CHARACTER ANIMATION
Dr. Andreas Aristidou

Image taken from https://marionettestudio.com/

How does the magic happen?
Overview

- **Introduction to Character Animation**
- **Character Rigging**
  - Setup the skeletal system (“rig”) of the character.
- **Character Skinning**
  - Attach a mesh (“skin”) to the skeletal system of the character.
- **Motion Capture**
  - Motion Capture Technologies.
  - Limitations
- **Motion Retargeting**
  - Retarget motion from one character to another.
- **Motion Synthesis**
  - Motion graphs.
  - Blending
- **Style Transfer**
  - Transfer style from one character to another or modify current to a different style.

Character Animation

**Motivation**

- Bring Animated characters to life
  - Animator analogous to film actors
- Many applications use **character** or **object** animation
  - Entertainment technology (e.g., films, games)
  - Virtual, or augmented reality
  - Simulations, Demonstrations, or training systems
- Other forms of animation?
  - Trees, liquids, animals, clouds, etc.
Character Animation

Introduction

• **Computer-assisted animation**
  – 2D & 2 1/2 D.
  – In-betweening.
  – Inking, virtual camera, managing data, etc.

• **Computer generated animation**
  – Low level techniques.
    • Precisely specifying motion.
  – High level techniques.
    • Describe general motion behavior.

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**Computer-assisted animation**

**Key-framing: Walk Cycle**

- Hip joint orientation

Image taken from: http://krznmedia.wordpress.com
Character Animation
Introduction

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Character Animation

Low level techniques

• Generate motion with set of rules or constraints
  – Physics-based motion
    • Take into consideration laws of physics
    • Centers of mass
    • Etc.

Character Animation

High level techniques
Character Animation
Physics-Based Animation

Physics-based techniques generate new motion without using existing clips – in theory.
Common for passive objects such as rag dolls, but still rare for living creatures in commercial games.

Rag doll from *Dark Souls*.

Character Animation
Challenges and Advantages of Physics-Based Animation

**Challenges**
- All motion must be applied through forces and torques – more difficult than poses.
- Must simulate biomechanics of the body.
- Hard to control the style of motion.

**Advantages**
- Inherently realistic.
- Not limited by database.
- Can simulate motion that is impossible in motion capture (dangerous stunts, imaginary animals).
Recently impressive results have been achieved using machine learning. Some approaches use motion capture data to train the animation system.

**Learning Approaches to Physics-Based Animation**

- Generate motion using a motion capture system
  - Acquire human subjects and re-use motion

**Character Animation**

High level techniques

- We will focus on these methods
What 3D character animation involves?

• Animating characters can be broken down to:
  – **Skeletal animation** – animating their main body parts.
  – **Facial animation** – animating their facial features.
What 3D character animation involves?

• Animating characters can be broken down to:
  – **Skeletal animation** – animating their main body parts.
  – **Facial animation** – animating their facial features.
  – **Hair (and Fur) animation**.
CHARACTER RIGGING & SKINNING

Anatomy of a 3D character

Rigging

• 3D rigging is the process of creating a skeleton for a 3D model so it can move.
• A ‘rig’ has numerous degrees of freedom (DOFs) that can be used to control various properties.
• One character could have several rigs. One rig could control several characters...
Anatomy of a 3D character

The rig

• A skeletal system (rig) is comprised of kinematic chains:
  – A hierarchical set of interconnected bones.
  – A chain:
    • starts from a root,
    • it has multiple bones,
    • connected by joints, and
    • ends at the end-effector.

The rig

Anatomy of a 3D character

The rig

• A skeleton allows higher-level control of the character’s animation.
• The skeleton is only a control mechanism – it is not rendered into the final image.
• Typically there are many constraints.
The rig

Skinning

• Skinning.
  – Attach a mesh ("skin") to the skeletal system of the character.
• The skin is represented as a polygon mesh, e.g. a set of vertices, or a parametric surface.
Anatomy of a 3D character

The skin

- We bind the skeleton to the mesh when we first associate them.
  - The T-pose (or “bind pose”) refer to the initial transformation matrices of the rig and skin when they are first associated.
  - The T-pose defines a coordinate system used later when animating the skin via the skeleton.
  - The T-pose is a convention used because:
    - modeling the mesh and the skeleton is easier, using symmetry.
    - rigging is much easier when the limbs are spread apart.

