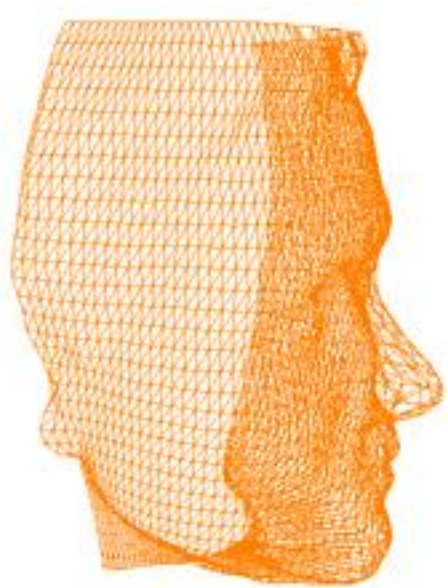
COSC422 Advanced Computer Graphics



10 Motion Capture Data and Skeletal Animation

Semester 2
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Lecture Outline

- Motion capture data
  - Mocap data formats
  - Joints and Joint Hierarchy
  - BVH Representations and Keyframe Animation
- Animating skeletons using BVH data
- Implementations using Assimp

Motion Capture (mocap)

- Motion capture data can be used to animate a character model based on realistic human movements
- An actor performs the movements and the joint positions and angles are computed from various sensors
  - Body sensors: Magnetic motion capture, accelerometers, gyroscopes
  - Optical sensors: Reflective markers, LEDs
  - Hybrid sensing, sensor fusion

Wikipedia.org

- The joint positions are then mapped to a character mesh via a skeletal structure, animated using joint angles.

Motion Capture Data Formats

- Acclaim : (ASF, AMC)
- **Biovision: BVH** (Biovision Hierarchy)
- 3D Biomechanics (c3d.org): C3D
- 3D Max Character Studio: BIP (Biped)
- Autodesk: **FBX** (Film box)

:

ASF, AMC, BVH are editable files in ASCII format.

ASF: Acclaim Skeleton File

AMC: Acclaim Motion Capture data

Joints

Motion data specifies

- the **rotational transformations** at the joints of a character model
- the movement (**translation**) of the whole character model

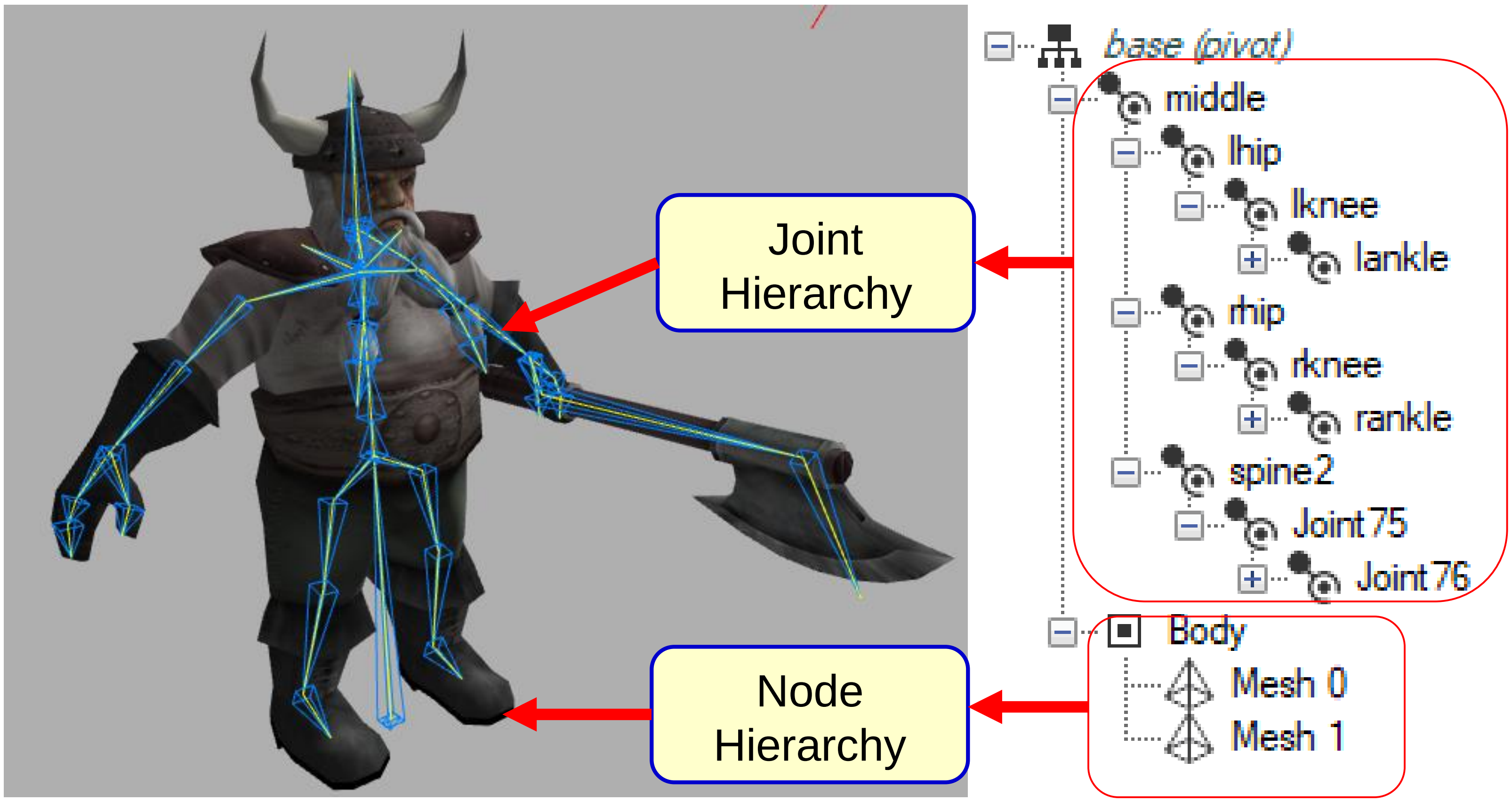
For character animation, we require a set of **joints** and a hierarchical structure similar to the node hierarchy.

Note:

A **node** hierarchy (scene graph) represents the mesh model, while a **joint** hierarchy (skeleton) specifies how motion transformation must be applied to the model.

(Both hierarchies are part of Assimp's node hierarchy)

