Speeding up Cloth Simulation by Linearizing the Bending Function of the Physical Mass-Spring Model

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Outline

- Introduction
- Related Work
- Objective
- Proposed Approach
- Experimental Results
- Conclusion

The Problem of Cloth Simulation

- How to model different kinds of textiles?
- How to model garment over a human body?




Cloth Simulation Requirement

- Efficiency
  - Fast and stable simulation
- Accuracy
  - Physically correct simulations
  - Ability to model different textiles

Related Work

- Accurately Simulating Intrinsic Properties of Textiles
- Fast and Efficient Cloth Simulation
- Controlling and Rectifying Cloth Simulations

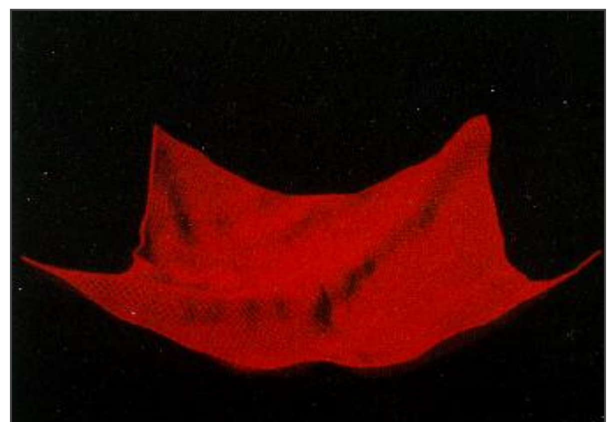
Accurately Simulating Intrinsic Properties of Textiles

- Adopted physical models (especially mass-spring model).
- Physical models gives high accuracy but slow simulations
- Physical models were adopted by: Terzopoulus **87**, Provot **95**, Volino et al **95**, **01**, Jakobsen **01**, Choi **02**, Bridson **03**, Zhou **08.**



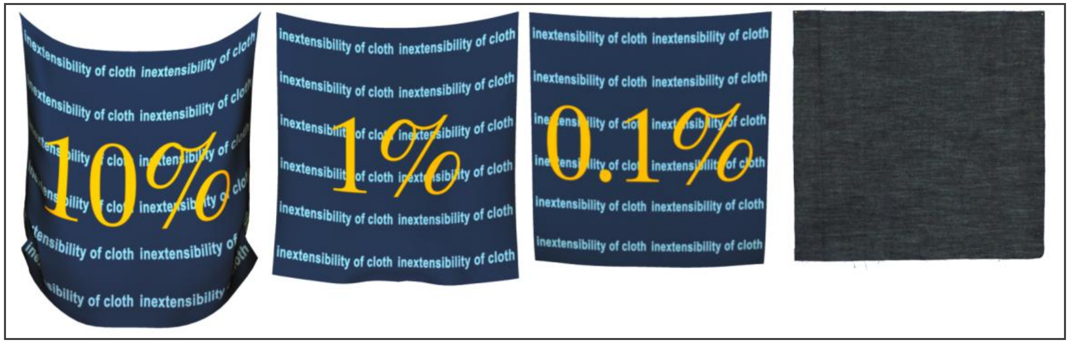
Fast and Efficient Cloth Simulation

- Adopted geometric (mathematical) models.
- Geometric models gives fast simulations but low accuracy and physically-incorrect simulations.
- Geometric models were adopted by: Weil **86**, Kang **07.**



Controlling and Rectifying Cloth Simulations

- Deal with drawbacks of using efficient (fast) integration techniques for cloth simulation.
- Add artificial forces purposefully to either correct the simulation, add user interactivity, or generate predictable animations.
- Proposed by Oh **06**, Harmon **07**, Barbic **07**, **08**



