
Skeletal Animation

关节动画

北京大学 前沿计算研究中心

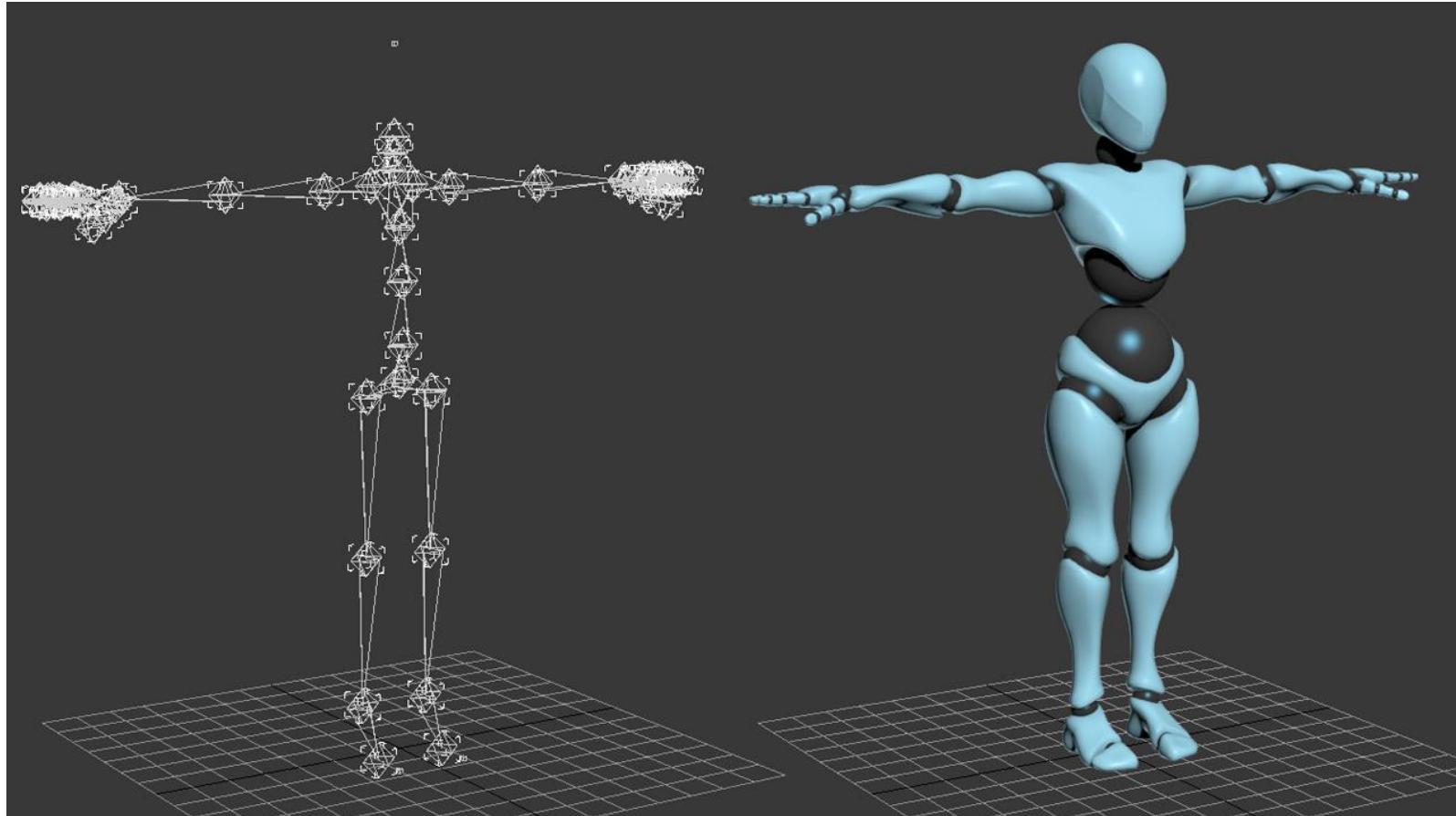
刘利斌





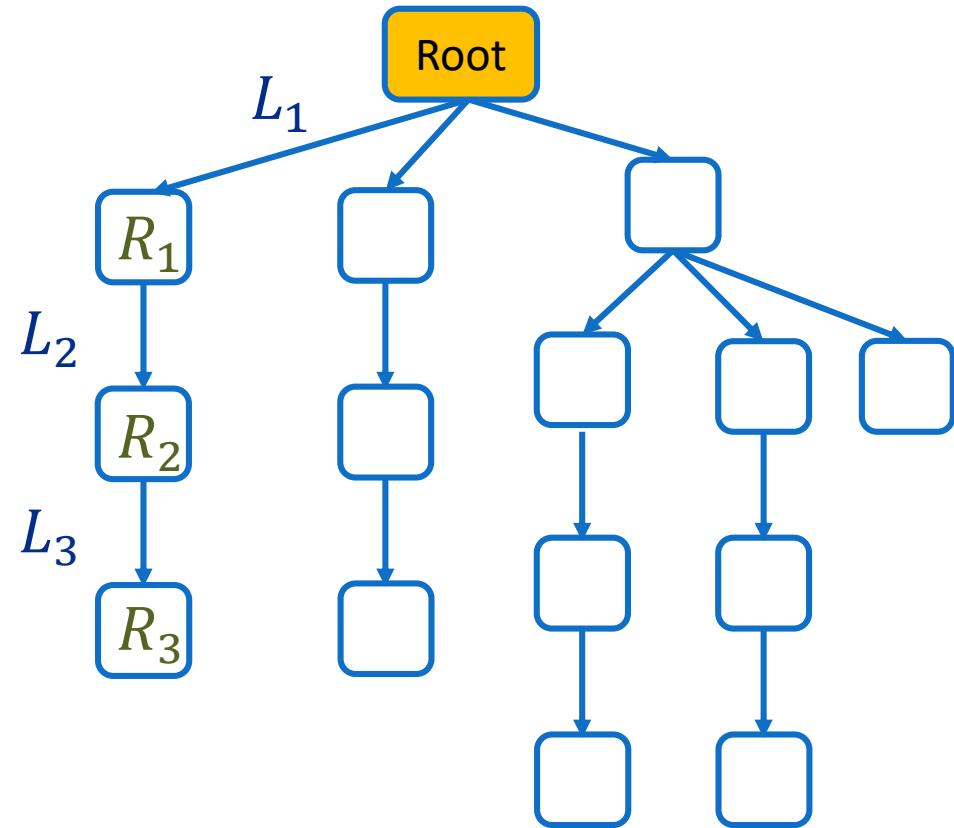
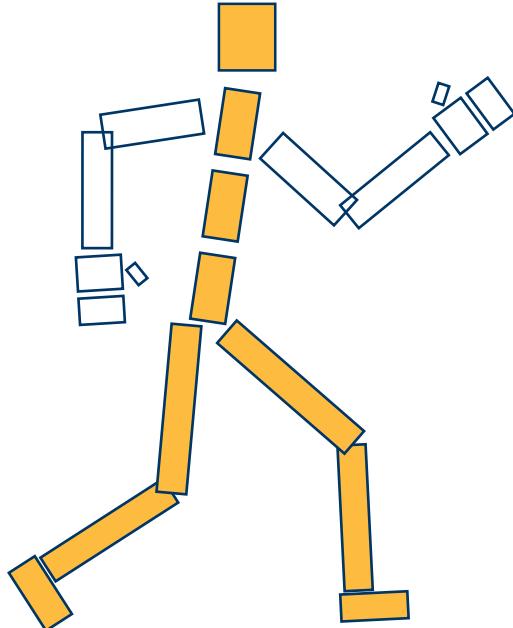
骨骼系统

- 用关节(joint) 链接的刚性骨骼 (bone/link) 系统



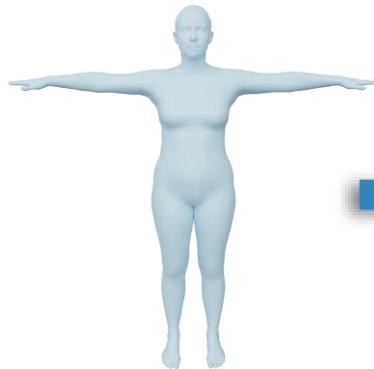
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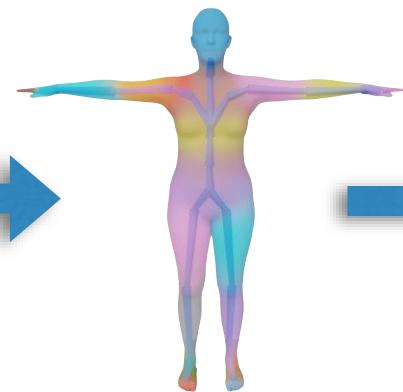


角色动画流程

人物模型



蒙皮绑定

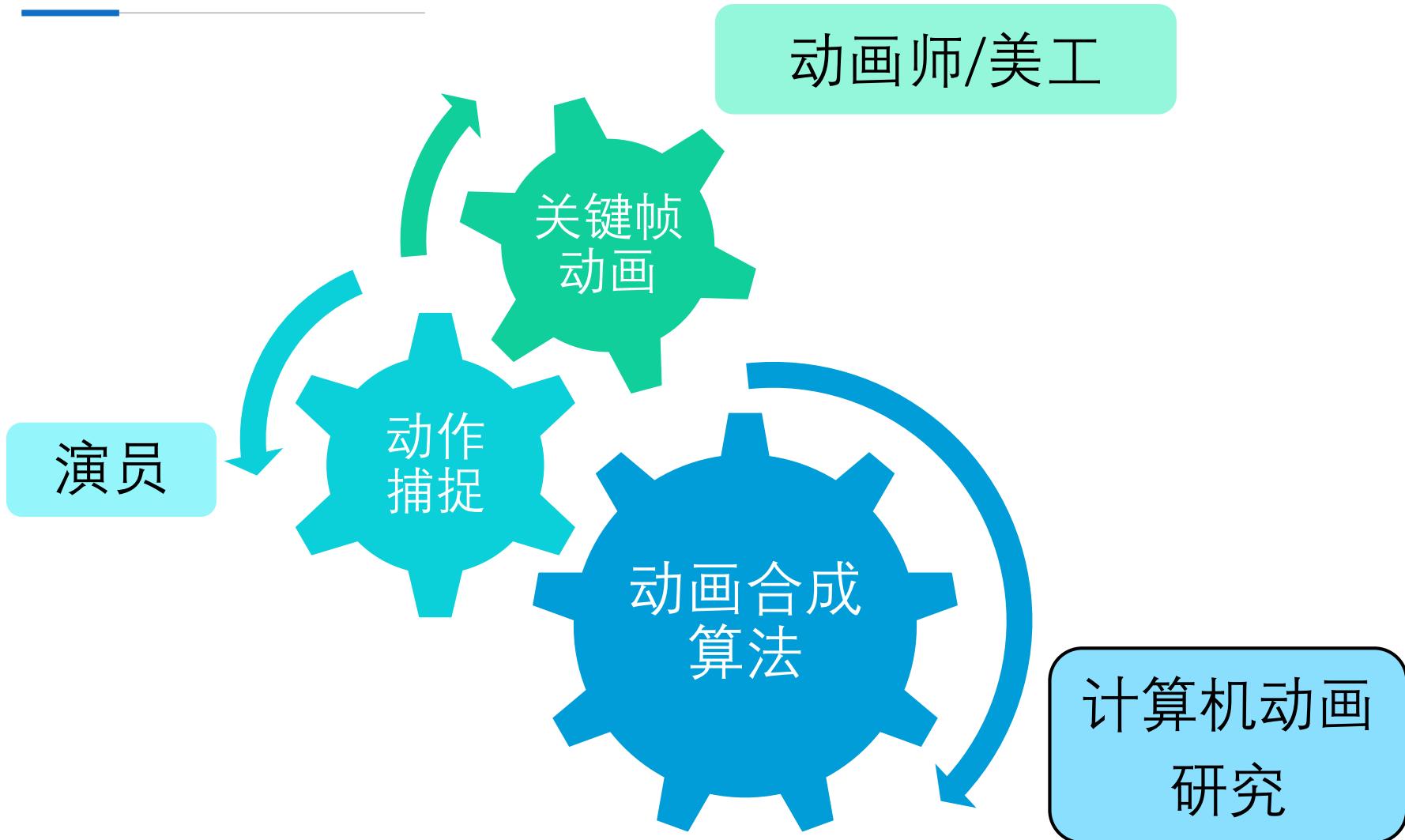


角色动画



骨骼动画

角色动画的制作



相关问题

- 3D关键帧动画
- FK/IK
- 动作捕捉
- 动作重定向
- 动作合成
- 蒙皮
- 绑定
- 仿真

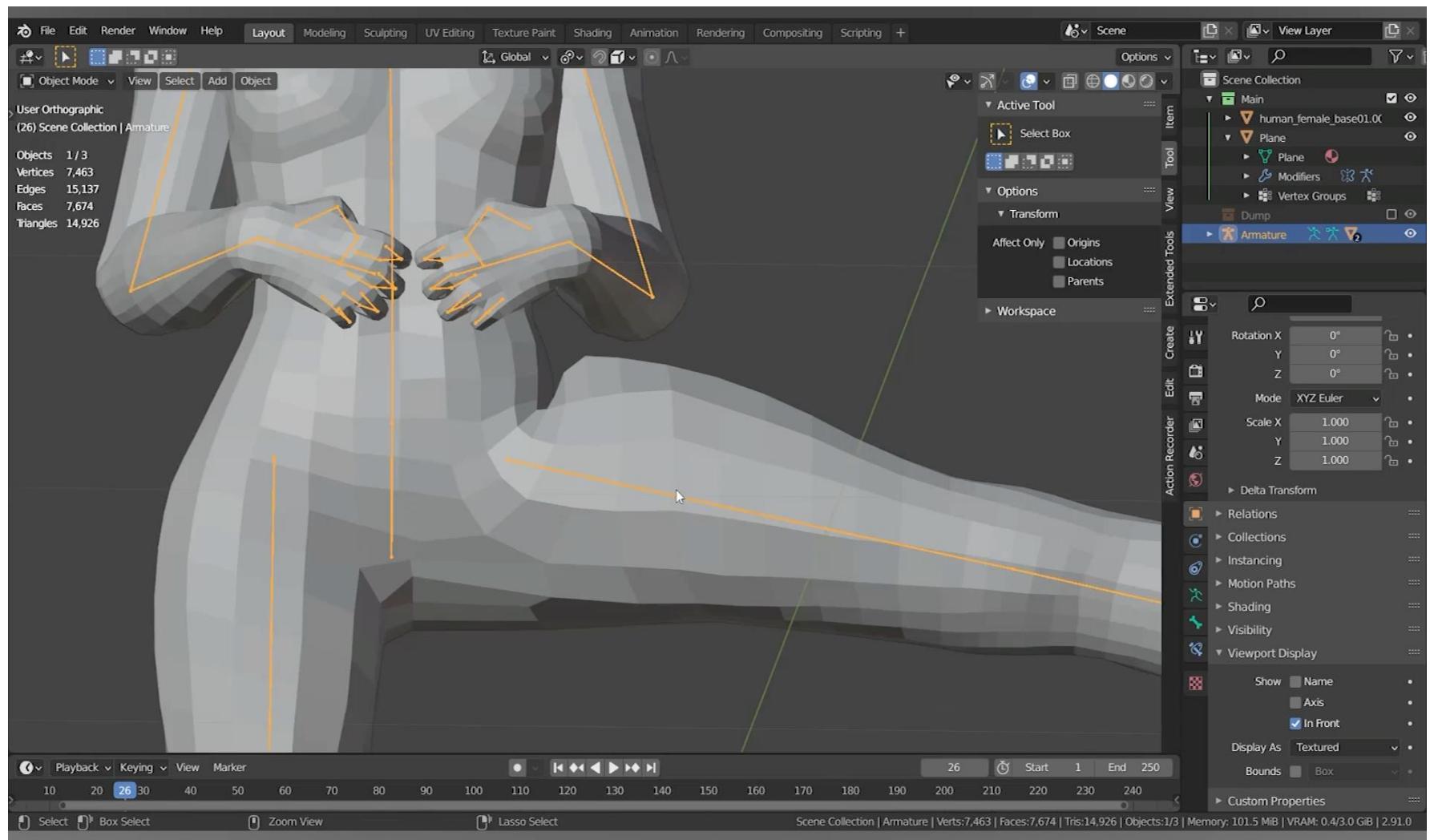
关键帧骨骼动画



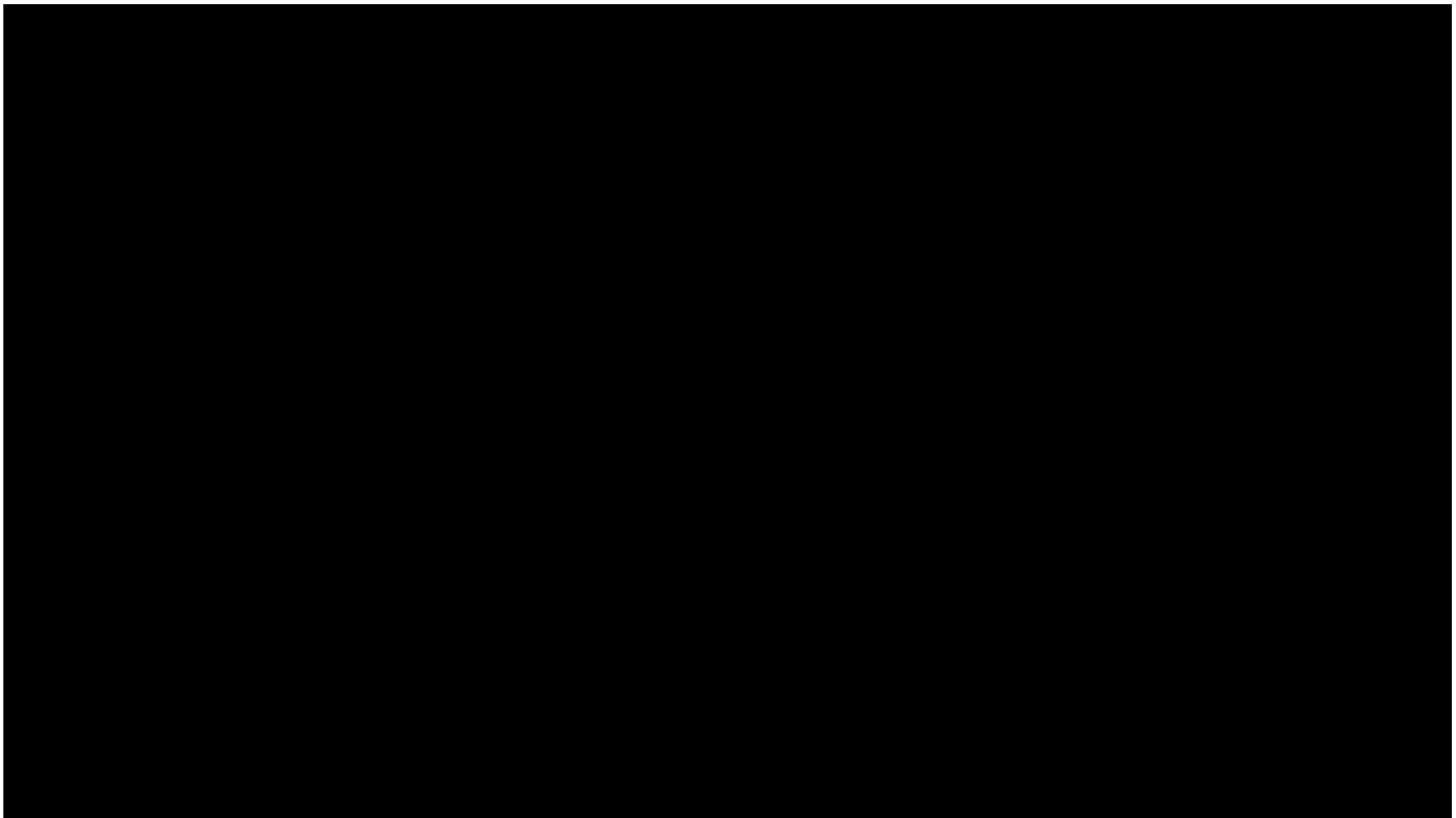


How to Animate 3D Characters in 1 Minute
<https://www.youtube.com/watch?v=TjJLluFKA20>

