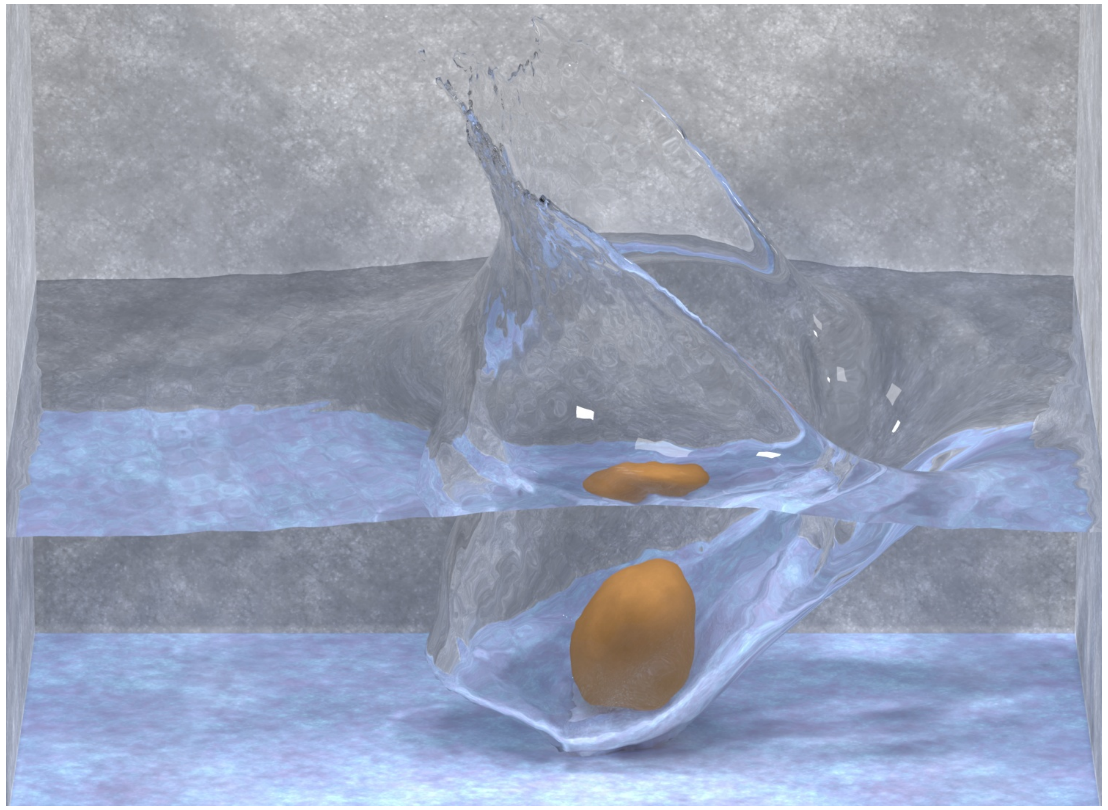
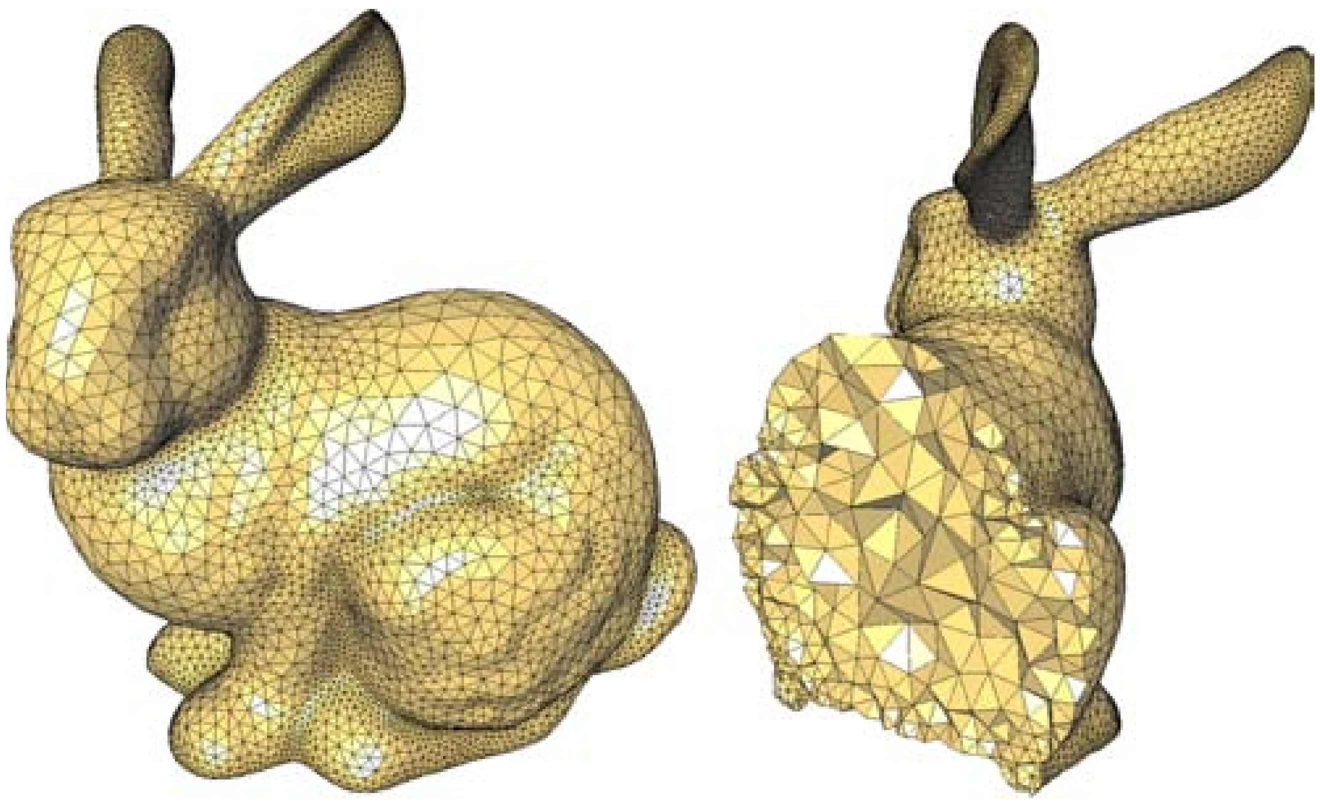
Discrete representations of geometric objects: Features, data structures and adequacy for dynamic simulation.

Part II : Levelsets & implicit surfaces





Implicit curves and surfaces (a.k.a. level-sets)

- Motivation
  - ✓ Accelerated geometric queries for problems such as:
    - ➡ Is a point (x^*,y^*) *inside* the object?
    - ➡ Is a point (x^*,y^*) *within a distance of* d^* from the object surface?
    - ➡ What is the point on the surface which is *closest* to the query point (x^*,y^*)?

Implicit curves and surfaces (a.k.a. level-sets)

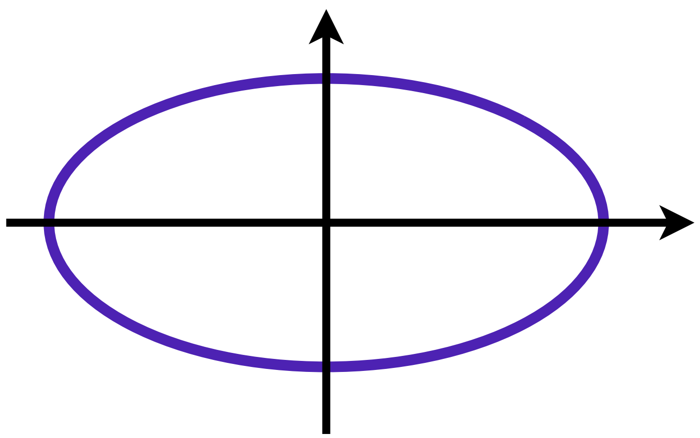
- Motivation

  ✓ Easy modeling of motions that involve topological change, e.g. shapes splitting or merging

  ✓ Such operations are difficult to encode with meshes, since they don't "split" or "merge" unless we force them to

Implicit curves and surfaces (a.k.a. level-sets)

- Familiar representations address *some* of these demands:
  - ✓ e.g. Analytic equations
    - ➡ For an ellipsis:



$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

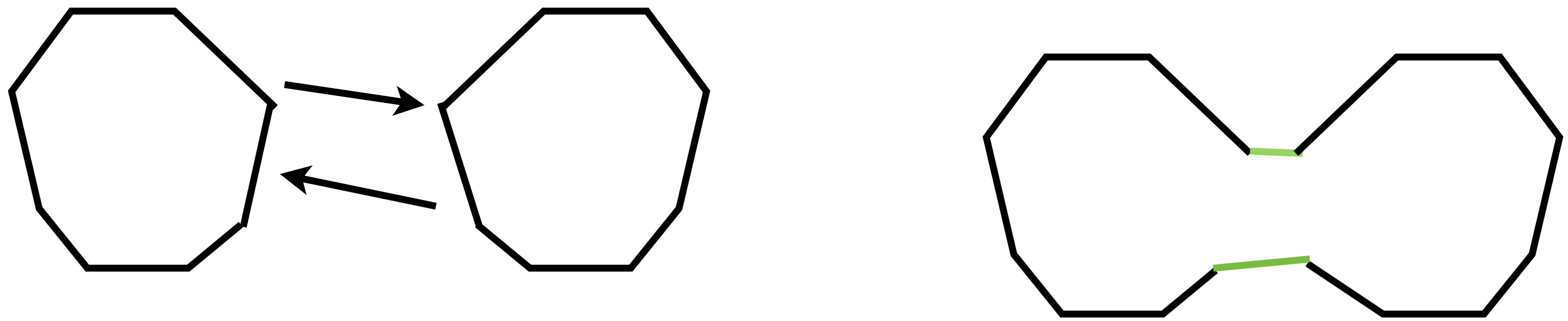
    - ➡ Easy inside/outside tests

$$\frac{x_*^2}{a^2} + \frac{y_*^2}{b^2} < 1 \Leftrightarrow (x_*, y_*) \text{ is inside}$$

Implicit curves and surfaces (a.k.a. level-sets)

- Familiar representations address *some* of these demands:

  ✓ Describe a closed region via its boundary; split and reconnect when necessary



  ➡ This may be tractable in isolated cases, but very cumbersome and impractical for more complicated cases, and with 3-dimensional surfaces

The level-set concept

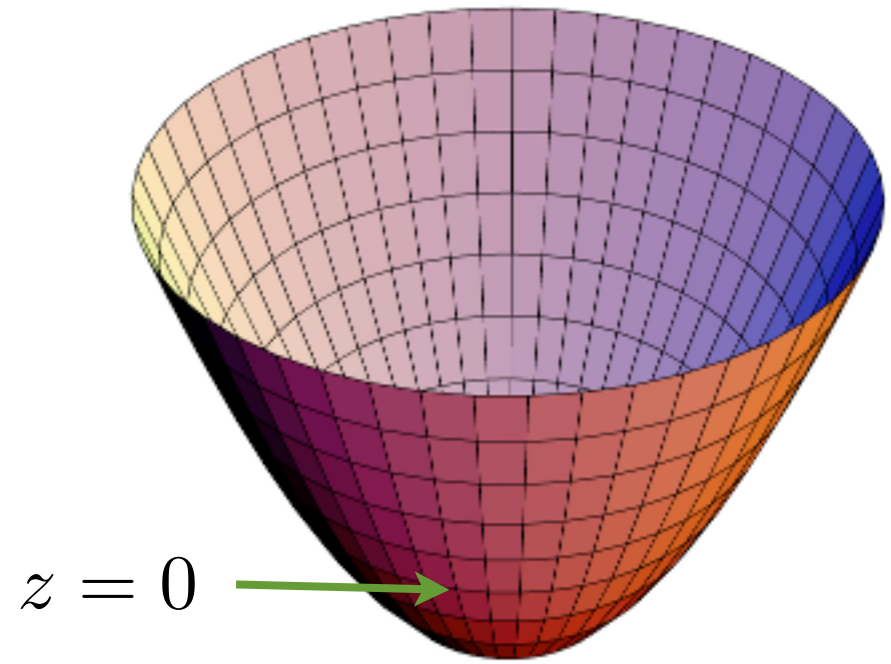
- Represent a curve in 2D (or, a surface in 3D) as the zero isocontour of a (continuous) function, i.e.

