Ciências ULisboa | Informática

# Animação e Ambientes Virtuais 2018/2019

## Mestrado

DI- FCUL

Guião das aulas teóricas

Ana Paula Cláudio



# Cloth Simulation



## Summary

Cloth Simulation

- Mechanical modeling of cloth properties
- Collision detection and response
  - in general
  - for cloth simulation
- Enhancing garments
  - Mesh smoothing
  - Ligthing
- Garment design tools



## Cloth Simulation

Essential for perceiving the identity- and the beauty- of a human being and its virtual counterpart, **garments** not only protect the body from the cold and rain, but also construct the **social appearance** of the being.

## Cloth Simulation

Textile or cloth comes in a variety of types or categories, based on how it is constructed.

For **woven textiles**, the fibers are usually oriented along **orthogonal directions**, while for **knitted fabrics**, they follow a complex but repetitive curved pattern.

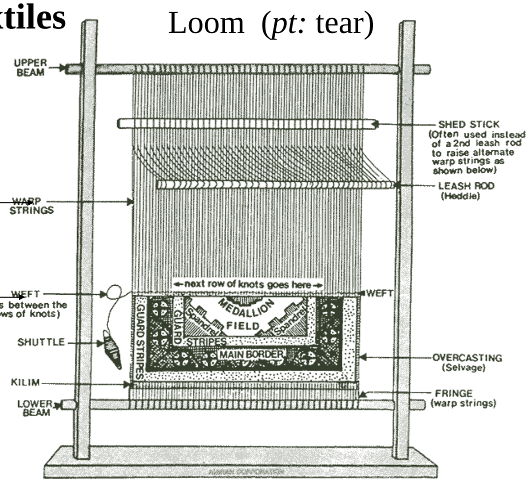


## woven textiles

Loom (*pt:* tear)

(*pt:* urdidura, urdume ou teia )

(*pt:* trama)






## Cloth Simulation

- Os tecidos são um tipo específico de superfícies deformáveis e a sua modelação é bem mais complexa que a das superfícies rígidas.
- Os graus de liberdade de uma superfície deformável são incomparavelmente maiores que os de uma superfície rígida.

[Birra 2006]



## Cloth Simulation

- Cada fio do tecido possui um conjunto de caracteríticas mecânicas, ópticas, térmicas ou outras, que resultam essencialmente da forma como foi **produzido** e da sua **composição em termos das fibras usadas**.
- Estas propriedades caracterizam a sua maior ou menor elasticidade quando lhe é aplicada uma tensão, ou o seu comportamento quando é comprimido, a facilidade que possui em torcer em cada um dos sentidos, a capacidade de curvar e, inclusivamente, a sua forma natural, em repouso, que poderá conter vincos ou torsões.
- Esta forma natural pode ainda depender de factores ambientais como a temperatura e a humidade.

[Birra 2006]

# Cloth Simulation

**Garment simulation and animation** are at the crossroads of many technologies, which essencially involve:

- **physically-based mechanical simulation** to adequately reproduce the shape and the motion of the garment,
- **collision detection** for modeling the interactions between the garments and the body

and

- modeling techniques to enable a designer to construct any complex garment in a simple and intuitive way.



# Cloth Simulation- **Mechanical modeling of cloth properties**

**There are two main approaches:**

- **finite-element continuum modeling**
- **particle systems modeling** ← Predominant method



# Cloth Simulation- **Mechanical modeling of cloth properties**

- The difference between these two schemes is that **particle systems** is a discrete model built on a related discrete surface representation, whereas **continuum mechanics** defines a continuous model which is then discretized.

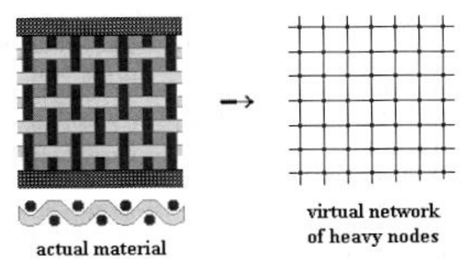
The finite-element method originated from the needs for solving complex elasticity, structural analysis problems in **civil engineering** and **aeronautical engineering**.



