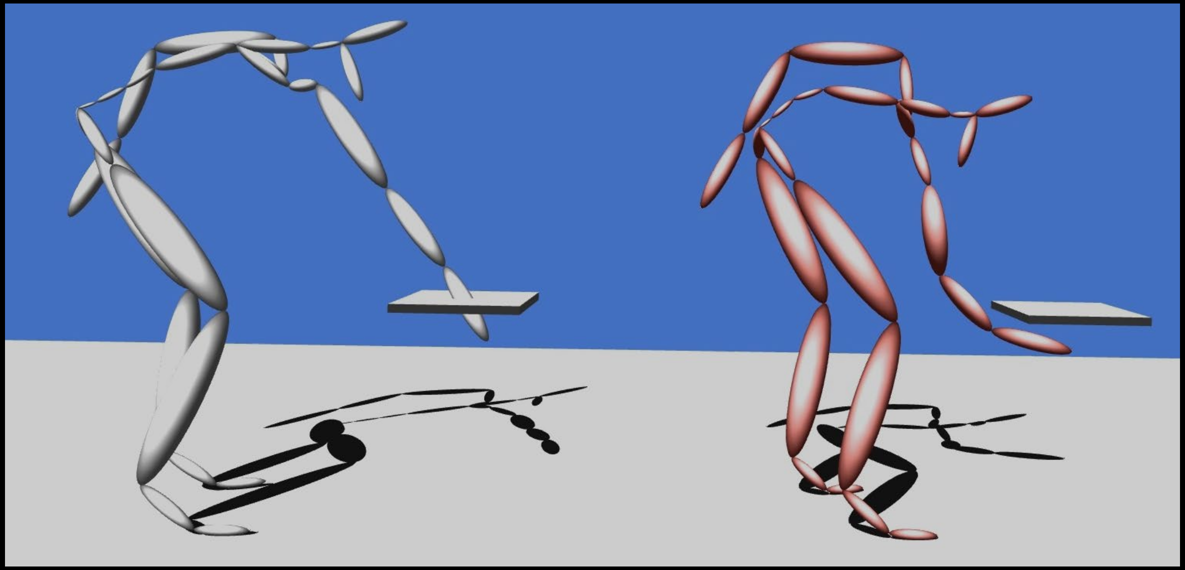
Geometric Deformation of Virtual Character Animation Using Cascaded Spacetime Constraints



Tomohiko Mukai Tokyo Metropolitan University

Who I Am

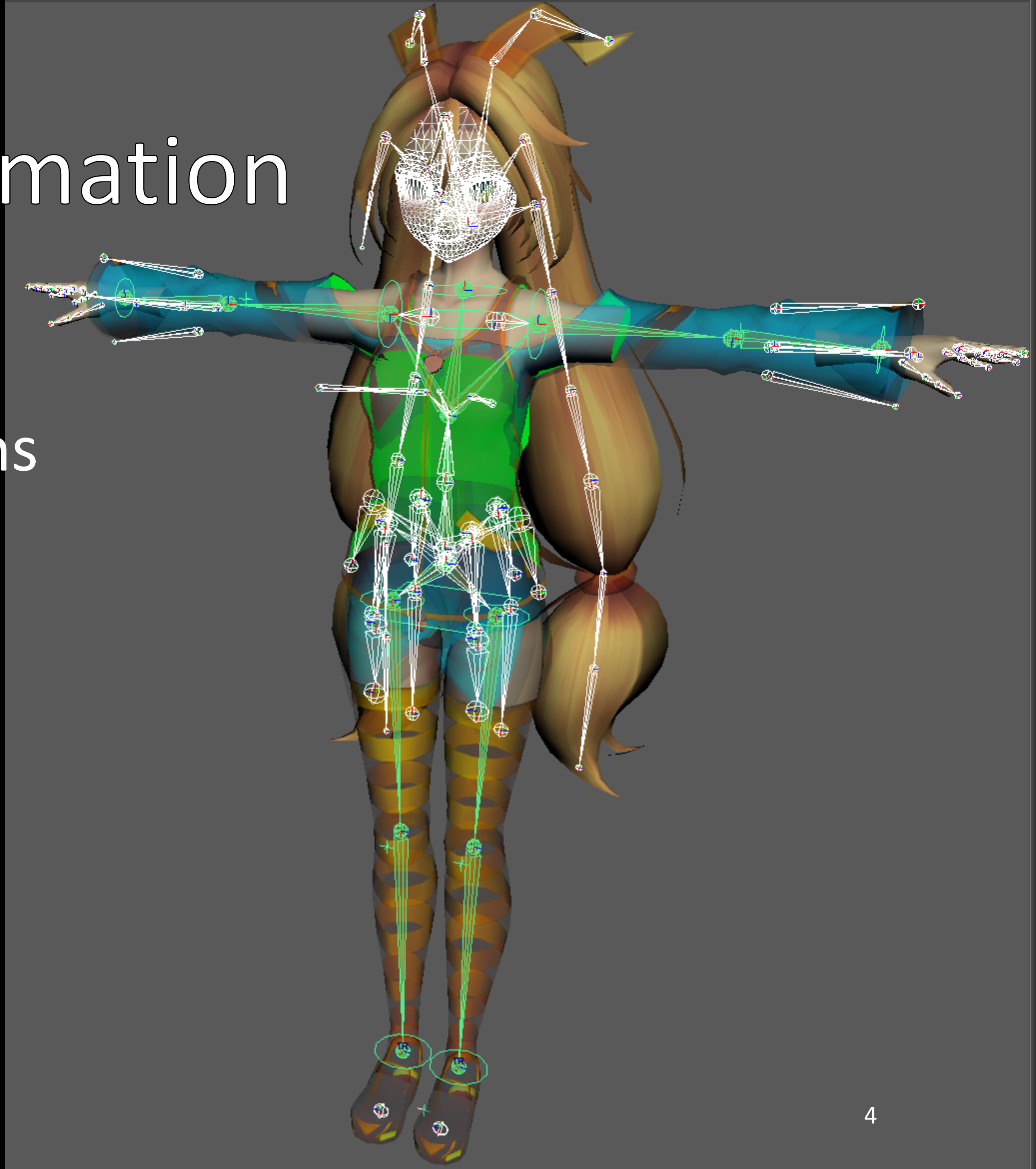
- Tomohiko Mukai, PhD (Eng.)
  - Associate Professor
  - Dept. Industrial Art,
    Tokyo Metropolitan University

- Major - Computer Animation
  - Data-driven animation synthesis using mathematical optimization
  - Five years experience at a game company

Typical animation workflow

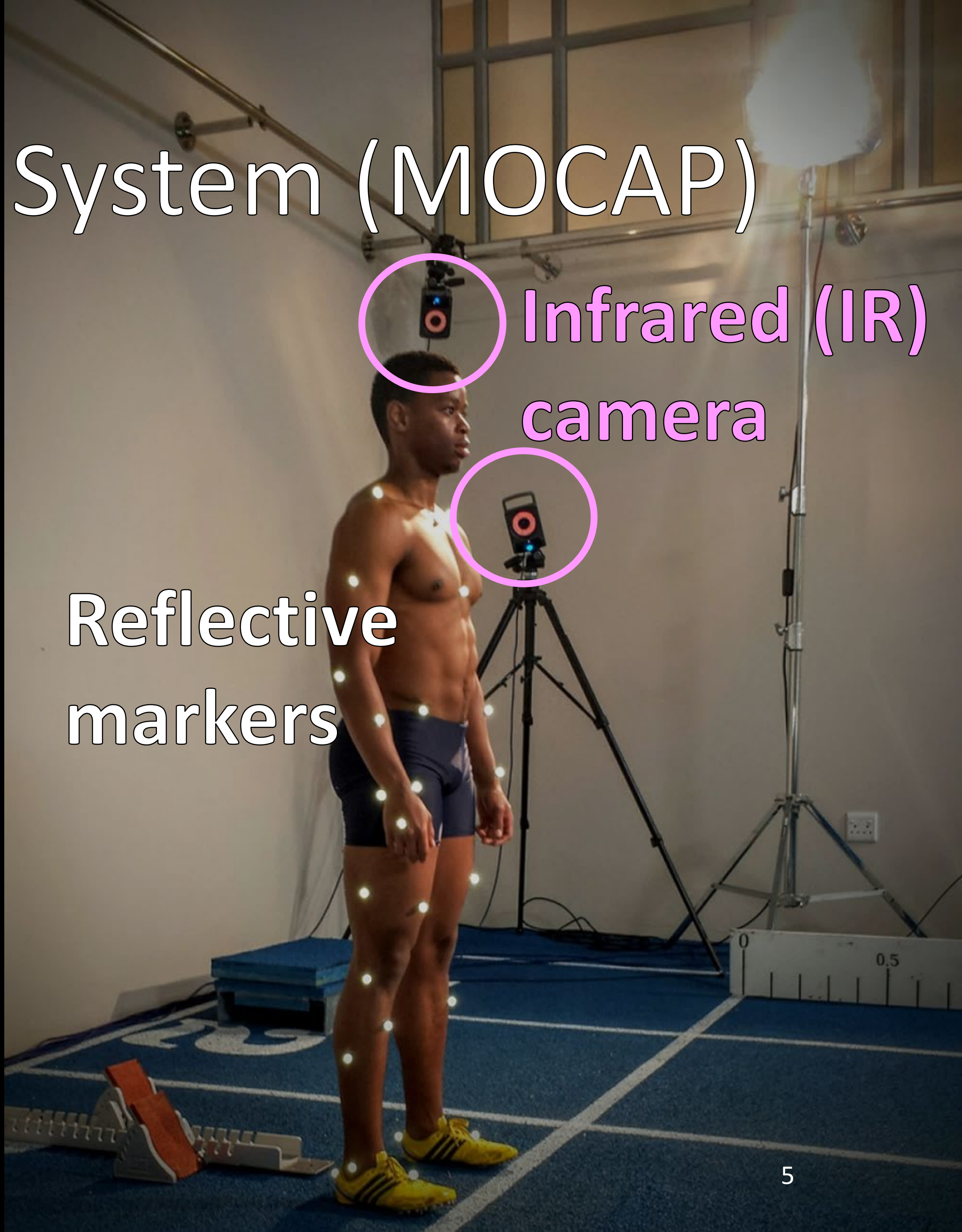
Virtual Character Animation

- Data
  - Time series of joint rotations
- Manipulation interface
  - Position of body part
  - Orientation of body part
  - Joint angles

