Computer Graphics

10 - Character Animation

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Outline

- Introduction to Character Animation
- Skeletal Animation
- Forward Kinematics
- Creating Character Animation
- BVH File Format

Traditional, Hand-Drawn, Cel Animation

Animation by Milt Kahl (Walt Disney Studios)

Animation by Marc Davis (Walt Disney Studios)

Animation by Mark Henn (Walt Disney Studios)

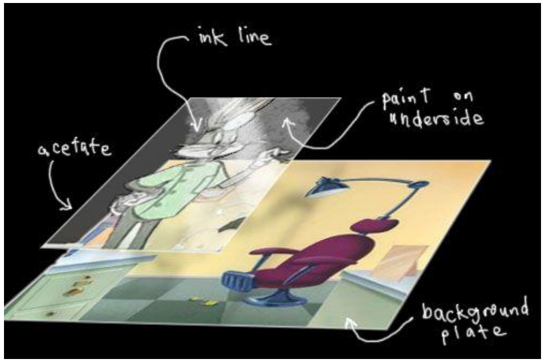
Animation by Milt Kahl (Walt Disney Studios)

* These images are from https://www.wnyc.org/story/sideshow-classic-disney-pencil-animations-come-life-gifs/

Traditional, Hand-Drawn, Cel Animation

- A *key animator* draw *key frames*.
- *Assistant animators* adds missing frames and details.
  - "inbetweening"
- Ink-and-paint, cel overlay, photography
- Labor-intensive process.

Peter Pan, 1953



Computer-Assisted Animation

- Cel painting with computers
  - Digitalized line drawing
  - Coloring using computer software
  - No need to take pictures frame by frame
  - Drawing-based 2D computer animation

The Lion King, 1994

Computer-Generated Animation

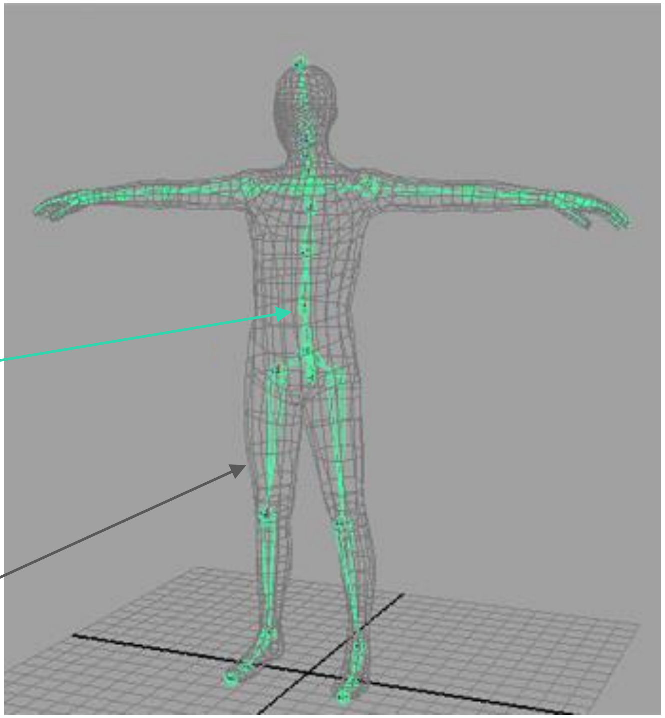
- Generating images by "rendering" 3D objects.
  - Modeling 3D objects or characters and giving them "motion".
  - 3D computer animation.
  - Today, most animations are made with this method.

Encanto, 2021

Computer-Generated Character Animation

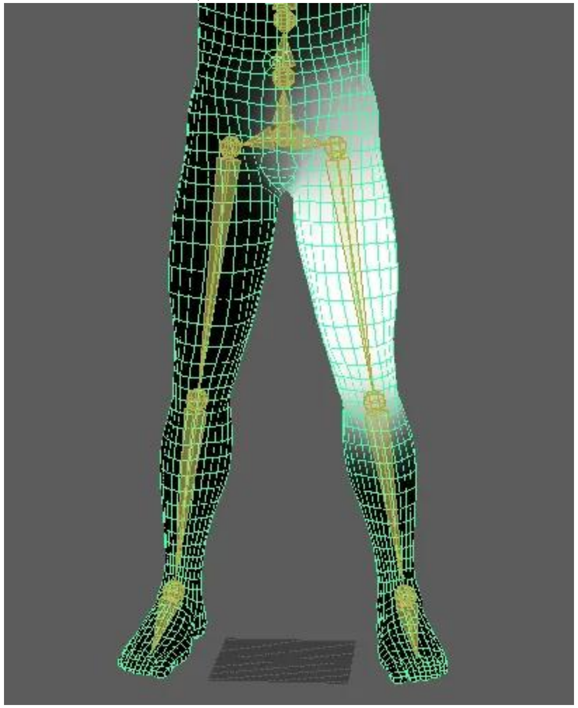
- For character animation,

- *Skeletal animation* is the most popular, which consists of:
  - *Skeleton*: Bone or joint hierarchy and related data
  - *Motion:* Joint movement data
  - *Skin (or mesh)*: Surface representation for rendering the character

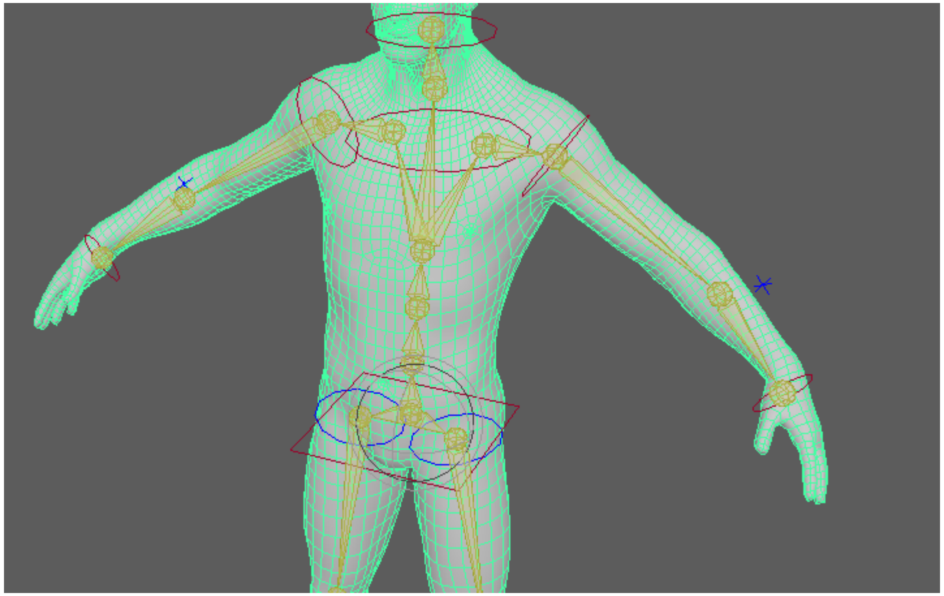


Visualizing Character in Skeletal Animation

- *Skin* can be deformable mesh(es)
  - *Skinning*: "Embedding" a skeleton into skin mesh (Details will be skipped).



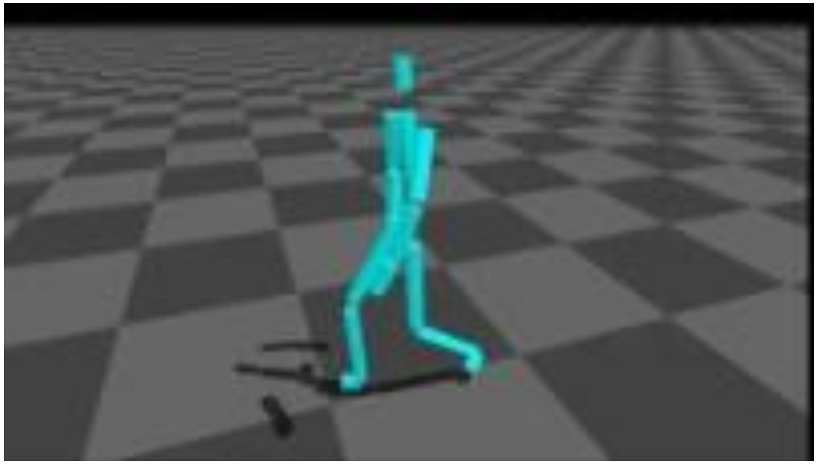
A human thigh with simple **skin weights** painted onto it



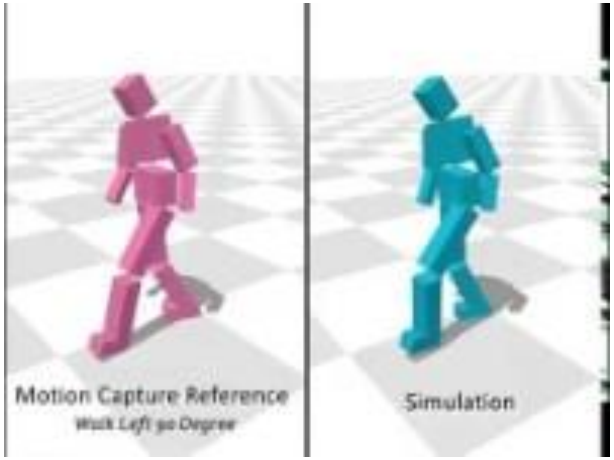
- These images are from https://gamedevinsider.com/making-games/rigging-and-skinning/

Visualizing Character in Skeletal Animation

- or *skin* can be separate "rigid" meshes.



https://youtu.be/PEhyWI8LGBY



https://youtu.be/hpeqxc_1vwo

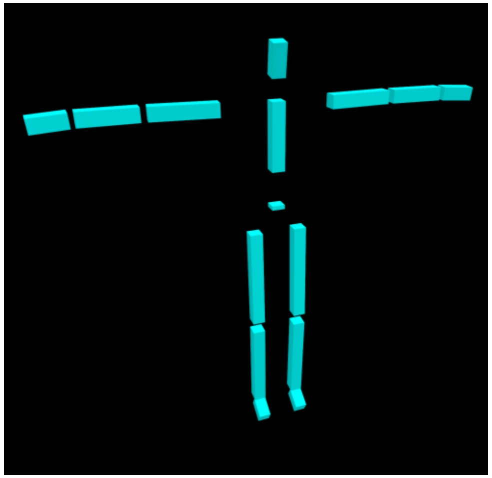
- Today's lecture focuses on "hierarchical structure" and "motion" in skeletal animation, not visualizing a character.

Skeletal Animation

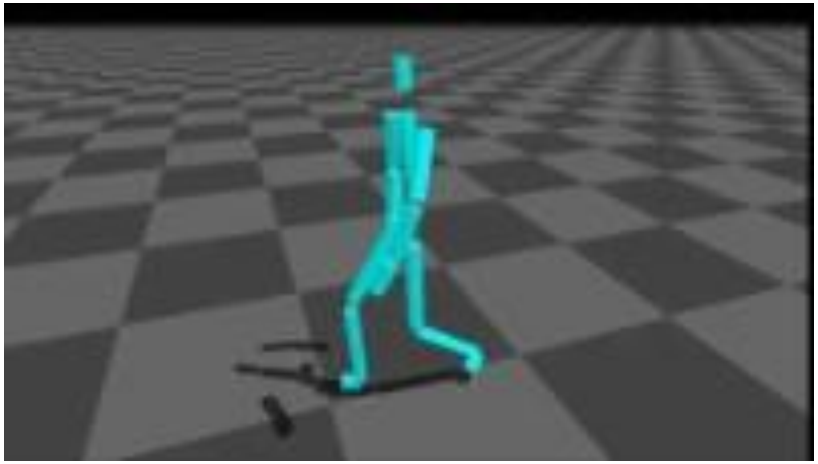
Skeletal Animation

- Skeletal animation consists of two parts:

- "*Skeleton*": static data



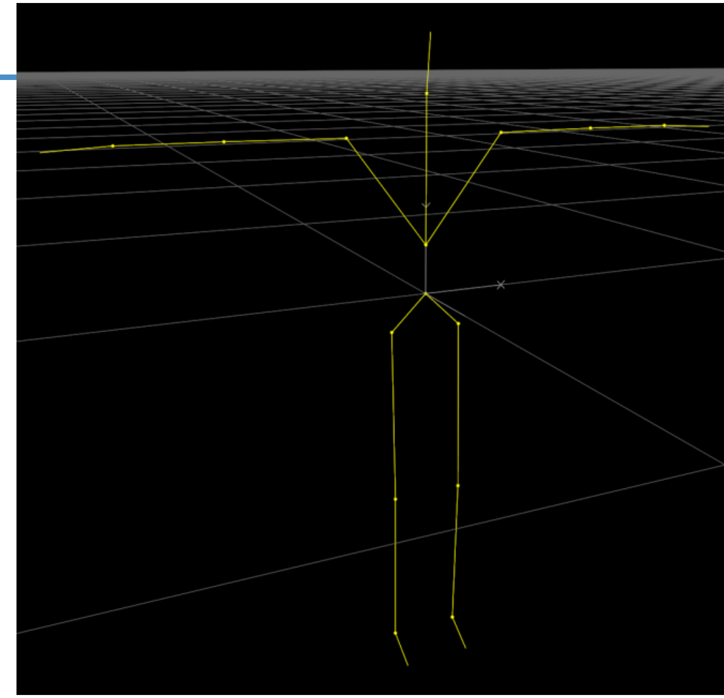
- "*Motion*": time-varying data

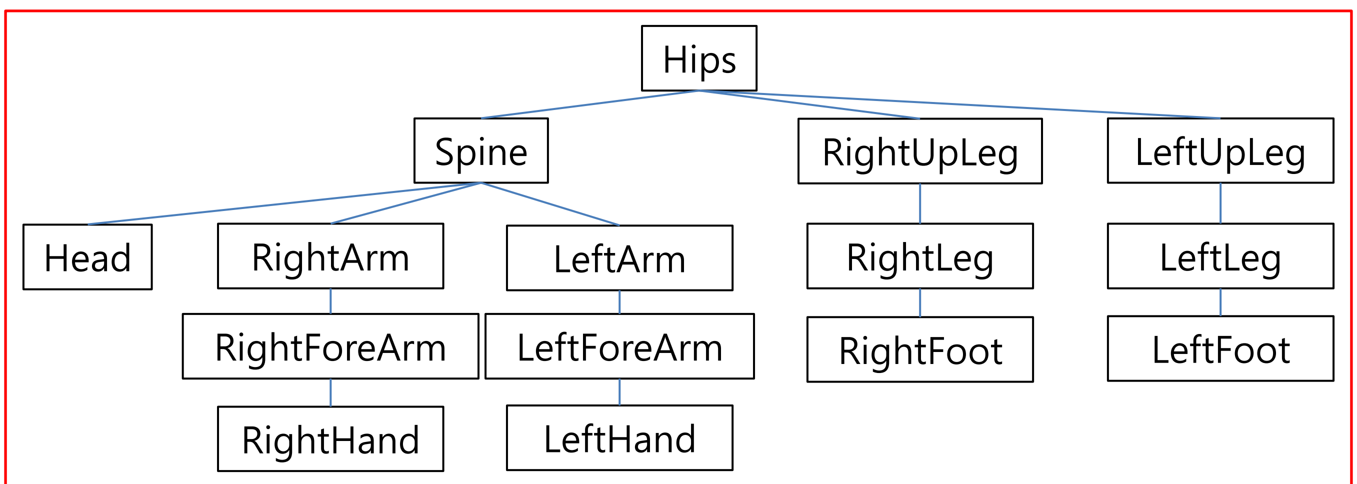


https://youtu.be/PEhyWI8LGBY

"Skeleton" Part

- "*Skeleton*": static data
  - joint hierarchy
  - joint offset from its parent joint
    - w.r.t. parent frame
    - usually translation





