Animação e Ambientes Virtuais 2018/2019

Pós-graduação

DI- FCUL

Guião das aulas teóricas
GU-AAV-19-Body Motion&Deformation

Beatriz Carmo

Outline

Body Motion
• Early motion analysis

• Body models
- Stick figure
- Simple volumetric primitives
- Multi-layered models
- Anatomically correct models

• Levels of abstraction of the musculo-skeletal system

• Idealized mechanical joints

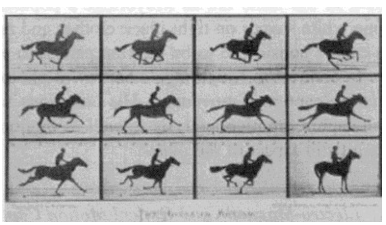
• Techniques to achieve motion:
- Dynamics-based animation techniques
- Kinematic animation techniques:
  - Keyframing
  - Motion capture
- Inverse Kinematics

Body Deformation

Issues in the production of 3D character animation

Early motion analysis

A motion is filmed or photographed at multiple instants and often from several viewpoints

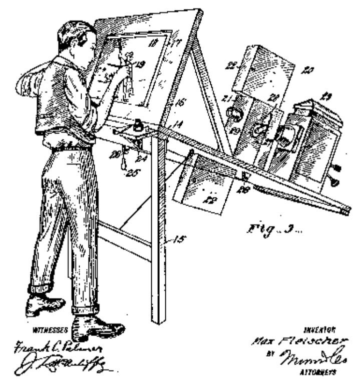


Muybridge's photos (1878)

Rotoscoping (1)

technique where animators trace live action movement, frame by frame, for use in animated cartoons.

Originally, pre-recorded live-film images were projected onto a matte windowpane and redrawn by an animator. This projection equipment is called a **Rotoscope**.



http://en.wikipedia.org/wiki/Rotoscope

Rotoscoping (2)

Animated horse, made by rotoscoping 19th century photos by Edweard Muybridge.

http://en.wikipedia.org/wiki/Image:Animhorse.gif

Body Models

To achieve a **realistic** representation we must have:

- an articulated skeleton
- establish its relations with a potentially deformed skin surface
- and derive realistic motion models

Body models

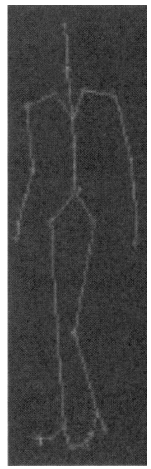
A good model is important to achieve realism

Basic methodologies for representing humans:

- stick figure
- simple volumetric primitives
- multi-layered models
- anatomically correct models

Body models

stick figure



Articulated structure (*articulated skeleton*)
composed
of links ----- an abstract representation of body parts
and joints ----- the intersection of links

Body models
simple volumetric primitives

Simple primitives such as **ellipsoids** and **cylinders** can be used to construct human models

Advantages:
simple
well-understood mathematical properties
(makes optimization and fitting to image-data easier)

Disadvantages:
they are not photo-realistic

Body models
multi-layered models

Articulated skeleton structure with multiple layers that represent the gross shape of bones, muscle and fat tissue.

1st layer – skeleton – connect set of segments corresponding to limbs and joints

2nd layer – bone, muscle and fat tissue – e.g. simulated with smooth implicit surfaces (also known as metaballs or soft objects)
Metaballs are attached to the skeleton and arranjed in an anatomically-based aproximation

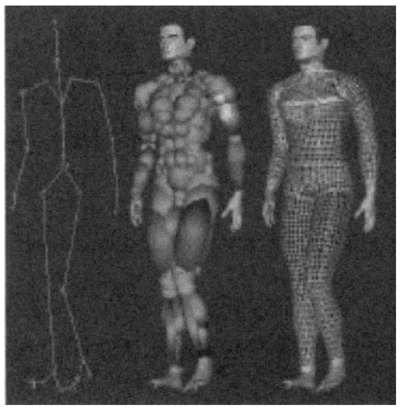
3rd layer – skin – can be modeled by any type of surface (polygonal, parametric, implicit)

Body models
multi-layered models

(a) 1st layer

(b) 2nd layer

(c) 3rd layer



(a) (b) (c)

Body models
anatomically correct models

Anatomically correct models should include as much **medical knownledge** as possible about body structure

However, such model are very **complex**.

