COL865: Special Topics in Computer Applications

Physics-Based Animation

1 — Introduction

23 September, 2018

What is physics-based animation?

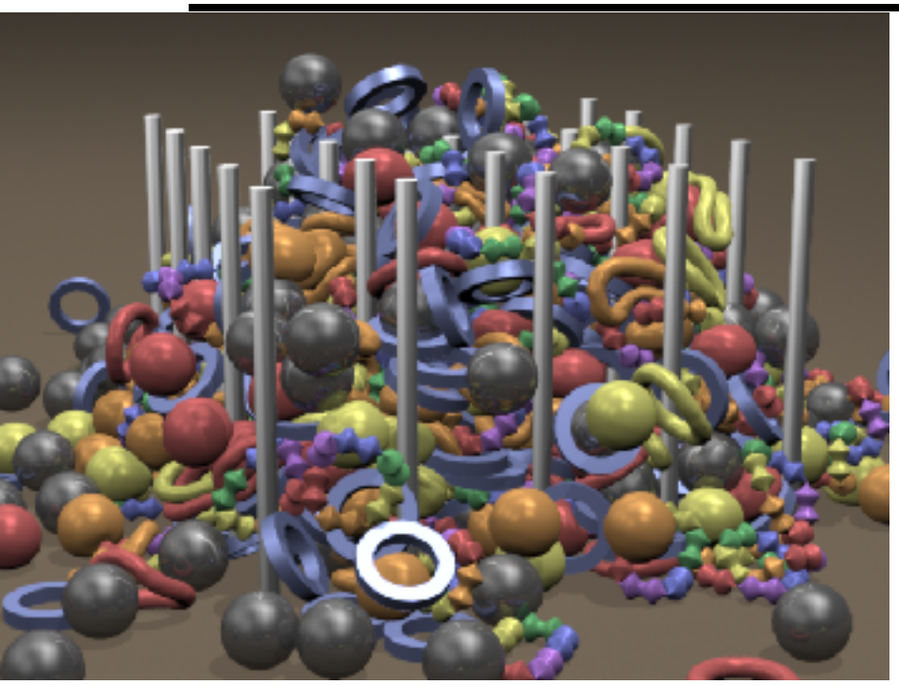
Animation

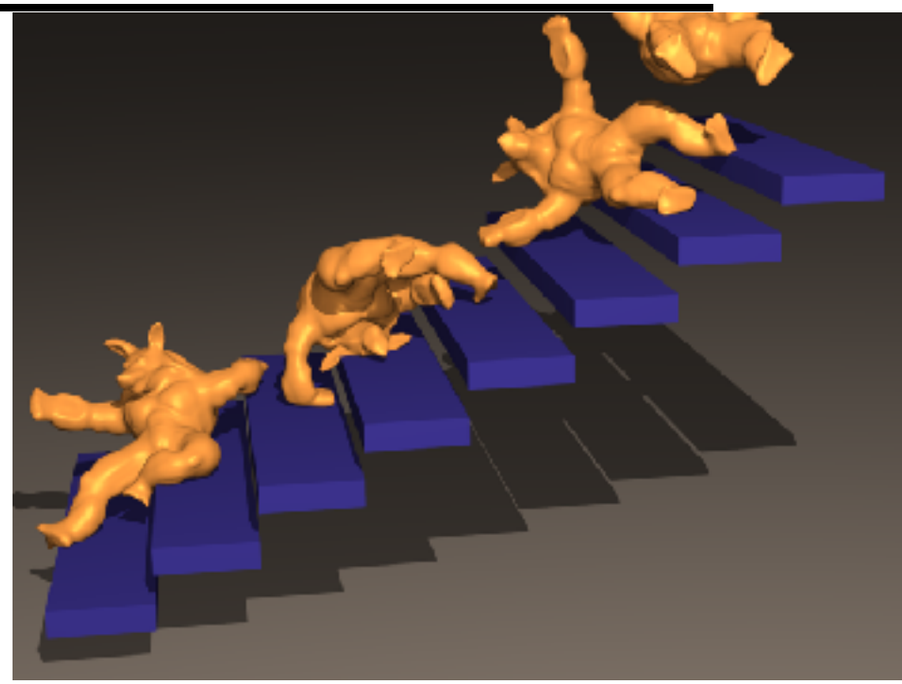
- **Manual**
  - e.g. keyframing
- **Recorded**
  - e.g. motion capture
- **Algorithmic**
  - e.g. physics-based (simulation)

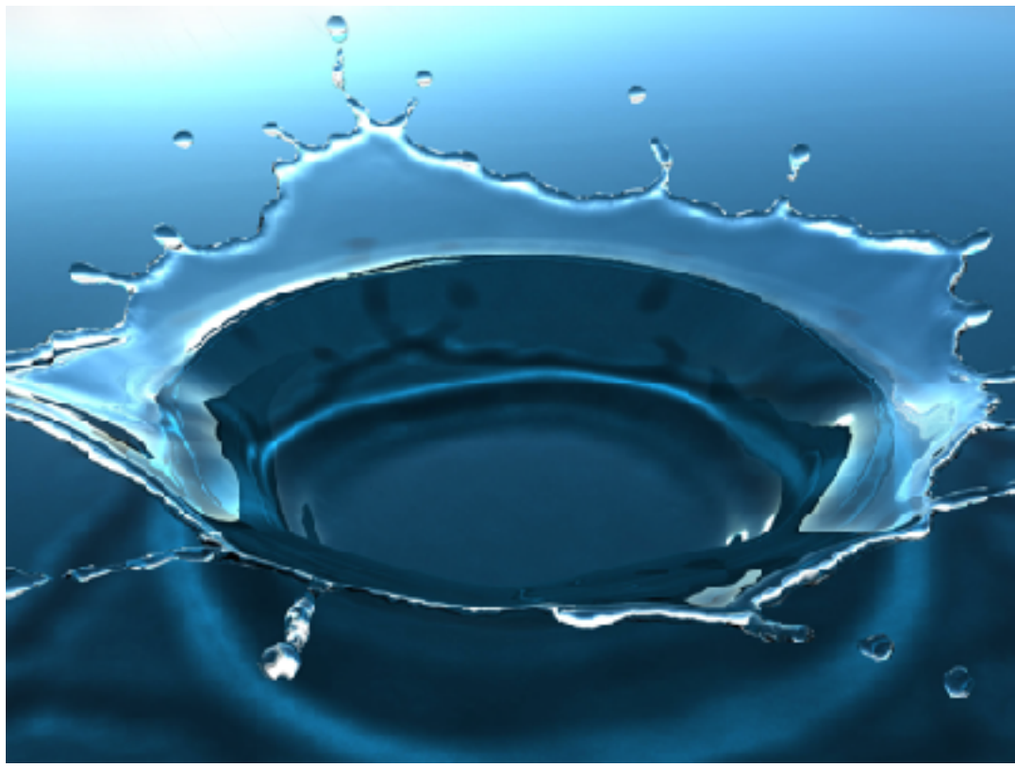
[Thürey et al. 2010]

