Computer Animation and Visualization

Lecture 6.

Motion Synthesis by Optimization / Motion Editing

Taku Komura

Overview

- Motion synthesis by Optimization
  - Using forward / inverse dynamics
- Motion Editing
  - Motion Warping
  - Motion Blending
  - Dynamic Time Warping
- CMU motion database

From the last lectures...

- Equation of motion $$F = M\ddot{x}$$
- Forward dynamics
- Inverse dynamics

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- Equation of motion $$F = M\ddot{x}$$
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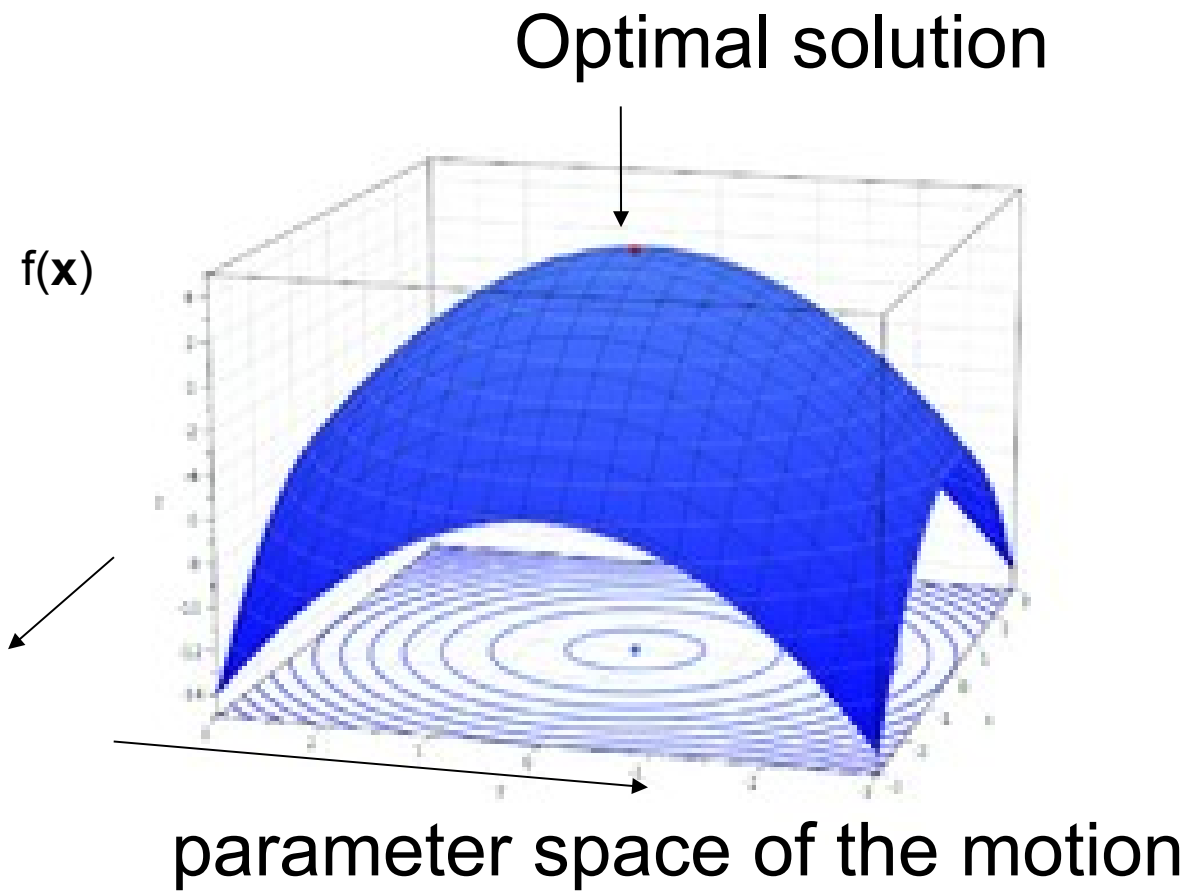
$\longrightarrow$ Use Optimization

What is Optimization?

- Given an objective function f(**x**), find the **x** that minimizes / maximizes f(**x**)

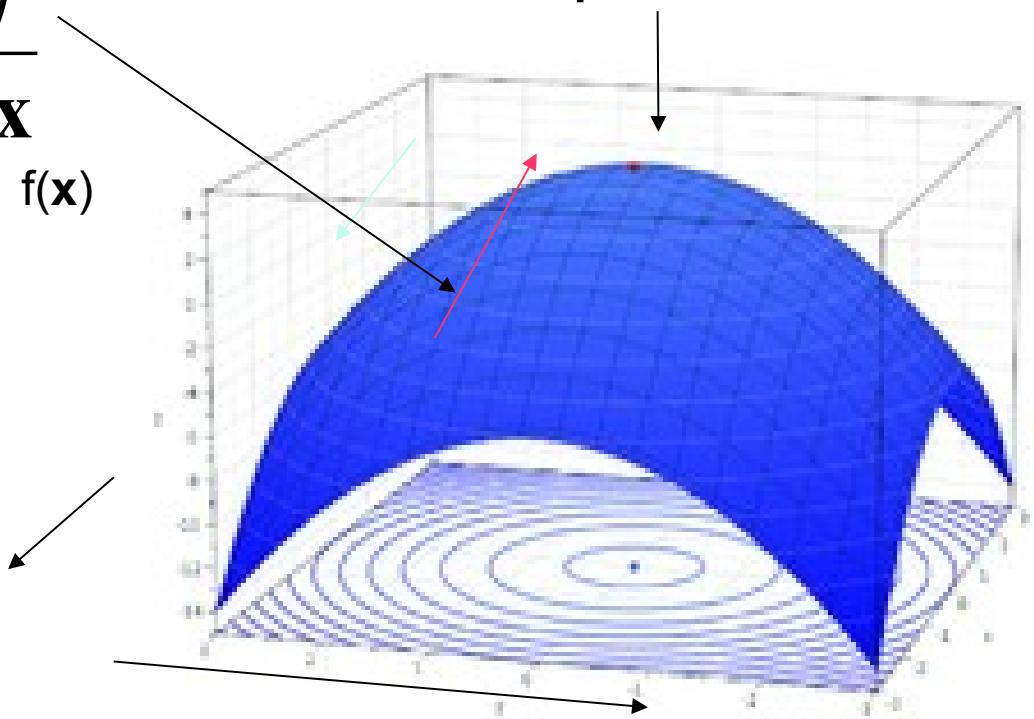


What is Optimization?

- Solution is found by iteratively computing the gradient at the current point, and moving in that direction

gradient direction $\frac{\partial f}{\partial \mathbf{x}}$

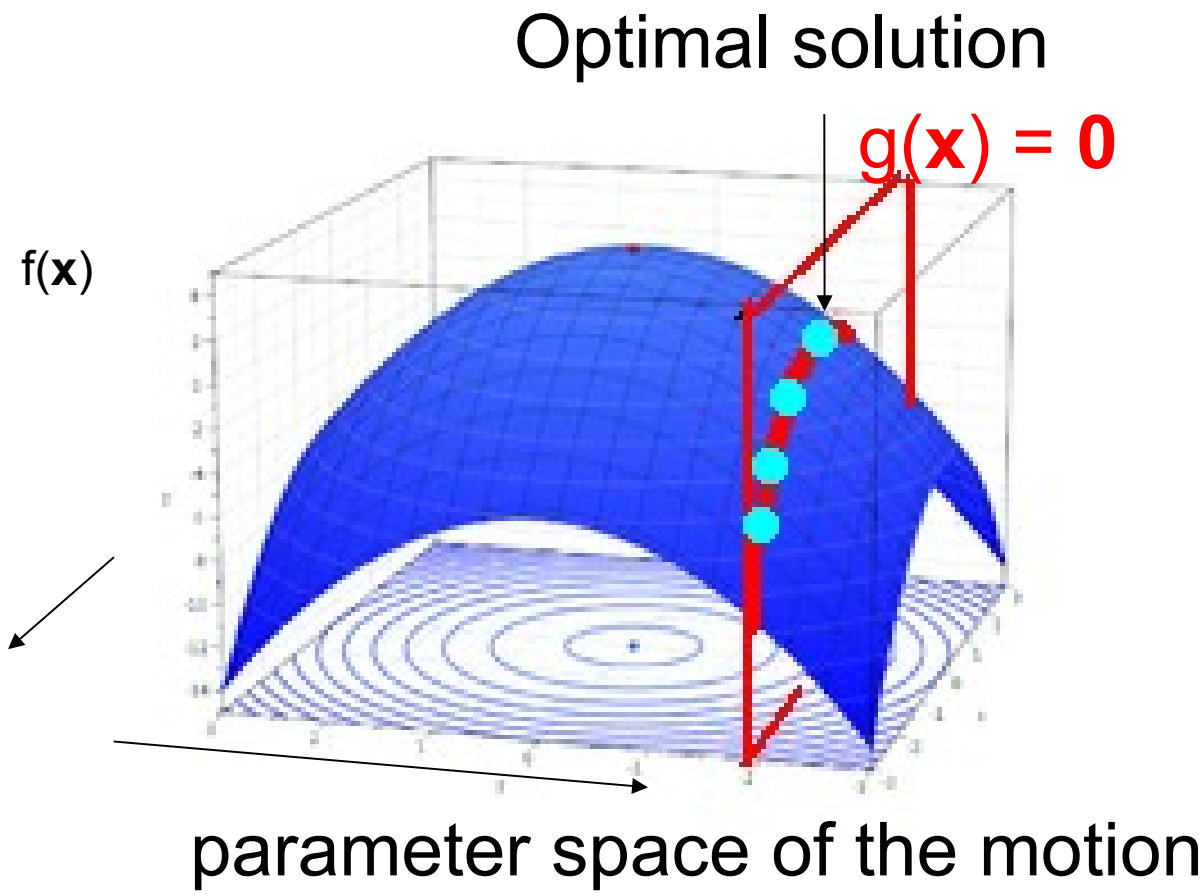
Optimal solution



parameter space of motion

What is Optimization?
with Constraints

- Given an objective function f(**x**), find the **x** that minimizes / maximizes f(**x**)
  - Subject to constraints g(**x**) = **0**



What are the parameters $\underline{X}$?

- Given some function f(**x**), find the **x** that minimizes f(**x**)
  - Subject to constraints g(**x**) = **0**

- Forward dynamics : Torque at the joints
- Inverse dynamics : Generalized coordinates

Background

Taking into dynamics for character animation

- Good but the control is difficult

  Torque at the joints,

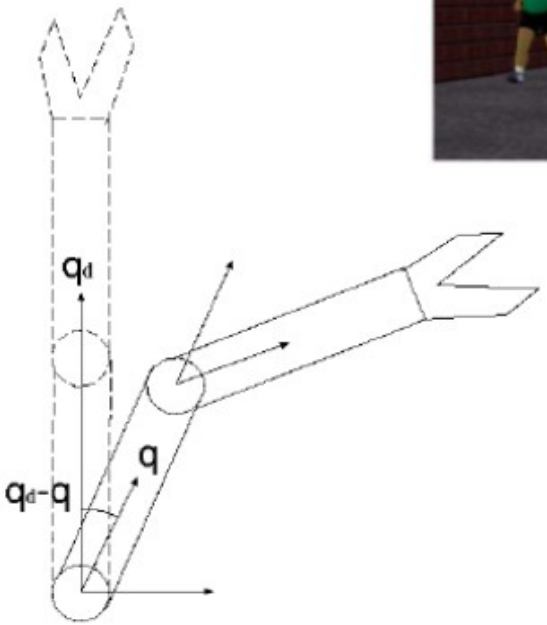
  Gains, desired joint angles

– $F = a\,(q - q_d) + c\,(q' - q'_d)$

a, c : constants,

q , q' : current state/velocity

q_d , q'_d : desired state/velocity



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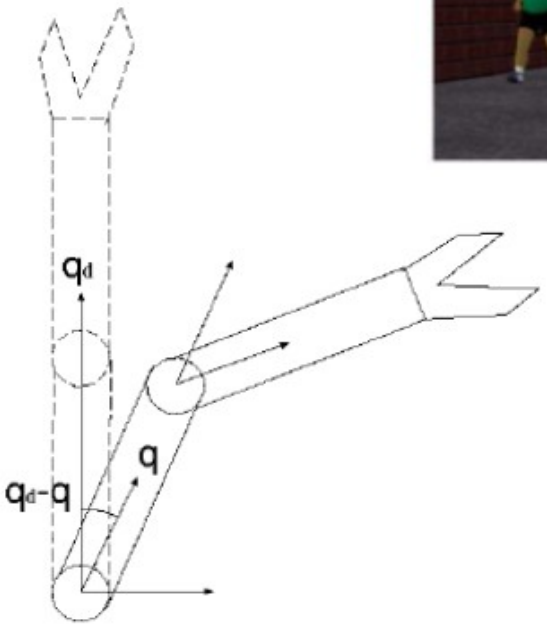

a, c : constants,

q, q' : current state/velocity

q_d, q'_d : desired state/velocity

→ Use Optimization

Motion Synthesis by Optimization Why?