Body Motion Control

The goal of **motion control** is to **achieve realism** through the **coordinate evolution of the character body**.

Traditional animation — the realism is judged by the **believarity** of the resulting motion (this is the most common approach to test realism)

vs

Simulation — aims a **deeper understanding of motion generation** through the finer modeling of the elements of the musculo-skeletal system and their physically-based interaction.

Levels of Abstraction of the Musculo-Skeletal System

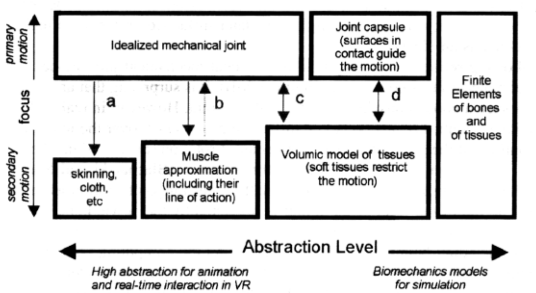
Motion control

Primary motion – animation of the internal motion

Secondary motion – animation of the external envelope and cloth
Modeled as a surface associated with a model of attachment to the body

Levels of Abstraction of the Musculo-Skeletal System

There are several approaches



▷(b)
▷(c)
▷(d)

Levels of Abstraction of the Musculo-Skeletal System (a)

Commercial systems use paradigm (a):

- It is the simplest approach.
- It considers that we have a bone structure and the movement of the skeleton drags the surface (skin) and the clothing that surround them.

Levels of Abstraction of the Musculo-Skeletal System (b)

(b) Take into account the **activity of all the muscles** through their **lines of action**.

the **direct problem**:

muscles + their lines of action →derive the torques (*forças de torção*) acting at the joints → obtain motion applying Newton's laws

the **inverse problem**:

given a desired motion →obtain the combination of muscles achieving the motion

Newton's laws

Newton's First Law of Motion →

Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it.

Newton's Second Law of Motion →

The relationship between an object's mass m, its acceleration a, and the applied force F is $\boldsymbol{F = ma}$.

Newton's Third Law of Motion →

For every action there is an equal and opposite reaction.

Levels of Abstraction of the Musculo-Skeletal System (c)

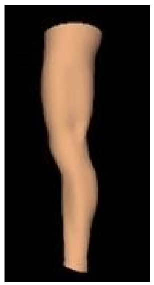
(c) **Integrate motion control** with **soft tissue deformation**

soft tissue deformation can affect motion

when

soft tissues reach their **elasticity limit**
or **collide with tissues** of another body segment

Example of soft tissue deformation



Levels of Abstraction of the Musculo-Skeletal System (d)

(d) Get rid of ideal mechanical joint model and solve the problem of **bone surface contact**

> the continuous modification of contact points or surface over the joint range leads to small variations of the joint rotation or center of rotation

Finally,

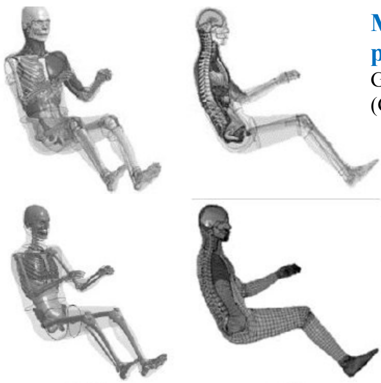
Complete **integration** of **motion** and **deformation models** obtained by modelling all the tissues, including bones, with **finite elements**

This approach is very demanding computationally

Crash simulation sleds

http://www.ariestesting.com/products/passive-safety/crash-simulation-sleds/

Human Body Finite Element Model



M50-O – model of the 50th percentile occupant

Global Human Body Models Consortium (GHBMC)

M50-OS (simplified model)

The M50-OS uses a comparatively coarser mesh (8–10 mm) for deformable elements than the M50-O (2–4 mm)

(D.Schwartz et al (2015), "Development of a Computationally Efficient Full Human Body Finite Element Model", Traffic Injury Prevention)

Human Body Finite Element Model

M50-O – model of the 50th percentile occupant

447 contacts and 2.2 million elements

M50-OS (simplified model)

11 contacts and 354 000 elements

Total element count was reduced by remeshing, homogenizing, or in some cases omitting structures

Bones are included as rigid bodies, with the exception of the ribs, which are deformable but were remeshed to a coarser element density

