Simulation and Control of Skeleton-driven Soft Body Characters

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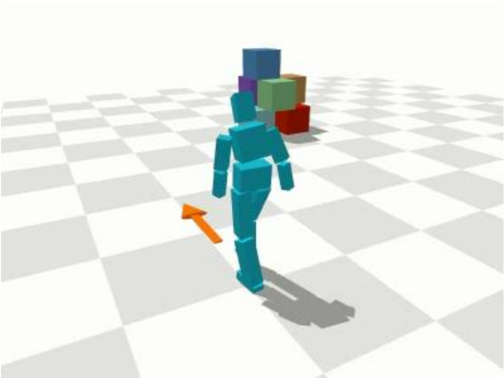
Motivation

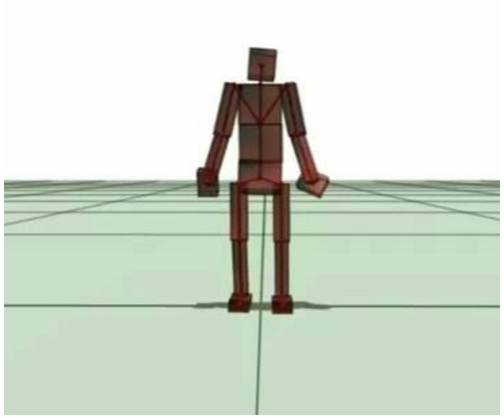
- Simulation and Control of Rigid Body Characters



[Lee et al. 2010]

[Coros et al. 2010]

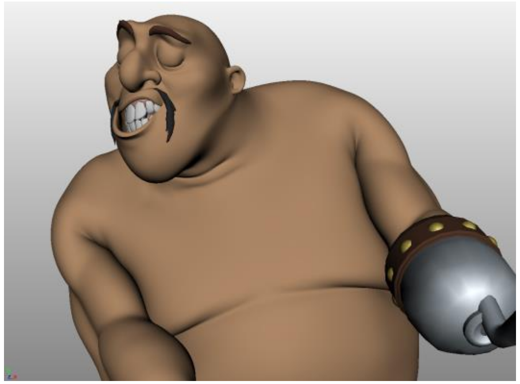
[Liu et al. 2012]



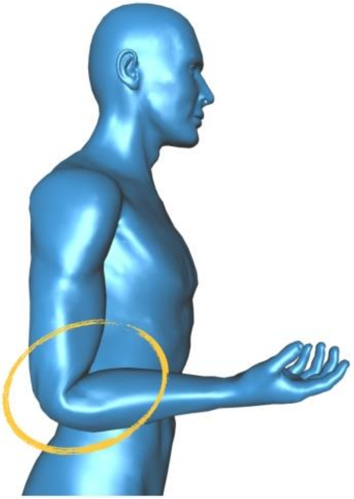
[Al Borno et al. 2013]

Motivation

- Deformation as Secondary Animation
  - Skinning



[McAdams et al. 2011]



[Kavan and Sorkine 2012]

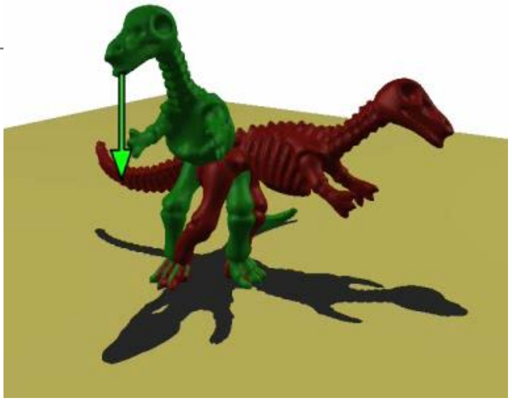
  - Skeleton-driven jiggling

[Capell et al. 2002]

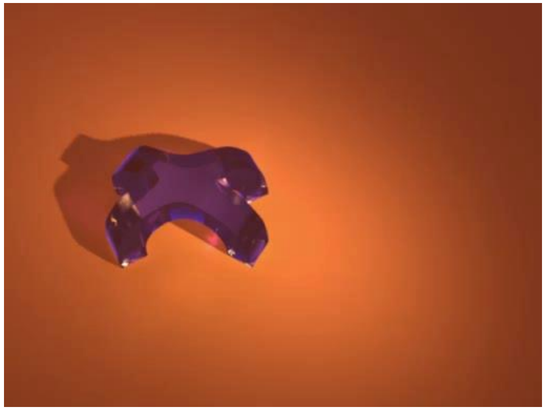
[Kim and Pollard 2011]

Motivation

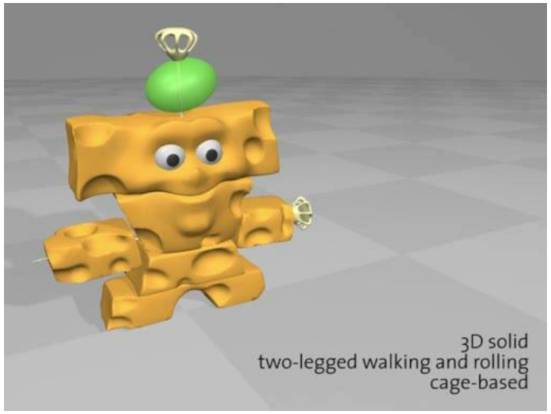
- Controllable Soft Bodies
  - External force
  - Internal force
    - Muscle fibers
    - Rest shapes
  - Skeleton-driven



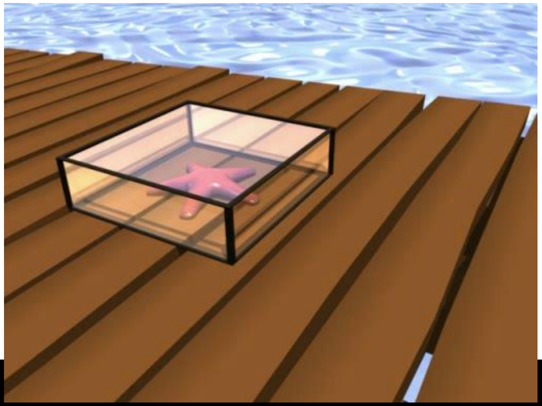
[Barbič and Popović 2008]



[Tan et al. 2012]



[Coros et al. 2012]

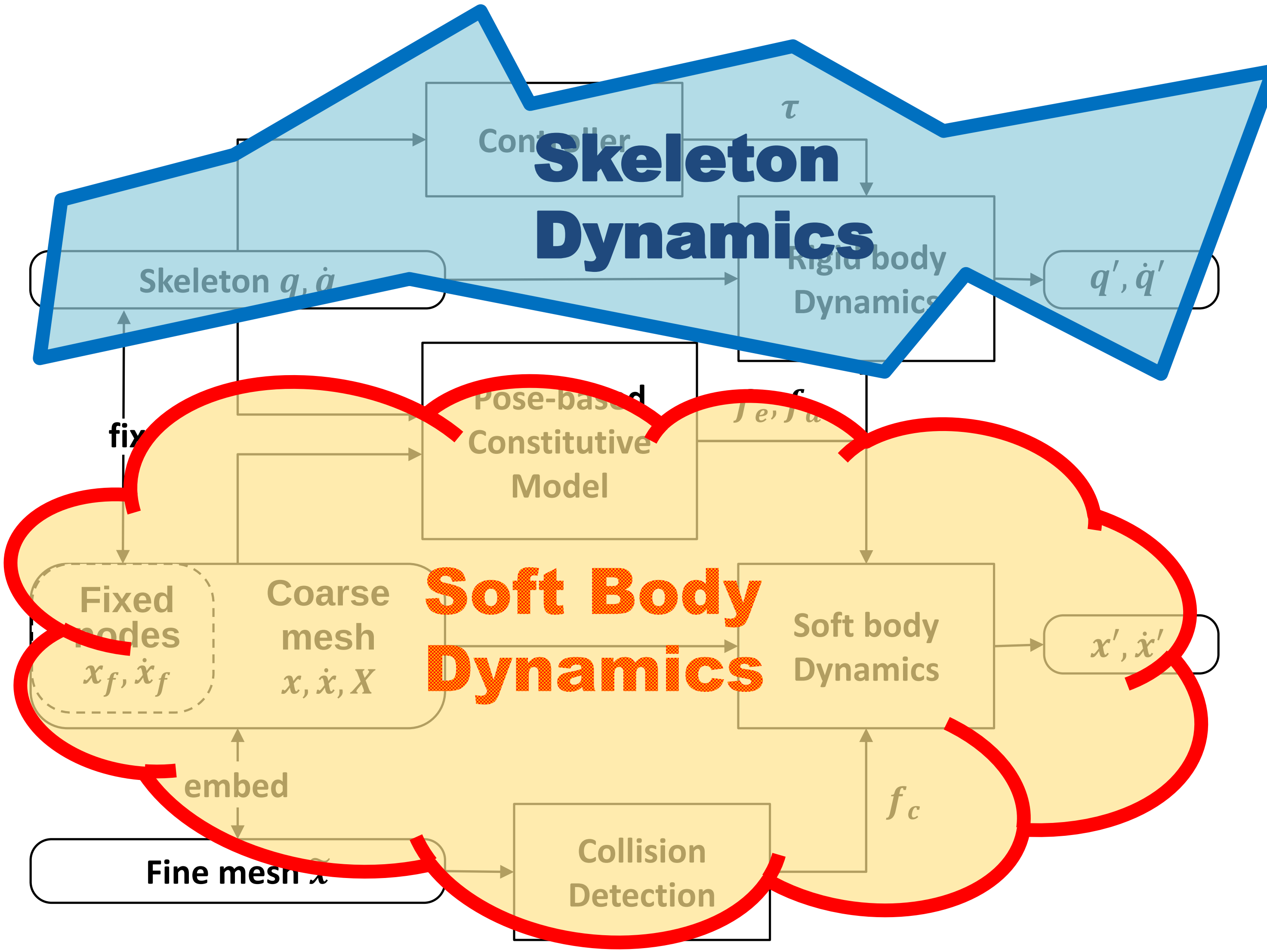


[Kim and Pollard 2011]

Outline

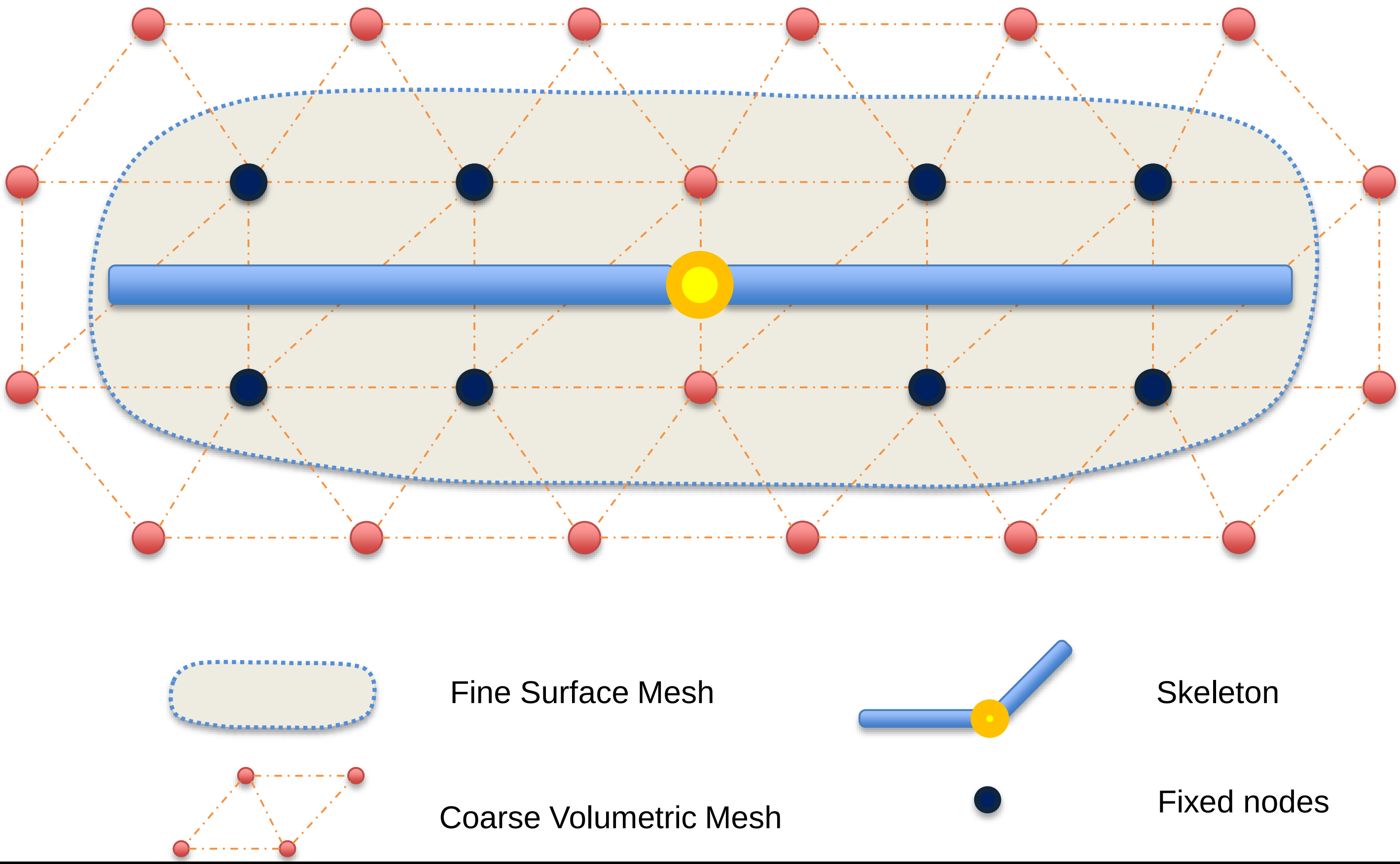
- Motivation
- System Overview
- Skeleton-driven Soft Body Dynamics
  - Skeleton dynamics
  - Soft body dynamics
- Motion Control
  - Inverse dynamics
  - Time scaling
- Conclusion

