GAMES 105
Fundamentals of Character Animation

Lecture 01:

Introduction to 3D Character Animation

Libin Liu

School of Intelligence Science and Technology
Peking University

GAMES105 课程交流

VCL @ PKU

Instructor

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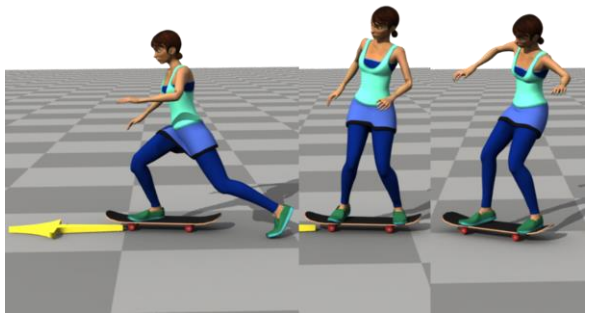
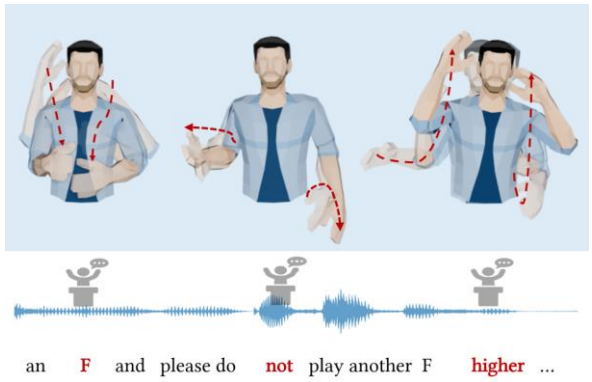
- Assistant Professor
- School of Intelligence Science and Technology, Peking University
- http://libliu.info





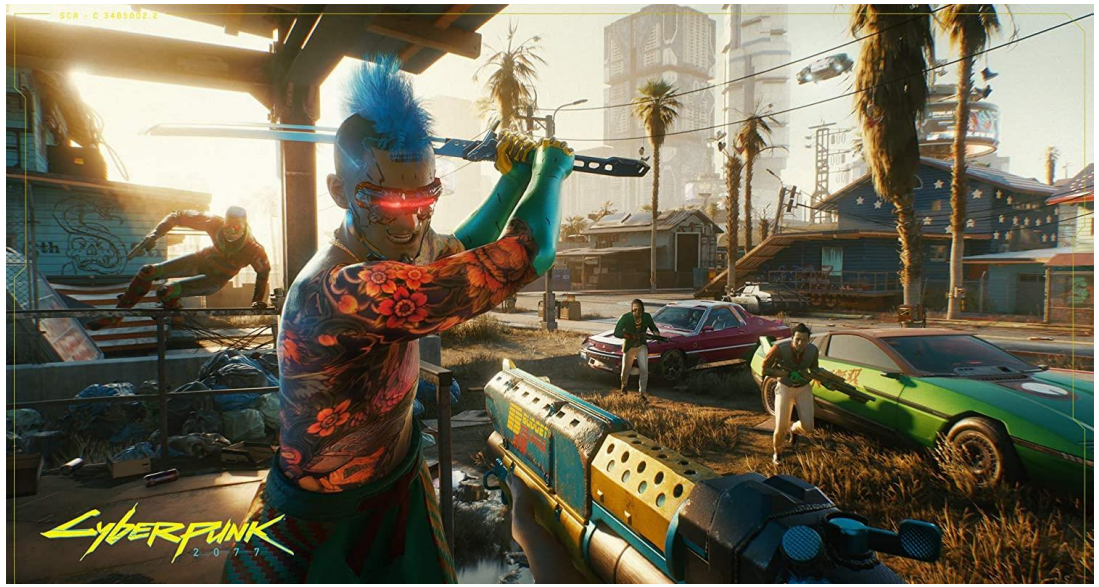
VCL @ PKU

Welcome & Course Information

- Instructor: Libin Liu (http://libliu.info)
- Website: https://games-105.github.io/
- Lecture: Monday 8:00PM to 9:00PM (12 Weeks)
- Prerequisites: linear algebra, calculus,
  programming skills (python),
  probability theory, mechanics, ML, RL…
- Exercise:
  - Codebase: https://github.com/GAMES-105/GAMES-105
  - Submission: http://cn.ces-alpha.org/course/register/GAMES-105-Animation-2022/
  - Register code: **GAMES-FCA-2022**
- BBS: https://github.com/GAMES-105/GAMES-105/discussions
- QQ Group: 533469817

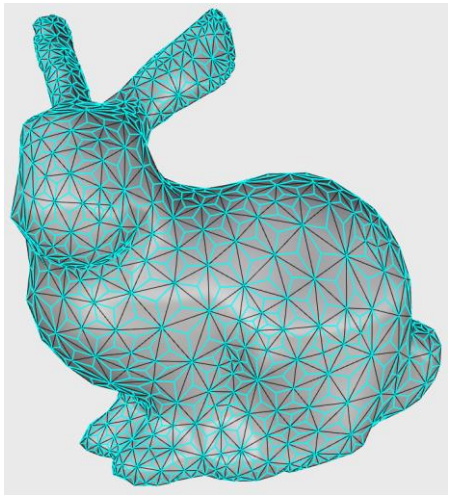
What is Character Animation

What is Character Animation



What is Character Animation

3D Computer Graphics



…

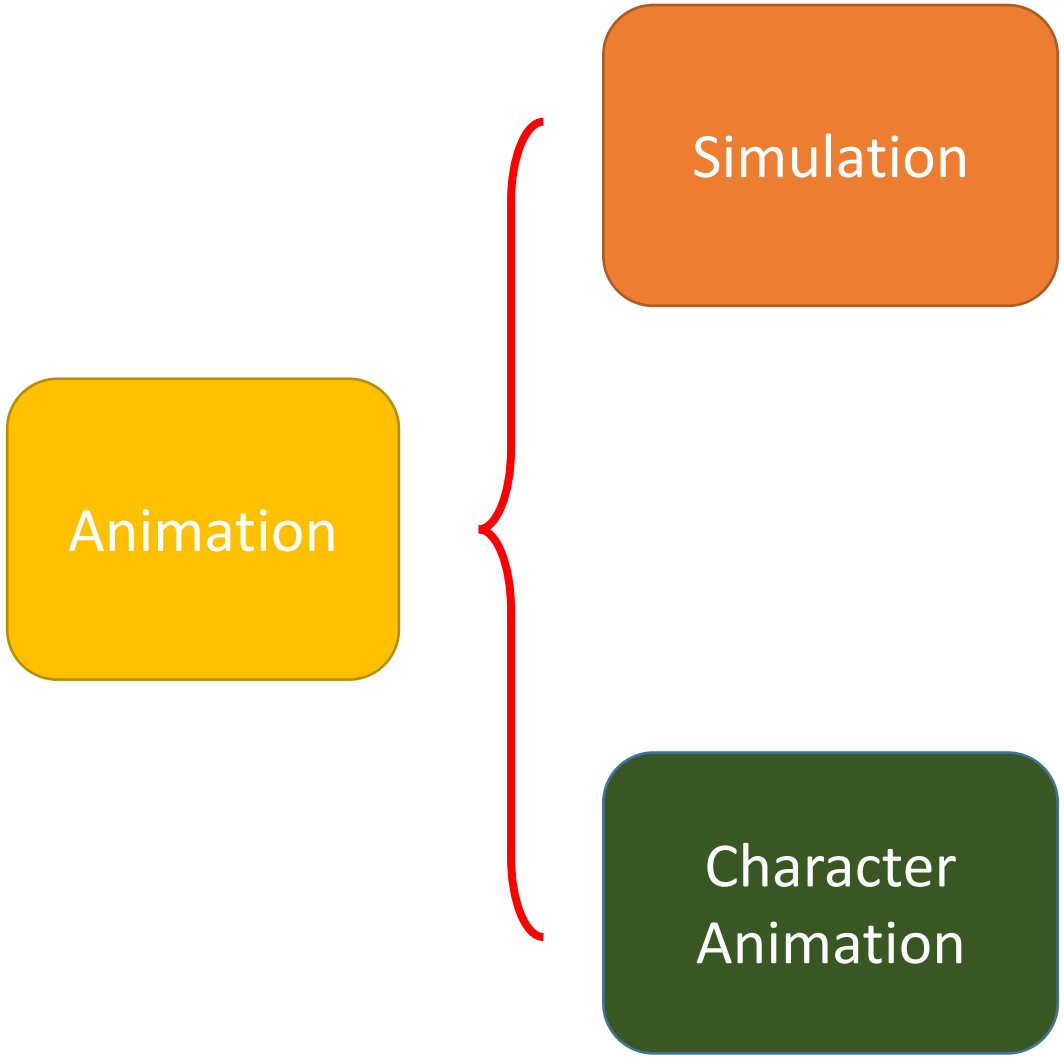
Geometry

Animation

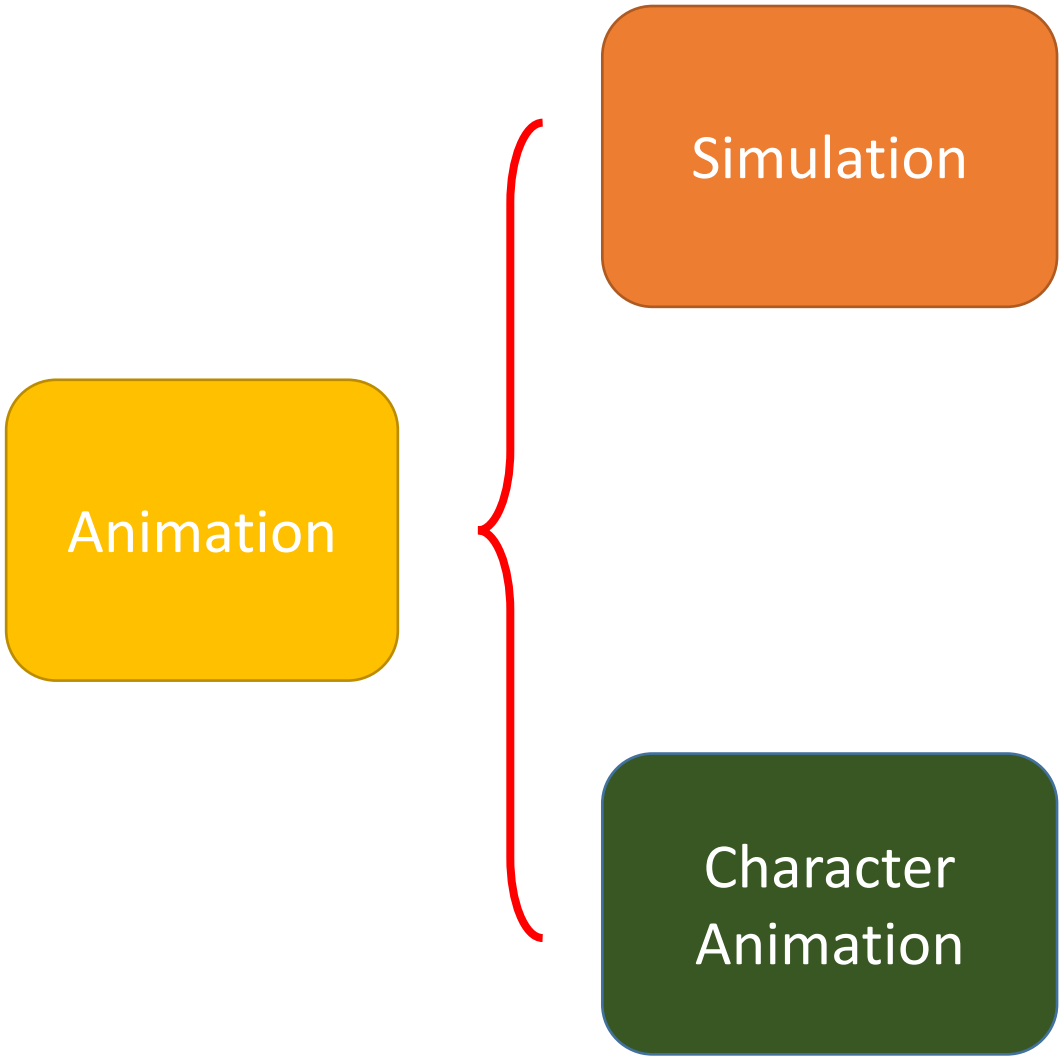
Rendering

…

3D Computer Animation



3D Computer Animation



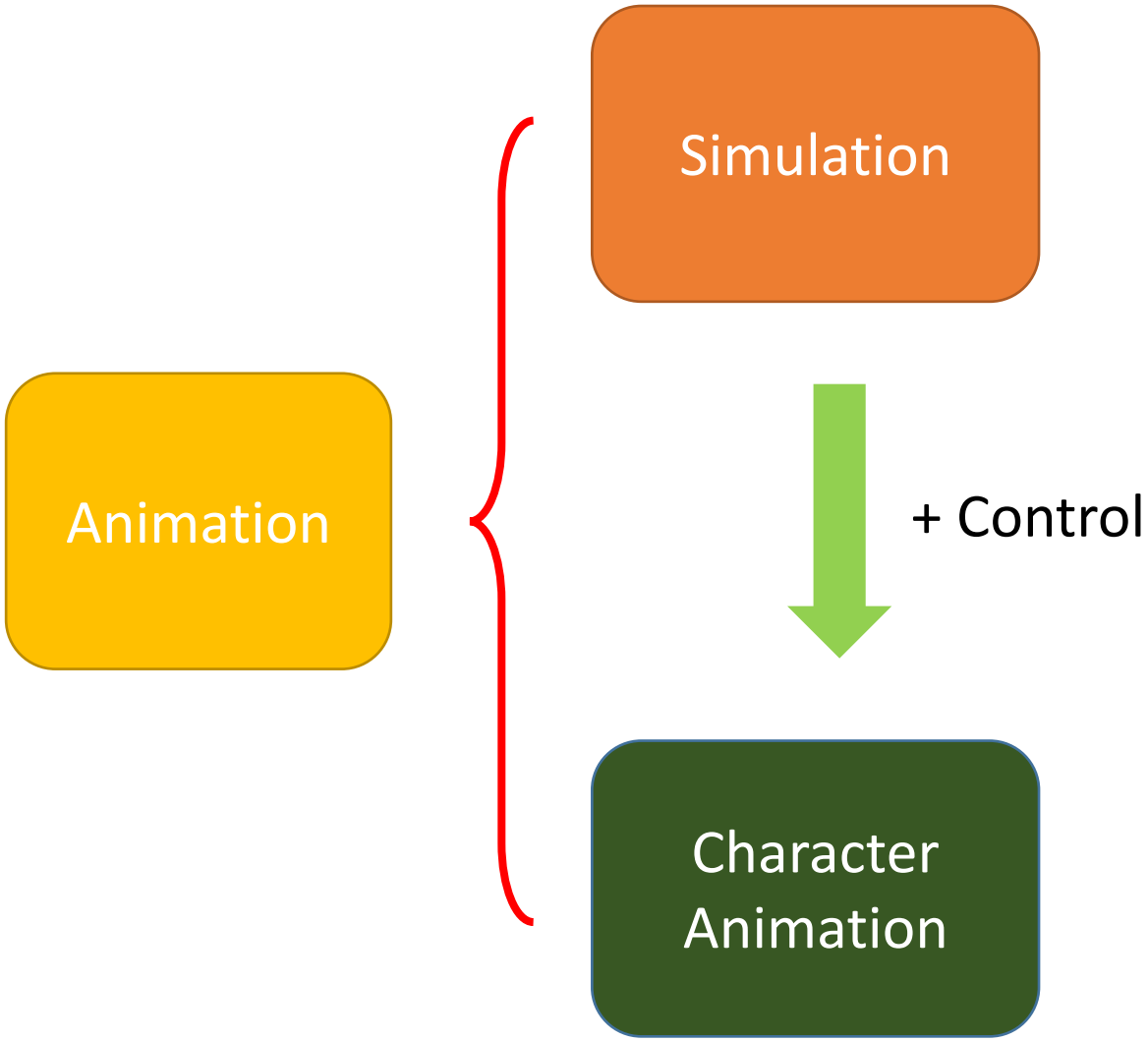
rigid bodies,
deformable solids,
ropes, thin shells, cloth,
fluid, smoke, sound…

Phenomenon

Behavior

humans, animals,
virtual creatures,
hands, robots,
crowds…

3D Computer Animation



rigid bodies,
deformable solids,
ropes, thin shells, cloth,
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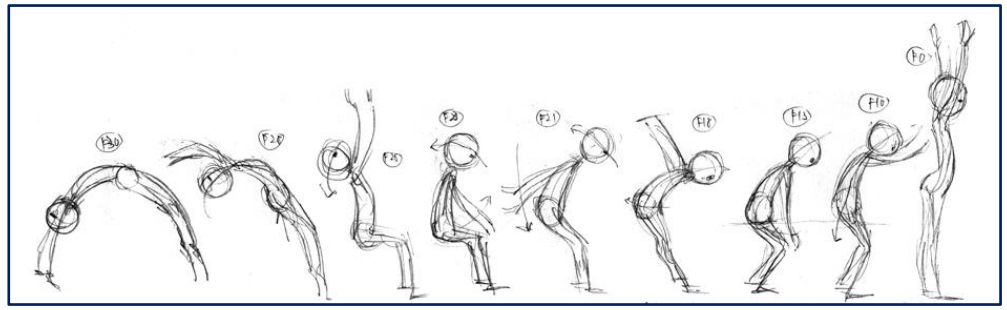
Phenomenon

Behavior

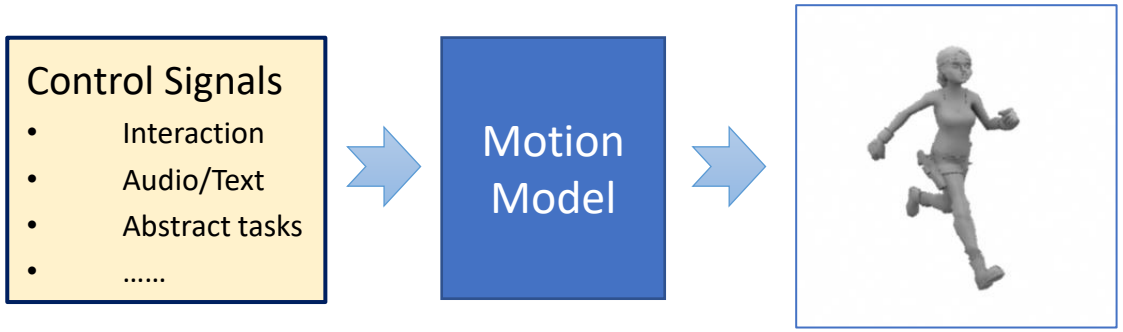
humans, animals,
virtual creatures,
hands, robots,
crowds…

Why Do We Study Character Animation

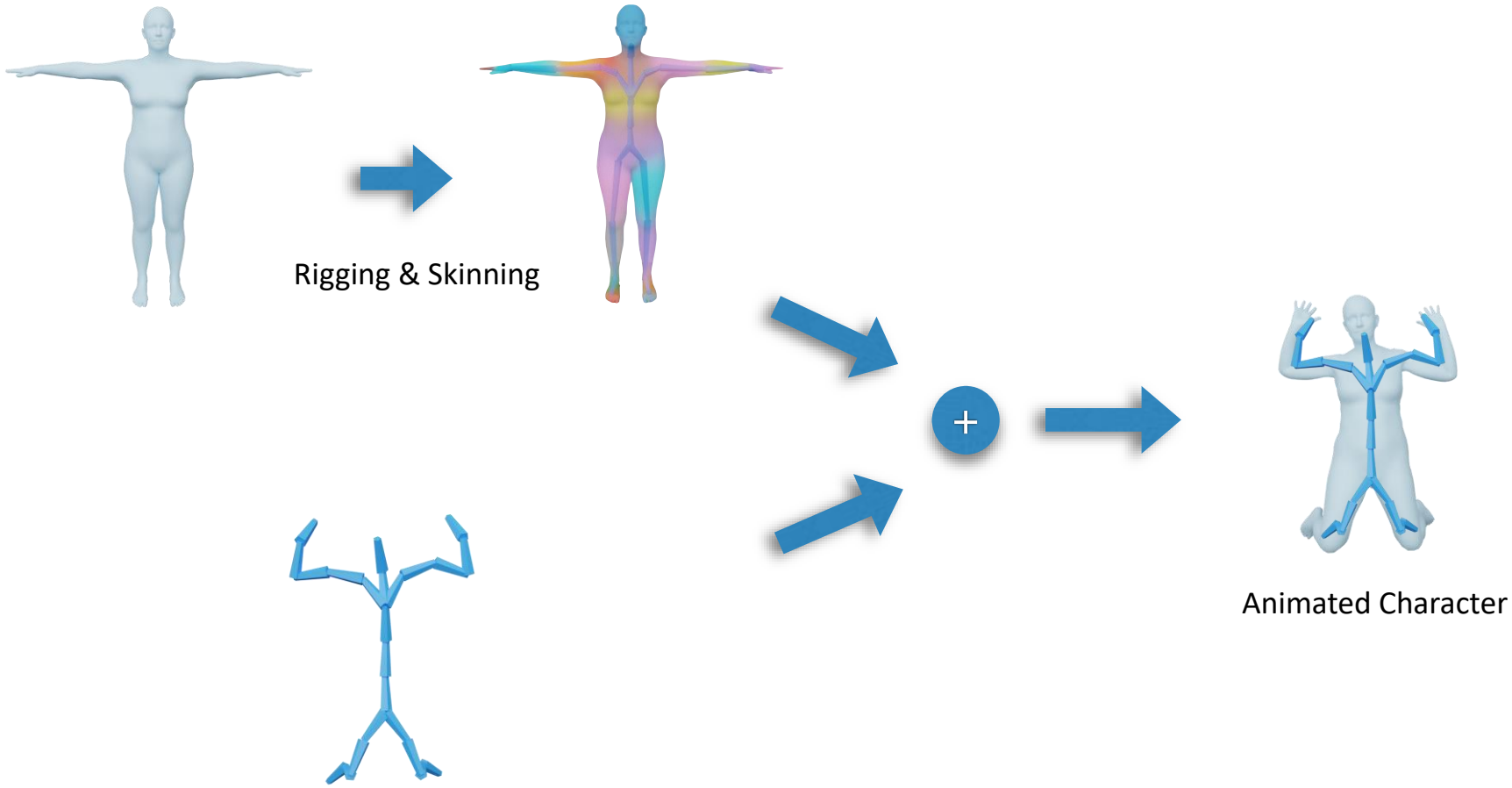
- A character typically has 20+ joints, or 50-100+ parameters
  - It is not super high-dimensional, so most animation can be created manually, by posing the character at keyframes
  - Labor-intensive, not for interactive applications



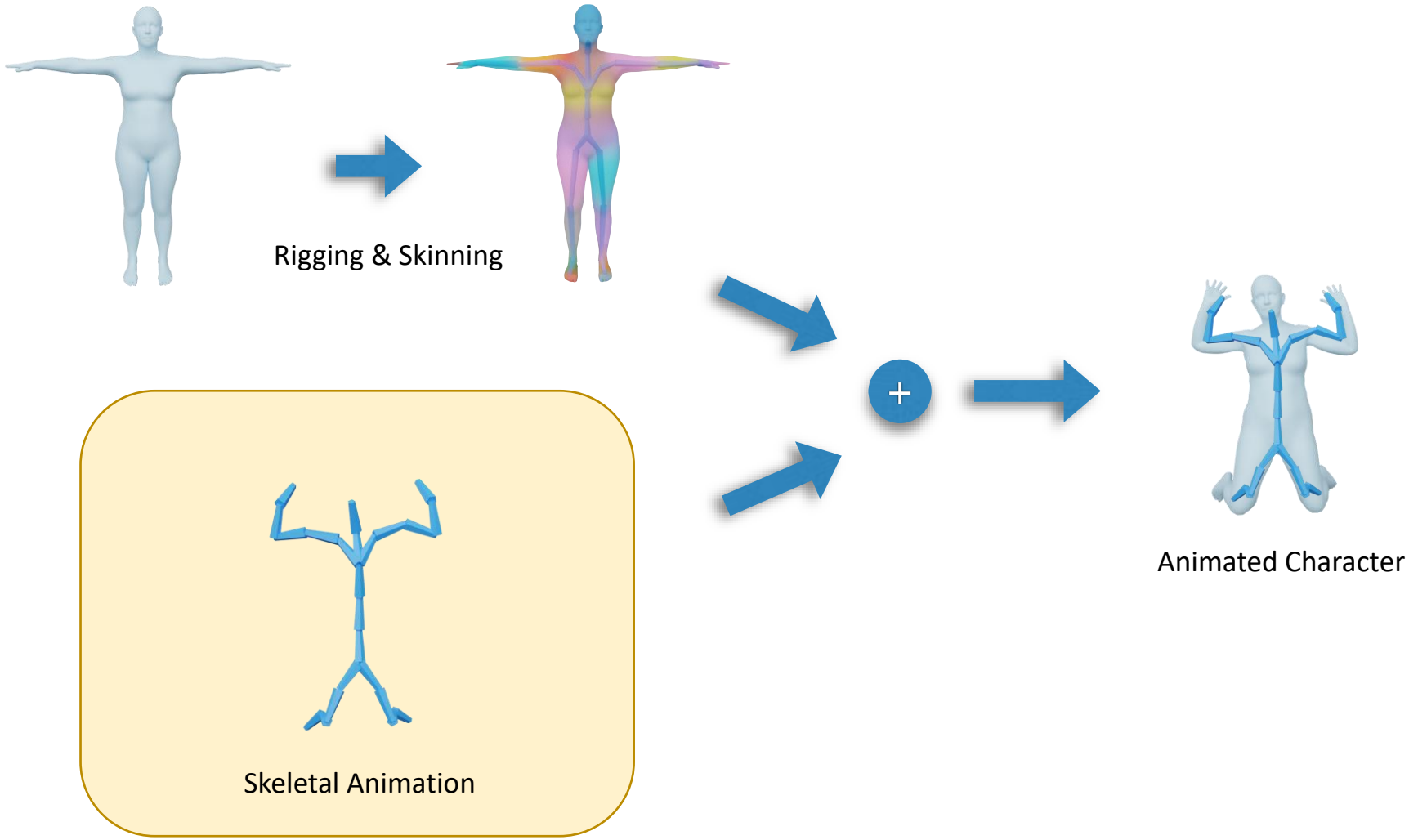
- Character animation techniques
  - Understanding the mechanism behind motions and behaviors
  - Smart editing of animation/ Reuse animation / Generate new animation
  - "Compute-intensive"



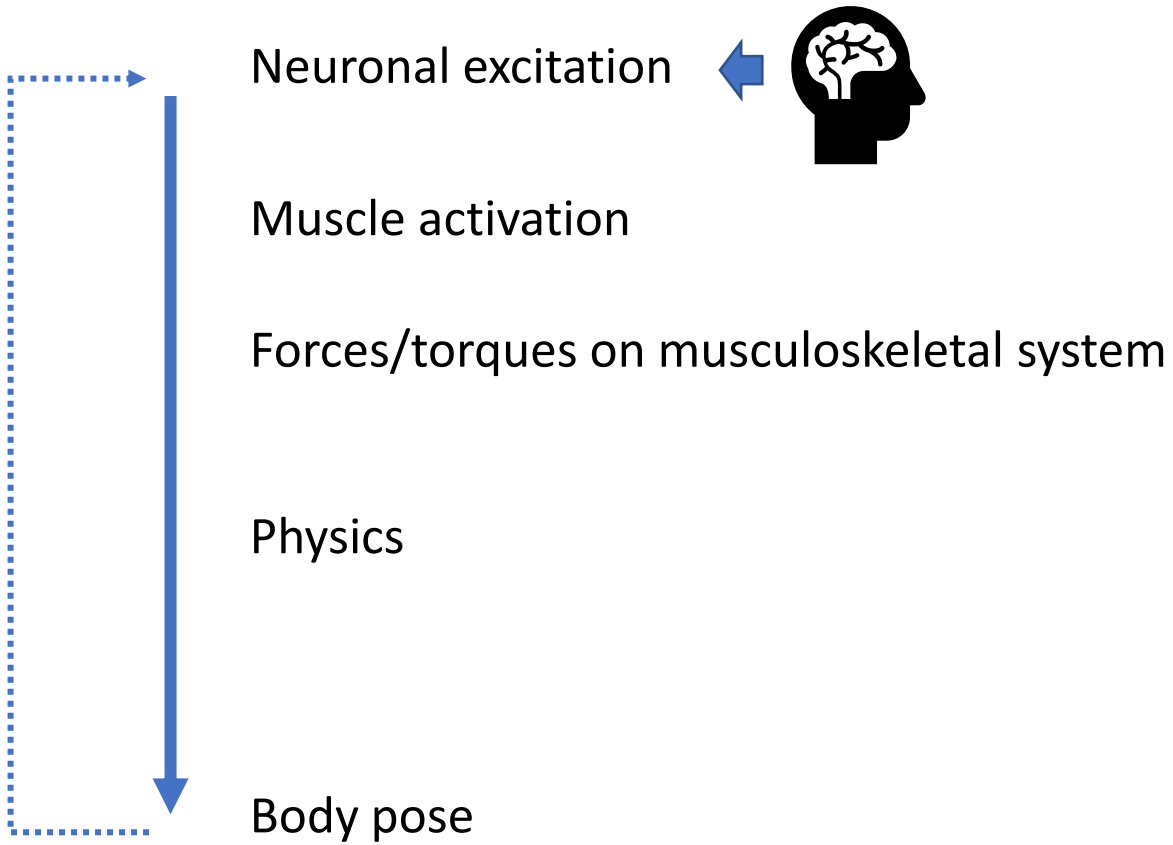
Character Animation Pipeline



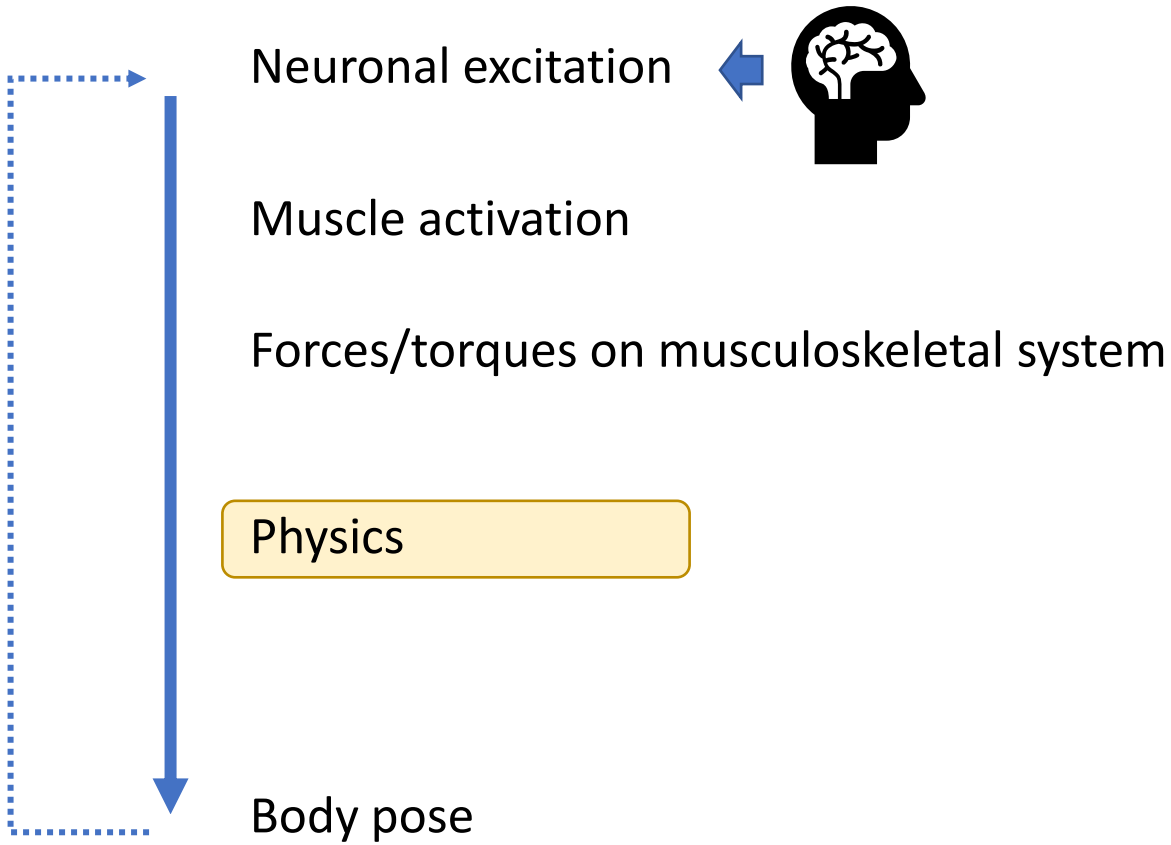
Character Animation Pipeline



Where does a Motion Come From



Where does a Motion Come From



Keyframe-based/Kinematic Approaches

Neuronal excitation

Muscle activation

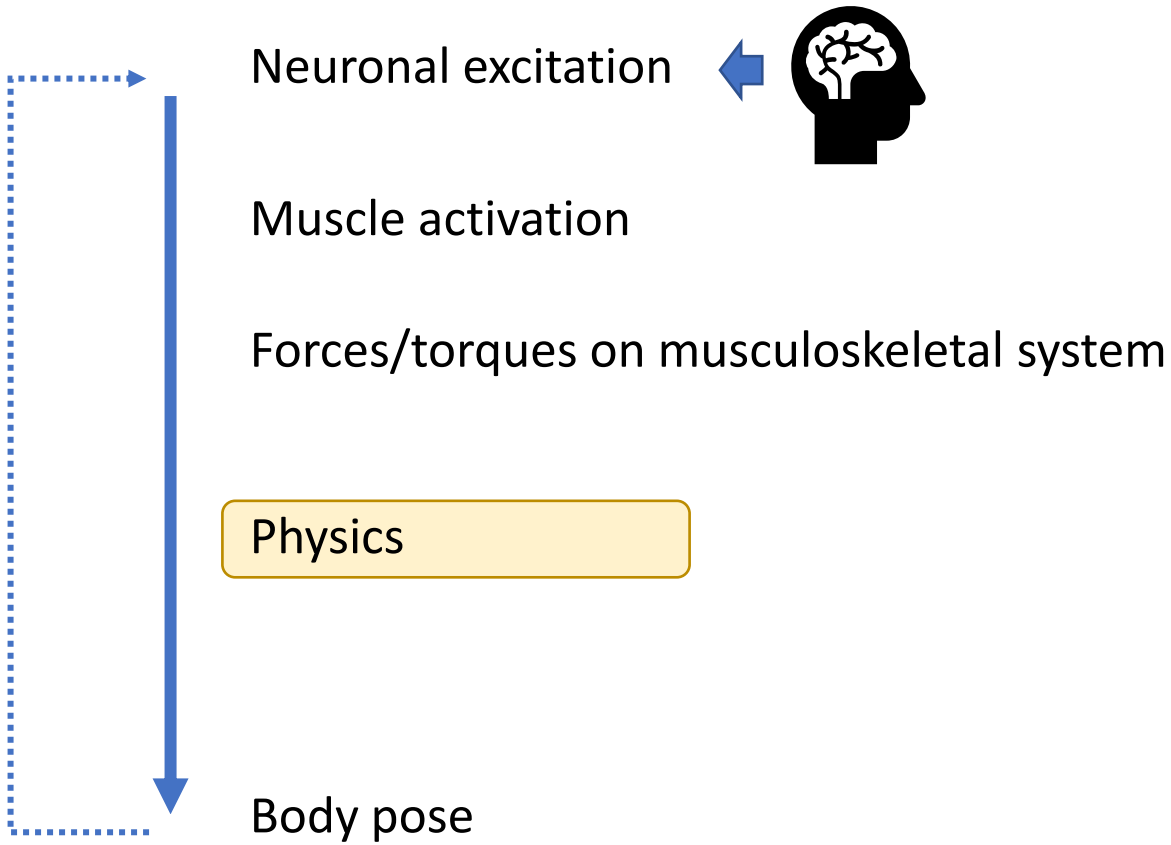
Forces/torques on musculoskeletal system