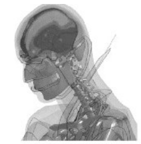
Human Body Finite Element Model

M50-OS (simplified model)

Joints that are intended to allow some motion

Kinematic joints were implemented at major articulations (shoulder, elbow, wrist, hip, knee, and ankle)

Human Body Finite Element Model



Head displacement at 75 ms in frontal sled impact simulation

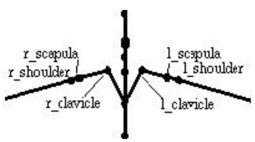
Results M50-OS (simplified model):

- The rigid impacts demonstrated a run time reduction of **35 times** on average
- The sled impact was reduced by **23 times**
- The model was 5 times faster when including deformable structures of the head and brain.

Idealized mechanical joints

A **joint** is the body component concerned with motion

It allows some degree of relative motion between the segments it connects



The shoulder joint model -- a succession of three joints, respectively the clavicle, the scapula and the shoulder joints

Idealized mechanical joints

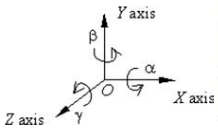
Ideal kinematic (*cinemáticos*) **joint models** are defined in order to formalize this **permitted relative motion**, called **range of motion**,

characterized by

- the number of parameters that describe the motion space
- and are constrained by joint limits

Idealized mechanical joints - **Rotational** limits of human joints

Right-handed coordinate system and it is assumed that **Z axis is oriented along the bone of the joint** [Maestri96]



Segment	Joint	Type	X	Y	Z
Foot	Ankle	Rotational	65 degrees	30 degrees	0 degrees
Shin	Knee	Hinge	135 degrees	0 degrees	0 degrees
Thigh	Hip	Ball & Socket	120 degrees	20 degrees	10 degrees
Spine	Hip & Spine	Rotational	15 degrees	10 degrees	0 degrees
Shoulder	Spine	Rotational	20 degrees	20 degrees	0 degrees
Bicep	Shoulder	Ball & Socket	180 degrees	105 degrees	10 degrees
Forearm	Elbow	Hinge	150 degrees	0 degrees	0 degrees
Hand	Wrist	Ball & Socket	180 degrees	30 degrees	120 degrees

Idealized mechanical joints

The <u>second key aspect</u> that should be integrated into the joint model is a model of its **strength** (Forces that the skeletal muscles apply on the bones)

• The muscular strength is an important component of a human model for **prediction purposes**, in manual lifting tasks e.g.

• Strength is a complex information and is difficult to measure for each muscle separately
So

Usually indirect measures are performed at the joint level: **the measured torque is due to the group of muscles acting on that joint**, for a given direction of exertion

Idealized mechanical joints

• A joint strength is also influenced by its own position and velocity, as well as those of adjacent joints. Moreover **strength decreases over time**, according to endurance of a person (**fatigue model**)

• Age, gender affects the strength of a person

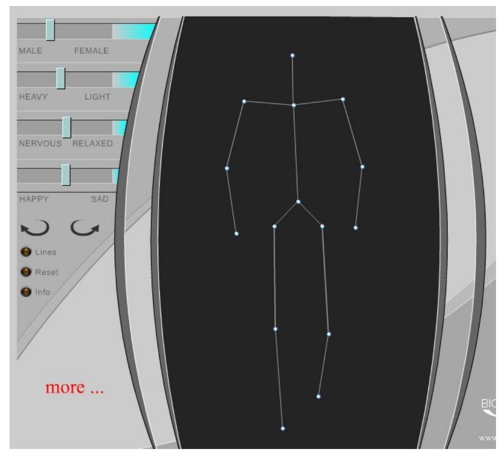
Because of the inherent difficulty in dealing with strength at the joint level,

a number of researchers directly **relate postures to the forces that can be exerted by an <u>end-effector</u> in the Cartesian space**

An **effector** is a location on the articulated body that the user wants to constraint in Cartesian space

BMLwalker

Biological motion patterns



http://www.biomotionlab.ca/Demos/BMLwalker.html

BMLwalker

BML walker interface includes

- sliders to select attribute values:
  - Male/female
  - Heavy/light
  - Nervous/relaxed
  - Happy/sad
- toggle buttons
  - Lines and dots/dots
  - Motion/stop

BMLwalker

The demo was developed in a research project that studies **how socially relevant information is encoded in biological motion patterns** and **how such information can be retrieved**

- This **demo** is based on walking data from 40 men and 40 woman (demo info).
- Their movement was recorded using an optical motion capture system.
- A set of **38** retroreflective markers were attached to their bodies.
- From the trajectories of the 38 original markers, they computed the location of **15** "virtual" markers positioned at major joints of the body.

