Programming Graphics Hardware

Cloth Simulation on GPU

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NVIDIA®

Cloth as a Set of Particles

- A cloth object is a set of particles
- Each particle is subject to:
  - A force (gravity or wind)
  - Various constraints:
    - To maintain overall shape (springs)
    - To prevent interpenetration with the environment
- Constraints are resolved by relaxation

- For more details, see:

  Jakobsen, T. "Advanced character physics", *GDC 2001*

Force

- The equation of motion for each particle at position P(t) subject to force F(t) is integrated using Verlet integration:

$$P(t + \Delta t) = P(t) + k\,(P(t) - P(t - \Delta t)) + \Delta t^2\, F(t) / m$$

  Δt is the simulation time step

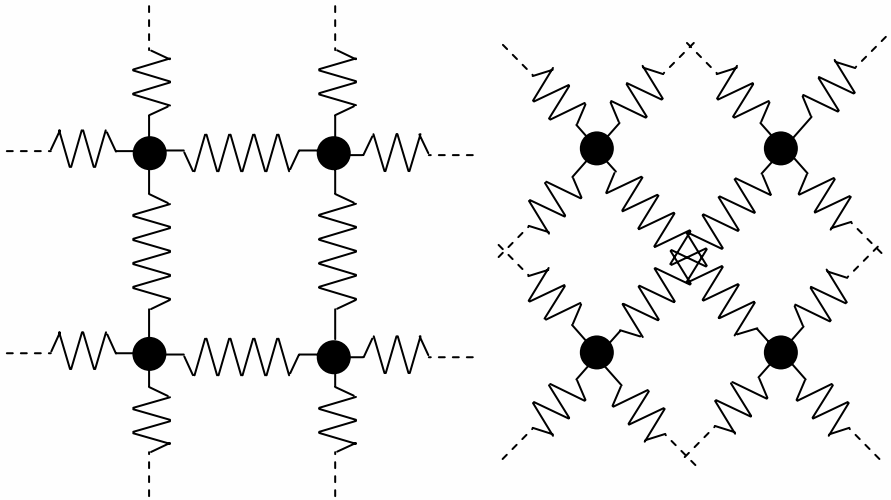
  k is an arbitrary damping coefficient very close to 1