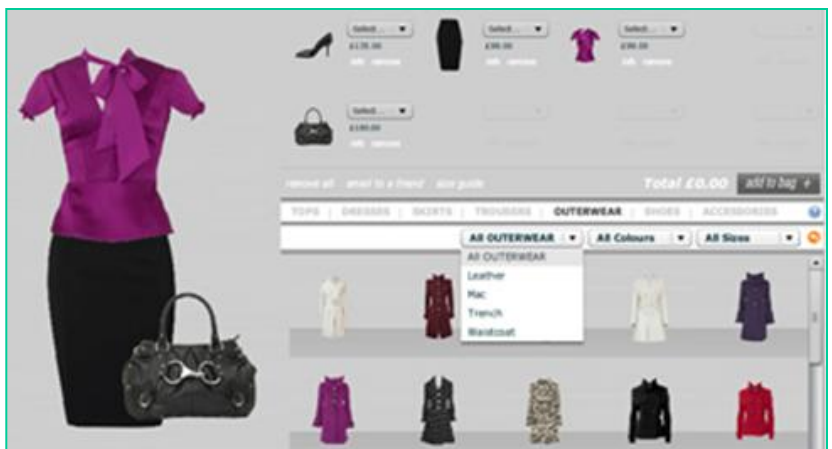
Related Work

- Accurate techniques use complex mechanical models and numerical integration techniques with a large number of iterations. This leads to slow simulations.

- Efficient techniques use simple mechanical models and small number of iterations for numerical integration which compromises the simulation accuracy and can not simulate different kinds of textiles.

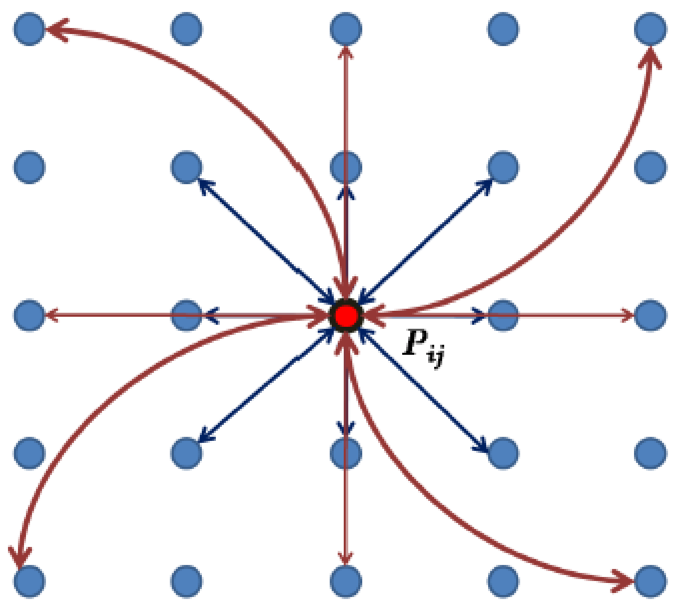
Objective

- Develop a technique for fast cloth simulation that is able to simulate different types of textiles accurately and handle:
  - Complex Mechanical Models
  - Slow Numerical Integration Schemes



Mass-Spring Physical Model

- The cloth is a matrix of particles connected by a group of springs. The springs connecting the particles are: stretch, sheer, and bending springs.
- Newton's law of motion is used to define the system behavior. Newton's law of motion stated that the total force acting on a mass particle is equal to the mass of this particle multiplied by its acceleration



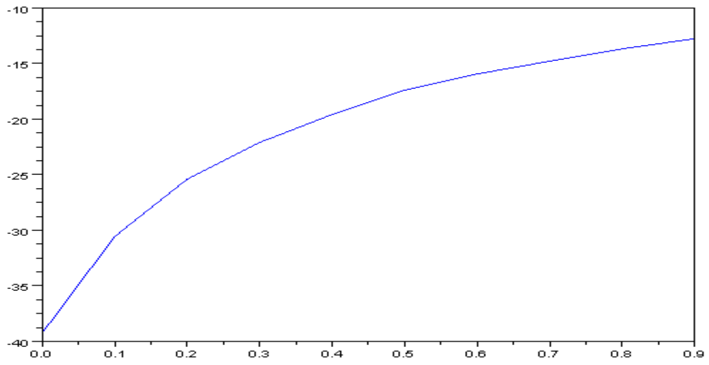
Forces Acting on particles

- The internal forces: stretching, sheering, and bending forces. Exist in the springs connecting the particles.
- The external forces can be any external forces acting on the cloth such as gravity and wind.
- We use the mechanical equations suggested by Choi and Ko in 2002.
  - linear spring equations for modeling the stretching and sheer behavior
  - a non-linear complex spring equation for modeling the bending behavior.