[Li et al. 2018]

Physics-based animation (a.k.a. *simulation*)





[Shinar et al. 2008, Pfaff et al. 2014, Irving et al. 2007, Narain et al. 2012, Daviet et al. 2011, Thürey et al. 2010]

An illustrative example

An illustrative example

- **Kinematic** model (shape and motion)
  - Approximate spring as line segment with endpoint positions x_1, x_2, velocities v_1, v_2
- **Dynamics** model (forces and inertia)
  - Approximate as point masses m_1, m_2 at endpoints
  - Forces due to elasticity, gravity, contact

$$f = -k(\ell - \ell_0) + mg + f_c$$

- Apply **Newton's second law**:

$$f_1 = m_1 a_1 \;\Rightarrow\; \mathrm{d}^2 x_1/\mathrm{d}t^2 = f_1/m_1$$

$$f_2 = m_2 a_2 \;\Rightarrow\; \mathrm{d}^2 x_2/\mathrm{d}t^2 = f_2/m_2$$

An illustrative example

$$\left.\begin{aligned} d^2x_1/dt^2 &= f_1/m_1 \\ d^2x_2/dt^2 &= f_2/m_2 \end{aligned}\right\} \text{System of ODEs}$$

- Specify initial conditions (x_1, x_2, v_1, v_2 at time $t = 0$)
  $\Rightarrow$ unique solution. How to find it?

- For “most” nontrivial forces, **no analytical solution**!

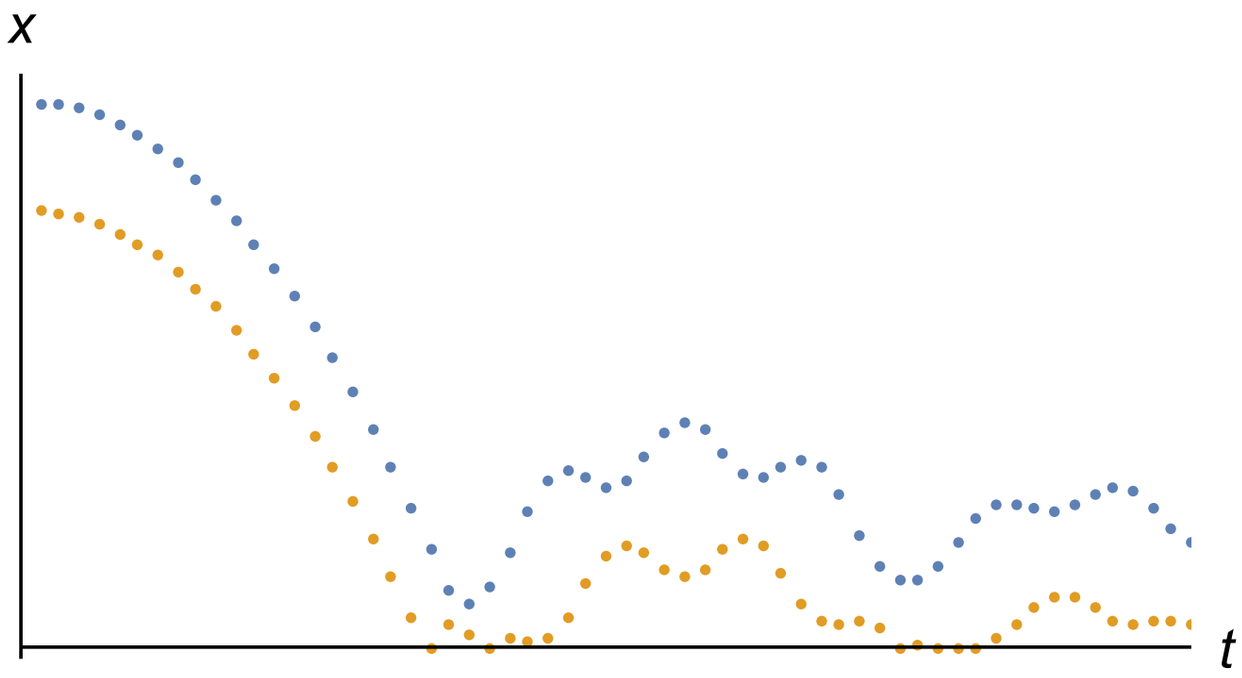
- Approximate the solution numerically, e.g.

$$x(t+\Delta t) \approx x(t) + v(t)\,\Delta t$$
$$v(t+\Delta t) \approx v(t) + f(t)/m\,\Delta t$$

(Don’t actually use this specific method! There are much better ones.)