- Each vertex is associated with a bone in the skeleton, and moves relative to that bone.
- Each vertex is multiplied by several “weighted” transformation matrices that provide the influence factor each bone has to the vertex, and the results are added together.
  - The skin’s vertices can then be assigned weights.
    - Rigid skinning: 1 bone per vertex (weight = 1.0)
    - Smooth skinning: Multiple bones per vertex (weights ≠ 1.0)
Anatomy of a 3D character

Texture

Skeletal Animation
Skeletal Animation

• Having setup and bound together the rig and skin, the character can be animated.
  – The most common ways to do this:
    • Forward or Inverse Kinematics (e.g., keyframing)
    • Motion Files (e.g., motion capture systems)

Motion Capture Data

• Depending on the sensors used
• Popular file formats:
  – ASF/AMC (Acclaim’s skeleton and motion capture files)
  – BVH (BioVision Hierarchy)
  – C3D (Coordinate 3D – biomechanics – C3D.org)
Motion Files
BioVision Hierarchy (BVH)

HIERARCHY (rig)

MOTION (animation)
Motion Files

BioVision Hierarchy (BVH)

120Hz

MOTION CAPTURE
What is Motion Capture?

- Motion capture (MOCAP) is an effective 3D animation tool for realistically capturing human motion.
- Motion: the act of physically changing location
- Capture: take into possession, to seize, to acquire

Any suggestions where motion capture can be used?
- Prosthetics and rehabilitation medicine (e.g. gait analysis)
- Movies, entertainment technology, games
- Sports, simulations, demonstrations, training systems
- Ergonomics
- Etc.

What can be motion captured?
- Human whole body
- Portions of body
- Facial animation
- Animals
- Athletes, multiple characters
- Other objects
Advantages of mocap animation

• Low latency; results can be obtained in real-time.
• Secondary motions and all the subtle motions are captured.
  • more realism!
• Physical interactions between performers and props can be captured.
  • more realism!

Disadvantages of mocap animation

• The cost of the software, equipment and personnel required can be prohibitive for small productions.
  – It is getting cheaper year by year
• Manipulating mocap data is often difficult.
  – Re-capturing or key framing a shot with bad data is often easier.
• Mapping mocap data of a performer to a 3D character with a different proportion may cause issues.
Popular Motion Capture Systems

- **Magnetic** – active sensors sense their position and orientation in magnetic field.
- **Electro-Mechanical** – attach of a skeletal-like structure.
- **Optical** – uses video capture.
  - passive – markers just reflect light.
  - active – markers emit light.
- **Inertial sensors (IMUs)** – Motion is capture using accelerometers, gyroscopes etc.
- **RGB-Depth** cameras and computer vision.

**Magnetic**

- Calculate position and orientation by the relative magnetic flux of three orthogonal coils.
- External transmitters establish magnetic fields in space.
- Sensors can then measure the position and orientation of the object.
Popular Motion Capture Systems

**Magnetic**

**Advantages**
- free-of occlusion.

**Disadvantages**
- the acquiring motion has less degrees of freedom than the human body.
- Noisy.
- capture volume is limited.
- interference from other metal objects.

**Old technology, not used anymore**

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**Electro-Mechanical**

- Known as exoskeleton motion capture systems (e.g. Gypsy),
- Performers attach the skeletal-like structure to their bodies,
- The articulated mechanical parts measure the performer’s relative motion by converting analog voltage changes to digital values.
  - Direct track of body joint angles
Popular Motion Capture Systems
Electro-Mechanical

**Advantages**
- computes rotations directly.
- self-contained with unlimited capture volume.
- inexpensive.
- can capture multiple performances simultaneously.
- free-of occlusion.

**Disadvantages**
- they are restrictive.
- they need to match body proportions.
- configuration of sensors is fixed.
- only return local motions.

Too restrictive, has never been popular
Popular Motion Capture Systems

Optical Systems

- The system combines the information of the tracked markers to describe the 3D position of the object.
  - Repeat this operation several times per second to obtain a volumetric trajectory of the marker according to time and space. (usually from 30Hz to 960Hz)
- Minimum number of cameras – 2
- Visible and occluded markers
  - Solution: use of multiple cameras
- **Capture volume** is the physical space where the cameras can combine their fields of view

This is currently the state-of-the-art motion capture technology.
Each person wears a mocapsuit with markers attached. Each marker coated with a retroreflective material to reflect.
The cameras are equipped with infrared LED's and filters. The cameras see reflector markers. 
• e.g. Vicon, Motion Analysis, Optitrack.

Popular Motion Capture Systems  
Optical Systems - Passive

**Advantages**
- freedom of movement.
- high quality capture.
- high throughput.
  - fast sampling (200 fps at a high resolution).
  - can capture fast motions.
  - can have a large capture space.
  - can capture many markers.
Popular Motion Capture Systems

Optical Systems - Passive

**Disadvantages**

- Occlusion, markers are can be hidden from the camera.
  - additional performers will increase occlusion,
  - may be able to add redundant cameras.
- Sensitive to environmental lights.
- Marker crossove; which marker are you looking at?
- High cost.
- Extensive post processing (the marker’s have to be located and identified).
- Provide only positional data.
  - joint angles need to be computed.

