Cloth Simulation

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KAIST (Korea Advanced Institute of Science and Technology)

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Overview

- Introduction
- Three Parts of Cloth Simulation
  - Cloth Model System
  - Numerical Solver
  - Collision Handling
- Sketch of Recently Developed Methods
- Challenging Problem
- Conclusion

Introduction

- Cloth Simulation is widely used in the world

Shrek the Third(2007)

"http://www.shrek3.co.kr"

King kong(2005)

"http://www.kingkong2005.co.kr"

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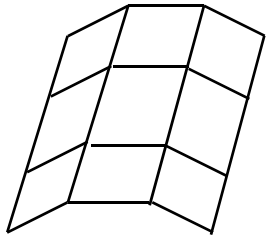
Introduction

- The Goal of Cloth Simulation

Reality ⟷ **Efficiency**

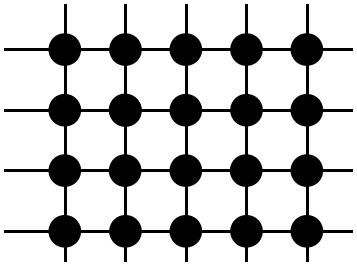
Get realistic results
by calculating intensive
computation

Continuum Model



Get fast results
by calculating efficient
computation

Particle System Model



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Introduction

- Steps of Cloth Simulation

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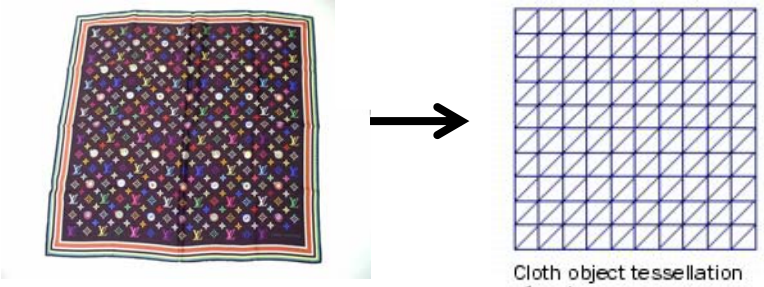
Introduction

- Steps of Cloth Simulation
  1. Model the cloth



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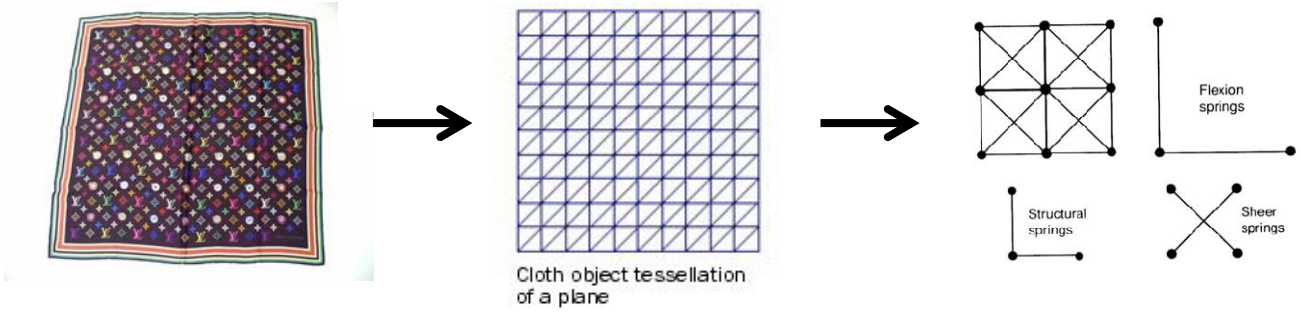
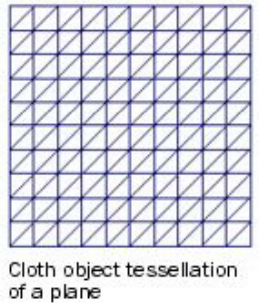
Introduction

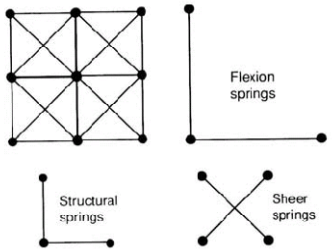
- Steps of Cloth Simulation
  2. Choose the cloth model system



Introduction

- Steps of Cloth Simulation
  3. Derive and solve an equation





$$\frac{d}{dt}\begin{pmatrix}\mathbf{x}\\ \dot{\mathbf{x}}\end{pmatrix}=\frac{d}{dt}\begin{pmatrix}\mathbf{x}\\ \mathbf{v}\end{pmatrix}=\begin{pmatrix}\mathbf{v}\\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x},\mathbf{v})\end{pmatrix}.$$

$$\begin{pmatrix}\Delta\mathbf{x}\\ \Delta\mathbf{v}\end{pmatrix}=h\begin{pmatrix}\mathbf{v}_0+\Delta\mathbf{v}\\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x}_0+\Delta\mathbf{x},\mathbf{v}_0+\Delta\mathbf{v})\end{pmatrix}$$

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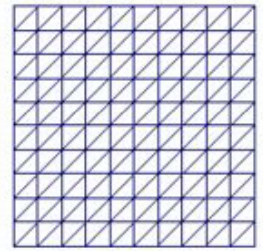
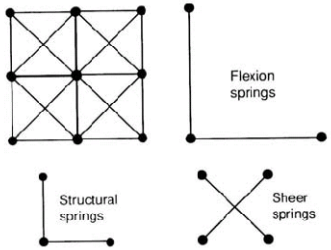
Introduction

- Steps of Cloth Simulation
  4. Collision handling (Collision detection + response)



Cloth object tessellation of a plane



$$\frac{d}{dt}\begin{pmatrix}\mathbf{x}\\ \dot{\mathbf{x}}\end{pmatrix}=\frac{d}{dt}\begin{pmatrix}\mathbf{x}\\ \mathbf{v}\end{pmatrix}=\begin{pmatrix}\mathbf{v}\\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x},\mathbf{v})\end{pmatrix}.$$

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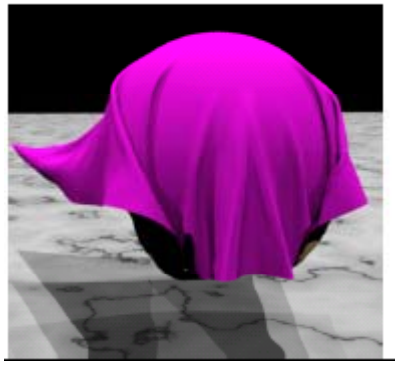

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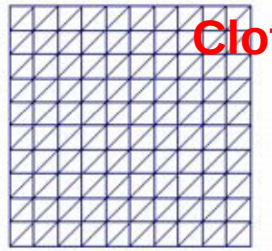
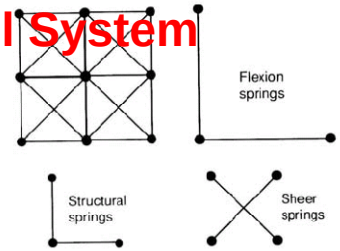


Cloth object tessellation of a plane

Cloth Model System



Numerical Solver

$$\frac{d}{dt}\begin{pmatrix}\mathbf{x}\\ \dot{\mathbf{x}}\end{pmatrix}=\frac{d}{dt}\begin{pmatrix}\mathbf{x}\\ \mathbf{v}\end{pmatrix}=\begin{pmatrix}\mathbf{v}\\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x},\mathbf{v})\end{pmatrix}.$$

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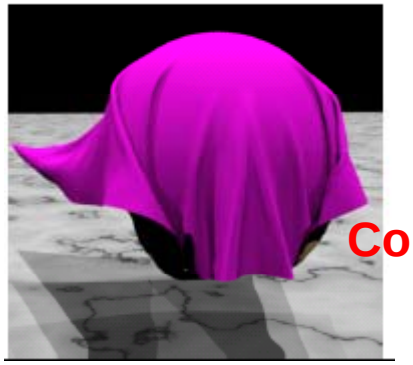
Collision Handling



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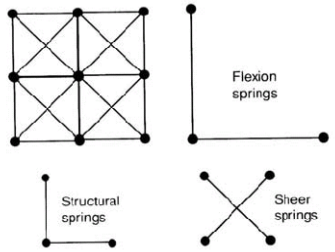
Three Parts of Cloth Simulation

1. Cloth Model System



2. Numerical Solver

$$\frac{d}{dt}\begin{pmatrix}\mathbf{x}\\ \dot{\mathbf{x}}\end{pmatrix}=\frac{d}{dt}\begin{pmatrix}\mathbf{x}\\ \mathbf{v}\end{pmatrix}=\begin{pmatrix}\mathbf{v}\\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x},\mathbf{v})\end{pmatrix}.$$

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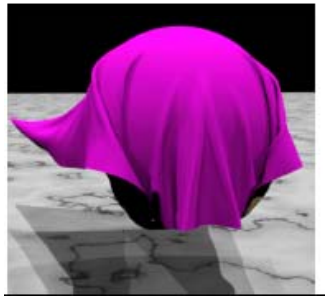
3. Collision Handling



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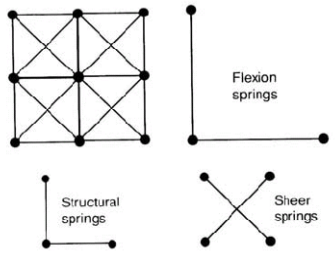

2. Numerical Solver

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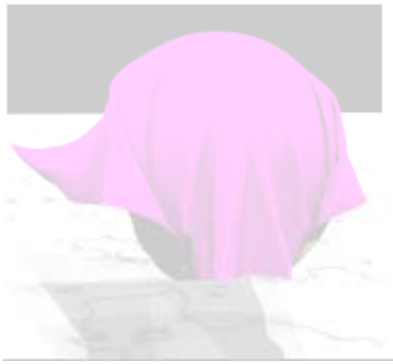

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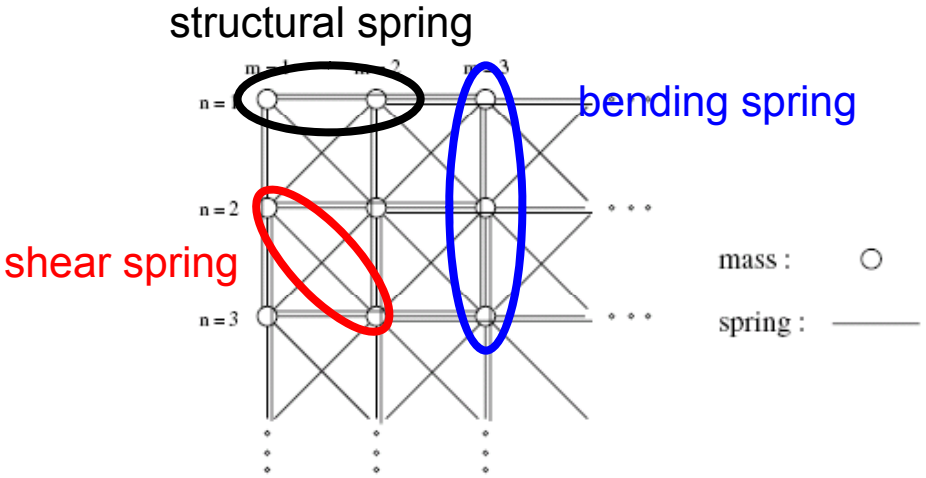
Three Parts of Cloth Simulation

1. Cloth Model System

- Deformation Constraints in a Mass- Spring Model to Describe Rigid Cloth Behavior

Xavier Provot, Graphics Interface, 1995.