蒙皮



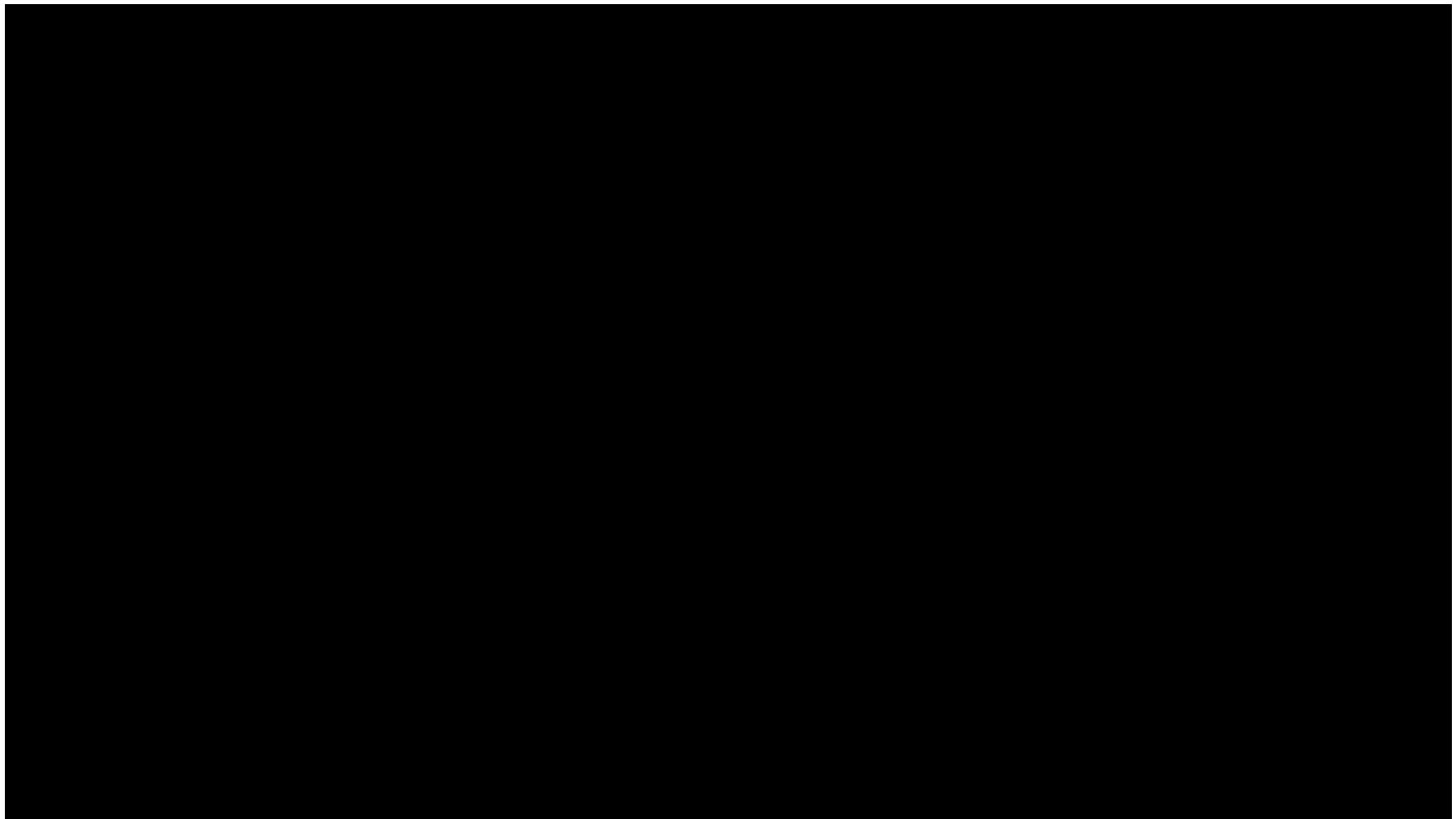
绑定



Human Body Rig in Blender

<https://www.youtube.com/watch?v=MAM7mF2v7dE>

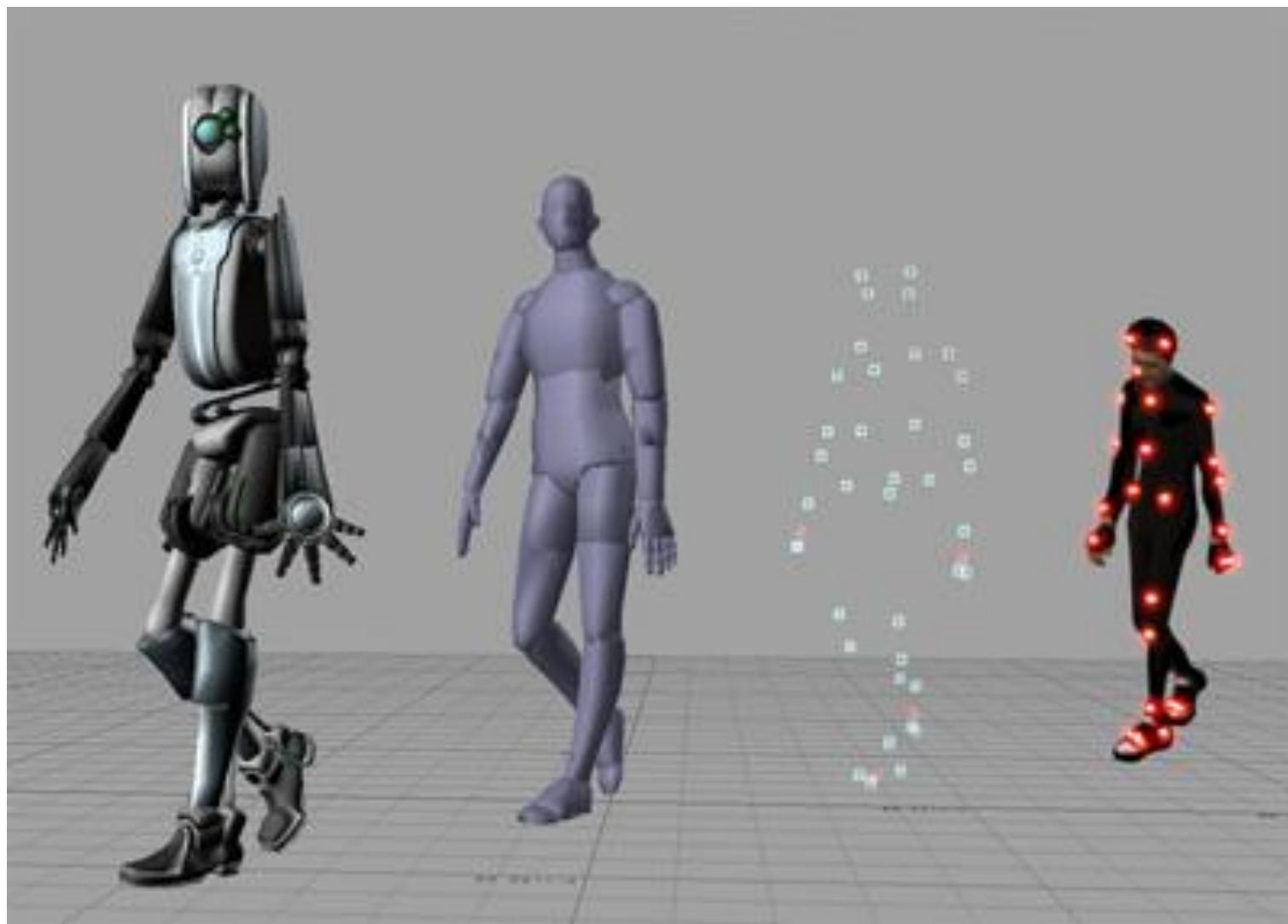
绑定



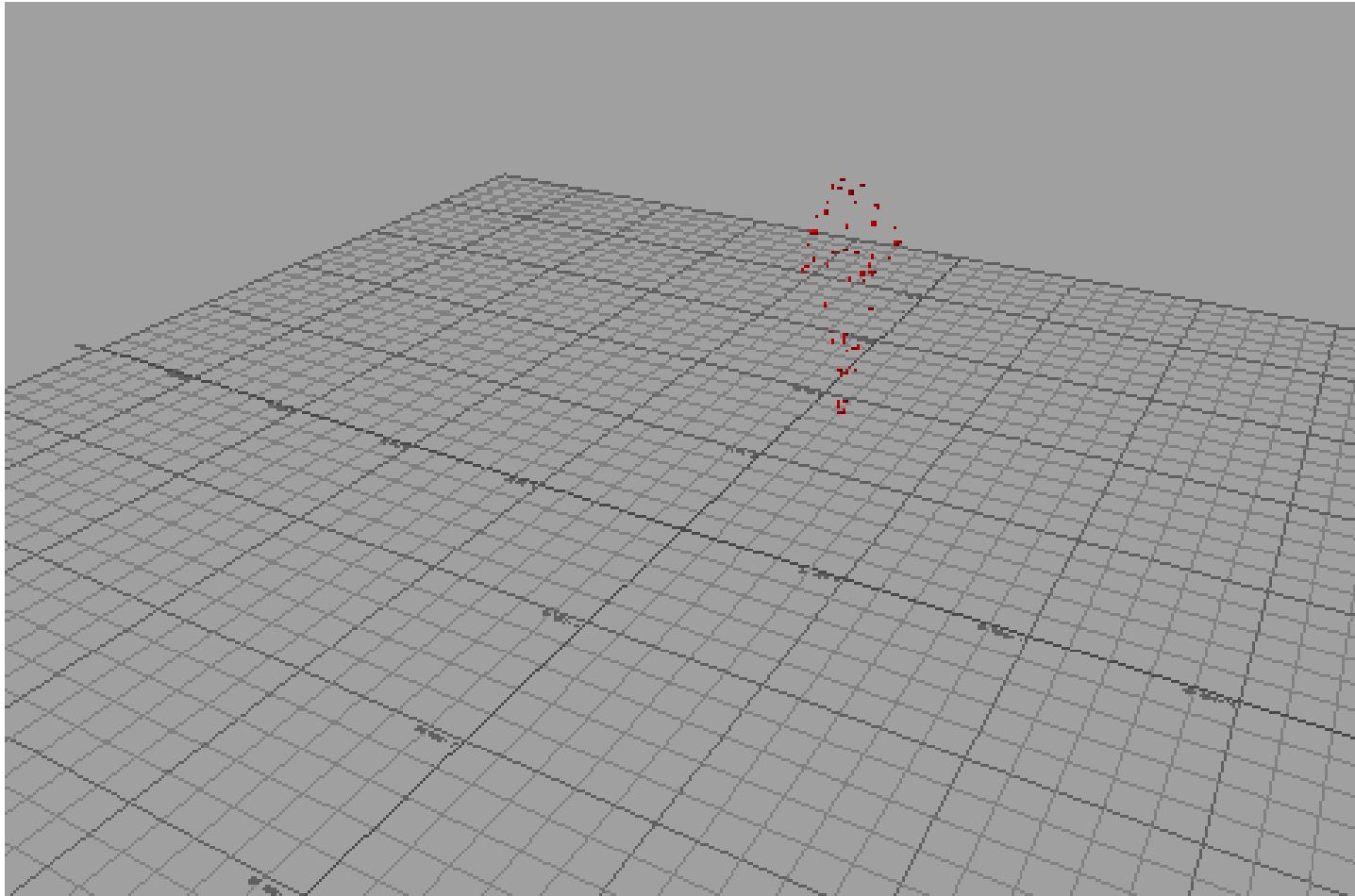
Face Rig

<https://www.youtube.com/watch?v=ueYtM2KprqY>

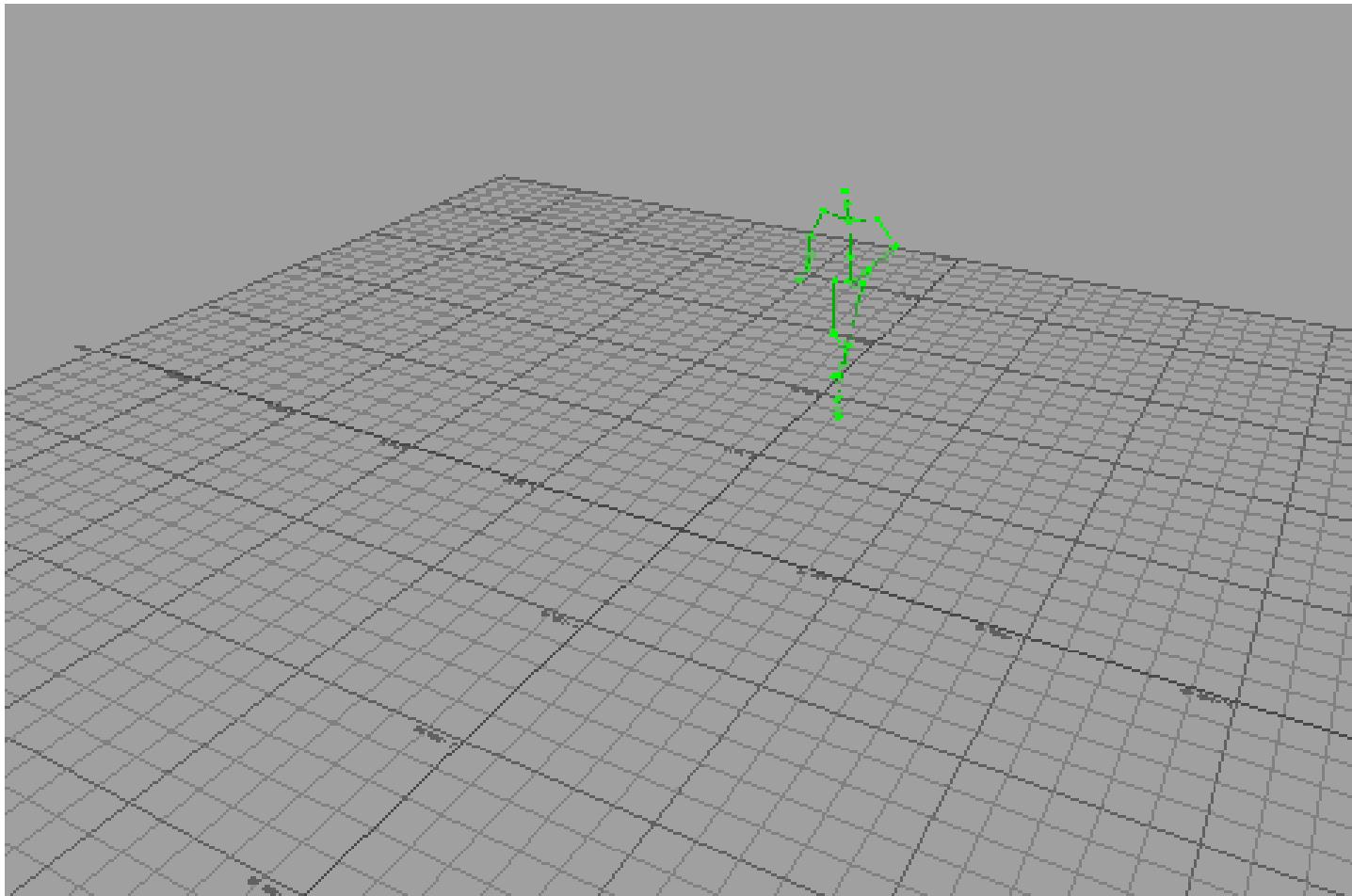
动作捕捉



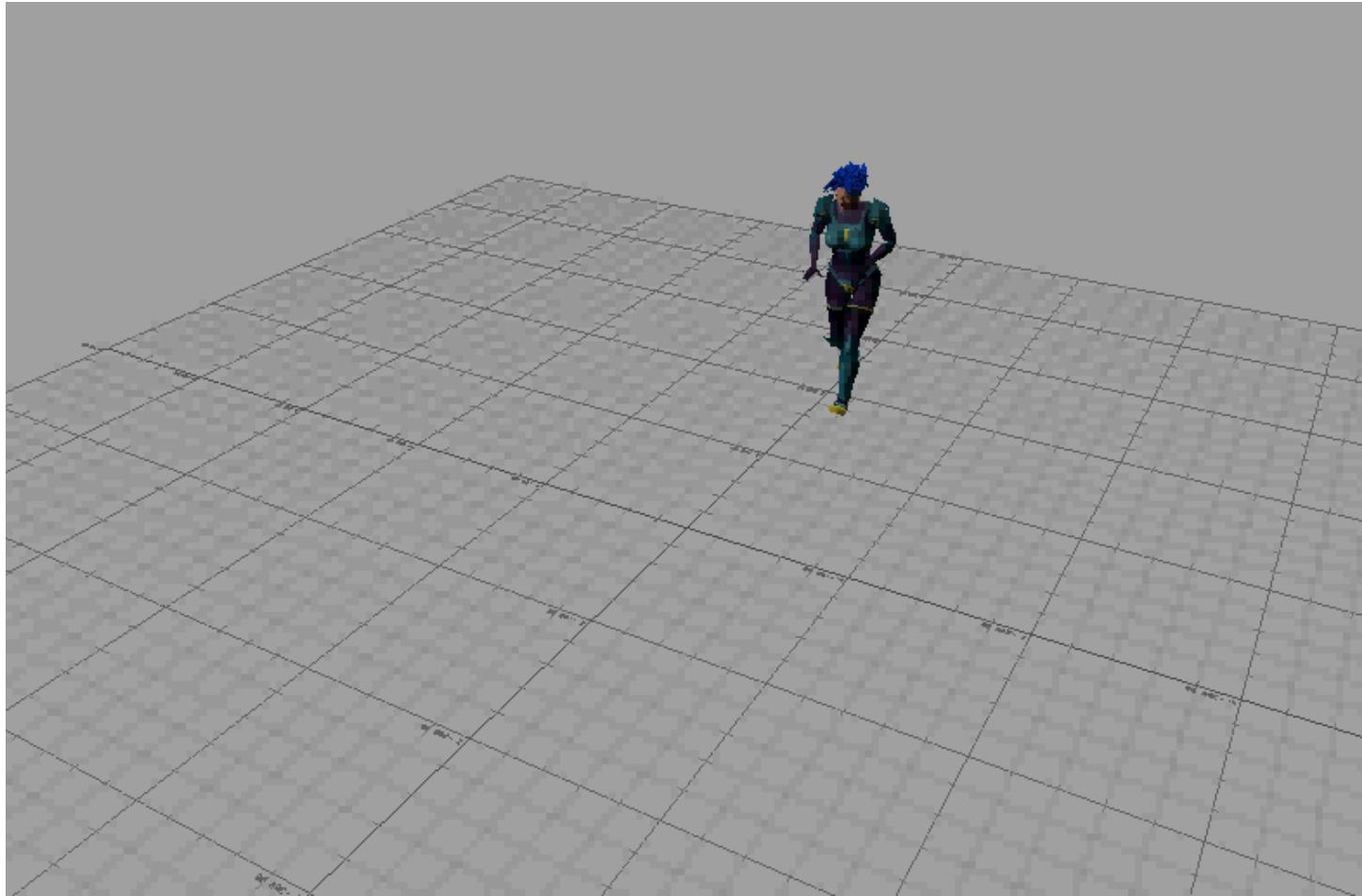
Marker Data (.c3d)



Skeletal Animation (.bvh)

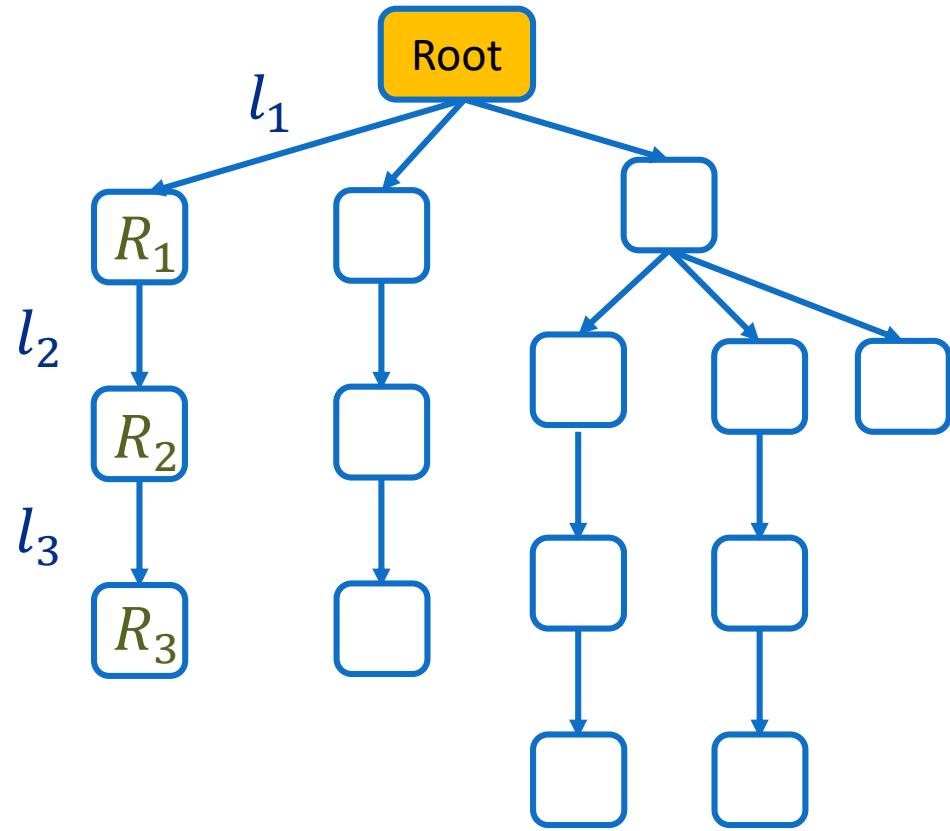
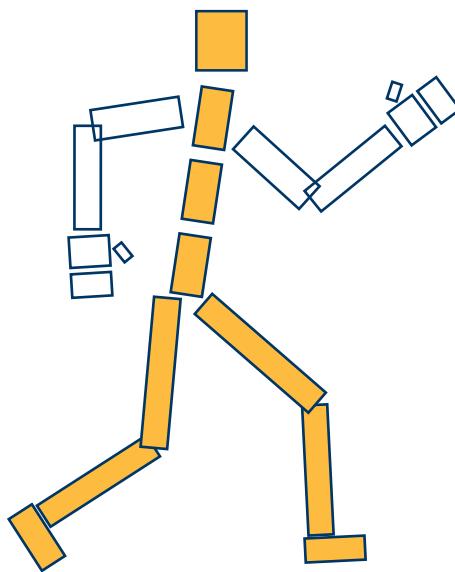


Skinning (.fbx)



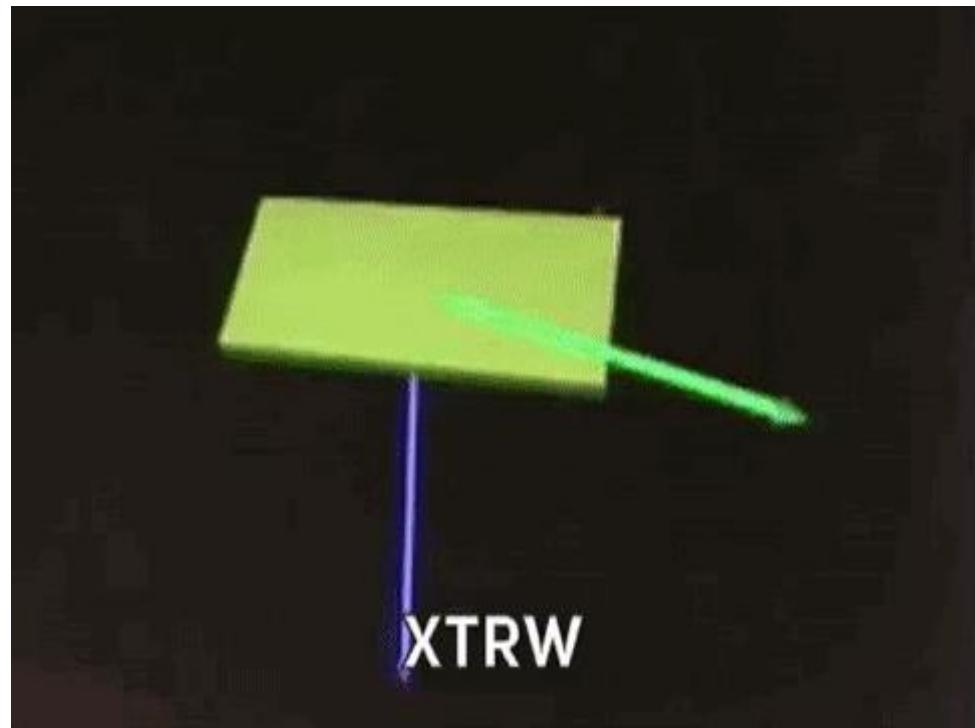
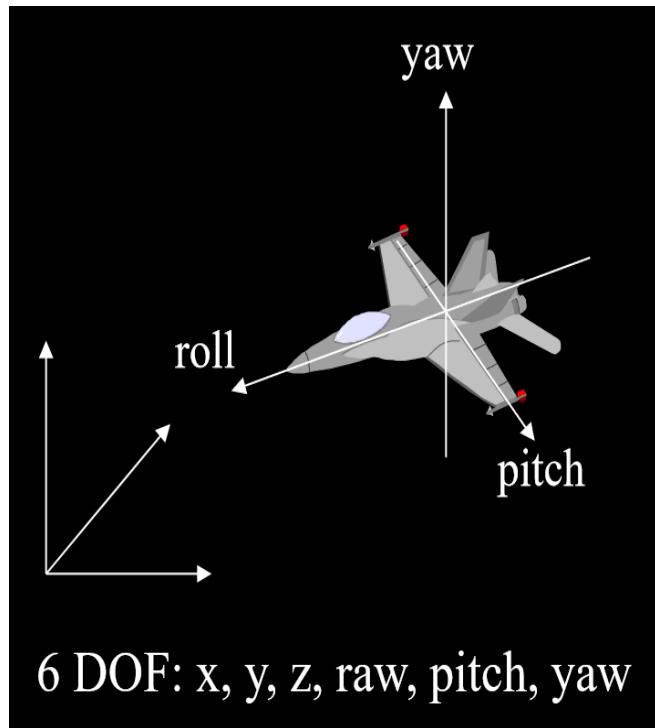
骨骼系统的表示

- 用关节(joint) 链接的刚性骨骼 (bone/link) 系统
 - 树结构
 - 节点代表关节
 - 边代表骨骼



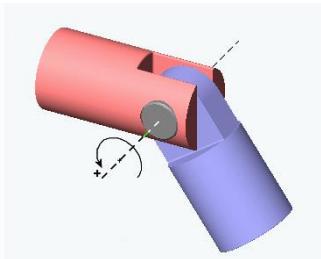
关节模型

- 自由度 (degrees of freedom, DoF)：
 - 完全指定一个物体运动所需的最小参数数量

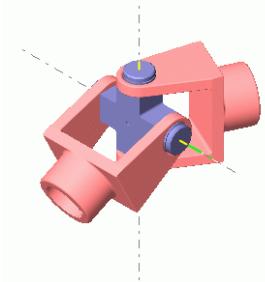


关节模型

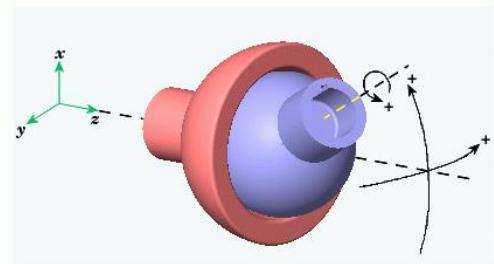
- 几种常见的关节



Hinge joint
Revolute joint



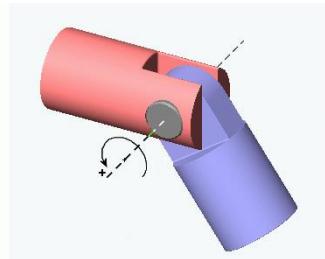
Universal joint



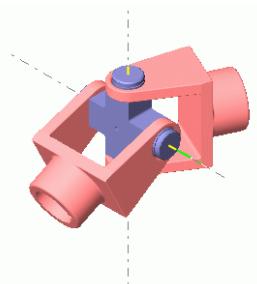
Ball-and-socket

关节模型

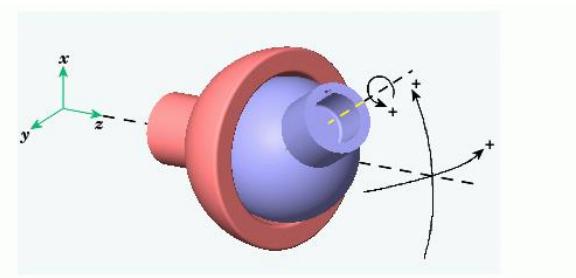
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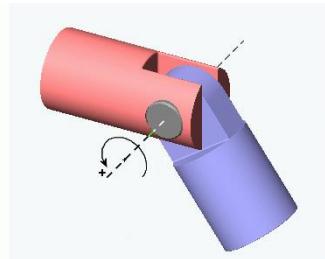


Ball-and-socket

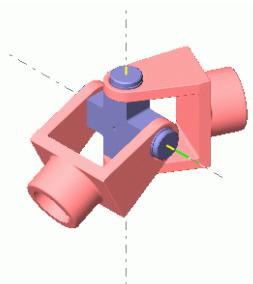


关节模型

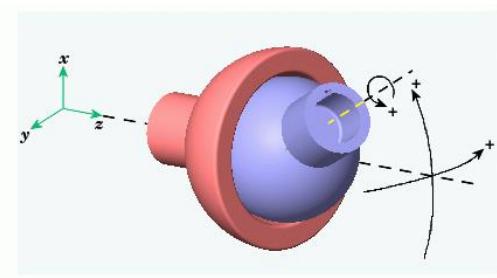
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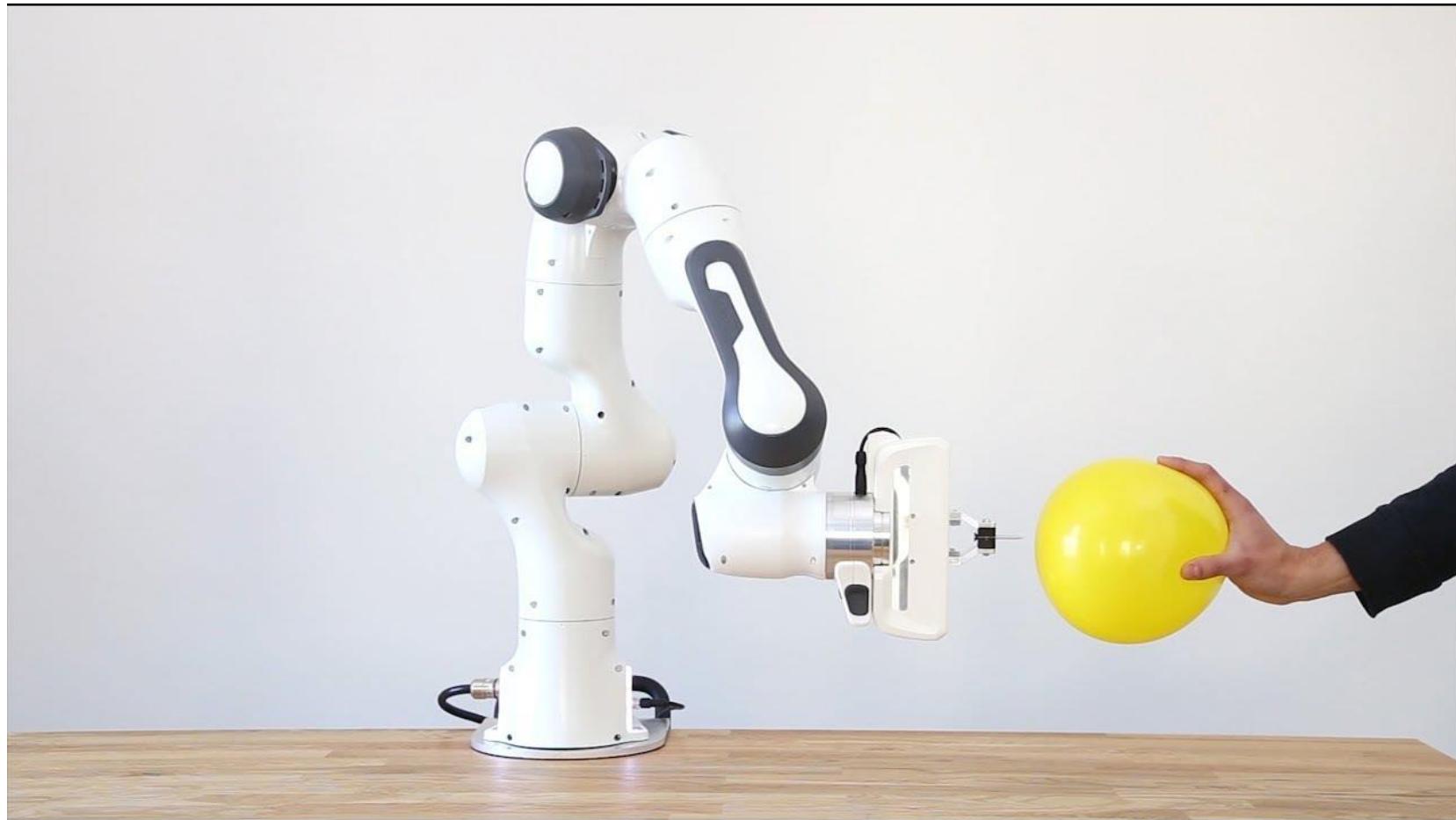
Universal joint



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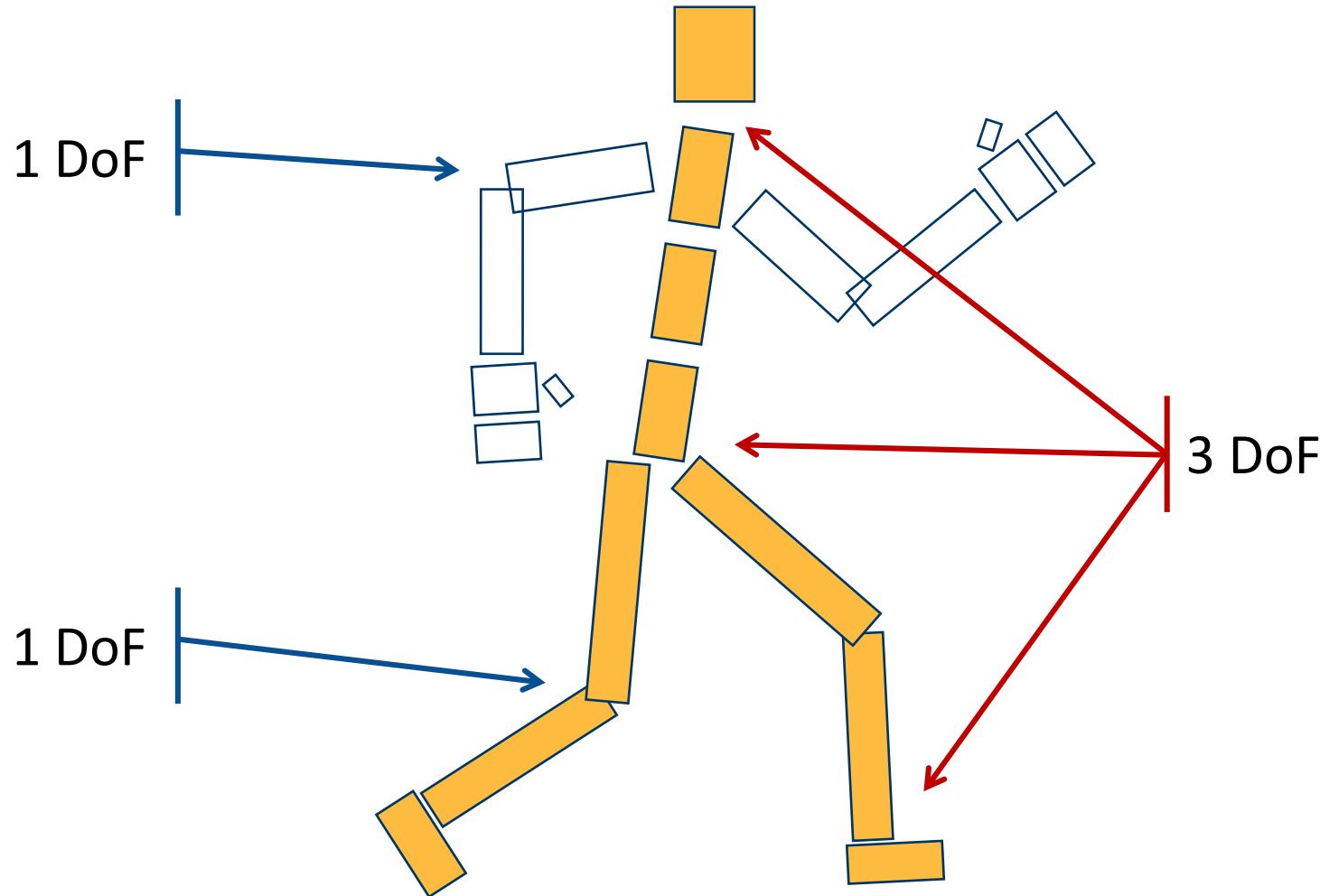
关节模型