(ankles, knees, hips, wrists, elbows,shoulders, centre of the pelvis, sternum, center of the head)

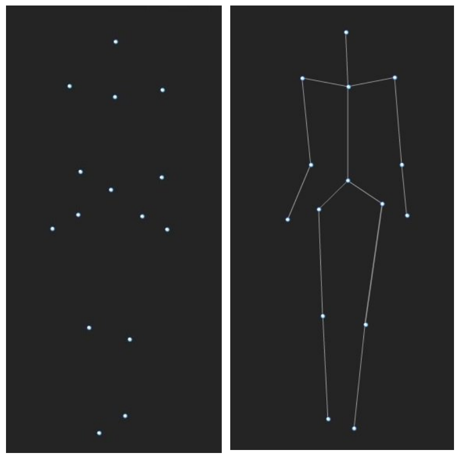
BMLwalker

The human **visual** system has a remarkable ability to **extract** complex 3-D **information** even from **sparse clues** such as **moving dots on a uniform background**.

Very low-level stimuli suffice to infer a motion types such as walking, runnig, dancing and so on.
It is also possible to infer if a load is being carried

BMLwalker

With the moving dots we can also understand the motion



What is motion?

Motion – change in the position of an object with respect to a reference

Mechanics is the science that studies the motion of objects and there are 2 approaches:

- **Dynamics** (*dinâmica*), based on Newton's laws of motion, relates the causes of motion (i.e. the forces) to the acceleration of a body, taking into account its mass.

- **Kinematics** (*cinemática*) deals with the geometry of motion regardless of its physical realization– it is concerned with the position, velocity and acceleration of bodies

There are two classes of techniques for the animation of articulated figures: dynamic methods and kinematic methods

Balance control

The mechanism of balance control (*equilíbrio*) in humans is not completely understood yet

One important rule is

to constrain the center of mass to remain on the vertical line passing through its base

This requires information about **body mass distribution** in order to calculate the center of mass

Balance control

Balance control is important when dealing with characters that <u>pull</u> or <u>push heavy objects</u>

Several approaches have been developed to deal with balance control based on dynamic methods

Dynamics-based animation techniques

Direct dynamics algorithms compute the motion of a complex articulated body according to the laws of rigid body dynamics given

- a set of **external forces** (such as gravity or wind)

- and **internal forces** (due to muscles) or **joint torques**

The **inverse dynamics problem** corresponds to identify a temporally coordinate sequence of force/torque activation to generate a desired active behavior (complex problem)

Dynamics-based animation techniques

Direct dynamics algorithms

• Algorithms developed in **robotics** have been used in computer animation

• Animation of passive structures (e.g., falling bodies on stairs) can be generated in this way with little input from the animator

• but as the animator has only indirect control over animation, adjustments are tedious

• Use of constraints to avoid the direct specification of torques
However, an important drawback of this technique is that
- interaction with the environment must be planned from the start
- thus unplanned collisions are not detected nor treated automatically

Kinematic animation techniques

The goal of **animation technique** is to generate believable motion.

Kinematics deals with positions, velocities and accelerations:

knowing that object A
at **time t** is in **position x** with **velocity v** and **acceleration a**
it is possible to determine its **position at time $t_1 > t$**

That is **direct kinematics**

Kinematic animation techniques

(1) Keyframing

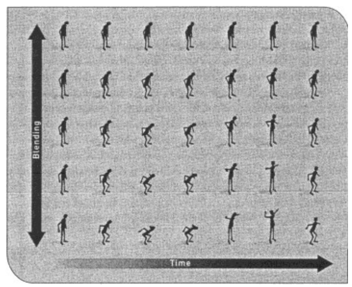
• **animators define** the **postures** of the articulated figure by directly **setting the parameters** of its **joints**

• the postures are **smoothly interpolated** over time to generate the full set of frames required for an animation

- Tedious technique
- However, it allows the fine tuning of complex motion, first the motion of all body and primary segments, then the motion of hands feet, etc