Optical Systems - Active

• Use of active markers
  (infra technology – LEDs).

**Advantage**

• Easier to be identified from the background.
• Labelling is achieved by using markers with different frequencies.
  • reduce the turnaround by eliminating marker swapping and providing much cleaner data.
Popular Motion Capture Systems

Optical Systems - Active

• Use of active markers (infra technology – LEDs).

Disadvantage
• Less portable.
• Users are required to wear wires or electronic equipment (markers are connected to a synchronization unit).
• Markers may still be occluded.

Popular Motion Capture Systems

Inertial Systems

• Micro-inertial sensors, biomechanical models and sensor fusion algorithms.
• Use a number of gyroscopes and accelerometers to measure rotational rates.
• These rotations are translated to a skeleton model.
Popular Motion Capture Systems

Inertial Systems

Advantages
• Inexpensive.
• No external cameras are required.
• No occlusions.
• Self-contained.
• Portable and functional outdoors.

Disadvantages
• High complexity.
• Inability to measure orientation of body segments.
• Incapacity to acquire the actual motion resulting in lower positional accuracy.
Popular Motion Capture Systems

**RGB & RGB-Depth**

- Use a combination of color cameras and depth sensors.
  - the subject’s silhouette is captured from multiple angles.
- Reconstruct the object’s volume (mesh) from the point clouds.
- Fit a skeleton into the 3D model to estimate motion.

**Generative methods**
- reconstruct human pose by fitting a template model to the observed data

**Discriminative methods**
- infer mode-to-depth correspondences, cluster pixels to hypothesize body joint positions, fit a model and then track the skeleton

**Hybrid methods**
- Combine the two methods
Popular Motion Capture Systems
RGB & RGB-Depth

**Advantages**
- No need to wear a suit or attach markers.

**Disadvantages**
- Not reached yet the same fidelity and versatility.
- Controlled lighting and background environments.
- Problems with subjects’ occlusion by other elements in the scene.

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Motion Capture Pipeline

1. **Sensor Calibration**: Compute the position and orientation of camera/transmitter
2. **Subject Calibration**: Place markers on body, compute skeleton structure (lengths of links)
3. **Record Movements**: Marker positions (and orientations) varying over time
4. **Mapping to characters**: Direct Mapping or retargeting
5. **Convert to Joint Angles**: Occlusion and correspondence problems
6. **Data Cleanup**:
Common Motion Capture Pipeline

- Marker-based motion acquisition
- Label Markers
- Marker Data Clean-up
- Convert to Joint Angles
Welcome to the Dance Motion Capture Databases

This website aims to create a publicly accessible digital archive of dance that, in addition to new video material held by local cultural institutions, includes all known historical dance recordings. The objective is to capture and preserve high-quality video data of Latin American and performing arts traditions. Our ultimate goal is to make these invaluable cultural treasures accessible to everyone.

This is an ongoing project and data will be added to our database as we capture them over time.

We store high-quality videos in the DCM database and video for every performance. You can download any of these currently available from Performance page. Please read the copyright statement before downloading.

http://dancedb.cs.ucy.ac.cy
Dance Motion Capture Database

Motion formats

Video
Dance recording using an HD camera. Data saved in MP4 (MPEG-4 part 10 H.264) or FLV (flash) format.

Mocap data
C3D - stored 3D coordinate information, analog data and associated information as it is recorded from the motion capture system.

Mocap data
BVH - The Biovision Hierarchy character animation file format that provides the skeleton hierarchy information as well as the motion data.

Actor data
FBX – the motion of the performer is saved as an actor. Any virtual character (avatar) can be incorporated to perform the dance.

Character data
FBX – A virtual character has been incorporated to the actor. The character cannot be removed.
Popular Motion Capture Systems

Limitations

- Only realistic motion captured (movement that does not follow the laws of physics cannot be captured).
  - Cartoony or superhero animations are not possible to be captured.
- WYSIWYG (what you see is what you get).
  - Can’t add more expression.
  - Continually need to recapture motion.
- What about muscles?

Data cleaning

Self-similarity Analysis for Motion Capture Cleaning

By Andreas Aristidou, Daniel Cohen-Or, Jessica Hodgins, Ariel Shamir
Motion Retargeting

• What is motion retargeting?
  – A method to retarget animations onto models with different morphologies.
  – A way to remap animations onto characters with very different animation-specific structures.

