CS 15-467/15-667: Simulation Methods for Animation and Digital Fabrication

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What is this course about?

Modeling the physics of daily life

- Equations known for a long time
  - Motion (Newton, 1660)
  - Elasticity (Hooke, 1670)
  - Fluids (Navier, Stokes, 1822)

$$d/dt(m\mathbf{v}) = \mathbf{f}$$

$$\boldsymbol{\sigma} = \mathbf{E}\boldsymbol{\varepsilon}$$

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = -k\nabla\rho + \rho\mathbf{g} + \mu\nabla^2\mathbf{v}$$

- Simulation made possible by computers

1938: Zuse Z1

0.2 ops

2014: Tianhe-2 @ NUDT (China)

54,902 teraflops (3.12M cores)

http://www.top500.org/list/2015/06/

Computational Sciences

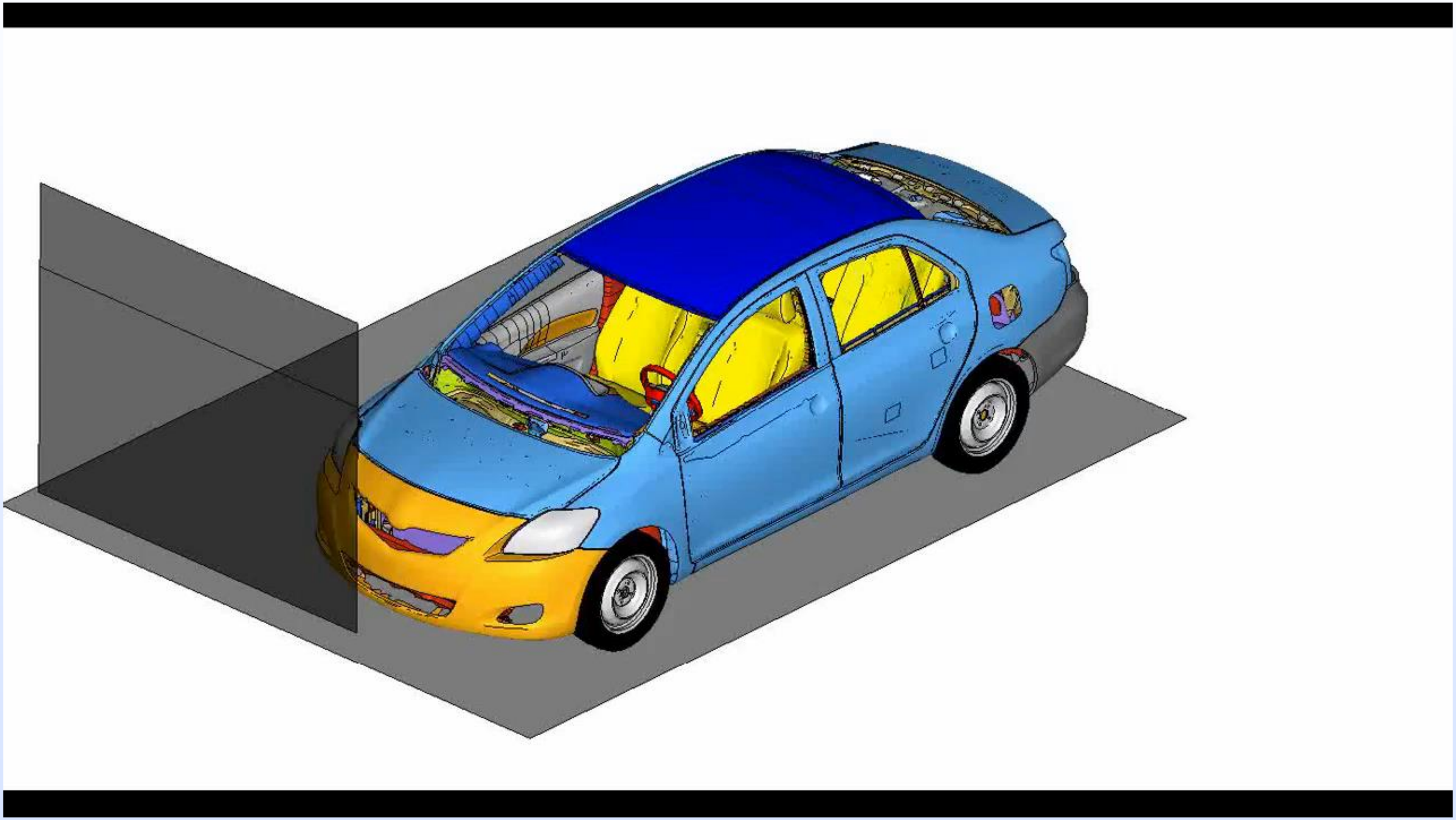
- Technological progress → *Scientific Computing*
  - Computational Elasticity
  - Computational Fluid Dynamics
  - Computational Astrophysics, …
- Leverages and drives Numerical Modeling
  - Basis for simulation of natural phenomena