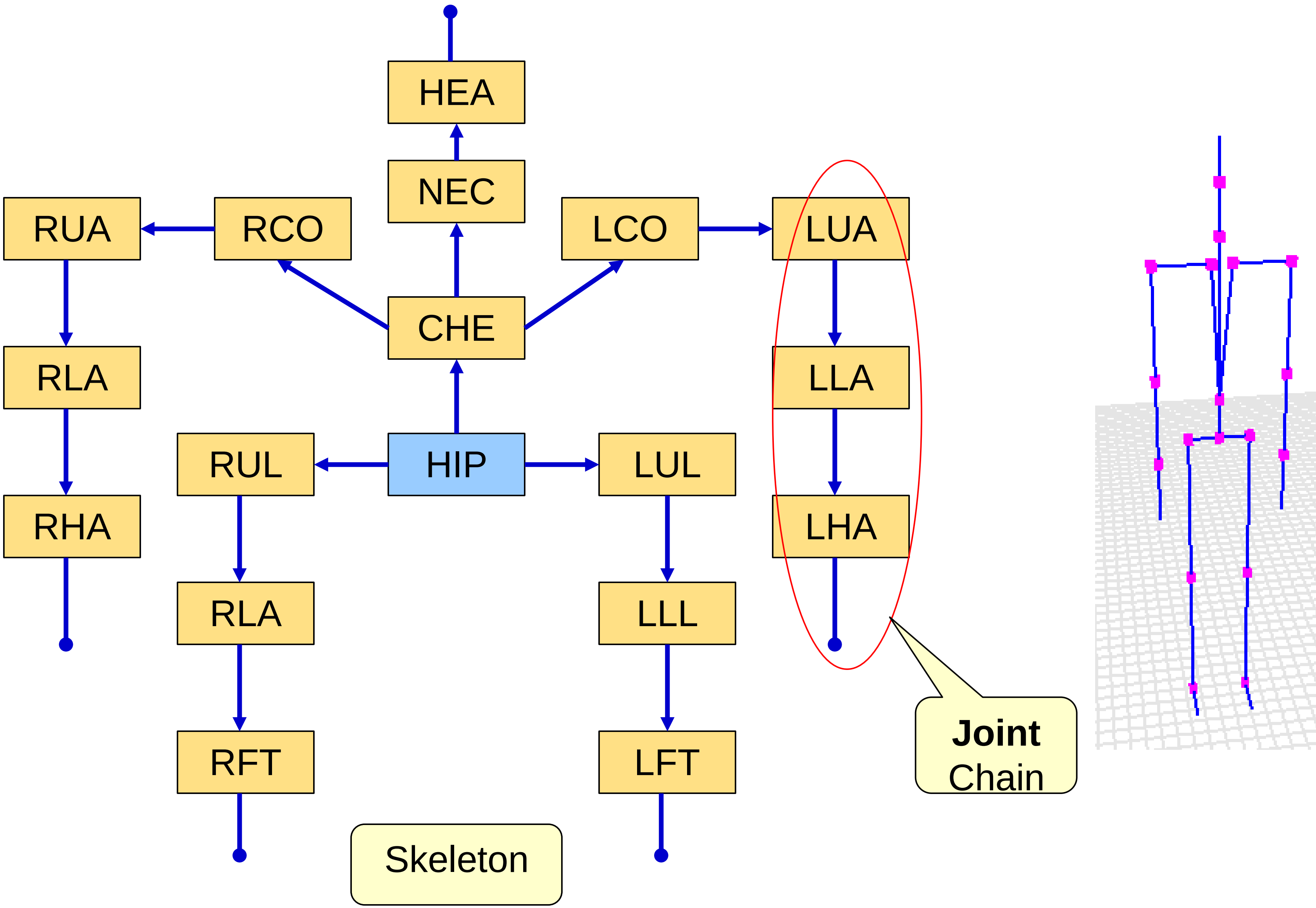
Node and Joint Hierarchies



Notation: = Node = Joint

Note: A joint does not contain any mesh data

Joint Hierarchy of a Character Model



Animation Using Motion Data

- Motion capture data are always associated with a skeleton structure consisting of one or more joint chains.
- However, motion capture files do not contain any mesh definitions.
- In this section, we look at the structure of motion capture data and ways to create skeletal animations using them.
- We will consider animations of rigged character models (models with attached skeletons as shown in slide 6) in the next section.

Motion Capture Data: Example

Format BVH

```
HIERARCHY
ROOT hip
{
  OFFSET 0 0 0
  CHANNELS 6 Xposition Yposition Zposition Zrotation Yrotation Xrotation
  JOINT abdomen
  {
    OFFSET 0 20.6881 -0.73152
    CHANNELS 3 Zrotation Xrotation Yrotation
    JOINT chest
    {
      OFFSET 0 11.7043 -0.48768
      CHANNELS 3 Zrotation Xrotation Yrotation
      JOINT neck
      {
        OFFSET 0 22.1894 -2.19456
        CHANNELS 3 Zrotation Xrotation Yrotation
        JOINT head
        {
          OFFSET -0.24384 7.07133 1.2192
          CHANNELS 3 Zrotation Xrotation Yrotation
          End Site
          {
            OFFSET 1 0 0
```

Joint Hierarchy **(HIERARCHY)**

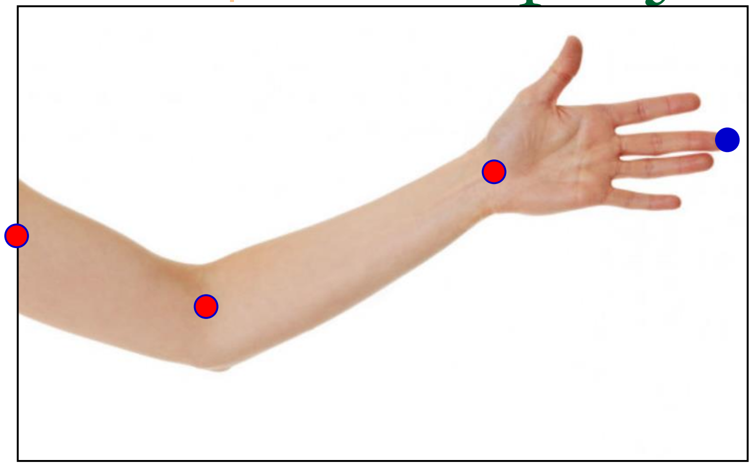
```
MOTION
Frames: 2752
Frame Time: .0083333
9.3722 17.8693 -17.3198 0 0 0 0 0 0 -17 0 0 0 0 0 0 0 0 0 0 0 0 0 17 0 0 0 0 0 0 0
9.3722 17.8693 -17.3198 -3.2316 -7.5970 -2.0168 0.0000 0.0000 0.0000 -13.8102 2.5002
9.3728 17.8666 -17.3192 -3.1009 -7.5883 -2.0638 0.0000 0.0000 0.0000 -13.9682 2.5229
9.3692 17.8658 -17.3215 -3.2095 -7.5354 -2.0862 0.0000 0.0000 0.0000 -13.8218 2.5041
9.3726 17.8597 -17.3260 -2.9561 -7.3832 -2.1994 0.0000 0.0000 0.0000 -14.1244 2.3274
9.3733 17.8536 -17.3317 -2.9110 -7.3527 -2.2688 0.0000 0.0000 0.0000 -14.1889 2.2258
9.3689 17.8530 -17.3350 -3.0434 -7.3807 -2.2750 0.0000 0.0000 0.0000 -14.0111 2.2992
9.3676 17.8526 -17.3375 -3.0382 -7.2530 -2.2686 0.0000 0.0000 0.0000 -14.0037 2.2152
9.3648 17.8499 -17.3463 -3.3020 -7.0875 -2.2158 0.0000 0.0000 0.0000 -13.6701 2.0739
9.3598 17.8506 -17.3603 -3.9143 -7.0800 -2.0917 0.0000 0.0000 0.0000 -12.9330 2.0239
9.3594 17.8548 -17.3683 -4.1461 -7.0678 -1.9856 0.0000 0.0000 0.0000 -12.6724 1.9580
9.3610 17.8550 -17.3711 -4.0020 -6.9770 -1.9689 0.0000 0.0000 0.0000 -12.8399 1.9037
9.3649 17.8511 -17.3802 -3.9286 -6.8873 -1.9864 0.0000 0.0000 0.0000 -12.9495 1.7424
9.3686 17.8470 -17.3957 -3.9244 -6.8022 -1.9956 0.0000 0.0000 0.0000 -12.9865 1.4917
9.3650 17.8439 -17.4052 -4.0625 -6.7236 -1.9711 0.0000 0.0000 0.0000 -12.7883 1.4626
9.3582 17.8410 -17.4103 -4.3298 -6.5852 -1.8964 0.0000 0.0000 0.0000 -12.3962 1.6119
```