# Cloth Simulation- **Mechanical modeling of cloth properties**

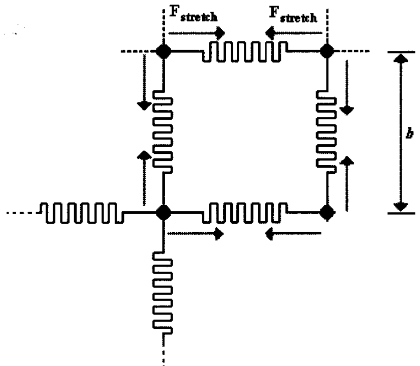
**Particle systems**

discretize the material itself as a set of point masses ('particles') that interact with a set of "forces" which approximately model the behaviour of the material.



## Cloth Simulation- **Mechanical modeling of cloth properties**

**Particle systems**
**(continued)**






## Cloth Simulation- **Mechanical modeling of cloth properties**

**Particle systems (continued)**

The particle network is a grid of square or triangular elements in which each grid node vertex is a particle.

**Input to the nodes of the network** for simulating different conditions of cloth-draping

- gravity
- the elastic modulus
  (a measure of the stiffness of the material)
- thickness
- weight per unit surface area of the cloth
- etc.



- A modelação de tecidos passa, quase sempre, por **malhas poligonais** formadas por triângulos ou quadriláteros. Nos vértices encontram-se **pontos com massa** que aproximam uma determinada área do tecido.
- Quer se usem forças, quer se trate de energias, os valores das grandezas são discretizadas ao longo da superfície do tecido, sendo apenas determinadas para os referidos pontos.
  [Birra 2006]

A **simulação física** poderá ser baseada em **equações diferenciais** que depois de integradas permitem obter as posições dos diversos pontos da malha a intervalos de tempo distribuídos pela simulação. [adaptado de Birra 2006]



## Cloth Simulation- **Collision**

The cloth reacts to its environment: there are **collisions with the environment objects** (including the body that wears the garment) and **self-collision** between various garment parts.

Collission effects are the consequences of the fact that **two objects cannot share the same volume at the same time.**

How Collisions Work in Games

https://www.youtube.com/watch?v=z7xMIRzIDpU



# Collision detection:

Detection of interpenetrating objects.

**Geometrical problem**



# Collision detection and response

Collission effects are the consequences of the fact that **two objects cannot share the same volume at the same time.**

Dealing with collision involves **two** types of problems:

- Collision detection: to find the geometrical contacts between the objects

**Geometrical problem**

- Collision response: to integrate the resulting reaction and friction effects in the mechanical simulation

**This problem interferes with mechanical simulation**



# Collision detection

Collision detection involves two phases: a **broad phase** and a **narrow phase**

- The **broad phase** finds those pairs of objects that may collide.
- The **narrow phase** determines the exact collision point (if any).

# Collision detection

**Broad phase** algorithms explore **different approaches**:

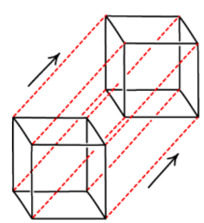
- **Temporal coherence**
- **Spatial coherence**
- **Bounding volumes or hierarchies of bounding volumes**



# Collision detection- Broad phase algorithms

## Temporal coherence

Four-dimensional space-time bounding volumes are associated with an object.



The broad phase is based on calculating the **earliest time that a collision may occur between any pair of objects** and doing **no further collision detection until that time has been reached**.

http://www.pitt.edu/~jdnorton/teaching/HPS_0410/chapters/four_dimensions/#four



# Collision detection- Broad phase algorithms

## Spatial coherence

This technic is most easily exploited by dividing the scene space up into unit cells (*).

