Lec 21 - Animation

- 动画是一种信息传递的工具
  - 美学经常比技术重要
- 是模型的延伸→连续性
  - Represent scene models as a function of time
- 输出：sequence of images that when viewed sequentially provide a sense of motion
  - 电影：24FPS
  - 视频：30FPS、29.994FPS
  - VR：90FPS （不晕的基础要求）

History

最早：狩猎鹿的动画(Shahr-e Sukhteh, Iran 3200 BCE)

圆盘旋转：(Phenakistoscope, 1831)

第一部Film：Edward Muybridge, “Sallie Gardner” (1878)

First Hand-Drawn Feature-Length (>40 mins) Animation：Disney, “Snow White and the Seven Dwarfs” (1937)

First Digital-Computer-Generated Animation：Ivan Sutherland, “Sketchpad” (1963) – Light pen, vector display

Early Computer Animation：Ed Catmull & Frederick Parke, “Computer Animated Faces” (1972)

Digital Dinosaurs!：Jurassic Park (1993)

First CG Feature-Length Film：Pixar, “Toy Story” (1995) （光栅化）

Computer Animation - 10 years ago：Sony Pictures Animation, “Cloudy With a Chance of Meatballs” (2009)

Computer Animation - last year：Walt Disney Animation Studios, “Frozen 2” (2019)

Keyframe animation关键帧动画

- Animator (e.g. lead animator) creates keyframes 关键帧
- Assistant (person or computer) creates in-between frames (“tweening”) 渐变帧

关键的技术难点 - Interpolation 插值

- Linear interpolation usually not good enough
- Recall splines for smooth / controllable interpolation

B样条……

Physical Simulation物理模拟

模拟、仿真：推导、实现公式，模拟出物体应该怎么变化

例子：布料模拟、流体模拟

质点弹簧系统 Mass Spring System: Example of Modeling a Dynamic System

Example: Mass Spring Rope, Hair, Mass Spring Mesh

- A Simple Idealized Spring
    - 没有初始长度
    - 随着拉力线性增长/缩短，线性系数是spring coefficient: stiffness
    - Force pulls points together
    - Strength proportional to displacement (Hooke's Law)
    - 问题：长度会倾向于0
- Non-Zero Length Spring
    - 初始长度Rest length不为零
    - Problem: oscillates forever 永远震荡

$$\boldsymbol{f}_{a\to b} = k_s \frac{\boldsymbol{b}-\boldsymbol{a}}{\|\boldsymbol{b}-\boldsymbol{a}\|}(\|\boldsymbol{b}-\boldsymbol{a}\| - l)$$

Dot Notation for Derivatives：

$$\begin{aligned} &\boldsymbol{x} \\ &\dot{\boldsymbol{x}} = \boldsymbol{v} \\ &\ddot{\boldsymbol{x}} = \boldsymbol{a} \end{aligned}$$

- Introducing Energy Loss
    - Simple motion damping 阻尼

$$\boldsymbol{f} = -k_d \dot{\boldsymbol{b}}$$

    - Behaves like viscous drag on
    - Slows down motion in the direction of velocity
    - k_d is a damping coefficient
    - 问题：Slows down all motion
        - Want a rusty spring's oscillations to slow down, but should it also fall to the ground more slowly? 跟全局速度挂钩
        - 无法表示弹簧内部的损耗
- Internal Damping for Spring

Relative velocity of b, assuming a is static (vector)

$$\boldsymbol{f_b} = -k_d \boxed{\frac{\boldsymbol{b}-\boldsymbol{a}}{||\boldsymbol{b}-\boldsymbol{a}||}(\dot{\boldsymbol{b}}-\dot{\boldsymbol{a}})} \cdot \frac{\boldsymbol{b}-\boldsymbol{a}}{||\boldsymbol{b}-\boldsymbol{a}||}$$

Damping force applied on b

Relative velocity projected to the direction from a to b (scalar)

Direction from a to b

- Viscous drag only on change in spring length
- Won't slow group motion for the spring system (e.g. global translation or rotation of the group)
- Note: This is only one specific type of damping 只是一种阻尼的近似

Structures from Springs

- Sheets
- Blocks
- Others
    - 比如说，一块布的进化

Step 1: Sheets

- This structure will not resist shearing切变会露馅
- This structure will not resist out-of-plane bending...