关节模型

LIMS2 - AMBIDEX
Mechanical Design

骨骼系统的表示

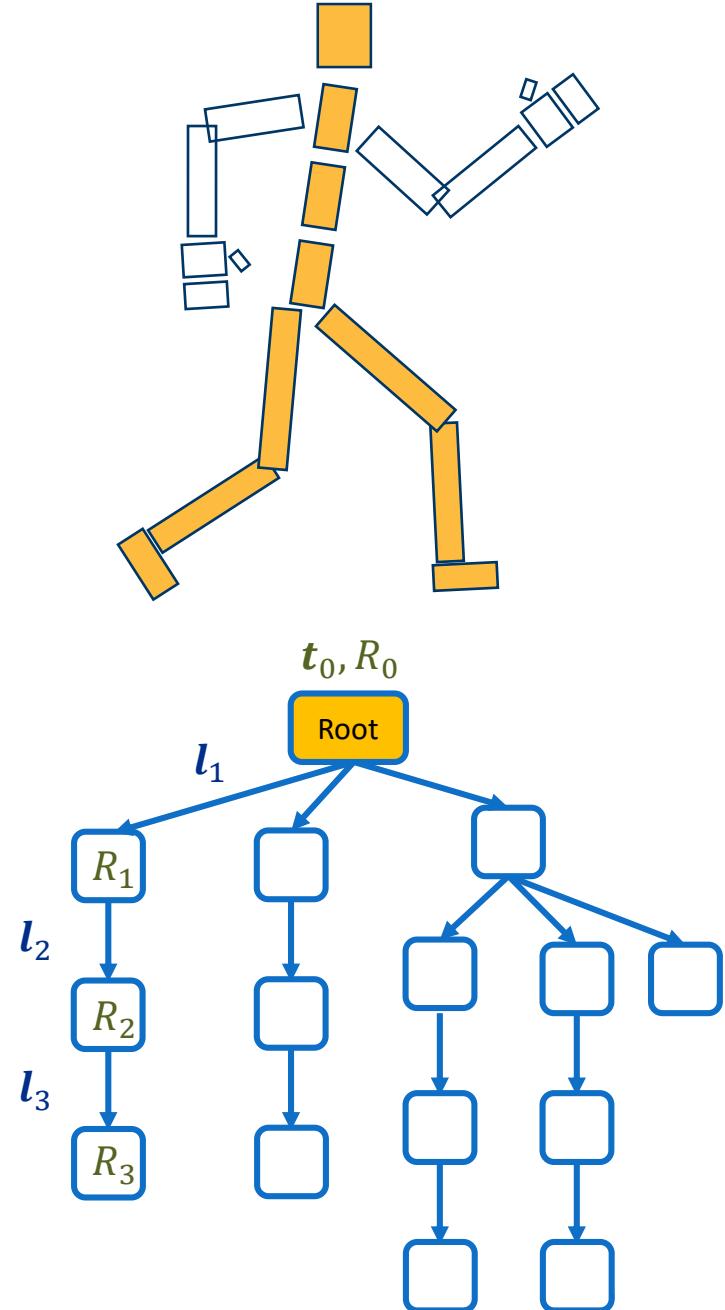


姿势与动作表示

- 姿势 (Pose) 可以表示为

$$(\mathbf{t}_0, R_0, R_1, R_2, \dots \dots)$$

root	internal joints
全局位置	局部关节旋转

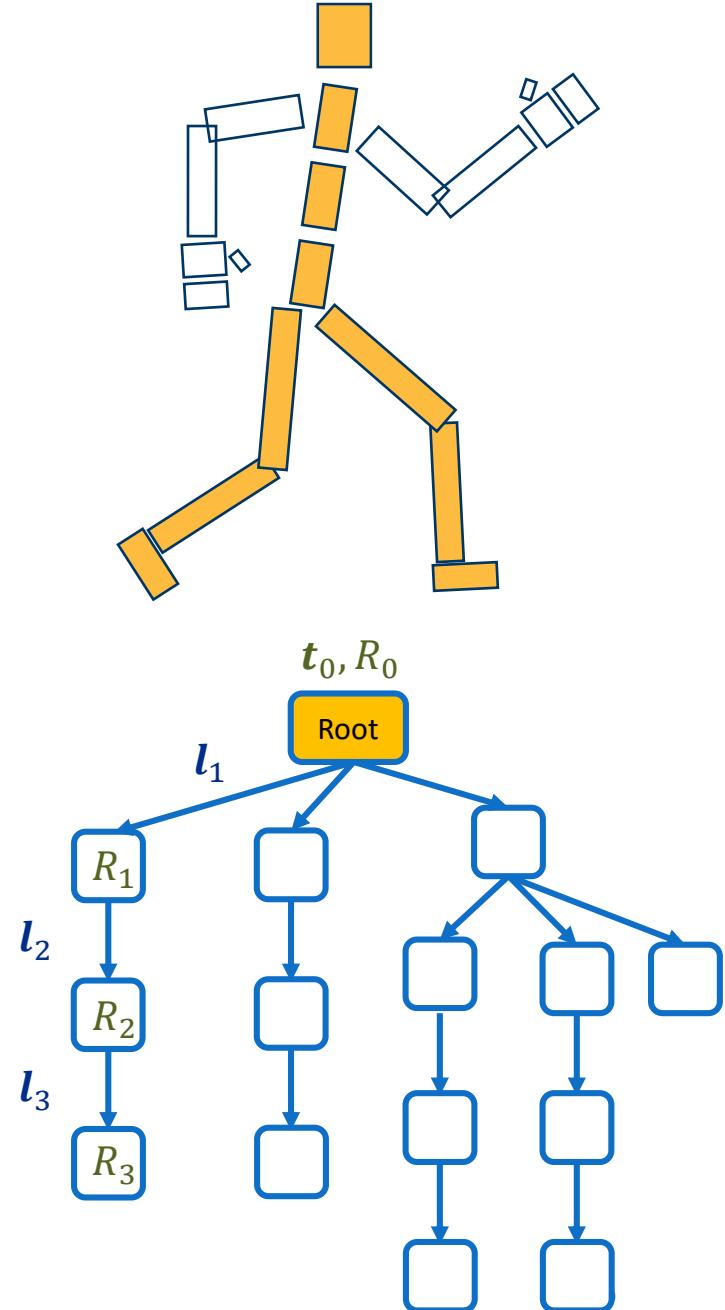


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姿势与动作表示

$(t_0, R_0, R_1, R_2, \dots)$

root | internal joints

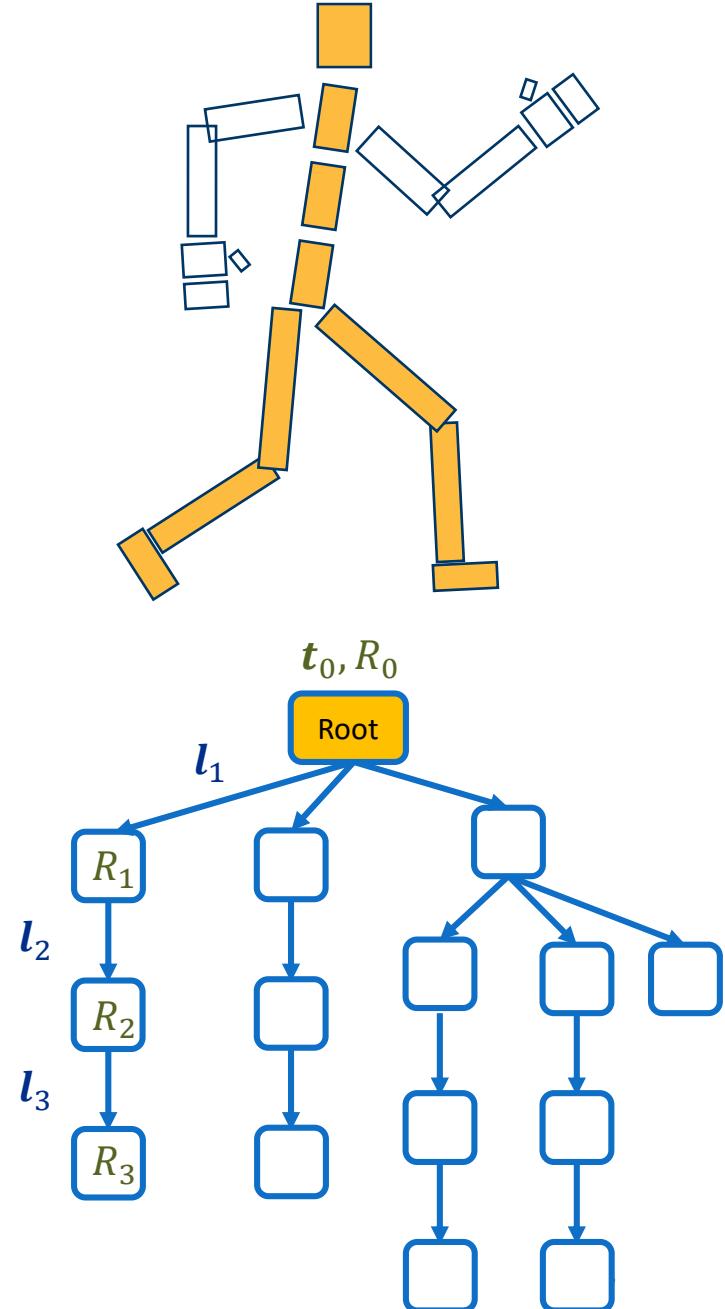
全局位置 | 局部关节旋转

依据正逆运动学顺序

前向运动学 (FK)

由关节旋转计算每个关节的**位置**、**朝向**

由关节旋转计算每个骨骼的**位置**、**朝向**



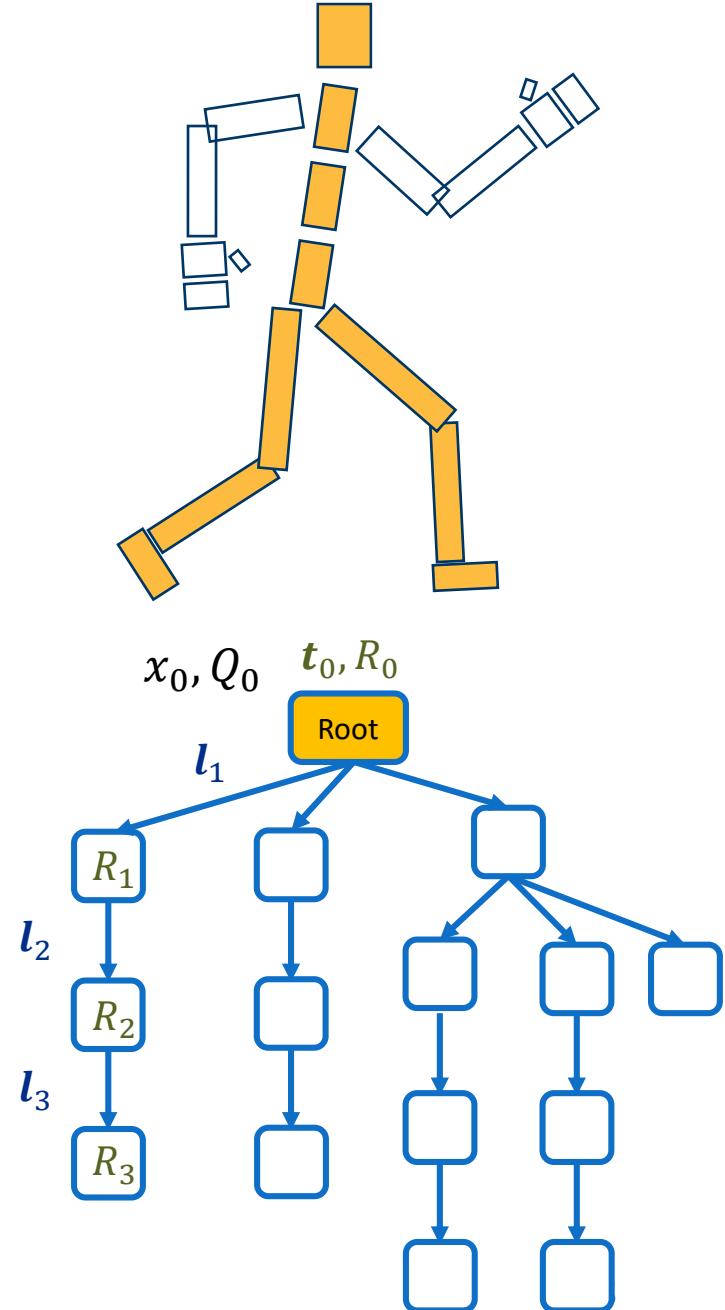
前向运动学 (FK)

$(t_0, R_0, R_1, R_2, \dots \dots)$

root | internal joints

全局位置 | 局部关节旋转

$$Q_0 = R_0 \quad x_0 = t_0$$



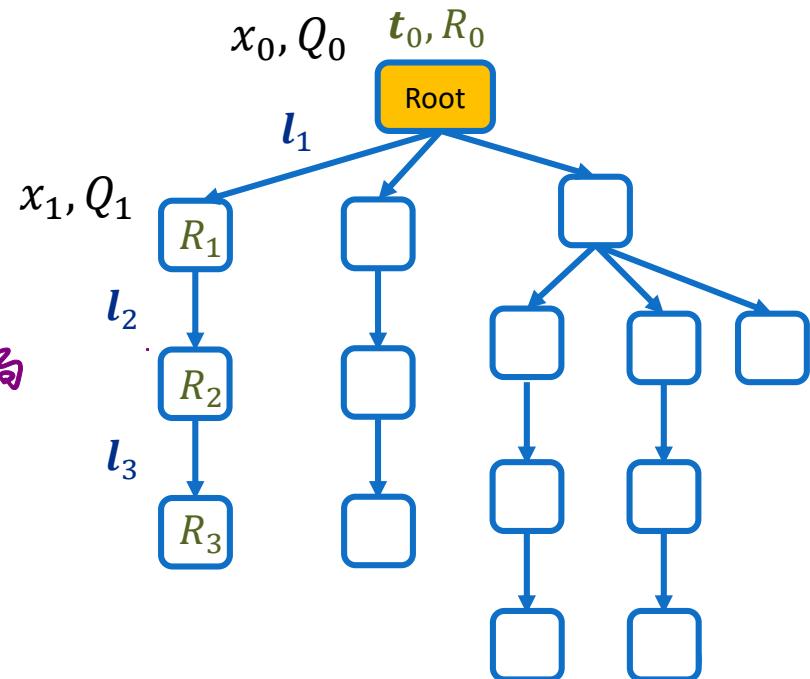
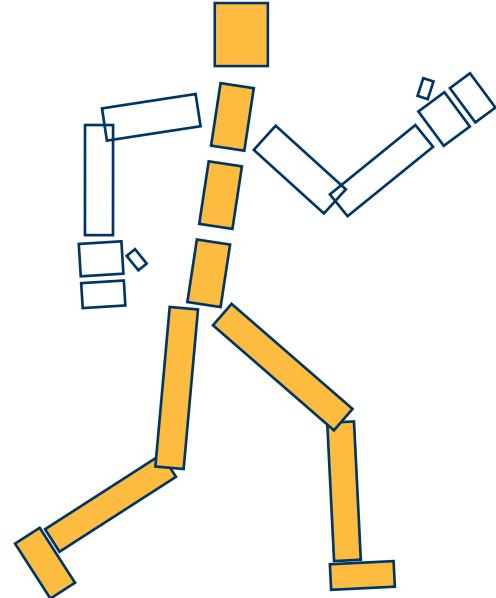
前向运动学 (FK)

$(t_0, R_0, R_1, R_2, \dots)$
root | internal joints
全局位置 | 局部关节旋转

$$Q_0 = R_0 \quad x_0 = t_0$$

$$\begin{aligned} Q_1 &= R_0 R_1 \quad x_1 = t_0 + R_0 l_1 \\ &= Q_0 R_1 \quad = x_0 + Q_0 l_1 \end{aligned}$$

R是相对上一个关节的旋转，又是全局



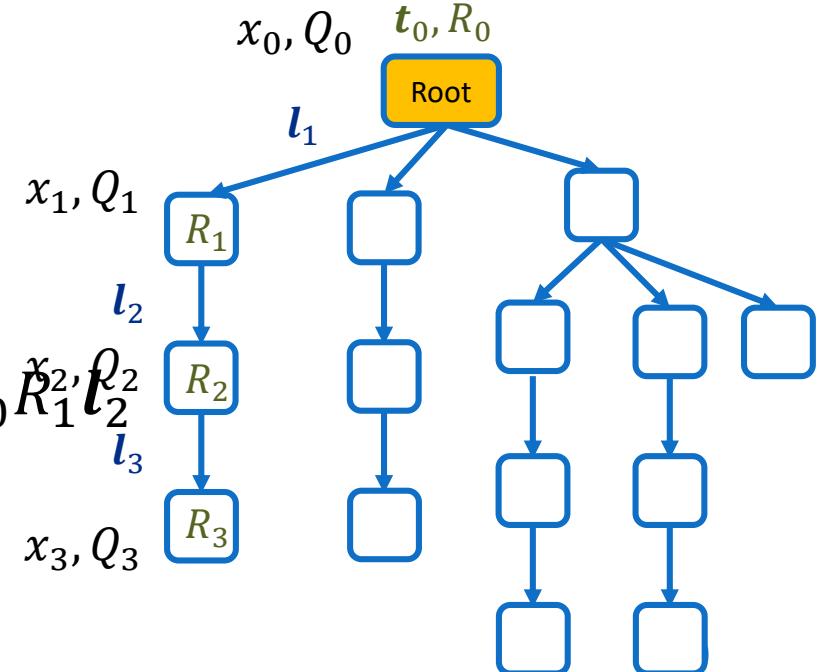
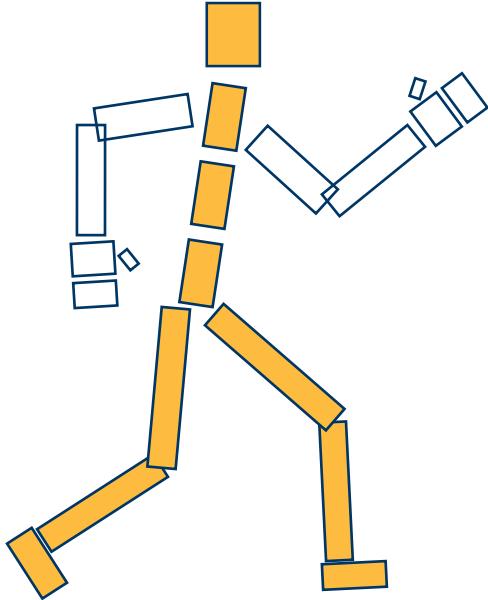
前向运动学 (FK)

$(\mathbf{t}_0, R_0, R_1, R_2, \dots)$
root | internal joints
全局位置 | 局部关节旋转

$$Q_0 = R_0 \quad \mathbf{x}_0 = \mathbf{t}_0$$

$$\begin{aligned} Q_1 &= R_0 R_1 \\ &= Q_0 R_1 \end{aligned} \quad \begin{aligned} \mathbf{x}_1 &= \mathbf{t}_0 + R_0 \mathbf{l}_1 \\ &= \mathbf{x}_0 + Q_0 \mathbf{l}_1 \end{aligned}$$

$$\begin{aligned} Q_2 &= R_0 R_1 R_2 \\ &= Q_1 R_1 \end{aligned} \quad \begin{aligned} \mathbf{x}_2 &= \mathbf{t}_0 + R_0 \mathbf{l}_1 + R_0 R_1 \mathbf{l}_2 \\ &= \mathbf{x}_1 + Q_1 \mathbf{l}_2 \end{aligned}$$



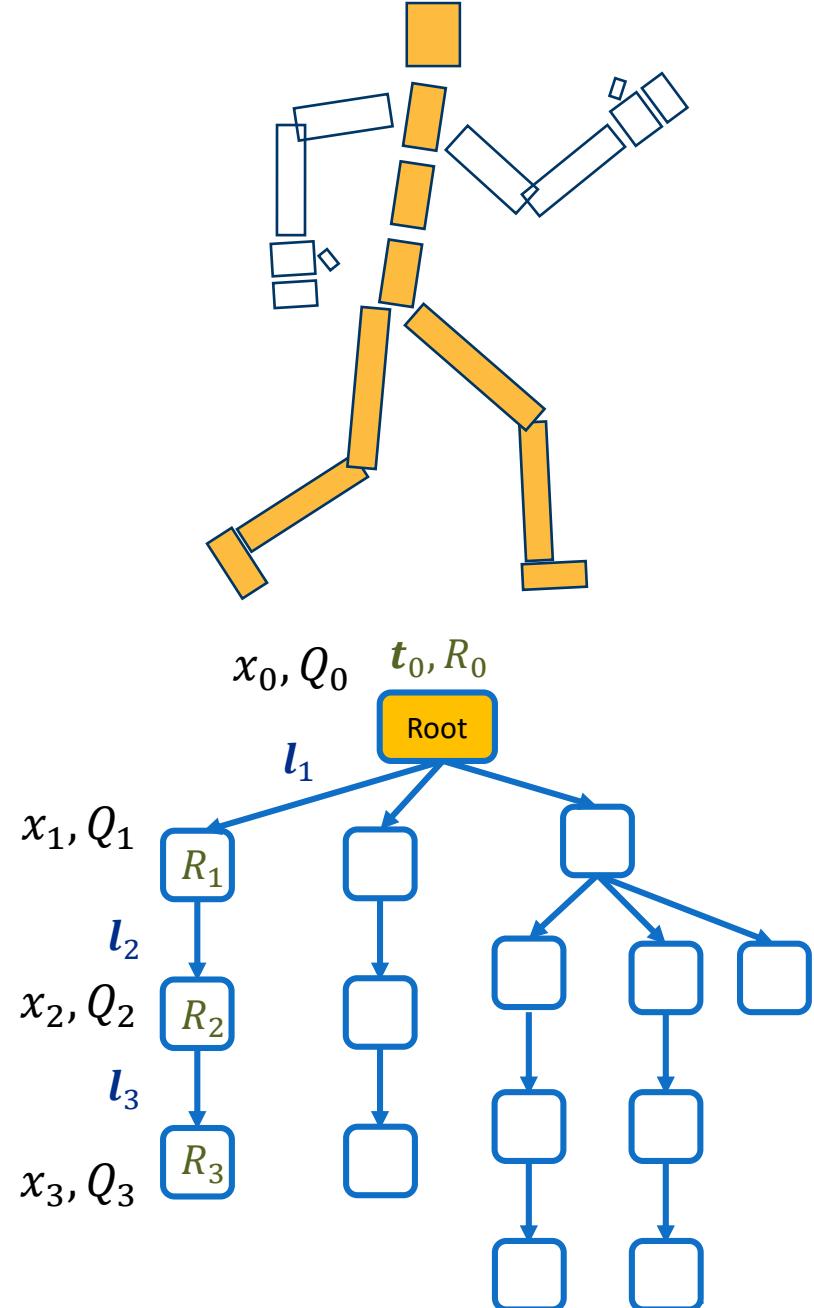
前向运动学 (FK)

$(t_0, R_0, R_1, R_2, \dots \dots)$
root | internal joints
全局位置 | 局部关节旋转

迭代计算：

```
for i in joint_list:  
     $p_i = i$ 's parent joint  
 $Q_i = Q_{p_i} R_i$   
 $x_i = x_{p_i} + Q_{p_i} l_i$ 
```

* joint_list 保证父关节在子关节前



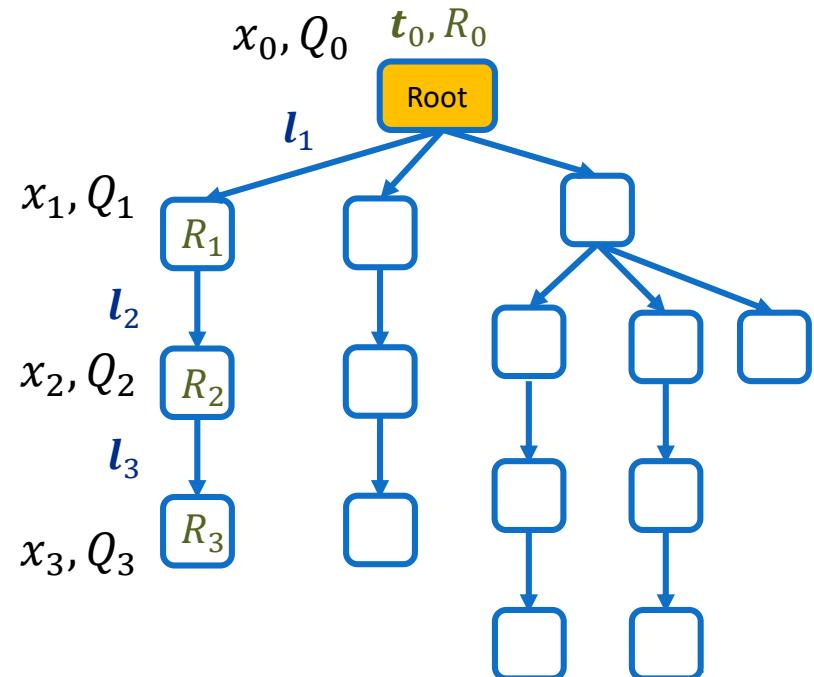
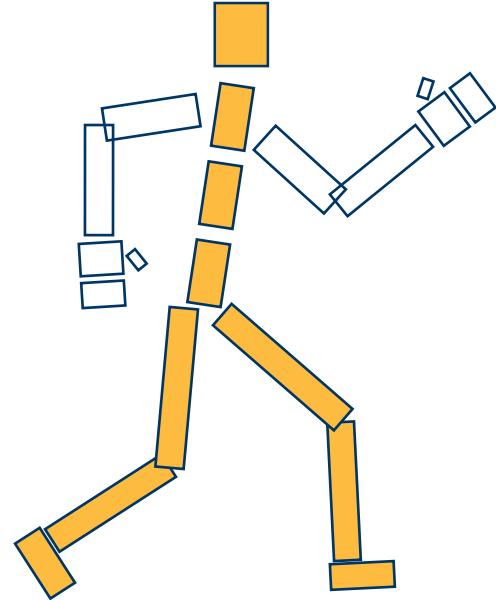
前向运动学 (FK)

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全局位置 | 局部关节旋转

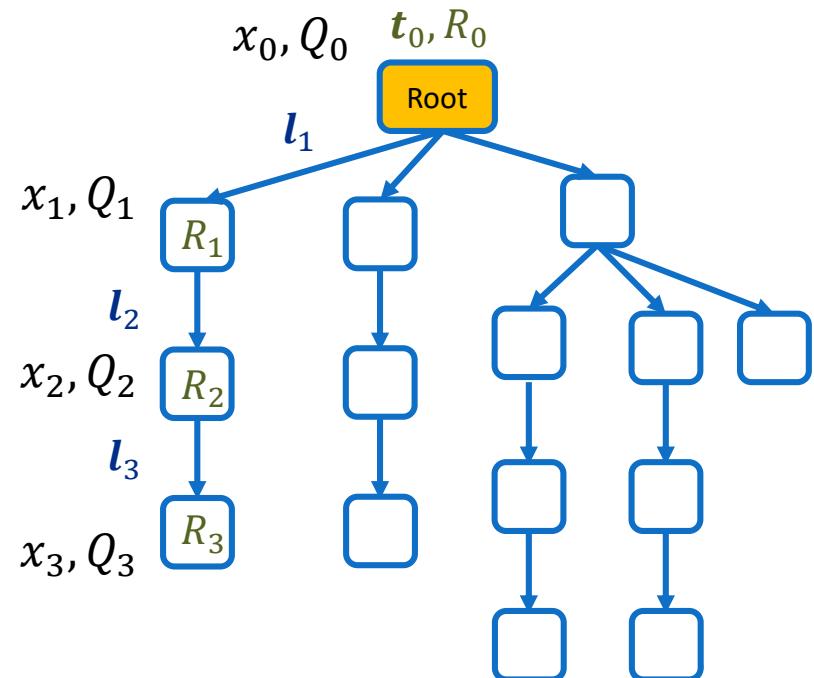
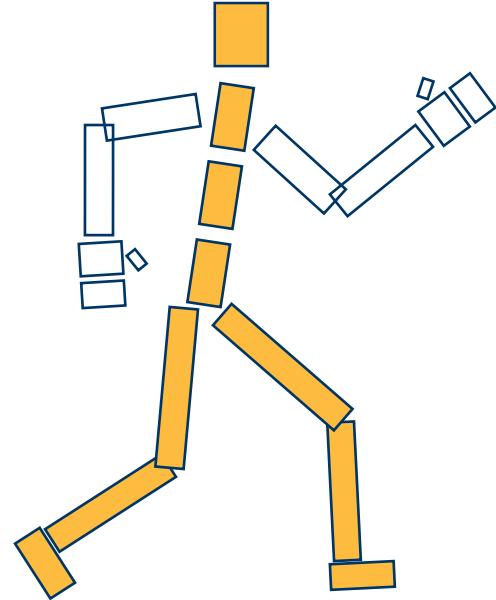
如果骨骼长度可变?



前向运动学 (FK)

$(t_0, R_0, R_1, R_2, \dots \dots)$
root | internal joints
全局位置 | 局部关节旋转

已知 x_i, Q_i ,
如何计算关节旋转?