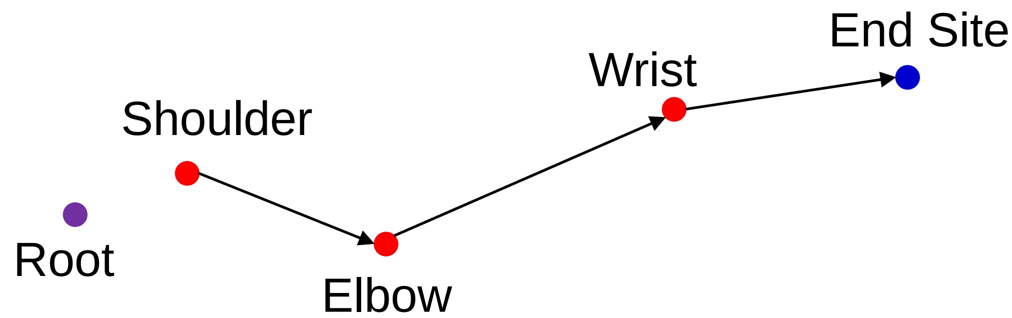
Animation Frames **(MOTION)**

Motion Data

- A motion data file contains
  - A structure specifying a joint hierarchy
  - Skeleton parameters (offsets)
    - The position of each joint ***relative to*** its parent
  - Animation data (key frames or channels)
  - No mesh data

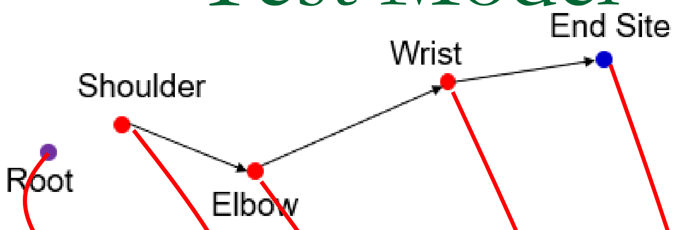
A Simple Joint Chain





- A joint is a point about which a rotation can be performed. A sequence of rotations about a joint is stored as a channel.
- Each joint's position is specified relative to the parent's joint.
- Special types of joints:
  - The root (has 6 degrees of freedom)
  - The last joint in a joint chain is called the "End Site"

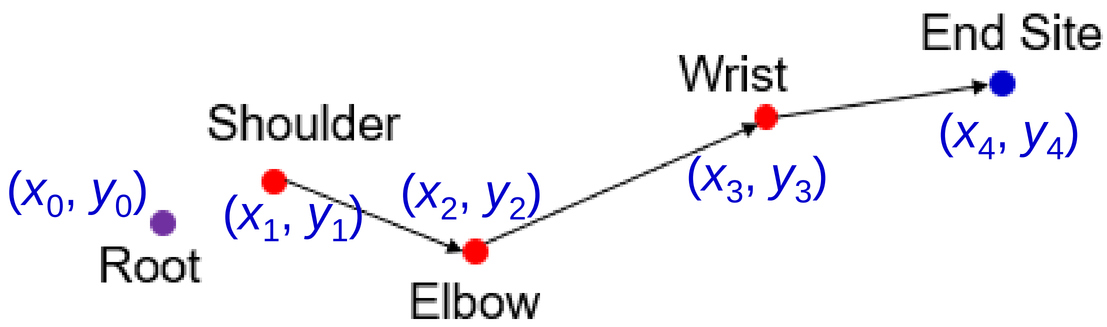
Test Model

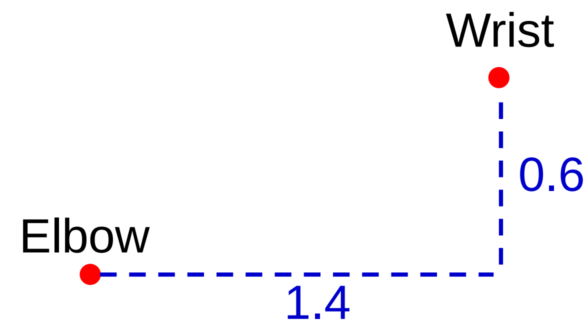



```
HIERARCHY
ROOT root
{
    OFFSET 0.00000 0.00000 0.00000
    CHANNELS 6 Xposition Yposition Zposition Zrotation Yrotation Xrotation
    JOINT Shoulder
    {
        OFFSET 0.5  0.3  0.0
        CHANNELS 3 Zrotation Yrotation Xrotation
        JOINT Elbow
        {
            OFFSET 1.0  -0.5 0.0
            CHANNELS 3 Zrotation Yrotation Xrotation
            JOINT Wrist
            {
                OFFSET 1.4  0.6 0.0
                CHANNELS 3 Zrotation Yrotation Xrotation
                End Site
                {
                    OFFSET 1.0 0.1 0.0
                }
            }
        }
    }
}
```

Test.bvh

Hierarchical Data: 2D Example





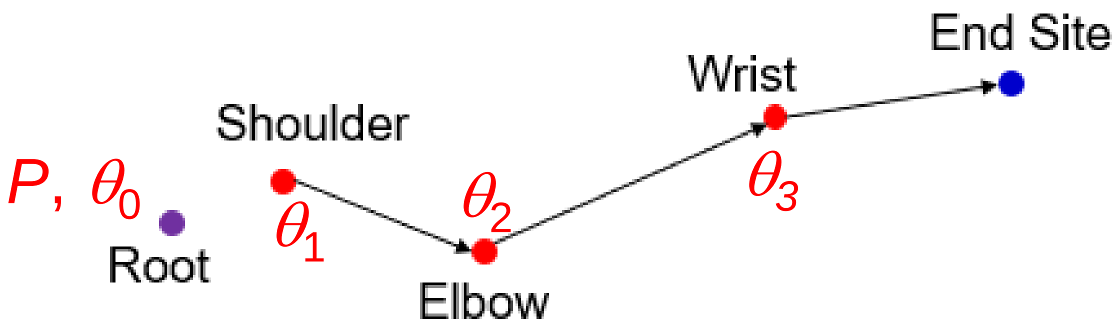
Relative Coordinates

- **Skeleton parameters (Offsets):**

  (x_0, y_0), (x_1, y_1), (x_2, y_2) , (x_3, y_3) , (x_4, y_4)

  - These are fixed parameters. Each offset is defined **relative** to the joint's parent. The skeleton parameters uniquely specify the locations of the joints in the initial configuration.
  - In the above example, (1.4, 0.6, 0) is the initial position of the wrist joint relative to the elbow joint. The absolute position of the wrist joint in the initial configuration is (2.9, 0.4, 0).

Hierarchical Data: 2D Example



- **Animatable parameters (Channel)**:

  P (global position), $\theta_0, \theta_1, \theta_2, \theta_3$ (joint angles)

  - These parameters are defined for each **animation frame.**
  - The root joint will have a translation parameter P specifying the motion of the whole joint chain in world space.
  - A joint angle specifies the rotation applied to a joint in its initial configuration.
  - The leaf node of a joint chain is known as the “end site” and it does not contain any animatable parameters.

BVH Data

Test.bvh

```
HIERARCHY
ROOT root
{
    OFFSET 0.00000 0.00000 0.00000
    CHANNELS 6 Xposition Yposition Zposition  Zrotation Yrotation Xrotation
    JOINT Shoulder
    {
        OFFSET 0.5  0.3  0.0
        CHANNELS 3  Zrotation Yrotation Xrotation
        JOINT Elbow
        {
            OFFSET 1.0  -0.5 0.0
            CHANNELS 3  Zrotation Yrotation Xrotation
            Joint Wrist
            {
                OFFSET 1.4 0.6 0.0
                …
```

Specifies what each channel (animatable parameter) represents.

