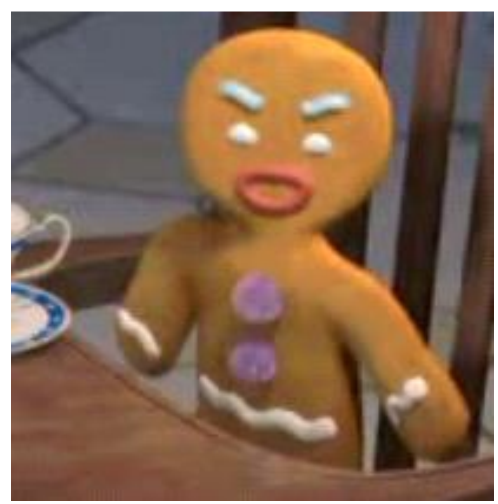
Data-Driven Computer Animation
Lecture 3.

Motion capture and physically-based animation of characters

Character Animation

- There are three methods
  - Create them manually
  - Use real human / animal motions
  - Use physically based simulation

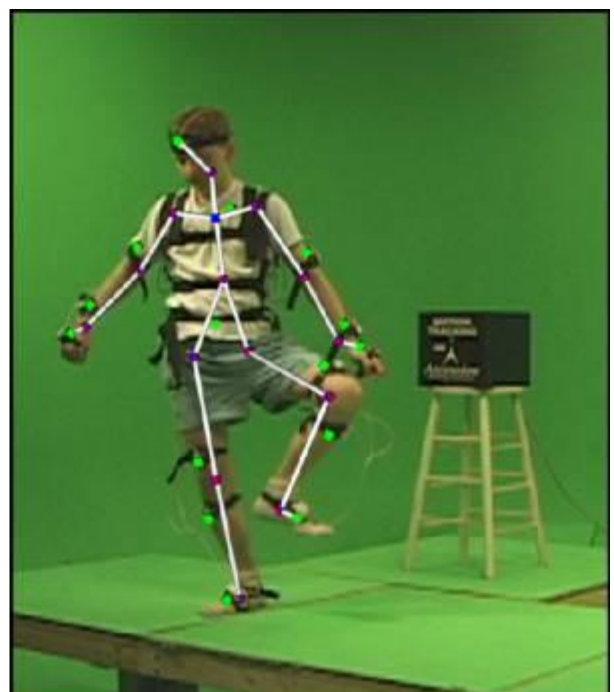

Using Real Human (Animal) Motion

Real human (animal) motion is realistic

Much faster and cheaper than manually producing the data

Capturing human motion

- We use the motion capture device (Mocap)
- There are three types of Mocaps
  - Optical
  - Magnetic
  - Mechanical
  - Inertial trackers
  - Video-based

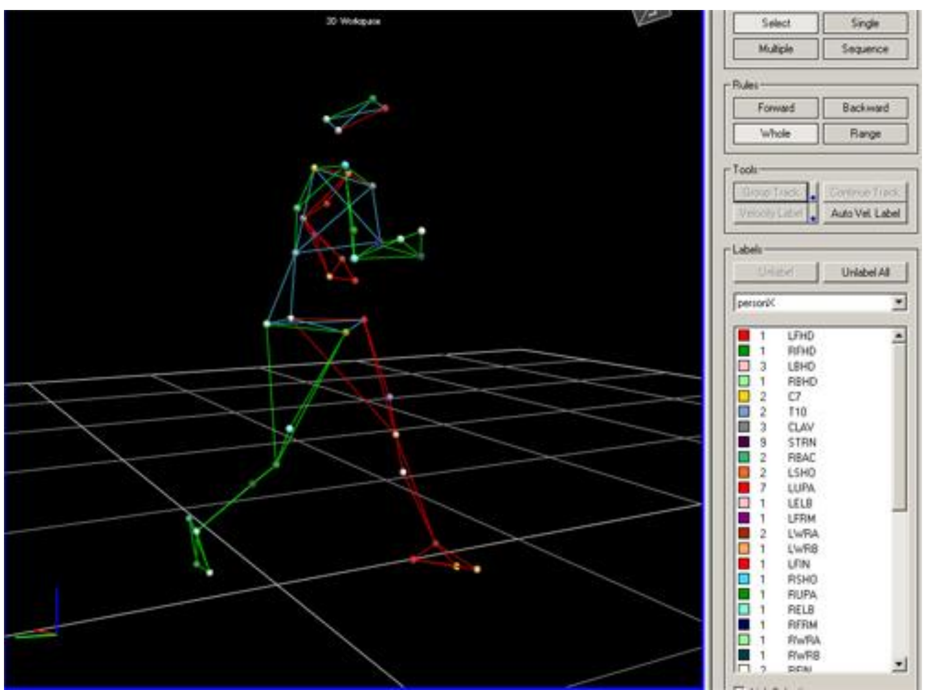


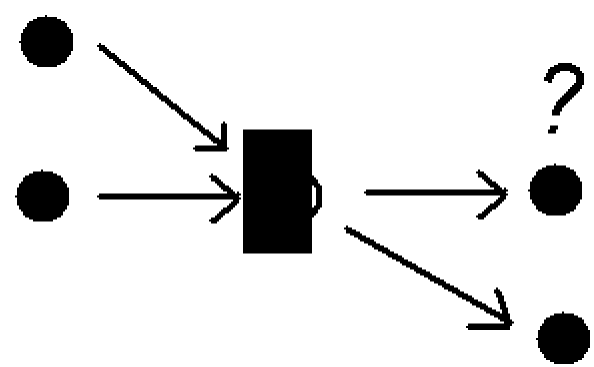
Optical Mocaps

- The actor puts reflective markers on his/her body
- The actor is shot by multiple cameras
- Light source around the camera.
- The light source casts light towards the actor
- The light is reflected by the markers back to the camera
- The 3D location of the markers are computed by stereo vision

1. Labeling and Post-processing

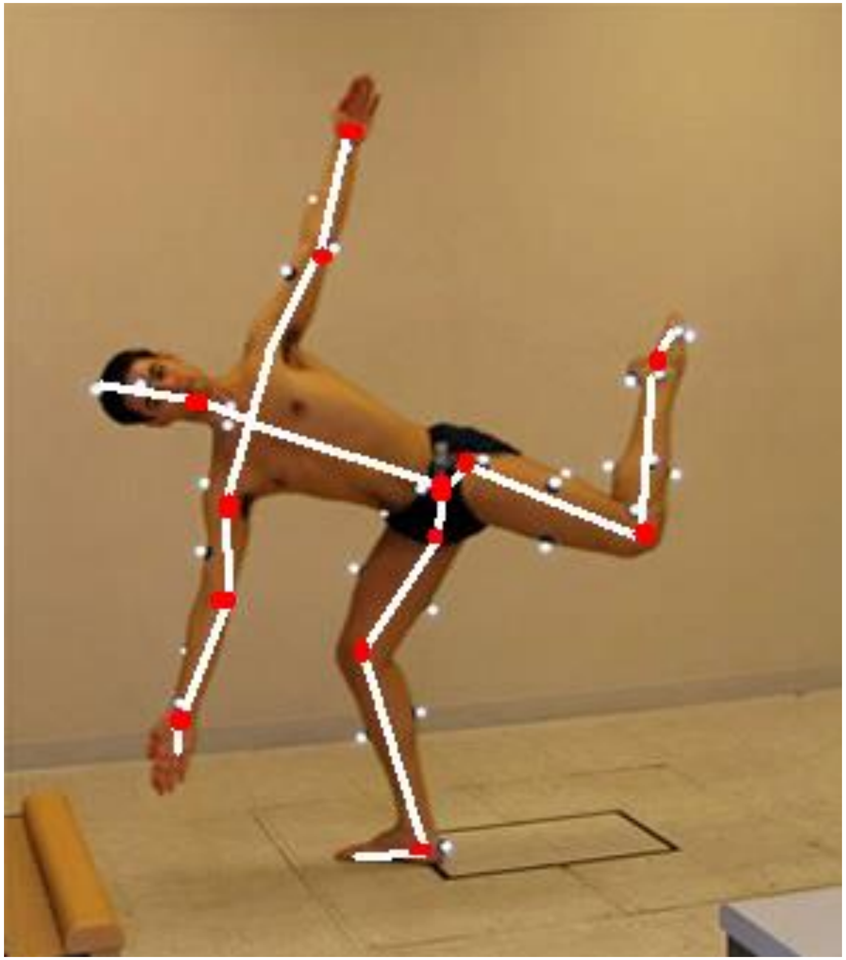
- The markers must be manually labelled first
- Once the markers get occluded, they have to be tagged manually again
    - The same process repeated for the whole motion
- Sometimes the body intersects, and then the system mix them up





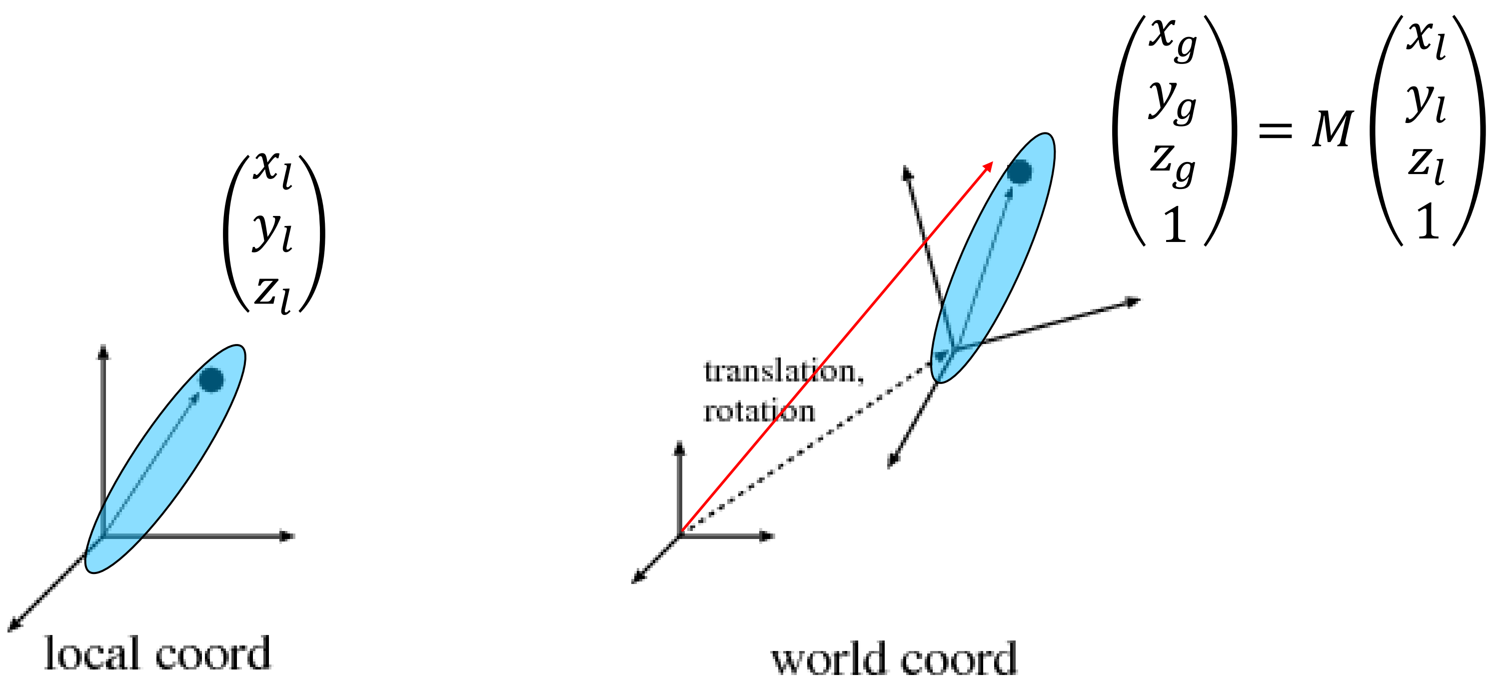
2. Computing the center of the joints from the marker positions

- To compute the joint angles of the skeleton



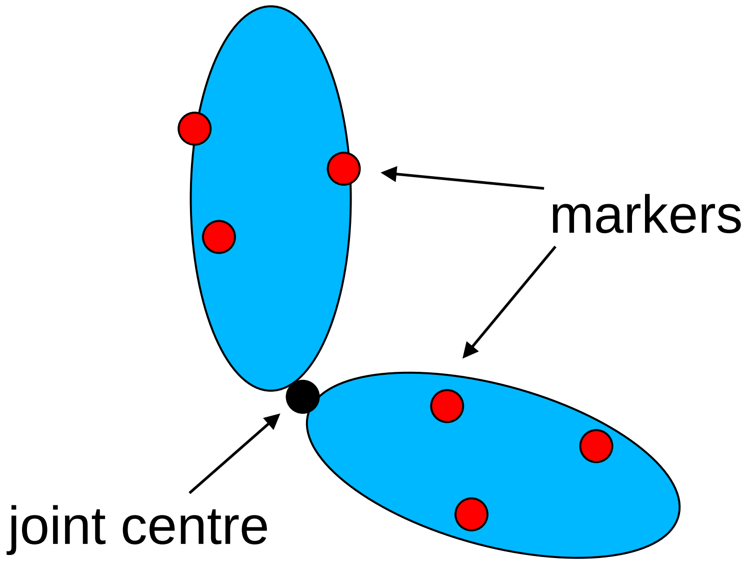
Background

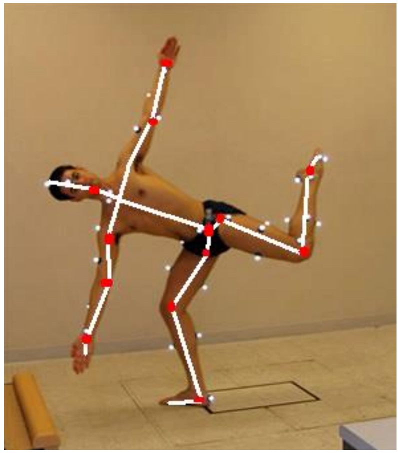
- A homogeneous transformation matrix *M* (4x4) is defined per bone
- It represents the pose of the bone
- It converts local coordinates to world coordinates



