Principle vs Observation: How do people move?

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What Determines How People Move?

Physics

Mass, inertia, force

Physiology

Muscle, skeleton, tendon

Culture and Psychology

Style, mood

Principle vs. Observation

Do we have any principles that determine our motion?

Or, do we simply imitate what we have seen before?

Principles of Motion

Physical laws

Do we need to understand Newton's law for walking?

Optimality principles

Do we optimize for efficiency?

Central pattern generator

Do we have a module that controls a specific motion?

Principles of Motion

Physical laws

Do we need to understand Newton’s law for walking?

Eg) Physically based simulation

Optimality principles

Do we optimize for efficiency?

Eg) Spacetime optimization

Central pattern generator

Do we have a module that controls a specific motion?

Eg) Controller design

Motion Capture

[*The Two Towers* | New Line Productions]

Making Use of Observed Data

Record-and-playback is not enough

Create something new from canned data

Toolbox for animators/programmers

edit, manipulate, segment, splice, blend, and adapt motion capture data.

Combine Principle and Observation

Learning principle from observation

Capture symmetry, regularity, and patterns in data

Observation drives principles

Data-driven physics simulation

Principle guides data manipulation

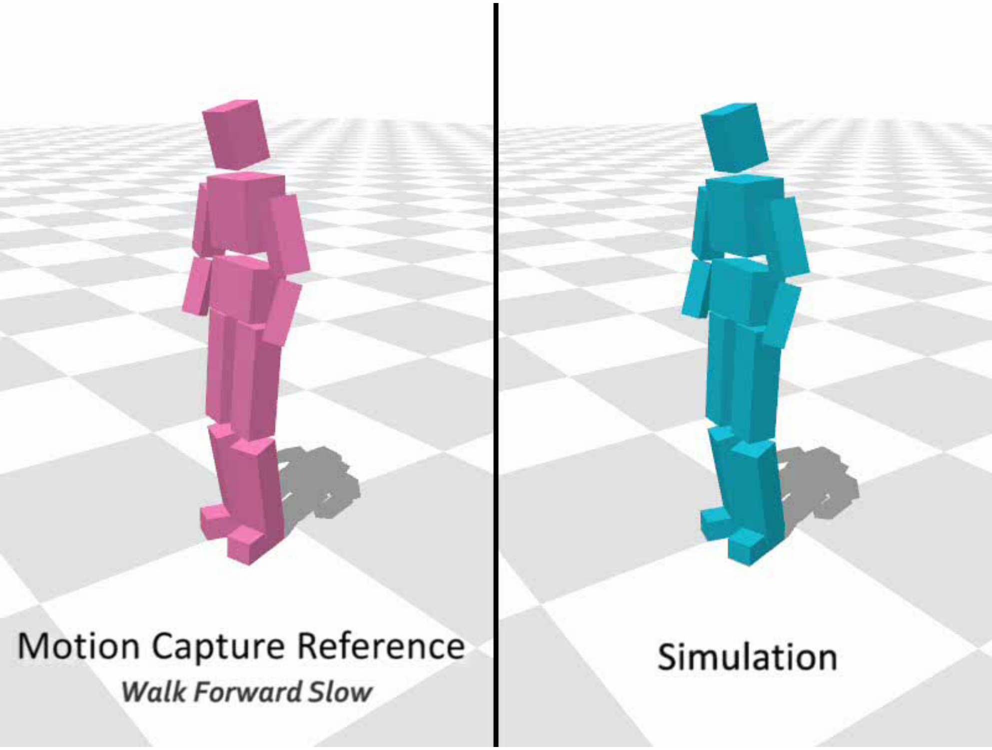
Motion editing using physical properties

Data-Driven Biped Control

Biped controller is difficult to design

- Balance, Robustness
- Looks natural, Stylistic gaits

This work was done in collaboration with Yunsang Lee and Sungeun Kim



Goal

Dynamically simulated in real time

As realistic as motion capture data

Equipped with a repertoire of motor skills

Controlled interactively

Motion Data for Controllers

Motion capture is NOT the ground truth

- Biped has fewer DOFs
- Ideal revolute/ball-and-socket joints
- Difficult to estimate body mass/inertia

Sometimes, physically implausible

Simple tracking data would fail

Previous Approaches

Advanced control theory
[Yin 2007] [Tsai 2010] [da Silva 2008] [Muico 2009]

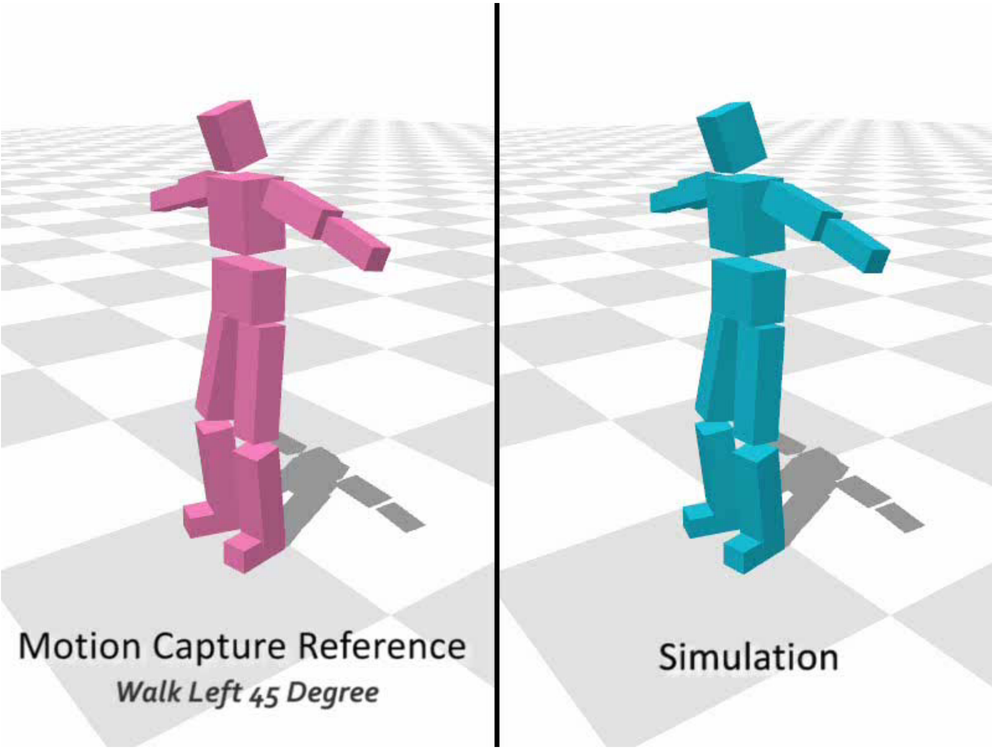
- Tracking while compensating error in data
- Balance feedback, inverted pendulum, LQR, NQR

Non-linear optimization
[Sok 2007] [da Silva 2008] [Yin 2008] [Muico 2009] [Wang 2009]

- Spacetime optimization for rectifying data
- Computationally heavy, cumbersome to implement

Data-driven approach [Sok 2007]

- A large collection of motion data
- Search and regression, statistical modeling



Key Idea

What we use

- Simple balance feedback
- Continuous modulation of reference trajectory
- Synchronization

What we don't use

- Model learning, optimization, precomputation

Any animation module can be plugged

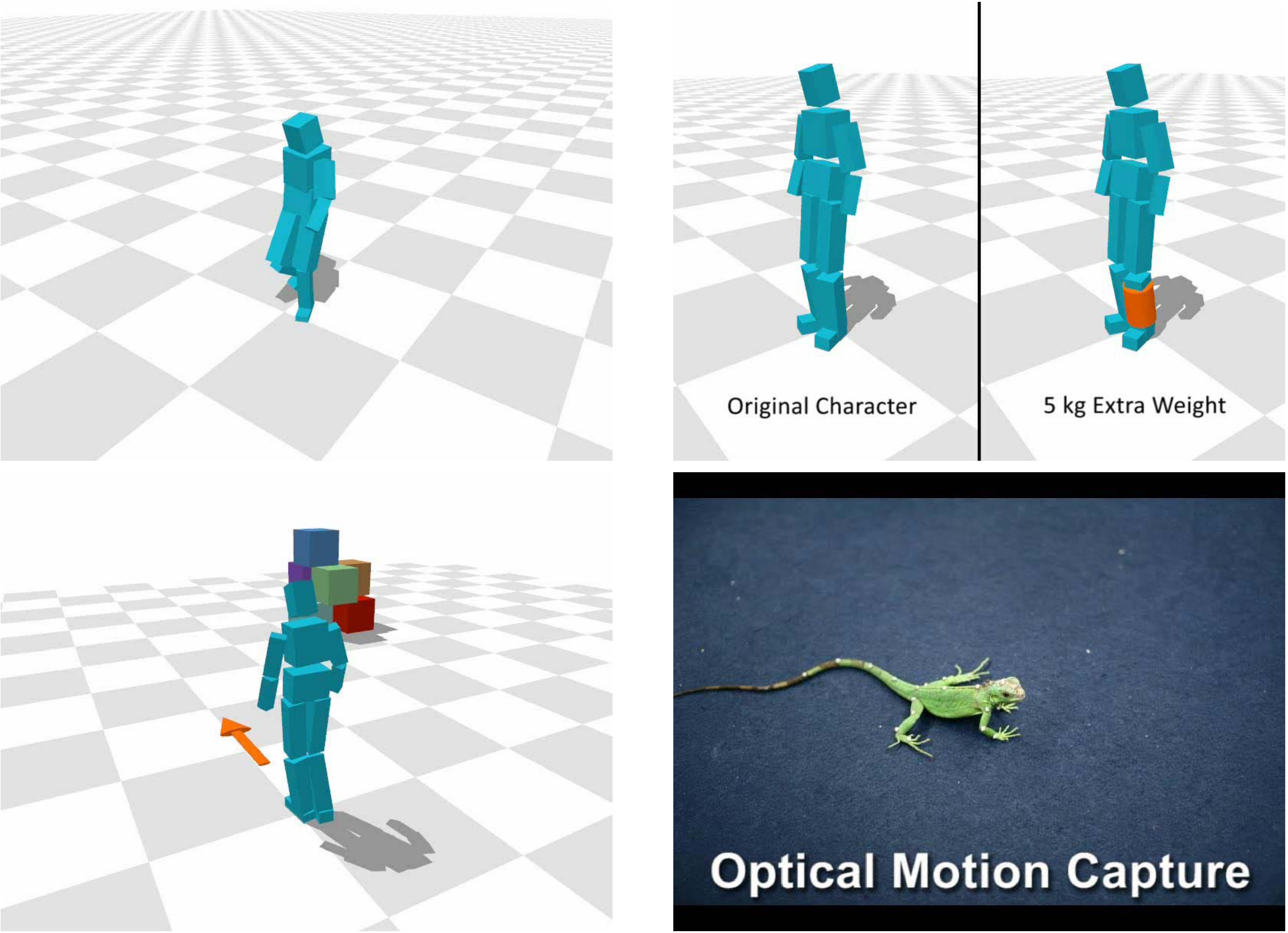
- Generate stream of reference data on-the-fly

Why is this Simple Approach Work?