$$\mathcal{C} = \{(x.y) \in \mathbf{R}^2 : \phi(x,y) = 0\}$$

e.g.

$$\text{circle } x^2 + y^2 = R^2 \equiv \{(x,y) : \phi(x,y) = 0\}$$

$$where\ \phi(x,y) = x^2 + y^2 - R^2$$



The level-set concept

- This representation may seem redundant (we store information everywhere, just to capture a curve), but it conveys important benefits:

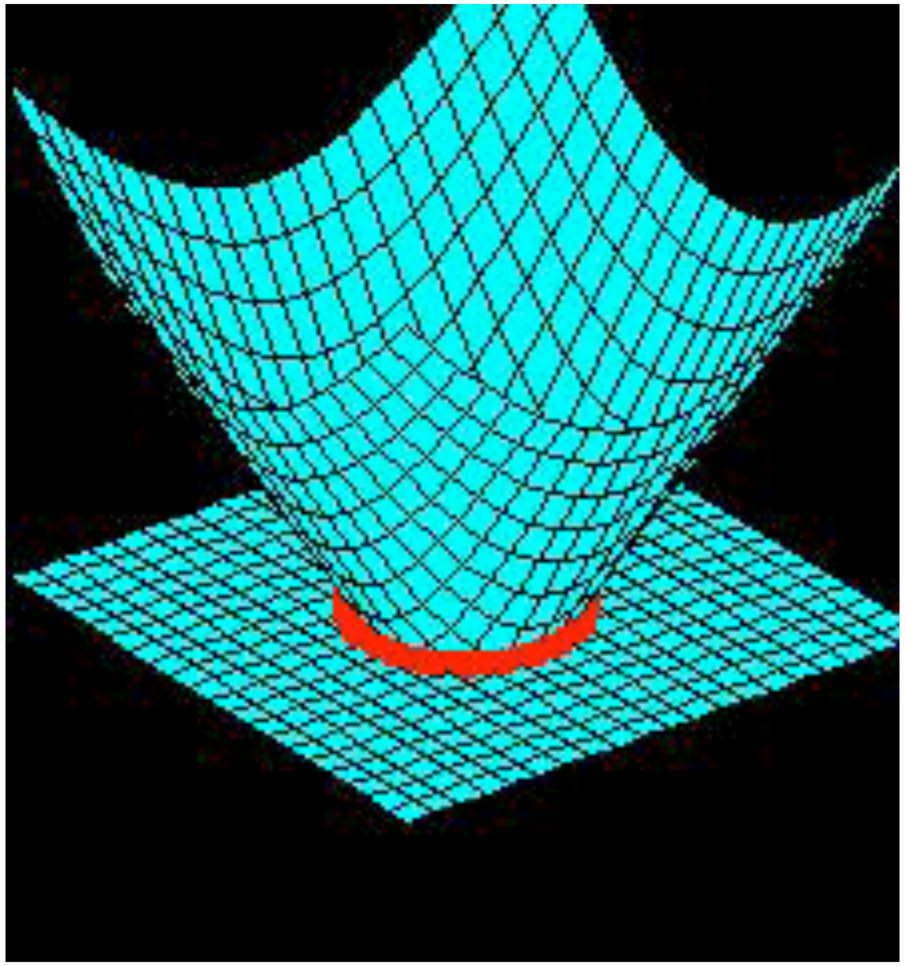
➡ Containment queries

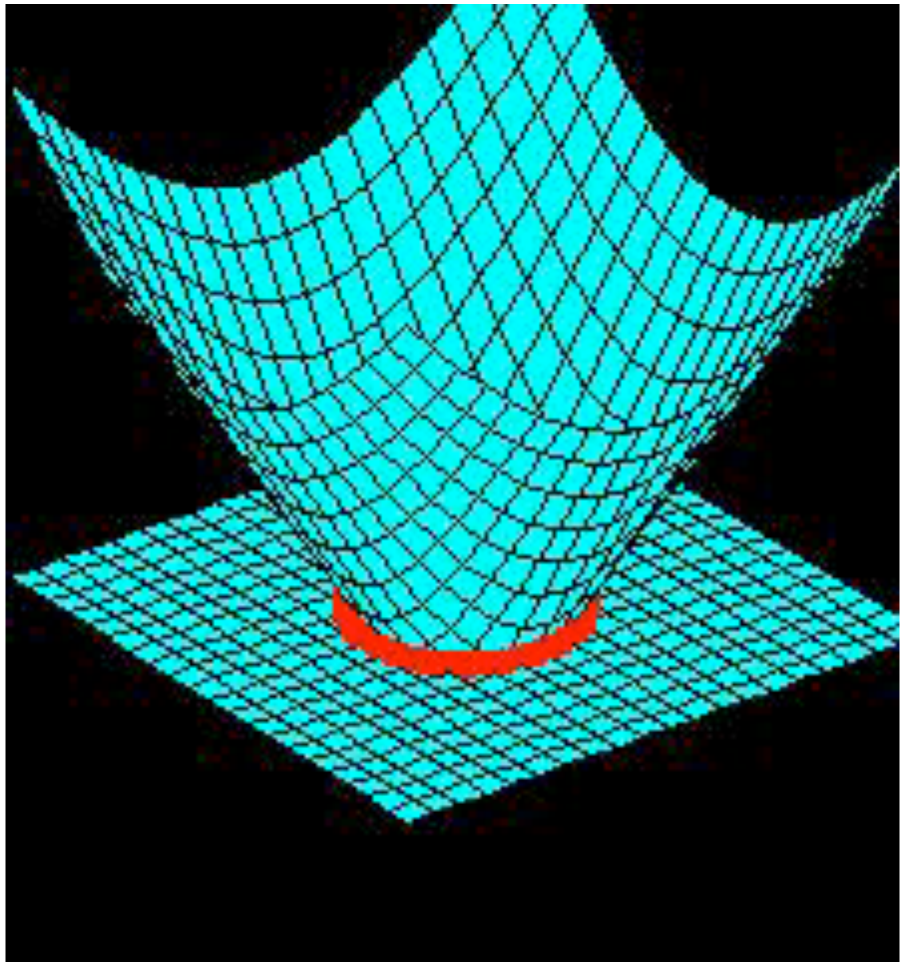
$$\text{Is } (x_*, y_*) \text{ inside } \mathcal{C}? \Leftrightarrow \phi(x_*, y_*) < 0$$

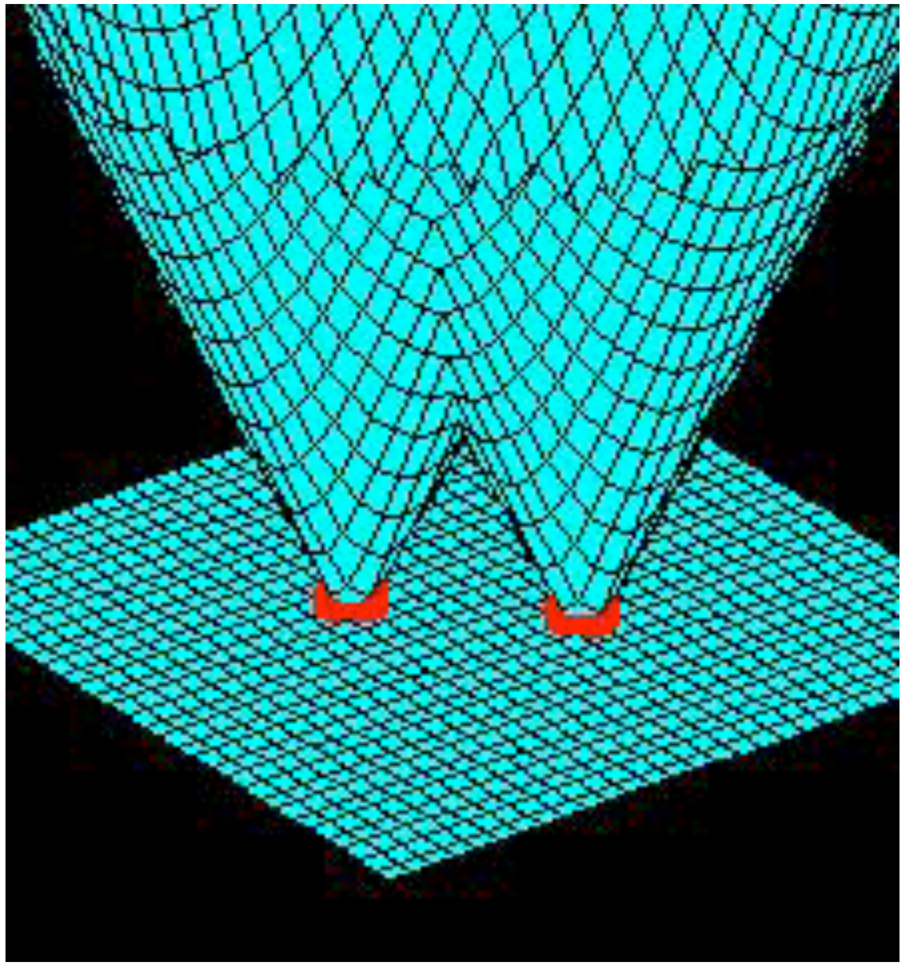
➡ Composability

$$\left.\begin{array}{l} \phi_1(x,y) \text{ encodes } \Omega_1 \\ \phi_2(x,y) \text{ encodes } \Omega_2 \end{array}\right\} \Rightarrow \begin{array}{l} \max(\phi_1, \phi_2) \text{ encodes } \Omega_1 \cap \Omega_2 \\ \max(\phi_1, \phi_2) \text{ encodes } \Omega_1 \cup \Omega_2 \end{array}$$

➡ We model both shape & topology change by simply varying the level set function







Levelset construction

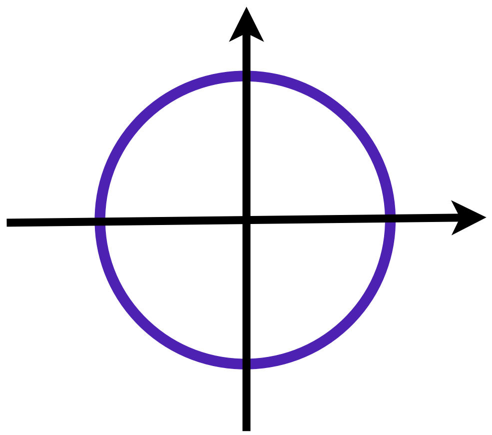
- By the initial definition, there are many level set functions that encode the same shape

$$\left.\begin{array}{c} \phi(x,y) = x^2 + y^2 - R^2 \\ \phi(x,y) = \sqrt{x^2+y^2} - R \\ \phi(x,y) = e^{x^2+y^2} - e^{R^2} \end{array}\right\} \text{all encode the circle } x^2+y^2=R^2$$

- A specific systematic construction process: *Signed distance functions*

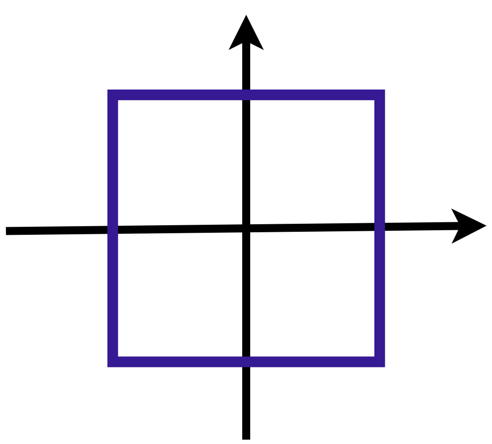
$$\left.\begin{array}{c} \phi(x,y) < 0, \text{ if } (x,y) \text{ is inside } \mathcal{C} \\ \phi(x,y) > 0, \text{ if } (x,y) \text{ is outside } \mathcal{C} \\ \phi(x,y) = 0, \text{ if } (x,y) \text{ is on } \mathcal{C} \end{array}\right\} \text{and } |\phi(x,y)| = \text{distance of } (x,y) \text{ from } \mathcal{C}$$