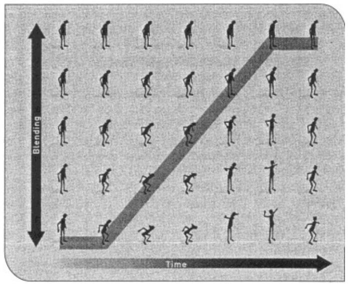
Keyframing - Blending

What is animation **blending**?
Usually we have a sequence of frames and we interpolate between keyframes
Blending interpolates between all keyframes and not only sequential keyframes



Horizontal ⟶ sequencial keyframes

Keyframing - Blending



Blending from “happy” to “sad”

Kinematic animation techniques

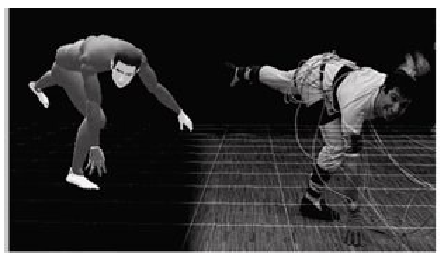
(2) Motion capture technique

• consists of **tracking and recording** of a set of markers (or sensors) positioned on the object of interest or extracted from a video sequence.

• the Cartesian positions of the keypoints have to be converted into a set of joint angles

- Requires expensive hardware
- but results in natural-looking motion and so it is extensively used in the entertainment industry

Motion capture
Electro-Magnetic Systems



• A few wired magnetic sensors are attached to the body of the performer
• One sensor per body part is sufficient because the sensors capture position as well as orientation

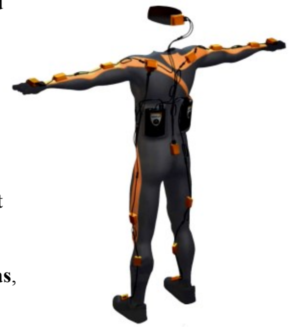
Motion capture
Electro-Magnetic Systems (2)

Cybertennis

(Nadia & Daniel Thalmann)

Motion capture

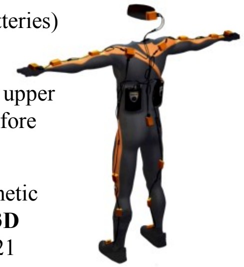
Wireless Electro-Magnetic Systems



- Xsens MVN consists of 17 inertial and magnetic sensor modules.
- Data is transmitted by a **wireless connection** to the laptop computer on which the processing is performed and visualized.
- A suit is used for quick and convenient placement of sensors and cables.
- MVN **does not need external cameras**, emitters or markers

http://www.xsens.com/

Xsens MVN



- The sensors and cables are integrated in a Lycra suit and the Xbus Masters are mounted on the back.
- The total **weigh**t of the system (including 8 AA batteries) is **1.9 kg**.
- Sensor modules are placed on the feet, lower legs, upper legs, pelvis, shoulders, sternum, head, upper arms, fore arms and hands
- **Each sensor** module (MTx) is an inertial and magnetic measurement unit and comprises **3D gyroscopes**, **3D accelerometers** and **3D magnetometers** (38×53×21 mm, 30 g). The sensor modules are daisy chained connected to the Xbus Masters, meaning that there is only one cable leading to each limb.

connect together in a linear series

Motion capture

Optical Systems

Optical motion capture systems do not need cabling, they rely on optical markers that can be tracked visually

Motion capture

Optical Systems

Several cameras are arranged around the capture space

more cameras mean
- more robusteness
- more data

Oxford Metric´s Vicon System --- 6 to 24 cameras

Motion capture
Electro-Magnetic Systems vs Optical Systems

Electro-Magnetic systems
- more reliable and precise for orientation sensing
- position measurements need difficult system calibration
- sensor´s accuracy is low and highly influenced by the surrounding environment, especially in the presence of metal
- wiring from the sensors or special suit with sensors and cables tend to preclude extreme movements on the part of the performers

Optical systems
- do not need cabling
- the capture rate can be very high which enables to capture slightest subtleties of the performer's motion.
- however, it is difficult to track many retro-reflective markers