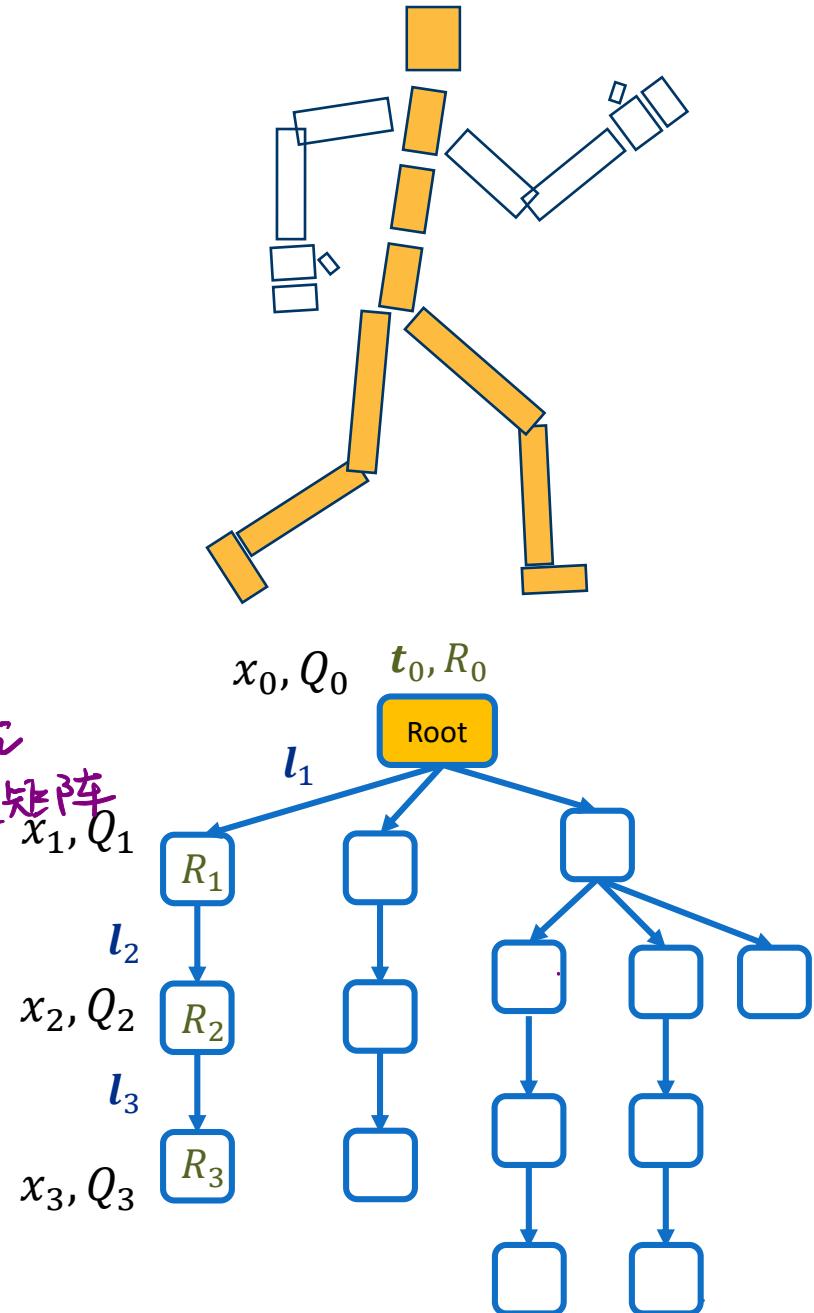


前向运动学 (FK)

$(t_0, R_0, R_1, R_2, \dots)$	
root	internal joints
全局位置	局部关节旋转

已知 x_i, Q_i ,
如何计算关节旋转?

$$R_i = Q_{p_i}^T Q_i$$



T-Pose

- 也被称作 **Bind Pose** 或 **Reference Pose**
- 所有关节旋转为0时的Pose ← 基本上

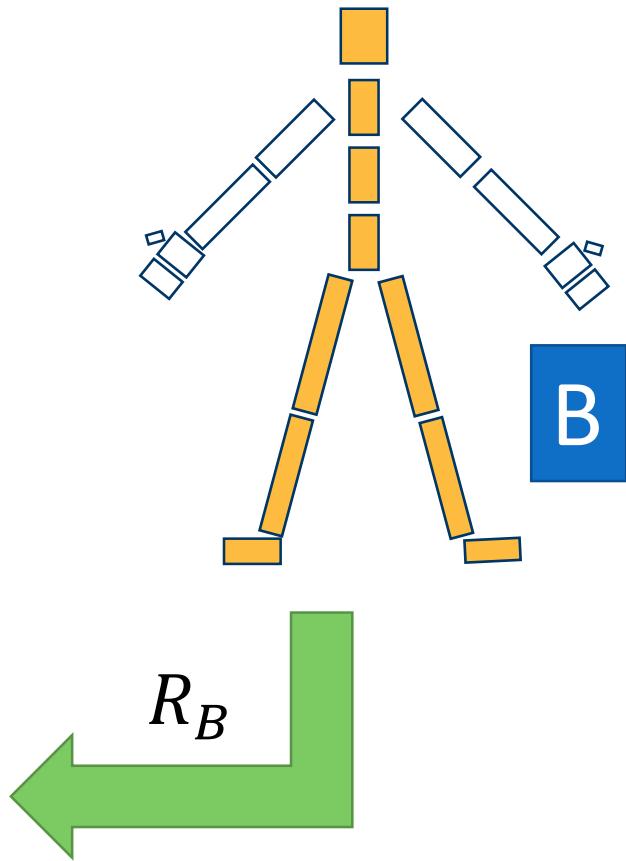
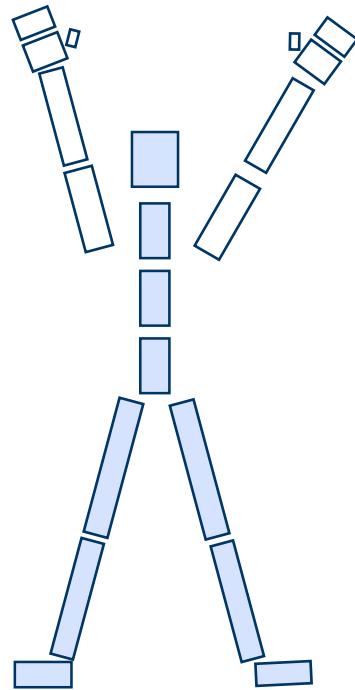
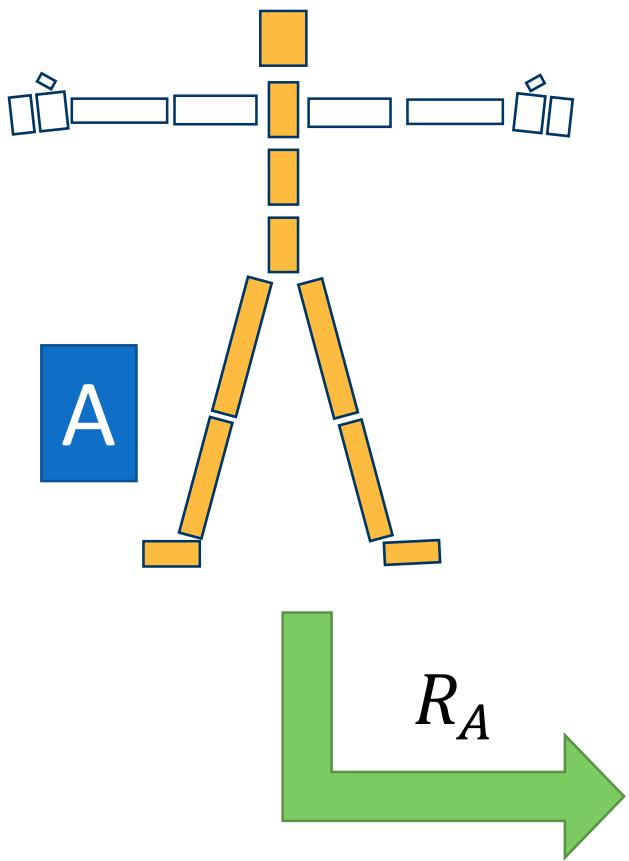


T-Pose?

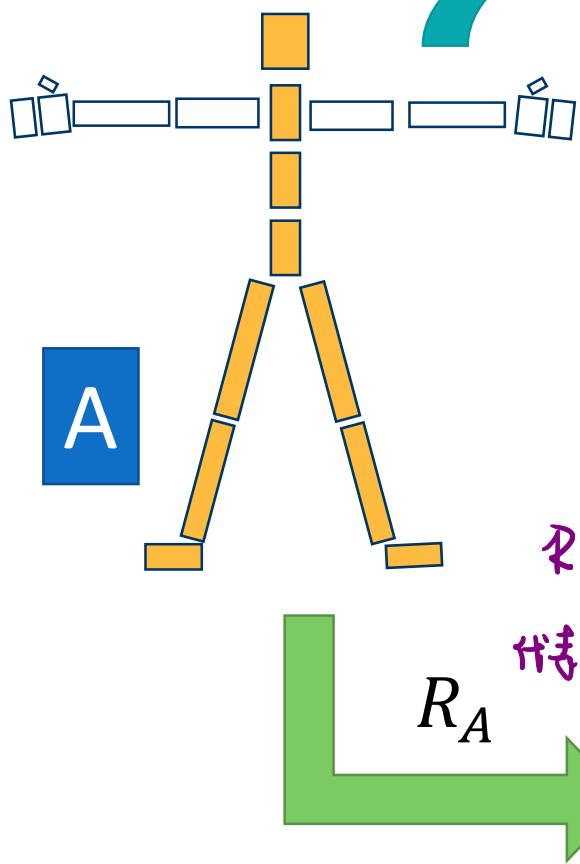


不同参考Pose的关系

$R_B = R_A ??$

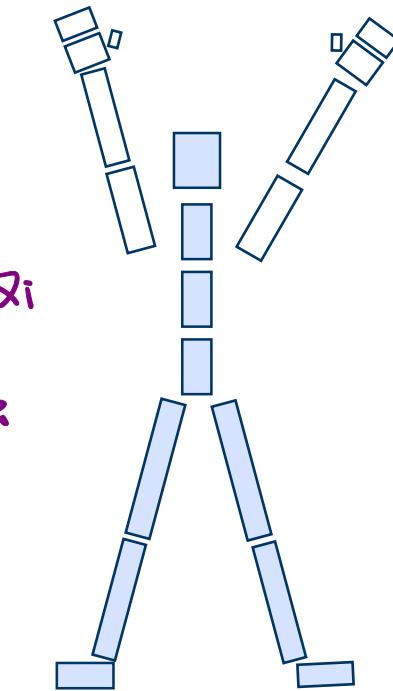


不同参考Pose的关系



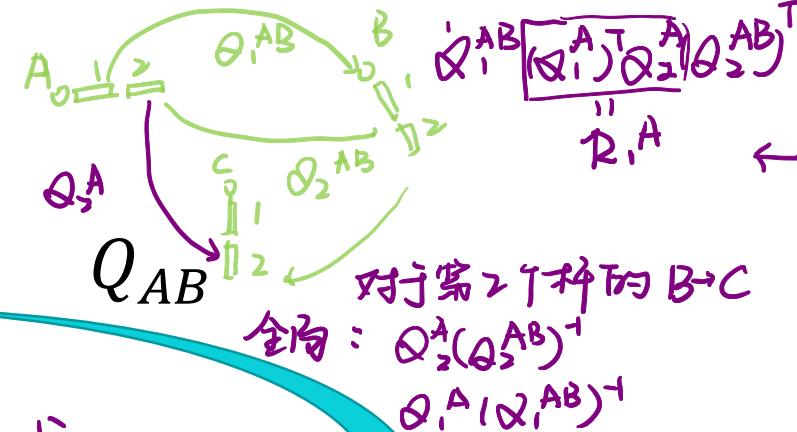
$$R_i = \mathbf{D}_{pi}^T \boldsymbol{\alpha}_i$$

代表关节旋转



$$R_i^B = Q_{pi}^{AB} R_i^A (Q_i^{AB})^T$$

retarget 公式



例子： BVH文件

- 常用动作数据文件之一
- 可用Blender、FBX Review、Motion Builder等软件查看
- 纯文本，可用记事本编辑
- 文件格式：
 - HIERARCHY： 定义T-Pose
 - MOTION： 每一帧每个关节的欧拉旋转
 - Frames\Frame Time: 帧数和帧率

```
HIERARCHY
ROOT Hips
{
    OFFSET 0 0 0
    CHANNELS 6 Xposition Yposition Zposition Zrotation Xrotation Yrotation
    JOINT LeftHip
    {
        OFFSET 3.5 0 0
        CHANNELS 3 Zrotation Xrotation Yrotation
        JOINT LeftKnee
        {
            OFFSET 0 -19.0555 0
            CHANNELS 3 Zrotation Xrotation Yrotation
            JOINT LeftHeel
            {
                OFFSET 0 -21.1464 0
                CHANNELS 3 Zrotation Xrotation Yrotation
                End Site
                {
                    OFFSET 0 0 9.64661
                }
            }
        }
    ...
}

MOTION
Frames: 2
Frame Time: 0.04166667
-9.533684  4.447926   -0.566564   -7.757381
             6.289016   -1.825344   -6.106647
             -14.391472  -3.461282  -16.504230
             2.533497   -28.283911  -6.862538
             2.951538   -3.418231   7.634442
             -18.352753  15.051558  -7.514462
             2.494318   -1.543435   2.970936
             7.093068   -1.507532  -2.633332
             12.803010  -28.692566  2.151862
             -12.596124  4.366460
             -8.489557  4.285263   -0.621559   -8.244940
```

根节点位置

根节点朝向

欧拉角顺序

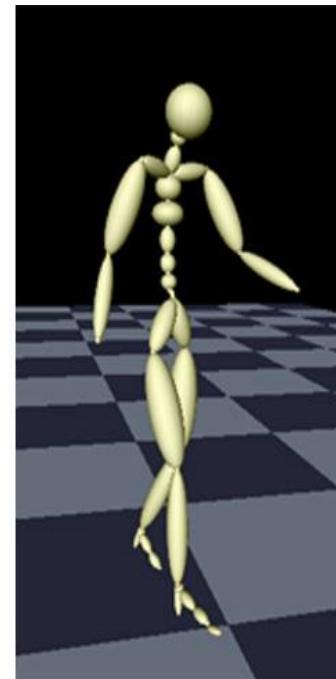
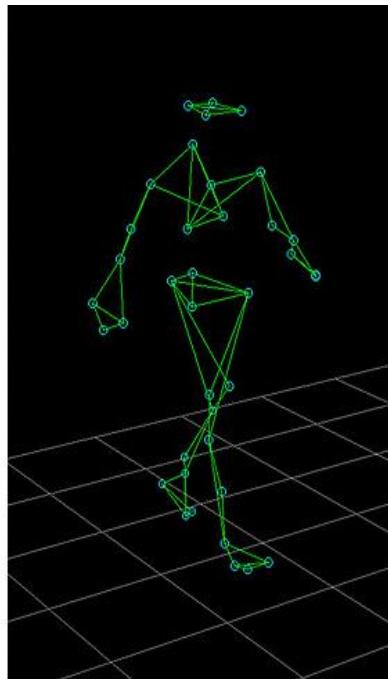
当前关节到父关节的距离

动作捕捉

Motion Capture

运动捕捉(motion capture)

- 人体运动的数字化过程
- 通过软/硬件方式记录、分析并处理人或其他物体动作的技术



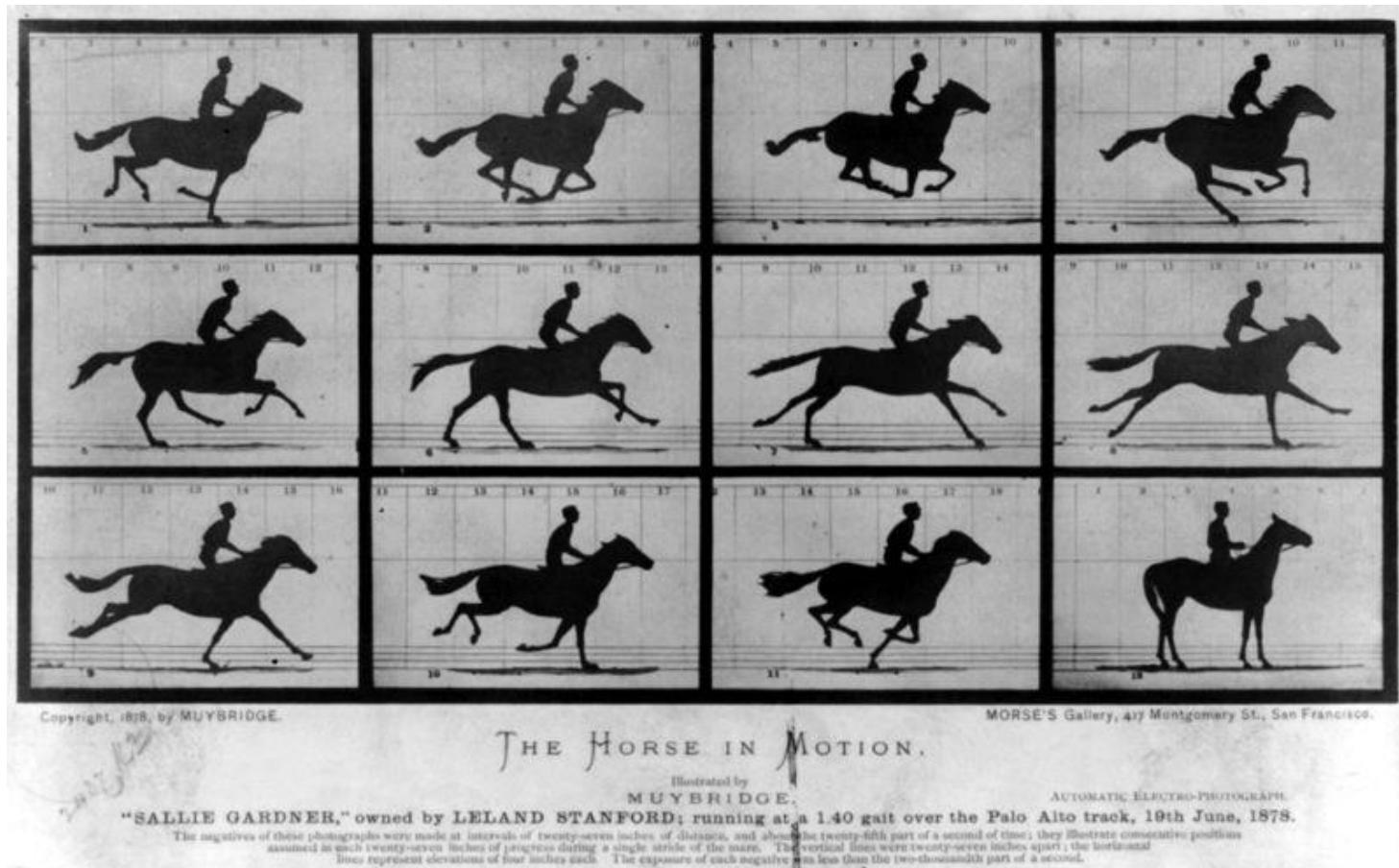
动作捕捉 (Motion Capture)

- 人体运动的数字化过程
- 娱乐：游戏、电影
- 体育：专业训练
- 生物力学：运动分析
- 医疗：运动相关疾病的诊断和复建
-



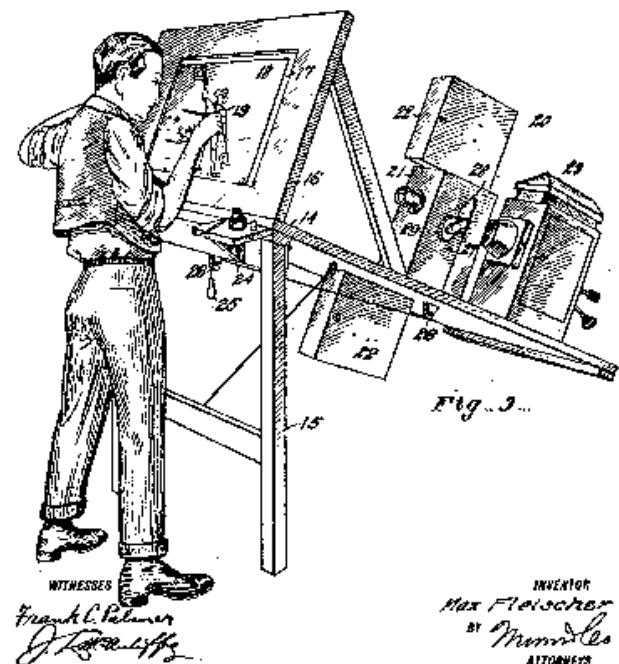
传统“动捕”技术

- Eadweard Muybridge (1830-1904)



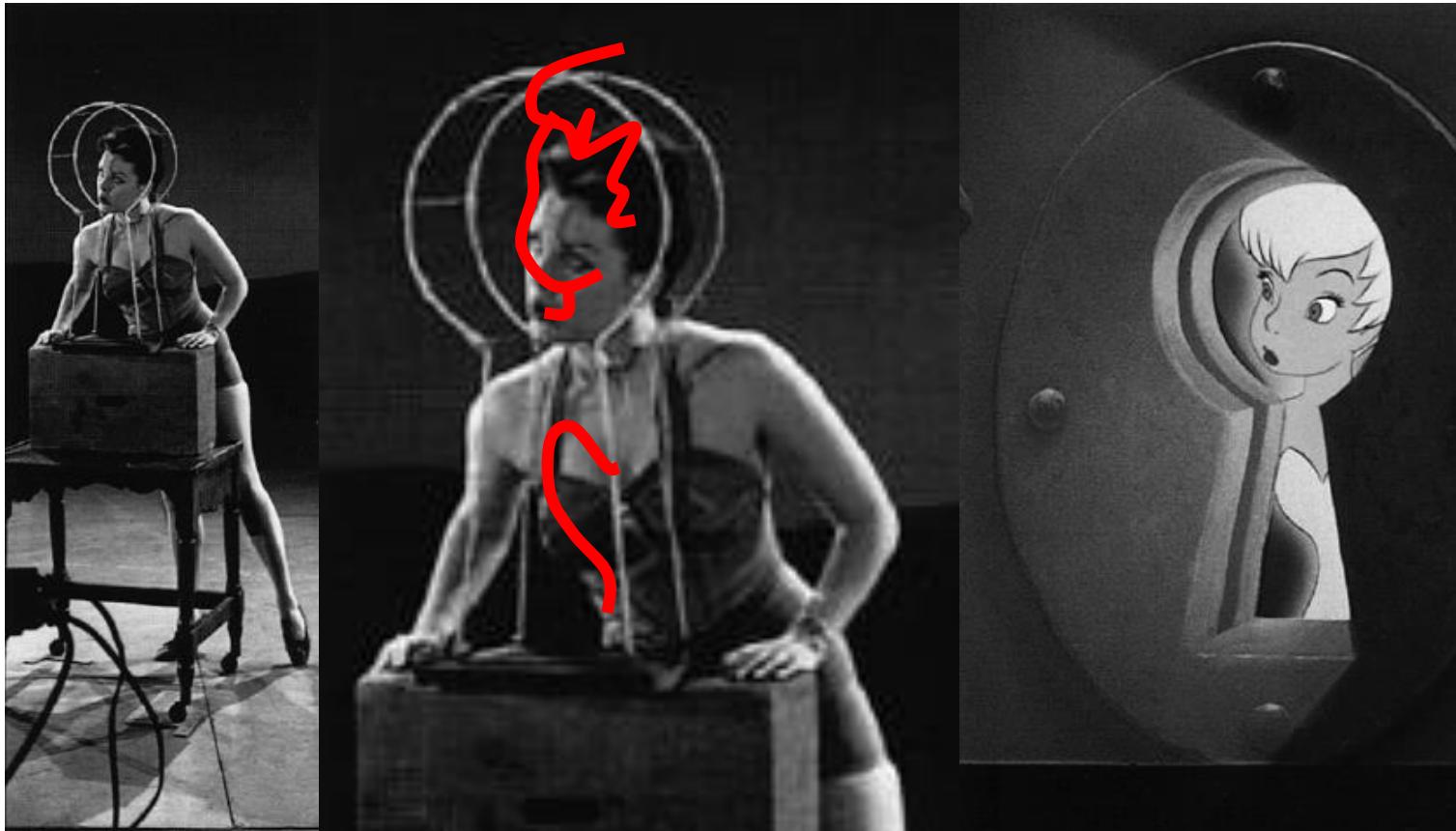
传统“动捕”技术

- Max Fleischer in 1915
 - 转描机 (Rotoscope)



转描

- 二维“人工”动捕

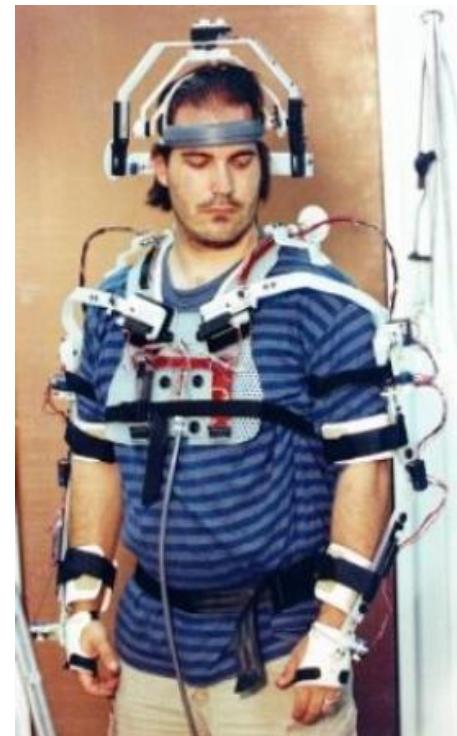


现代动捕技术

- 三维“转描”：测量身体各部分的位置/朝向
- 动捕系统
 - 机械
 - 惯性
 - 电磁
 - 光纤
 - 光学标记
 - 深度
 - 视觉动捕

机械式动捕

- 机械外骨骼



机械式动捕

- 机械外骨骼



惯性动捕系统

- 惯性测量单元 (IMU)

<http://www.xsens.com/>

<https://www.noitom.com.cn/>



惯性动捕系统

- 惯性测量单元 (IMU)