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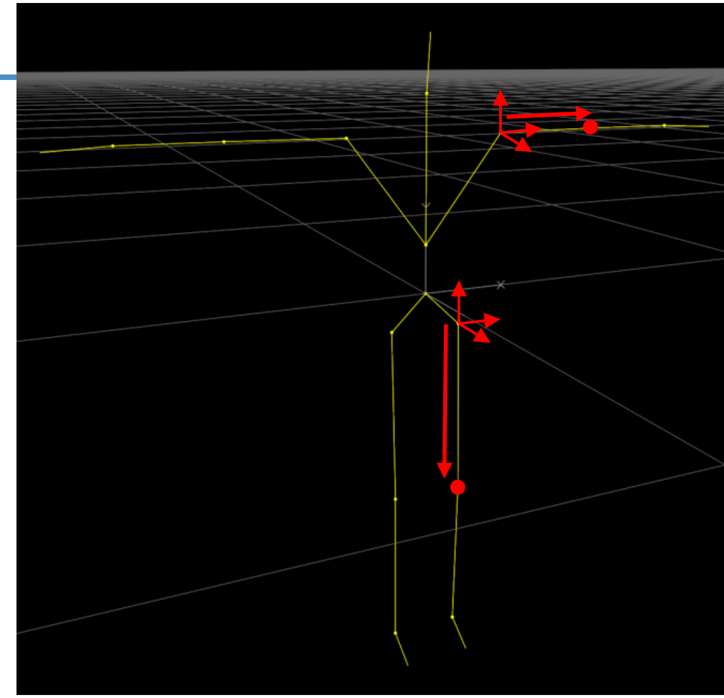
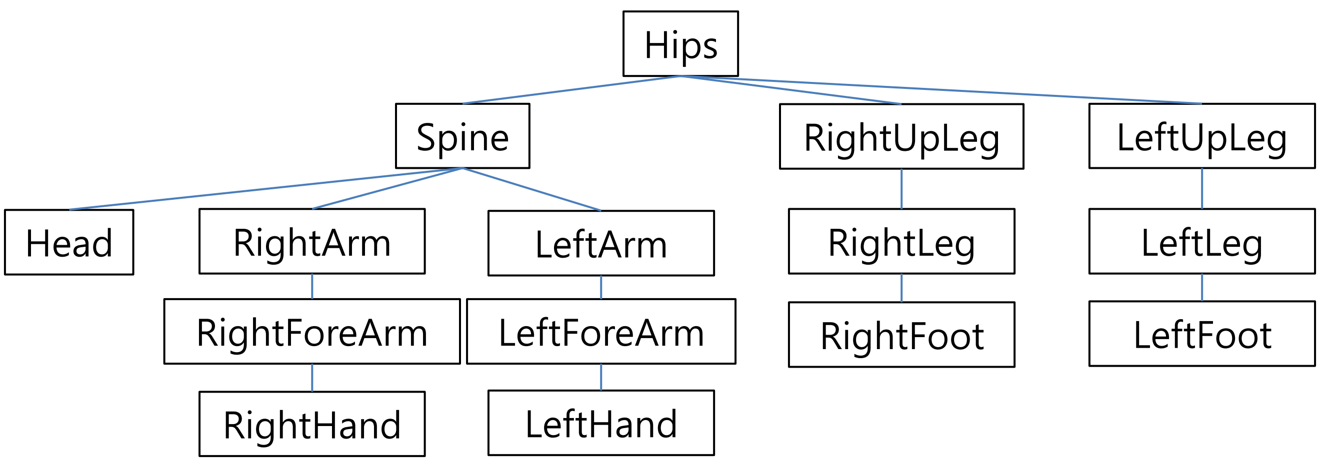
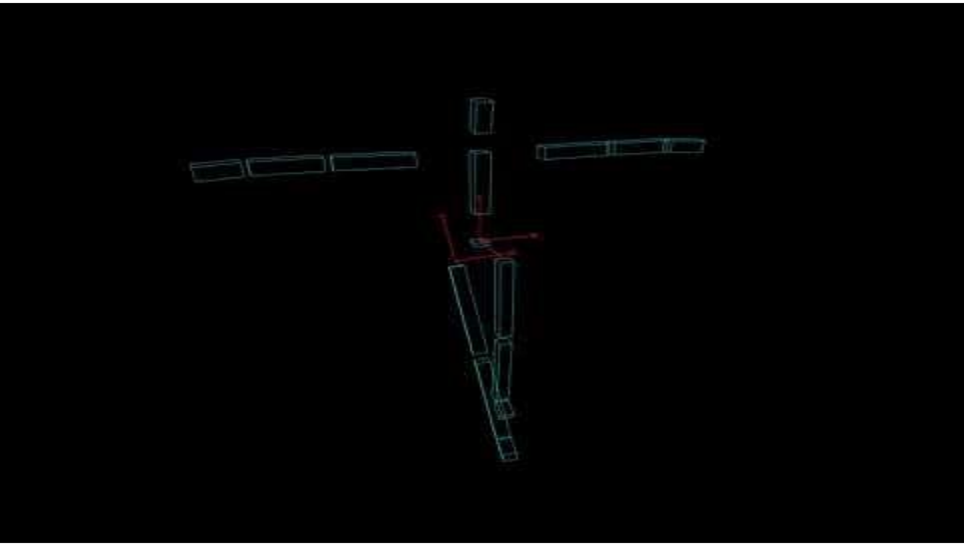
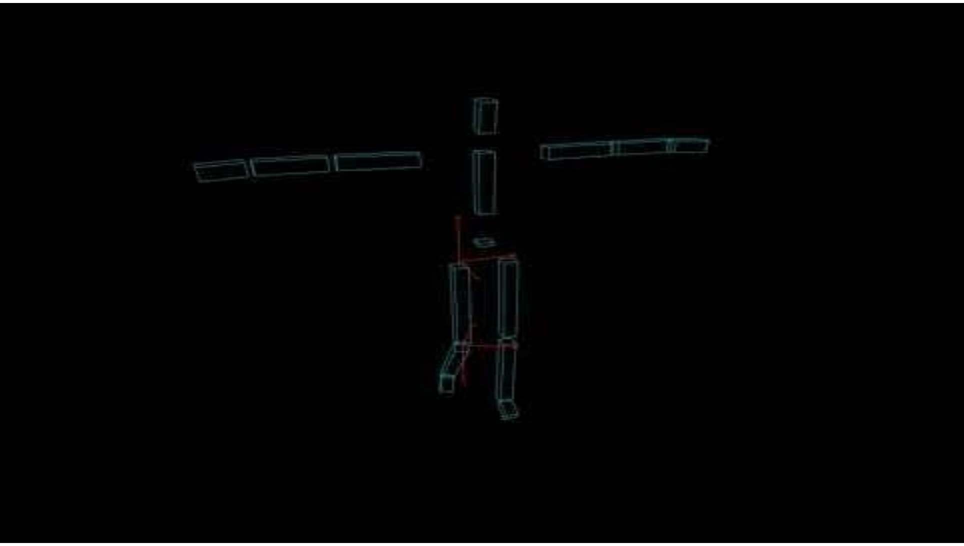




Recall: Hierarchical Model - Human Figure



https://youtu.be/Q7lhvMkCSCg

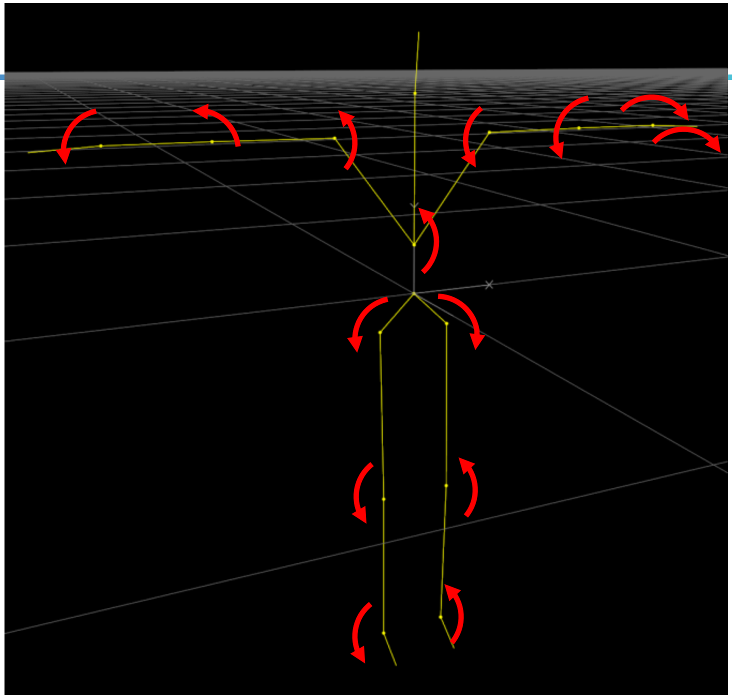


https://youtu.be/Q5R8WGUwpFU

- Each part's movement is described w.r.t. its parent's frame.
- → Each part has its own transformation w.r.t. parent's frame.
  - **Static** transformation: **joint offset**
  - **Time-varying** transformation: **"motion"**

"Motion" Part

- "*Motion*": time-varying data
  - movement of internal joints
    - w.r.t. default frame of each joint
      - the frame after applying joint offset to the parent frame
    - usually rotation
  - (translational and rotational) movement of skeletal root
    - w.r.t. world frame
    - usually the pelvis part



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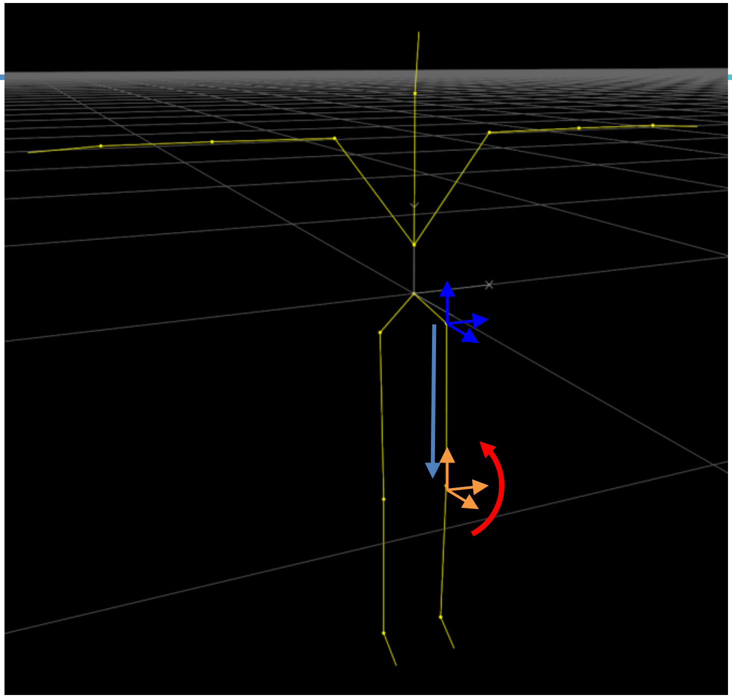
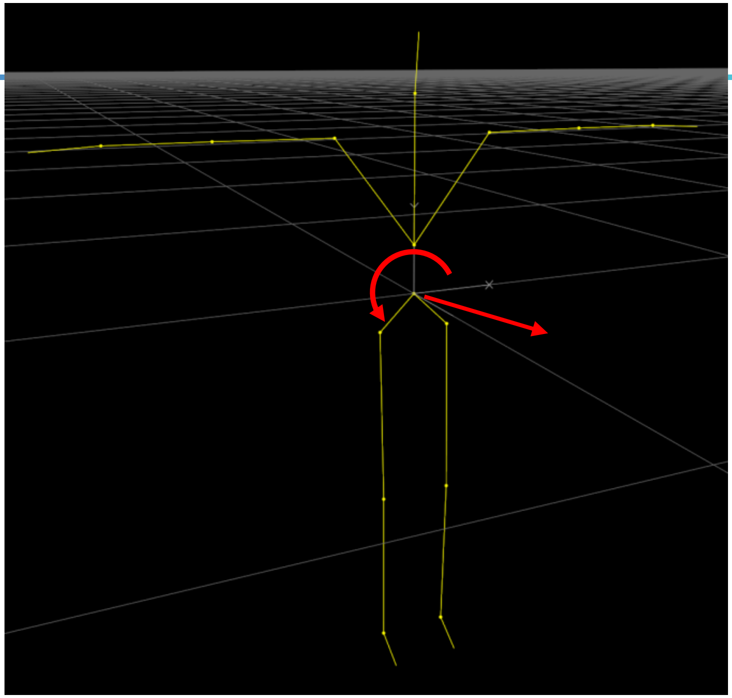