Physics

Body pose

Direct update of character's pose/velocity/acceleration…

Physics-based/Dynamic Approaches

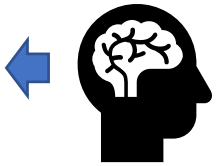


Physics-based/Dynamic Approaches

Neuronal excitation

Muscle activation

Forces/torques on skeleton

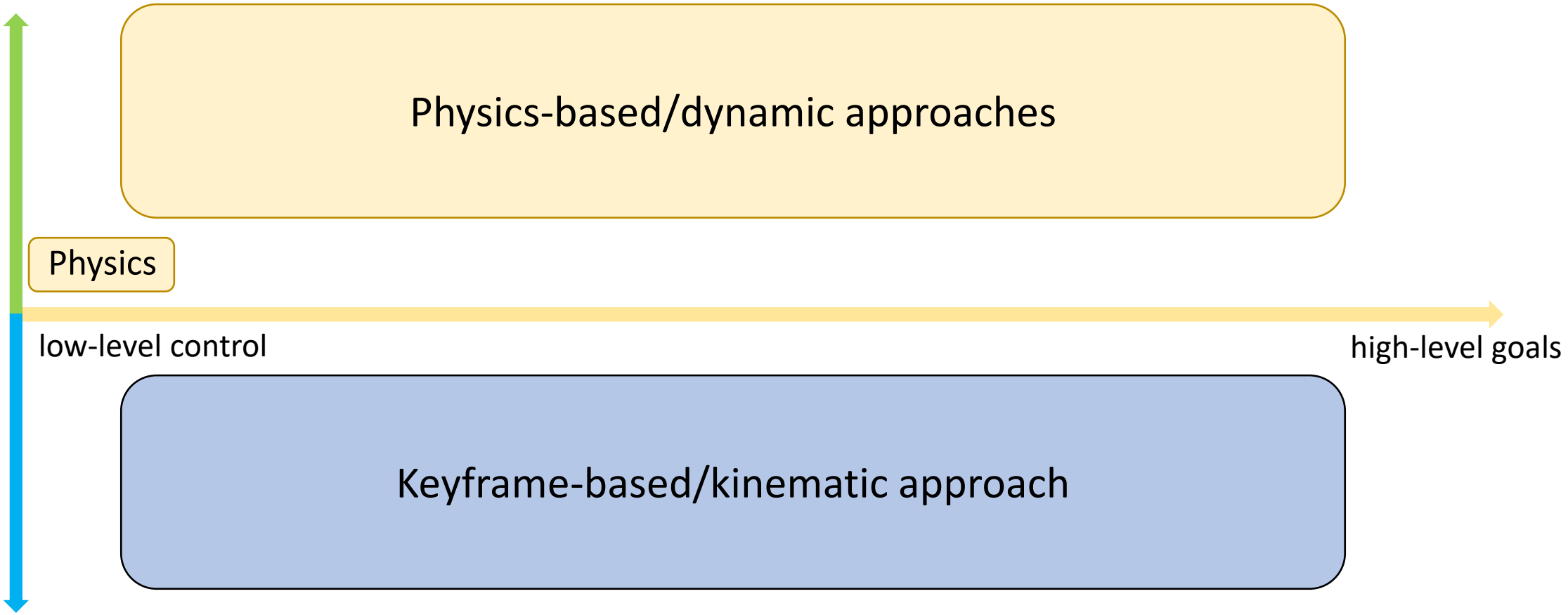


Simplified control & physics

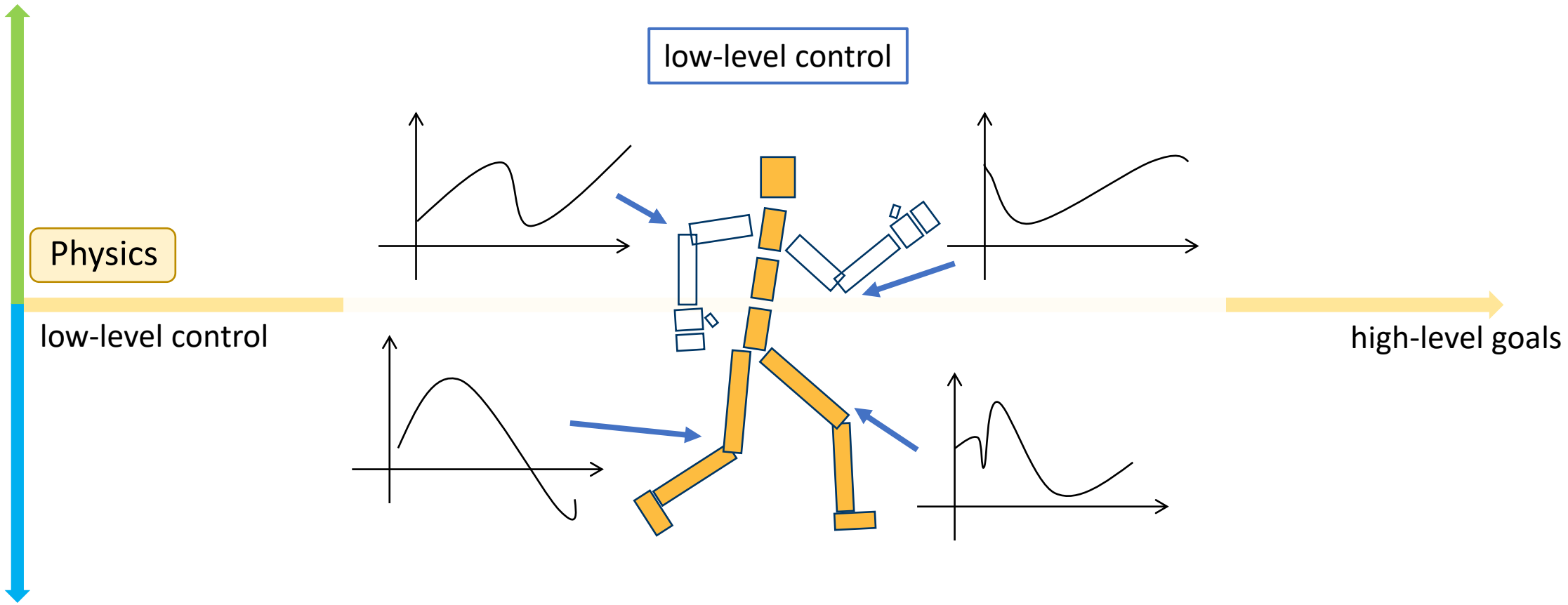
Physics

Body pose

Character Animation Methods



Character Animation Methods



Character Animation Methods

Physics-based/dynamic approaches

high-level control

Physics

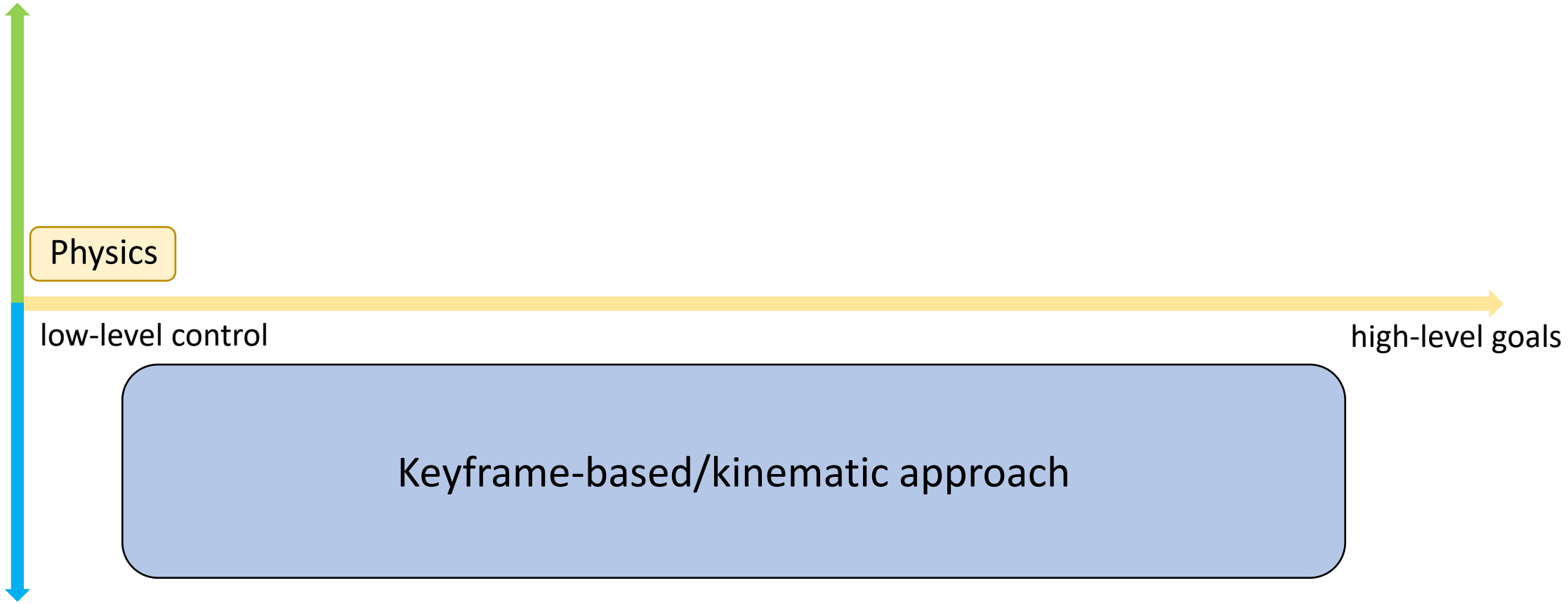
low-level control

high-level goals

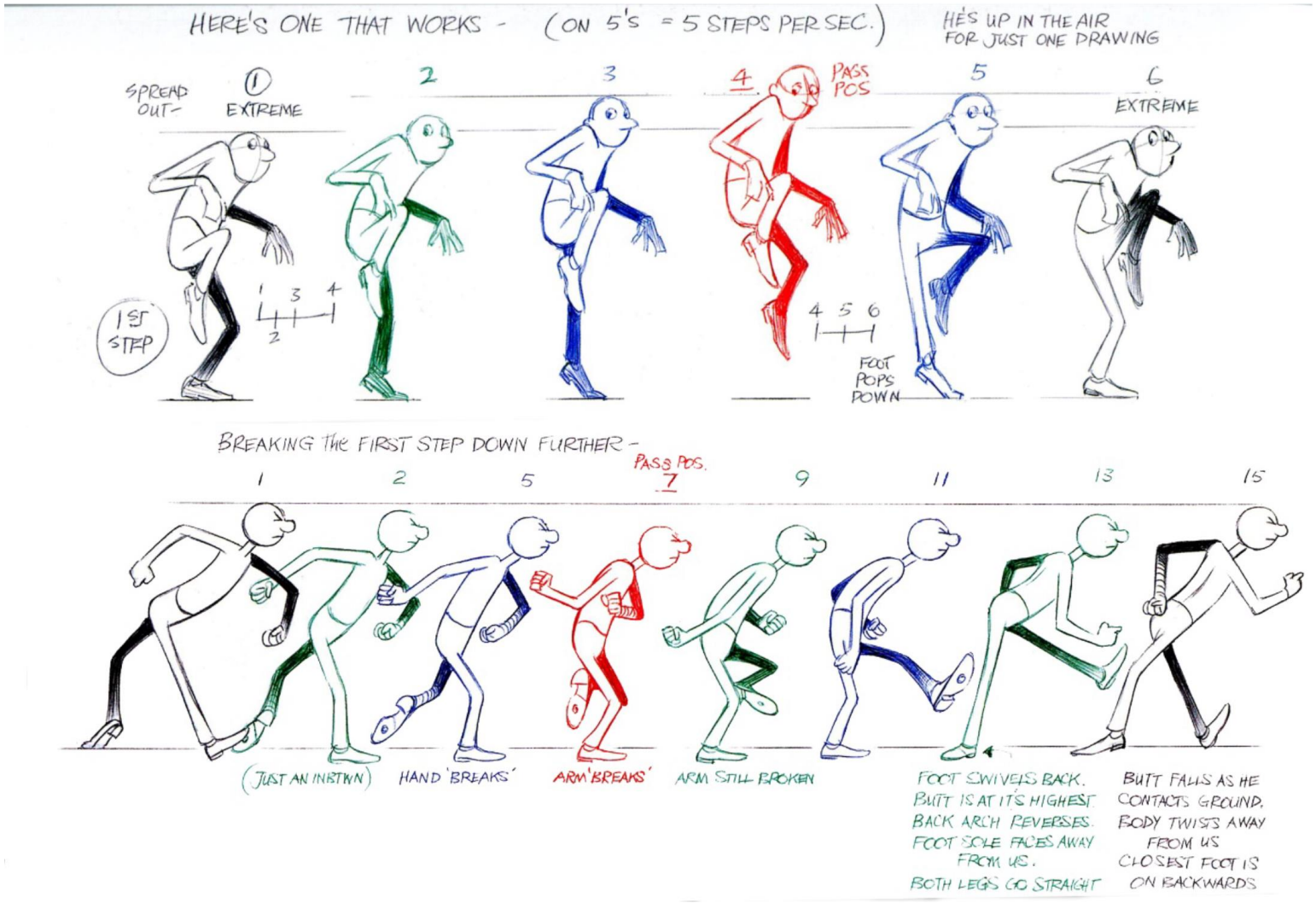
"go there and bring me a glass of water"

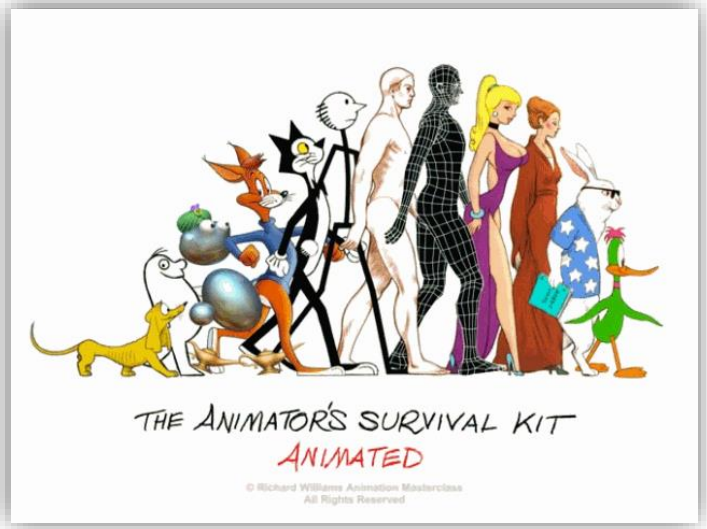
Keyframe-based/kinematic approach

Character Animation Methods



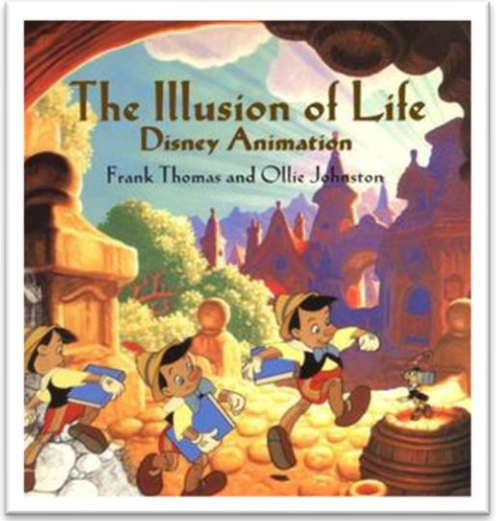
Keyframe Animation





http://www.theanimatorssurvivalkit.com/

Disney's 12 Principles of Animation

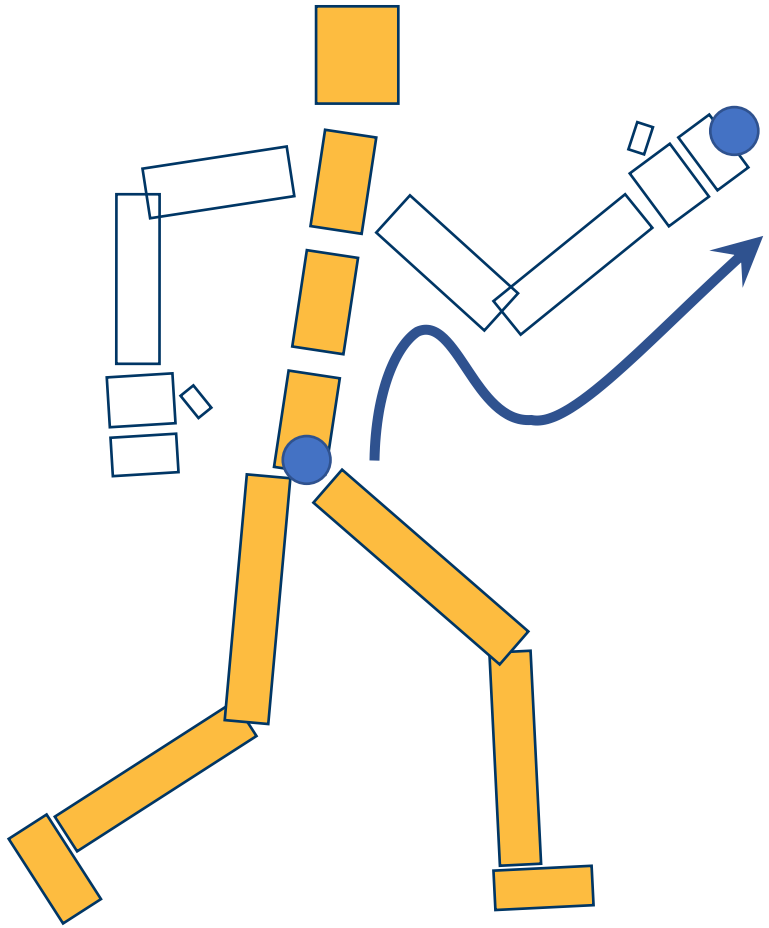


[http://the12principles.tumblr.com/]

Keyframe 3D Animation

How to Animate 3D Characters in 1 Minute https://www.youtube.com/watch?v=TjJLIuFKA20

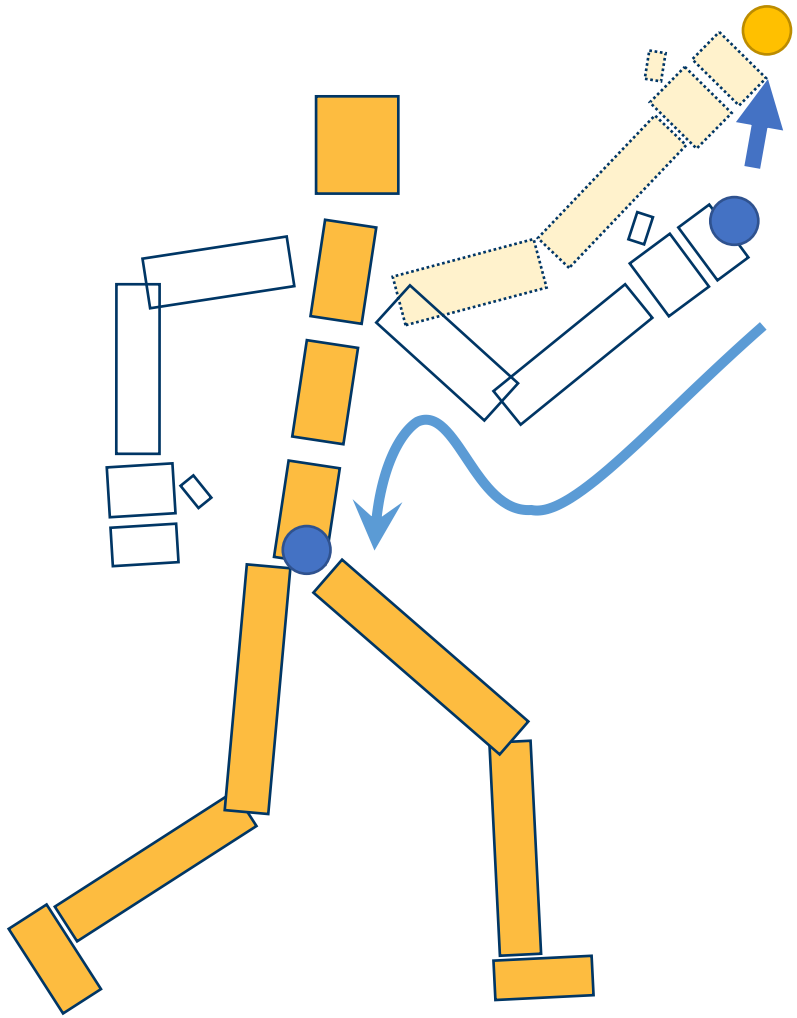
Forward Kinematics



Given rotations of every joints

Compute position of end-effectors

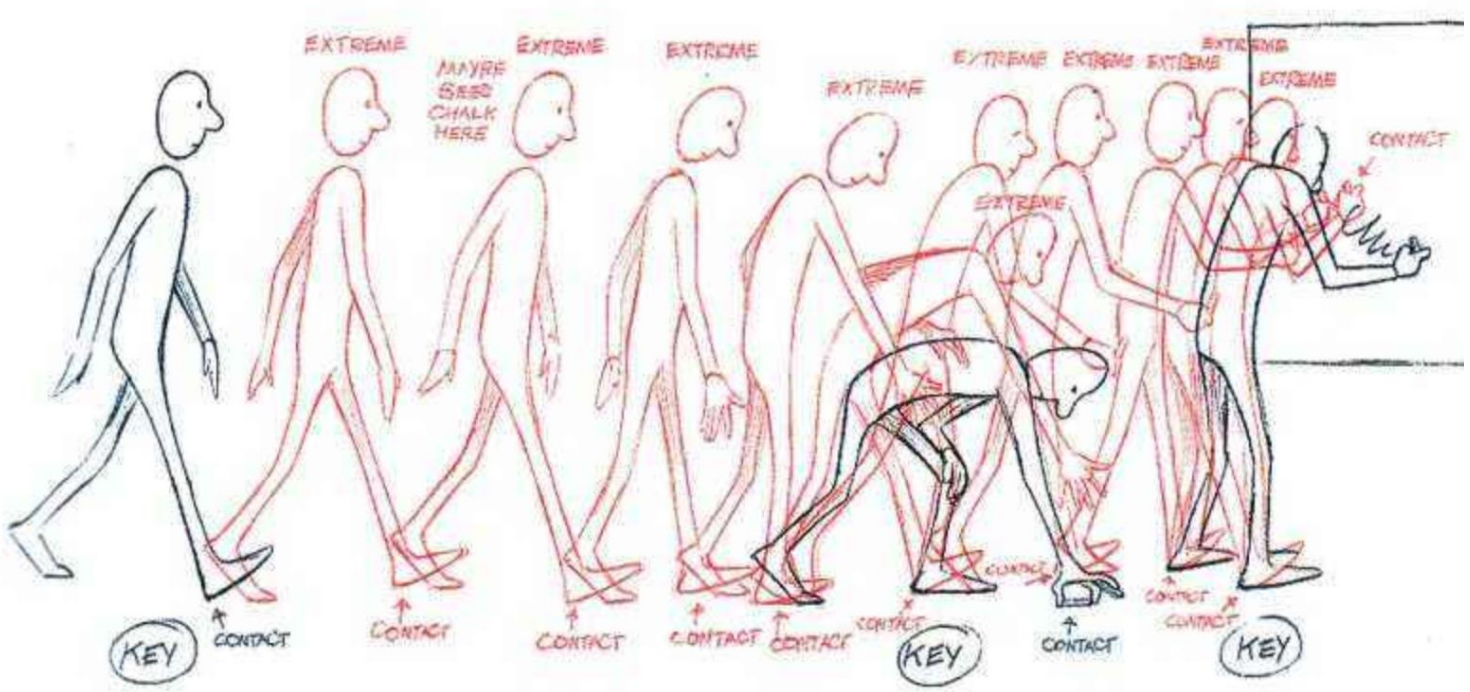
Inverse Kinematics



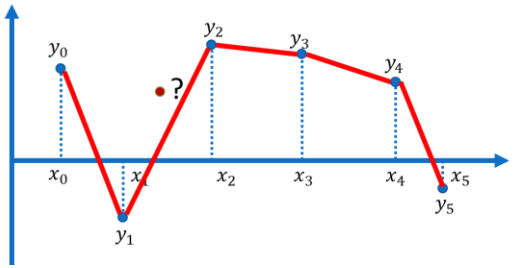
Given position of end-effectors

Compute rotations of every joints

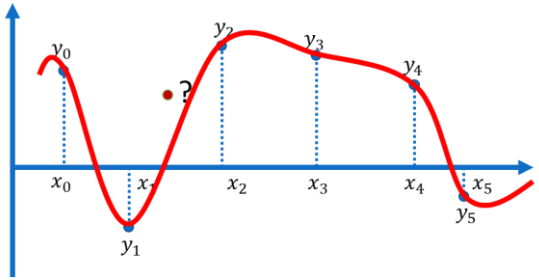
Interpolation



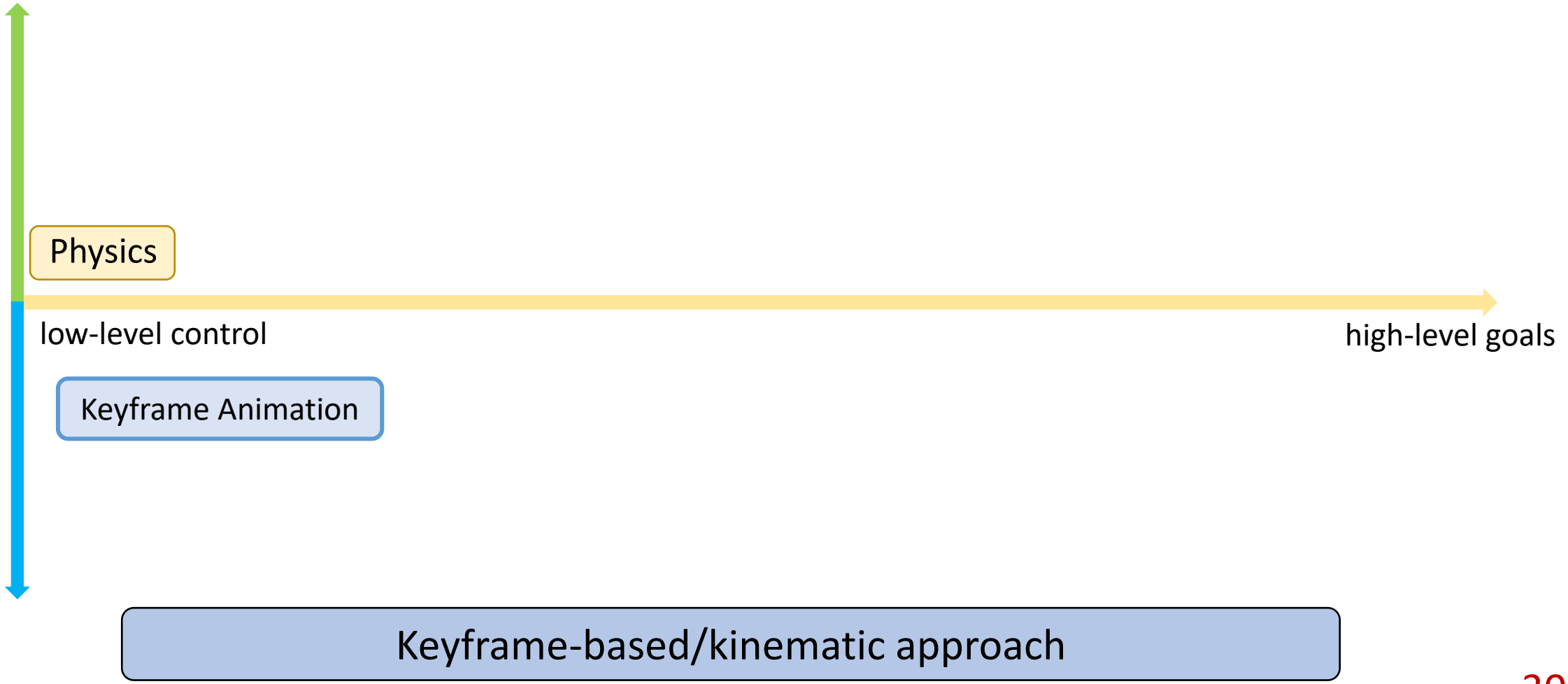
$$f(x) = y_1 + \frac{x - x_1}{x_2 - x_1}(y_2 - y_1)$$



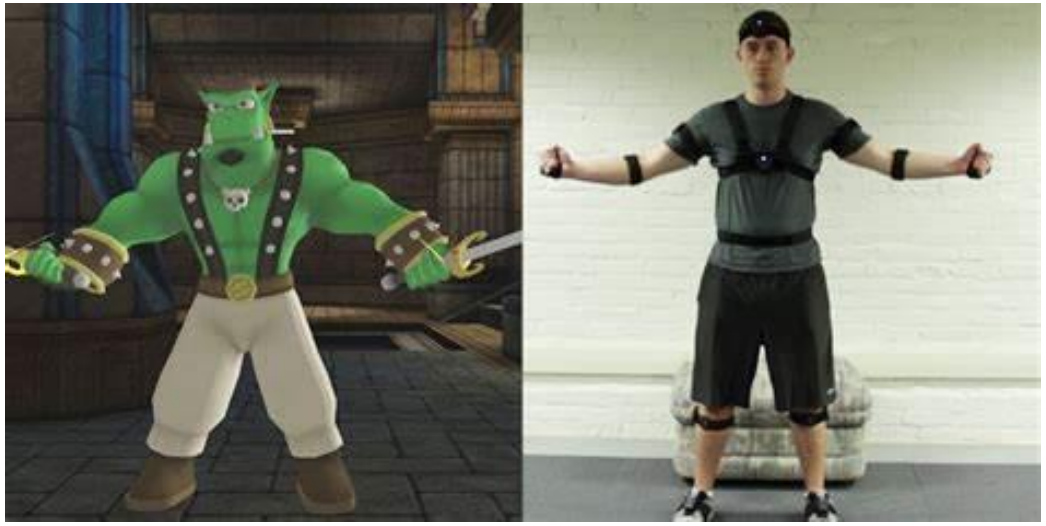
$$S_i(x) = a_i x^3 + b_i x^2 + c_i x + d_i$$



