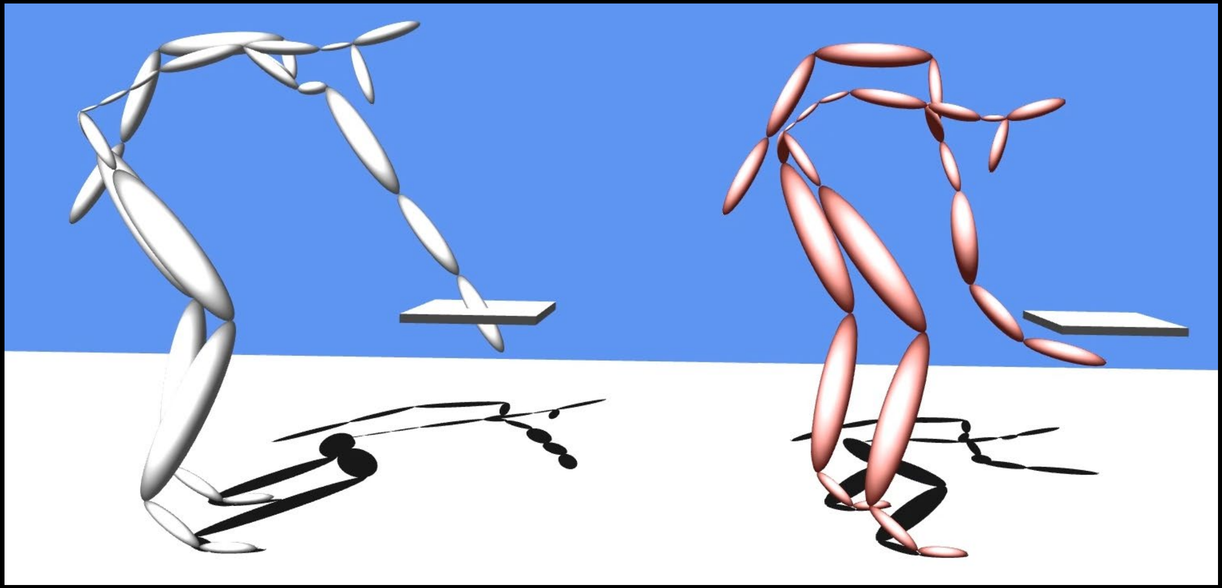

Motion Adaptation with Cascaded Inequality Tasks

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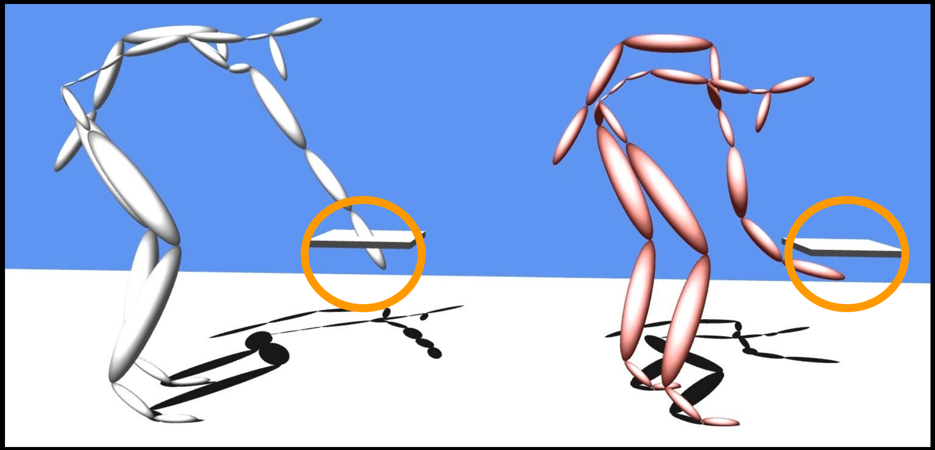
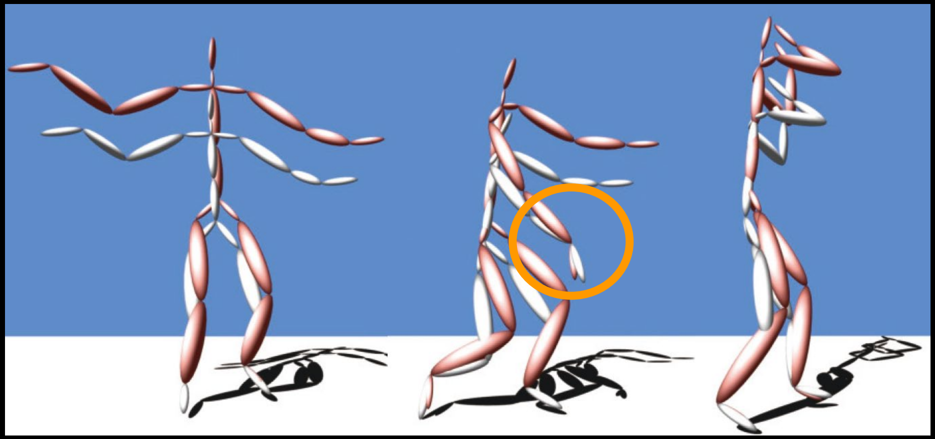
Toyohashi University of Technology