Predicting the Centre of Joints

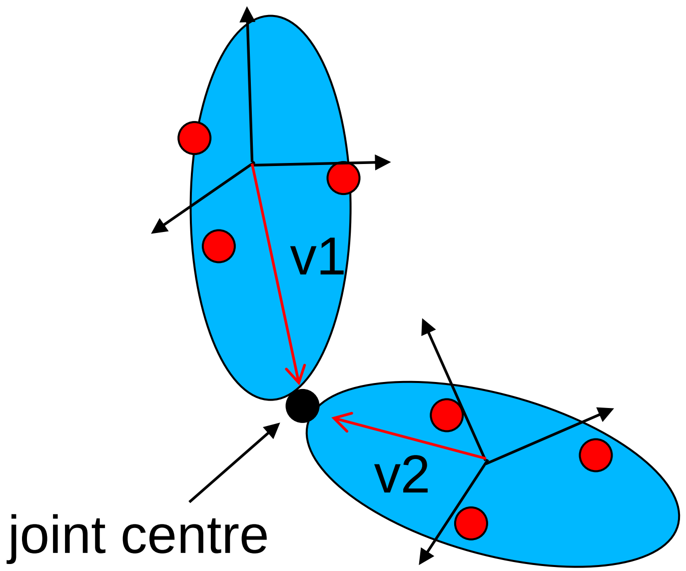
- Let's assume we have two adjacent points connected at a joint
- We assume three markers are attached to each bone
- How can we predict the joint centres with respect to the markers?

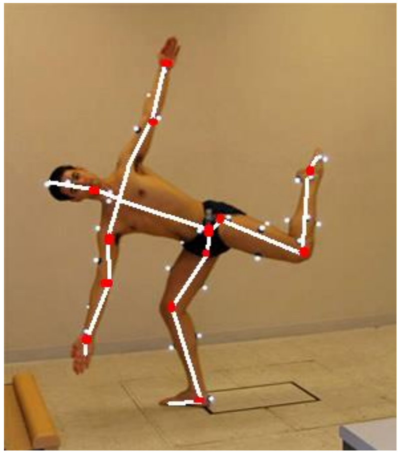




Predicting the Centre of Joints

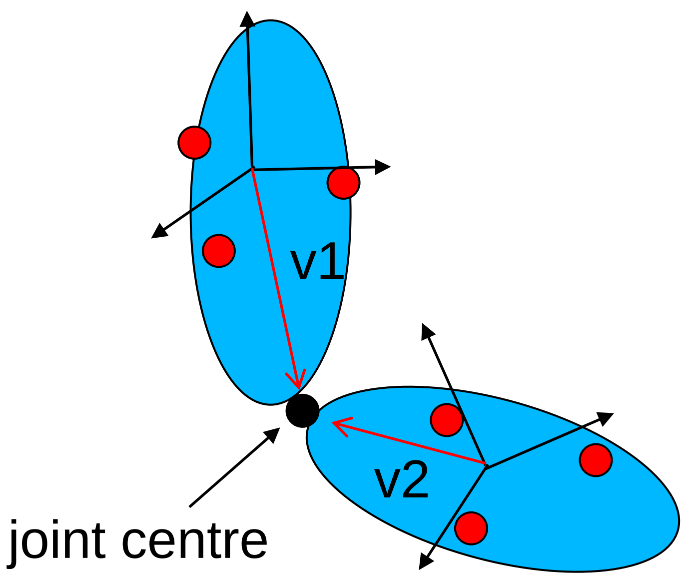
- Define the coordinate system of each bone using the markers
- Compute the transformation matrix for each bone in each frame: M_1, M_2
- Define the vector from each bone coordinate to the joint (v_1, v_2)





Predicting the Centre of Joints

- The equation to compute the joint centre for each frame: $M_1 v_1$, $M_2 v_2$
- As the positions should be the same, $M_1 v_1 - M_2 v_2 = 0$
- Decomposing this into the rotation and translation part, it will be $R_1 v_1 + t_1 = R_2 v_2 + t_2$
- We have this equation for each frame.



$$
\begin{gathered}
R_1^1 v_1 + t_1^1 = R_2^1 v_2 + t_2^1 \\
\vdots \\
R_1^N v_1 + t_1^N = R_2^N v_2 + t_2^N
\end{gathered}
$$

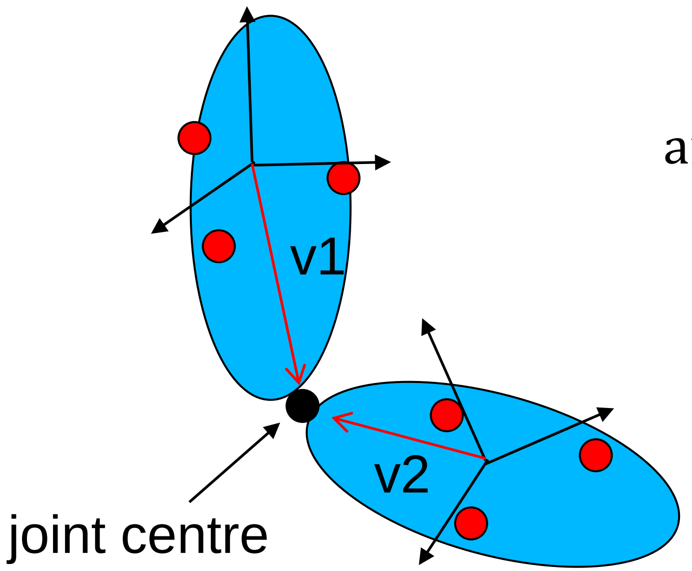
Predicting the Centre of Joints

We have this equation for each frame.

$$R_1^1 v_1 + t_1^1 = R_2^1 v_2 + t_2^1$$
$$\vdots$$
$$R_1^N v_1 + t_1^N = R_2^N v_2 + t_2^N$$

The only unknowns are $v_1 \ v_2$

We can solve a least squares problem



$$\arg min_{v_{1,}\, v_2} \sum_{n=1}^{N} \| R_1^n v_1 + t_1^n - R_2^n v_2 - t_2^n \|^2$$

Cons and Pros of Optical Mocaps

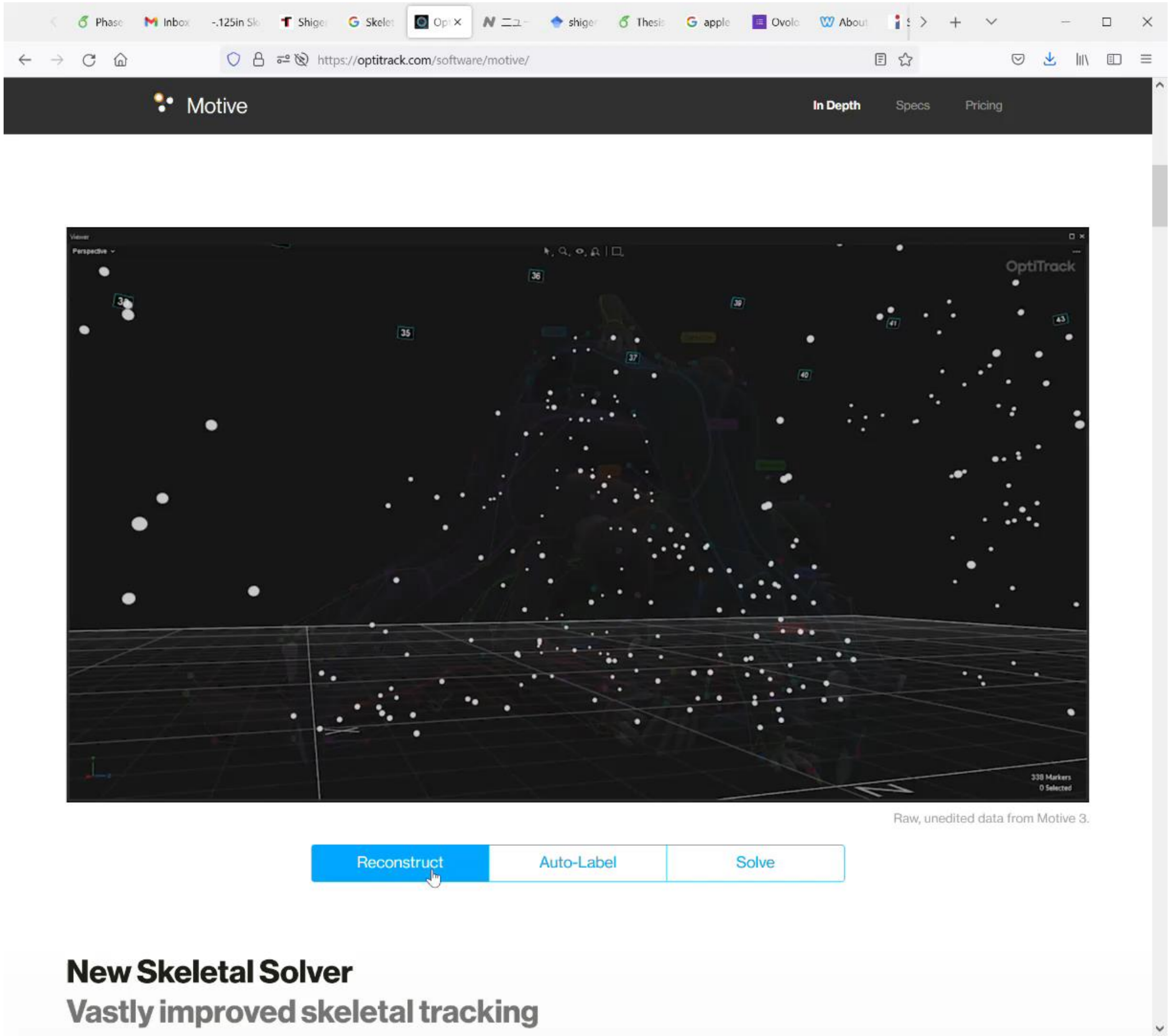
Advantages

- Less intrusive (only the markers are attached to the body)
- Very accurate
- Can capture not only the human (animal) motion, but also skin movements

Shortcomings

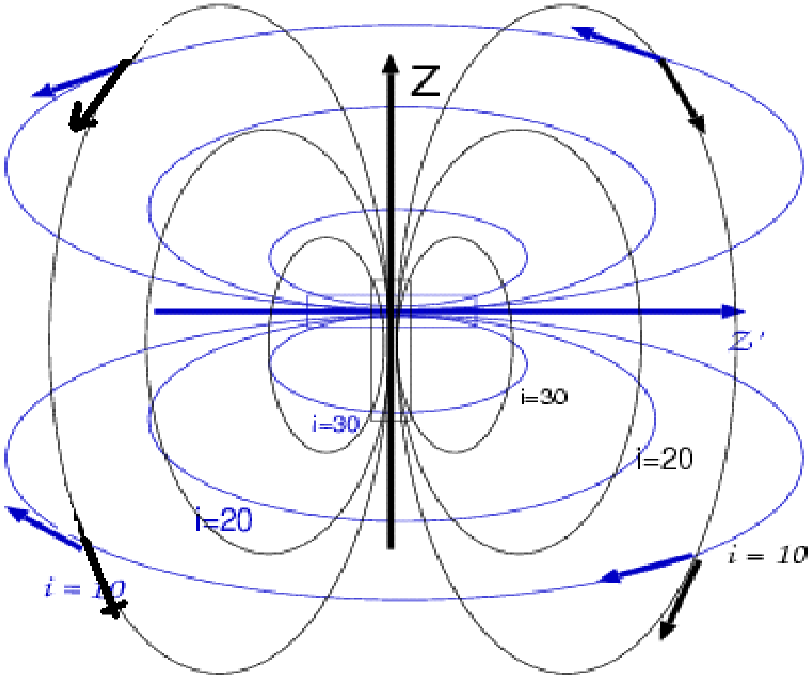
- Suffer from occlusions (the body hiding the markers)
- A lot of post-processing is required if occlusion happens
  - Labelling which marker is which
- Need a large studio for a capturing outdoor movements