System Overview



System Overview

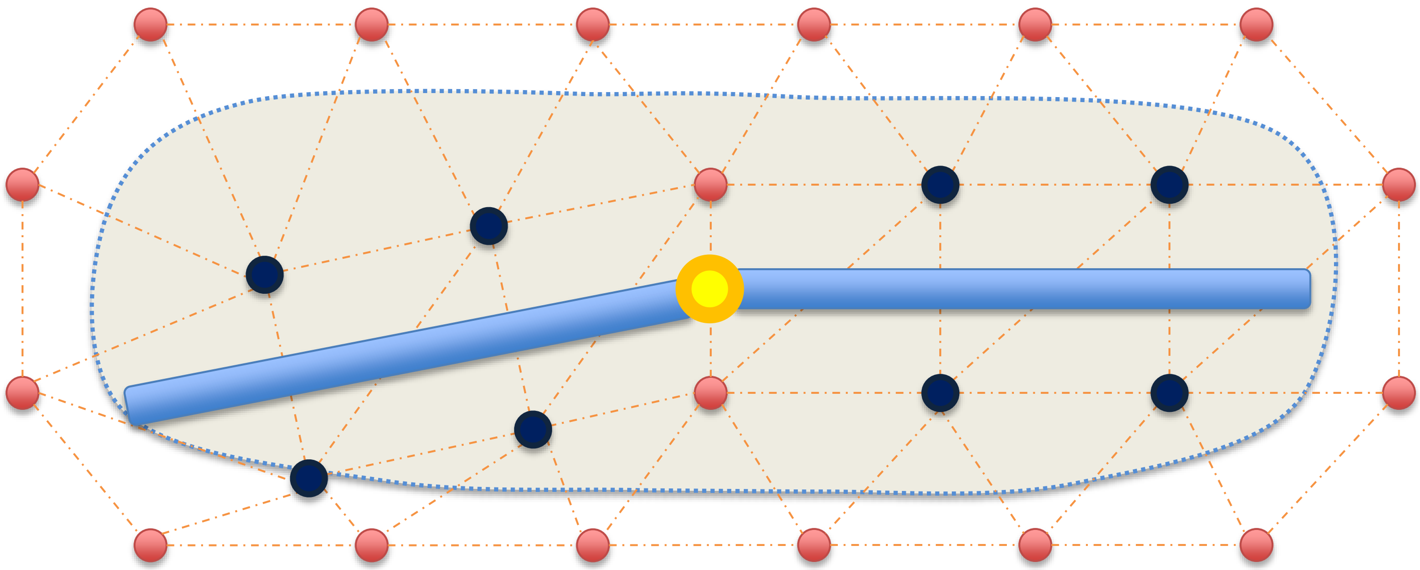
Skeleton & Soft Body



System Overview

Simulation

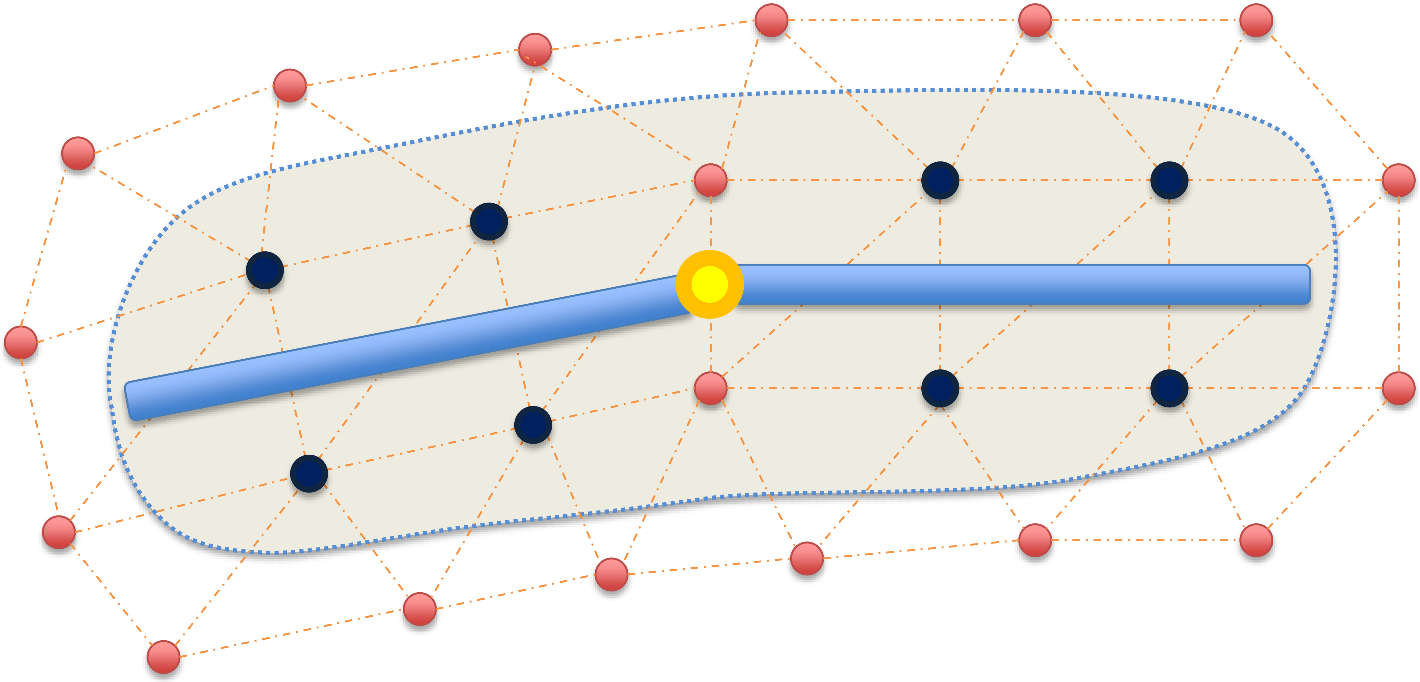
Simulate skeleton



System Overview

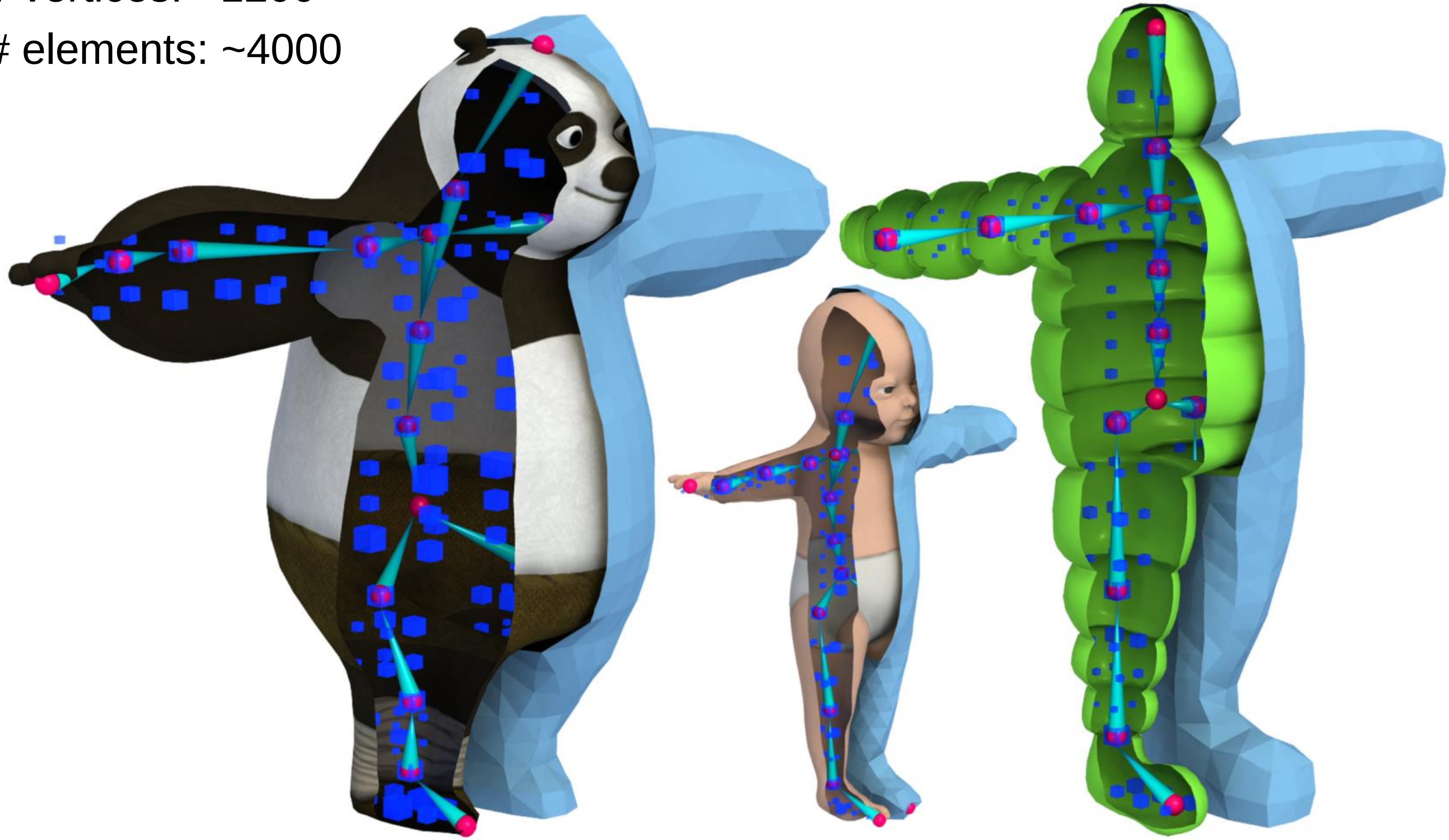
Simulation

Simulate soft body

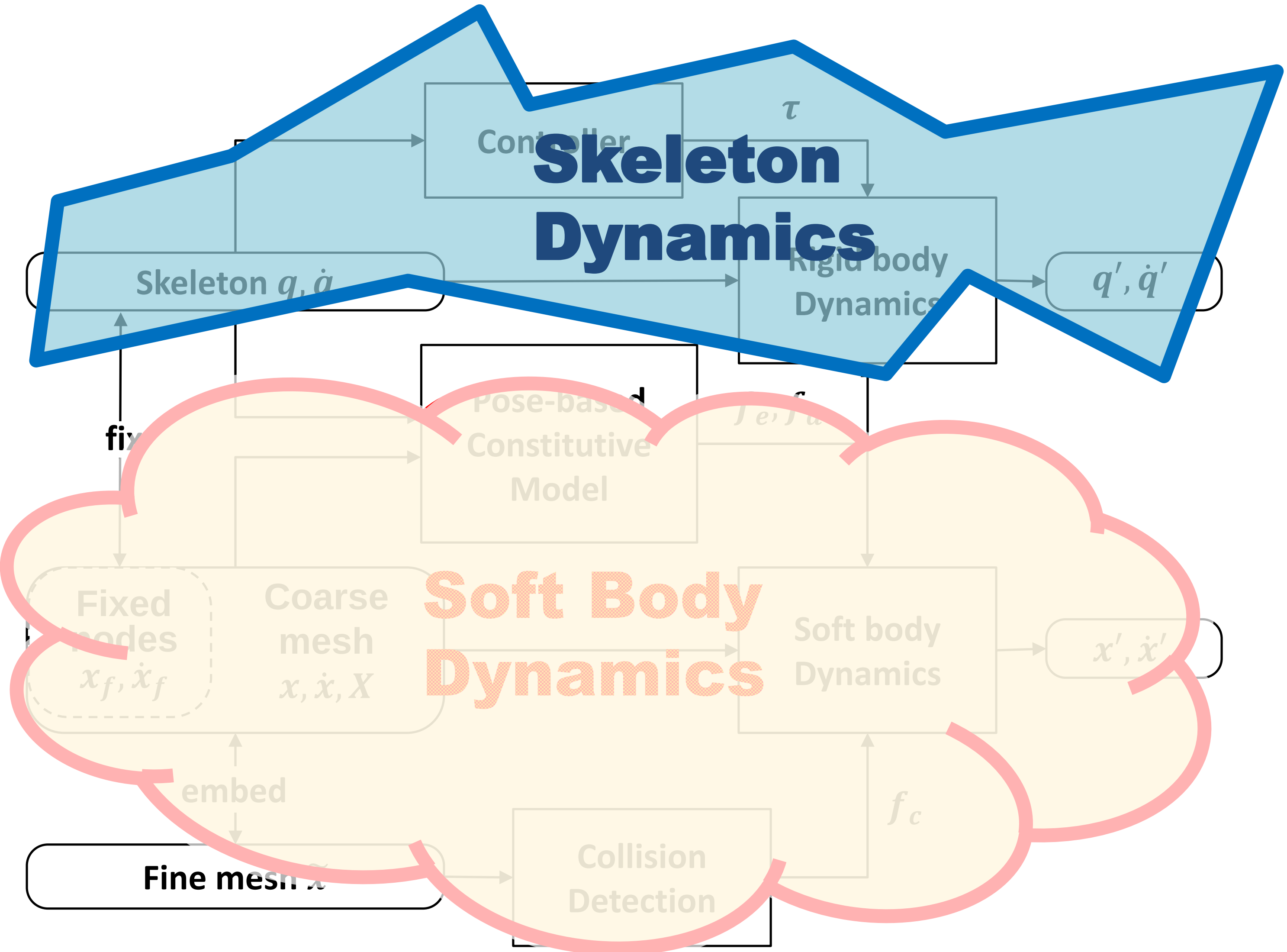


Models

- Model Statistics
  - # vertices: ~1200
  - # elements: ~4000

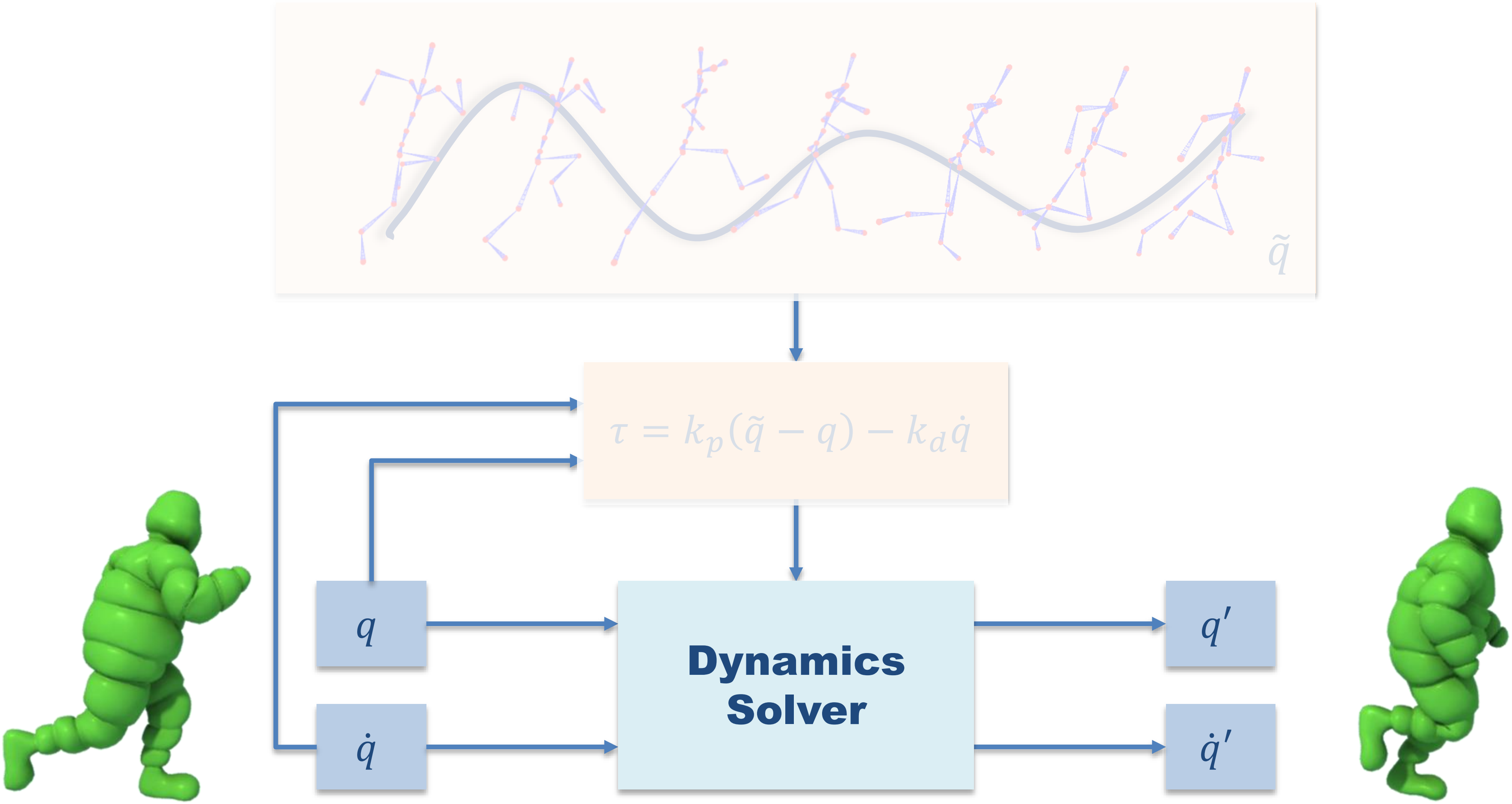


System Overview



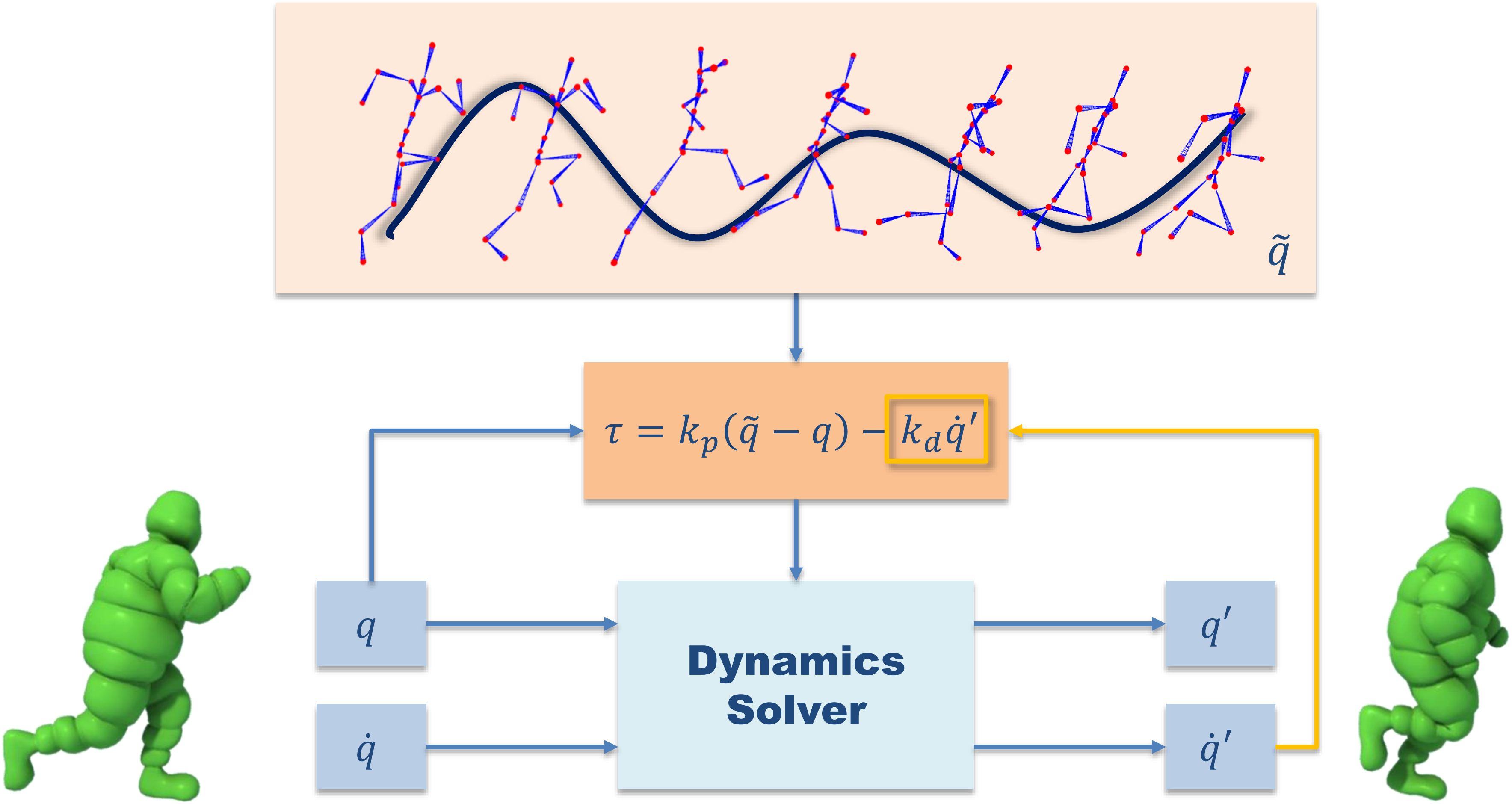
Skeleton Dynamics

- PD-servos



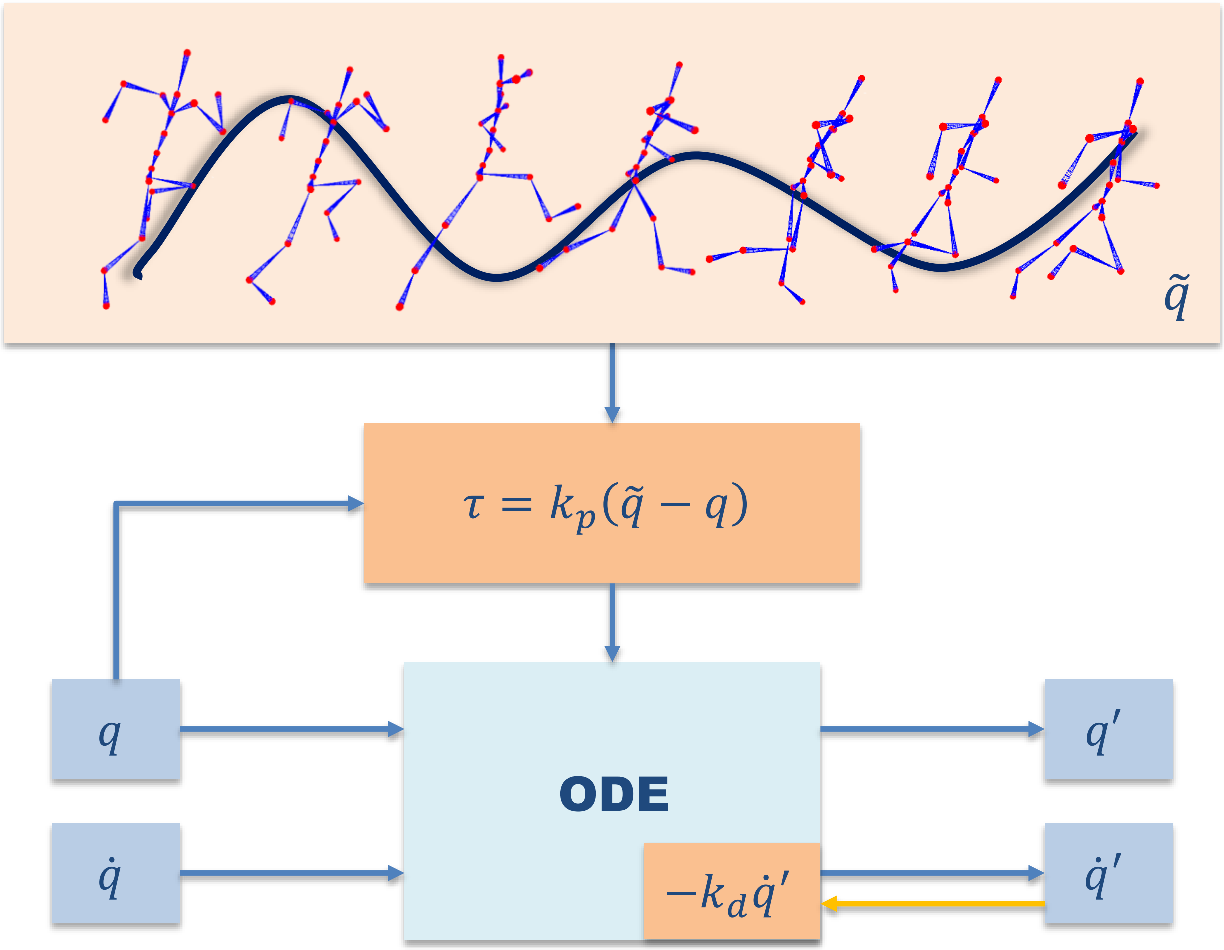
Skeleton Dynamics

- Stable PD-servos [Baraff and Witkin 1998; Tan et al. 2011]

