# Animation by Example
# Lecture 1: Introduction, Human Representation

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## Why animate humans?

- Movies
- Television
- Videogames

- Training
- Simulation
- Analysis

## Why is this hard?

- People are good at watching people!
- Human appearance is very complex

- People do many things
  - In many ways
- Subtlety matters
- Hard to describe movement
- "Normal" movements aren't interesting

## Aspects of the Problem

- "Gross" Body movement

NOT:

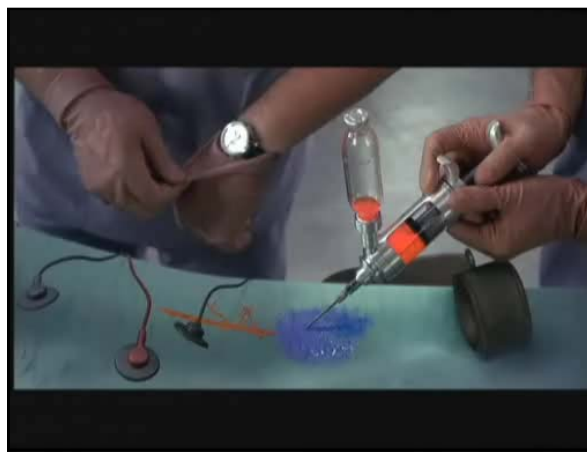
- Appearance Models
- Facial animation
- Cloth, clothing, secondary movement
- Hands

## These lectures

1. Representation of humans
2. Motion capture processing and editing
3. Concatenative synthesis
4. Parametric synthesis
5. Skinning

## Animation Apreciation 101

- Luxo Jr. Pixar, 1986
- Brilliance (Sexy Robot)
  - Robert Abel and Associates, 1985
  - Early motion capture
  - Early computer graphics look (chrome)
- Final Fantasy
  - Square Studios, 2001
  - Realistic, animated, human characters
- Hollowman
  - Sony Imageworks (effects), 2000
  - Complex human models, terrible dialog



## Why did I show those?

- Motion is rich, expressive, complex
- Hard to describe mathematically

- Amount of detail in characters varies
  - Different representations needed

## Where's the math problem?

- How do we describe movement mathematically?
  - So we can use it on a computer

- How do we describe the thing that is moving?
  - The "character"

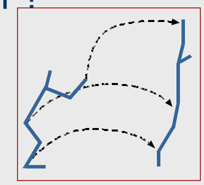
## What is the character?

- Way to interpret a configuration

- A vector of parameters
- Some interpretation of these parameters such that a value can be drawn

- Representation

## What is a motion ?

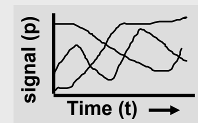


- A motion maps times to configurations

$$\mathbf{m}(t) \in \Re \Rightarrow \Re^n$$

- Vector-valued, time-varying signal
- Representation comes from creation

- All we have to do is define the functions!




## Why is this so hard?

- We are good at looking at motion!
- Motion is very expressive
  - Mood, activity, personality, …
- But those attributes are subtle
  - What makes a motion sad? Realistic?
- We lack vocabulary
  - Talk about motion with metaphor

## Three main ways to make motion

- Create it by hand
- Compute it
- Capture it from a performer

- Animate by example
  - Re-use existing motions
  - Editing
  - Synthesis by Example

## Creating Motion by Hand: Keyframing

- Skilled animators place “key” poses
  - Computer “in-betweens”
- Requires incredible amounts of talent
  - But can be done extremely well

**Verdict**: Produces the highest quality results, at a very high cost

## Computing Motion: Procedural and Simulation

- Define algorithms to create motions
- Ad-hoc rules, or simulate physics
- Physics provides realism
- But how do you control it?

**Verdict**: Good for secondary effects, not for characters (yet)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## Motion Capture and Performance Animation

- Use sensors to record a real person
- Get high-degree of realism
  - Which may not be what you want…
- Possibility for real-time performance

**Verdict**: Good for realistic human motions. Scary to animators.


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## Motion Capture Technology: Optical Tracking