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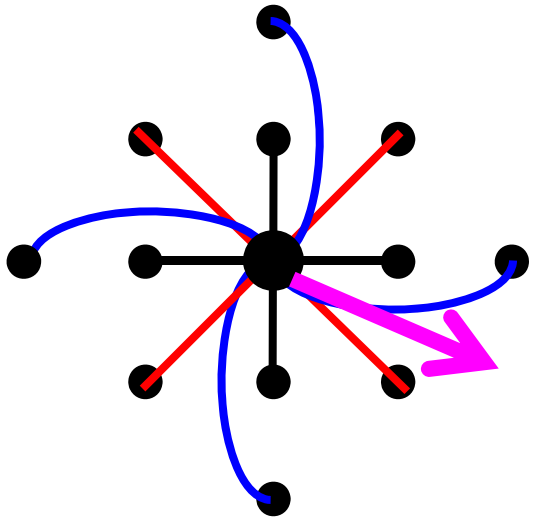

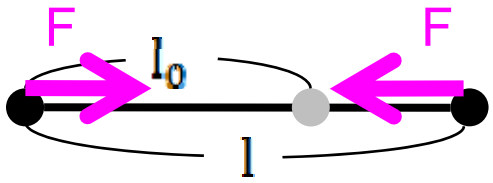

$$F = -K \times (l - l_0)$$

$$\begin{cases} \mathbf{a}_{i,j}(t+\Delta t) = \frac{1}{\mu}\mathbf{F}_{i,j}(t) \\ \mathbf{v}_{i,j}(t+\Delta t) = \mathbf{v}_{i,j}(t) + \Delta t\, \mathbf{a}_{i,j}(t+\Delta t) \\ P_{i,j}(t+\Delta t) = P_{i,j}(t) + \Delta t\, \mathbf{v}_{i,j}(t+\Delta t) \end{cases}$$

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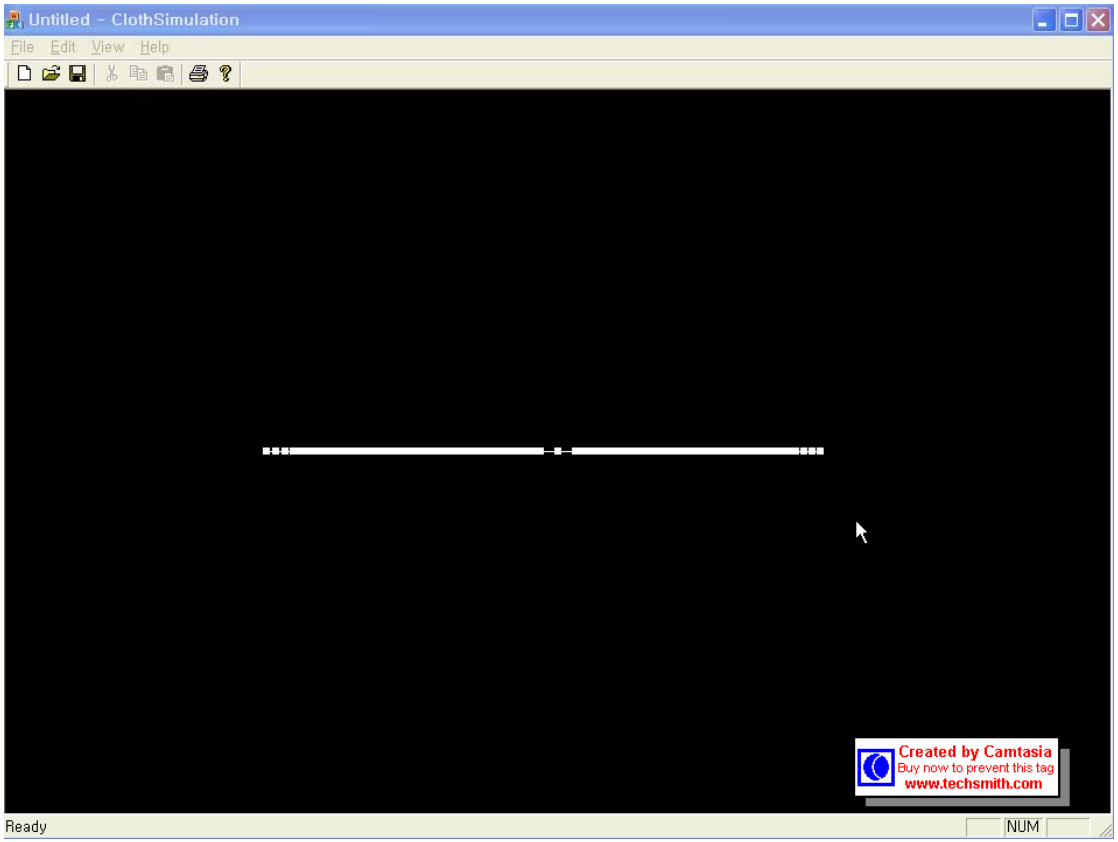

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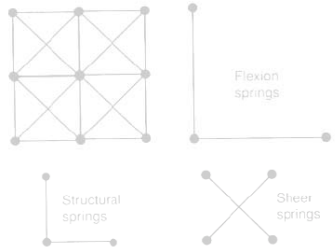

2. Numerical Solver

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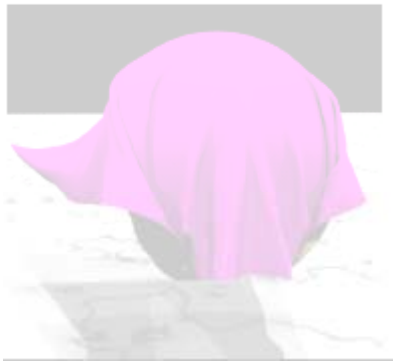
3. Collision Handling



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Three Parts of Cloth Simulation

2. Numerical Solver

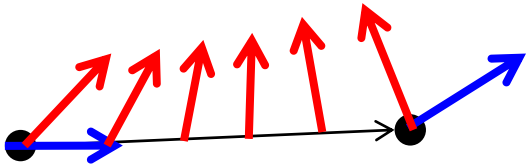
- Large Steps in Cloth Simulation

David Baraff, et al., SIGGRAPH, 1998.

$$\ddot{\mathbf{x}} = \mathbf{M}^{-1}\mathbf{f}(\mathbf{x}, \dot{\mathbf{x}}).$$

Newton's law

$$\frac{d}{dt}\begin{pmatrix}\mathbf{x}\\ \dot{\mathbf{x}}\end{pmatrix} = \frac{d}{dt}\begin{pmatrix}\mathbf{x}\\ \mathbf{v}\end{pmatrix} = \begin{pmatrix}\mathbf{v}\\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x}, \mathbf{v})\end{pmatrix}$$



$\mathbf{f}(\mathbf{x}, \mathbf{v}) = ?$

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Three Parts of Cloth Simulation

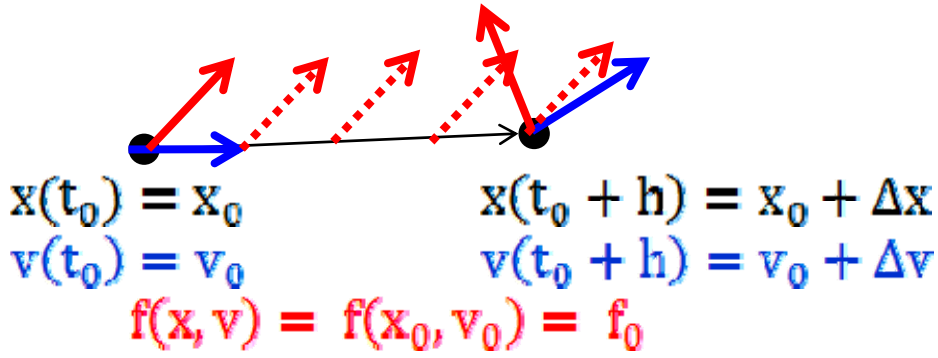
2. Numerical Solver

- Large Steps in Cloth Simulation

David Baraff, et al., SIGGRAPH, 1998.

1. Explicit Method

$$\begin{pmatrix} \Delta \mathbf{x} \\ \Delta \mathbf{v} \end{pmatrix} = h \begin{pmatrix} \mathbf{v}_0 \\ \mathbf{M}^{-1}\mathbf{f}_0 \end{pmatrix}$$



calculation cost is very low

time step(h) must be small to ensure stability

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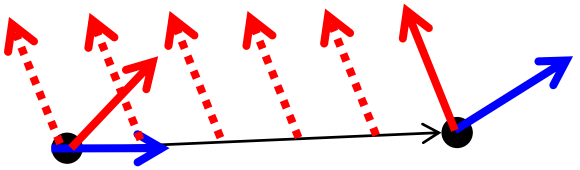
Three Parts of Cloth Simulation

2. Numerical Solver

- Large Steps in Cloth Simulation

David Baraff, et al., SIGGRAPH, 1998.

2. Implicit Method



$$\begin{pmatrix} \Delta\mathbf{x} \\ \Delta\mathbf{v} \end{pmatrix} = h \begin{pmatrix} \mathbf{v}_0 + \Delta\mathbf{v} \\ \mathbf{M}^{-1}\mathbf{f}(\mathbf{x}_0 + \Delta\mathbf{x}, \mathbf{v}_0 + \Delta\mathbf{v}) \end{pmatrix}$$

$$\mathbf{x}(t_0) = \mathbf{x}_0 \qquad \mathbf{x}(t_0 + h) = \mathbf{x}_0 + \Delta\mathbf{x}$$

$$\mathbf{v}(t_0) = \mathbf{v}_0 \qquad \mathbf{v}(t_0 + h) = \mathbf{v}_0 + \Delta\mathbf{v}$$

$$\mathbf{f}(\mathbf{x}, \mathbf{v}) = \mathbf{f}(\mathbf{x}_0 + \Delta t, \mathbf{v}_0 + \Delta\mathbf{v})$$

$$\mathbf{f}(\mathbf{x}_0 + \Delta\mathbf{x}, \mathbf{v}_0 + \Delta\mathbf{v}) = \mathbf{f}_0 + \frac{\partial \mathbf{f}}{\partial \mathbf{x}}\Delta\mathbf{x} + \frac{\partial \mathbf{f}}{\partial \mathbf{v}}\Delta\mathbf{v}$$

$$\left(\mathbf{I} - h\mathbf{M}^{-1}\frac{\partial \mathbf{f}}{\partial \mathbf{v}} - h^2\mathbf{M}^{-1}\frac{\partial \mathbf{f}}{\partial \mathbf{x}}\right)\Delta\mathbf{v} = h\mathbf{M}^{-1}\left(\mathbf{f}_0 + h\frac{\partial \mathbf{f}}{\partial \mathbf{x}}\mathbf{v}_0\right)$$

calculation cost is expensive

time step(h) can be large

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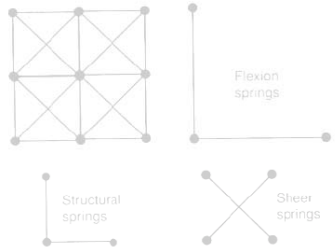
Three Parts of Cloth Simulation

1. Cloth Model System



2. Numerical Solver

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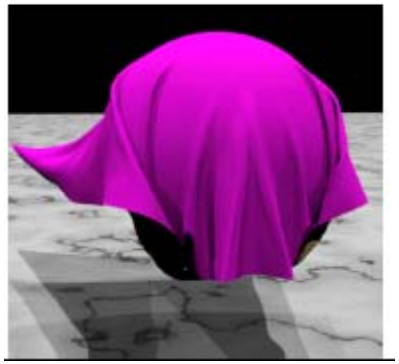
3. Collision Handling



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Three Parts of Cloth Simulation

3. Collision Handling

- Collision Handling

Three Parts of Cloth Simulation

3. Collision Handling

- Collision Handling

  = Collision Detection + Collision Response

Three Parts of Cloth Simulation

3. Collision Handling

- Collision Handling

  = Collision Detection + Collision Response

Collision detection

- Cloth-Body Collision

- Cloth-Cloth Collision
  (Self-collision)