...Continued on next slide.

BVH Representation

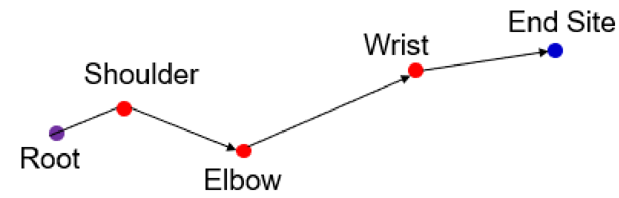
Test.bvh

MOTION

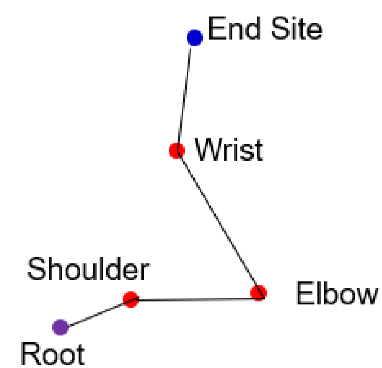
Frames: 10

Frame Time: 0.1

Root	Shoulder	Elbow	Wrist
0 0 0 0 0 0	3 0 0	8 0 0	-3 0 0
0 0 0 0 0 0	6 0 0	16 0 0	-6 0 0
0 0 0 0 0 0	9 0 0	24 0 0	-9 0 0
0 0 0 0 0 0	12 0 0	32 0 0	-12 0 0
0 0 0 0 0 0	15 0 0	40 0 0	-15 0 0
0 0 0 0 0 0	18 0 0	48 0 0	-18 0 0
0 0 0 0 0 0	21 0 0	56 0 0	-21 0 0
0 0 0 0 0 0	24 0 0	64 0 0	-24 0 0
0 0 0 0 0 0	27 0 0	72 0 0	-27 0 0
0 0 0 0 0 0	30 0 0	80 0 0	-30 0 0



Initial Configuration



Final Configuration

The above list contains 10 key frames.

A channel is a set of values of animation parameters for a single joint.

Test Model

Initial Configuration

Final Configuration

- Assimp creates a **dummy mesh** for each link of joint chains when a motion file is loaded.

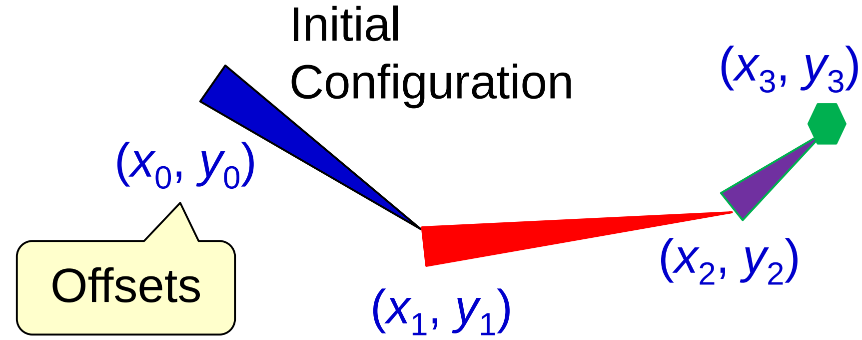
```
scene = aiImportFile  ( "Test.bvh",
aiProcessPreset_TargetRealtime_MaxQuality |
aiProcess_Debone );
```

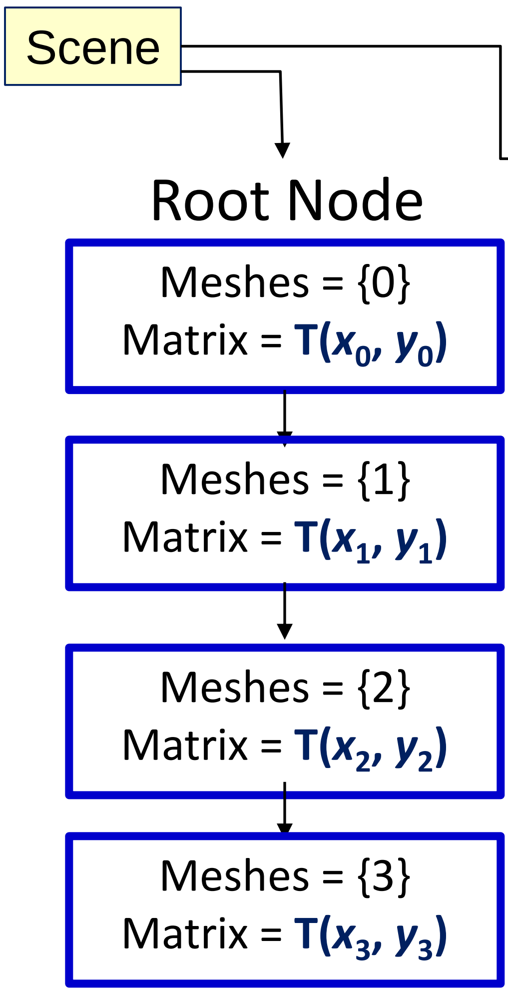
BVH – Another Example

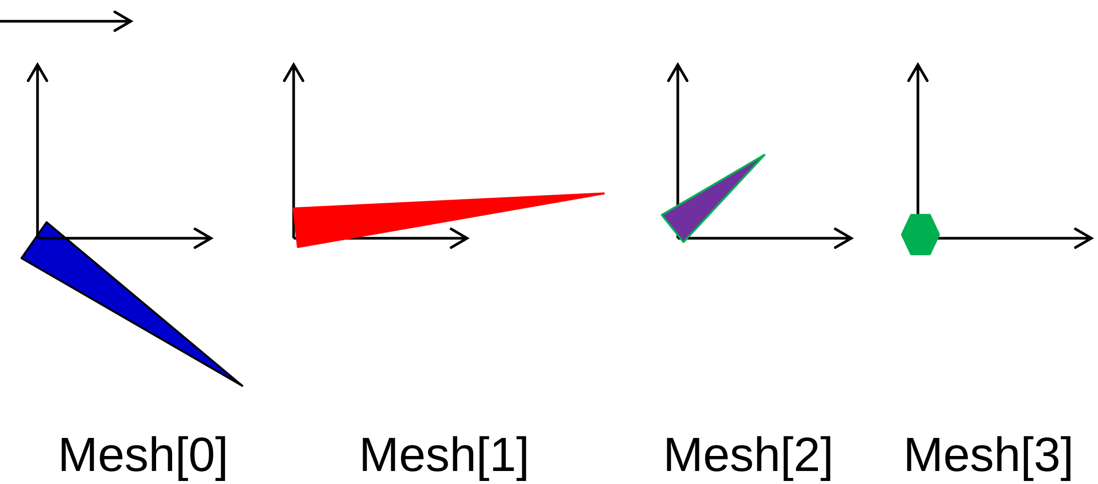
```
HIERARCHY
ROOT Hips
{
        OFFSET  0.00    0.00    0.00
        CHANNELS 6 Xposition Yposition Zposition Zrotation Xrotation Yrotation
        JOINT LeftUpLeg
        {
                OFFSET   3.430000        0.000000        0.000000
                CHANNELS 3 Zrotation Xrotation Yrotation
                JOINT LeftLowLeg
                {
                        OFFSET   0.000000        -18.469999       0.000000
                        CHANNELS 3 Zrotation Xrotation Yrotation
                        JOINT LeftFoot
                        {
                                OFFSET   0.000000        -17.950001       0.000000
                                CHANNELS 3 Zrotation Xrotation Yrotation
                                End Site
                                {
                                        OFFSET   0.000000        -3.119996        0.000000
                                }
                        }
                }
        }
        JOINT RightUpLeg
        {
                OFFSET  -3.430000        0.000000        0.000000
                CHANNELS 3 Zrotation Xrotation Yrotation
                JOINT RightLowLeg
                {
                        OFFSET   0.000000        -18.809999       0.000000
                        CHANNELS 3 Zrotation Xrotation Yrotation
                        JOINT RightFoot
                        {
                                OFFSET   0.000000        -17.570000       0.000000
                                CHANNELS 3 Zrotation Xrotation Yrotation
                                End Site
                                {
                                        OFFSET   0.000000        -3.250000        0.000000
                                }
```