Masaki Oshita
Kyushu Institute of Technology

Motion Adaptation

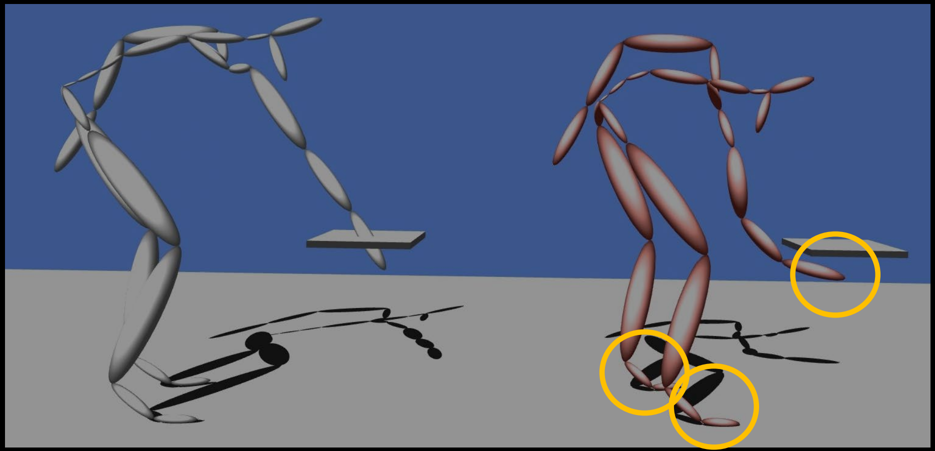


Environmental adaptation



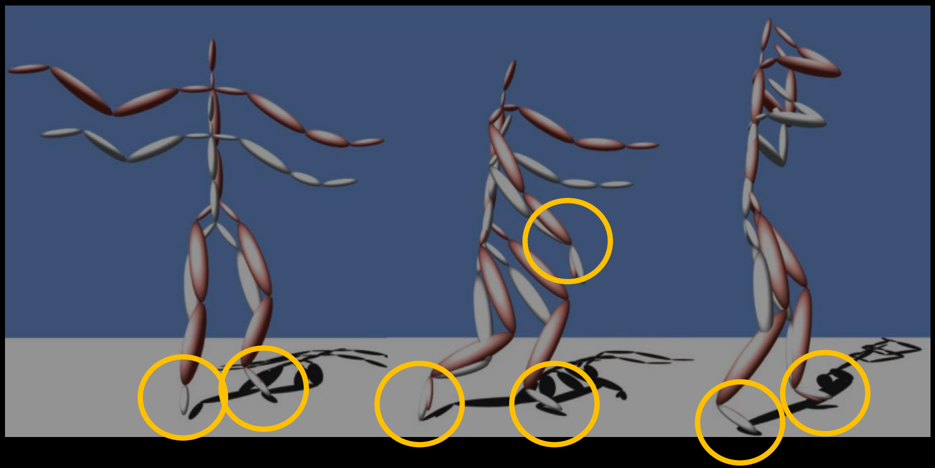
Adaptation to different character (retargeting)

Priorities of Adaptation Tasks



Inequality constraint

1. Range of joint motion
2. Collision avoidance
3. Ground contact
4. Reaching target
5. Similarity to source



Inequality constraint

1. Range of joint motion
2. Foot motion
3. Hand pose at the hit
4. Similarity to source

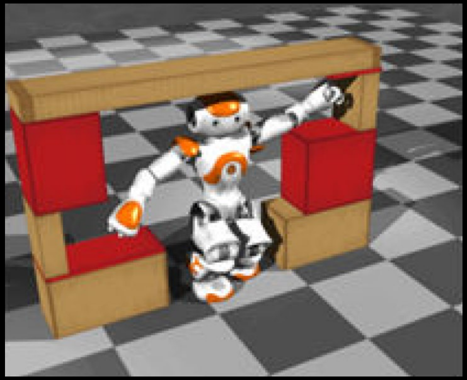
Related Work – Adaptation, Prioritized IK

- Spacetime optimization w/ soft & hard constraints
  [Ho and Shum 2013]

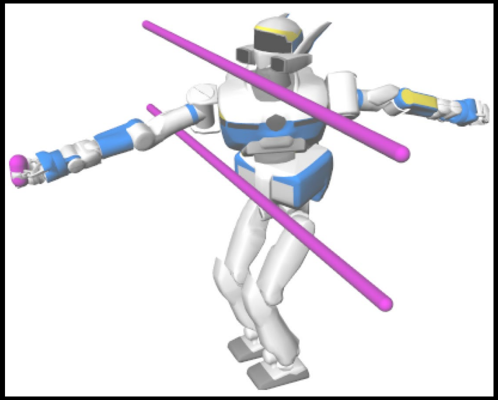
$$\min f(\mathbf{m})$$
$$\text{s.t. } C(\mathbf{m}) = 0$$