  m is the mass of the particle

- No force is applied to fixed or user-moved particles

Distance Constraints

- **Particles are linked by springs:**



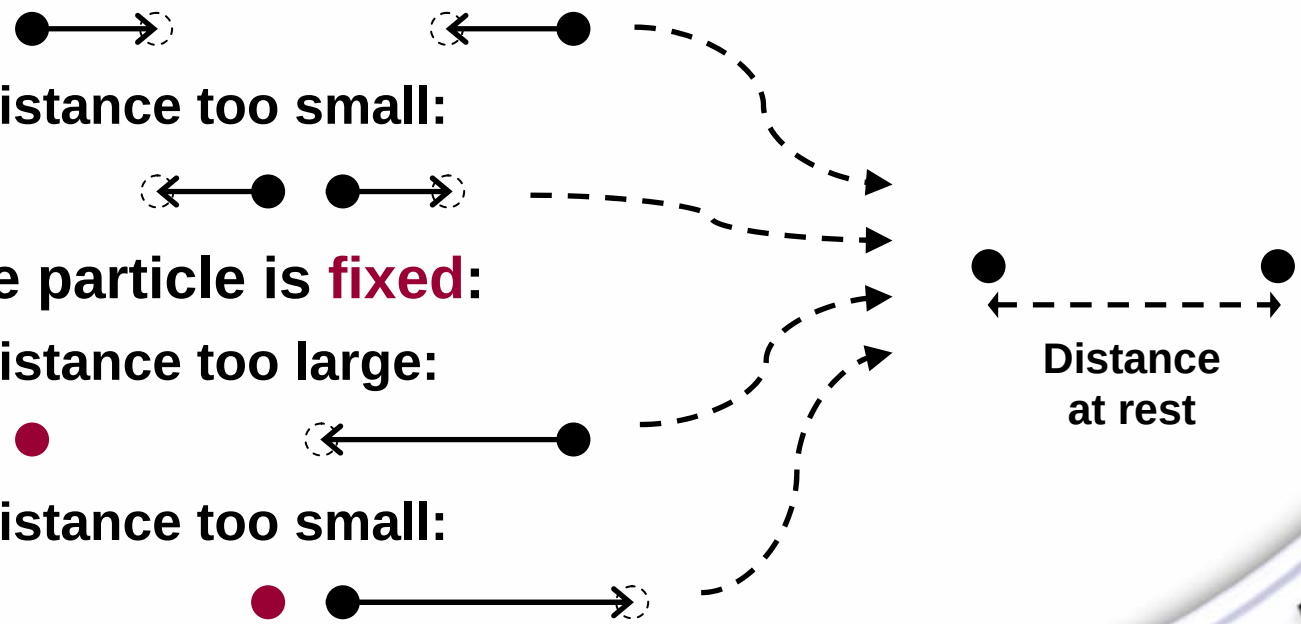
Structural springs

Shear springs

- **A spring is simulated as a distance constraint between two particles**

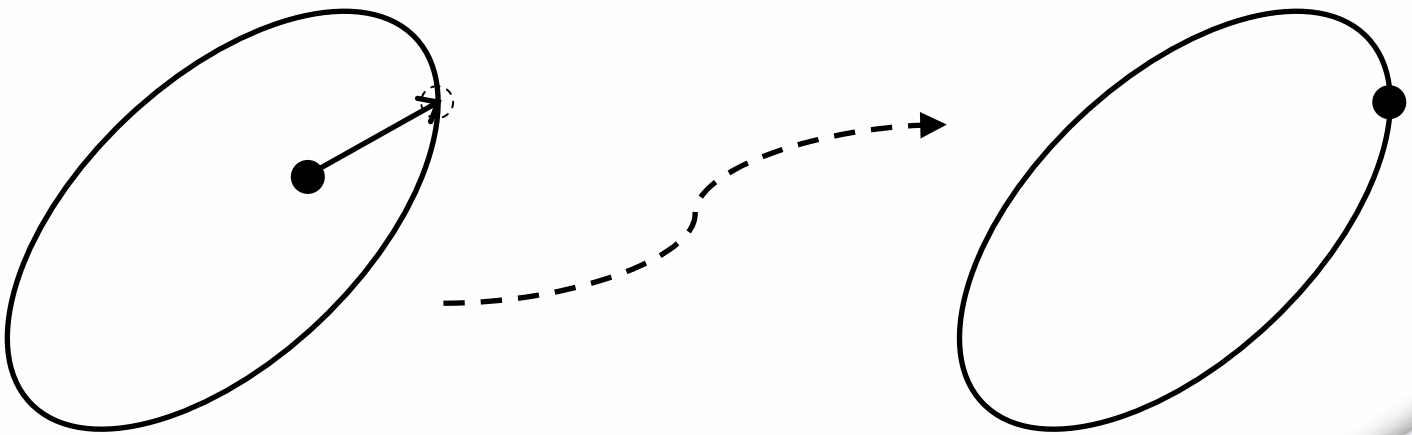
Distance Constraints

- A distance constraint between two particles is enforced by moving them away or towards each other:
  - If both particles are free:
    - Distance too large:
    - Distance too small:
  - If one particle is fixed:
    - Distance too large:
    - Distance too small:



Collision Constraints

- The environment is defined as a set of collision objects (planes, spheres, boxes and ellipsoids)
- A collision constraint between a particle and a collision object is enforced by moving the particle outside the object



Algorithm Outline

- For every simulation time step:
  - For every particle that isn't fixed or user-moved:
    - Apply force
  - For every relaxation step:
    - For every distance constraint:
      - Reposition particles
    - For every particle:
      - For every collision object:
        - If the particle is inside, move the particle out of the object

GPU Implementation

- The particle positions and normals are stored into floating-point textures PositionTex and NormalTex
  - The CPU never reads the content of these textures!
- At every frame:
  - GPU simulation: Compute PositionTex and NormalTex
  - Rendering:

Vertex buffer contains only texture coordinates

```
void VertexShader(float2 texCoord)
{
  position = tex2Dlod(PositionTex, texCoord);
  normal   = tex2Dlod(  NormalTex, texCoord);
   ...
}
```