Three Parts of Cloth Simulation

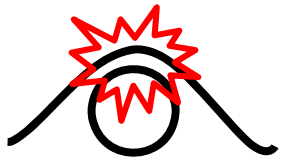
3. Collision Handling

- Collision Handling

  = Collision Detection + Collision Response

Collision detection

- Cloth-Body Collision



- Cloth-Cloth Collision
  (Self-collision)

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Three Parts of Cloth Simulation

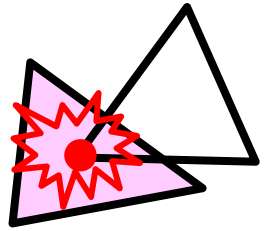
3. Collision Handling

- Collision Handling

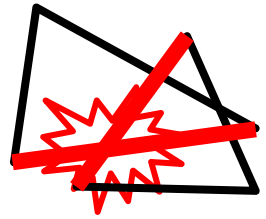
  = Collision Detection + Collision Response

Collision detection

- Vertex-Face Collision



- Edge-Edge Collision



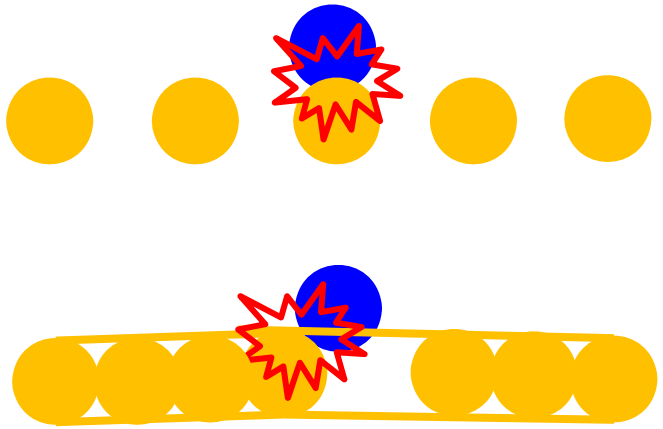
Three Parts of Cloth Simulation

3. Collision Handling

- Collision Handling

  = Collision Detection + Collision Response

Collision detection
- Discrete CD
- Continuous CD



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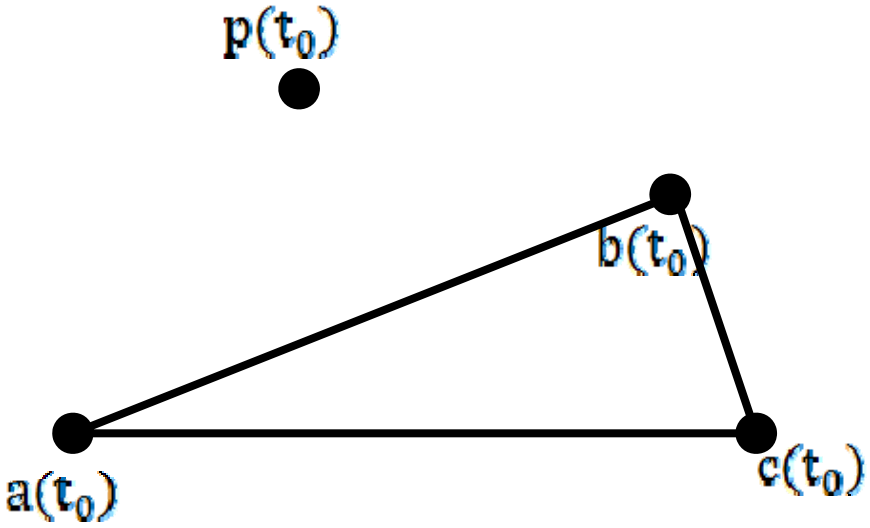
Three Parts of Cloth Simulation

3. Collision Handling

- Collision and self- collision handling in cloth model dedicated to design garments

Xavier Provot, Graphics Interface, 1997.



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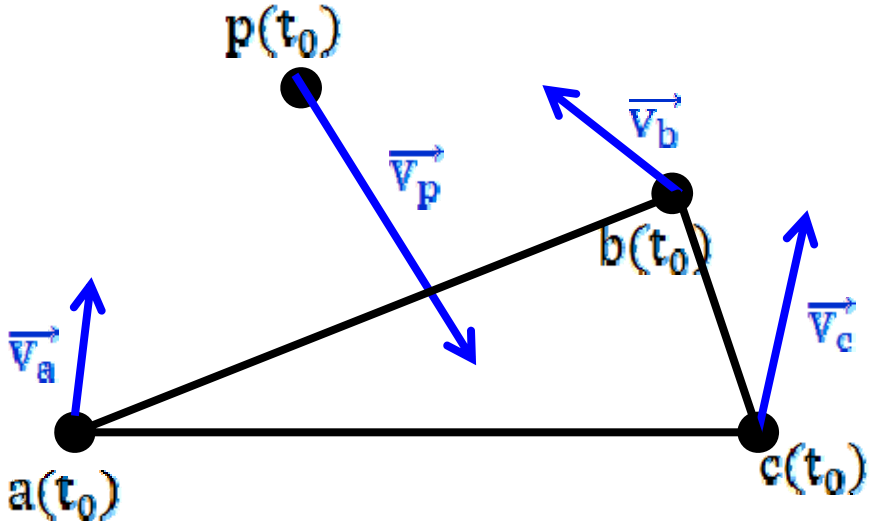

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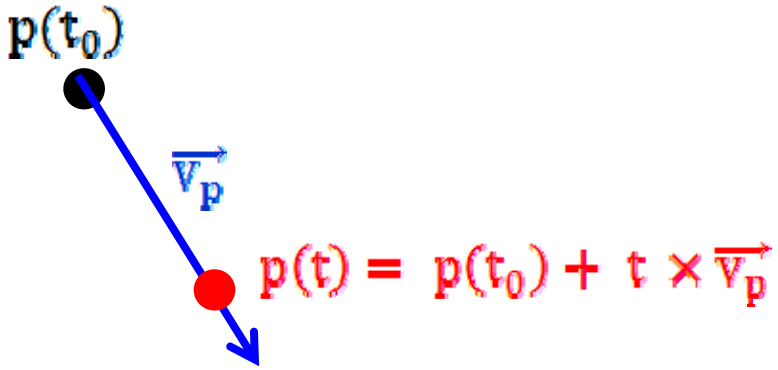

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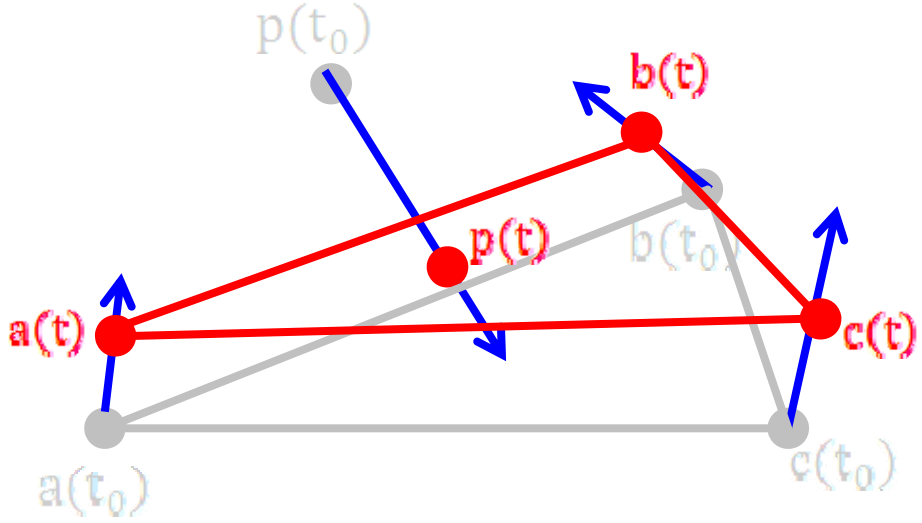

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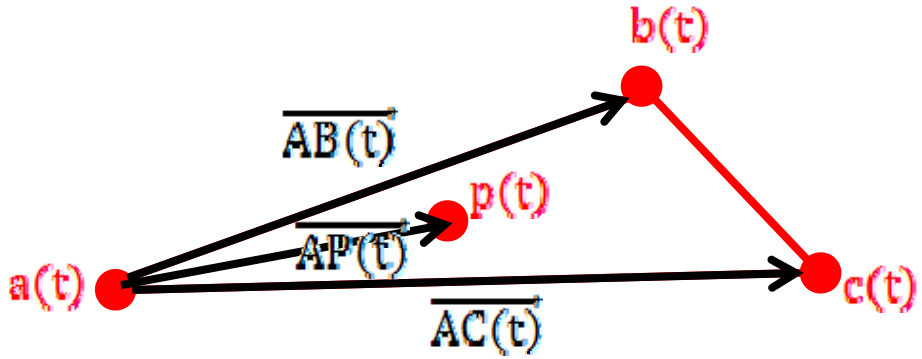
$$\exists\, t \in [t_0, t_0 + \Delta t] \text{ such that}$$
$$\exists u, v \in [0,1],\ u + v \leq 1,\ \overrightarrow{AP}(t) = u\overrightarrow{AB}(t) + v\overrightarrow{AC}(t)$$



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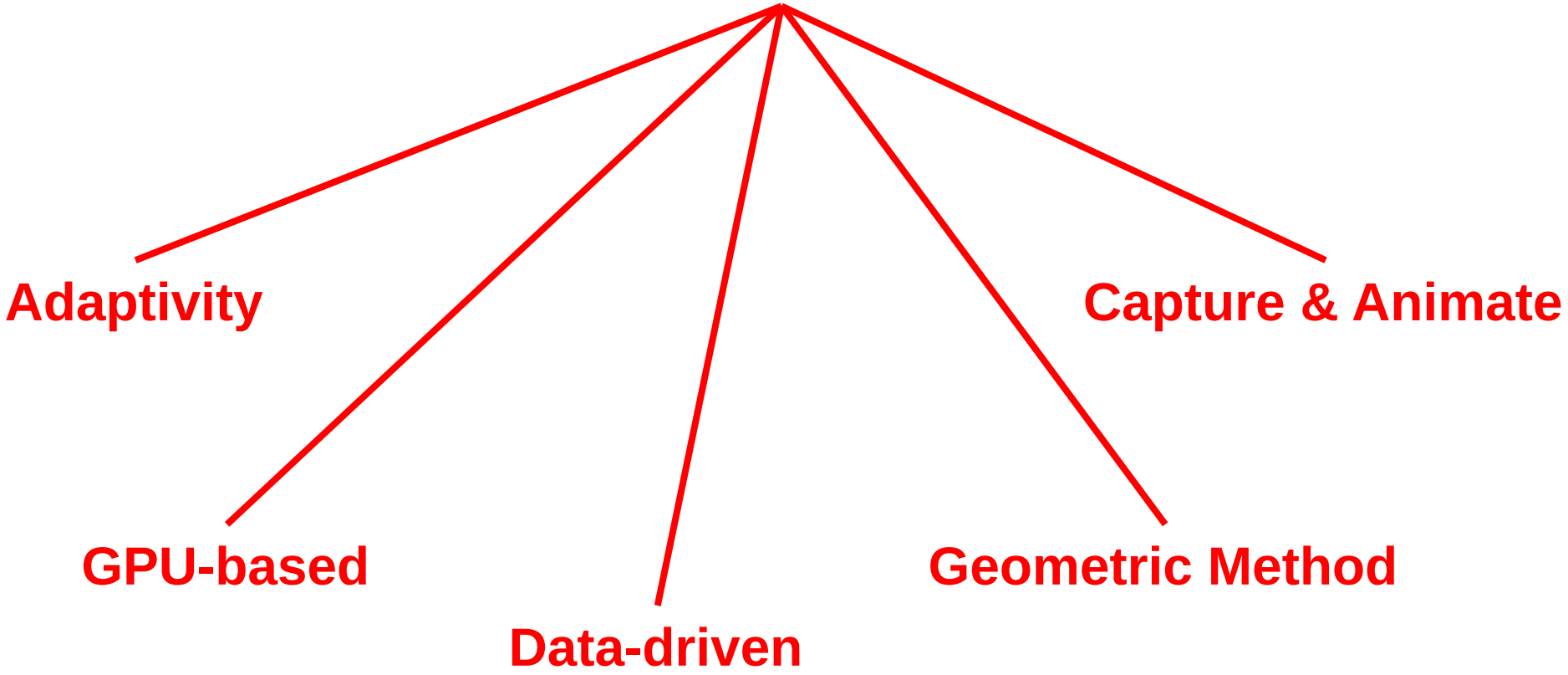
Sketch of recently developed methods