Soft constraints (equality) → $\min f(\mathbf{m})$

Hard constraints (equality) → $C(\mathbf{m}) = 0$



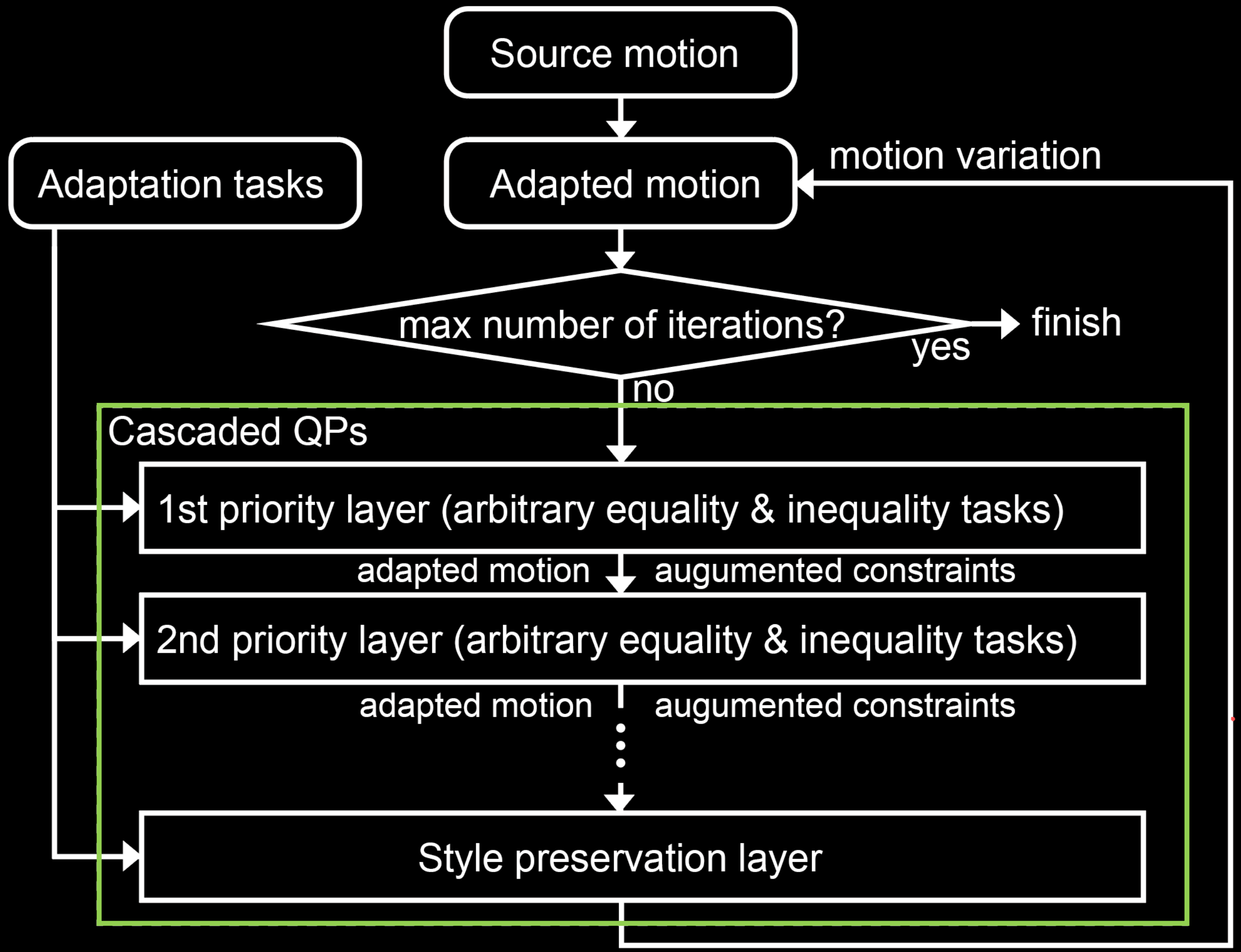
- Hierarchical quadratic programming
  [Kanoun et al. 2011]
  - Arbitrary number of priority layers
  - Equality and inequality tasks



Approach

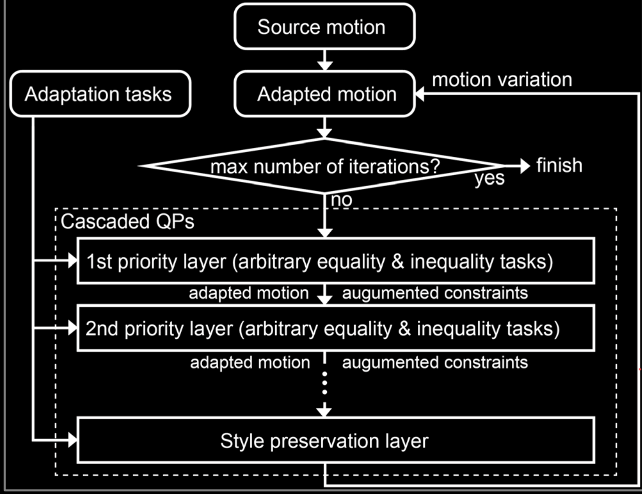
- Relaxing the constrained least-square problem
  - Iterative optimization of motion variables
- Equality & inequality spatiotemporal tasks
  - Joint position, Joint angle, Positional / angular displacement, Distance
  - Cascading priority layer
- Cascaded series of quadratic programs (QPs)
  - satisfy the tasks as much as possible while preserving the fulfillment of the more important tasks

Overview



Source motion
Adaptation tasks
Adapted motion
motion variation
max number of iterations?
yes
finish
no
Cascaded QPs
1st priority layer (arbitrary equality & inequality tasks)
adapted motion
augumented constraints
2nd priority layer (arbitrary equality & inequality tasks)
adapted motion
augumented constraints
Style preservation layer

Iterative QP

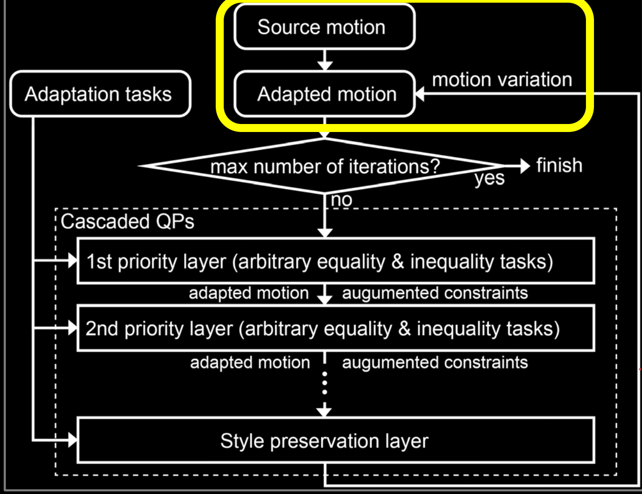


$$\min_{\Delta\mathbf{m}_u} \operatorname{diff}(\mathbf{m}_u + \Delta\mathbf{m}_u, \bar{\mathbf{m}})$$

$$\text{s.t.} \quad \begin{aligned} \forall e \in E,\ \ \mathbf{A}_e \Delta\mathbf{m}_u = \Delta\mathbf{b}_e \\ \forall i \in I,\ \ \mathbf{C}_i \Delta\mathbf{m}_u \leq \Delta\mathbf{d}_i \end{aligned}$$

$$\mathbf{m}_{u+1} = \mathbf{m}_u + \Delta\mathbf{m}_u,\ \ \mathbf{m}_0 = \bar{\mathbf{m}}$$