Levelset examples



$$\phi(x,y) = \sqrt{x^2+y^2} - R$$

$$\phi(x,y) = \max\{x-R, -x-R, y-R, -r-R\}$$



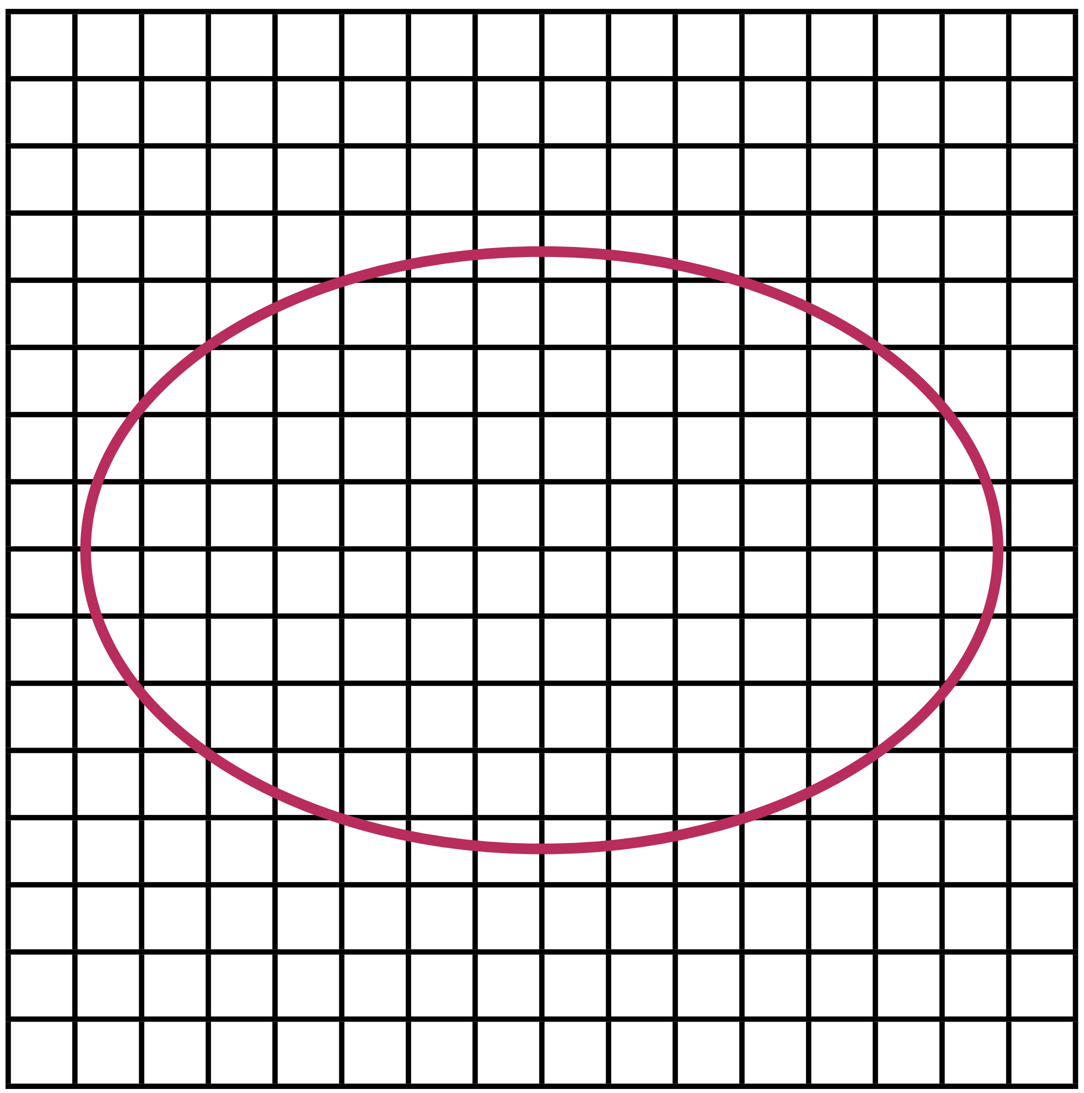
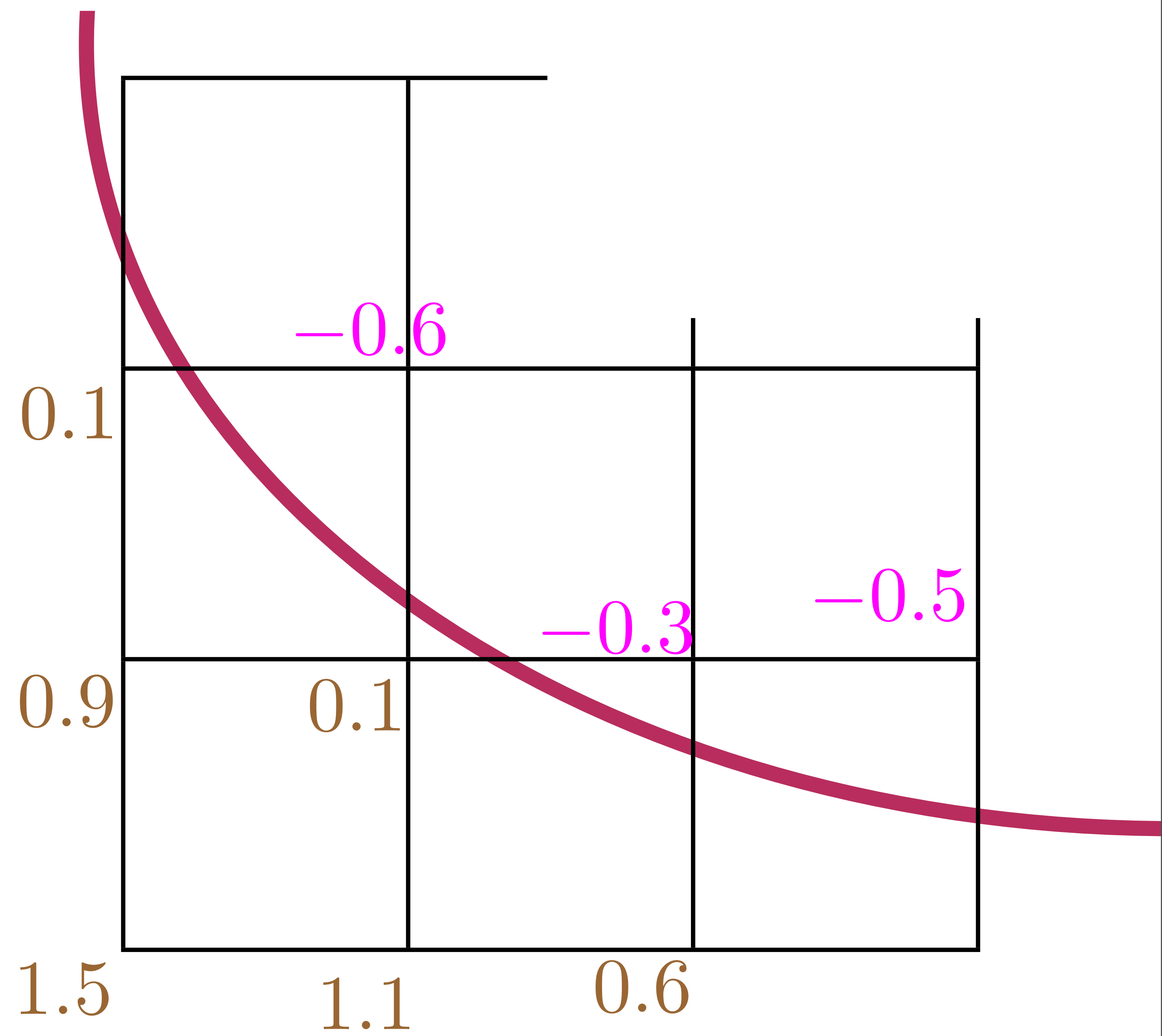
Levelset properties

- We can offset the surface by a fixed distance D, by simply adding/subtracting D from the levelset function
- Proximity queries can be answered in O(1) time
  - ✓ e.g. *Is point (x*,y*) within 0.1units of the surface?*
- The level set gradient is a unit normal, parallel to the direction of the closest point on the surface
- We can project to the surface in O(1) time

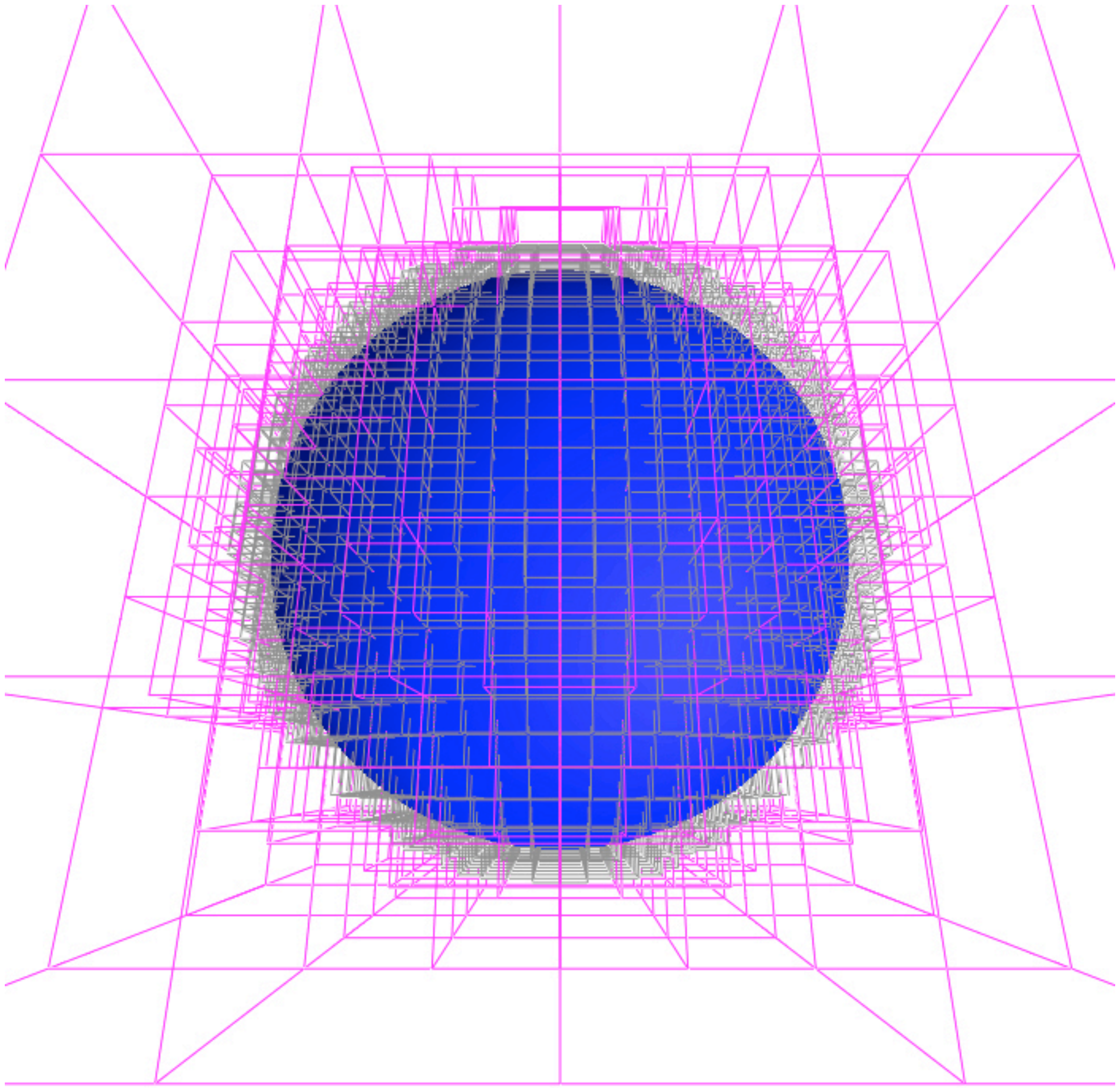
$$(x_c, y_c) = (x, y) - \phi(x, y) \cdot \nabla\phi(x, y)$$