Bending Models

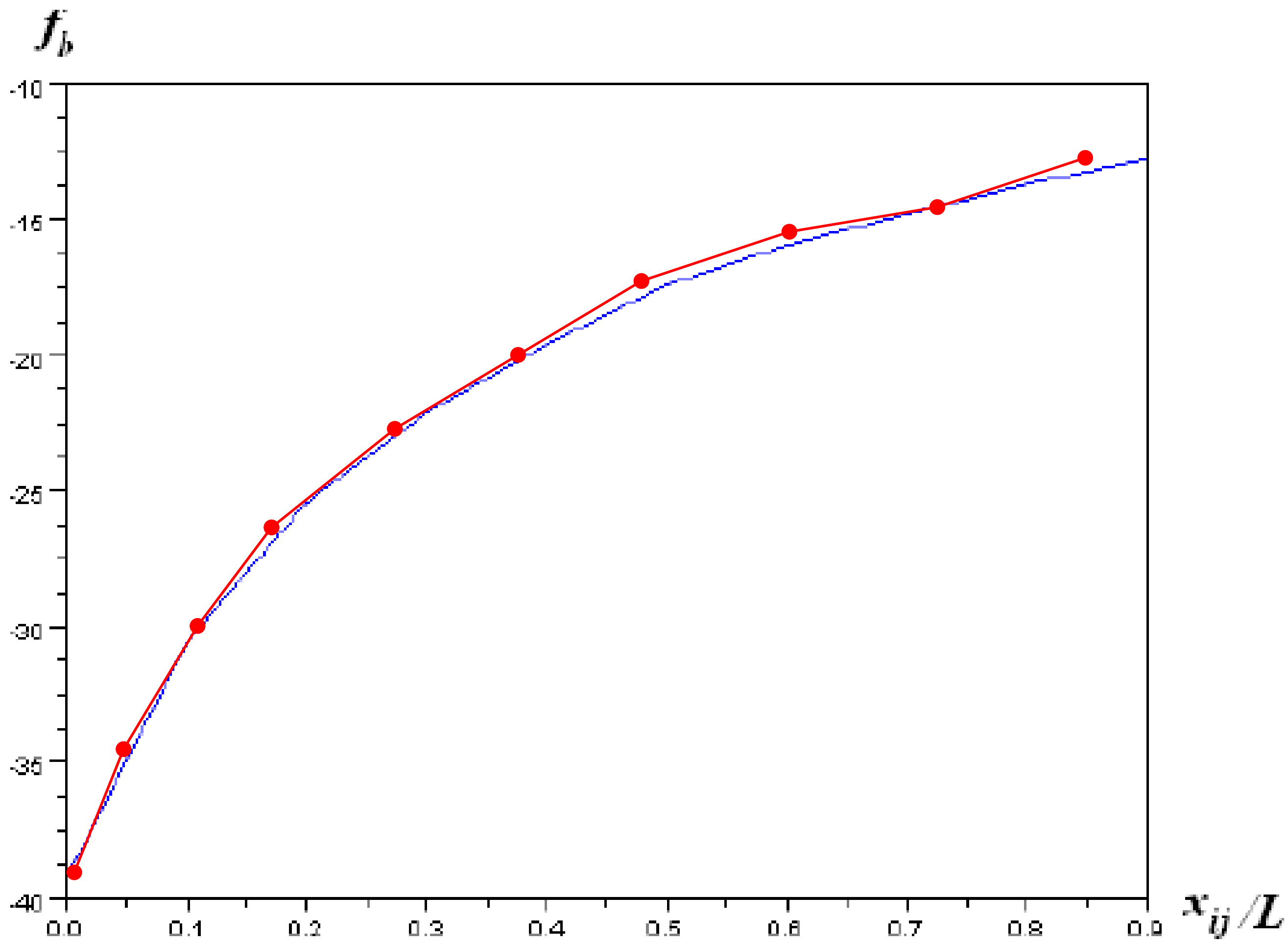
Bending models proposed by Choi et al (2002) required complex computations