Step 2: 加强筋

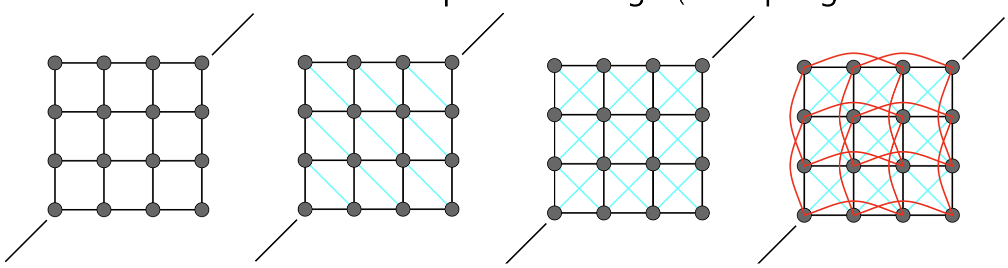
- This structure will resist shearing but has anisotropic bias 各向异性
- This structure will not resist out-of-plane bending either...

Step 3: 加强筋 plus

- This structure will resist shearing. Less directional bias.
- This structure will not resist out-of-plane bending either... 弯折

Step 4: 加强筋 max （skip connection）

- This structure will resist shearing. Less directional bias.
- This structure will resist out-of-plane bending （Red springs should be much weaker）



FEM (Finite Element Method) Instead of Springs

有限元方法

- 车辆碰撞

力传导扩散适合用有限元方法建模做

动画系统之Particle Systems粒子系统

- 建模定义很多粒子
- 每个粒子有自己的属性

Model dynamical systems as collections of large numbers of particles

Each particle’s motion is defined by a set of physical (or non-physical) forces

Popular technique in graphics and games

• Easy to understand, implement

• Scalable: fewer particles for speed, more for higher complexity

Challenges

• May need many particles (e.g. fluids)

• May need acceleration structures (e.g. to find nearest particles for interactions)

For each frame in animation

• [If needed] Remove dead particles

• Calculate forces on each particle

• Update each particle’s position and velocity

• [If needed] Create new particles

• Render particles

定义个体和群体之间的关系

Particle System Forces

Attraction and repulsion forces

• Gravity, electromagnetism, …

• Springs, propulsion, …

Damping forces

• Friction, air drag, viscosity, …

Collisions

• Walls, containers, fixed objects, ...

• Dynamic objects, character body parts, ...

星系模拟、Particle-Based Fluids

Example: Simulated Flocking as an ODE

- 定义鸟儿之间交互的规则：个体对群体的观察
- Model each bird as a particle Subject to very simple forces:
- attraction to center of neighbors
- repulsion from individual neighbors
- alignment toward average trajectory of neighbors Simulate evolution of large particle system numerically Emergent complex behavior (also seen in fish, bees, ...)

Example: Molecular Dynamics

Example: Crowds + “Rock” Dynamics

Kinematics

运动学：正向和反向

Forward Kinematics 正向运动学

明确骨骼之间的运动关系→计算出各个部位的位置

Articulated skeleton

- Topology (what’s connected to what)
- Geometric relations from joints
- Tree structure (in absence of loops)

Joint types

- Pin (1D rotation)
- Ball (2D rotation)
- Prismatic joint (translation)

Strengths

- Direct control is convenient 无法直接控制
- Implementation is straightforward

Weaknesses

- Animation may be inconsistent with physics
- Time consuming for artists

Inverse Kinematics 逆运动学

限制各个部位（通常只有终端）的位置、限制骨骼的运动方式→计算骨骼的运动

方便控制形体整体形状

解特别复杂，可能并不唯一

解法：随机化算法（优化方法，梯度下降）

Numerical solution to general N-link IK problem

• Choose an initial configuration

• Define an error metric (e.g. square of distance between goal and current position)

• Compute gradient of error as function of configuration

• Apply gradient descent (or Newton’s method, or other optimization procedure)

例子：Style-Based IK

Rigging

对形体的控制，像木偶一样

Rigging is a set of higher level controls on a character that allow more rapid & intuitive modification of pose, deformations, expression, etc.

Important

• Like strings on a puppet

• Captures all meaningful character changes

• Varies from character to character

Expensive to create

• Manual effort 定控制点，拉控制点（应该怎么定、应该怎么拉 → 动画师）

• Requires both artistic and technical training

Blend Shapes 控制点间的位置插值计算

Instead of skeleton, interpolate directly between surfaces

E.g., model a collection of facial expressions:

Simplest scheme: take linear combination of vertex positions

Spline used to control choice of weights over time

Motion Capture

真人控制点反映到虚拟角色中去，需要建立真实和虚拟的联系

Data-driven approach to creating animation sequences

- Record real-world performances (e.g. person executing an activity)
- Extract pose as a function of time from the data collected

Strengths

• Can capture large amounts of real data quickly

• Realism can be high

Weaknesses

• Complex and costly set-ups 复杂、花钱

• Captured animation may not meet artistic needs, requiring alterations 不符合艺术家要求，不可能实现的动作

捕捉条件限制

不同的捕捉方法：

- Optical (More on following slides)
    - Markers on subject
    - Positions by triangulation from multiple cameras
    - 8+ cameras, 240 Hz, occlusions are difficult
- Magnetic Sense magnetic fields to infer position / orientation. Tethered.
- Mechanical Measure joint angles directly. Restricts motion.