We want the characters to satisfy the laws of dynamics
○ Newton’s law, preservation of momentum

We want characters not to spend too much energy
○ Humans move efficiently

We also want them to satisfy constraints
○ passing some specific postures, feet on the ground
etc.

What is Optimization?

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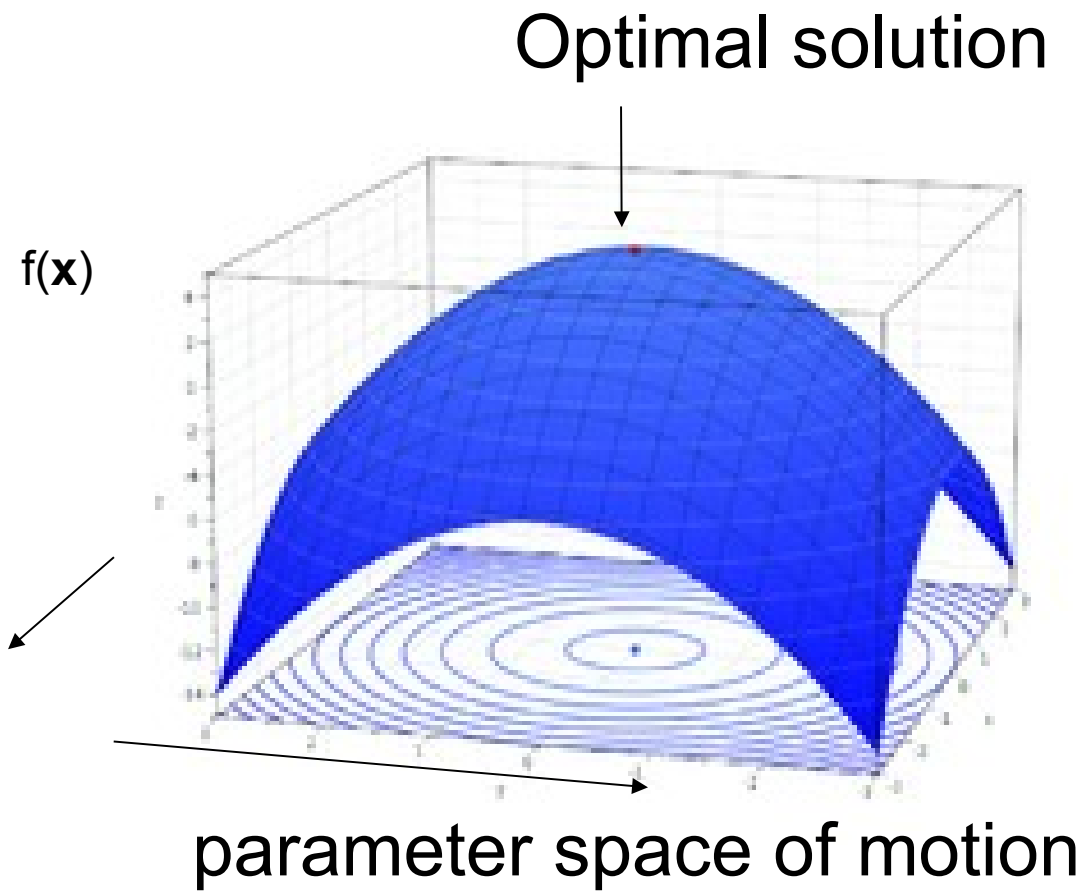

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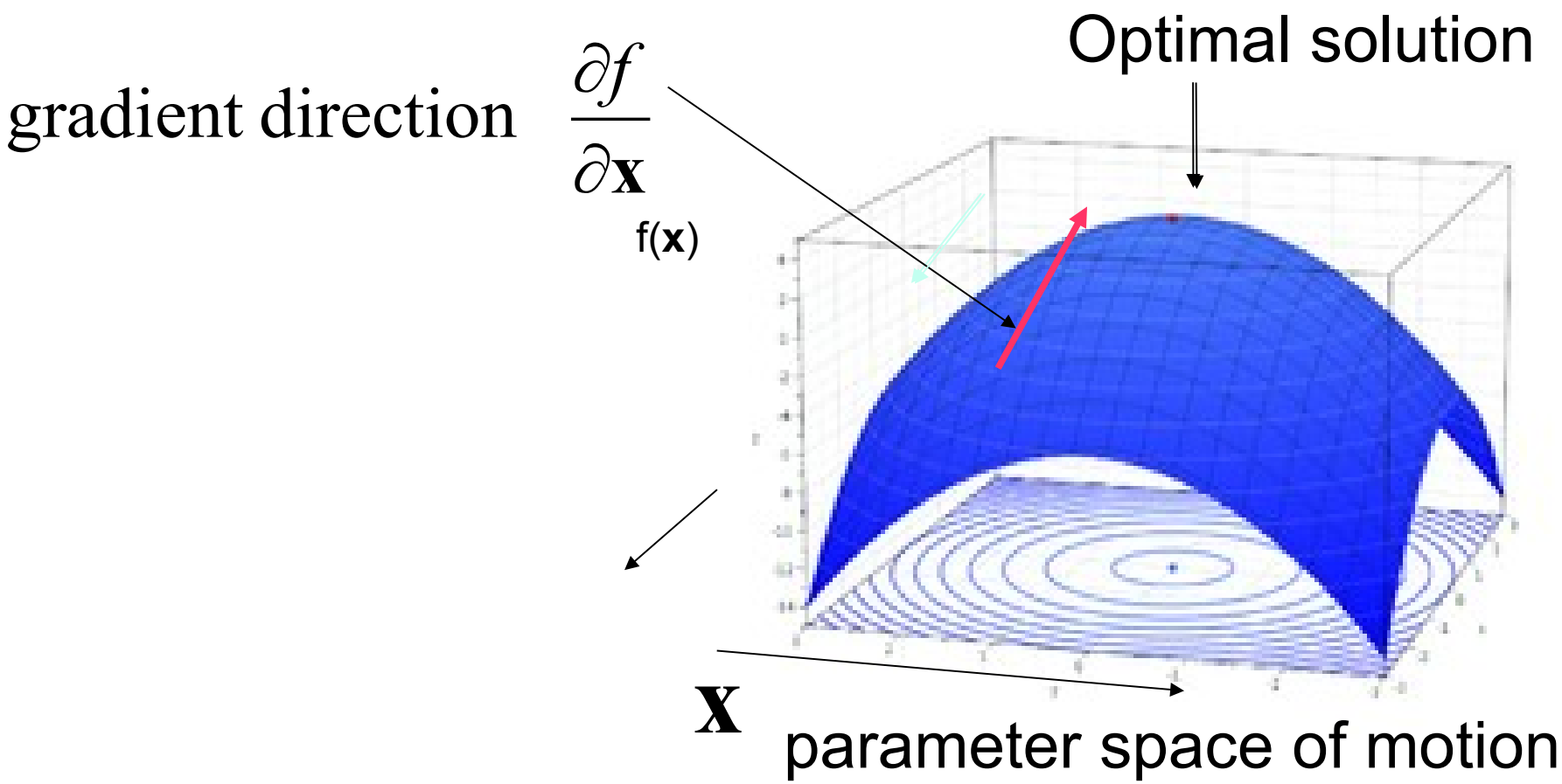

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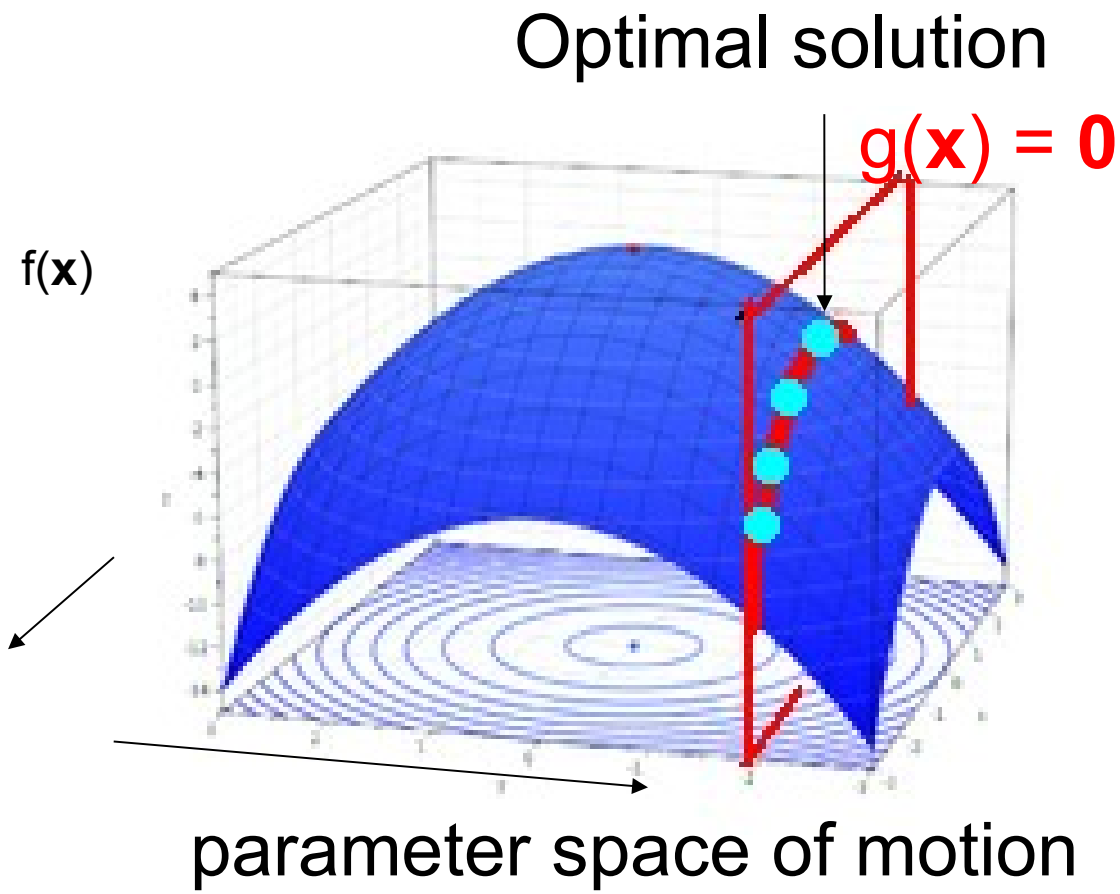

Issue 1: High Dimensionality

- The body has many degrees of freedom
- There are many frames in one motion :
- Even we simplify the control (reducing the number of keyframes), the problem can still be very high dimensional

- i.e. motion

$$\mathbf{q}_1 = (q_1, q_2, q_3, q_4, q_5, q_6, q_7, \ldots, q_m)$$
$$\mathbf{q}_2 = (q_1, q_2, q_3, q_4, q_5, q_6, q_7, \ldots, q_m)$$
$$\vdots$$
$$\mathbf{q}_n = (q_1, q_2, q_3, q_4, q_5, q_6, q_7, \ldots, q_m)$$