"Motion" Part



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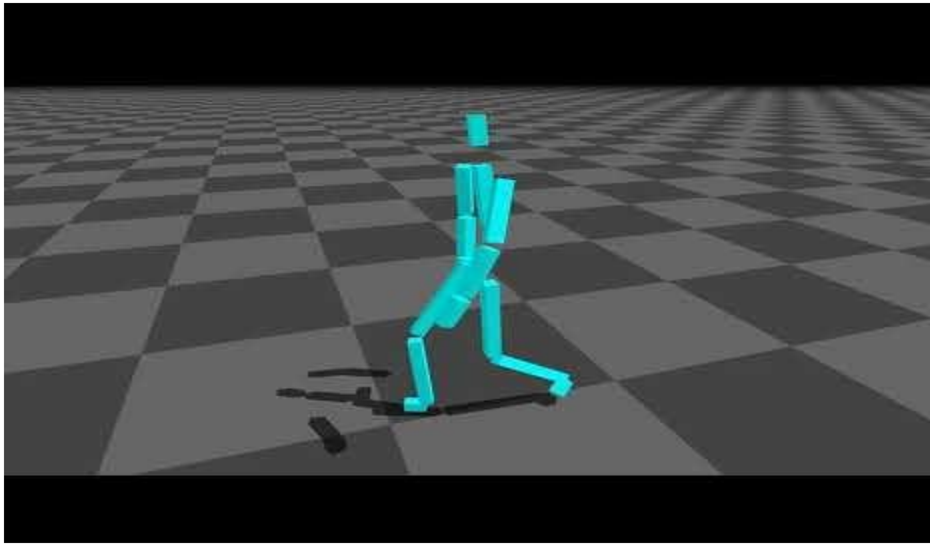
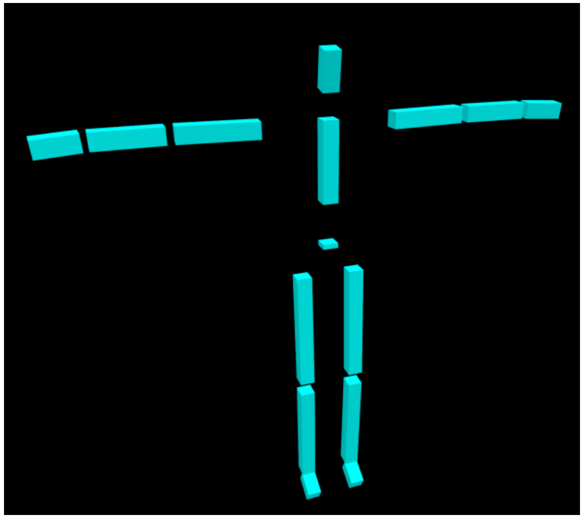
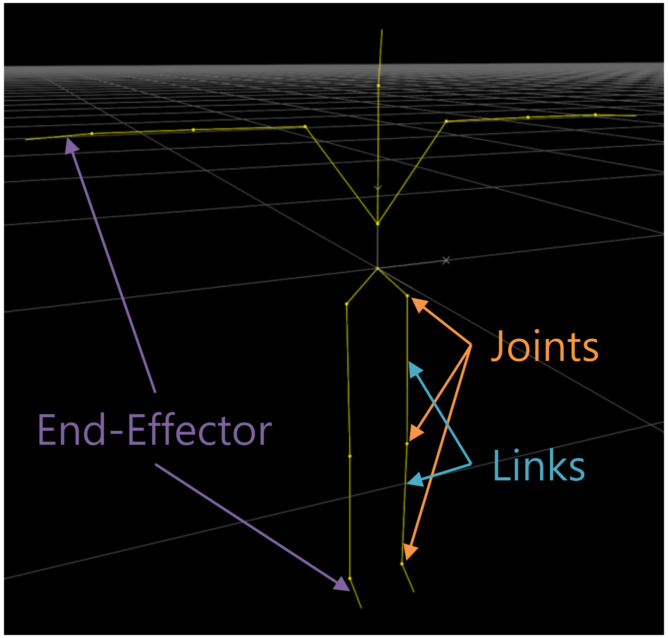


https://youtu.be/PEhyWI8LGBY

Terminologies

- ***Posture (pose)***: *"motion"* at a single frame
- ***Rest pose***: a pose where all joint movements are "zero"
- ***Joint*** - a connection between two objects which allows some movement
- ***Link*** - a rigid object between joints
- ***End effector*** - a free end of a kinematic chain



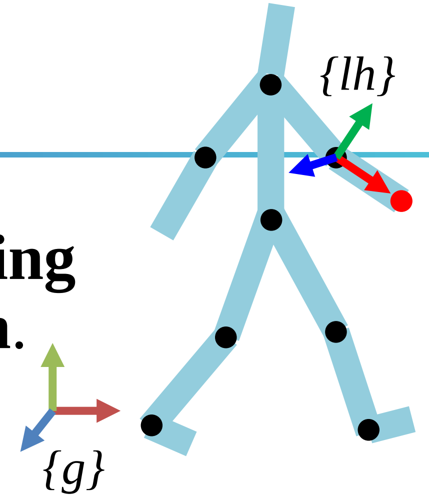


Forward Kinematics

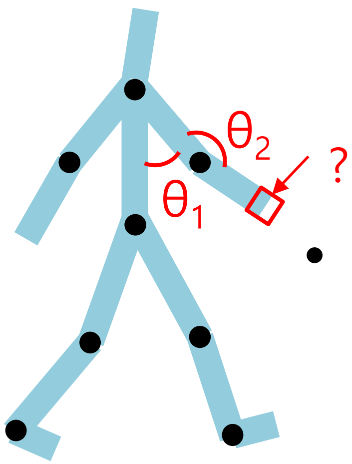
Kinematics

- *Kinematics* is the study of motion of objects without considering mass or forces.
  - By contrast, *Dynamics* is the study of the relationship between motion and its causes, specifically, forces and mass.
- In computer graphics, kinematics is about skeletal animation.
  - *Forward kinematics*: Given **joint angles**, compute **the position & orientation of end-effector**
  - *Inverse kinematics*: Given **the position & orientation of end-effector**, compute **joint angles**
- Understanding forward kinematics helps in understanding skeletal animation.

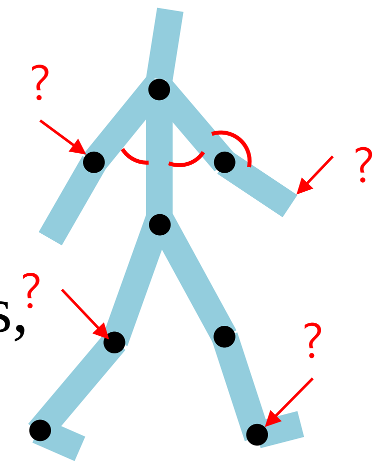
Forward Kinematics (FK)



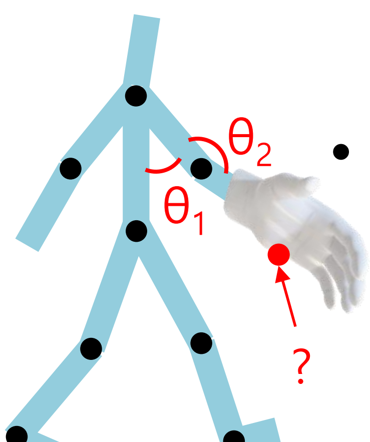
- *Forward kinematics map **T*** is a **mapping from *local* position to *global* position**.
  - ***T*** is calculated using joint angles.



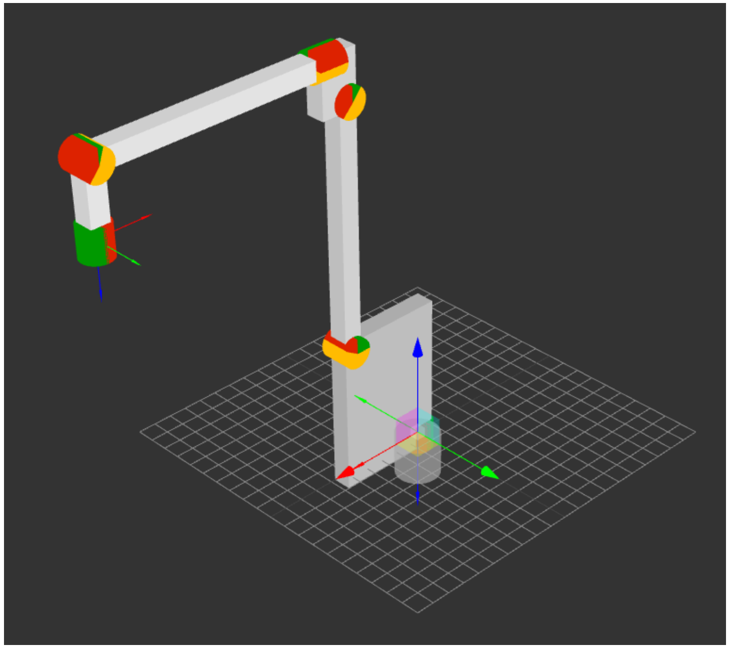
- *Forward kinematics*: **(Calculate *T* from)** given <u>joint angles</u>, compute <u>the position & orientation of end-effector</u> **(using this *T*)**.



- In fact, it's not limited only to end effectors,
- and can be applied to any point "attached" to any link.



[Demo] Forward / Inverse Kinematics



http://robot.glumb.de/

- Forward kinematics : Open “angles” menu and change values
- Inverse kinematics : Move the end-effector position by mouse dragging

Forward Kinematics Map

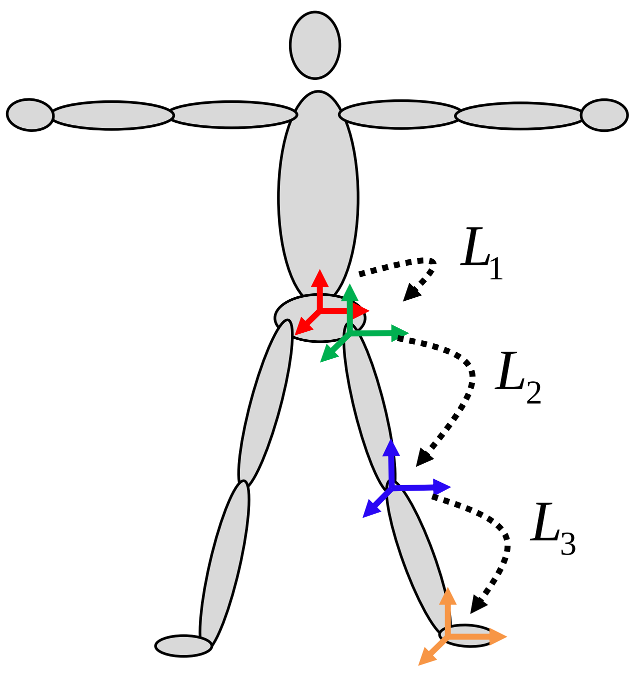
- A *forward kinematics map T* is an alternating multiple of ...
- **Joint transformations** (time-varying)
  - : Joint movement (*"motion"*)
- **Link transformations** (static)
  - : Joint offset (*"skeleton"*)

translation to 1st joint

$$T = J_0 L_1 J_1 L_2 J_2 L_3 J_3$$

rotation of 1st joint

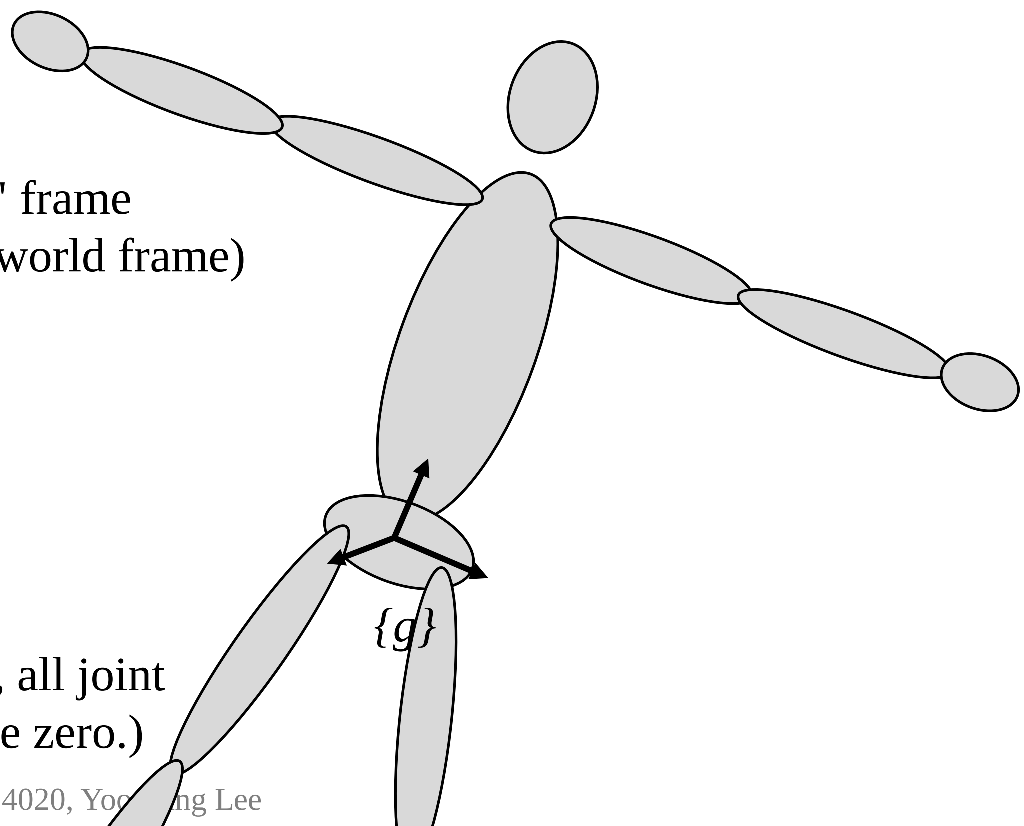
position & orientation of 0th joint
(the root segment)