很花钱

Data可以可视化成一些曲线

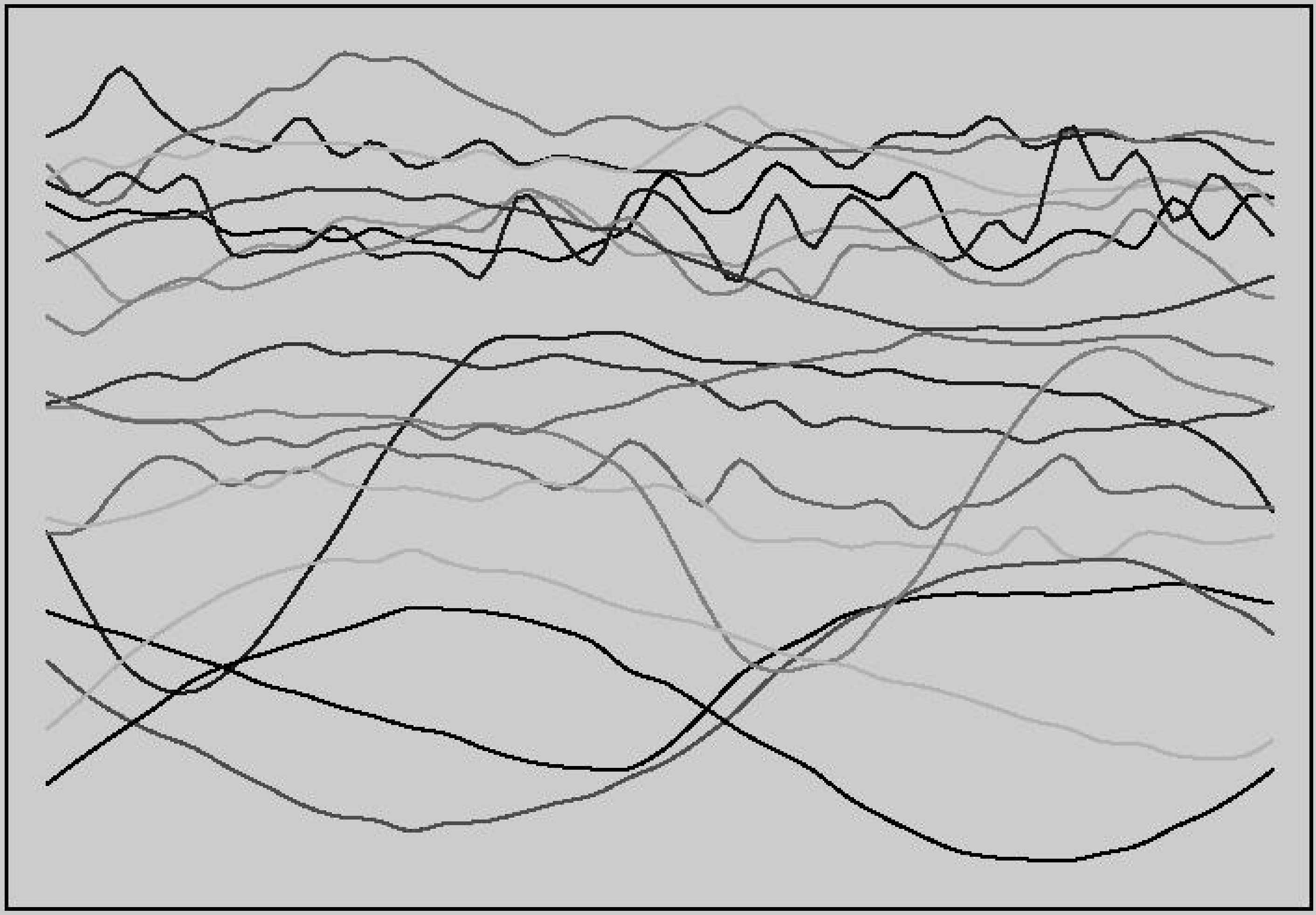


Figure 1: Some of the captured motion curves of human walking.

Challenges of Facial Animation

- Uncanny valley
    - In robotics and graphics
    - As artificial character appearance approaches human realism, our emotional response goes negative, until it achieves a sufficiently convincing level of realism in expression

Facial Motion Capture

Example：阿凡达