Modelling a 2D Skeleton

A node hierarchy for the dummy mesh created using skeleton parameters:

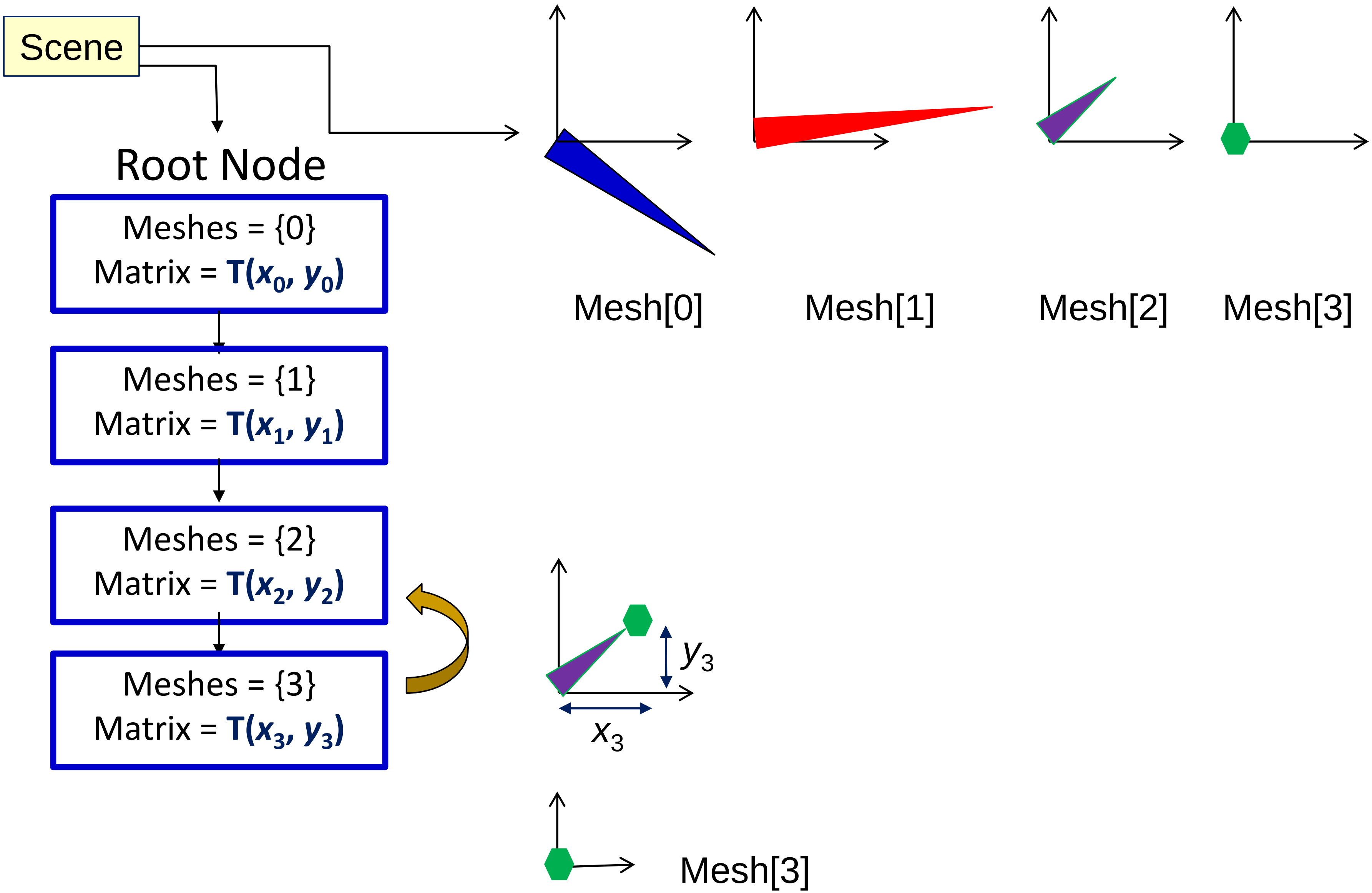




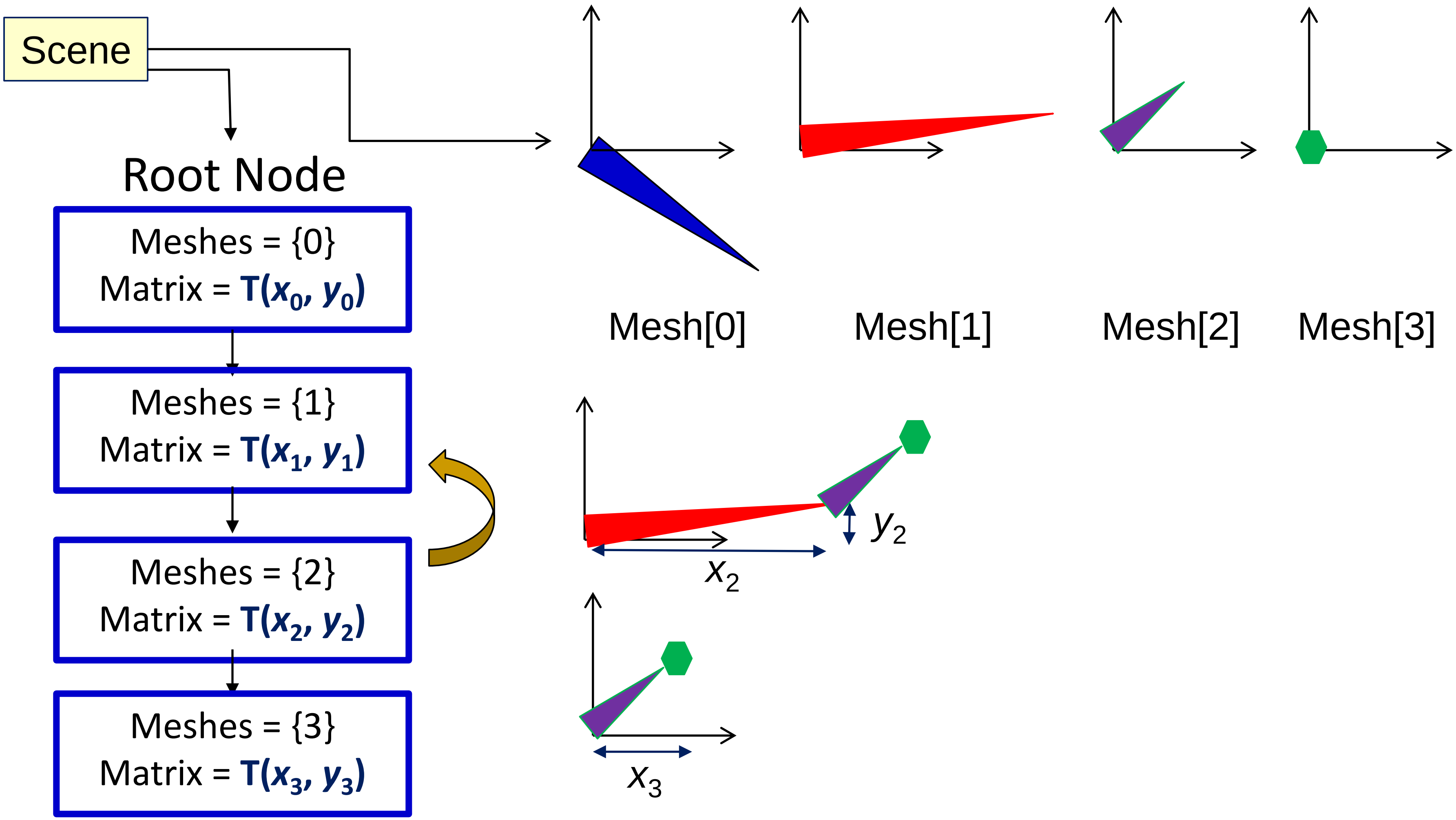


Note: The matrices give the transformation from a node's local coordinate system to its parent's coordinate system.

Modelling a 2D Skeleton



Modelling a 2D Skeleton



Modelling a 2D Skeleton

Scene

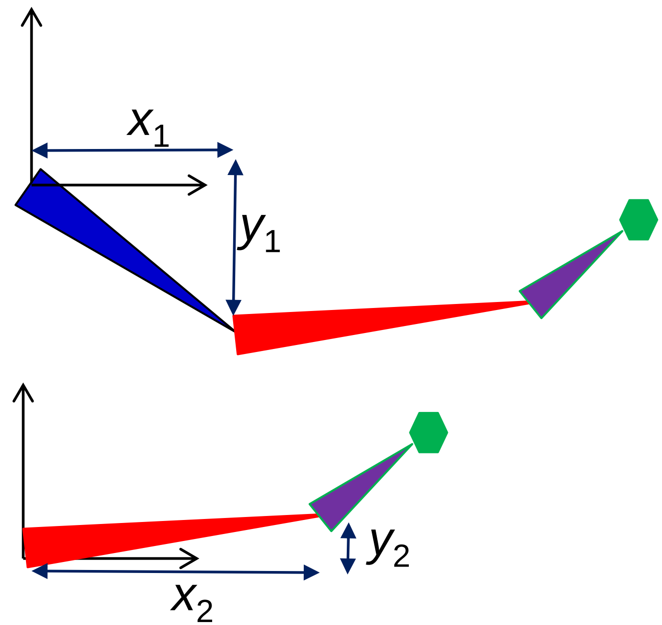
Root Node

Meshes = {0}
Matrix = **T(*x_0*, *y_0*)**

Meshes = {1}
Matrix = **T(*x_1*, *y_1*)**

Meshes = {2}
Matrix = **T(*x_2*, *y_2*)**