Forward Kinematics Map

$T = \mathrm{I}$

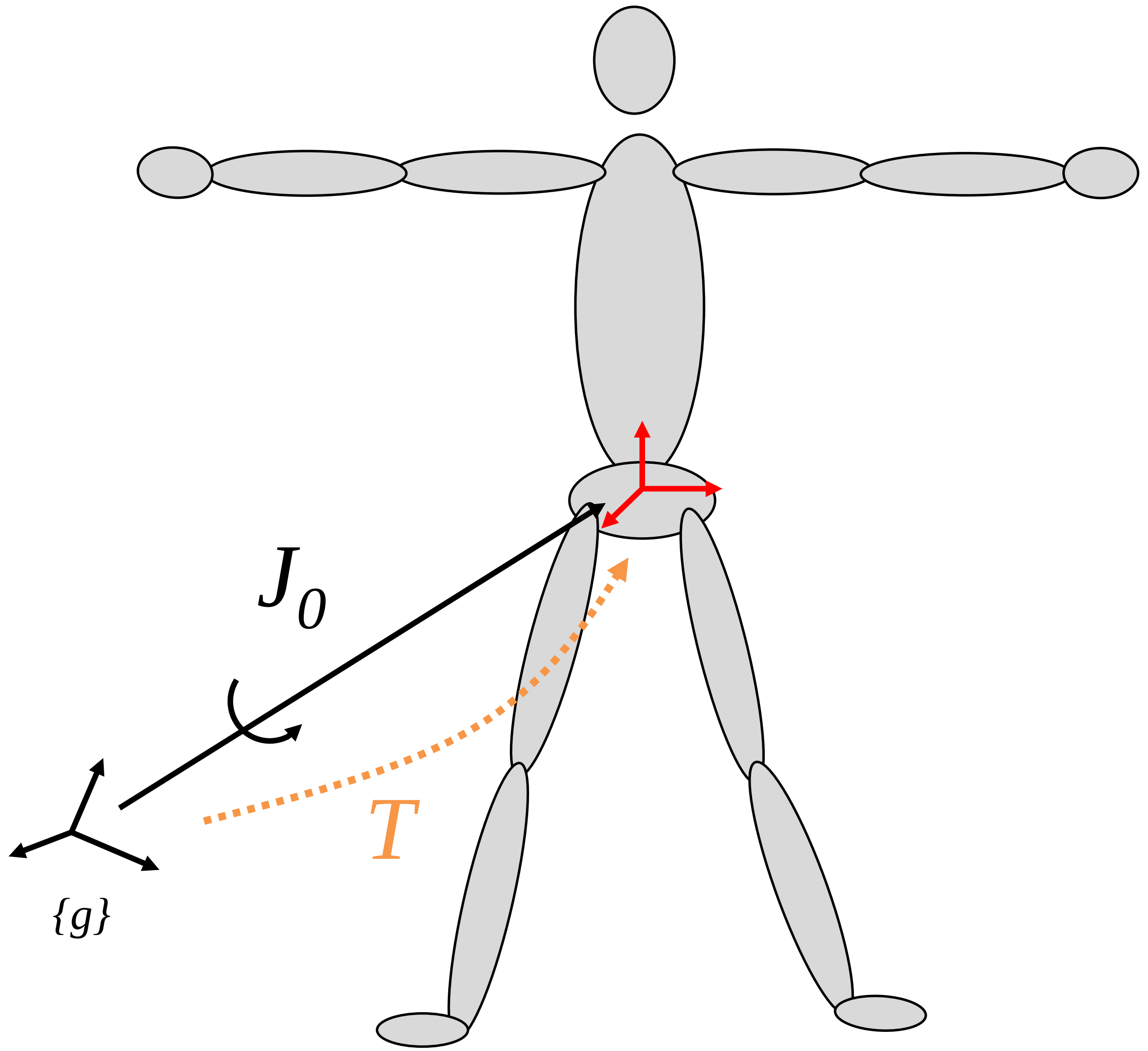
current "local" frame
(expressed in world frame)



(In this figure, all joint movements are zero.)

Forward Kinematics Map

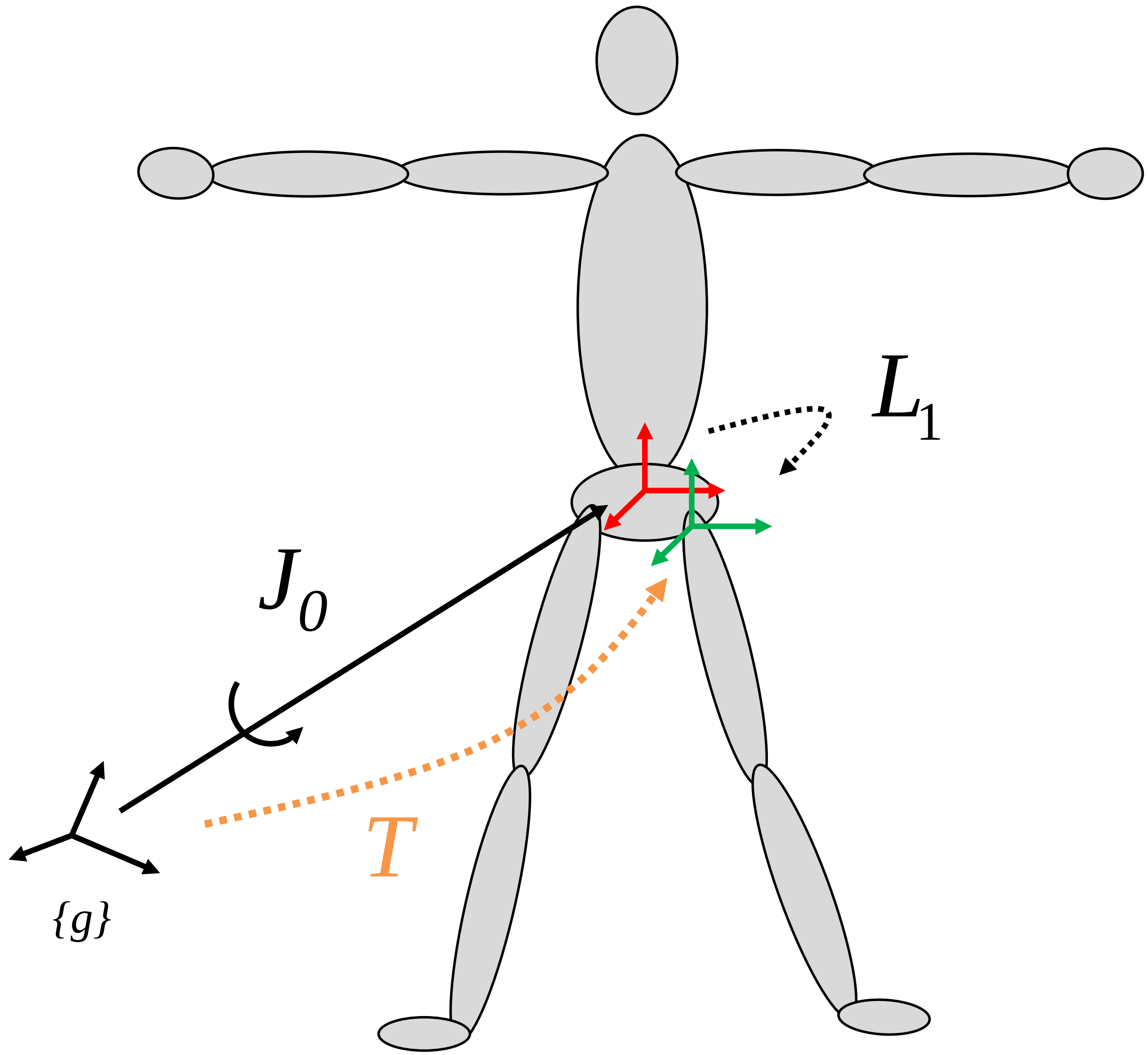
$$T = J_0$$



(In this figure, all joint movements except J_0 are zero.)

Forward Kinematics Map

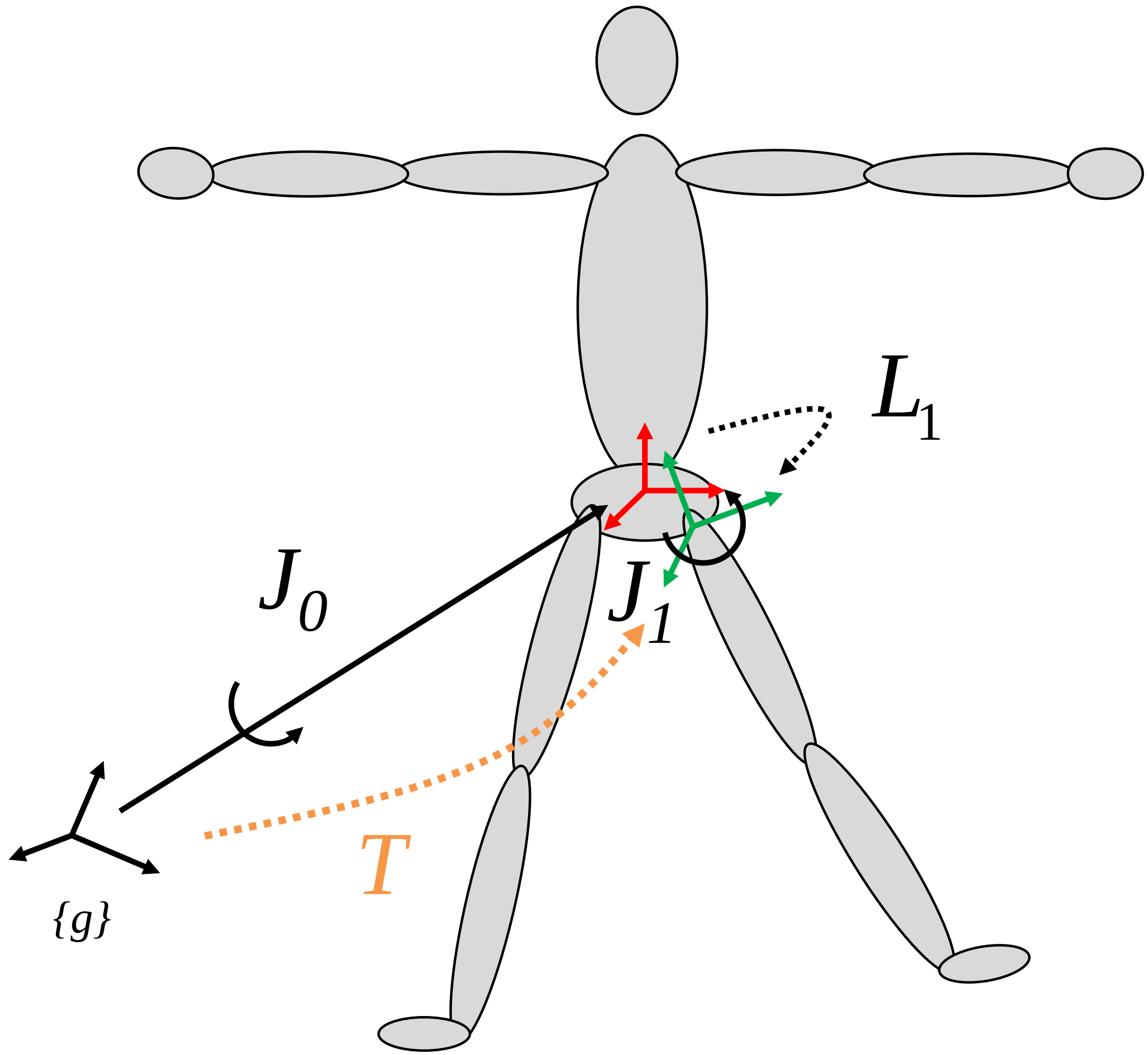
$$T = J_0 L_1$$



(In this figure, all joint movements except J_0 are zero.)

Forward Kinematics Map

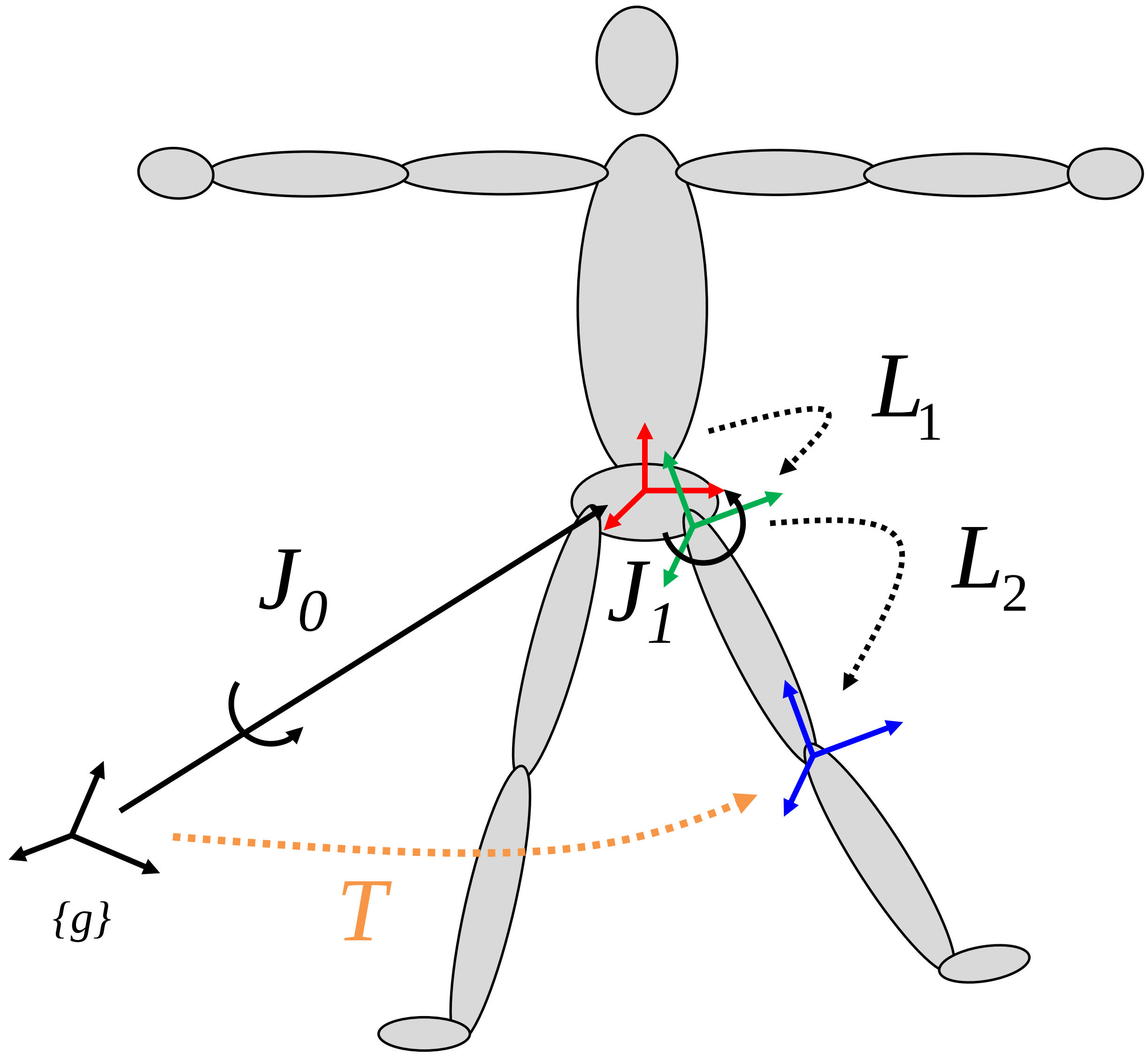
$$T = J_0 L_1 J_1$$



(In this figure, all joint movements except J_0, J_1 are zero.)