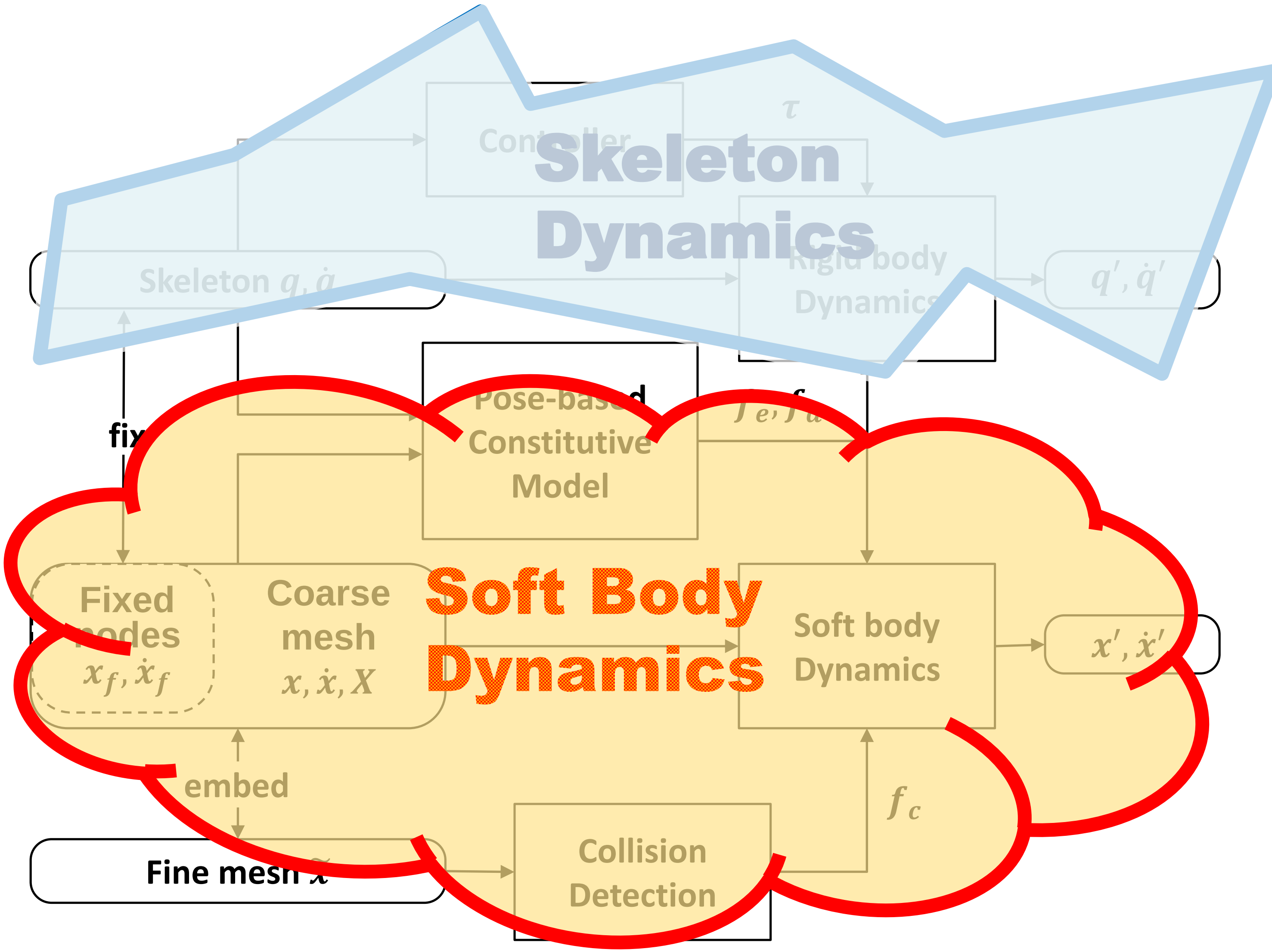


Skeleton Dynamics

- Integration with Open Dynamic Engine

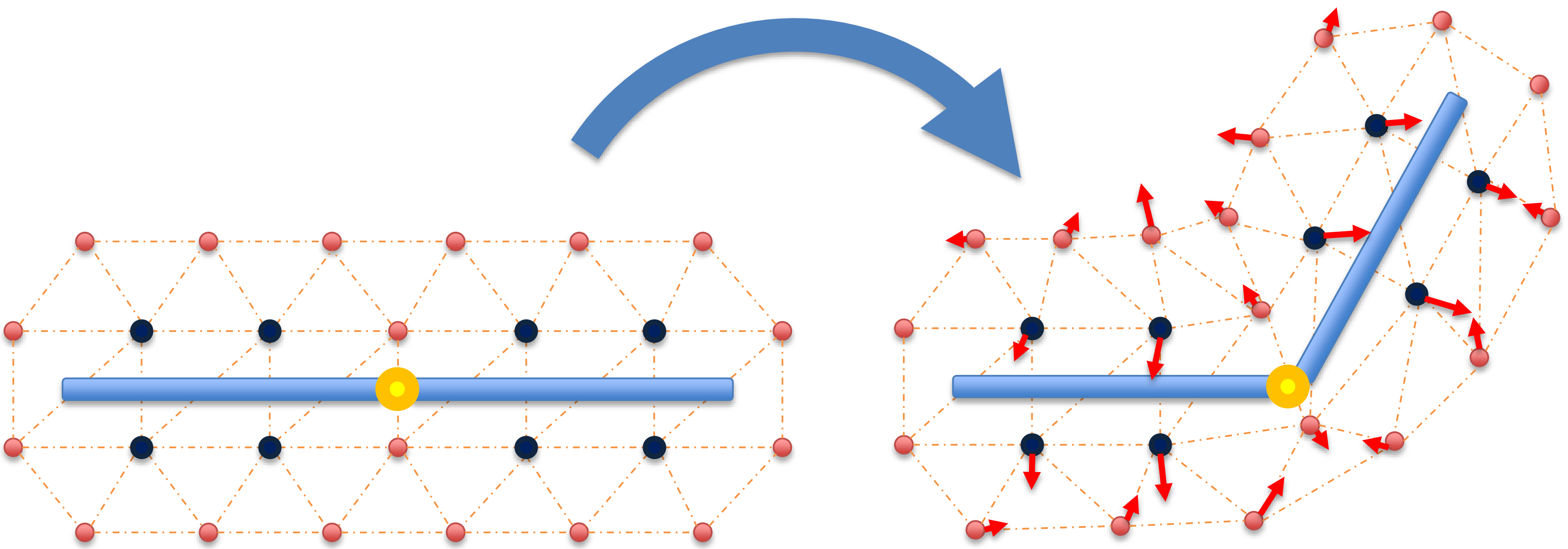


System Overview



Soft Body Dynamics

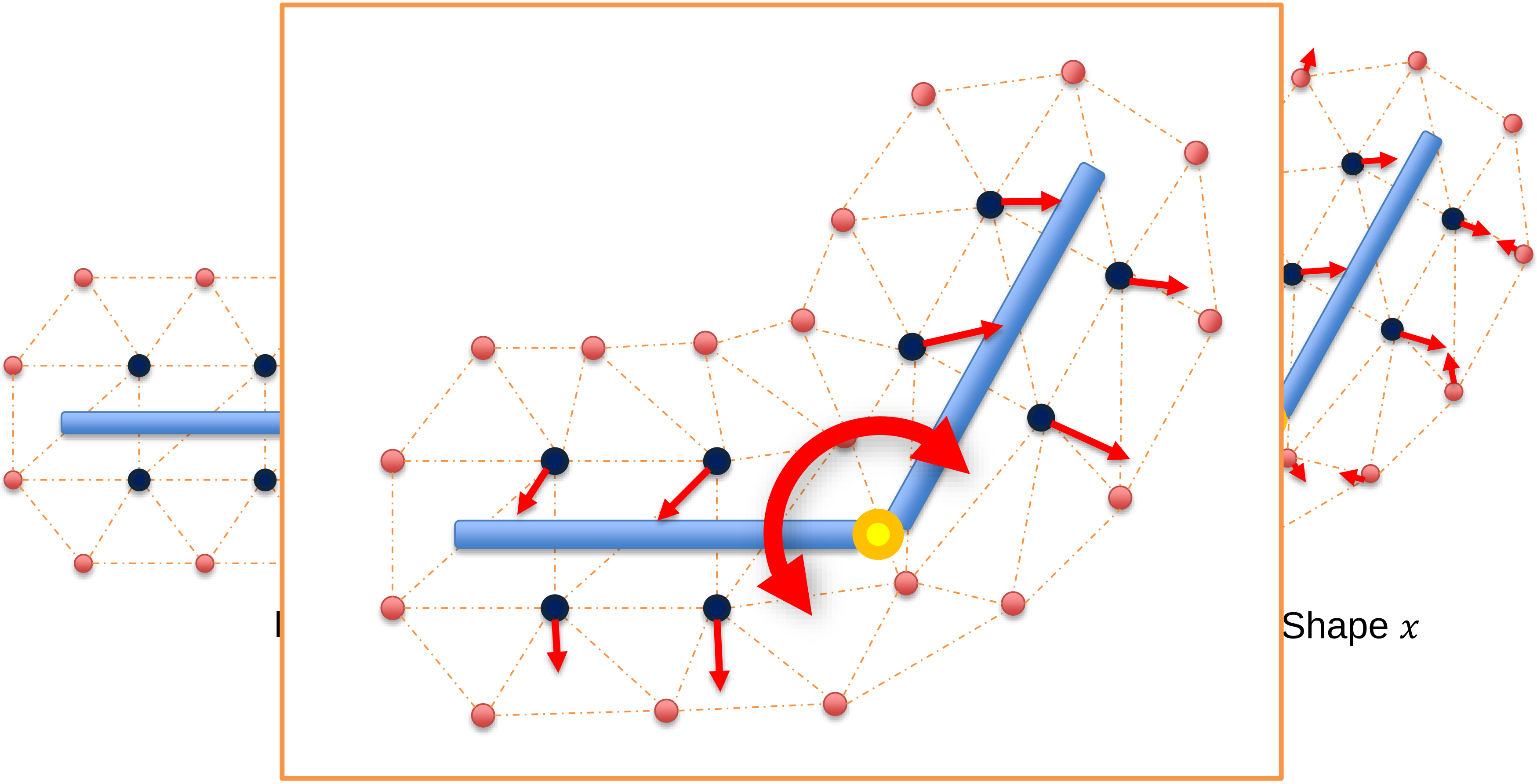
- Elastic Force



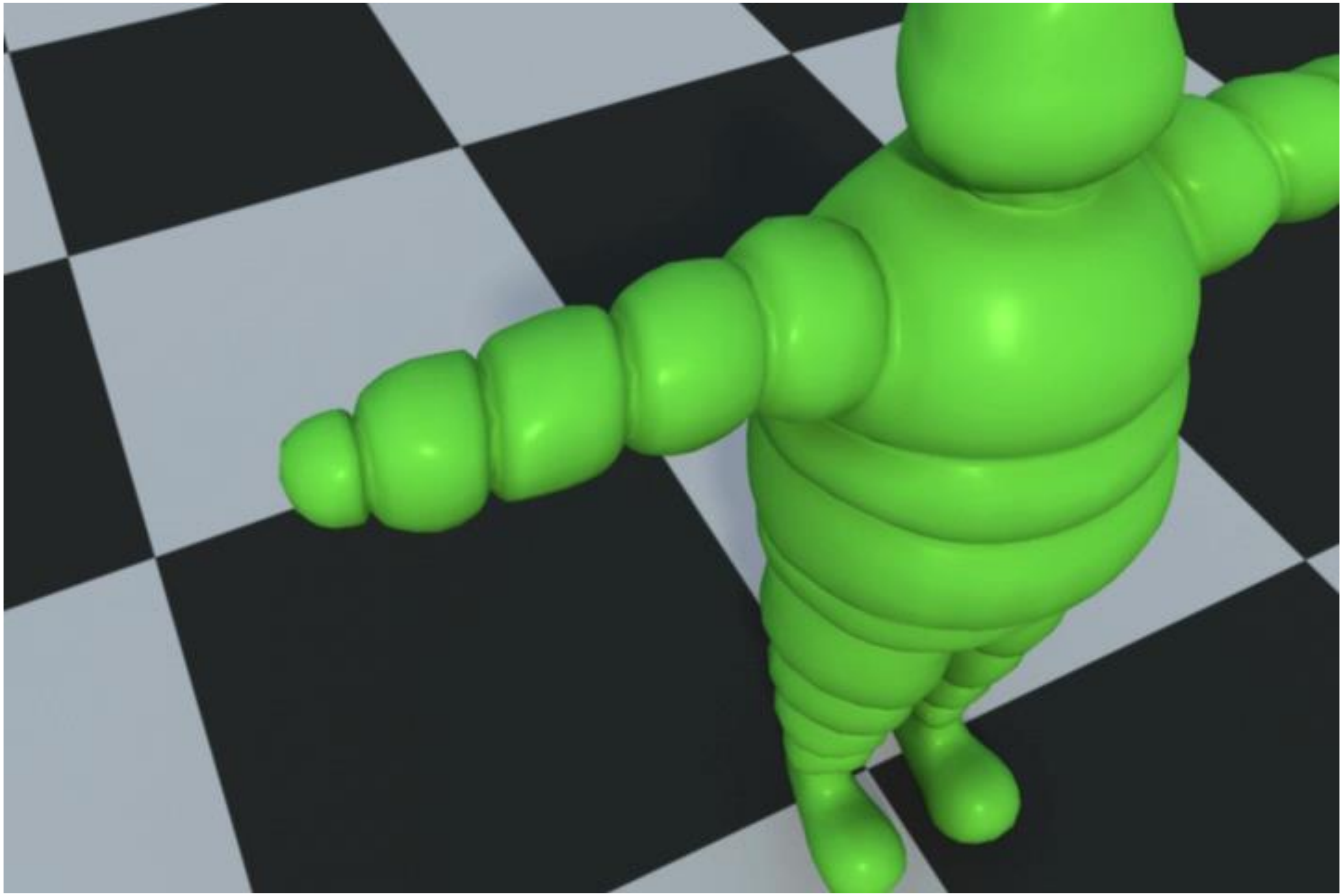
Rest Shape X

Deformed Shape x

- Problem of Large Deformations



Soft Body Dynamics



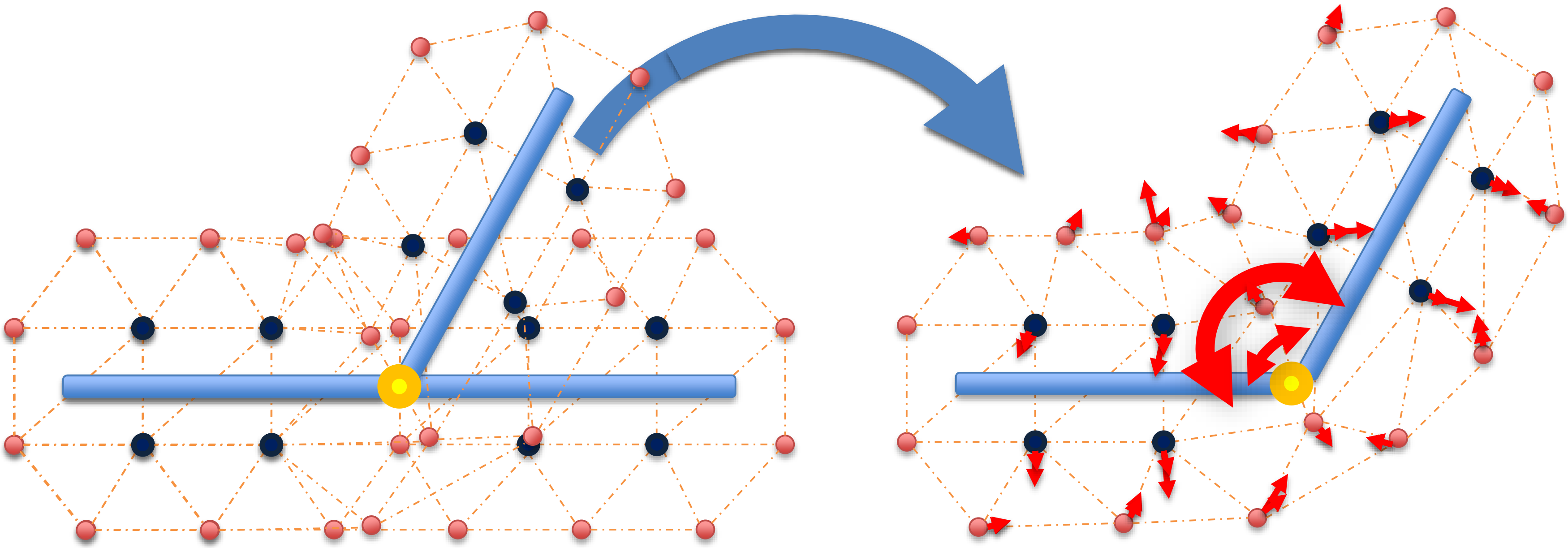
Soft Body Dynamics

- Solution
  - Musculoskeletal models
  - Pose-based Plasticity

[Lee et al. 2009]

Soft Body Dynamics

- Pose-based Plasticity

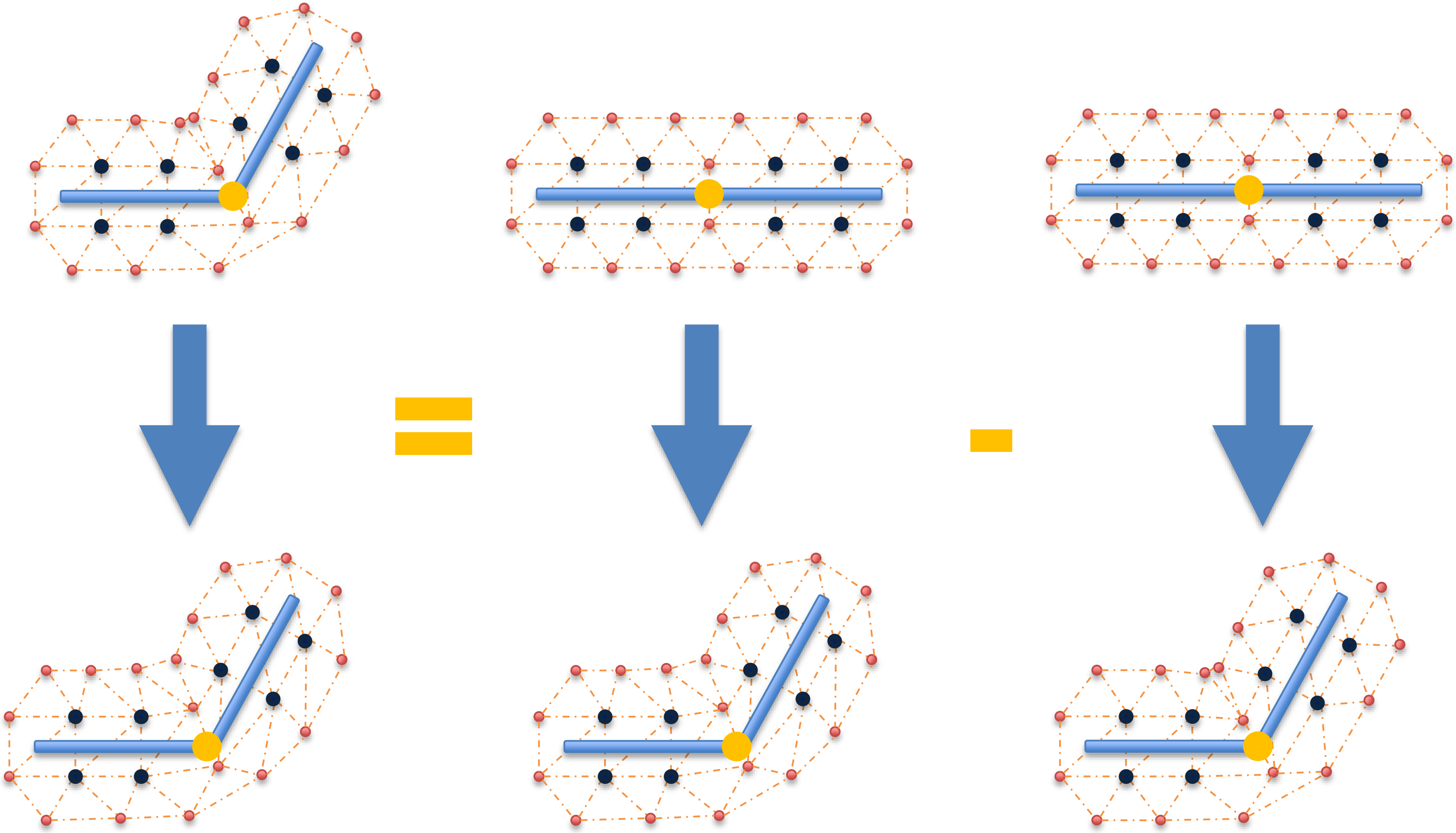


Reference Shape X / Pose-based Rest Shape $\bar{x}$

Deformed Shape x

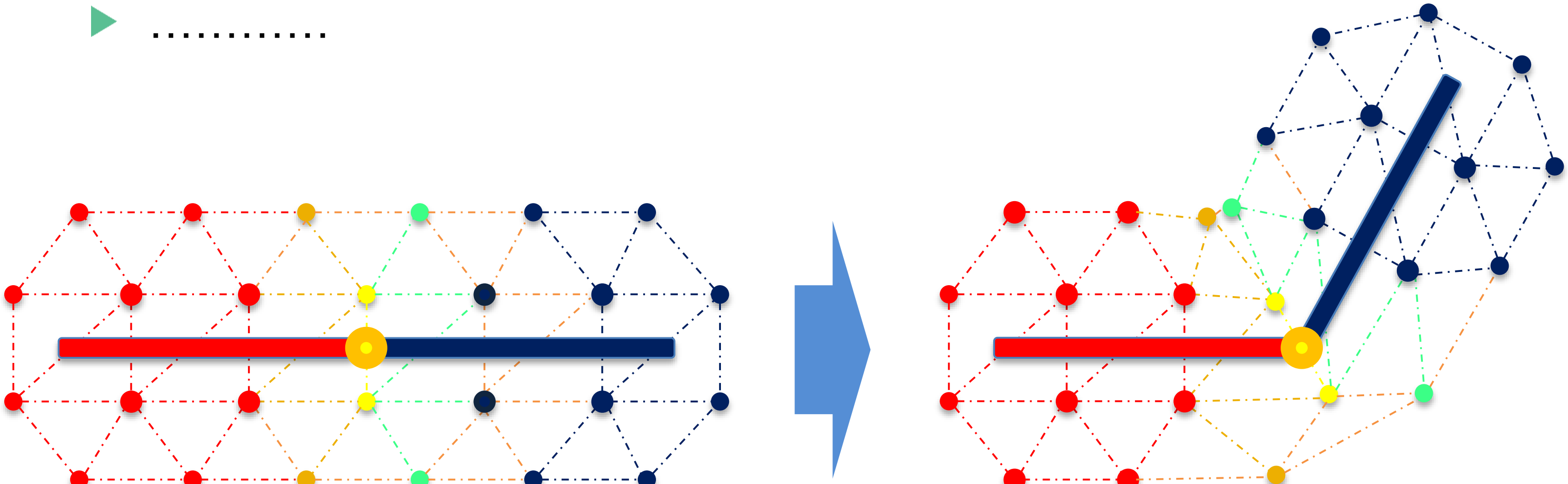
Soft Body Dynamics

- Additive Plasticity



Soft Body Dynamics

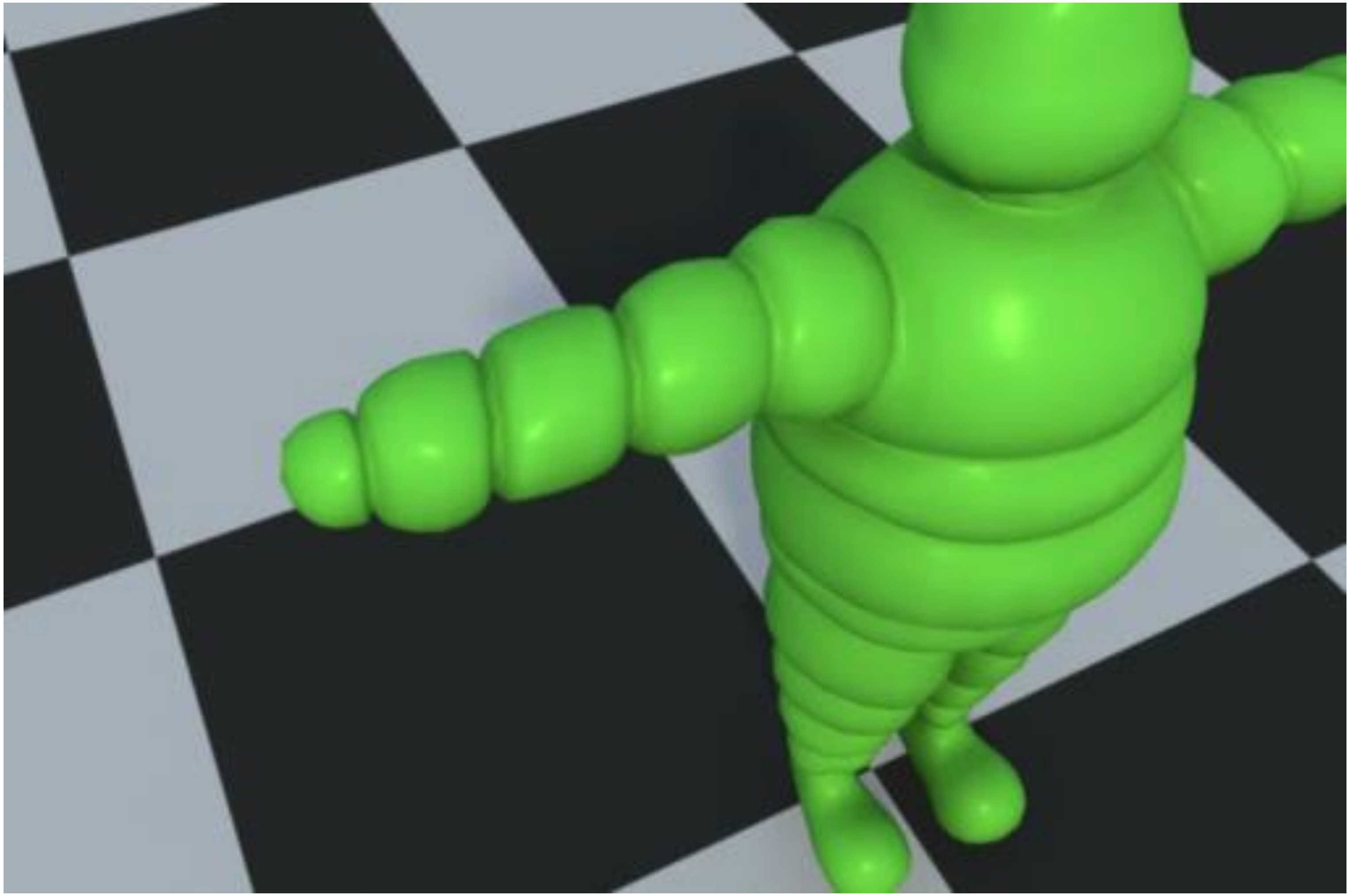
- Generate Reference Shape
  - Linear Blend Skinning
  - Dual Quaternion Skinning [Kavan et al. 2007]
  - Elasticity-inspired methods [Kavan and Sorkine 2012]
  - Physically based methods [McAdams et al. 2011]
  - …………