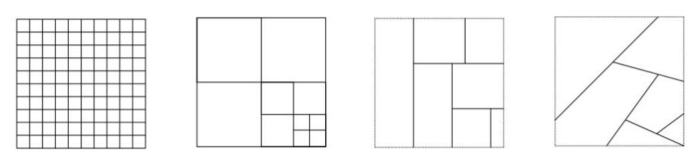
**Only those cells that contain more than one object are examined and collisions are checked.**

(*) **If the moving objects remain on the ground then the cells become a 2D grid.**



# Space Partitioning

- **Algorithms:**
  - Voxel Grid
  - Quadtree
  - Octree
  - *k*-d Tree
  - BSP



**Voxel Grid** **Quadtree & Octree** ***k*-d Tree** **BSP**

## **Collision detection-** Broad phase algorithms

**Spatial coherence - OCTREES**

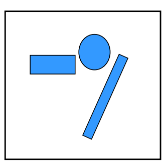
- Octrees are based on subdividing the full voxel space containing the represented object **into 8 octants by planes perpendicular to the three coordinate axes**.
- <u>**Octants that completely contain a single object are denoted as being pure**</u>. <u>Octants that contain multiple objects are recursively split into 8 new smaller octants</u>. This splitting continues until all volumes are either pure, **or some volume size limit is reached.**
- Each octant is labelled with a number.
- A **tree** data structure can be used to represent the **octree**.

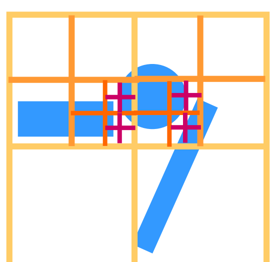
http://homepages.inf.ed.ac.uk/rbf/GRDICT/grdict.htm



## **Collision detection-** Broad phase algorithms

**Spatial coherence (continued)**

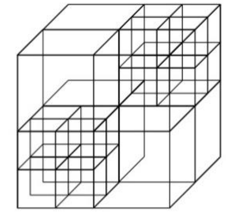


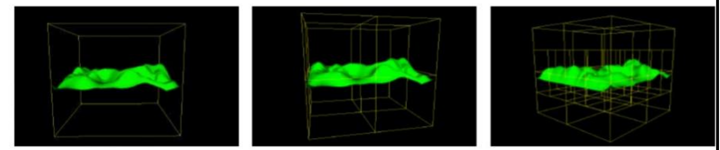


**Quadtree (2D)**



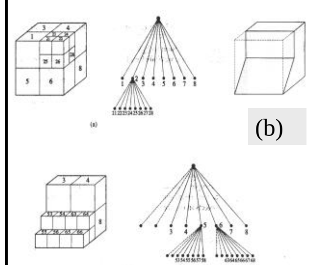
## **Octree**







## **Collision detection-** Broad phase algorithms




Um espaço cúbico pode ser recursivamente subdividido até à precisão necessária, construindo-se assim uma árvore de cubos cada vez mais pequenos. **Imaginemos a figura** (b) contida num espaço cúbico deste tipo. Para este objecto em particular cria-se uma árvore em que **os nós não ocupados por partes do objecto são ignorados** e <u>apenas se consideram os espaços ocupados.</u>

# **Collision detection-** Broad phase algorithms

**Spatial coherence (continued)**

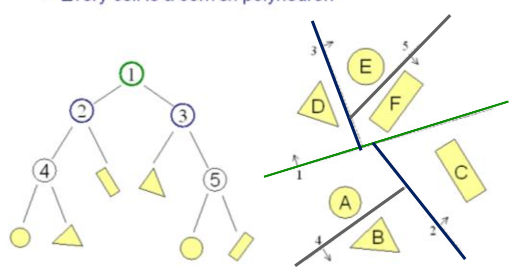
To check for potential colliding pairs the tree is descended and **only those regions that contain more than one object are examined**.

When objects are moving the **octree must be updated at each timestep**. This can result in significant extra computation.



# BSP Tree- Binary Space Partition Tree

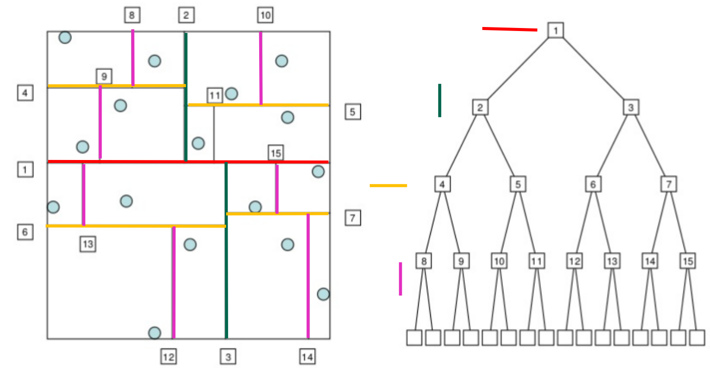
- Recursively partition space by planes
  - Every cell is a convex polyhedron




https://www.cs.princeton.edu/courses/archive/fall00/cs426/lectures/raycast2/sld018.htm



