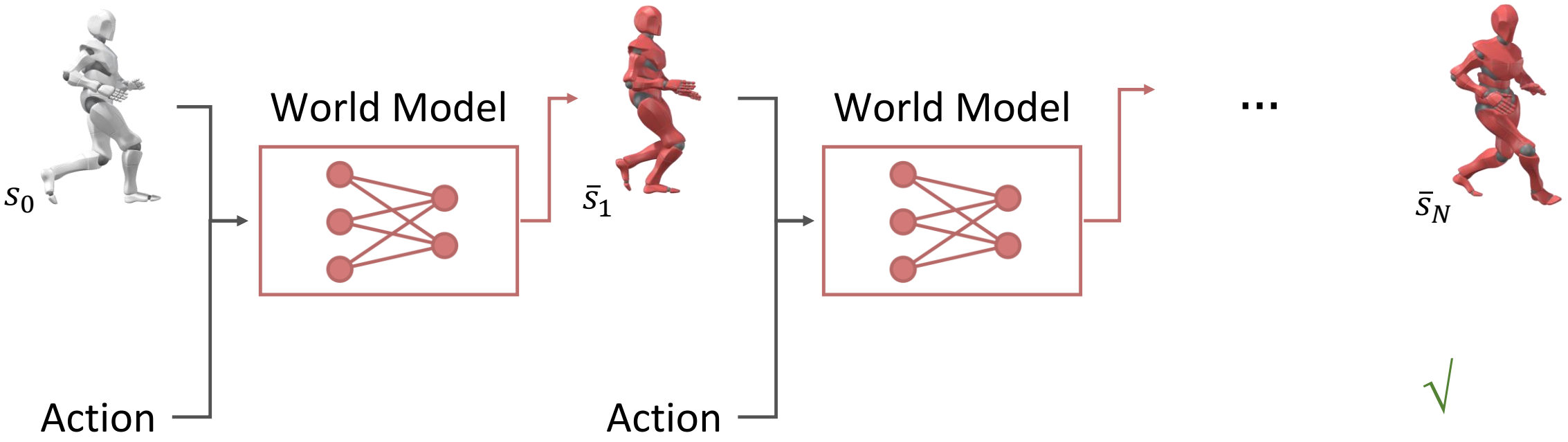
$< 1h$

Scale up?

MoConVQ: Unified Physics-Based Motion Control via Scalable Discrete Representations



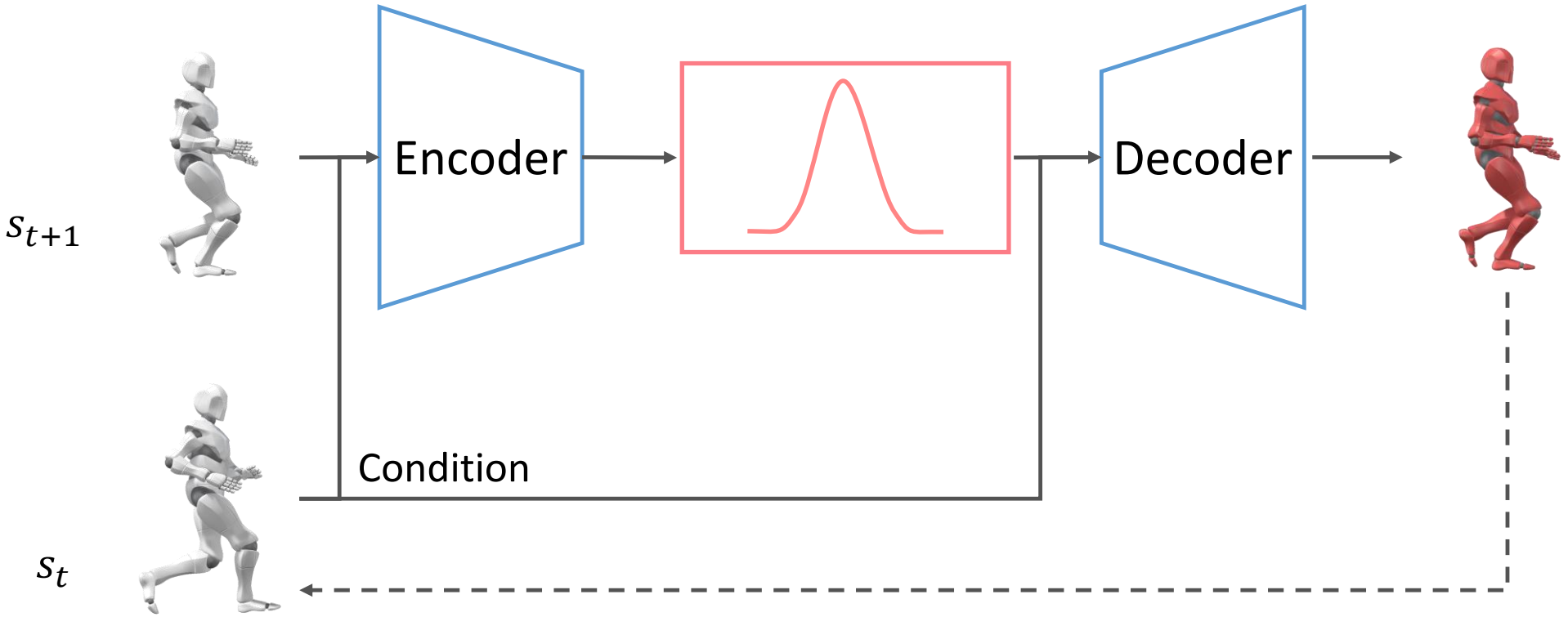
Tracking Capacity



$$L = \sum_{t=1}^{N} \|s_i - \bar{s}_i\|$$

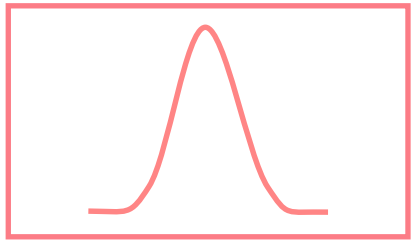
SuperTrack, Fussell et al.[2021]