- User markers and special cameras
- Tracking + Math



## Motion Capture Technology: Video

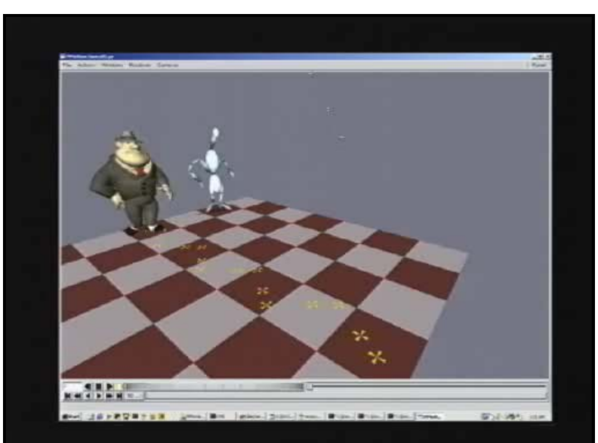
- An interesting and open problem…
- Limited information
  - But seemingly enough
- Problem can be arbitrarily hard
  - Or easy – if you make assumptions
- Video is surprisingly bad

The subject of these lectures…

## Animation by Example

- Good motion is hard to get
- Can't get everything you need
- Need to create motion on the fly

- Re-use existing motions
  - Editing (change an existing motion)
  - Synthesis by example
    - (make a new motion from old ones)



## Where to begin… Some preliminaries

- Human Representation
  - Rigid bodies
  - Kinematics
- Motion Capture and Processing
  - Motion Signal Processing

## Representation of Humans

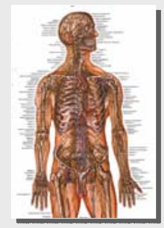
- Need concise description of pose

Goal:
- Summarize pose as a vector
- Motion is vector valued function

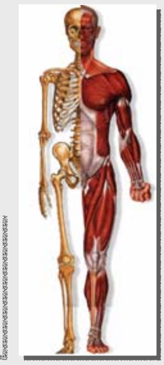
- Compact, yet flexible
- Make constraints implicit

## Modeling Humans

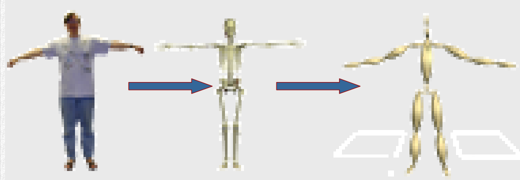
- Humans are complex!



Human motion can be understood at a very fine level of detail!



## Abstractions

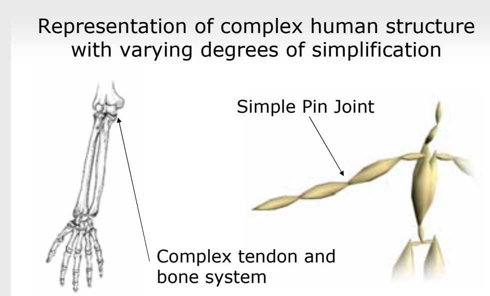


206 bones, muscles, fat, organs, clothing, …

206 bones, complex joints

53 bones Kinematic joints

## Abstractions vs. Reality (skeletons vs. humans)




## How Realistic do you need?

- It depends!

- Generally, small numbers of degrees of freedom (50-60)
- Easier to animate/specify
- Don't really see the details from far away

## Standard simplified models of humans

- Small numbers of degrees of freedom for *gross* motion
- Articulated figures
  - Rigid pieces
  - Sometimes stretching alowed
- Kinematic joints
  - Rotations between pieces
- Why this?

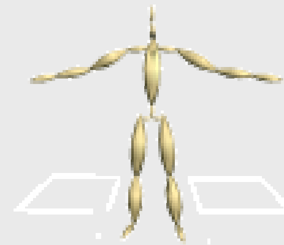
## How to best match

- Can't be exact
- Something gets lost
  - Don’t want to lose what is important
- What is important?
  - Essence! (not details)
- Data provides details, essence is hidden inside

## Articulated figure representation

Sets of rigid pieces

What are the rigid pieces?



## Rigid Body

- A set of points that undergoes a rigid transformation
- Describe configuration by the rigid transformation

$$P' = f(q, P)$$

Transformed points

Transform parameters

“Rest” state points

## Rigid Transforms

- Mapping $f : R^n \text{->} R^n$
- Defined by properties:
  - Has a zero
  - Preserves distances
  - Preserves handedness
- Is a linear mapping

## Parameterizing Rotations

- Goal: encode rotations in a vector
  - $R^n$ - > “set of rotations”
- Give “names” to members of the set of possible rotations
- Many ways to do this, all flawed
  - No perfect method
  - Use the best one for the job

## Goals for Parameterization

- Compact
  - (as few variables as possible)
- Complete
  - Every rotation can be represented
- 1-to-1
  - Every rotation has one value
  - Every value has one rotation
- Singularity free
  - “close” rotations are “close” in value