Aims of Physical Simulations

Computational Sciences

- Reproduction of physical phenomena
- Predictive capability (accuracy!)

Aims of Physical Simulations:
Substitute expensive experiments



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Aims of Physical Simulations:
Predictive Models for Robotics Applications

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Predictive Models for Robotics Applications

Ever wonder what it would be like
to see evolution happening
right before your eyes?

Aims of Physical Simulations:
Computational Design and Digital Fabrication

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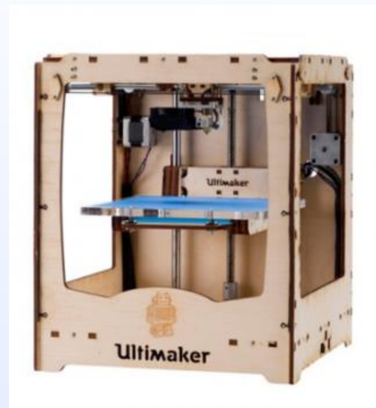
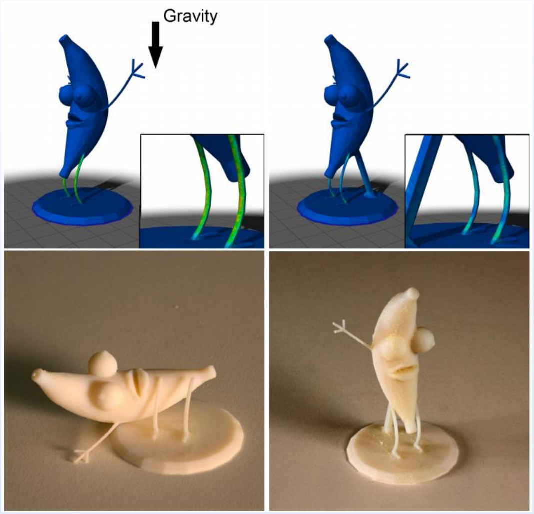
Computational Design and Digital Fabrication