Demo movie of an optical Mocap system



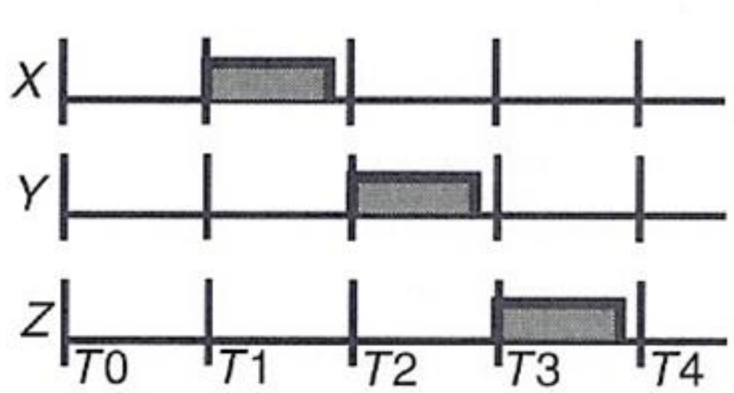
Magnetic Mocaps

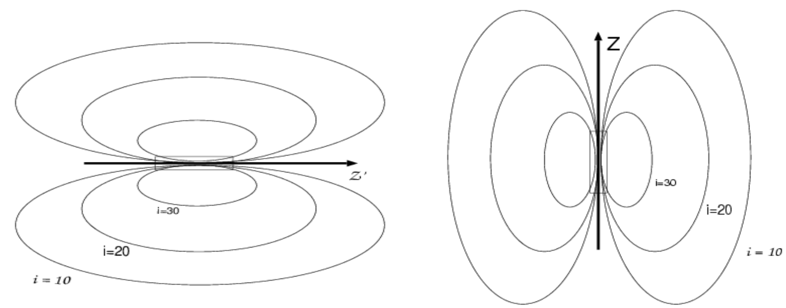
- Predicting the 3D pose using the magnetic field
- The magnetic field is constructed by a transmitter
- The strength of the magnetic field is detected by sensors attached to the body



Magnetic Mocaps

- The transmitter produce three orthogonal magnetic fields sequentially

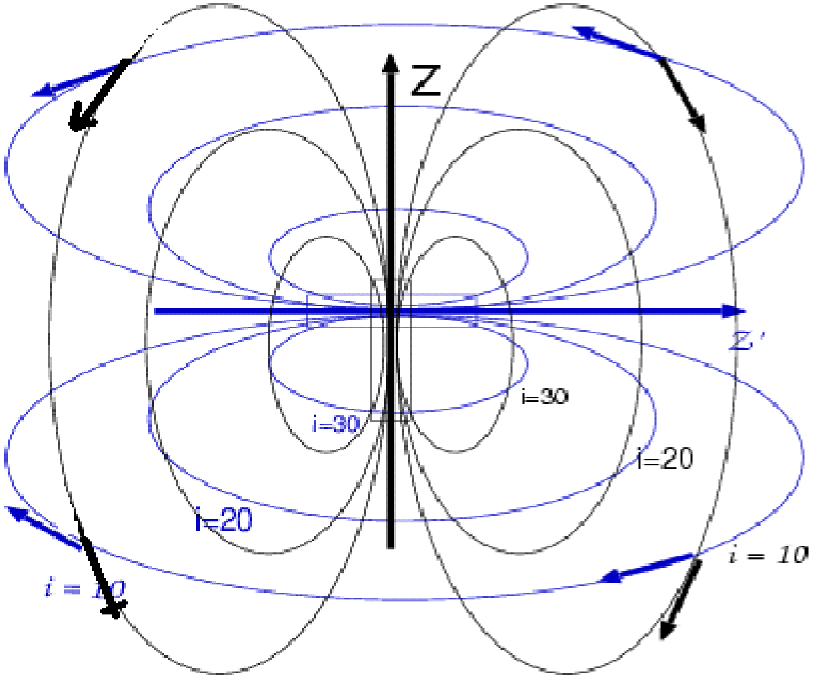




- The actor wears a suit to which the magnetometers are attached

Magnetic Mocaps

- The magnetometers on the body detects the magnetic field, and the 3D location can be computed by the amplitude of the magnetic field
- The farther you go away, the weaker the magnetic field is



Cons and Pros of Magnetic Mocaps

Advantages

- We do not have to worry about occlusion
    - Motions of close contact can be captured
- No manual post-processing is required

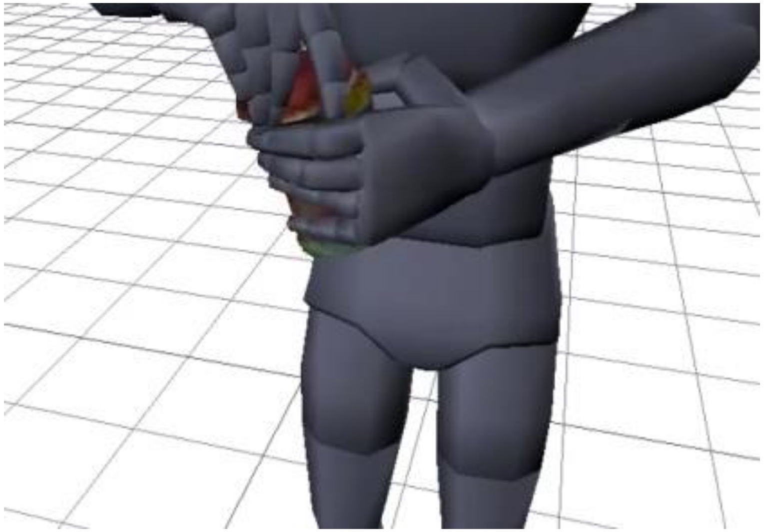
Shortcomings

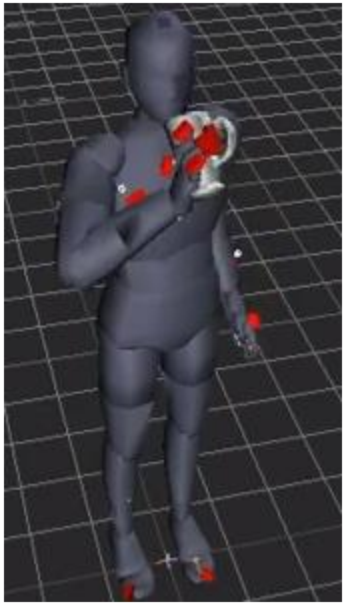
- Less accurate
    - The absolute positions are highly distorted
    - Easily affected by the noise
    - Cannot have metal/electronic devices in the capturing area
        - Affects the magnetic field
- The capturing volume is very small
    - Only 2-3 m away from the transmitter

Edinburgh Interaction Database

By Peter Sandilands, Myung Geol Choi

- We captured the human movements as well as the objects manipulated
- Also captured the geometry of the objects

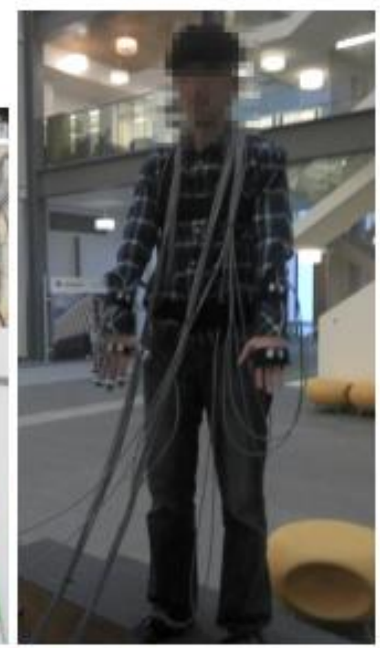




Edinburgh Interaction Database: Motion Capture Using Magnetic Sensors and the Kinect

Peter Sandilands
Myung Geol Choi
Taku Komura

THE UNIVERSITY of EDINBURGH
informatics
ipab
Institute of Perception, Action and Behaviour



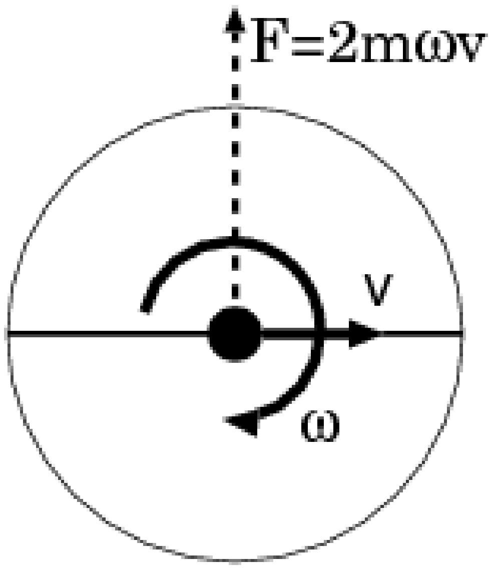
Inertial trackers

- Inertial trackers measure the rate of change in
  - Angular velocity - gyro sensor
  - Translational acceleration - accelerometer
- These values are integrated to compute the
  - Orientation and
  - Position

of the tracker

Orientation

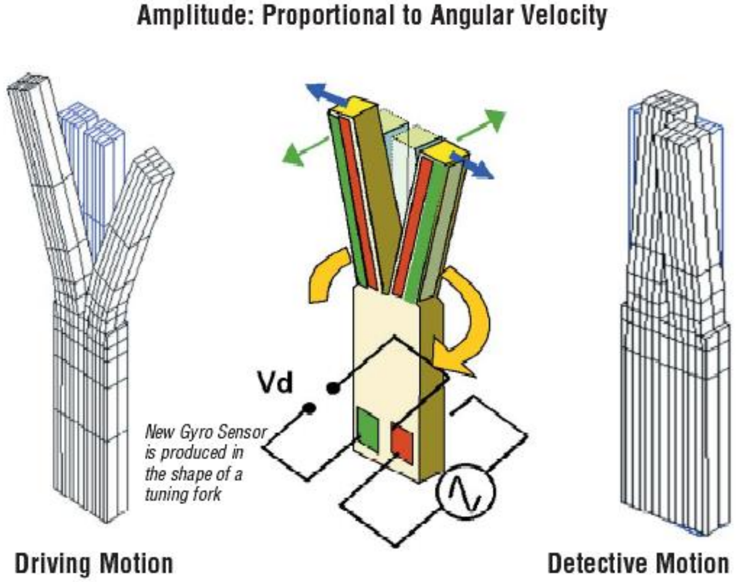
- The rate of change in object orientation or angular velocity, is measured by Coriolis-typed gyroscopes

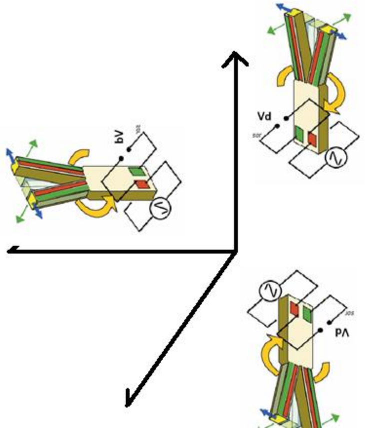


ω:angular velocity, v:velocity
m: mass, F: coriolis force

An example of a Gyro sensor

- Fujitsu Gyro Sensor
- The sensor is shaped like a tuning fork, and vibrates continuously.
- As the sensor turns, it is rotated and the Coriolis force affects it in the direction perpendicular to the vibration.
- this is converted into a proportional voltage, allowing the degree of rotation to be measured.
- **Amplitude: Proportional to Angular Velocity**





Translation

- The translation velocity or acceleration is calculated using accelerometers
- Three accelerometers machined coaxially
- the position of the tracker is calculated by double integration of the acceleration