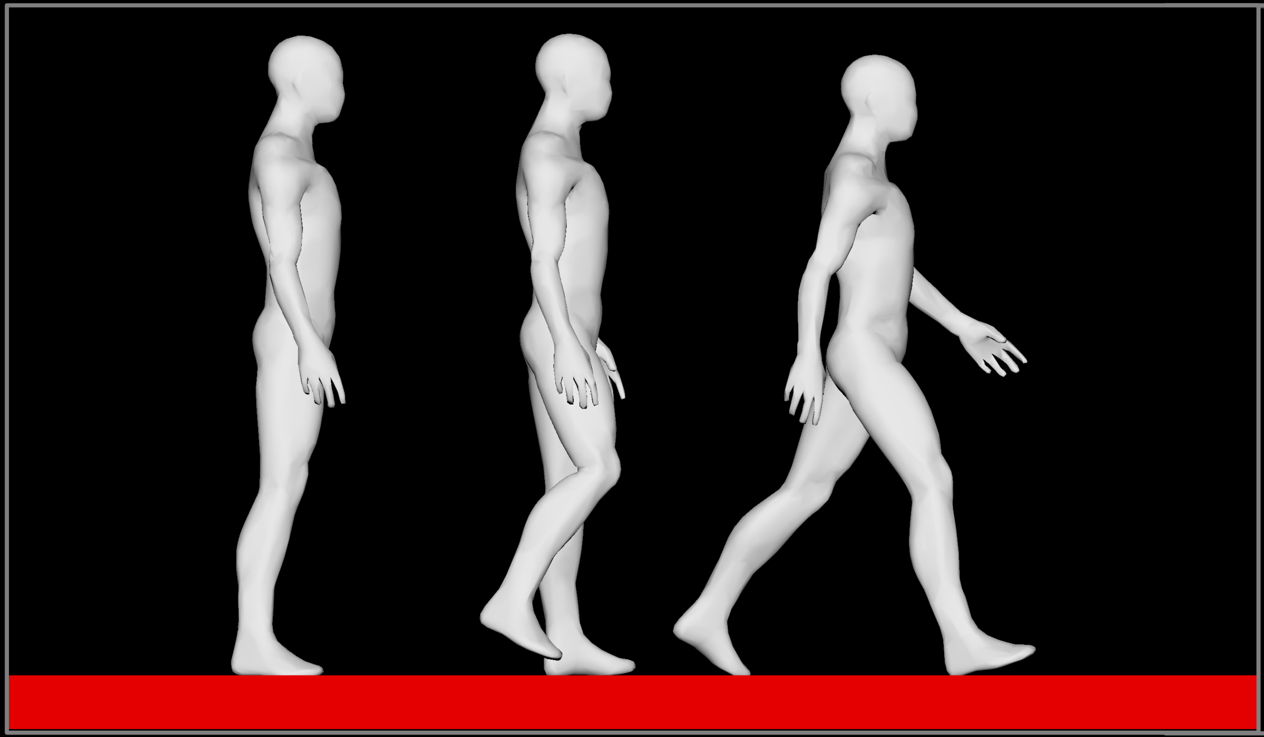


Optical Motion Capture System (MOCAP)

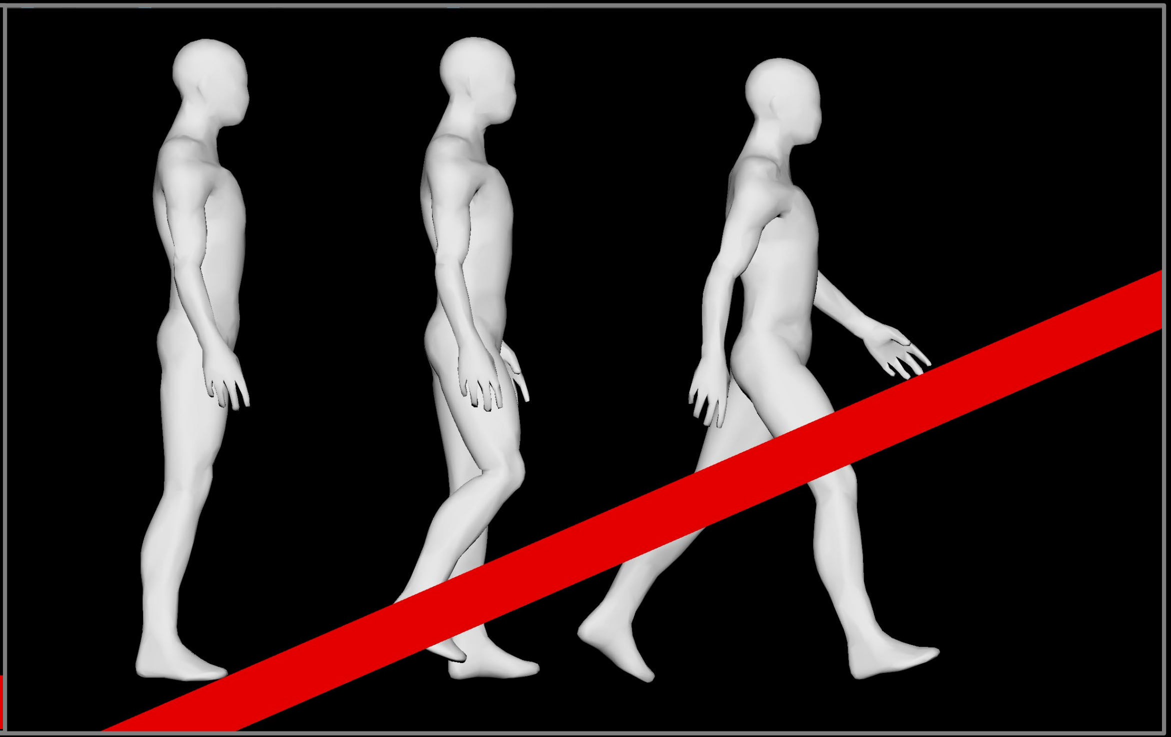
- Measure spatial position of reflective markers
  - Measure the distance between IR camera and markers
  - Reconstruct the 3D position using geometric operations
- Estimate human pose
  - i.e. joint rotations
  - DNN-based method [Holden, 2018]



Adaptation of MOCAP data

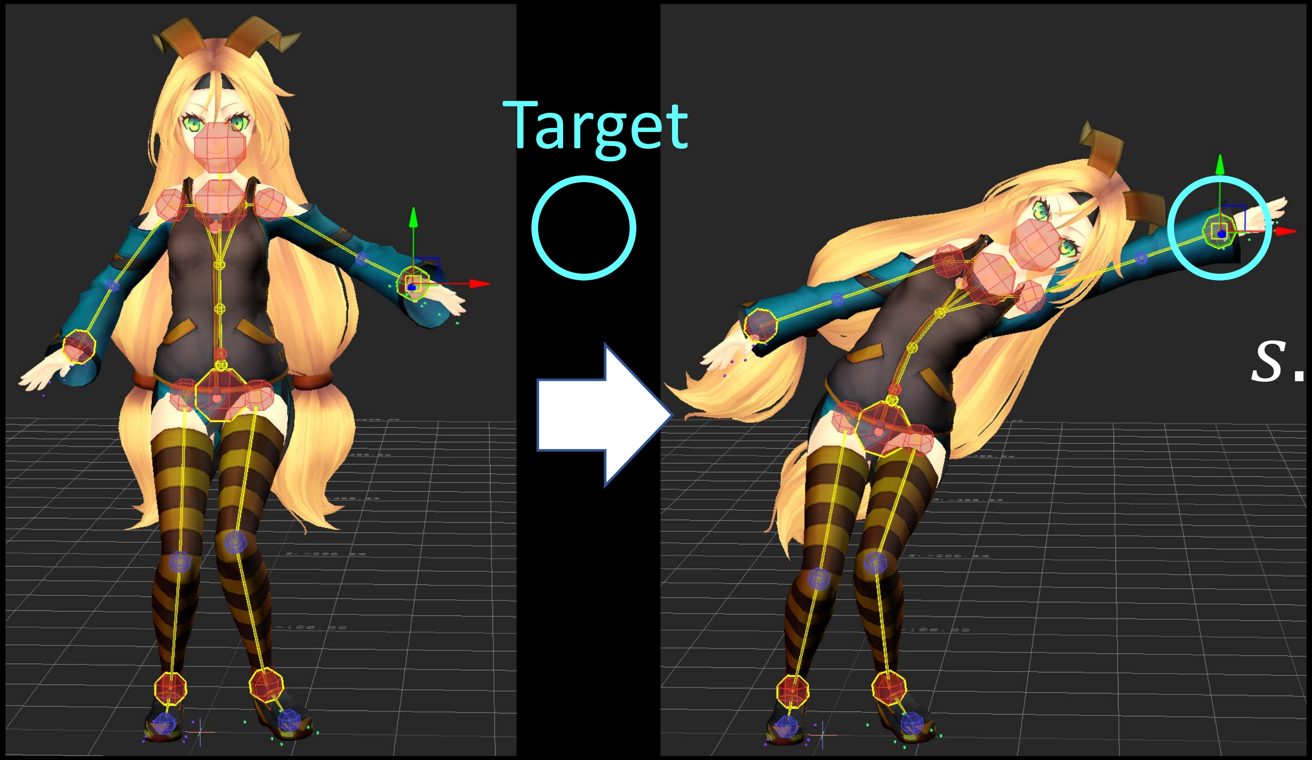


Captured motion
(walking on floor)