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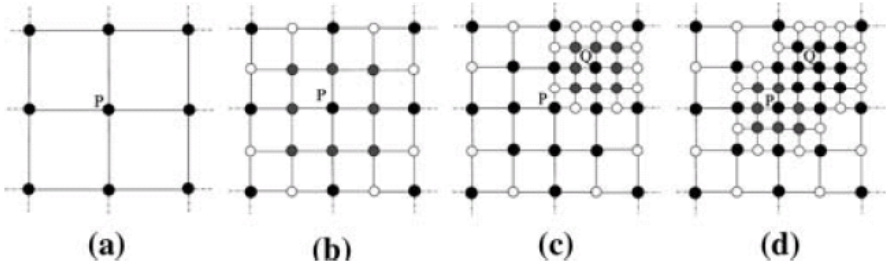
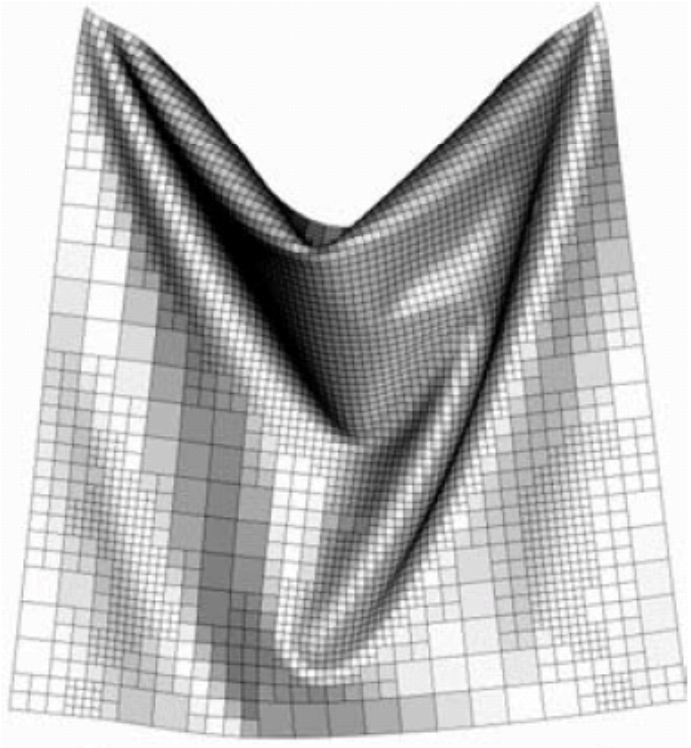
Sketch of Recently Developed Methods

- Adaptive meshing for cloth animation

J. Villard, et al., Engineering with Computers, 2005.





“Adaptivity”

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Sketch of Recently Developed Methods

- GPU Based cloth simulation with Moving Humanoids

J. Rodriguez- Navarro, et al., 2005.

	fixed iter(20/40)	quasi-feedback
64×64	105/86	88-124
128×128	63/43	44-90
256×256	22/14	14-42

Table 1: Frame rate results for different cloth dimensions considering all body parts.

	fixed iter(20/40)	quasi-feedback
64×64	90-144/77-108	107-200
128×128	54-77/41-50	40-133
256×256	20-24/14-15	14-55

Table 2: Frame rate results for different cloth dimensions considering only body parts which can collide.

"GPU"

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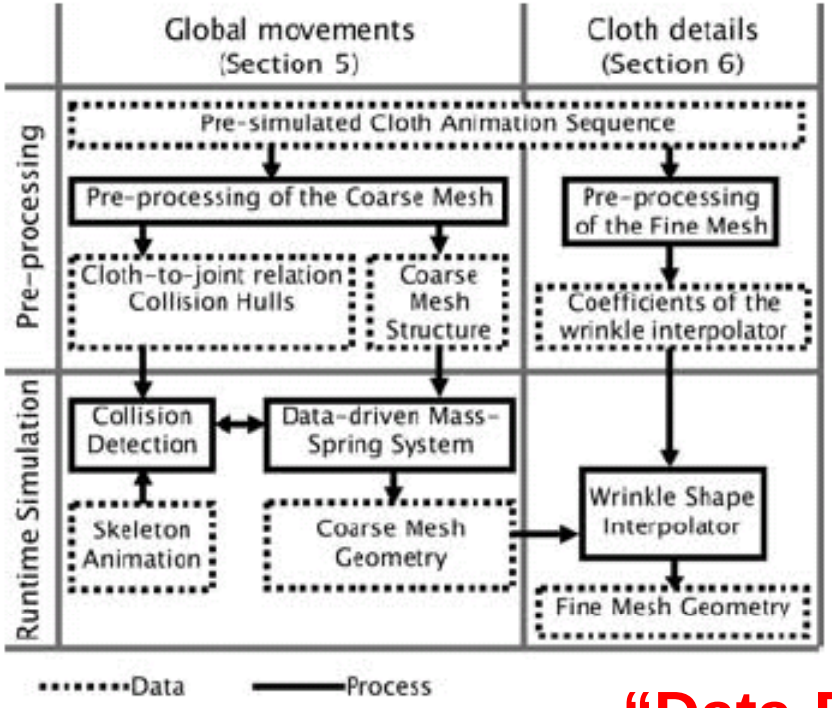
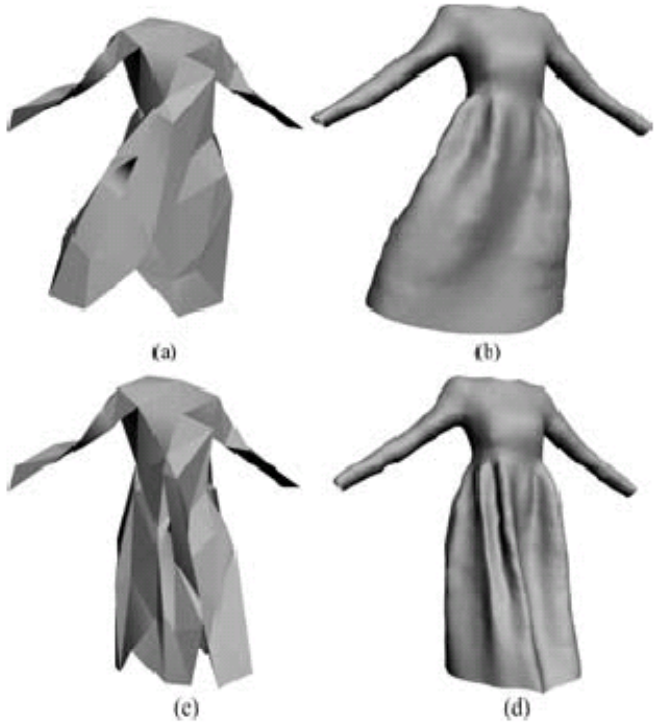
Sketch of Recently Developed Methods

- A Data- Driven Approach for Real- Time Clothes Simulation

Frederic Cordier, et al., Pacific Graphics, 2005.





"Data-Driven"

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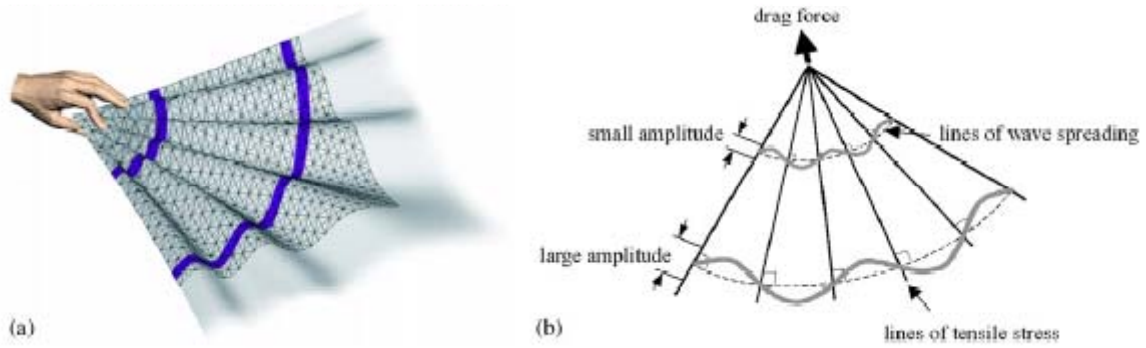
Sketch of Recently Developed Methods

- A real- time cloth draping simulation algorithm using conjugate harmonic functions

M. K. Kang, et al., Computers & Graphics, 2007.



“Hybridization of geometric and physically based method”

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Sketch of Recently Developed Methods

- Capturing and Animating Occluded Cloth

Ryan White, et al., SIGGRAPH, 2007.

“Capture & Animate”

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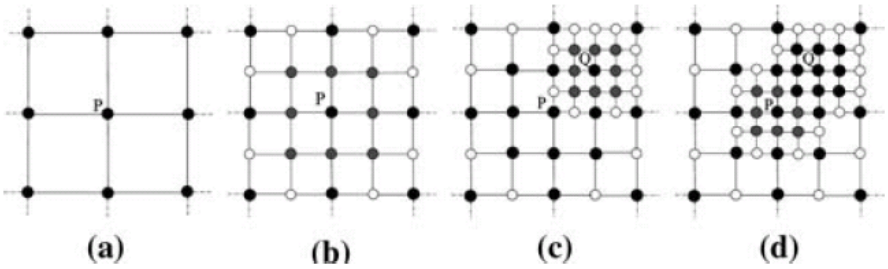
Challenging Problem

My works on adaptive simulation



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Challenging Problem

- Adaptive Cloth Simulation

fixed fixed

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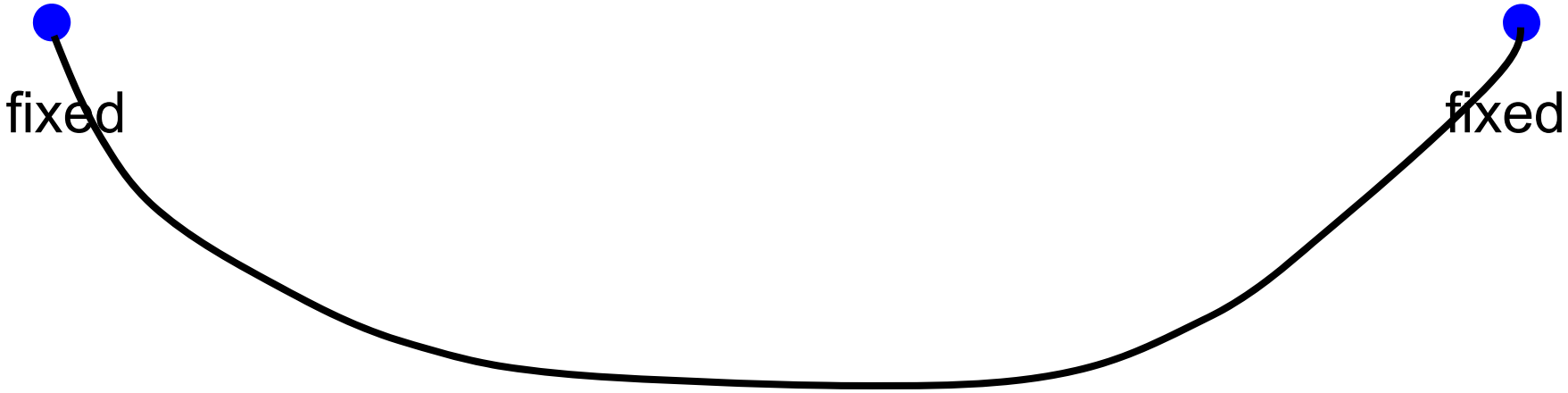
Challenging Problem