Methods

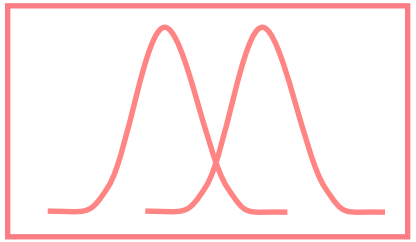


Learn representations and dynamics together

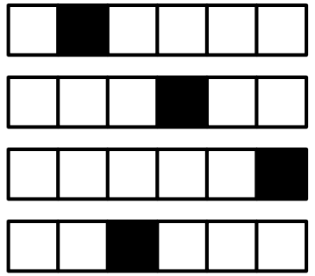
Methods



Gaussian



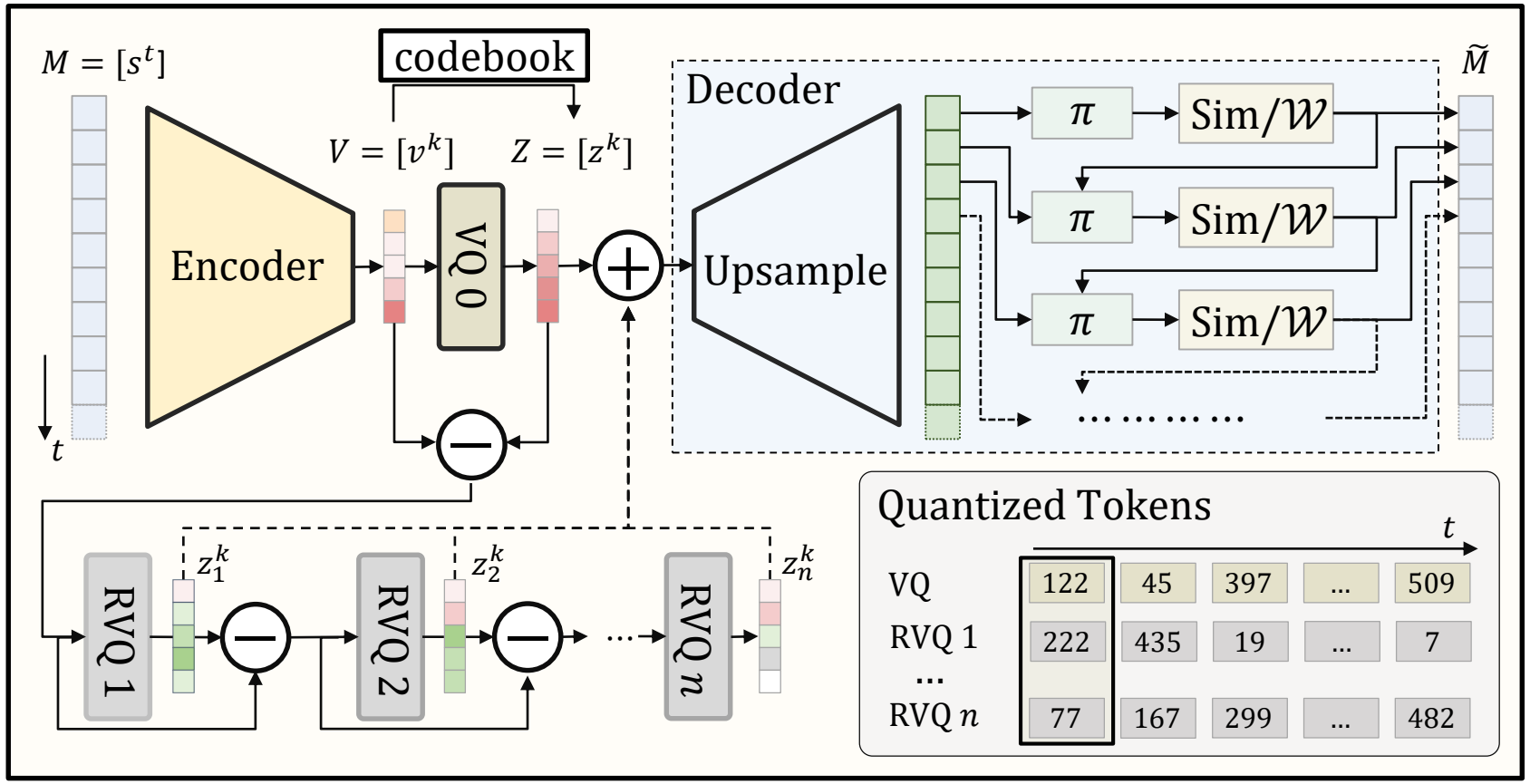
Mixture of Gaussian



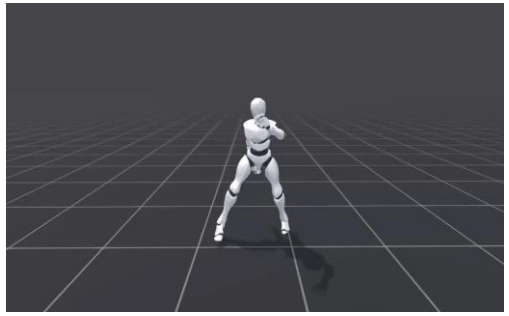
Categorical/
Mixture of
Categorical

VQ-VAE

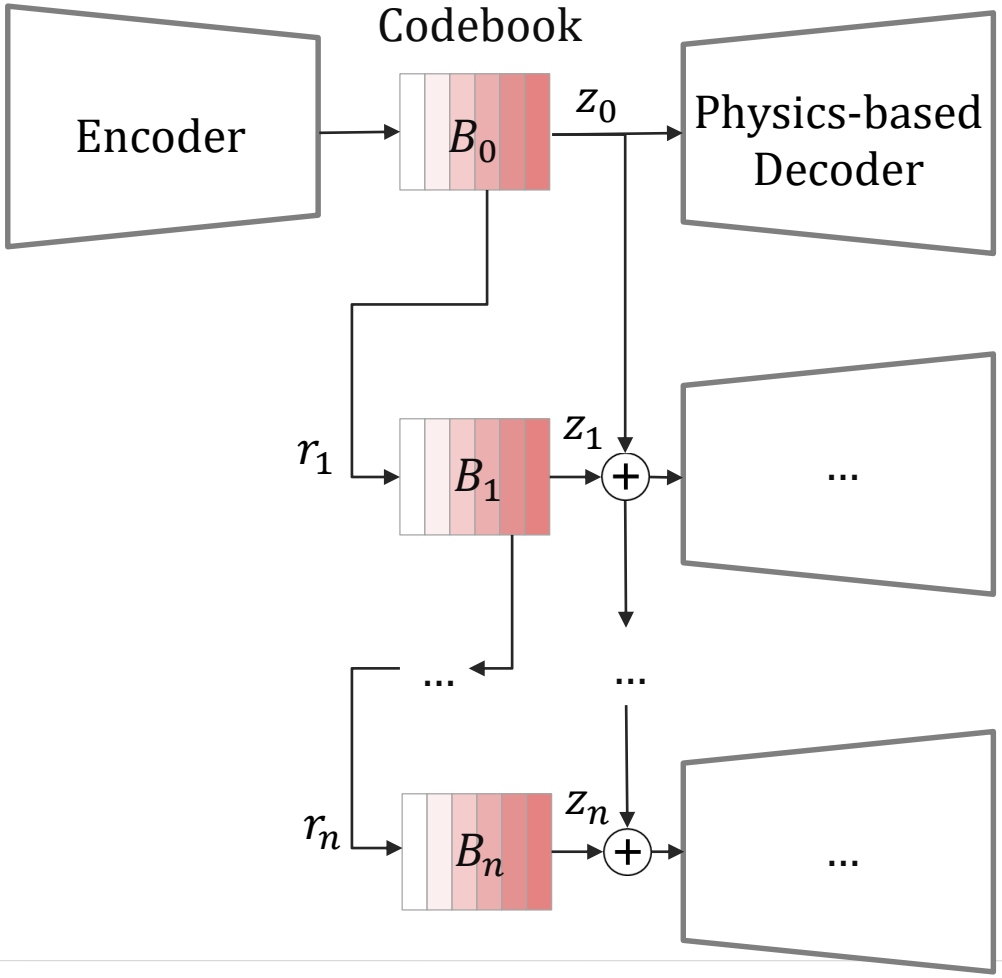
Pipeline

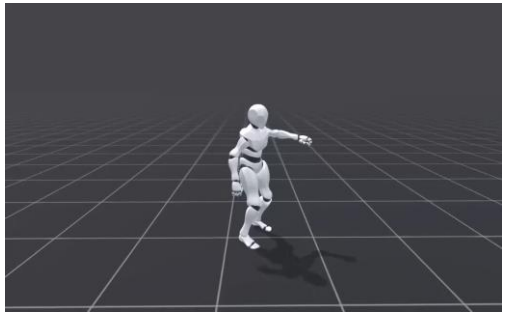

$M = [s^t]$
codebook
$V = [v^k]$
$Z = [z^k]$
Encoder
VQ 0
Decoder
Upsample
π
Sim/$\mathcal{W}$
$\widetilde{M}$
t
RVQ 1
RVQ 2
RVQ n
z_1^k
z_2^k
z_n^k
Quantized Tokens
VQ
RVQ 1
RVQ n
122 45 397 ... 509
222 435 19 ... 7
77 167 299 ... 482