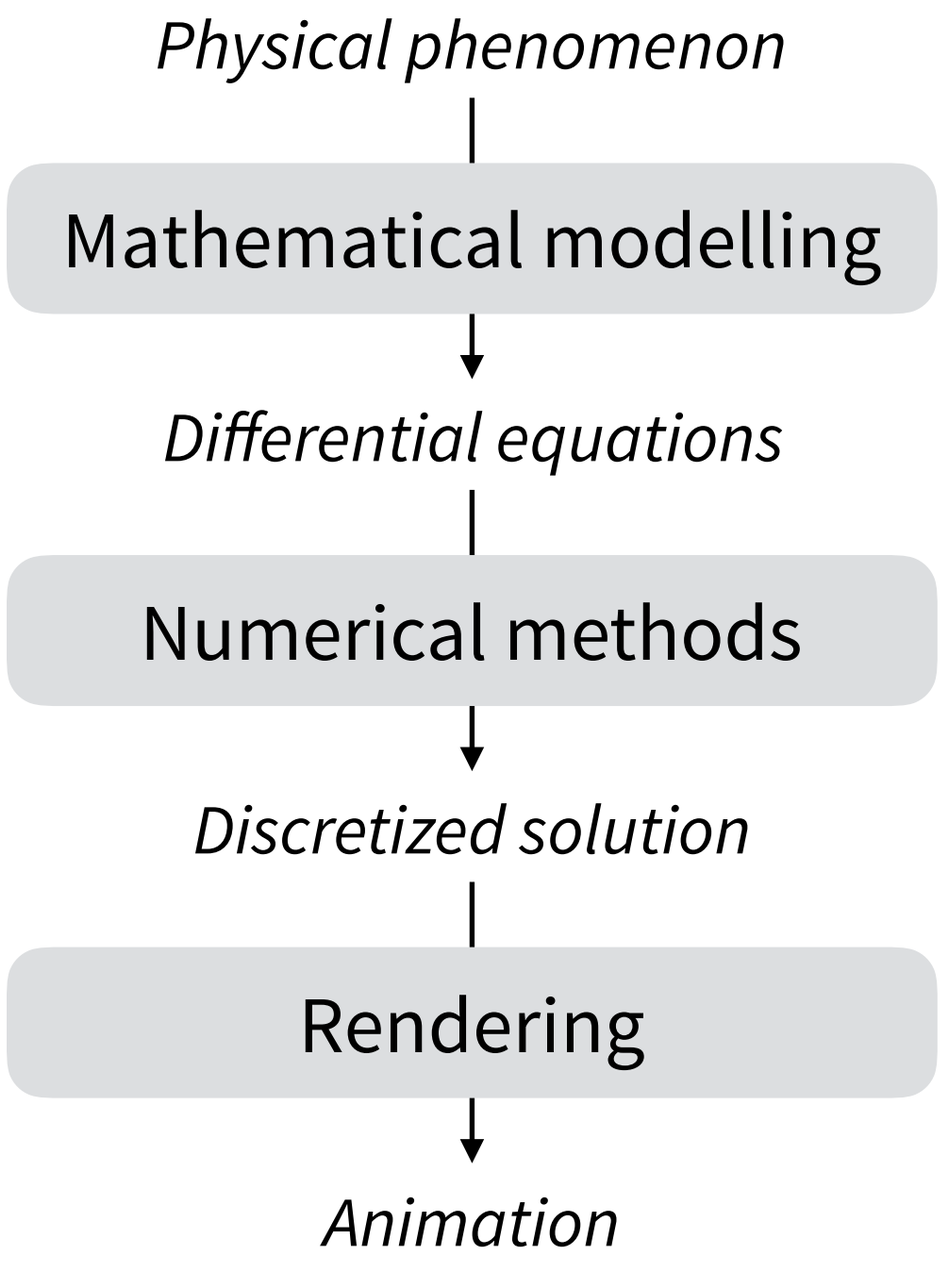
An illustrative example

- Numerical solution:
  sequence of values (x_1, x_2) at times $0, \Delta t, 2\Delta t, 3\Delta t, \ldots$



- Render it and get an animation!