Character Animation Methods

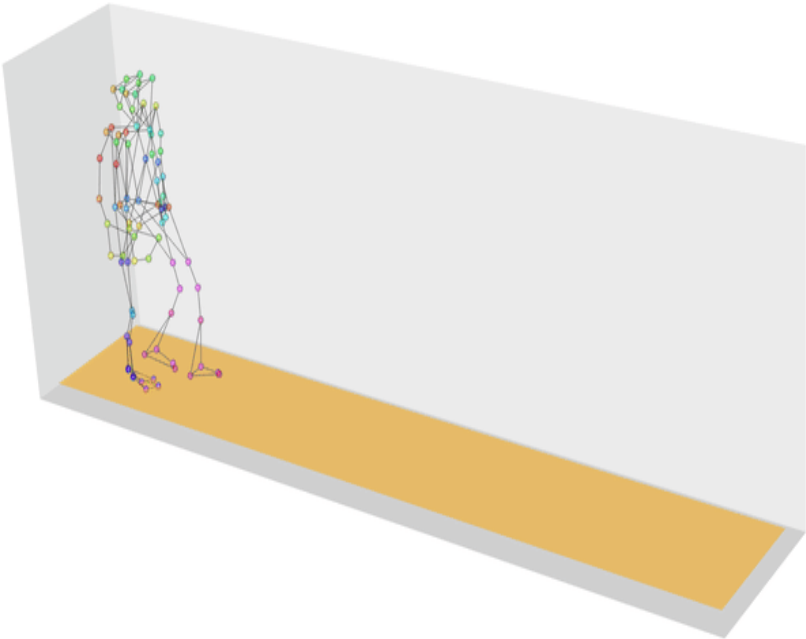


Motion Capture

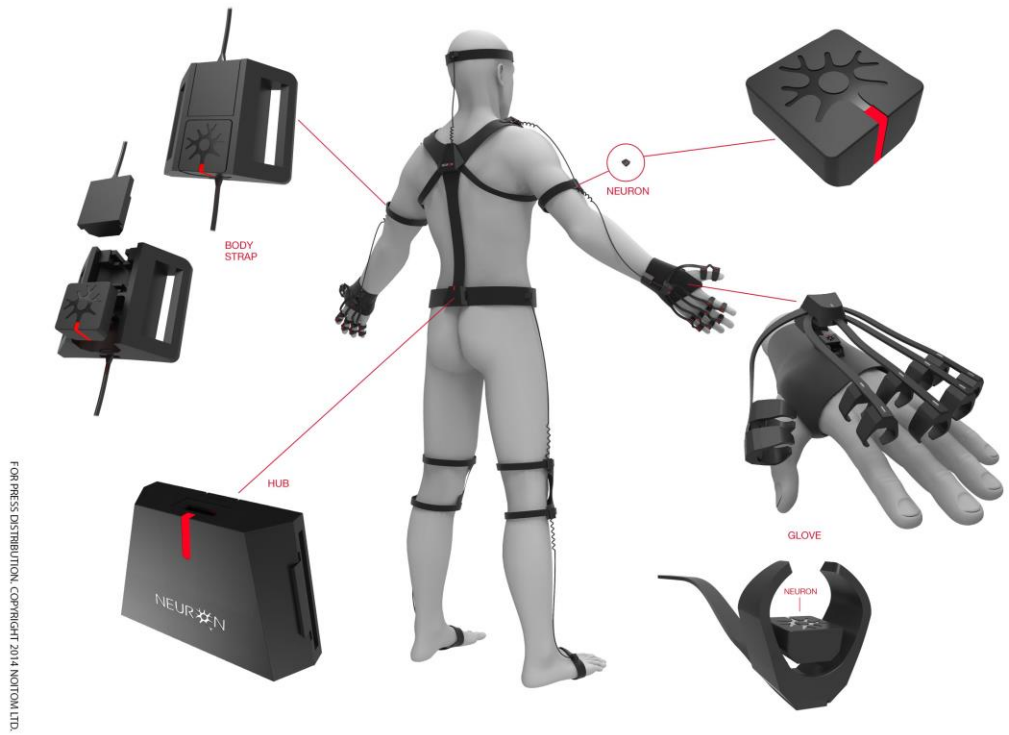


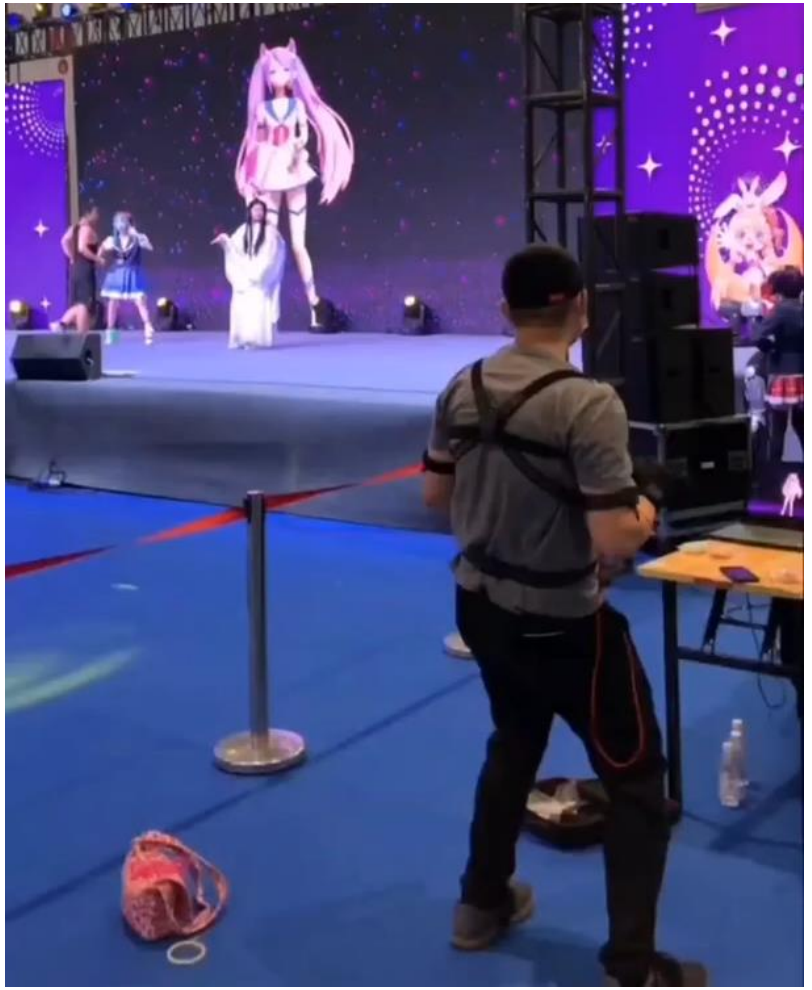
Motion Capture

Behind the Scenes - God of War PS5 | Mocap Footage
https://www.youtube.com/watch?v=HVXoOK4R8M0



Motion Capture

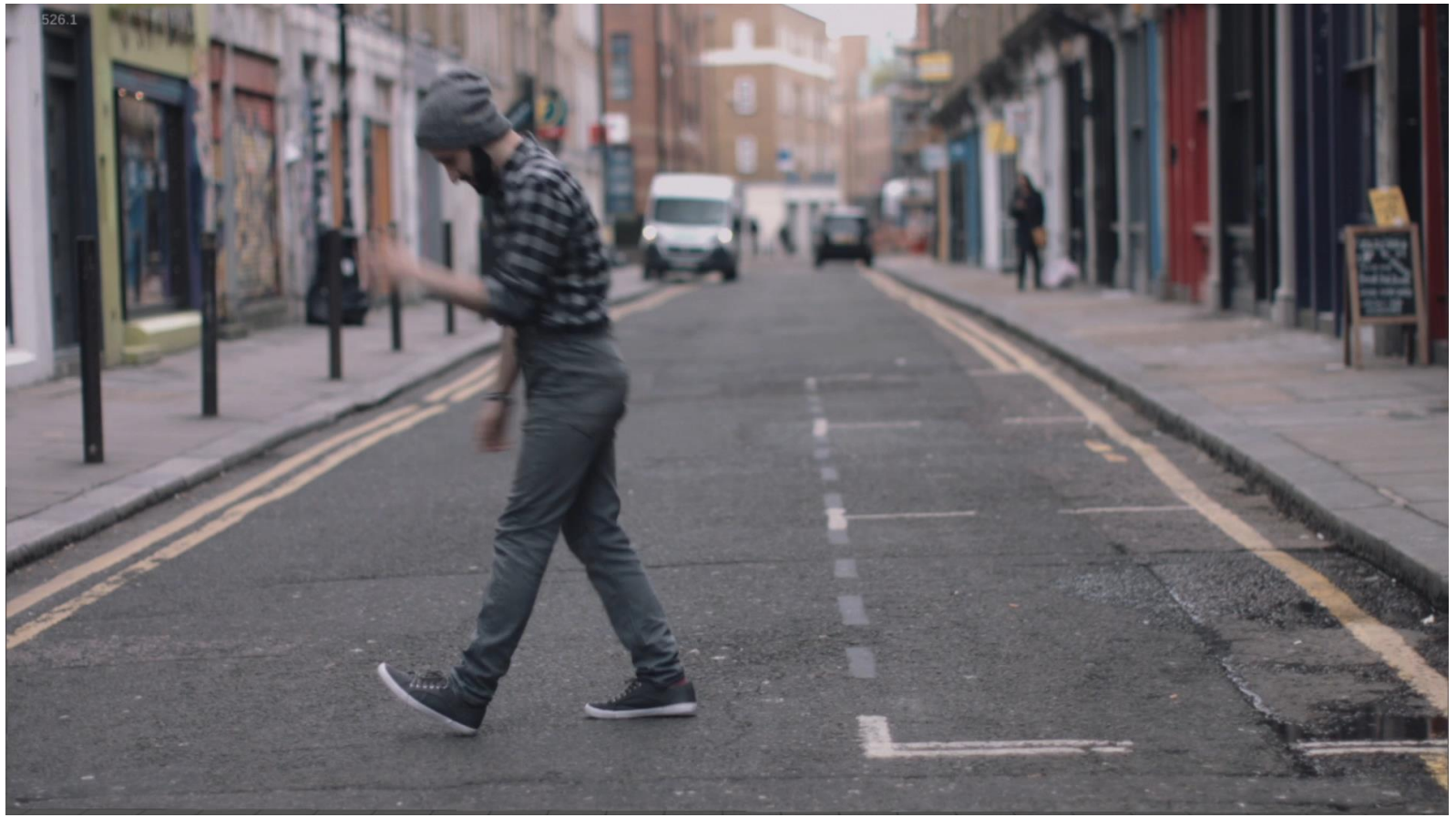




Source: douyin

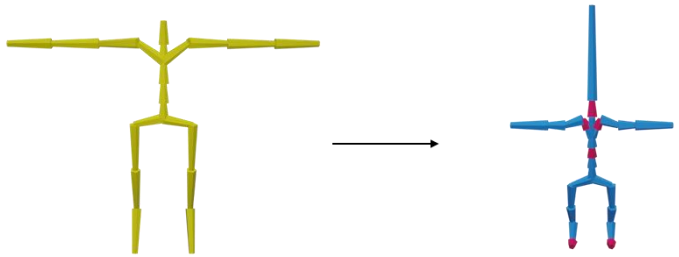
Motion Capture

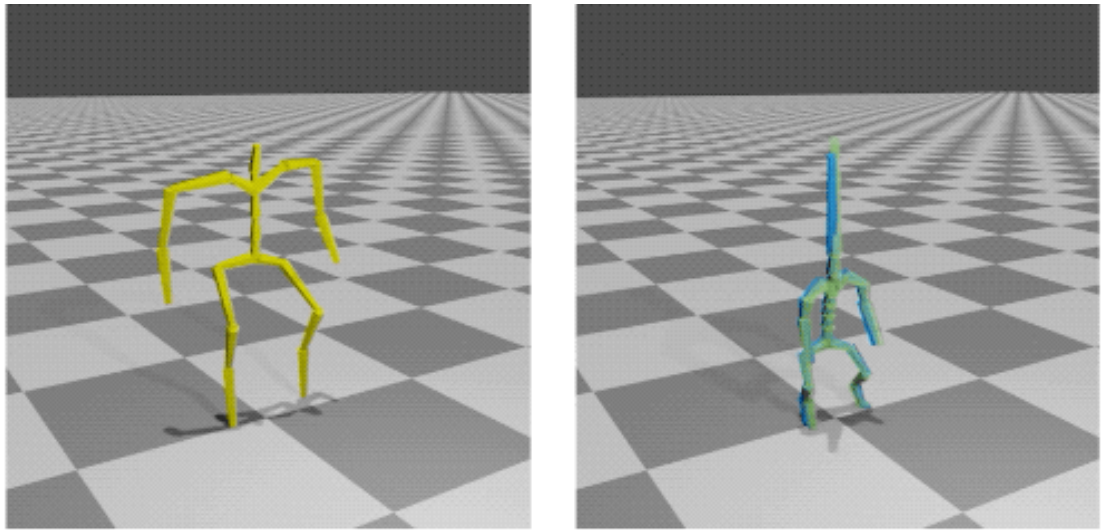
[OpenPose, 2D Pose estimation]



[3D Video-based Pose estimation, source: DeepMotion Inc.]

Motion Retargeting





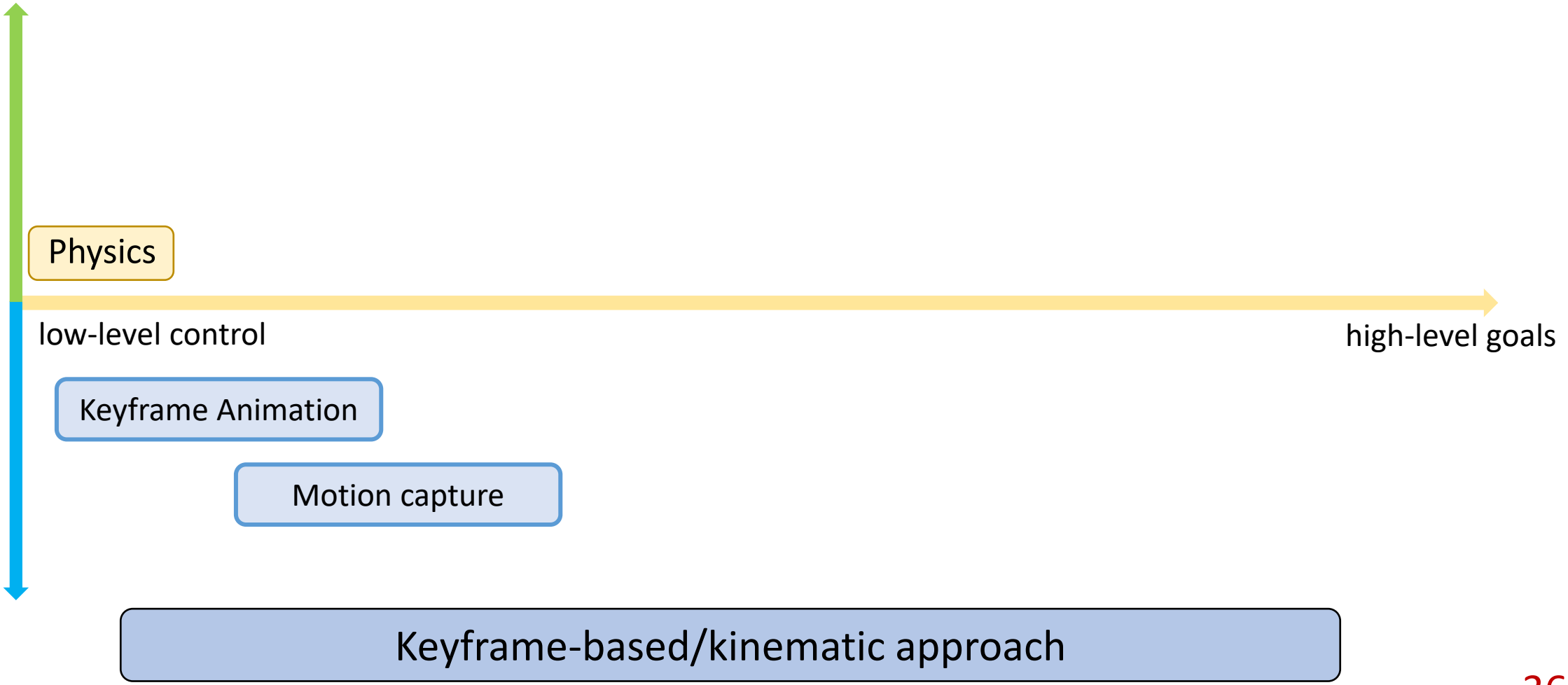
[Aberman et al. 2020 SIGGRAPH]

Given motions of a source character

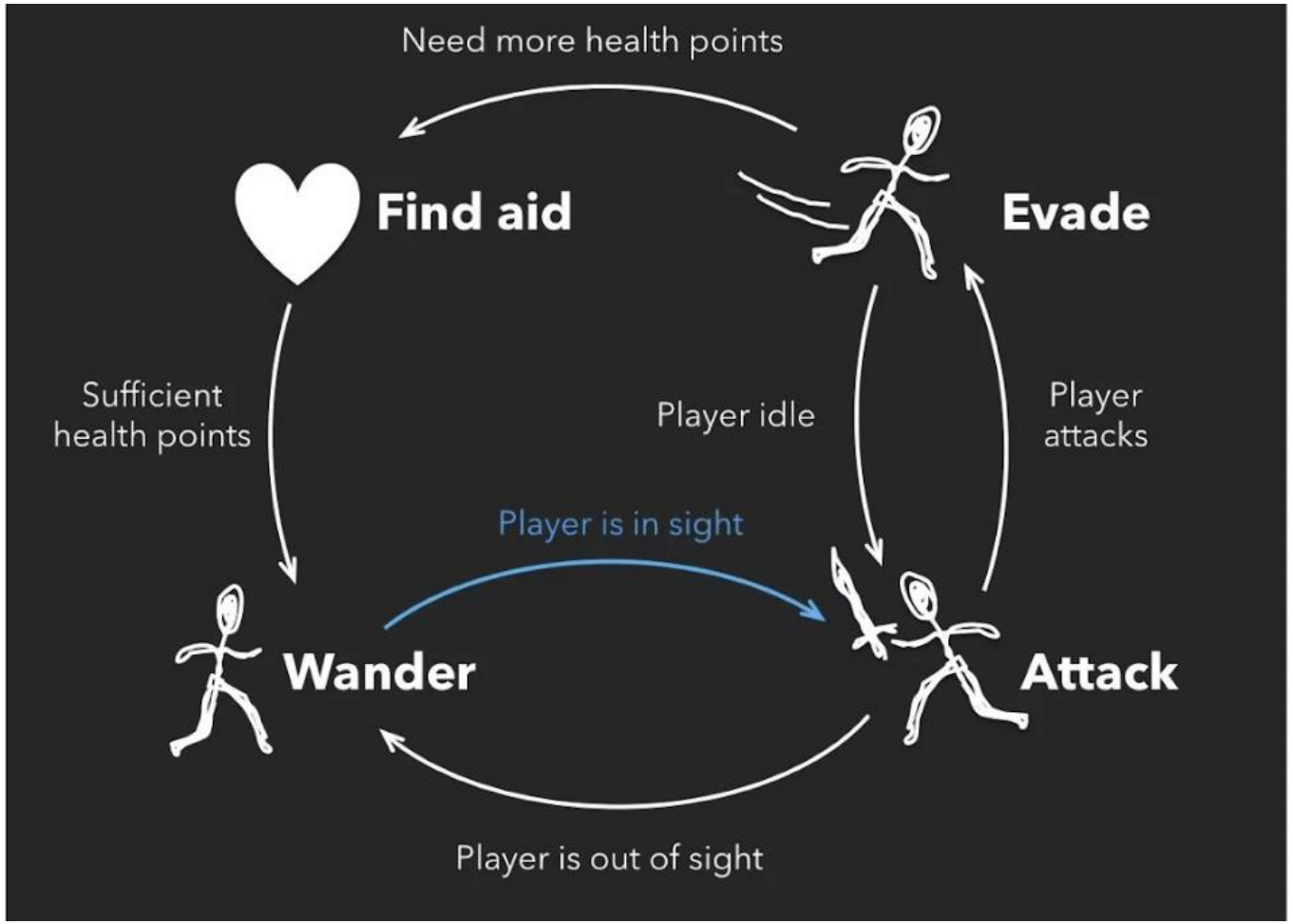
Compute motions for target characters with

- different skeleton sizes
- different number of bones
- different topologies
- …..

Character Animation Methods



Motion Graphs / State Machines



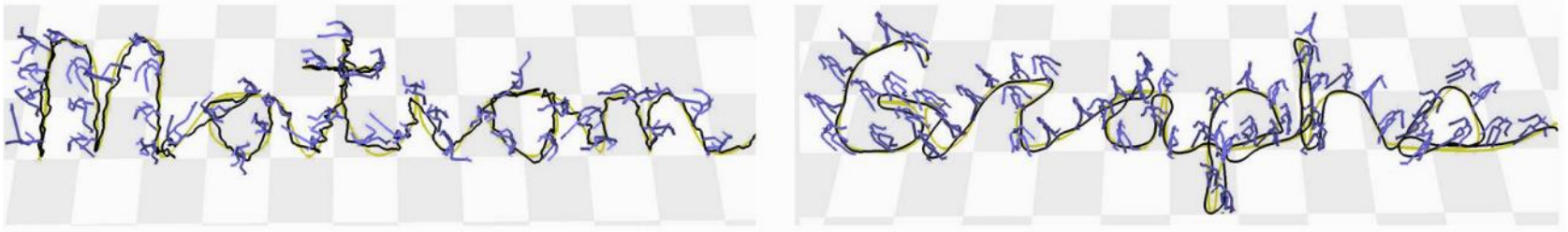
Motion Graphs / State Machines

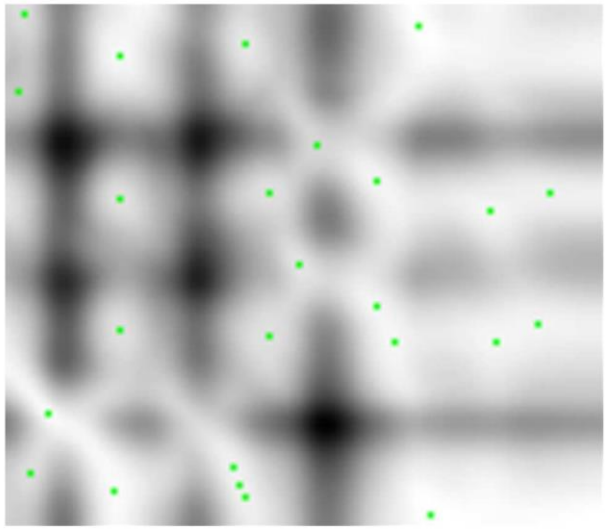
Motion Graphs

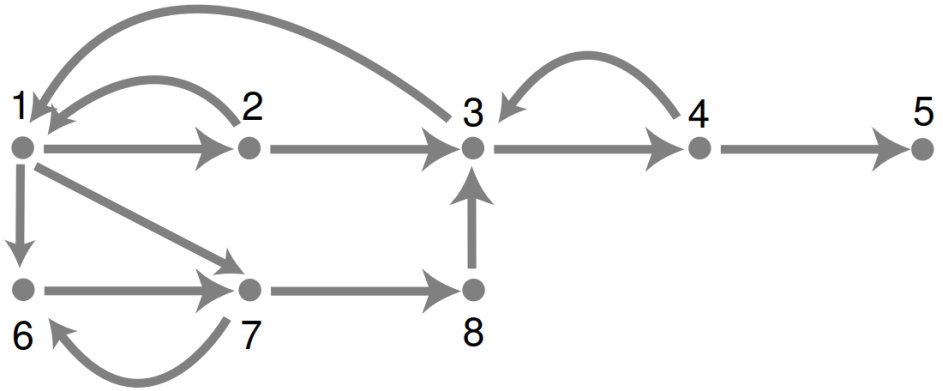
Lucas Kovar
University of Wisconsin-Madison

Michael Gleicher*
University of Wisconsin-Madison

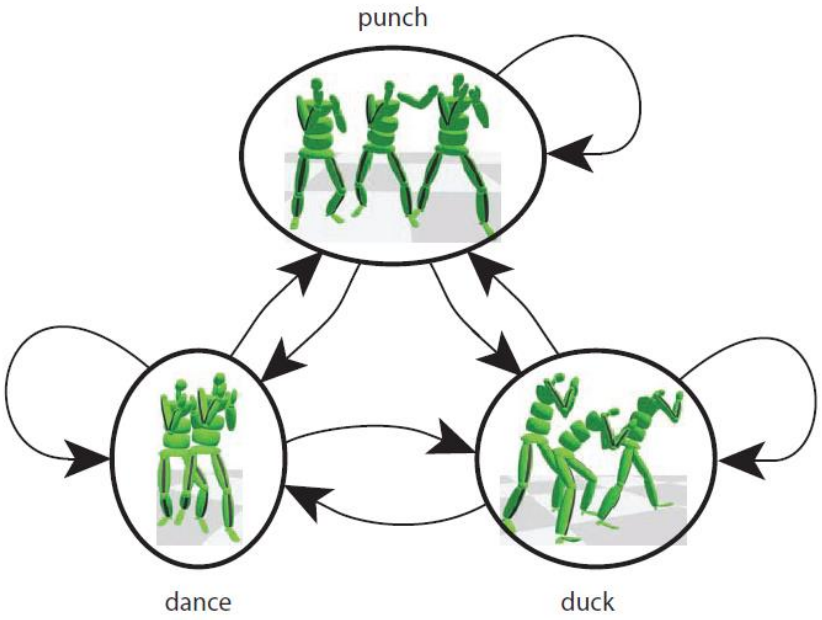
Frédéric Pighin†
University of Southern California
Institute for Creative Technologies

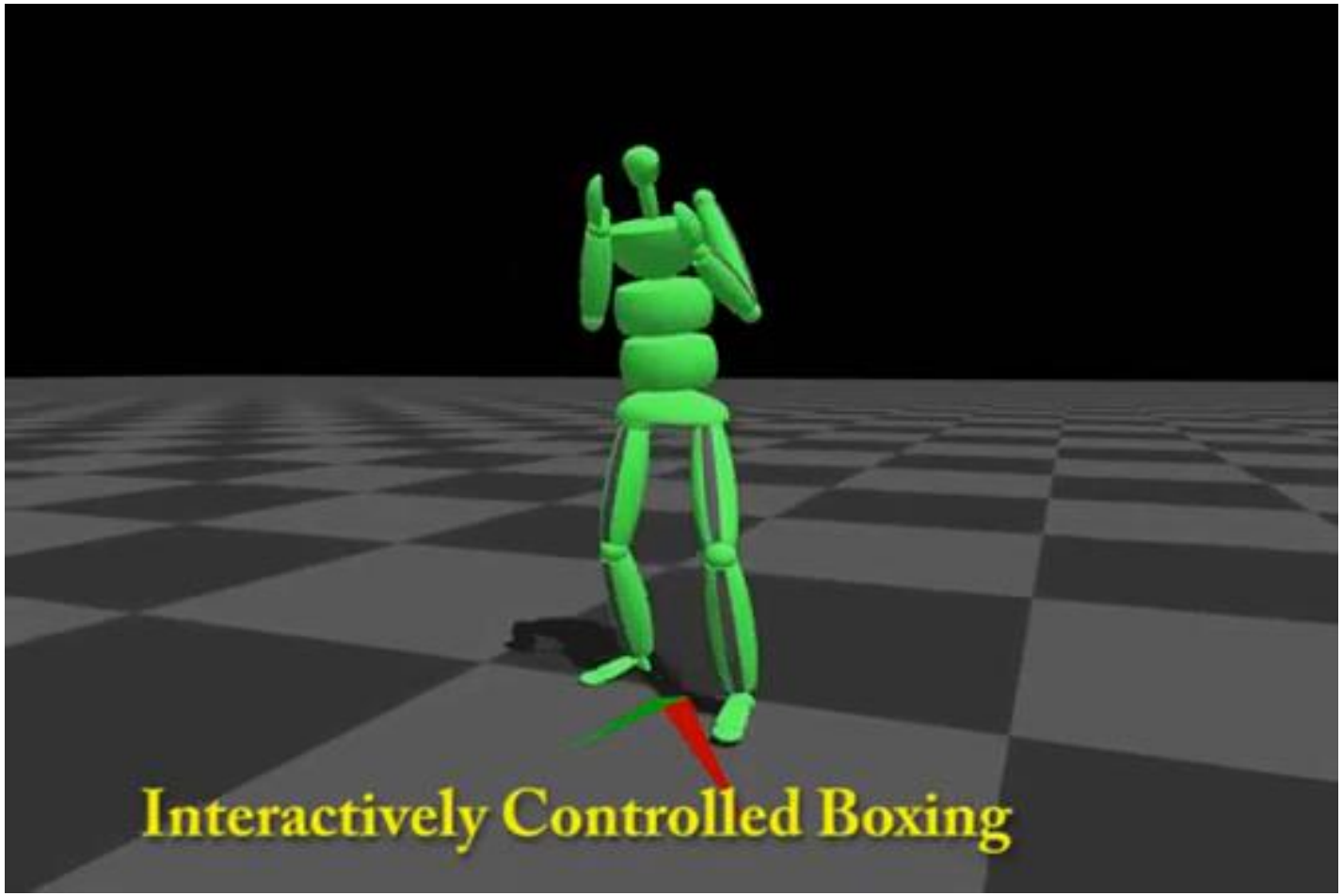






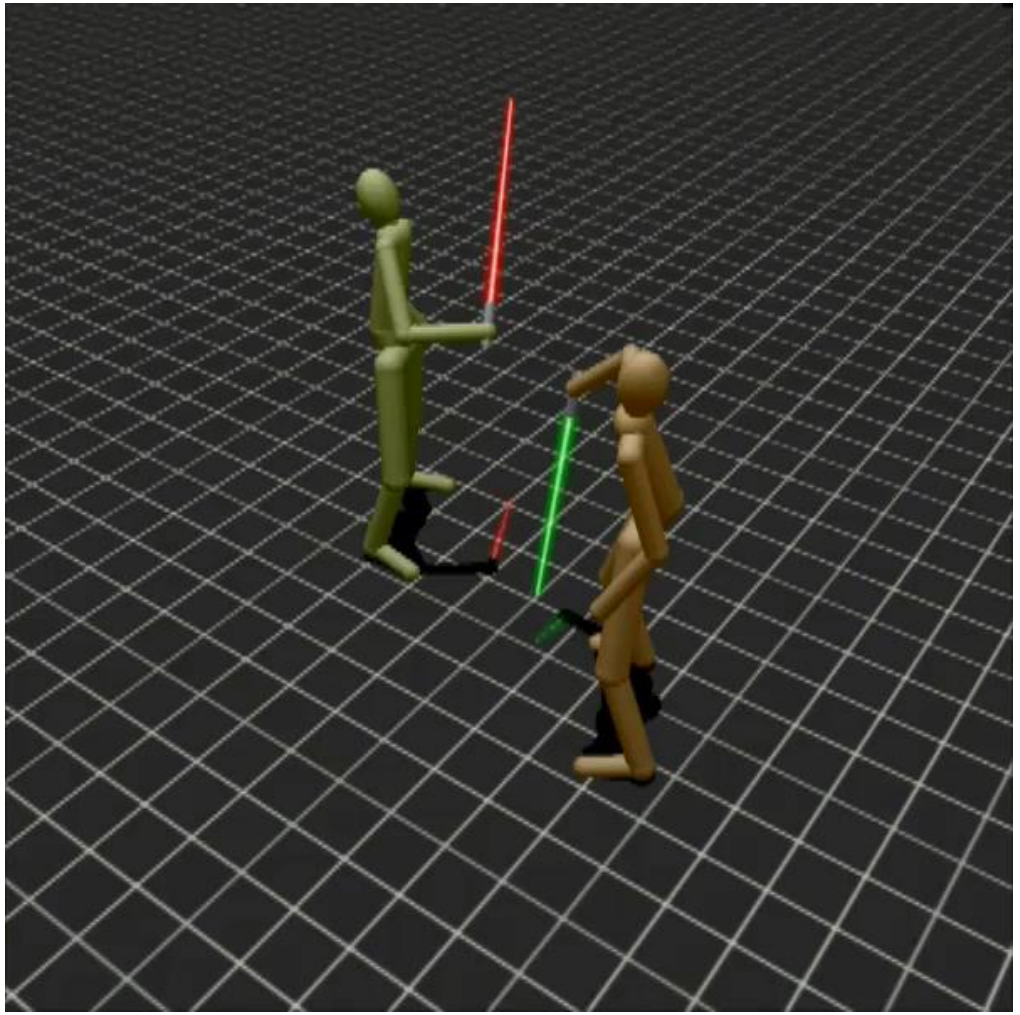
Motion Graphs / State Machines





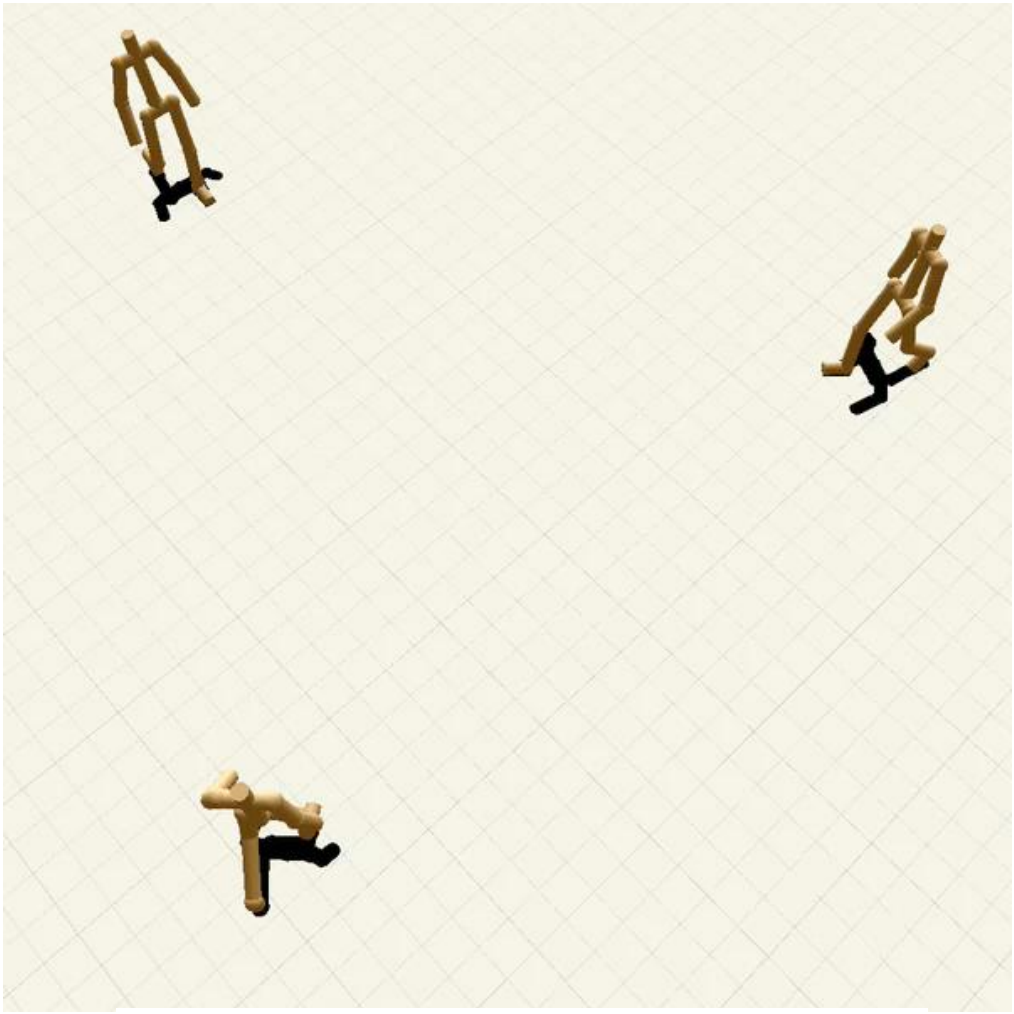
[Heck and Gleicher 2007, Parametric Motion Graphs]