$$\begin{aligned} \mathbf{f}_i &= k_b \kappa L \frac{d\kappa}{d|\mathbf{x}_{ij}|}\frac{\mathbf{x}_{ij}}{|\mathbf{x}_{ij}|} = k_b \kappa L \left(\frac{d|\mathbf{x}_{ij}|}{d\kappa}\right)^{-1} \frac{\mathbf{x}_{ij}}{|\mathbf{x}_{ij}|} \\ &= k_b \kappa^2 (\cos\frac{\kappa L}{2} - \mathrm{sinc}(\frac{\kappa L}{2}))^{-1} \frac{\mathbf{x}_{ij}}{|\mathbf{x}_{ij}|} \\ &\equiv f_b(|\mathbf{x}_{ij}|)\frac{\mathbf{x}_{ij}}{|\mathbf{x}_{ij}|} \end{aligned}$$



Complex Computations

Approximate the bending curves by a group of straight lines.



Approximating The Bending Curve

1. The bending magnitude $\mathbf{f_b}$ is defined for the values of $\mathbf{x_{ij}/L}$ on the interval [0→1].
2. We divide the interval [0→1] into a group of subintervals.
3. The actual value of $\mathbf{f_b}$ is computed at the points defining the beginning and ending of each interval.
4. The two points representing an interval is used to specify the slope and intercept of the straight line connecting them.
5. For any value of $\mathbf{x_{ij}/L}$, we compute its corresponding $\mathbf{f_b}$ value approximately by applying the equation of the corresponding straight line.

Computation Savings

Operation	Original Model	Proposed Method
Addition	9	1
Subtraction	2	0
Multiplication	105	1
Division	13	0
Sqrt	1	0
Cos	1	0
Sinc	1	0
Comparisons	3	Avg = Num Intervals/2, Max = Num Intervals
Enhancement	Computations performed by the original model are almost eleven times the computations performed by the proposed method.	

Slow Numerical Integration Scheme

- Integration is mainly used to integrate Newton's law of motion **F = m * a**:
  - F = Force, m = mass, a = acceleration
  - Compute **a**
  - Integrate to get velocity **v**
  - Integrate to get the new position **x**

Using Velocity-less Verlet Integration

- The velocity **v** is approximated by the new and old position **x**. Thus one integration only
- Use Verlet Integration to compute the new particle position
- We assume non-constant stiffness coefficients
- We decrease the time step to preserve numerical stability