Human locomotion is inherently robust

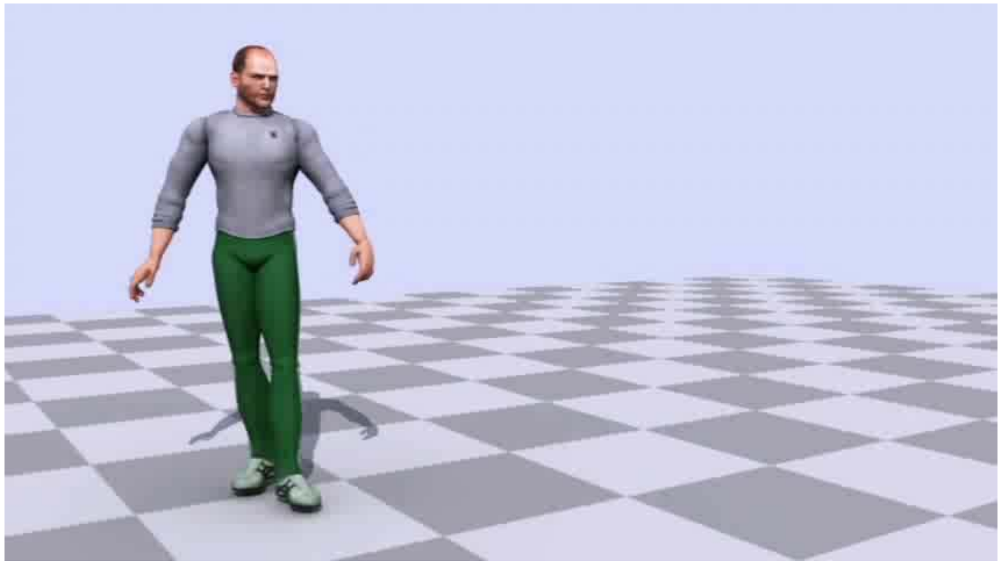
Mimicking what we are doing everyday

- Reference trajectory (learned or innate)
- A little bit of tweaking


Original Character
5 kg Extra Weight
Optical Motion Capture

Editing Dynamic Human Motions via Momentum and Force

This work was done in collaboration with Kwang Won Sok, Katsu Yamane, and Jessica Hodgins (SCA 2010)



Manipulating Momentum/Force

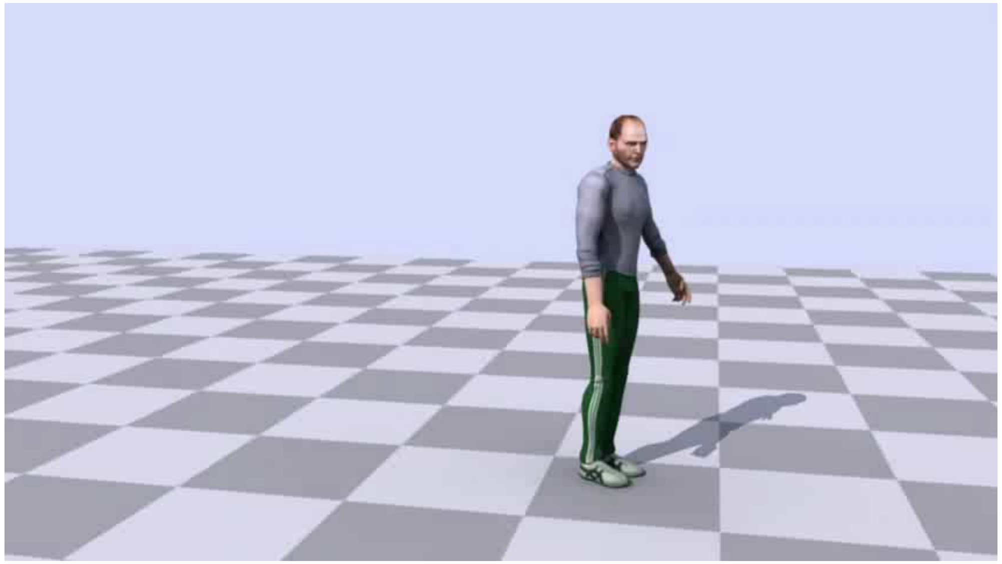
Making dull motion more dynamic

- Jump higher and wider
- Kick harder
- Making super heroes from normal persons

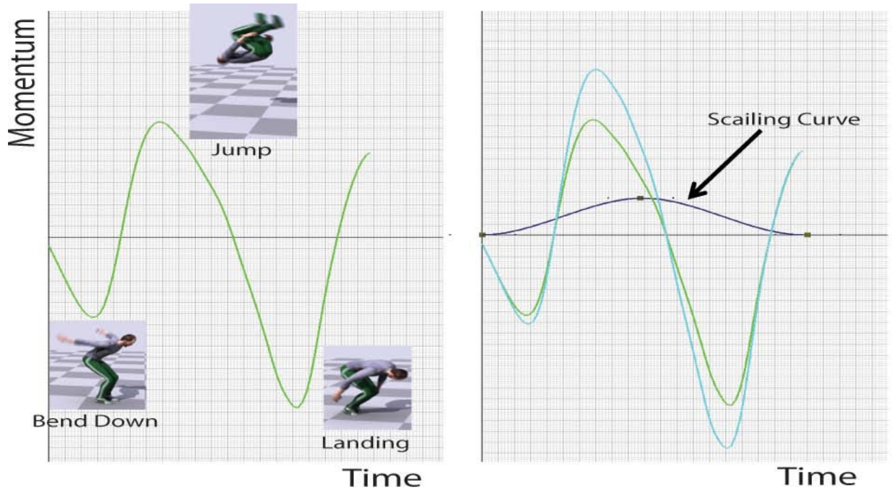
Why is it challenging?

- Need to modulate through multiple channels
- Time, position/orientation, distance
- Linear/angular momentum, force/torque