Rest Shape X

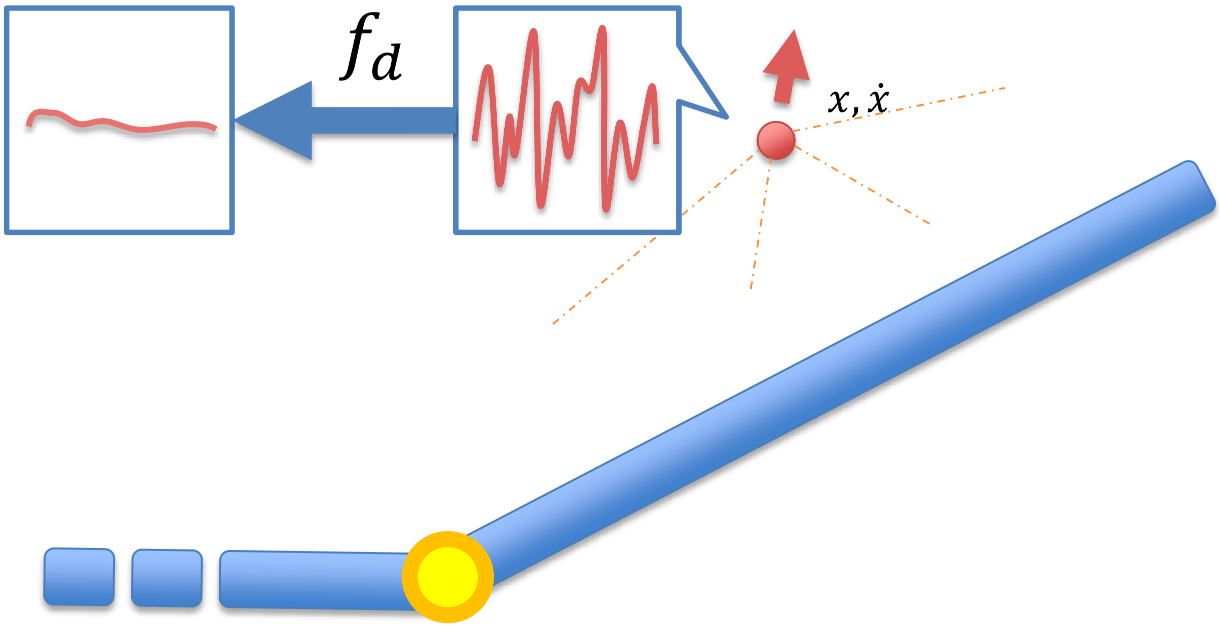
Pose-based Reference Shape $\bar{x}$

Soft Body Dynamics



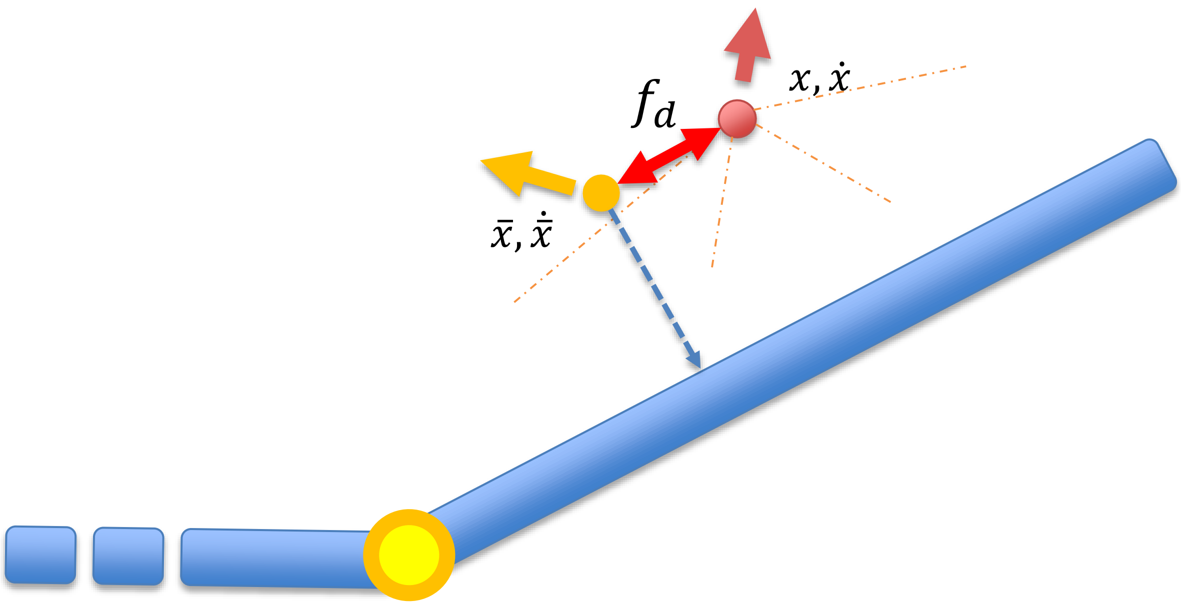
Soft Body Dynamics

- Pose-based Damping

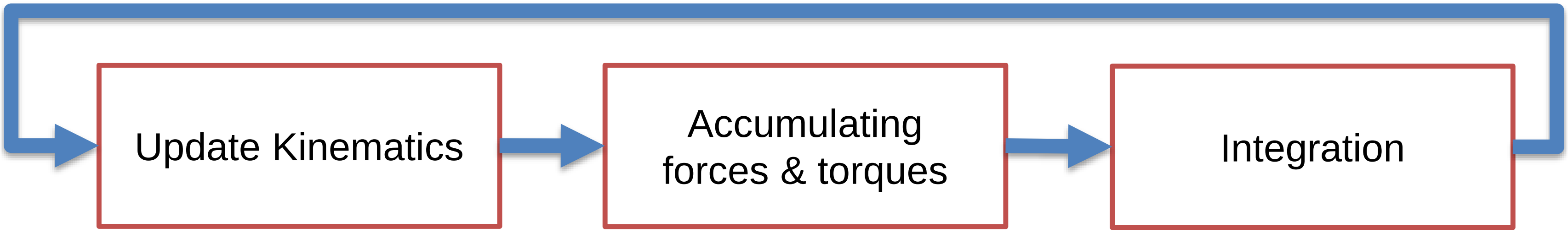


Soft Body Dynamics

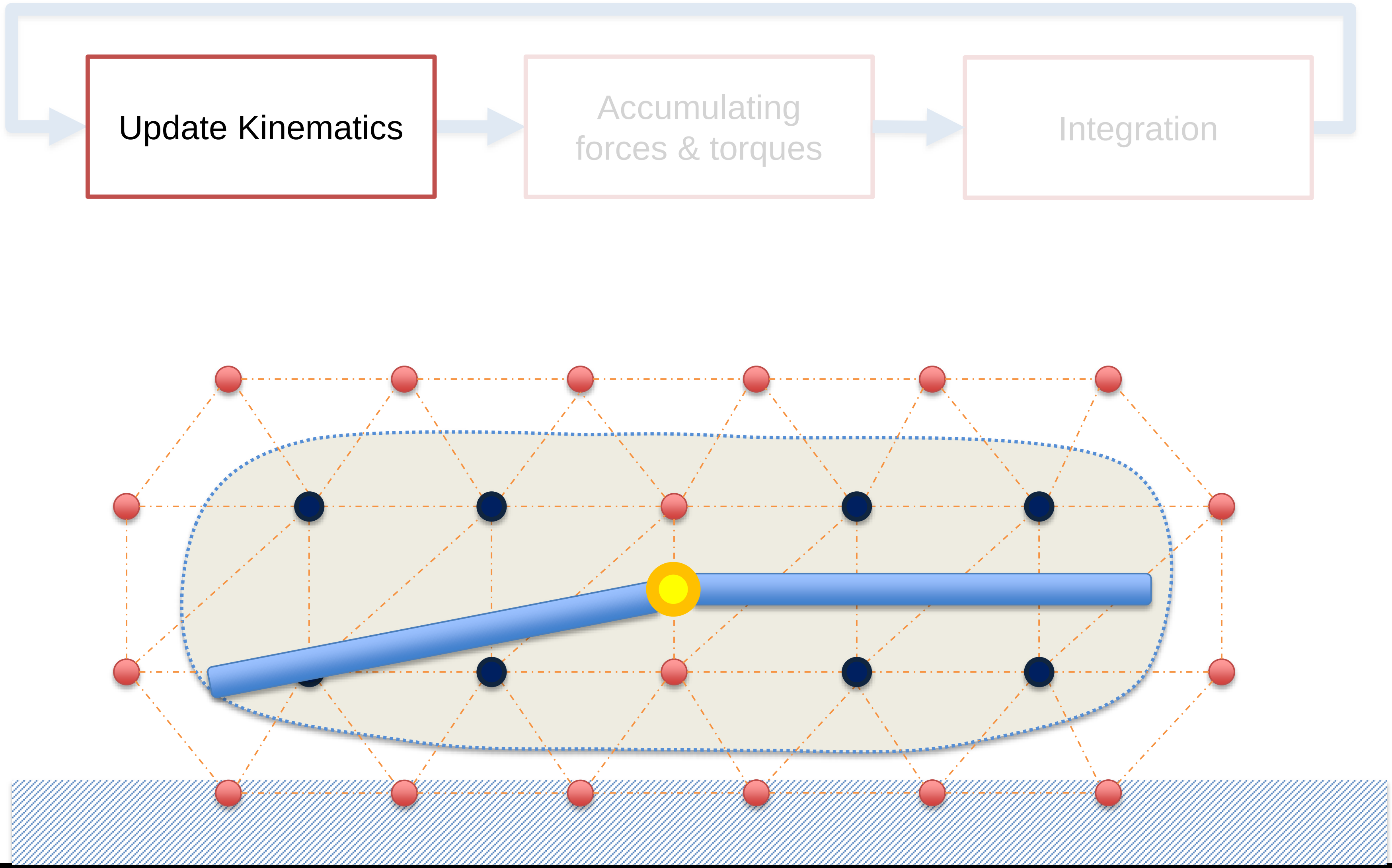
- Pose-based Damping
  - Damping reference point