被动式光学动捕

- 利用专用标记点反射特定光（通常为红外线）
- 多视角测量标记点全局位置



<https://www.vicon.com/>

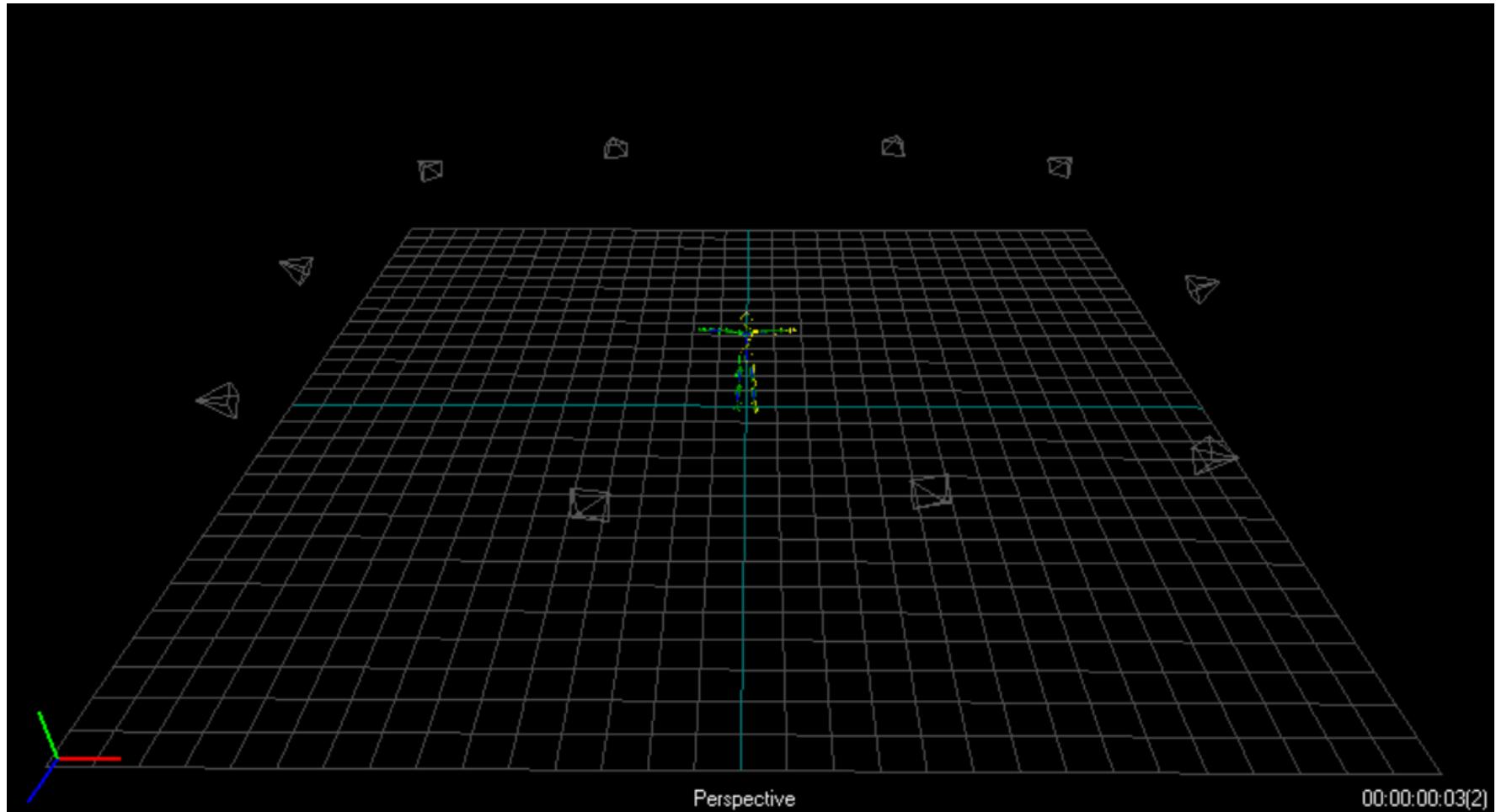
<https://www.motionanalysis.com/>

<https://www.optitrack.com/>

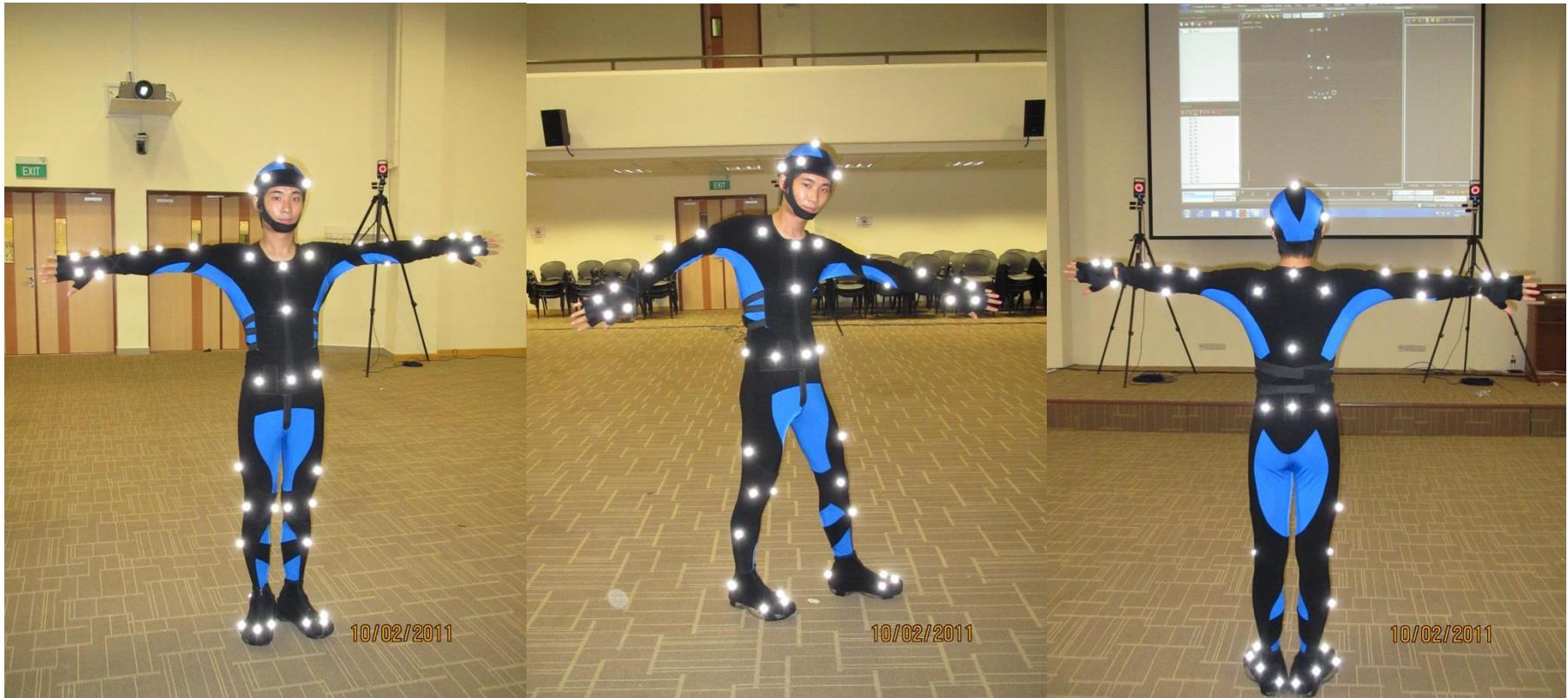
被动式光学动捕



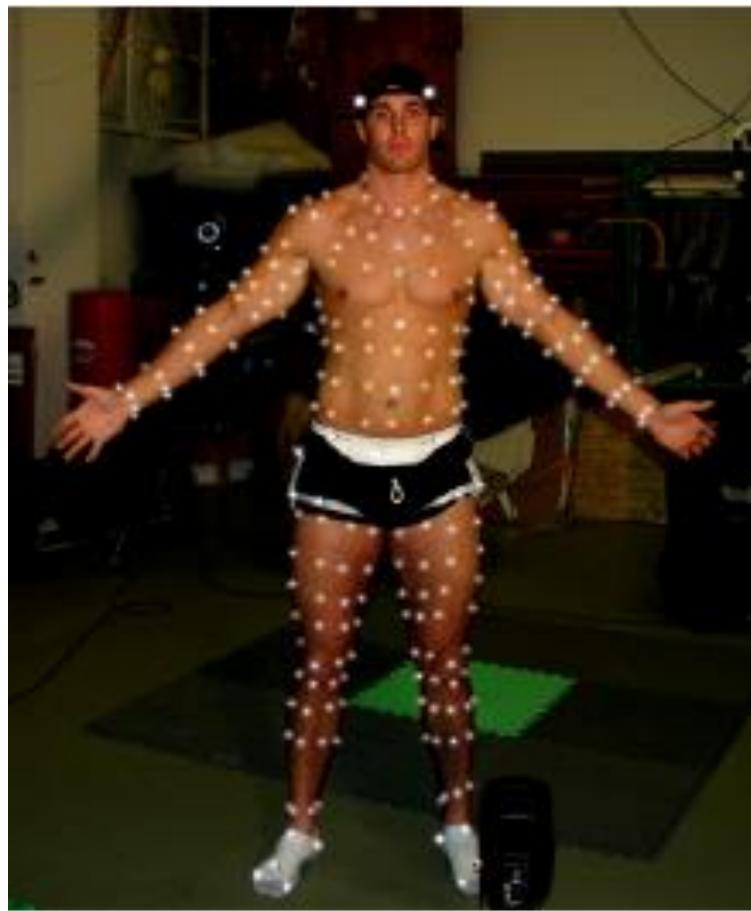
动捕场景



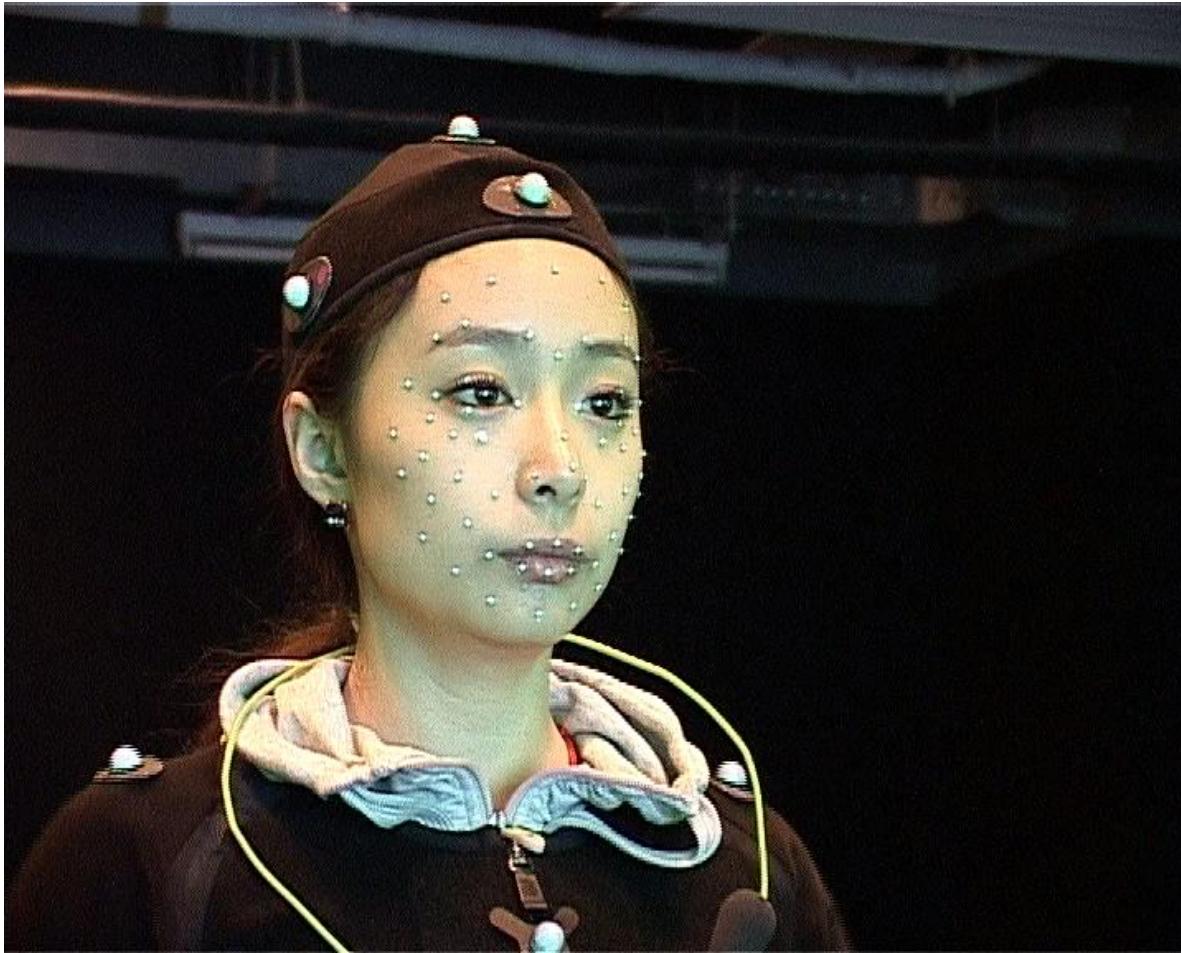
反光标记点



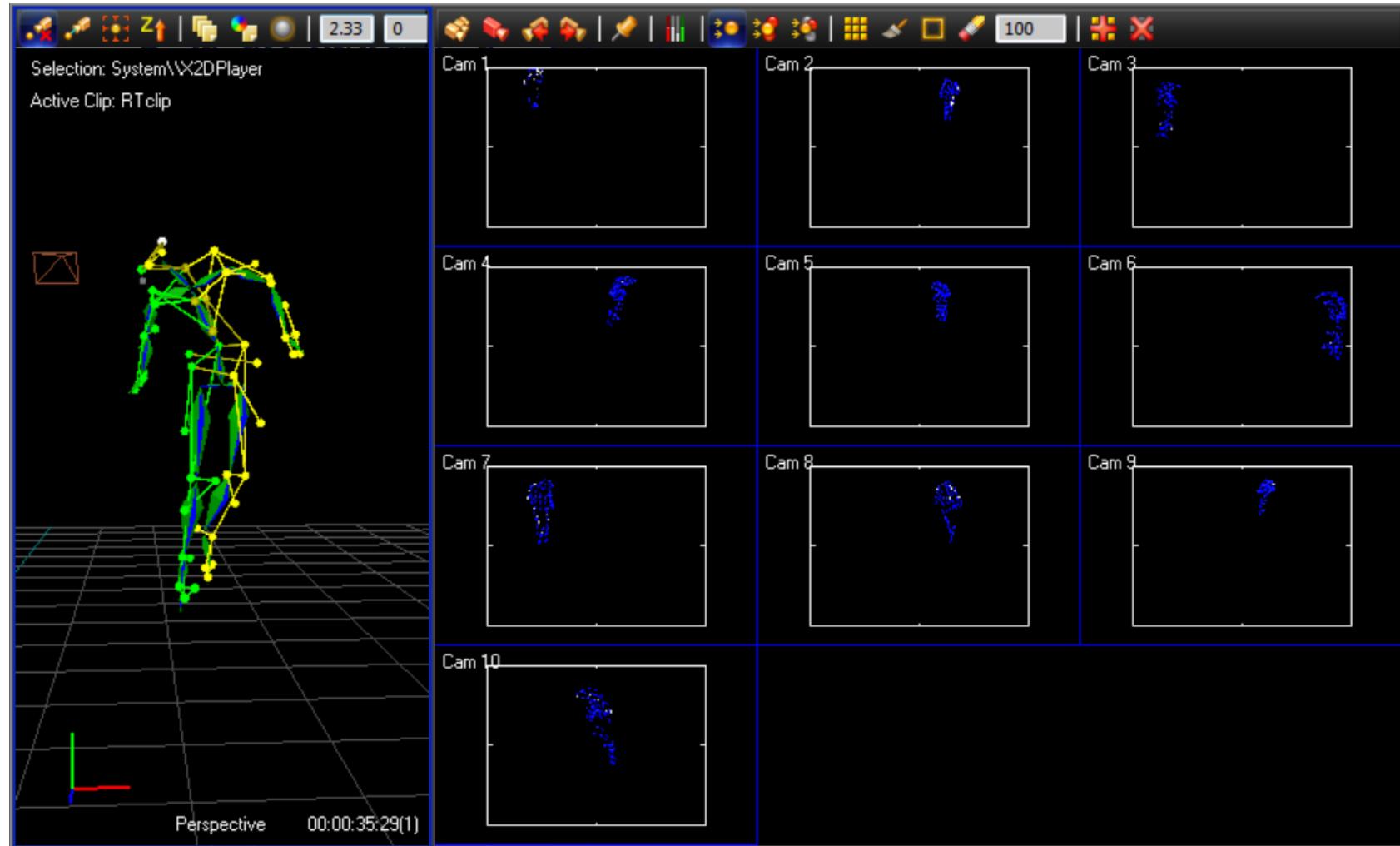
反光标记点



脸部动捕

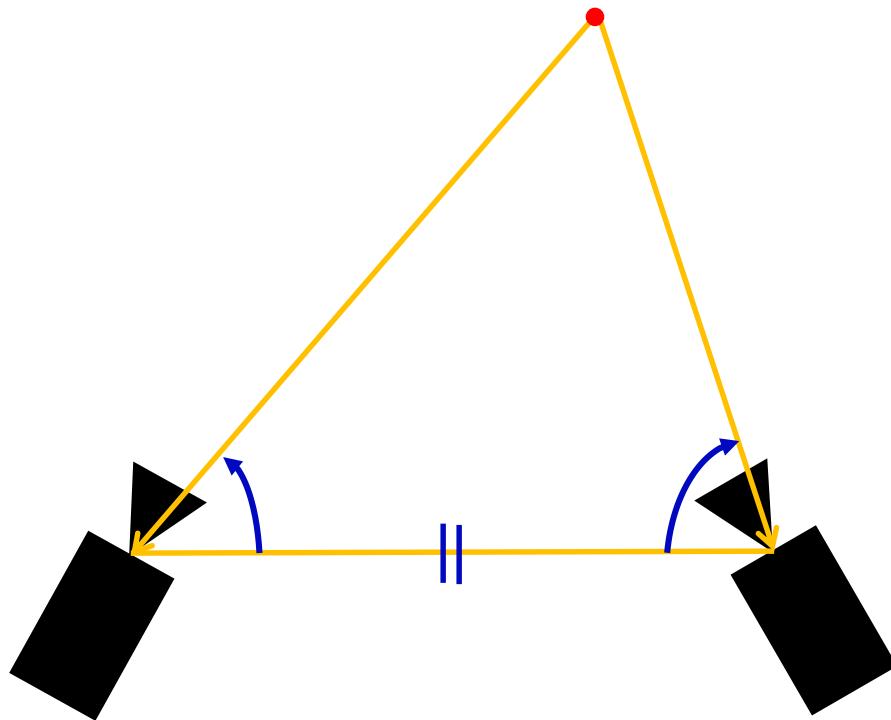


动捕界面



三角测量法

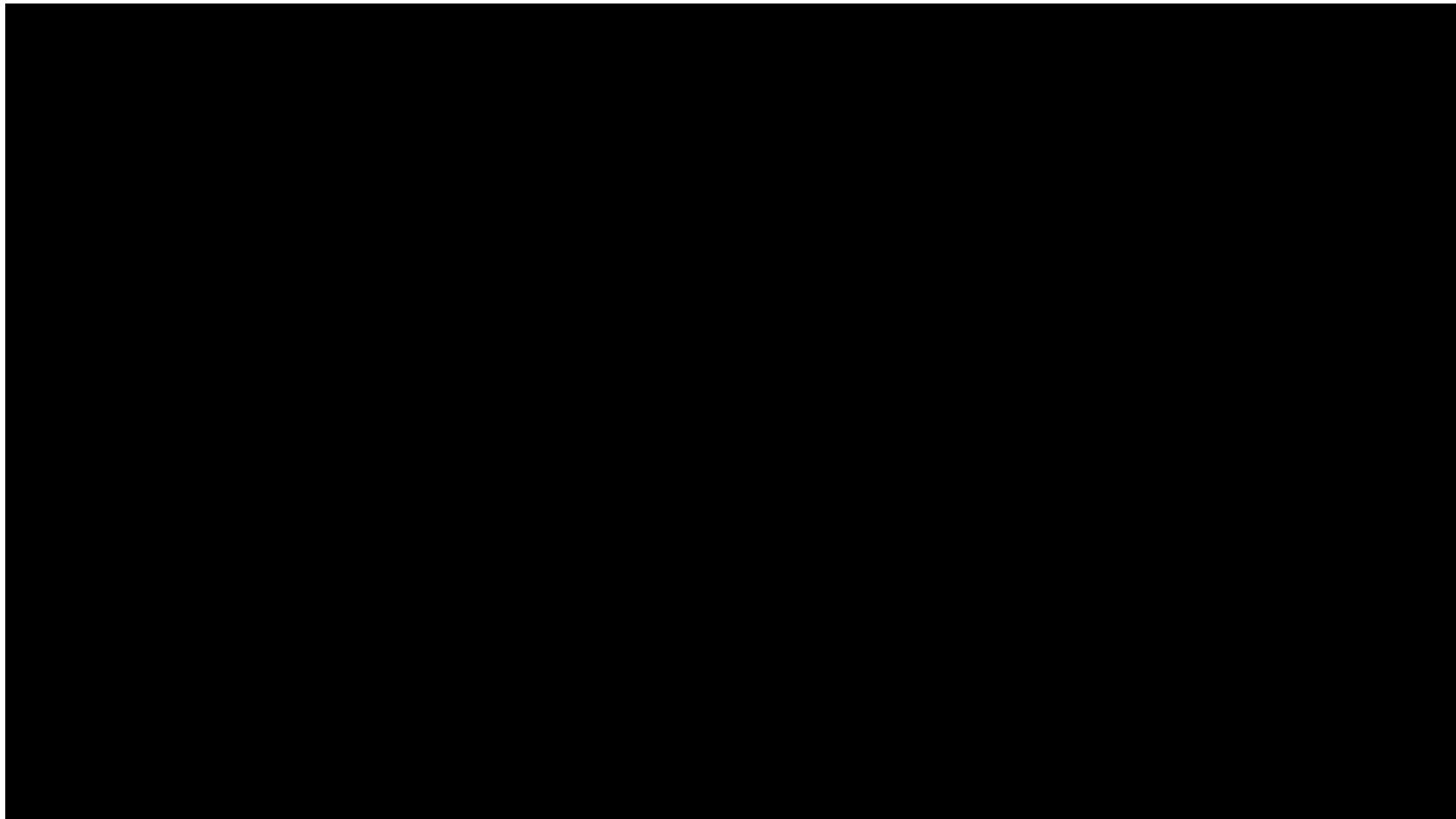
- 利用至少两个已标定的相机测量空间一个点的相对三维坐标



动捕场景



动捕场景



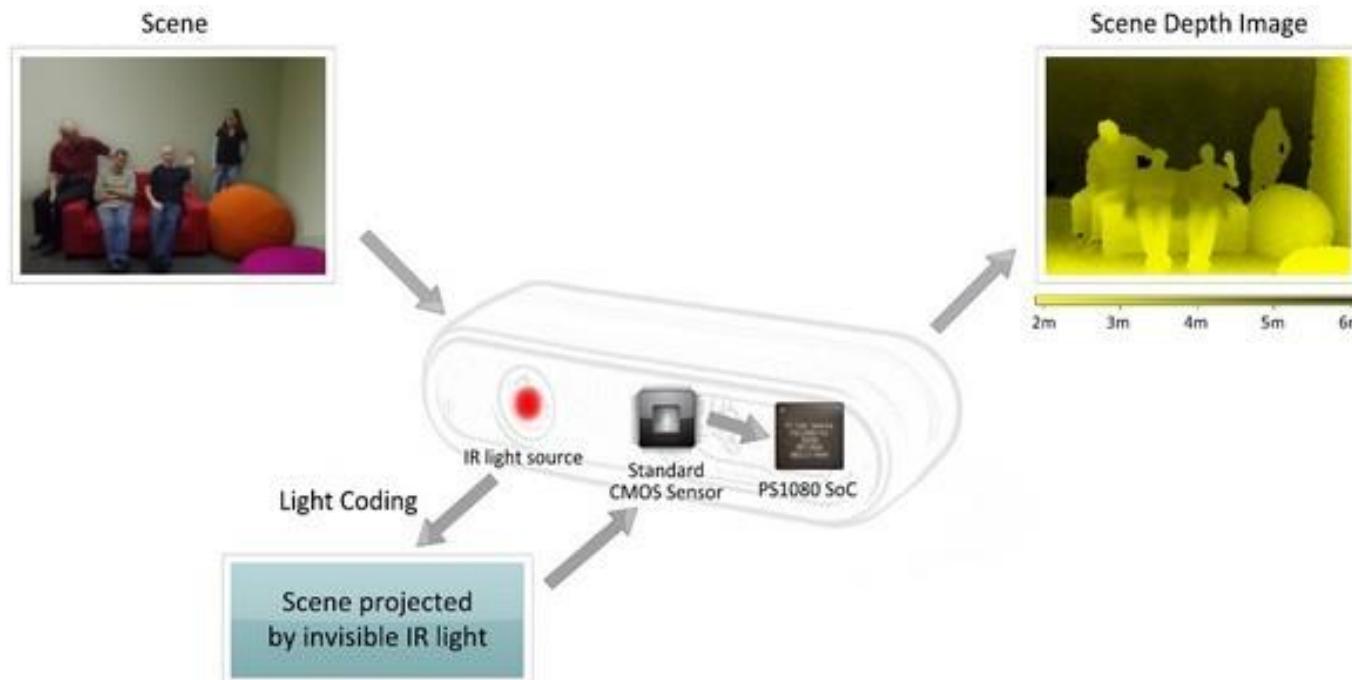
主动光学动捕

- 类似被动光学动捕，利用自发发光标记点



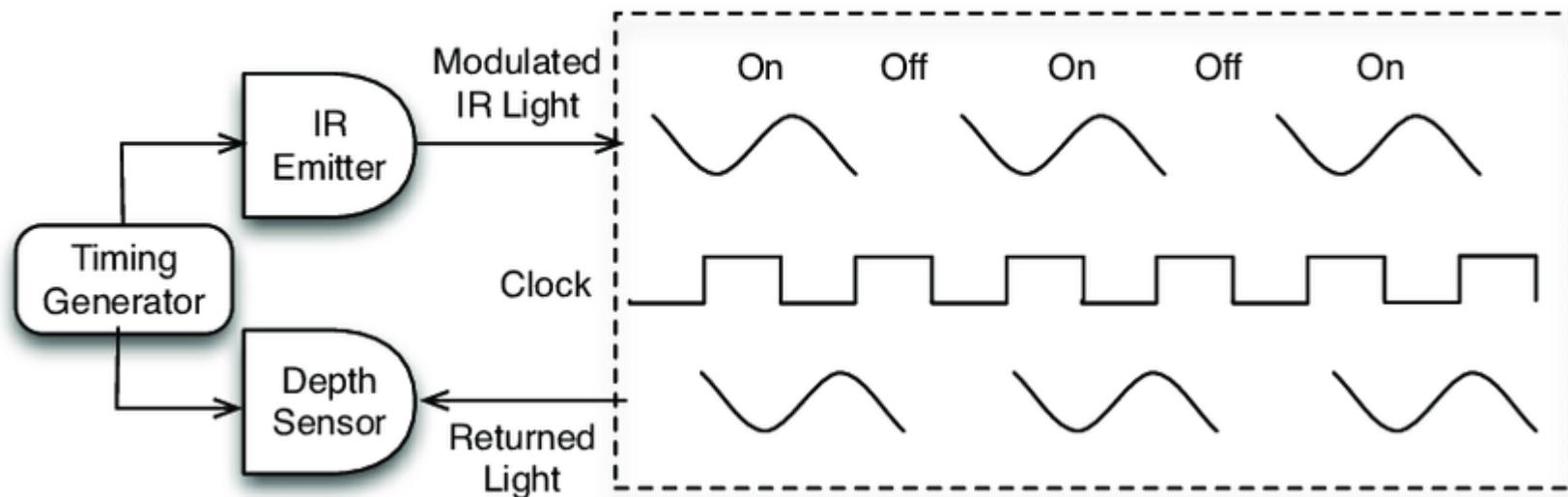
基于深度传感器的动捕系统

- 结构光 (Kinect v1): PrimeSense

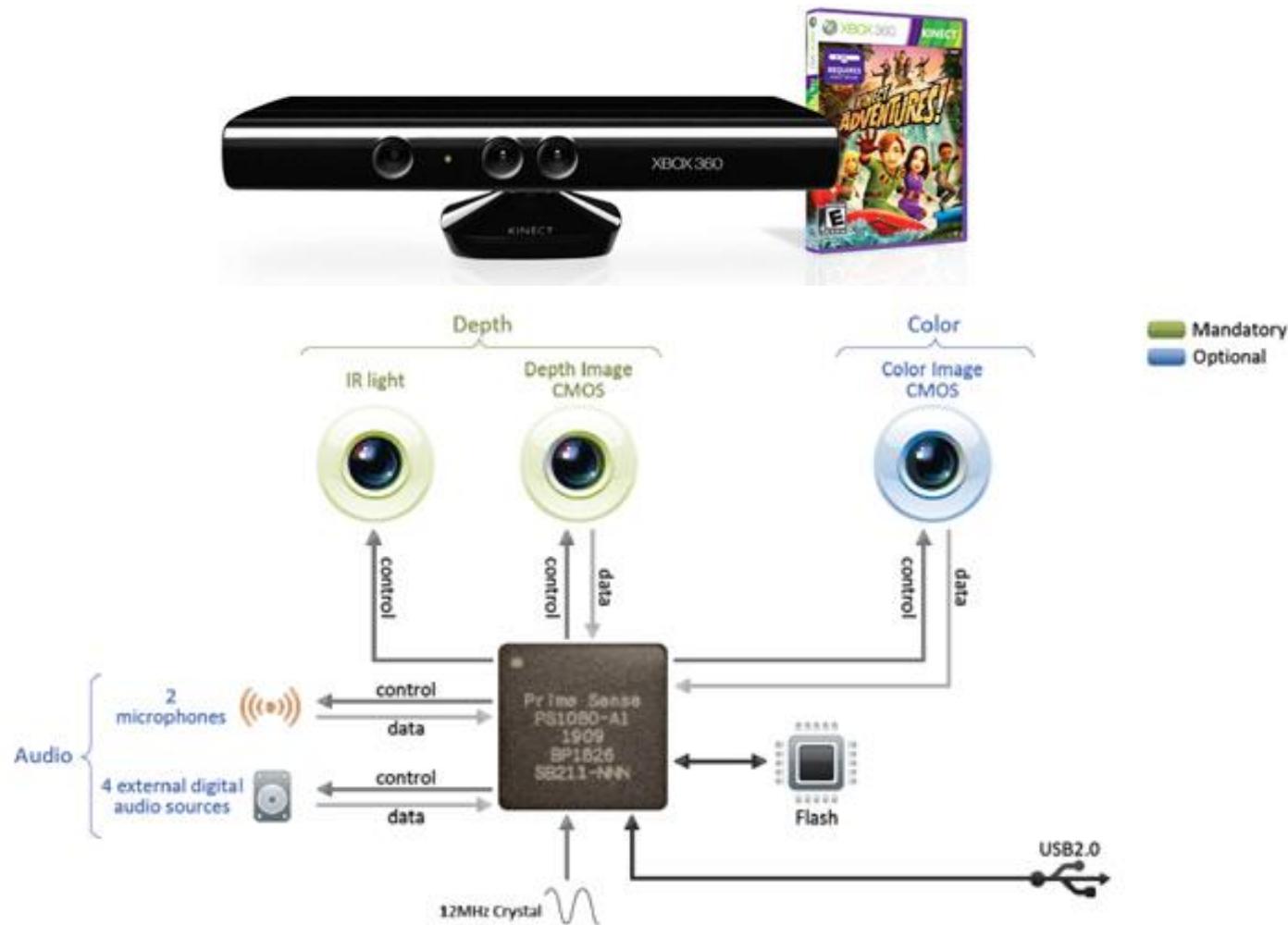


基于深度传感器的动捕系统

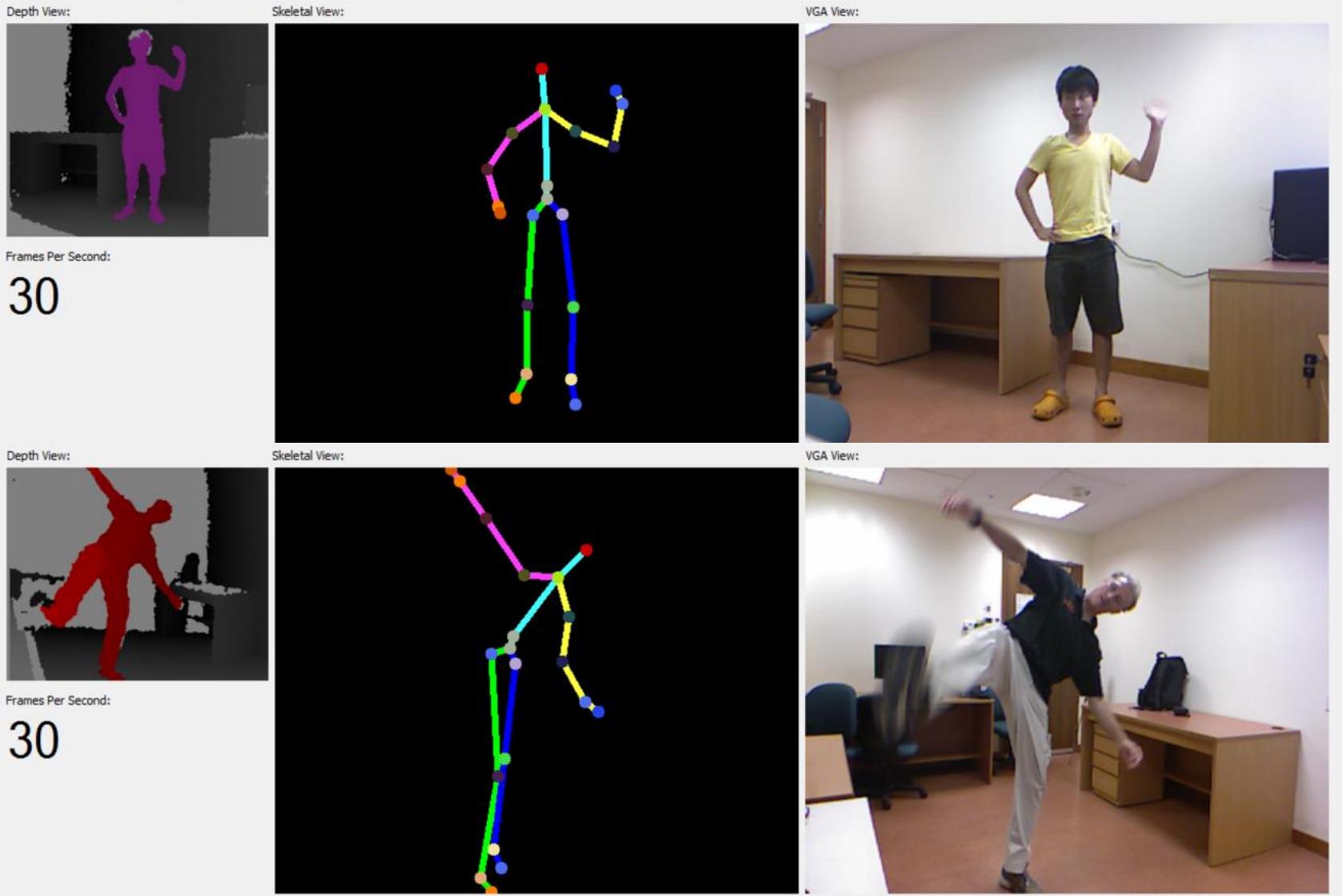
- 时差法 Time-of-Flight (Kinect v2)
 - 测量光传播的时间以计算距离