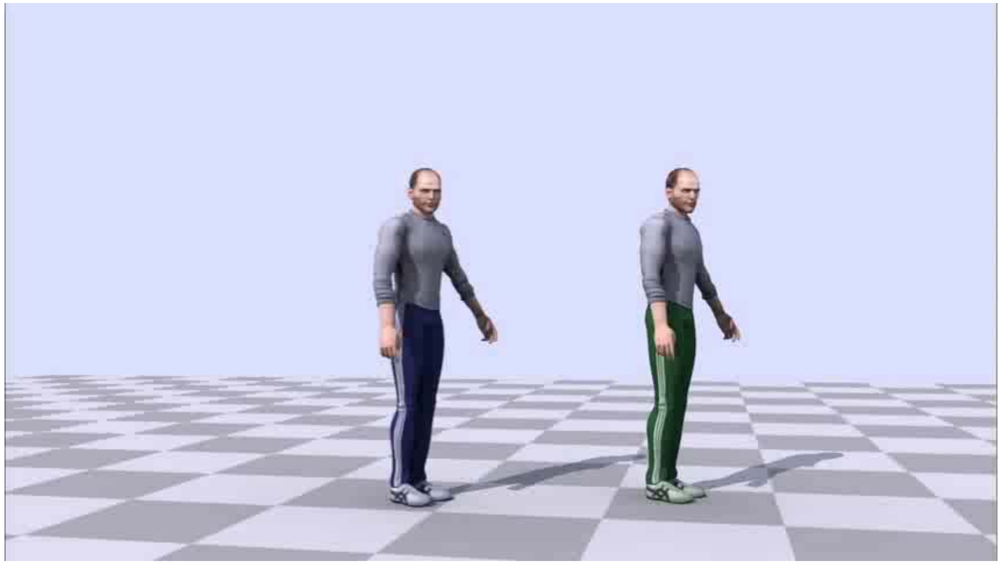
Back Flip



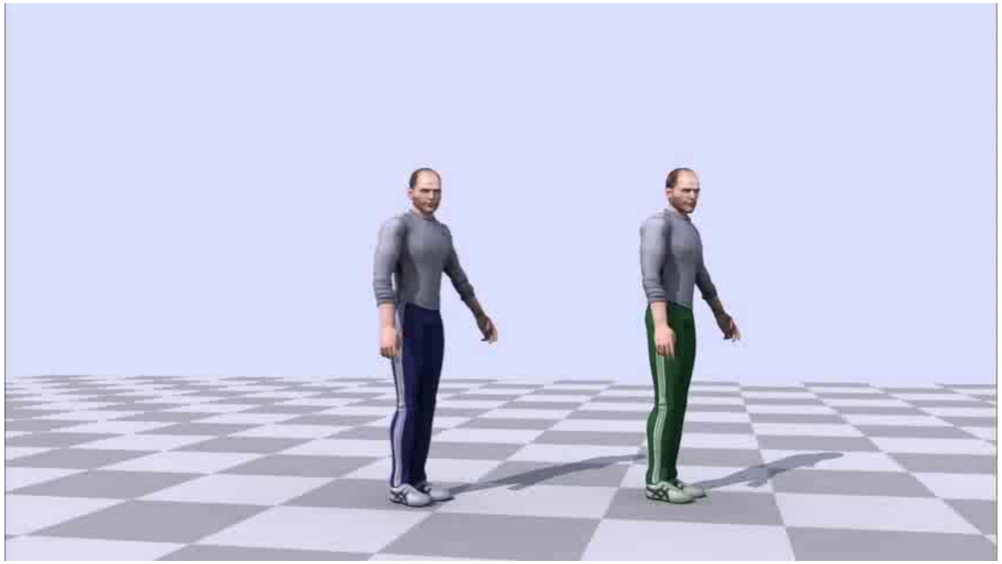
Editing Momentum in Vertical Axis



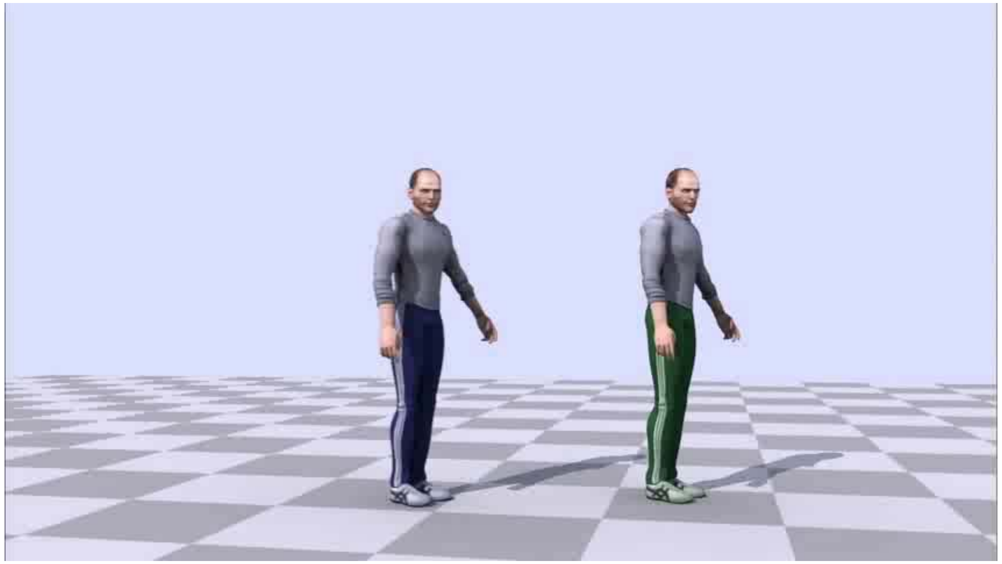
Higher Jump, Fixed Flight Time



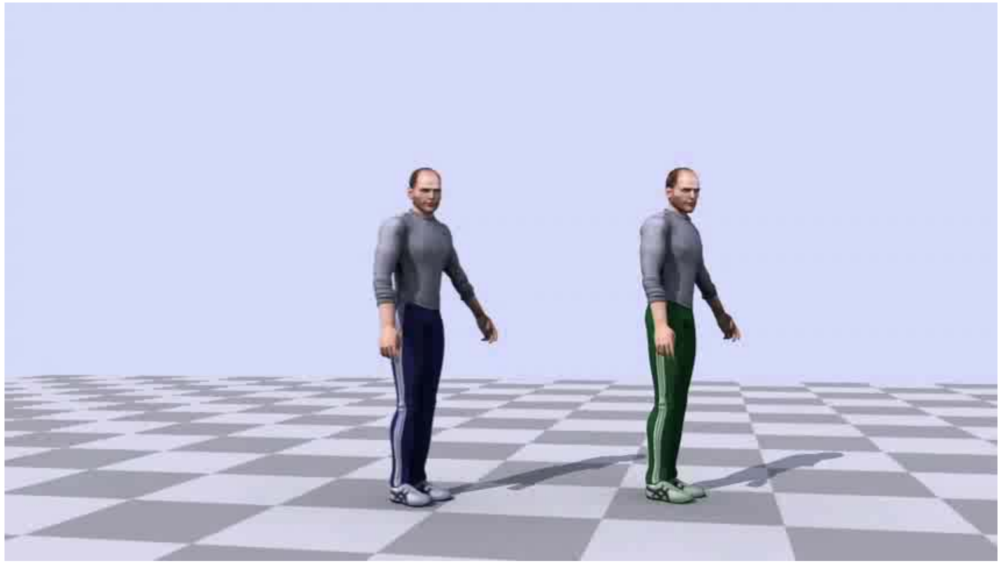
Position Constraint Make Unrealistically Fast Flip



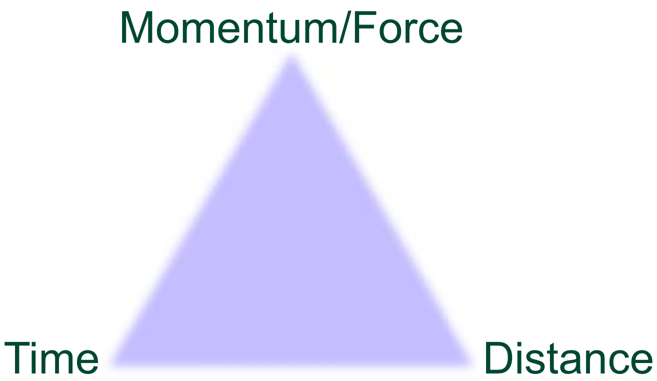
Time Scaling Makes Moon Jump



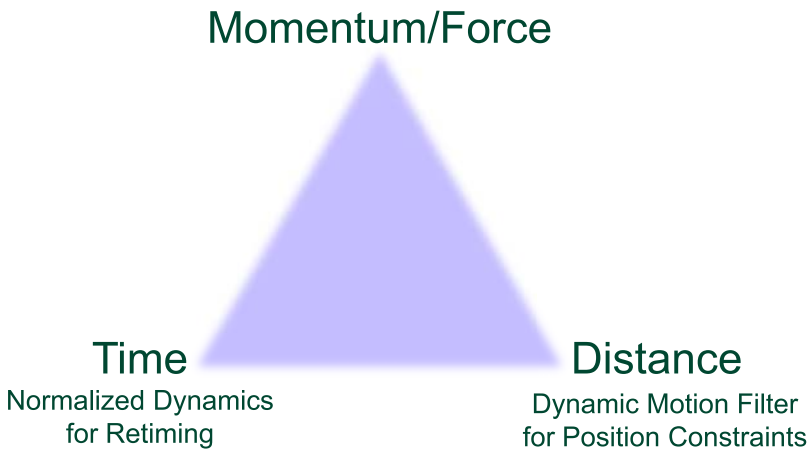
Physically Plausible, Higher Jump

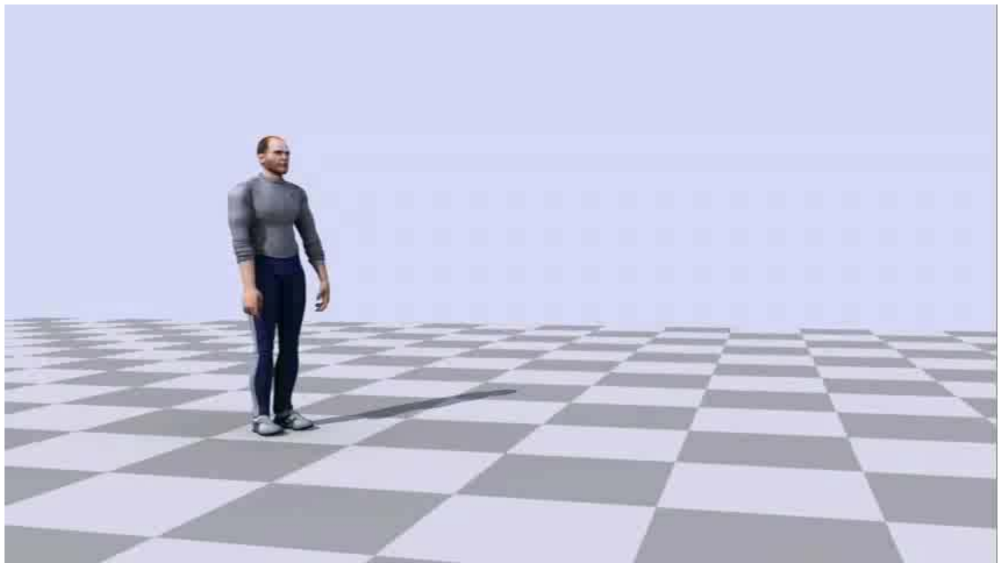


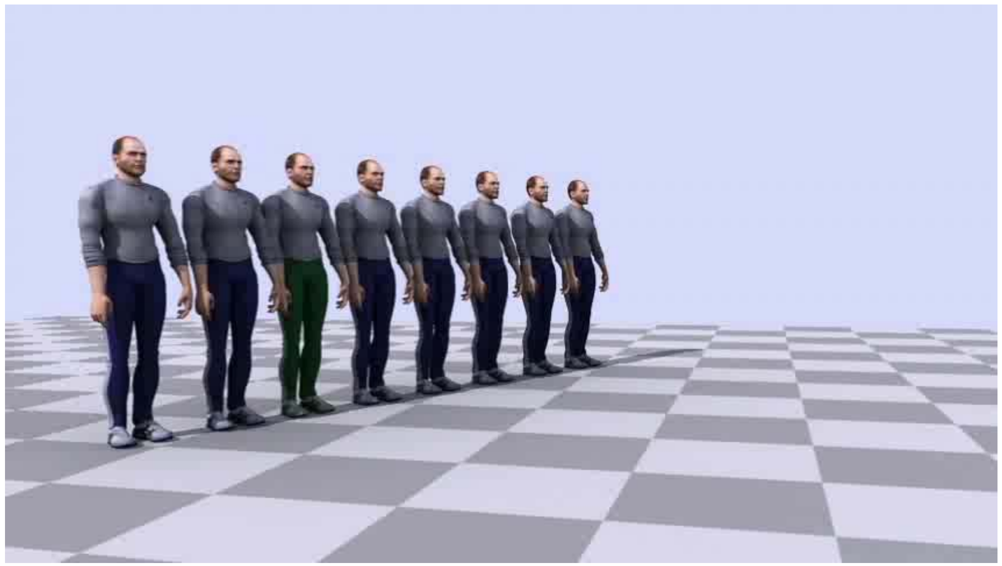
Reciprocity

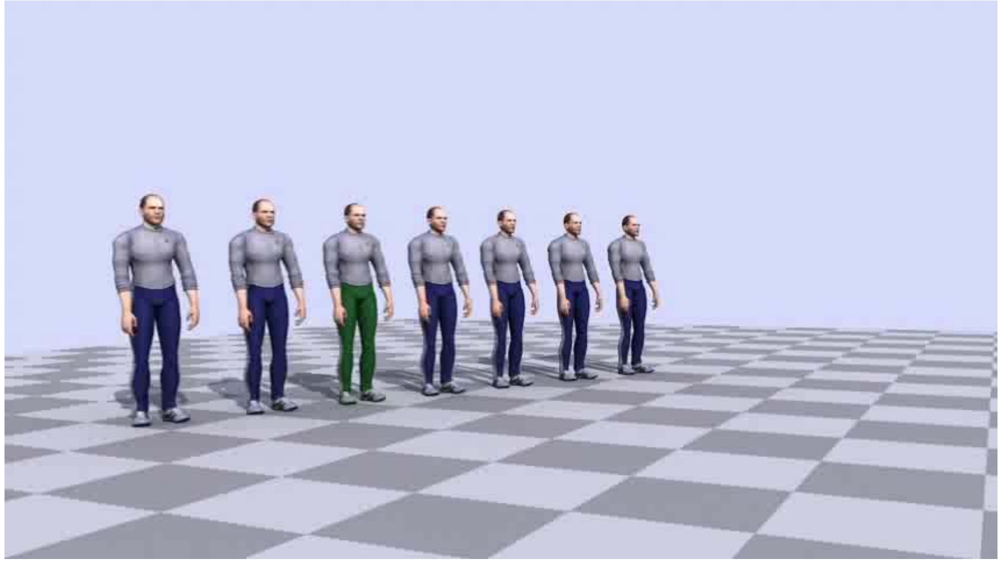
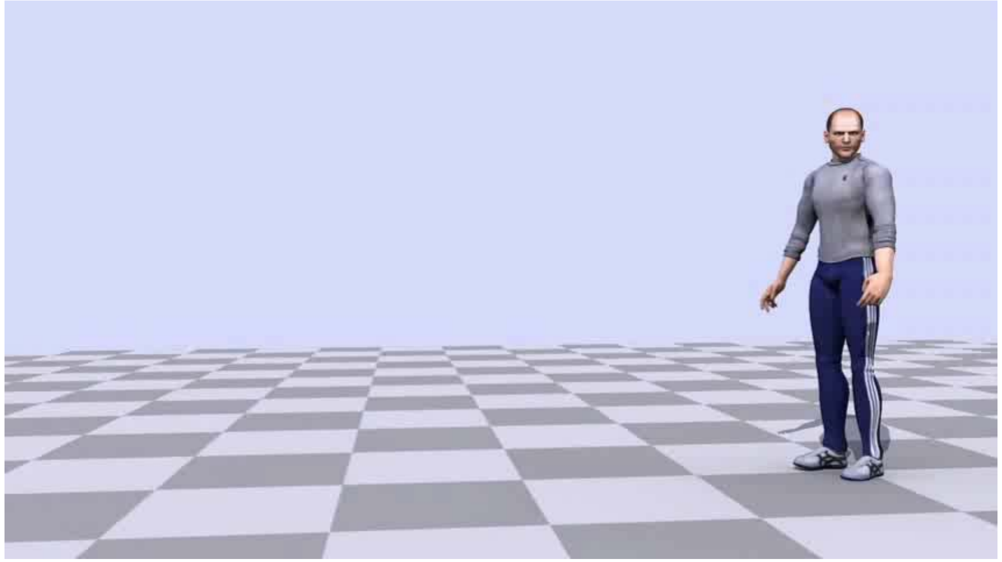
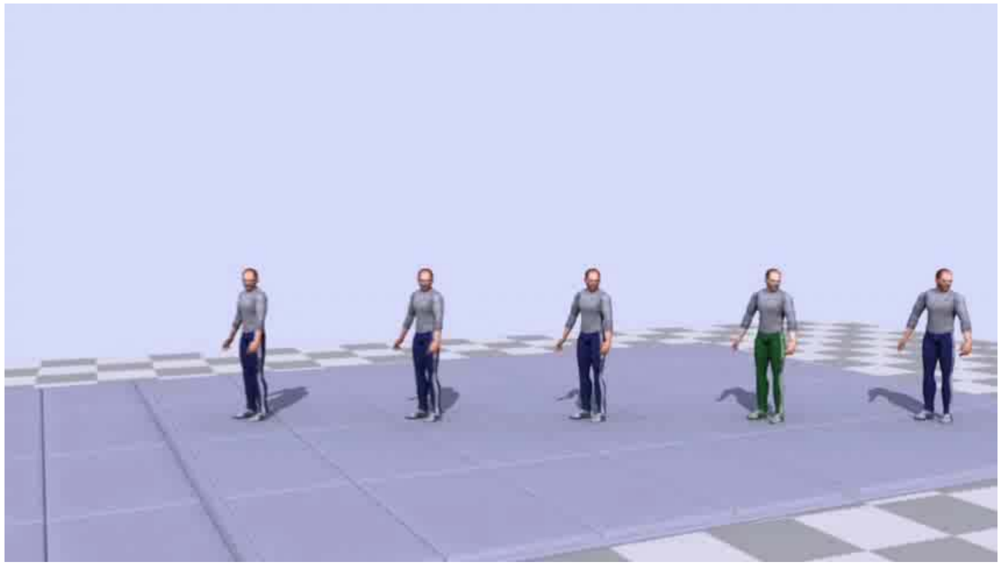