Ma = -k x

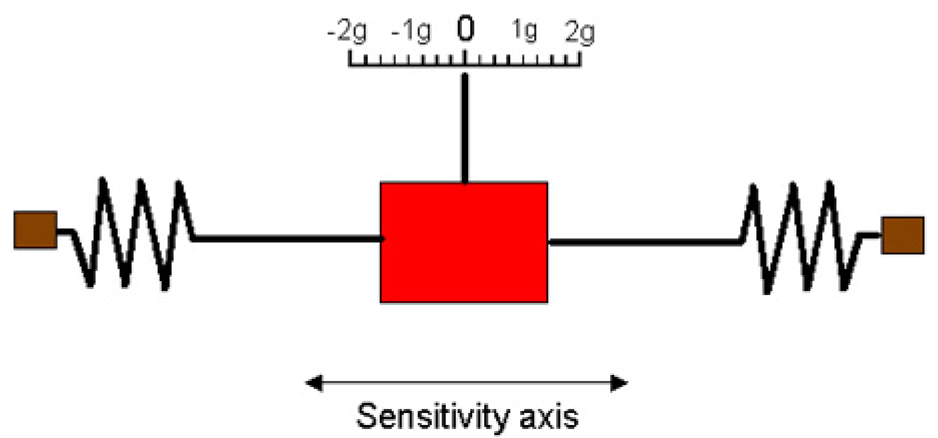


Fig. 1. Schematic structure of an accelerometer

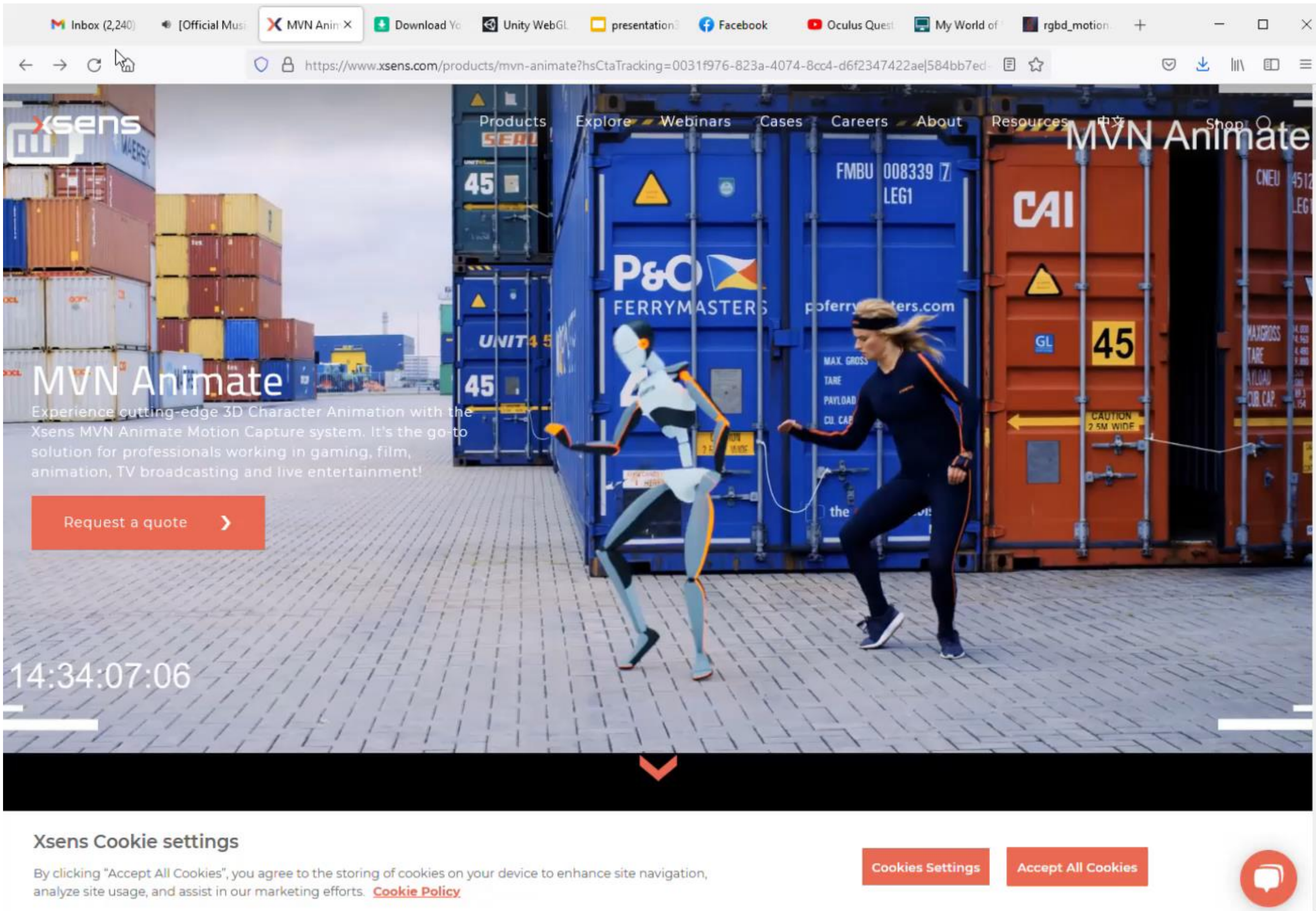
CONS and PROS of inertia trackers

Advantages

- Unlimited range of tracking
- No line-of-sight constraints

Shortcomings

- Rapid accumulating errors, or drift
- Gyroscope bias leads to an *orientation error that increases proportionally with time* due to integration
- Accelerometer bias induces an error that *increases with the square of time*
- The only answer is to periodically *reset the error using other types of trackers*



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Mechanical Mocaps

- Kinematic structure composed of links interconnected using sensorized joints
- The mechanical joints can directly measure the rotation of the human joints

Advantages

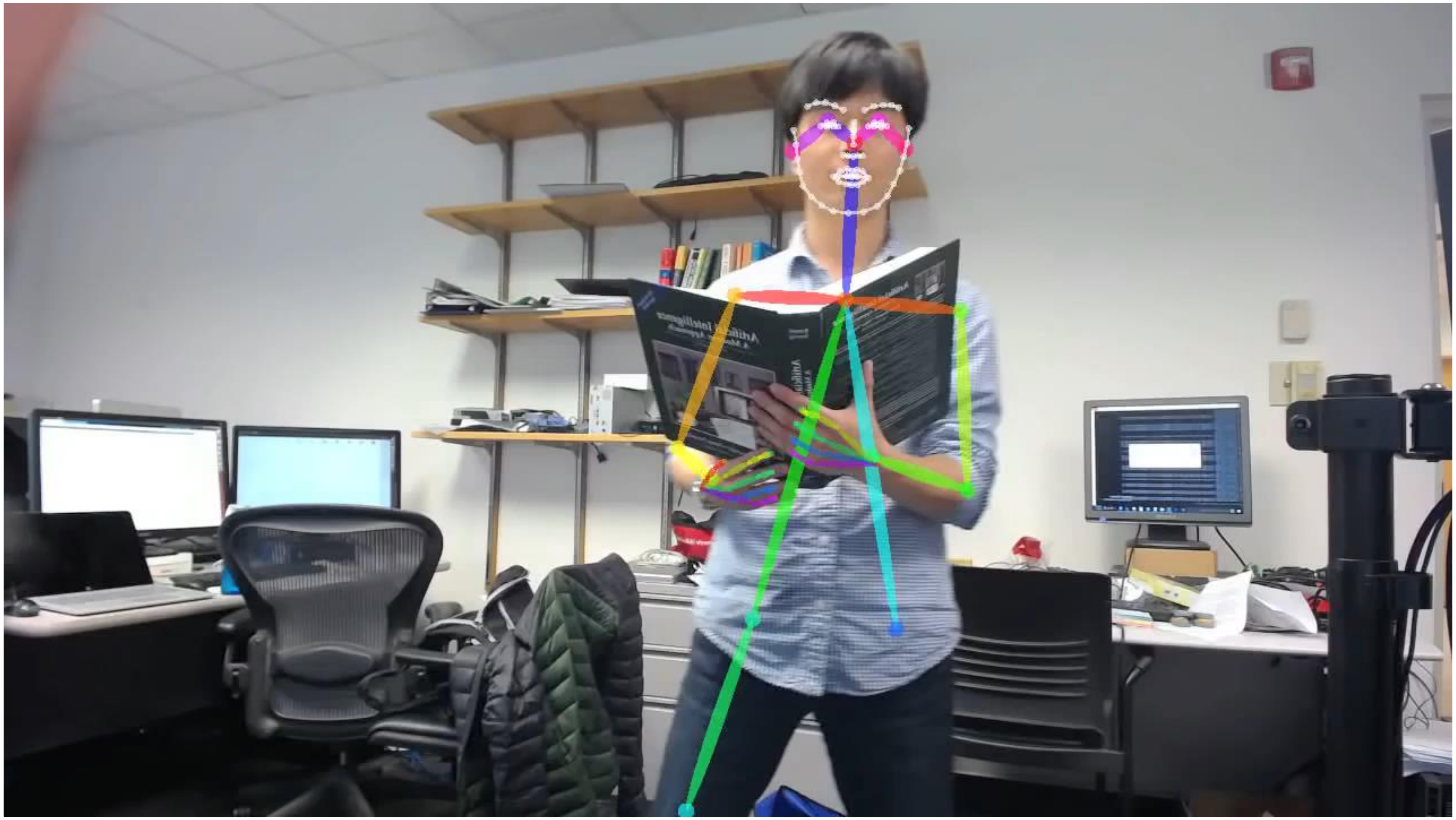
- Very accurate
- Little latency
- Again, we don't have to worry about the occlusion
- Unlimited range of capturing

Shortcomings

- More interference with the actor
  - Affects the performance of the actor
- Vulnerable
- Need an additional sensor to detect the location of the body root

Video-based Motion Capture Systems

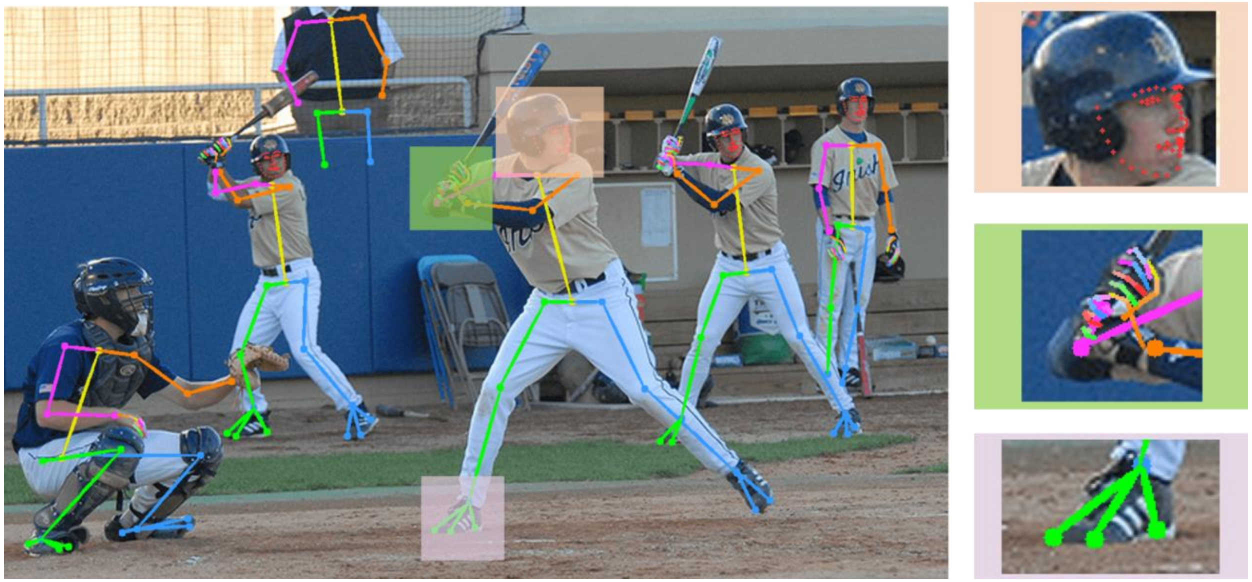
- Video-based systems capture the body motion from one or more RGB videos
- Using machine learning methods for 2D/3D pose prediction



OpenPose

Training Data

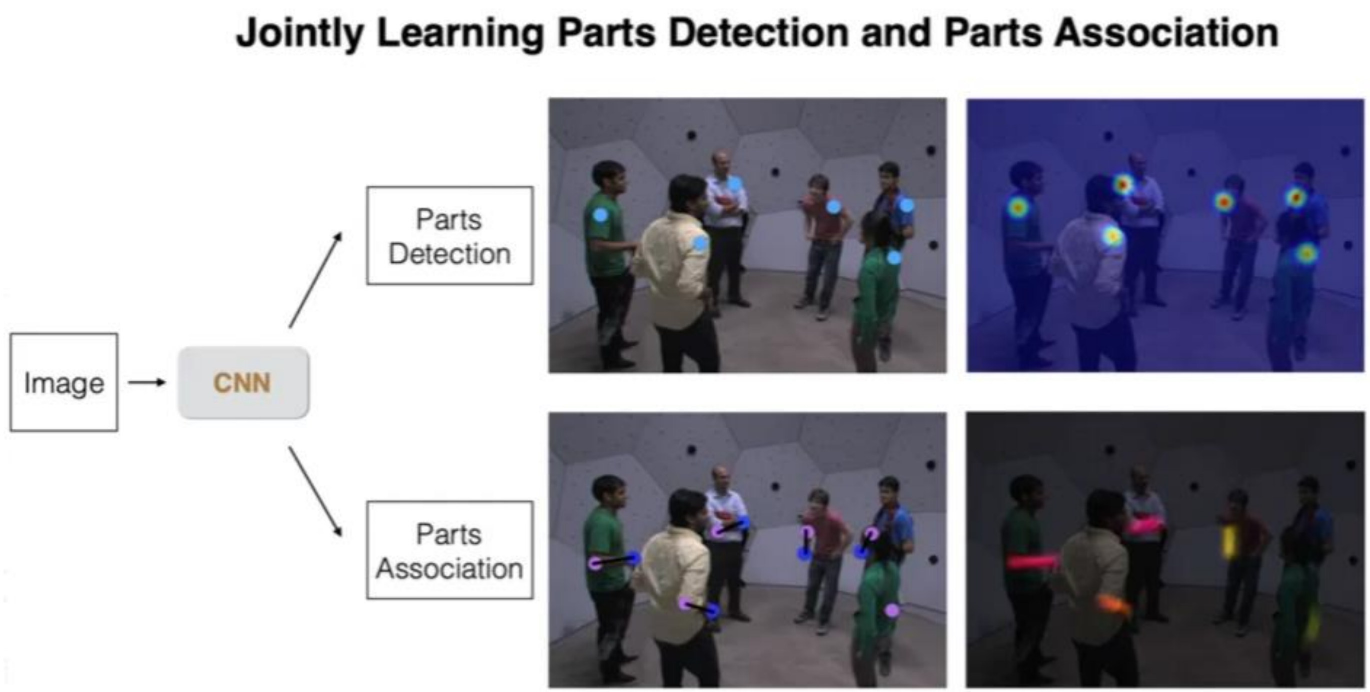
Body key-points dataset



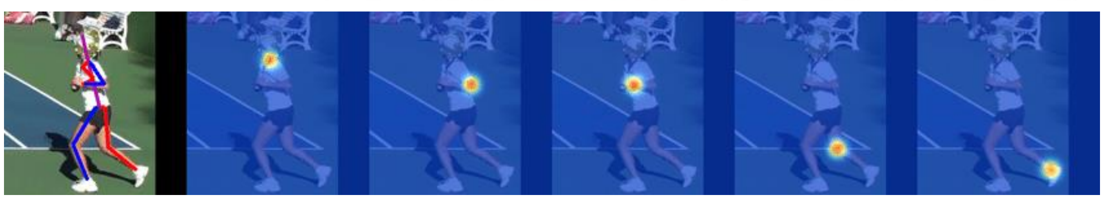
COCO-WholeBody, ECCV 2020

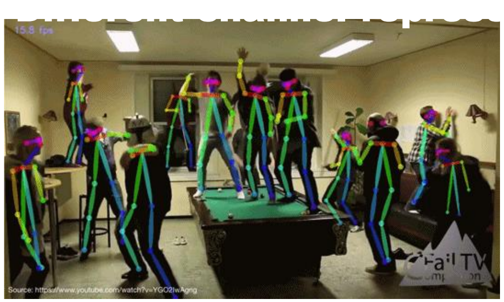
1. Labeled by real human
2. Huge data scale (For example, COCO-WholeBody has more than 200K image-label pair)
3. Train a deep learning model that predicts the joint position from the given image