# Kd -Tree





# **Collision detection-** Broad phase algorithms

**Bounding volumes**

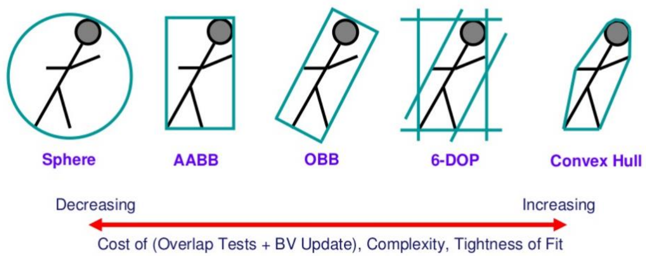
The use of **bounding volumes** in broad phase collision detection is extremely common.

**If the bounding volumes do not collide then the objects cannot collide either.**

# Collision detection- Broad phase algorithms

**Bounding volumes**

types of **volumes** usually used as bounding volumes




**DOP** = discrete oriented polytope



# Collision detection- Broad phase algorithms

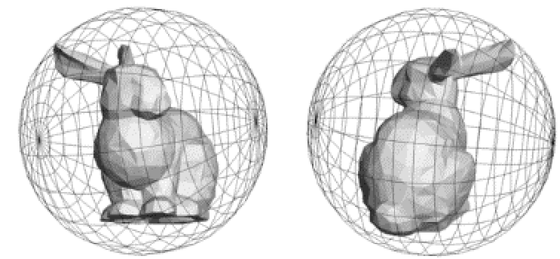

DOP- discrete orientation polytopes

In elementary geometry, a **polytope** is a geometric object with flat sides, and may exist in any general number of dimensions *n* as an *n*-dimensional polytope or ***n*-polytope**.



# Collision detection- Broad phase algorithms

**Bounding volumes (spheres)**



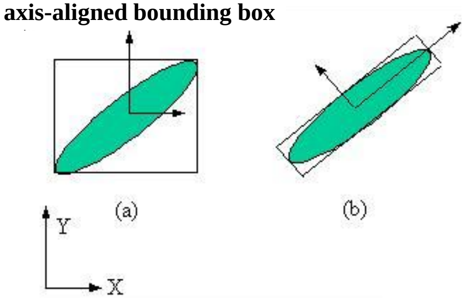
http://mathforum.org/mathimages/imgUpload/thumb/Tighter_bounding_sphere.png/530px-Tighter_bounding_sphere.png



# Collision detection- Broad phase algorithms

(a) **AABB**

**axis-aligned bounding box**

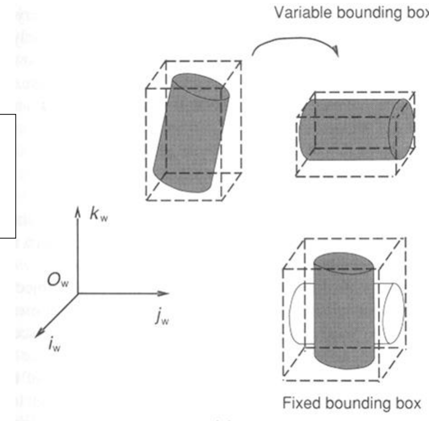



(b) **OBB**

**object-aligned bounding box**

(oriented **bounding boxes-** whose orientation "best suits" the object they are bounding)