Coarse to Fine Reconstruction

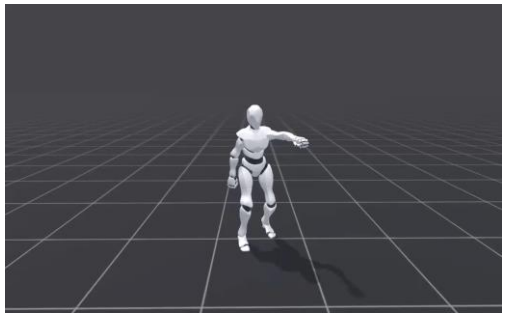


Mocap Data



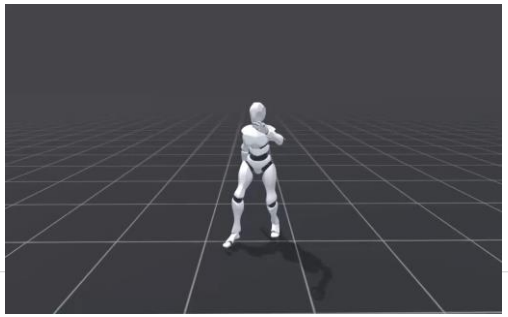


Vanilla VQ-VAE



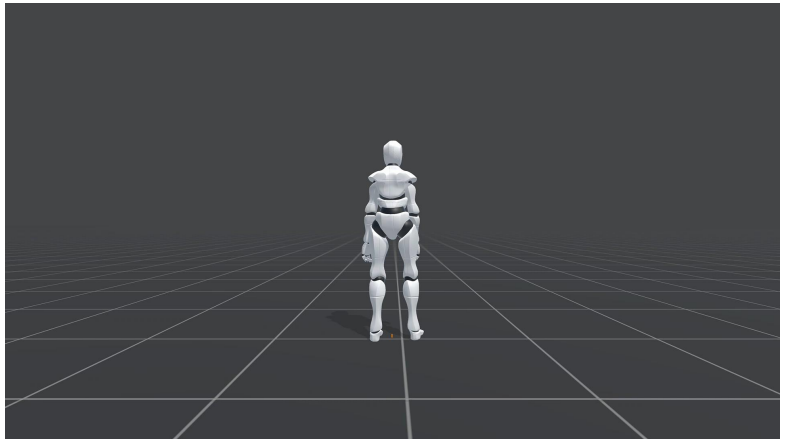
Add Residual 1

...

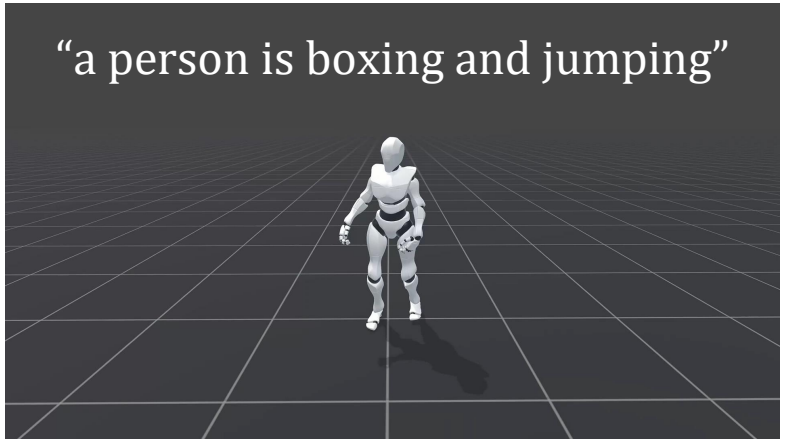


Add Residual n

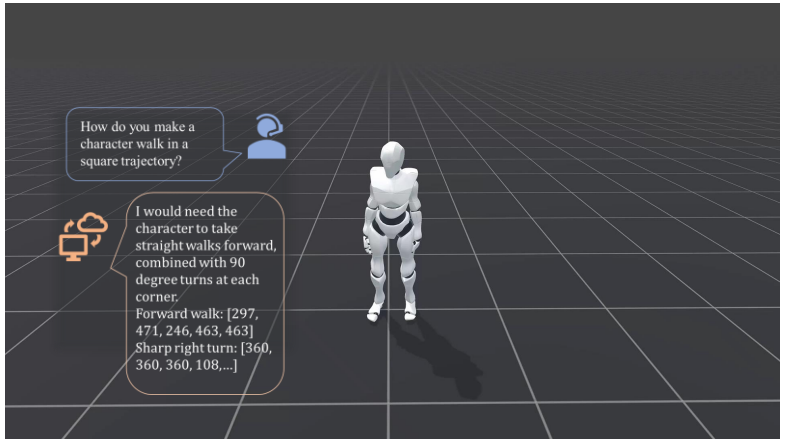
Downstream Tasks



Interactive Control



Text2Motion



Integration with LLM

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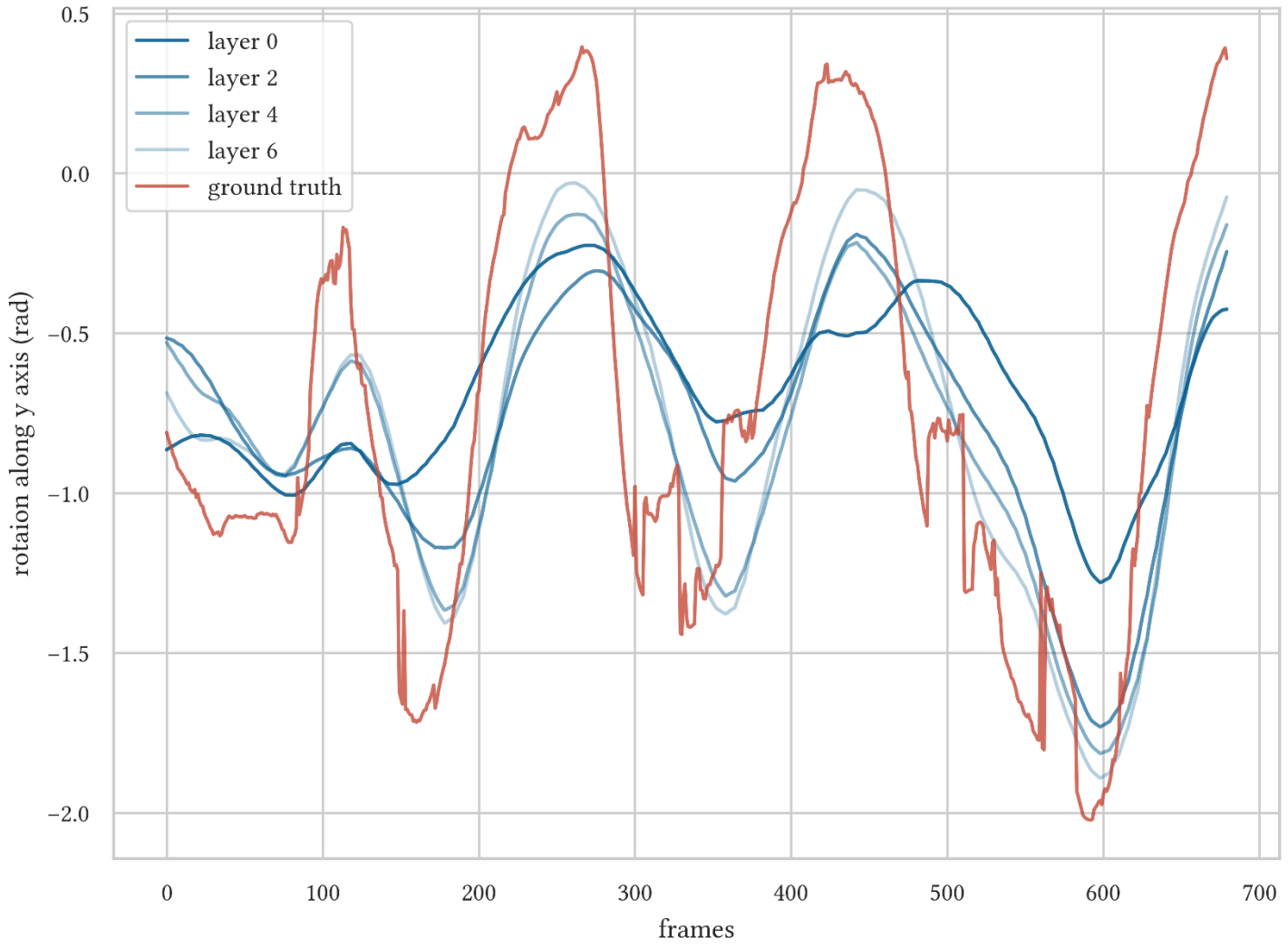
Comparison with ControlVAE