Forward Kinematics Map

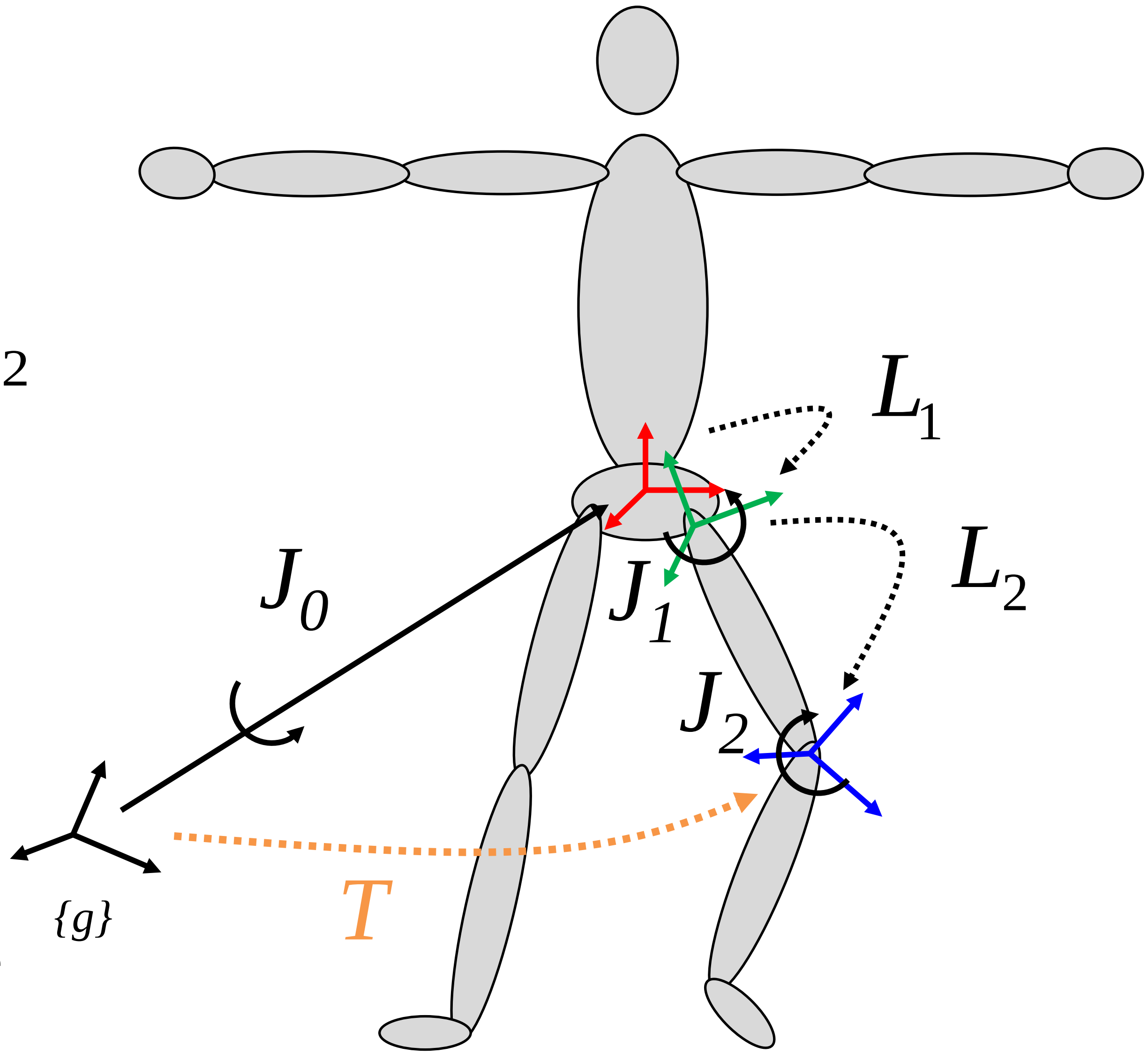
$$T = J_0 L_1 J_1 L_2$$



(In this figure, all joint movements except J_0, J_1 are zero.)

Forward Kinematics Map

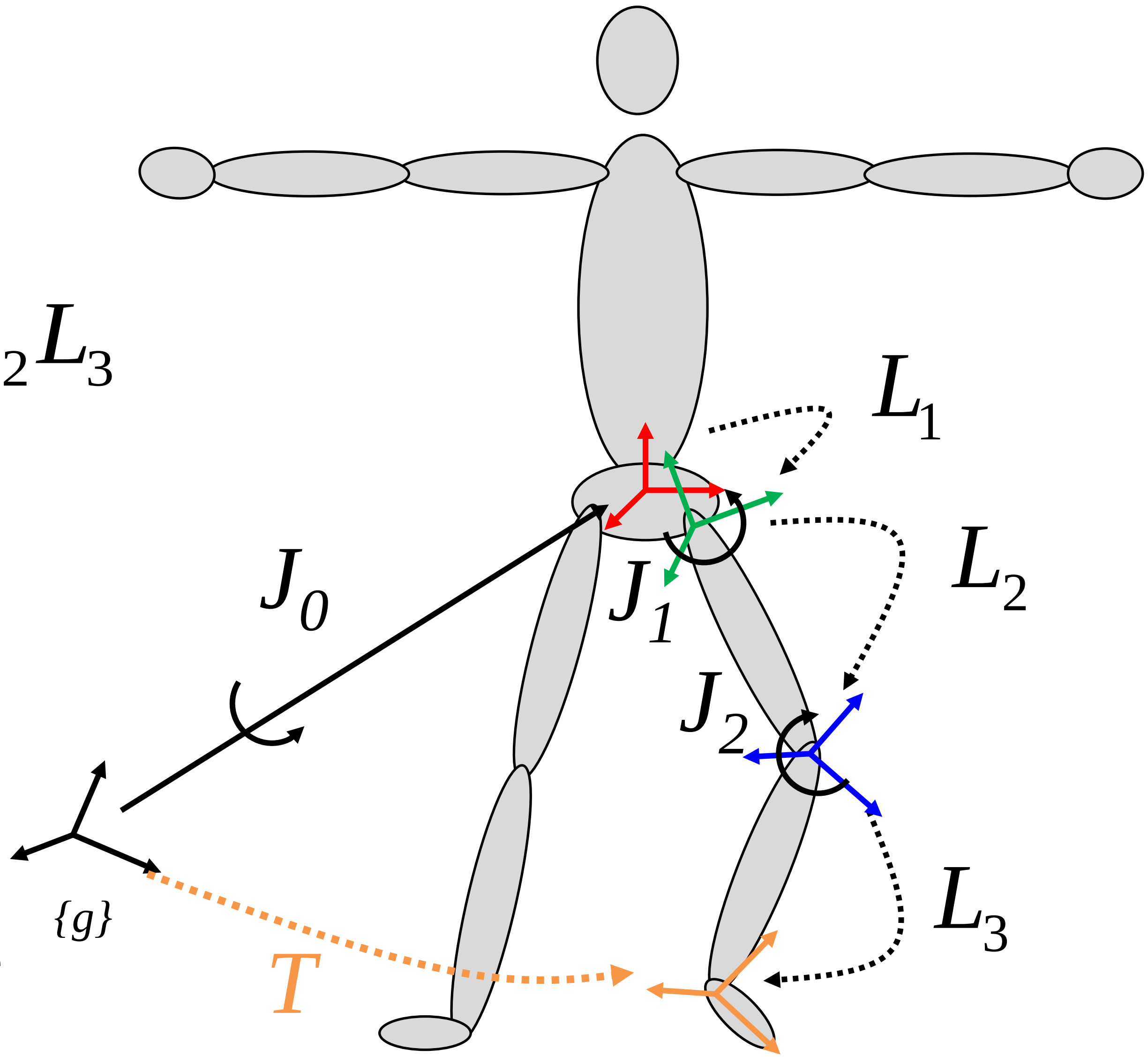
$$T = J_0 L_1 J_1 L_2 J_2$$



(In this figure, all joint movements except J_0, J_1, J_2 are zero.)

Forward Kinematics Map

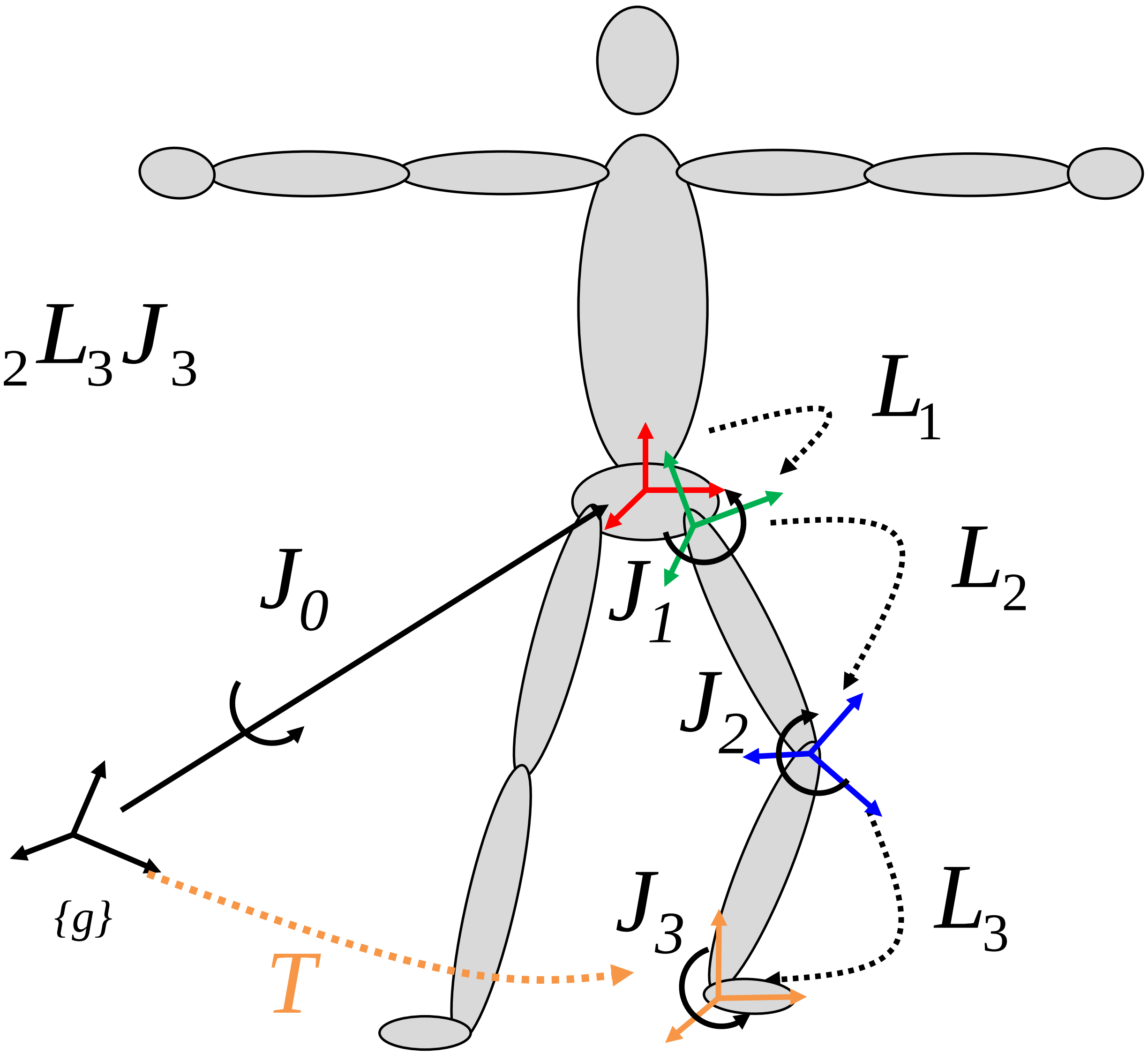
$$T = J_0 L_1 J_1 L_2 J_2 L_3$$



(In this figure, all joint movements except J_0, J_1, J_2 are zero.)