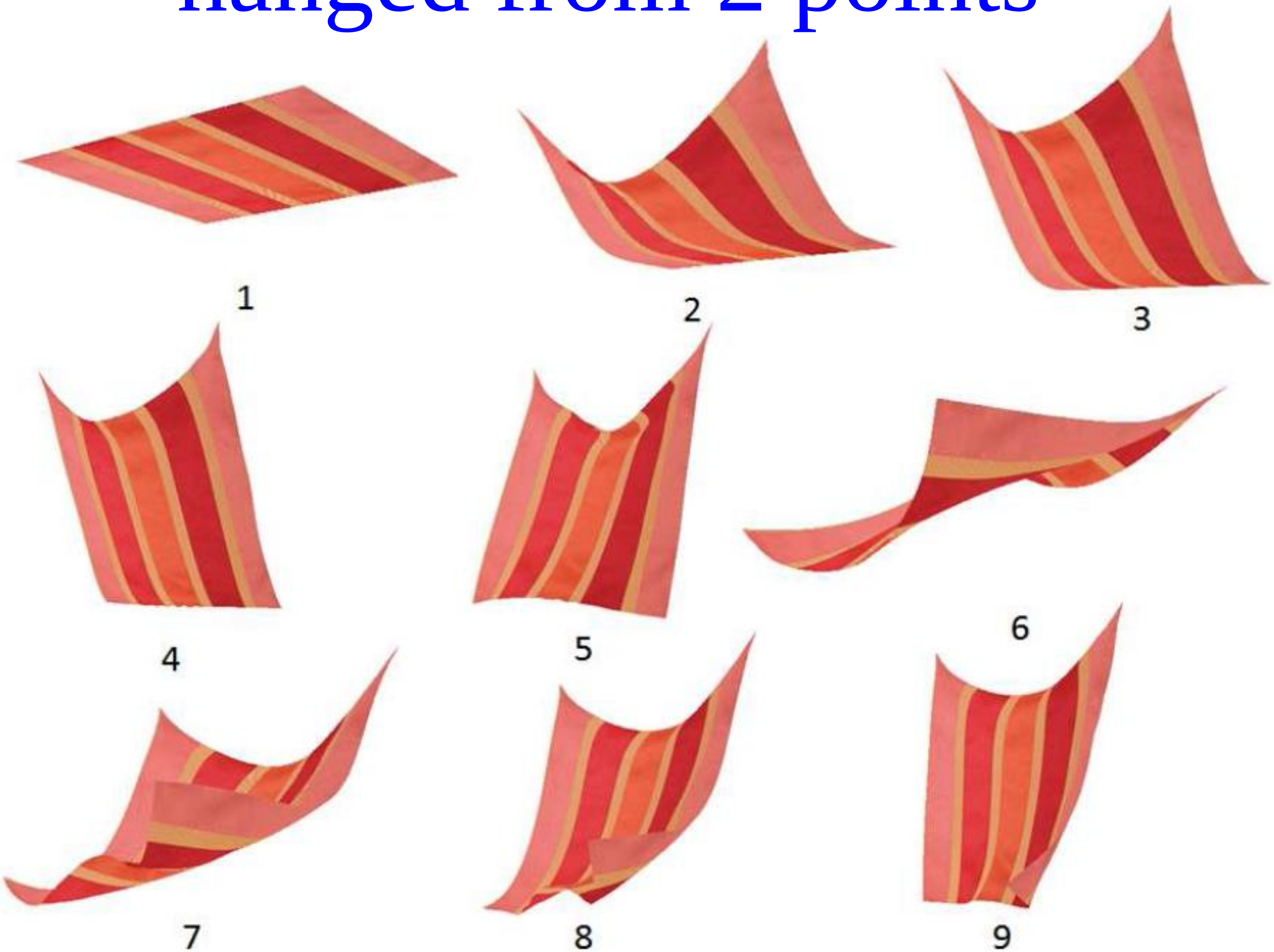
Experimental Results

- Machine Specifications:
  - Intel Pentium M735A Processor
  - Intel Graphics Media Accelerator 900 with Shared Memory of up to 128MB
  - 1GB of RAM

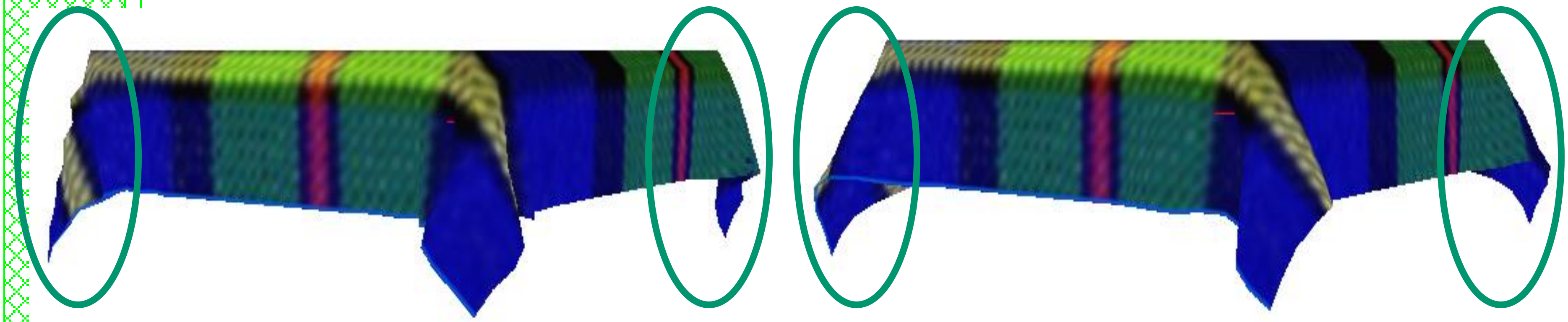
Experimental Results (cont'd)