- m x n parameters

torque

$$F_1 = (\tau_1, \tau_2, \tau_3, \ldots, \tau_{m-6})$$
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$$\vdots$$
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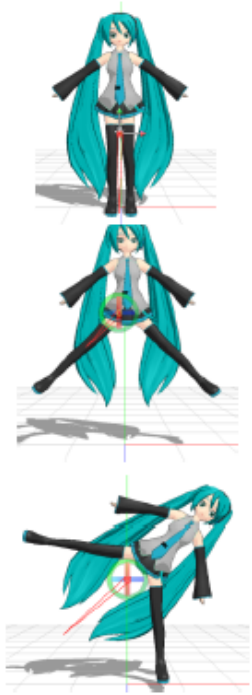
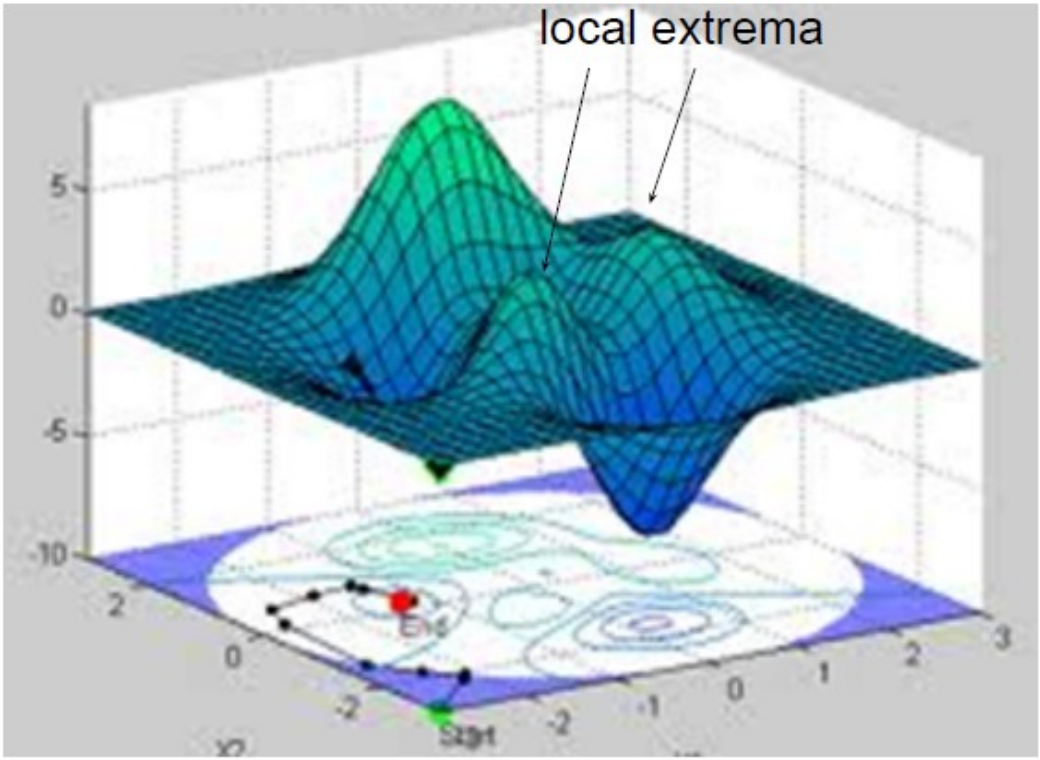
(m-6) x n parameters



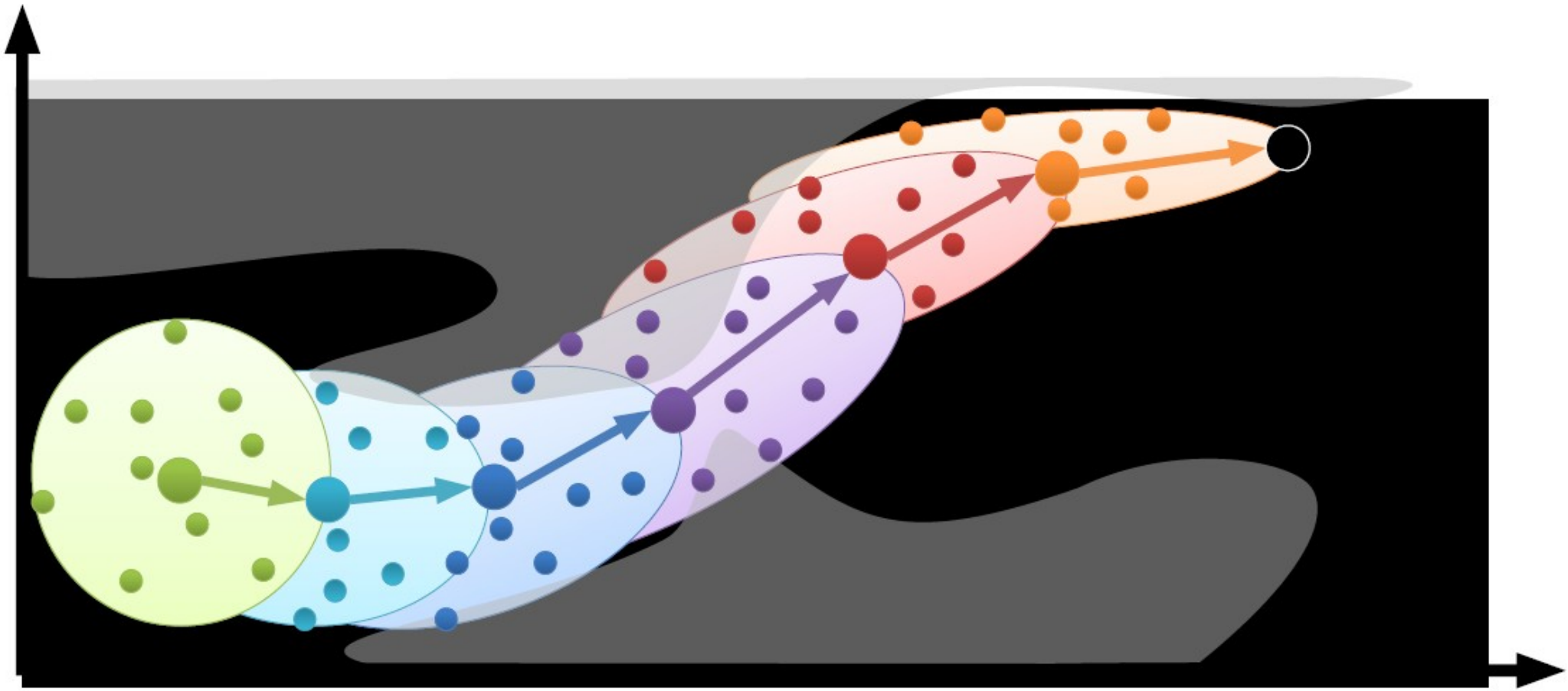
Issue 2: Local Extrema

- Functions with many parameters can have lots of local extrema
- An ordinary optimization method can get trapped in local extrema



Stochastic Optimisation

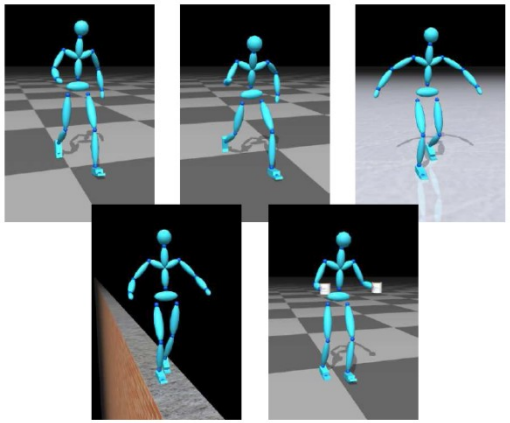
ex. Covariance matrix adaptation



Sampling a lot of points around the current point to decide the direction to further search

Optimization in Forward Dynamics

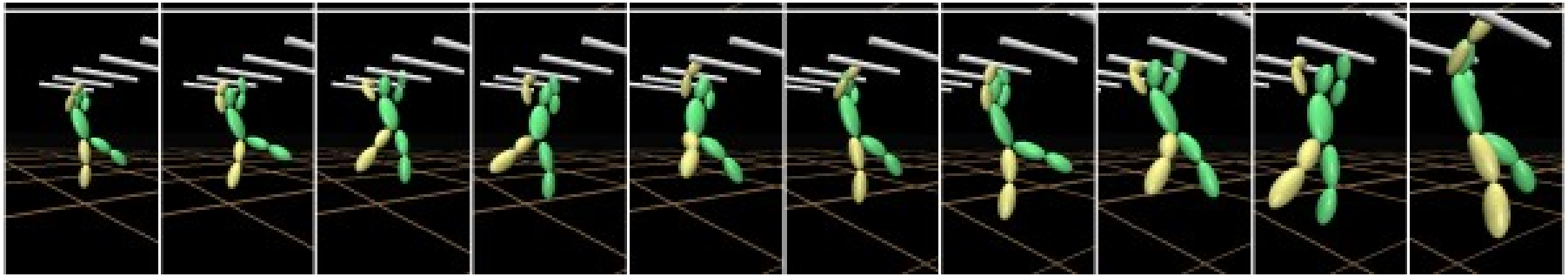
- Compute the trajectories of torque / PD control parameters such that the character performs the best action
- Need to specify the criteria that evaluates the motion
  - Height of the jump
  - How stable the character can walk
  - How similar the motion is to the motion capture data

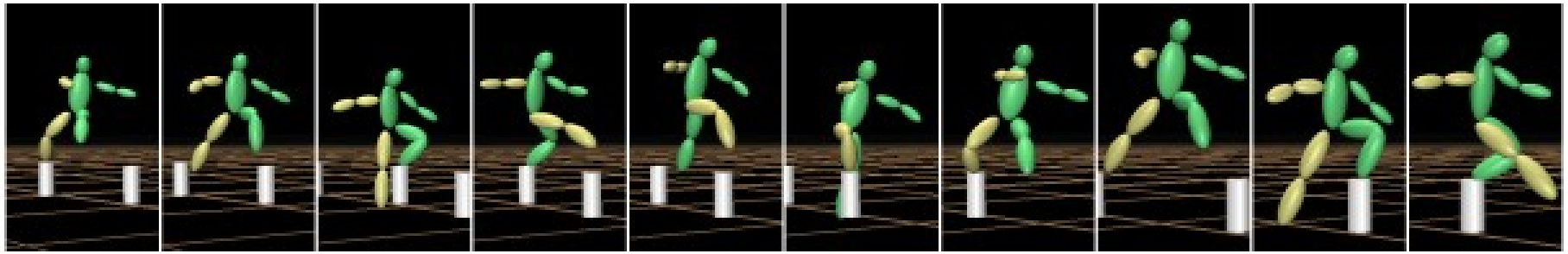


http://www.youtube.com/watch?v=9pGH6-QY-sQ&feature=player_embedded

Optimization in Inverse Dynamics

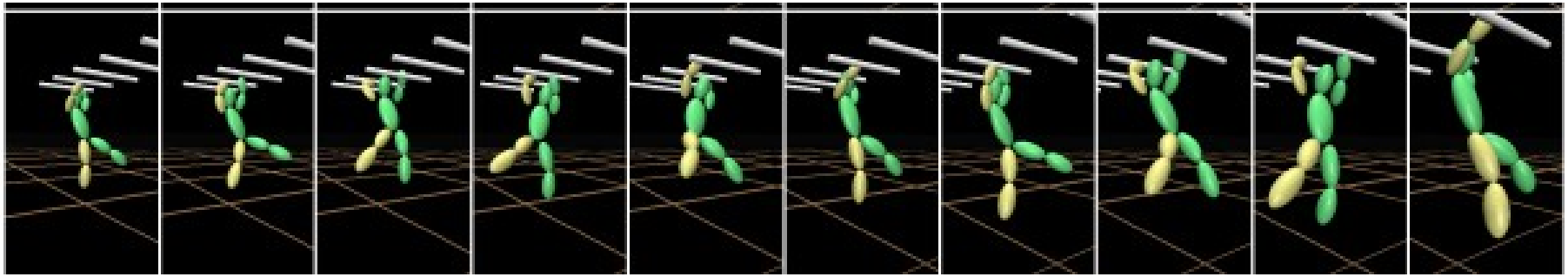
- Compute the trajectories of the body such that the motion follows the laws of physics