Iterative QP



Motion variation

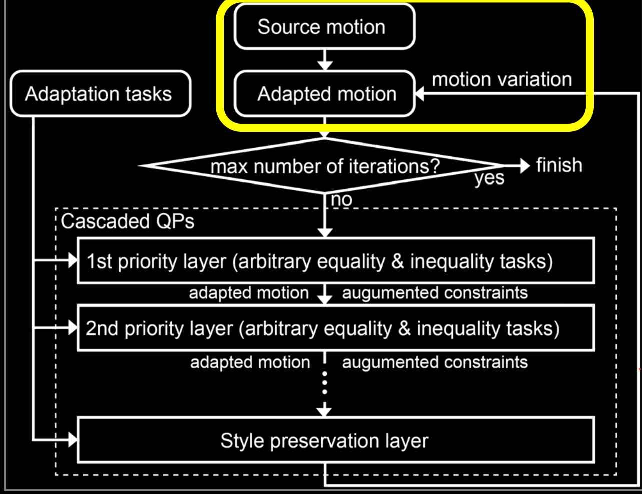
$$\min_{\Delta \mathbf{m}_u} \operatorname{diff}(\mathbf{m}_u + \Delta \mathbf{m}_u, \bar{\mathbf{m}})$$

Adapted motion   Source motion

$$\text{s.t.} \quad \forall e \in E,\ \mathbf{A}_e \Delta \mathbf{m}_u = \Delta \mathbf{b}_e$$
$$\forall i \in I,\ \mathbf{C}_i \Delta \mathbf{m}_u \leq \Delta \mathbf{d}_i$$

$$\mathbf{m}_{u+1} = \mathbf{m}_u + \Delta \mathbf{m}_u, \ \ \mathbf{m}_0 = \bar{\mathbf{m}}$$

Iterative QP



$$\min_{\Delta \mathbf{m}_u} \mathrm{diff}(\mathbf{m}_u + \Delta \mathbf{m}_u, \bar{\mathbf{m}})$$

s.t. $\forall e \in E, \ \mathbf{A}_e \Delta \mathbf{m}_u = \Delta \mathbf{b}_e$

$\forall i \in I, \ \mathbf{C}_i \Delta \mathbf{m}_u \leq \Delta \mathbf{d}_i$

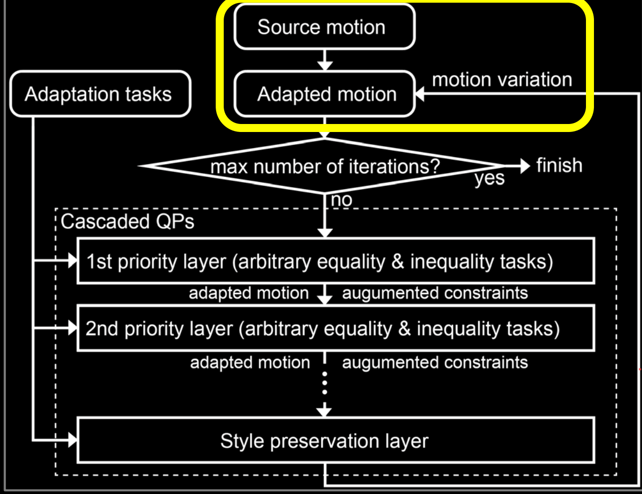
Variation of task variables

Set of equality tasks

Task Jacobian wrt motion vector

$$\mathbf{m}_{u+1} = \mathbf{m}_u + \Delta \mathbf{m}_u, \quad \mathbf{m}_0 = \bar{\mathbf{m}}$$

Iterative QP



$$\min_{\Delta \mathbf{m}_u} \operatorname{diff}(\mathbf{m}_u + \Delta \mathbf{m}_u, \bar{\mathbf{m}})$$

$$\text{s.t.} \quad \begin{aligned} &\forall e \in E, \quad \mathbf{A}_e \Delta \mathbf{m}_u = \Delta \mathbf{b}_e \\ &\forall i \in I, \quad \mathbf{C}_i \Delta \mathbf{m}_u \leq \Delta \mathbf{d}_i \end{aligned}$$

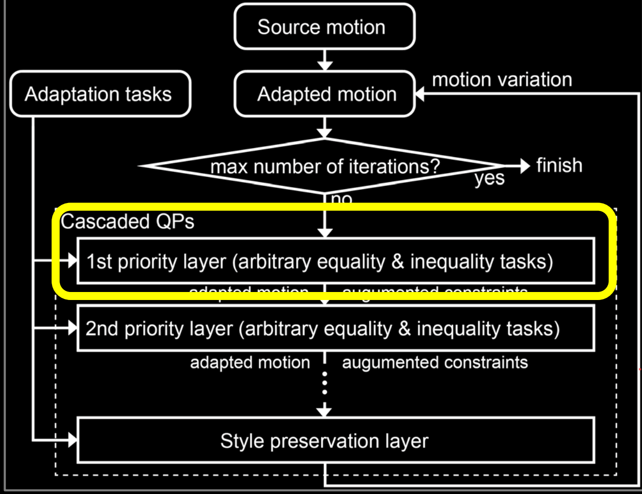
Variation of task variables

Set of inequality tasks

Task Jacobian wrt motion vector

$$\mathbf{m}_{u+1} = \mathbf{m}_u + \Delta \mathbf{m}_u, \quad \mathbf{m}_0 = \bar{\mathbf{m}}$$

Relaxation of Constrained Optimization [Kanoun et al. 2011]



$$\min_{\Delta \mathbf{m}_u} \operatorname{diff}(\mathbf{m} + \Delta \mathbf{m}_u, \bar{\mathbf{m}})$$

$$\text{s.t.} \begin{cases} \forall e \in E, & \mathbf{A}_e \Delta \mathbf{m}_u = \Delta \mathbf{b}_e \\ \forall i \in I, & \mathbf{C}_i \Delta \mathbf{m}_u \leq \Delta \mathbf{d}_i \end{cases}$$