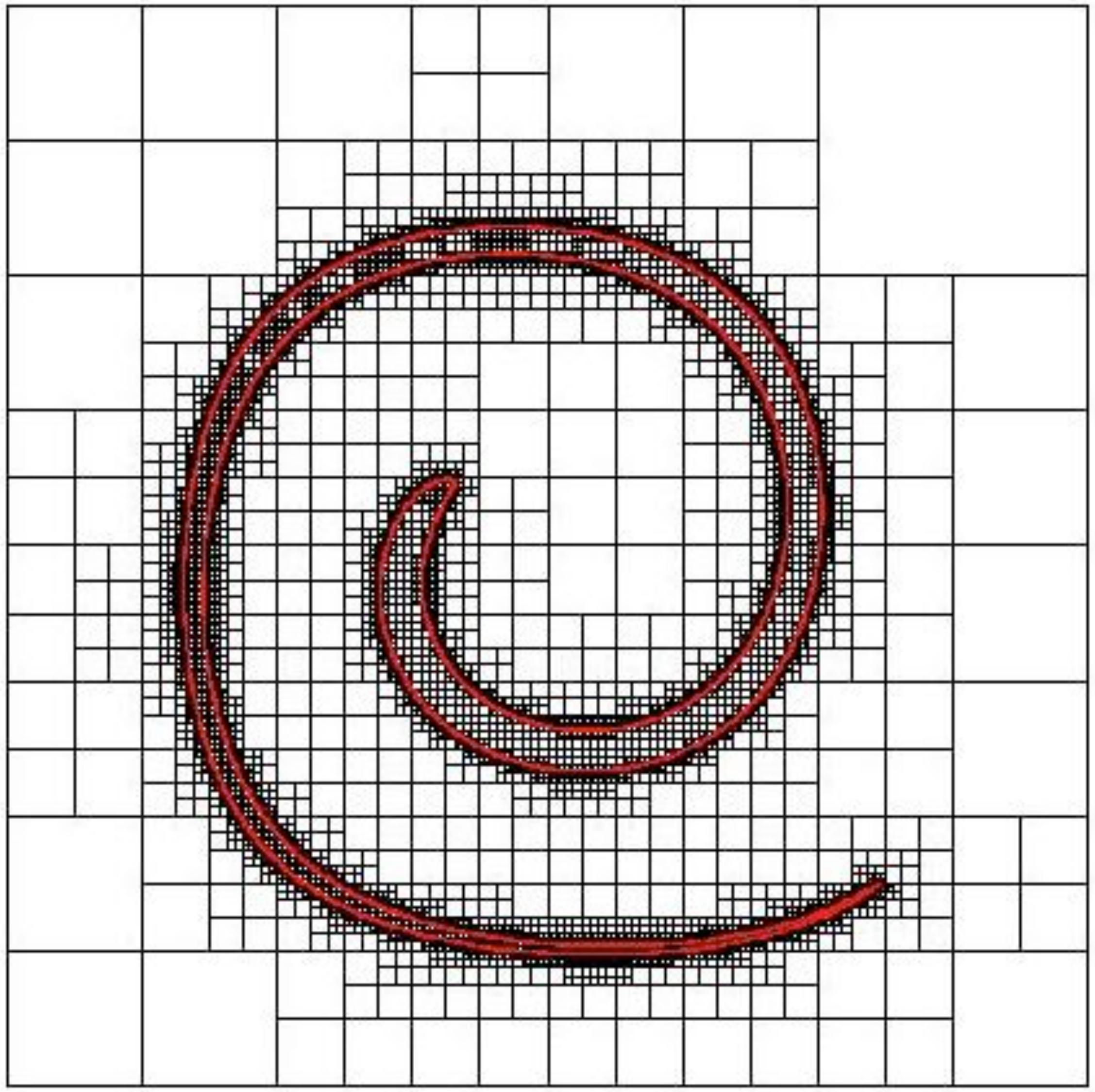
- SDFs are composable over unions/intersections of implicit domains

Implementation

Implementation (adaptive)





Introduction to PhysBAM

- Lecture outline:
  - Obtaining the software
  - Set up and compilation
  - The debugging visualization tool
  - Setting up a basic, procedurally animated scene
  - Overview of basic data structures

Introduction to PhysBAM

- BSD licensed
- Two versions in existence
  - A fully featured version for modeling & dynamics
    - Used primarily for academic development
    - Not guaranteed to be stable
    - "Relatively" stable partial snapshots used in industry
  - A "reasonably" stable and tested open source version
    - Includes modeling tools, data structures, visualization and rendering
    - Excludes most dynamics algorithms (currently)

Introduction to PhysBAM

- Compatible (in principle) with several platforms
  - Has occasionally been built and deployed on Windows, Linux, MacOS, Android
  - Linux is considered the "primary" platform
  - Developers will currently support only Linux issues

Introduction to PhysBAM

- Recommended build system (Linux & Mac OS X) : *<u>SCons</u> (use with MacPorts, on OS X)*
  - Recommended compiler for public version: gcc 4.5.2
    - Versions >4.2.X should work as well.
    - Gcc 4.1.X has some known issues
  - Makefiles can be used, but not supplied
  - Can build on Windows with Cygwin/gcc
  - Visual Studio mostly ok (certain template classes may pose issues, due to VC++ not being strictly standard-compliant).

Obtaining the code

- Developer website (Stanford)
  - http://physbam.stanford.edu (main page)
  - http://physbam.stanford.edu/links/download.html (download page)
  - Up-to-date with fixes & additions, but may change at any point in time
- CS838 snapshot
  (with some fixes and modifications) :
  - http://pages.cs.wisc.edu/~cs838-2/software/PhysBAM-CS838.zip
  - Derived from public release (minus ray tracer)

Building PhysBAM (linux)

- Prerequisites : g++ (>4.2.X), scons, python (For visualization: freeglut, libjpg, libpng)
- Download and unzip the package (denoted by <basedir>, below)
- Set up PLATFORM environmental variable
  - On 64-bit systems, set to "nocona"
    - Using *bash* : "export PLATFORM=nocona"
- Set up symbolic links for SCons:
  - Go to <basedir>/Scripts/Archives/scons
  - Execute "python ./setup_scons.py"

Building PhysBAM (linux)

- Try the compilation setup by building "opengl_3d" (the debugging visualization tool for 3D scenes)
  - Go to the opengl_3d "Project" directory: <basedir>/Projects/opengl_3d
  - Run SCons:
    - *scons -u TYPE=release CXX=<C++ compiler> -j <# cores>*
    - Substitute *TYPE=debug* to build in debug mode
    - Example:
      - *scons -u TYPE=release CXX=g++44 -j 4*
  - Object/Library/Executable files placed in <basedir>/build
  - A symbolic link "*opengl_3d_nocona*" is generated inside the project directory (or *opengl_3d_nocona_debug*, in debug mode)

The debugging visualization tool

- Separate executables for 1D,2D,3D
- Takes as argument the "output directory" produced by a simulation application
- 3D axes : Color coded R-G-B for x-y-z
- Left mouse : Rotate
- Middle mouse : Pan
- Right mouse : Zoom
- Most important key : "?" (interactive legend!)

High-level structure

- Two top-level directories
  - Public Library :
    Basic data structures and modeling object classes.
    Structured as a stand-alone library.
    (need not be modified for most tasks)
  - Projects :
    "User-space" applications, each in its own subdirectory.
    Structured such that each project is independent of others; should not cross-link.

High-level structure

- *Public_Library* structure
  - Subdirectory *PhysBAM_Tools* :
    - Contains basic data structures, numerical solvers, and defines C++ classes that are not *directly* related to modeling and simulation (hashtables, arrays, graphs, matrices, vectors etc)
    - Each file is named after the SINGLE class it implements. Can search for class definitions by doing a tree search for the class name (with .h or .cpp)
  - Subdirectory *PhysBAM_Geometry* :
    - Geometry data structures, related to physics simulation
  - Subdirectory *PhysBAM_Rendering* :
    - Debugging visualizer + Ray tracer

Jump-starting a new project

- Create a new Project subdirectory
  - e.g. *<basedir>/Projects/physbam-test*
- Create a stub *SConscript* file, for compilation, e.g.

```
Import('env Automatic_Program')
env=env.Copy(warnings_are_errors=0)
Automatic_Progam(env)
```

- Code in *main.cpp*, compile using SCons
- Run executable ("*physbam-test_nocona*")
- Simulation and visualization and *decoupled*
  - Simulation outputs results to disk, without displaying them on-line
  - The debugging visualizer runs over the stored results, e.g. ../opengl_3d/opengl_3d_nocona <output_directory>

```
    using namespace PhysBAM;

int main(int argc,char* argv[])
{
    typedef float T;
}
```

```
#include <PhysBAM_Tools/Log/LOG.h>
using namespace PhysBAM;

int main(int argc,char* argv[])
{
    typedef float T;

    LOG::Initialize_Logging();

    LOG::Finish_Logging();
}
```

```
#include <PhysBAM_Tools/Log/LOG.h>
#include <PhysBAM_Geometry/Geometry_Particles/GEOMETRY_PARTICLES.h>
using namespace PhysBAM;

int main(int argc,char* argv[])
{
    typedef float T;

    typedef VECTOR<T,3> TV;

    LOG::Initialize_Logging();

    GEOMETRY_PARTICLES<TV> particles;

    LOG::Finish_Logging();
}
```

```
#include <PhysBAM_Tools/Log/LOG.h>
#include <PhysBAM_Geometry/Geometry_Particles/GEOMETRY_PARTICLES.h>
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int main(int argc,char* argv[])
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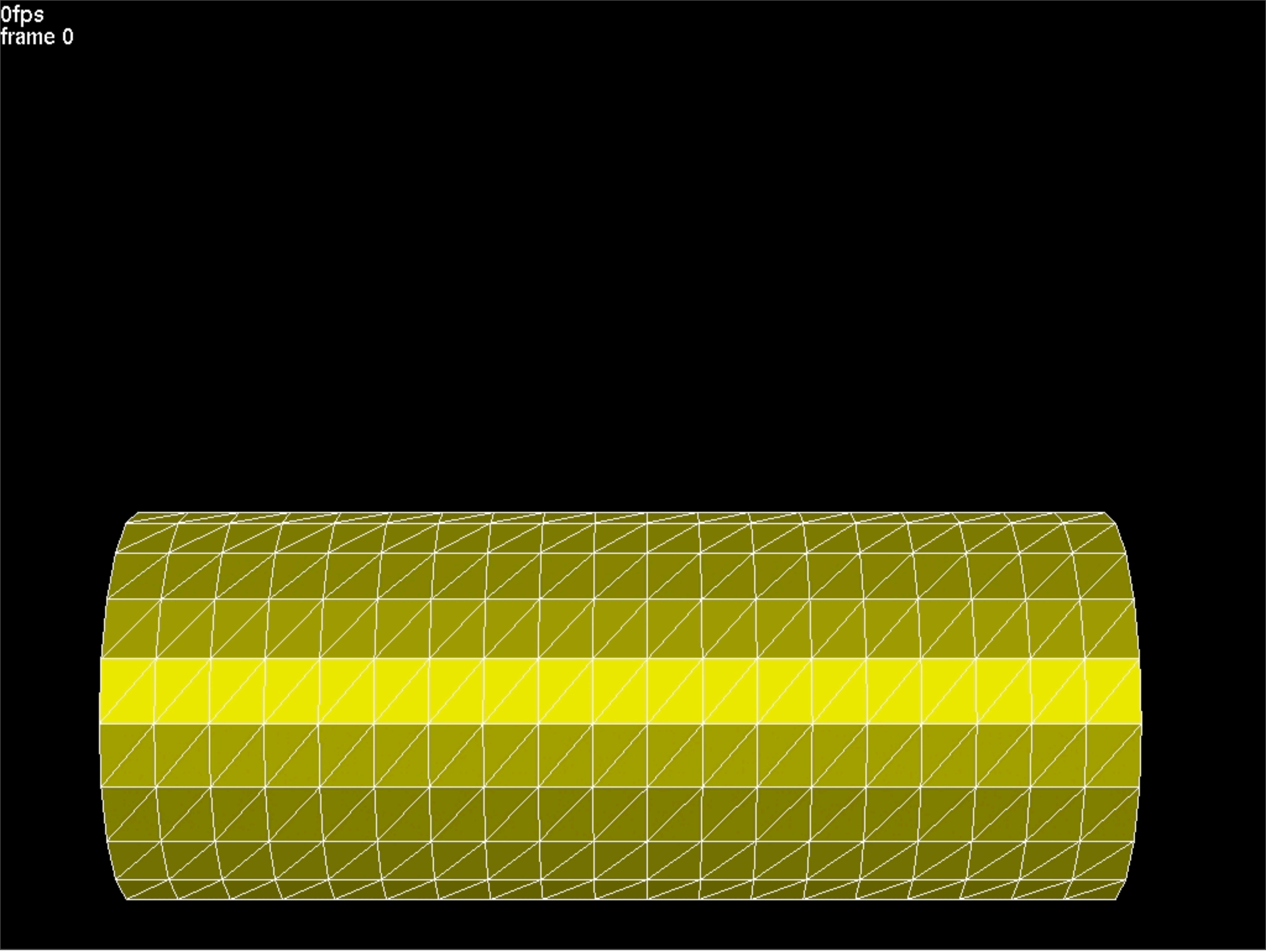
    GEOMETRY_PARTICLES<TV> particles;
    TRIANGULATED_SURFACE<T>& cylinder_surface=*TRIANGULATED_SURFACE<T>::Create(particles);
    cylinder_surface.Initialize_Cylinder_Mesh_And_Particles(20,20,5,1,false);

    LOG::Finish_Logging();
}
```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#include <PhysBAM_Tools/Log/LOG.h>
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    DEFORMABLE_GEOMETRY_COLLECTION<TV> collection(particles);
    collection.Add_Structure(&cylinder_surface);