Simulation in context



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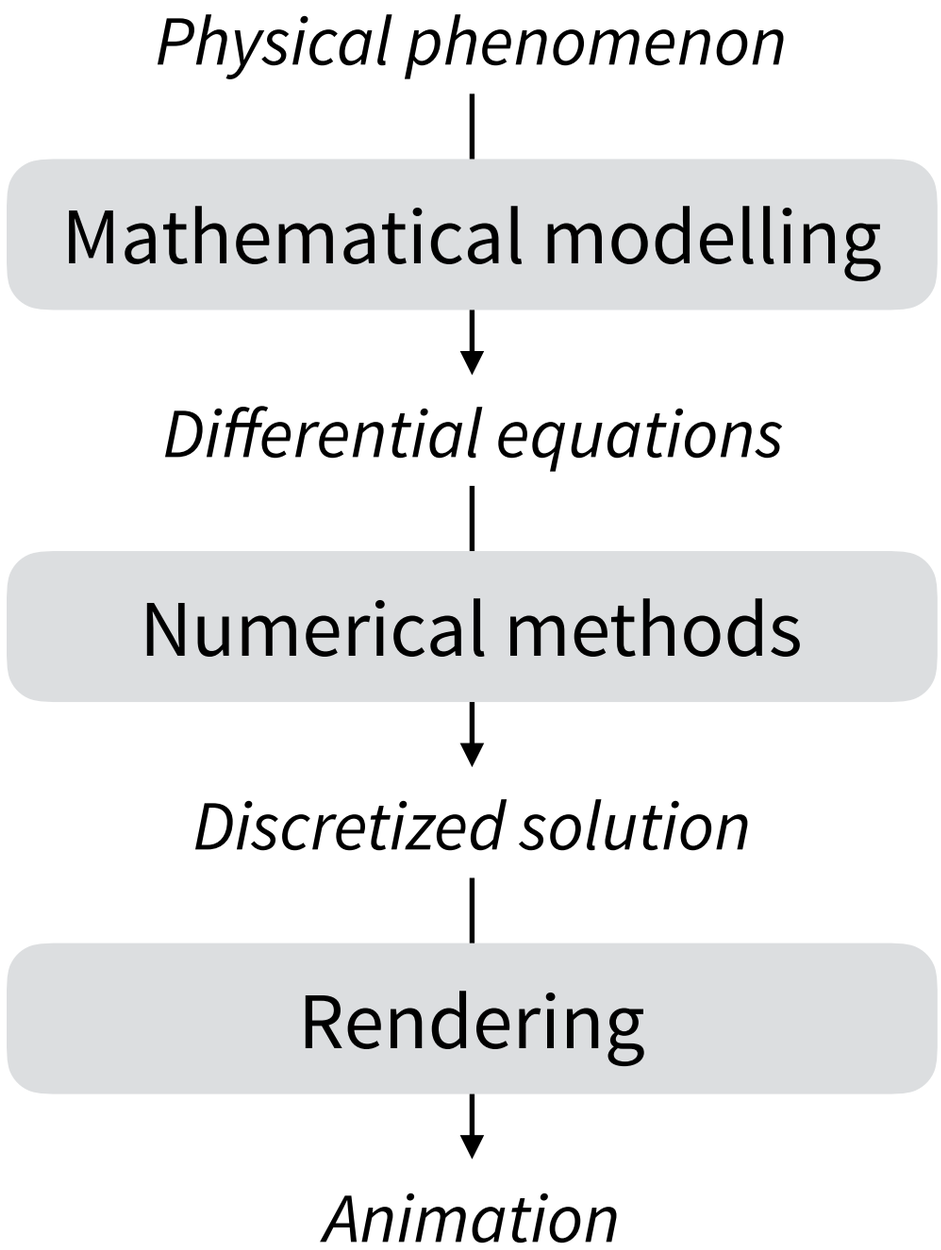
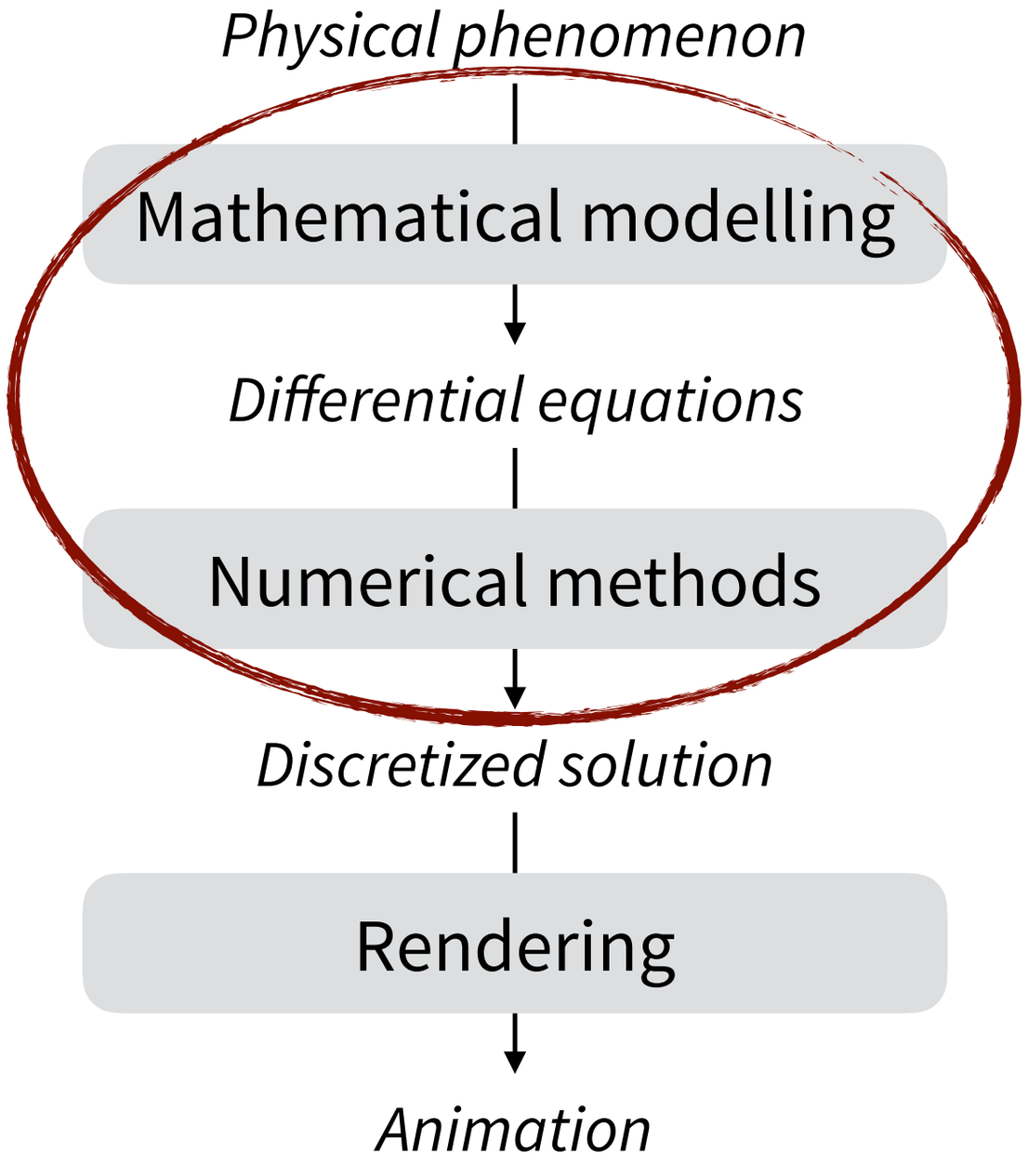