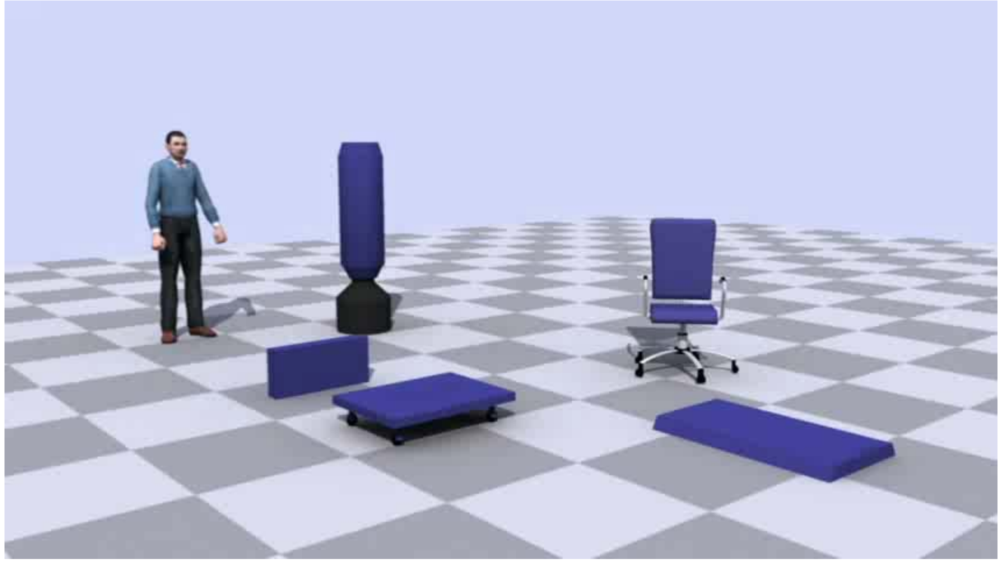
Reciprocity

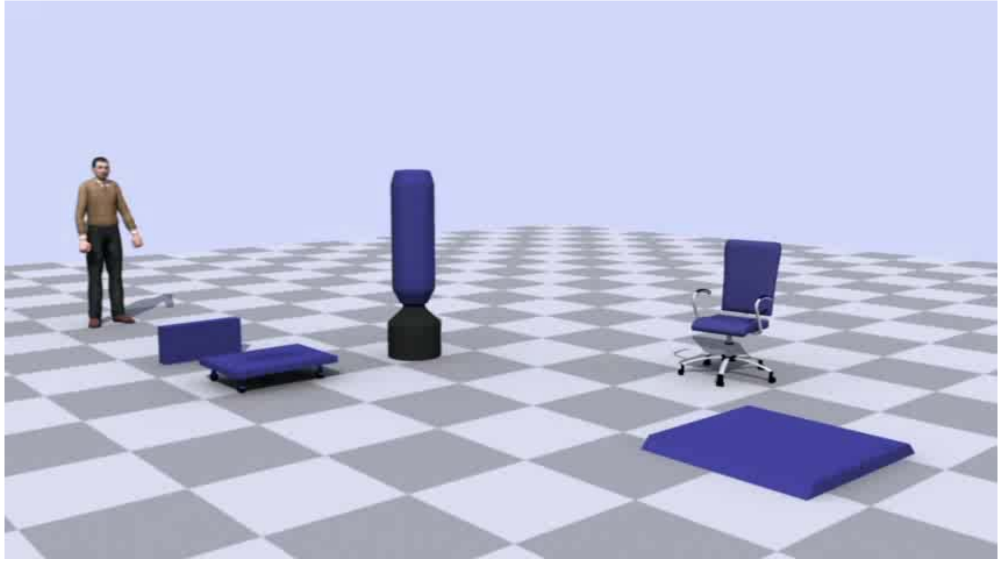








Physical Plausibility

We obey some of physics

- Momentum conservation
- Consistent with given momentum profiles

Not completely physically correct

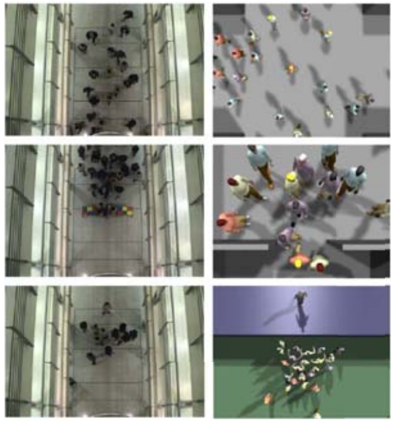
- Possible violation of friction cone/torque limit
- Original motion may not be physically plausible

Data-Driven Crowds

Record real human crowds

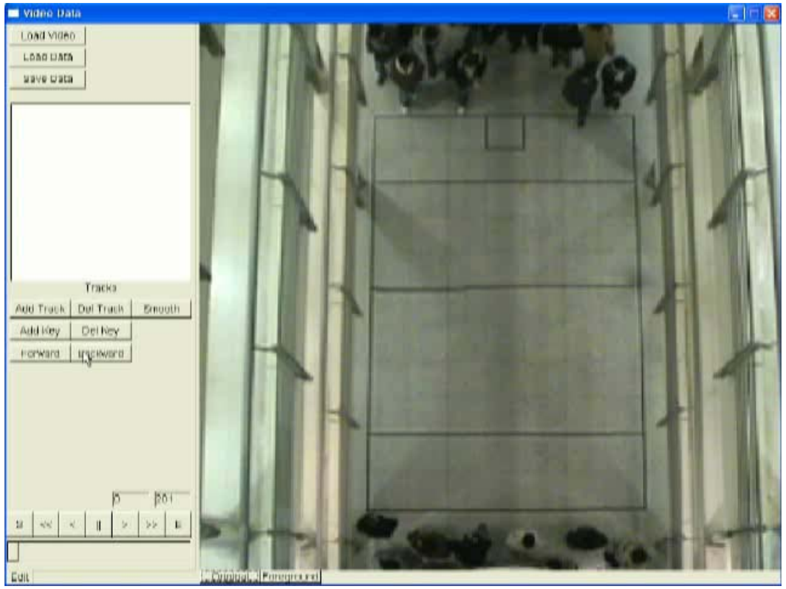
Reproduce their behaviors in virtual crowds

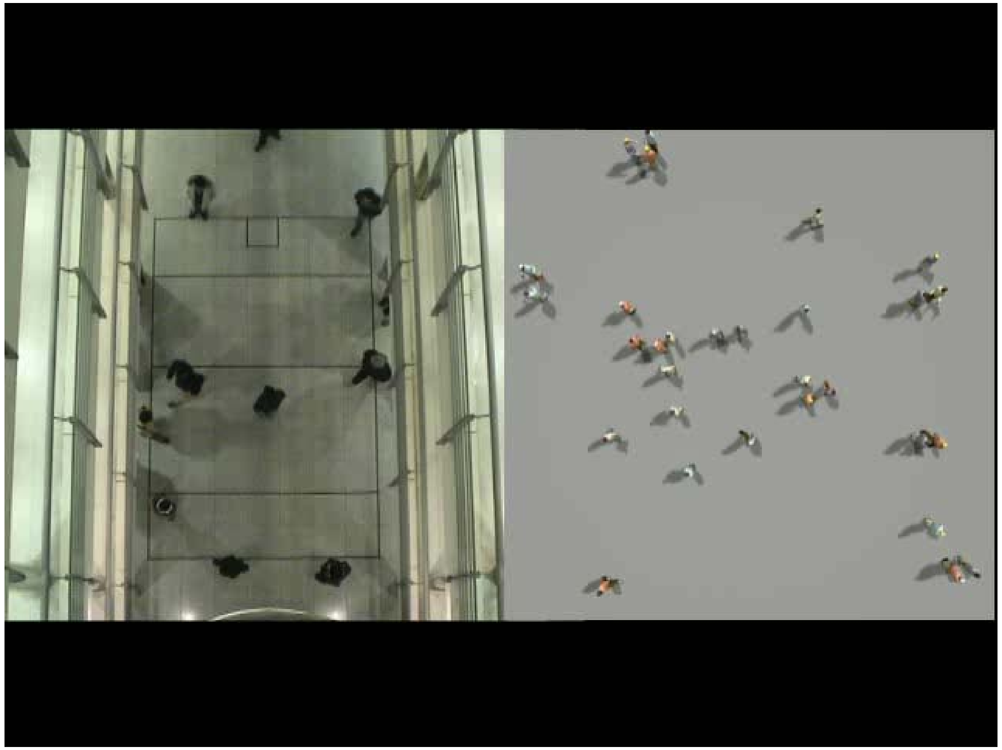
Generalize, manipulate, blend crowd data



This work was done in collaboration with Eunjung Ju, Kang Hoon Lee, Myung Geol Choi, Minji Park, Qyoun Hong, Shigeo Takahashi