- Cloth Matrix= 31 * 31 = 961 particles
- Time step=0.1 second
- Particle mass= 1 gram
- Using Verlet Integration with velocity approximation
- Dividing the bending curve into 10 intervals
- Speed Up:
  - **33.625 msec vs. 5.875 msec**
  - **An average speed up of almost *600%***

Simulation results for cloth hanged from 2 points

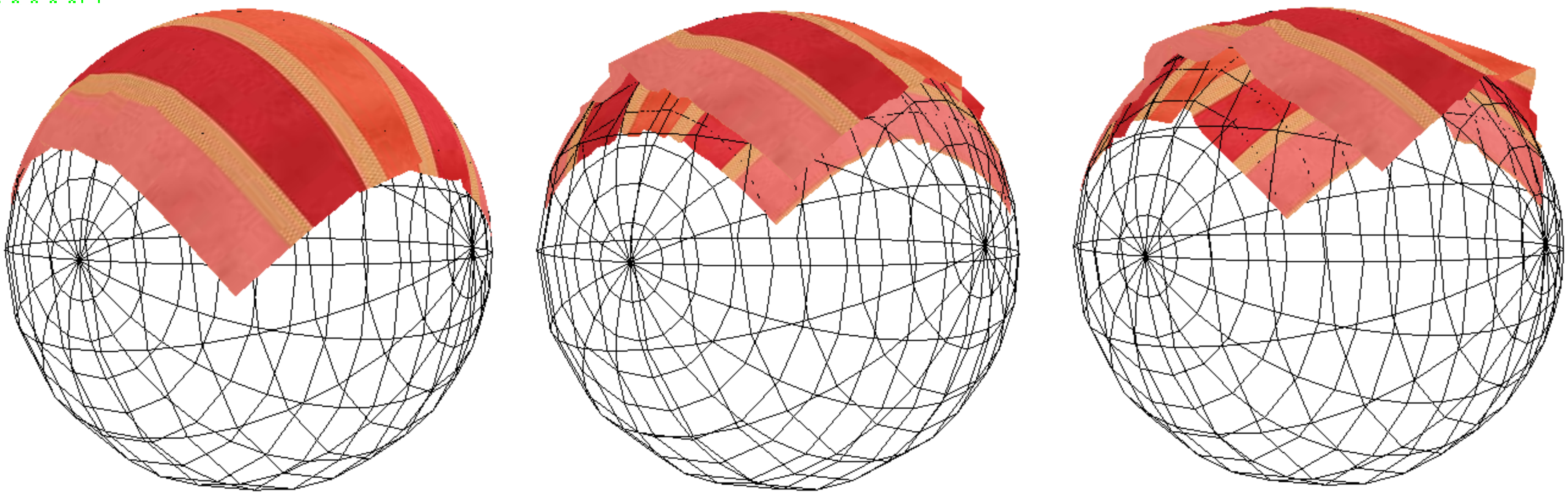


Different behavior of cloth draping on a box for different bending stiffness



$K_b = 0.0$ $K_b = 0.1$

Cloth draping behavior on a sphere for different bending stiffness

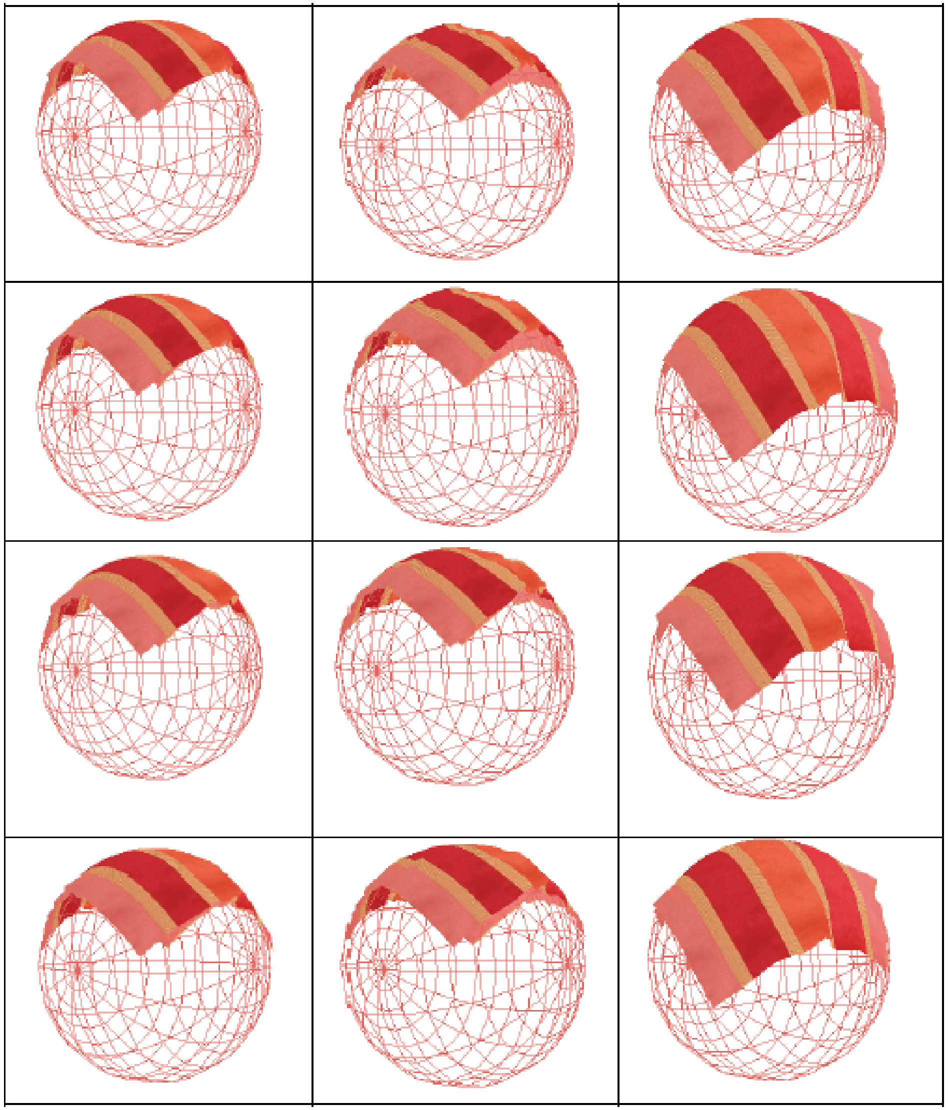


$K_b = 0.0$ $K_b = 0.1$ $K_b = 0.3$

The effect of using different numbers of segments to approximate the bending curve

Small number of segments

Large number of segments



Conclusion

- **By**
  - linearizing the bending function of the physical mass-spring model and
  - using velocity-less Verlet integration with
  - various stiffness coefficients and
  - small time steps
- **We are able to**
  - Simulate different kinds of textiles and
  - Speed up the original model 6 times.

Future Work

- Use the proposed approach and specify different parameter values for different textiles.
- Embed the proposed techniques in an apparel design tool.