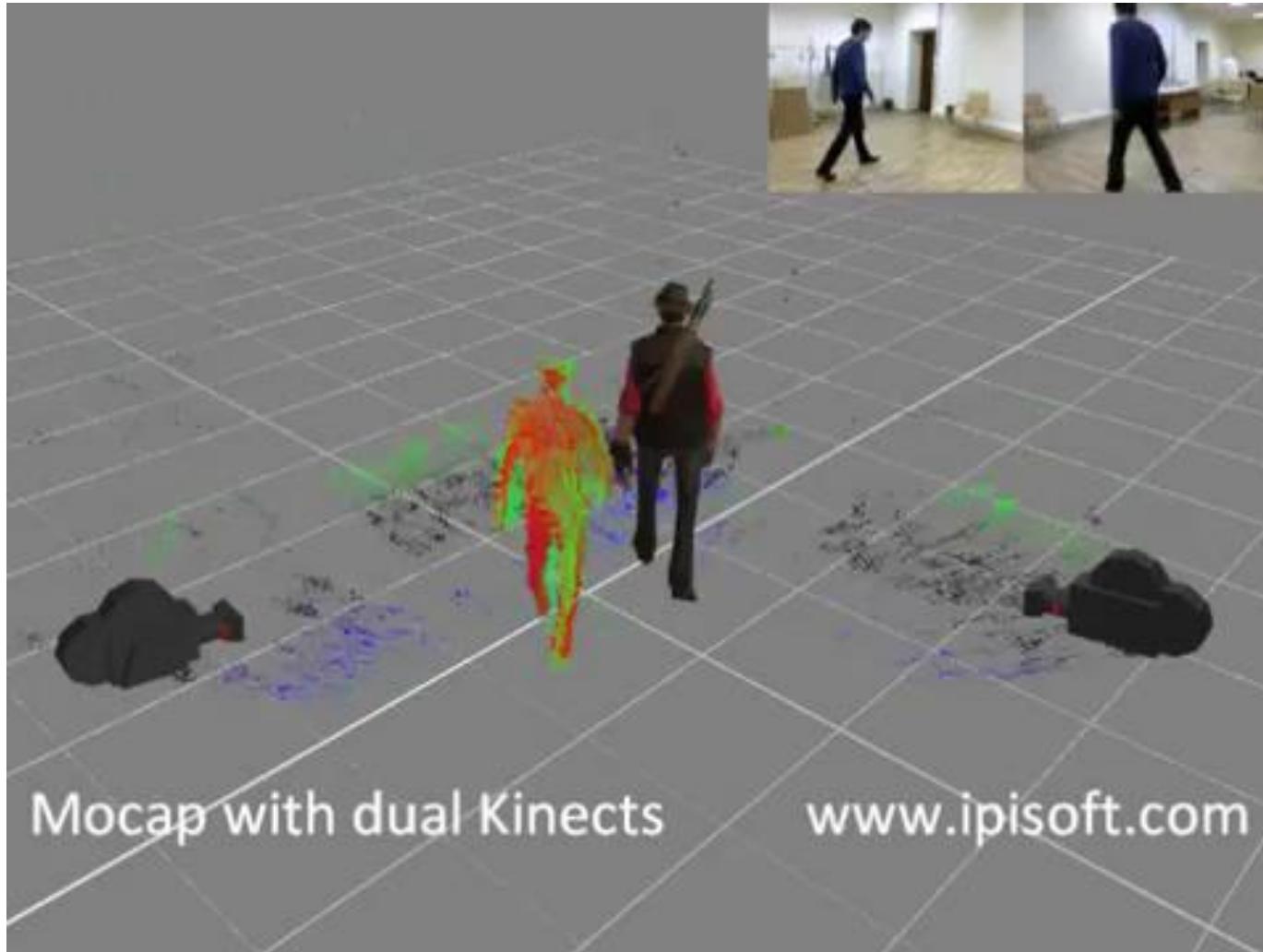
Kinect



Kinect动捕的一些问题



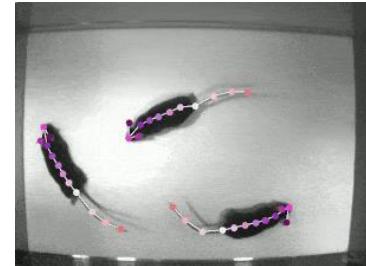
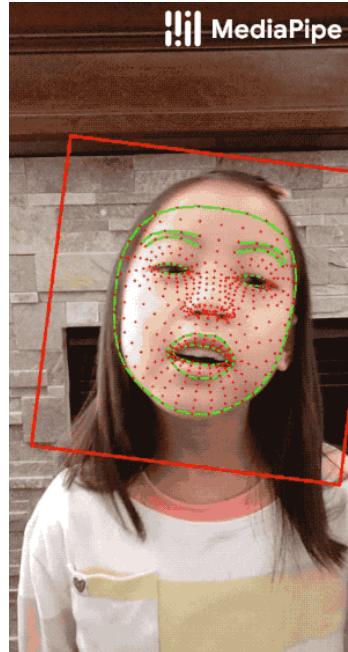
基于深度传感器的动捕系统



基于视觉/图像的动捕技术



基于视觉/图像的动捕技术



一些开源动作捕捉数据库

- CMU mocap database
 - <http://mocap.cs.cmu.edu/>
- HDM05
 - <http://www.mpi-inf.mpg.de/resources/HDM05/>
- SFU database (live demo)
 - <http://mocap.cs.sfu.ca/>
- AMASS
 - <https://amass.is.tue.mpg.de/>
- Lafan1
 - <https://github.com/ubisoft/ubisoft-laforge-animation-dataset>

运动数据的使用

Reusing Mocap Data



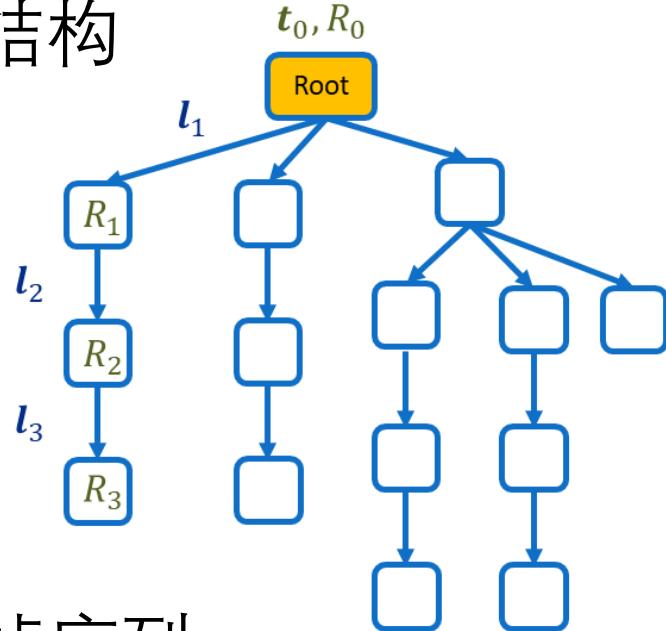
ISOFT
R O N T O
sZadziuk



- Motion Matching
The Future of Games Animation
- Kristjan Zadziuk - Animation Director

运动数据

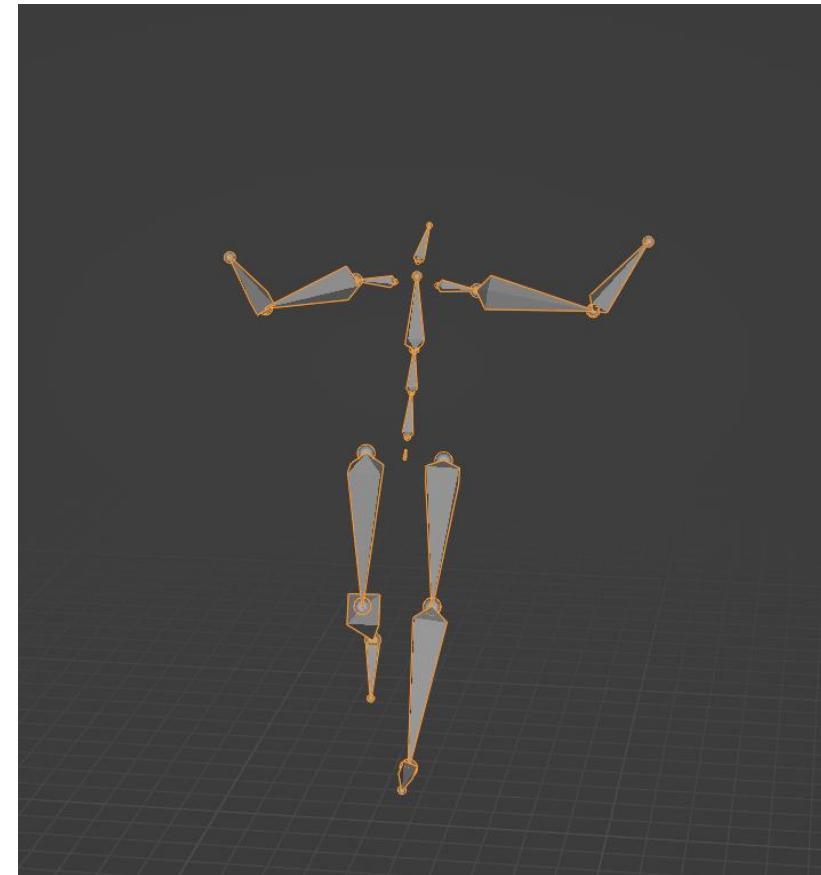
- 骨骼结构



- 关键帧序列

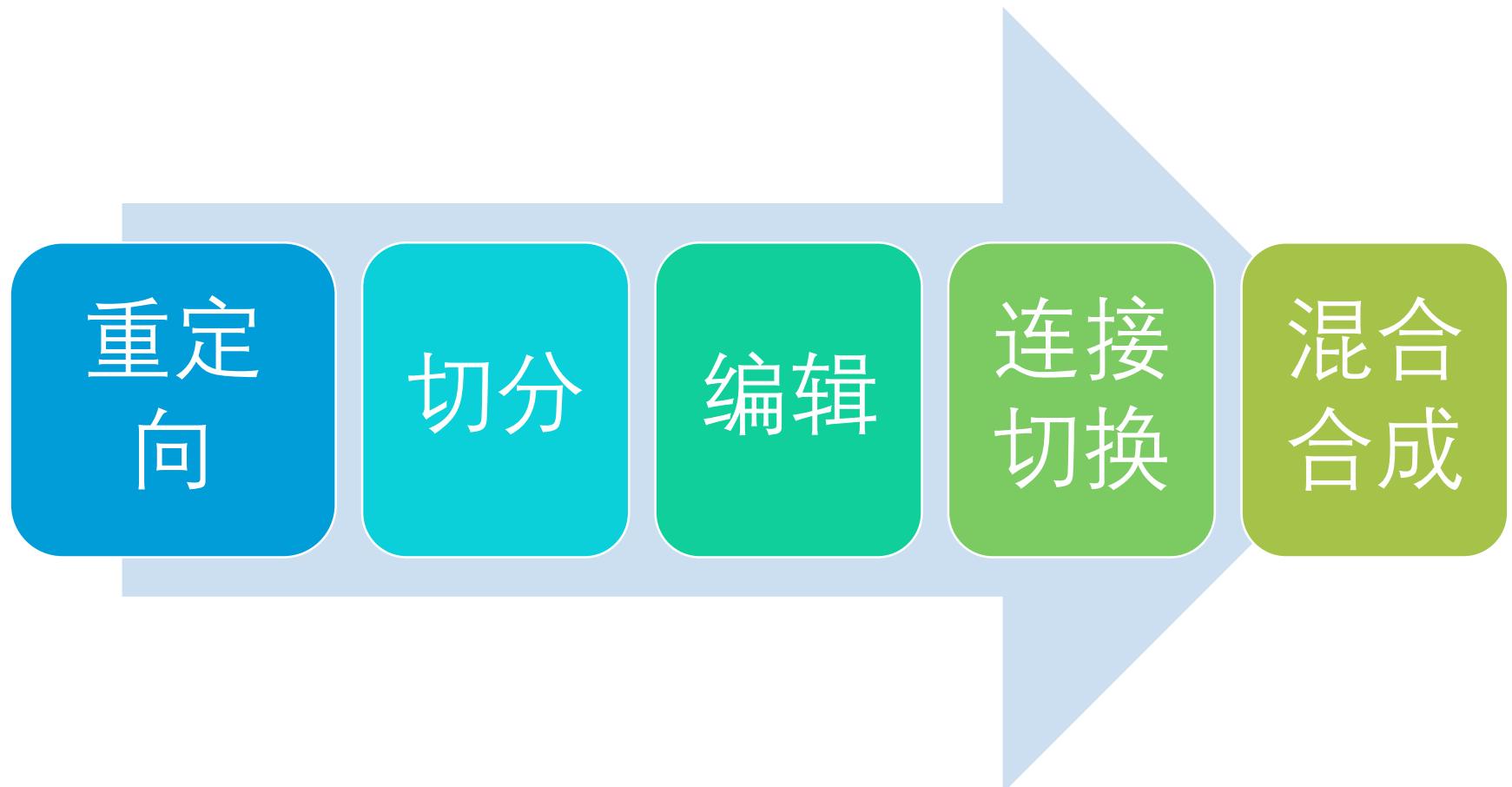
$$\{p_i\}, i = 1, \dots, N$$

$$p_i = (t_0, R_0, R_1, R_2, \dots)$$

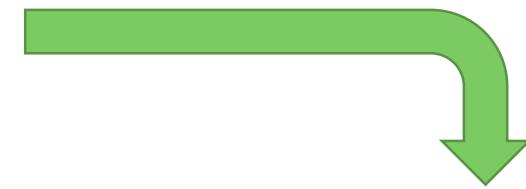
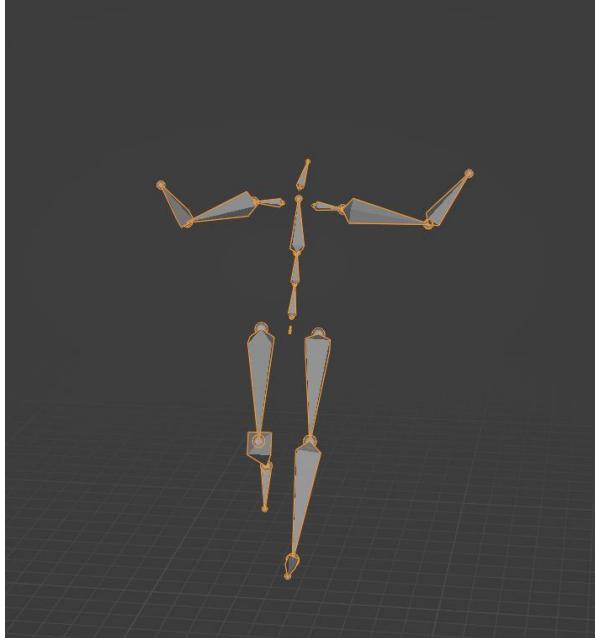


运动数据的使用

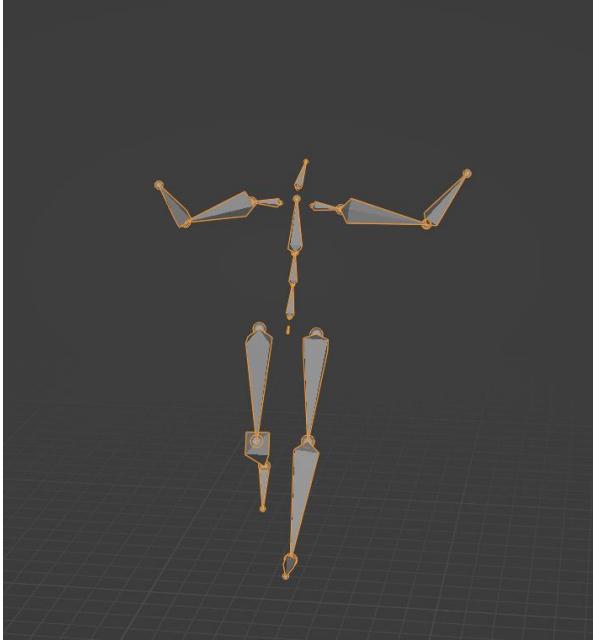
- 计算机角色动画的主要研究内容



运动的重定向



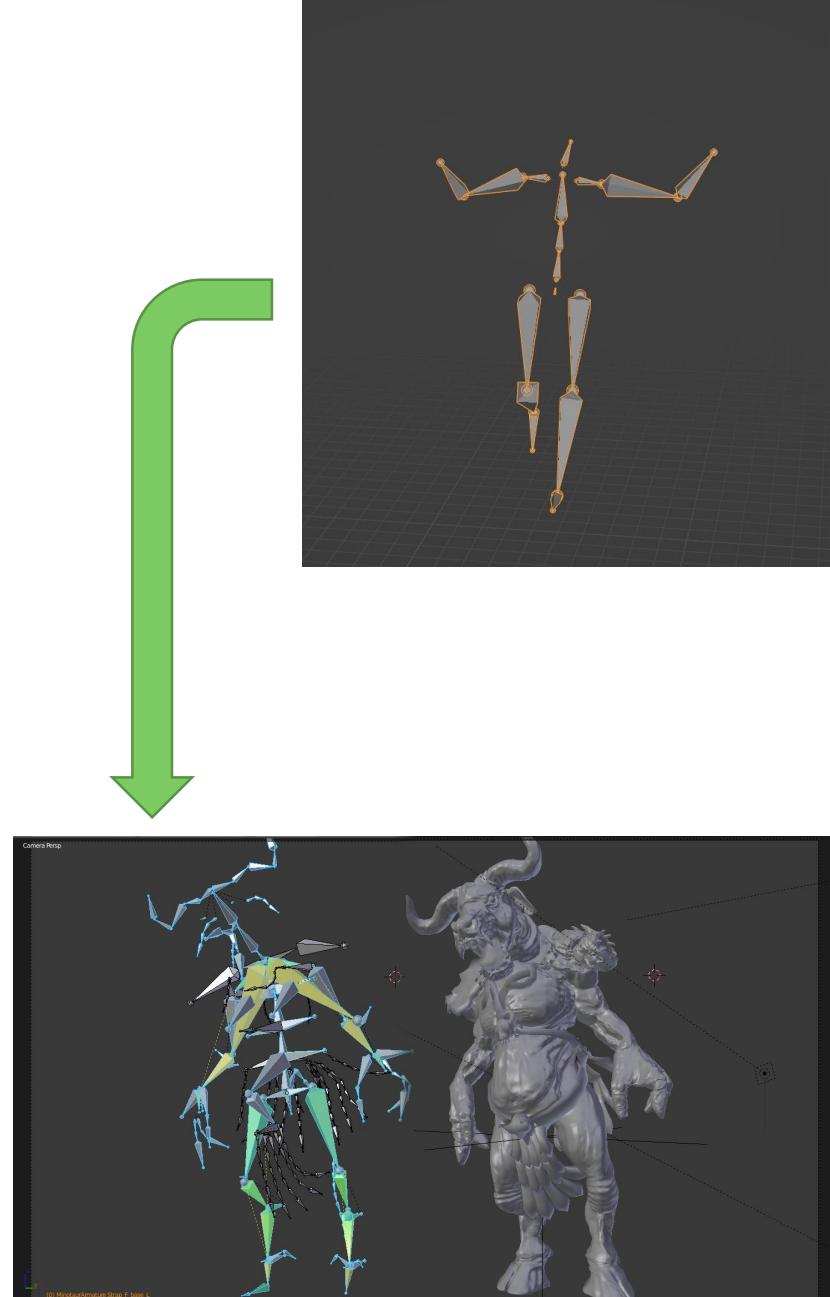
运动的重定向



骨骼名字不同
骨骼数量不同
骨骼长度不同
骨骼结构不同
骨骼T-pose不同

运动的重定向

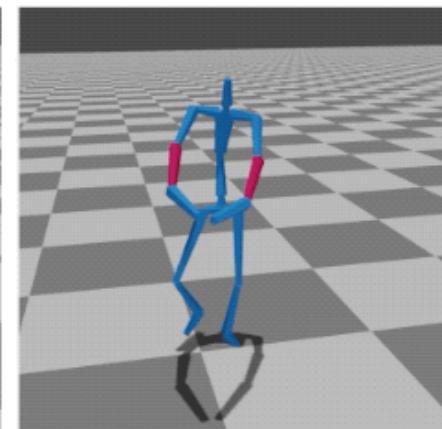
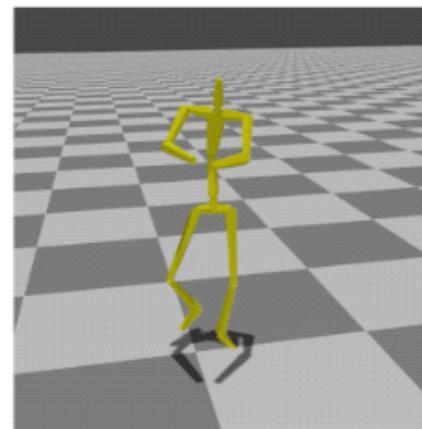
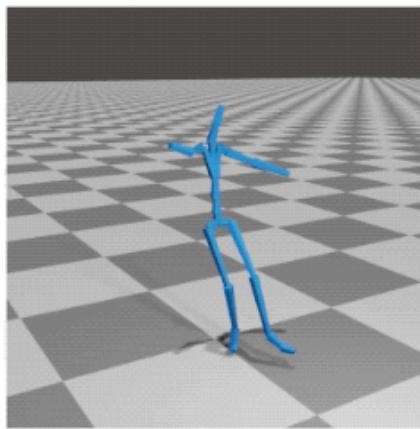
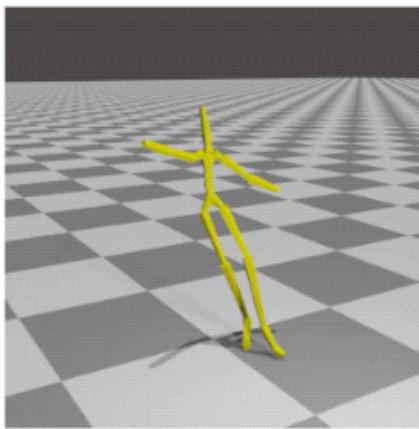
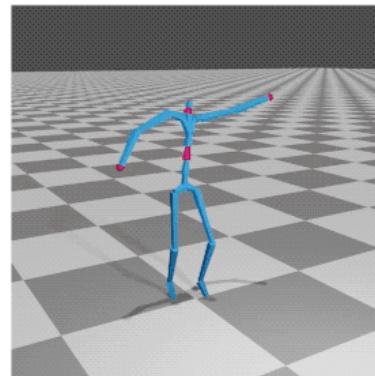
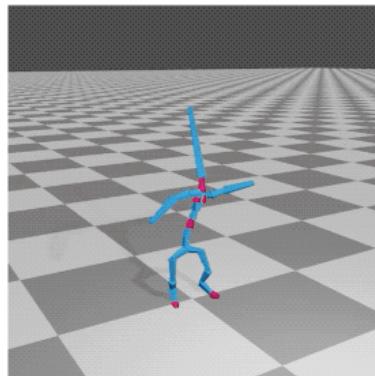
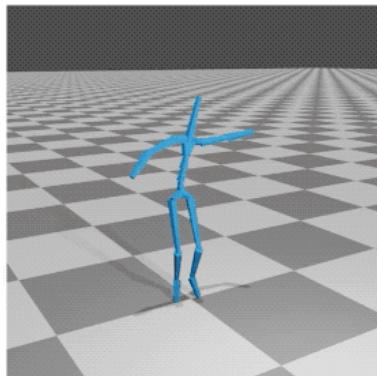
- 基本流程
 - 根据骨骼名字建立映射
 - 处理尺寸区别
 - 处理T-pose区别
 - 复制对应关节旋转
 - 处理动作缺陷
 - Foot-skating
 - 自相交
 - 动作不自然
- 其他修正



运动的重定向

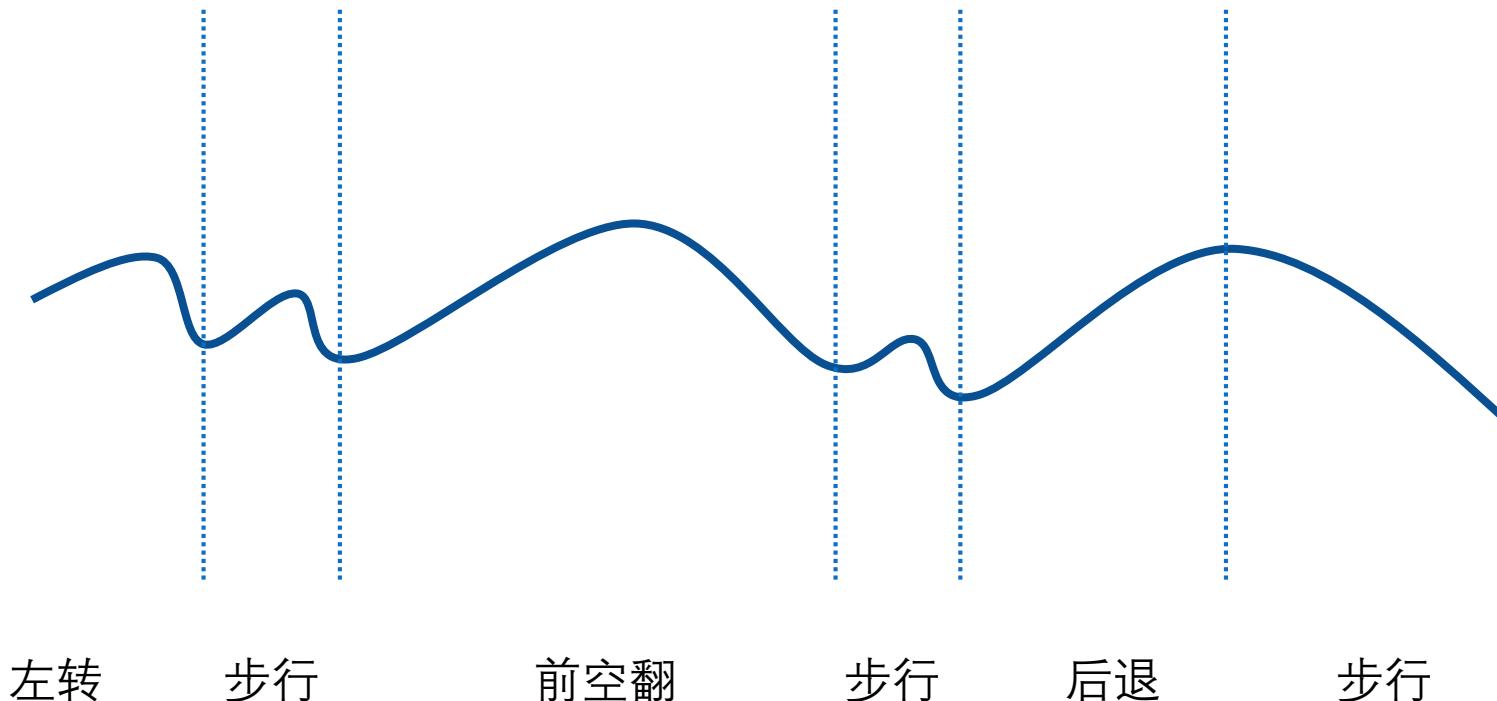


运动的重定向



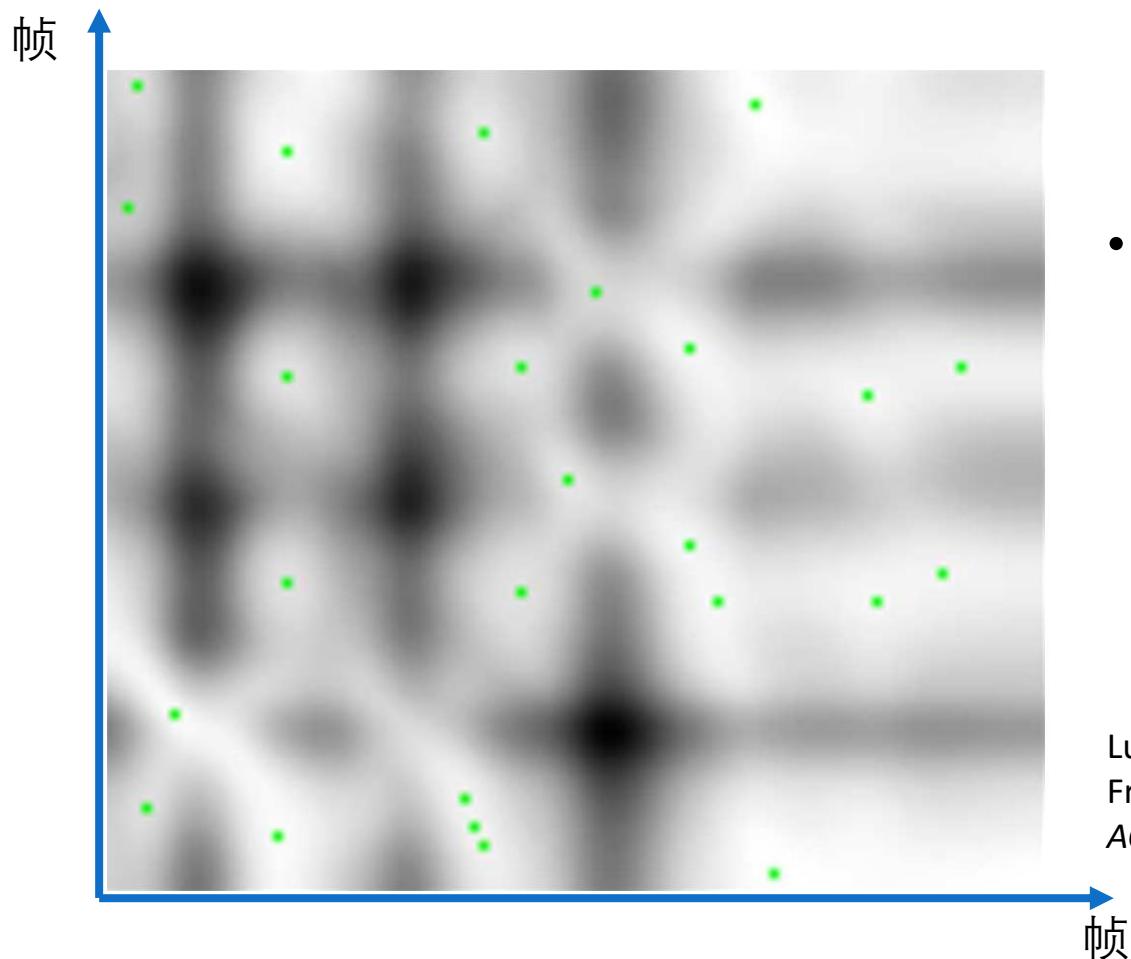
Kfir Aberman, Peizhuo Li, Dani Lischinski, Olga Sorkine-Hornung, Daniel Cohen-Or, and Baoquan Chen. 2020. *Skeleton-aware networks for deep motion retargeting*. ACM Trans. Graph. 39, 4 (July 2020), 62:62:1-62:62:14