Tracking Pedestrians

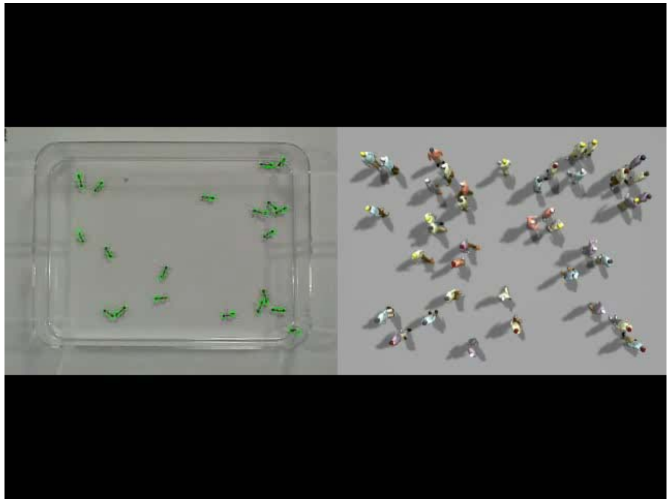




Lining Up

Cluttered Formation

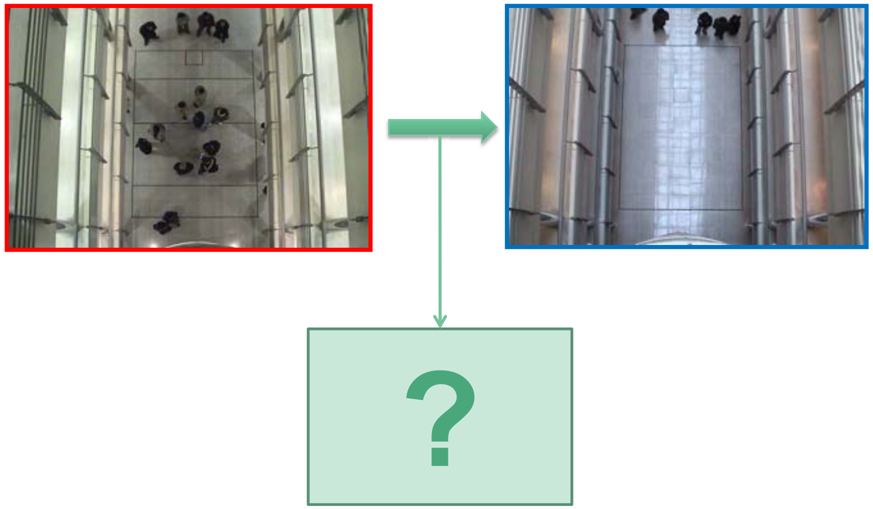
Group Behavior of Ants



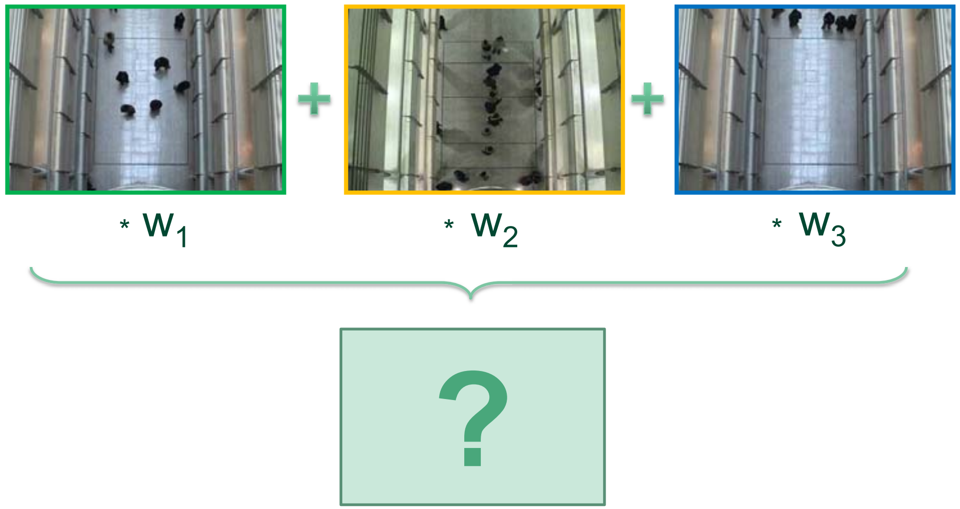
Each Crowd Exhibit Particular "Style"

- Density, locomotion styles
- Regularity/persistency of formations
- Distribution of individual velocities
- Reaction to potential collisions

Style Transition



Interpolating Crowd Styles



Why is it Challenging?

Unstructured formation

- Random, regular, clustered
- Persistent vs time-varying

Crowds are time-series data

- Eg) Aggressive pedestrians try to pass each other

Arbitrary number of agents

- No one-to-one correspondence

Data-Driven Crowd Model

Collect state-action pairs from training data

Features include

- Formation of neighbors
- Speed
- Intended moving direction
- Presence of obstacles
- Relative location with respect to environment objects