## Collision detection- Broad phase algorithms



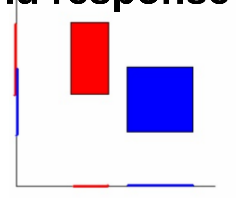

**Types of axis-aligned bounding boxes** (AABBs):

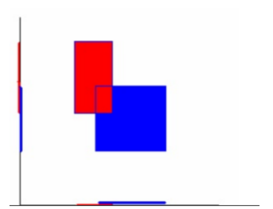
- fixed-size
- variable-size



## Collision detection and response

AABB-based collision detection



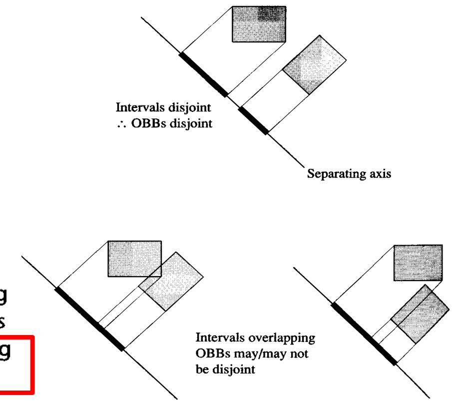


There is a collision if there is overlapping in all dimensions



## Collision detection and response

OBB-based collision detection

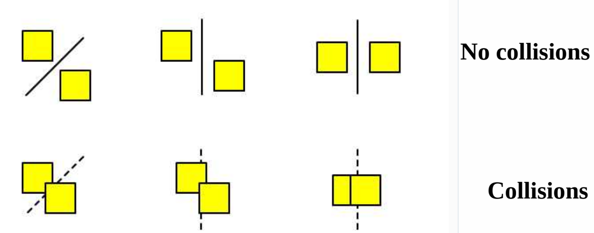



Projecting OBBs onto an axis. If the intervals are disjoint, the axis is a separating axis. Checking for disjoint OBBs involves searching for a separating axis.



## The Separation Axis Theorem

This Theorem essentially states that: if you are able to draw a line to separate two polygons, than they do not collide.




http://gamedevelopment.tutsplus.com/tutorials/collision-detection-using-the-separating-axis-theorem--gamedev-169

## Collision Response

**Collision response** is strictly application dependent. The application may not admit collisions, for example in path planning.

When objects are allowed to collide the **reactions depend on the nature of the objects and the calculations involved are properly part of dynamic simulation**.



## Cloth Simulation- Collision Detection

The cloth reacts to its environment: there are **collisions with the environment objects** ( including the body that wears the garment) and **self-collision** between various garment parts.

Most objects used for cloth and garment simulation are complex and deformable geometries described as polygonal meshes. **Collision detection aims to detect geometrical contacts between mesh elements (vertices, edges polygons).**

Possible approaches :

- **Octree subdivisions**
- **Bounding volume hierarchy**



## Cloth Simulation- **Collision Detection**

**Bounding volume hierarchy**

A suitable hiearachy can be built using a recursive process, starting from **each mesh polygon as a leaf node of the tree**. Two adjacent nodes are merged into a parent node using a criteria for obtaining regions.

The structure of the hierarchies, which should reflect to some extent the **neighborhood relations between the mesh elements can remain constant**, and build during pre-processing. Between each frame, only the **update of the bounding volumes** is required.



## Cloth Simulation- **Collision Detection**

**Bounding volume hierarchy (continued)**

**Collision detection** between two surface regions is carried out by testing the collision between the bounding volumes of the nodes representing the regions, and propagating the test to their children, if it is positive.

# Cloth Simulation- **Enhancing garments**

**Mesh smoothing**

The computation requirements of mechanical simulation impose some practical **limitations on the size of cloth meshes** that can be simulated in a realistic amount of time. A **basic rendering of such rough meshes** would not produce visually satisfactory results.

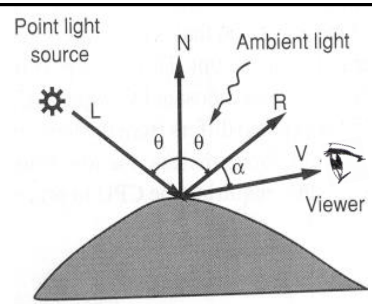
The simplest way to deal with this is to use **smooth shading** techniques during rendering.