Why Motion Retargeting?

- Improves content reuse.
- Allows for a more dynamic game experience.
- Easy integration of procedurally generated animations.
- Sometimes is not possible to motion capture the subject (e.g. animal with human behavior, character does not exist – fiction movies).

Challenges in Motion Retargeting

- Solving locally for each frame generates unwanted artifacts.
  - Preserve angles or end-effector positions (flying).
  - foot-skating.
- Characters with different proportions may have body penetration.
Challenges in Motion Retargeting

- Identify constraints in original motion.
  - joint limits, interaction with environment, collisions, physical laws.
  - parameter in range, point in location, point in region, same place at two different times.
  - time range of a constraint.
- Adapt the motion to target character.
- Re-establish violated constraints (by optimization).

Principles of Motion Retargeting
Animation for Game Characters

Special requirements:
• Respond to player input.
• Respond to unexpected events.
• Realtime performance.

Traditional approach:
Store a library of animation sequences, play them in response to player input and other game events.

AnimationMontage
Motion Graphs in Unreal Engine 4

Graph is hand authored.
Provide explicit code to choose between multiple possible next clips when a transition point is reached.
Designer manually chooses good transitions and avoids bad transitions.
Plan out required transitions before recording motion capture data.
Example of an Animation Montage

Start
Punch

Punch Right

Stop Punch Right

Stop Punch Left

Punch Left

Idle

Start

Motion Graphs

Overview of Motion Graphs

• Automatically add transitions within a motion database so as to allow synthesis of different actions.
  – Allow re-use of motion capture data.
• Motion graphs (Kovar et al.)
  – Multiple timesteps are grouped into a clip.
  – The clips are connected to one another in a graph.

Motion Synthesis

Example


Automatic Generation of Motion Graphs

Approach:
• Record a long clip of actor doing various motions.
• Compare all frames to find difference between every possible pair of poses – O(N^2), but offline.
• Add transitions at local minima that meet some minimum criteria for similarity.
  – White values correspond to lower errors and black values to higher errors. The colored dots represent local minima.
• Avoid bad transitions.
Navigation on a Generated Motion Graph

- No hand-written rules.
- Choose a desired end state, search the graph for a series of animation clips that will get you there.
- Sometimes results in strange animations.
- Can be improved by annotating animations with information about when they should be used.
  - Automatic classification of motion is a research area.

Another approach is to select motions that minimize the distance from a desired path. The path can be input by the user or generated by a pathfinding algorithm.
Issues with Automatic Generation of Motion Graphs

Graph may be poorly connected:
- Loops
- Dead ends (need to find strongly connected components).
- Unreachable motions
  - Search for paths that produce desired motion (branch and bound search)
  - Poor blending between, resulting in unnatural and not smooth motion.
    - Transitioning from one clip to another is not as easy as cross-fade or morph from image domain

Still need to produce and store every required transition.

Player Input with Motion Graphs

Natural conflict between smooth transitions and quick response to player input.
- Might miss required transitions if graph is not planned before motion capture session.

Commercial games prefer to use a poor transition rather than imposing a delay on the player.

Return as often as possible to standard “idle” pose.
Extending Motion Graphs

• Motion Graphs have been extended to generate motions that meet certain goals or constraints.

• Stylistic coherence.

Overview of Animation Blending

• Using a library of existing clips limits the range of actions a character can perform.
• Mix together two (or more) animation clips to create a new animation.
• Make animation library more versatile without requiring additional motion capture.
Style Transfer

- Human movements are characterized by style.
  - Personal style.
  - Male/Female.
  - Age.
  - Emotions.
  - Intentions.
  - Etc.
- One of the mocap limitations is that you cannot add more expression in captured data.
  - Usually need to recapture the session -> Expensive

Reference: Shihong Xia, Congyi Wang, Jinxiang Chai, and Jessica Hodgins. Realtime style transfer for unlabeled heterogeneous human motion. ACM Trans. Graph. 34, 4, (July 2015)
Style Transfer

• Altering the style expressed is of high-importance for control over the animation.
• How to modify motion style?

Style Transfer

• Style Transfer
  – Interpolate and extrapolate stylistic variations learned from unsupervised training data.
• Style modification
  – Learning motion parameters from stylized motion examples.
  – Synthesize motion to satisfy constraints.

Morphing

- Morphing is a deformation applied to a set of vertices.
- Morphing is used for character facial animation.
  - Morph targets are keyframes of facial vertex positions.
  - Morph targets allow finer control of vertex animation compared to skeletal animation.
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Thank you - תודה

• Questions?