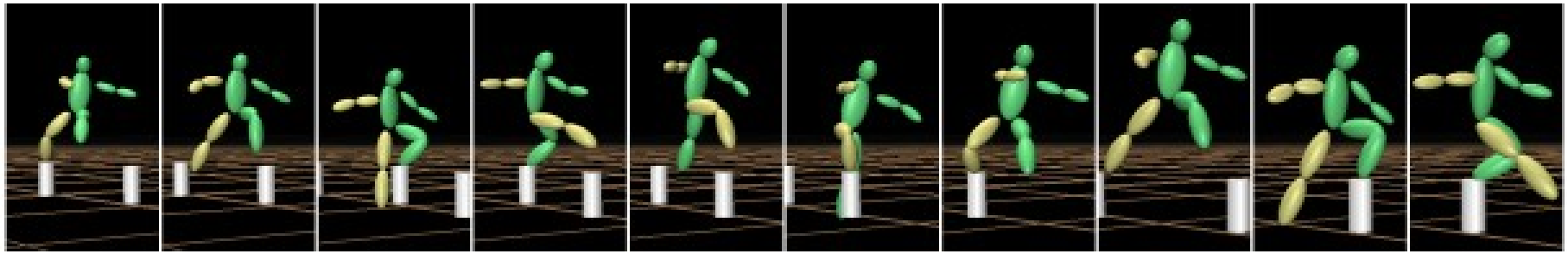




Optimization in Inverse Dynamics

- Compute the trajectories of the body such that the motion follows the laws of physics
  - What kind of motion is following laws of physics?
  - What kind of motion is not following laws of physics?

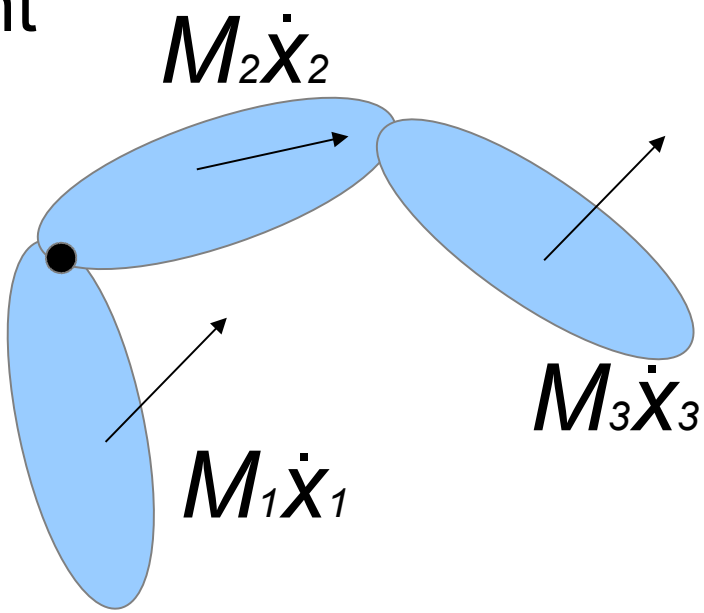




Optimizing the Motion: Spacetime Constraints

- Compute the trajectories of the body such that the momentum of the whole body is preserved while the body is flying in the air
  - When objects / bodies fly in the air, the linear / angular momentum is preserved

$$C_l = \sum_{i:\text{body}} M_i \dot{x}_i = \text{constant}$$



Optimizing the Motion: Spacetime Constraints

- Compute the trajectories of the body such that the momentum of the whole body is preserved while the body is flying in the air
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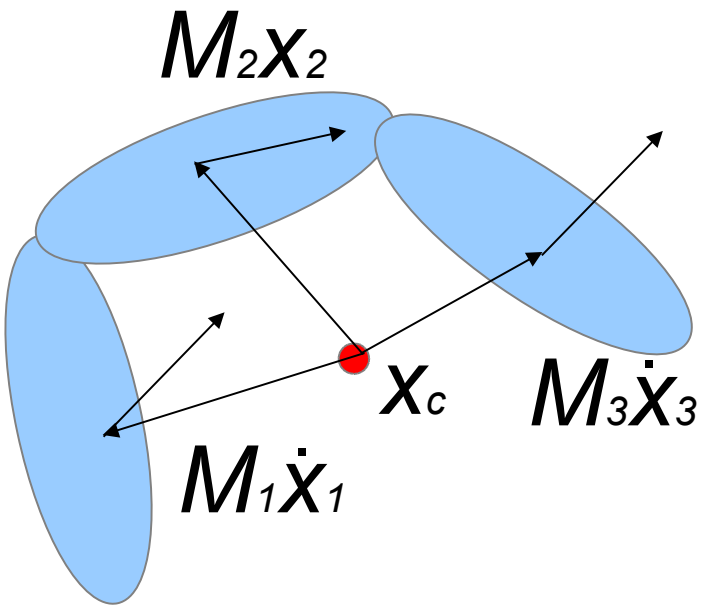
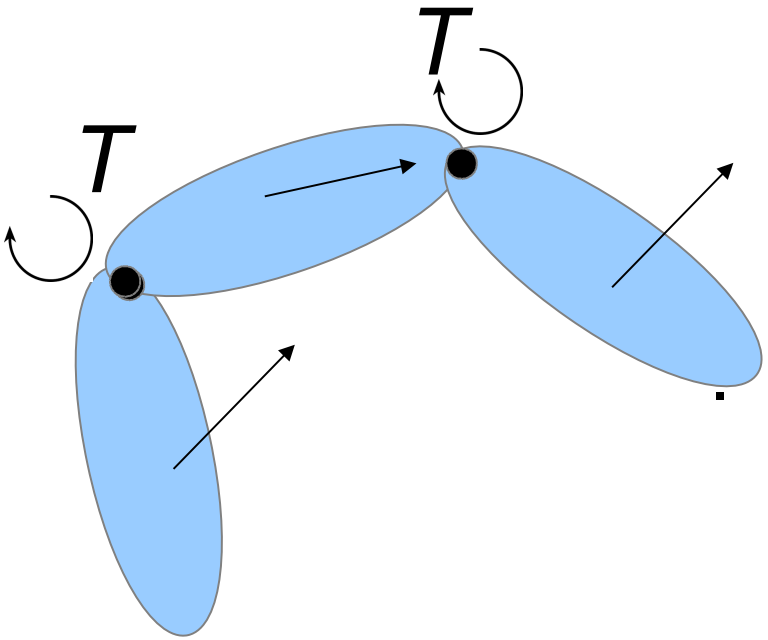
$$C_a = \sum_{i:\text{body}} (x_i - x_c) \times M_i (\dot{x}_i - \dot{x}_c) = \text{constant}$$



Optimizing the Motion: Spacetime Constraints

- Minimum energy
  - We wish to not move our body too much
  - We can minimize the torque at the joints

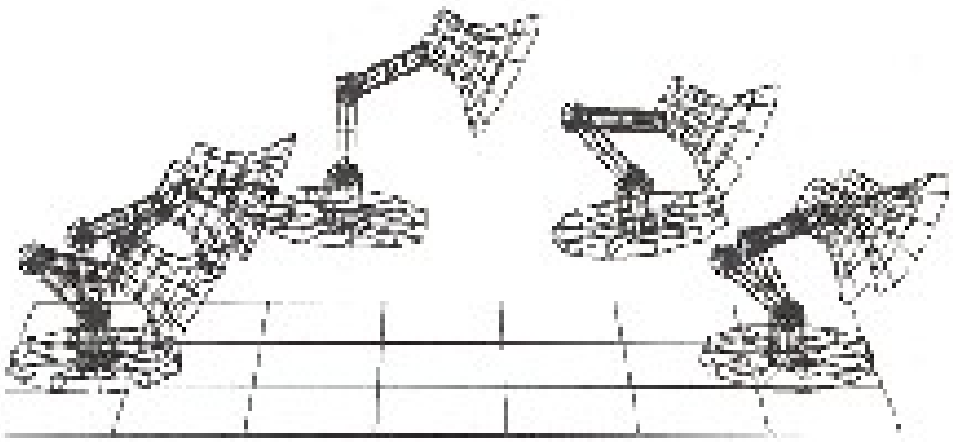
$$E = \sum_{i:\text{joints}} T^2$$



Optimizing the Motion: Spacetime Constraints

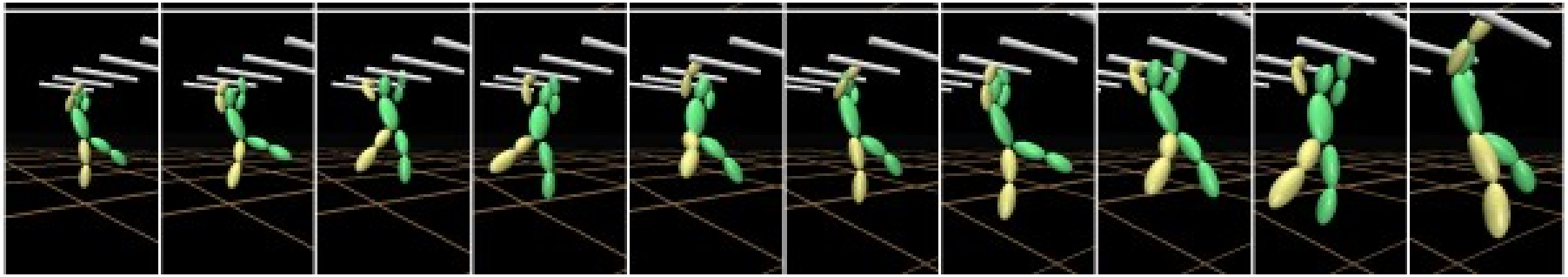
- Compute the motion (***q***) such that the body uses minimum energy during the motion, while following the laws of physics,

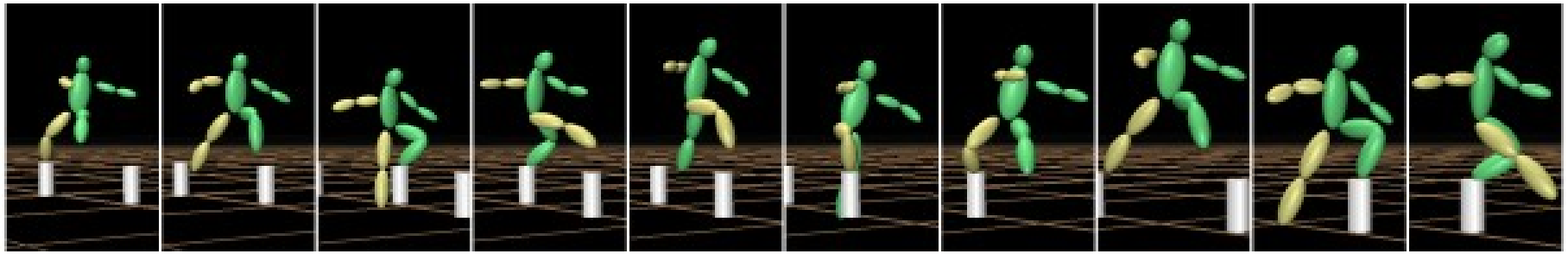
- $\min_{q} E$ s.t. $C_a = a,\ C_l = b$



Optimization in Inverse Dynamics

- Compute the trajectories of the body such that the amount of torque exerted by joints is minimal
  - Fang, Pollard ‘03