Forward Kinematics Map

$$T = J_0 L_1 J_1 L_2 J_2 L_3 J_3$$

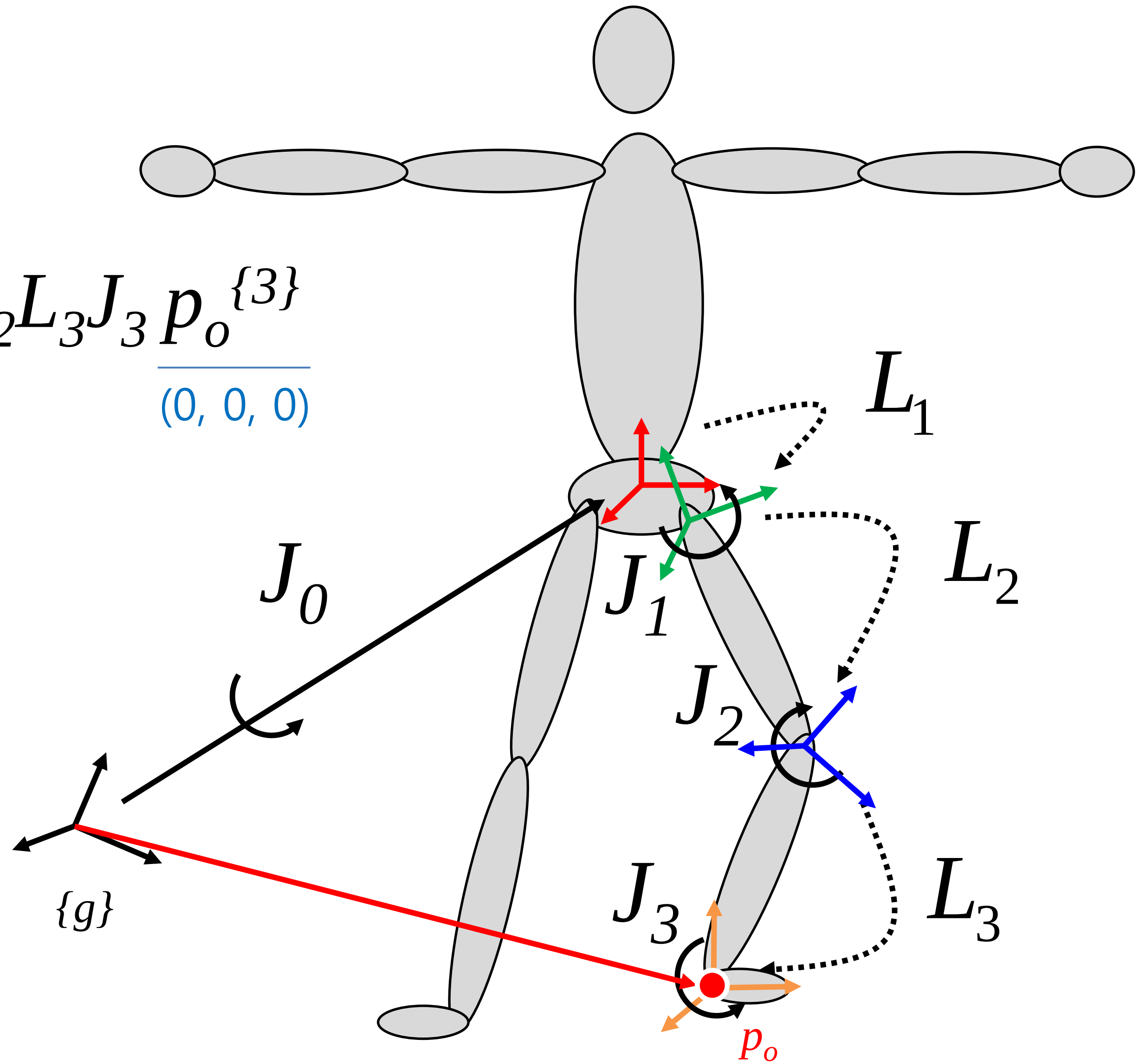


(In this figure, all joint movements except J_0, J_1, J_2, J_3 are zero.)

Forward Kinematics Map

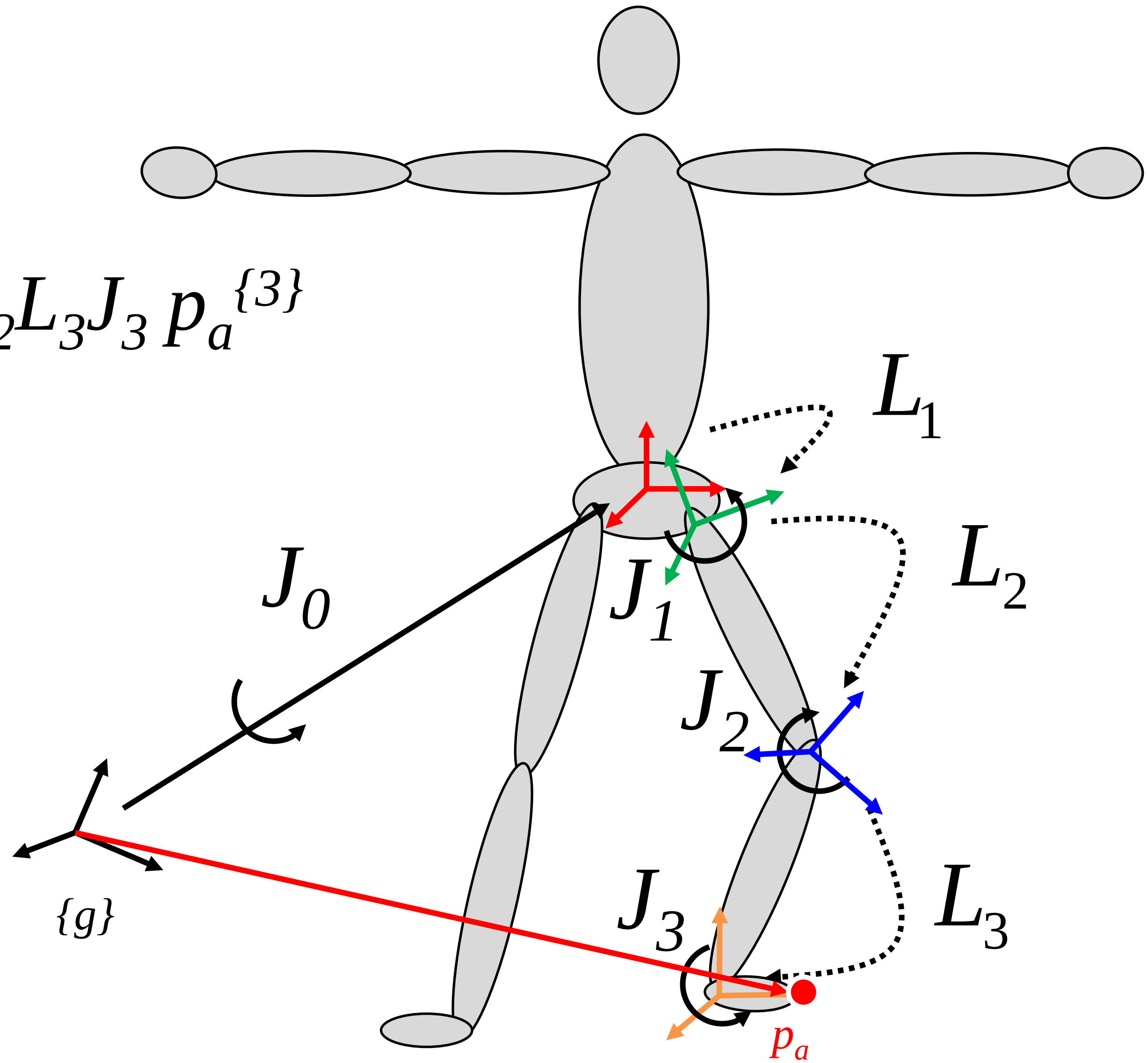
$$p_o^{\{g\}} = J_0 L_1 J_1 L_2 J_2 L_3 J_3 \underline{p_o^{\{3\}}}$$

(0, 0, 0)



Forward Kinematics Map

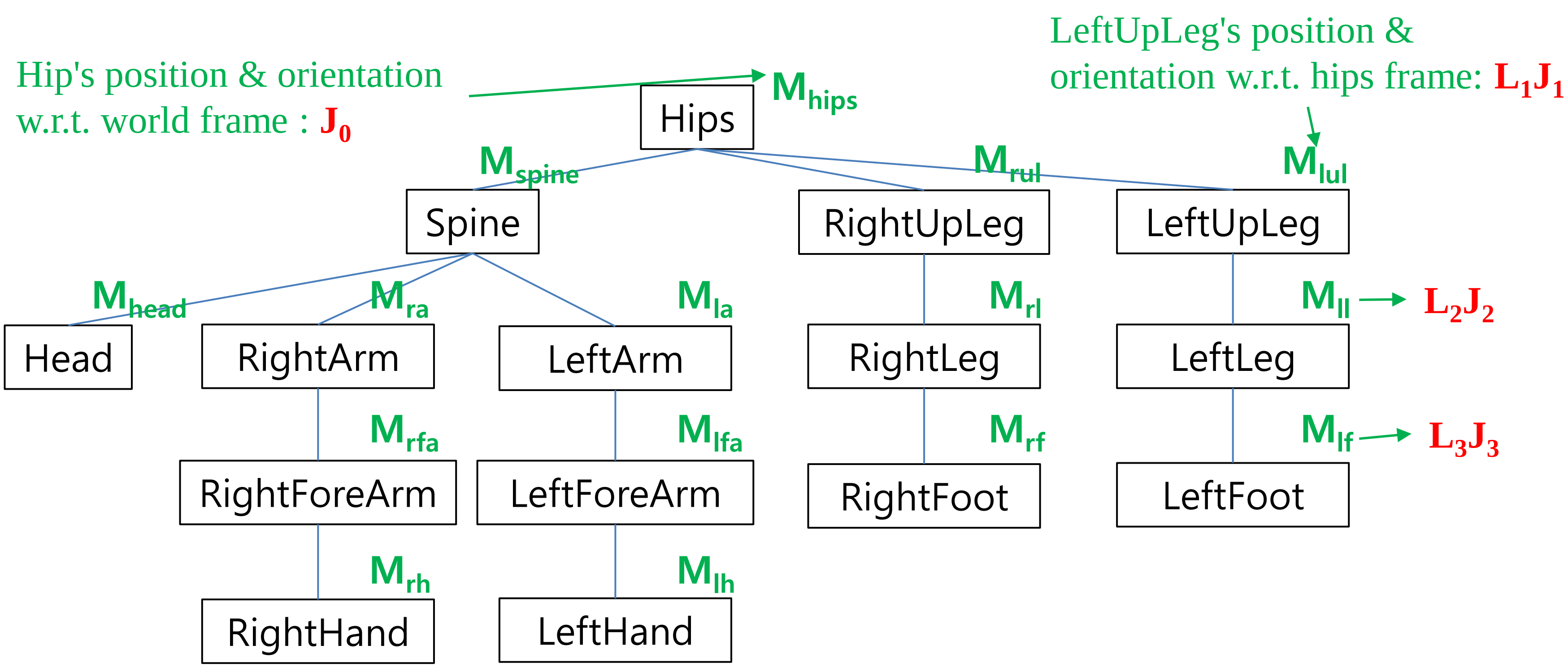
$$p_a^{\{g\}} = J_0 L_1 J_1 L_2 J_2 L_3 J_3 \, p_a^{\{3\}}$$



Recall: Rendering Hierarchical Models

- Each node has its own <u>transformation w.r.t. parent node's frame.</u>

  → **Local transformation**



Forward Kinematics Map

- This is how a skeletal animation is defined by

- Joint hierarchy
- Link transformations $\boldsymbol{L_i}$
- → "*Skeleton*"

- Joint transformations $\boldsymbol{J_i}$
- → "*Motion*"

Quiz 1

- Go to https://www.slido.com/
- Join #**cg-ys**
- Click "Polls"

- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2021123456: 4.0**

- Note that your quiz answer must be submitted **in the above format** to receive a quiz score!

Quiz 2

- Go to https://www.slido.com/
- Join #**cg-ys**
- Click "Polls"

- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2021123456: 4.0**

- Note that your quiz answer must be submitted **in the above format** to receive a quiz score!

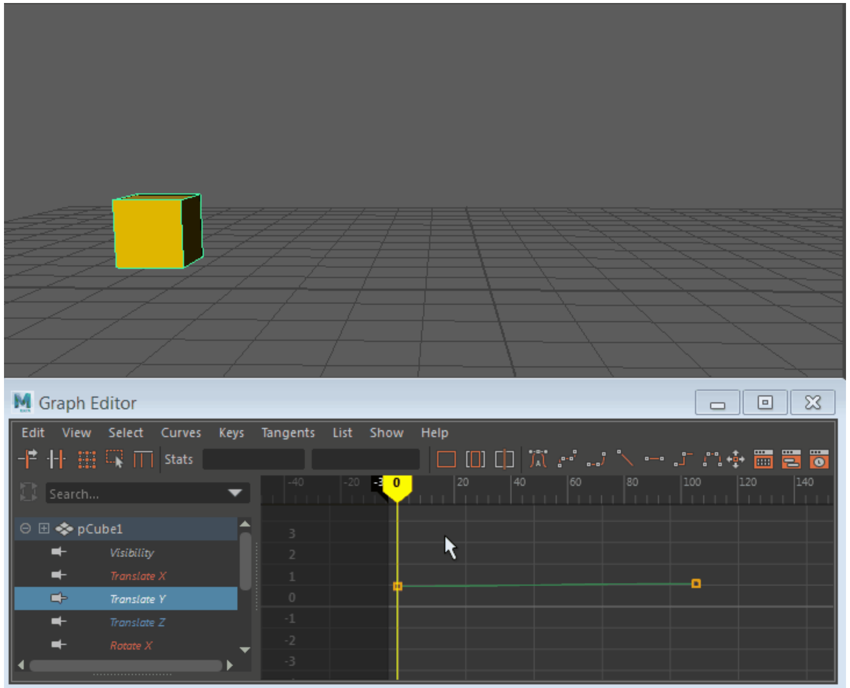
Creating Character Animation

Methods for Creating Character Animation

- How to create and set *"skeleton"* and *"motion"*?
- Keyframe Animation
- Motion Capture
- Data-Driven Animation
- Physics-Based Animation