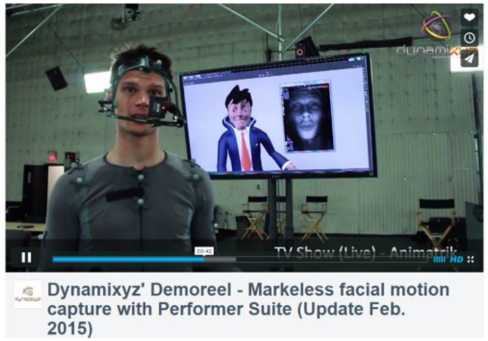
Markerless Motion Capture

Dynamixyz' video-based facial capture

Natural features (eyebrows, eyes, mouth) are the markers

http://www.dynamixyz.com/

http://vimeo.com/70540889



https://vimeo.com/120797900

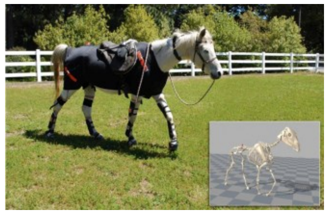
Motion capture

- **Mocap Advantages**
  - It take few hours to animate a character than with traditional animation
  - It can capture secondary animation
    (e.g., a slight movement of the hip by the actor may cause his head to twist slightly)
  - It can accurately capture difficult-to-model physical movement

Motion capture

Mocap disadvantages

- It is difficult to manipulate once captured and processed.
- It is not possible to create new animations
- The equipment is expensive



- It is more difficult, but not impossible, to apply motion capture to animals or things (e.g., cars)

Kinematic animation techniques
Inverse kinematics

Given the positions of the object at t and t_1,
the system calculates the movement (positions and velocities)

The solution to this problem is not unique and rules or restrictions are usually added

Inverse Kinematics

Inverse kinematics techniques
are used when the Cartesian position of an **end effector** is important

However,
there is **no guarantee** that the resulting **motion** is **continuous** or looks right because a small change in the goal position can result in a huge change in the configuration

An **effector** is a location on the articulated body that the user wants to constraint in Cartesian space

Inverse Kinematics

The inverse kinematics technique is useful both for the **manipulation** and **animation** of articulated figures.

The problem is to determine a joints configuration for which a desired task is achieved

The **equations** that arise from this problem are generally
- non-linear
- and are difficult to solve

Moreover <u>it can occur that</u>
- the problem has **no exact solution**
- the problem has **more than one solution**
- **multiple constraints cannot be satisfied** at the same time

Inverse Kinematics
over-constrained and under-constrained problems

The problem has no exact solution
when a constraint cannot be satisfied (the goal is unreachable)
or
when 2 or more tasks are in conflict and cannot be satisfied simultaneously

The problem has several solutions
when there are more degrees of freedom in the structure than constraints

Inverse Kinematics

Multiple constraints that cannot be satisfied at the same time

There are 2 strategies:

Weighting strategy – (most frequent)

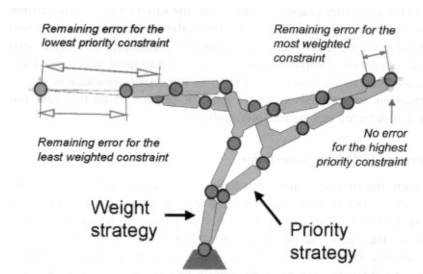
weigths can be assigned to each constraint to define their relative importance
a compromise is found
(none of the constraints is satisfied exactly)

Task-priority strategy –

constraints have different priority levels
(every constraint is satisfied as much as possible but without affecting the satisfaction of more important ones)

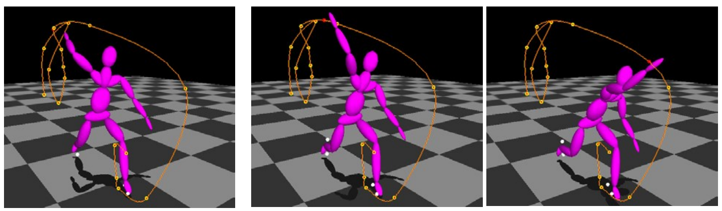
Inverse Kinematics

Multiple constraints that cannot be satisfied at the same time



"Style-Based Inverse Kinematics"[Grochow04]

http://grail.cs.washington.edu/projects/styleik/



- the animator creates an animation by constraining a small set of points on the character
- the rest of the pose for each time frame is automatically synthesized using style-based IK.