**Local Lighting Model**



# Local Lighting Model

In an abstract level, the equation for the Local Lighting Model may be viewed as a sum of three parcels:




$$I = \underbrace{I_{ambient}} + f_{att} \left( \underbrace{I_{diffuse}} + \underbrace{I_{specular}} \right)$$

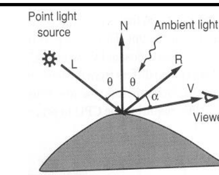
**Ambient light**

**Diffuse reflection: Depends on the angle θ (<u>it does not depend on the position of the observer</u>)**

**Specular reflection: depends on the angle θ and on the angle α (that is, <u>it depends on the position of the observer</u>)**



# Equation for the Local Lighting Model




Adding the three components

(ambient light, diffuse light, reflected light), assuming that R (direction of reflection) and V (direction of visualization) are unitary vectors and including an attenuation factor, we obtain the intensity of light in a single point with this formula:

$$\mathbf{I = I_a k_a + I_p f_{at} [ k_d (L.N) + k_s (R.V)^n ]}$$

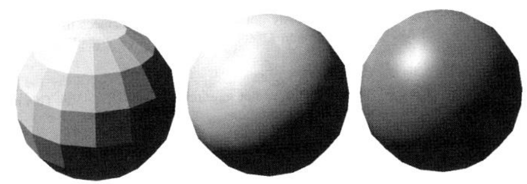
To treat color it is necessary to consider similar separate expressions for each colour (RGB).



# Cloth Simulation- **Enhancing garments**

**Mesh smoothing (continued)**

**Gouraud shading:** interpolates the light color computed on the vertices over the mesh polygons
**Phong Shading:** interpolates the shading normal direction



| **Flat** | **Gouraud** | **Phong** |
|---|---|---|
| also called: **constant shading** | **smooth shading** **vertex shading** | **pixel shading** |

## Cloth Simulation- **Enhancing garments**

**Mesh smoothing (continued)**

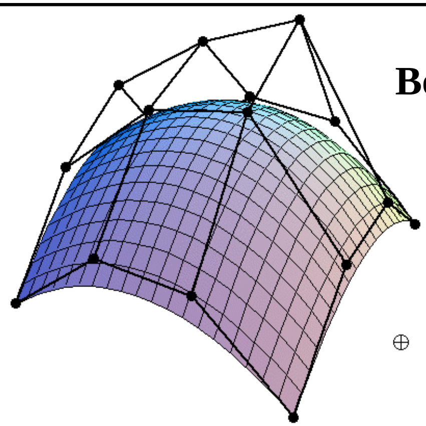
Shading techniques do not, however, change the **real shape of the surface**, and this is particularly visible on the surface contours.

- Replacing the polygonal mesh by a smoother representation is one way to address this.
- Among other, one method is to replace the mesh polygons by **smooth** patches derived from **Bézier** or **Spline** surfaces.

A Bézier patch is a curvilinear quadrilateral, it as four vertices connected by curved edges.



## Bezier patches



https://stackoverflow.com/questions/34650830/bicubic-bezier-patch-trouble-with-understanding



## Cloth Simulation- **Enhancing garments**

**Lighting**

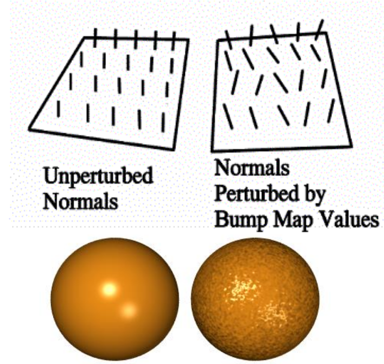
The structure of fabric materials is anisotropic (*).

Lighting can be computed using advanced **texture and bump map techniques**.

(*) Anisotropy (the opposite of isotropy) is the property of being directionally dependent.



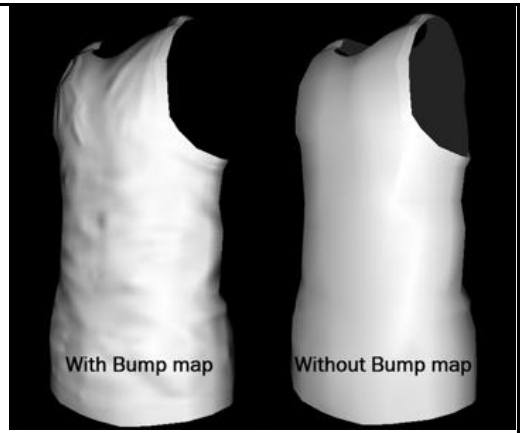
## Bump mapping




http://viz.aset.psu.edu/gho/sem_notes/color_3d/html/surfaces.html

http://upload.wikimedia.org/wikipedia/commons/4/45/Bump-mapping_example.png

## Bump mapping in cloth




http://simswiki.info/images/c/c7/Pic1.png



## Cloth Simulation

## Garment design tools

These tools implement techniques to design complex garments, and their application in the fields of computer graphics (**dressing virtual characters**) and garment industry (**garment prototyping**, **e-commerce applications**).