- Mathematical models usually from physics & engineering
  - Often must be simplified or augmented for animation
  - *"All models are wrong, some models are useful"*
  - Can make up nonphysical models for artistic effects, imaginary phenomena
- Rendering is covered in other computer graphics courses

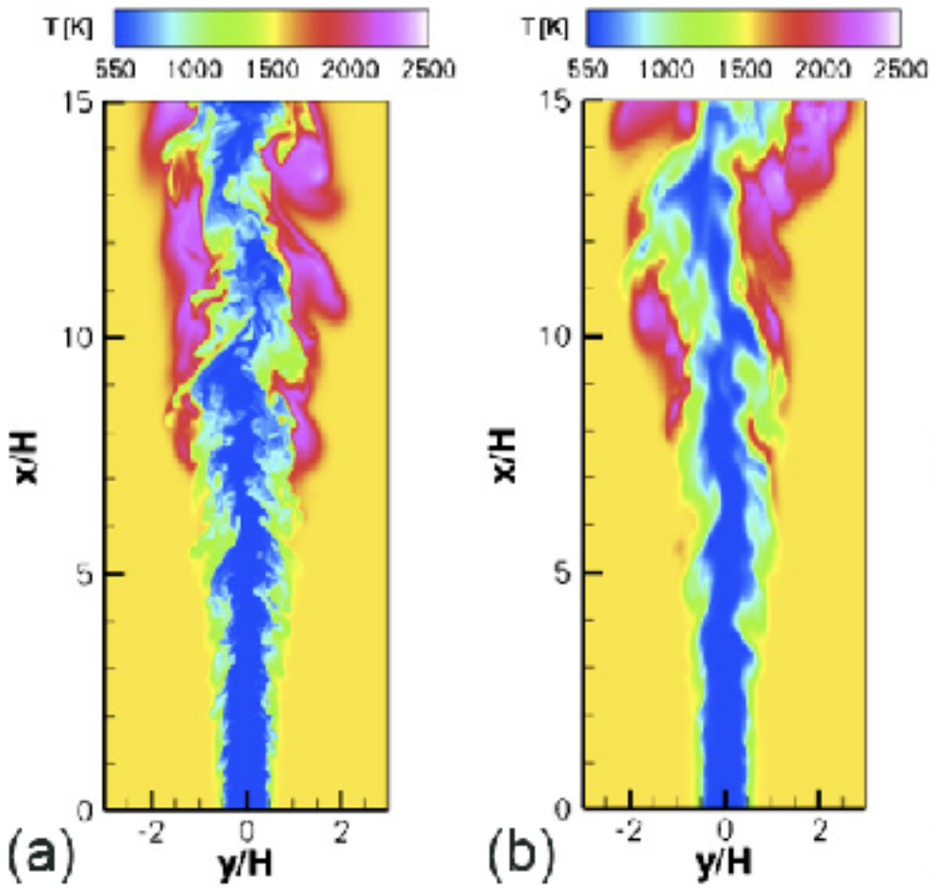
Simulation in context



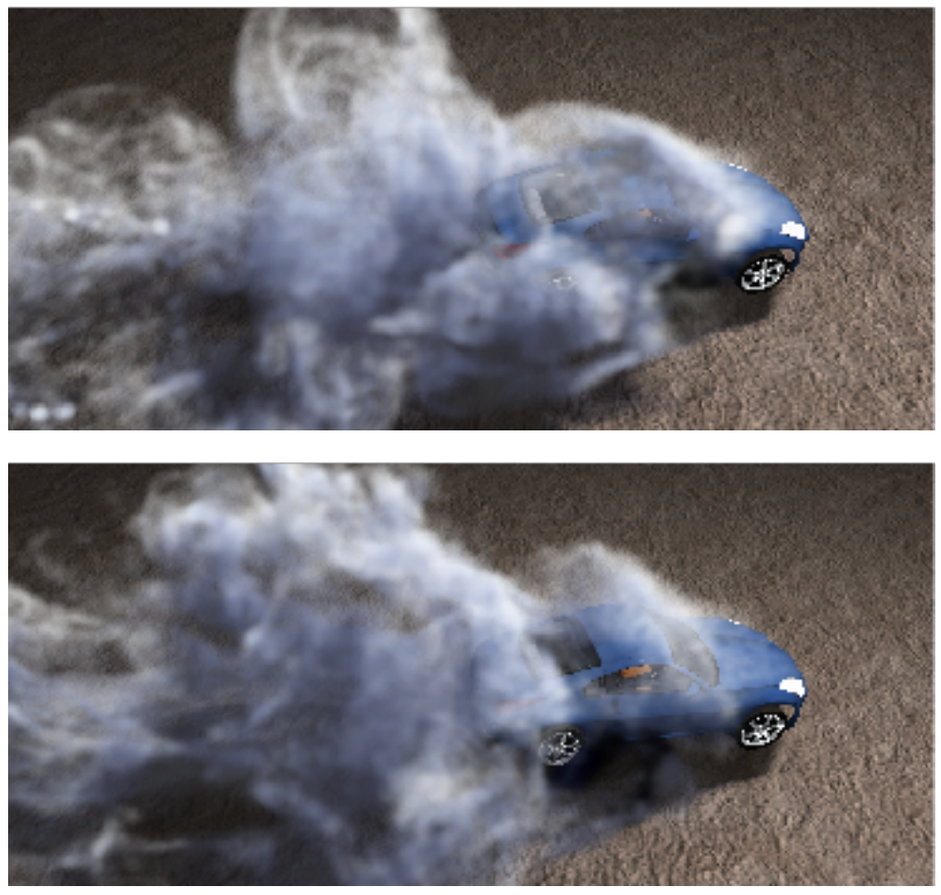
- Primary focus of this course: *mathematical models and numerical methods for animating physical phenomena*
- Three goals of numerical methods:
  - Accuracy
  - Efficiency
  - Stability
- Wait, isn't all this basically scientific computing?