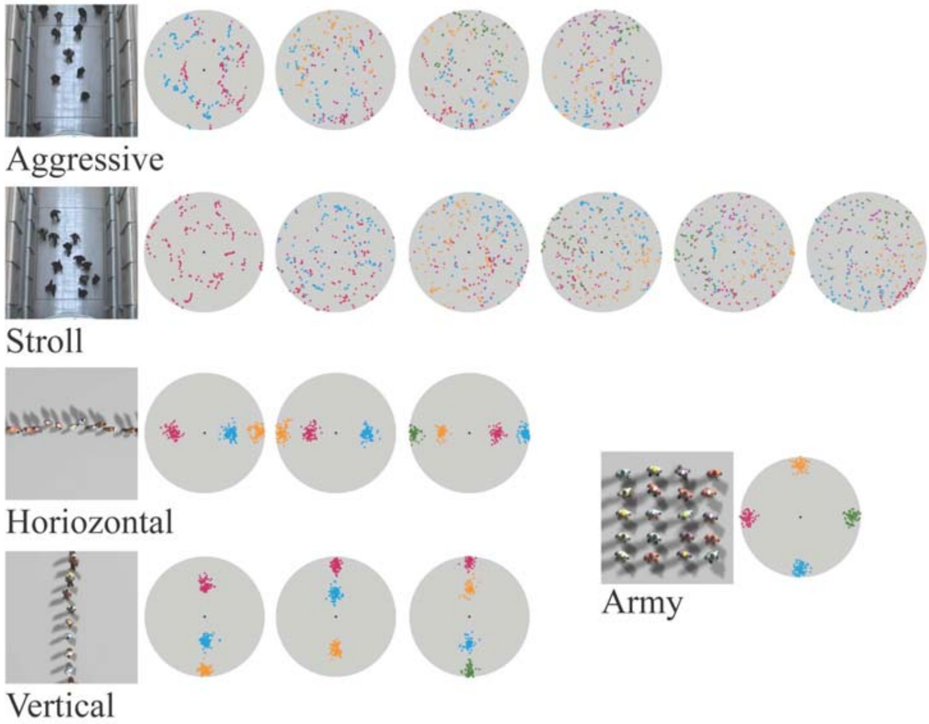
Morphable Crowds

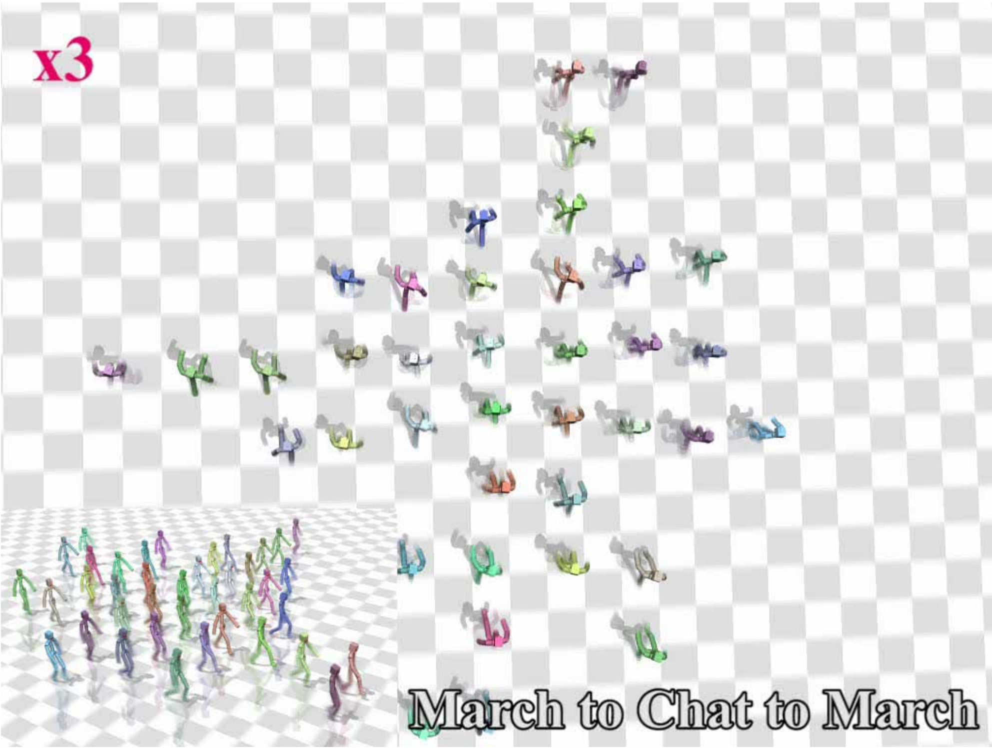
Interpolate models instead of data

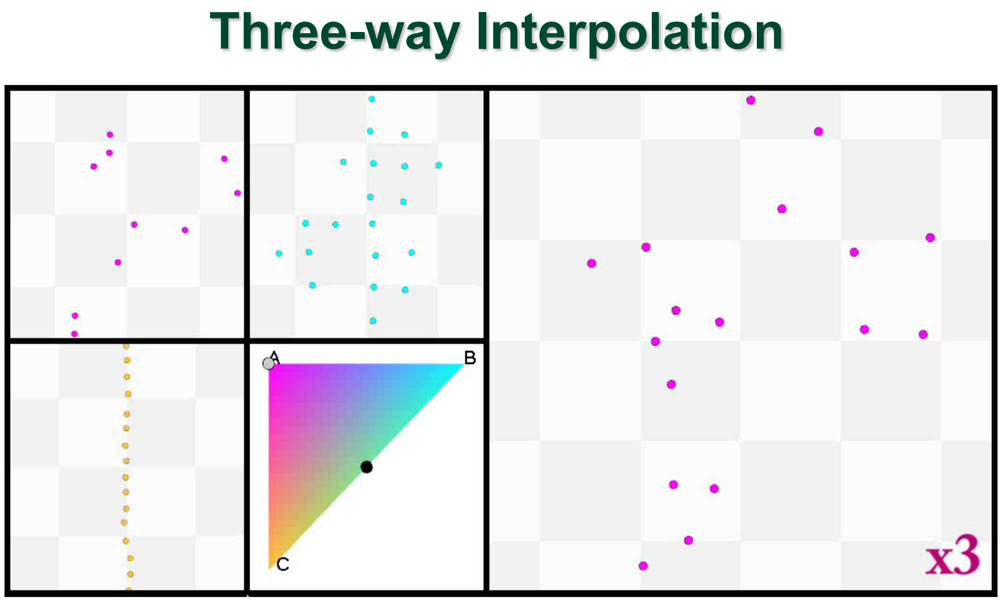
Models should have blendable features

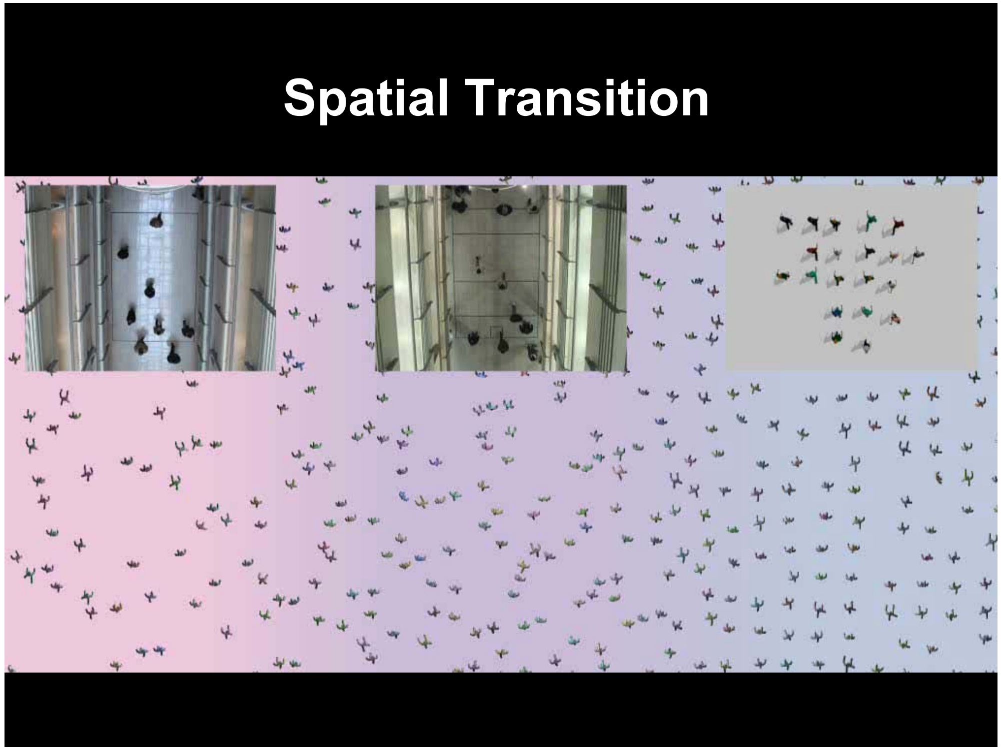
Sampling-based modeling of

- high-dimensional neighborhood formation
- individual trajectory

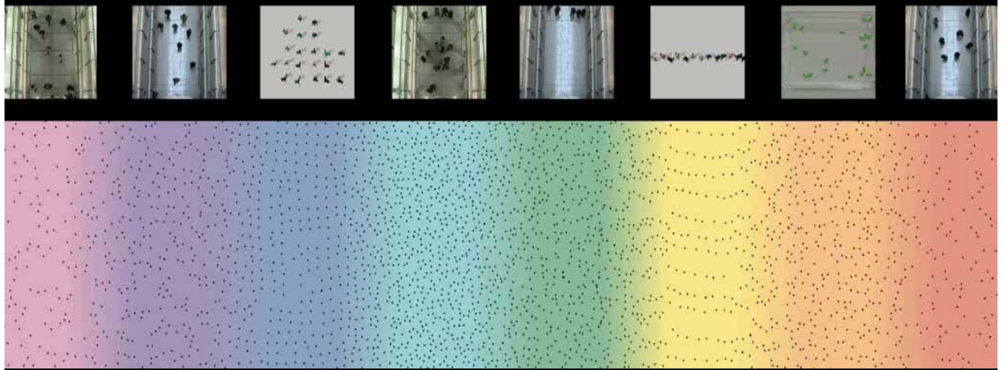



x3
March to Chat to March


Three-way Interpolation
A
B
C
x3


Spatial Transition

Spatial Transition

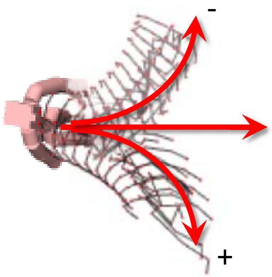


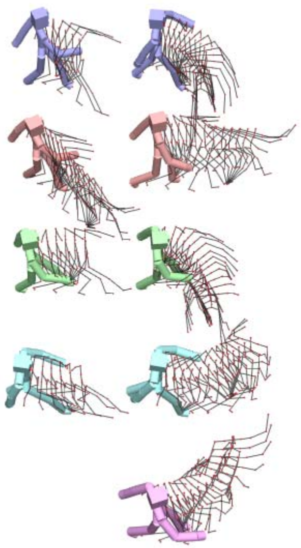
Deformable Motion: Squeezing into Cluttered Environments

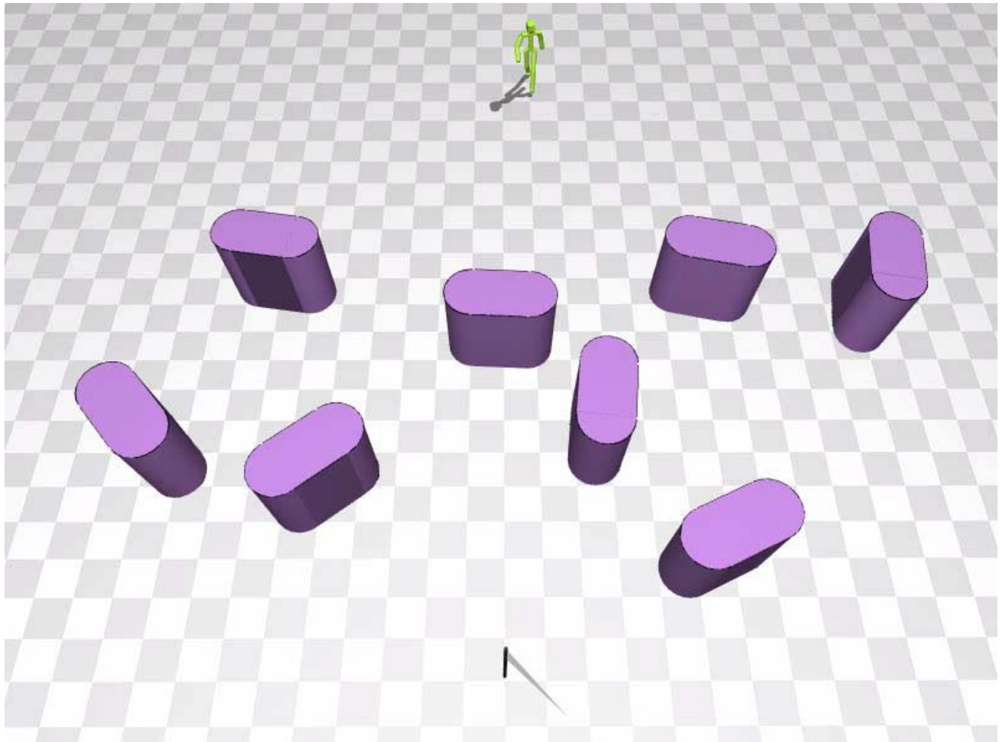
This work was done in collaboration with Myung Geol Choi, Manmyung Kim, Kyung Lyul Hyun

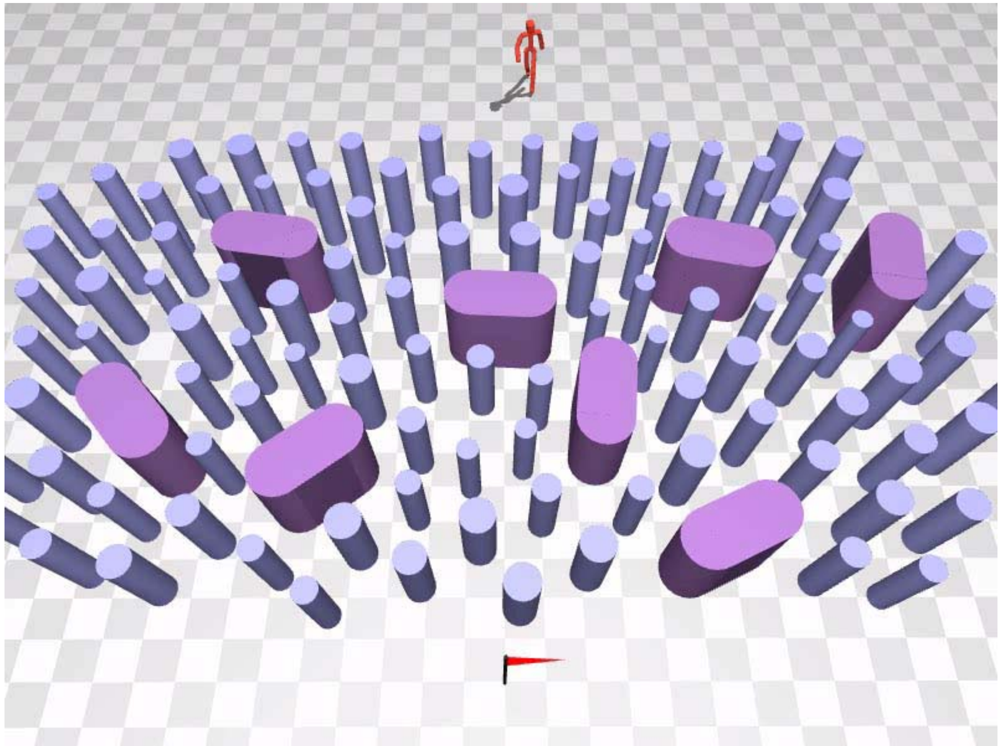
Path Planning with Motion Graphs

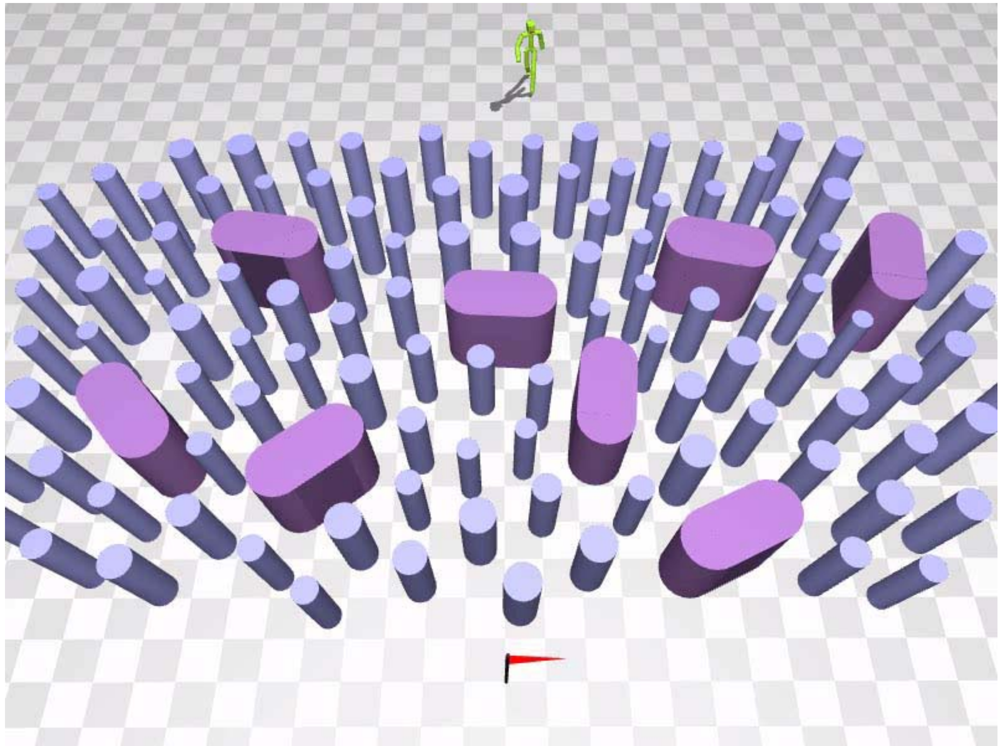
- Repertoire of motion choices
- Linear warping to add flexibility
- (Limited horizon) A*-search