Discussions

- Optimization in Forward Dynamics
  - Finding a good initial motion is not easy
  - Need to keep the balance
- Optimization in Inverse Dynamics
  - Easier to start as the motion does not have to satisfy dynamic rules
  - Need a good objective function that well describes the motion
- In both cases, the cost of computation is very high
  - Due to the large number of variables

Overview

- Motion synthesis by Optimization
  - Using forward / inverse dynamics
- **Motion Editing**
  - **Motion Warping**
  - **Motion Blending**
  - **Dynamic Time Warping**
- CMU motion database

Motion Editing : Background

- We learnt about motion capture
- It can provide realistic movements for characters
- However,…

Animators are not so happy with the raw motion capture data

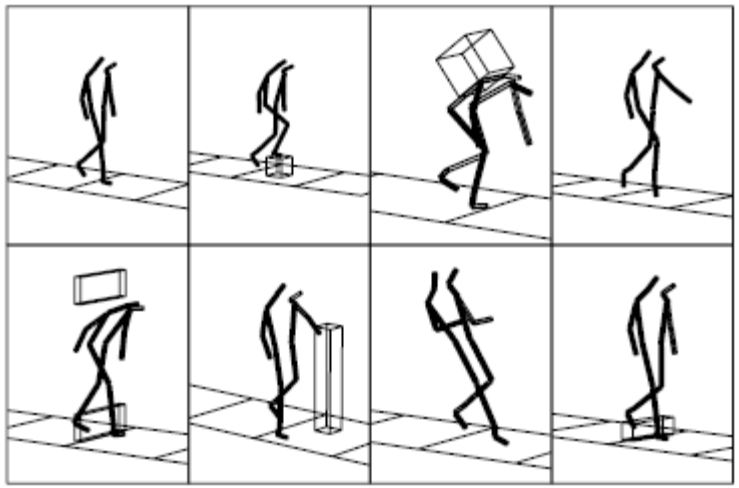
- There might be obstacles in the scene – the character needs to avoid them while walking
- The character's body is different from those of humans
  - The hand not reaching the right position
  - Need to "retarget" the motion to the character size while maintaining constraints
- The style of motions are not stylised
  - Want to exaggerate some expressions

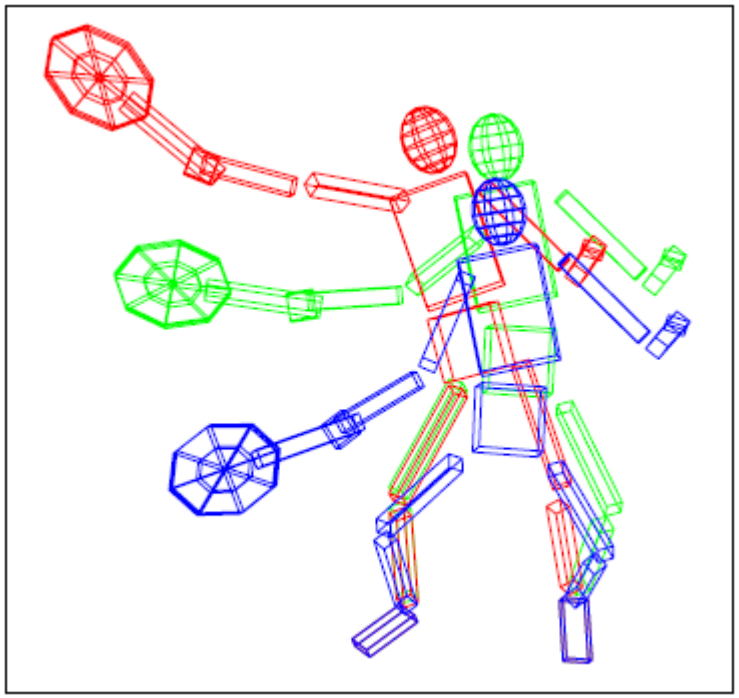
Editing motions

- Need an efficient method to edit the trajectories of the body
- Whilst satisfying constraints
- Must be interactive – the tools are used by animators

Motion Warping

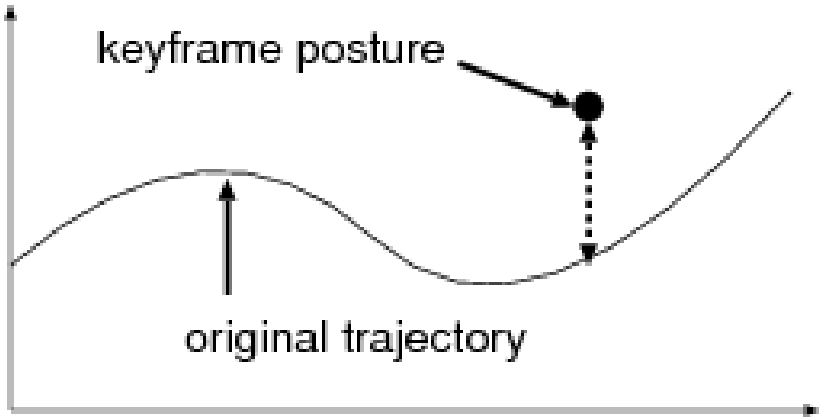
- Edit the captured motion a little bit so that it satisfies the requirements
  - Effective for changing the location the hand or the foot passes

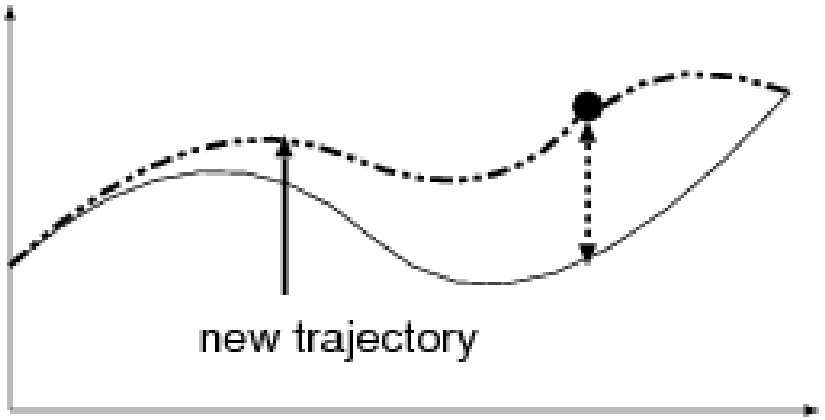




Basic idea

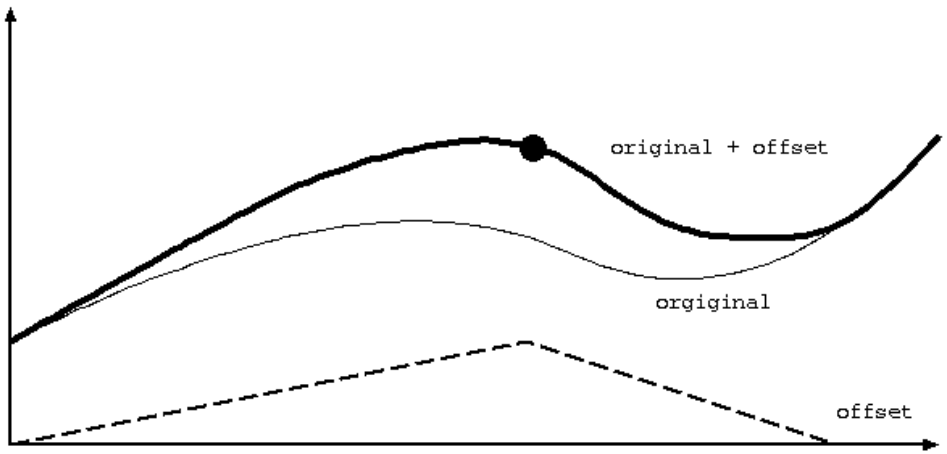
- Adding offset to the data so the constraint is satisfied





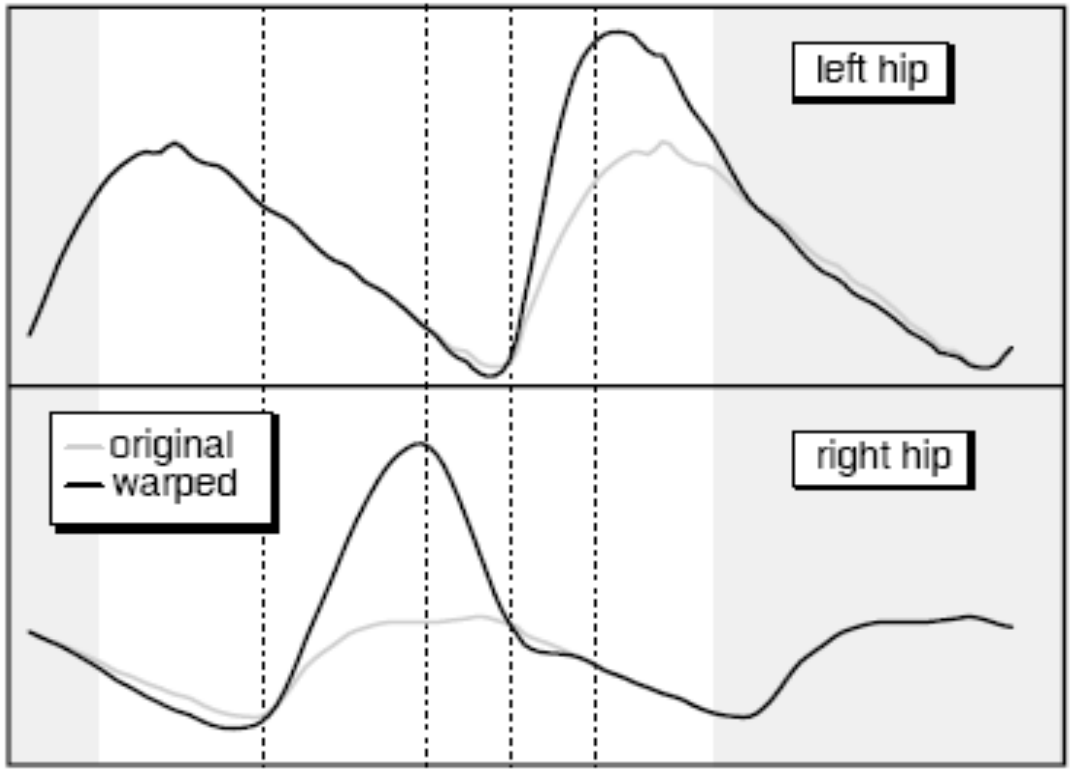
Warped Motion = original motion + offset