- Adaptive Cloth Simulation



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Challenging Problem

- Adaptive Cloth Simulation

Challenging Problem

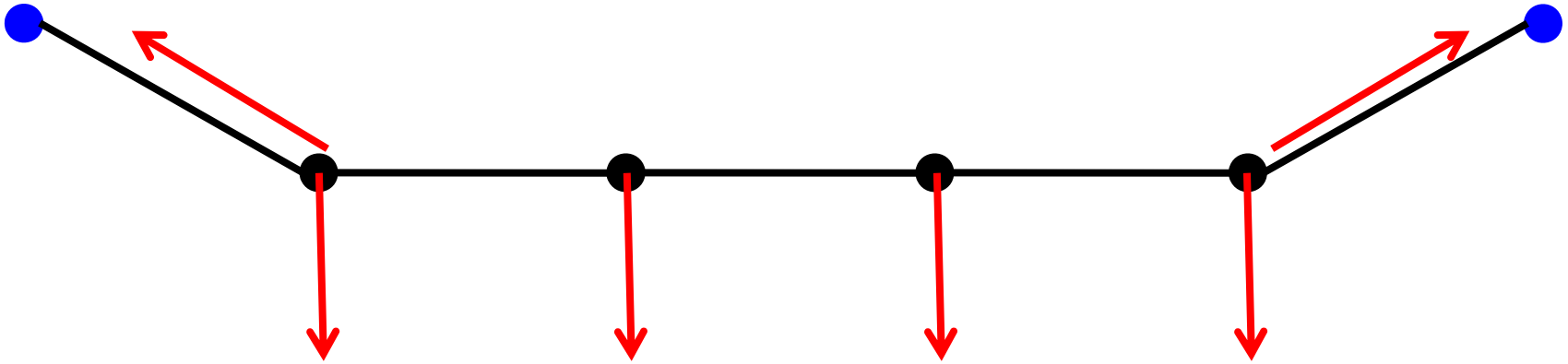
- Adaptive Cloth Simulation

Challenging Problem

- Adaptive Cloth Simulation

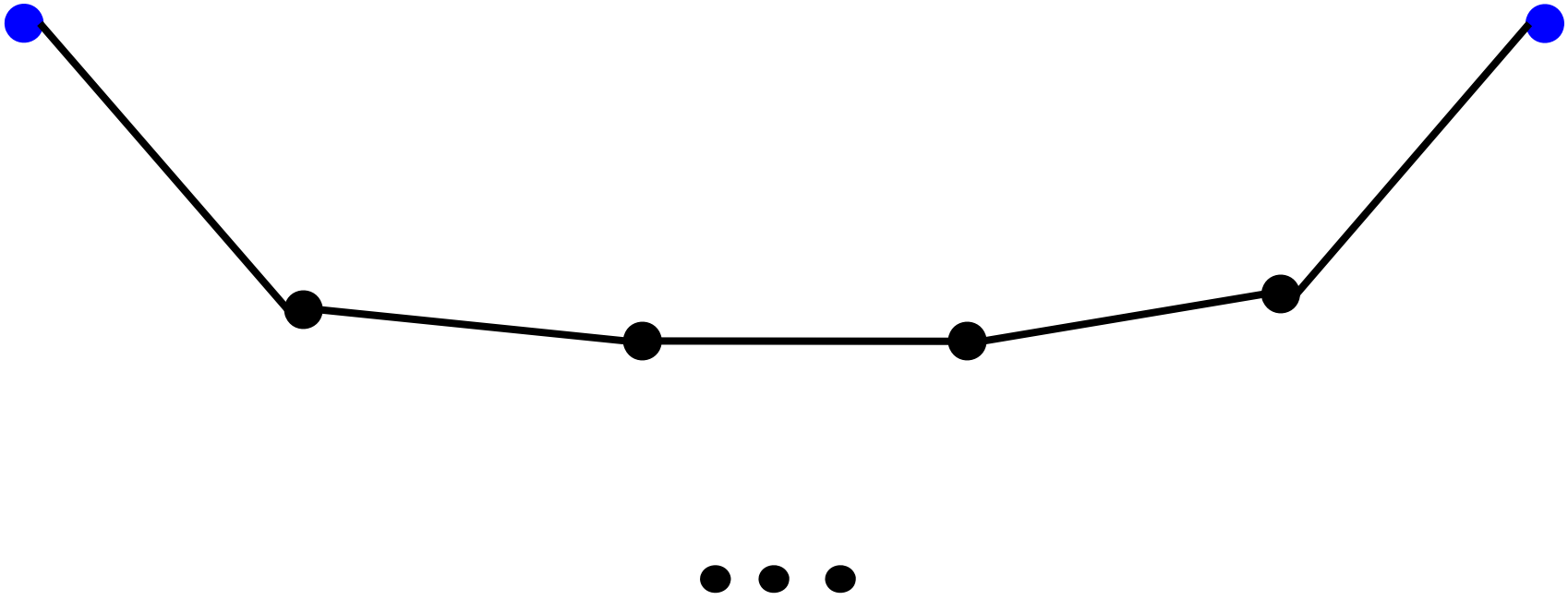
Challenging Problem

- Adaptive Cloth Simulation



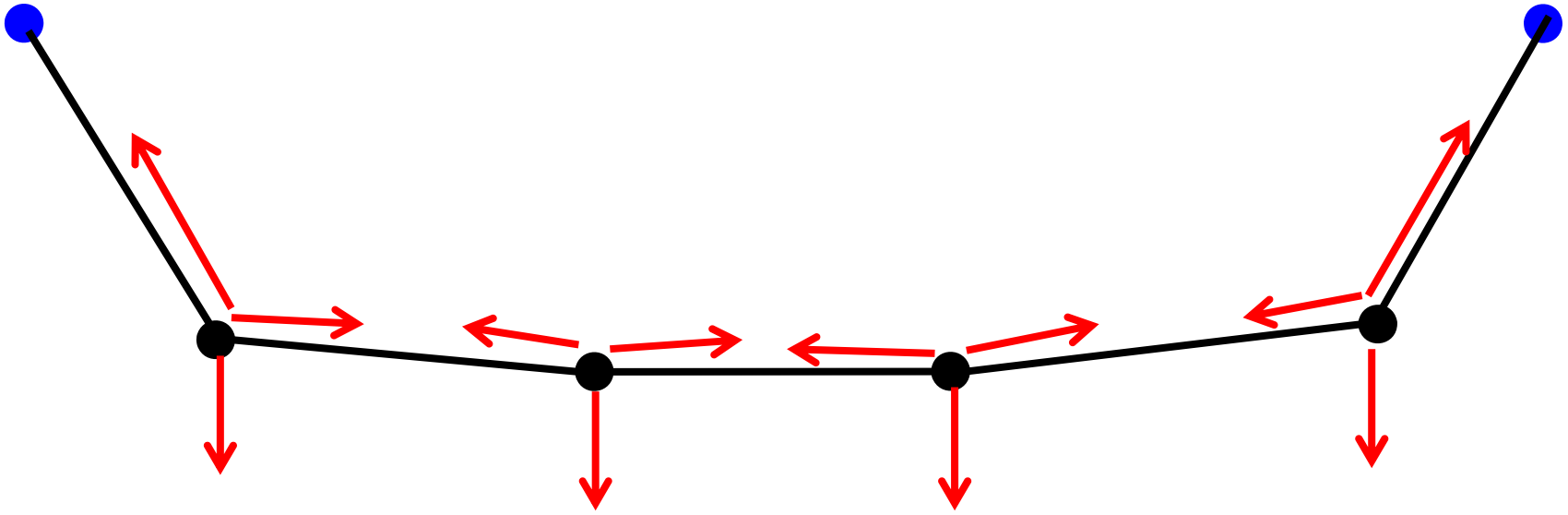
Challenging Problem

- Adaptive Cloth Simulation



Challenging Problem

- Adaptive Cloth Simulation



“equilibrium status”

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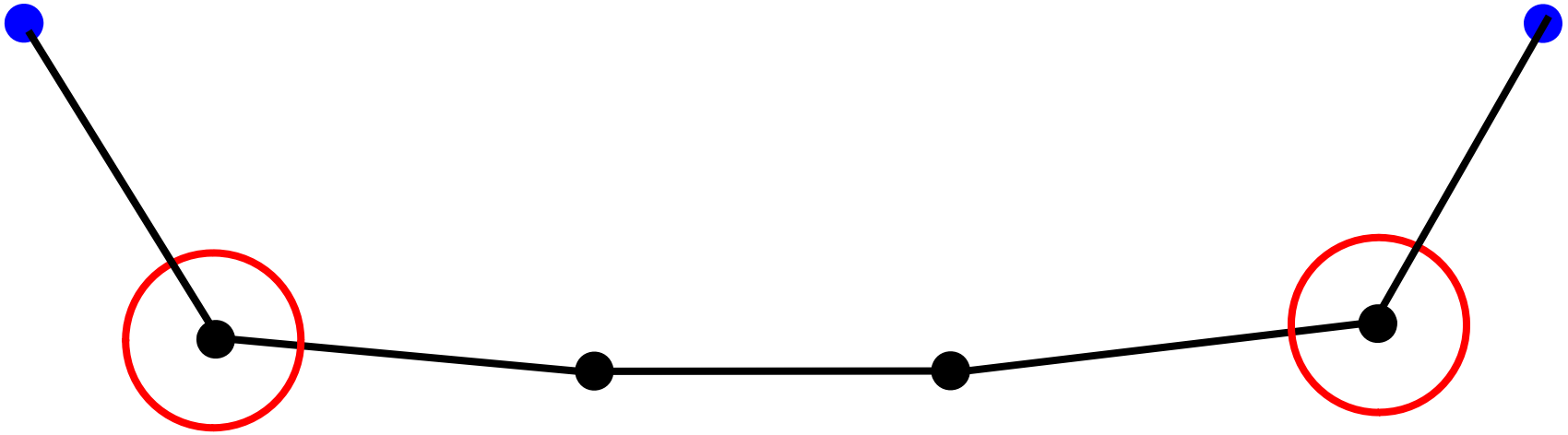
Challenging Problem

- Adaptive Cloth Simulation



“Refine”