Field	ControlVAE	MoConVQ
Compress	VAE	Residual VQ-VAE
Latent Dynamic	MLP	MLP/Transformer
Data	10 min	20~70 hours
Task	Locomotion only	Generalized Control, Text2Motion…

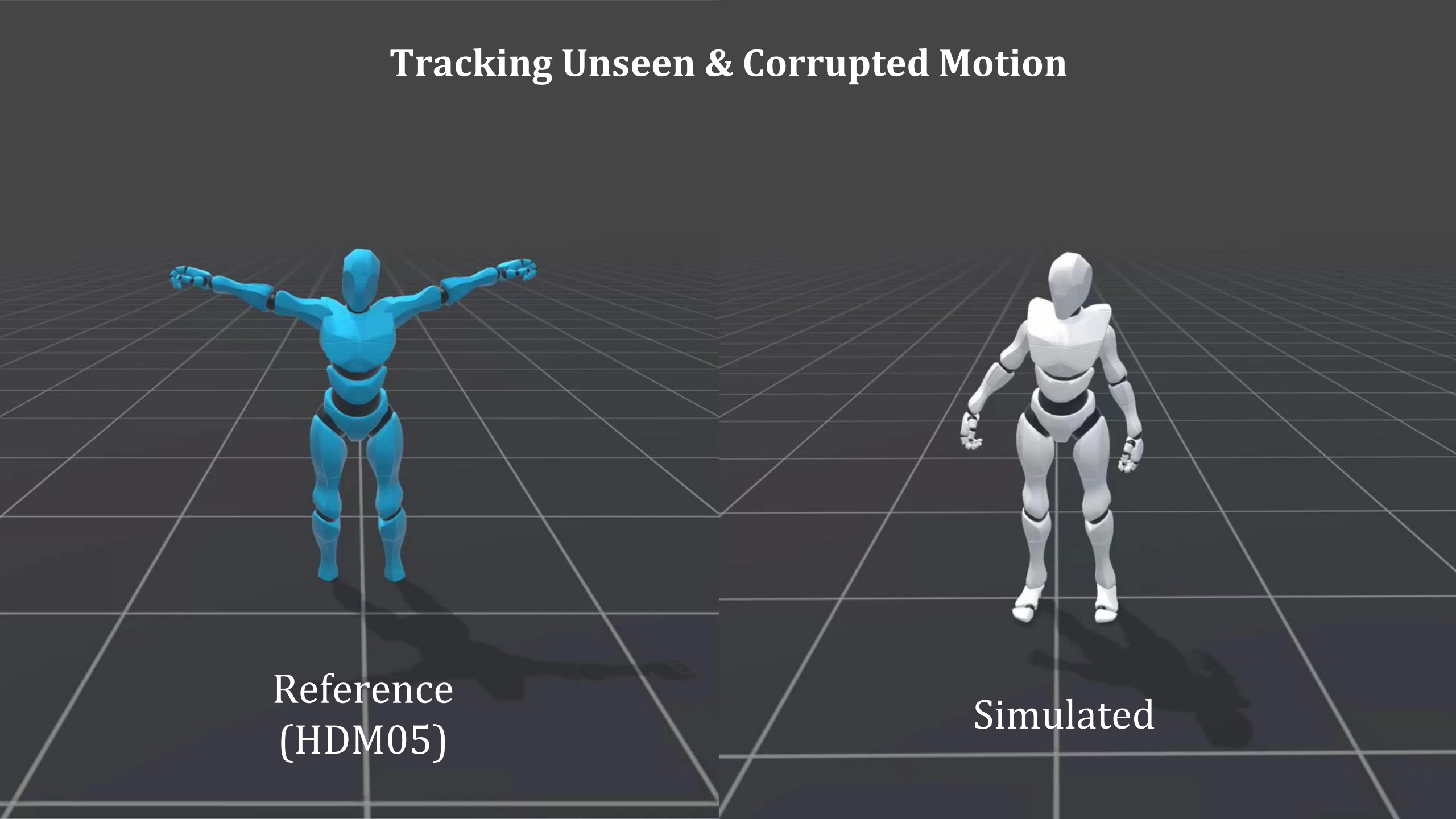
Universal Tracking Control

Unseen Motion

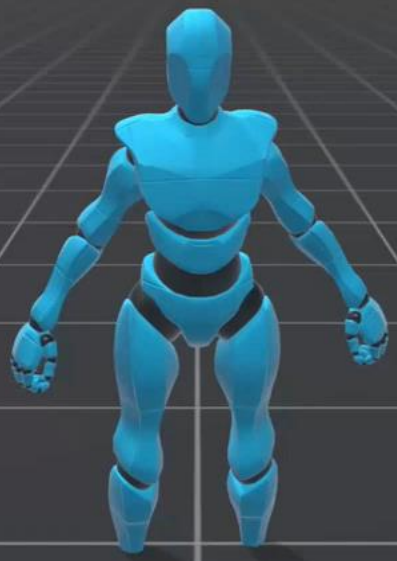
Coarse to Fine Reconstruction



Tracking Unseen & Corrupted Motion



Tracking Motion Generation Result

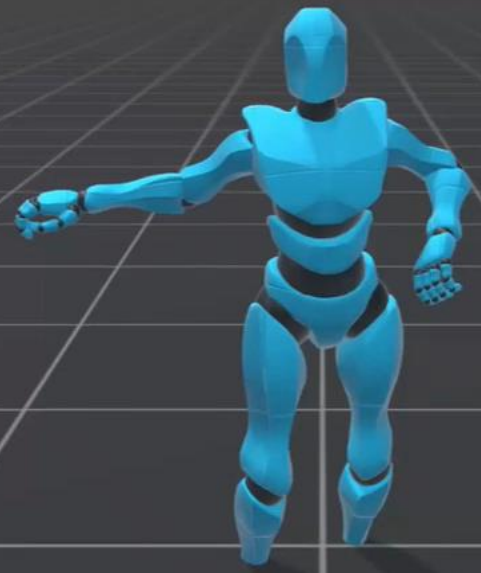


MLD [Xin et al. 2023]