Offset can be a simple 1D motion



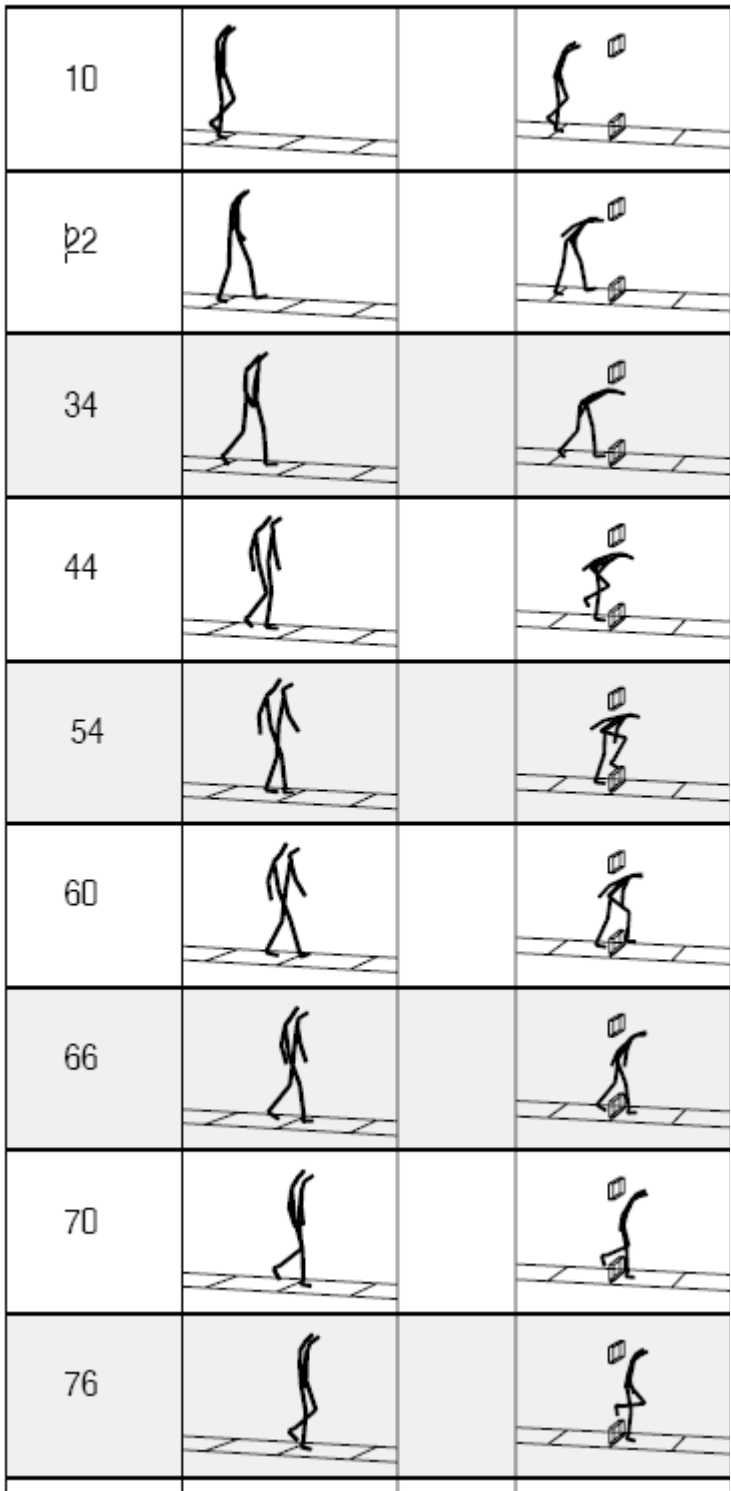
Motion Warping

- Add an offset to the trajectories to edit the motion
  - Determine the duration the motion should be edited
  - Insert a keyframe so that the motion satisfies the requirements



Motion Warping

- Very simple
- Good for avoiding obstacles



http://www.youtube.com/watch?v=BzfxGwO7swg

http://www.youtube.com/watch?v=Ro30uWsWl_s

How to satisfy constraints?

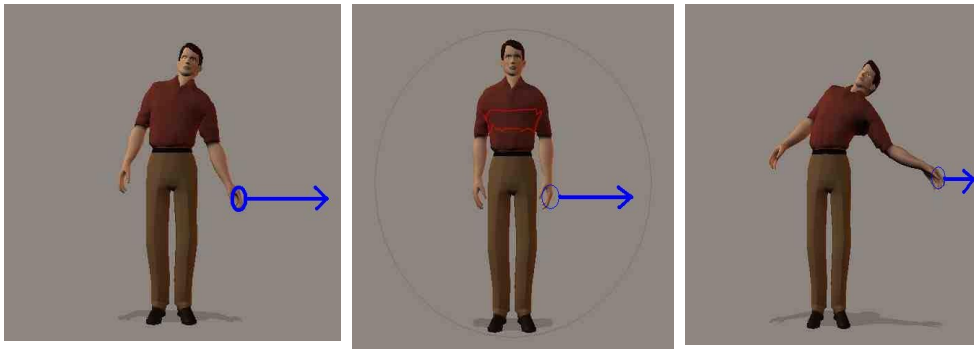
- We warp the motion in the level of generalized coordinates (root position, root orientation and joint angles)
  - No information about contacts

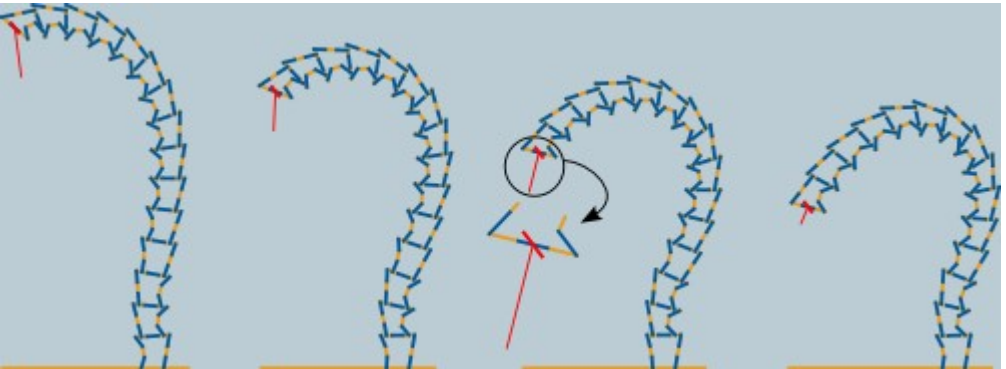
The supporting foot/feet slides when the motion is simply blended

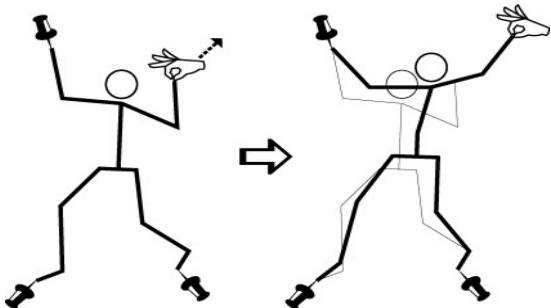
http://www.youtube.com/watch?v=KumgRt895EU

Inverse Kinematics

- Editing the postures/motions by specifying the 3D location of the avatars
- We can use IK to solve the problem of foot sliding
- Edit the postures, frame by frame, and drag the foot to the original position

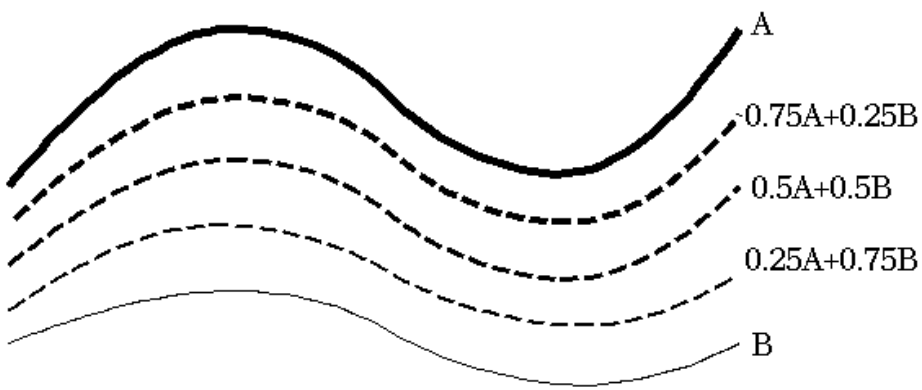


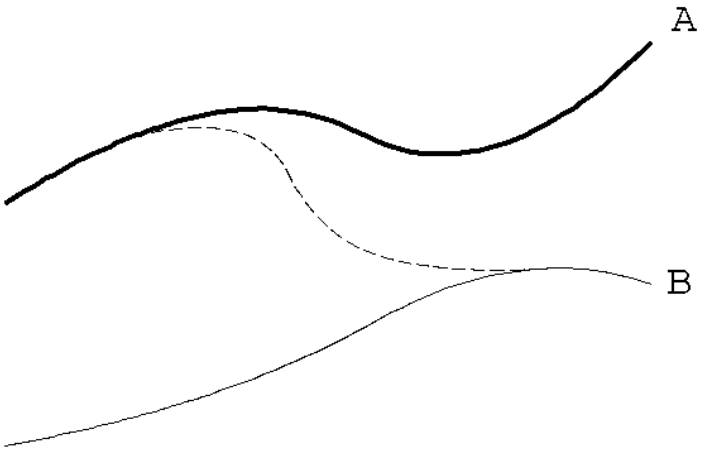




Motion Blending

- Given two different motions A and B
  Blended Motion = A * (1-s) + B *s (0<s<1)
- How can we use this?
  - Generate a motion in between
  - Gradually shift from motion A to motion B
  - Concatenating two motions – blending the two ends by gradually shifting s from 0 to 1





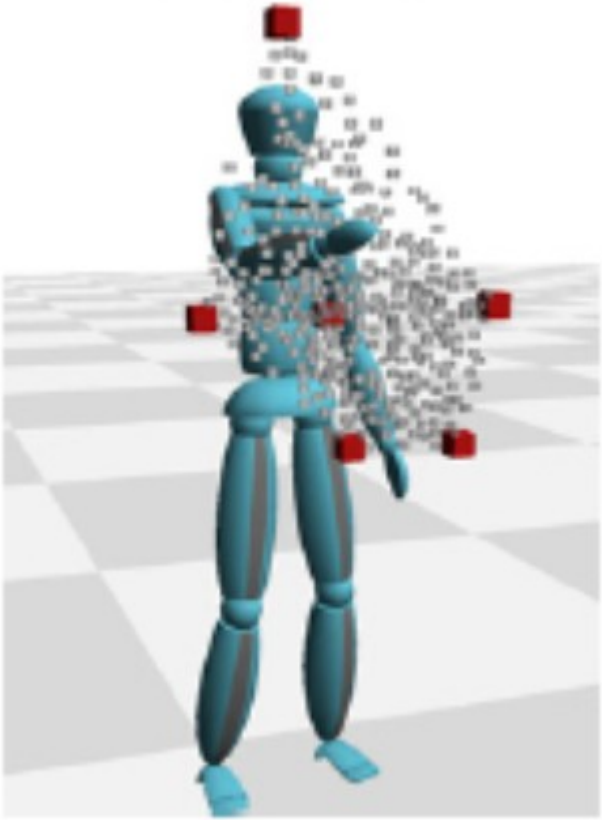
Motion Blending: Blending Multiple Motions

Given example motions $M1, M2, \ldots, Mn$ we blend them by weights $\boldsymbol{W}=(w_1, w_2, \ldots, w_n)$ such that

$$w_1+w_2+\ldots+w_n = 1$$

And then blend the motion by

$$w_1M_1+w_2M_2+\ldots+w_nM_n$$



Motion Blending: Blending Multiple Motions

How do we compute the weights?

Say we have a target hand position p.

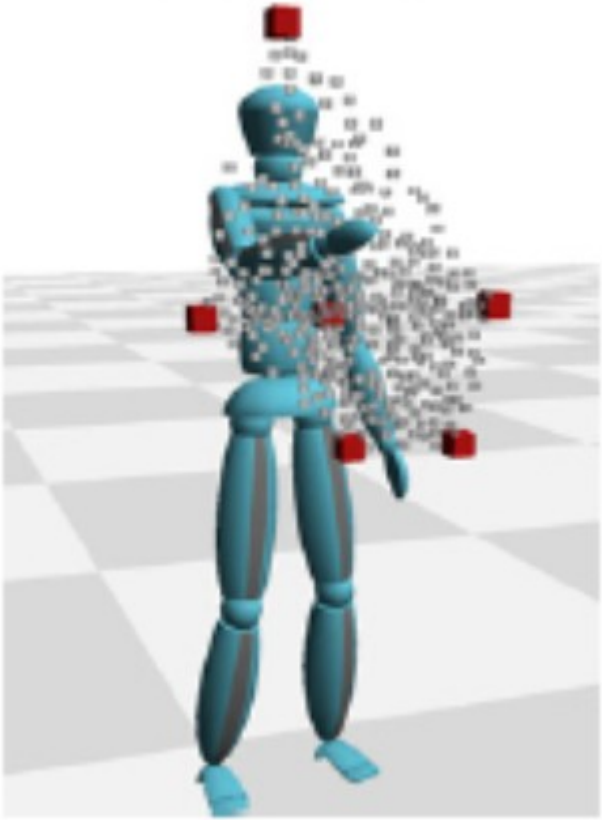
And the position of the hand in each motion is $(p_1, p_2, \ldots, p_n)$.