Relaxed equality tasks of the first priority layer

Slack variable

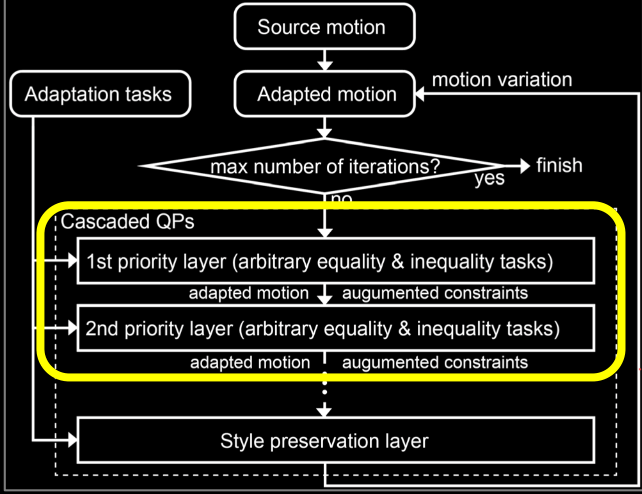
$$\min_{\Delta \mathbf{m}_1, \mathbf{w}} \|\mathbf{A}_1 \Delta \mathbf{m}_1 - \Delta \mathbf{b}_1\|^2 + \|\mathbf{w}\|^2$$

$$\text{s.t.} \begin{cases} \mathbf{C}_1 \Delta \mathbf{m}_1 \leq \Delta \mathbf{d}_1 + \mathbf{w} \\ \mathbf{w} \geq \mathbf{0} \end{cases}$$

Relaxed inequality tasks of the first priority layer

Cascaded Series of QPs

[Kanoun et al. 2011]



$$\min_{\Delta \mathbf{m}_1, \mathbf{w}} \|\mathbf{A}_1 \Delta \mathbf{m}_1 - \Delta \mathbf{b}_1\|^2 + \|\mathbf{w}\|^2$$

$$\text{s.t.} \begin{cases} \mathbf{C}_1 \Delta \mathbf{m}_1 \leq \Delta \mathbf{d}_1 + \mathbf{w} \\ \mathbf{w} \geq \mathbf{0} \end{cases}$$

first layer

second layer

$$\min_{\Delta \mathbf{m}_2, \mathbf{w}} \|\mathbf{A}_2 \Delta \mathbf{m}_2 - \Delta \mathbf{b}_2\|^2 + \|\mathbf{w}\|^2$$

$$\text{s.t.} \begin{cases} \mathbf{A}_1 \Delta \mathbf{m}_2 = \mathbf{A}_1 \Delta \mathbf{m}_1 \\ \mathbf{C}_1^{\mathrm{fes}} \Delta \mathbf{m}_2 \leq \Delta \mathbf{d}_1^{\mathrm{fes}} \\ \mathbf{C}_1^{\mathrm{inf}} \Delta \mathbf{m}_2 = \mathbf{C}_1^{\mathrm{inf}} \Delta \mathbf{m}_1 \\ \mathbf{A}_2 \Delta \mathbf{m}_2 = \Delta \mathbf{b}_2 \\ \mathbf{C}_2 \Delta \mathbf{m}_2 \leq \Delta \mathbf{d}_2 + \mathbf{w} \\ \mathbf{w} \geq \mathbf{0} \end{cases}$$

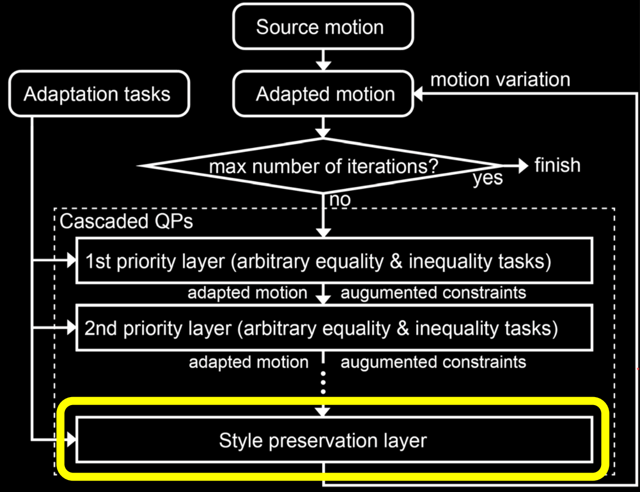
least-square solution of equality tasks

feasible inequality tasks

violated inequality tasks

Tasks of the second priority layer

Style Preservation Layer



$$\min_{\Delta \mathbf{m}_L} \ \mathrm{diff}(\mathbf{m} + \Delta \mathbf{m}_L, \bar{\mathbf{m}})$$

$$\text{s.t.} \begin{cases} \mathbf{A}_1 \Delta \mathbf{m}_L = \mathbf{A}_1 \Delta \mathbf{m}_1 \\ \vdots \\ \mathbf{A}_{L-1} \Delta \mathbf{m}_L = \mathbf{A}_{L-1} \Delta \mathbf{m}_{L-1} \\ \mathbf{C}_1^{\mathrm{fes}} \Delta \mathbf{m}_L \leq \Delta \mathbf{d}_1^{\mathrm{fes}} \\ \vdots \\ \mathbf{C}_{L-1}^{\mathrm{fes}} \Delta \mathbf{m}_L \leq \Delta \mathbf{d}_{L-1}^{\mathrm{fes}} \\ \mathbf{C}_1^{\mathrm{inf}} \Delta \mathbf{m}_L = \mathbf{C}_1^{\mathrm{inf}} \Delta \mathbf{m}_1 \\ \vdots \\ \mathbf{C}_{L-1}^{\mathrm{inf}} \Delta \mathbf{m}_L = \mathbf{C}_{L-1}^{\mathrm{inf}} \Delta \mathbf{m}_{L-1} \end{cases}$$