Keyframe Animation

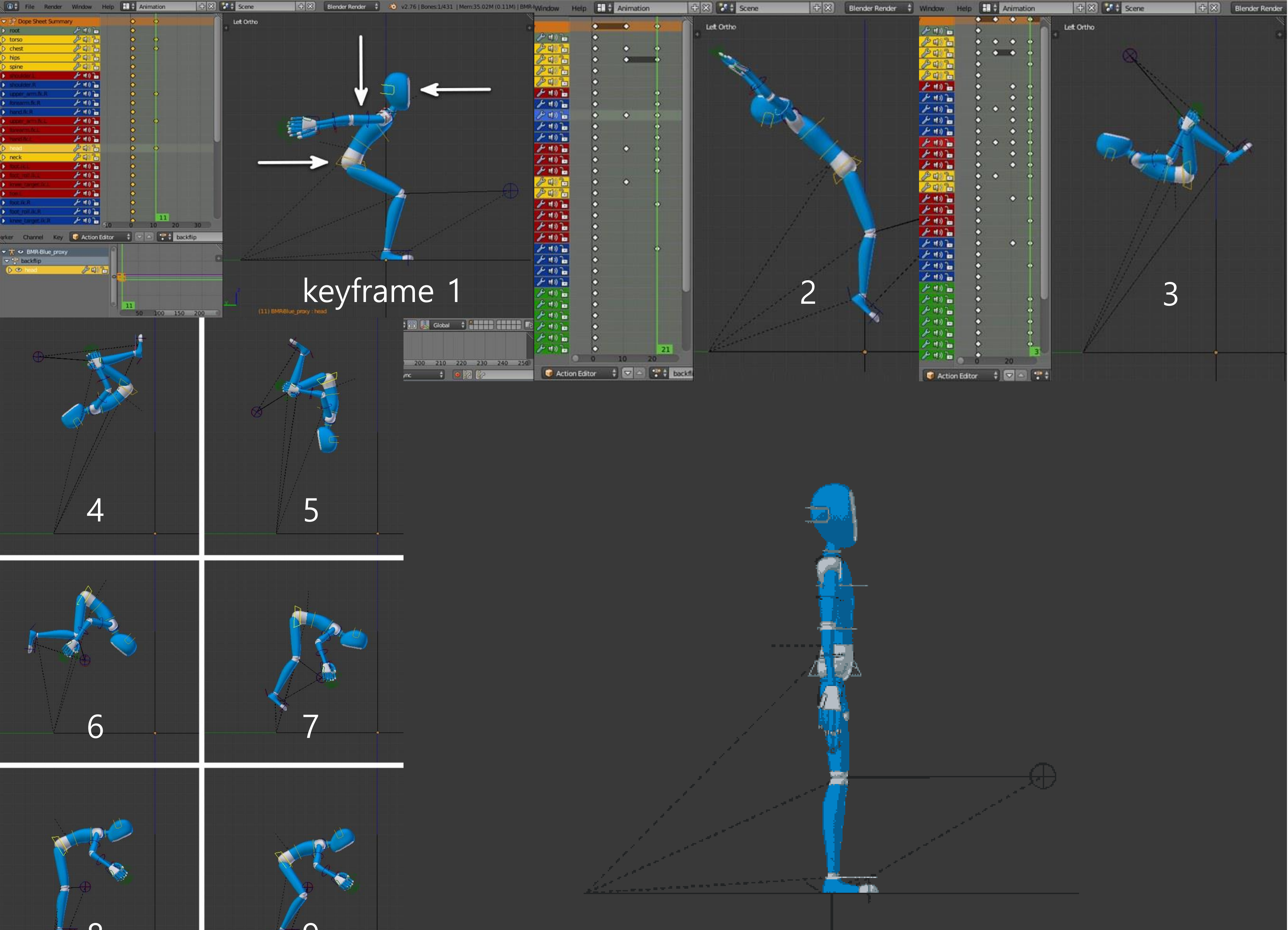
- Idea: Replace labor-intensive "inbetweening" processes with computing
  - Animators specifies important events at *key frames*.
  - Computer software fills inbetween frames using interpolation.



- Usually, *"skeleton"* is manually created.

- *"Motion"* is controlled by setting keyframes and manipulating various parameter curves.

* This image is from https://help.autodesk.com/view/MAYAUL/2022/ENU/?guid=GUID-9E69ABB3-E94B-4D67-9935-40F77FD2E9E0



- * These images are from https://cgi.tutsplus.com/tutorials/character-animation-how-to-animate-a-backflip-in-blender--cms-26511

Keyframe Animation

- A traditional method to produce computer animation,
  - which has roots in hand-drawn traditional animation.

- Difficult to create “realistic” and “physically plausible” motions.
  - The quality of the output largely depends on the skill of the individual artist.

- Still used a lot.

Motion Capture

- Idea: Use “real” human motion to create realistic animation.

- Motion capture system “captures” movement of people or objects by measuring
  - position of each marker on the skin
  - position and orientation of each body part (or joint)

- *"Motion"* and *"skeleton"* are extracted through post-processing.

Motion Capture

https://youtu.be/YzS73UCOk20

Bvh Motion Capture Data Example

```
HIERARCHY  →"Skeleton" ↓
ROOT Hips
{
  OFFSET 0.0 0.0 0.0
  CHANNELS 6 XPOSITION YPOSITION ZPOSITION ZROTATION XROTATION YROTATION
  JOINT Spine
  {
    OFFSET 0.0 0.118905 0.0
    CHANNELS 3 ZROTATION XROTATION YROTATION
    JOINT Head
    {
      OFFSET 0.0 0.3439156 0.00139004
      CHANNELS 3 ZROTATION XROTATION YROTATION
      End Site
      {
        OFFSET -0.0029 0.127742 0.0251395
      }
    }
    JOINT RightArm
    {
      OFFSET -0.192727 0.25291768 0.00229786
      CHANNELS 3 ZROTATION XROTATION YROTATION
      JOINT RightForeArm
      {
        ...
}
MOTION  →"Motion" ↓
Frames: 199
Frame Time: 0.033333
1.95769 0.989769479321 0.039193 -4.11275998891 -0.490682977769 -91.3519974695 0.45458697547  ...
1.95769 0.989769479321 0.0392908 -4.11760985011 -0.48626597981 -91.3734989051 0.513819016282  ...
1.95769 0.989769479321 0.039424 -4.12004011679 -0.488125979059 -91.387002189 0.592700017233  ...
1.95771 0.989769479321 0.0395518 -4.0961698863 -0.500940000911 -91.3840993586 0.61126399115  ...
1.95779 0.989759479321 0.0396999 -4.05799980101 -0.510696019006 -91.3839969058 0.58299101005  ...
1.9579 0.989719479321 0.0398625 -4.0423300664 -0.503295989288 -91.3842018115 0.57718001317  ...
...
```

Motion Capture

- Now widely used in movies & games (mainly by major companies).

- Very expansive
  - Expensive devices
  - High operating cost

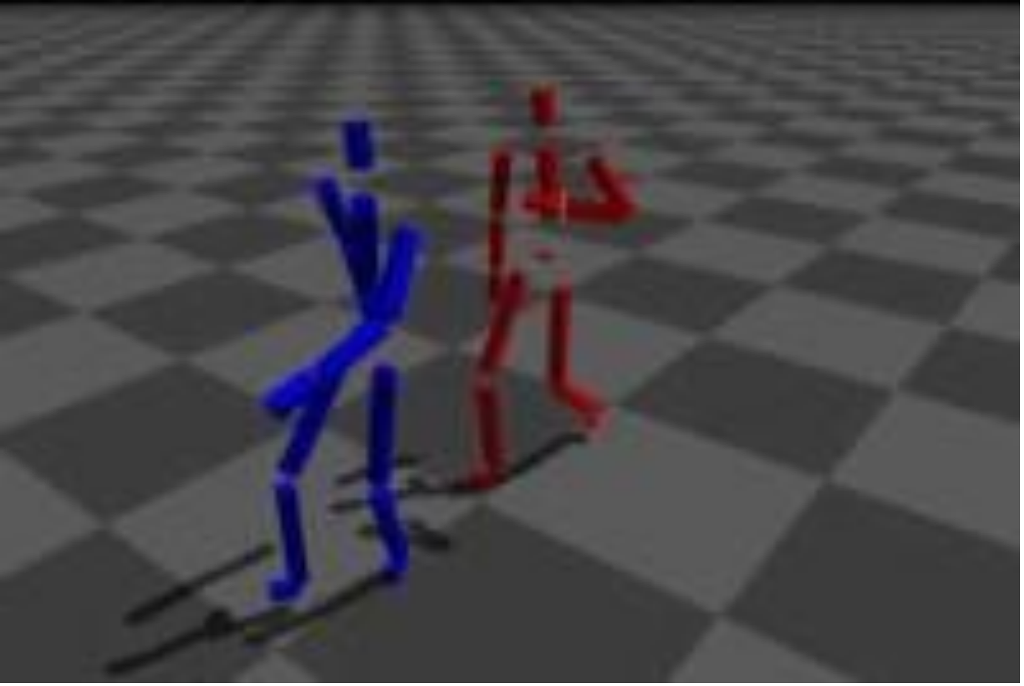
- Limitation: Motion captured data is very realistic **only** in the same virtual environment as capture environment.

Data-Driven Animation

- Idea: Maximize the reuse of / add flexibility to captured motion data by editing, restructuring, or learning.

- *"Skeleton"* from the motion dataset is used.
- "*Motion"* is edited / reconstructed / synthesized based on the motion dataset.

- Motion editing techniques
  - time warping, motion blending, ...
- Data-driven techniques
  - motion graphs, motion matching, ...
- Deep learning-based motion synthesis

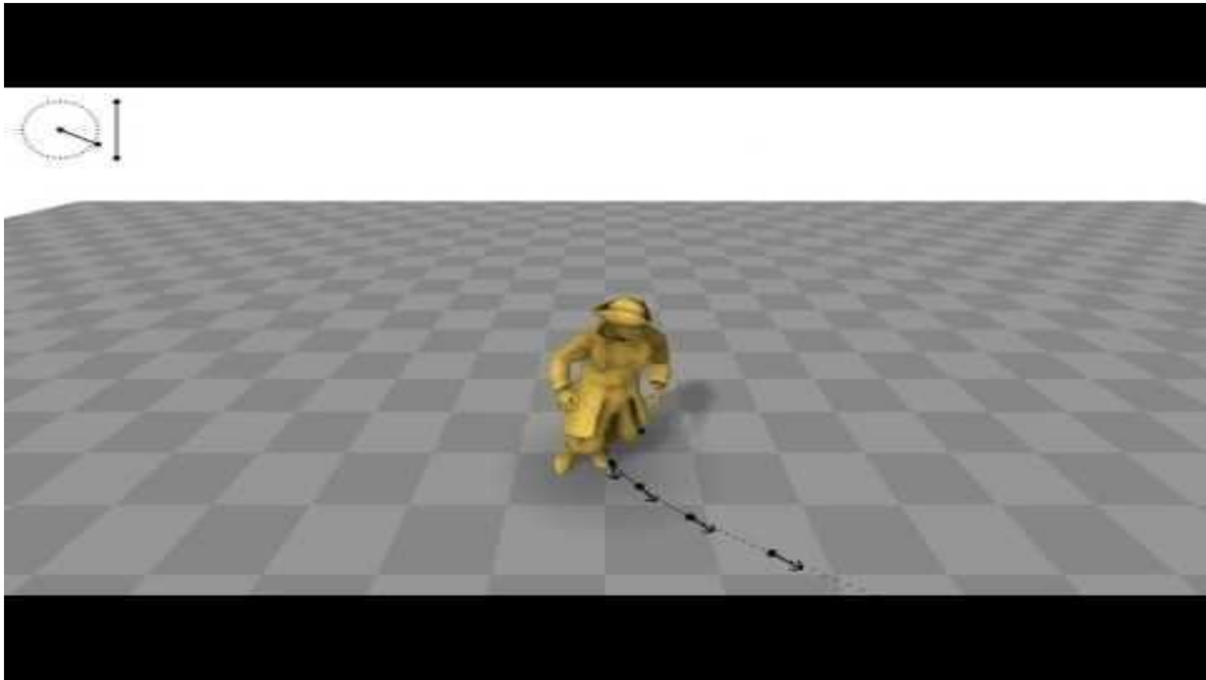


Motion Warping example

https://youtu.be/VH4QuV2mFcg

Deep Learning-Based Motion Synthesis - PFNN

https://youtu.be/Ul0Gilv5wvY



Physics-Based Animation (Simulation-Based)

- Idea: Use physics simulation to generate motion.
  - Physical reality plays a key role in creating high-quality motion.
  - Physic simulation generates a motion that is always physically plausible.

- *"Skeleton"* is often loaded from a model file description such as .urdf.
- *"Motion"* is computed by physics simulation.

- Requires a "controller".
  - Determines joint torques at each timestep to perform desired action while maintaining balance.