运动的切分



运动的切分

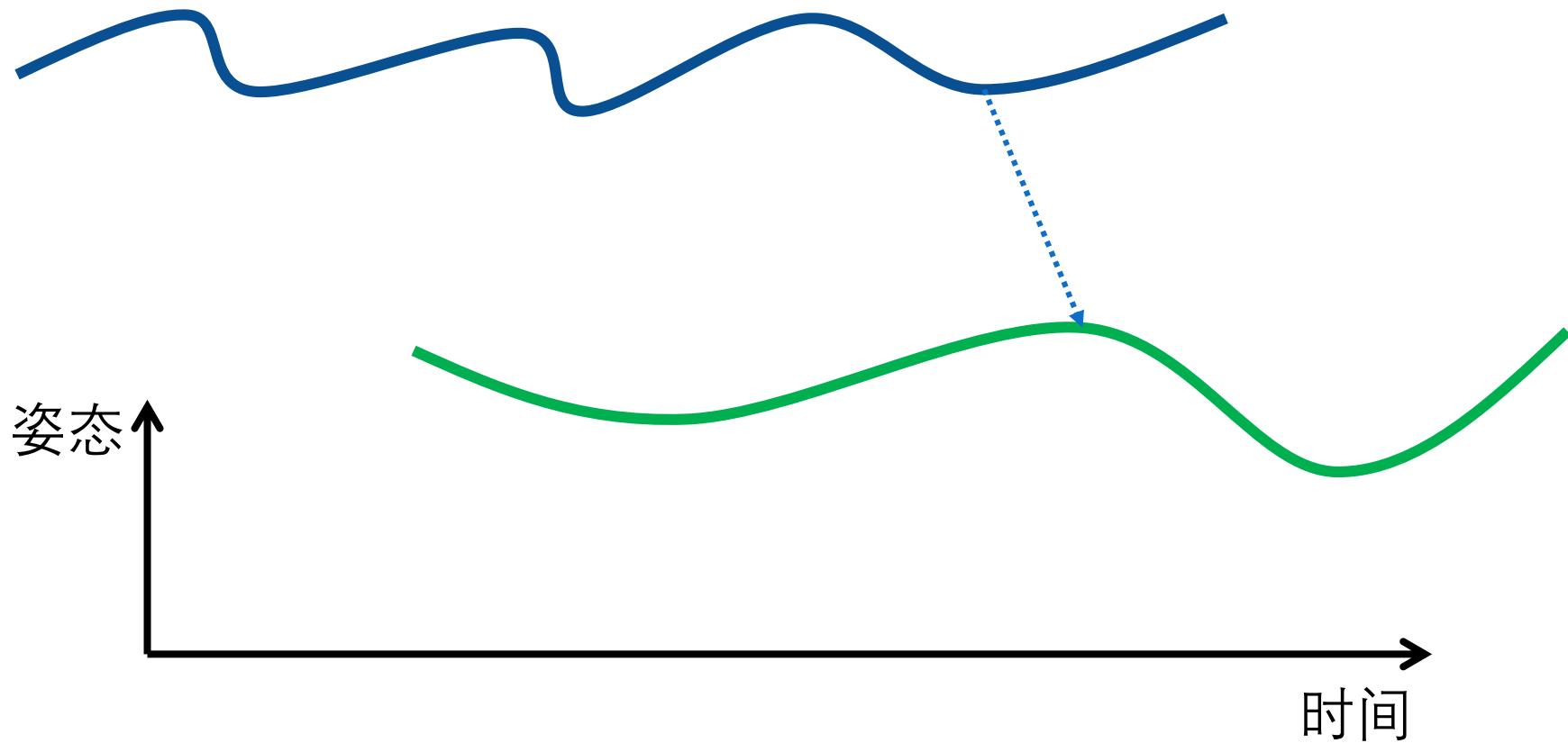
- 如何找到合适的切分点？



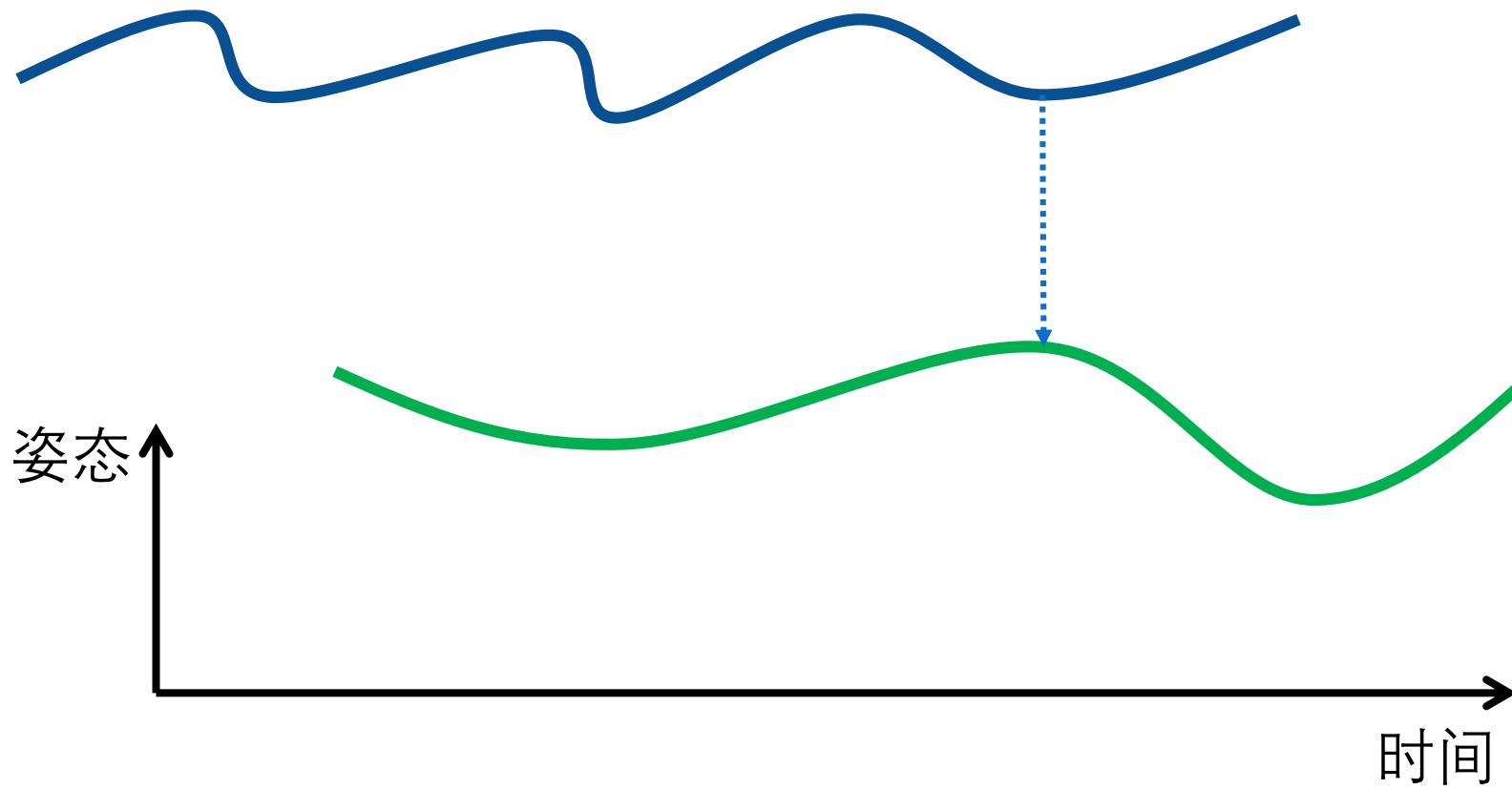
- 距离图：
 - 像素值代表任意两帧姿态间的差别
 - 局部极值点为可能的切分点

Lucas Kovar, Michael Gleicher, and Frédéric Pighin. 2002. **Motion graphs**. ACM Trans. Graph. 21, 3 (July 2002),