Thank You

For Further Questions
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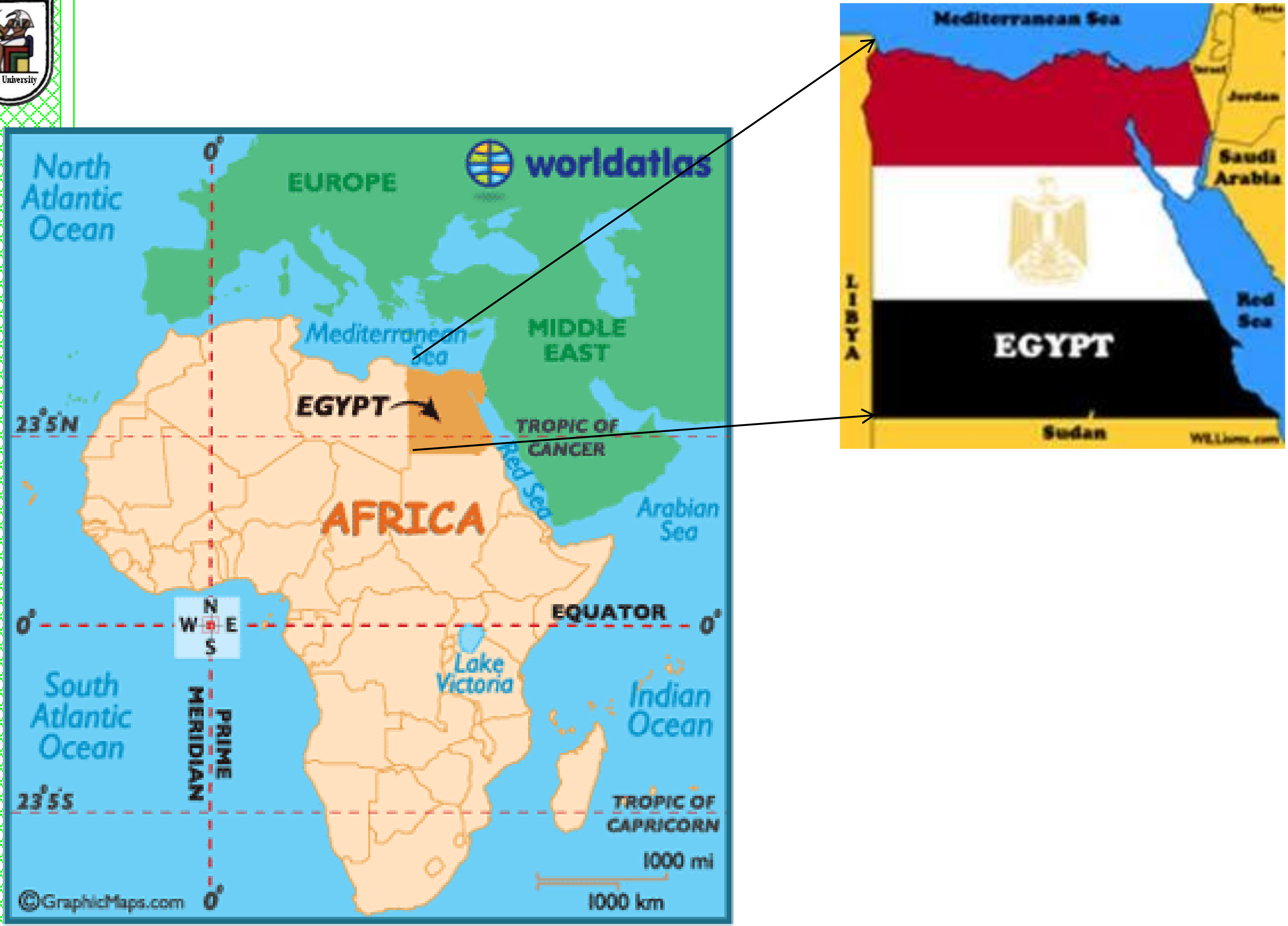
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EUROPE
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Mediterranean Sea
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EGYPT
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TROPIC OF CANCER
Red Sea
AFRICA
Arabian Sea
EQUATOR
0°
N
W
E
S
Lake Victoria
South Atlantic Ocean
PRIME MERIDIAN
Indian Ocean
23°5'S
TROPIC OF CAPRICORN
1000 mi
1000 km
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