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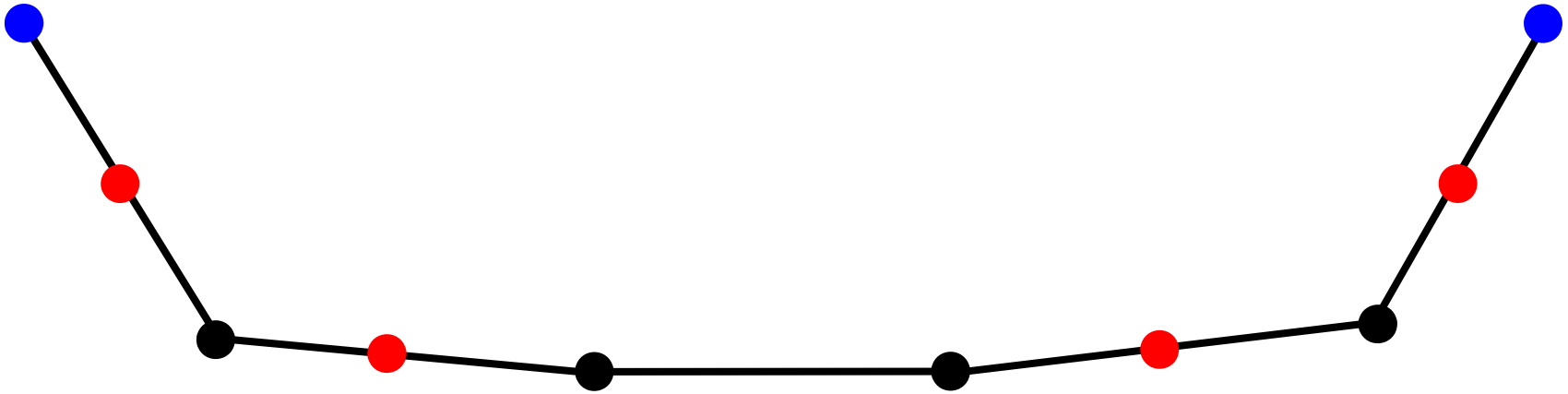
Research

- Adaptive Cloth Simulation



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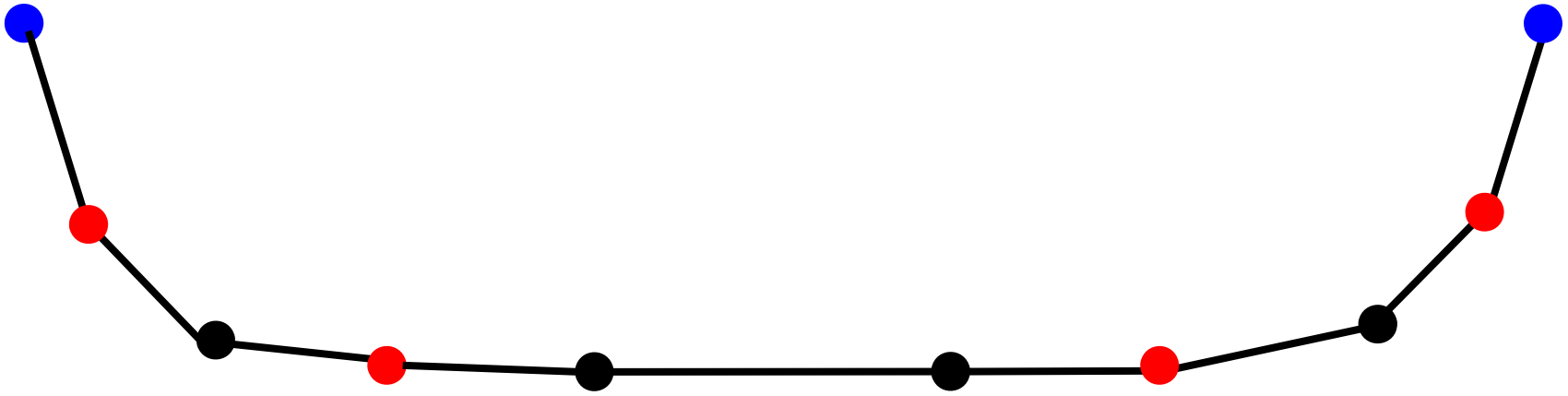
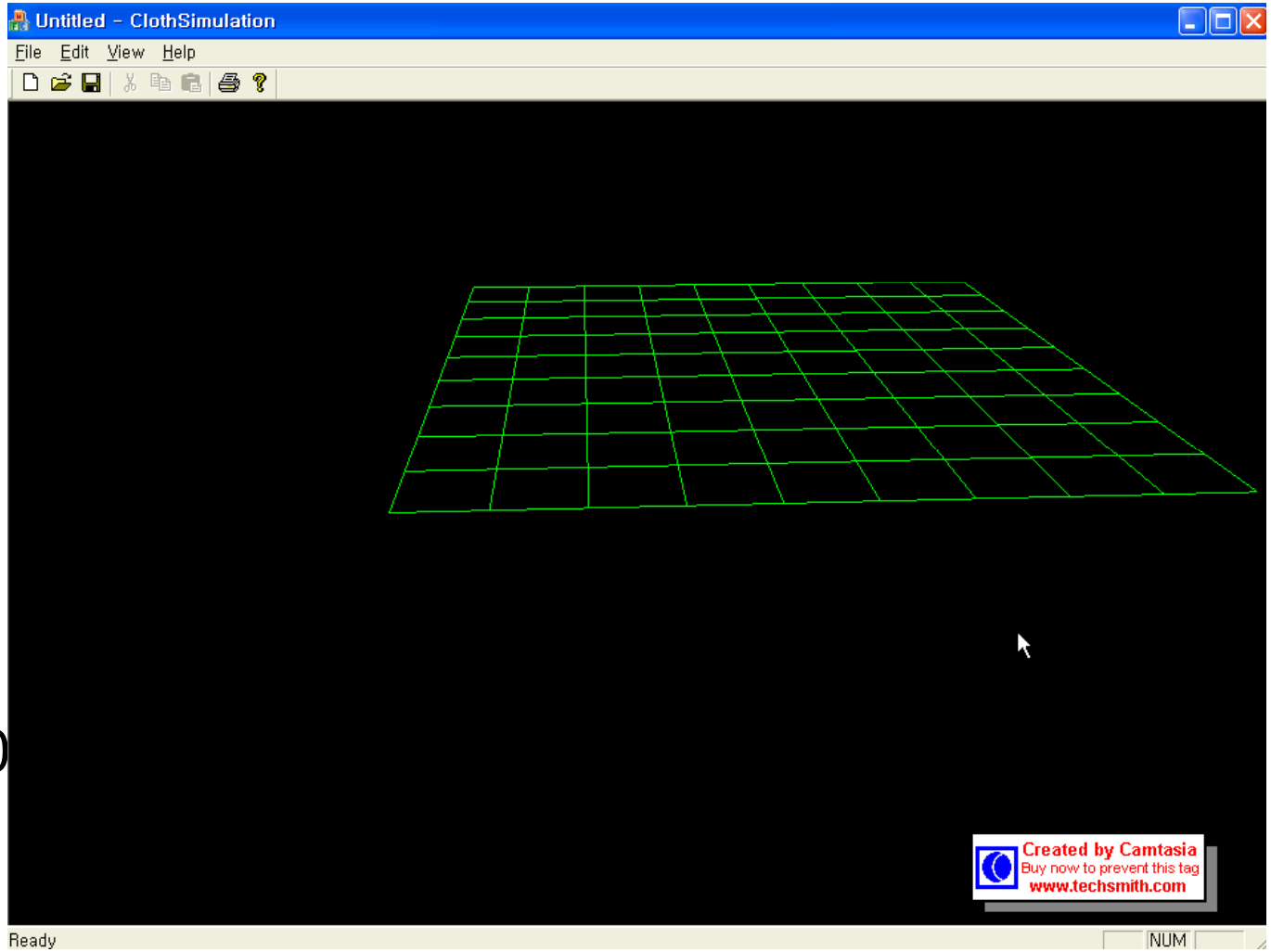
Challenging Problem