    LOG::Finish_Logging();
}
```

```
#include <PhysBAM_Tools/Log/LOG.h>
#include <PhysBAM_Tools/Read_Write/Utilities/FILE_UTILITIES.h>
#include <PhysBAM_Geometry/Geometry_Particles/GEOMETRY_PARTICLES.h>
#include <PhysBAM_Geometry/Solids_Geometry/DEFORMABLE_GEOMETRY_COLLECTION.h>
#include <PhysBAM_Geometry/Topology_Based_Geometry/TRIANGULATED_SURFACE.h>
using namespace PhysBAM;

int main(int argc,char* argv[])
{
    typedef float T;
    typedef float RW;

    RW rw=RW();STREAM_TYPE stream_type(rw);
    typedef VECTOR<T,3> TV;

    LOG::Initialize_Logging();

    GEOMETRY_PARTICLES<TV> particles;
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#include <PhysBAM_Geometry/Geometry_Particles/GEOMETRY_PARTICLES.h>
#include <PhysBAM_Geometry/Geometry_Particles/REGISTER_GEOMETRY_READ_WRITE.h>
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    Initialize_Geometry_Particle();Initialize_Read_Write_Structures();

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    DEFORMABLE_GEOMETRY_COLLECTION<TV> collection(particles);
    collection.Add_Structure(&cylinder_surface);

    FILE_UTILITIES::Create_Directory("output/0");
    collection.Write(stream_type,"output",0,0,true);

    LOG::Finish_Logging();
}
```

```
#include <PhysBAM_Tools/Log/LOG.h>
#include <PhysBAM_Tools/Parsing/STRING_UTILITIES.h>
#include <PhysBAM_Tools/Read_Write/Utilities/FILE_UTILITIES.h>
#include <PhysBAM_Geometry/Geometry_Particles/GEOMETRY_PARTICLES.h>
#include <PhysBAM_Geometry/Geometry_Particles/REGISTER_GEOMETRY_READ_WRITE.h>
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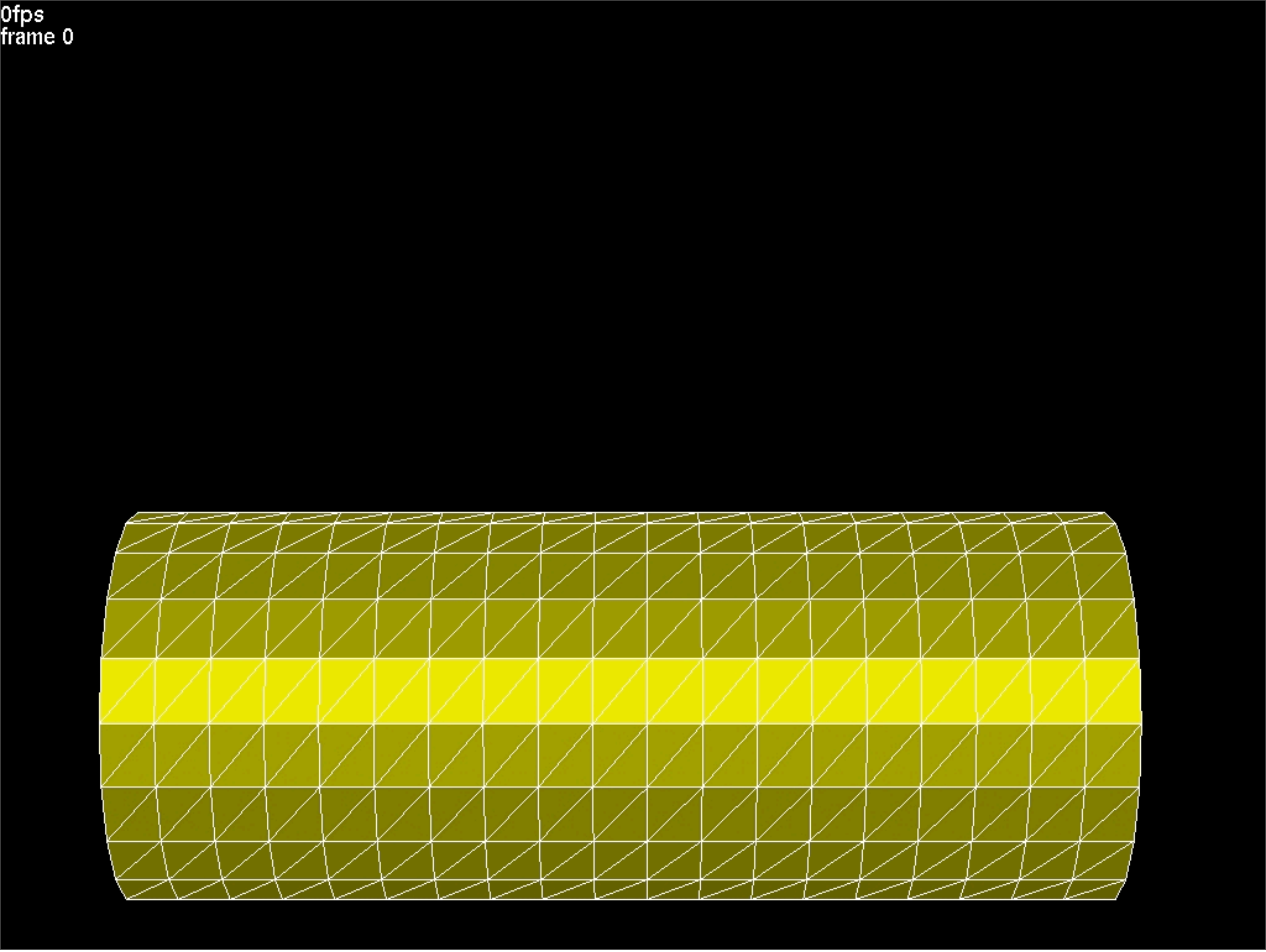
    DEFORMABLE_GEOMETRY_COLLECTION<TV> collection(particles);
    collection.Add_Structure(&cylinder_surface);

    for(int i=0;i<=10;i++){
        FILE_UTILITIES::Create_Directory("output/"+STRING_UTILITIES::Value_To_String(i));
        collection.Write(stream_type,"output",i,0,true);

        for(int p=1;p<=particles.X.Size();p++)
            particles.X(p).y+=particles.X(p).x*particles.X(p).x*(T).01;}