Sloped floor

Pose Deformation - Inverse Kinematics



$$\min \| \, pose\ variation \, \|$$

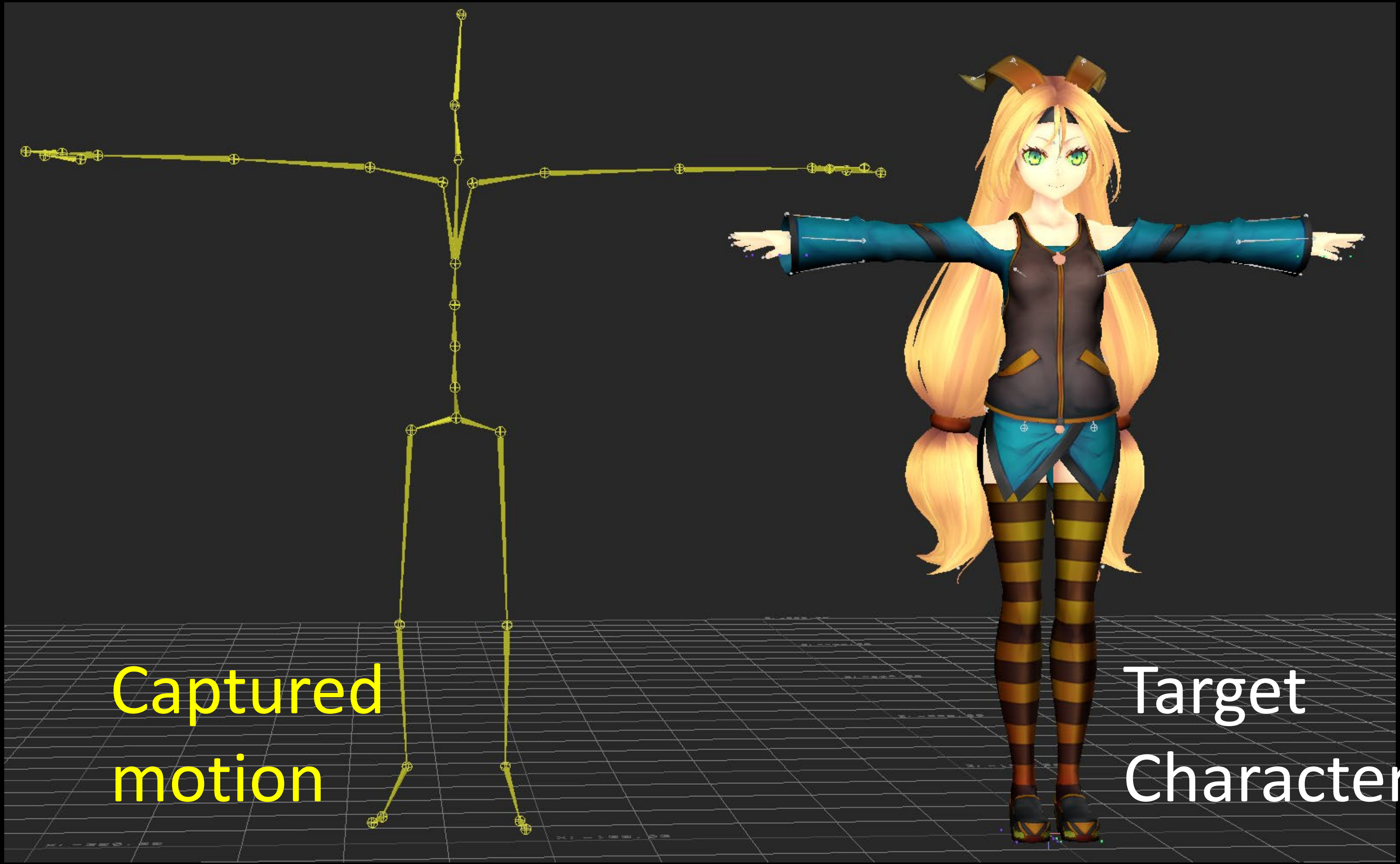
$$s.t.\ \left\|\mathbf{p}_{target} - \mathbf{p}_{\text{left hand}}\right\| = 0$$

Reaching task

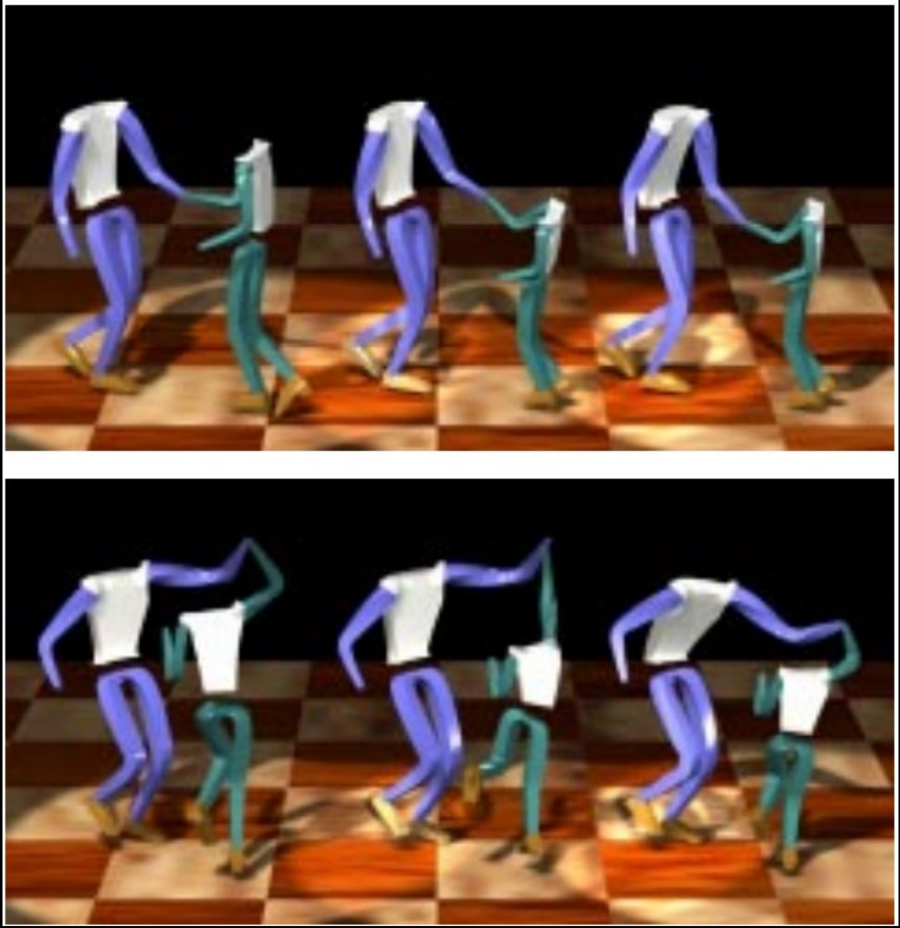
$$\forall n, \|\mathbf{p}_n - \mathbf{p}_{n+1}\| = l_n$$