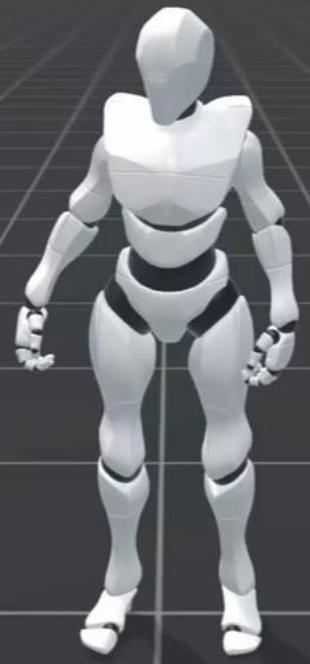
Simulated

‘A person goes from standing to sitting’

Tracking Motion Generation Result



MLD [Xin et al. 2023]



Simulated

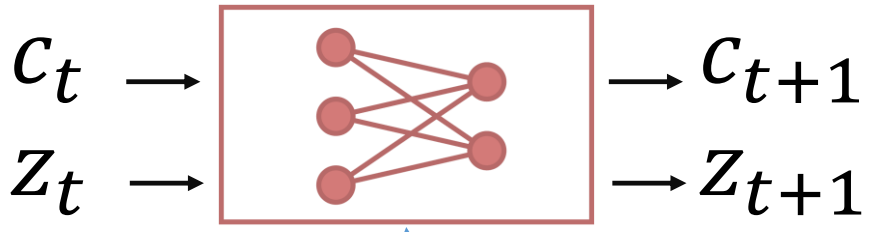
‘A person is dancing wildly’

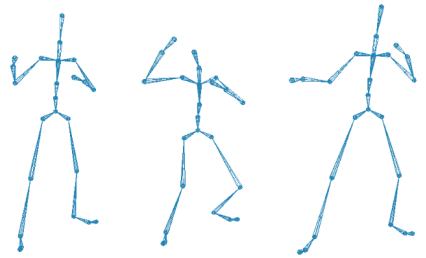
Tracking Pose Estimation Output

HybrIK
[Li et al. 2021]

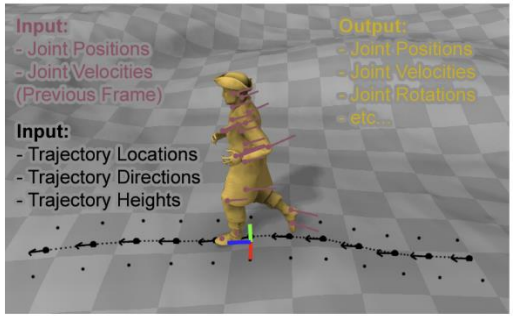
Simulated

Downstream Tasks: Interactive Control





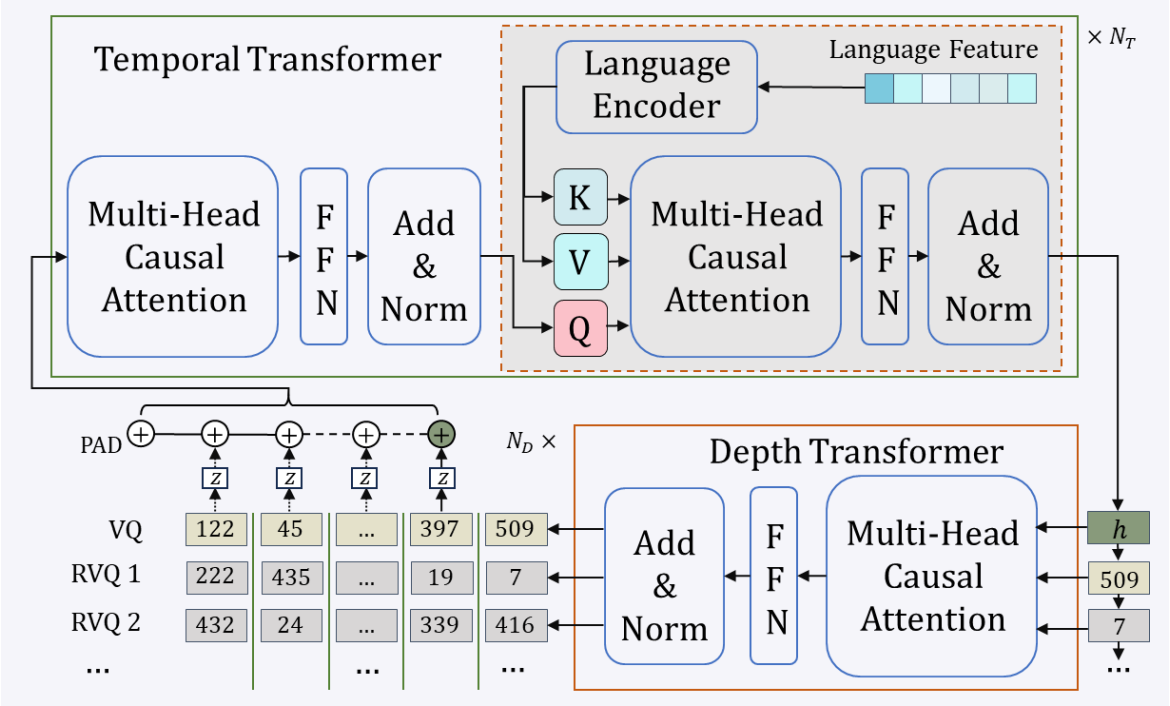
Supervised Training



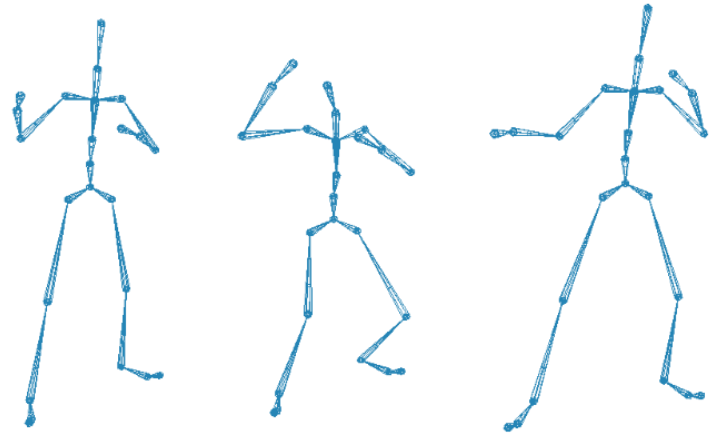
PFNN[2017]