## Cloth Simulation - **Garment design tools**

**Cordier and Magnenat-Thalmann 2002** describe a complete system that can display real-time animations of dressed characters. It is based on a hybrid approach where **cloth is segmented into various sections where different algorithms are applied**:

- **Layer 1**: Tight and streched garment parts (e.g. gloves)
- **Layer 2**: Loose clothes which remain within a certain distance around the body (e.g. sleeves, pants)
- **Layer 3**: Loose cloth which is not specifically related to a body part (e.g. skirts)



## Cloth Simulation - **Garment design tools**

From the garment in its rest shape on the initial body, **the distance between the garment and the skin surface** is used to determine to which category the cloth triangles belong:

- **Layer 1:** Tight and streched garment parts
- **Layer 2:** Loose clothes which remain within a certain distance around the body
- **Layer 3:** Loose cloth which is not specifically related to a body part

## Cloth Simulation - **Garment design tools**

- **Layer 1: Tight and streched garment parts** (gloves) are modeled directely with **textures and bump maps on the skin surface** itself.

  An offset on the skin mesh possibly models cloth thickness.

  These garment parts **directly follow the motion of the body** without any extra impact on the processing time.



## Cloth Simulation- **Garment design tools**

- **Layer 2: Loose clothes which remain within a certain distance around the body** (e.g. sleeves, pants) are simulated by **mapping the cloth mesh into a simple simplified particle system** where the particles are constrained to move freely within a sphere attached to the original skin position.

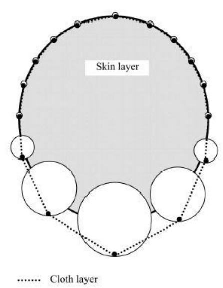



Fig.12. Cross section of a limb with a garment.



## Cloth Simulation- **Garment design tools**

- **Layer 2 (cont.):**

  The relative movements of clothes to the skin remain relatively small, keeping a certain distance from the skin surface.

**Example**
The movement of sleeve in relation with the arm: for a certain region of the garment, the collision area falls within a fixed region of the skin surface during simulation. Therefore, the scope of the collision detection can be severily limited.



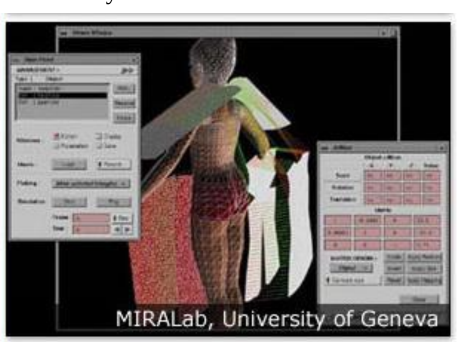
## Cloth Simulation- **Garment design tools**

- **Layer 3: Loose cloth which is not specifically related to a body part** (e.g. skirts) are computed using a **simple mass-spring system** – this layer requires the implementation of a numerical integration scheme and is the heaviest in terms of computation.



# Cloth Simulation - **Garment design tools**

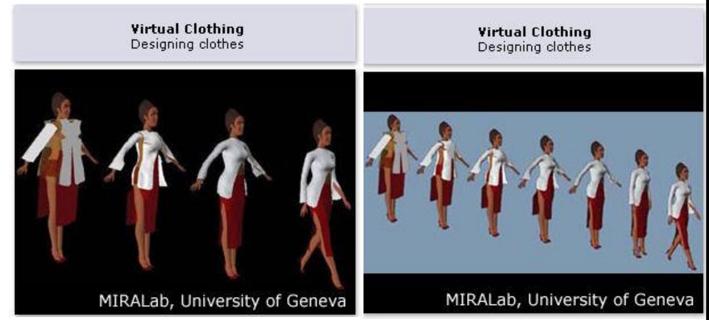
*Draping:* the draping rest shape of a garment is computed on an immobile body






# Cloth Simulation - **Garment design tools**

*Animation :* the accurate garment animation is computed on a moving body.