Motion Graphs / State Machines



Character Animation in Two-Player Adversarial Games

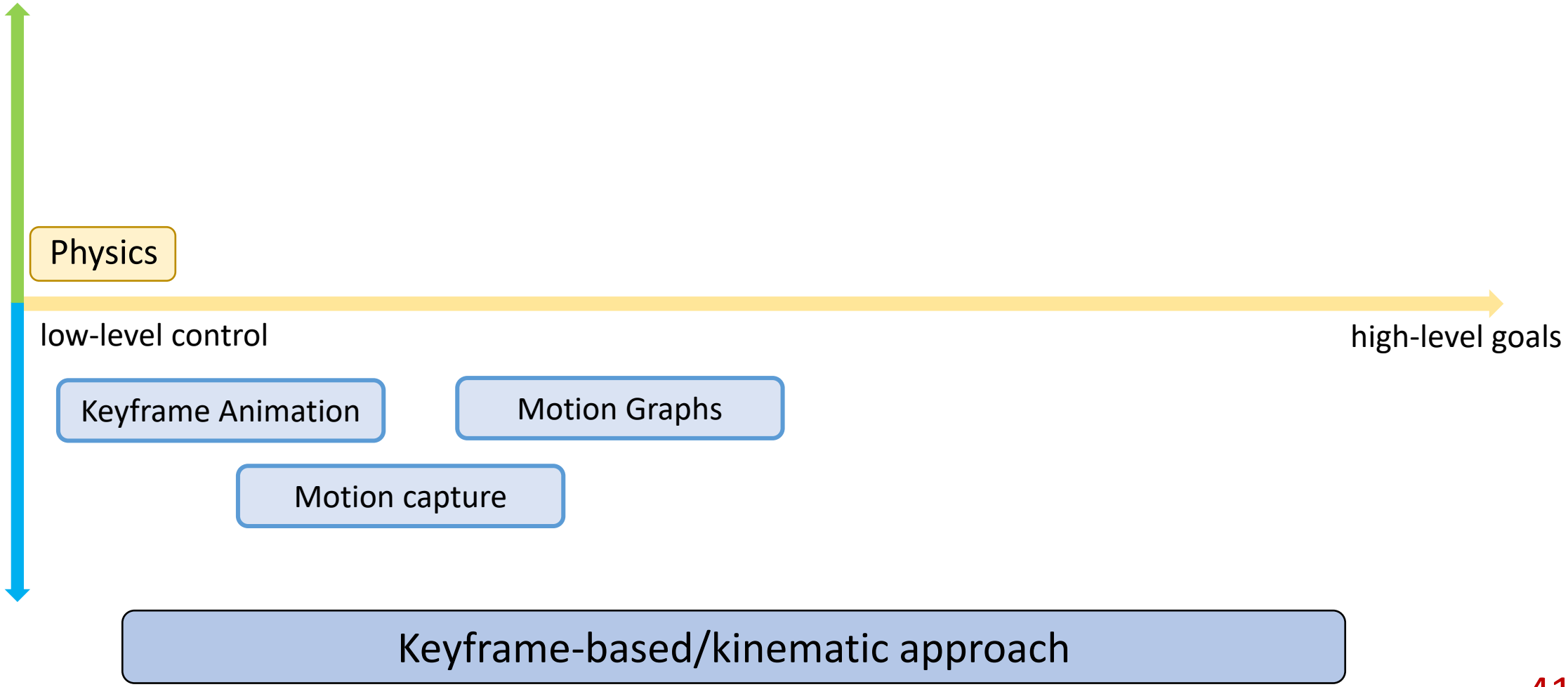
KEVIN WAMPLER, ERIK ANDERSEN, EVAN HERBST, YONGJOON LEE, and ZORAN POPOVIĆ
University of Washington



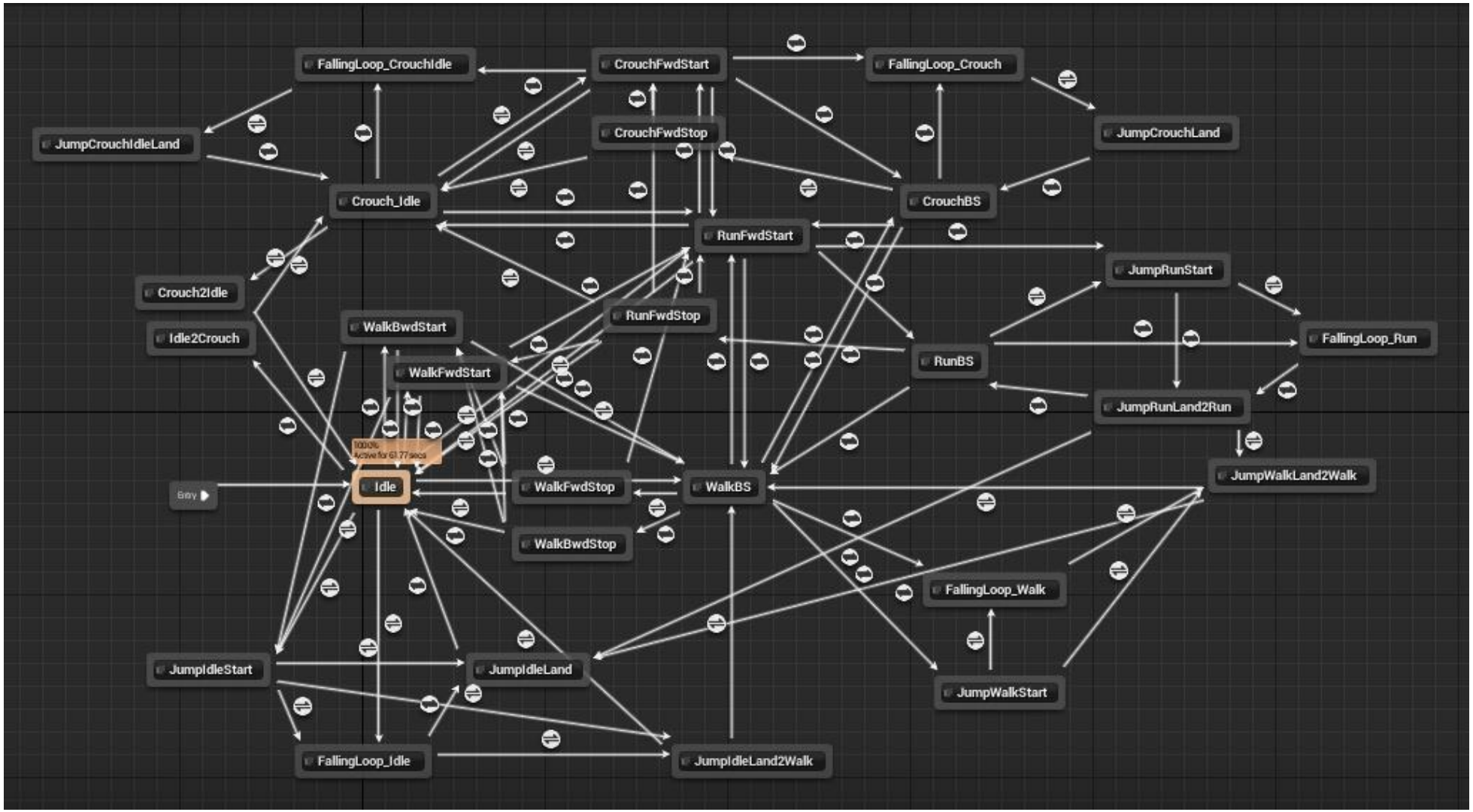
Near-optimal Character Animation with Continuous Control

Adrien Treuille Yongjoon Lee Zoran Popović
University of Washington

Character Animation Methods

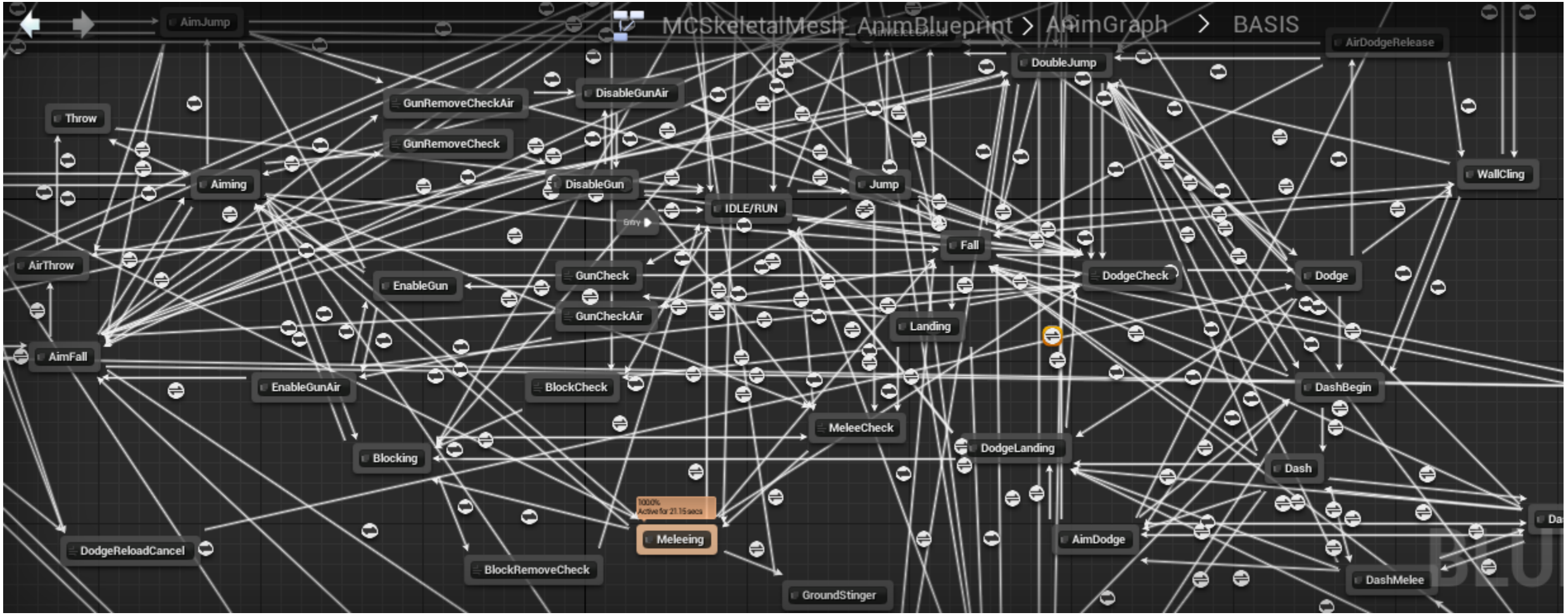


Complex Motion Graphs



https://forums.unrealengine.com/t/cleaning-up-state-machine-spaghetti/

Complex Motion Graphs

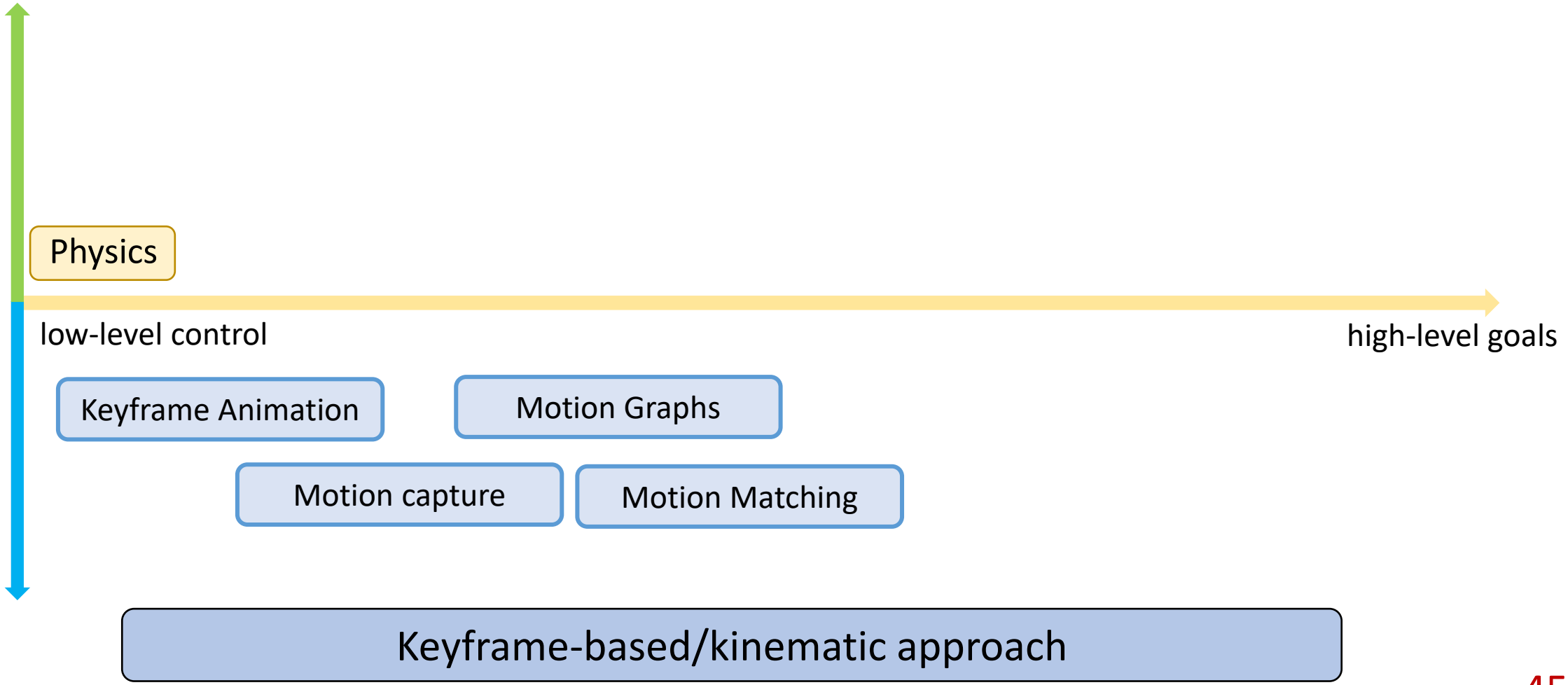


https://forums.unrealengine.com/t/cleaning-up-state-machine-spaghetti/

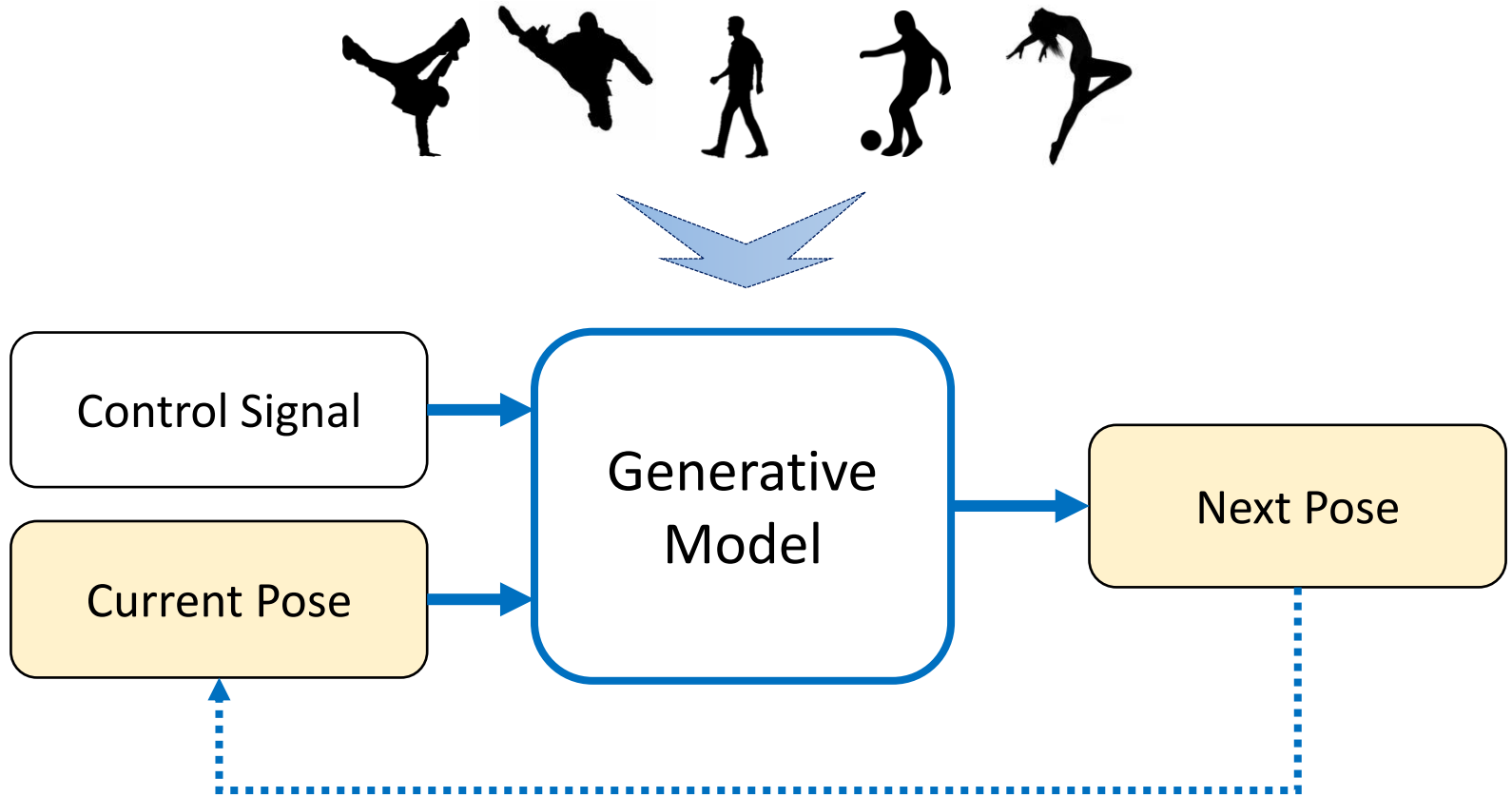
Motion Matching

https://www.gdcvault.com/play/1023280/Motion-Matching-and-The-Road

Character Animation Methods



Learning-based Approaches



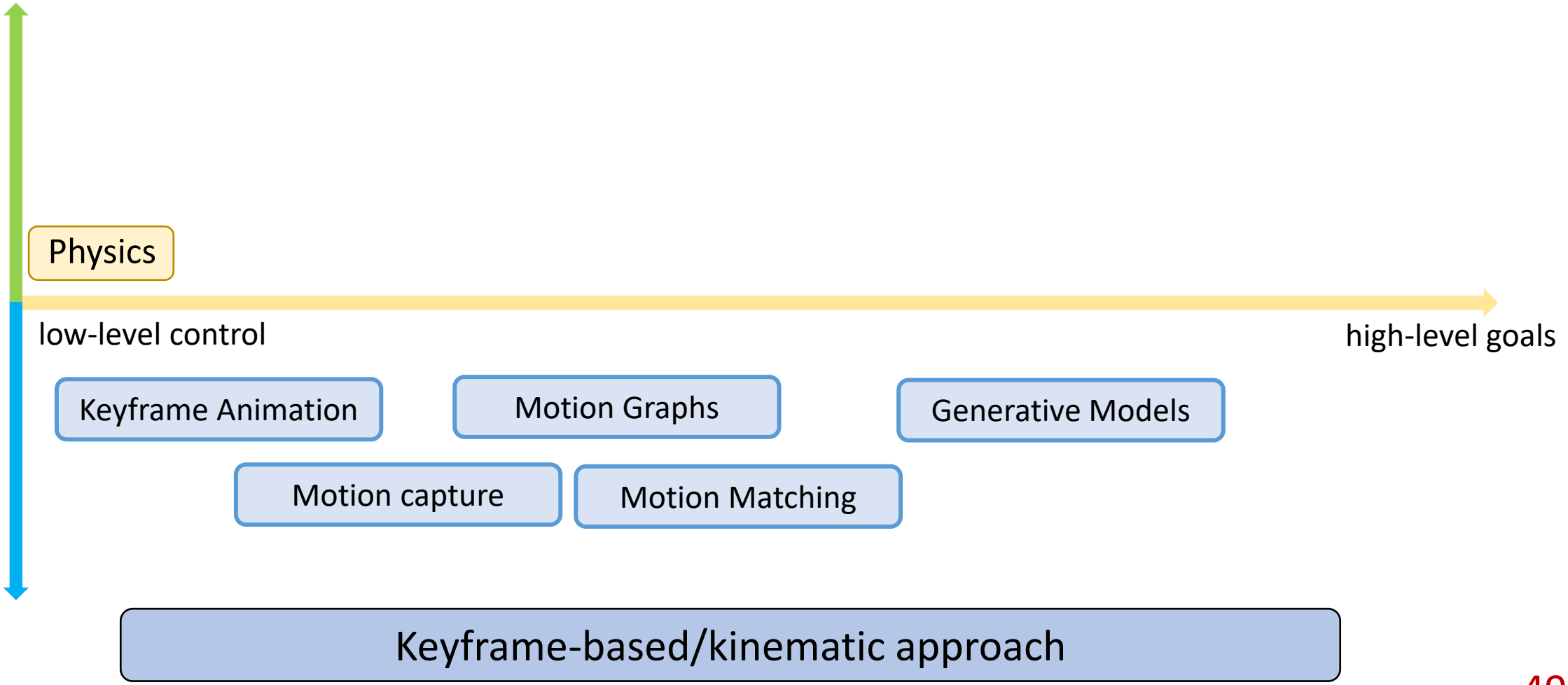
Learning-based Approaches

[Starke et al 2020, Local Motion Phases for Learning Multi-Contact Character Movements]

Motion Generative Models

[Ling et al. 2021 Character Controllers Using Motion VAEs]

Character Animation Methods



Cross-Modal Motion Synthesis

- Audio-driven animation
  - Music to dance
  - Co-speech gesture
  - …….

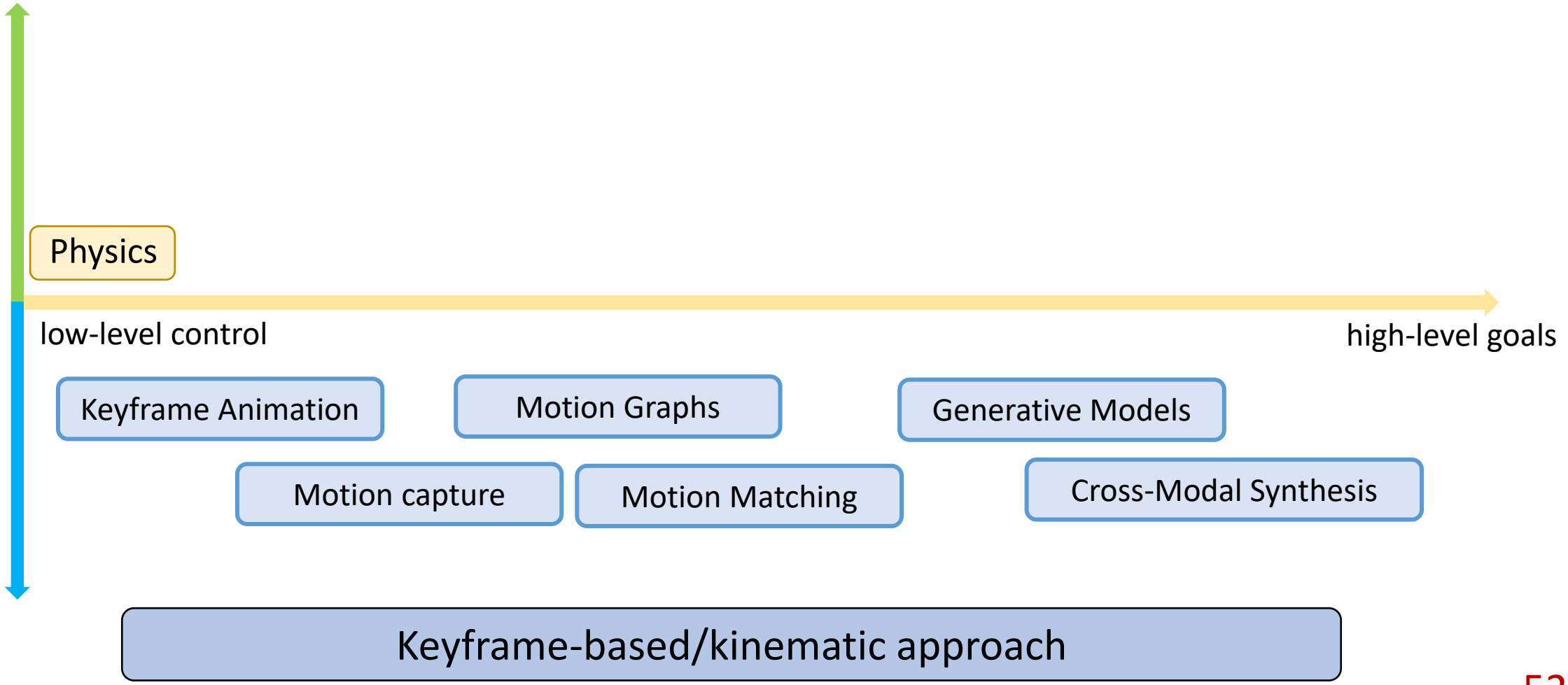
[Ao et al. 2022. Rhythmic Gesticulator. SIGGRAPH Asia 2022]

Cross-Modal Motion Synthesis

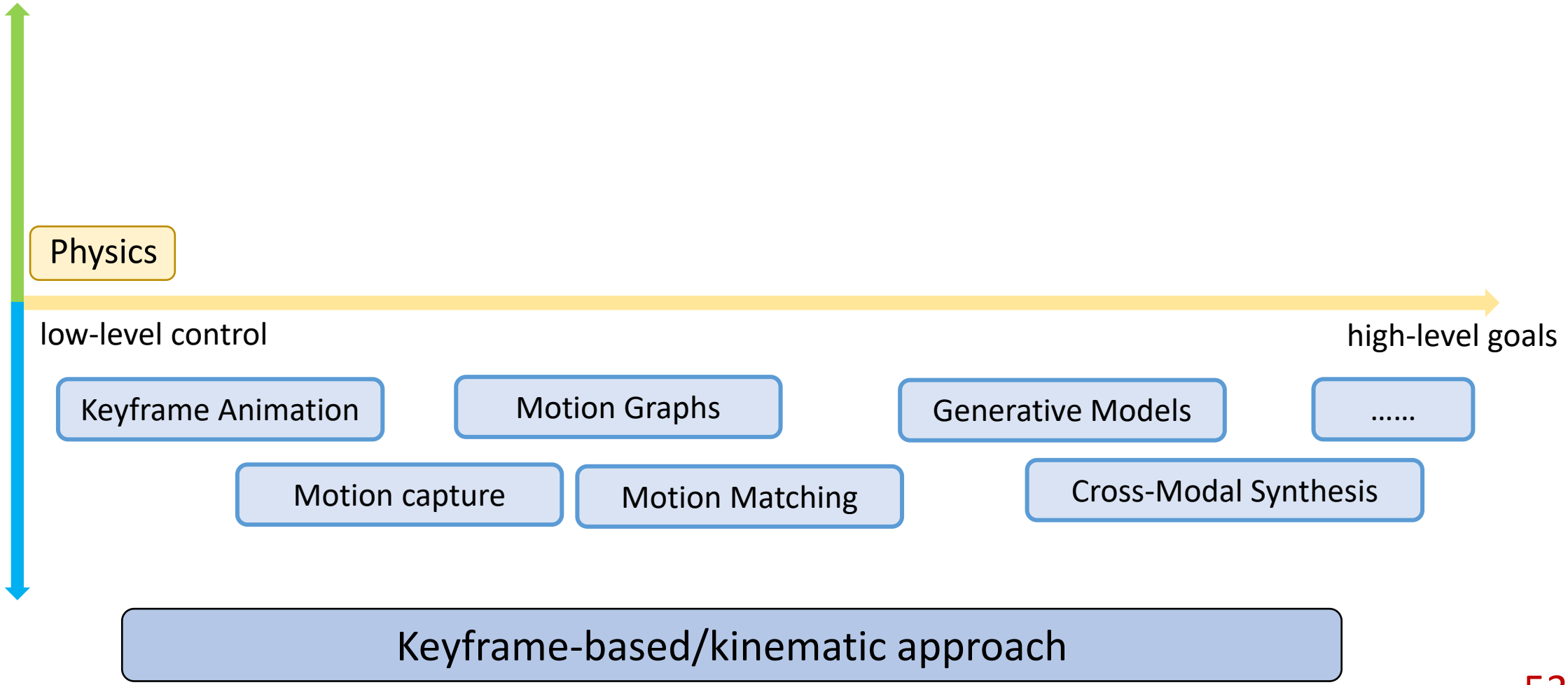
- Natural language to animation
  - Descriptions to actions
  - Scripts to performance
  - ……

[Tevet et al. 2022. MotionCLIP]