Length constraint on all bones

Mocap based Animation Creation - Retarget



Optimization-based Retargeting [Gleicher, 1998]



$$\min \| \textit{pose variation} \|$$

$$s.t.\ \|\mathbf{p}_{\text{hand}} - \mathbf{p'}_{\text{hand}}\| = 0$$

Touching

$$\|\mathbf{p}_{\text{feet}} - \mathbf{p}_{\text{floor}}\| = 0$$

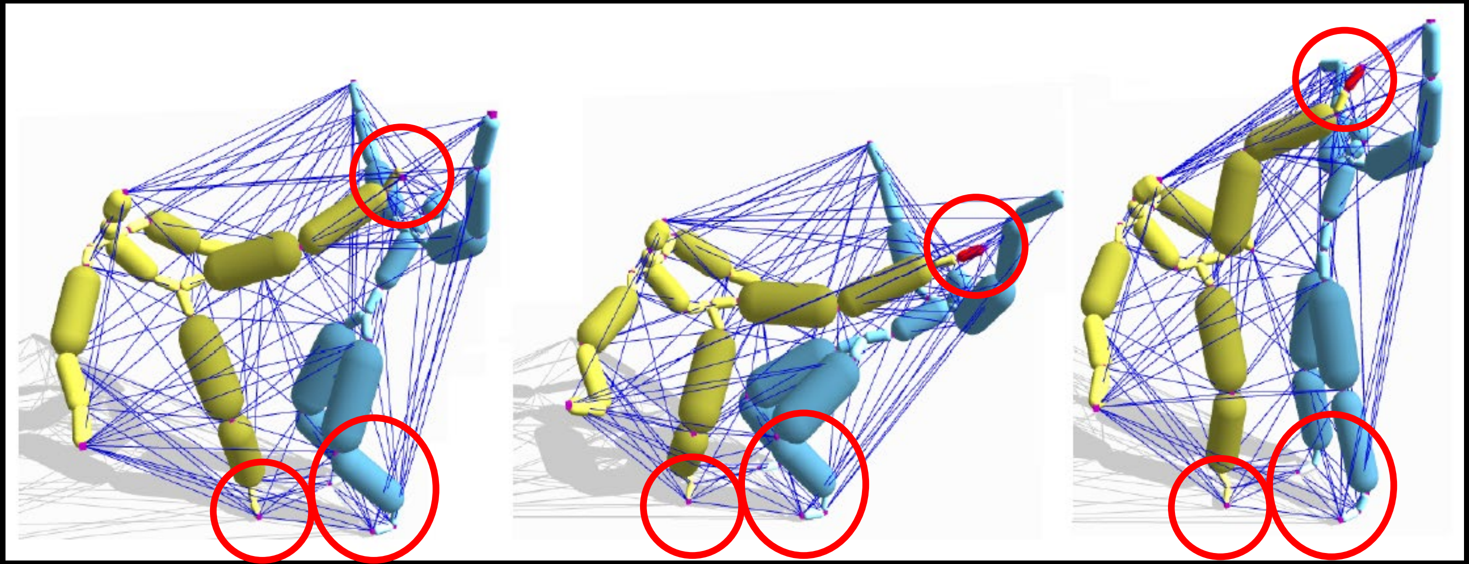
Floor contact

$$\forall n, \|\mathbf{p}_n - \mathbf{p}_{n+1}\| = l_n$$

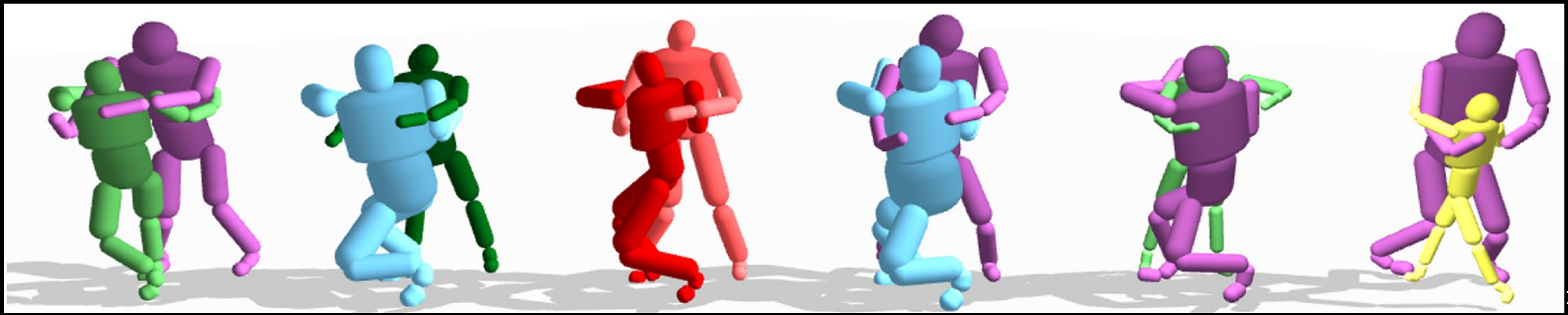
New length of each bones

Spatial Relationship Preserving Adaptation

[Ho et al, 2010]



Minimizing distance change between body parts
- Convex Delaunay graph
- Graph Laplacian energy

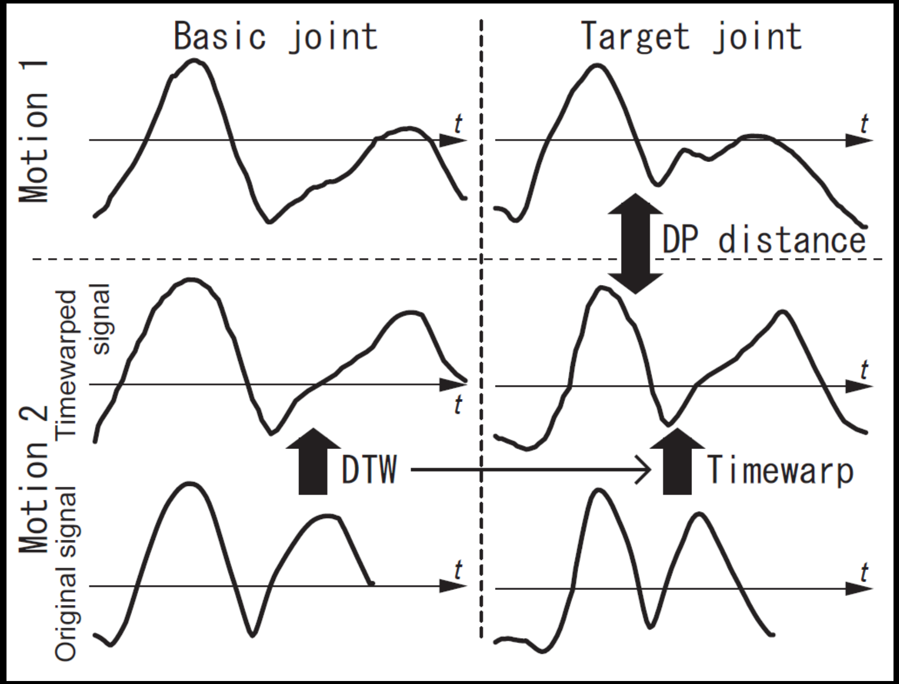


“Distance” in motion

- Physics, Dynamics, Believability ~~Reality~~
  - Ground contact (aka. foot sliding)
- Semantics, Intention, Thinking
  - Touch, Reach, Avoid, etc..

- Data processing
  - Dissimilarity between motions

Past research - Human Skill Map [2007]



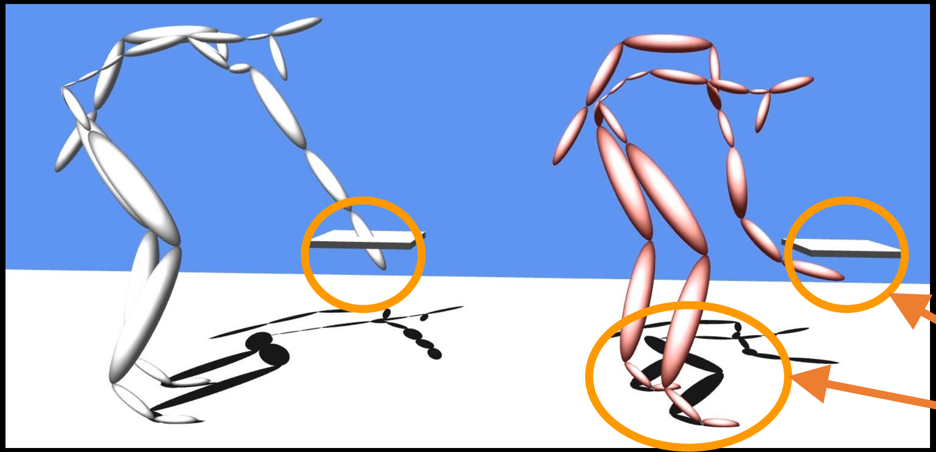
Quantitative evaluation of difference of temporal coordination among multiple body parts

Past research - Inbetweening [2011]

Our Approach for Motion Adaptation

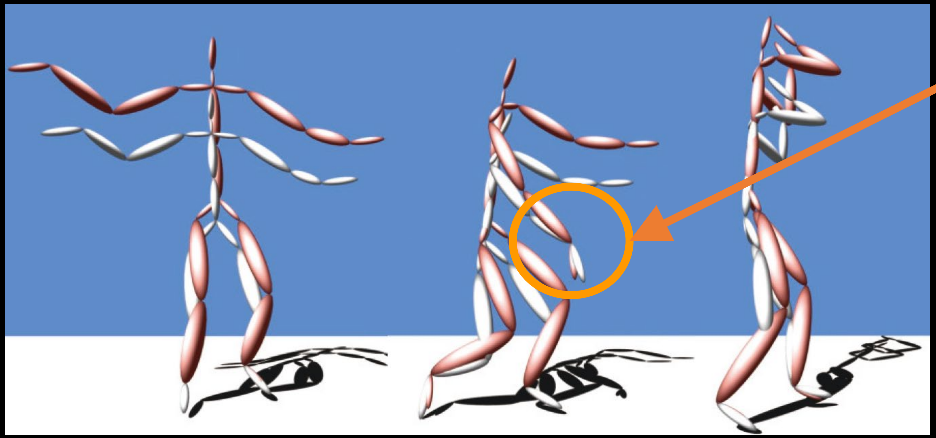
Tomohiko Mukai, Shigeru Kuriyama, Masaki Oshita,
"Motion Adaptation with Cascaded Inequality Tasks",
ACM SIGGRAPH Conference on Motion, Interaction and Games 2019