Aims of Physical Simulations:
Computational Design and Digital Fabrication

Lu et al., Siggraph 2014



Stava et al., Siggraph 2012

Wang et al., Siggraph Asia 2013

Aims of Physical Simulations:
Computational Design and Digital Fabrication

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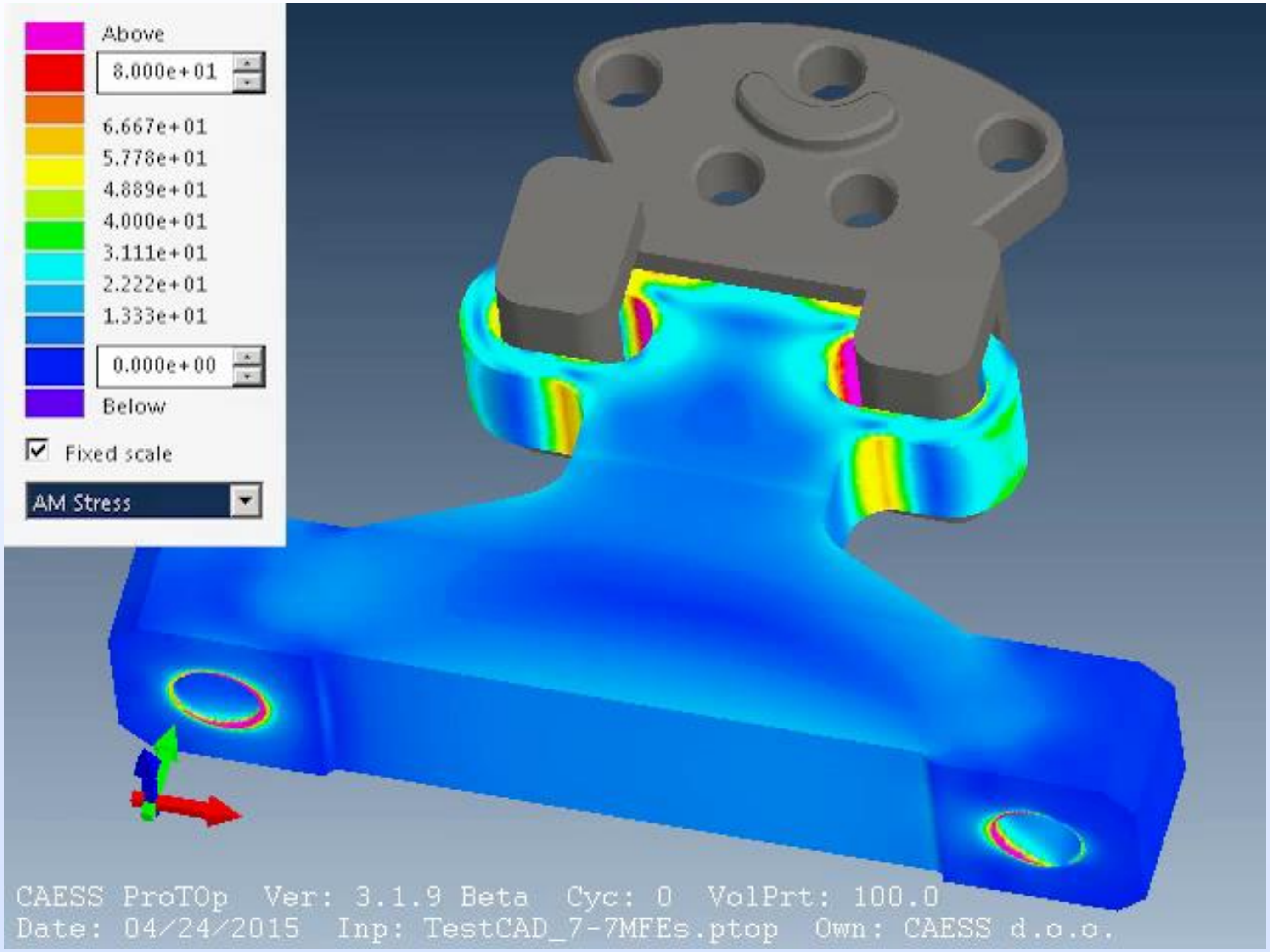