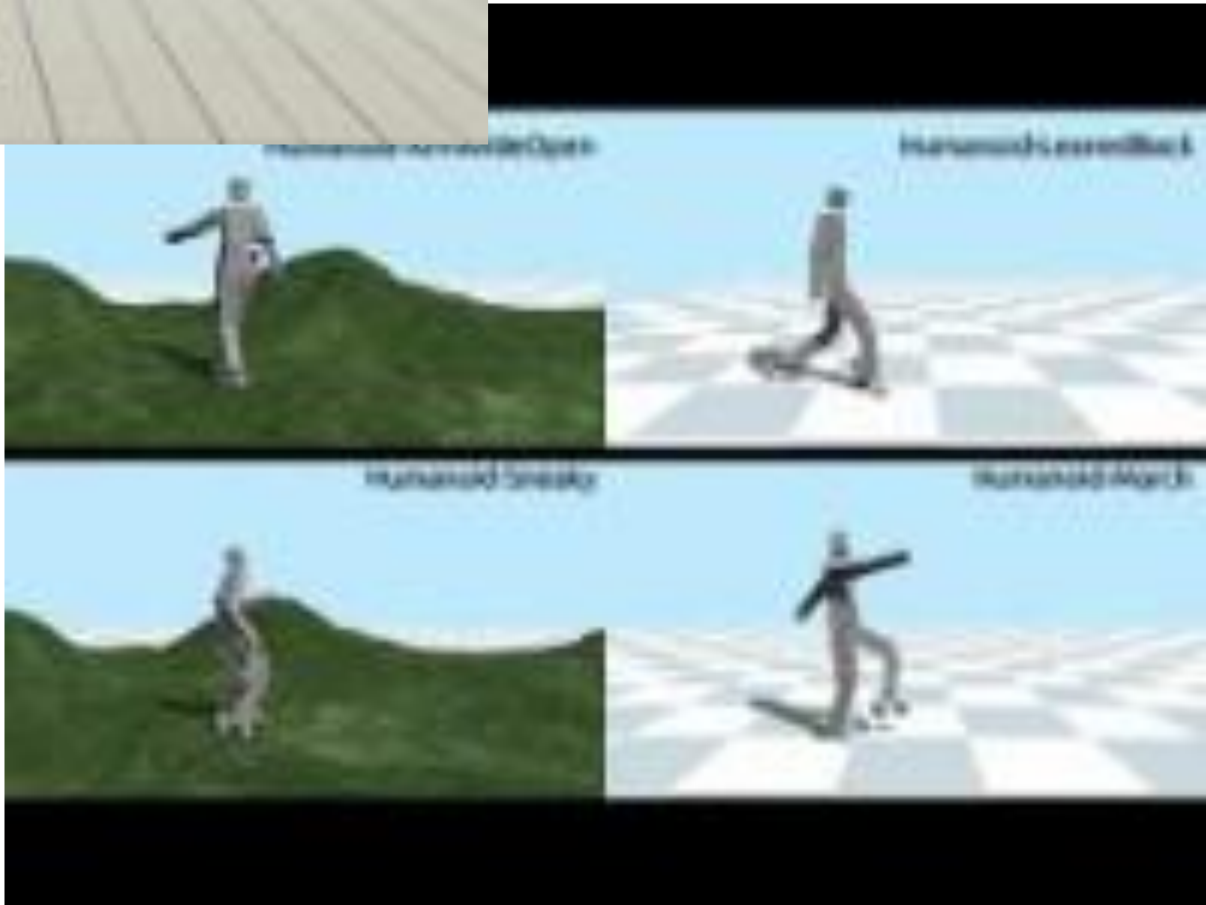
- Now deep reinforcement learning (DRL) is widely used to learn control policies.

DeepMimic [Peng et al. 2018]

https://youtu.be/vppFvq2quQ0

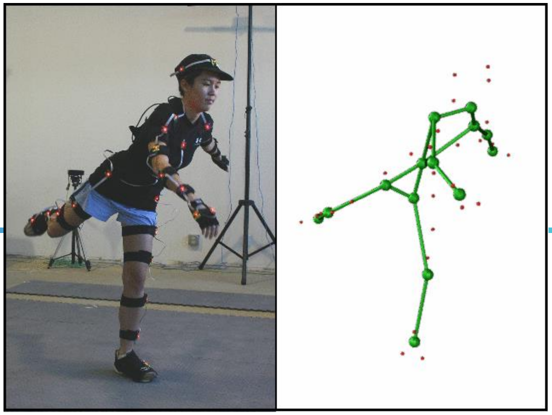
Fast and Flexible Multilegged Locomotion [Kwon et al. 2020]

https://youtu.be/fGwMrRoC5bw



BVH File Format

BVH File Format

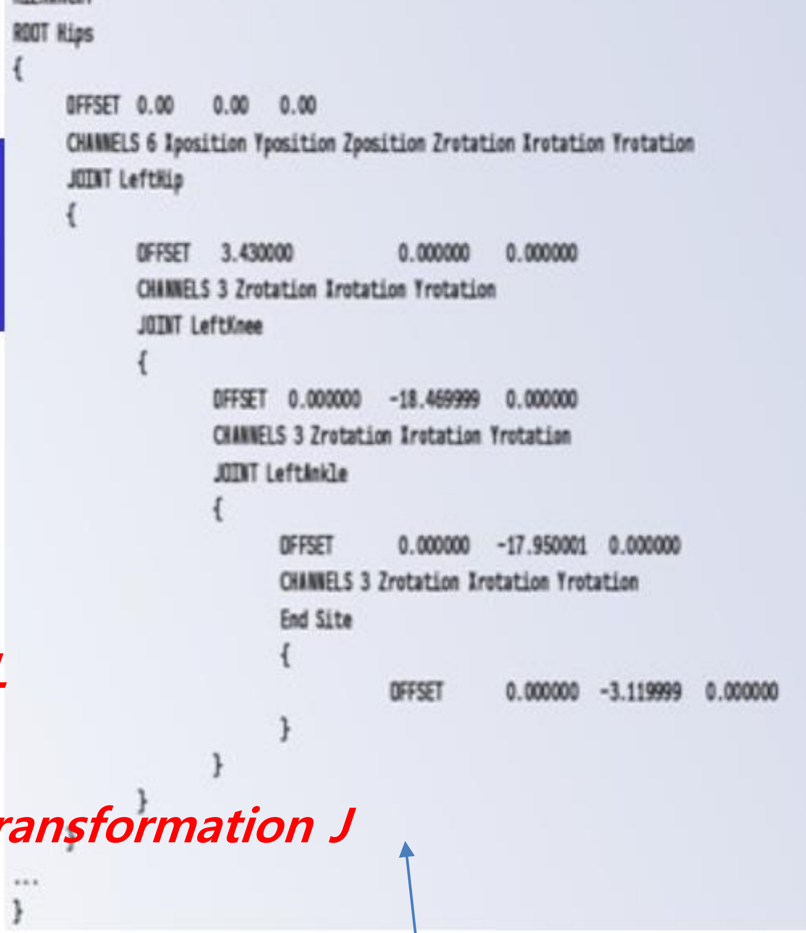


- BVH (**B**io**V**ision **H**ierarchical data)
  - Developed by Biovision, a motion capture company

- Consists of two parts:
- **Hierarchy section**
  - Describes the "*Skeleton*": static data
- **Motion section**
  - Describes the "*Motion*": time-varying data

- Text file format (human-readable)

Biovision BVH



```
ROOT Hips
{
    OFFSET 0.00 0.00 0.00
    CHANNELS 6 Xposition Yposition Zposition Zrotation Xrotation Yrotation
    JOINT LeftHip
    {
        OFFSET 3.430000 0.000000 0.000000
        CHANNELS 3 Zrotation Xrotation Yrotation
        JOINT LeftKnee
        {
            OFFSET 0.000000 -18.469999 0.000000
            CHANNELS 3 Zrotation Xrotation Yrotation
            JOINT LeftAnkle
            {
                OFFSET 0.000000 -17.950001 0.000000
                CHANNELS 3 Zrotation Xrotation Yrotation
                End Site
                {
                    OFFSET 0.000000 -3.119999 0.000000
                }
            }
        }
    }
...
}
```

- **Hierarchy section**
  - **"HIERARCHY"**
    - **"ROOT"**
      - followed by the name of the root
      - **" { "** and **" } "** pair
      - **"OFFSET"** ***: link transformation L***
        - » X,Y and Z offset of the segment from its parent
      - **"CHANNELS"** ***: type of its joint transformation J***
        - » the number of channels
        - » the type of each channel
    - **"JOINT"**
      - identical to the root definition except for the number of channels
      - **"OFFSET " , "CHANNELS"**
    - **"End Site"**
      - **indicates that the current segment is an end effector** (no children)
      - **"OFFSET "**

in this example,

- **6 channels for the root (Tx Ty Tz Rz Rx Ry)**
- **3 channels for every other object (Rz Rx Ry)**

```
HIERARCHY
ROOT Hips
{
  OFFSET 0.0 0.0 0.0
  CHANNELS 6 XPOSITION YPOSITION ZPOSITION ZROTATION XROTATION YROTAT
    JOINT chest
    {
            OFFSET  0.096536 3.475309 -0.289609
            CHANNELS 3 Xrotation Zrotation Yrotation
            JOINT neck
            {
                    OFFSET  -0.096536 13.901242 -2.027265
                    CHANNELS 3 Xrotation Zrotation Yrotation
                    JOINT head
                    {
                            OFFSET  -0.166775 1.448045 0.482682
                            CHANNELS 3 Xrotation Zrotation Yrotation
                            JOINT leftEye
```

```
HIERARCHY
ROOT Hips
{
  OFFSET 0.0 0.0 0.0
  CHANNELS 6 XPOSITION YPOSITION ZPOSITION ZROTATION XROTATION YROTAT
    JOINT chest
    {
            OFFSET  0.096536 3.475309 -0.289609
            CHANNELS 3 Xrotation Zrotation Yrotation
            JOINT neck
            {
                    OFFSET  -0.096536 13.901242 -2.027265
                    CHANNELS 3 Xrotation Zrotation Yrotation
                    JOINT head
                    {
                            OFFSET  -0.166775 1.448045 0.482682
                            CHANNELS 3 Xrotation Zrotation Yrotation
                            JOINT leftEye
```

Root offset is generally zero

J0 channels

L1

J1 channels

L2

J2 channels

L3

J3 channels

Biovision BVH

```
MOTION
Frames:     20
Frame Time: 0.033333
 0.00  39.68   0.00    0.65   ...
...
```

■ Motion Section

- "MOTION"
  - followed by a line indicating the number of frames
  - **"Frames:"**
    - the number of frames
  - **"Frame Time:"**
    - the sampling rate of the data
    - Ex) 0.033333 ➔ 30 frames a second
  - The rest of the file contains the actual motion data
    - The numbers appear in the order of the channel specifications as the skeleton hierarchy was parsed
  - **Each line has motion data for a single frame**
  - **Each number in a line is a value for a single channel**
  - **The unit of rotation channel values is degree**

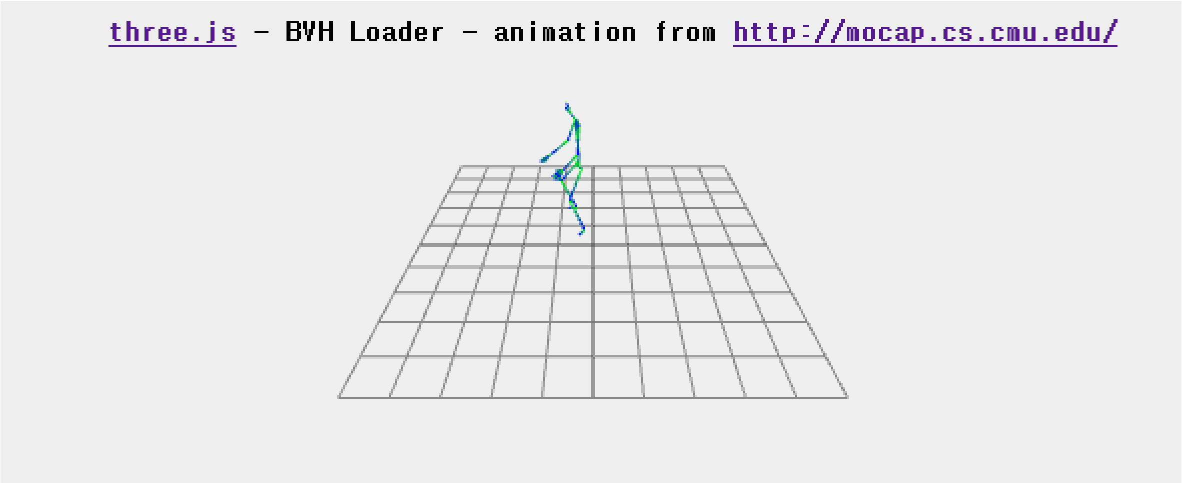
```
HIERARCHY
ROOT Hips
{
  OFFSET 0.0 0.0 0.0
  CHANNELS 6 XPOSITION YPOSITION ZPOSITION ZROTATION XROTATION YROTATION
    JOINT chest Column 1    Column 2    Column 3    Column 4    Column 5    Column 6
    {
          OFFSET  0.096536 3.475309 -0.289609
          CHANNELS 3 Xrotation Zrotation Yrotation
          JOINT neck    Column 7    Column 8    Column 9
          {
                OFFSET  -0.096536 13.901242 -2.027265
                CHANNELS 3 Xrotation Zrotation Yrotation
                JOINT head    Column 10    Column 11    Column 12
                {
                      OFFSET  -0.166775 1.448045 0.482682
                      CHANNELS 3 Xrotation Zrotation Yrotation
                                Column 13    Column 14    Column 15
MOTION
Frames: 199
Frame Time: 0.033333
1.95769 0.989769479321 0.039193 -4.11275998891 -0.490682977769 -91.3519974695 0.45458697547  ...
1.95769 0.989769479321 0.0392908 -4.11760985011 -0.48626597981 -91.3734989051 0.513819016282  ...
1.95769 0.989769479321 0.039424 -4.12004011679 -0.488125979059 -91.387002189 0.592700017233  ...
1.95771 0.989769479321 0.0395518 -4.0961698863 -0.500940000911 -91.3840993586 0.61126399115  ...
1.95779 0.989759479321 0.0396999 -4.05799980101 -0.510696019006 -91.3839969058 0.58299101005  ...
1.9579 0.989719479321 0.0398625 -4.0423300664 -0.503295989288 -91.3842018115 0.57718001317  ...
...
```

Biovision BVH

Interpreting the data

- To calculate the position of a segment
  - Translation information
    - For any joint segment
      - the translation information will simply be the offset as defined in the hierarchy section
    - For the root object
      - The translation data will be the sum of the offset data and the translation data from the motion section
  - Rotation information
    - comes from the motion section
  - **The "CHANNELS" order is important: If the order is "ZROTATION XROTATION YROTATION"**
    - **Apply transformation in order of rotation about z, rotation about x, rotation about y w.r.t. body frame**
    - **→ ZXY Euler angles**
  - **Do not assume ZXY Euler angles. Other sequences may also be used.**

[Demo] BVH Viewer



http://motion.hahasoha.net/

- Select other motions from the list.
- Download corresponding BVH files and open them in a text editor.

Quiz 3

- Go to https://www.slido.com/
- Join #**cg-ys**
- Click "Polls"

- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2021123456: 4.0**

- Note that your quiz answer must be submitted **in the above format** to receive a quiz score!

Lab Session

- Now let's start the lab session.