least-square solution of equality tasks

feasible inequality tasks

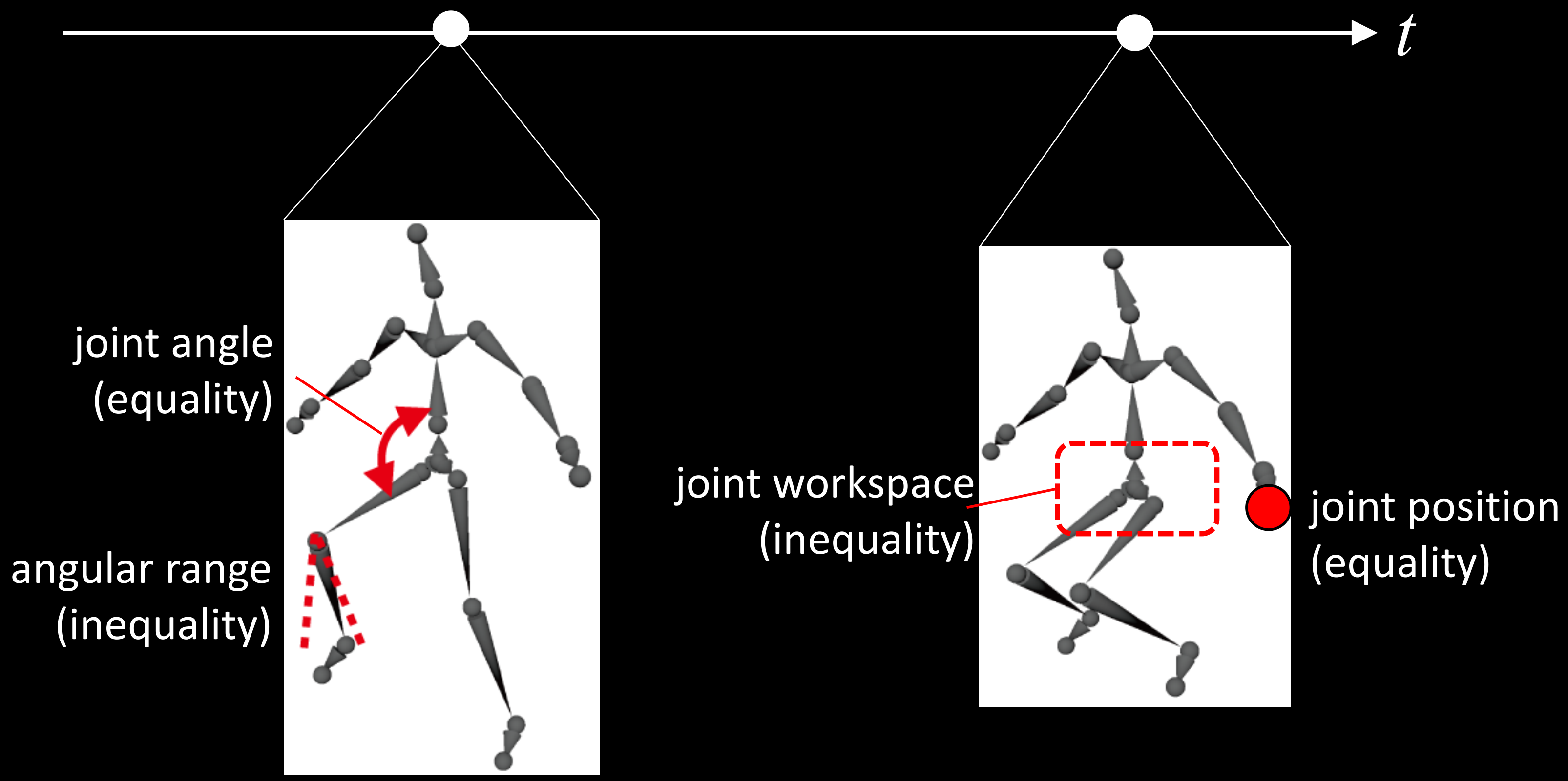
violated inequality tasks

Per-frame Task

$$\mathbf{A}_l \Delta \mathbf{m}_l = \Delta \mathbf{b}_l$$

Jacobian of joint position/angle wrt motion vector

displacement toward target position

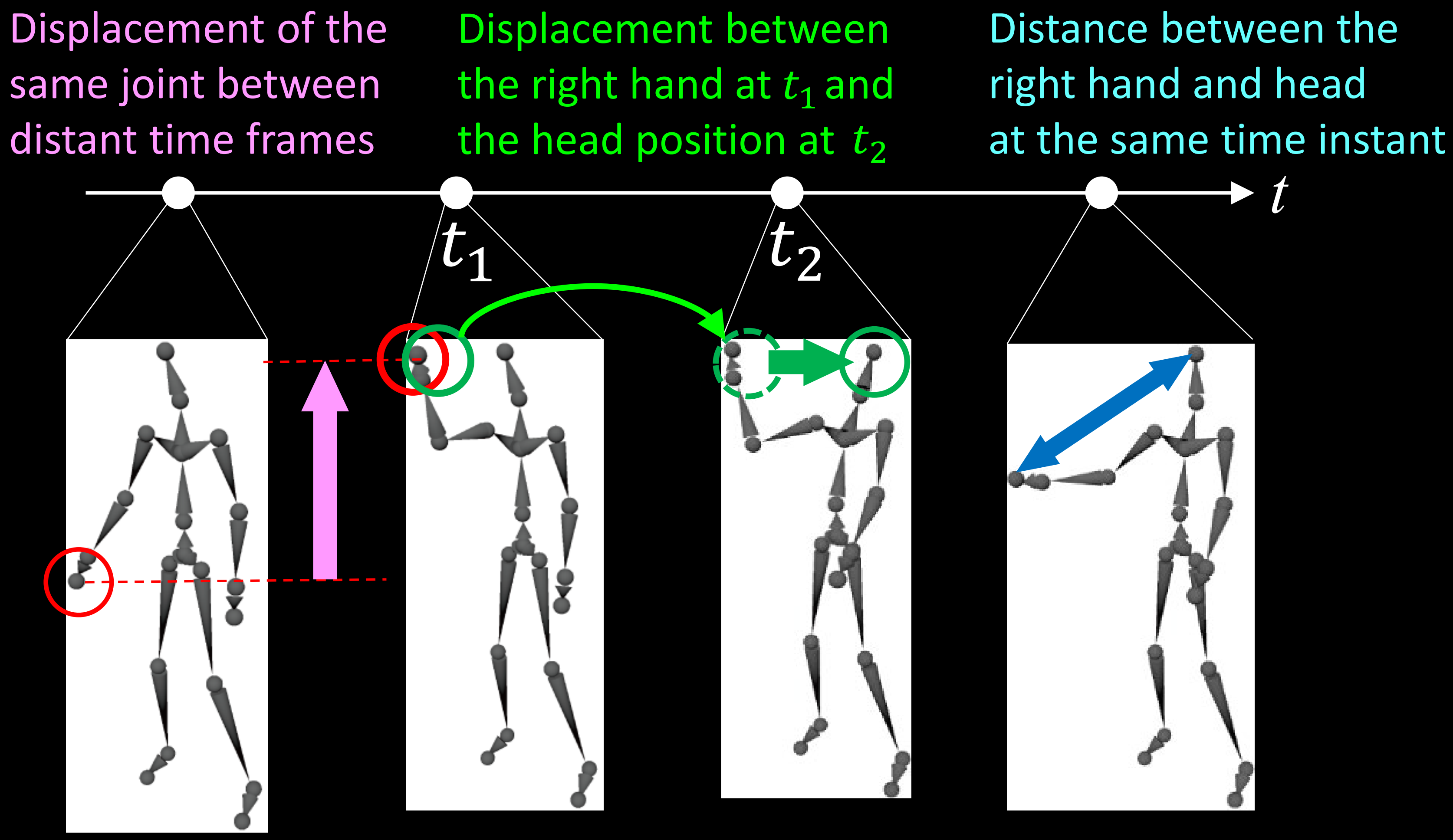


Spatiotemporal Relation

$$\mathbf{A}_l \Delta \mathbf{m}_l = \Delta \mathbf{b}_l$$