    LOG::Finish_Logging();
}
```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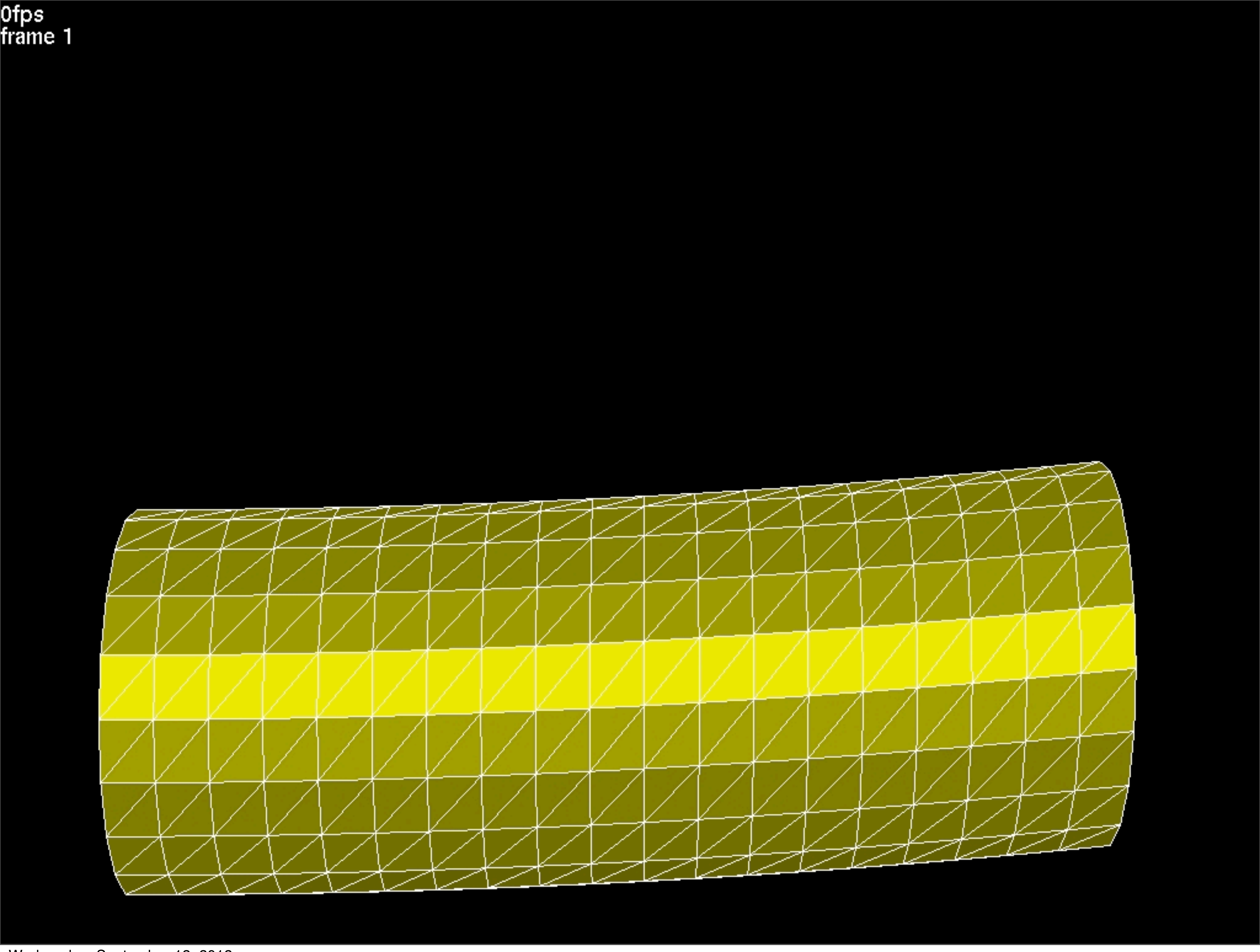
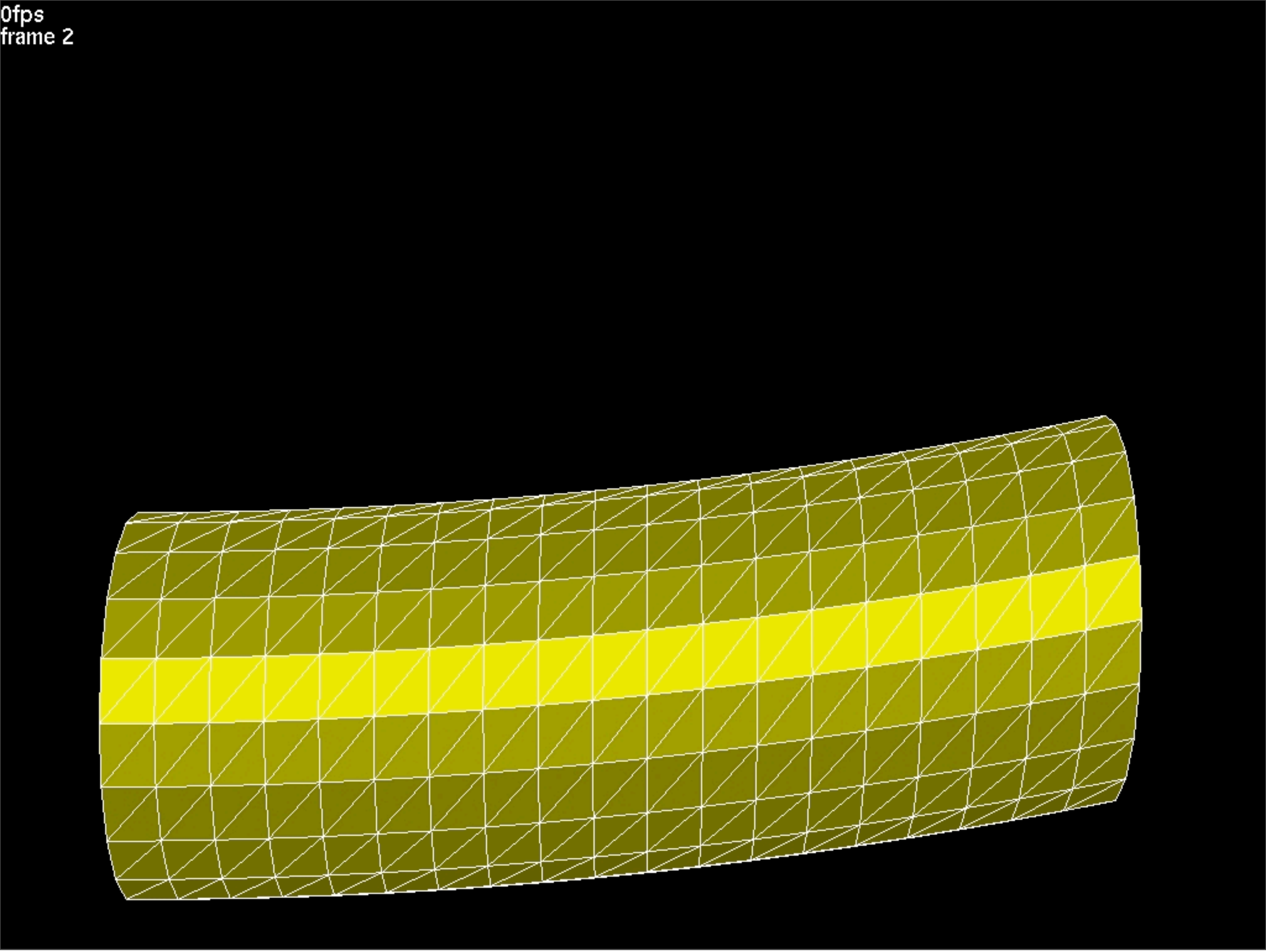


Wednesday, September 12, 2012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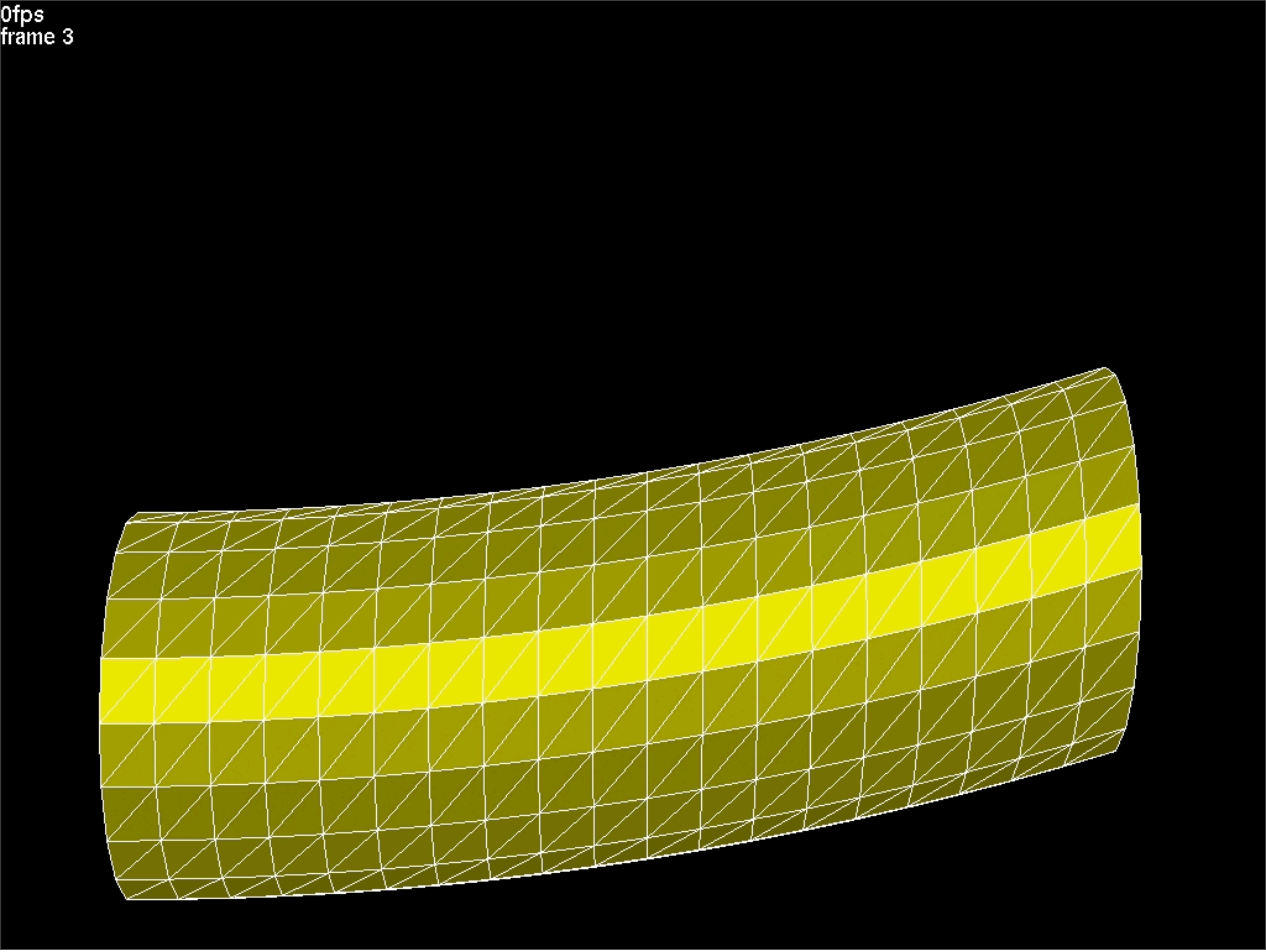
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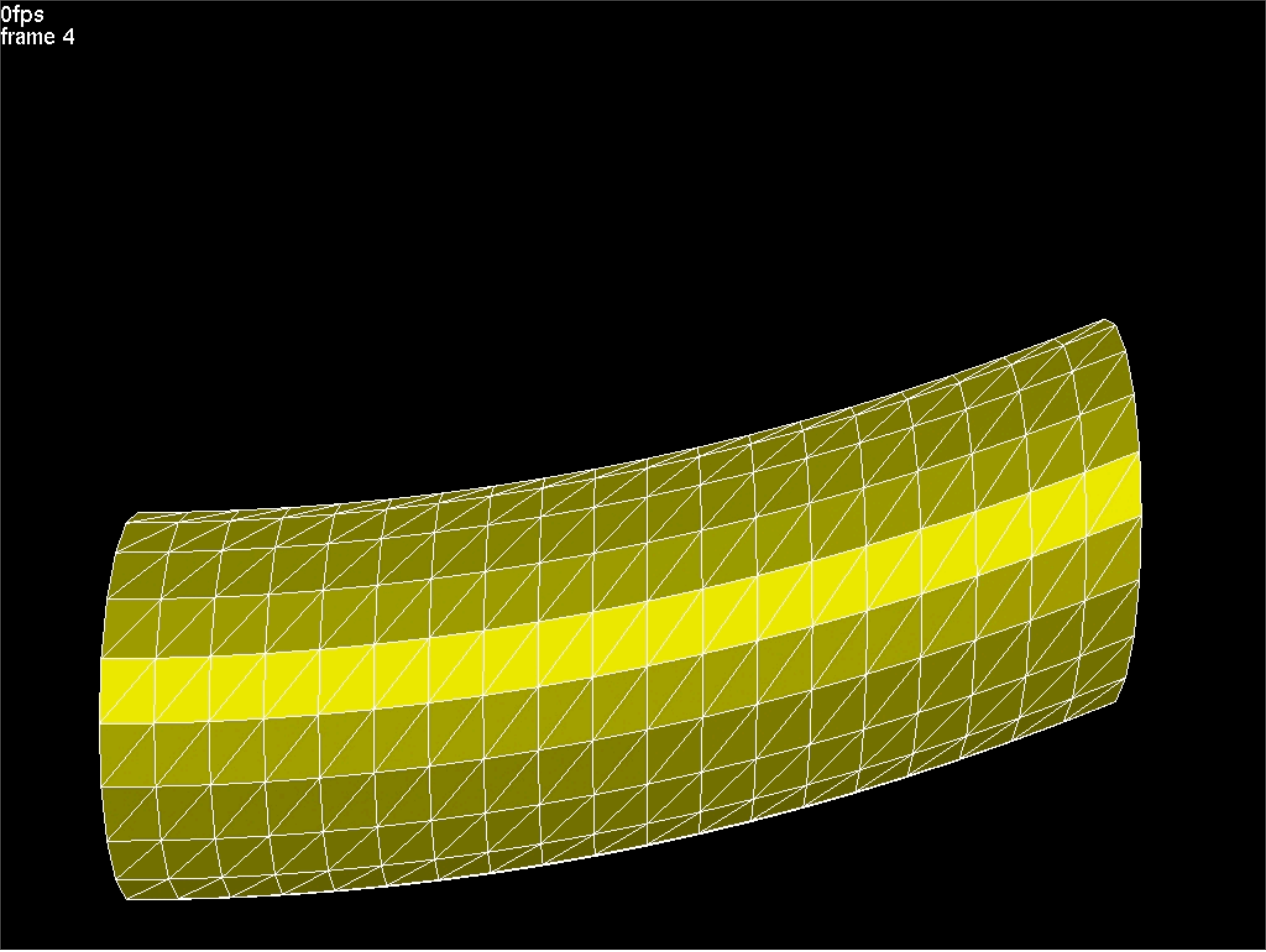
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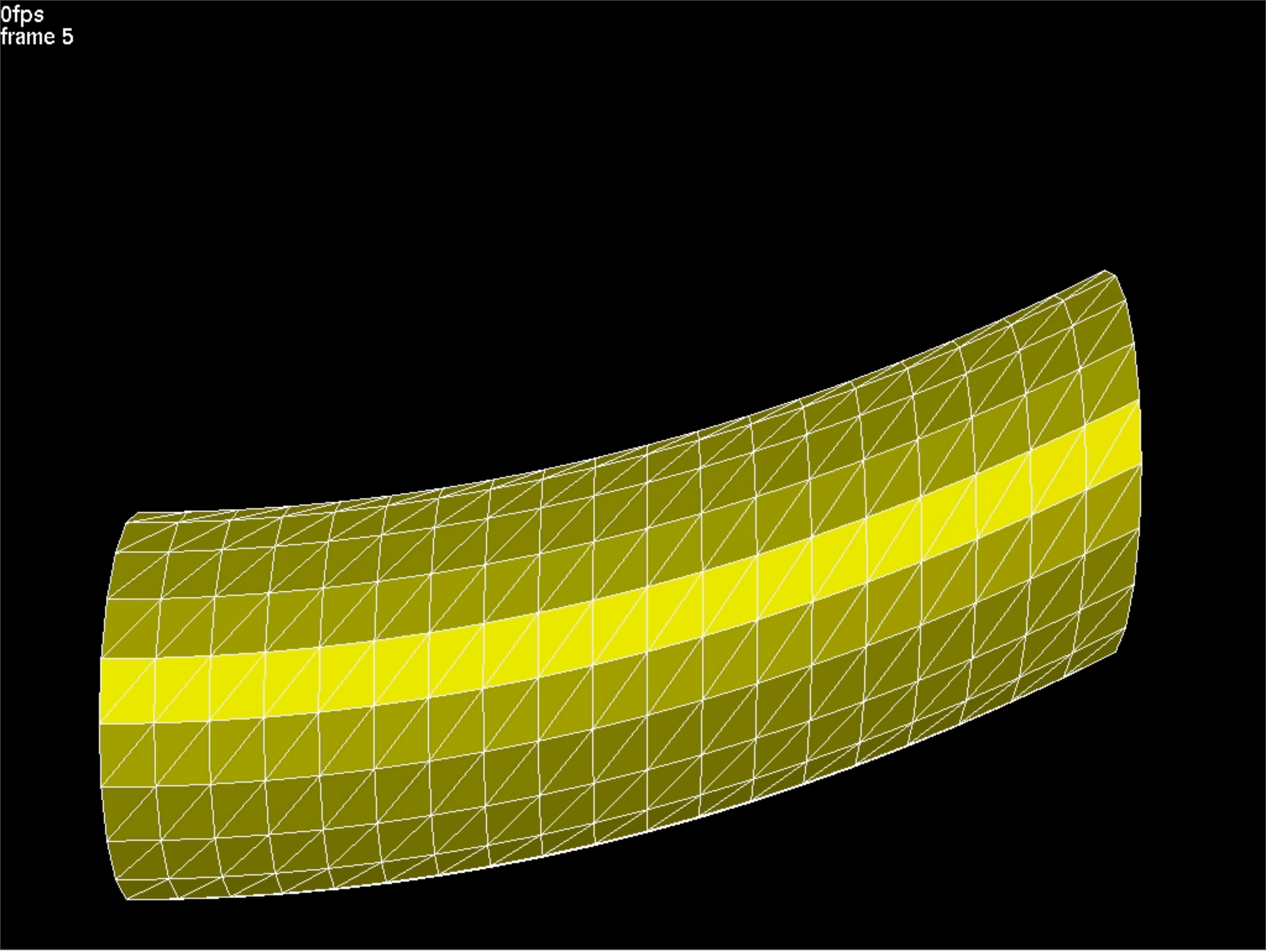
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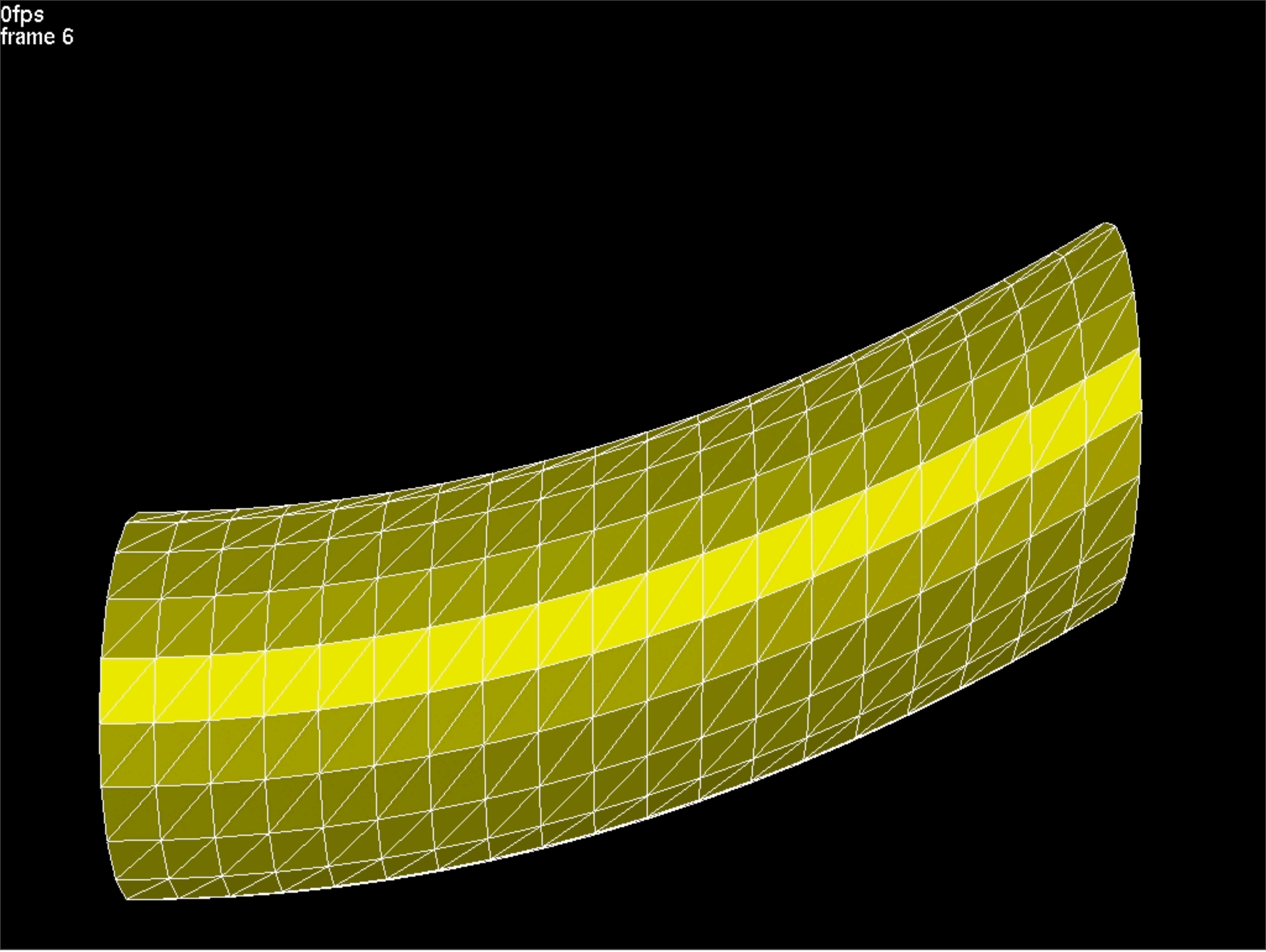