Character Animation Methods

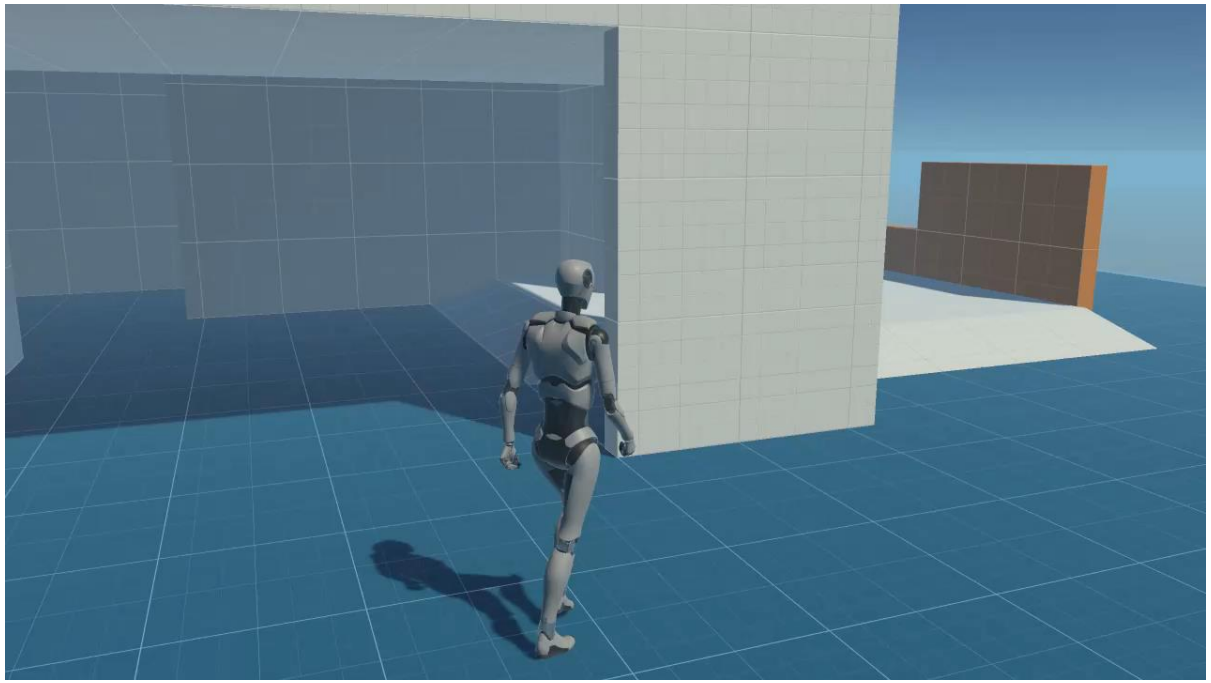


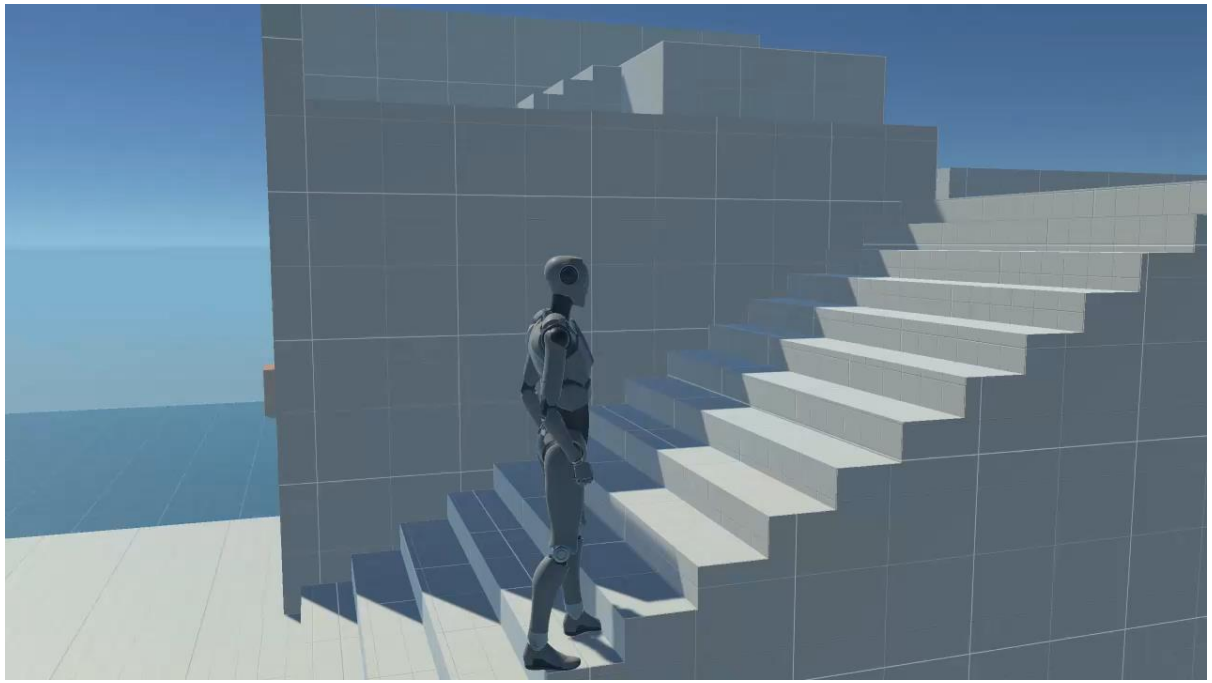
Character Animation Methods



Problems of Kinematic Methods

- Physical plausibleness

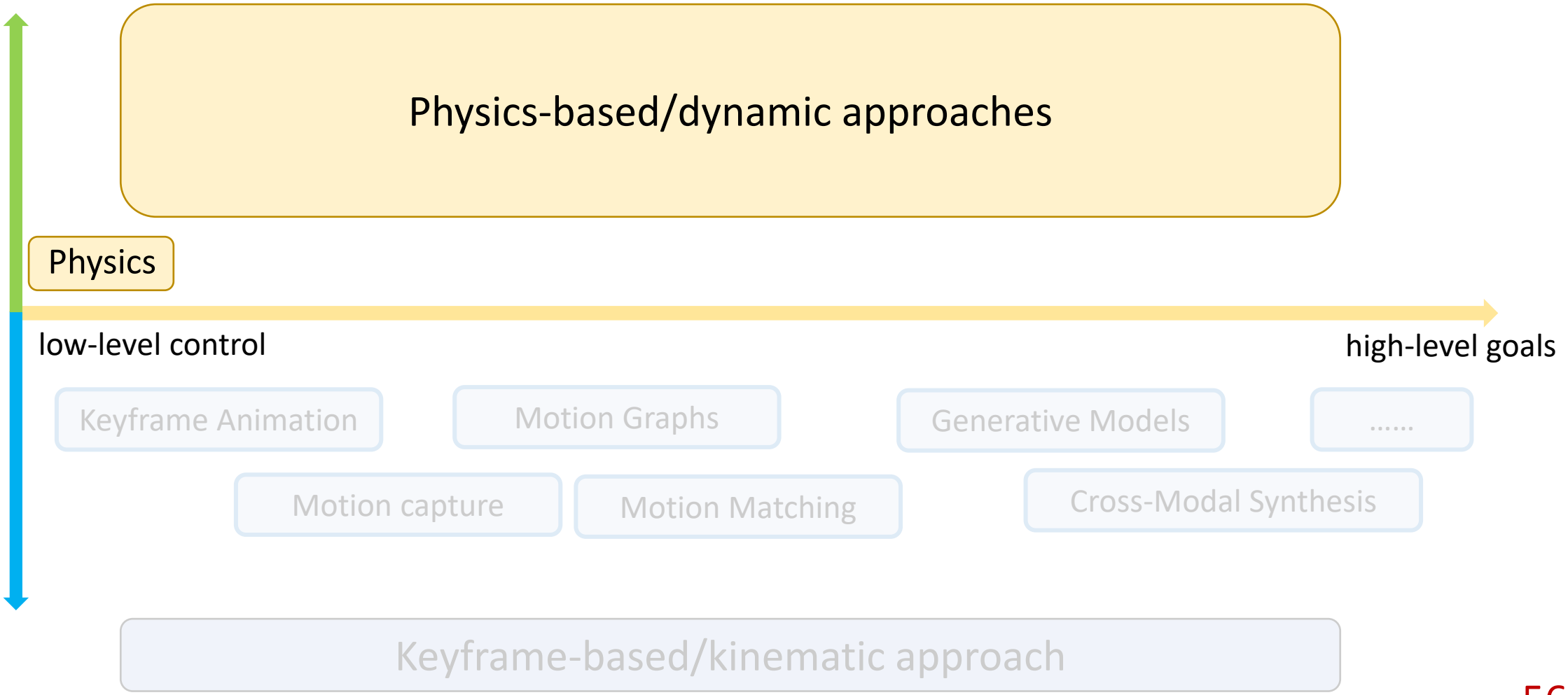




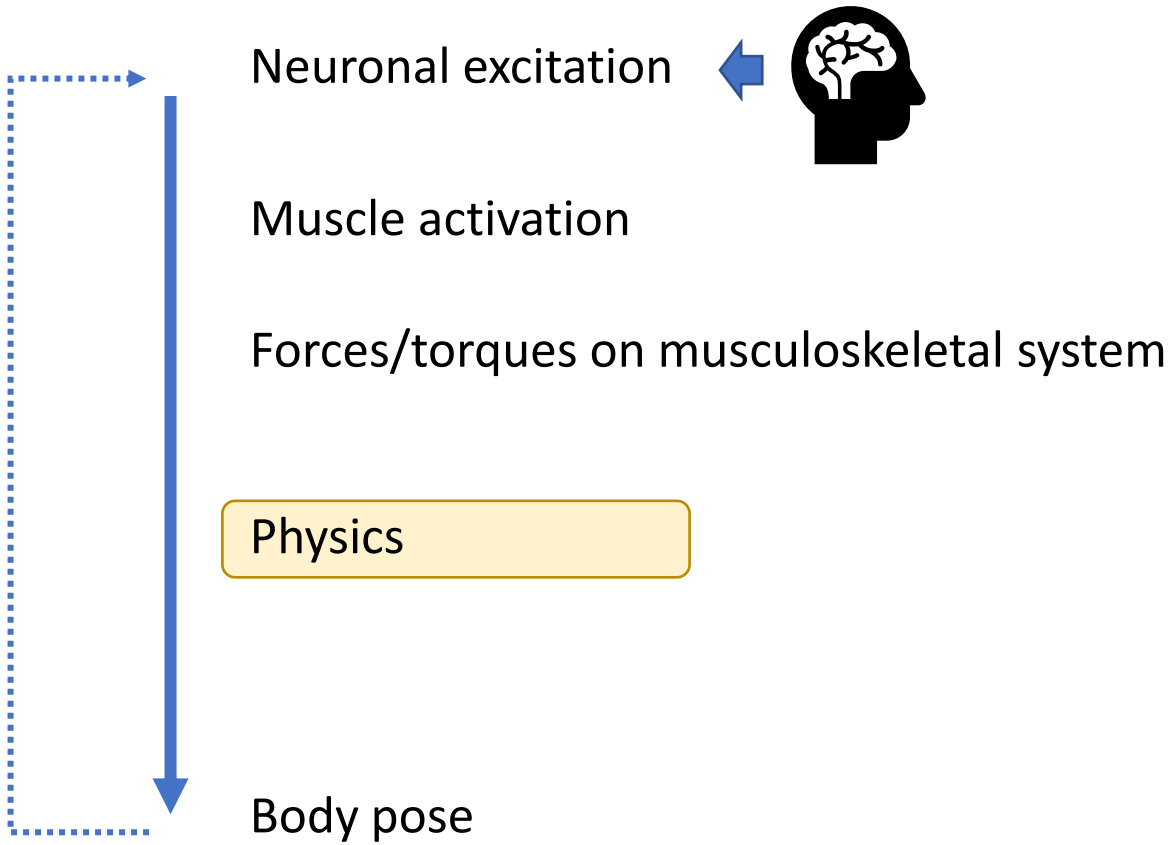
Problems of Kinematic Methods

- Interaction with the environment

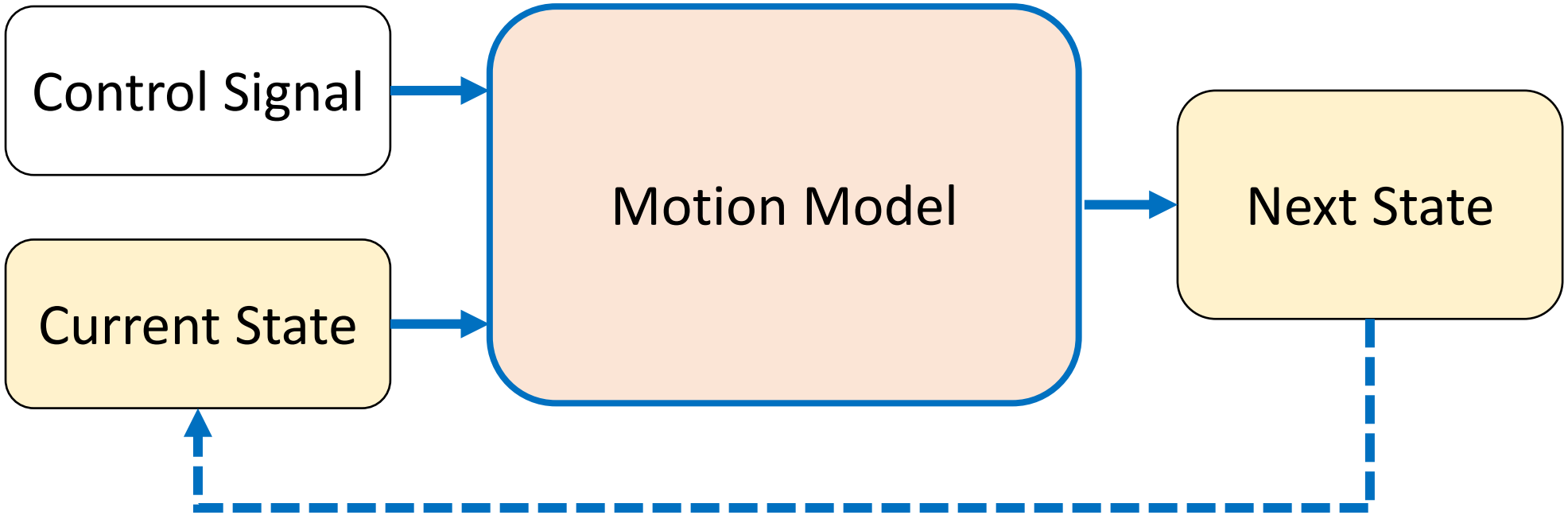
Character Animation Methods



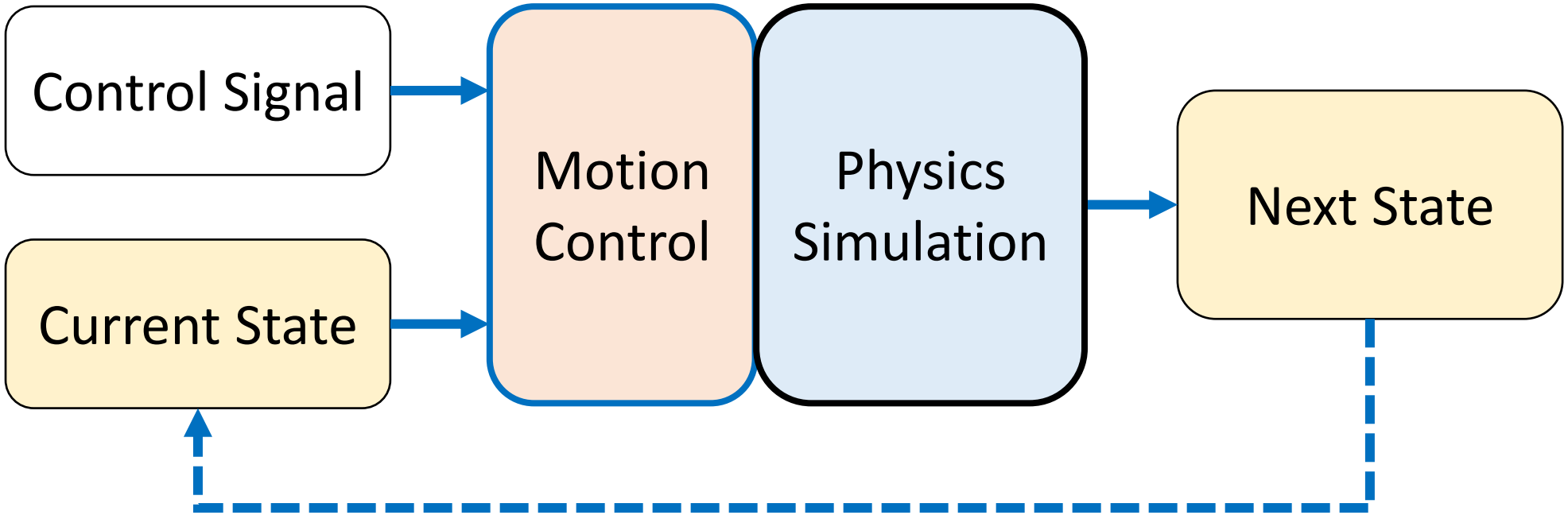
Physics-based/Dynamic Approaches



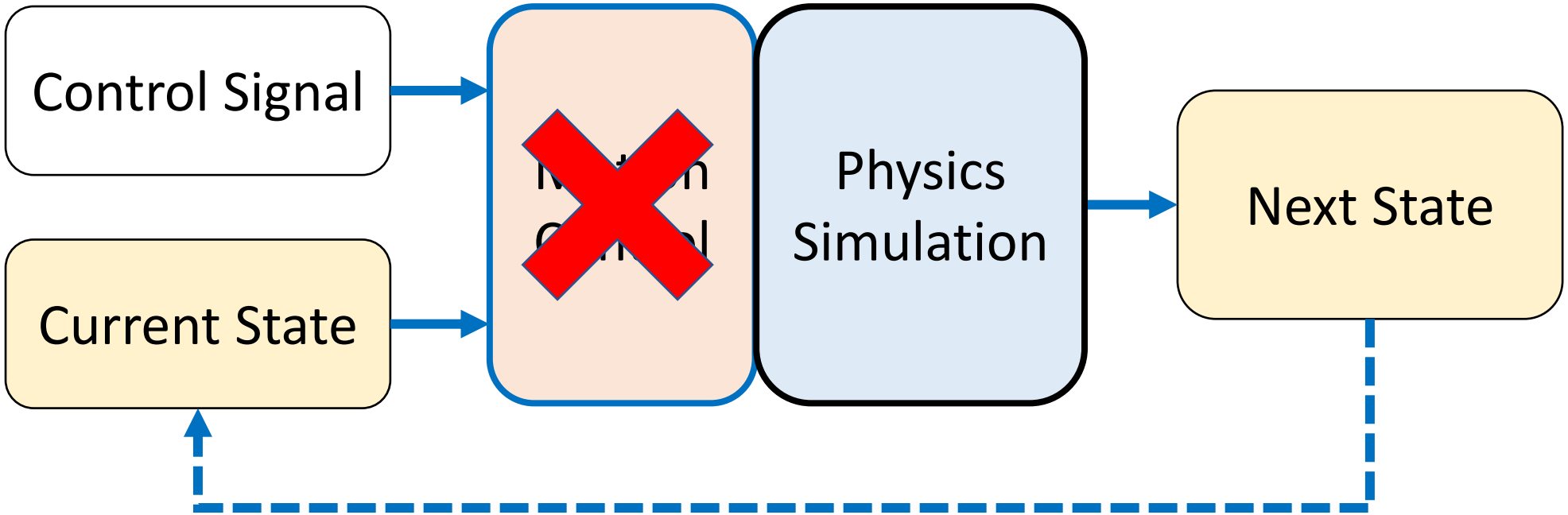
Kinematic Approaches



Physics-based Character Animation



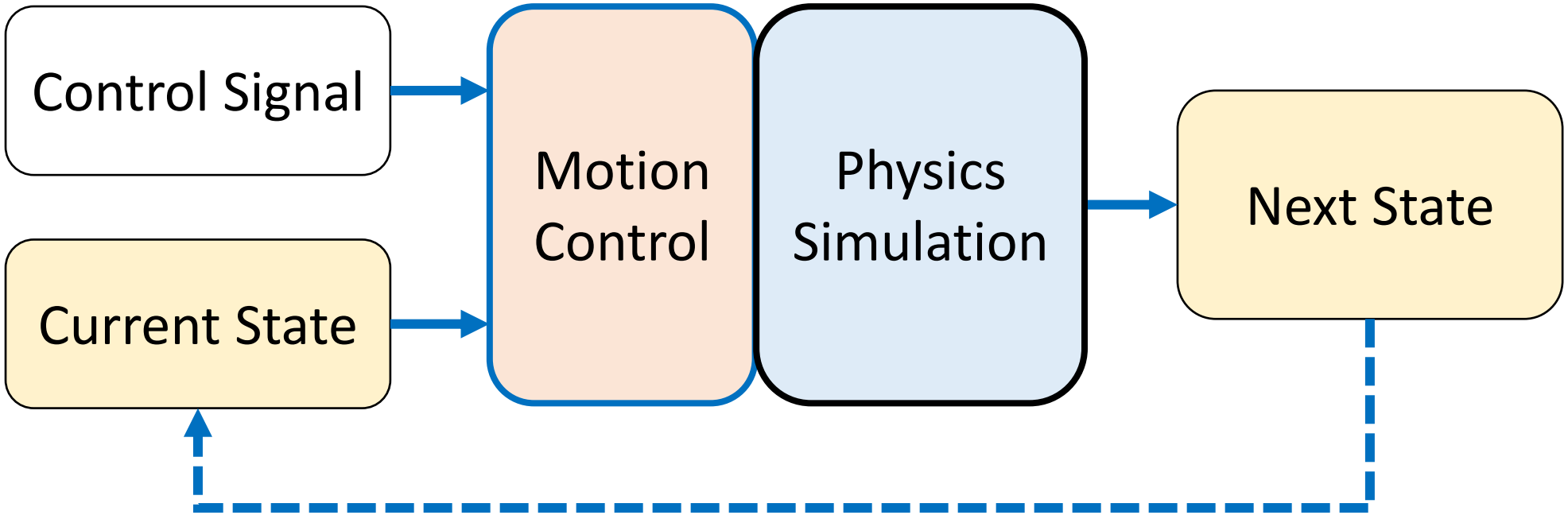
Ragdoll Simulation



Ragdoll Simulation

Ivan Elizarov - **RagDoll Realistic - Unreal engine 4**
https://www.youtube.com/watch?v=4pWBtoGzwwE

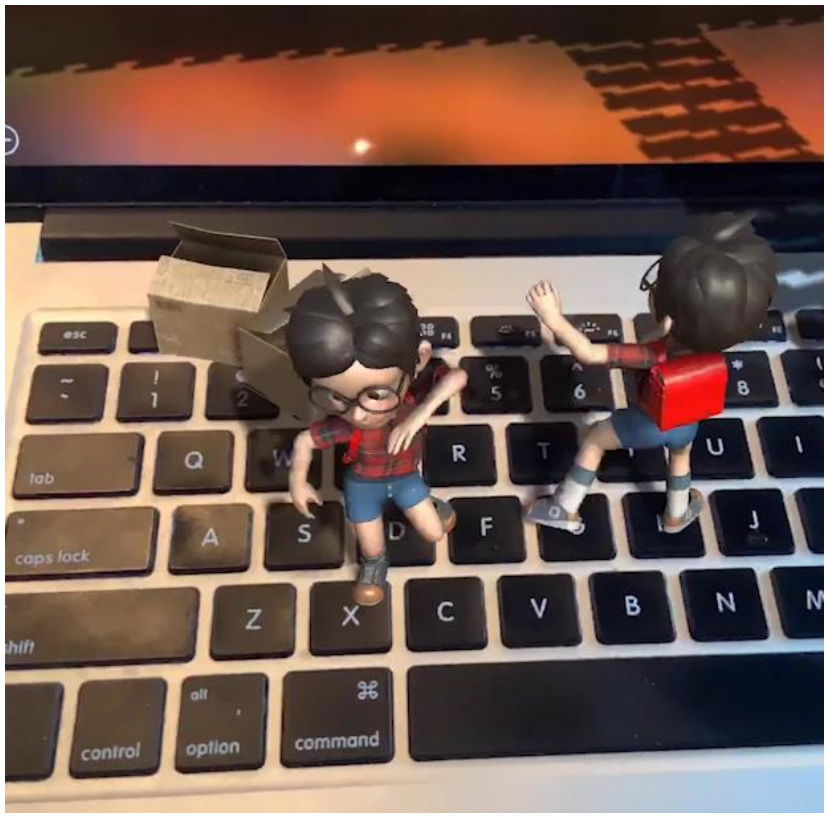
Physics-based Character Animation



Physics-based Character Animation

Clumsy Ninja

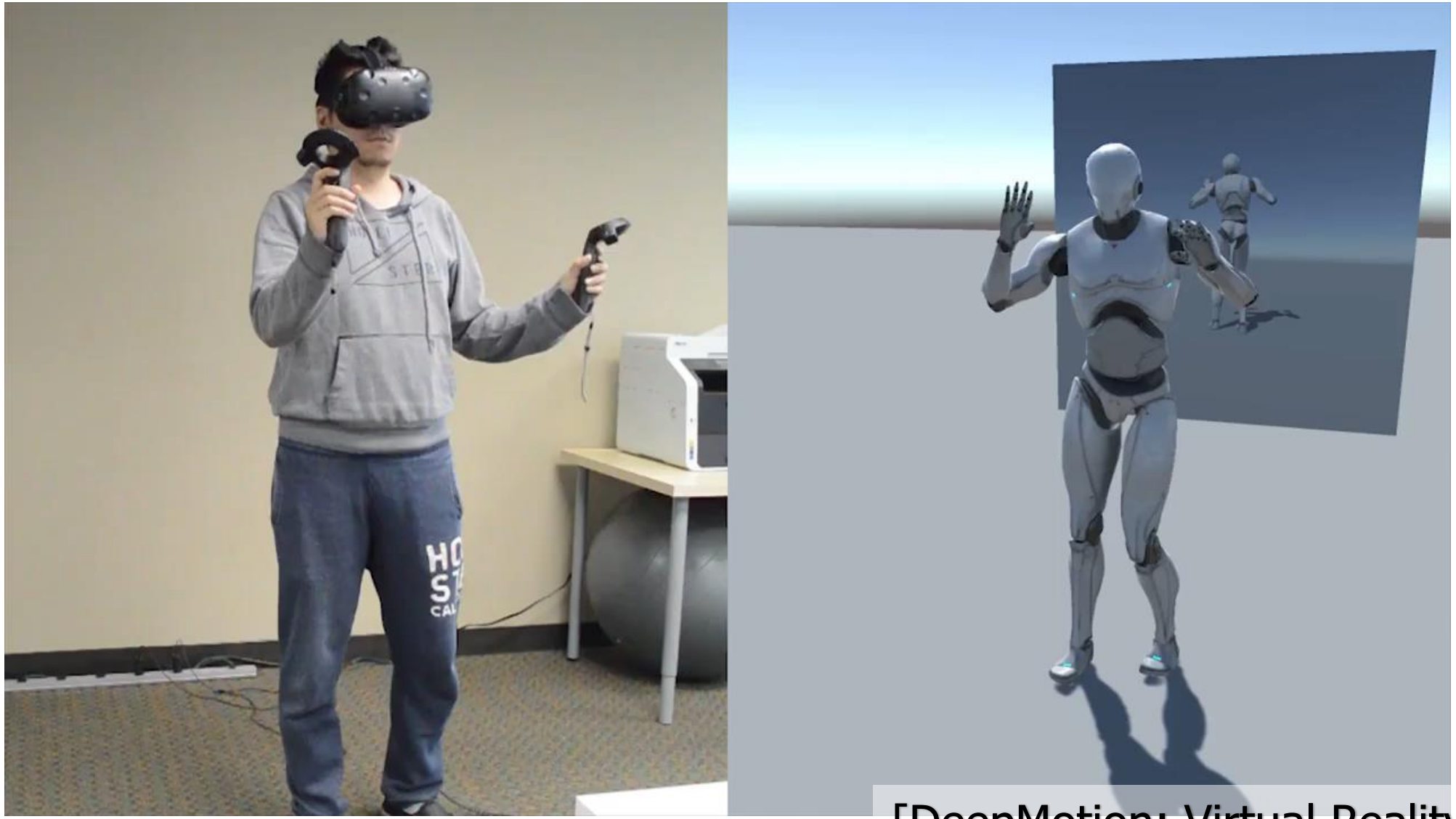
Party Animals



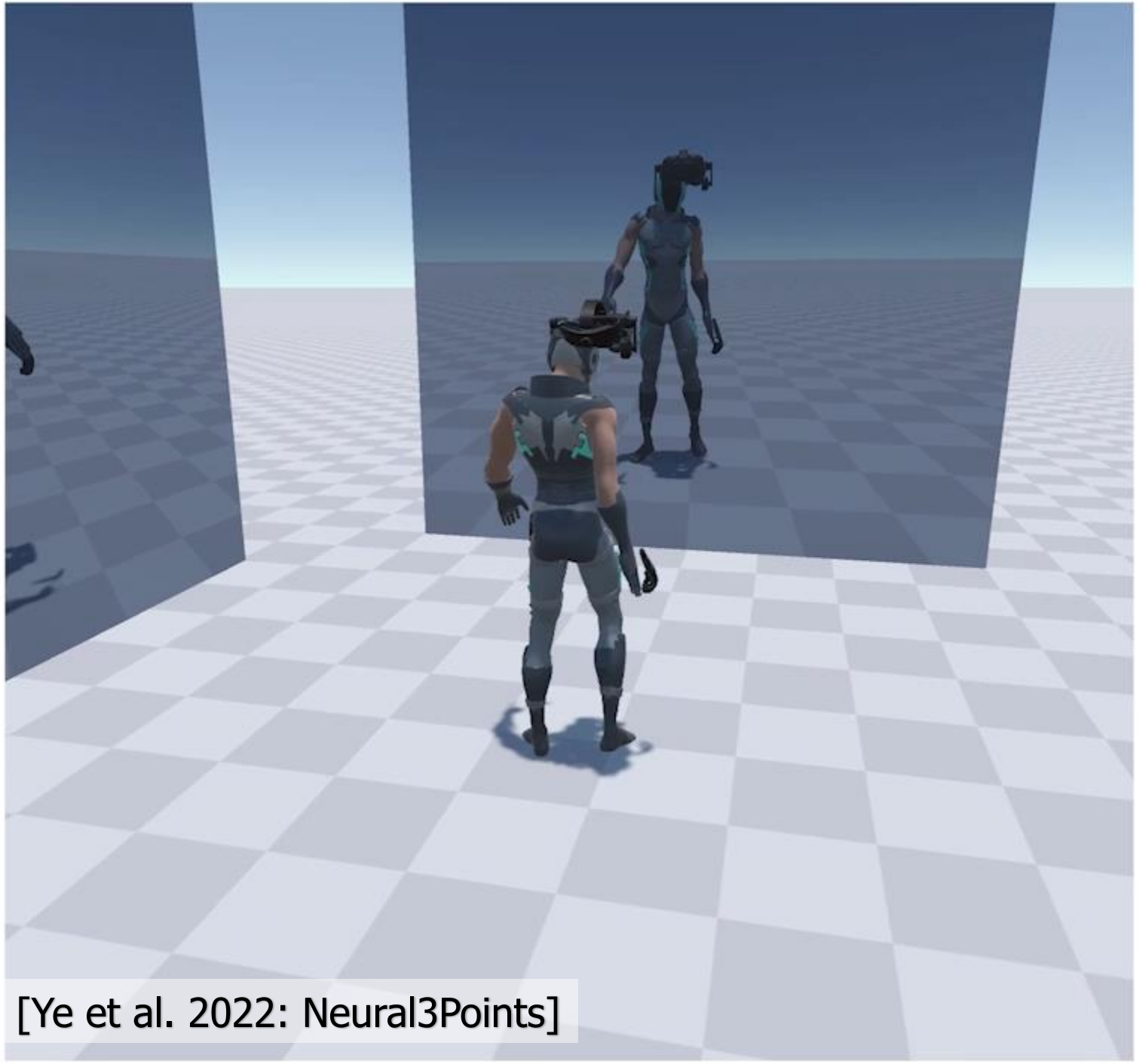
DeepMotion Brain

Motion Reconstruction with Sparse Sensors

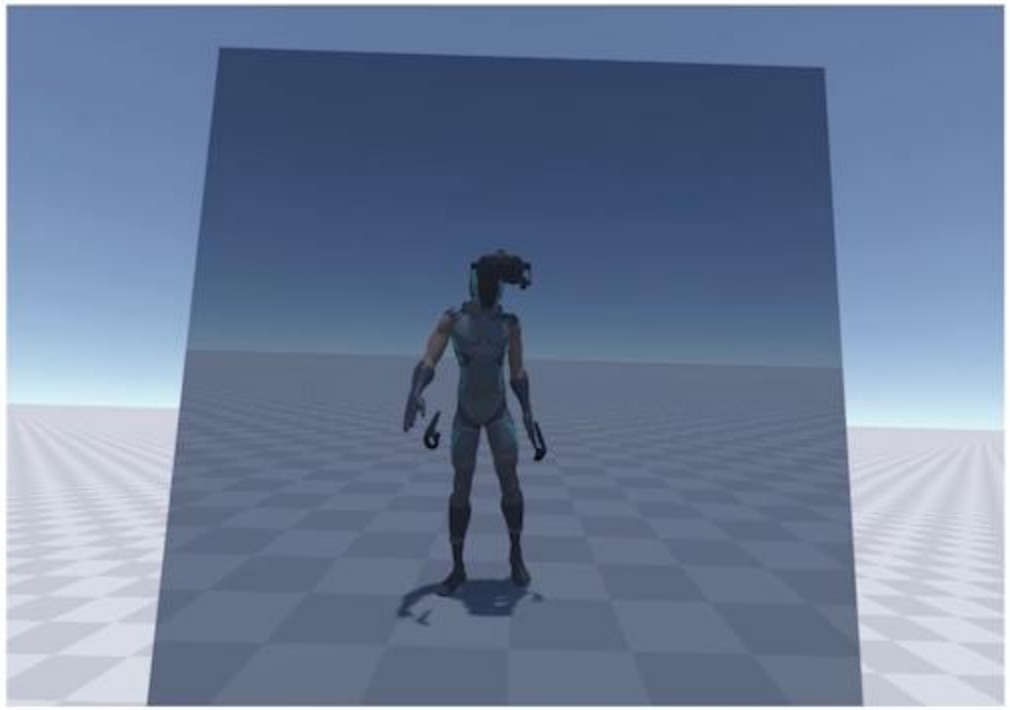
Motion Reconstruction with Sparse Sensors

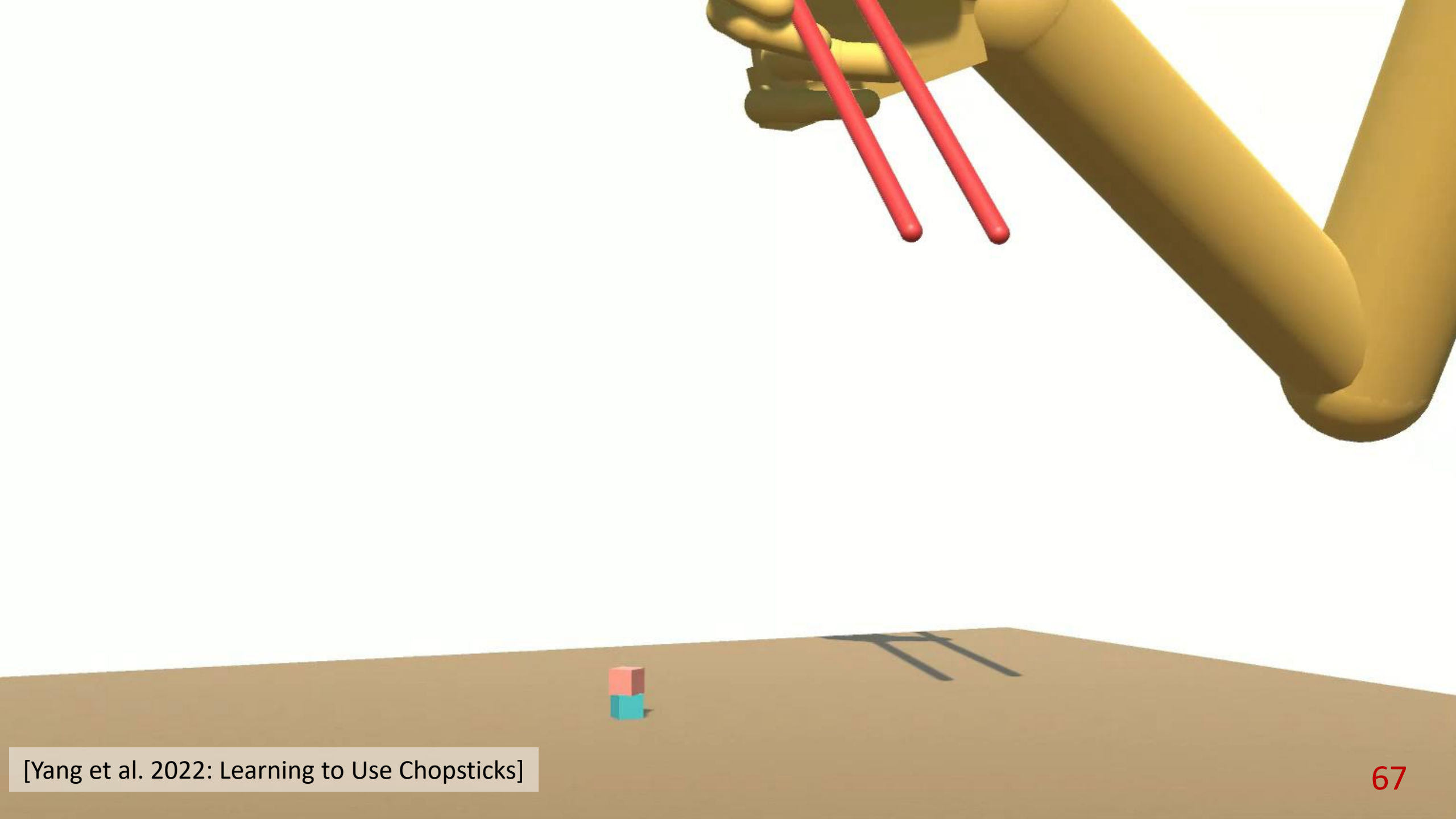


[DeepMotion: Virtual Reality Tracking]