Video-based motion capture



1. The network produces a heatmap of the joints
2. A confidence value also predicted





https://www.youtube.com/watch?v=C1Sxk6zxWLM

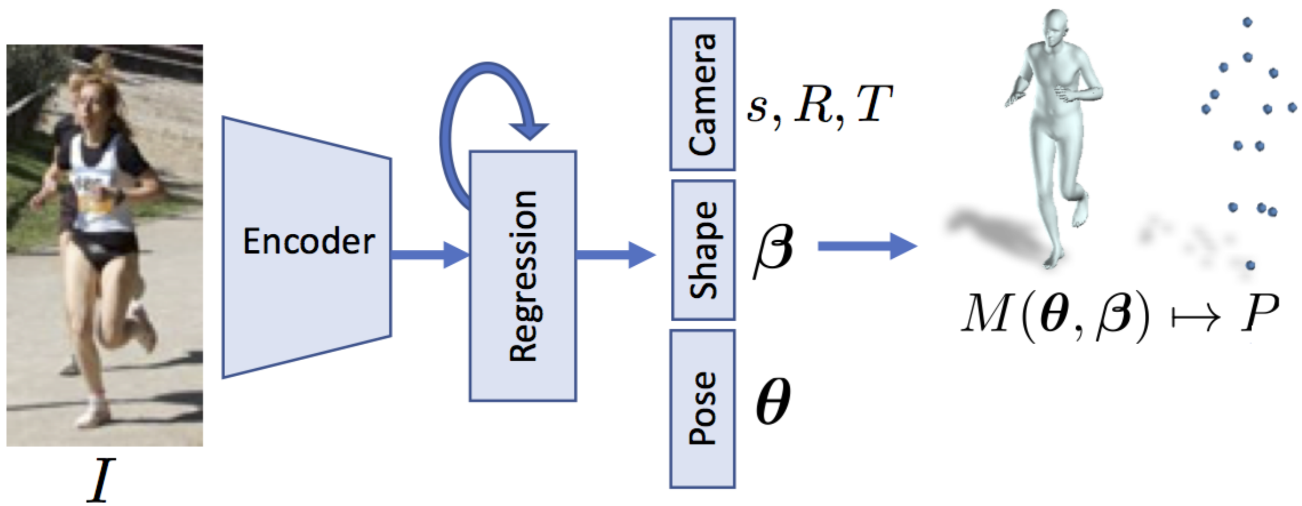
CVPR paper video

Real-time Multi-Person 2D Pose Estimation Using Part Affinity Fields

Zhe Cao, Tomas Simon, Shih-En Wei, Yaser Sheikh

Carnegie Mellon University

Video-based motion capture: 2D to 3D

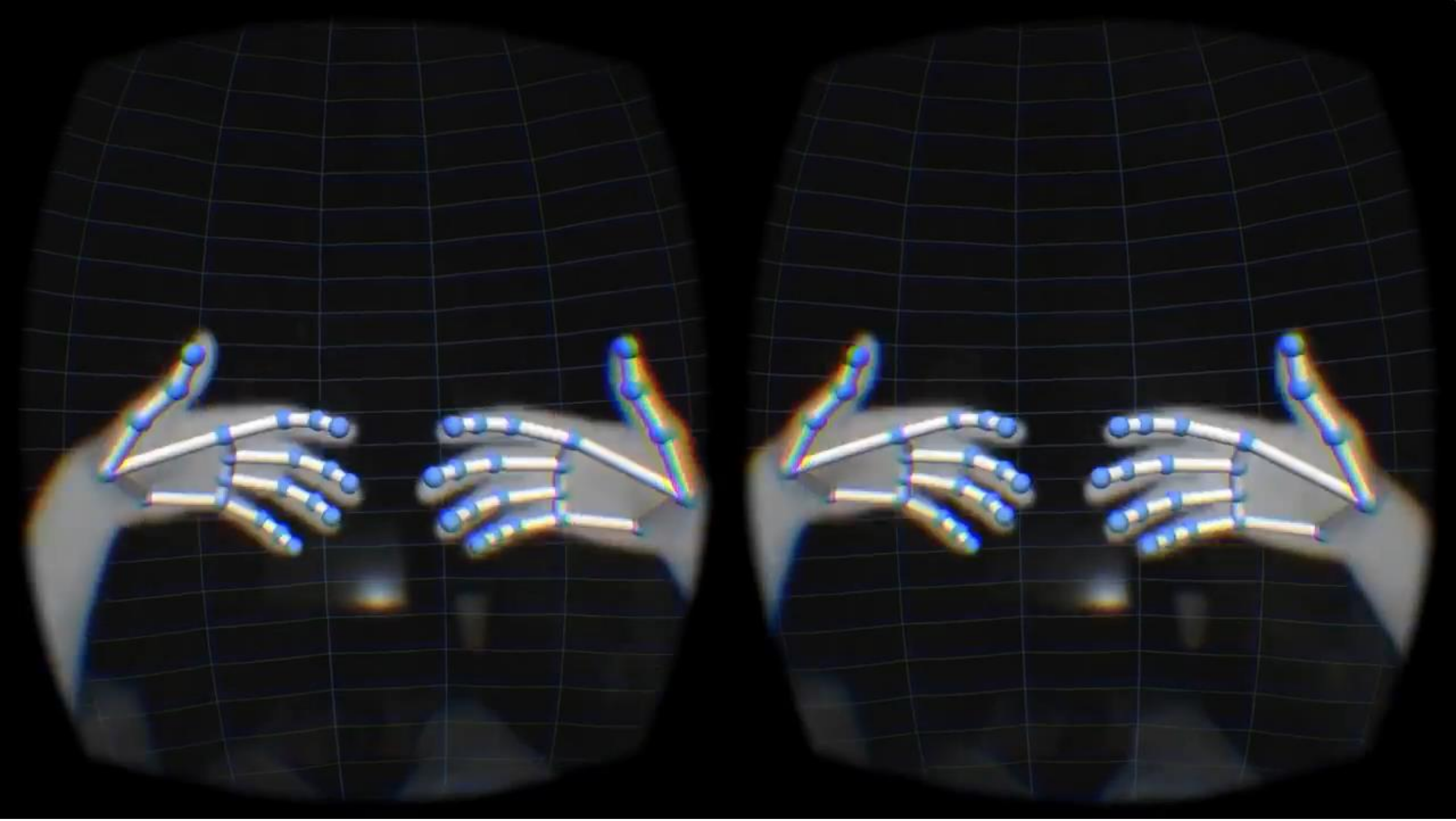


After predicting the 2D joint positions, the other parameters such as body shape, 3D pose, and camera parameters can be predicted

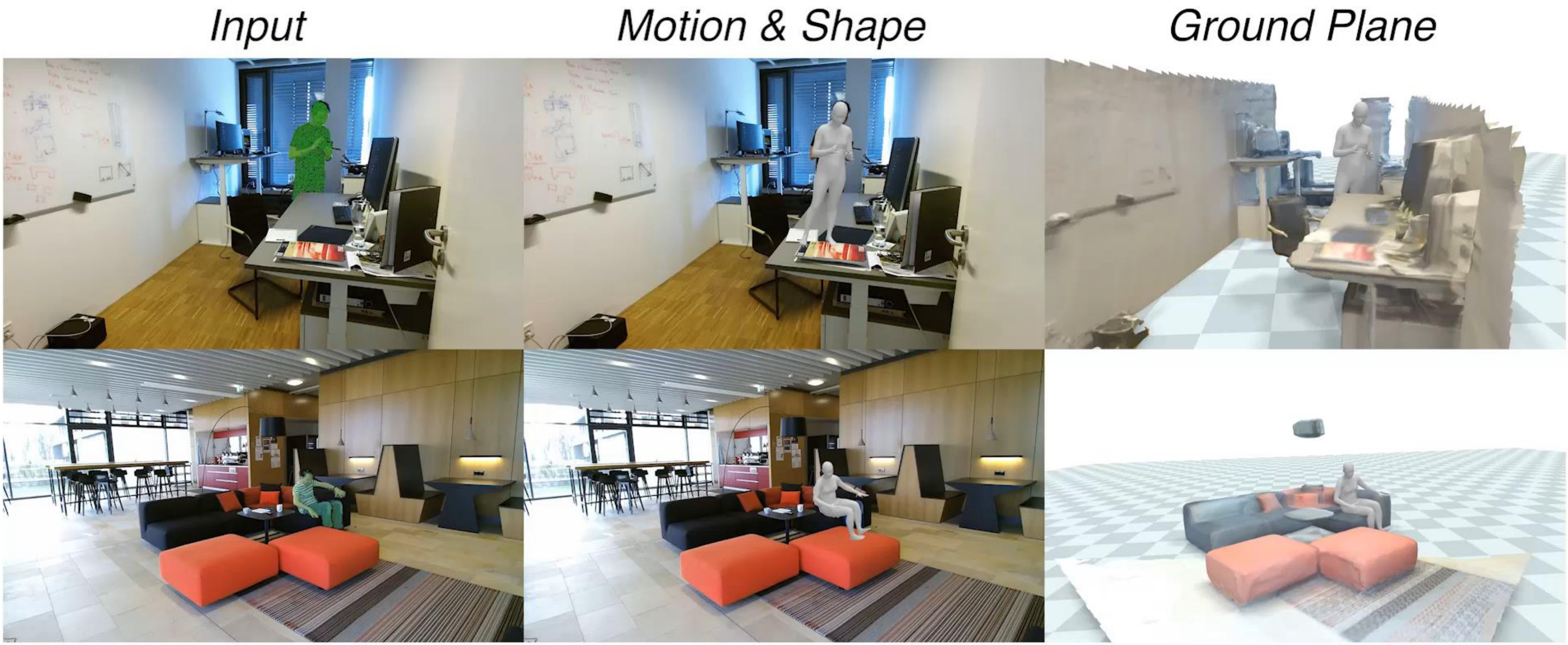
A 2D projected pose can be computed and a 2D loss can be computed


GLEN COVE
0
79% : run
32% : watch (a P)
6% : stand
50% : run
35% : carry (an O)
10% : jump
42% : run


HONDURAS
www.salsahonduras.com
SalsaHonduras
0
70% : dance
12% : watch (a P)
8% : hug (a P)
63% : dance
37% : watch (a P)
5% : stand



Oculus Quest



We can further consider a motion model trained with motion capture data to predict the poses while the body is occluded

Video-based Motion Capture Systems

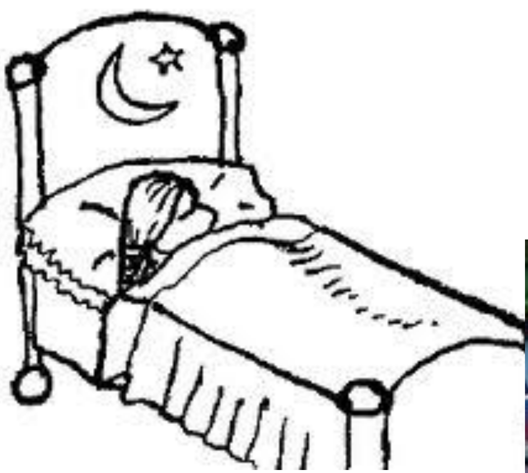
Advantages

- Require no expensive devices
- No markers/sensors required

Shortcomings

- Most methods cannot track the global body motion
- Accuracy still not high
- Many models assuming weak perspective projection

Which mocap system will be good for the following motions?



Summary

- Different mocap systems are appropriate for different movements
  - Optical mocap is the most popular system
  - Magnetic systems are good for capturing close interactions but the capture volume is small
  - Inertia-based systems show more flexibility for the users
  - Video-based motion capture is becoming better and better – can expect more improvement for practical usage soon.