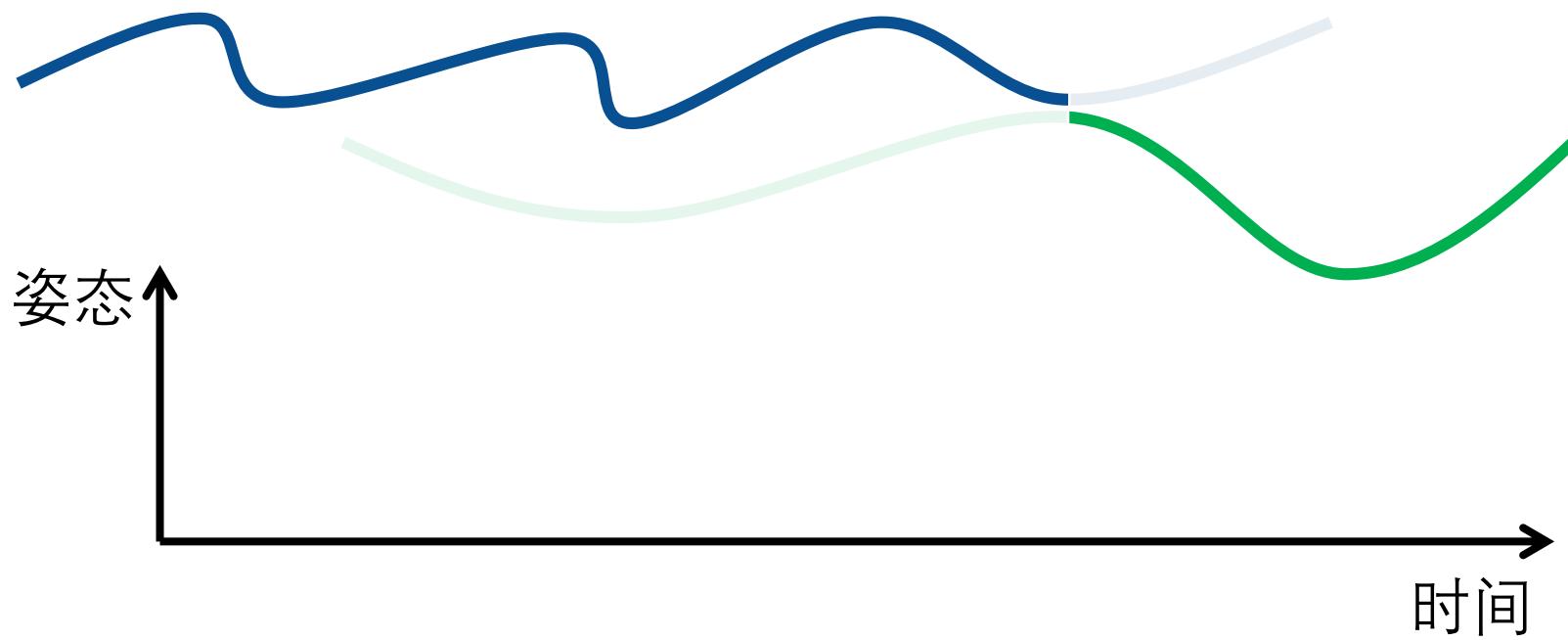
运动的连接



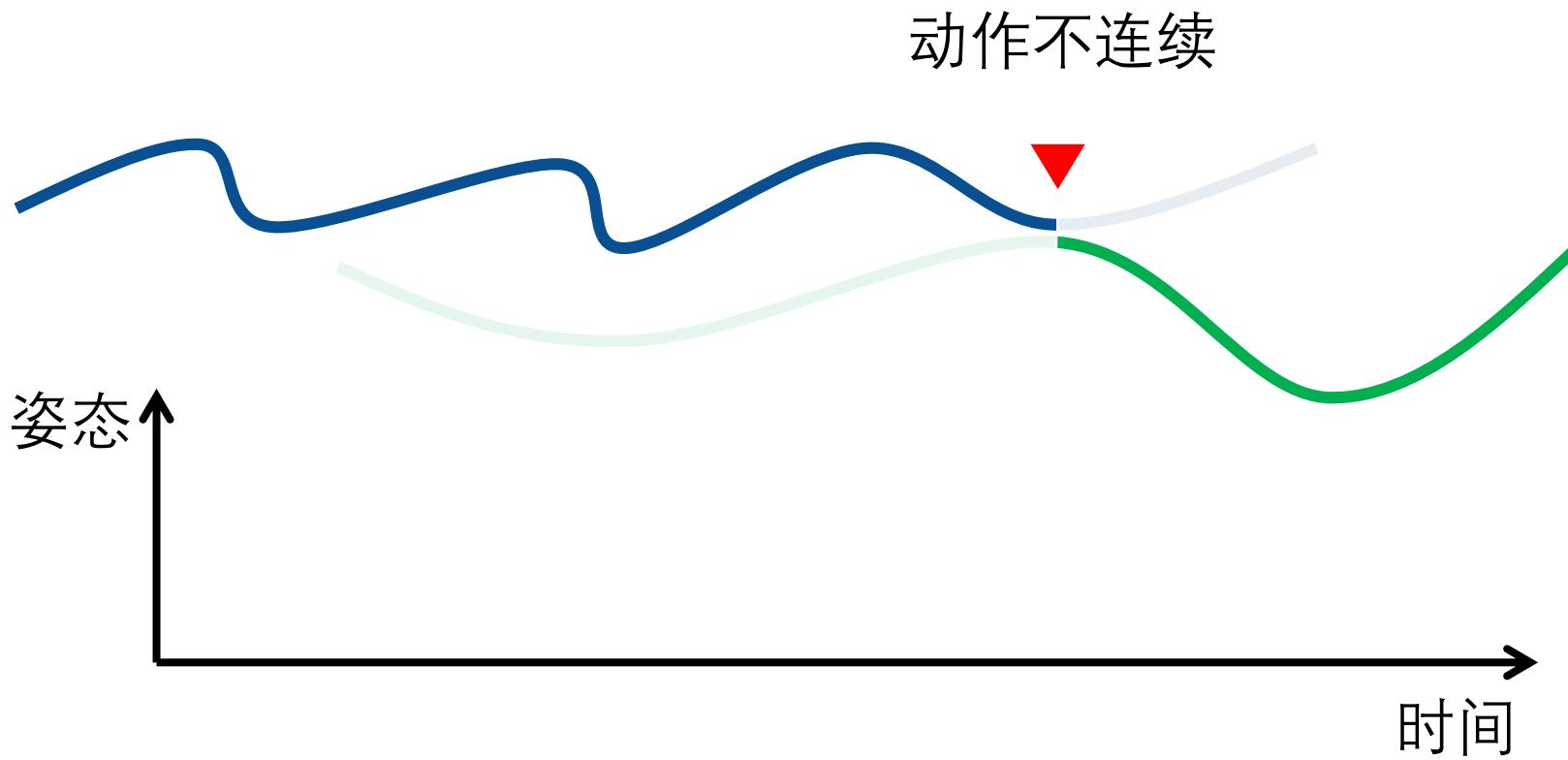
运动的连接



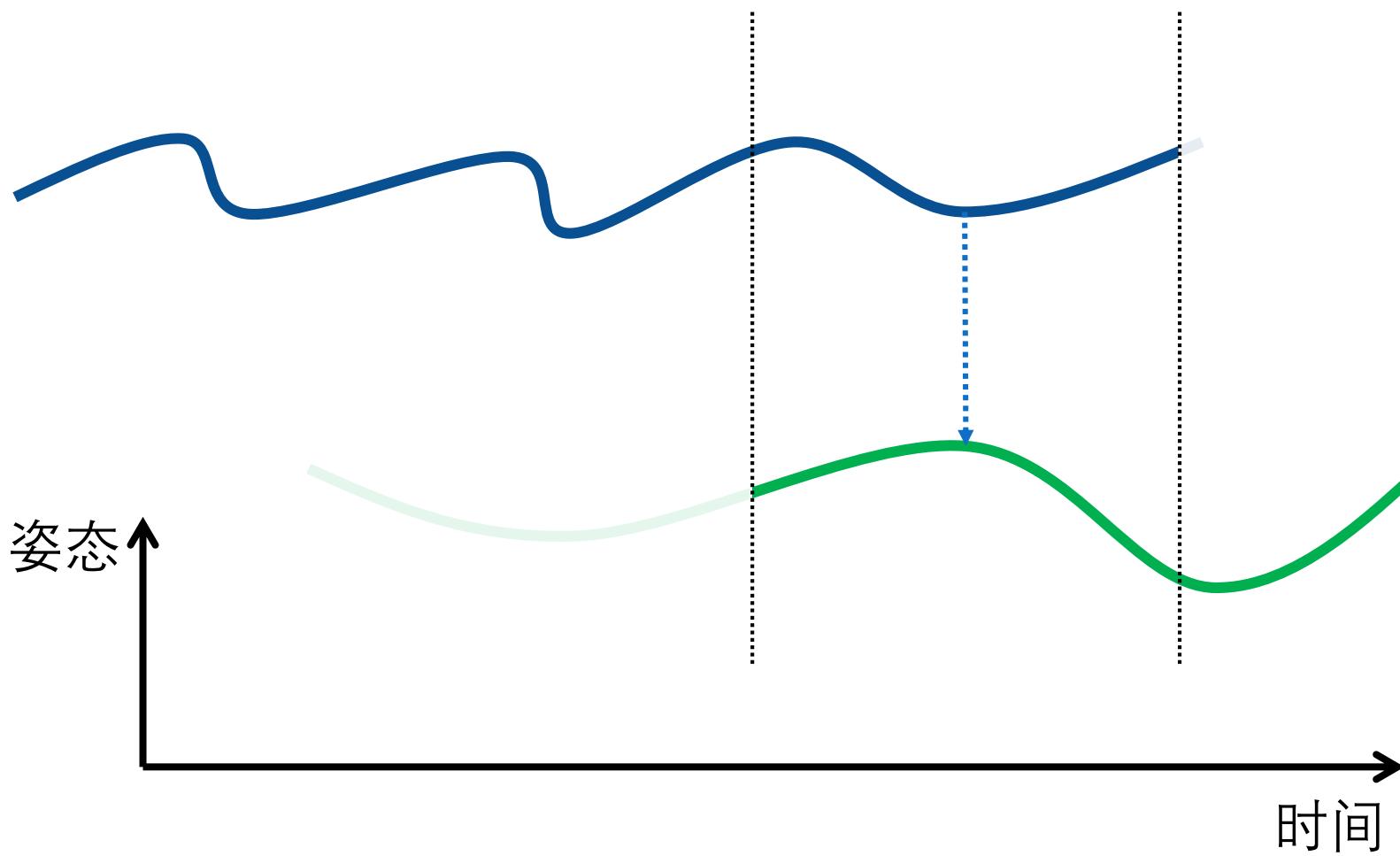
运动的连接



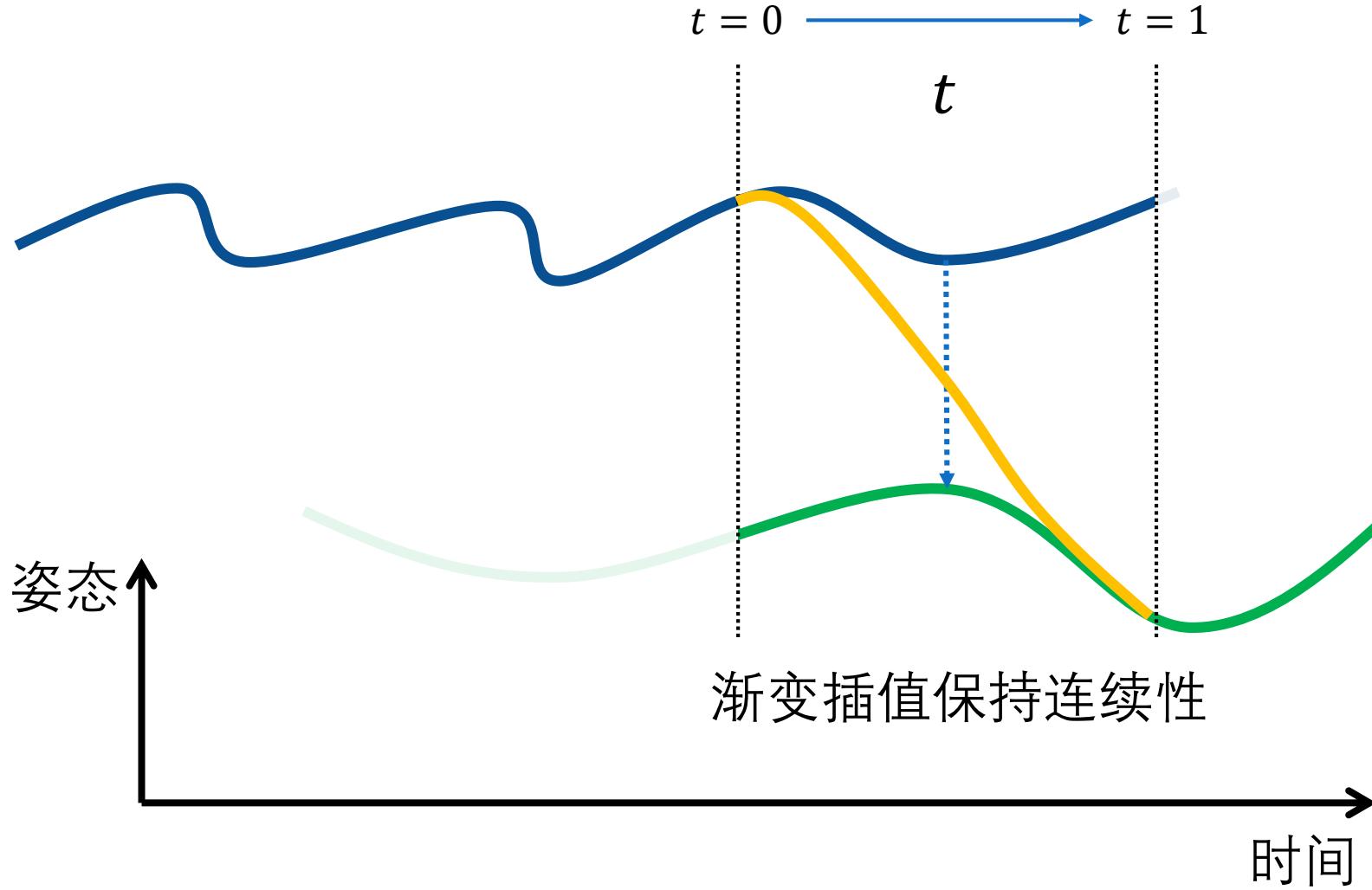
运动的连接



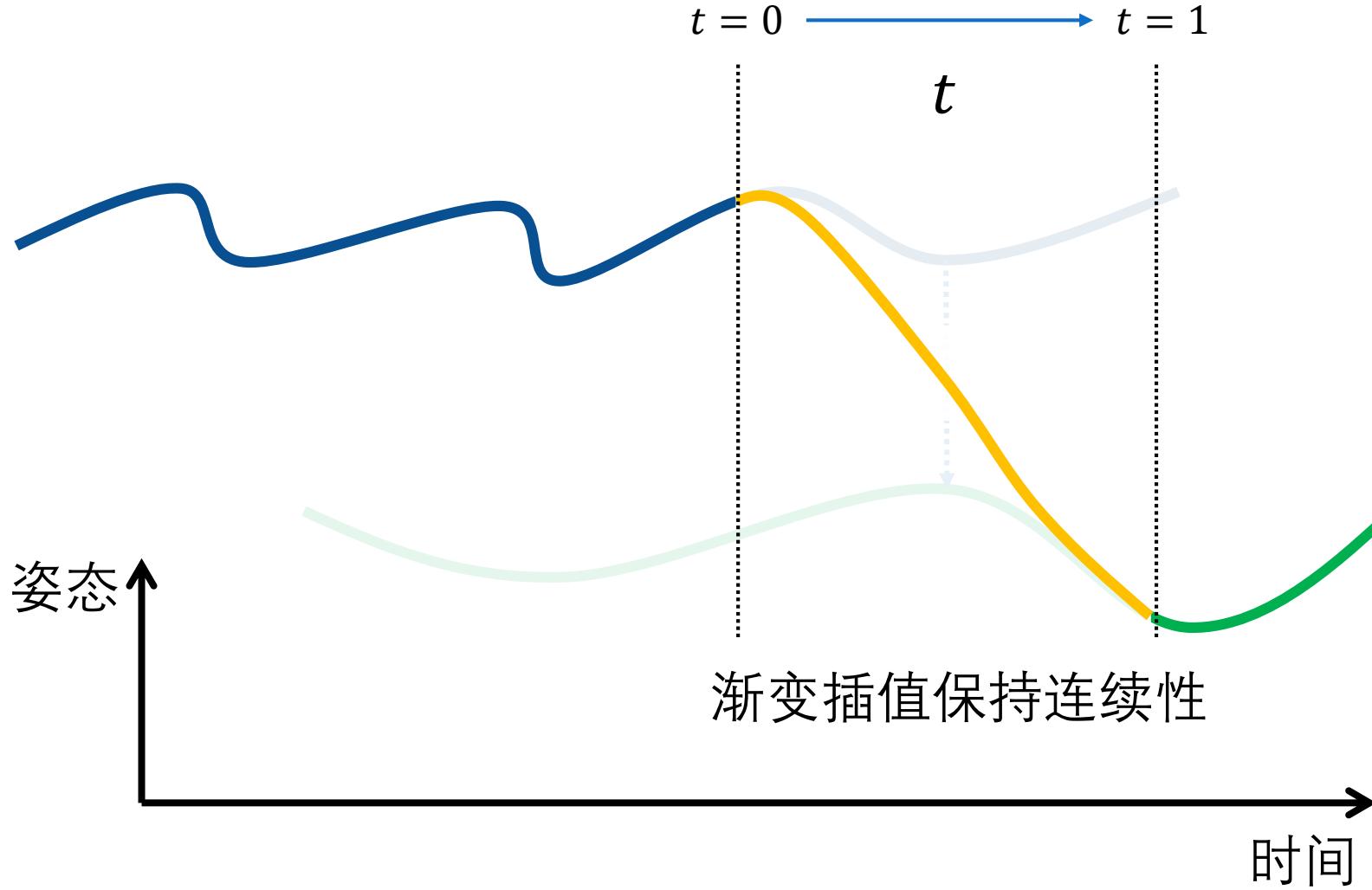
运动的连接



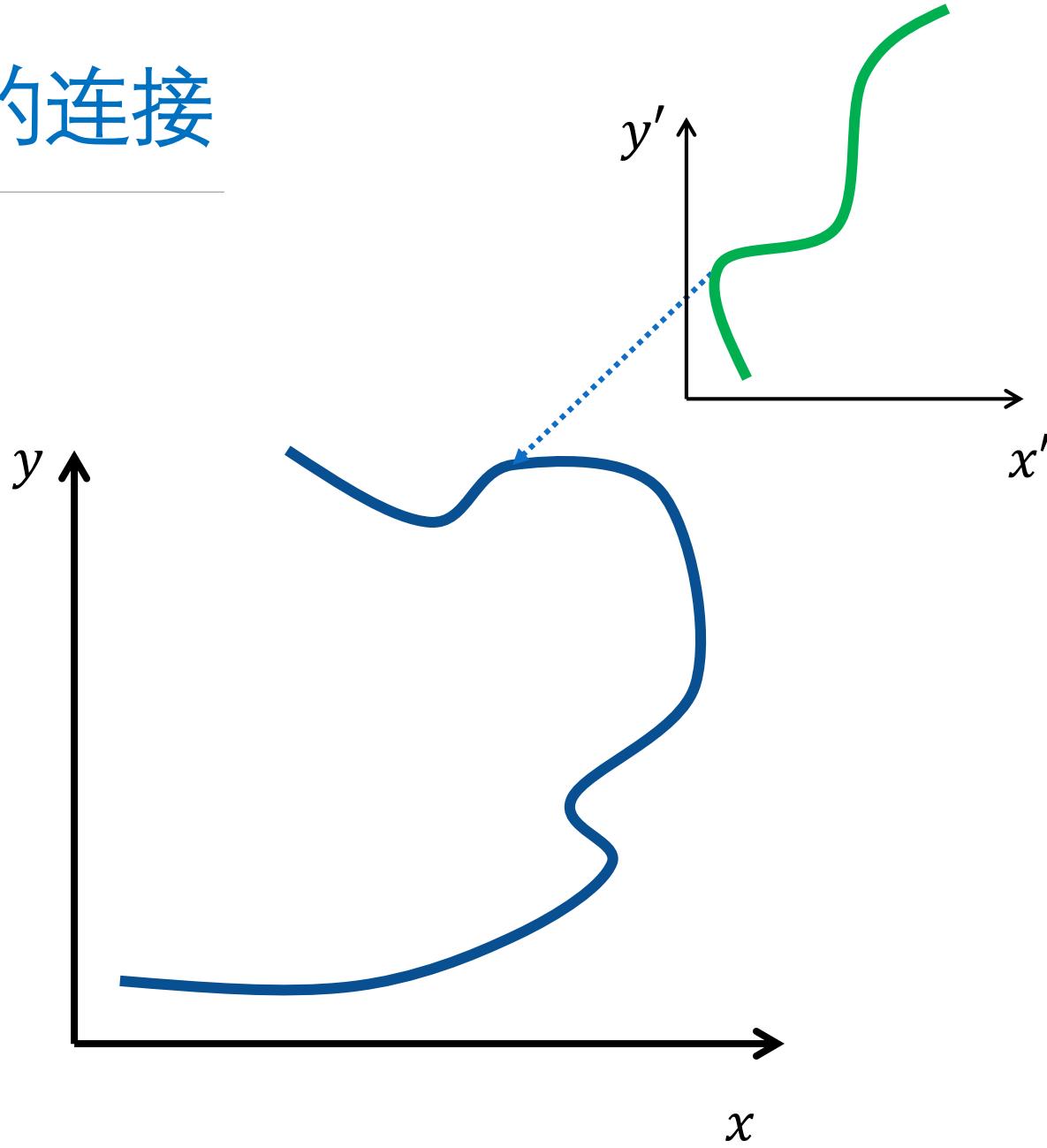
运动的连接



运动的连接

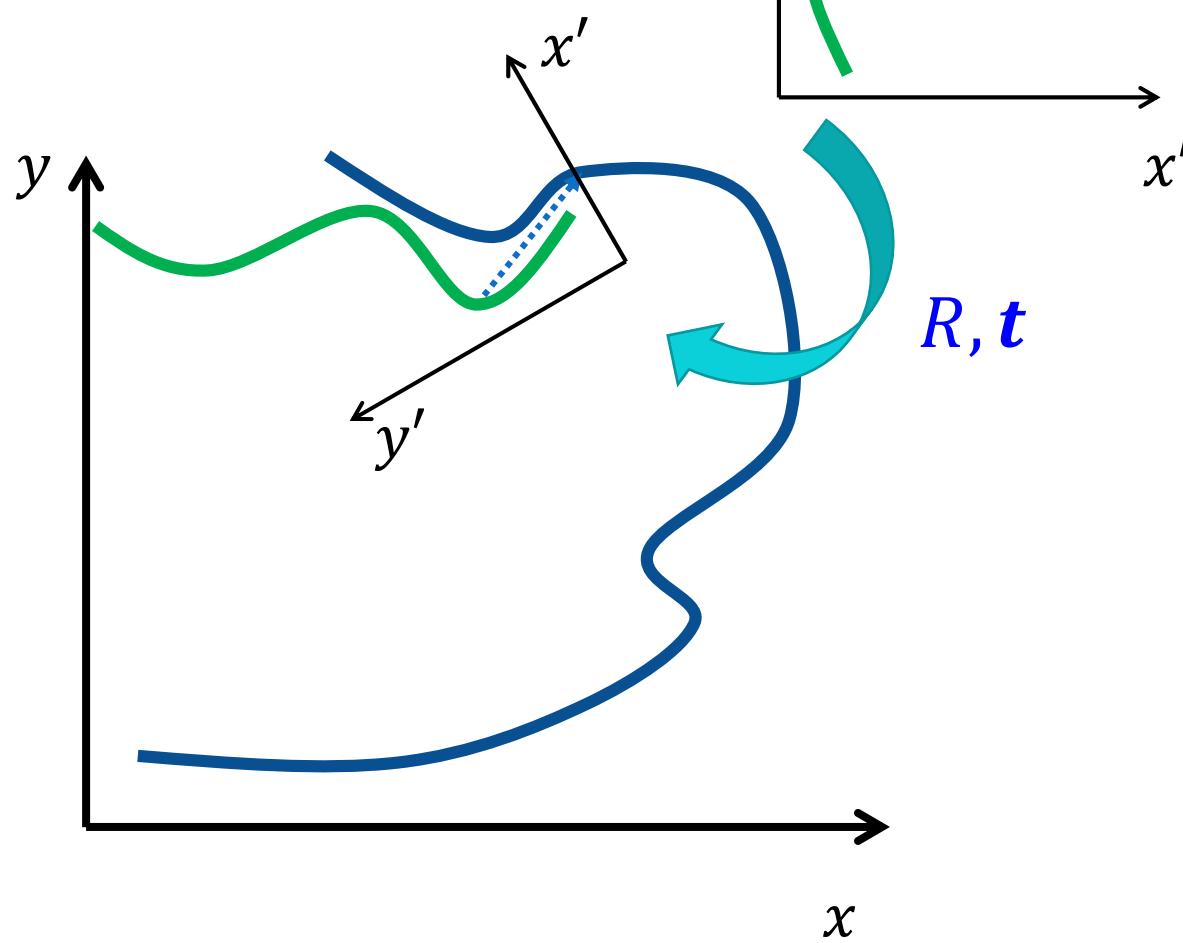


运动的连接



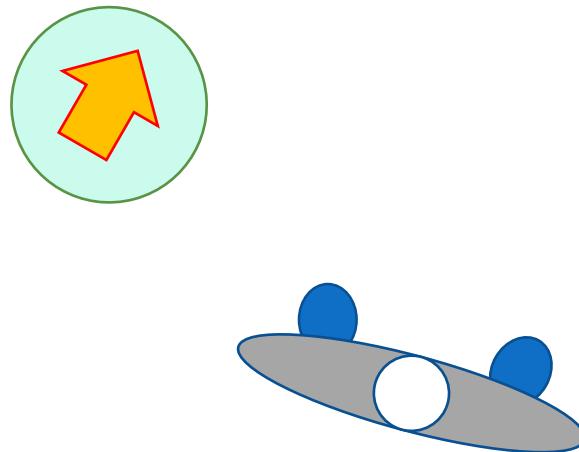
运动的连接

- 在连接前需要对齐动作



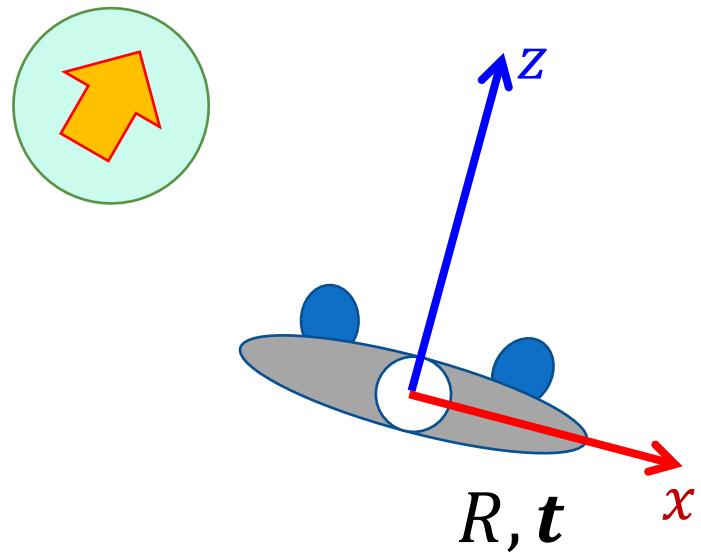
朝向坐标系 Heading/Facing Frame

- 与当前角色的位置重合，且一个坐标轴指向角色面向/前进方向



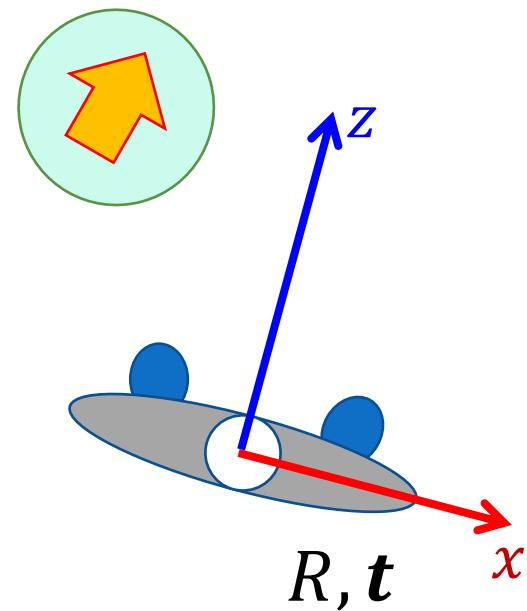
朝向坐标系 Heading/Facing Frame

- 与当前角色的位置重合，且一个坐标轴指向角色面向/前进方向

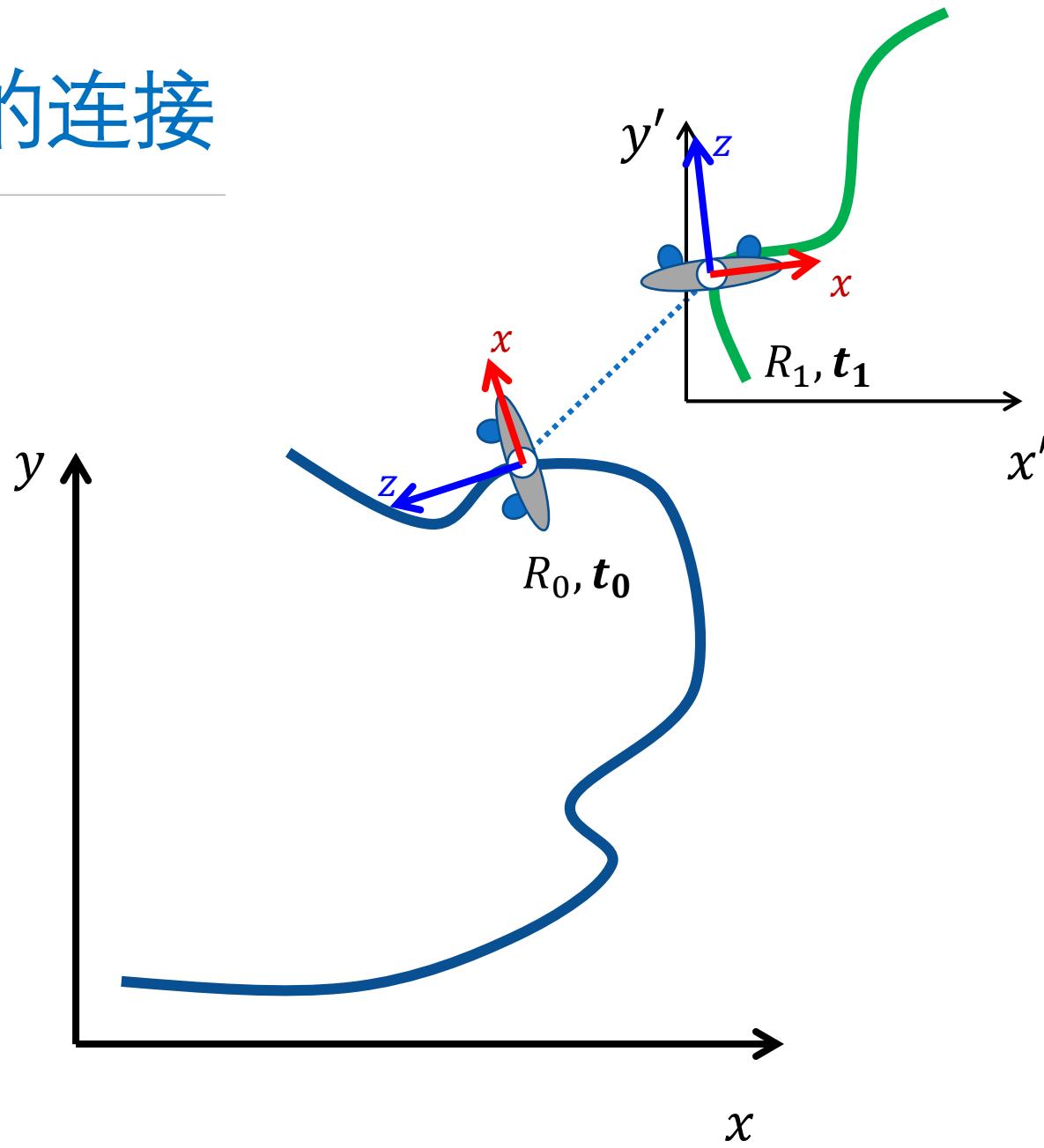


朝向坐标系 Heading/Facing Frame

- 与当前角色的位置重合，且一个坐标轴指向角色面向/前进方向
 - R 仅有沿竖直轴的旋转
 - t 仅含有平面位移
- 几种常见的定义 R 的方法
 - 将肩膀/髋骨连线设定为 x 轴，叉乘计算 z 轴
 - 计算 R 将世界 z 轴旋转到角色的前进方向
 - 分解角色的根节点旋转

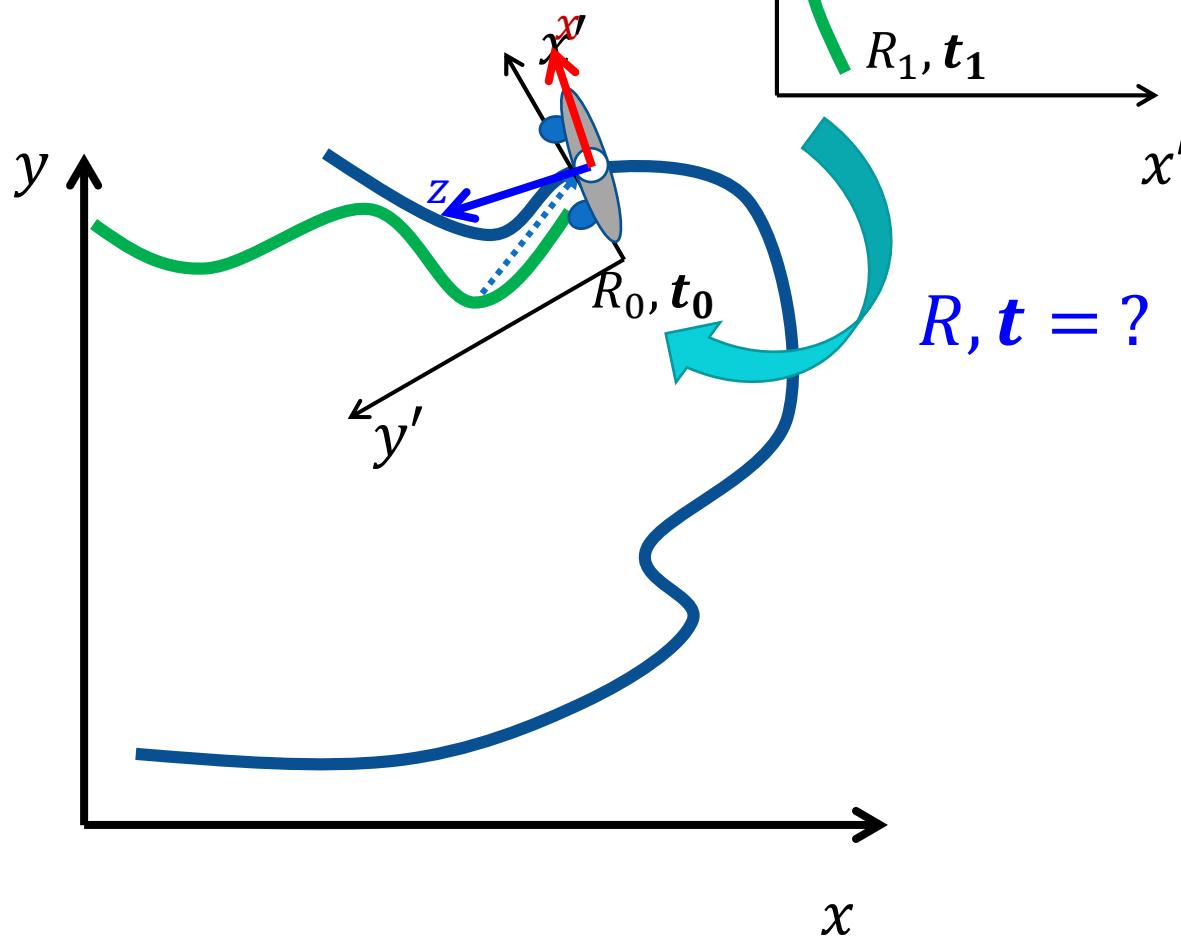


运动的连接



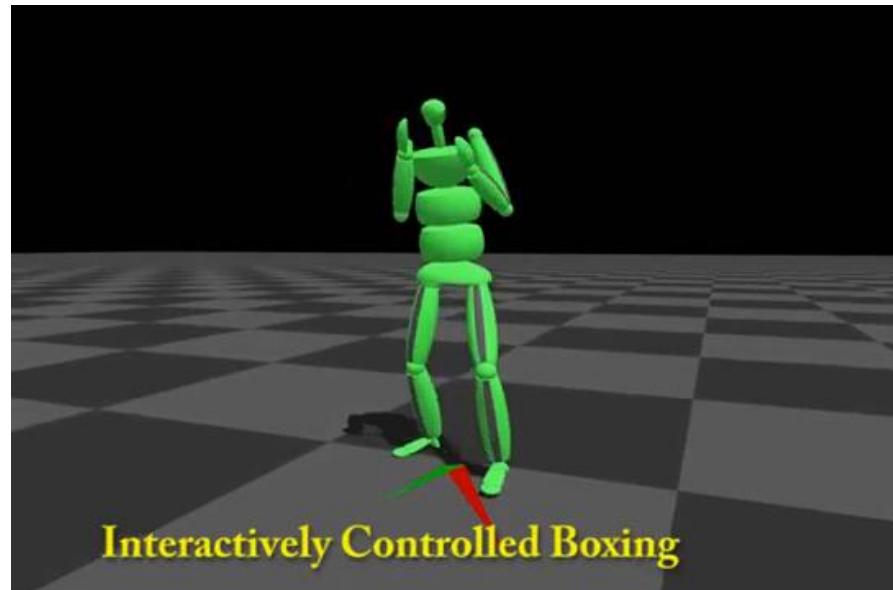
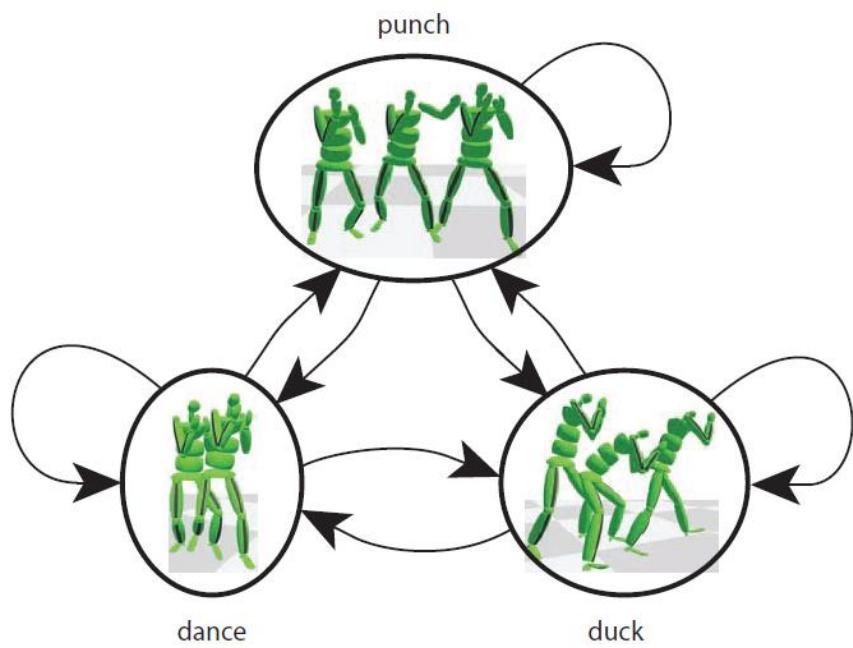
运动的连接

- 在连接前需要对齐动作

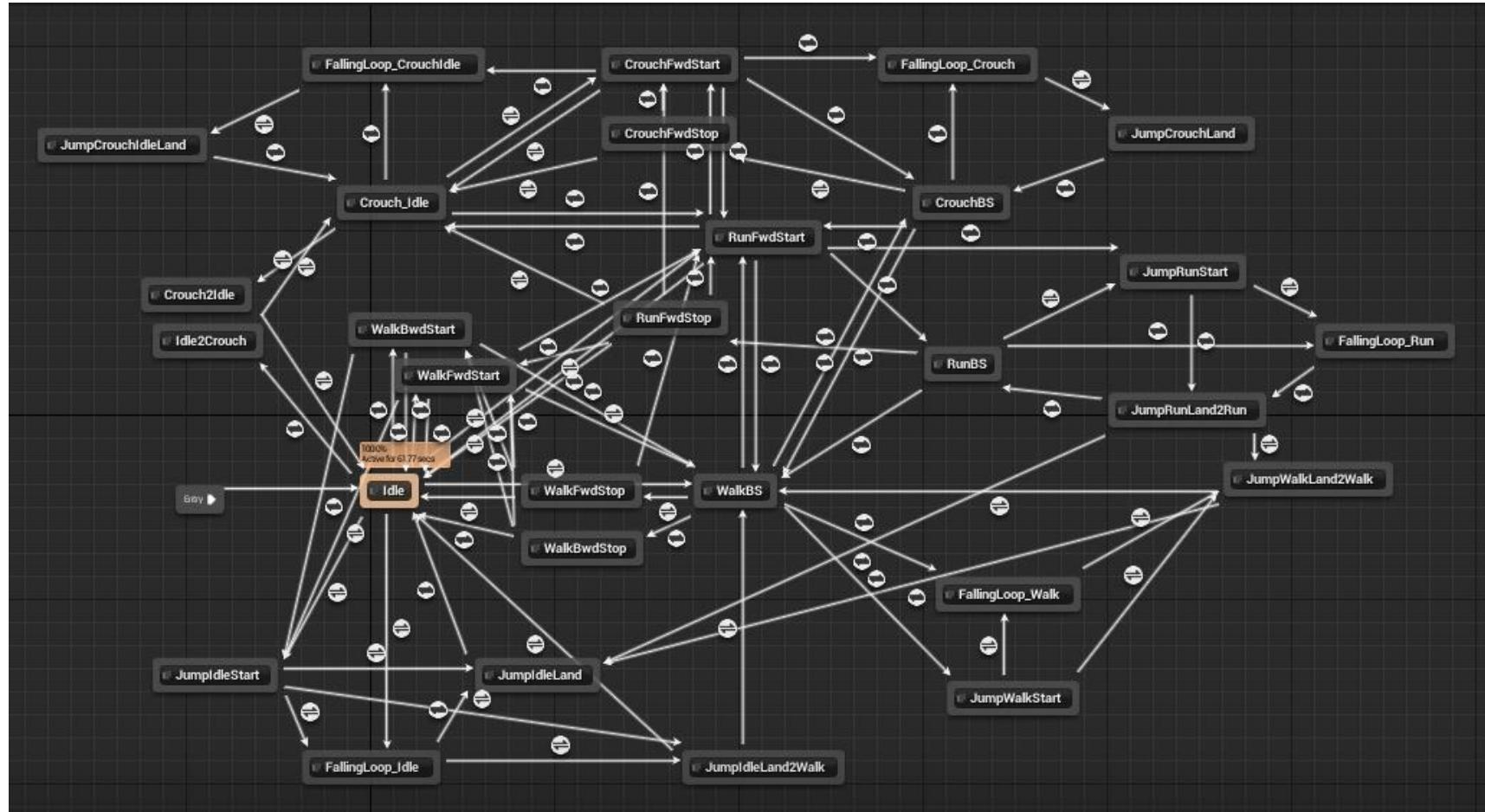


运动的合成

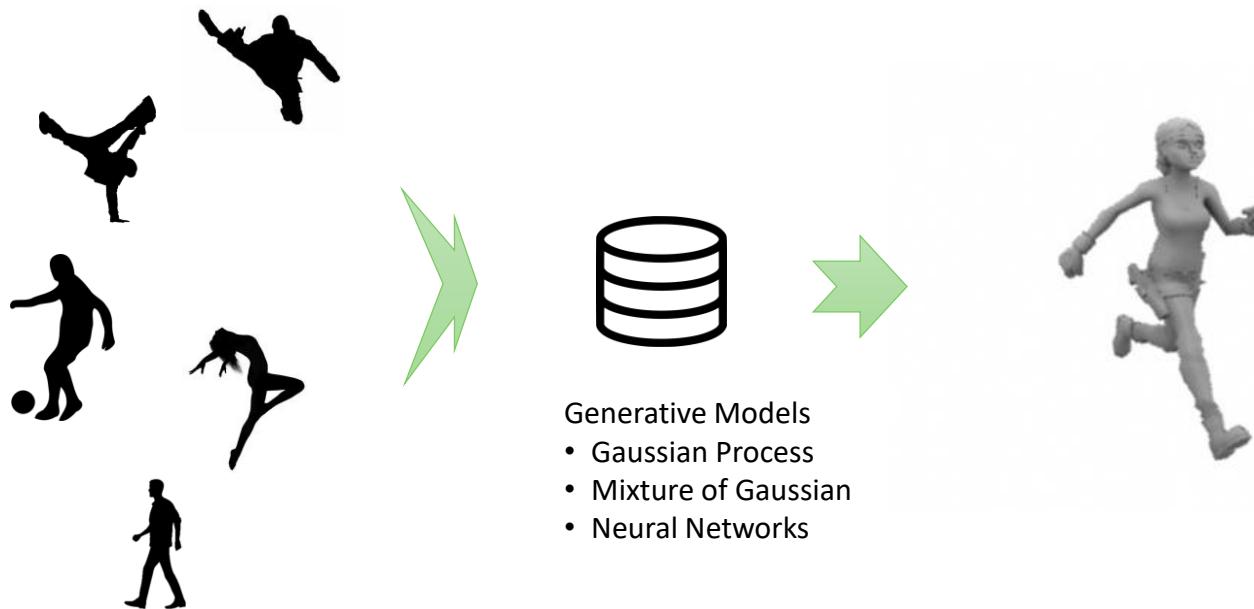
- Motion Graphs: 状态机模型



一个复杂一点的状态机



运动生成模型

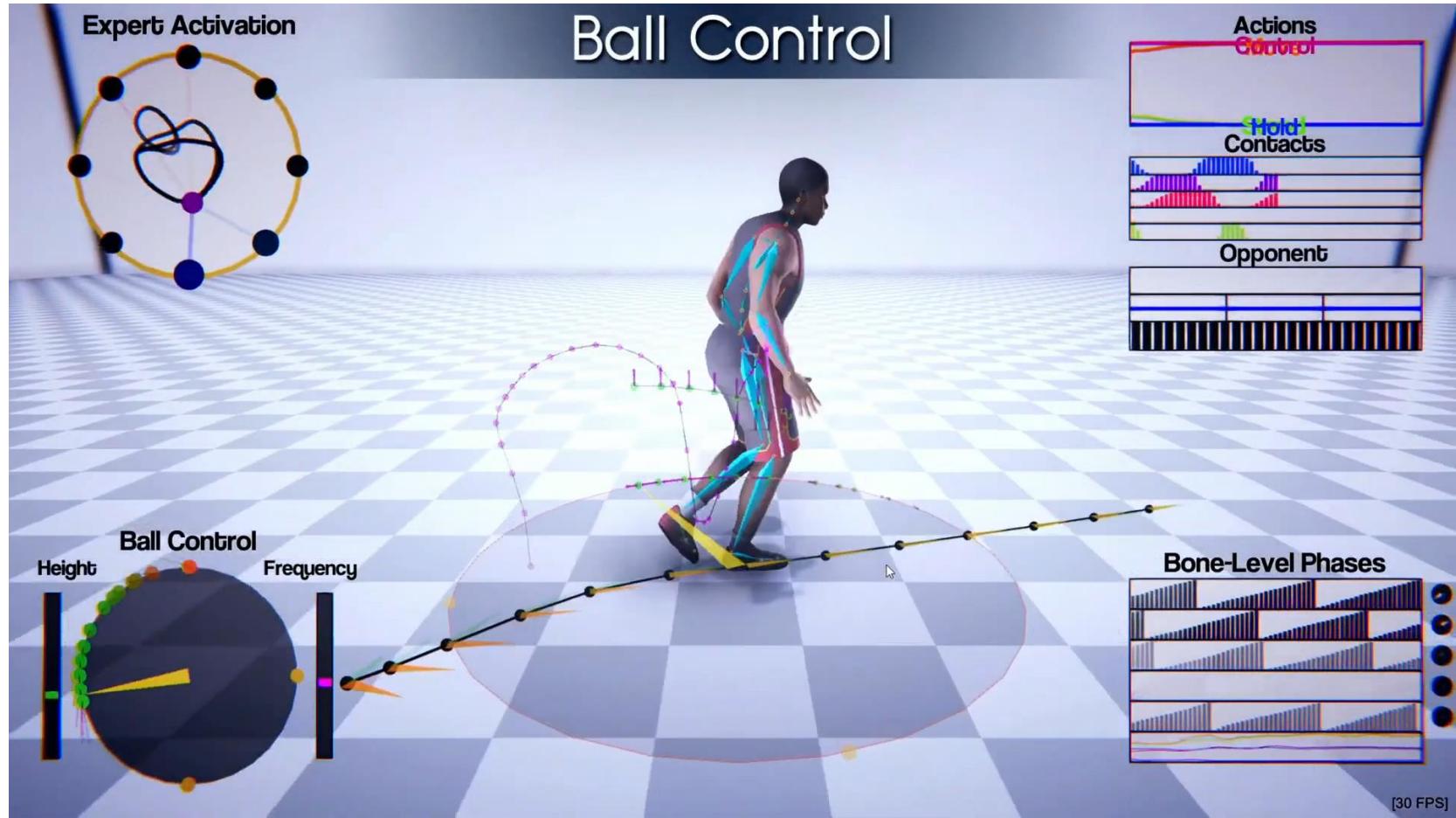


Motion Matching



<https://www.gdcvault.com/play/1023280/Motion-Matching-and-The-Road>
<https://zhuanlan.zhihu.com/p/136971426>

基于机器学习的运动生成模型



[Starke et al 2020, Local Motion Phases for Learning Multi-Contact Character Movements]

想想有没有问题