Animation vs scientific computing

1. We want the computed result to be as close as possible to the correct solution. But what does “close” mean?



[Kaul et al. 2013]



[Pfaff et al. 2010]

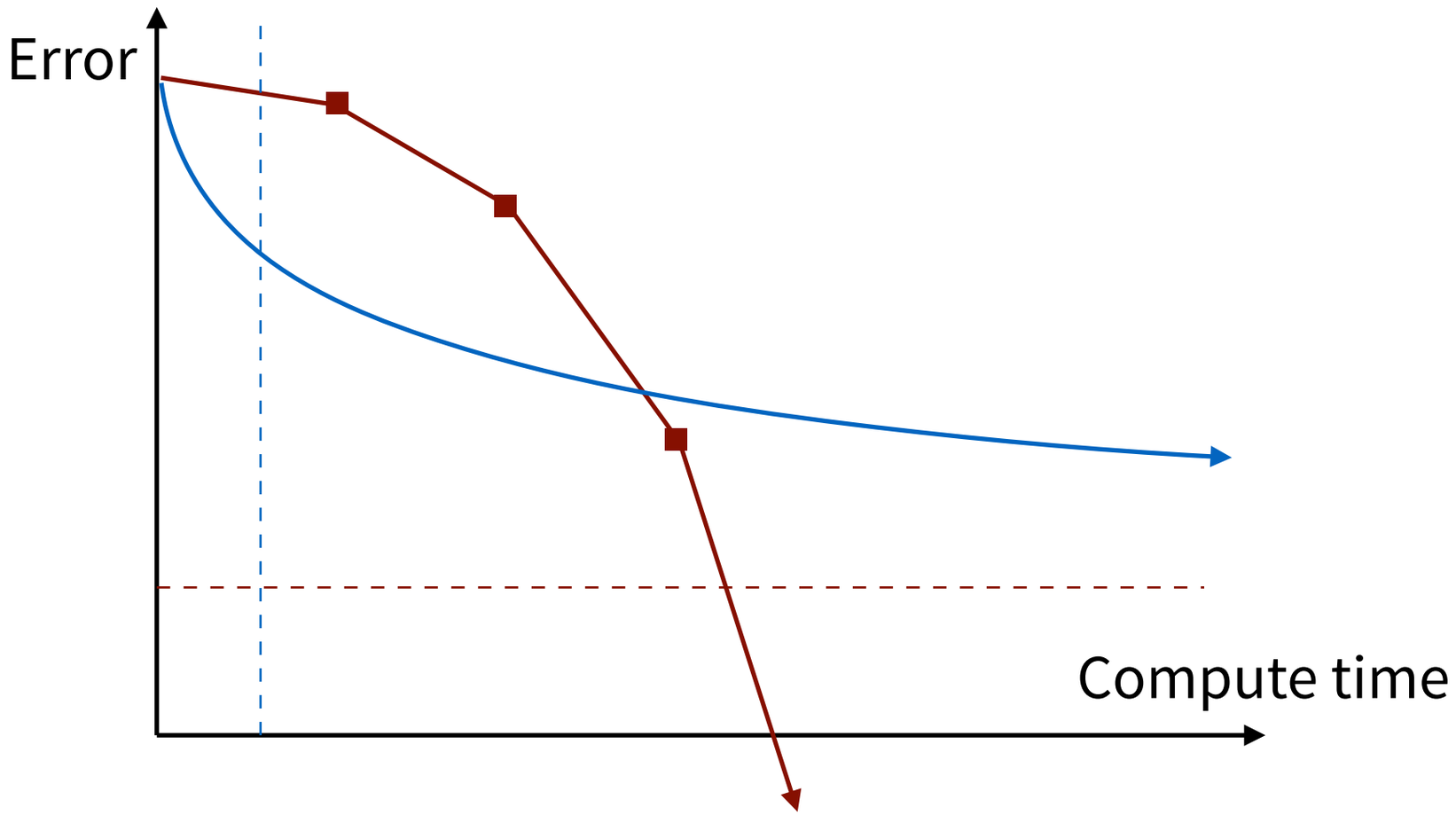
“Eyeball metric” (find a solution that *looks* good)

Animation vs scientific computing

2. Given required accuracy, find a solution as quickly as possible

   vs.

   Given limited time, find solution that's as accurate as possible



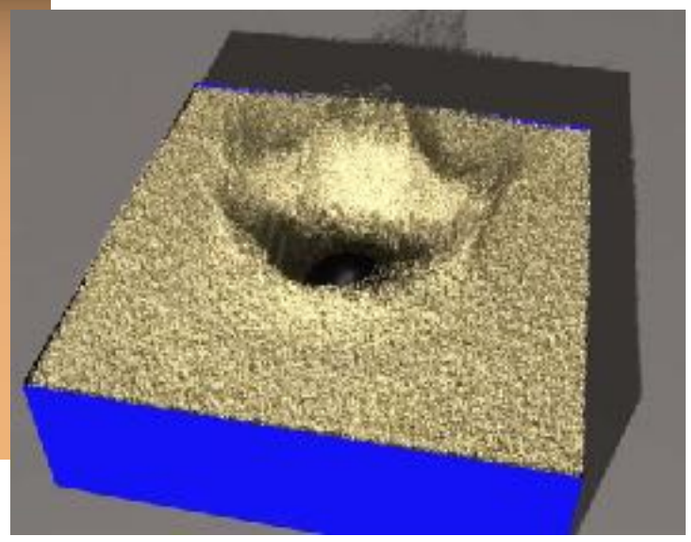
Prefer cheap low-order methods to expensive higher-order ones