Character Animation

- There are three methods
  - –Create them manually
  - –Use real human motion
  - –Use physically based simulation

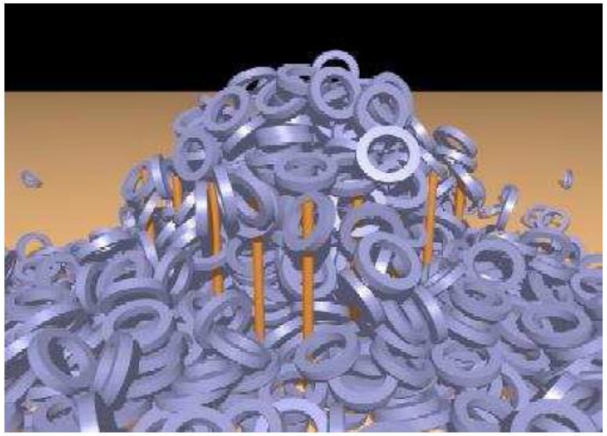


Overview

- Physically-based animation
  - Using Newton Physics to simulate events
  - Applicable to human animation
- Methods based on
  - Forward dynamics
  - Inverse dynamics
- Forward dynamics – need to decide torque
  - PD control

Physically-based animation

- Using Newton's laws of dynamics to simulate various phenomena
  - Drop objects in the scene, and let them collide and see what happens
  - Blowing hair by a dryer
  - Controlling bodies by force/torque

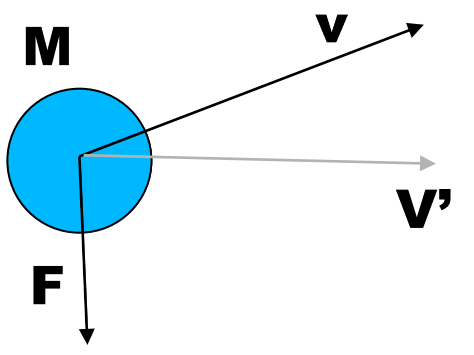
Newton's Law of Dynamics

F = M a

F : force

M : mass

a : acceleration



Given the force F,

calculate the acceleration by a = F / M

then integrate

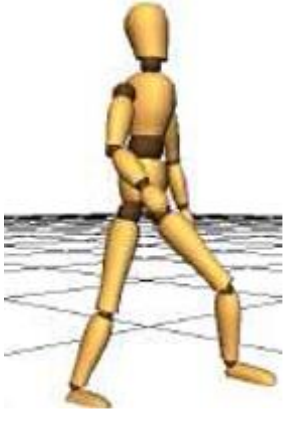
$$\mathbf{v} = \mathbf{v}' + \mathbf{a}\Delta t$$

$$\mathbf{x} = \mathbf{x}' + \mathbf{v}\Delta t$$

Newton's Law of Dynamics

- For multi-body objects like human bodies, it is a bit more complex

$$\boldsymbol{\tau} = \mathbf{H}\,\ddot{\mathbf{q}} + \mathbf{C}(\mathbf{q}, \dot{\mathbf{q}}) + \boldsymbol{\tau}_g$$



$\mathbf{q}, \dot{\mathbf{q}}, \ddot{\mathbf{q}}$: generalized coords, velocity, acceleration

$\boldsymbol{\tau}$: force, or torque made at the joints

- $\mathbf{H}$: Mass matrix, $\mathbf{C}(\mathbf{q}, \dot{\mathbf{q}})$ Coriolis force
- $\boldsymbol{\tau}_g$: gravity

Forward vs. Inverse Dynamics

Inverse Dynamics

- The calculation of forces given a set of accelerations

Forward Dynamics

- The calculation of accelerations given a set of forces

$$\boldsymbol{\tau} = \mathbf{H}\,\ddot{\mathbf{q}} + \mathbf{C}(\mathbf{q}, \dot{\mathbf{q}}) + \boldsymbol{\tau}_g$$

Using Forward Dynamics for Human Animation: **Problem:** How do we decide the internal force?

- *Must decide how the muscles exert force*
  - *Passive motions*
    - *Falling down (No force or torque, rag-doll)*
    - *pushed and stepping back*
  - *Voluntary motions → Walking, Running*

Passive motions - *Rag doll physics*

- *The body just falls down powerlessly*
- *No active force exerted by the muscles*
- *Some passive force*
  - *elastic force by the ligaments and muscles*

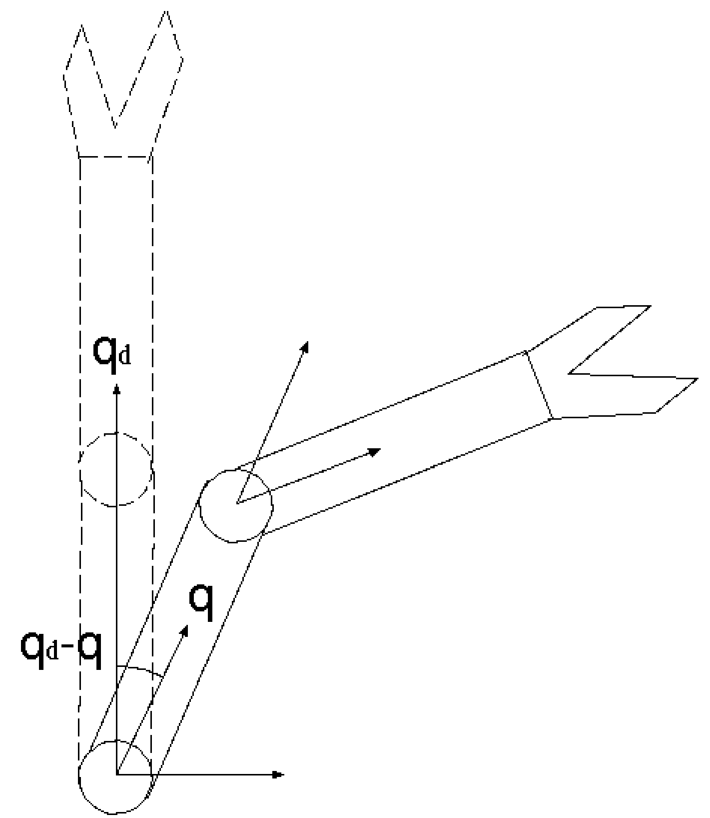
Voluntary motions

- Motions like walking, running, reaching
- Humans control the body by exerting force by the muscles
- To simulate such motions, need to determine the torque
  - PD control
  - More complex control methods (optimal control, evolutionary control, reinforcement learning etc.)

PD control : Introduction

- A method used in robotics
- The larger the difference between the current state and the desired state, the larger the force/torque is

$$\boldsymbol{\tau} = a(\mathbf{q} - \mathbf{q}_d) + c(\dot{\mathbf{q}} - \dot{\mathbf{q}}_d)$$



a, c : constants,

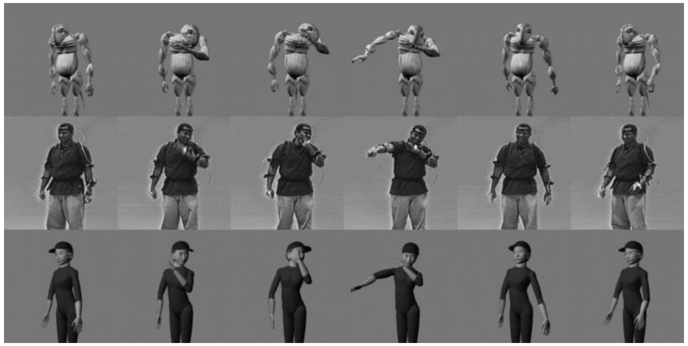
q , q' : current state/velocity

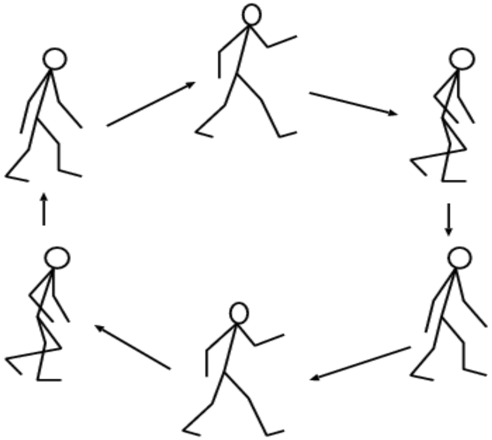
$\mathbf{q}_d$, $\dot{\mathbf{q}}_d$: desired state/velocity

Voluntary motions by PD control

- Prepare a number of keyframes
- Compare the current state of the avatar and the keyframes (desired state)
- Apply torque proportional to the difference of the current state and the target state

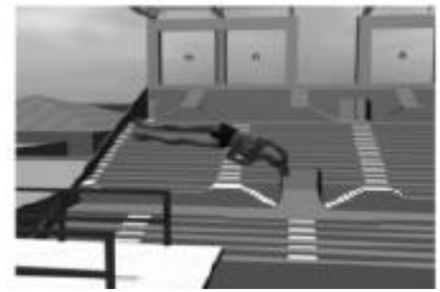
Switch the desired state once the body is close enough to it





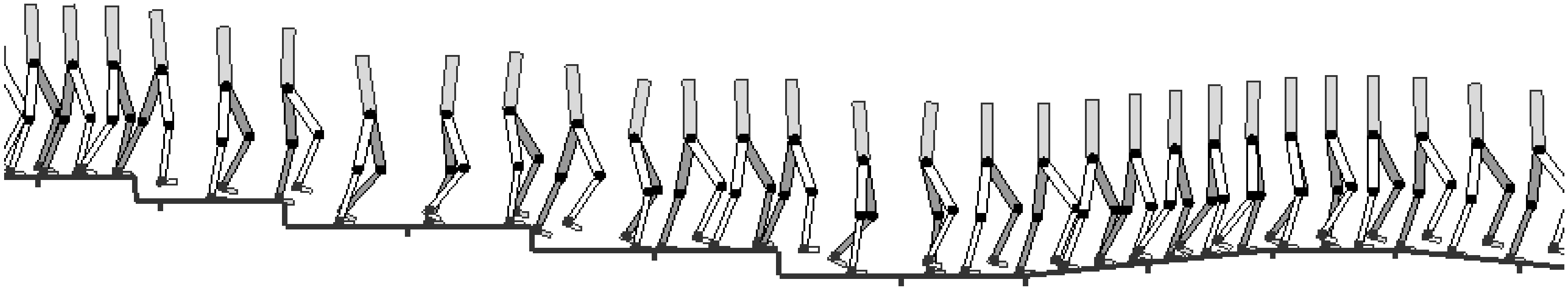
Simulating Athlete's Motions

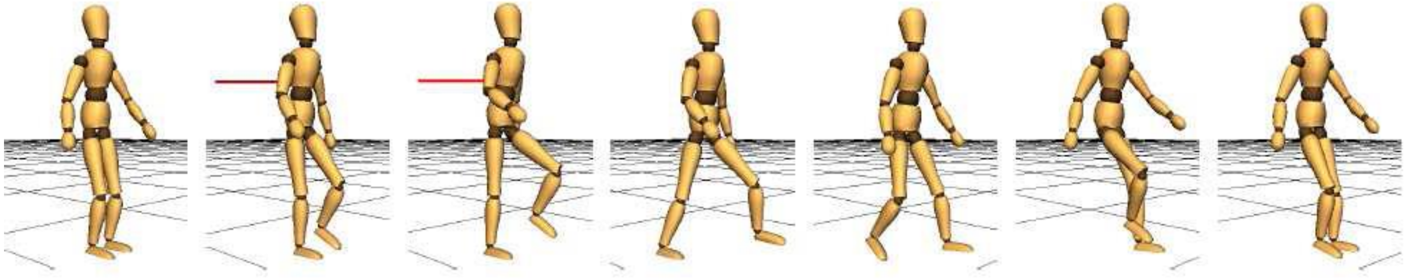
- Diving
- Running
- Cycling



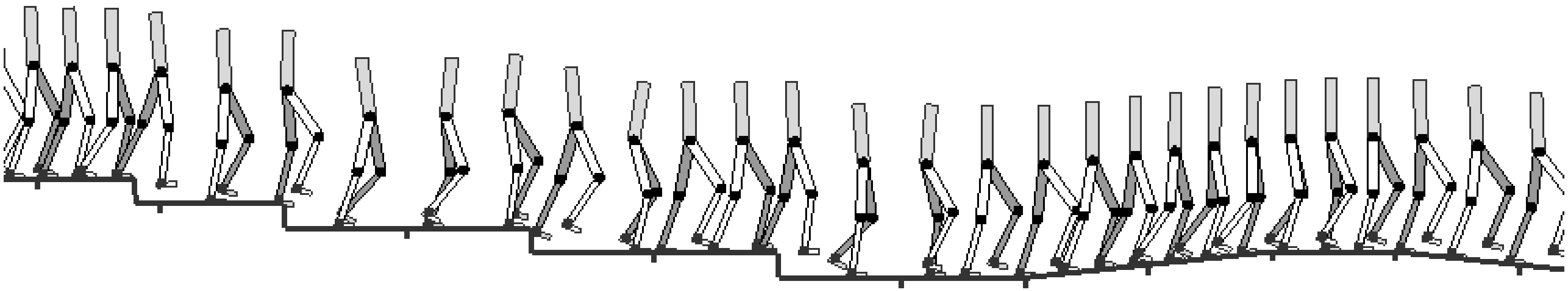
SIMBICON (Yin et al. 2007)

- A good PD controller-based biped locomotion controller
- Extra ideas for keeping the body well balanced