- Adaptive Cloth Simulation



Challenging Problem

- Adaptive Cloth Simulation
  - Demo



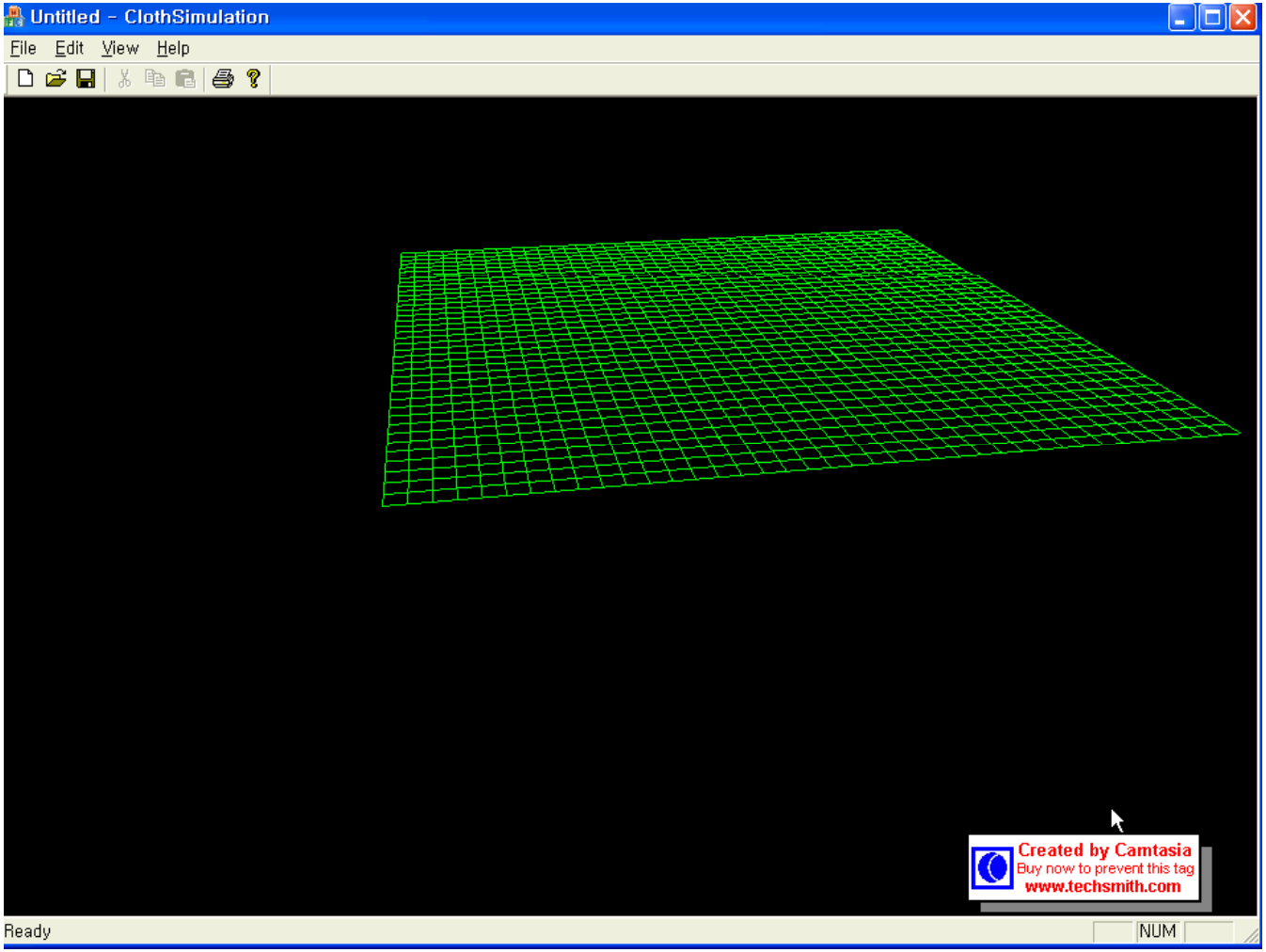
Grid size = 2

# of grid = 10 x 10

NO refine

Challenging Problem

- Adaptive Cloth Simulation
  - Demo



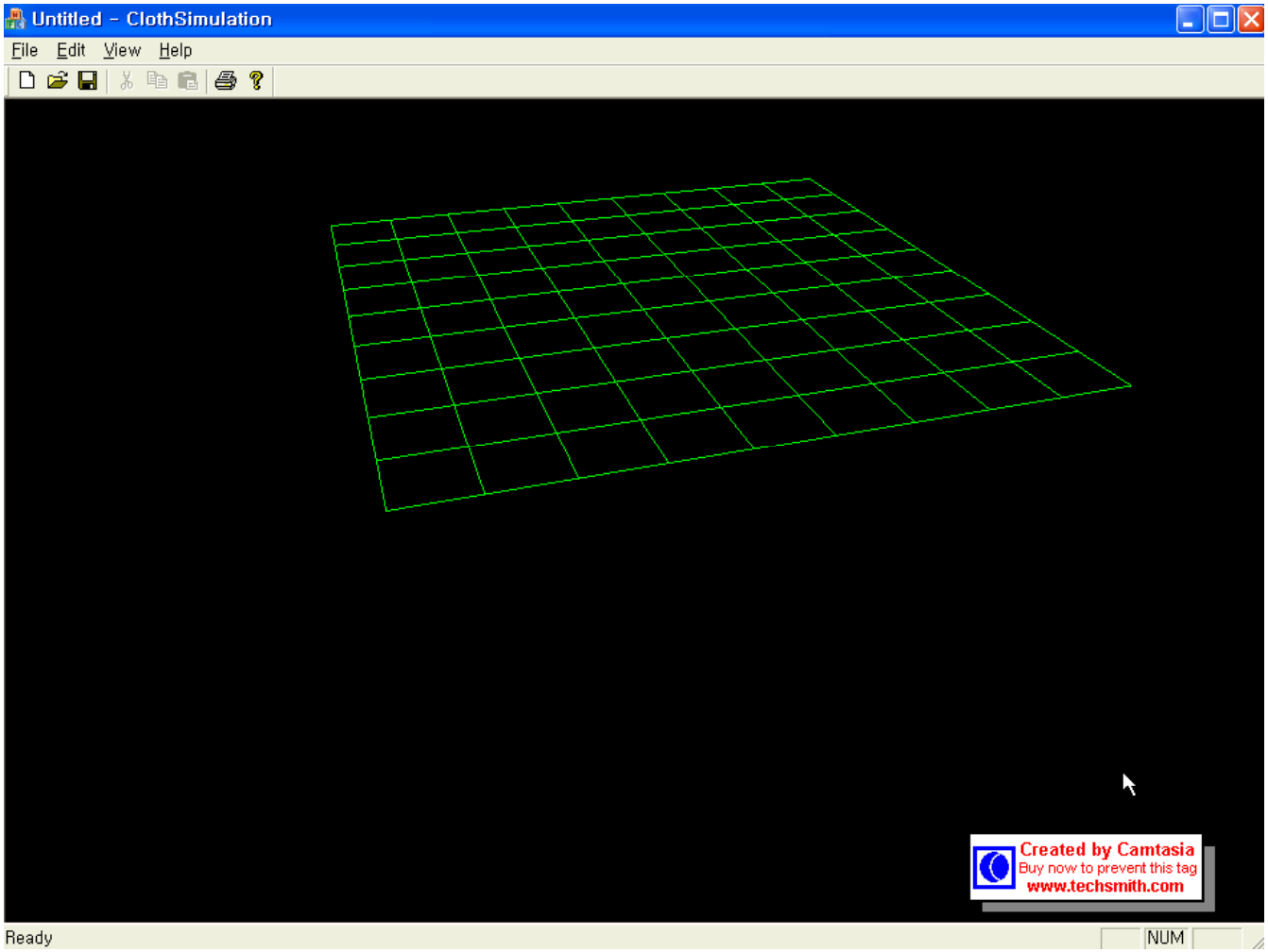
Grid size = 0.5

# of grid = 40 x 40

NO refine

Challenging Problem

- Adaptive Cloth Simulation
  - Demo



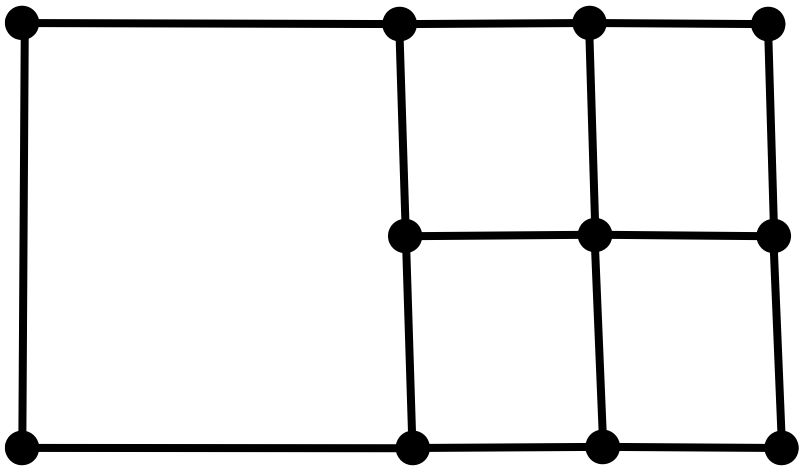
Grid size = 2

# of grid = 10 x 10

refine level : 2

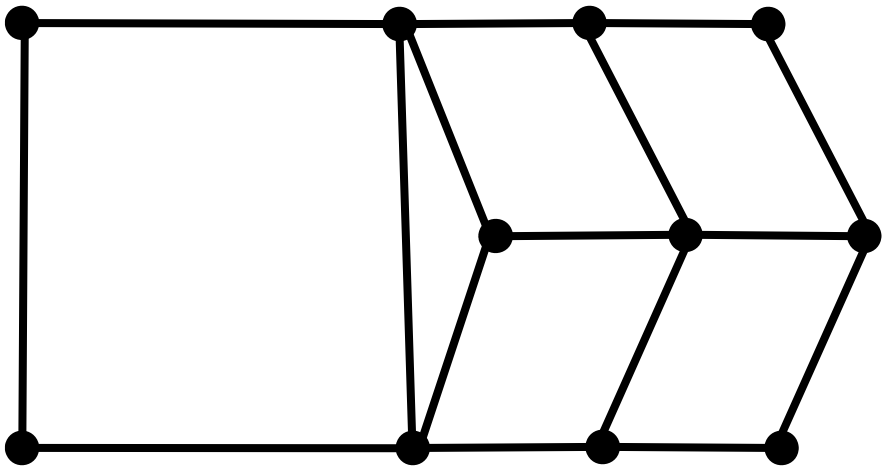
Challenging Problem

- Adaptive Cloth Simulation
  - Problem
    1. T- junction Problem



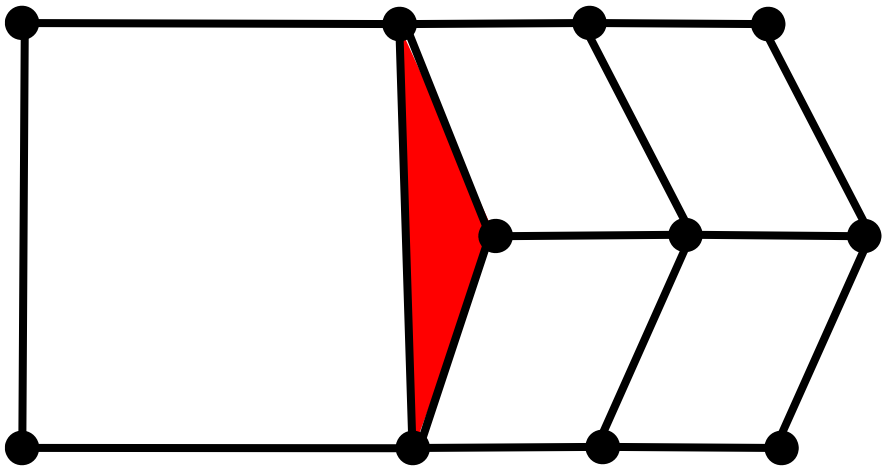
Challenging Problem

- Adaptive Cloth Simulation
  - Problem
    1. T- junction Problem



Challenging Problem

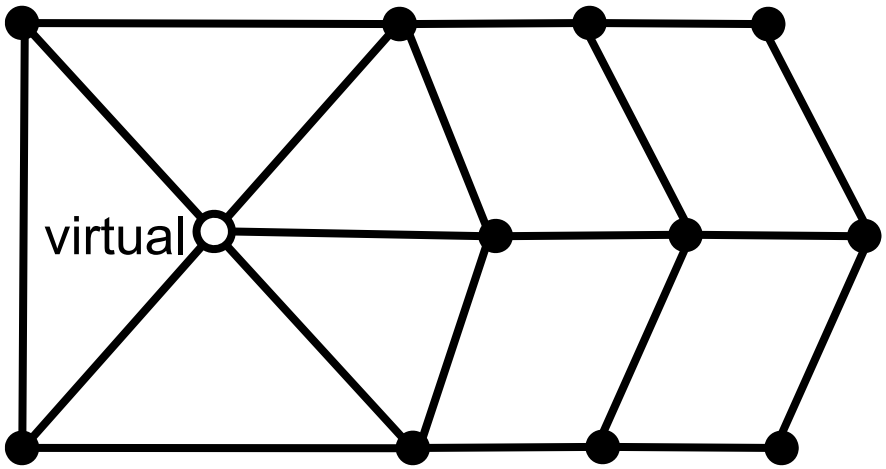
- Adaptive Cloth Simulation
  - Problem
    1. T- junction Problem



“T-junction”

Challenging Problem

- Adaptive Cloth Simulation
  - Problem
    1. T- junction Problem



“4-8 subdivision rule”

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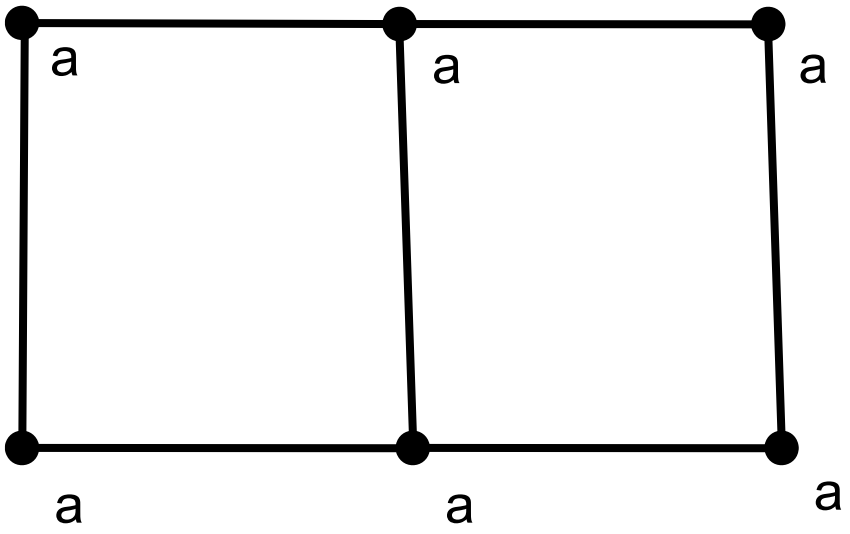
Challenging Problem