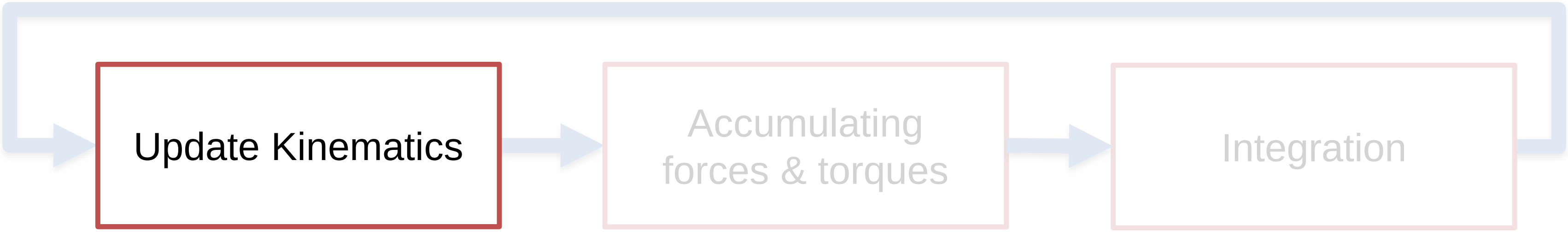
Simulation Pipeline



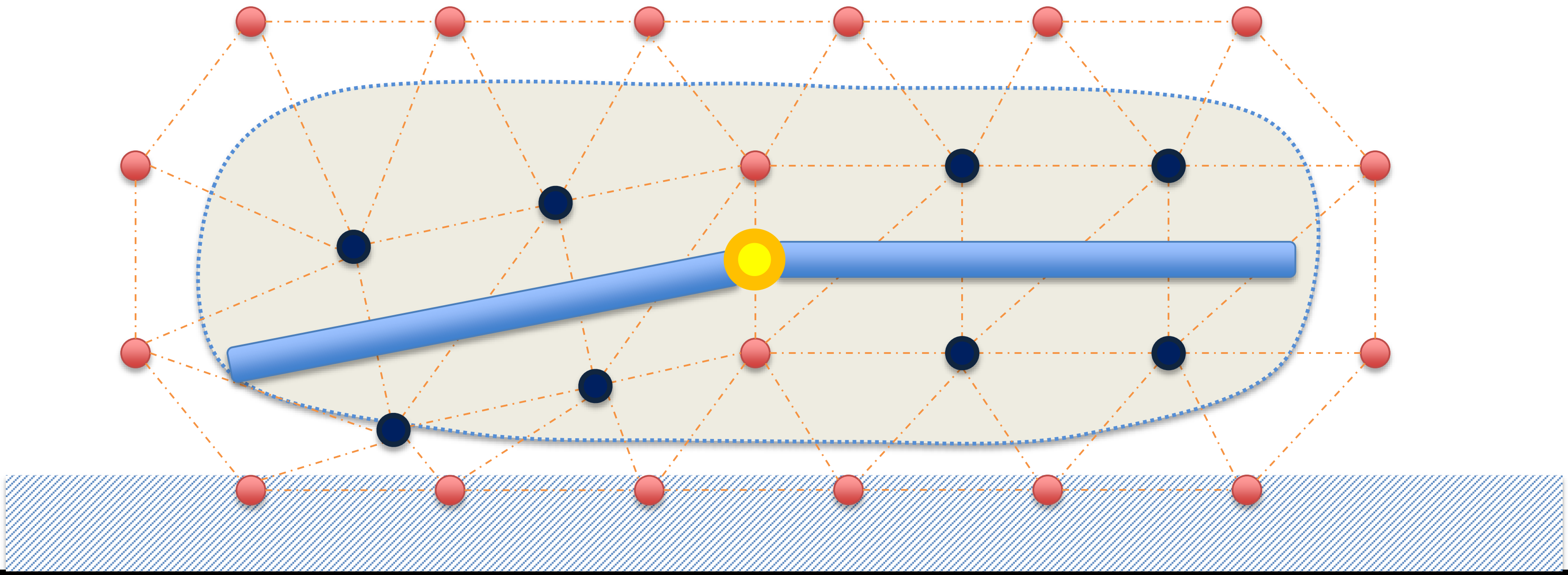
Simulation Pipeline



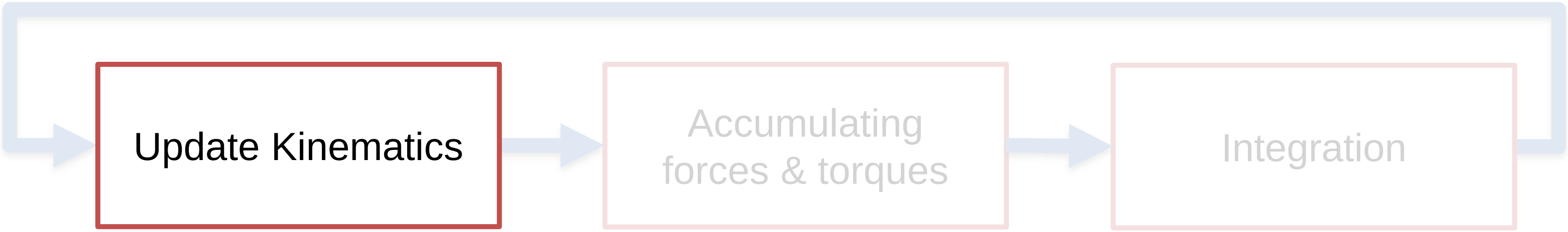
Simulation Pipeline



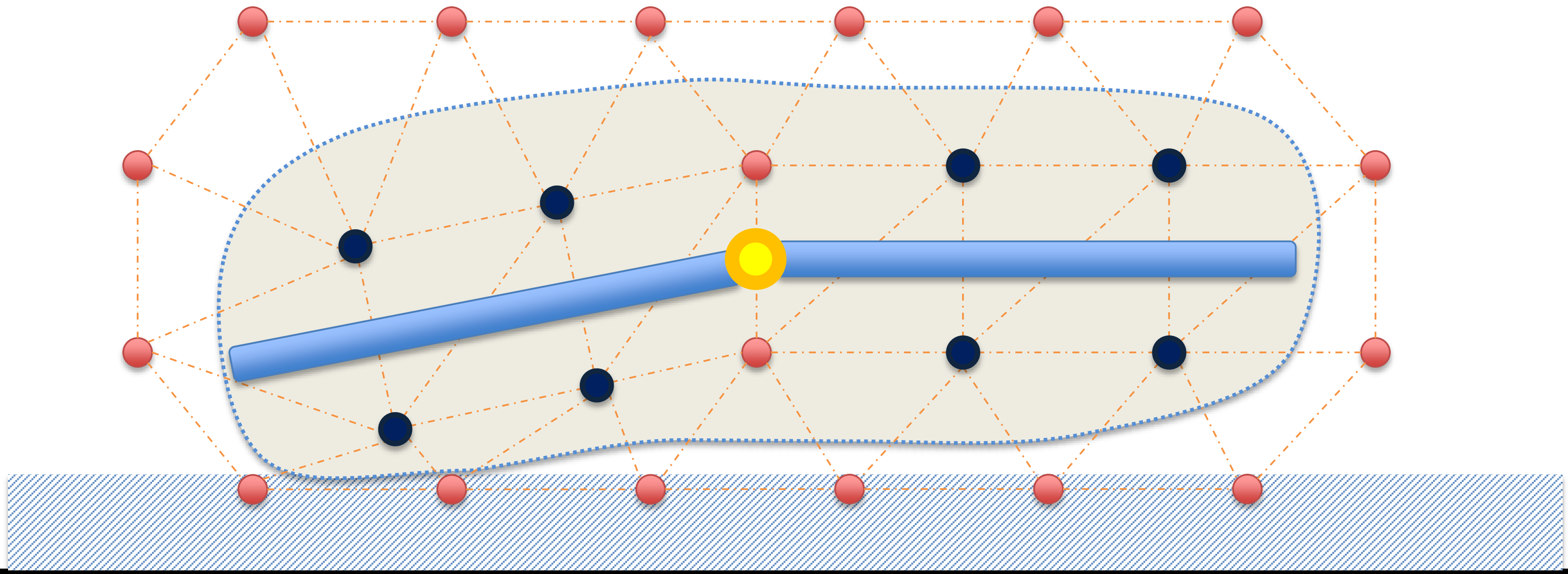
- Update fixed nodes



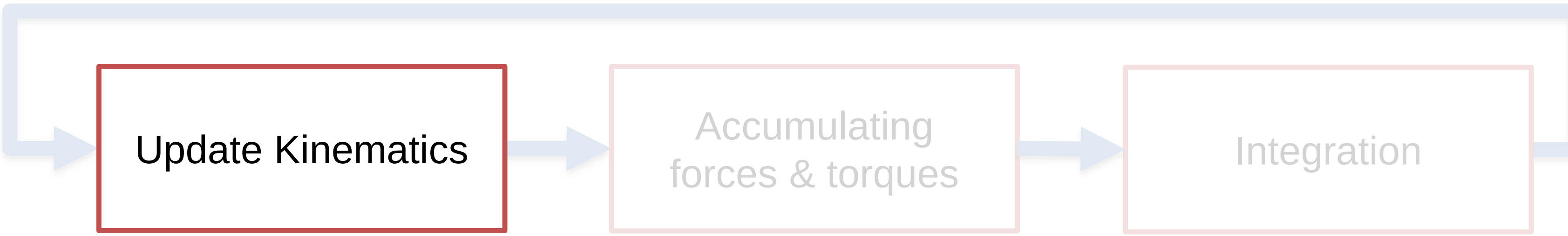
Simulation Pipeline



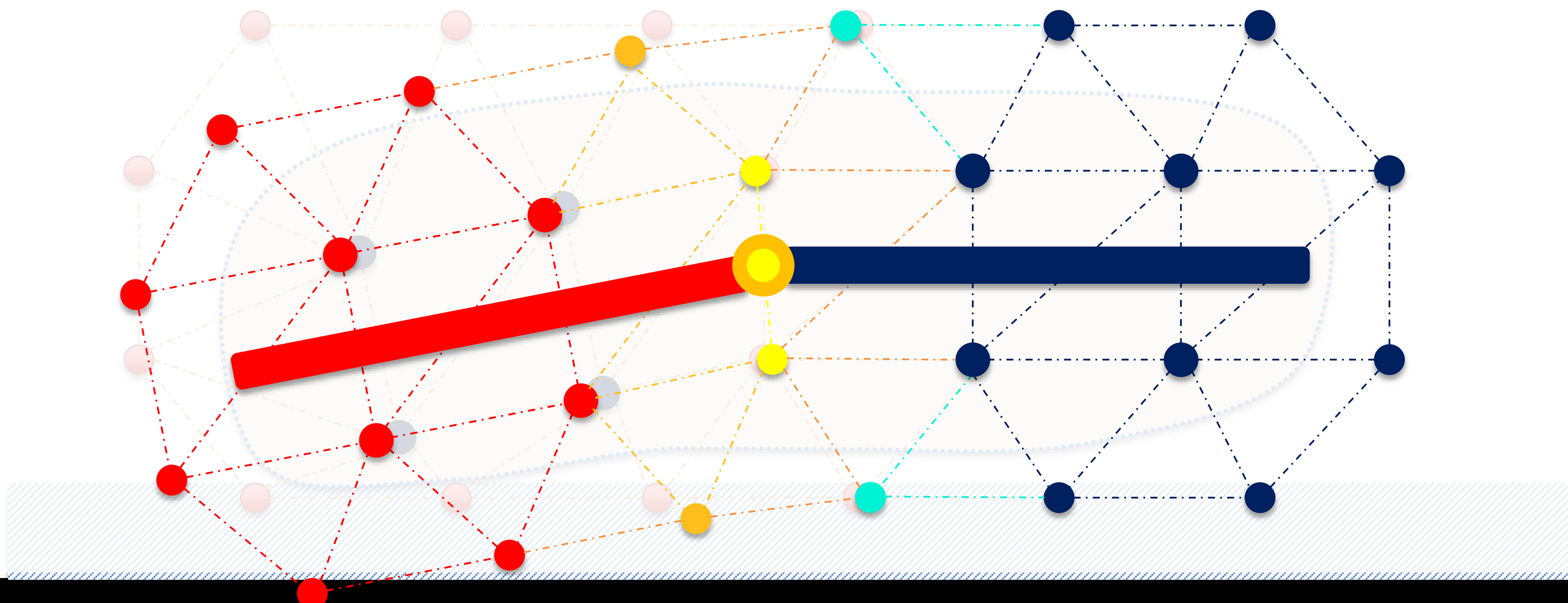
- Update fine surface mesh



Simulation Pipeline



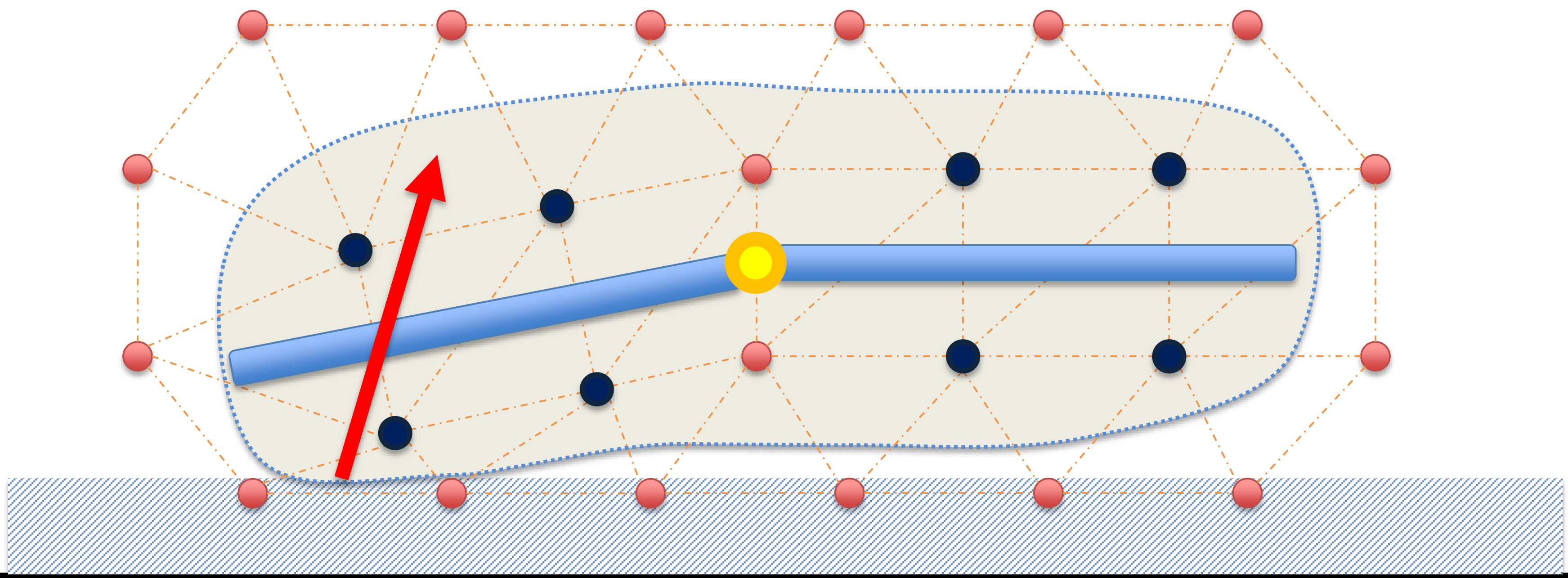
- Update reference pose and velocity



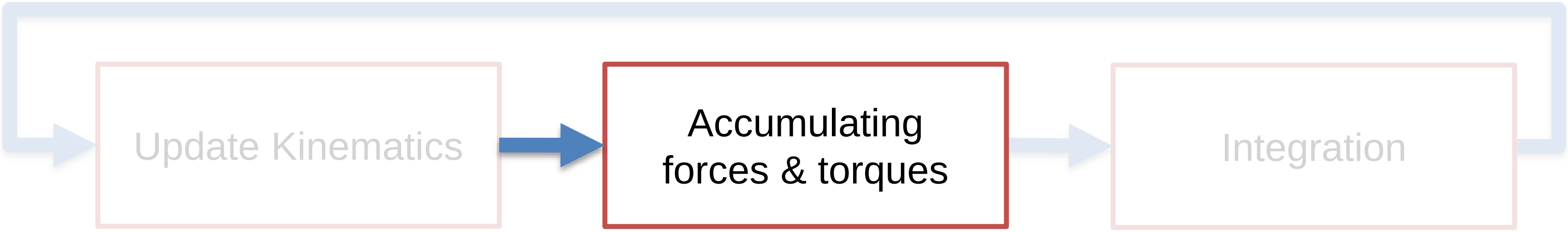
Simulation Pipeline

Update Kinematics → **Accumulating forces & torques** → Integration

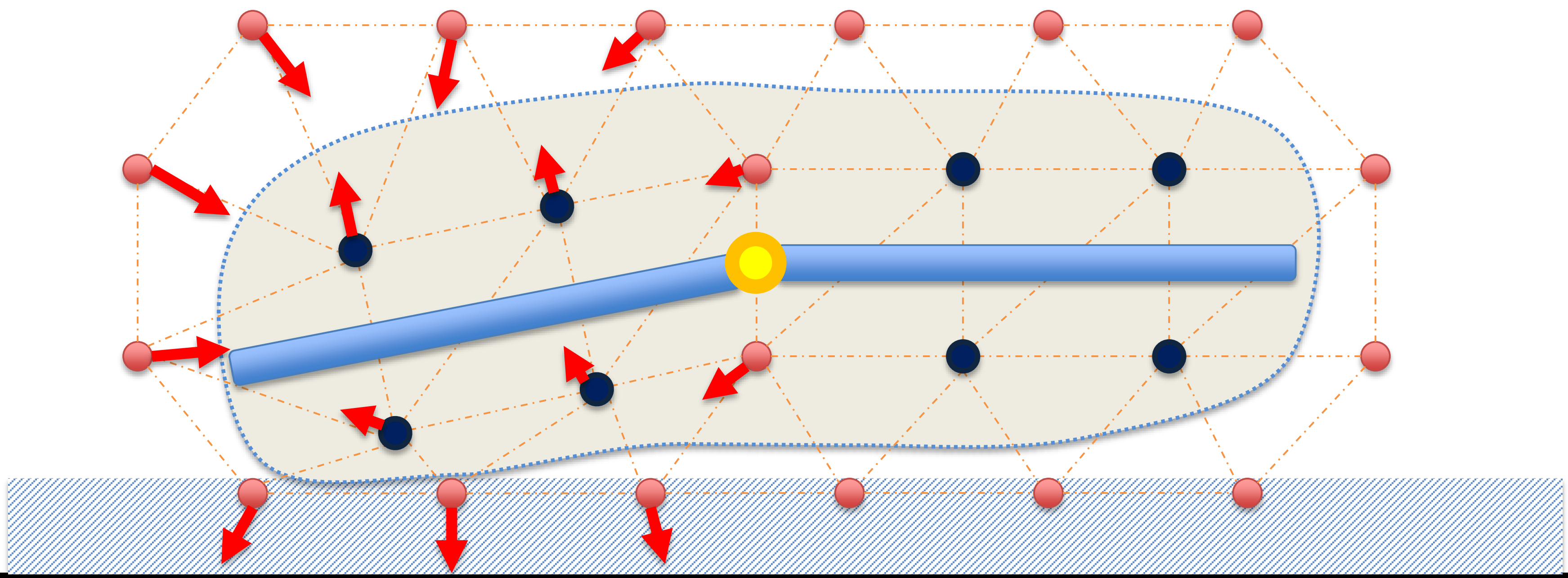
- Soft body: contact force



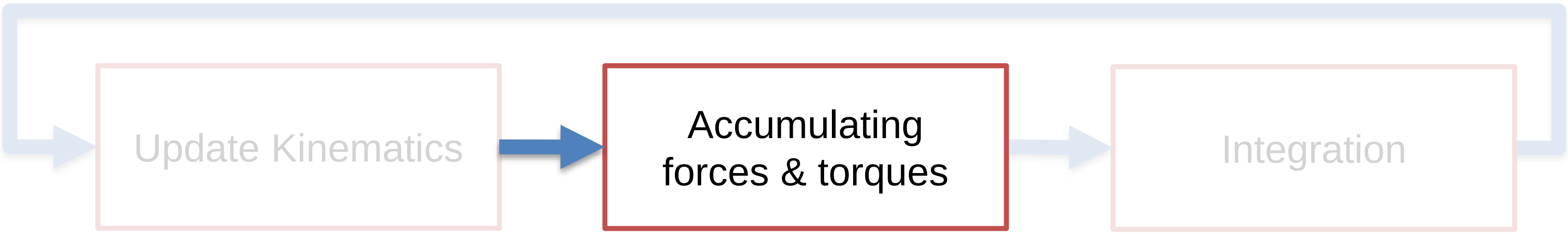
Simulation Pipeline



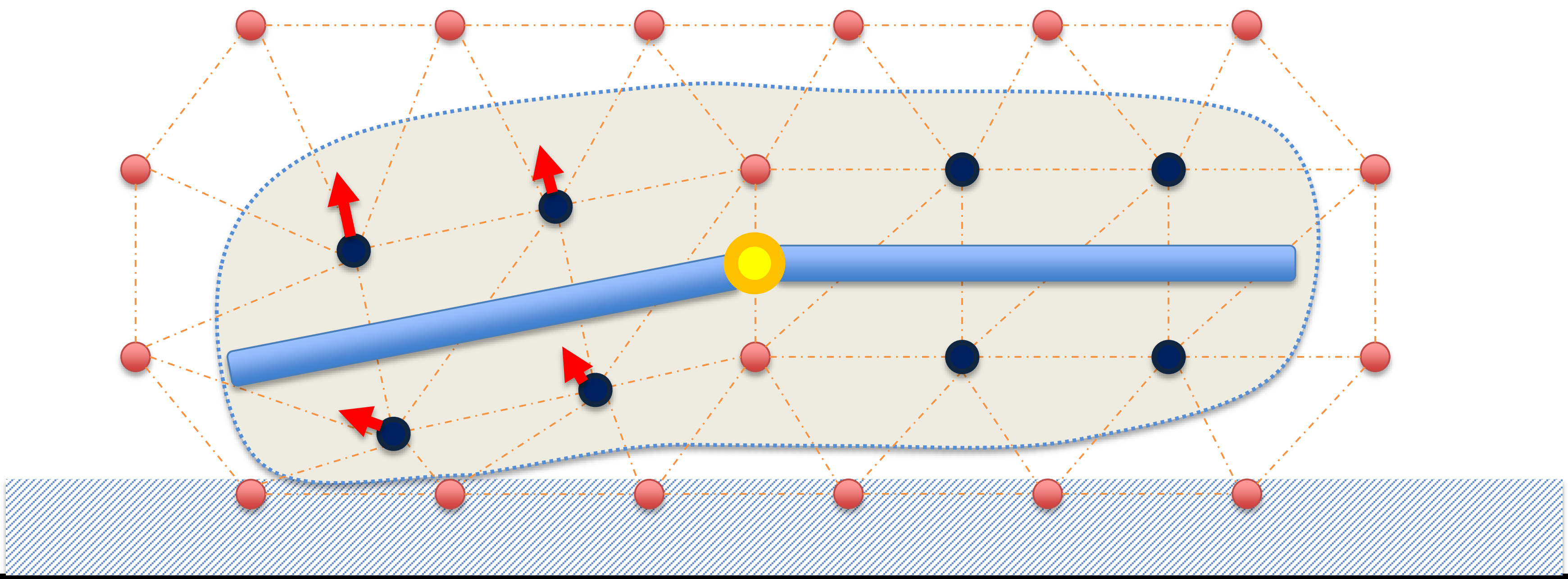
- Soft body: elastic forces and damping forces



Simulation Pipeline



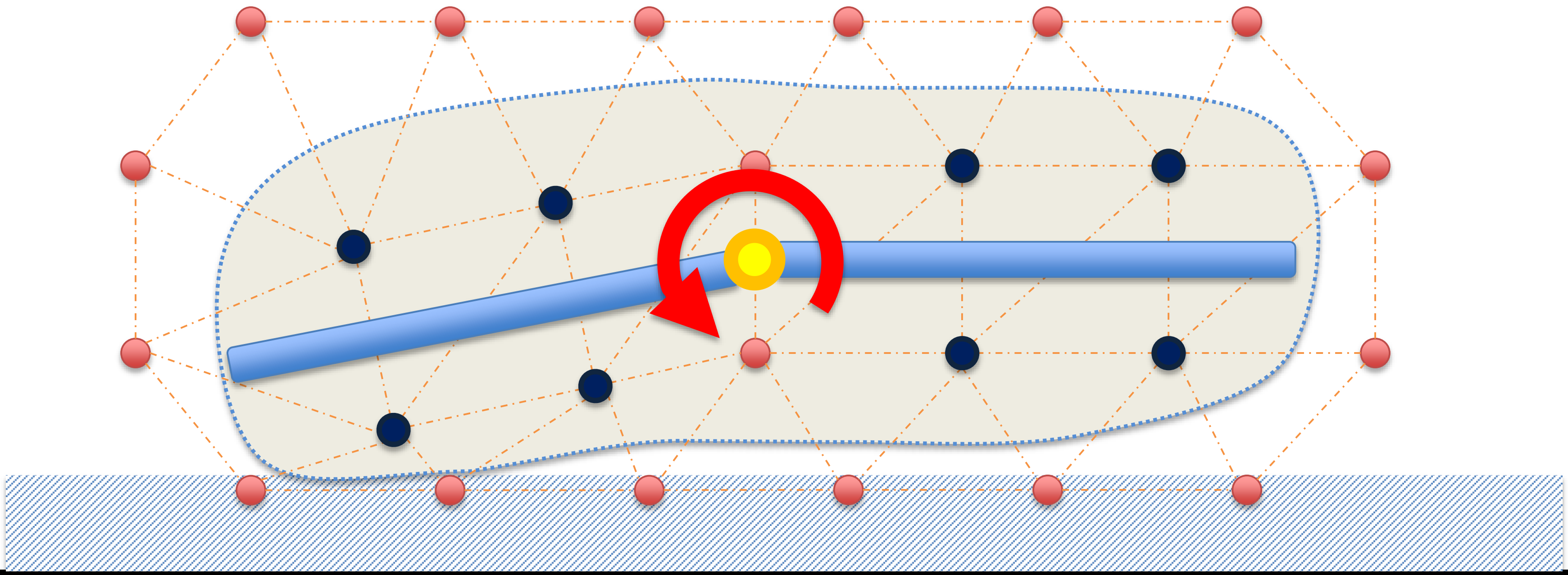
- Skeleton: elastic forces & damping forces from soft body