Jacobian of inter-joint position/inter-joint angle wrt motion vector

displacement toward target relational value



Combinational Tasks

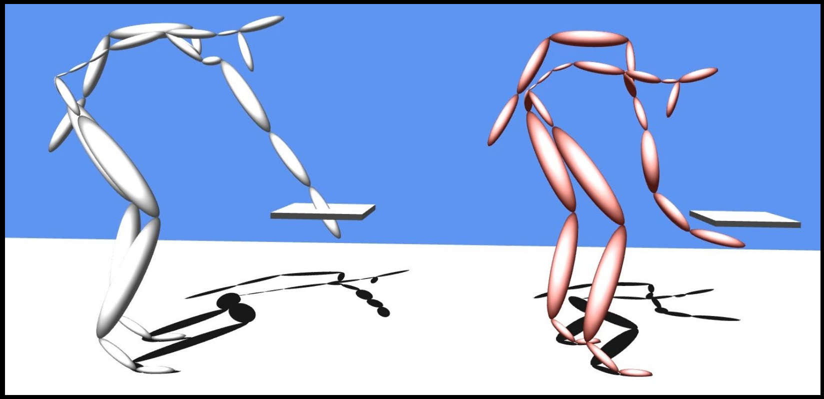
- Joint hull shape
  - Spatial relation among three or more joints
- Curvature of joint trajectory
  - Temporal derivative of joint configuration
  - e.g. monotonic increase
- Center of mass
  - Weighted combination of joint positions