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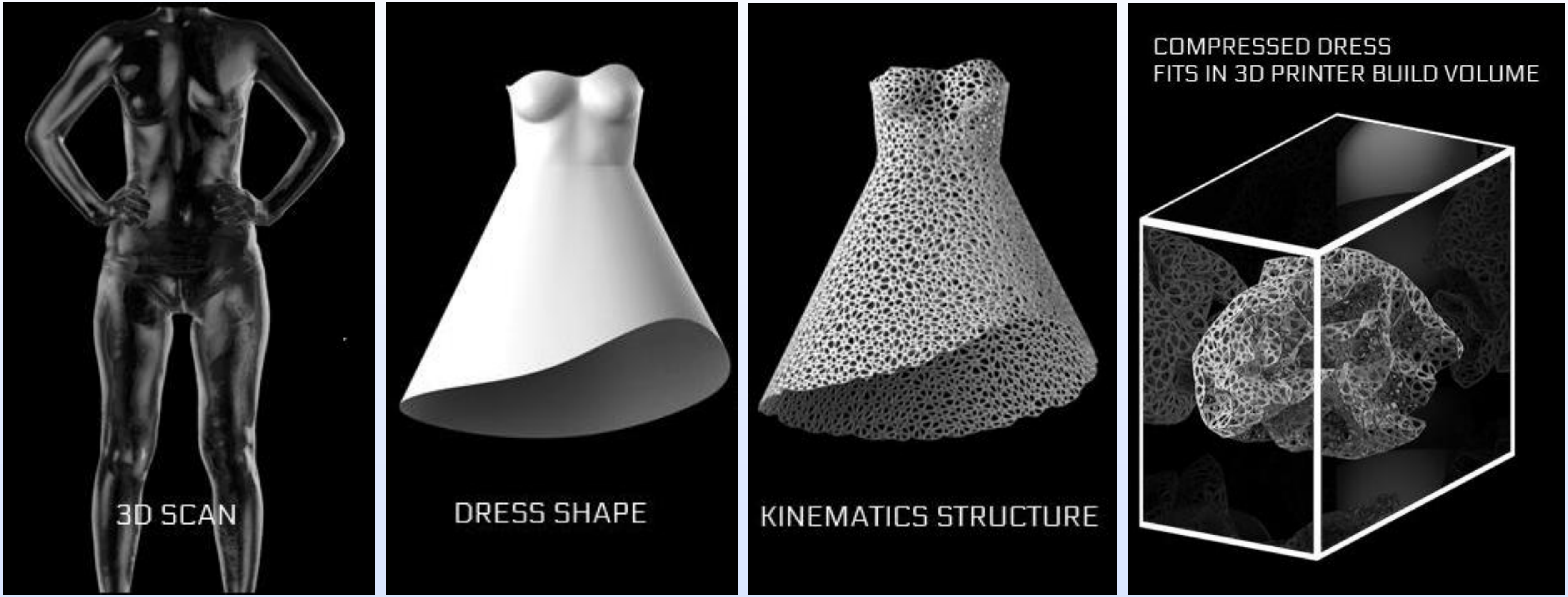


Aims of Physical Simulations:
Computational Design and Digital Fabrication

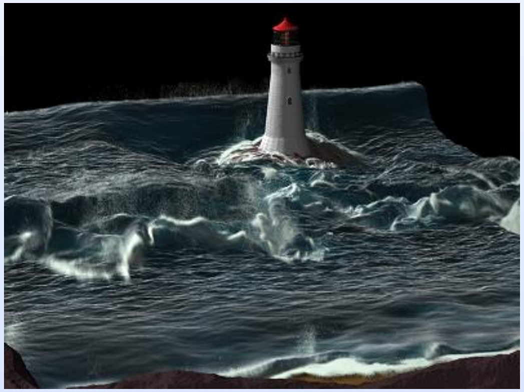
Aims of Physical Simulations

Computational Sciences

- Reproduction of physical phenomena
- Predictive capability (accuracy!)