The weights $(w_1, w_2, \ldots, w_n)$ can then be computed by

$$w_i = b_i / (b_1 + b_2 + \ldots + b_n)$$

$$\text{where } b_i = 1 / |p - p_i| - 1 / |p - p_k|$$

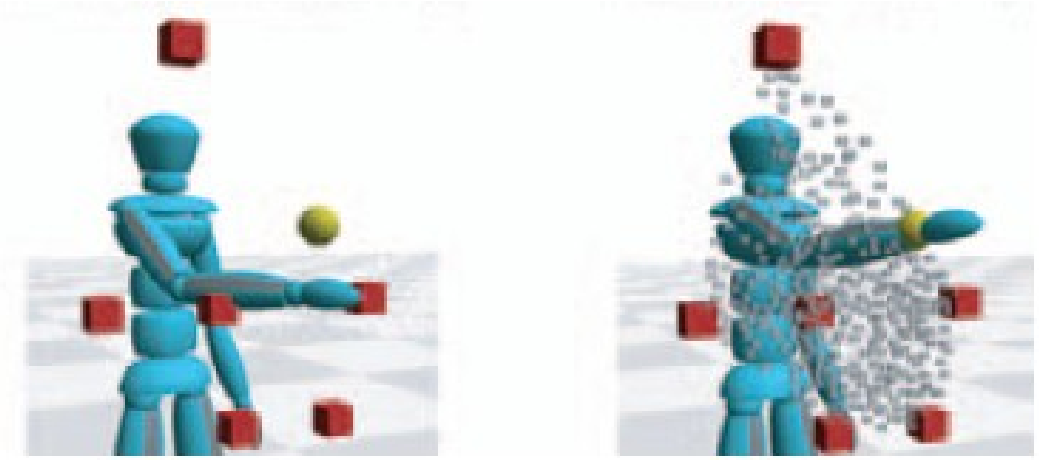
k is the farthest sample



Motion Blending: Blending Multiple Motions Some issues:

There can be issues when the hand target position is far from the samples

Because the linear blending in the generalized coordinates do not result in a linear blend in the task space (Cartesian space, hand position)



Motion Blending: Solution:

- Increase the number of samples by linear blending (producing new examples)

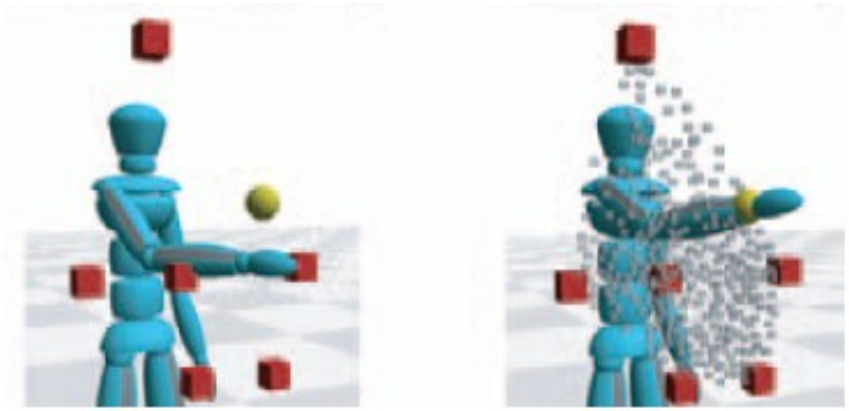
- We can use these for new samples

- In the case below,

$$W_j = normalize((W_{(1)} + W_{(2)} + W_{(3)} + W_{(4)}) /4)$$

as we can interpolate samples in tetrahedra

And we compute the corresponding hand position p_j accurately
(not by linearly blending $p_{(i)}$)



Motion Blending: Solution (2):

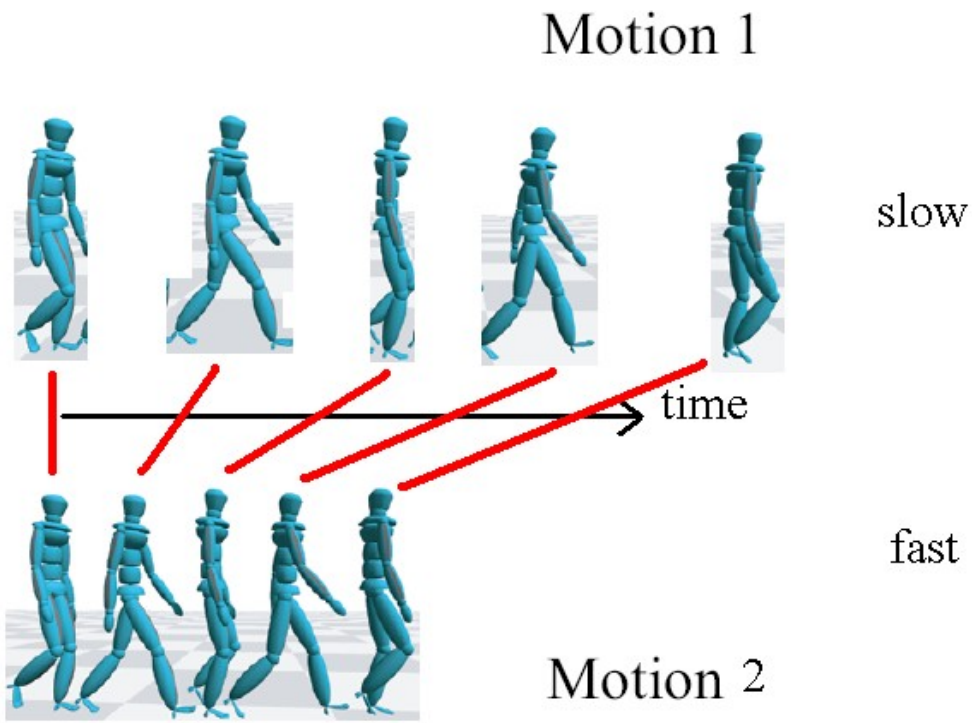
- Find the k-nearest neighbours, and then blend them

- As the samples are much denser and as the target is much closer to the samples, a linear blend in weights will result in a linear blend of the hand position

http://www.youtube.com/watch?v=qtNsF-nTp4A (around 0:50)

Another problem when blending motions

- The durations of motions are different
- The timing of some events are different
  - Suppose we blend two walking motions
  - The timing of steps are different
  - Need to synchronize the motions



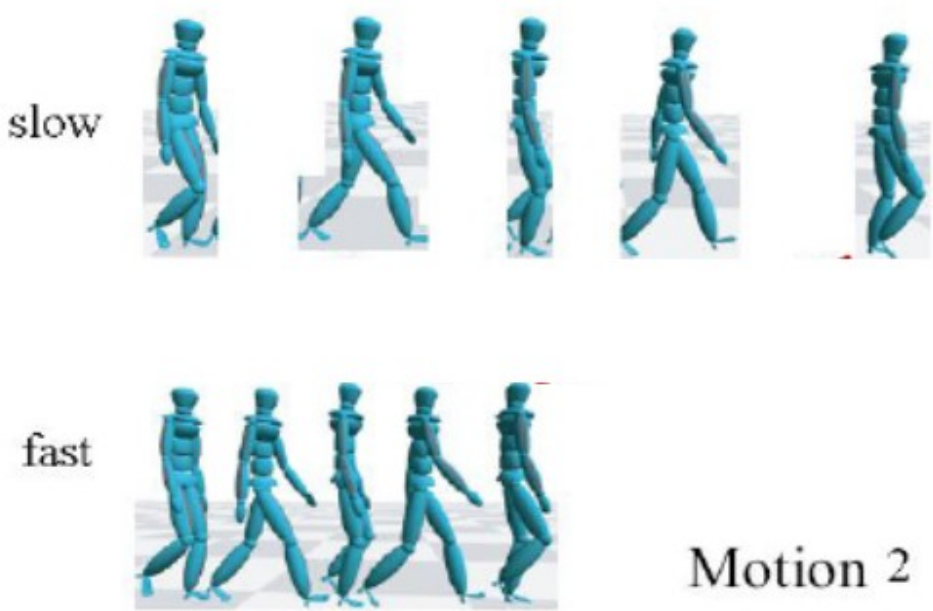
Dynamic Time Warping (DTW)

–Define difference of postures at every frame in motion 1 and motion 2

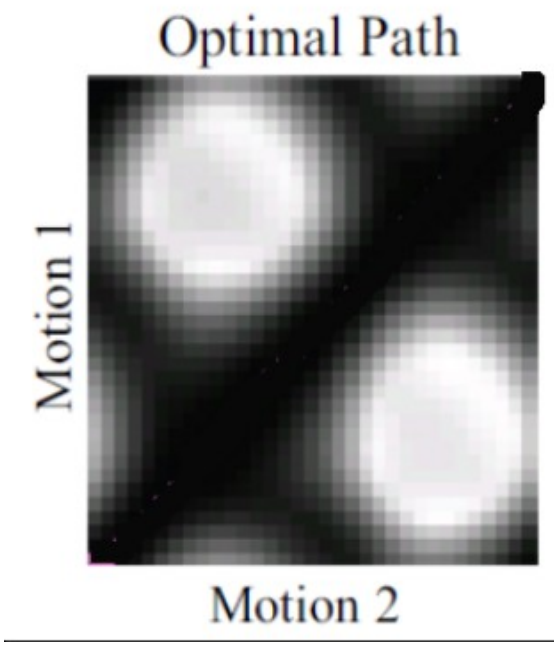
$$D(\mathbf{q}_1, \mathbf{q}_2) = d(\mathbf{q}_1, \mathbf{q}_2) + \alpha d(\dot{\mathbf{q}}_1, \dot{\mathbf{q}}_2)$$

like Euclidean distance of generalized coordinates

–Create a similarity matrix of all frames



http://www.youtube.com/watch?v=EL7ARaH5jHU



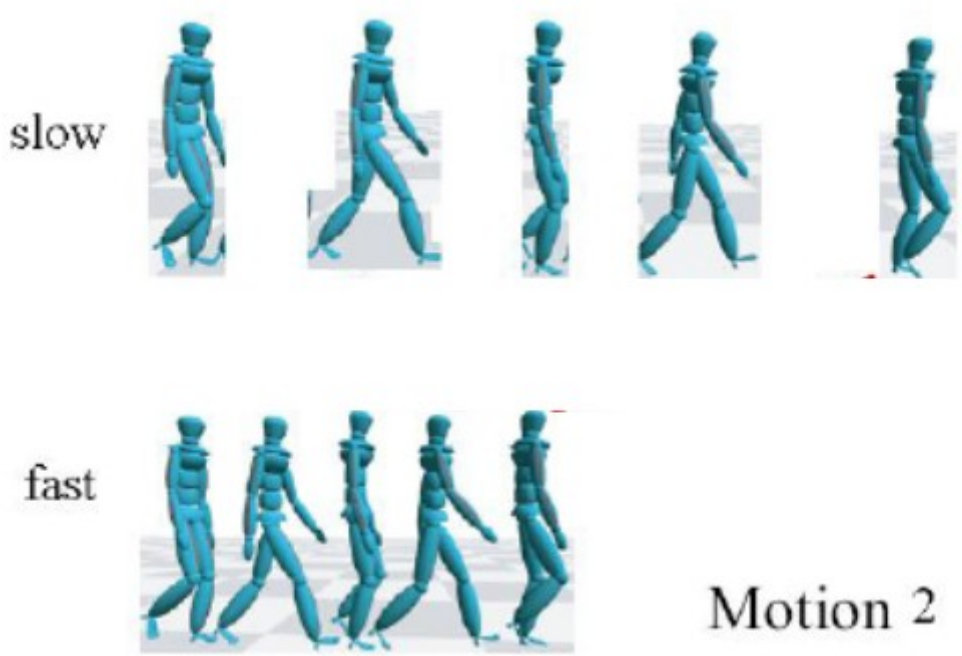
Dynamic Time Warping (DTW)