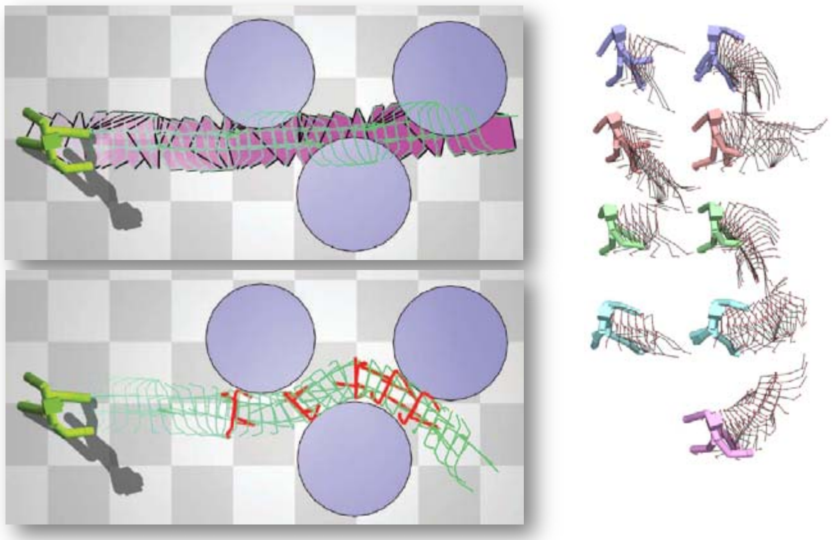




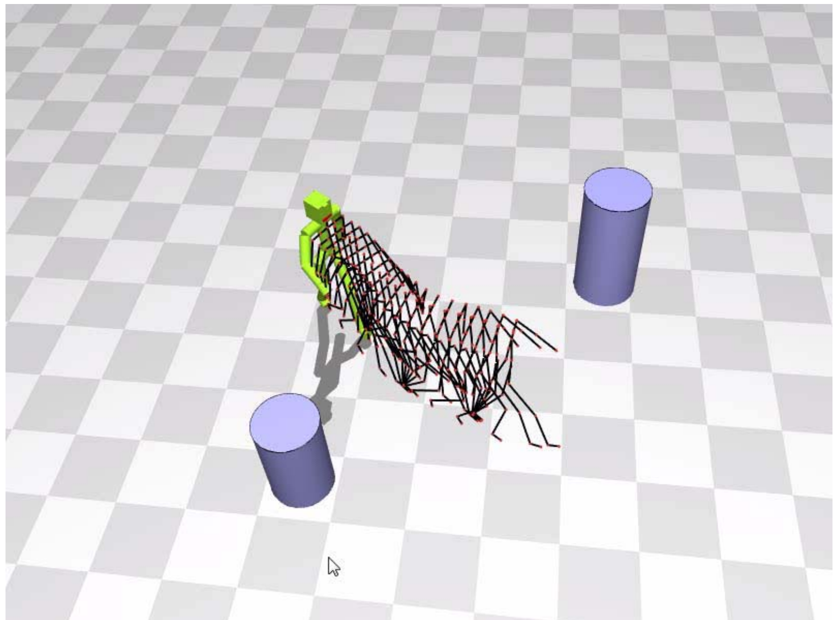




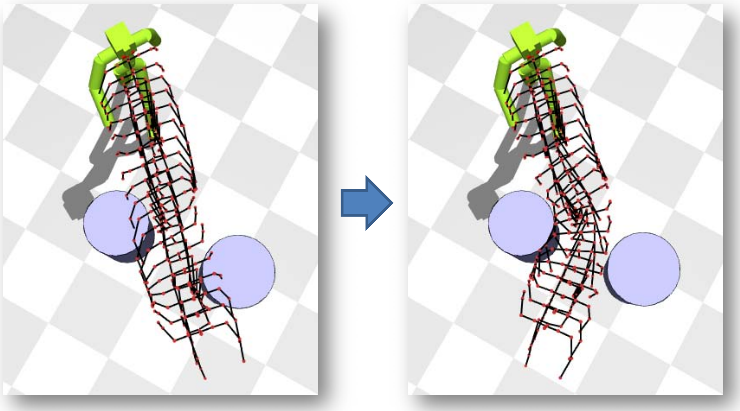
Highly-Constrained Environment



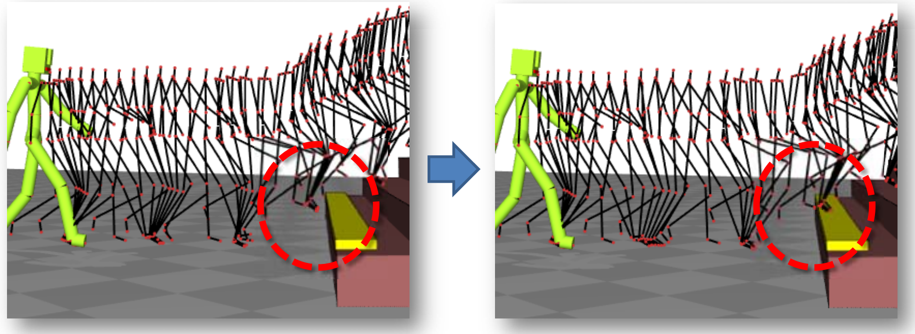
Deformable Motion



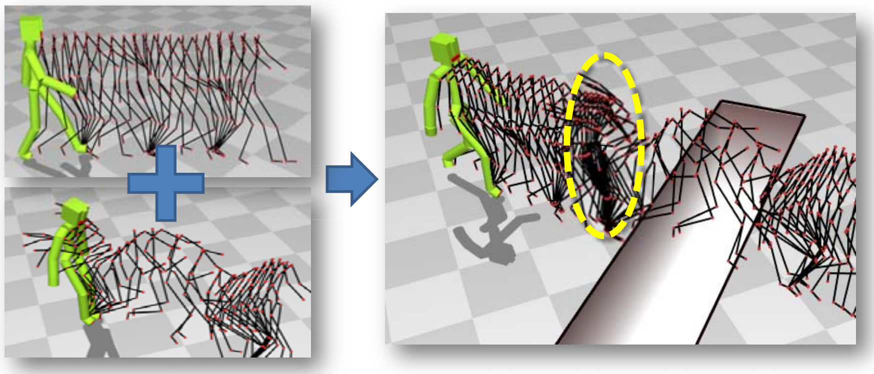
Non-Penetration Constraints



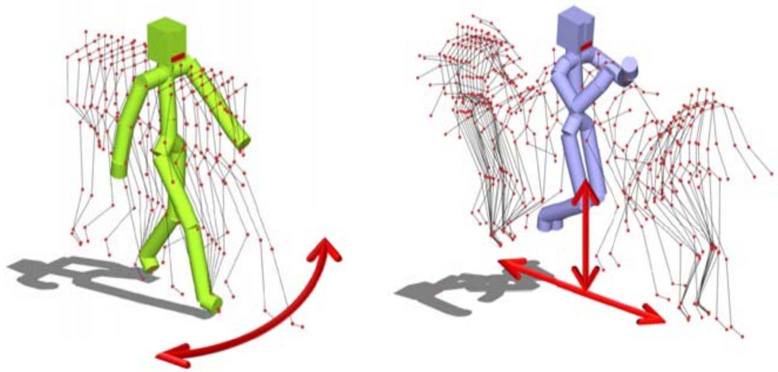
Contact Constraints

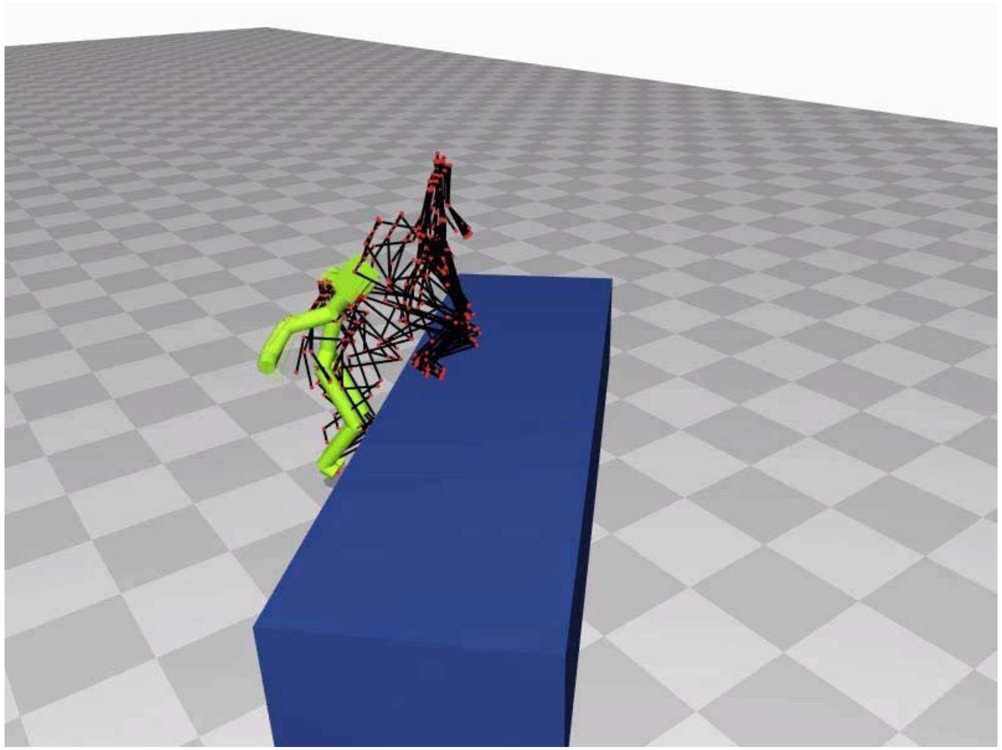


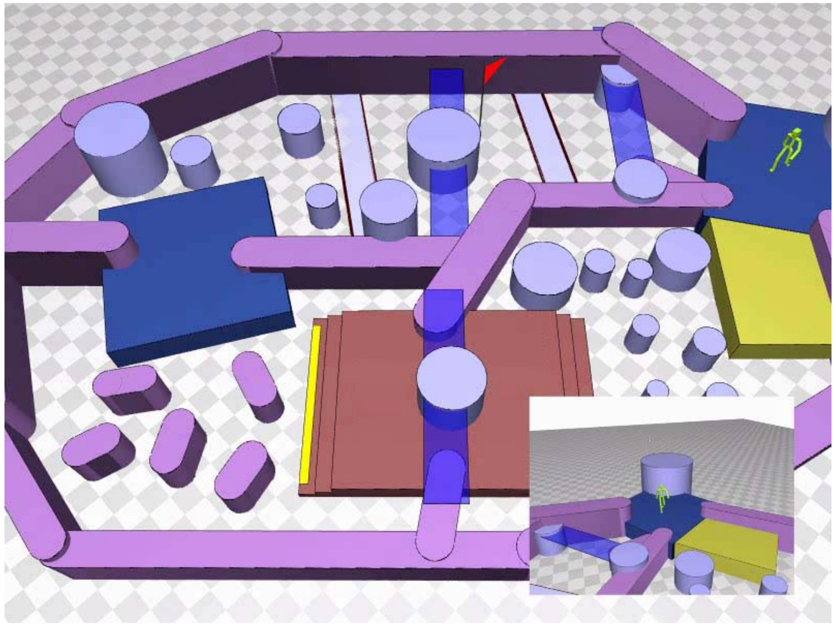
Continuity Constraints



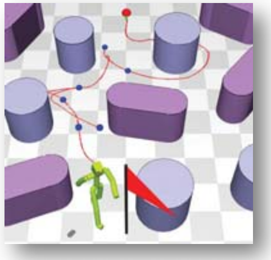
Motion Constraints



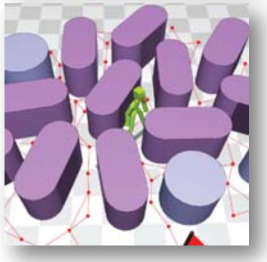




Global Path Planning

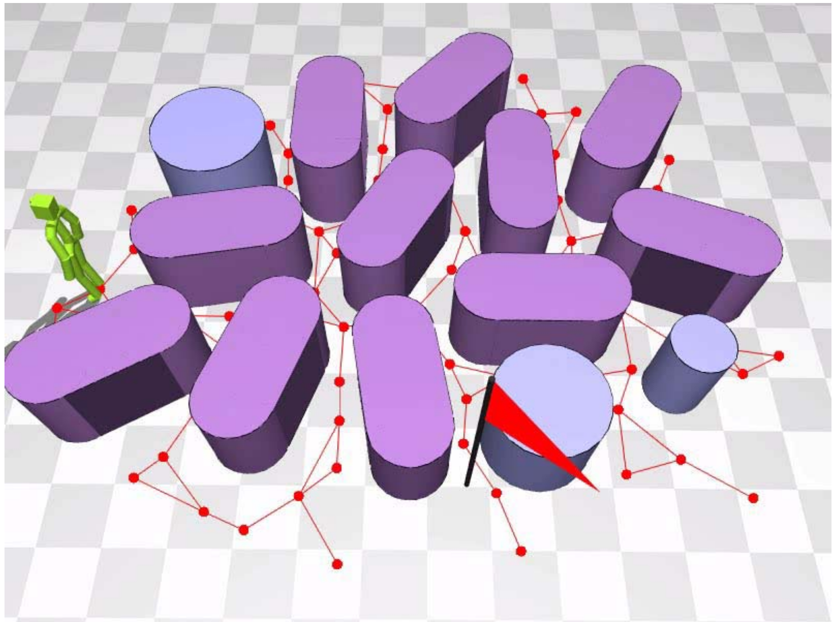


Rapidly-exploring random trees (RRT)



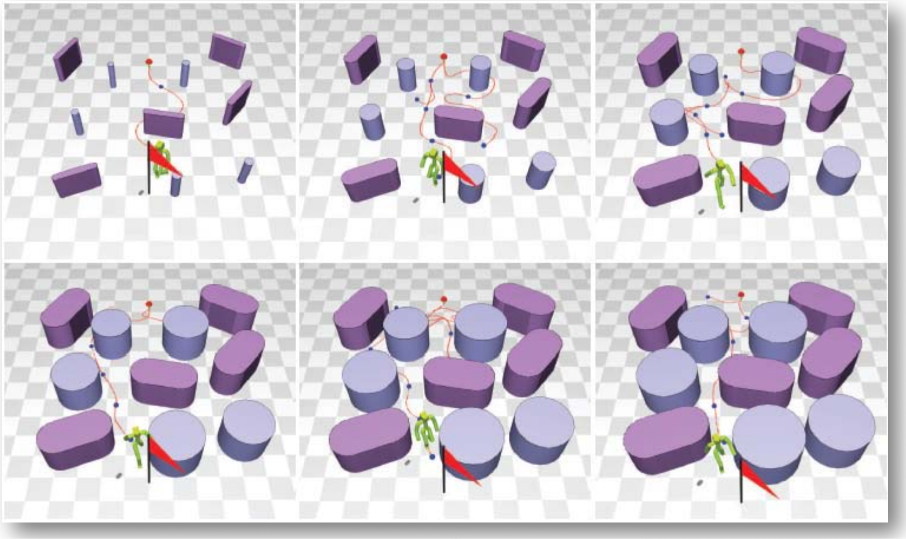
Probabilistic Roadmap (PRM)

PRM for Narrow Passages



Linear Warping vs. Deformable Motion

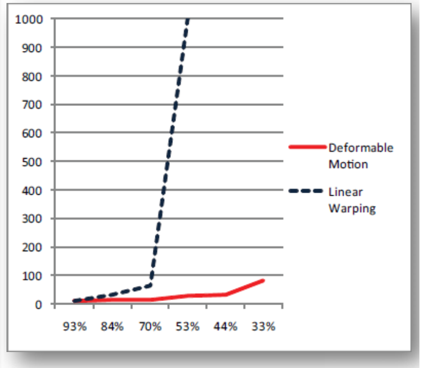
RRTs for progressively denser environments