Interactive Control

Downstream Tasks: Text2Motion



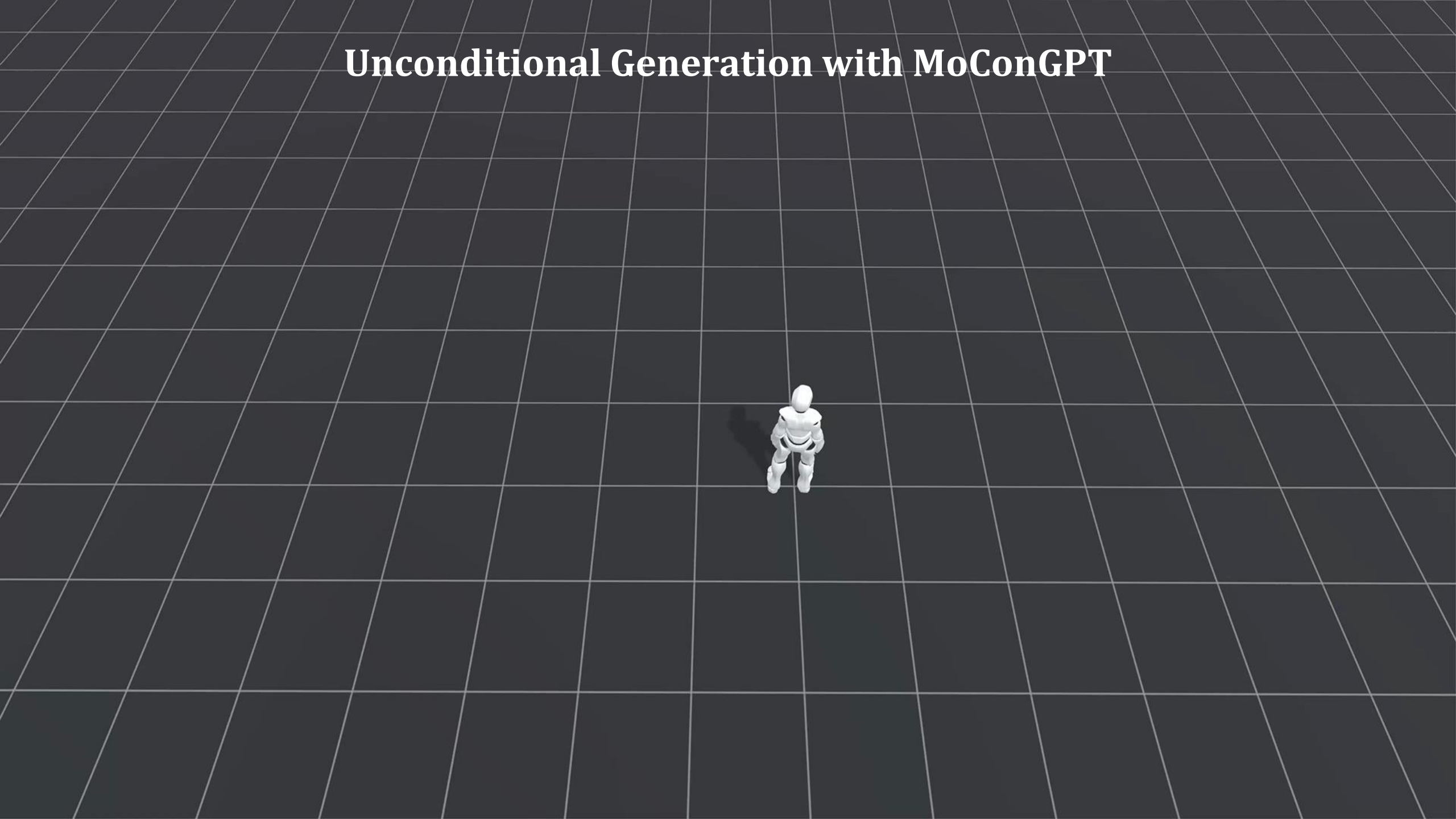
GPT



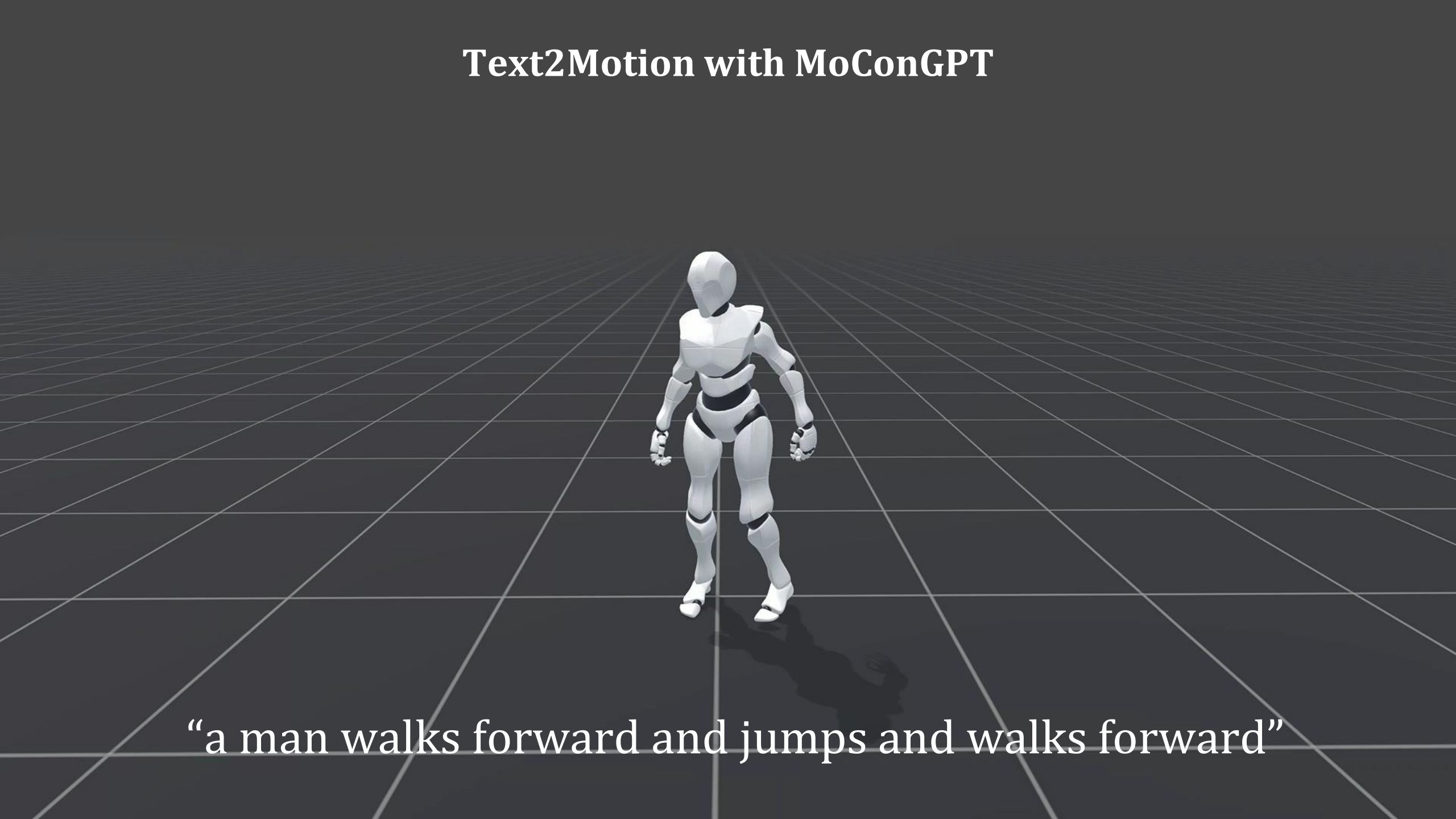
×14k clips

Teacher Forcing

Unconditional Generation with MoConGPT

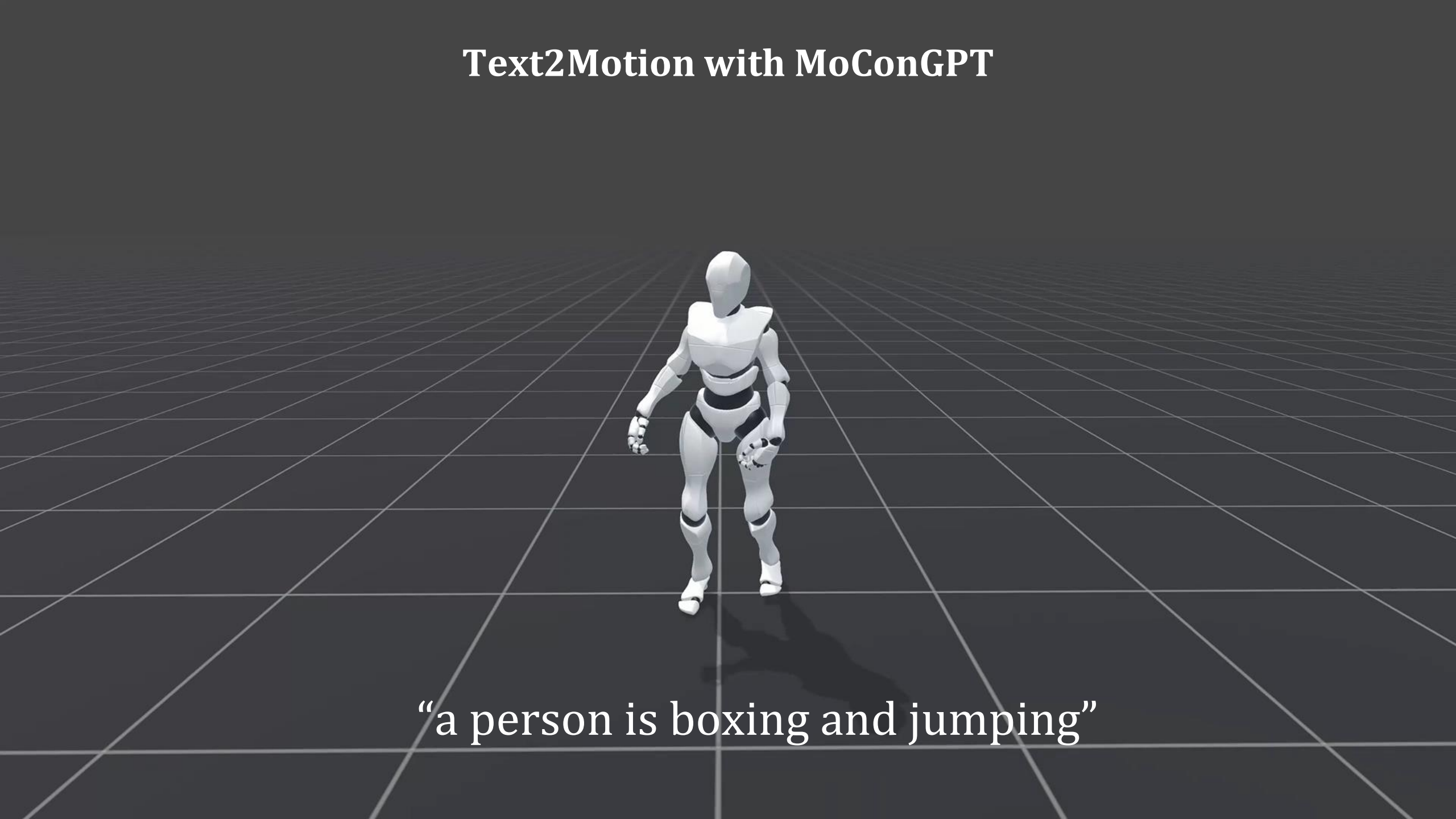


Text2Motion with MoConGPT



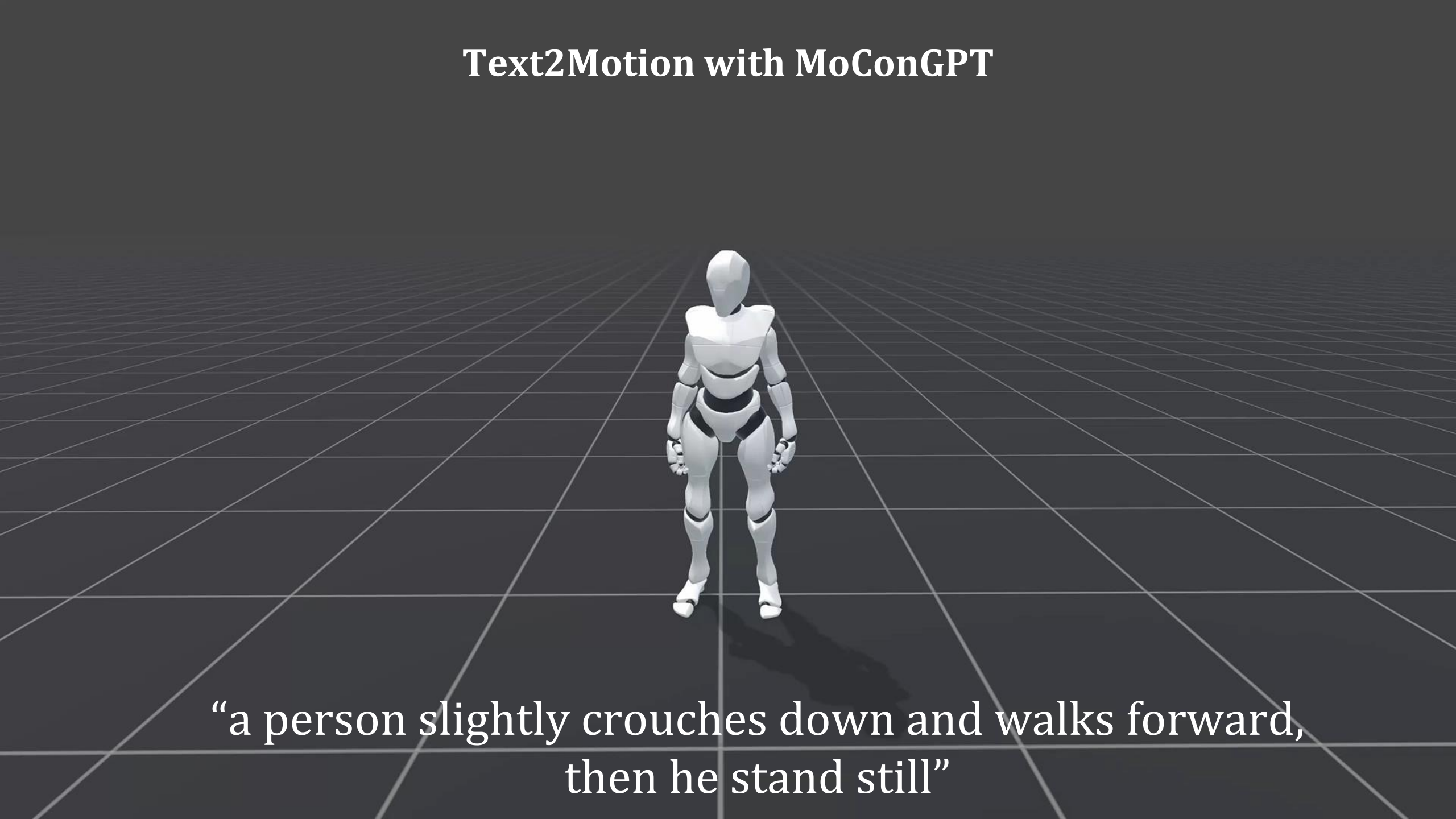
“a man walks forward and jumps and walks forward”

Text2Motion with MoConGPT



“a person is boxing and jumping”

Text2Motion with MoConGPT



"a person slightly crouches down and walks forward, then he stand still"

Downstream Tasks: LLM+

Here are some examples of our motion embedding.