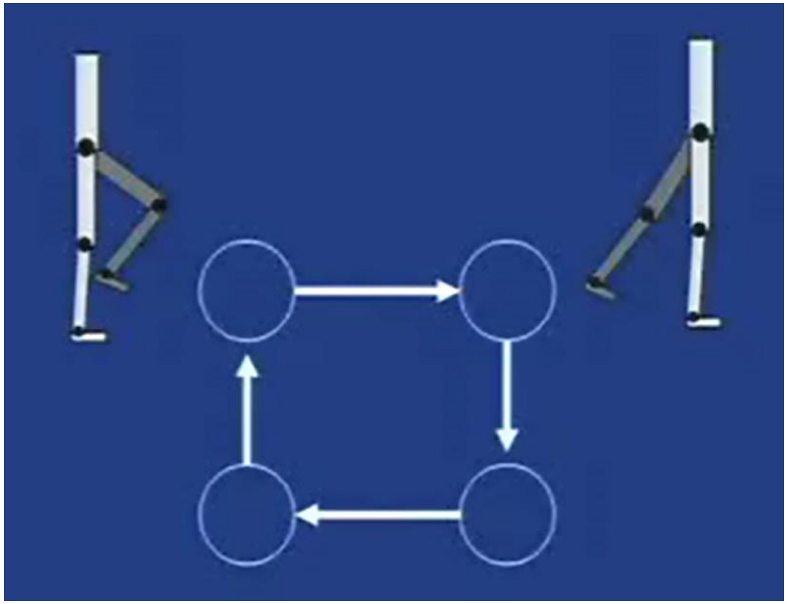




SIMBICON (Yin et al. 2007)



- PD targets: the keyframes for computing the torques: 4 targets for walking, 2 for running

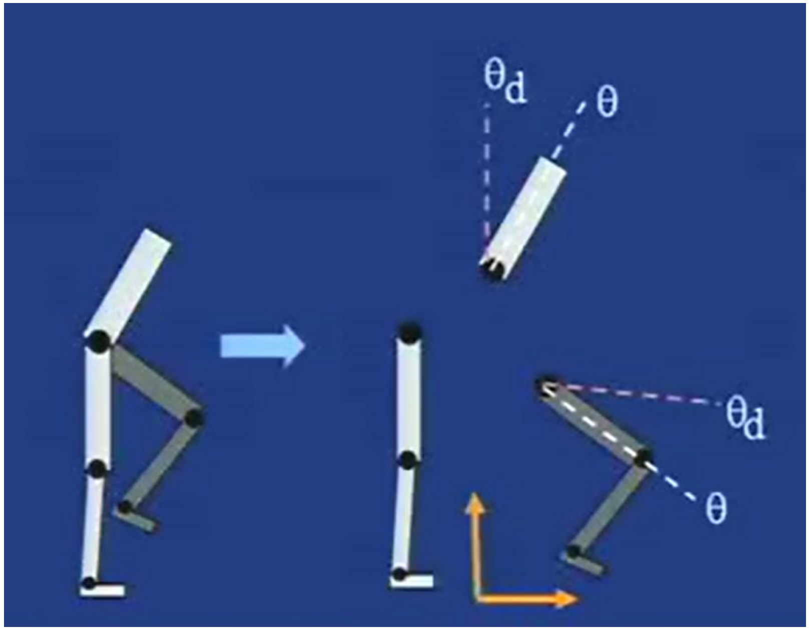


SIMBICON

Tip 1.

Some PD targets in the world space

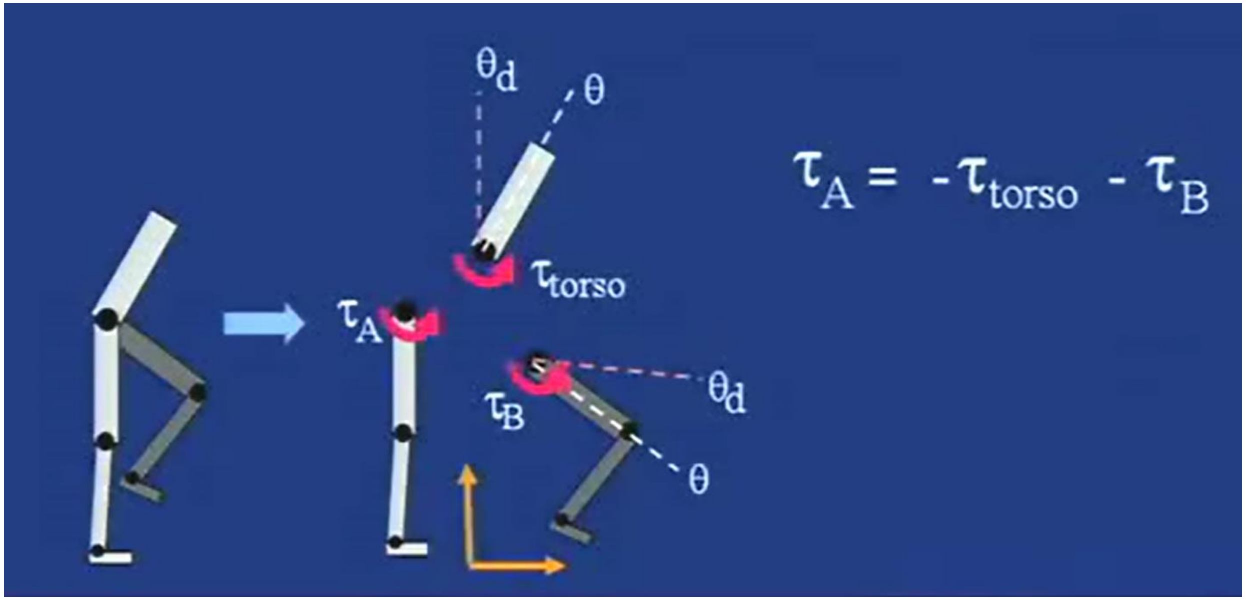
- The upright orientation of the torso
- The swing hip



SIMBICON

Tip 2.

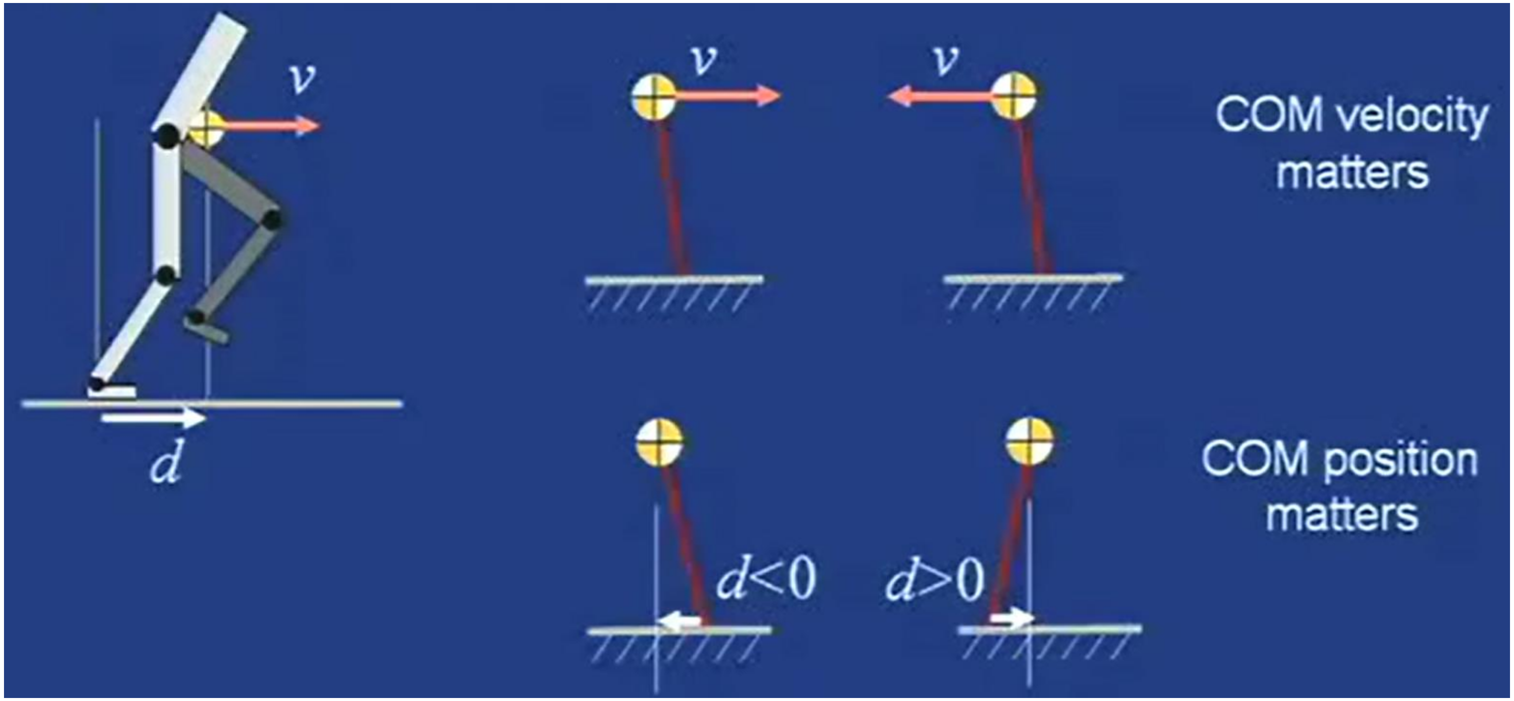
The relationship of the torque between the hips and torso follow Newton's law



SIMBICON

Tip 3.

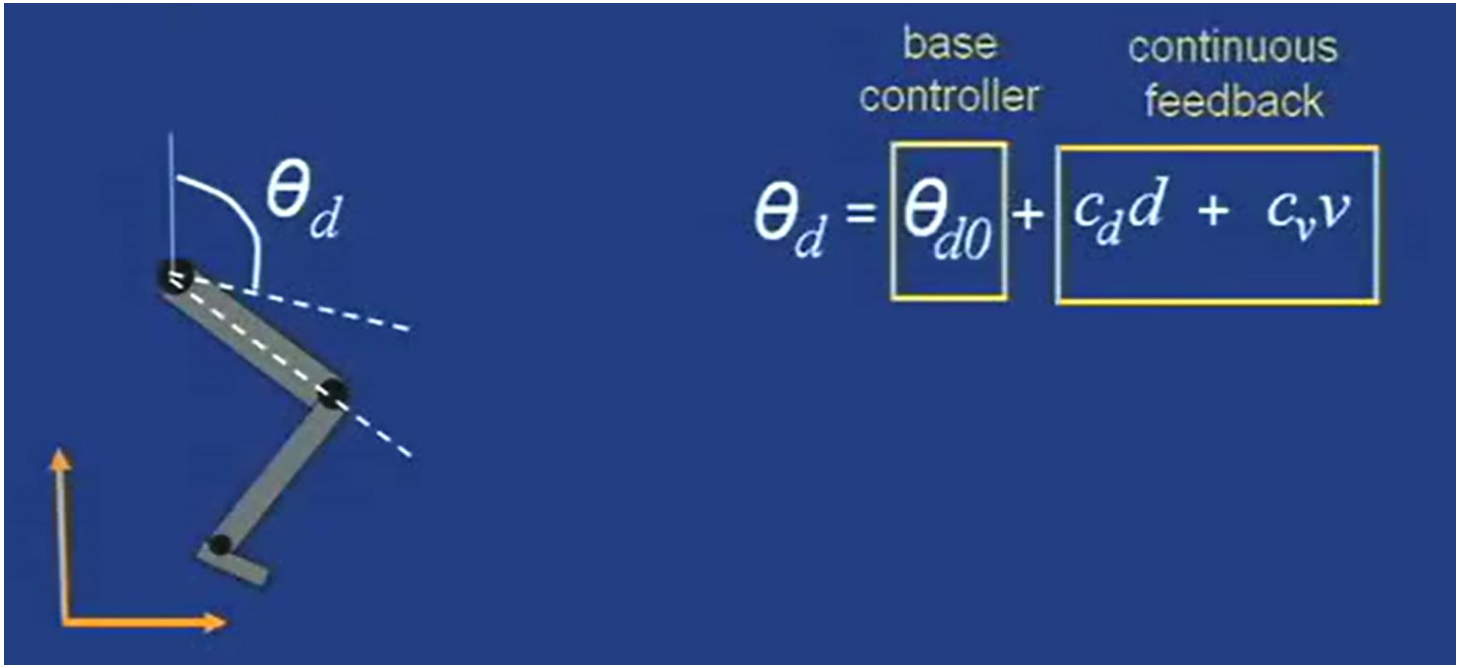
Adjusting the stepping leg/supporting leg according to the center of mass