Meshes = {3}
Matrix = **T(*x_3*, *y_3*)**



Modelling a 2D Skeleton

Scene

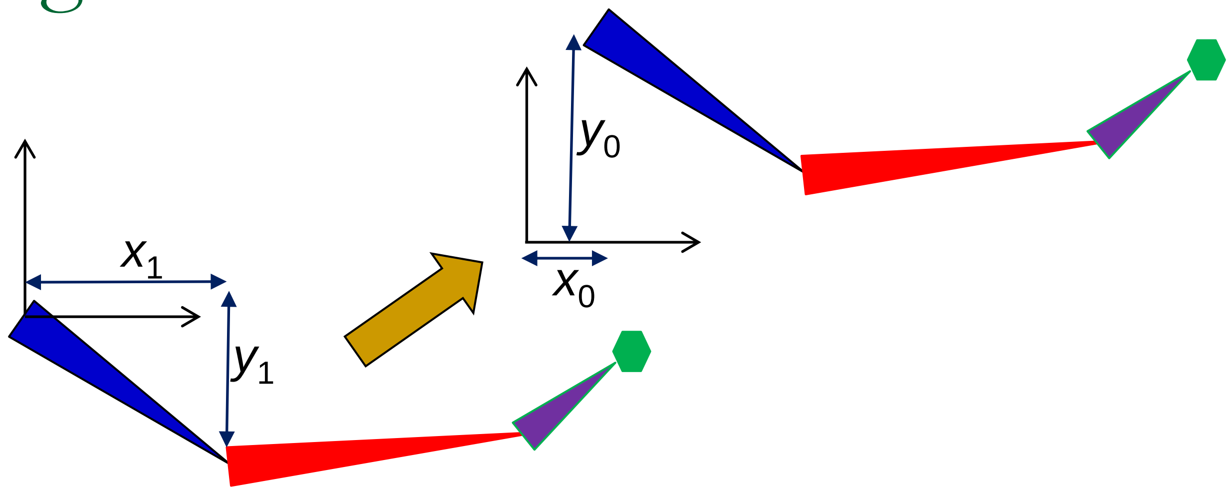
Root Node

Meshes = {0}
Matrix = **T(x_0, y_0)**

Meshes = {1}
Matrix = **T(x_1, y_1)**

Meshes = {2}
Matrix = **T(x_2, y_2)**

Meshes = {3}
Matrix = **T(x_3, y_3)**



Animating a 2D Skeleton

Each mesh is moved by transformations defined using animatable parameters:

Root Node

Meshes = {0}
Matrix = $\mathbf{T}(x_0, y_0)\ \mathbf{R}(\theta_0)$

↓

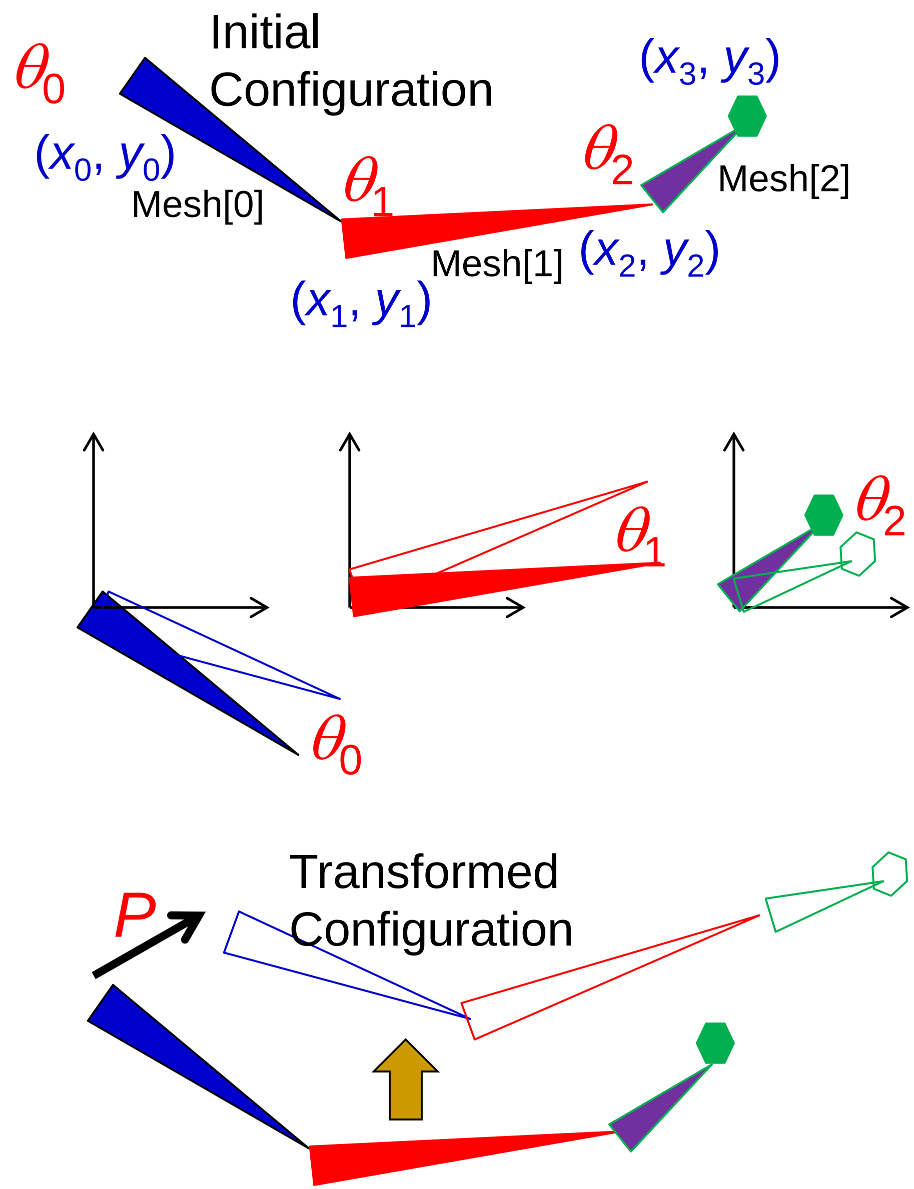
Meshes = {1}
Matrix = $\mathbf{T}(x_1, y_1)\ \mathbf{R}(\theta_1)$