- Adaptive Cloth Simulation
  - Problem

    2. Mass distribution

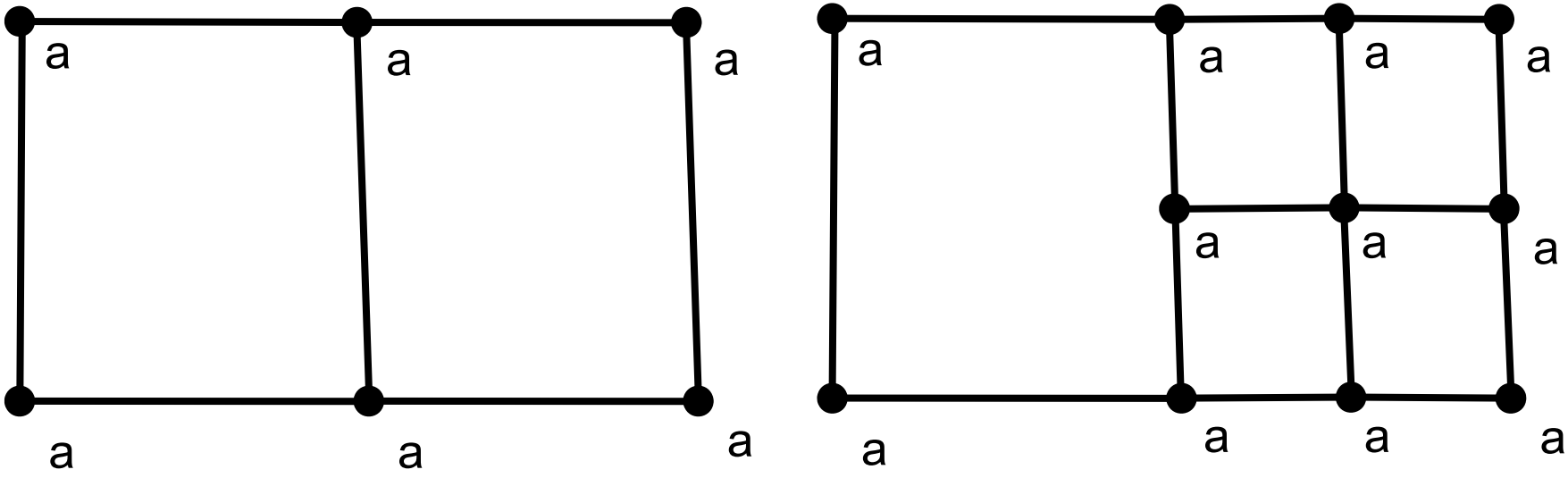


total mass = 6a

Challenging Problem

- Adaptive Cloth Simulation
  - Problem

    2. Mass distribution



total mass = 6a ≠ total mass = 11a

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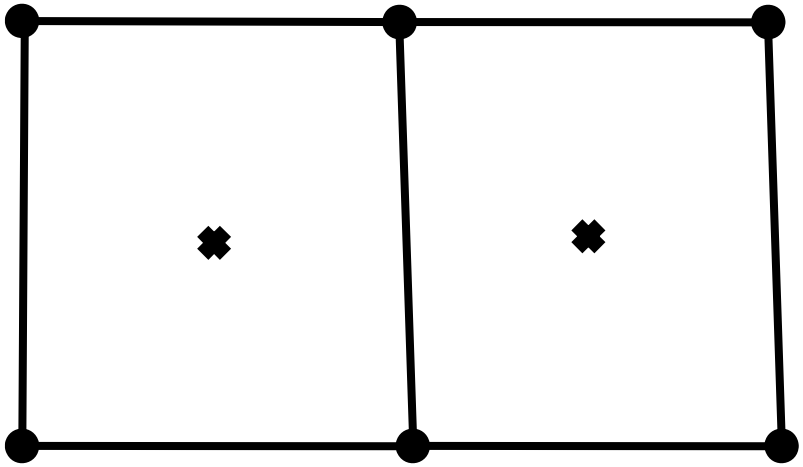
Challenging Problem

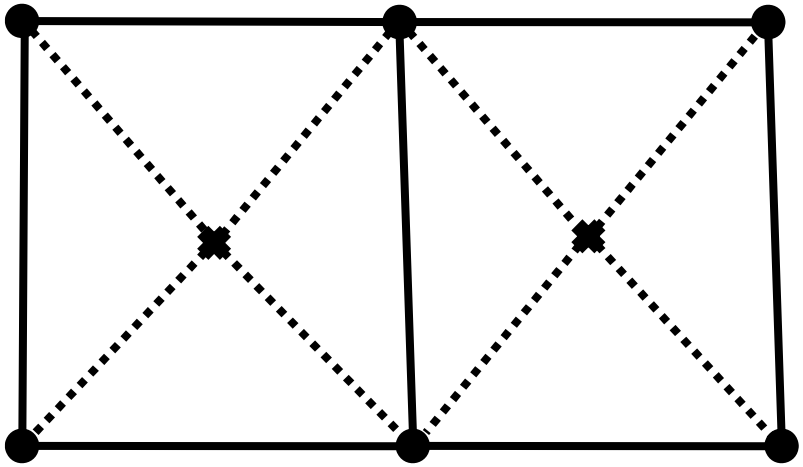
- Adaptive Cloth Simulation
  - Problem
    2. Mass distribution



Villard, et al. "Adaptive Meshing for cloth simulation", 2002.

Challenging Problem

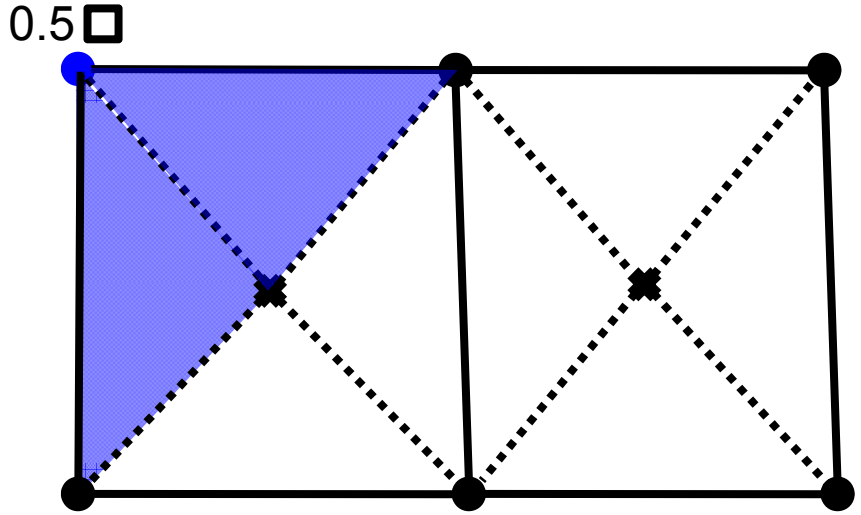
- Adaptive Cloth Simulation
  - Problem
    2. Mass distribution



Villard, et al. "Adaptive Meshing for cloth simulation", 2002.

Challenging Problem

- Adaptive Cloth Simulation
  - Problem
    2. Mass distribution

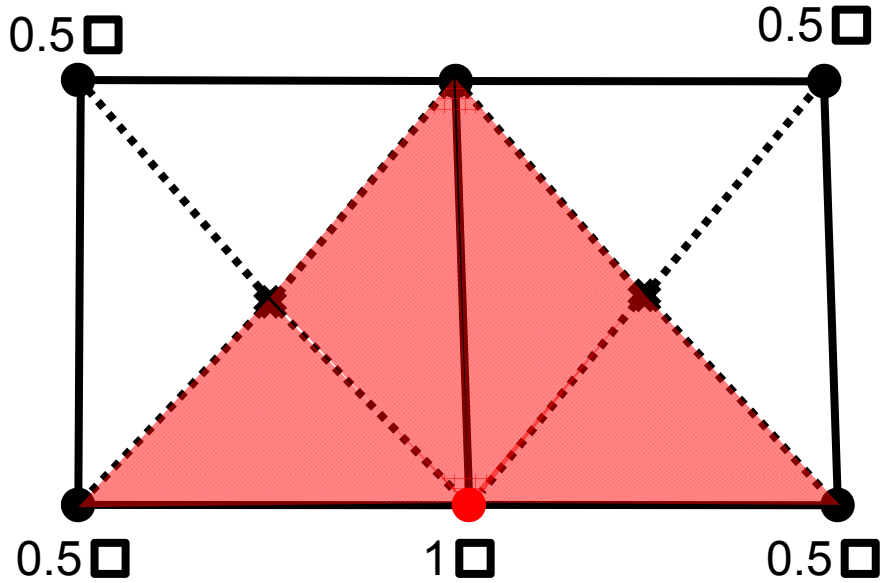


Villard, et al. "Adaptive Meshing for cloth simulation", 2002.

Challenging Problem

- Adaptive Cloth Simulation
  - Problem

    2. Mass distribution

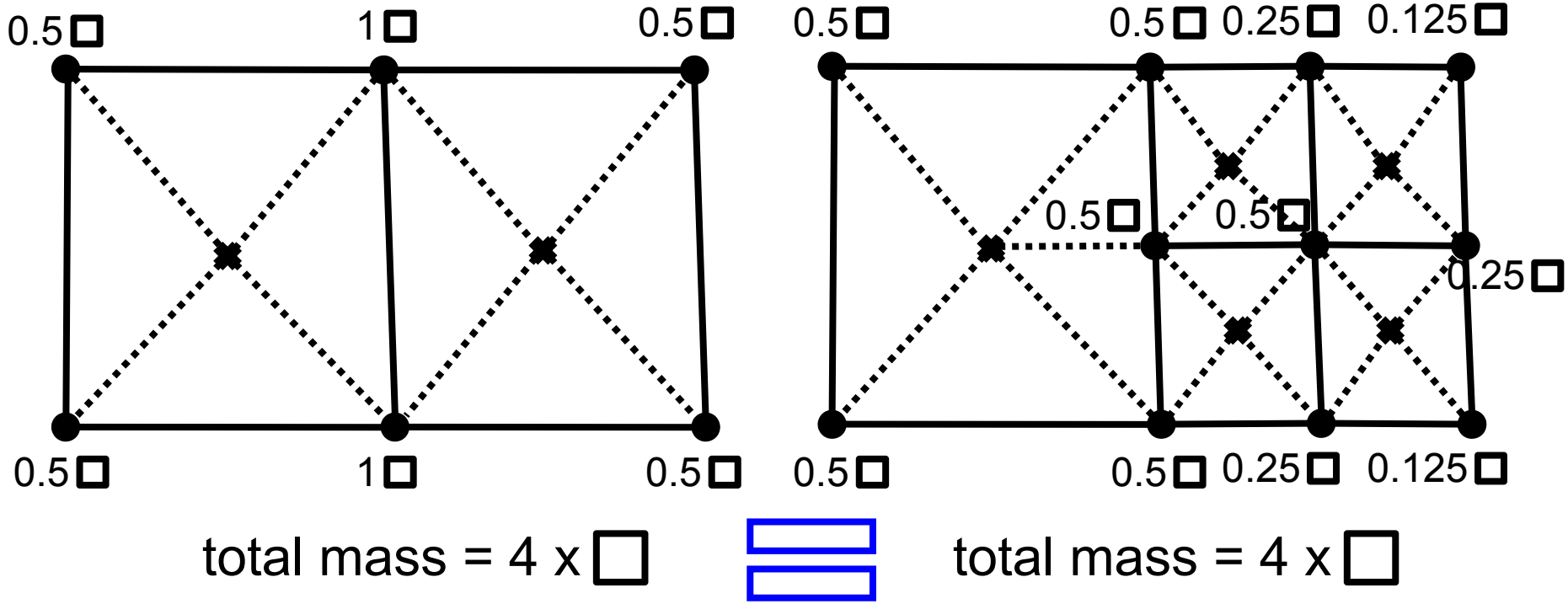


Villard, et al. "Adaptive Meshing for cloth simulation", 2002.

Challenging Problem

- Adaptive Cloth Simulation
  - Problem

    2. Mass distribution

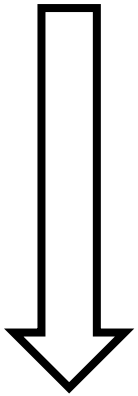


Villard, et al. "Adaptive Meshing for cloth simulation", 2002.

Challenging Problem

- Adaptive Cloth Simulation
  - Goal

Fast Cloth Simulation ✚ Adaptive Cloth Simulation



View-dependent Multi-resolution

Adaptive Meshing

Crowd Cloth Simulation

Conclusion

- Cloth Simulation is popular since 1980s.
- Three Parts of Cloth Simulation is..
  - Cloth- Model System
  - Numerical Solver
  - Collision Handling
- But, still there is some challenging problem
- Crowd Cloth Simulation!