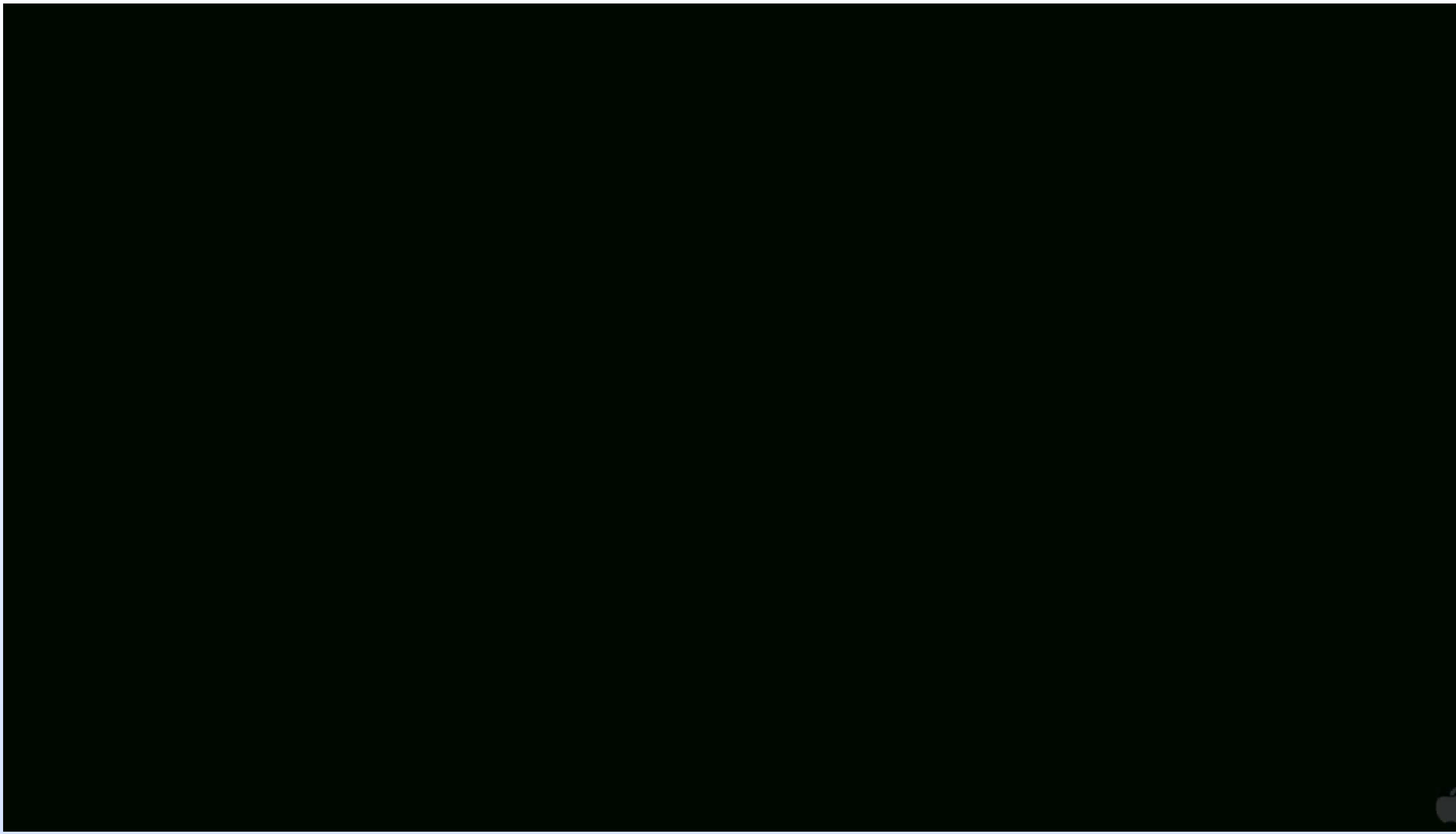
Computer Graphics/Animation

- Imitation of physical phenomena
  - Visually plausible behavior
- Speed, stability, art-directability



Different goals require different methods!

If you understand how the physical world works, you can create your own worlds…



Animation

***Goal**: create believable and compelling virtual worlds!*

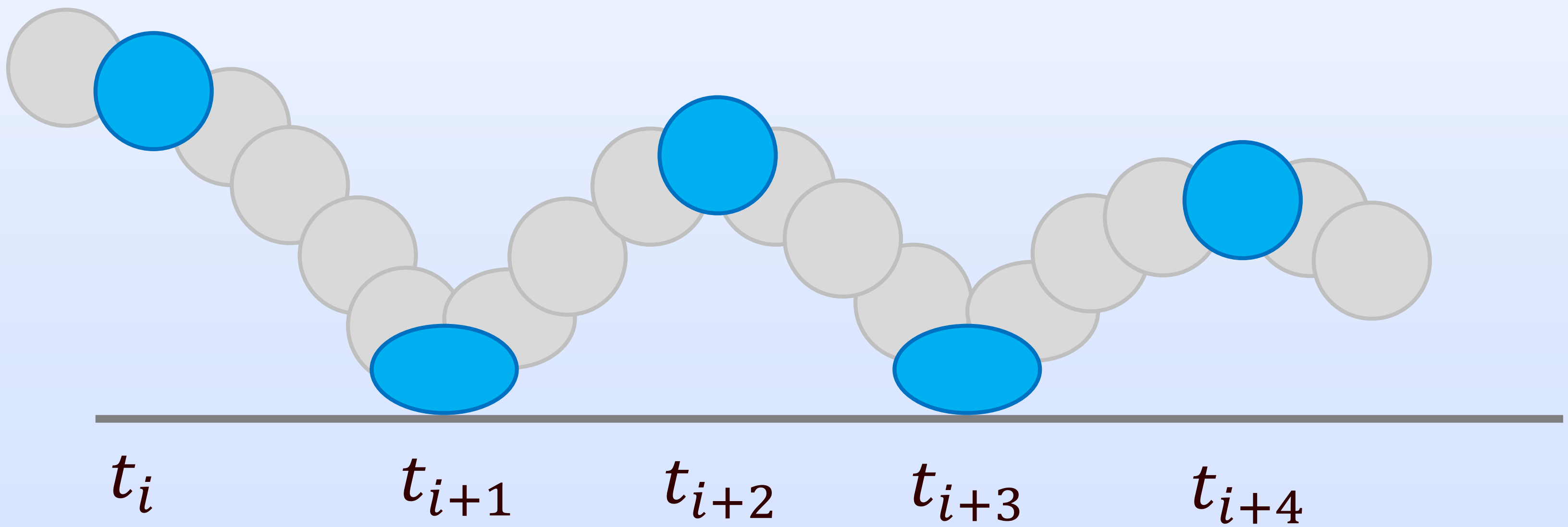
Examples:

- Character animation (humans, animals)
- Secondary motion (hair, cloth)
- Physical world (rigid bodies, water, fire)

Animation Techniques

Keyframing

- Manually specify system state at times t_i
- Interpolate inbetween



Animation Techniques

Keyframing

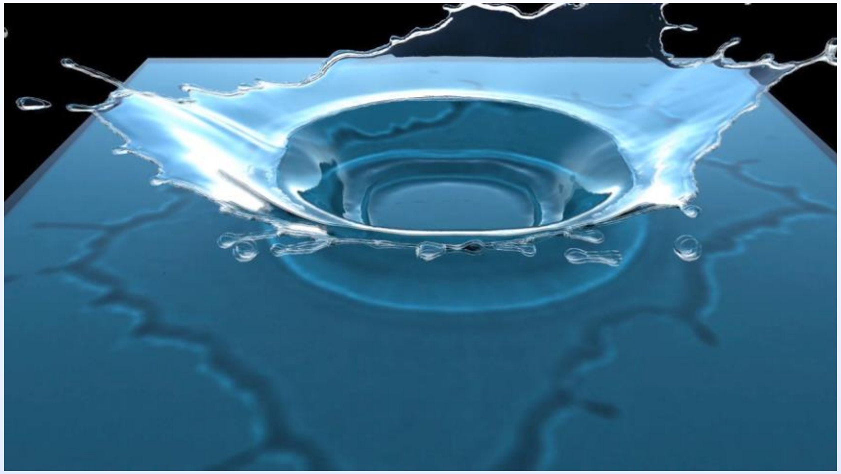
- Animator moves/poses characters by hand

Animation Techniques

Motion Capture

- Record motion of actors to move/pose characters

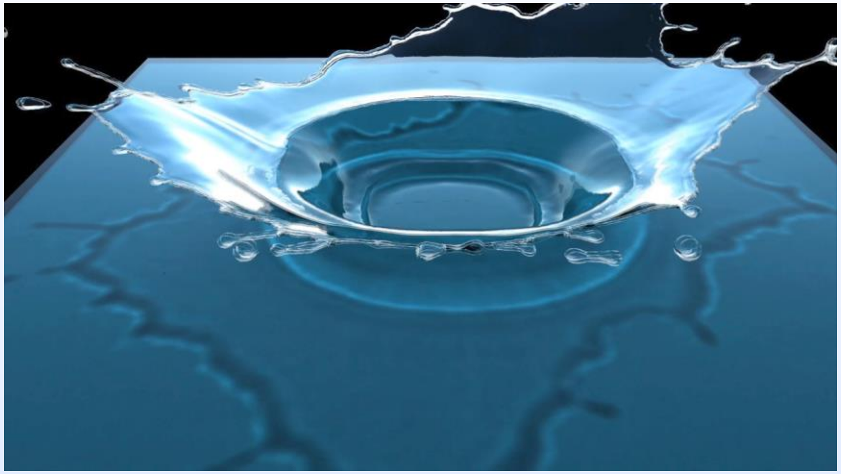
Animating Complex Systems?