## Parameterization 1: The Rotation Matrix

- We know the rotation is a linear function (e.g. Matrix)
- Use the matrix as the parameterization!
- Any rotation is represented by 1 matrix

- Must preserve distance
- Must preserve handedness
- Must preserve angles
- Positive, Orthonormal matrices

## Problems with Matrix as Parameterization

- Not compact
  - 9 numbers (but 3 d.o.f.)
- Not all matrices are orthonormal
  - Change 1 number, its not orthonormal
    - Sensitive to numerical issues
  - Can't tell quickly
    - Given a matrix, determine if orthonormal
  - Can't project quickly
    - Given a matrix, find the "closest" orthonormal one

## More problems…

- Given two rotation matrices, $M_1$ and $M_2$
  - Can you measure how different they are?
  - Can you interpolate them?
    - (e.g. find halfway)

- Fortunately, they are closed under multiplication
  - Modulo numerical issues

## Problems are worse in 3D

- 3x3 matrices – 9 parameters
- No intuitive meaning to parameters
- Only supports a few operations
  - Apply to point
  - Multiply (compose) – beware drift

- Use rotation matrices to apply rotations
- Use other methods to parameterize and manipulate them

## Parameterizations of Rotations

- Rotation Matrices
- Euler Angles
- Axis Angle formulation
- Unit Quaternions
- Exponential Co-Ordinates
  - Local linearizations

## Two theorems of Euler

- Any rotation can be represented by a single rotation about an arbitrary axis

  Axis / Angle Representation

- Any rotation can be represented by a sequence of 3 rotations around fixed axes

  Euler Angles

## Axis / Angle

- Not compact (4 numbers, not 3)
- Each rotation represented by many groups of 4 numbers
- Can't compute with
  - Hard to compose
  - Hard to compare
  - Hard to interpolate
- Inefficient

## Euler Angles

- Pick 3 axes (XYZ, ZXZ, ZXY, …)
- Compact
- Any 3 numbers is a rotation
- Every rotation has many values

- Singularities
- Not metric (close rotations->different numbers)
- Interpolations can be weird

- OK when 1 axis at a time
- False sense of security that can do math

## What else?

- Other parameterizations more recent in Computer Graphics

- Quaternions (introduced 1985, popular recently)
- Exponential co-ordinates (introduced 1995, popular recently)

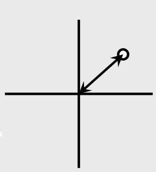
- Both method are old
  - Graphics just took a while to discover them

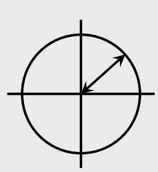
## Easy case: 2D

- Rotations in 2D aren't too hard
  - Examine them to see what happens in 3D (where it is much harder)
  - Basic problems still occur

## 2D Rotations

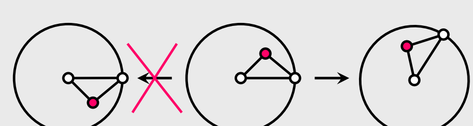
- Consider 1 point in 2D, center is the origin
- A rotation maps the point somewhere on the circle





## Each rotation is a point on the circle

- Not exactly…
  - There's the handedness thing

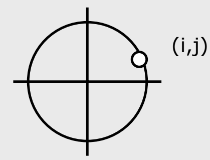


## So how to name points on a circle?

- No good mapping to the real line
  - Real line goes on forever
  - Circle wraps around
- Same problems as rotation!
- Note: circle (in 2D) is a 1D set

## Method 1: use a 2D coord

- Name point by x,y on circle
  - Could be a complex number




## Extra coordinates

- Good points
  - Every point can be named
  - Every point has a unique name
  - Close points have similar names
    - (no singularity)
- Bad points
  - Not all points are on the circle
  - Can't manipuate vectors
    - How to add? Takes you off the circle

## Quaternions

- Extension of this idea to 3D rotation
  - 4 dimensional complex number
  - Real part, 3 imaginary axes (vector)
- Represent 3D rotation as a point on the unit 4-sphere
- Need to stay on sphere
  - E.g. UNIT Quaternions

## Good points about Quaternions

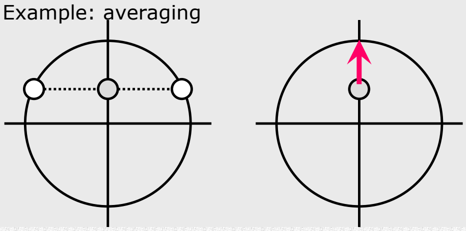
- Multiplication is defined
  - Easy composition
- Interpolation is defined
  - Special methods worked out
  - Linear (1985), Cubic (1995)
- Relatively compact
- Singularity free
- "Nearly" 1-to-1