Our approach for motion adaptation



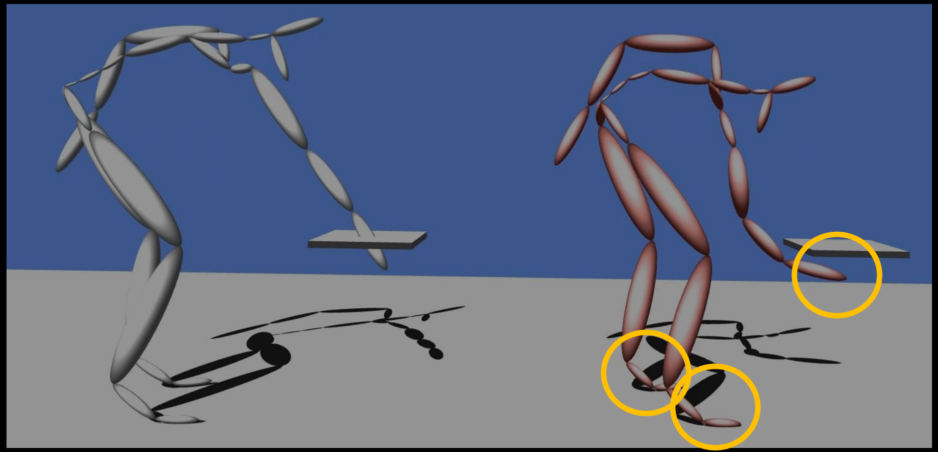
Environmental adaptation

Adaptation Task



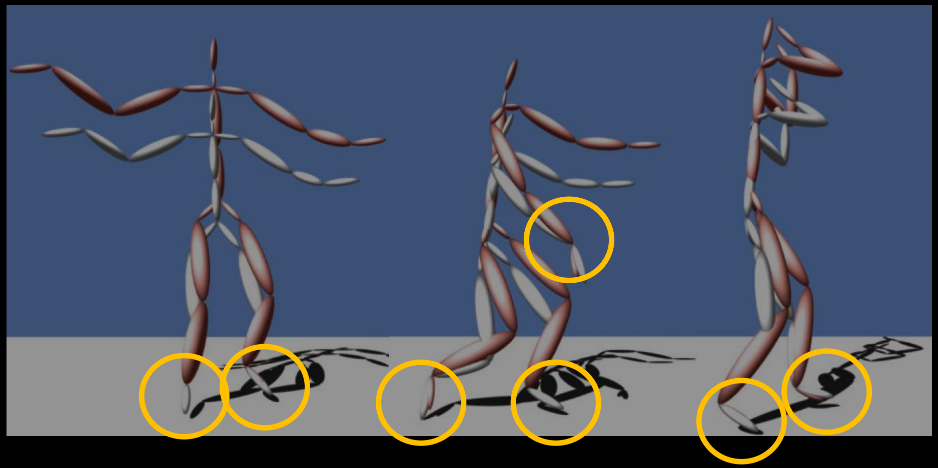
Adaptation to different character (retargeting)

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

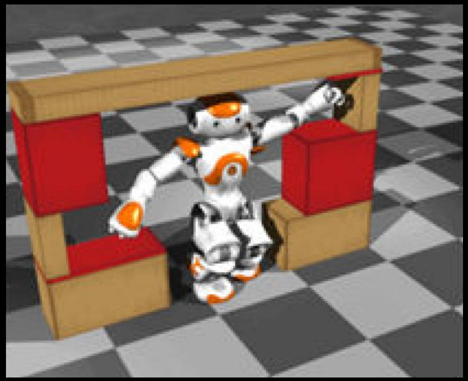
Related Work – Adaptation, Prioritized IK

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

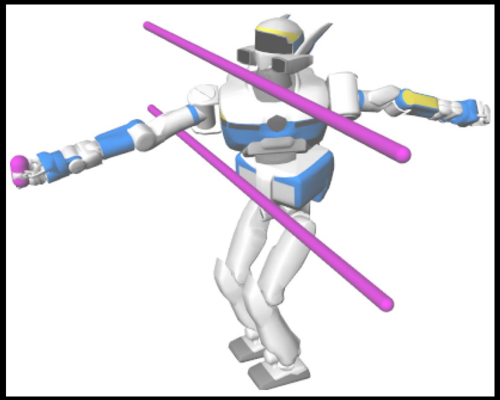
$$\min f(\mathbf{m})$$
$$\text{s.t. } C(\mathbf{m}) = 0$$

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

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



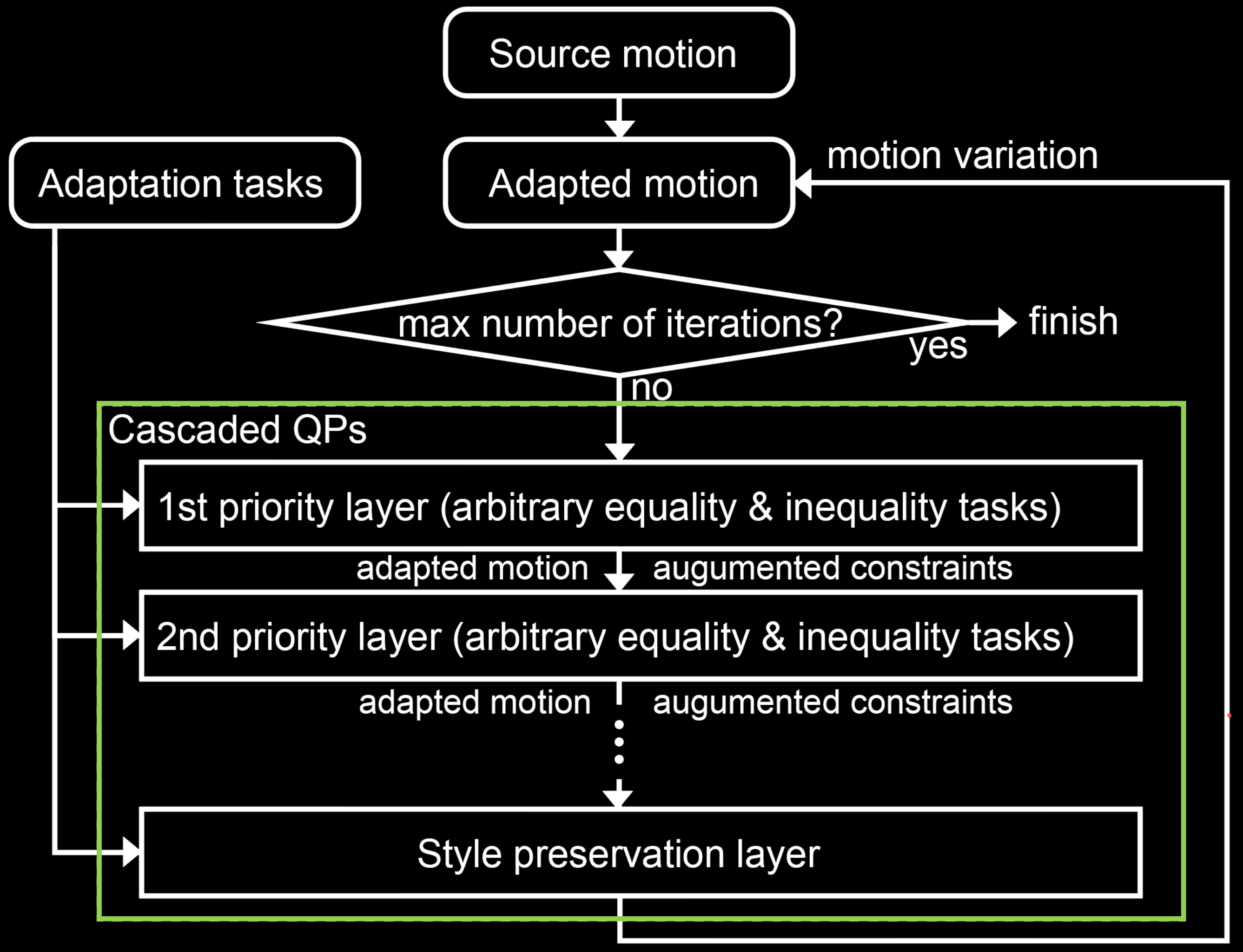
- Hierarchical quadratic programming
  [Kanoun et al. 2011]
  - Arbitrary number of priority layers
  - Equality and inequality tasks