Body Deformation

There are different approaches according to the human body model:

- **Surface** models (skeleton+skin)
  - Skinning
  - Shape keys
- **Volumetric** models
- **Multi-Layered** models

Body Deformation

Surface models - Skinning

Surface models have two layers:

- an articulated structure or **skeleton**
- an external geometric envelope (**skin**) –

  the deformations of skin are driven by the underlying articulated structure

Skinning

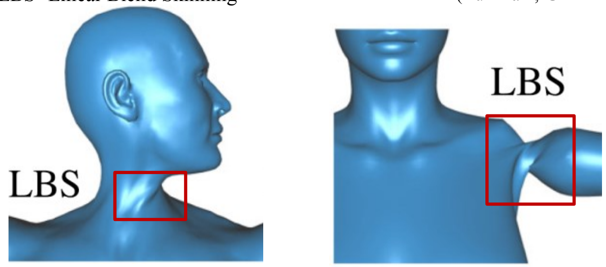
is the process of defining how the geometric surface of the character deforms according to a function of the skelectal poses

Body Deformation

Surface models - Skinning

"**candy-wrapper artefact**"- problem that arises near the joints with linear skinning due to volume loss while twisting

LBS- Linear Blend Skinning (Rummani, GRAPP 2016)



Body Deformation

Surface models - Skinning

Rigid deformations

- the skin model consists of a collection of **independent polygonal meshes** placed on top of the skeleton
- each mesh is **anchored to a specific joint**
- the **skin follows** the **motion** of the underlying articulated structure

•Problems

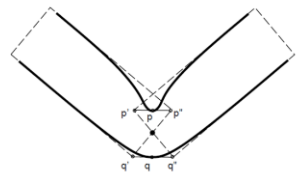
near the joints body parts can interpenetrate or appear unconnected

Local Surface Operators

The above problem can be solved using a **continuous deformation** function with respect to the joint values

Body Deformation

Surface models - Skinning



Linear Blending

- its a special type of surface deformer that works locally
- it can be applied to all kinds of joints

Skinning is basically an interpolation algorithm

- each **skin vertex P** is expressed as a linear combination of offset points P_i, each one rigidly transformed by an associated skeletal coordinate frame
- there are **weights,** w_i**,** assigned to the various joints that influence the vertex

Problems

- the weights are assigned manually
- in areas with considerable mobility (shoulder), some combination of weights may produce good results in certain postures and bad results in others

Body Deformation

Surface models - Shape keys

Shape keys

- produces <u>skin deformation</u> by **blending** pre-defined examples or **shape keys**
- **shape keys** are triangle meshes in various poses
- shape keys form an **abstract space** from which new shapes can be created by interpolation or extrapolation
- <u>prerequisite</u>:

  all shape keys share the same number of vertices and the same connectivity

(Blending interpolates between all keyframes and not only sequential keyframes)

Body Deformation

Volumetric models

Volumetric models add the notion of inside/outside

→ well suited to collision detection and processing

Volumetric models allow handling **collisions** between different models or different parts of the same model

Body Deformation

Multi-Layered models

- Skeleton layer
- Muscle layer
- Fat layer
- Skin layer

Different techniques can be applied to represent each layer

Body Deformation

Multi-Layered models

Issues in the production of 3-D character animation

Problems faced by animation techniques with the growing demand of games for permanent on-line worlds:

- Fast production of families of motions reflecting precise skills (there is a wide range of skills)
- Their automatic adjustment to a wide population of more or less human like characters
- The possibility of chaining and/or combining their activation on the fly
- Their adaptation resulting from interaction with the environment

Issues in the production of 3-D character animation

The produtivity of animation pipeline is low due
- to the intrinsic complexity of the 3-D human structure
- and our ability to perceive unnatural animation artefacts

Advances will be obtained with
methods able to **re-use** the growing amount of captured and physically-based motions.

One problem to re-use is
the lack of standardization of the human skeleton resulting in additional conversion between representations

Animation can classified into 3 categories according to their potential to direct re-use:

Animation type		Re-use potential for dfferent skeleton
Task-driven animation for interaction with real world through precisely defined effectors' position or orientation constraints		Very limited re-use (due to new location of effectors)
Expressive animation through gestures and body language	Involving self-contact (e.g. applauding)	Small re-use (due to new trajectories of end effectors)
	No interaction of body parts	High re-use for simililarly sized skeletons