## Bad point about Quaternions

- Can't add
- Can't take linear combinations
- Can't average
- Can't linear filter
- Distance metric is unclear

## A "hack"

- Its easy to get "back on the circle" via reprojection
- Pretend points are in 2D, then project back
- Example: averaging

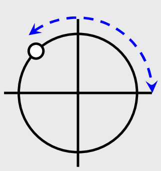


## Warning on the hack…

- Gets the right answer for averaging
  - Not for other linear combinations
- Works well when difference is small
  - Small angle approximation
  - Fails when opposite
- Useful since we can renormalize if computations have problems

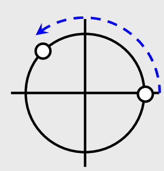
## Method 2: distance

- How far around circle?
  - (unit radius makes things easier)
- Basically an angle



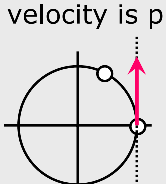
## Method 3: velocity

- Suppose the particle starts "at zero" and has a constant velocity ω
- Where does it end up at the end of a unit of time?



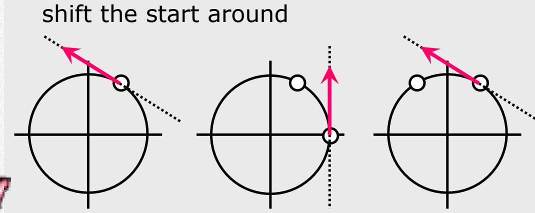
## Method 4: velocity

- Velocity is tangent to circle – therefore it is initially upwards
- If circle is in the complex plane, the velocity is purely imaginary



## Velocity (cntd)

- Velocity as "up" only works if we start at origin
- so always measure from origin shift the start around



## Initial velocity is good…

- It's linear!
  - Linearizes the circle around the origin
- Can operate on it
  - Add
  - Scalar multiply
- Not perfect…
  - Many different ways to get to any place

## Local linearization

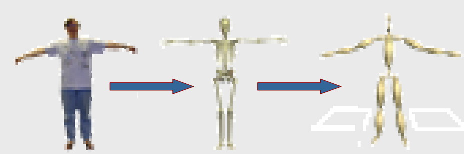
- Logarithmic map / Exponential map
- Good for describing the differences between orientations
- Good basis for performing linear operations on orientations
- Filtering
- Averaging

## In general…

- Use quaternions to represent orientation
- Use tangent space (log map) to perform linearized computations
  - Hack often works, almost as well
  - Don't tell anyone I said that!

Back to our real question…

## Abstraction of Human Motion

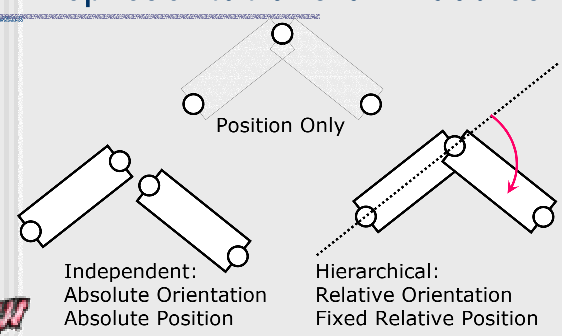


- Humans too complex
  - Need tractable models
- Some number of connected, rigid pieces
  - (usually)

## Representations of Motion

- Angle vs. positional data
- Global vs. relative
- Hierarchical vs. non-hierarchical
- Skeletal vs. Non-Skeletal

## Representations of 2 bodies



## Good Points of Hierarchical Skeletons

- Enforce key constraints
  - Connected segments
  - Rigid limbs
- Fewer Dof's
  - Only store angles between segments
- Easy for skinning
  - Local coordinate systems defined

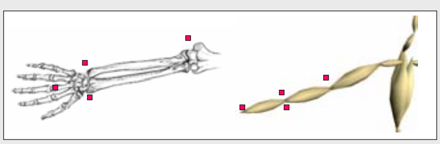
## Bad Points of Hierarchical

- Need 3D rotations
- Coupled parameters
- End effector controls require IK
- Forces rigidity
- Problems with reference
  - Different ways of defining things

## Complexities of Skeletal Representation

- Can't just measure

(even x-rays wouldn't help, no real "joints")



- Abstraction
- Don't know parameters
- Need to know skeleton and relation of skeleton to markers