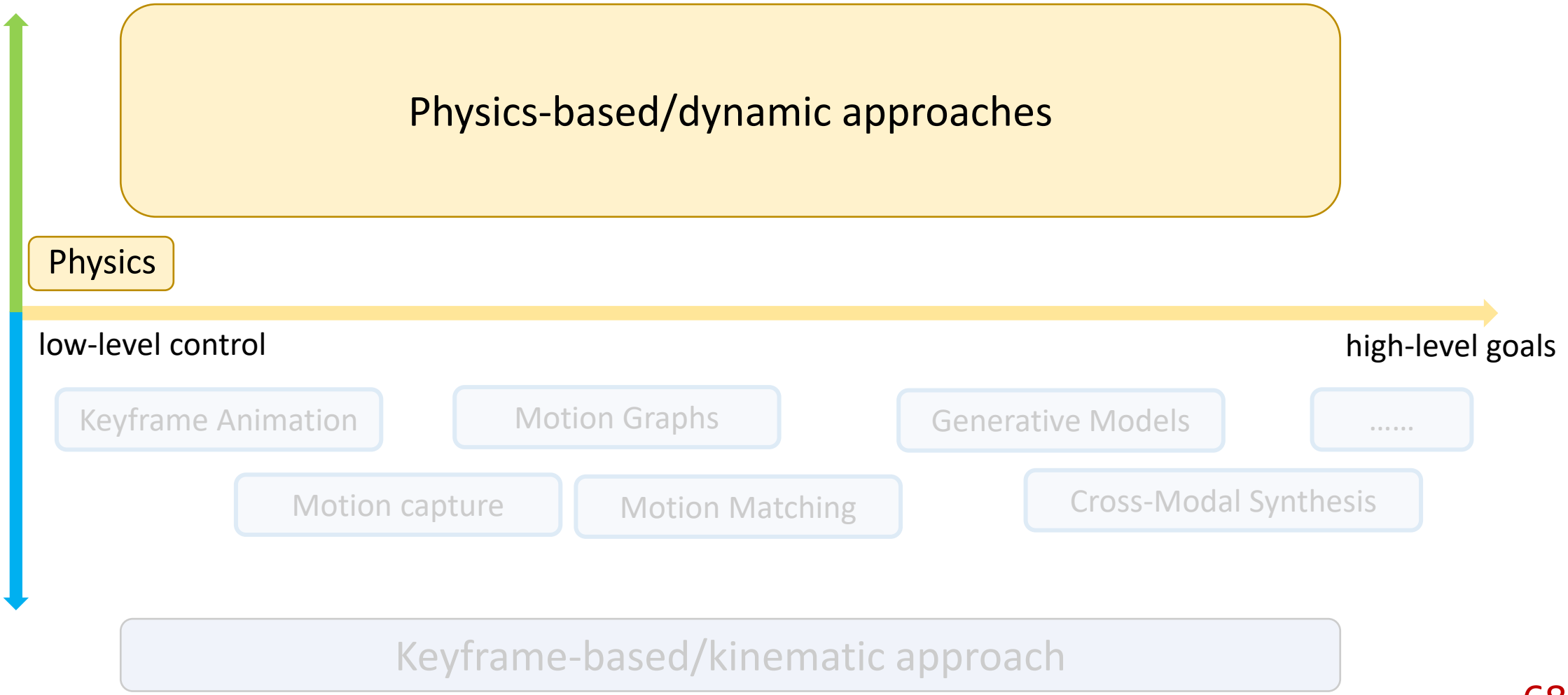
[Ye et al. 2022: Neural3Points]



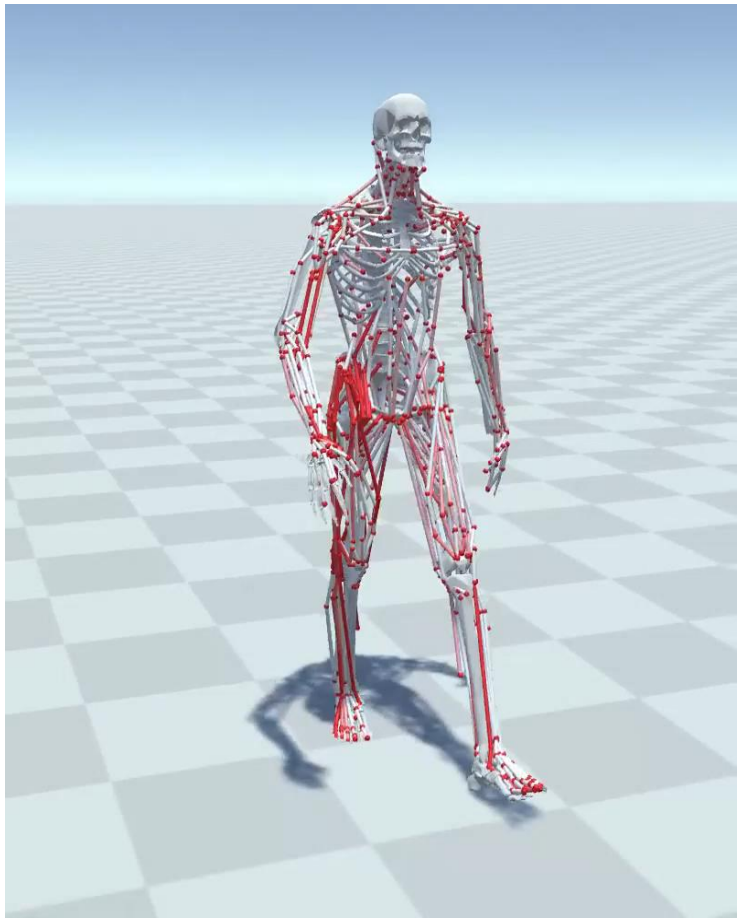


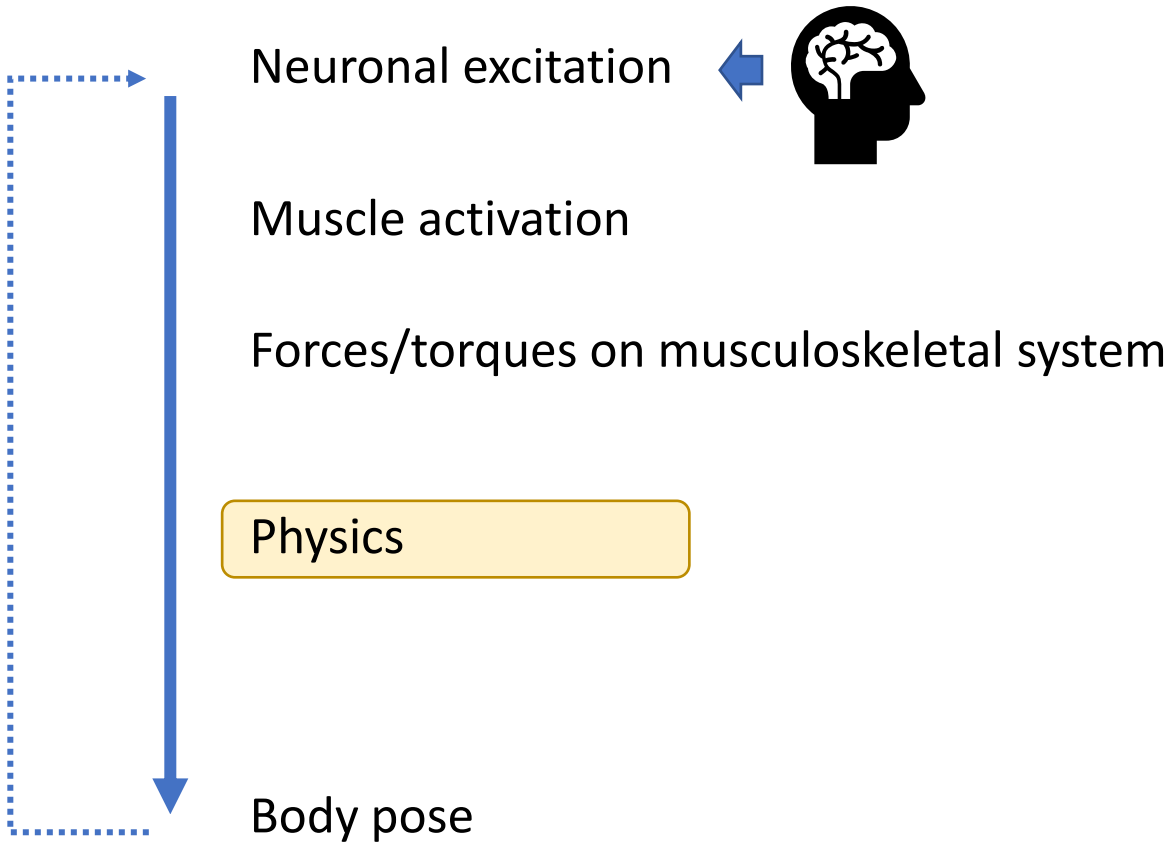
[Yang et al. 2022: Learning to Use Chopsticks]

Character Animation Methods



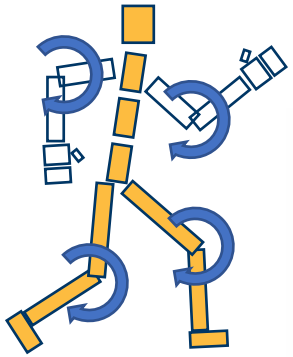
Physics-based/Dynamic Approaches

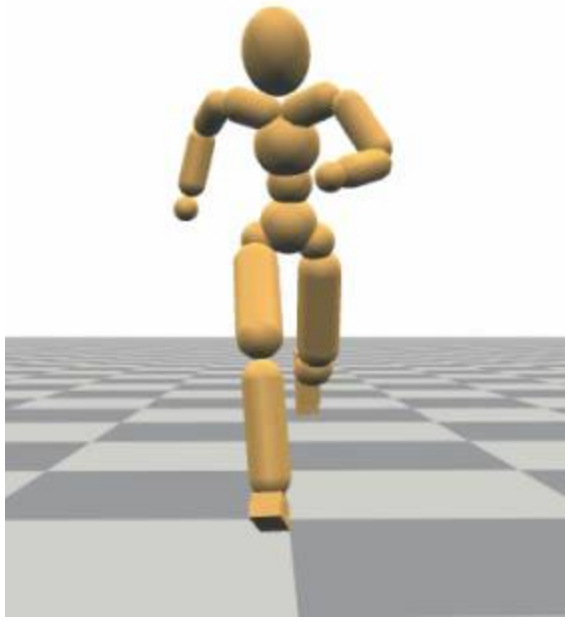




Physics-based/Dynamic Approaches

Simplified control & physics

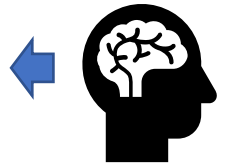




Neuronal excitation

Muscle activation

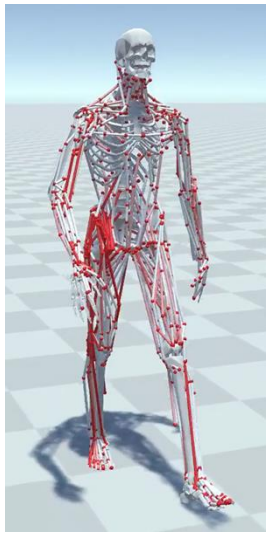
Forces/torques on skeleton

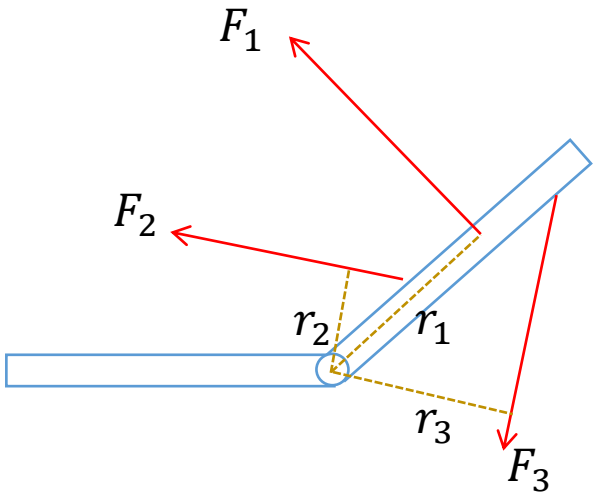


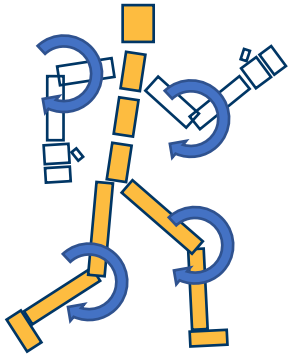
Physics

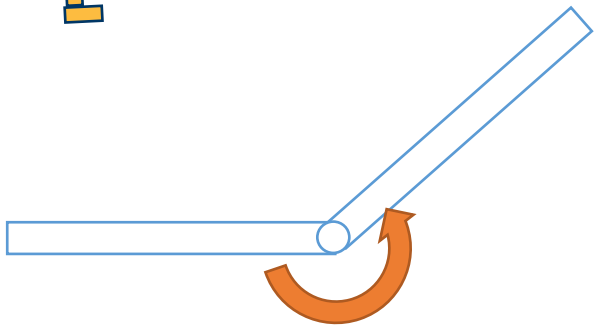
Body pose

Force & Torque



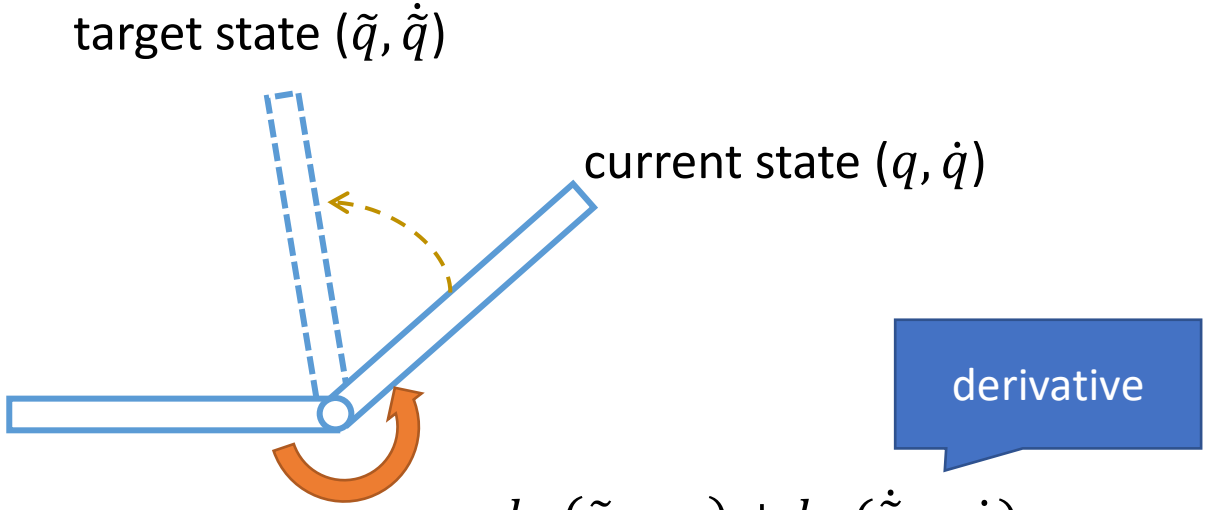




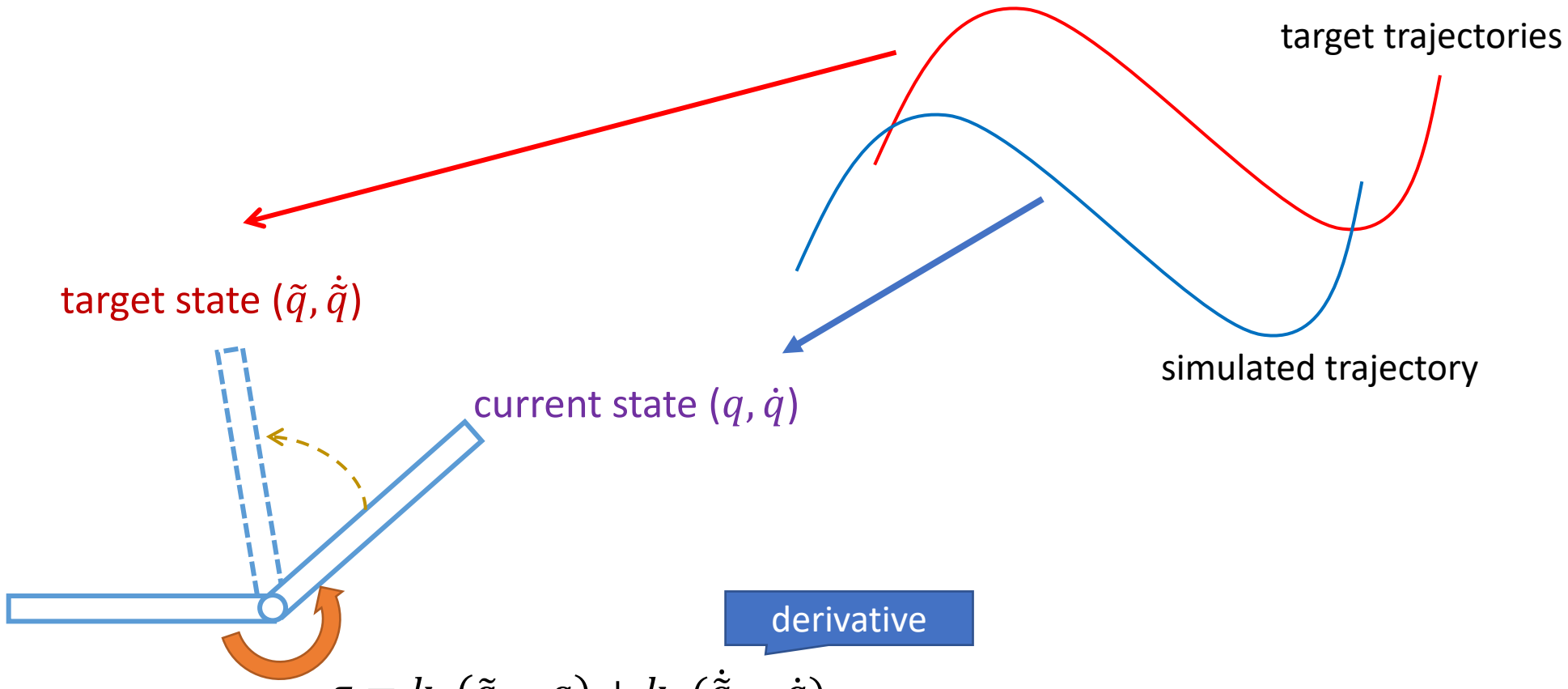


$$\tau = \sum r_i \times F_i$$

Proportional-Derivative (PD) Control



Tracking Controllers



$$\tau = k_p(\tilde{q} - q) + k_d(\dot{\tilde{q}} - \dot{q})$$

derivative

proportional

Tracking Controllers

[Hodgins and Wooten 1995, Animating Human Athletics]

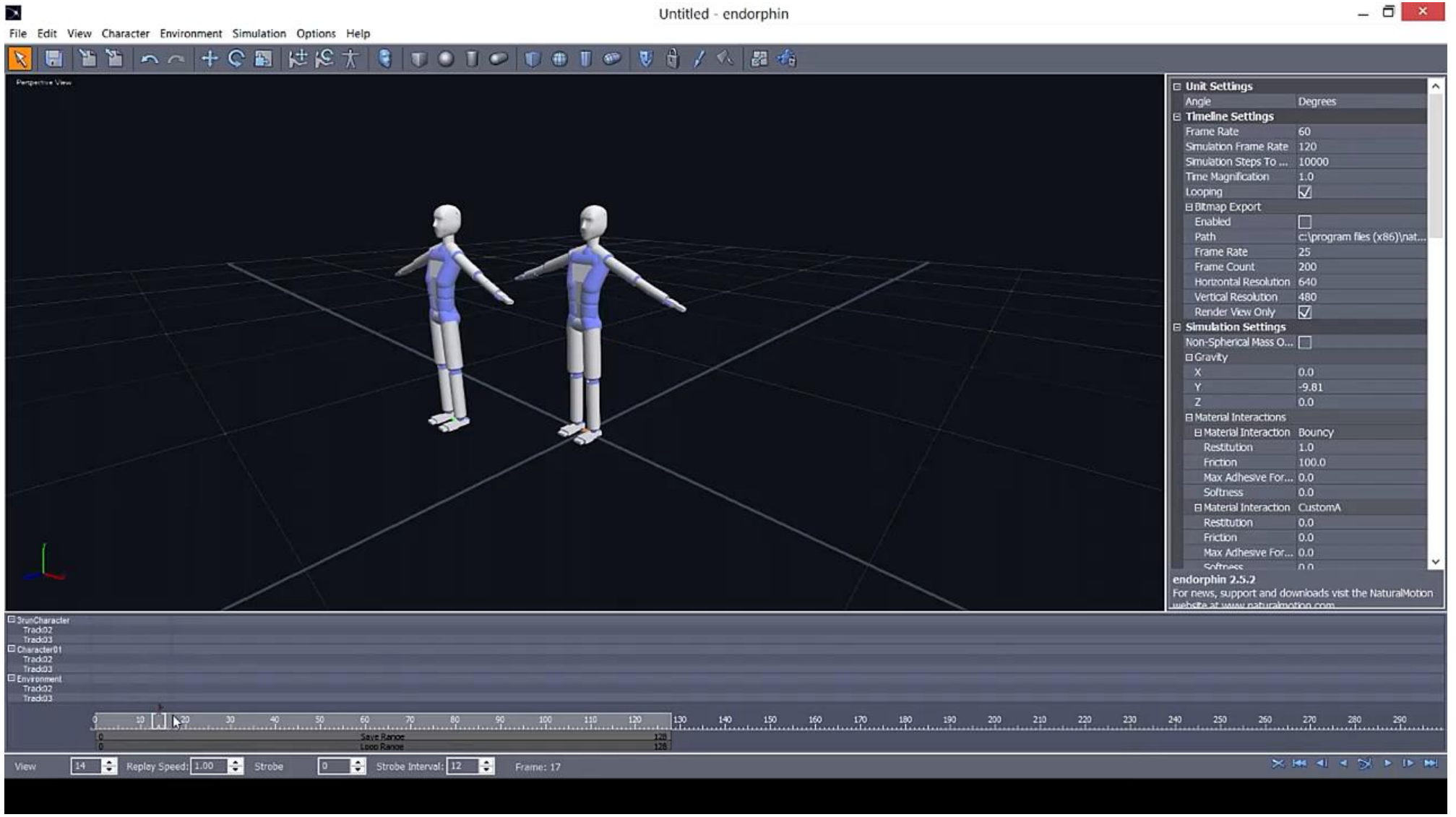
Control is Hard

QWOP - http://www.foddy.net/Athletics.html

Control is Hard

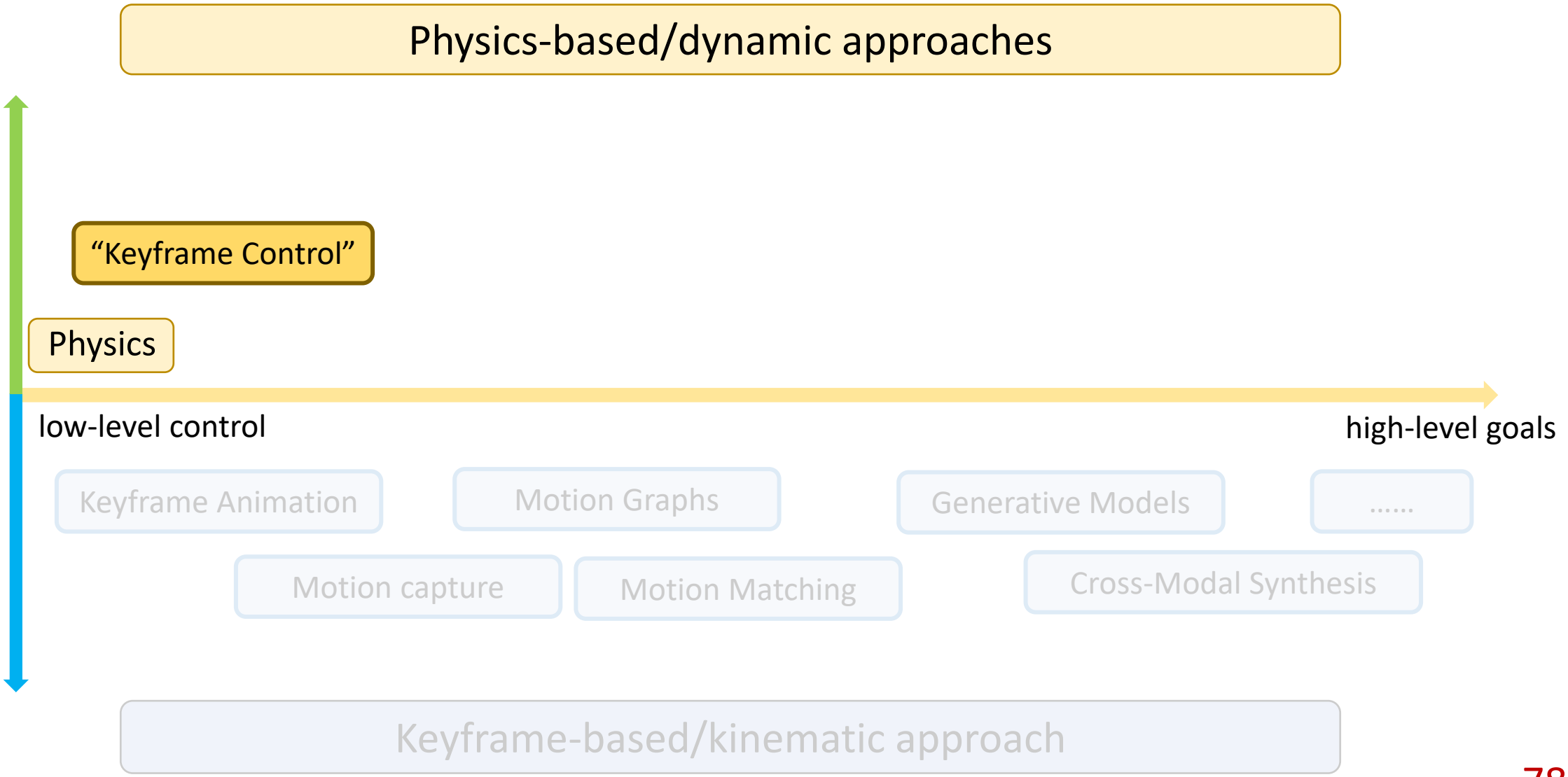
QWOP Cosplay At Anime North 2013 https://www.youtube.com/watch?v=MfIgs3rH-Y8

Trajectory Crafting

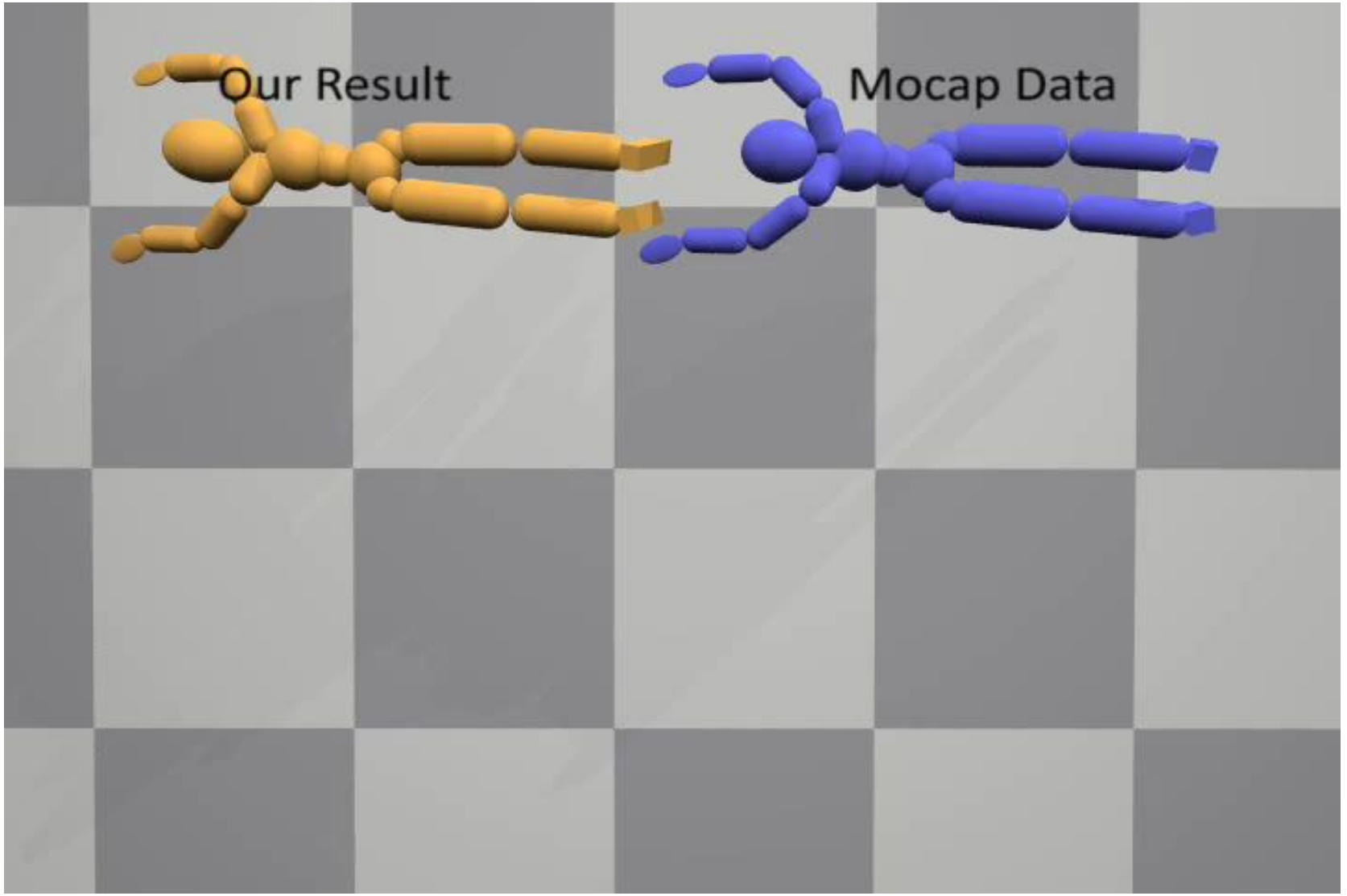


NaturalMotion - Endorphin

Character Animation Methods

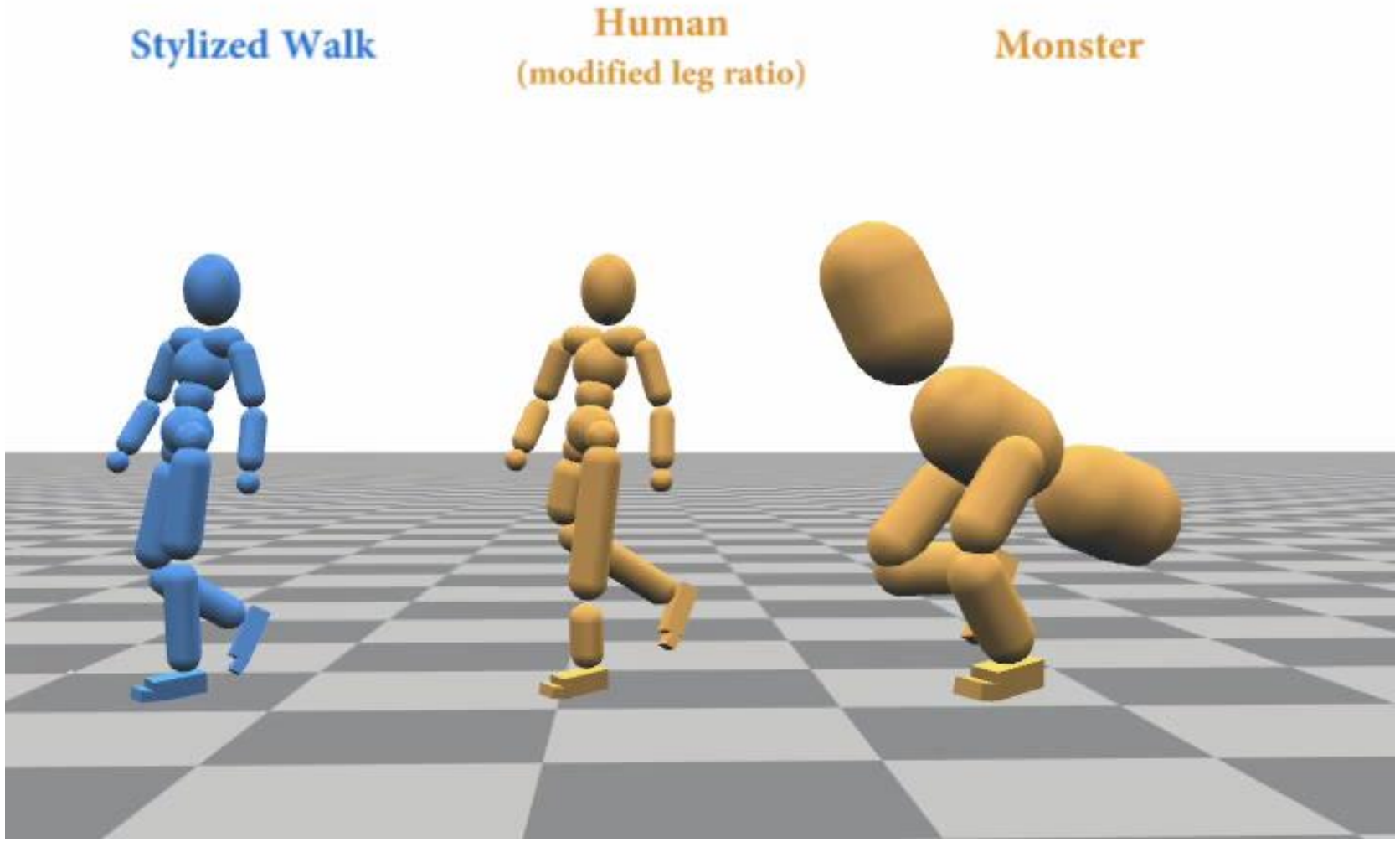


Spacetime/Trajectory Optimization



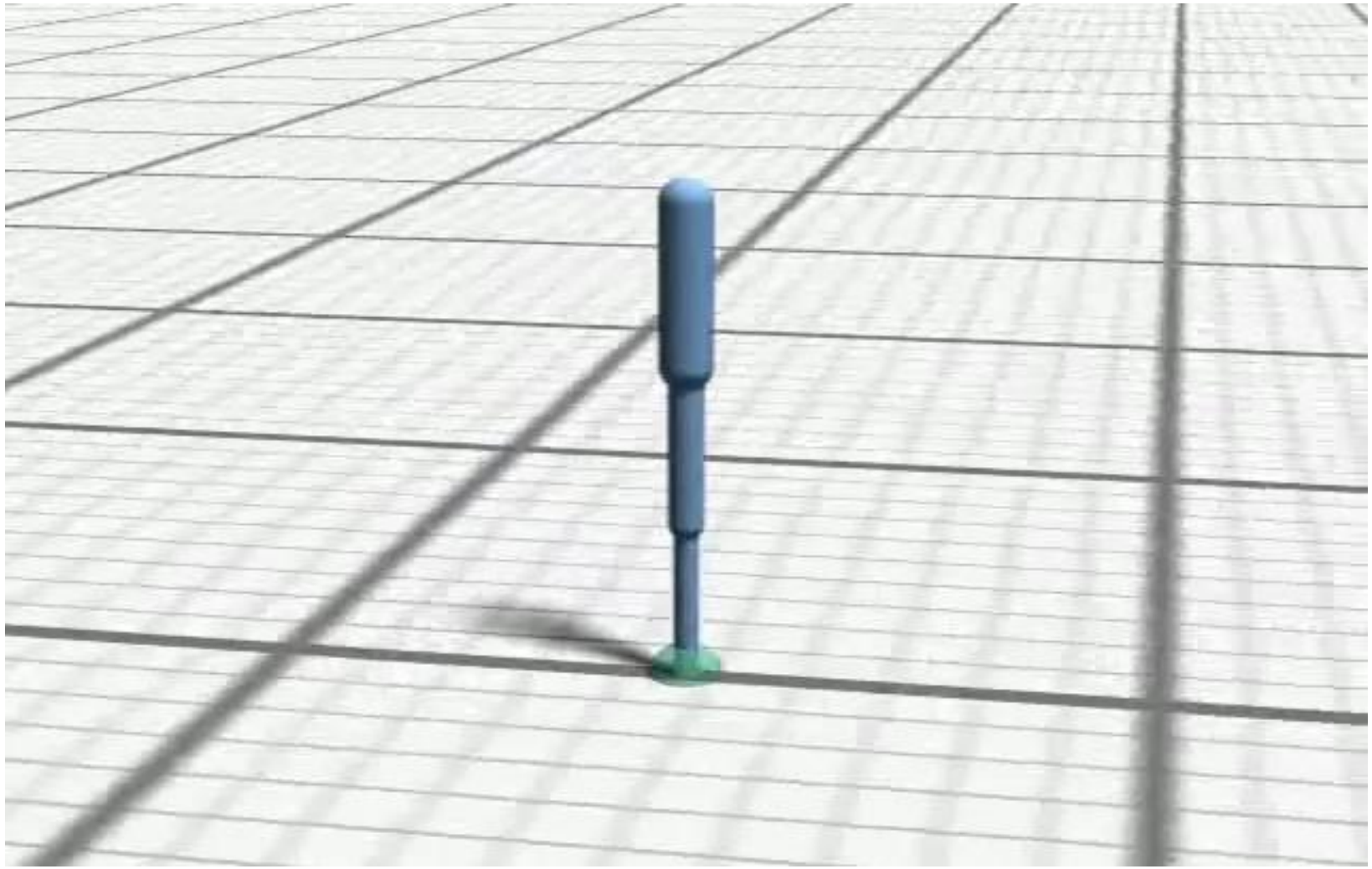
[Liu et al 2010. SAMCON]