↓

Meshes = {2}
Matrix = $\mathbf{T}(x_2, y_2)\mathbf{R}(\theta_2)$

↓

Meshes = {3}
Matrix = $\mathbf{T}(x_3, y_3)$



The combined transformation matrix for mesh[1] is $\mathbf{T}(x_0, y_0)\ \mathbf{T}(\mathbf{P})\mathbf{R}(\theta_0)\mathbf{T}(x_1, y_1)\ \mathbf{R}(\theta_1)$

Animating a Skeleton

- Assimp creates a dummy mesh as shown on previous slides when a BVH file is loaded.
- The mesh can be animated only if it is "segmented" (i.e., the mesh for each link is assigned to a separate node as shown on previous slide, so that each link can be independently transformed using its animatable parameters).
- Please make sure that you use Assimp post process flag *aiProcess_Debone* when loading a BVH file:

```
scene = aiImportFile  ( fileName,
aiProcessPreset_TargetRealtime_MaxQuality |
aiProcess_Debone );
```

Ticks

Test.bvh

Ticks are equally spaced markers along the time axis.
In a BVH file, each keyframe corresponds to a tick and can be used as an index to keyframes.

```
MOTION
Frames: 10
Frame Time: .1
0 0 0 0 0 0   3 0 0    8 0 0    -3 0 0     Tick 0
0 0 0 0 0 0   6 0 0    16 0 0   -6 0 0
0 0 0 0 0 0   9 0 0    24 0 0   -9 0 0
0 0 0 0 0 0   12 0 0   32 0 0   -12 0 0
0 0 0 0 0 0   15 0 0   40 0 0   -15 0 0
0 0 0 0 0 0   18 0 0   48 0 0   -18 0 0
0 0 0 0 0 0   21 0 0   56 0 0   -21 0 0
0 0 0 0 0 0   24 0 0   64 0 0   -24 0 0
0 0 0 0 0 0   27 0 0   72 0 0   -27 0 0
0 0 0 0 0 0   30 0 0   80 0 0   -30 0 0    Tick 9
```

Ticks

Test.bvh

In the previous example,

Duration (ticks) = Frames–1 = 9

Ticks per sec = 1/(Frame Time) = 10

The animation speed or frame rate is determined by “Ticks per sec”.

For example, if you require an animation speed of 30 frames per sec, you should set the “Frame Time” in the BVH file as 0.033

We can access animation parameters from motion data as follows:

channel

0 0 0 0 0 0	3 0 0	8 0 0	-3 0 0
0 0 0 0 0 0	6 0 0	16 0 0	-6 0 0
0 0 0 0 0 0	9 0 0	24 0 0	-9 0 0
0 0 0 0 0 0	12 0 0	32 0 0	-12 0 0
0 0 0 0 0 0	15 0 0	40 0 0	-15 0 0

tick

```
channel->mRotationKeys[tick].mValue
```

Assimp Classes

- Animation Object (aiAnimation)
  - **Array of Channels**: anim->mChannels
  - **Ticks per Second:** anim->mTicksPerSecond
  - **Duration in Ticks:** anim->mDuration
- Channels (aiNodeAnim): A channel is also known as an animation node.
  - The first channel corresponding to “Shoulder” is obtained as anim->mChannels[0], “Elbow” anim->mChannels[1], etc.
  - **Channel’s position Keys**: channel->mPositionKeys
  - **Channel’s rotation Keys:** channel->mRotationKeys.
  - Each channel has a name (channel->mNodeName) that corresponds to a joint’s name.

Assimp Output for **Test.bvh**

- Number of animations (scene->mNumAnimations): 1
- Animation object (anim): scene->mAnimations[0]
- Number of channels (anim->mNumChannels): 3
- Animation duration in ticks (anim->mDuration): 9
- Number of ticks per sec (anim->mTicksPerSecond): 10

Please refer to the `printAnimInfo()` function of "assimp_extras.h" for examples of Assimp expressions used for accessing animation/channel parameters.

Position and Rotation Keys

MOTION

Frames: 10

Frame Time: .1

	Shoulder	Elbow	Wrist
0 0 0 0 0 0	3 0 0	8 0 0	-3 0 0
0 0 0 0 0 0	6 0 0	16 0 0	-6 0 0
0 0 0 0 0 0	9 0 0	24 0 0	-9 0 0
0 0 0 0 0 0	12 0 0	32 0 0	-12 0 0
0 0 0 0 0 0	15 0 0	40 0 0	-15 0 0
0 0 0 0 0 0	18 0 0	48 0 0	-18 0 0
0 0 0 0 0 0	21 0 0	56 0 0	-21 0 0
0 0 0 0 0 0	24 0 0	64 0 0	-24 0 0
0 0 0 0 0 0	27 0 0	72 0 0	-27 0 0
0 0 0 0 0 0	30 0 0	80 0 0	-30 0 0

The values of rotation keys are stored as **quaternions**.

Assimp Output

Channel: 0 Name: Shoulder
posKey 0: Value = 0.1 0 0
...
posKey 9: Value = 1 0.18 0
rotnKey 0: Value = 0.99 0 0 0.04
...
rotnKey 9: Value = 0.91 0 0 0.42
Channel: 1 Name: Elbow
posKey 0: Value = 2 0 0
rotnKey 0: Value = 0.99 0 0 0.08
...
rotnKey 9: Value = 0.64 0 0 0.76
Channel 2: Name = Wrist
posKey 0: Value = 1.5 0 0
rotnKey 0: Value = 0.99 0 0 0.07
...
rotnKey 9: Value = 0.76 0 0 0.64

Position and Rotation Keys

- Number of position keys of the first channel: 10
- Number of rotation keys of the first channel: 10
- Number of position keys of the second channel: 1
- Number of rotation keys of the second channel: 10

Important Notes:

If a position key has the same set of values for all ticks, then there will be only one key. Similarly, if the angles for a channel have the same values for all ticks, there will be only one rotation key.

For the second and subsequent channels, there will be only one position key which is the joint's offset value.