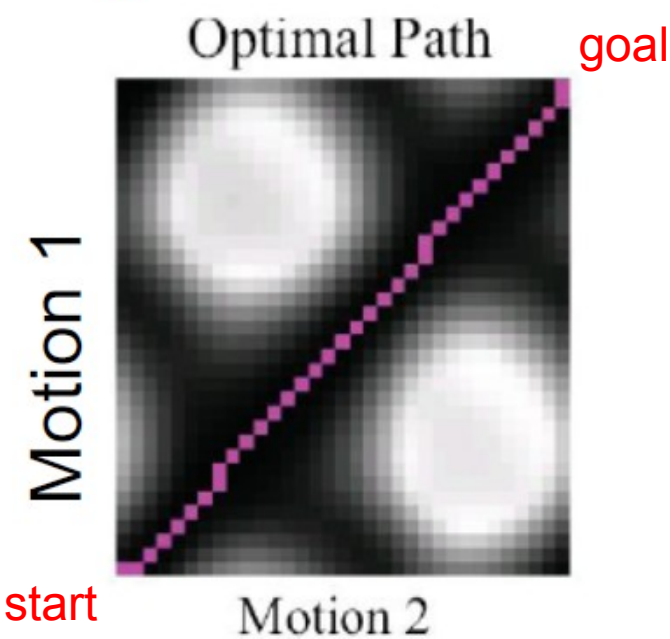
–Define difference of postures at every frame in motion 1 and motion 2

–Create a similarity matrix of all frames

–Find the shortest path from the left bottom to the right top in this matrix (assume the matrix is a map) - this gives

$$min \sum_i d_i(q_1, q_2)$$





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Dynamic Time Warping (DTW)

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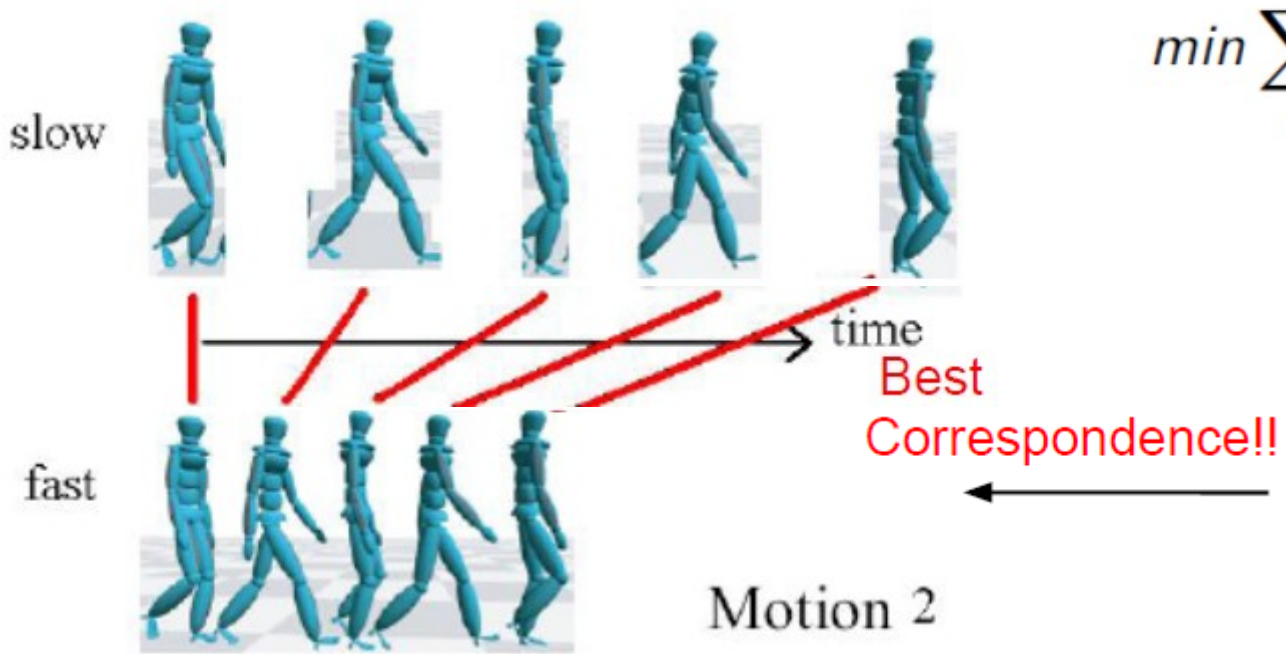

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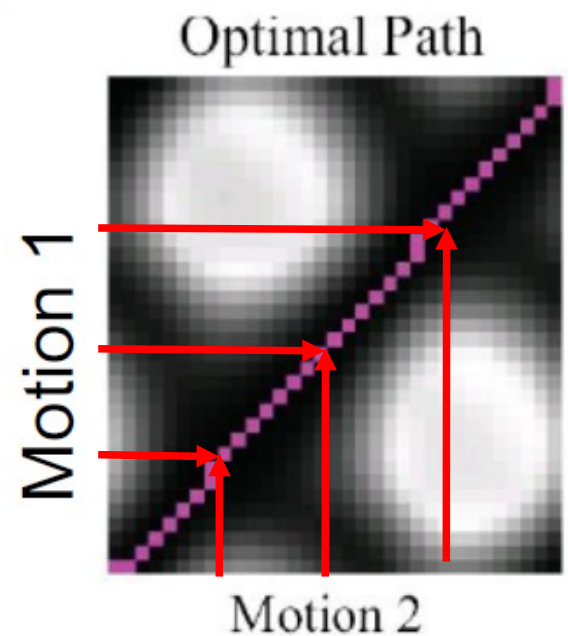
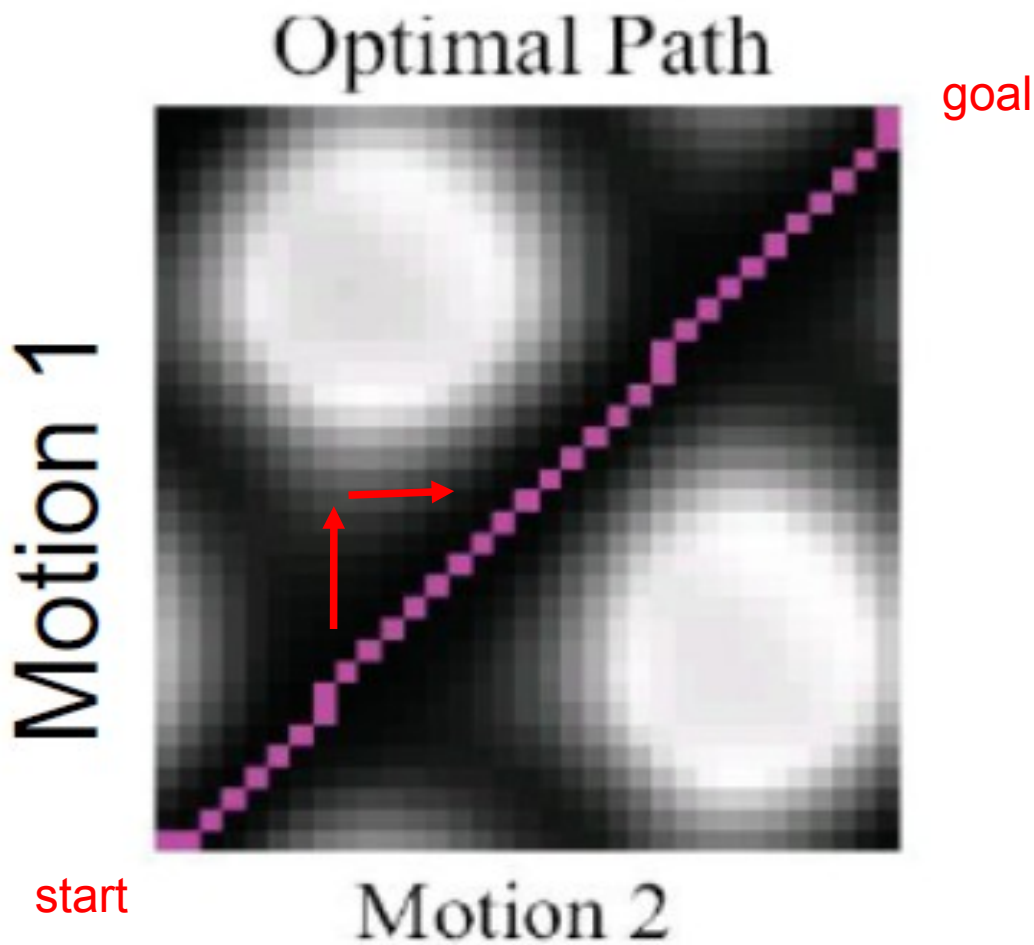


http://www.youtube.com/watch?v=EL7ARaH5jHU

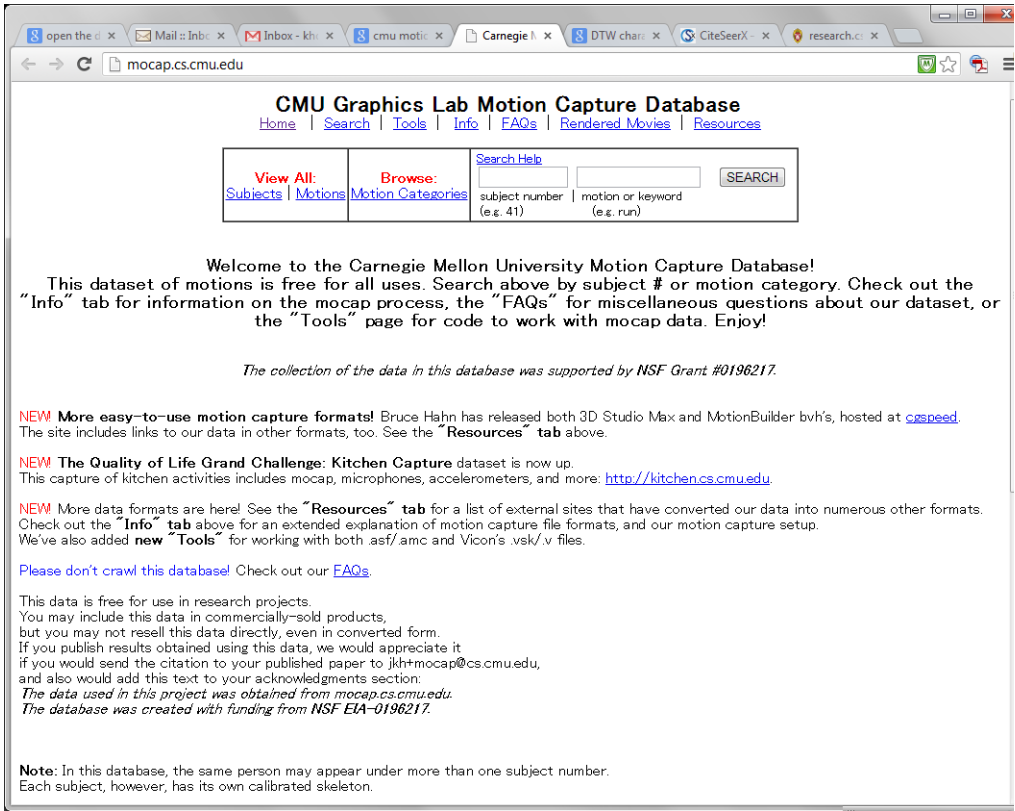
Dynamic Time Warping (DTW): Notes

- Only movements to the right and up are allowed (A directed graph)



Carnegie Mellon University Motion Database

- Various motion data in different topics
  - Locomotion
  - Physical activity and sports
  - Human interactions
- Can search motion by topics
- Can preview the animation at the website



Readings / References

- Witkin and Popovic “Motion Warping”, SIGGRAPH 95
- Witkin and Kass, “Spacetime Constraints”, SIGGRAPH 88
- , SIGGRAPH 2003
- Wang et al., Optimizing Walking Controllers for Uncertain Inputs and Environments , SIGGRAPH 2010
  - CMU Motion Database