Spacetime/Trajectory Optimization



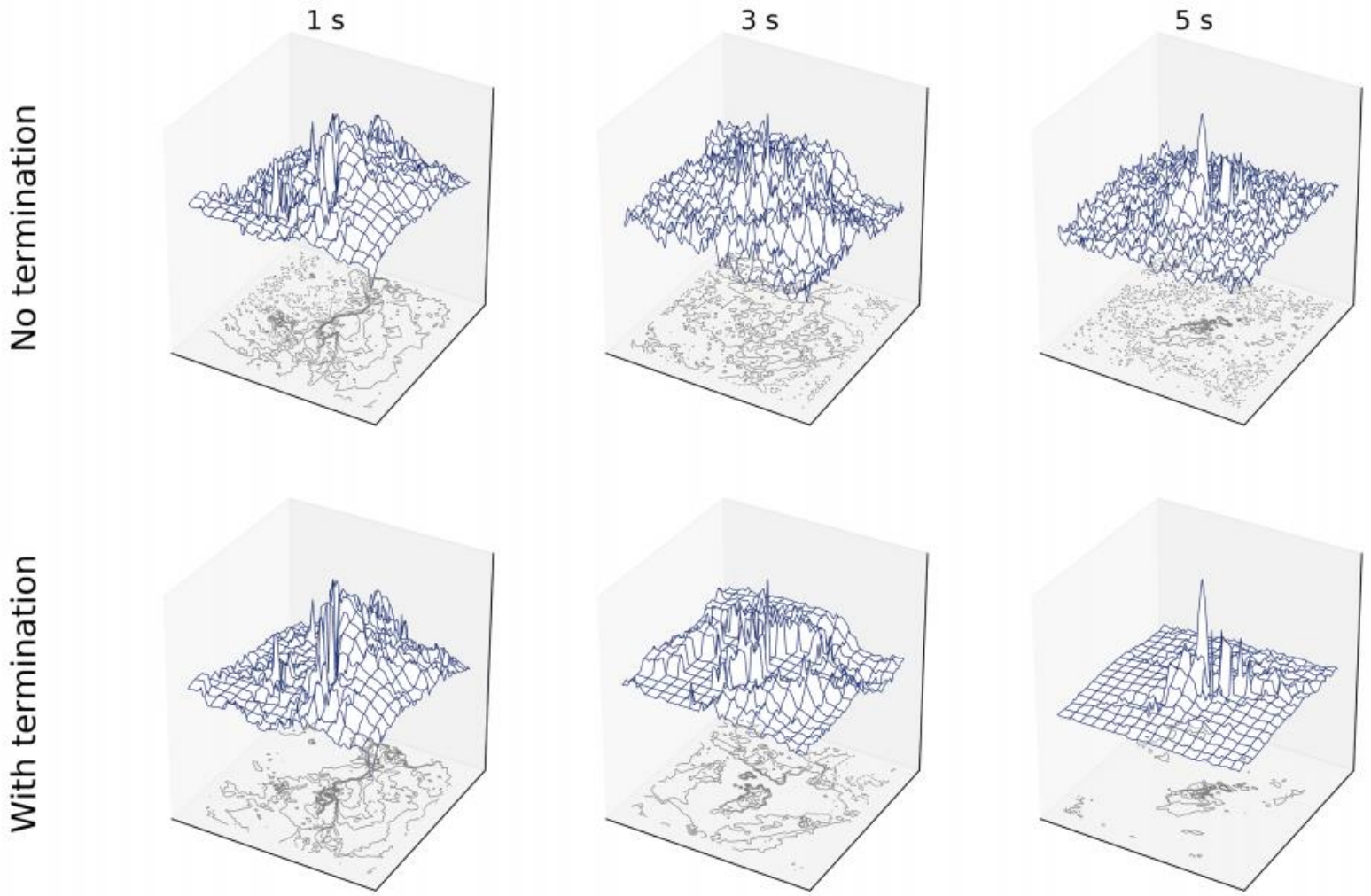
[Liu et al 2010. SAMCON]

Spacetime/Trajectory Optimization



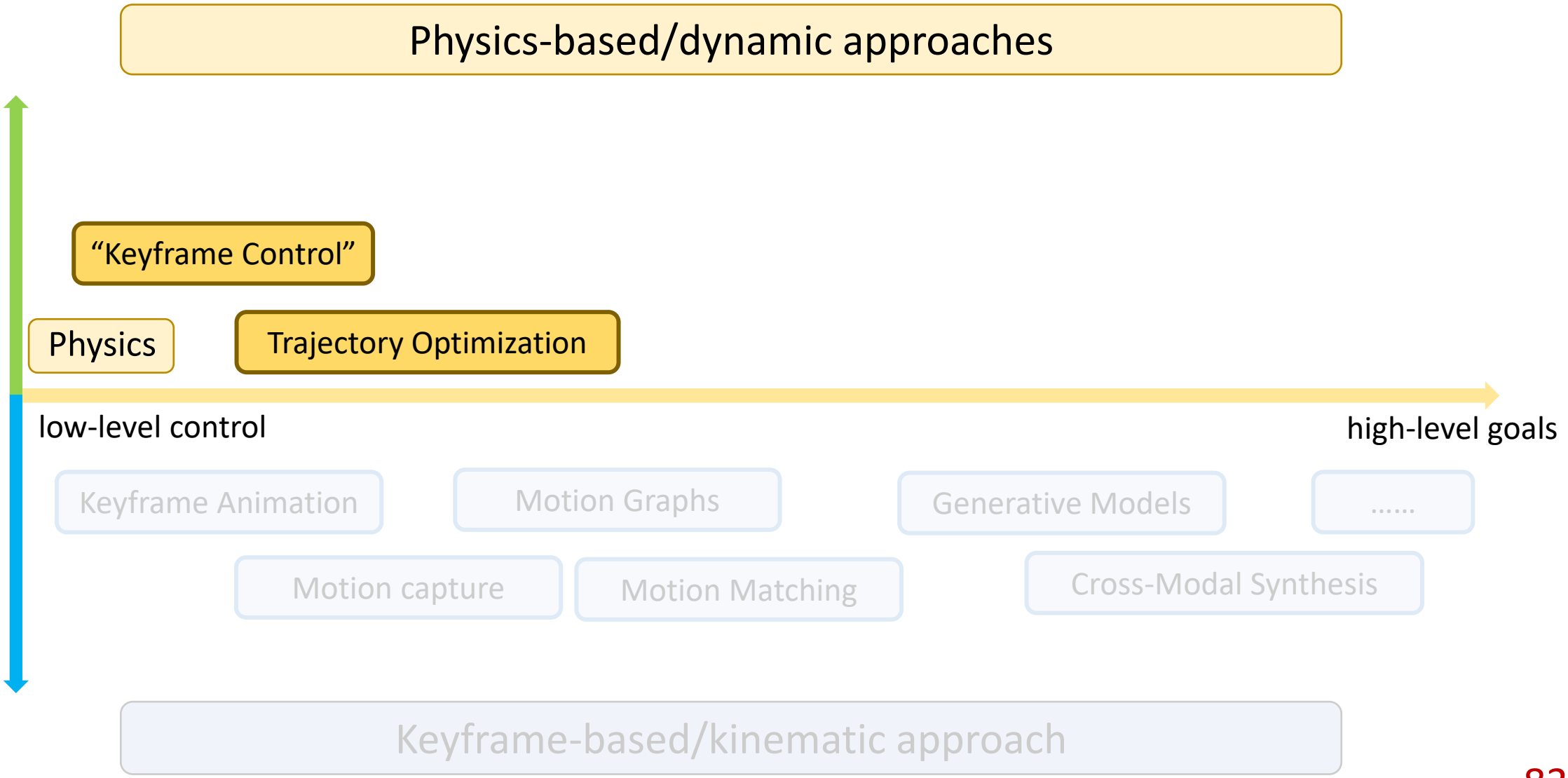
[Wampler and Popović. 2009. Optimal gait and form for animal locomotion]

Spacetime/Trajectory Optimization

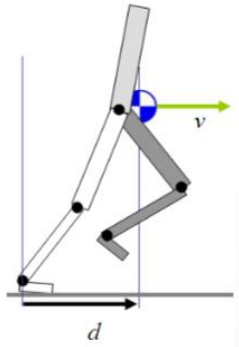


[Hamalainen et al. 2020, Visualizing Movement Control Optimization Landscapes]

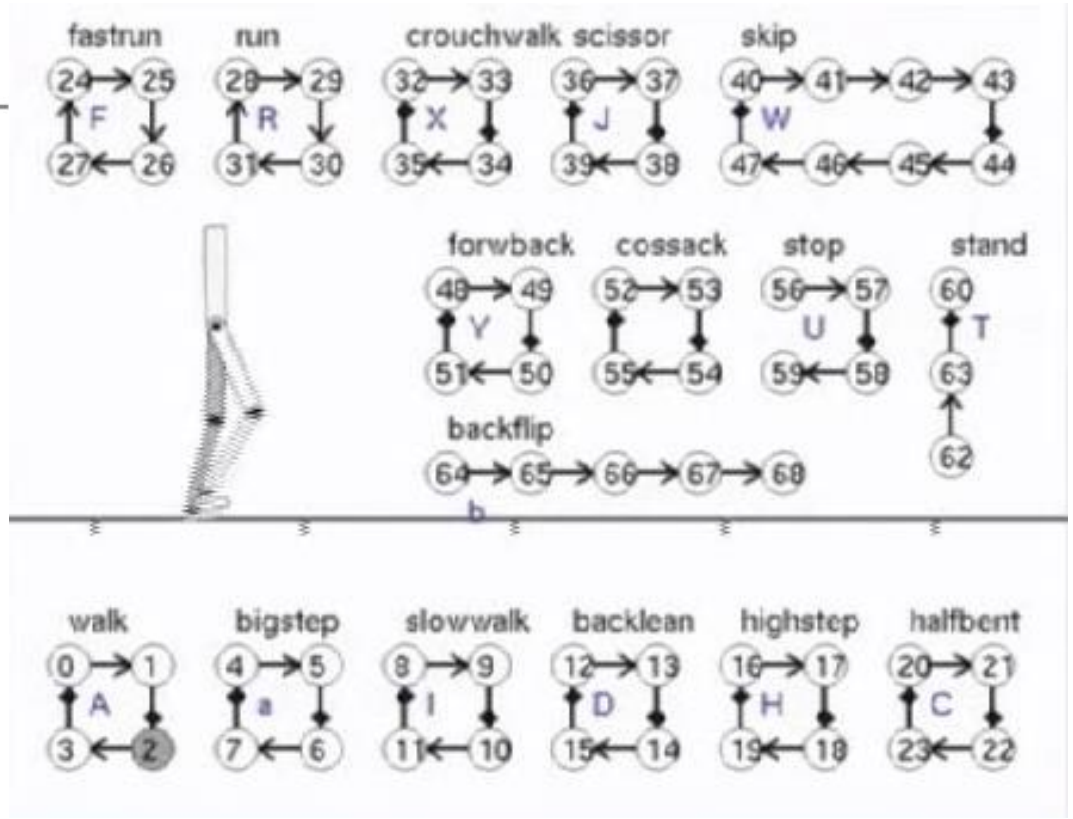
Character Animation Methods



Abstract Models

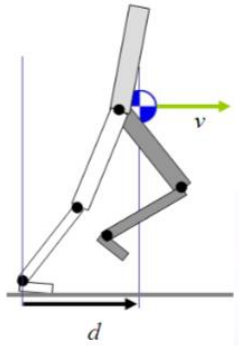


Linear Feedback Control + FSM

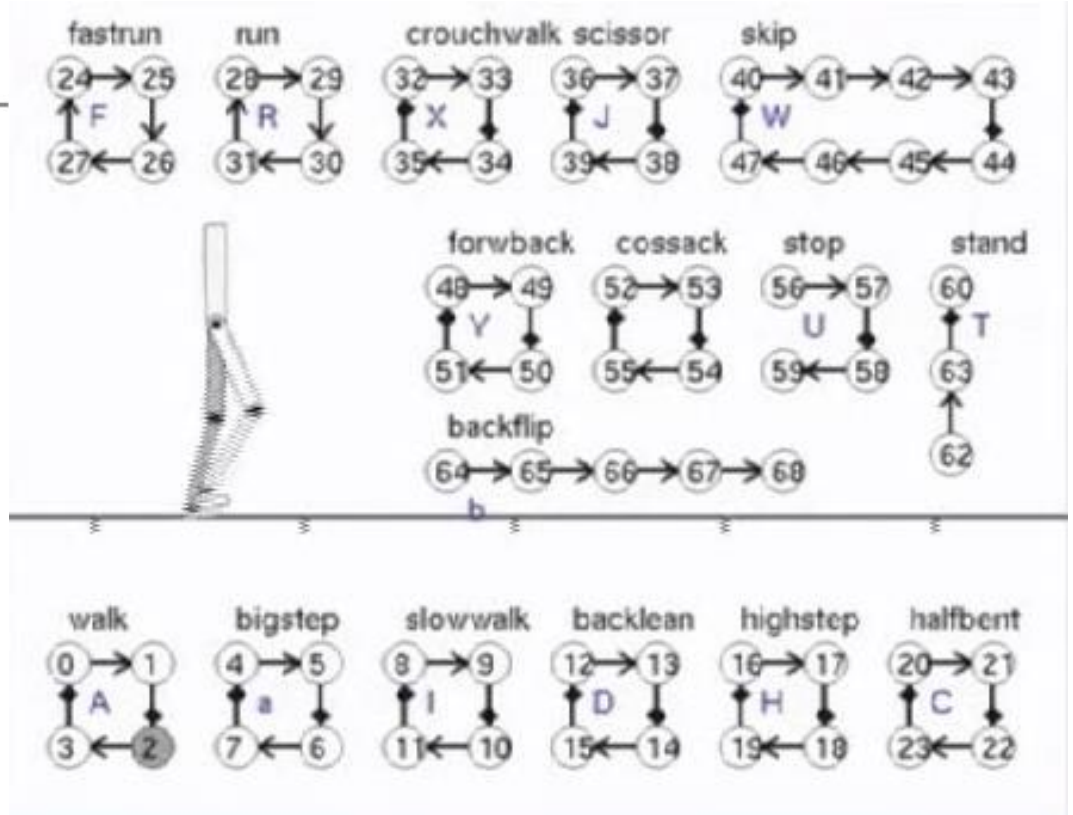


[Yin et al. 2007, SIMBICON]

Abstract Models



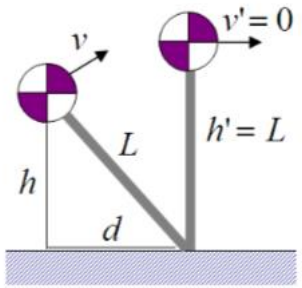
Linear Feedback Control + FSM



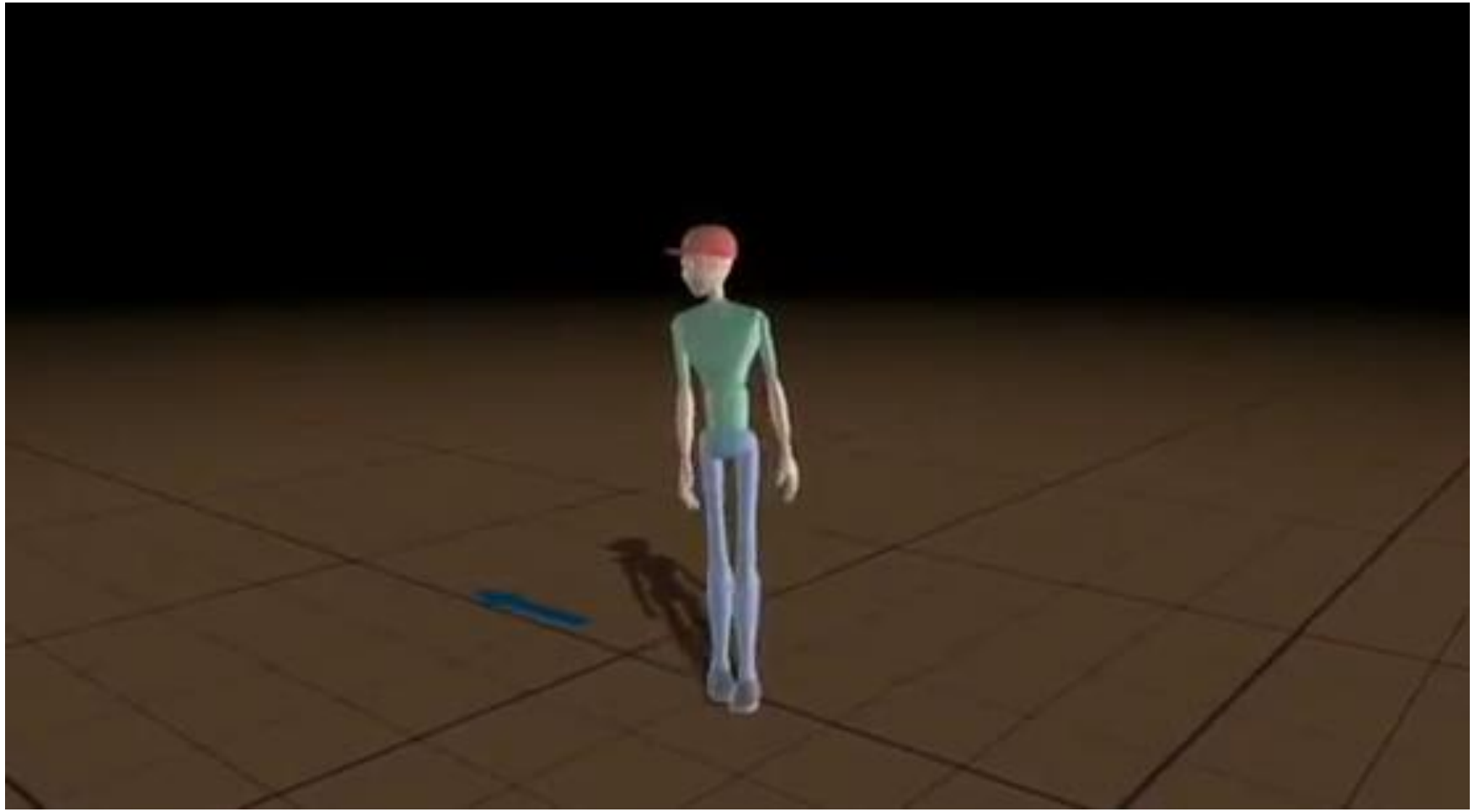
[Yin et al. 2007, SIMBICON]

Abstract Models

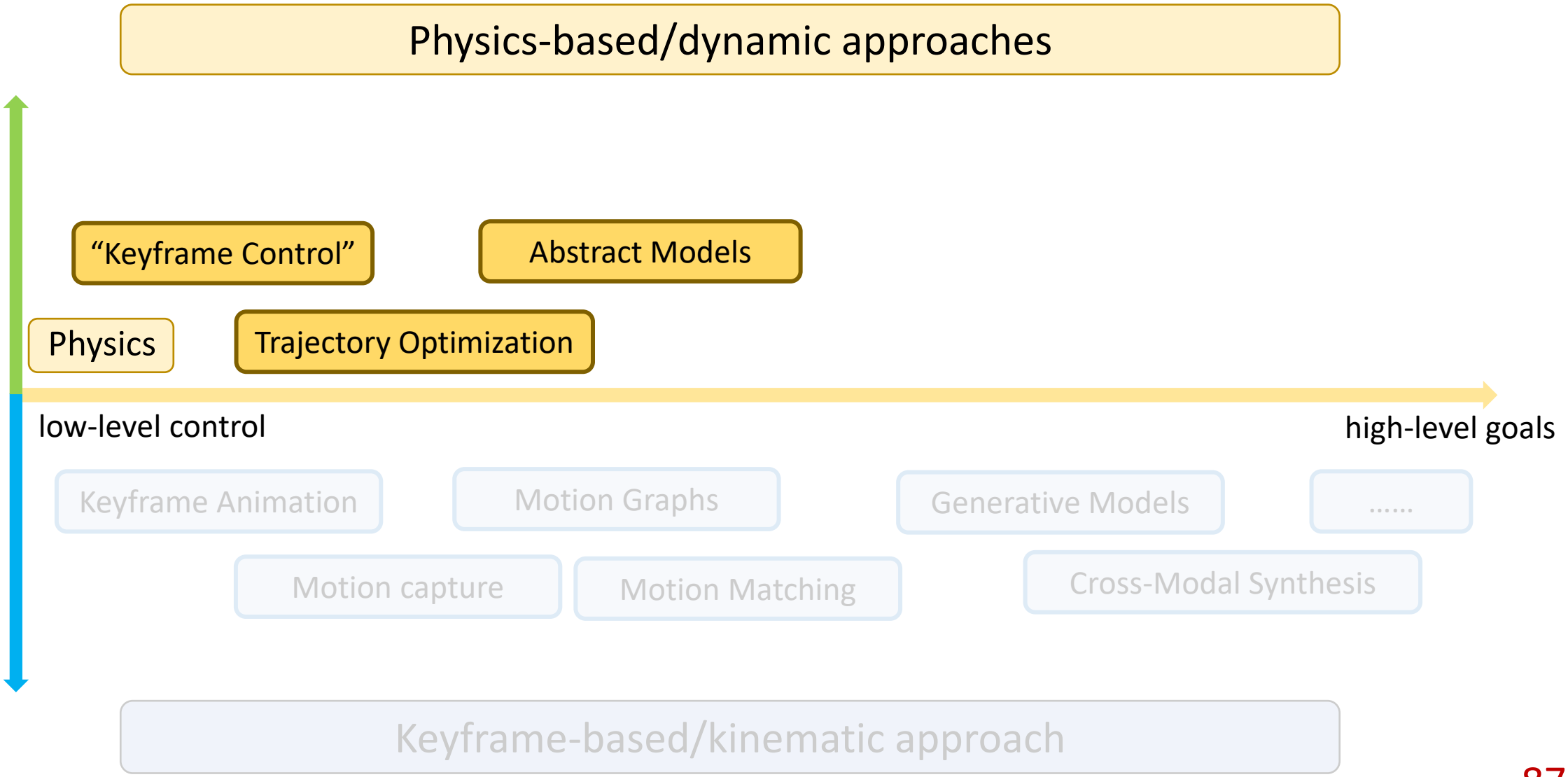
Inverted Pendulum Model



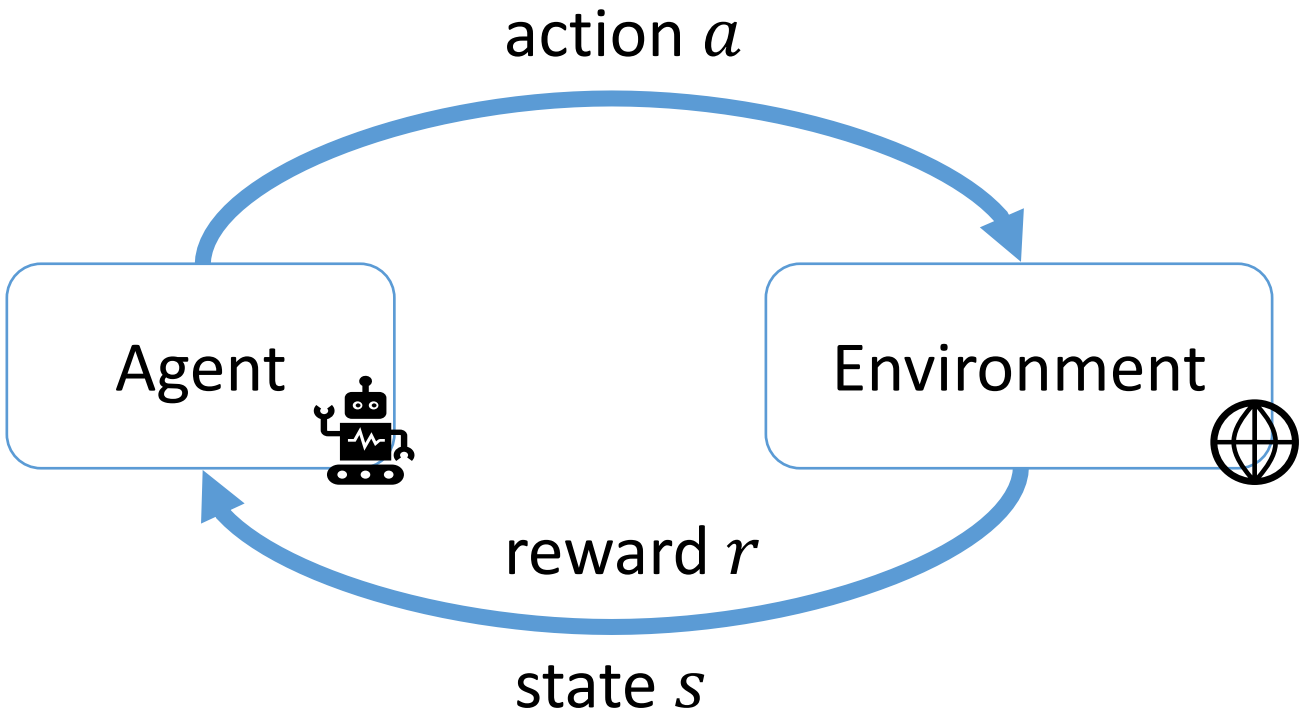
[Coros et al. 2010]



Character Animation Methods



Reinforcement Learning



Deep Reinforcement Learning

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Published: 25 February 2015

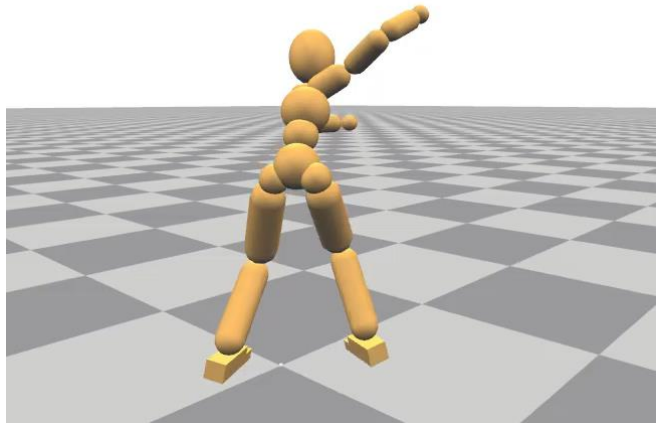
Human-level control through deep reinforcement learning

Volodymyr Mnih, Koray Kavukcuoglu, David Silver, Andrei A. Rusu, Joel Veness, Marc G. Bellemare, Alex Graves, Martin Riedmiller, Andreas K. Fidjeland, Georg Ostrovski, Stig Petersen, Charles Beattie, Amir Sadik, Ioannis Antonoglou, Helen King, Dharshan Kumaran, Daan Wierstra, Shane Legg & Demis Hassabis

Nature **518**, 529–533 (2015) | Cite this article

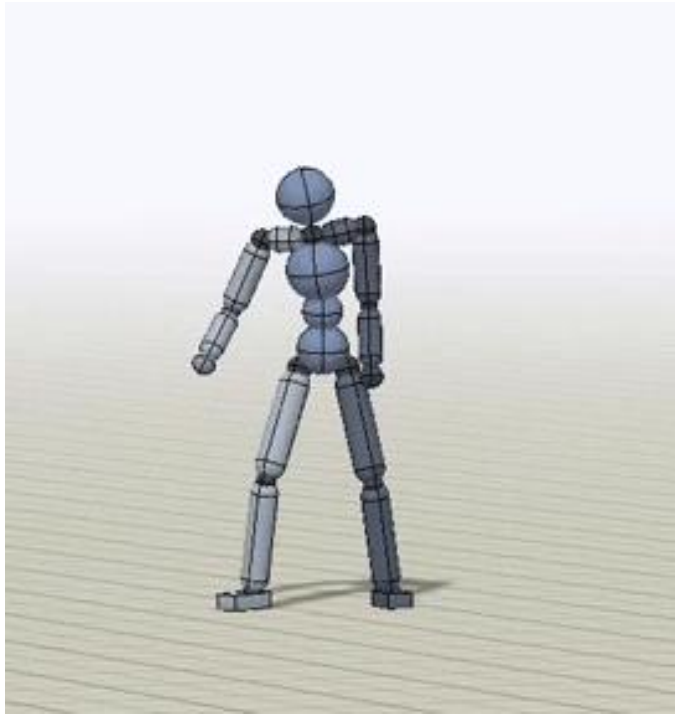
412k Accesses | **8860** Citations | **1562** Altmetric | Metrics

DRL-based Tracking Controllers



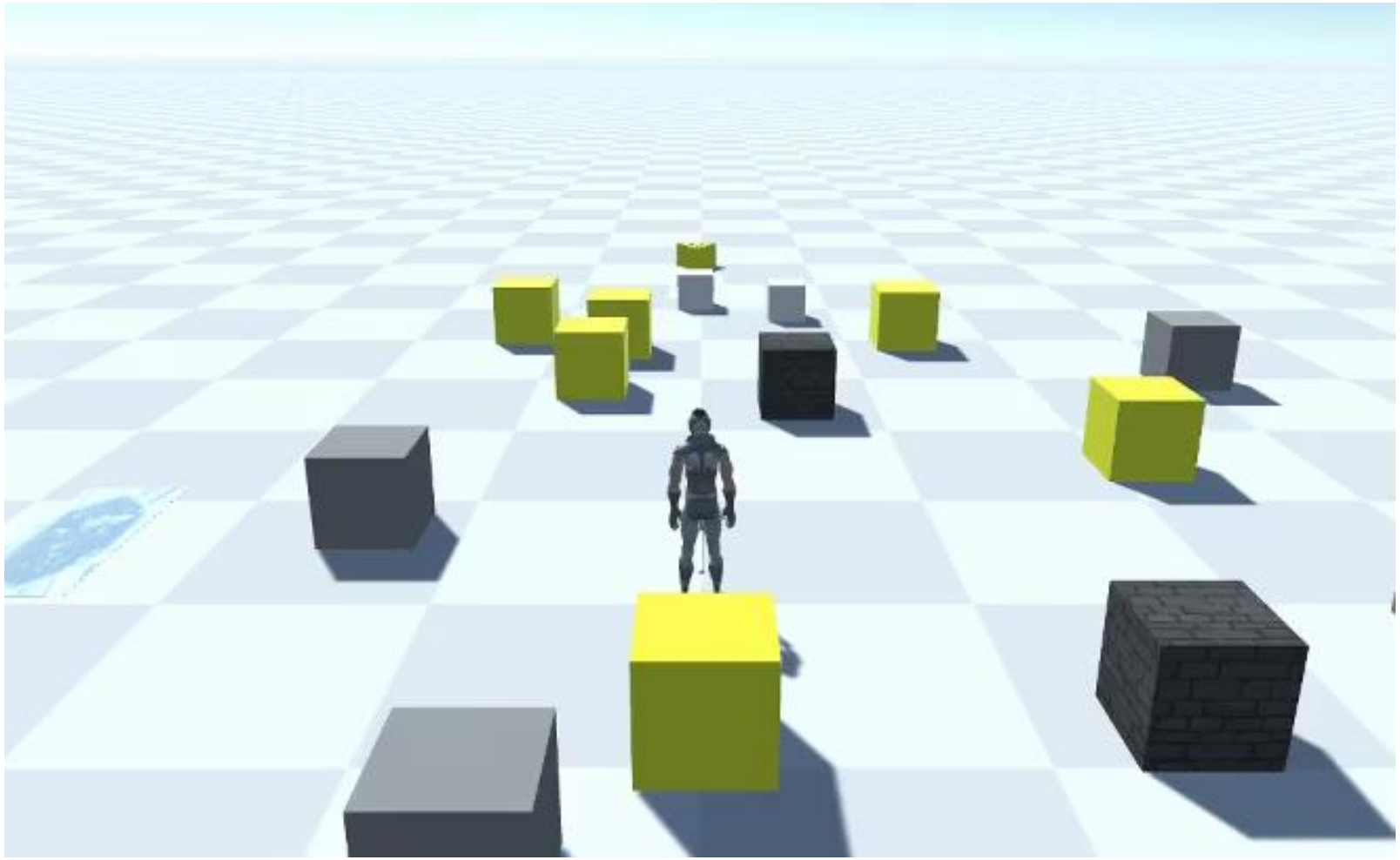
[Liu et al. 2016. ControlGraphs]