Animating a Skeleton

Initial Configuration	Transformed Configuration
Root Node	Root Node
Meshes = {0} Matrix = $T(x_0, y_0)$	Meshes = {0} Matrix = $T(x_0, y_0)\ T(P)R(\theta_0)$
Meshes = {1} Matrix = $T(x_1, y_1)$	Meshes = {1} Matrix = $T(x_1, y_1)\ R(\theta_1)$
Meshes = {2} Matrix = $T(x_2, y_2)$	Meshes = {2} Matrix = $T(x_2, y_2)R(\theta_2)$
Meshes = {3} Matrix = $T(x_3, y_3)$	Meshes = {3} Matrix = $T(x_3, y_3)$

Position Key

Rotation Key

Animation Using BVH Data

- Use a timer function for animation:

```
glutTimerFunc(timeStep, update, 0);
```

- The timer callback function updates “tick”:

```
void update(int value) {
    if (tick > tDuration) return;
    updateNodeMatrices(tick);
    glutTimerFunc(timeStep, update, 0);
    tick++;
    glutPostRedisplay();
}
```

- For each channel *i*, get the values of position and rotation keys:

Check if valid

```
anim = scene->mAnimations[0];
chnl = anim->mChannels[i];
posn = chnl->mPositionKeys[tick].mValue;
rotn = chnl->mRotationKeys[tick].mValue;
```

aiVector3D

aiQuaternion

Animation Using BVH Data

- Convert the values of keys to matrices and construct the product matrix (position * rotation):

aiMatrix4x4

aiMatrix3x3

```
matPos.Translation(posn, matPos);
matRotn3 = rotn.GetMatrix();
matRot = aiMatrix4x4(matRotn3);
matprod = matPos * matRot;
```

- Find the node with the same name as the channel:

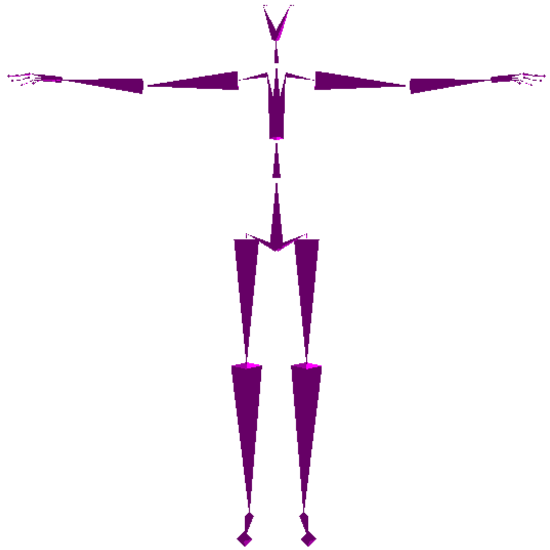
```
node = scene->mRootNode->FindNode(chnl->mNodeName);
```

- Replace the node's transformation matrix with the product matrix obtained above. Repeat this for every channel.

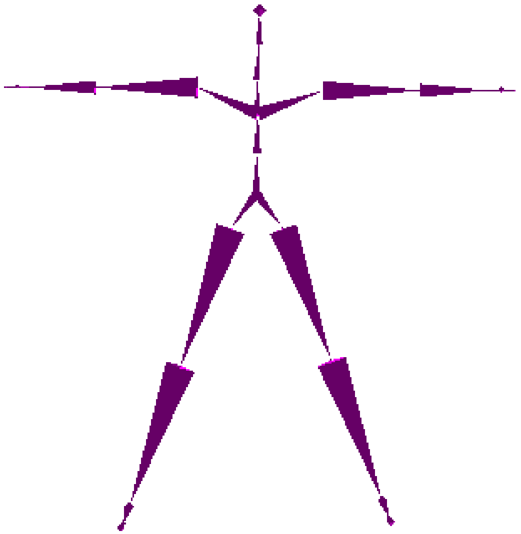
Ex. 15

Human Model Skeletons

3DS Max



DAZ-Studio



Motion Builder

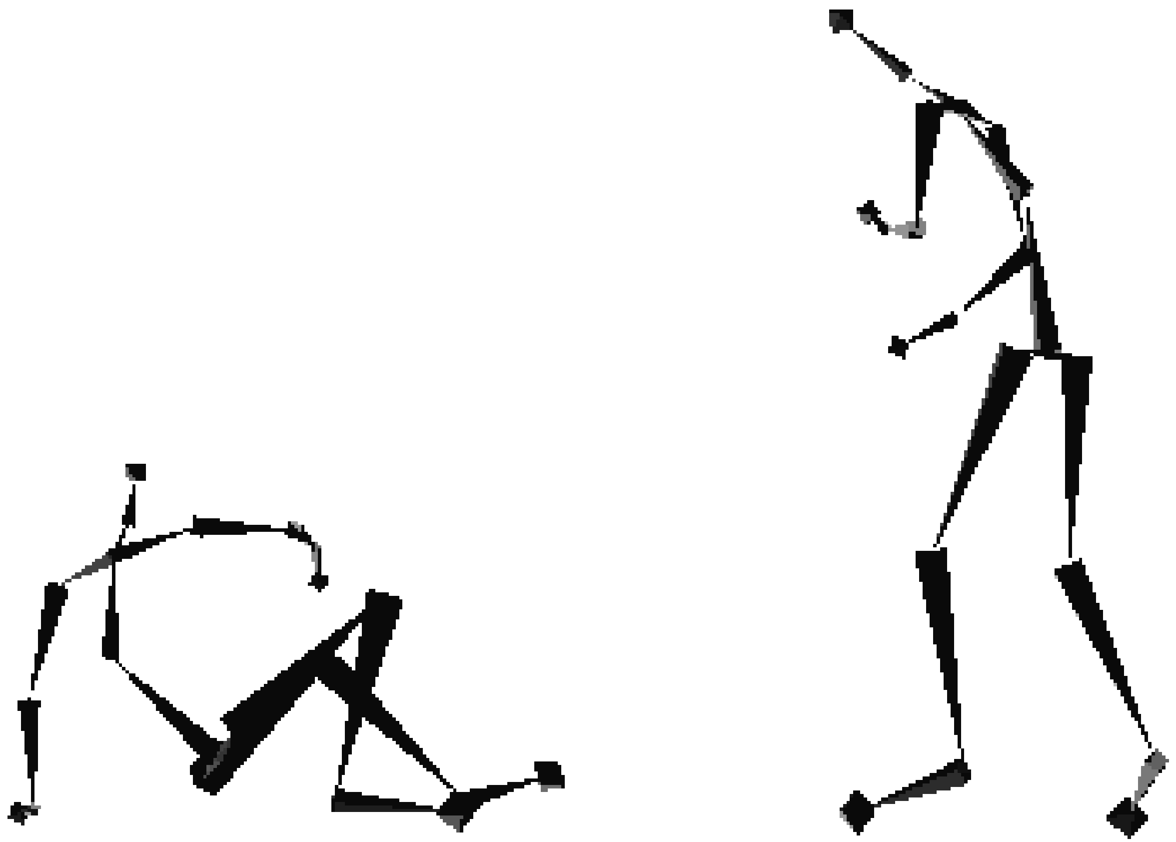
- BVH Repository:

https://sites.google.com/a/cgspeed.com/cgspeed/motion-capture

This page contains links and information about Motion Capture software and datasets.

BVH conversions of the 2500-motion Carnegie-Mellon motion capture dataset:

1. **Daz-friendly version** (released July 2010, by B. Hahne)
2. **3dsMax-friendly version** (released May 2009, by B. Hahne)
3. **MotionBuilder-friendly version** (released July 2008, by B. Hahne)



Boxing.bvh