Vestido da bailarina em tempo real:
https://www.youtube.com/watch?v=KBfxnayIlOY

# Simulating Cloth in Blender
(example)

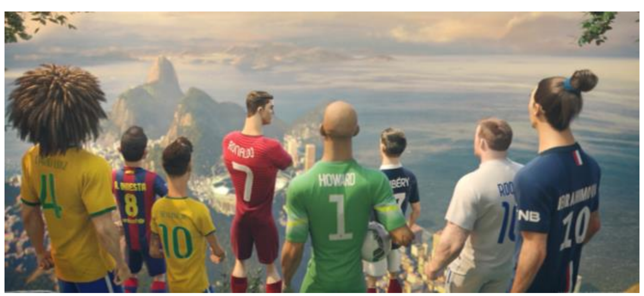
https://www.youtube.com/watch?v=z_c3LvrlOzk



Exemplo de **ferramenta comercial**

http://www.marvelousdesigner.com/

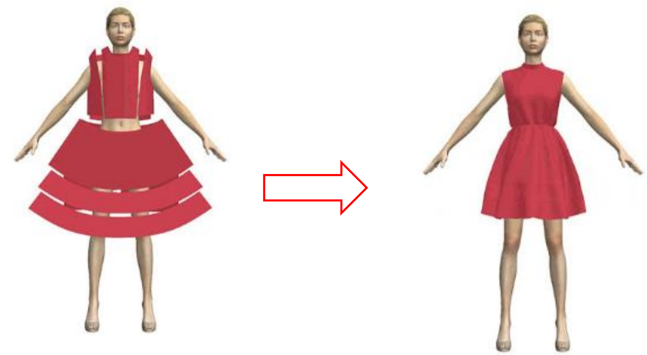
https://www.youtube.com/watch?v=ZIvAanBOL8Y





Outro exemplo de ferramenta comercial

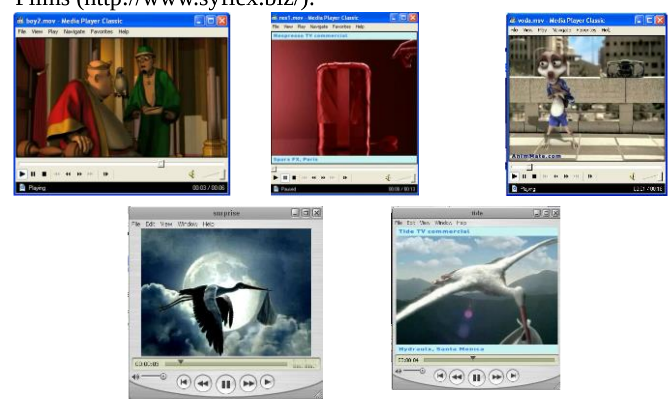
https://clo3d.com/home/tour





# Cloth Simulation

Films (http://www.syflex.biz/):



## References

[Birra 2006] Fernando Birra, “Técnicas Eficientes de Simulação de Tecidos com Realismo Acrescido”, Tese de Doutoramento, FCT-UNL, Lisboa, 2006

*Handbook of Virtual Humans*
Edited by N. Magnenat-Thalmann, D. Thalmann,
John Wiley & Sons

*3D Computer Graphics*, Alan Watt, Addison Wesley, 2015

Cloth Modeling and Animation
Edited by Donald H. House and David E. Breen
AK Peters

http://www.nbb.cornell.edu/neurobio/land/OldStudentProjects/cs490-96to97/anson/BezierPatchApplet/

http://www.syflex.biz/

http://www.miralab.ch/



http://www.gamasutra.com/view/feature/4383/the_secrets_of_cloth_simulation_in_.php?print=1

https://www.youtube.com/watch?v=fkKr4q9W8oM

http://www-ljk.imag.fr/Publications/Basilic/com.lmc.publi.PUBLI_Inproceedings@117681e94b6_1860ffd/bounding_volume_hierarchies.pdf

https://clo3d.com/home/tour