Reaching Motion

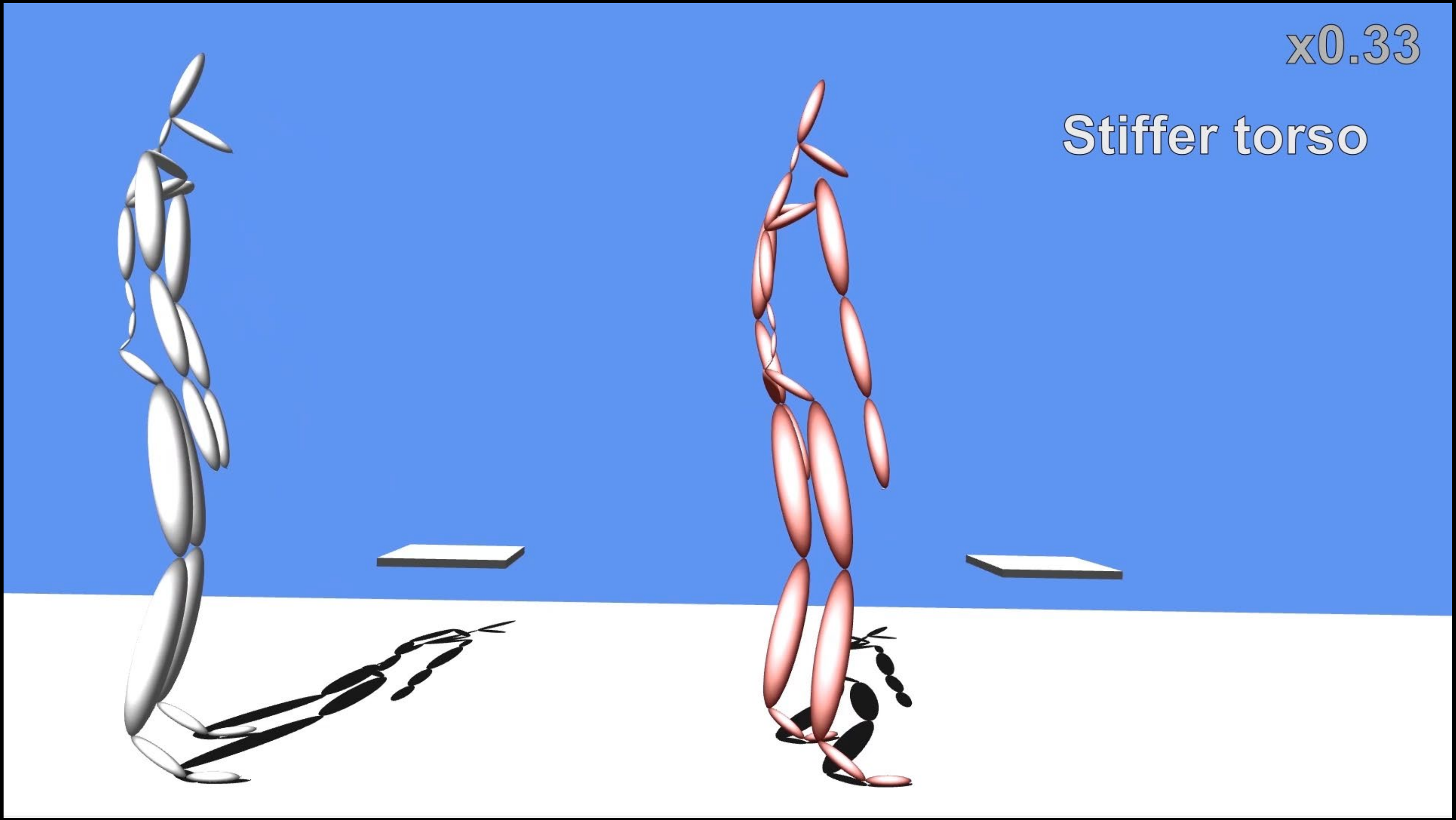
Adaptation of Reaching Motion

Task priority

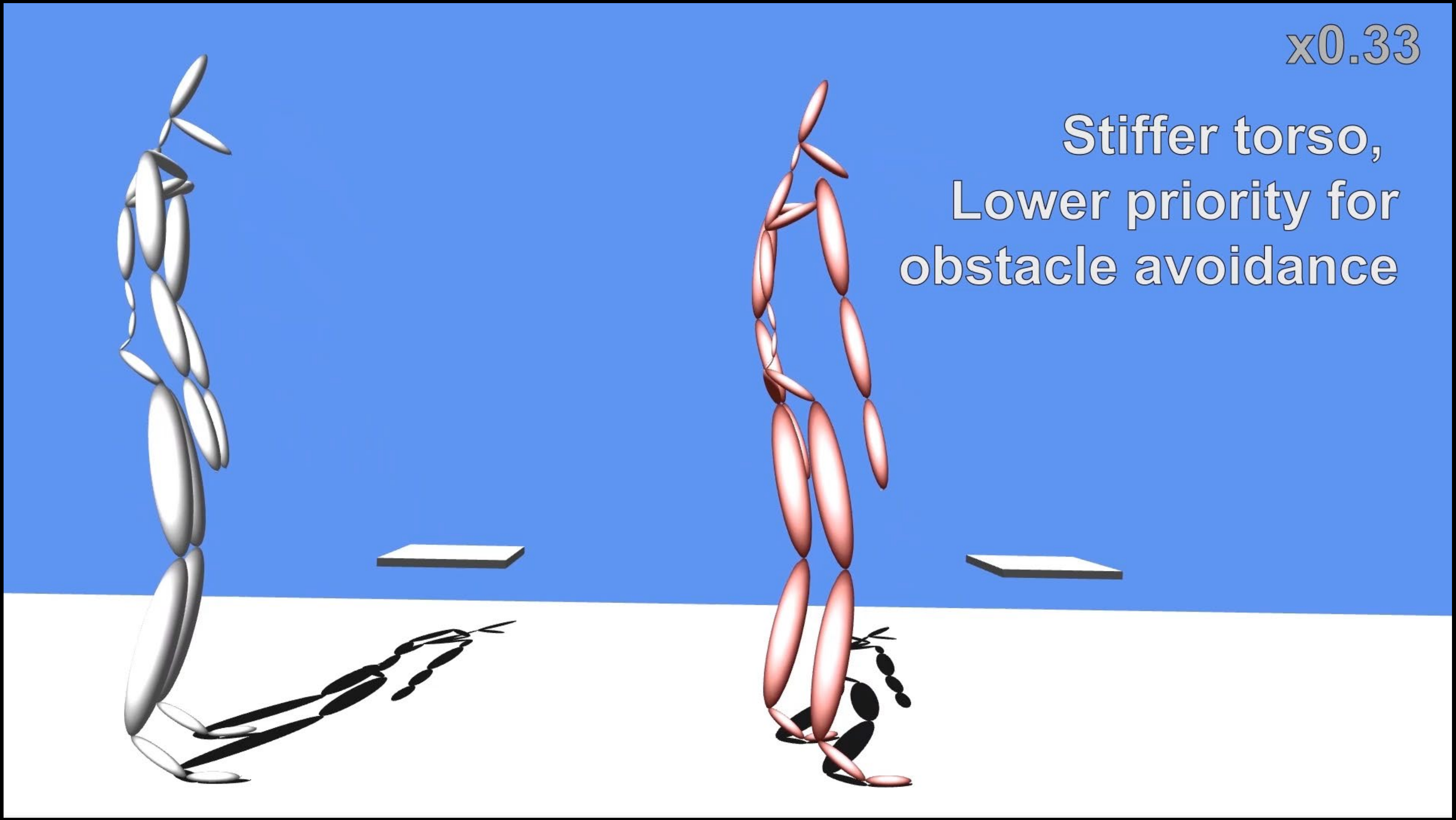
1-a. Range of joint motion
1-b. Poses at both end frames
2-a. Foot positions
2-b. Obstacle avoidance
3. Goal position of right hand



Reaching Motion – Avoidance > Goal



Reaching Motion – Avoidance < Goal



Reaching Motion - Weighting strategy

Single-layer QP
(uniform task weight)

Single-layer QP
(nonuniform task weight)

Tennis Backhand Stroke

Retarget of Two-Fisted Backhand Stroke

Task priority

1. Range of joint motion
2. Foot positions
3. Right hand trajectory around the shooting moment
4. Joint hull shape among the wrists, left hand, and right hand

Walking on Stairs

Walking on Flat Surface to Climbing Up Stairs

Task priority

1. Range of joint motion
2. Foot positions during ground contact
3. Vertical foot movement during flight (inequality)

Multi-character Interaction

Multi-character Interaction

The white character stretches his right hand to grasp the other's right hand, and the red character attempts to avoid it

Task priority

1. Range of joint motion
2. Foot positions
3. Minimal distance between the right hands
4. Contact between the right hands

Summary

- ☺ Strictly prioritized equality and inequality tasks
- ☺ Stable solution even for complicated scenario
- ☺☹ Flexible but unintuitive design of adaptation tasks
- ☹ High computational cost
- ☹ Purely kinematic framework

Acknowledgement: JSPS KAKENHI 15K16110 & 15H02704