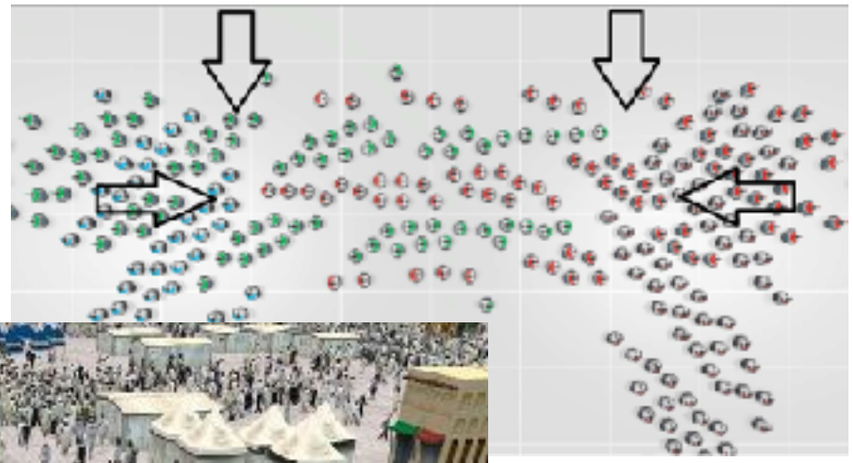
Structure of this course

Basic info

- **Instructor:**
  Rahul Narain
  http://rahul.narain.name/
  narain@cse.iitd.ac.in
- **Time and venue:**
  Slot H (Mon 11am, Wed 11am, Thu 12pm)
  Bharti IIA-305
- **Office hours:**
  Mon 12-1pm
  Bharti IIA-517

Turbulent fluids and granular materials

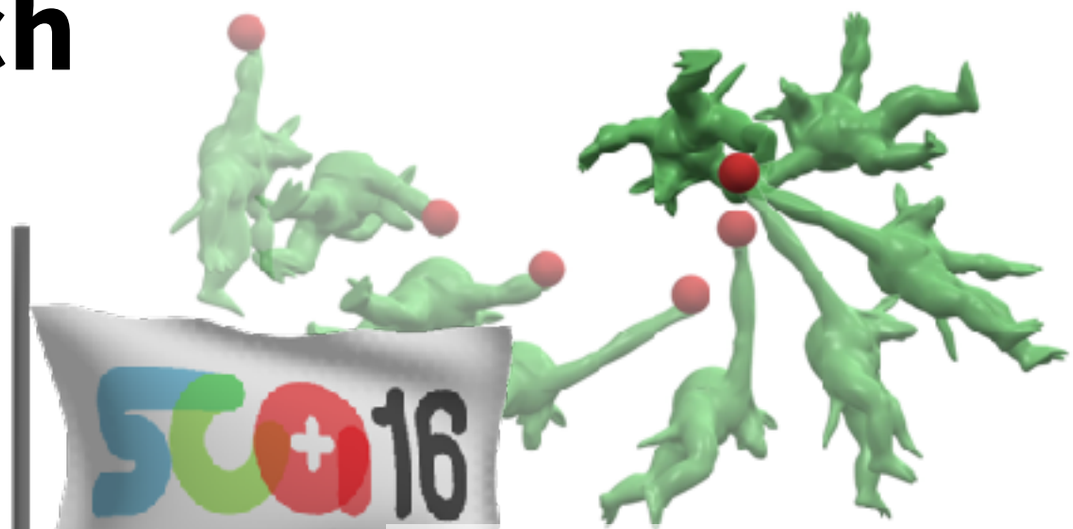




Crowd simulation

My research

Cloth modeling

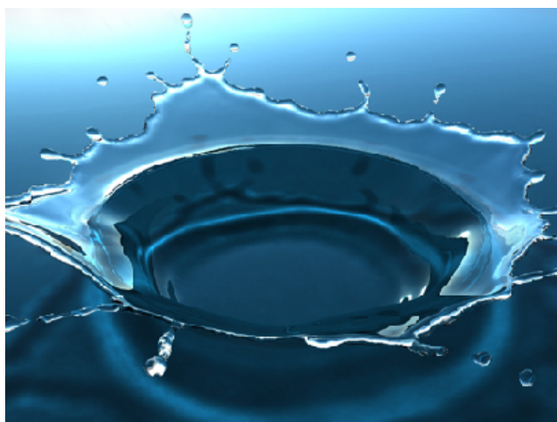


Parallel algorithms for interactive simulation

Breadth of topics

- Various topics
  - Rigid and articulated bodies, deformable objects, collisions, cloth, hair, smoke, liquids, …
  - Key numerical methods relevant to each
- Basics to sophisticated techniques to current research



Course format

- Mixture of lectures and discussions
  - Lectures for core topics
  - Paper presentations and discussions for interesting applications / related ideas
- Three programming assignments (2 weeks each)
- Final project (last month of semester)