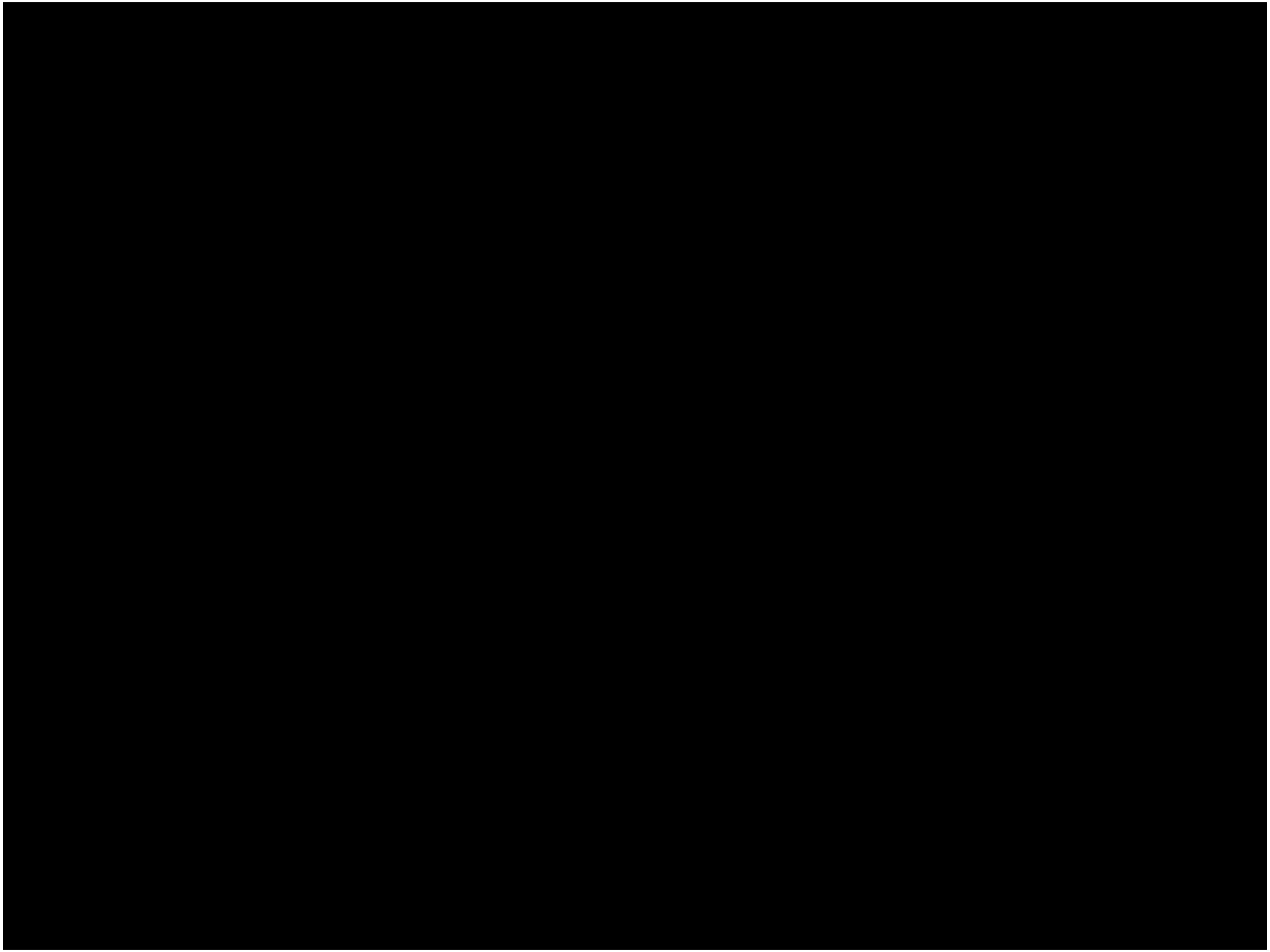
SIMBICON

Tip 3.

Adjusting the stepping leg/supporting leg according to the center of mass

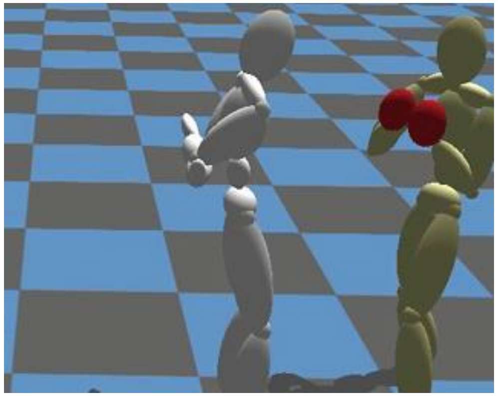


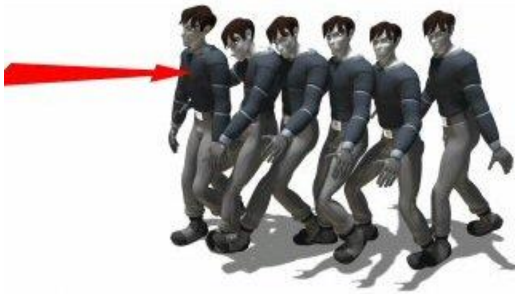
SIMBICON : Demo video



Response Motion by PD control

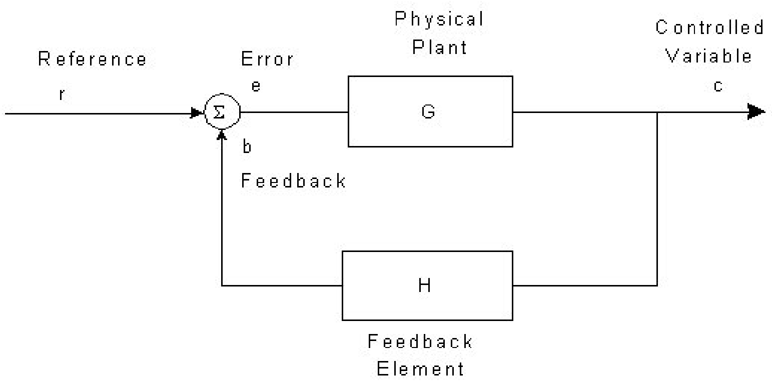
- Moving back to the original motion when perturbed
  - Feedback control
- Keeping balance or falling back

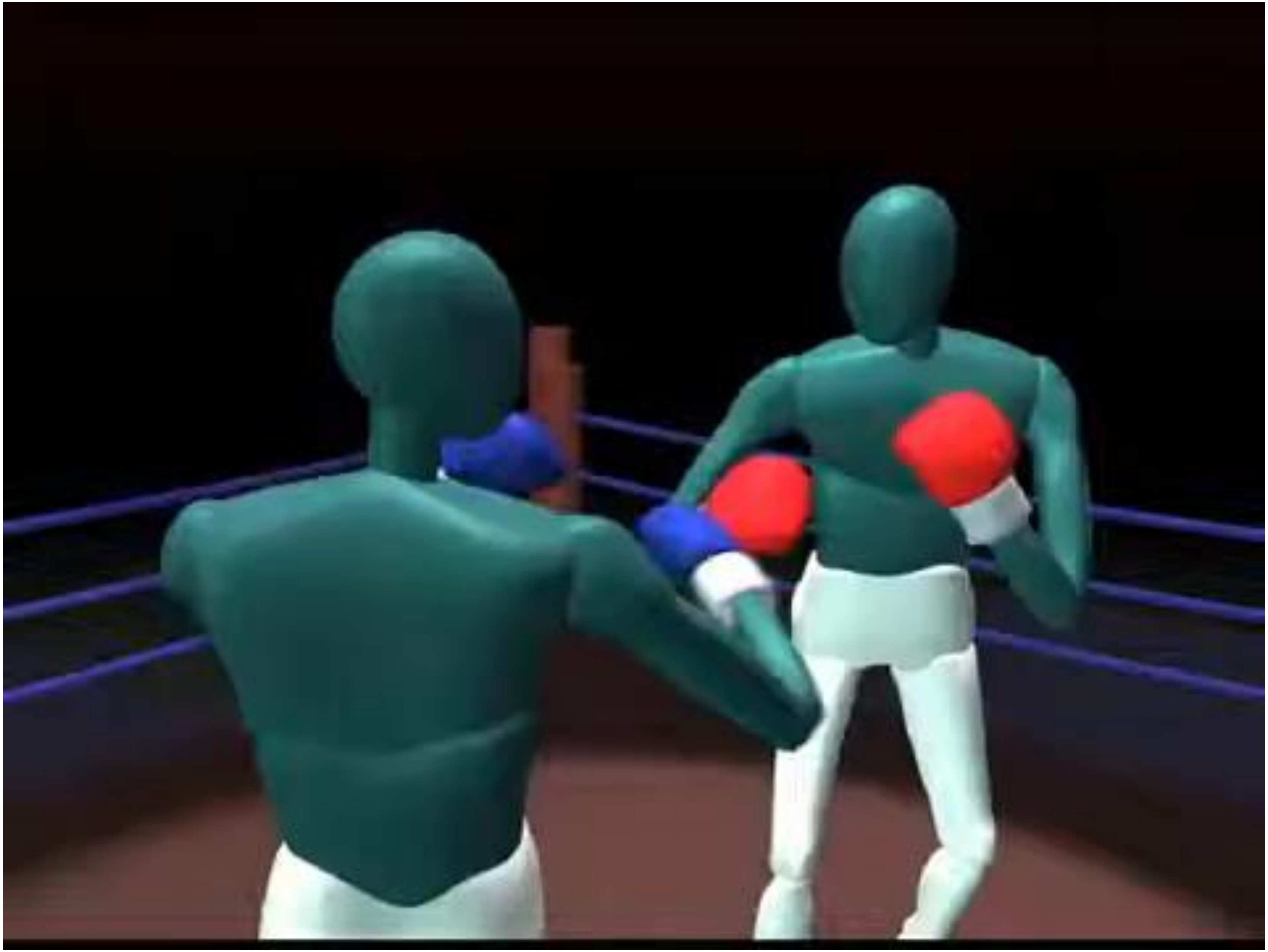




Feedback Control

- Moving back to the original posture / motion when perturbed





PD control : Difficulty

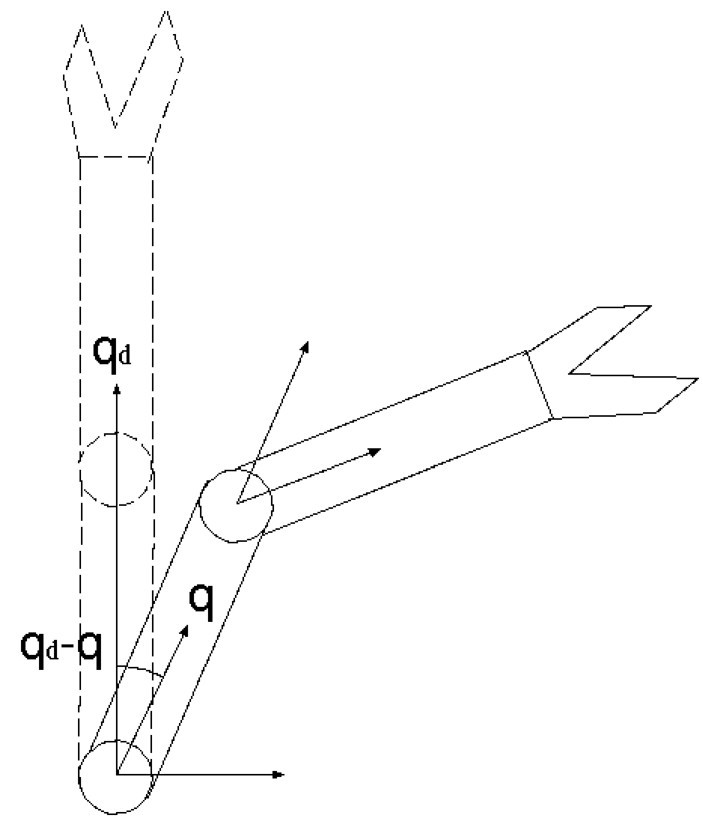
- Parameter tuning not easy

$$\boldsymbol{\tau} = a(\mathbf{q} - \mathbf{q}_d) + c(\dot{\mathbf{q}} - \dot{\mathbf{q}}_d)\ ))$$

a, c : constants,

q , q' : current state/velocity

$\mathbf{q}_d$, $\dot{\mathbf{q}}_d$: desired state/velocity



Quick Quiz again

- Which method to solve the following problem?
- Find how fast you can break dance?
- Find how much forces are made by your muscles when punching?
- Produce an animation of falling down
- Produce an animation of hopping

Readings

Skeletal Parameter Estimation from Optical Motion Capture Data
Adam G. Kirk et al.
IEEE Conf. on Computer Vision and Pattern Recognition (CVPR) 2005.

Automatic Joint Parameter Estimation from Magnetic Motion Capture Data James F. O'Brien
Robert E. Bodenheimer, Jr. Gabriel J. Brostow Jessica K. Hodgins, GI2001
http://www.cc.gatech.edu/gvu/animation/Papers/obrien:2000:AJP.pdf

Motion capture
Sang Il Park, and Jessica K. Hodgins: Capturing and Animating Skin Deformation in Human Motion, *ACM Transactions on Graphics*, 25(3): 881-889 (2006)

Angjoo Kanazawa – video-based mocap https://people.eecs.berkeley.edu/~kanazawa/

Response motion
•Zordan, V. B., Hodgins, J. K., Motion capture-driven simulations that hit and react, ACM SIGGRAPH/Eurographics Symposium on Computer Animation, 2002, pp. 89-96.
•Zordan, V. B., Majkowska, A., Chiu, B., Fast, M., Dynamic Response for Motion Capture Animation , ACM SIGGRAPH 2005.
•Pushing People Around Okan Arikan David Forsyth James O'Brien
Symposium on Computer Animation (SCA) 2005

Locomotion
Raibert, Hodgins, Animation of Dynamic Legged Locomotion, SIGGRAPH'91
Jack Wang et al. Optimizing Walking Controllers for Uncertain Inputs and Environments, SIGGRAPH 2010

SIMBICON: https://www.cs.ubc.ca/~van/papers/Simbicon.htm