Simulation Pipeline

Update Kinematics → **Accumulating forces & torques** → Integration

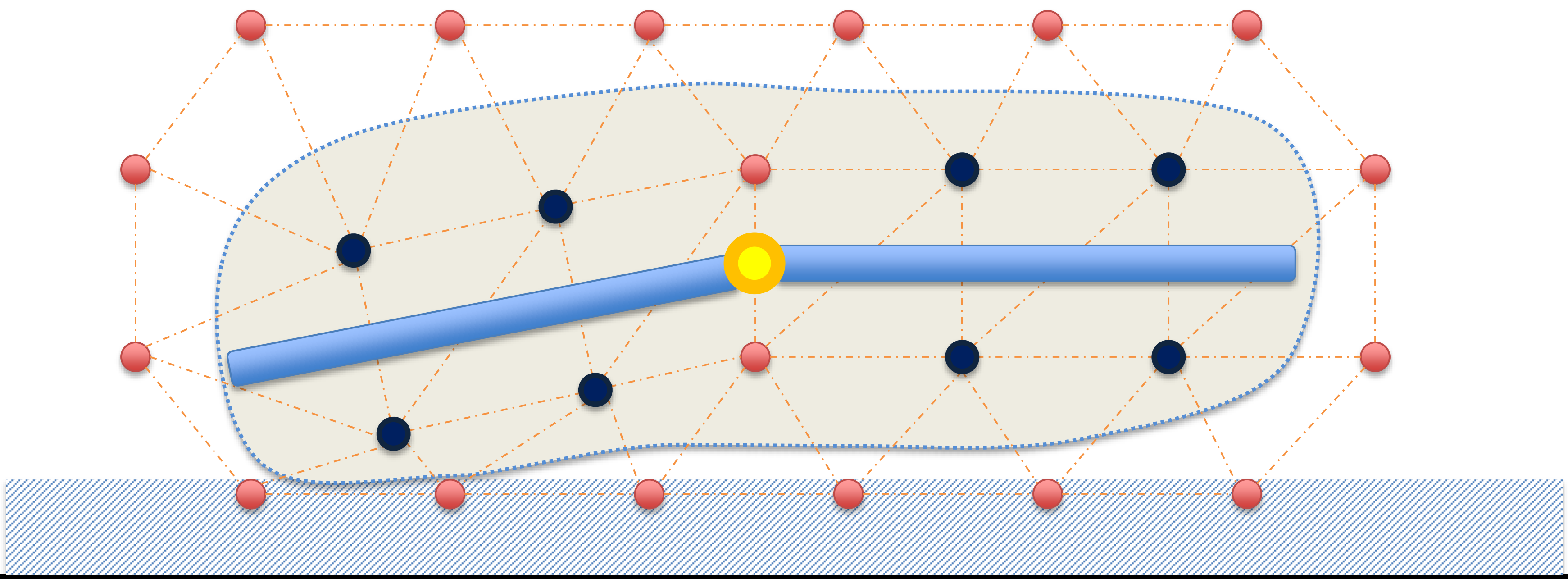
- Skeleton: actuation PD torques



Simulation Pipeline

Update Kinematics → Accumulating forces & torques → **Integration**

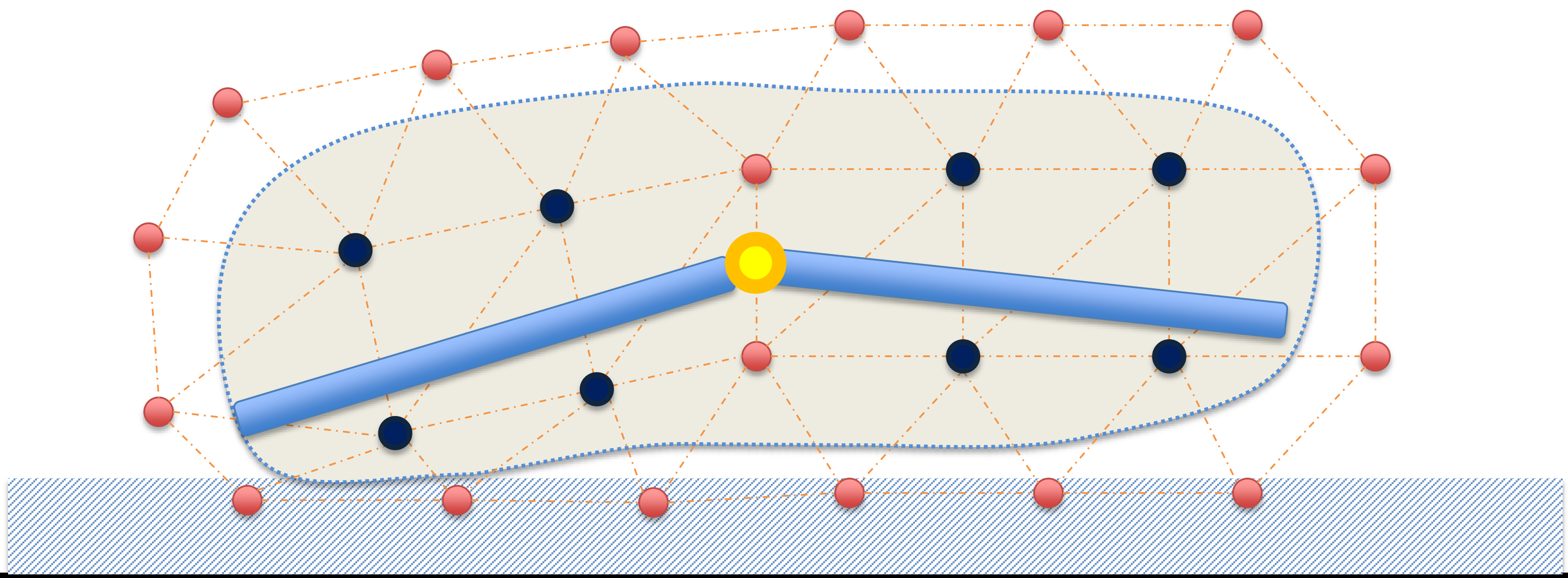
- Integration



Simulation Pipeline

Update Kinematics → Accumulating forces & torques → Integration

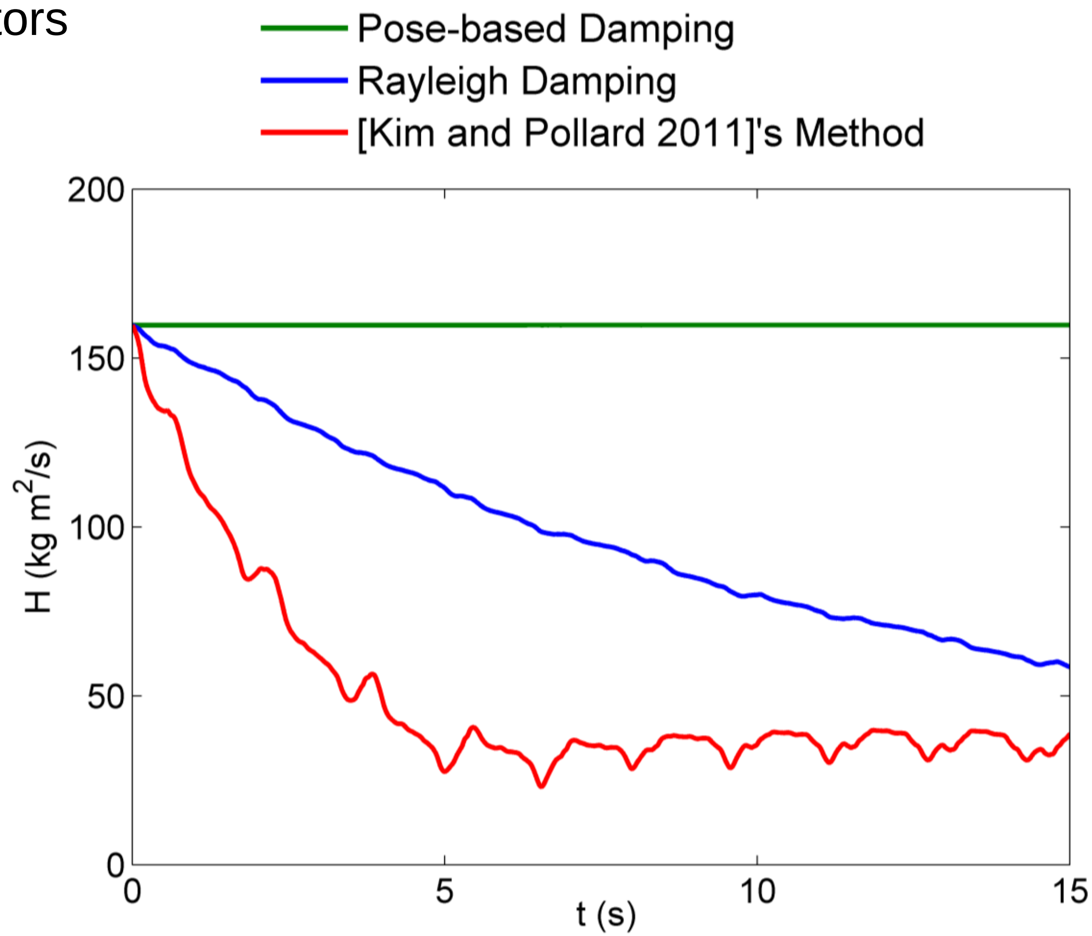
- Integration



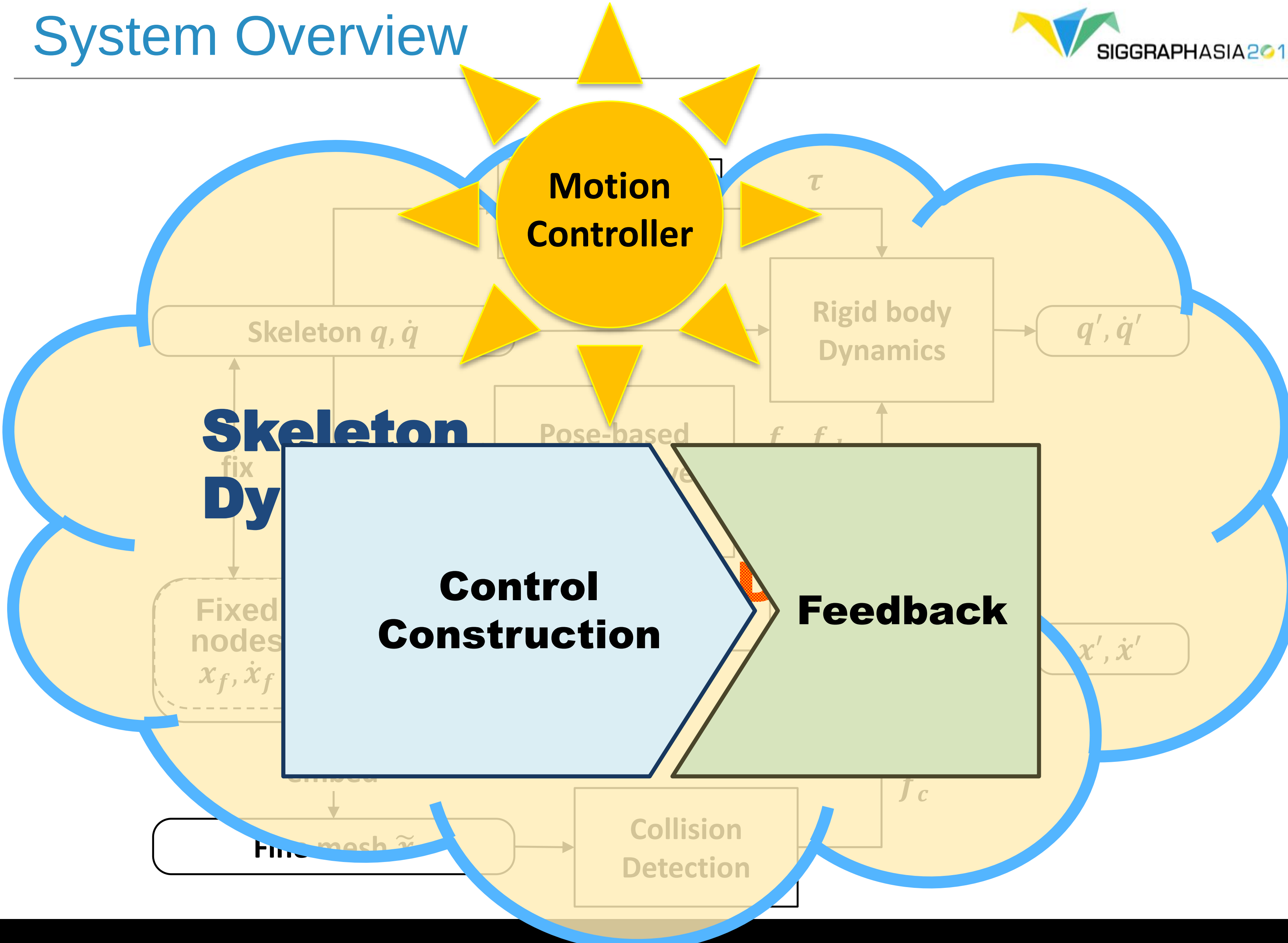
Angular Momentum Conservation

SIGGRAPHASIA2013

- The framework conserves angular momentum
  - Symplectic Euler integrators
  - Pose-based plasticity
  - Pose-based damping

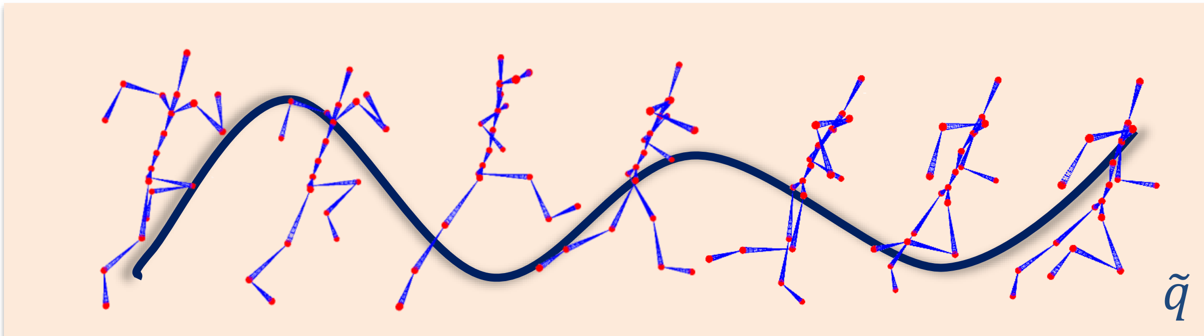


System Overview



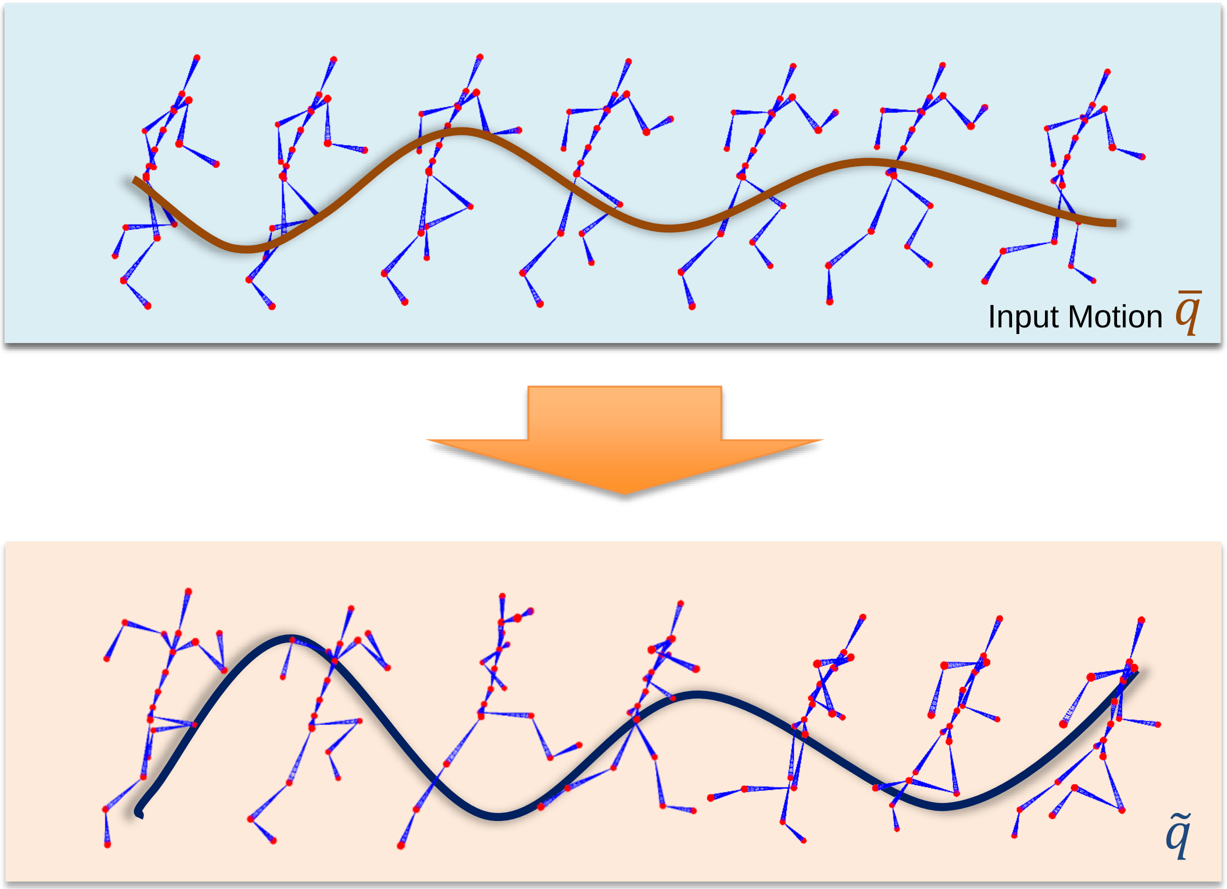
Motion Control

- Skeleton Dynamics System



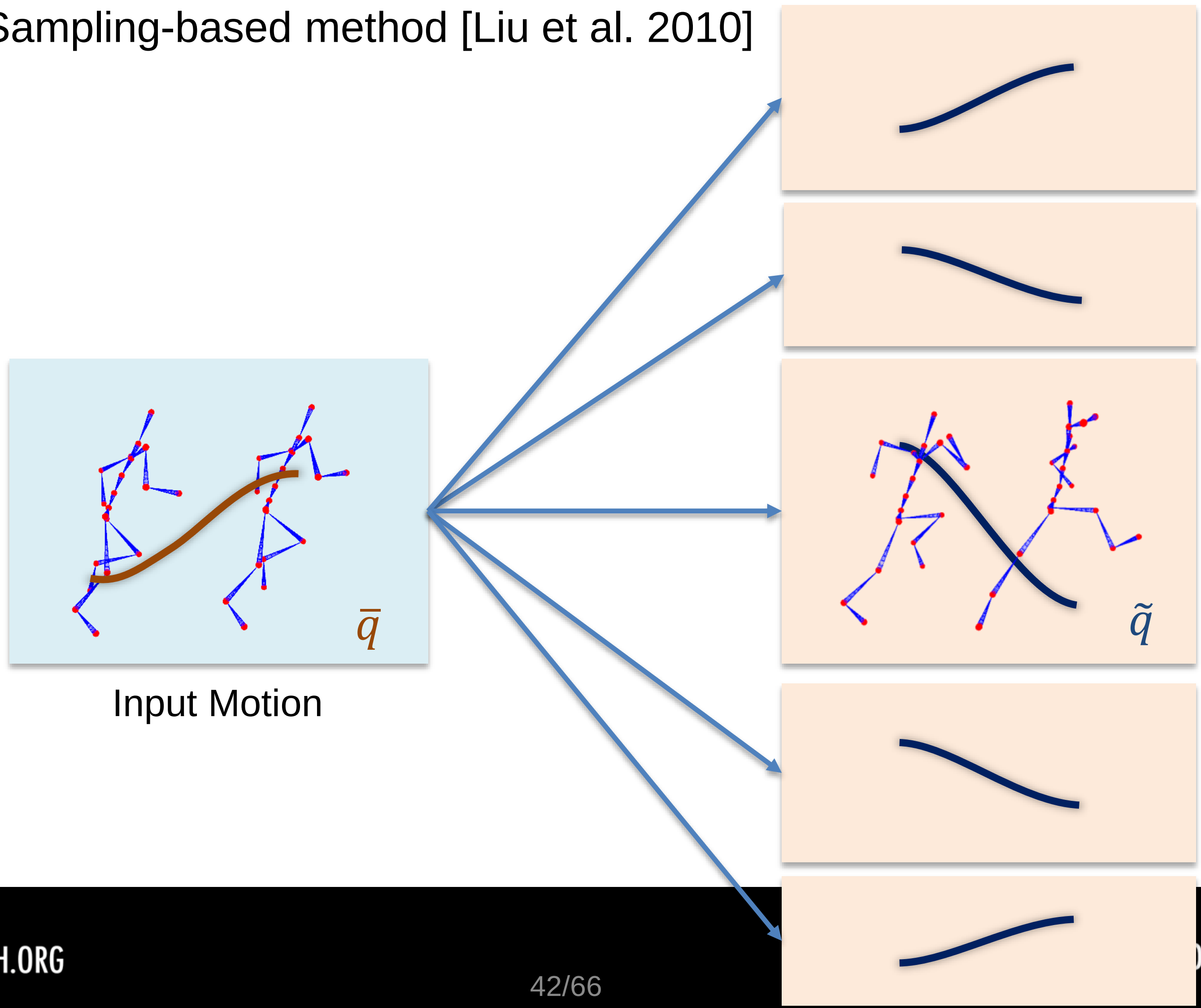
Motion Control

- Control Construction



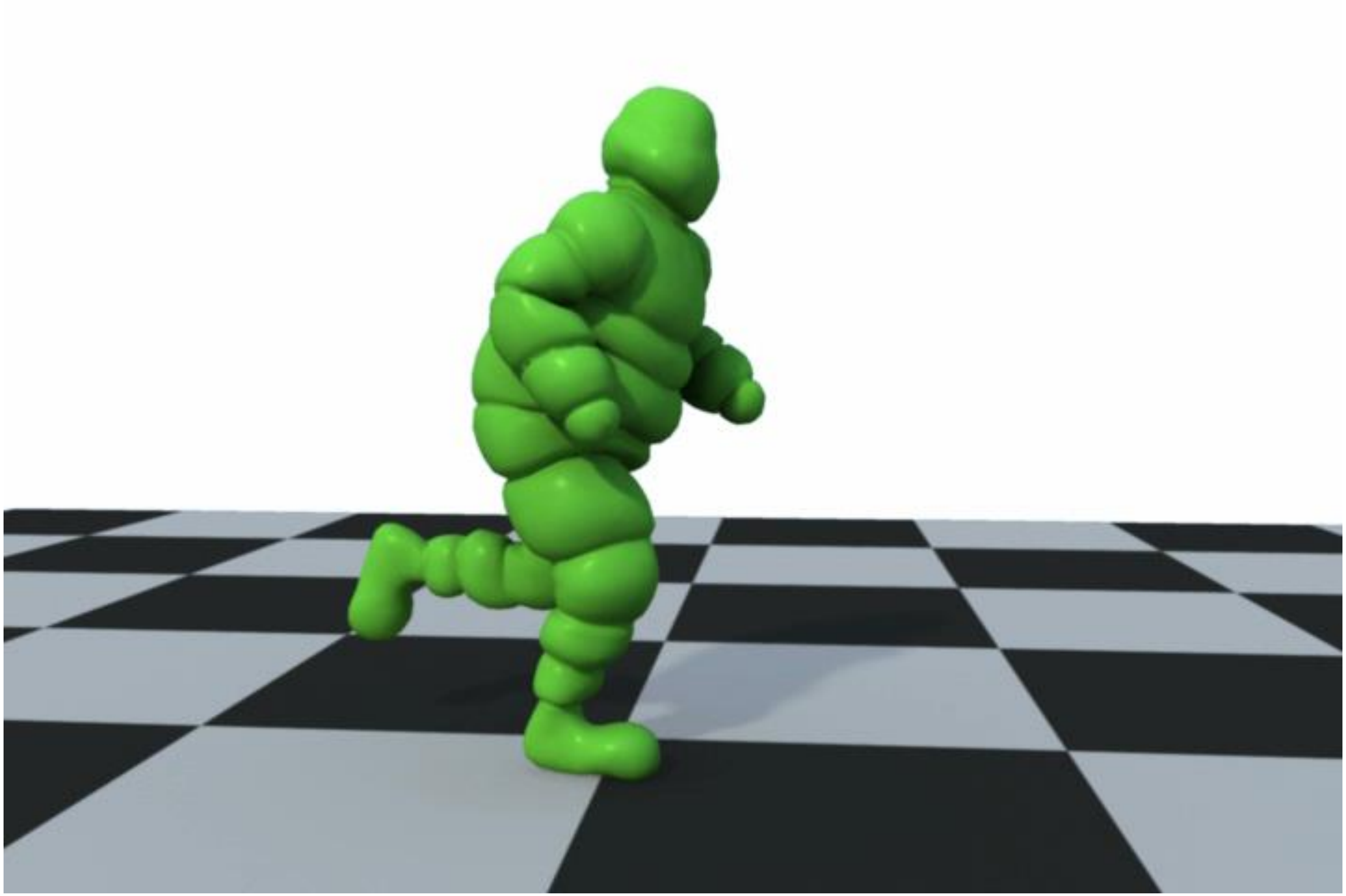
Motion Control

- Control Construction
  - Sampling-based method [Liu et al. 2010]