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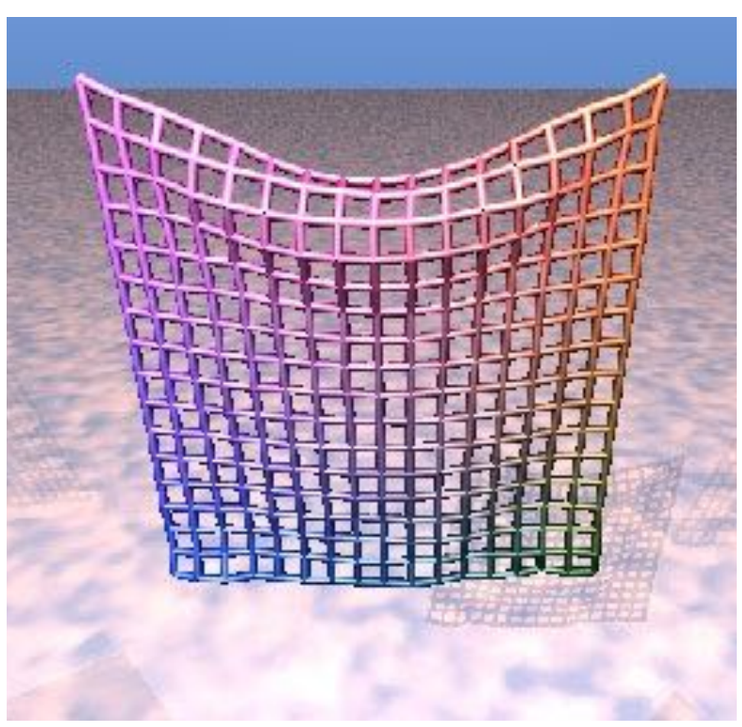
You will be evaluated on the bolded items.

Paper discussions & presentations

- **Paper discussions**
  - One student designated lead, gives 6-8 minute paper intro
  - Lead also shepherds discussion for remainder of 20 minutes
- **Paper presentations**
  - One student gives 30-40 minute presentation on a paper, answers questions afterwards
- Everyone else:
  - Must also have read paper beforehand!
  - Points for asking questions, participating in discussion

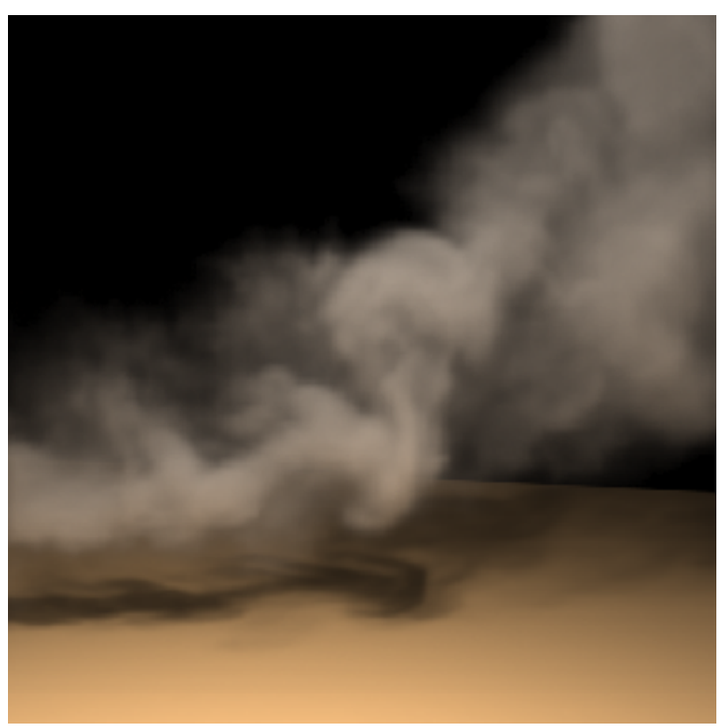
Assignments

- Each assignment has base requirement + several extras
  - Base = 60%, extras = 20% each, total capped at 100%
  - Welcome to do more than 2 extras if you want to stand out
- Submission: report + video + code



[Provot 1995]

[Bender et al. 2014]

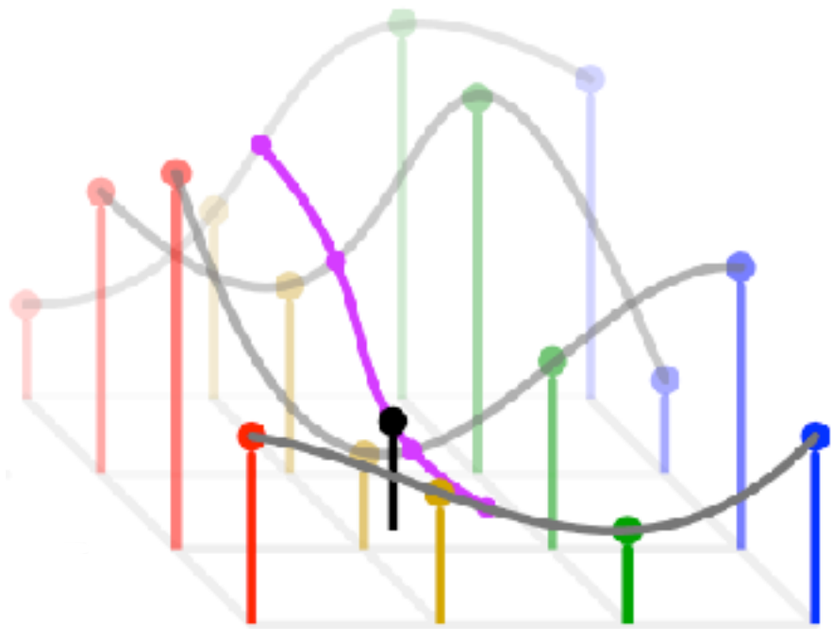


[Fedkiw et al. 2001]

Final project

- Individual or in pairs
- Your choice of topic: either choose a recent research paper to implement, or pursue a new idea extending existing methods
  - Submit a proposal soon after Assignment 3
  - Final submission due at end of semester, project demos during last two classes

Next class



- Crash course in **numerical analysis**:
  - Interpolation, numerical differentiation, numerical integration, multivariable calculus, linearization