A person is taking a long jump. [39, 762, 4, 483, …]
The peraon is getting down to play leapfrog. [421, 67, 30 , …]
A person waves with right hand. [157, 157, 420, …]
……

Question: A person walks forward and sits down.

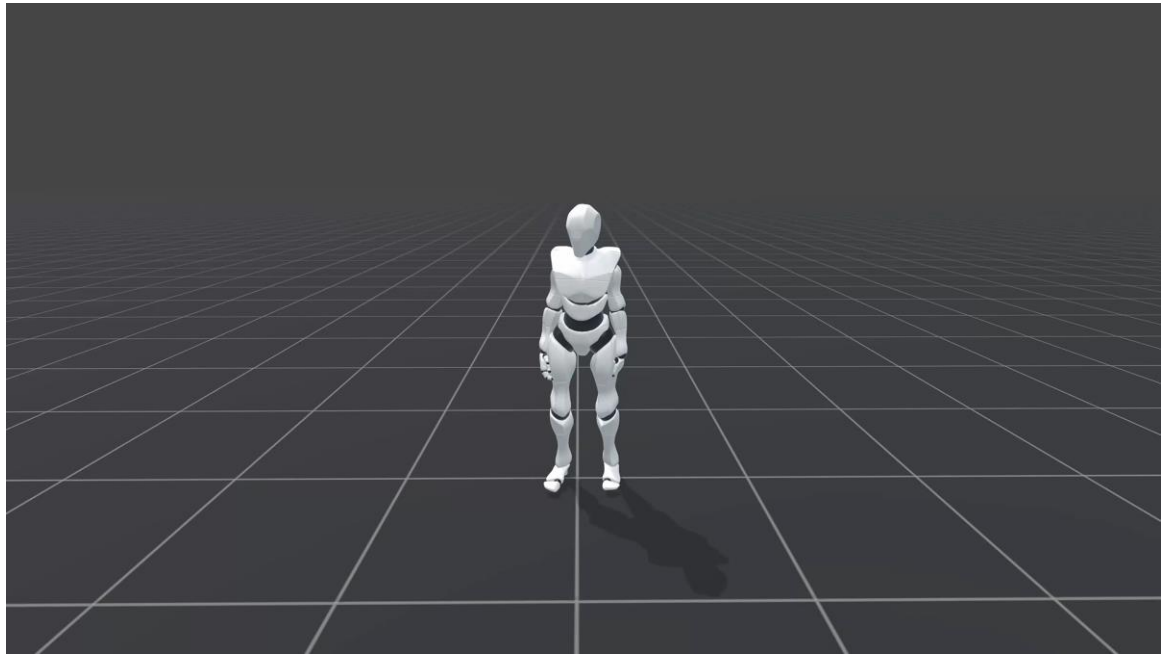
[297, 471, 246, 463, 463, 511, 456, 206, 274, 370, 41, 41, 370, 370]

Codebook

B_0

z_0

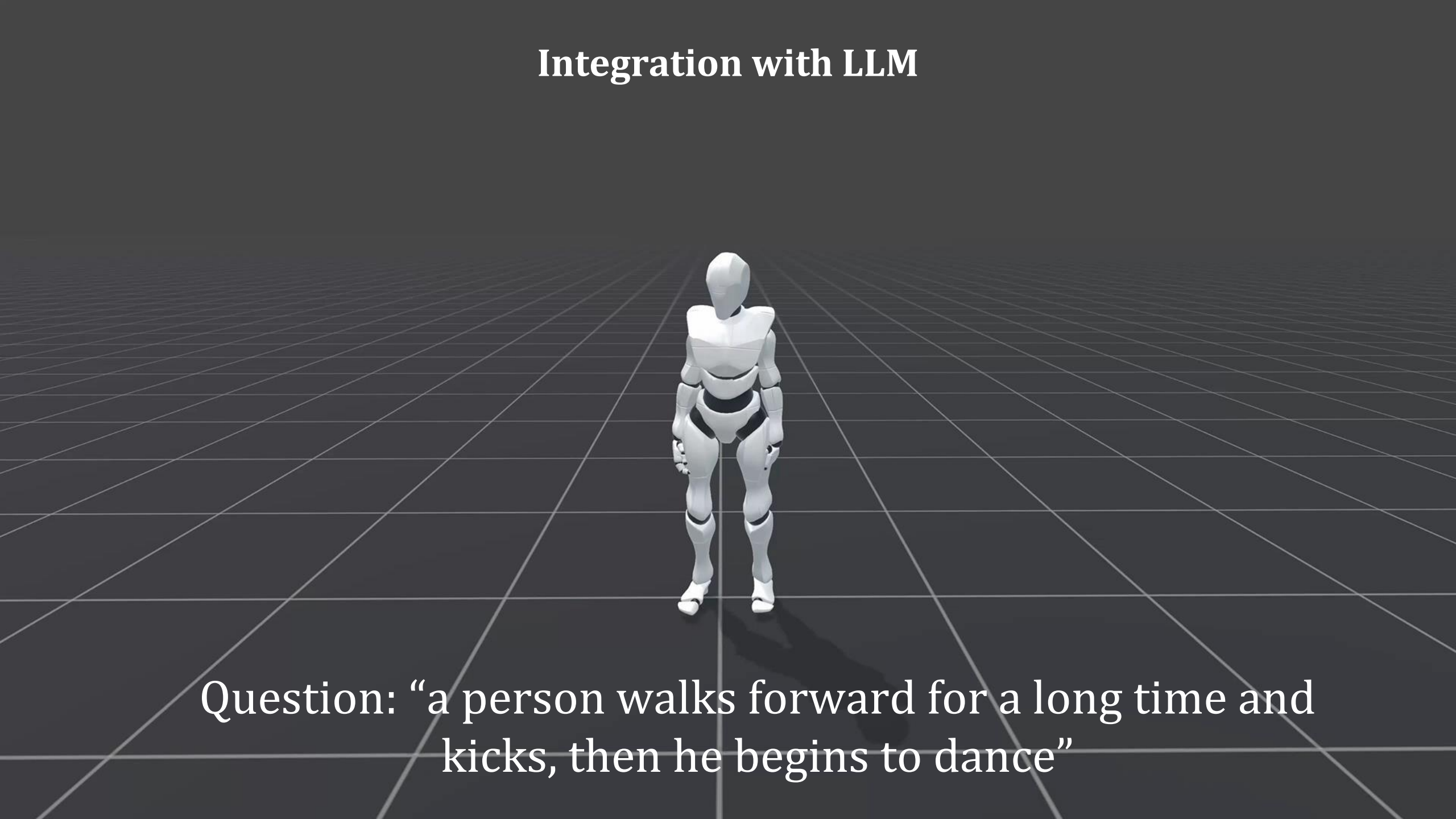
Physics-based Decoder



Integration with LLM

Question: “a person picking up a item and about to place it down”

Integration with LLM



Question: “a person walks forward for a long time and kicks, then he begins to dance”

Abstract Tasks with LLM

How do you make a character walk in a square trajectory?

I would need the character to take straight walks forward, combined with 90 degree turns at each corner.
Forward walk: [297, 471, 246, 463, 463]
Sharp right turn: [360, 360, 360, 108,...]

Abstract Tasks with LLM

Suppose there is a door in front of you, and a key on the ground. you want to open the door and sit on the chair, how do you perform?

I would:

1. Walk forward [297,...]
2. Bend down and pick up the key [246,...]
3. Insert the key into the door [129,...]
4. Walk through the doorway [297,...]
5. Sit down on chair [241,...]