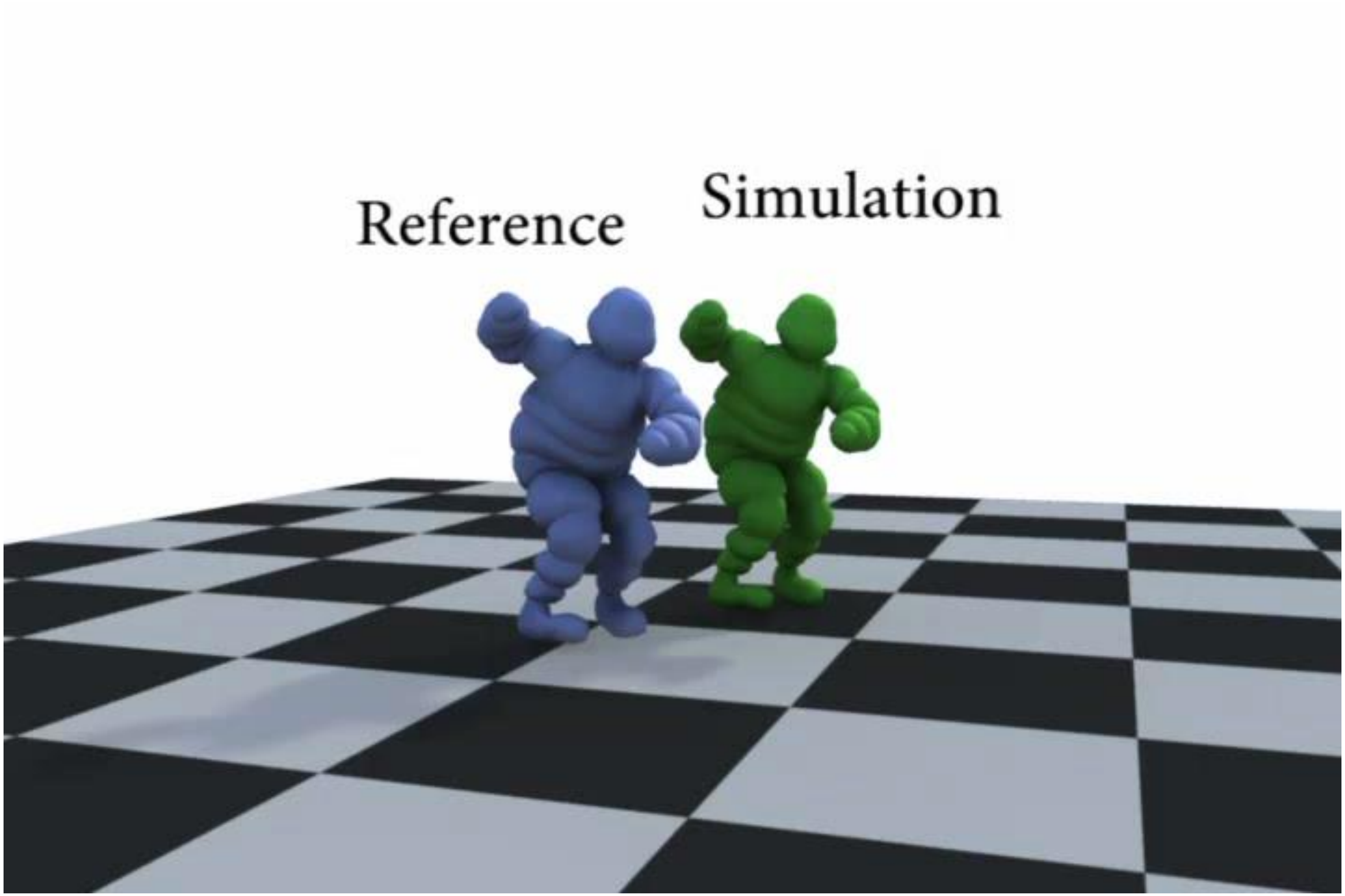


Input Motion

Motion Control

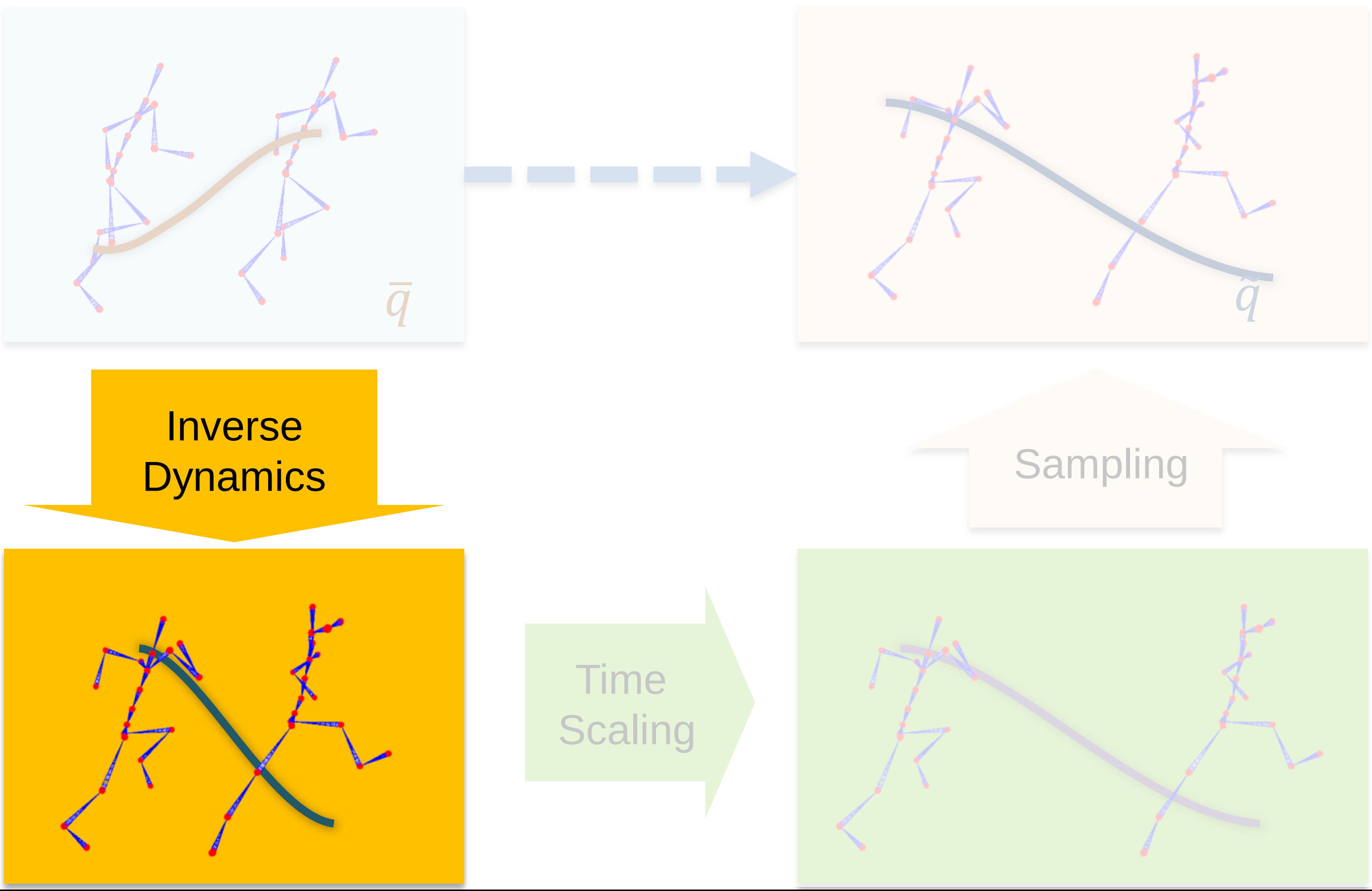


Motion Control



Motion Control

- Control Construction
  - Augmented sampling-based method



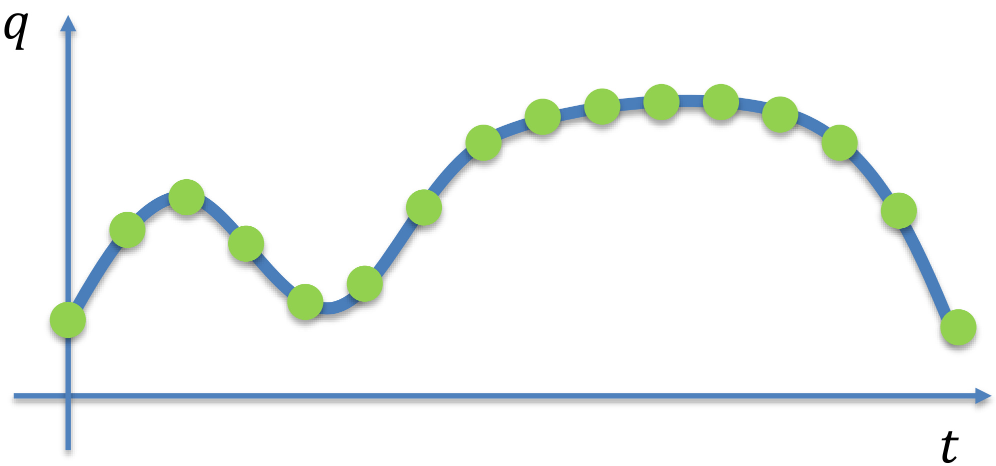
Inverse Dynamics

$$\tau = ID(q, \dot{q}, \ddot{q}, f_{ext}, \tau_{ext})$$

Inverse Dynamics

$$\tau = ID(\underline{q, \dot{q}, \ddot{q}}, f_{ext}, \tau_{ext})$$

- Estimate $\dot{q}, \ddot{q}$
  - forward finite differencing

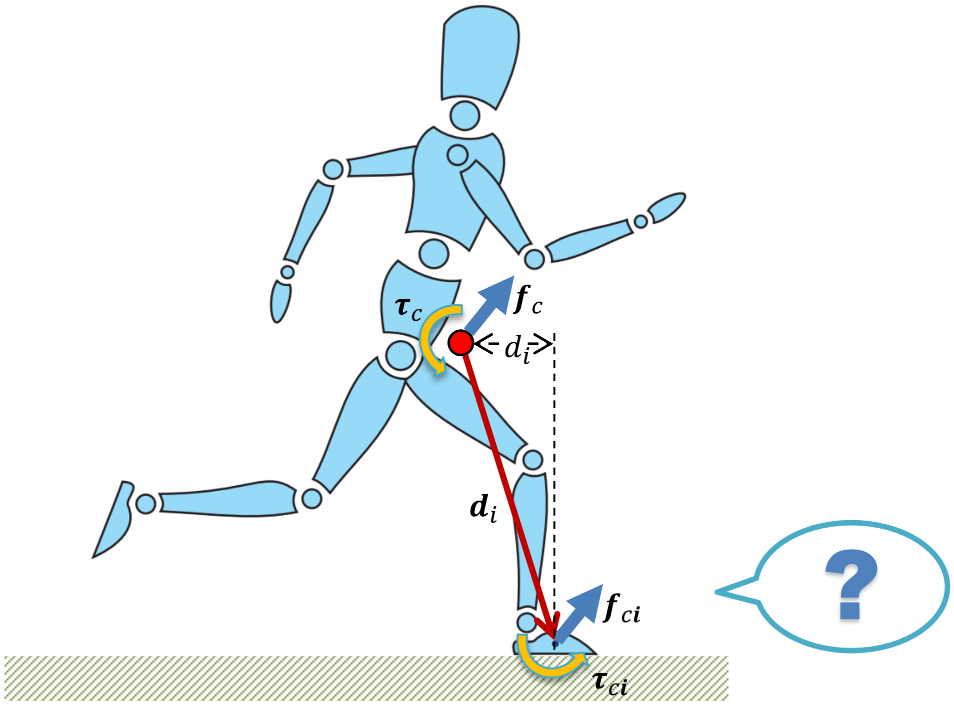


Input Motion

Inverse Dynamics

$$\tau = ID(q, \dot{q}, \ddot{q}, \underline{f_{ext}}, \underline{\tau_{ext}})$$

- Estimate f_{ext}, τ_{ext}
  - f_{ext}, τ_{ext} = Gravity + GRF (Ground Reaction Force)