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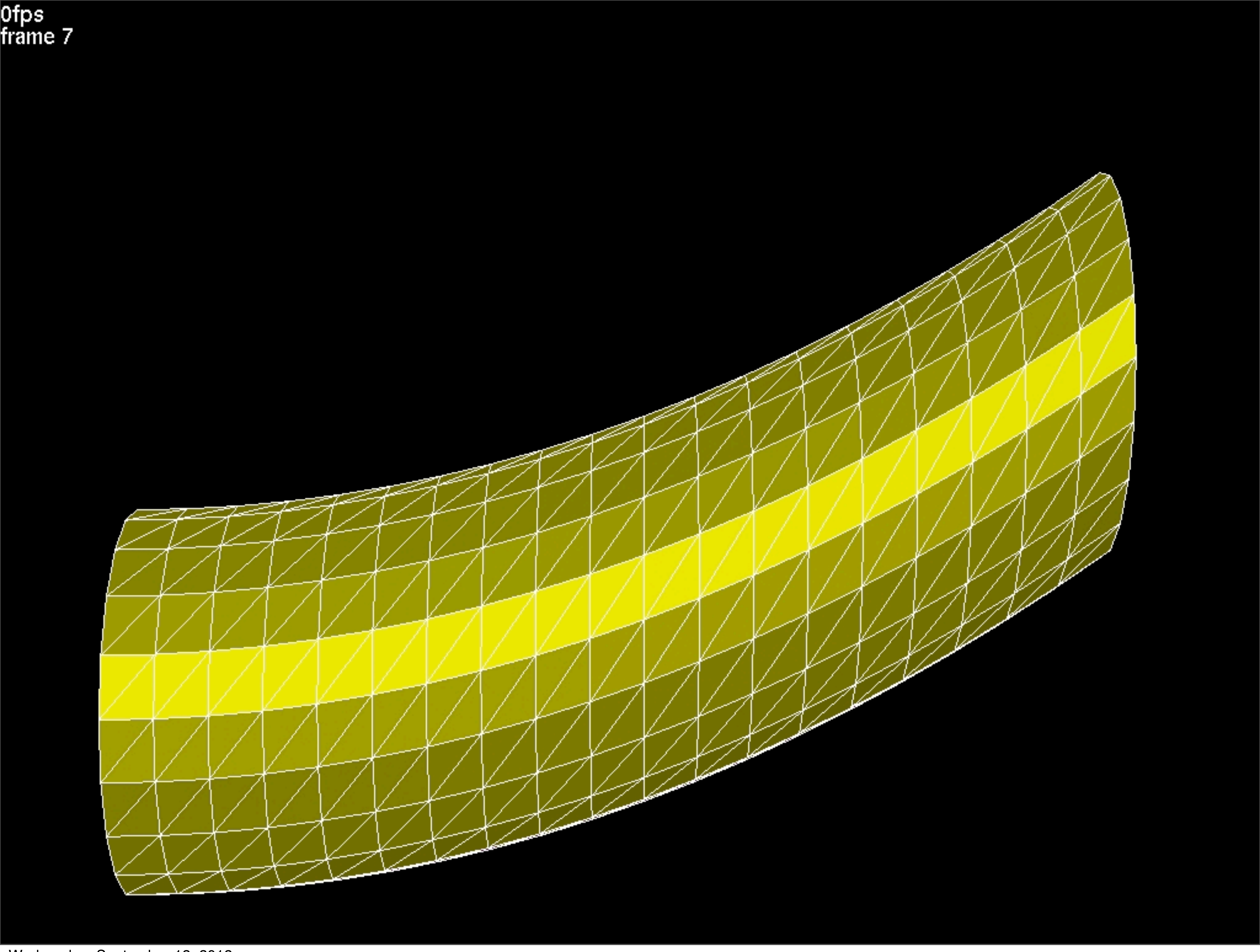
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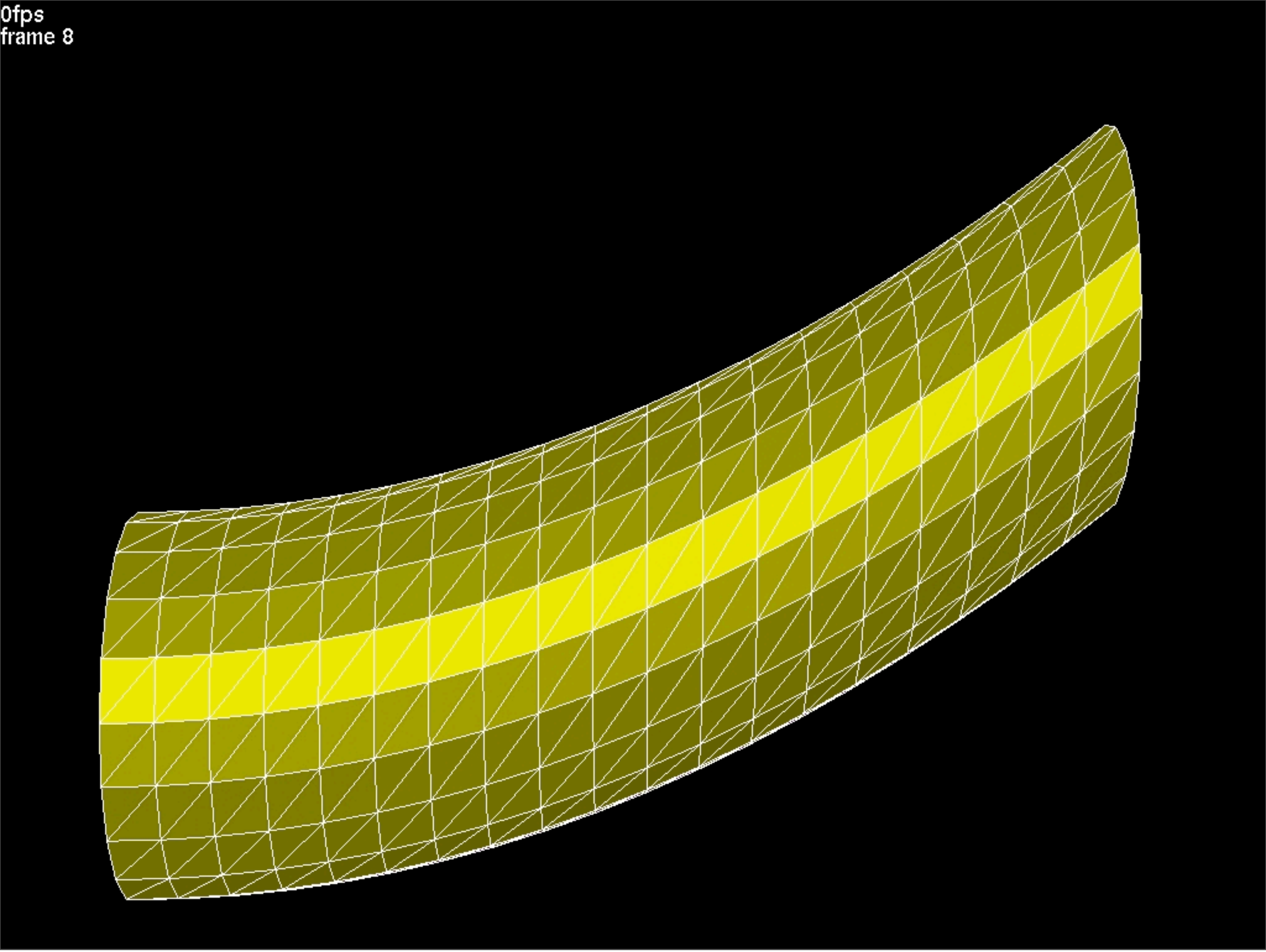
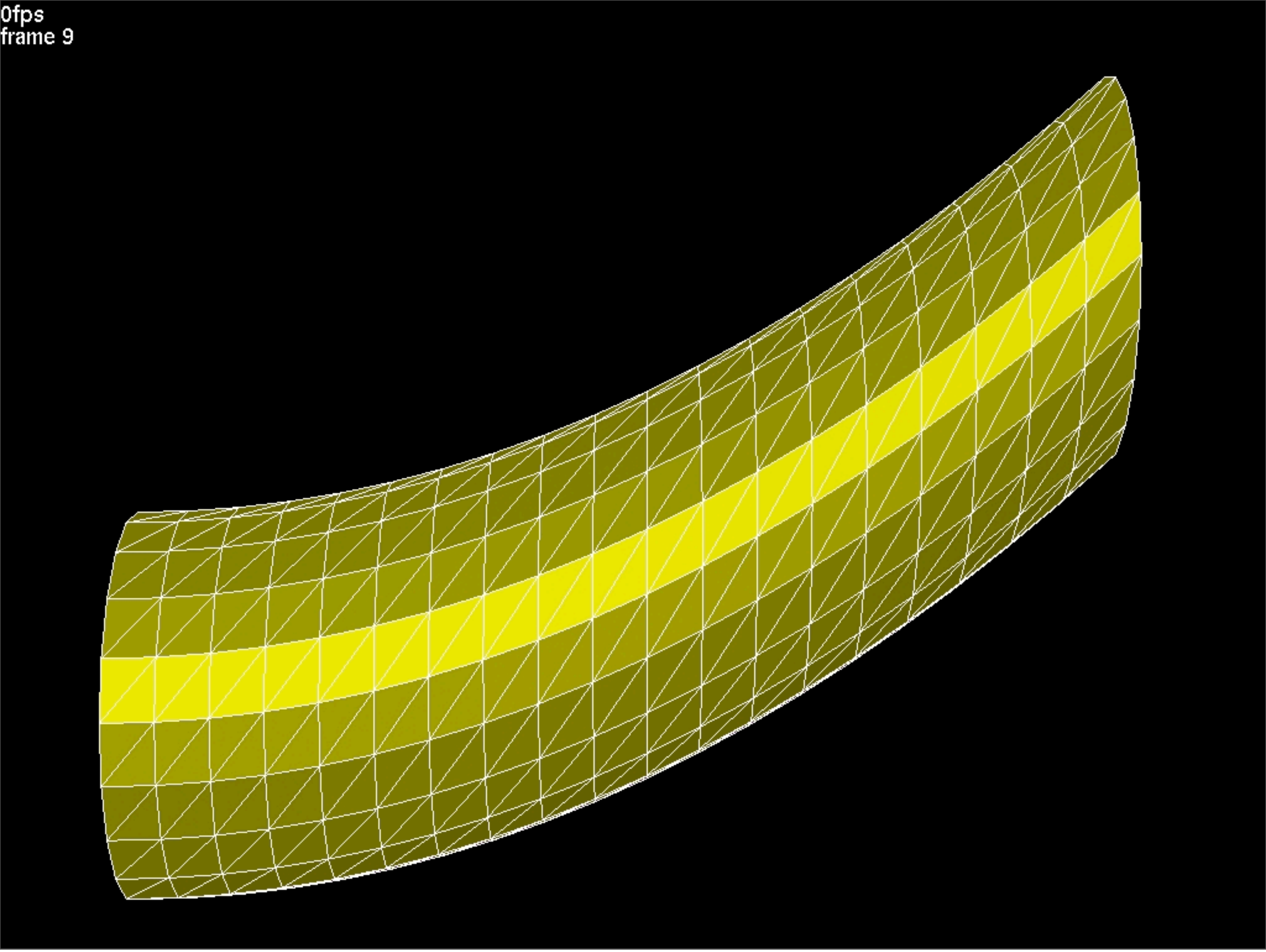
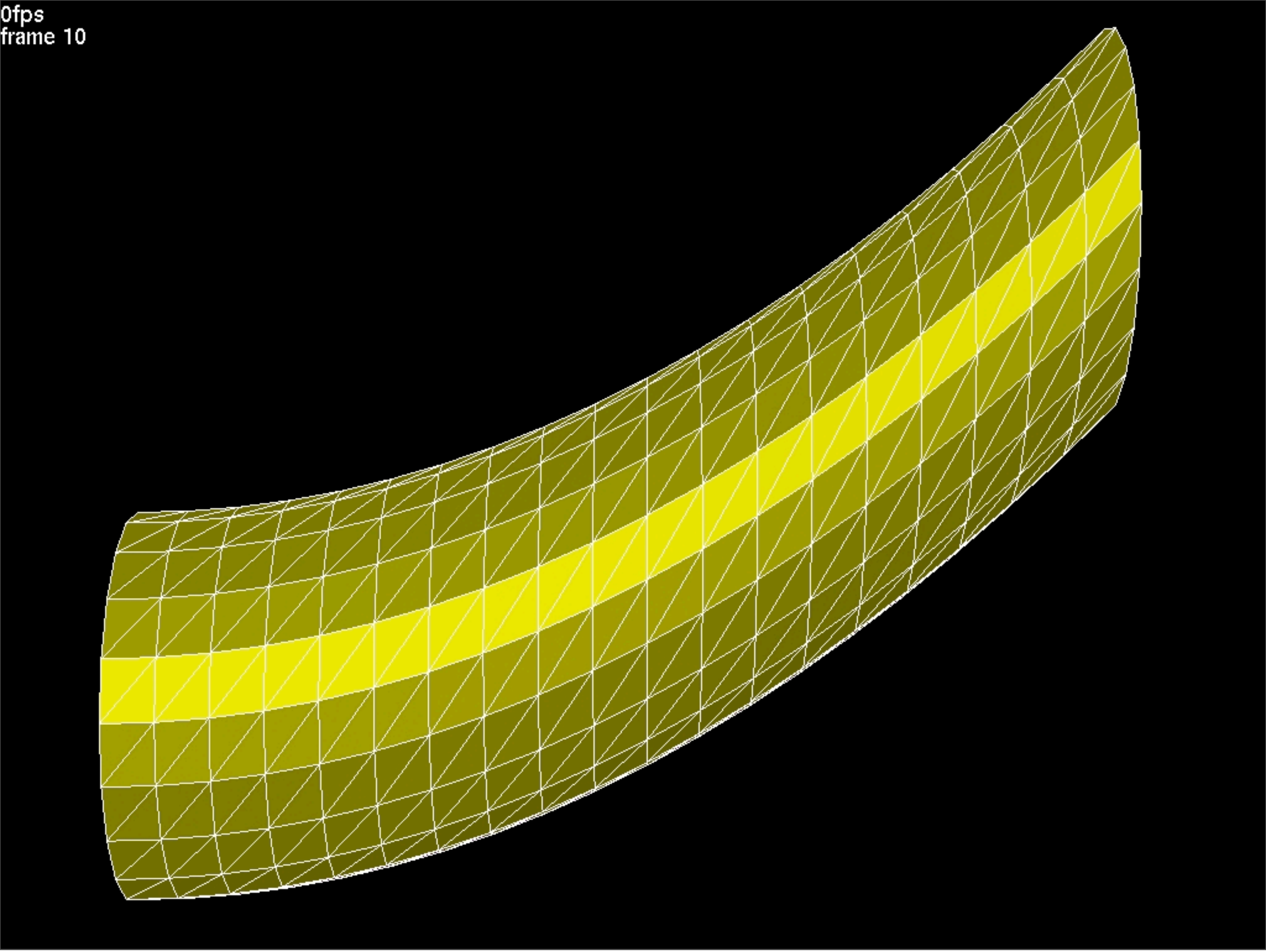

0fps
frame 8


0fps
frame 9


0fps
frame 10

Basic data structures

- Arrays (dynamic)
  - Templatized as *ARRAY<T>*
  - Dynamically sizeable, with elbow room for amortized O (1) insertion/resize cost.
  - *One-based!* (Unfortunate Fortran legacy)
- Vectors
  - Corresponding to "geometric" notion of vector, in the n-dimensional space
  - Fixed length (contrast with *std::vector)*
  - Doubly templatized as *VECTOR<T,d>*(e.g. *VECTOR<float,3>)*

Basic data structures

- Matrices (fixed size)
  - Templatized as *MATRIX<T,d>(square)* or *MATRIX<T,d1,d2>*
  - Coordinated templates and function with *VECTOR<T,d>*
  - Special cases : *SYMMETRIC_MATRIX,DIAGONAL_MATRIX,...*
- Other structures
  - Arbitrary-size matrices and vectors (dense & sparse)
  - Hashtables, Graphs, Complex Numbers, Random Number Generators, etc.
  - Abstract numerical routines (Krylov methods, Newton...)
- More on *Geometrical* strucures, in the next lectures