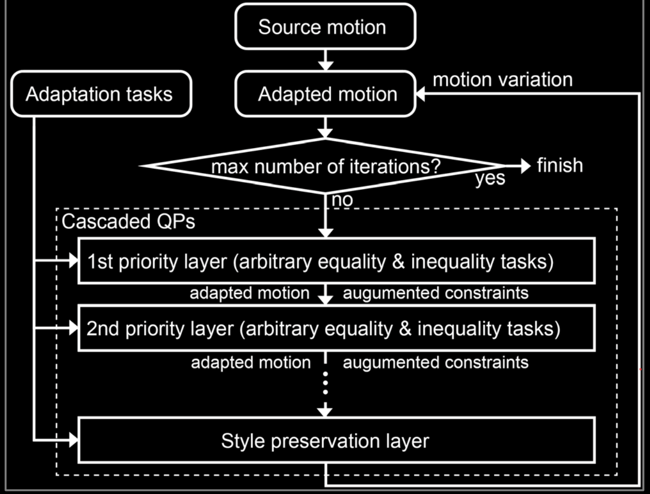
Approach

- 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

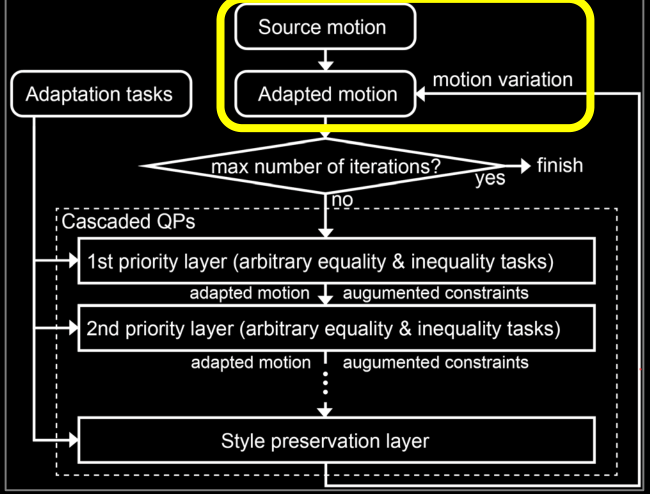
Iterative QP



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

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

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



Iterative QP

Motion variation

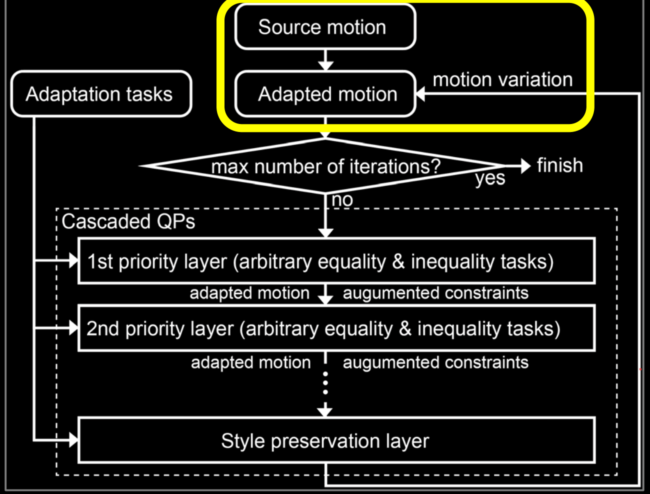
$$\min_{\Delta \mathbf{m}_u} \operatorname{diff}(\mathbf{m}_u + \Delta \mathbf{m}_u, \bar{\mathbf{m}})$$

Adapted motion Source motion

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

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

Iterative QP



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

s. t.

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

Variation of task variables

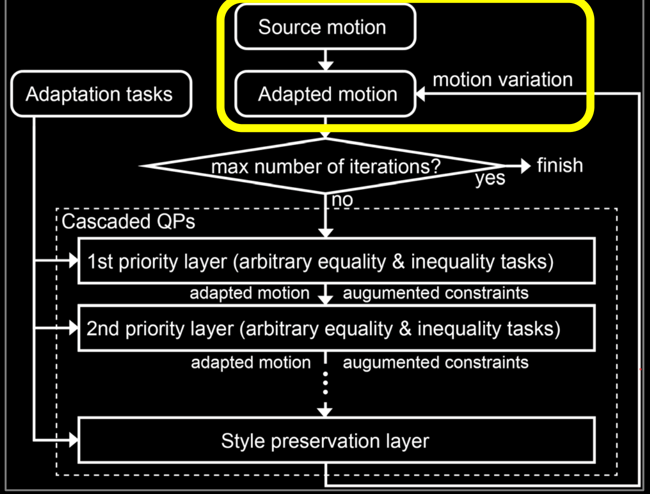
$$\forall i \in I, \quad \mathbf{C}_i \Delta \mathbf{m}_u \leq \Delta \mathbf{d}_i$$

Set of equality tasks

Task Jacobian wrt joint rotations

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

Iterative QP



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

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

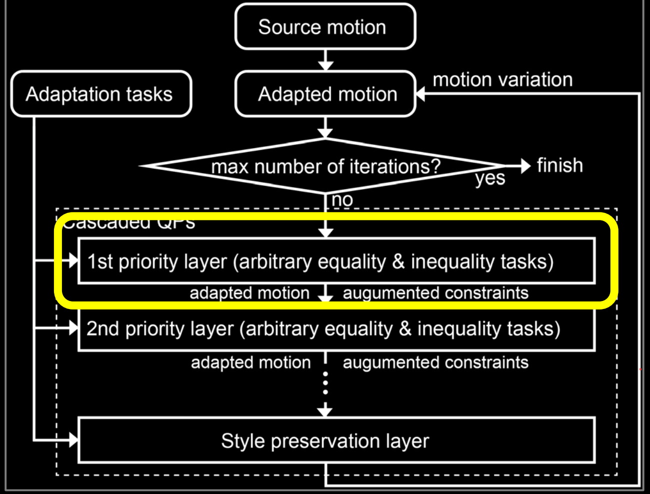
Variation of task variables

Set of inequality tasks

Task Jacobian wrt joint rotations

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

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

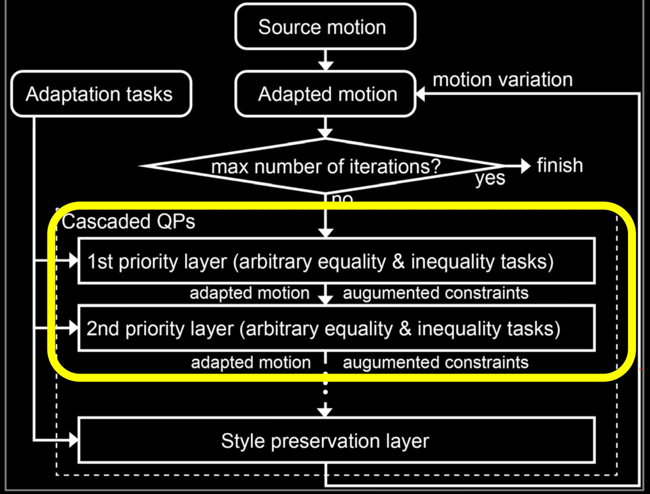
Slack variable

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

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

Relaxed inequality tasks of the first priority layer

Cascaded Series of QPs [Kanoun et al. 2011]