[Liu et al. 2018]



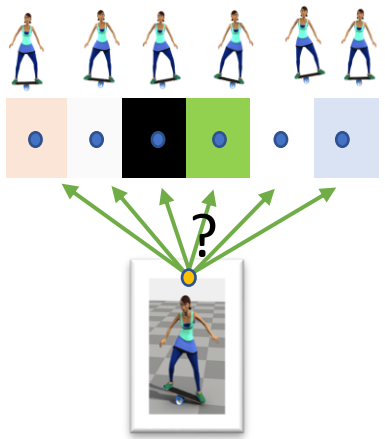
[Peng et al. 2018. DeepMimic]

Multi-skill Characters



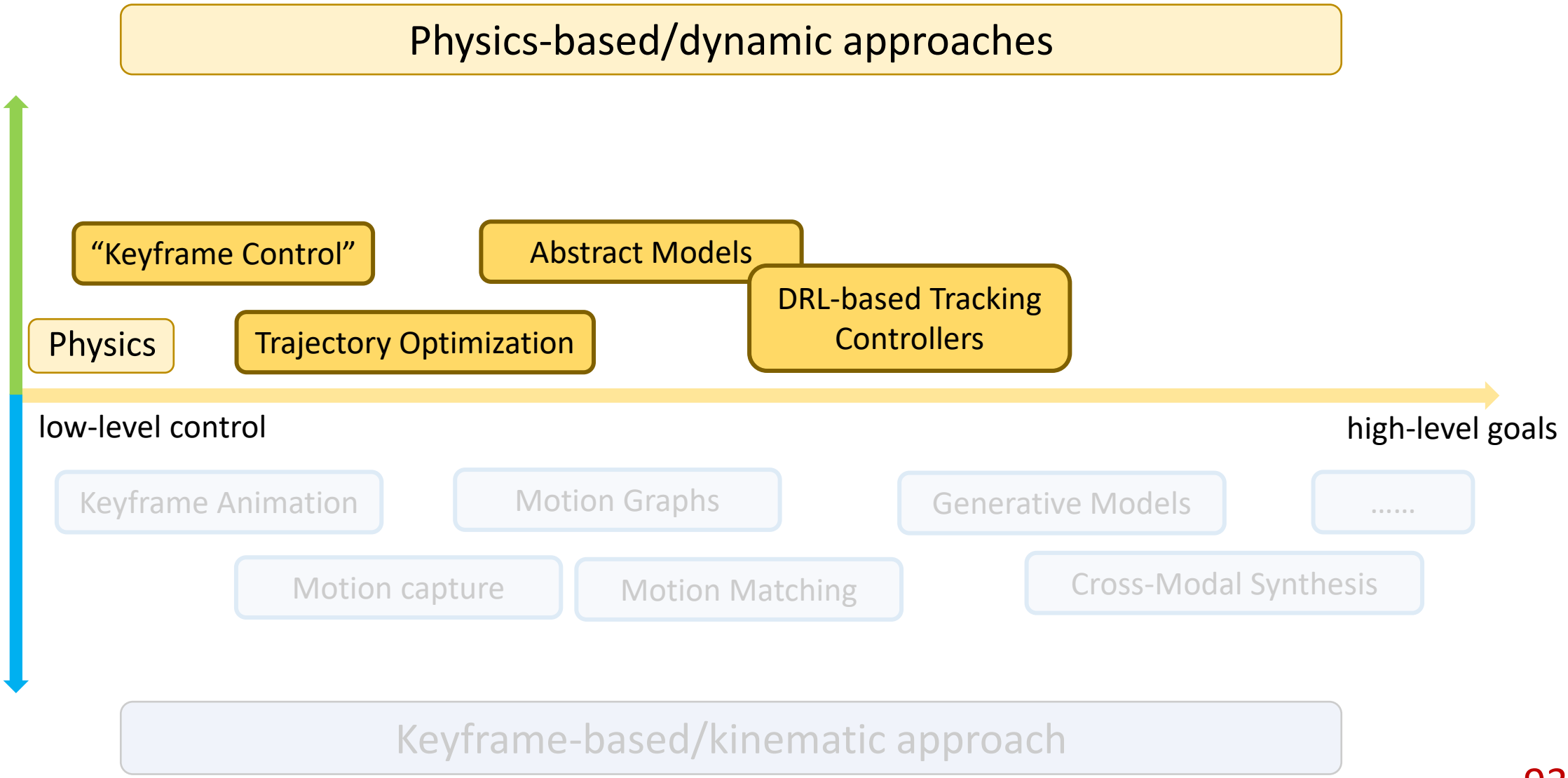
State Machines of
Tracking Controllers

Multi-skill Characters

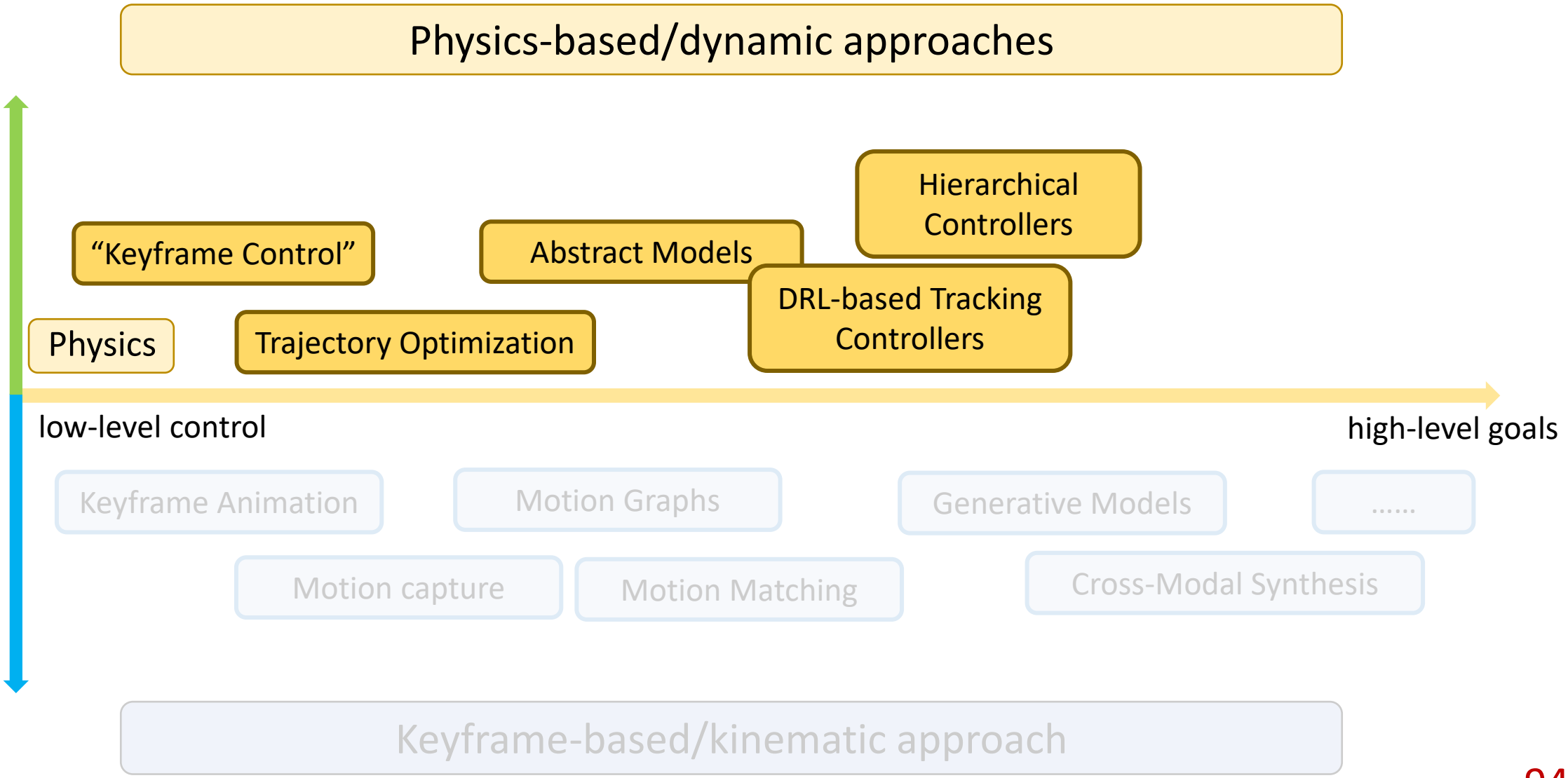


[Liu et al. 2017: Learning to Schedule Control Fragments]

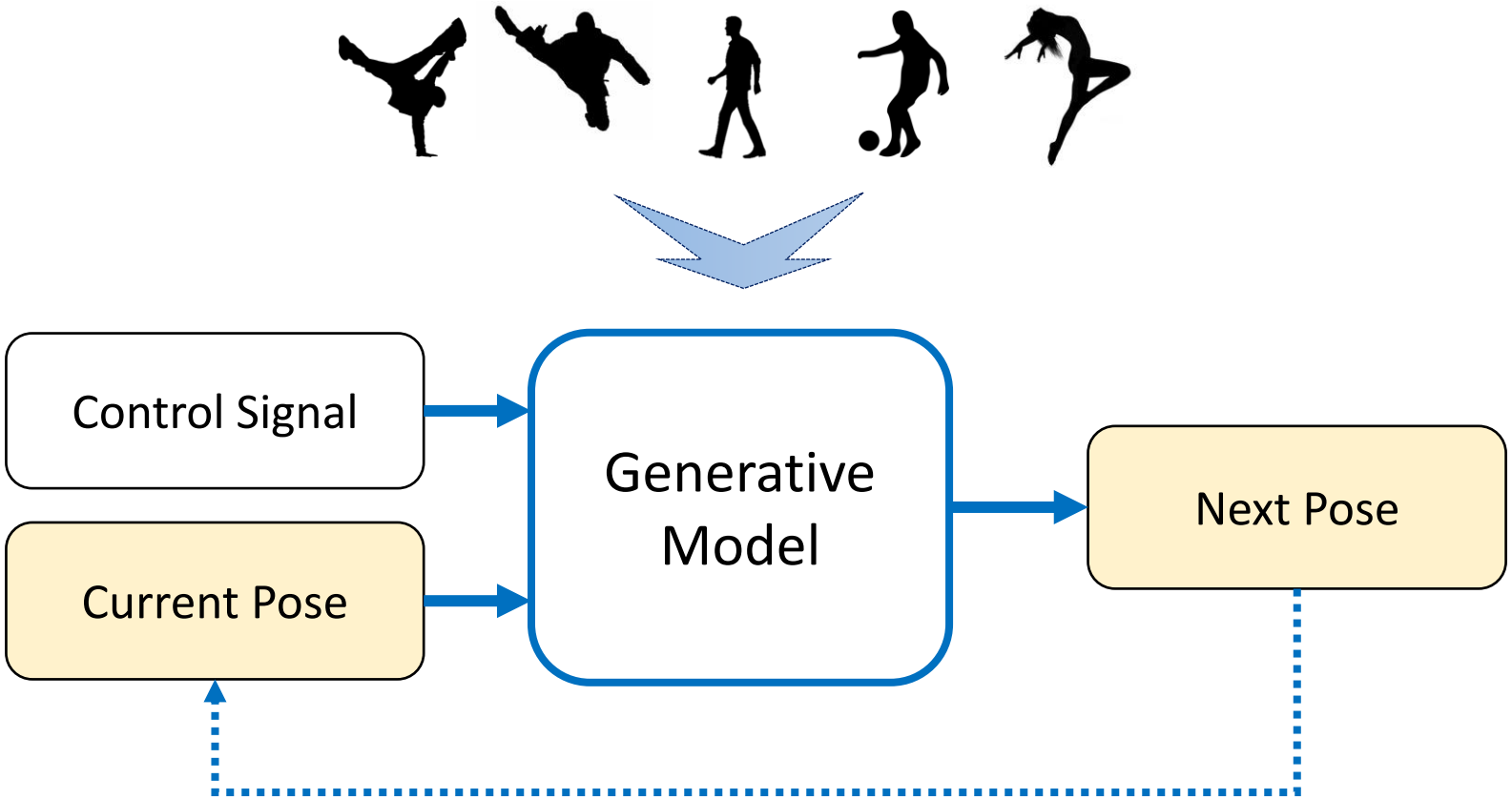
Character Animation Methods



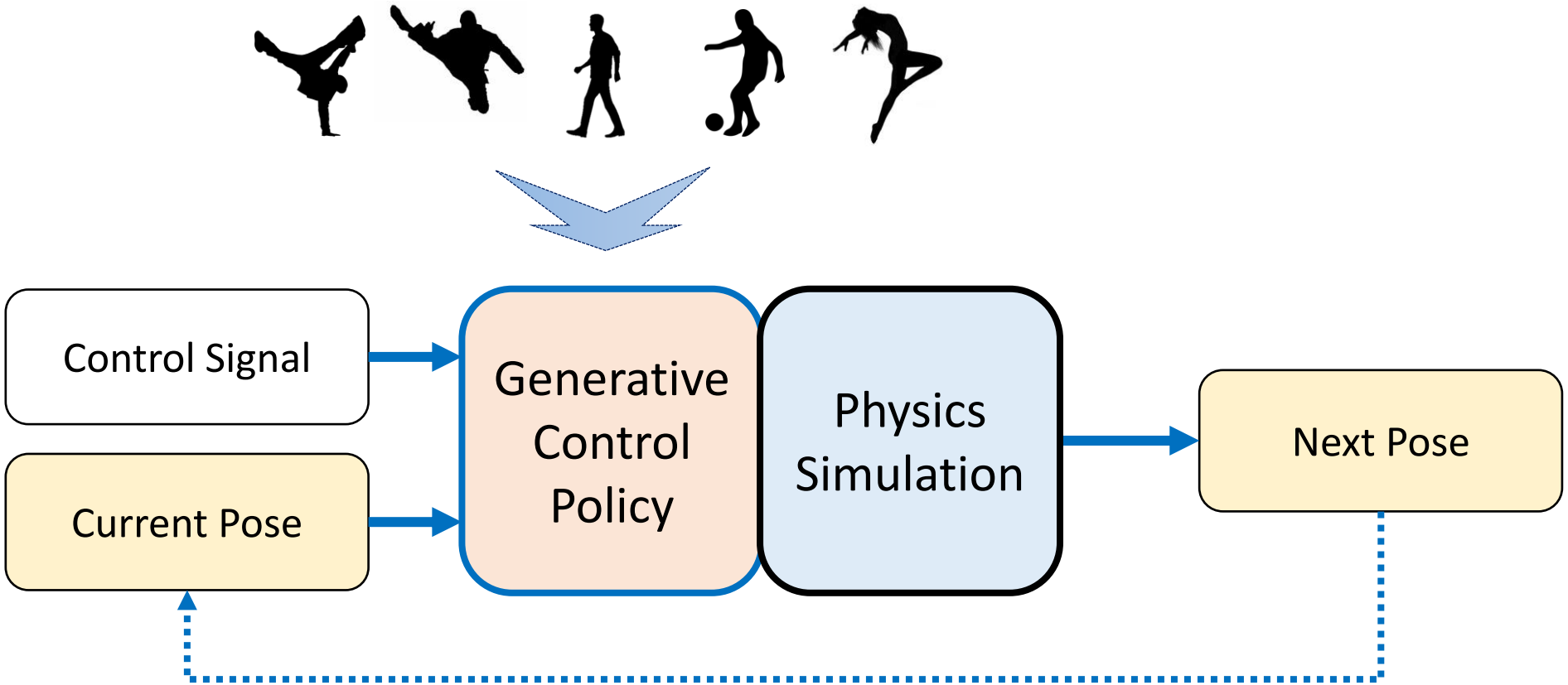
Character Animation Methods



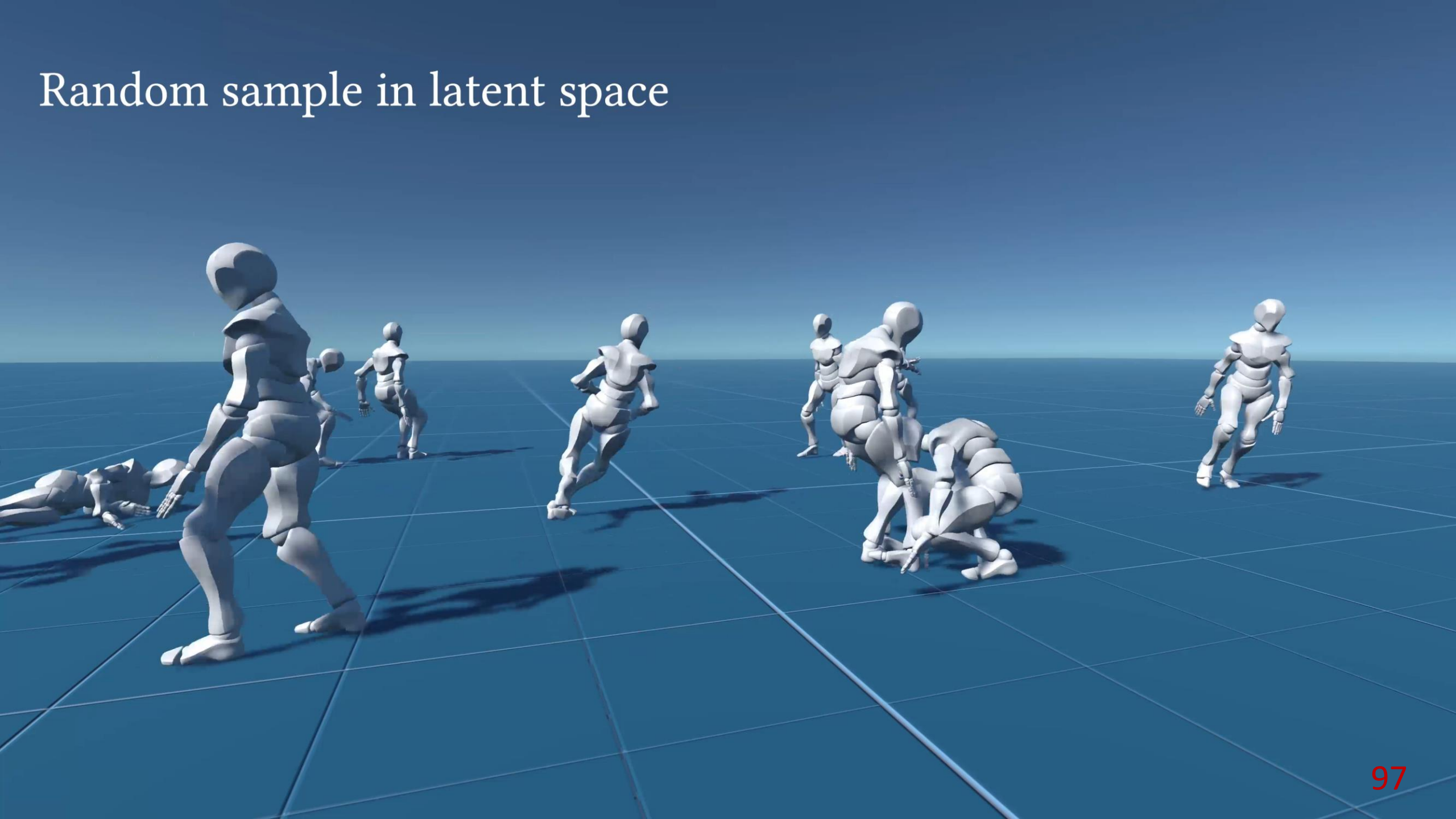
Generative Control Policies



Generative Control Policies

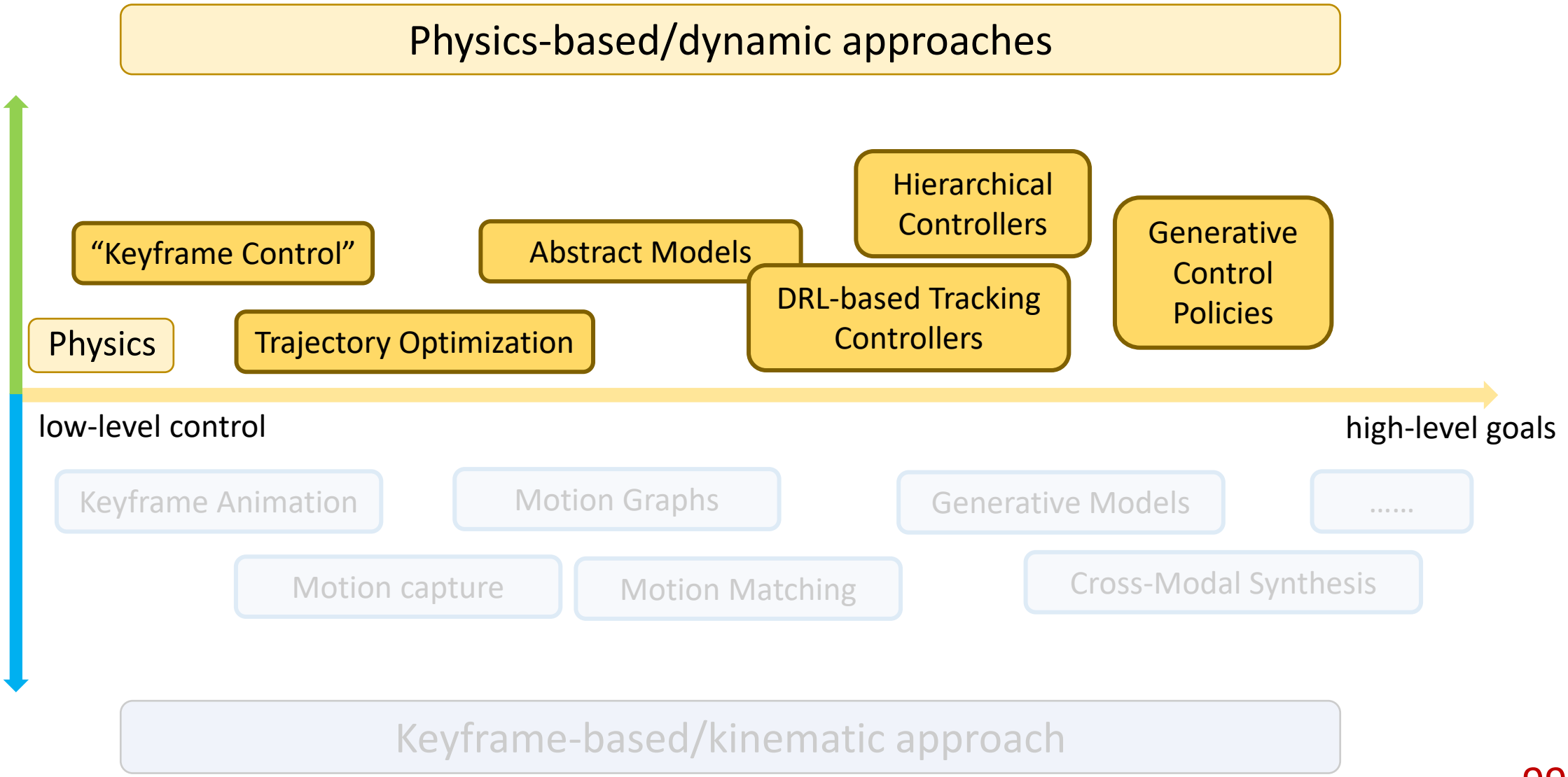


Random sample in latent space

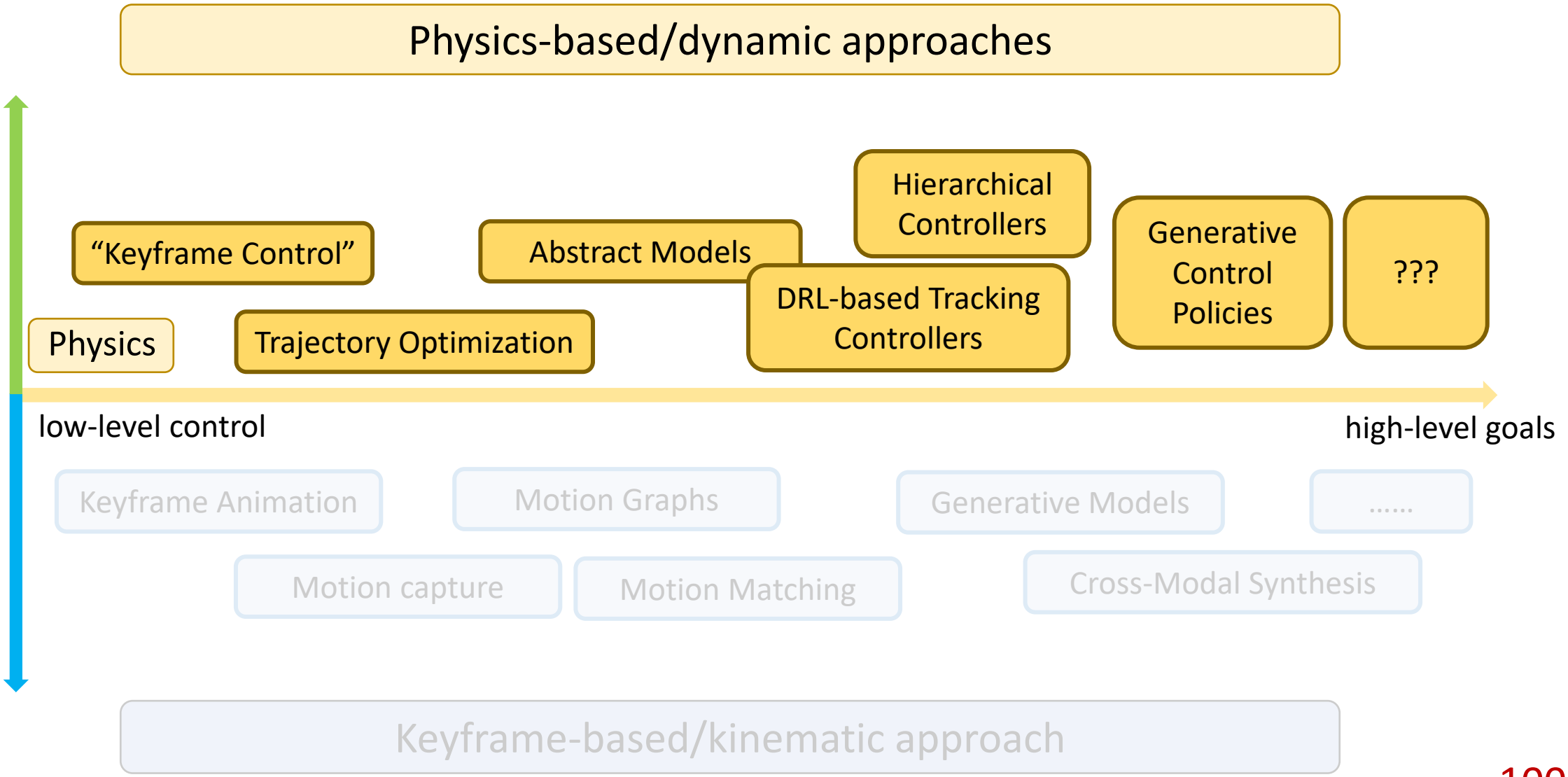


Switch heading and skills

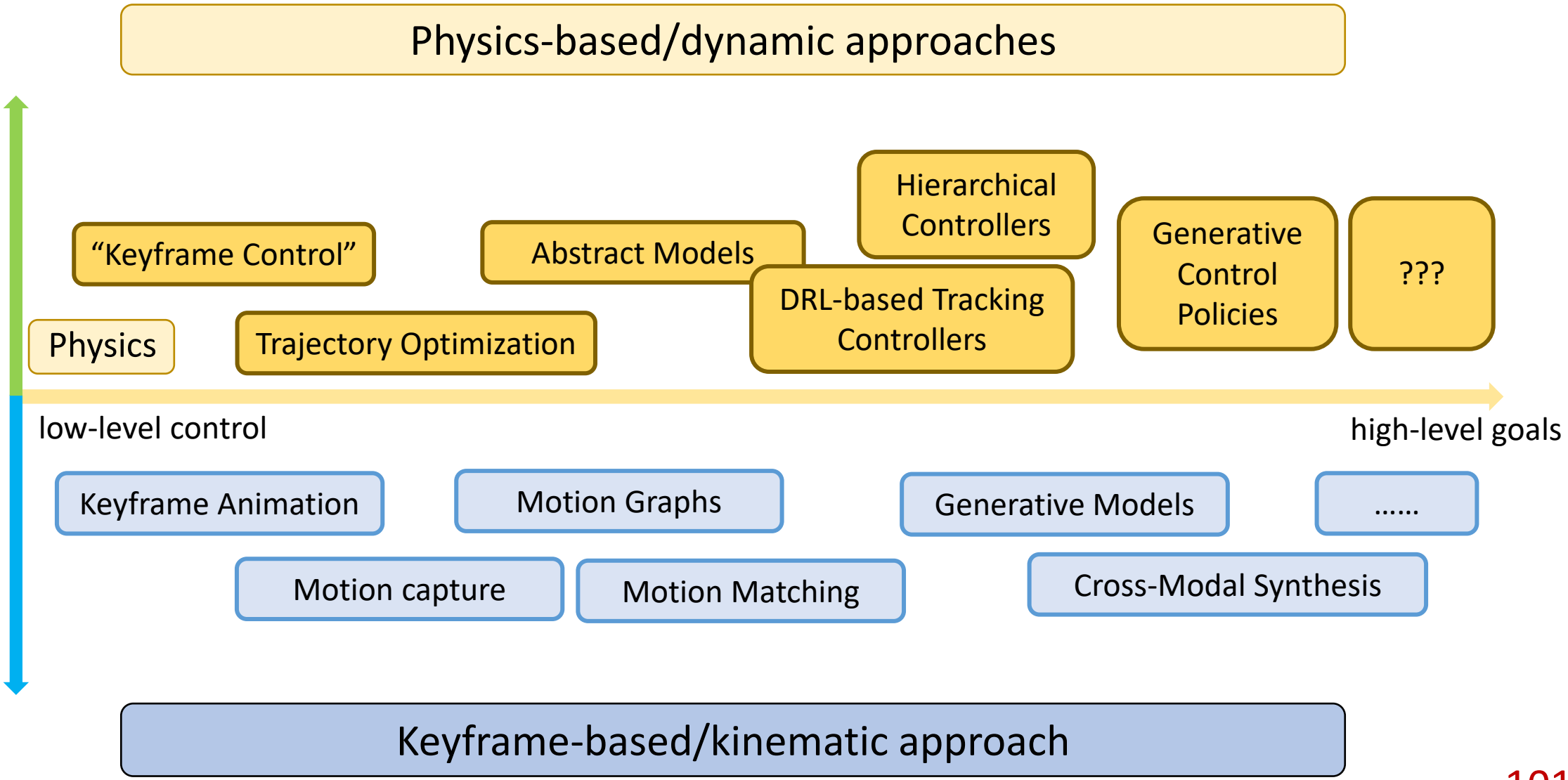
Character Animation Methods



Character Animation Methods



Character Animation Methods



About This Course

About This Course

- What will not be covered
  - How to use Maya/Motion Builder/Houdini/Unity/Unreal Engine…
  - How to become an animator

- What will be covered
  - Methods, theories, and techniques behind animation tools
    - Kinematics of characters
    - Physics-based simulation
    - Motion control

  - Ability to create an interactive character

Welcome & Course Information

- Instructor: Libin Liu (http://libliu.info)
- Website: https://games-105.github.io/
- Lecture: Monday 8:00PM to 9:00PM (12 Weeks)
- Prerequisites: linear algebra, calculus,
  programming skills (python),
  probability theory, mechanics, ML, RL…
- Exercise:
  - Codebase: https://github.com/GAMES-105/GAMES-105
  - Submission: http://cn.ces-alpha.org/course/register/GAMES-105-Animation-2022/
  - Register code: **GAMES-FCA-2022**
- BBS: https://github.com/GAMES-105/GAMES-105/discussions
- QQ Group: 533469817

群名称:GAME105课程交流群
群　号:533469817

Lectures

2022年10月10日	Introduction to Character Animation	
2022年10月17日	Rotation, Transformation, and Forward Kinematics	
2022年10月24日	Inverse Kinematics	Proj1
2022年10月31日	Keyframe Character Animation	
2022年11月07日	Data-driven Character Animation	
2022年11月14日	Learning-based Character Animation	Proj2
2022年11月21日	Skinning and Facial Animation	Proj S
2022年11月28日	Physics-based Simulation and Articulated Rigid Bodies	
2022年12月05日	Actuating Character and Feedback Control	Proj3
2022年12月12日	Learning to Walk with Simplified Models	
2022年12月19日	Optimal Control and Trajectory Optimization	Proj4
2022年12月26日	Reinforcement Learning and Multiskilled Characters	

may change according to course progress

Exercise

- Instruction to be announced
- Program in Python, with physics engine (pybullet/ode/…)
- Five projects
  - Project 1: FK/IK, play with motion data
  - Project 2: Interactive character
  - Project S: Skinning
  - Project 3: Simulation and Ragdoll
  - Project 4: A simulated walking character

Relationship to Other GAMES “1” Courses

- This source is designed to be self-contained, but it is good to also learn:

GAMES在线课程

GAMES 102

GAMES 103

GAMES 104

Questions?

That’s all for today. See you next week!

aban·don [əˈband(ə)n]

adj. 常看常新