Keyframing/motion capture

- fine for characters and simple motions
- but many physical systems are just too complex

Alternative: Physical Simulation

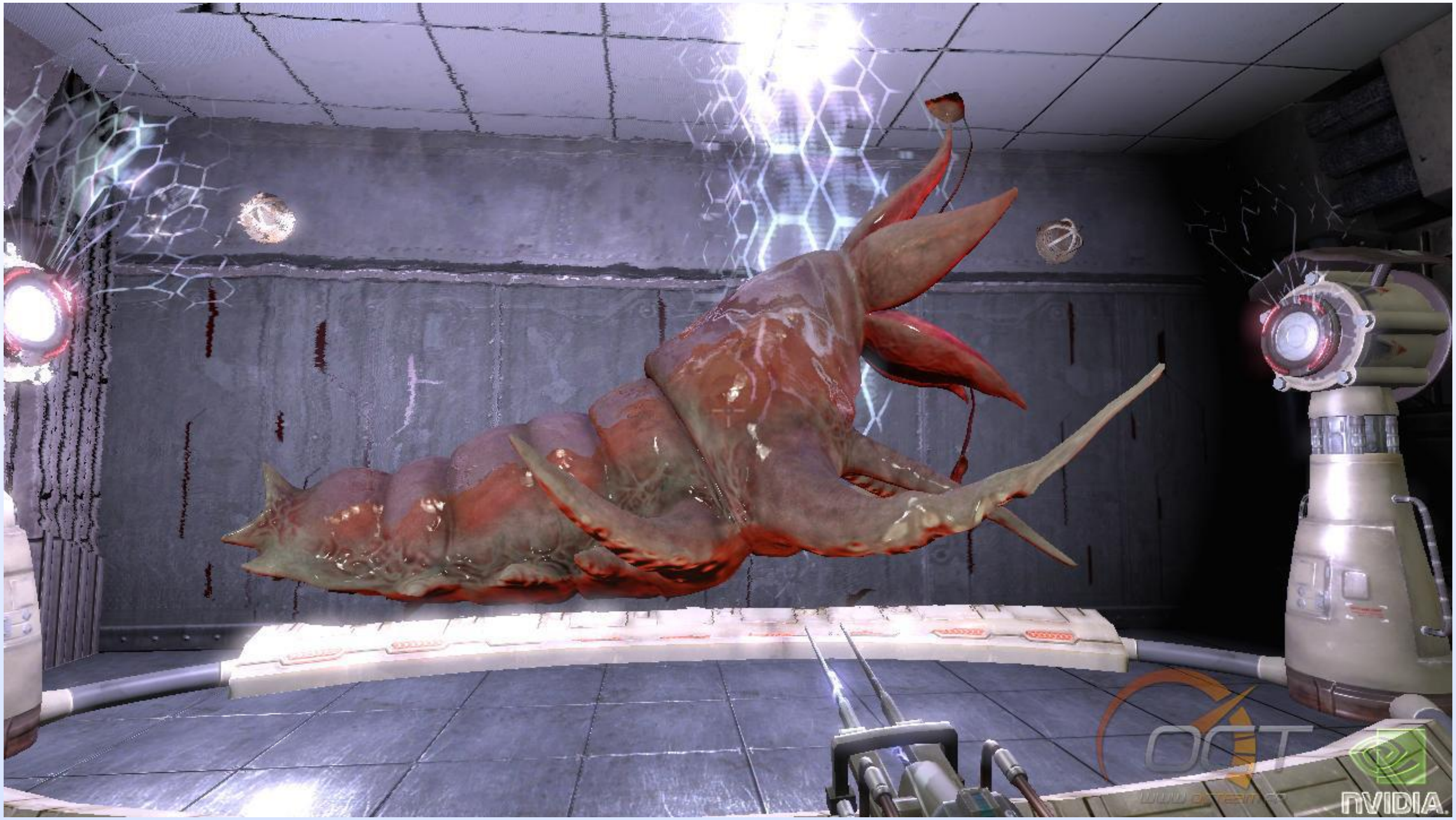


1. Identify/derive mathematical model (ODE, PDE)
2. Develop *computer* model
3. Simulate

Cloth & Hair

Disney's Tangled

Muscles & Flesh



Nvidia's The Great Kulu


The Great Kulu
Nvidia Tech Demo, 2008
NVIDIA

Fluids

Movie *Battleship*

Fluids

Movie *Battleship*

Particles & Rigid Bodies

Movie *2012*

Particles & Rigid Bodies

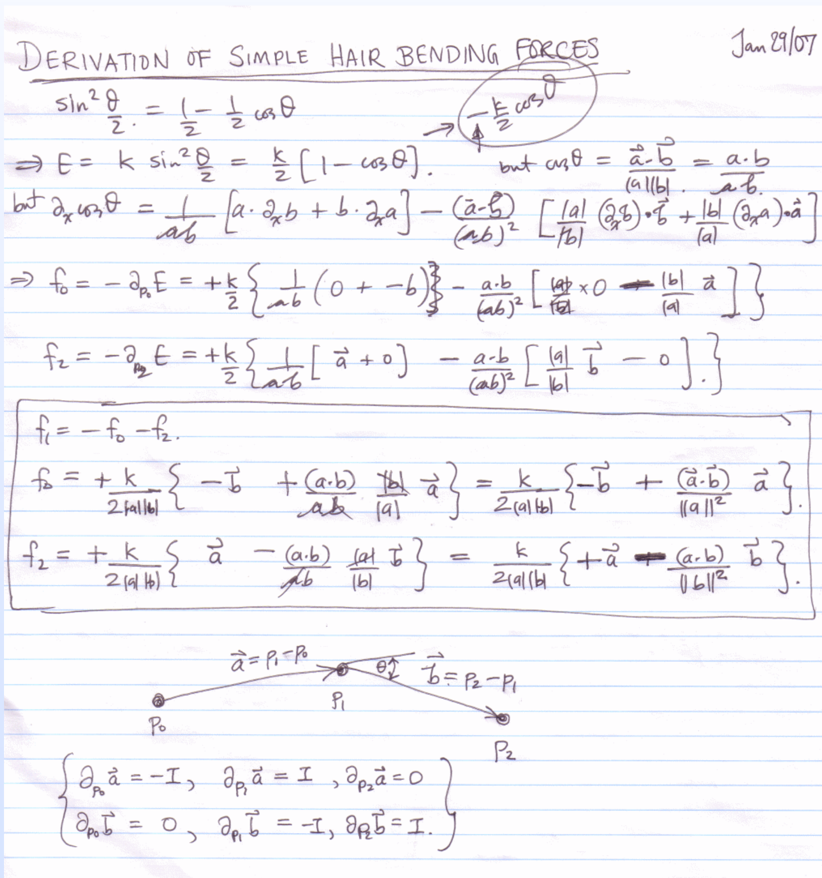
Course Fast Forward

- Will explore various phenomena
- Questions you should ask:
  - What do you want to simulate?
  - How do you want to simulate it?
    - Interactively? Accurately? Other criteria?
  - How do you know the simulation model works well?
  - Where does the model break?

Course Fast Forward

The book of nature is written in the language of mathematics.

Galileo Galilei



Course Fast Forward

- ODEs & Numerical Integration
- Particle & Mass-Spring Systems
- Intro to PDEs
- Fluid Simulation
- Continuum Mechanics and Finite Elements
- Rigid Body Kinematics and Dynamics
- …
- Applications to animation, robotics and digital fabrication

Course Fast Forward

- Goals
  - Learn techniques & some cool math
  - Fun coding & problem solving
  - Presentation Skills

Course Fast Forward

- Grading Scheme
  - Assignments (40%) (+ Prizes!)
    - Mass-spring systems (10%)
    - Particle-based fluids (10%)
    - Finite Element Method (10%)
    - Rigid Body Dynamics (10%)
  - Test (10%)
  - Final Project (50%)
    - Paper presentation & project proposal (20%)
    - Final report & presentation (30%)
    - Talk to me about topics as early as possible

Questions?

Questions for you

- What is your name?
  - Tell us about yourself
- Experience
  - OpenGL? C++? Math?
- What do you hope to learn? What do you want to simulate?