First layer

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

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

Second layer

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

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

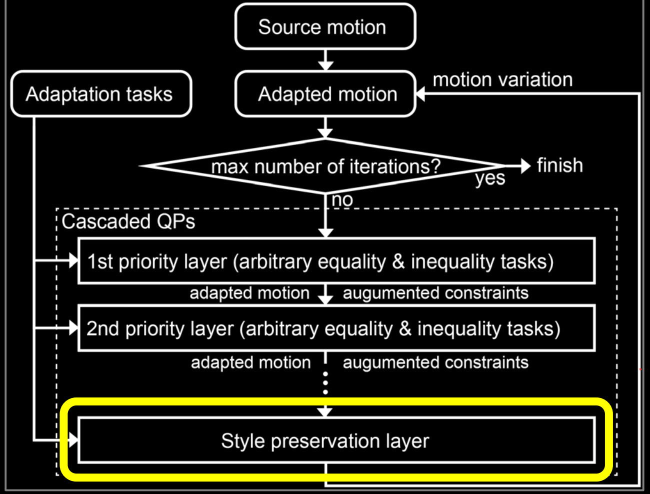
least-square solution of equality tasks

feasible inequality tasks

violated inequality tasks

Tasks of the second priority layer

Style Preservation Layer



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

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

least-square solution of equality tasks

feasible inequality tasks

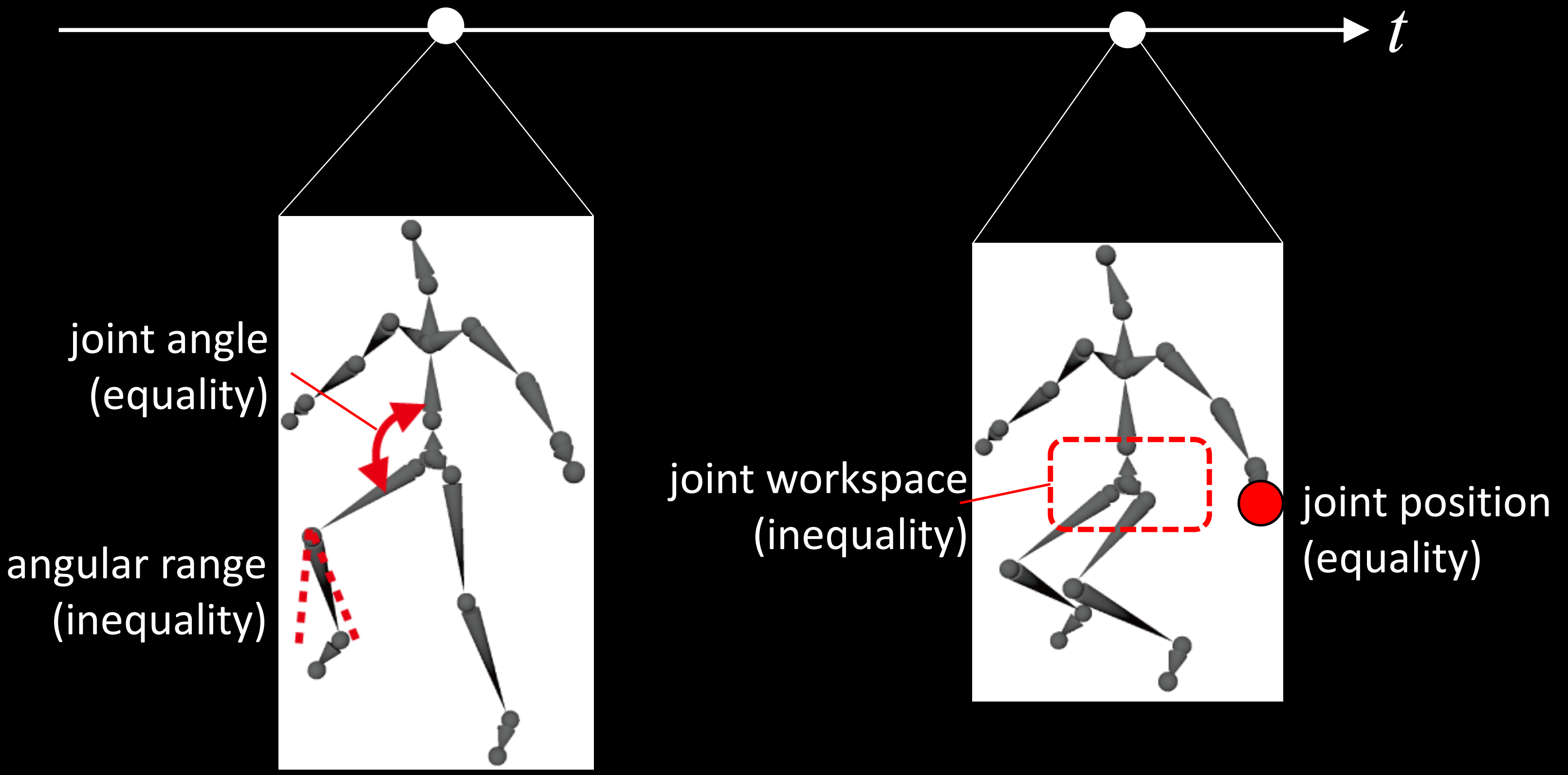
violated inequality tasks

Per-frame Task

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

Jacobian of joint position/angle wrt joint rotations

displacement toward target position



Spatiotemporal Relation

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

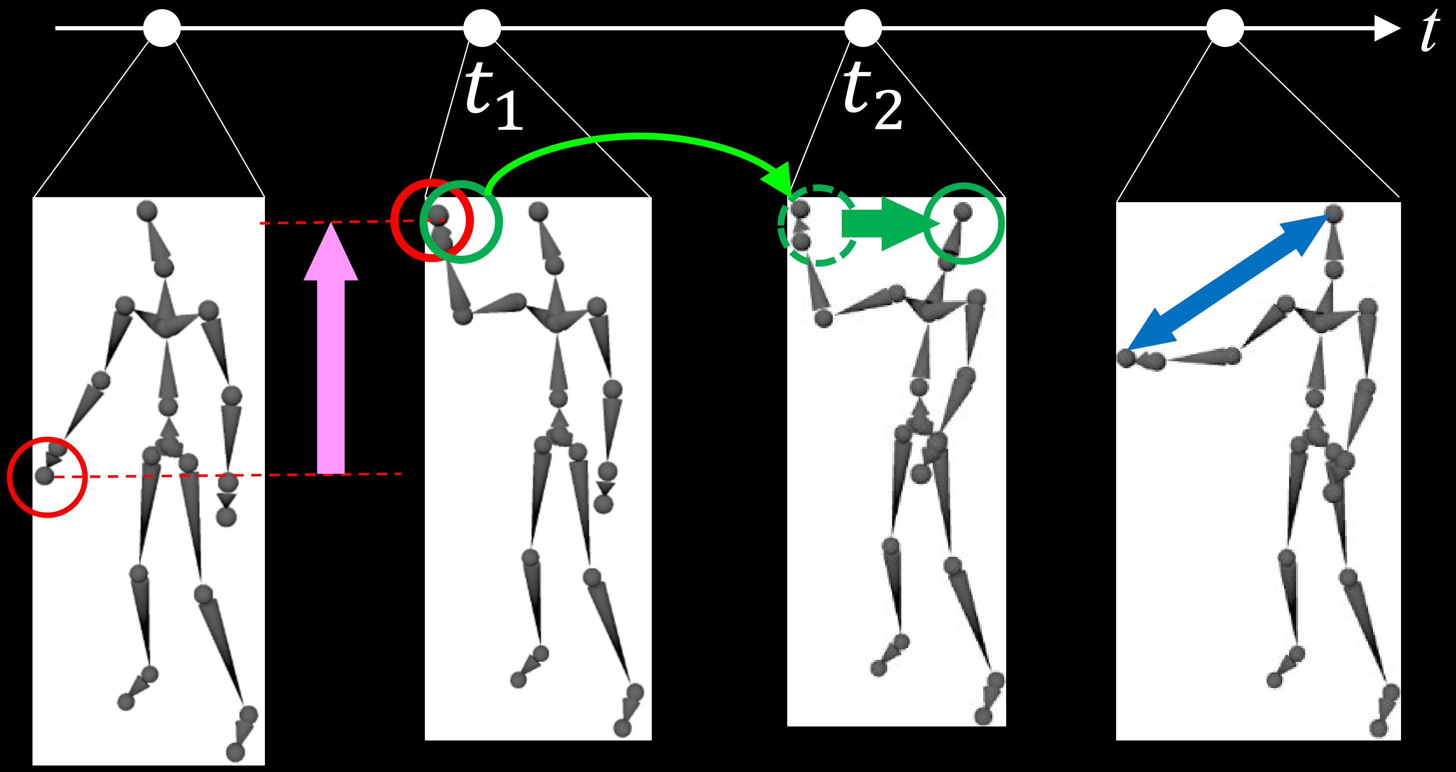
Jacobian of inter-joint position/inter-joint angle wrt joint rotations