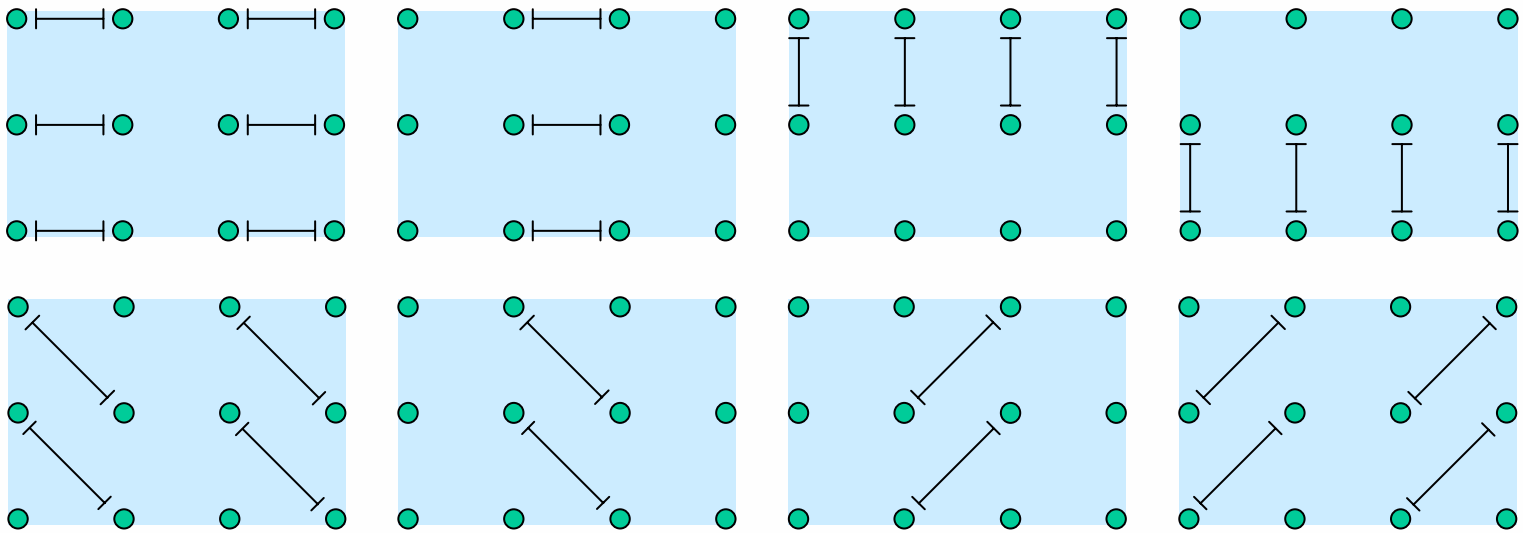
GPU Simulation: Force

- Three floating point textures:
  - OldPositionTex
  - CurrentPositionTex
  - NewPositionTex (used as render target)
  - Rotated after each draw call
- Draw fullscreen quad with:

```
float4 PixelShader(float2 texCoord)
{
  float3 oldPos     = tex2D(    OldPositionTex, texCoord);
  float3 currentPos = tex2D(CurrentPositionTex, texCoord);
  float3 force = ComputeForce();
  float3 newPos = currentPos
                + 0.99 * (currentPos – oldPos)
                + force * TimeStep * TimeStep; // Verlet
  return newPos;
}
```

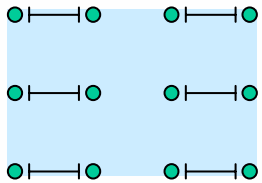
GPU Simulation: Distance Constraints

- **8 fullscreen quad draw calls to simulate the 8 springs attached to a particle:**



GPU Simulation: Distance Constraints

- **Stiffness** coefficients stored into 2D textures to deal with:
  - Cloth boundary
  - Fixed particles
  - Cut springs
- Fullscreen quad draw call for:



```
float4 PixelShader(float2 texCoord, float2 pixel : VPOS)
{
  float2 offset      = float2((pixel.x % 2 ? – Dx : Dx), 0);
  float3 currentPos  = tex2D(CurrentPositionTex, texCoord);
  float3 neighborPos = tex2D(CurrentPositionTex, texCoord + offset);
  float3 delta       = neighborPos – currentPos;
  float  dist        = length(delta);
  float  stiffness   = tex2D(StiffnessTex, texCoord);
  float3 newPos = currentPos
                + stiffness * (1 – DistanceAtRest / d) * delta;
  return newPos;
}
```

Equal to either 0.5 or 0

GPU Simulation: Collision Constraints

- Collision objects stored into 1D textures
  - 1 texture per geometric type
  - Can't index constant registers
- Draw fullscreen quad with:

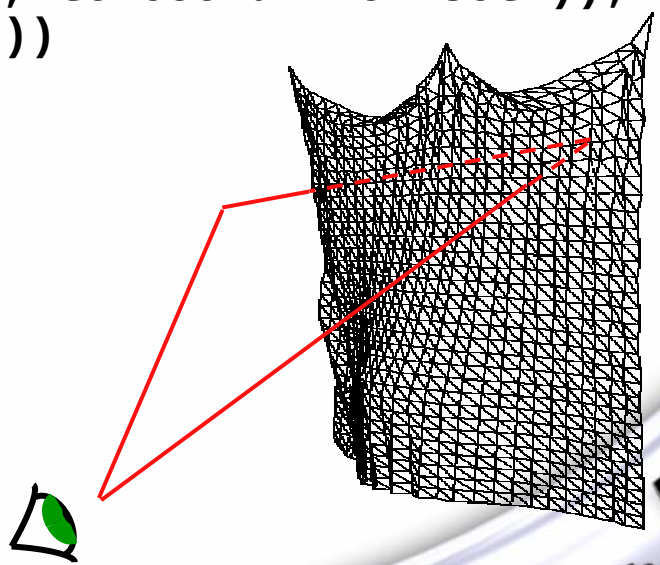
```
float4 PixelShader(float2 texCoord)
{
  float3 currentPos = tex2D(CurrentPositionTex, texCoord);
  for (int i = 0; i < NumPlanes;     ++i) ...
  for (int i = 0; i < NumSpheres;    ++i) {
    float4 sphere = tex1D(SphereTex, Ds * i);
    currentPos += SphereConstraint(currentPos, sphere);
  }
  for (int i = 0; i < NumBoxes;      ++i) ...
  for (int i = 0; i < NumEllipsoids; ++i) ...
  return currentPos;
}
```

GPU Simulation: Cloth Cutting

- Set a render target with one pixel per triangle and clear it to 0
- Draw fullscreen quad with:

```
float4 PixelShader(float2 texCoord, uniform Triangle Cutter)
{
  Triangle tri;
  tri.V0 = tex2D(CurrentPositionTex, texCoord);
  tri.V1 = tex2D(CurrentPositionTex, texCoord + offset1));
  tri.V2 = tex2D(CurrentPositionTex, texCoord + offset2));
  if (TriangleIntersect(tri, Cutter))
    return 1;
  else
    discard;
}
```

- Read back render target to CPU
- Modify stiffness textures
- Modify cloth index buffer



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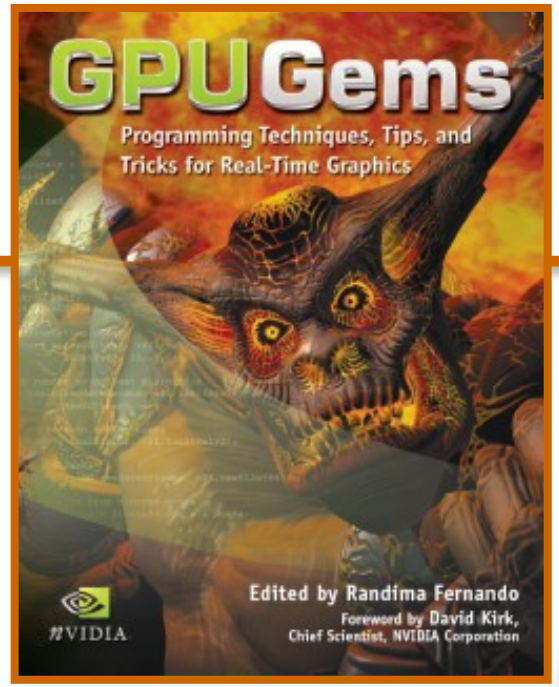

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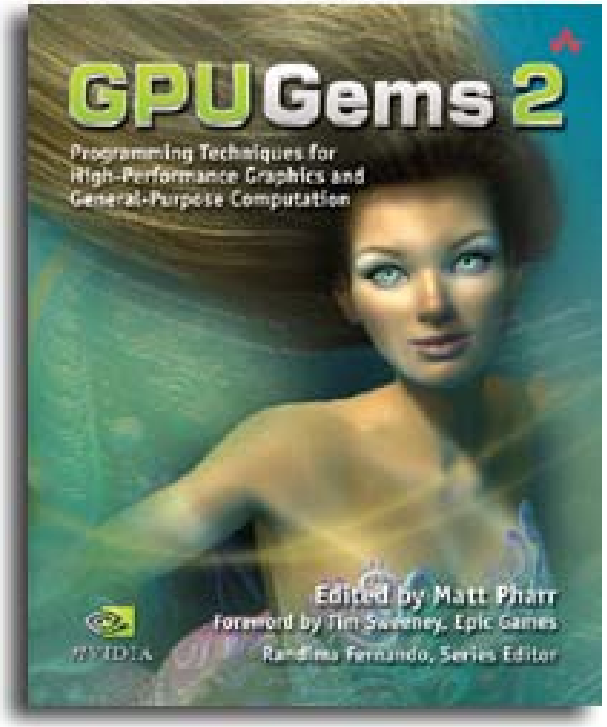

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