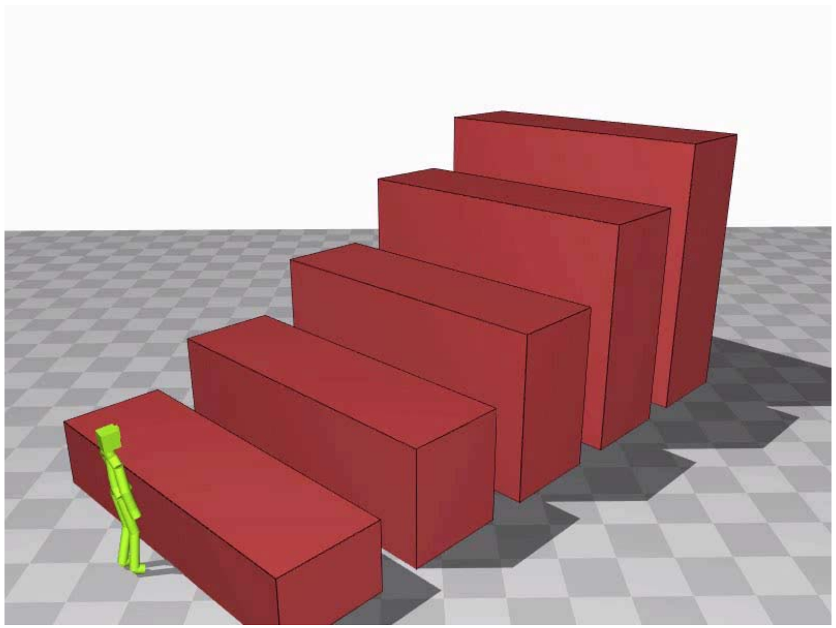
Linear Warping vs. Deformable Motion

Free Space	Deformable Motion	Linear Warping
93%	10.71(0.28)	9.43(1.29)
84%	14.00(1.29)	30.43(13.29)
70%	14.57(4.29)	63.86(36.71)
53%	29.00(7.14)	1007.29(803.57)
44%	32.00(10.43)	∞
33%	81.43(43.86)	∞

average # of sampling (failure)



Dynamic Environment

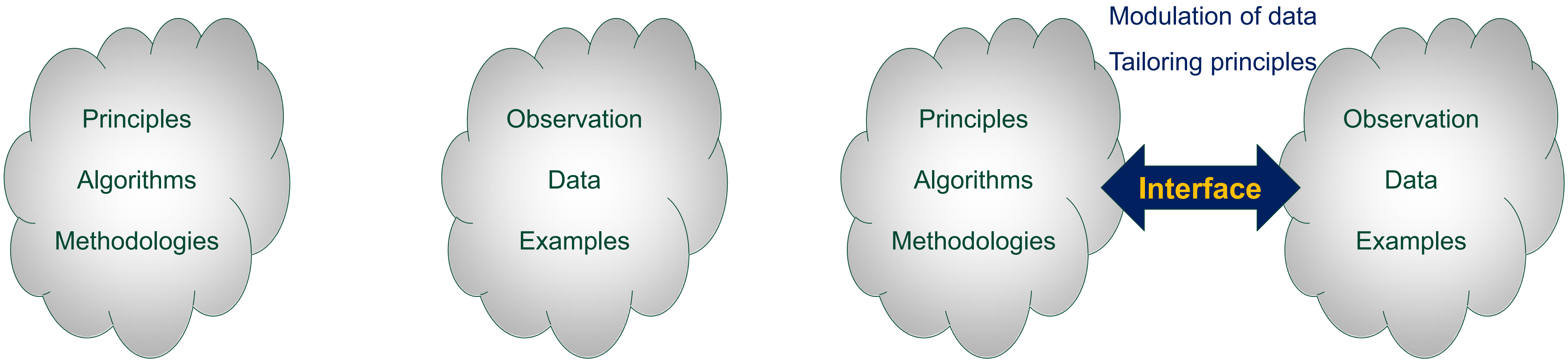


Why does it Work?

Known algorithms + motion data

- Adding flexibility on data makes big difference
- Mimicking what we are doing everyday

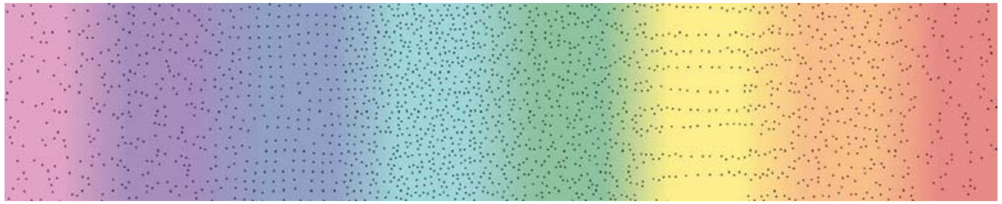
Powerful local planner for narrow passages



Complexity **Size** **Simplicity** **Small**

The papers and videos are available at **SNU Movement Research Lab**

http://mrl.snu.ac.kr



Collaborators

Myung Geol Choi, Kyung Lyul Hyun, Eunjung Ju, Manmyung Kim, Sungeun Kim, Kang Hoon Lee, Yoonsang Lee, Minji Park, Kwang Won Sok, Jessica Hodgins, Shigeo Takahashi, Katsu Yamane