Inverse Dynamics

$$\tau = ID(q, \dot{q}, \ddot{q}, f_{ext}, \tau_{ext})$$

- Estimate Ground Reaction Force (GRF)
  - GRF can only push the character

$$f_\perp \geq 0$$

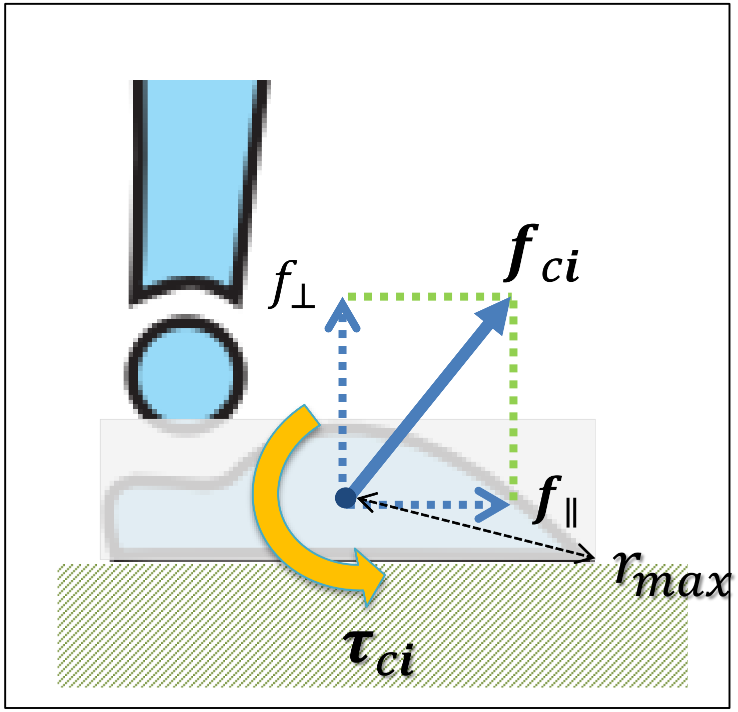
  - Max possible friction

$$\|\boldsymbol{f}_\parallel\| \leq \mu f_\perp$$

  - Max possible torque

$$\|\boldsymbol{\tau}\| \leq r_{max} f_{max}$$

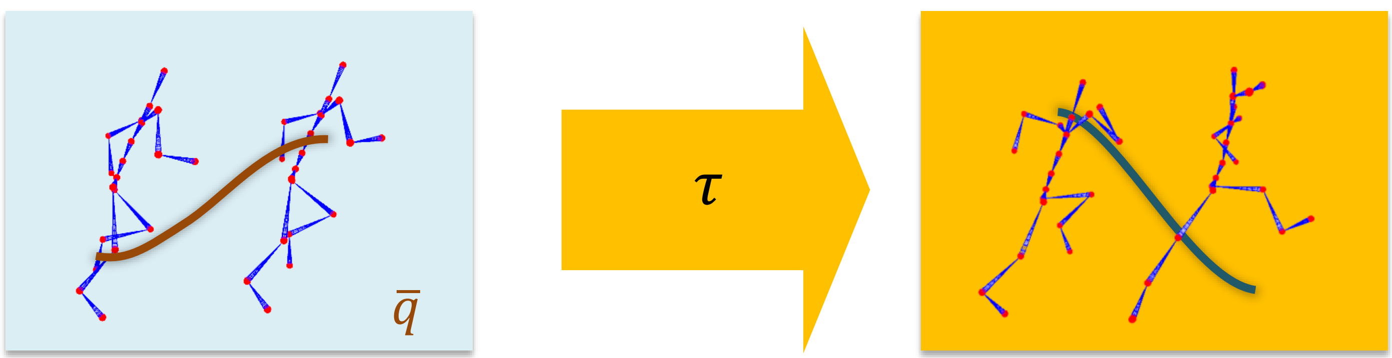
$$f_{max} = \sqrt{1+\mu^2} f_\perp$$



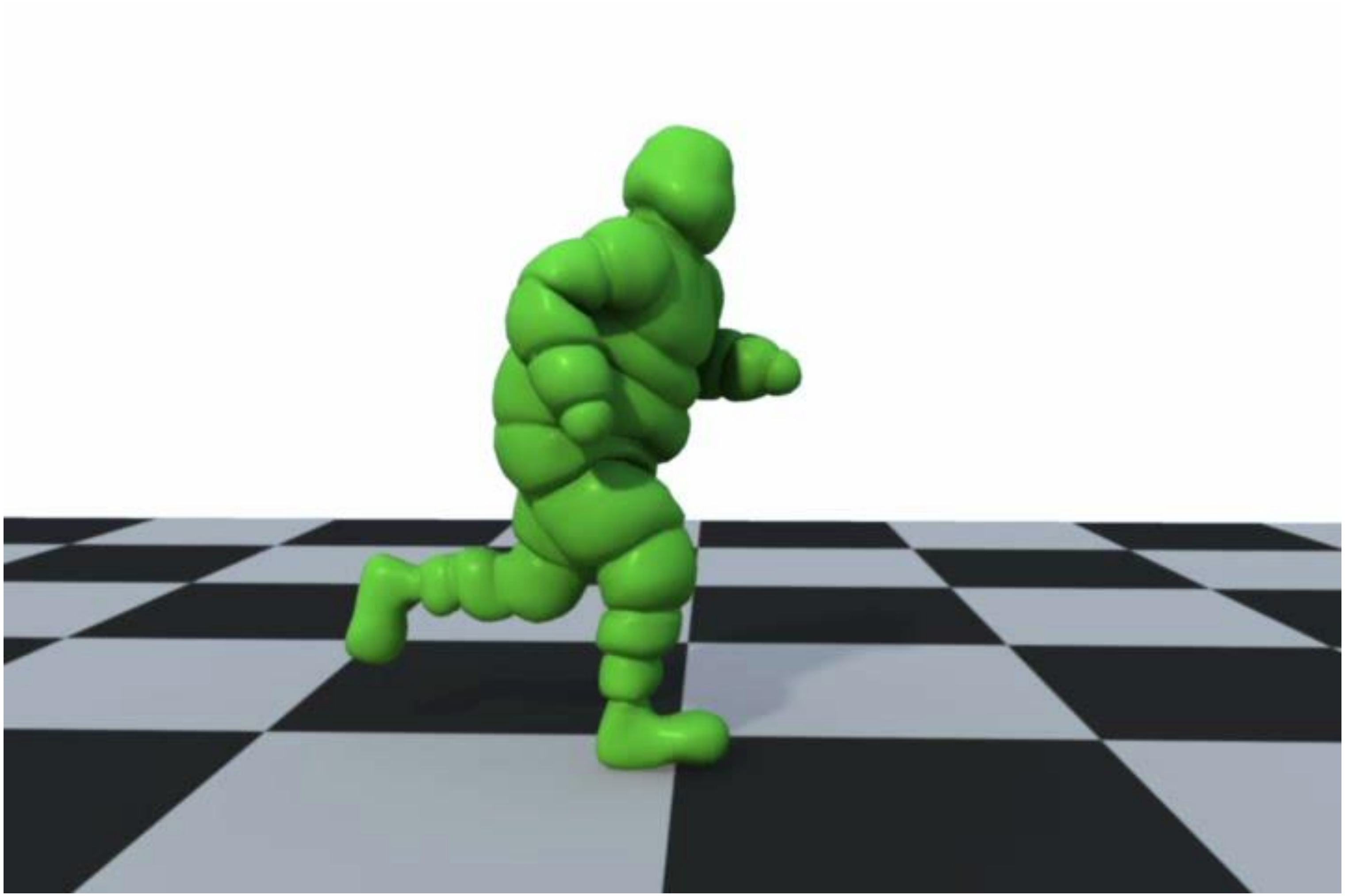
Inverse Dynamics

$$\tau = ID(q, \dot{q}, \ddot{q}, f_{ext}, \tau_{ext})$$

- Estimate Target Pose

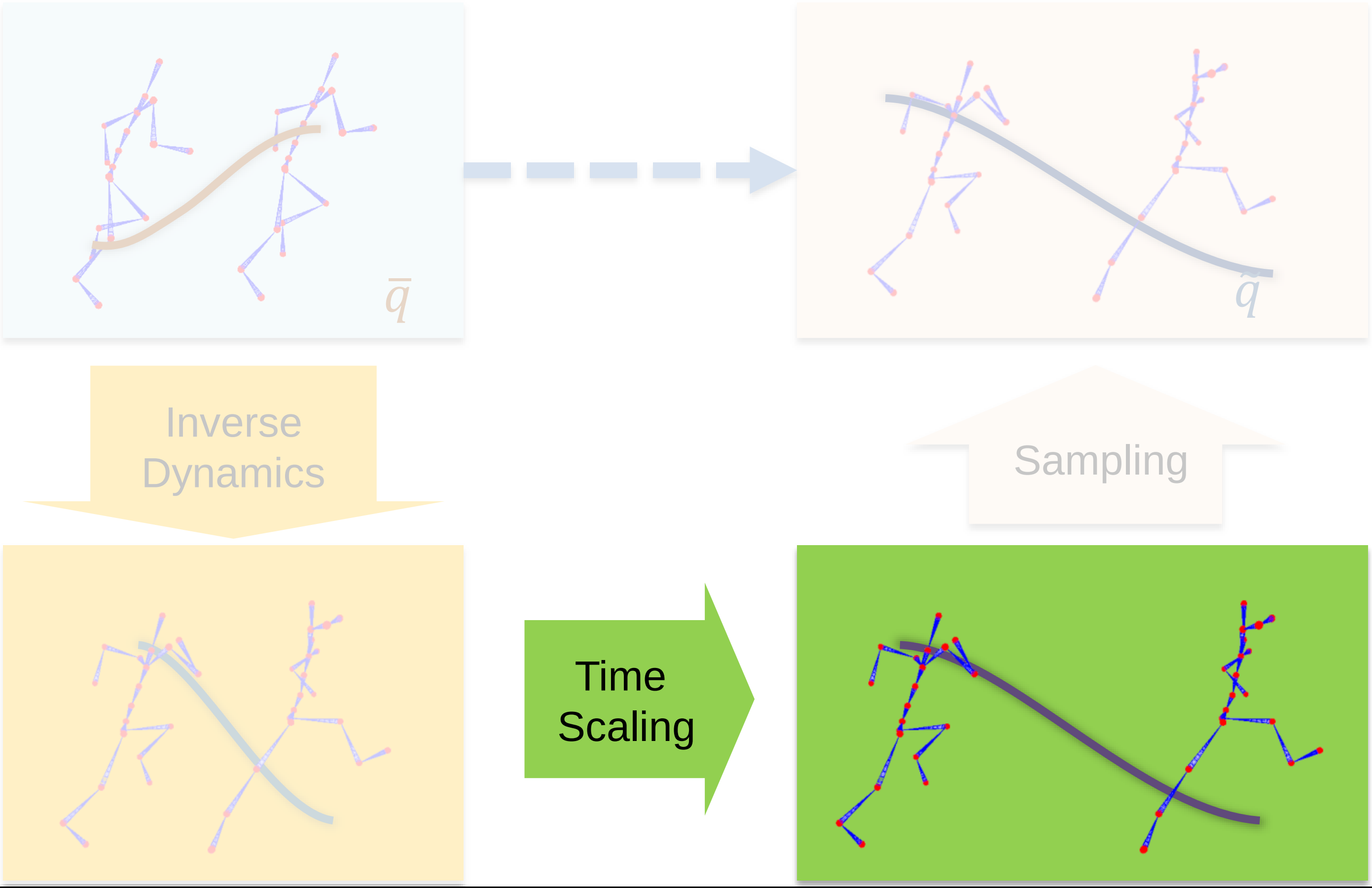


Inverse Dynamics



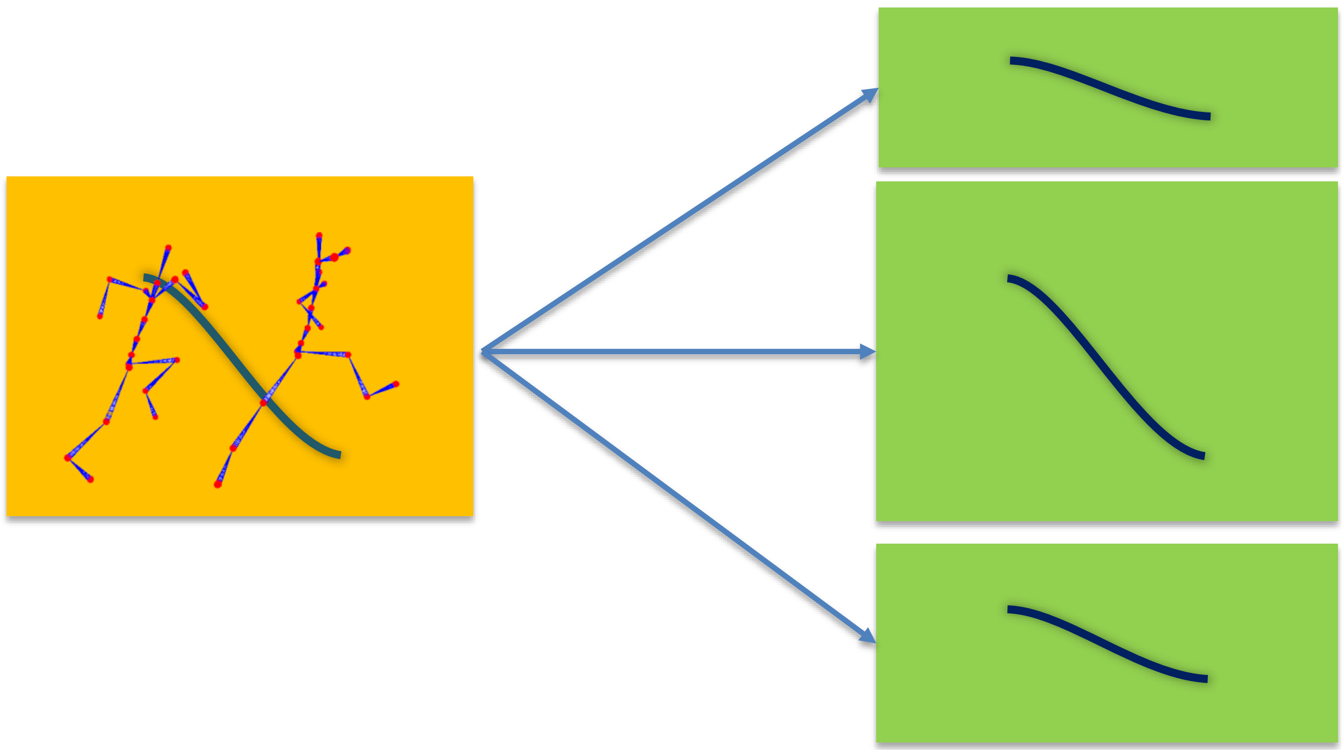
Motion Control

- Control Construction
  - Augmented sampling-based method



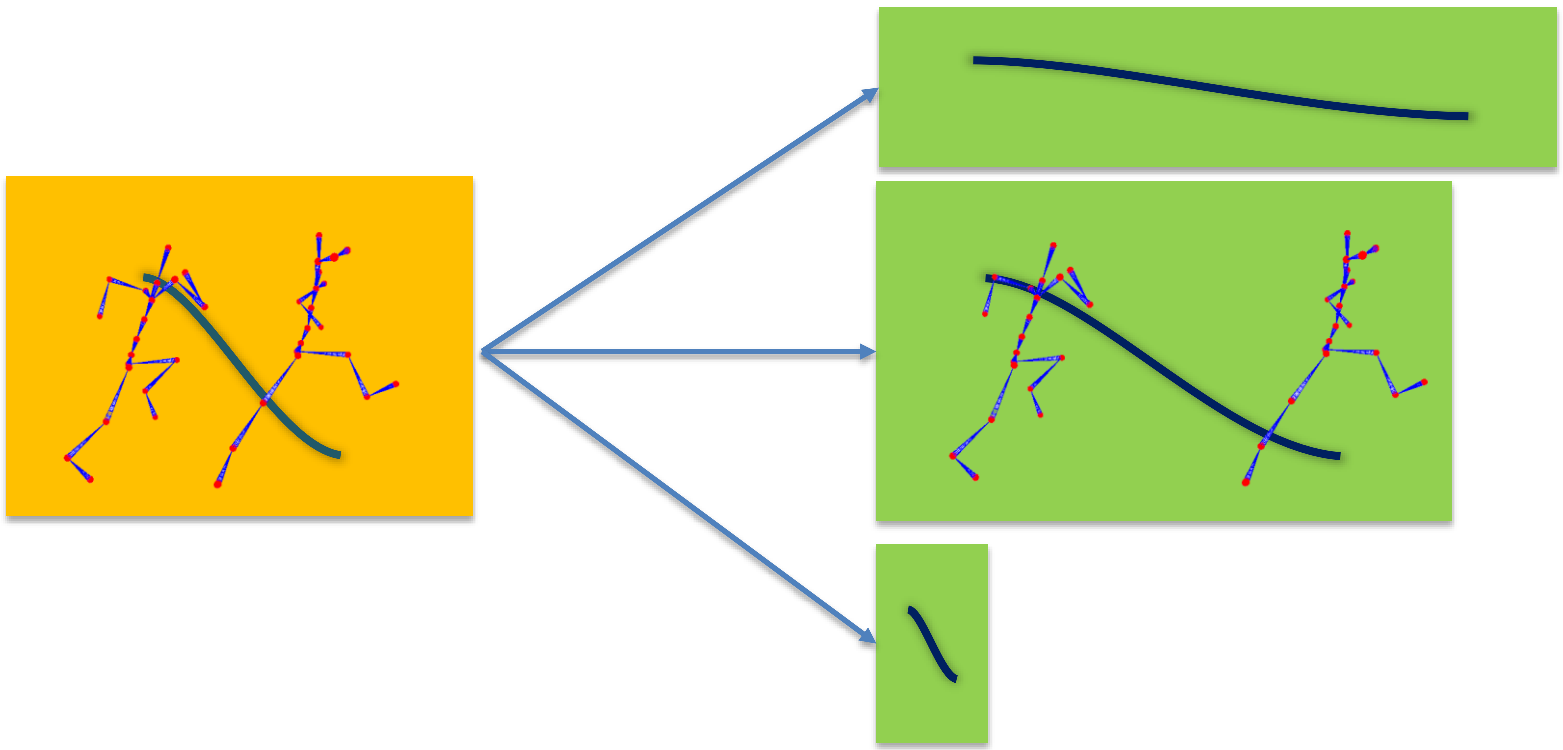
Time Scaling

- Sample Time Scaling Parameter

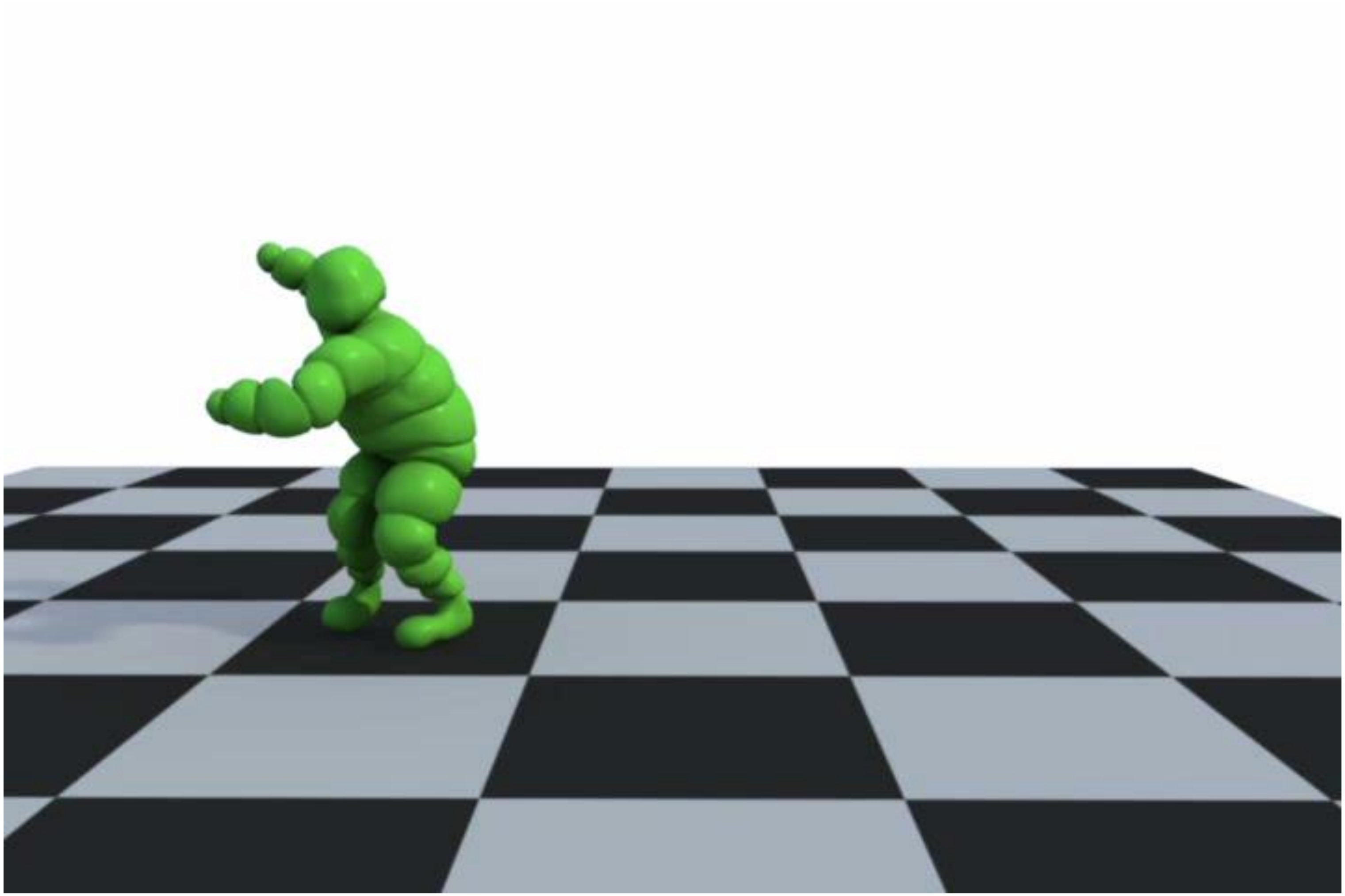


Time Scaling

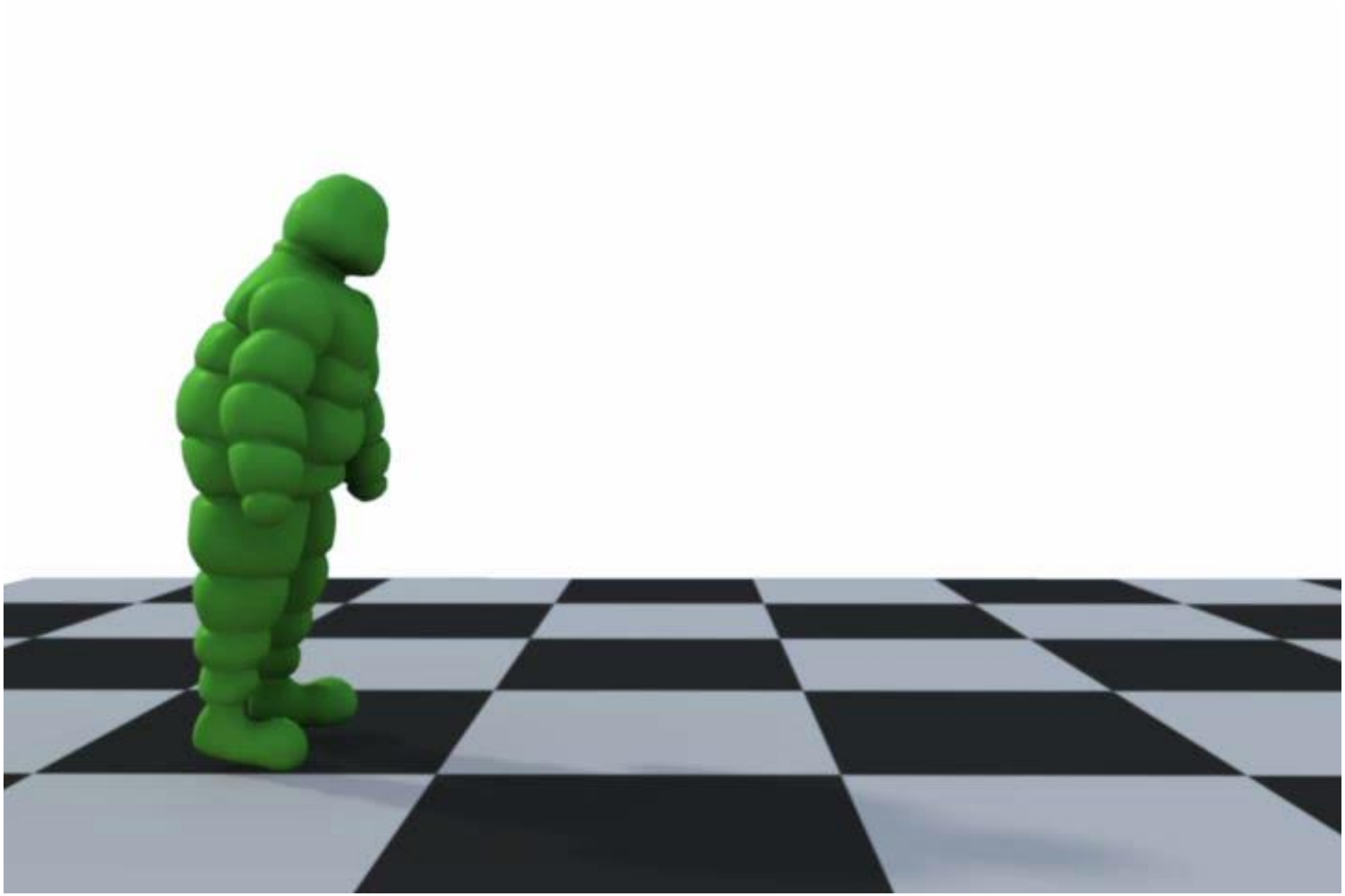
- Sample Time Scaling Parameter



Time Scaling

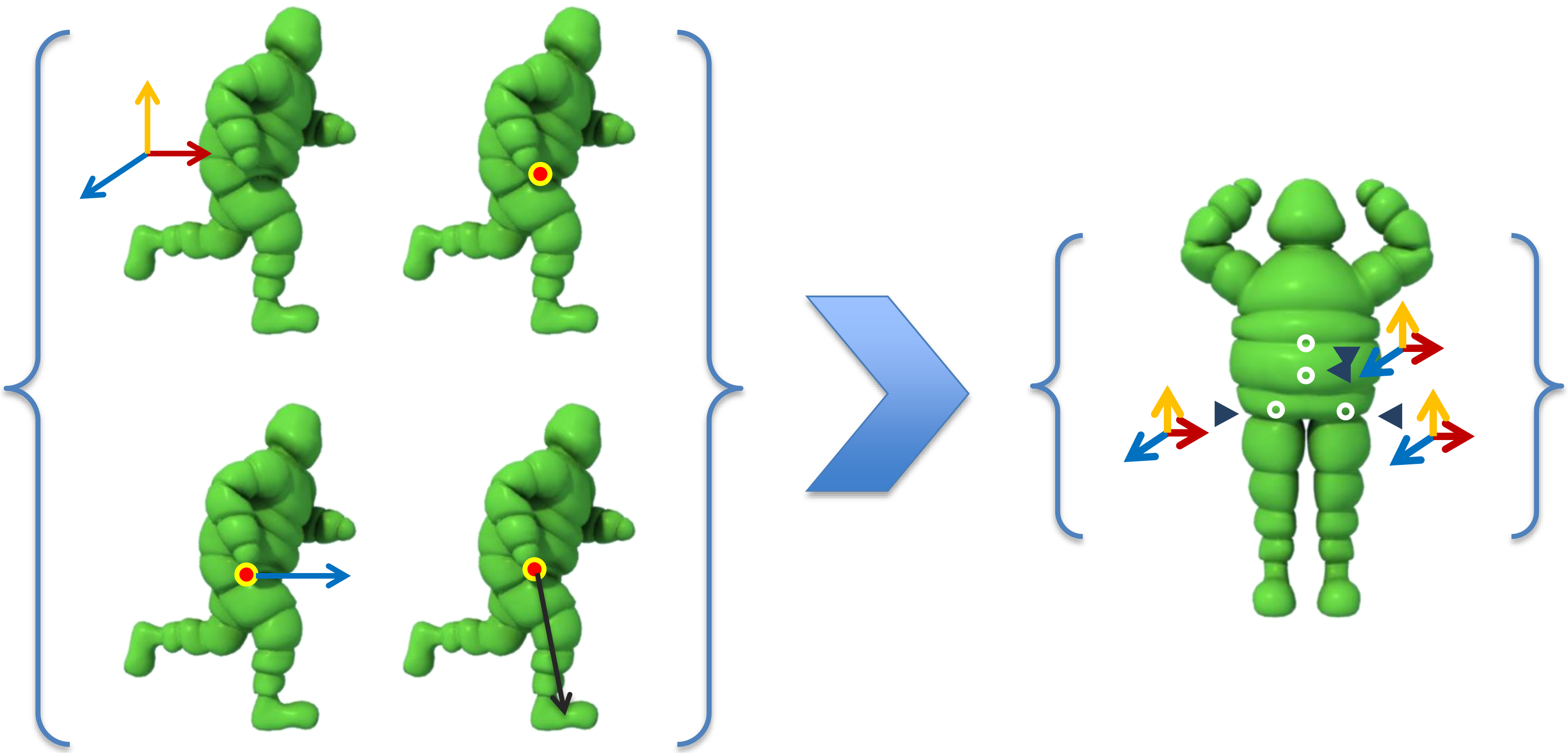


Control Construction



Motion Control

- Closed-loop Feedback Policies
  - Linear feedback policies [Liu et al. 2012]



Closed-loop Feedback Policies

Conclusion

- Two-way simulation framework for soft body characters
  - Pose-based plasticity
  - Angular momentum Conservation
  - Interactive rates
- Augmented sampling-based control construction
  - Inverse Dynamics
  - Time Scaling

Limitations

- Stability Issues
  - Explicit coupling and solver
- Quality Issues
  - Low-res volumetric mesh
  - Linear skinning method
- Capability Issues
  - Success rate < 100%

Future Work

- More stable coupling with implicit integrators
- Remeshing and better skinning techniques
- Incorporating material properties and planning

Thanks