displacement toward target relational value

Displacement of the same joint between distant time frames

Displacement between the right hand at t_1 and the head position at t_2

Distance between the right hand and head at the same time instant



Combinational Tasks

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

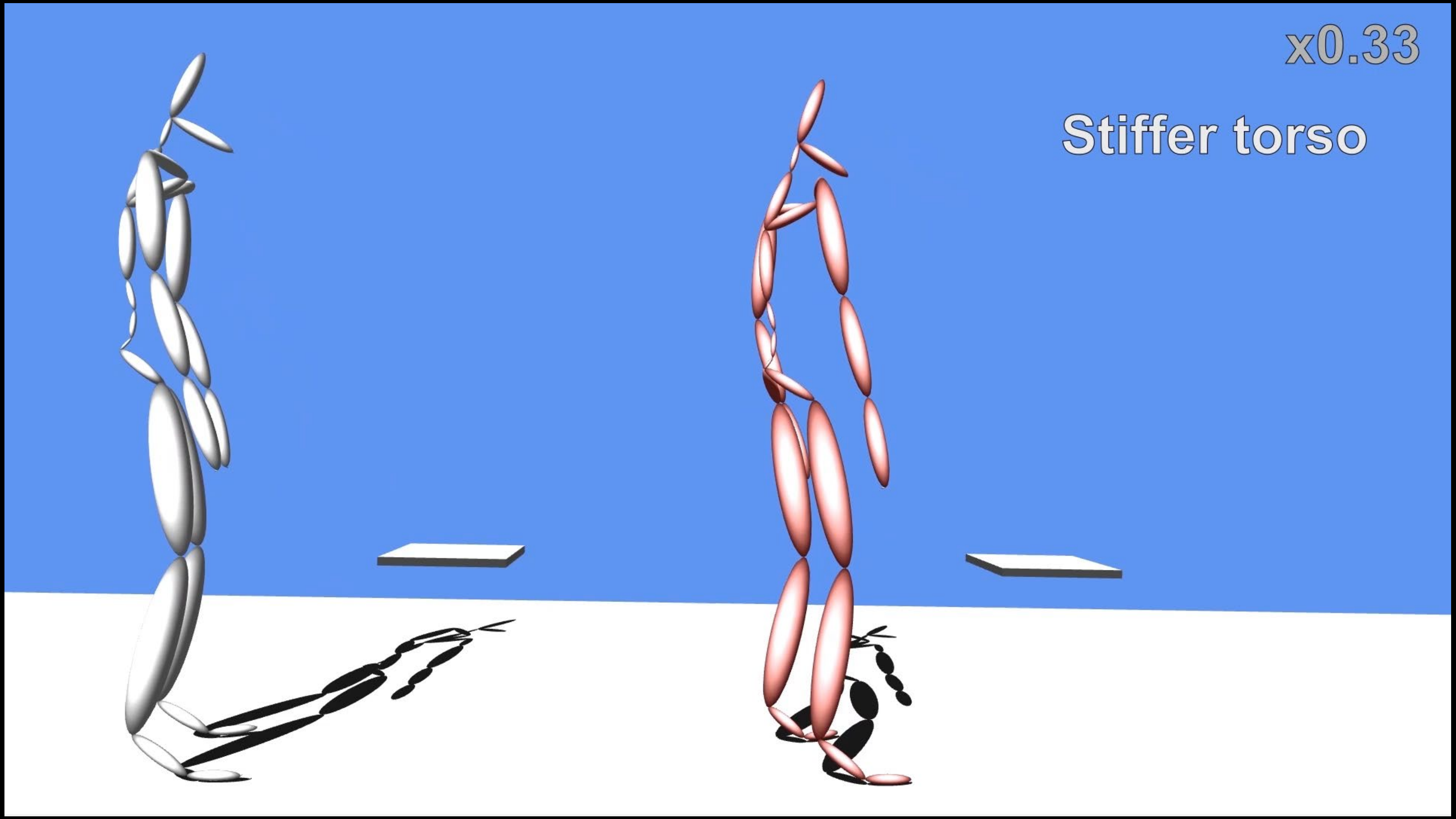
Reaching Motion

Adaptation of Reaching Motion

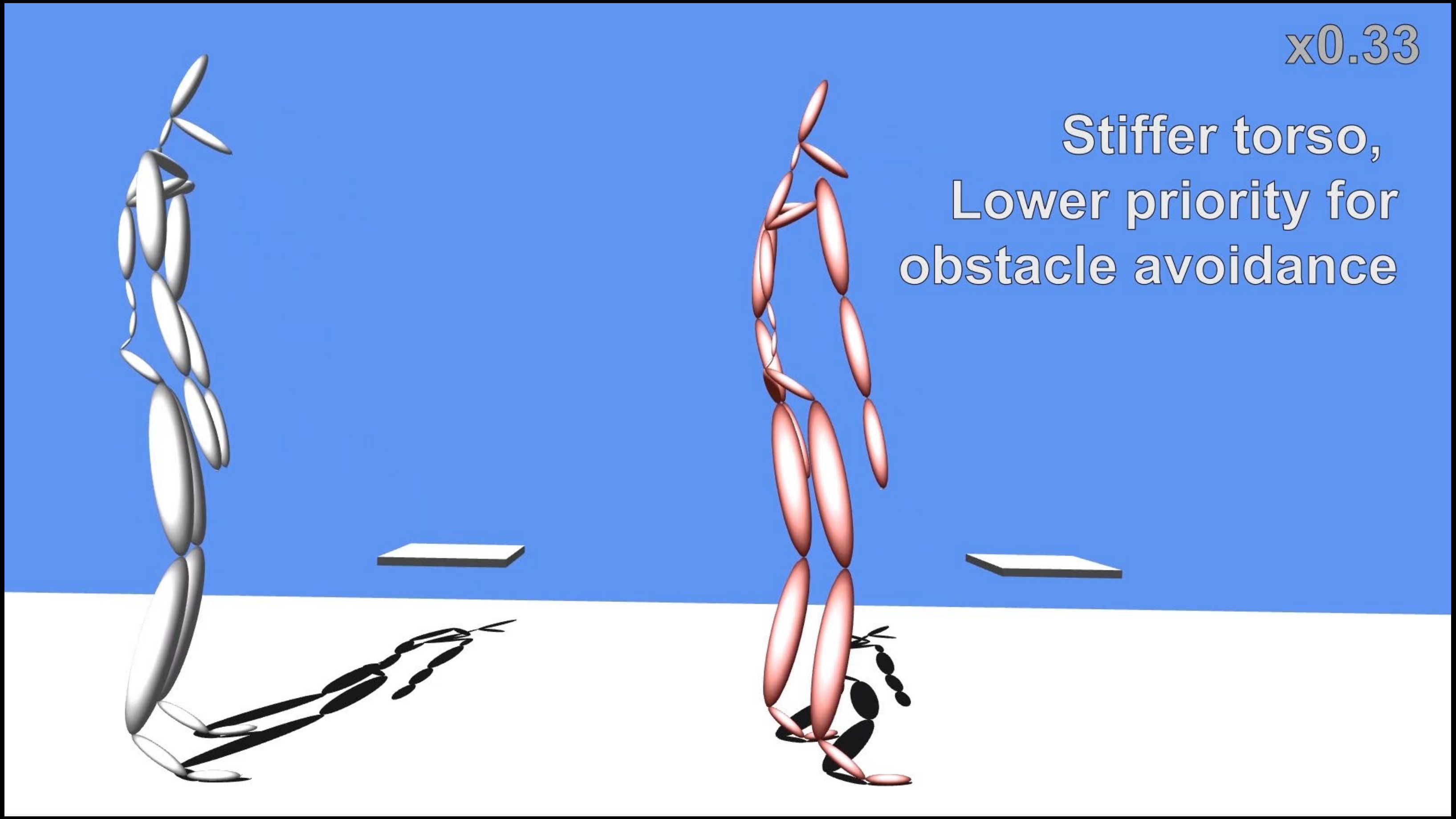
Task priority

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

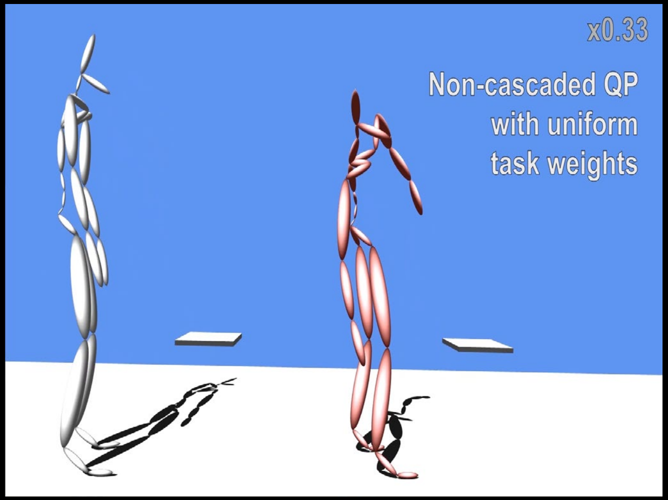
Reaching Motion – Avoidance > Goal



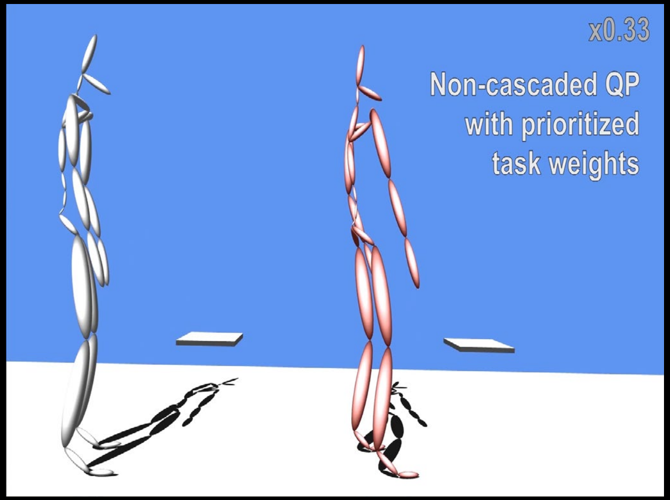
Reaching Motion – Avoidance < Goal



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

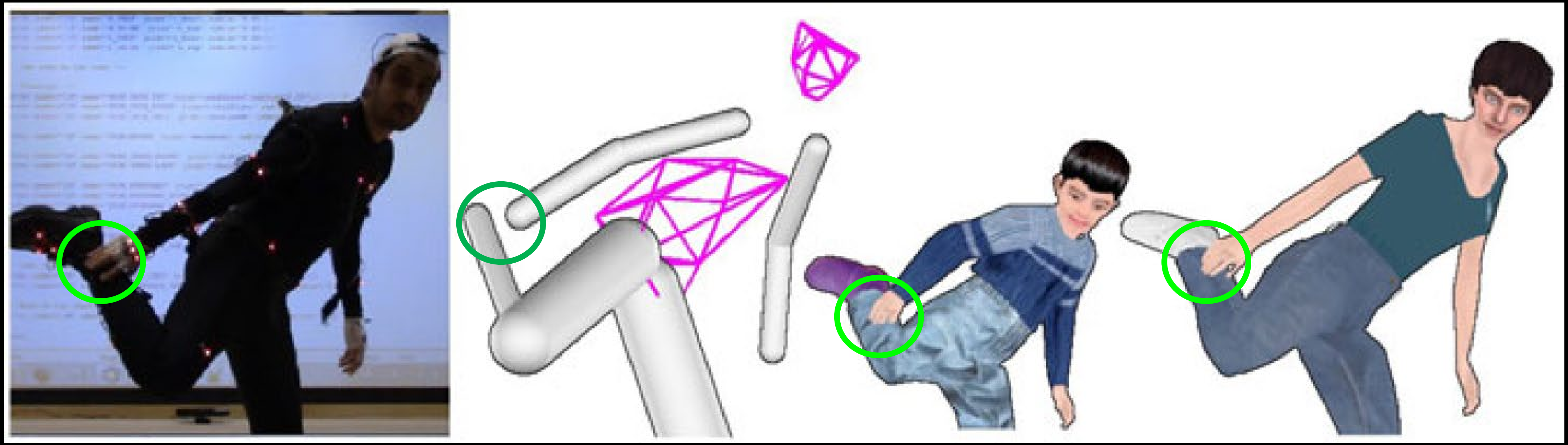
Task priority

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

Pros and Cons

- 🙂 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

Egocentric Constraint Mapping [Molla et al, 2018]



Distance Information in Motion Editing

- Physics, Dynamics, Believability ~~Reality~~
  - Ground contact (aka. foot sliding)

- Semantics, Intention
  - Touch, Reach, Avoid, etc..

- Data processing
  - Dissimilarity between motions

Acknowledgement: JSPS KAKENHI 15K16110 & 15H02704