- Related Graphics Research
  - dynamic simulations
  - optimizations & satisfying constraints
  - interactive vs. offline
  - high vs. low resolution models
  - procedural modeling
  - surface vs. volume representations
- Where does our problem fit?
  - Which aspects are most important?
  - Which things can be approximated or eliminated?

Warning…

- Lots of stuff
  - Took many people, many years to do
  - I won't explain (don't know) all the details
- Random sampling of SIGGRAPH
  - Not an exhaustive list
  - I may have missed some obviously more relevant citations… sorry!
- Interruptions encouraged!
  - Ask questions, make comments

- Related Graphics Research
  - dynamic simulations
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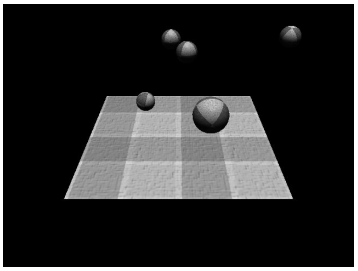
Rigid Body Dynamics

- Physics
  - Velocity
  - Acceleration
  - Angular Momentum
- Collisions
- Friction

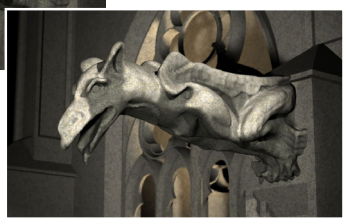


from: Darren Lewis
http://www.stanford.edu/~dalewis/cs448a/rigidbody.html

Particle Systems

based on:
Dorsey, Peterson & Hanrahan
Flow and Changes in Appearance
SIGGRAPH 1999

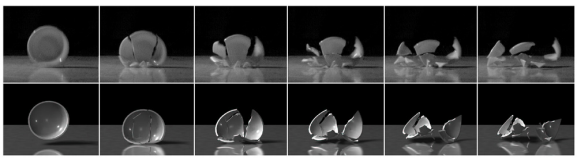
images from:
Cutler, Dorsey, McMillan, Mueller & Jagnow
A Procedural Approach to Authoring Solid Models
SIGGRAPH 2002



Fracture

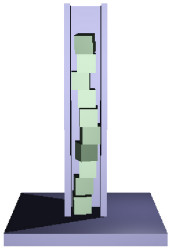
James O'Brien & Jessica Hodgins
Graphical Modeling and Animation of Brittle Fracture
SIGGRAPH 1999

- Fracture threshhold
- Remeshing
- Material properties
- Parameter tuning



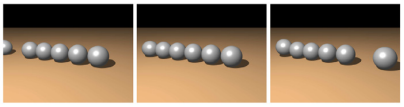
Collisions

Victor J. Milenkovic & Harald Schmidl
Optimization-Based Animation
SIGGRAPH 2001



- We know how to simulate bouncing really well
- But resting collisions are hard to manage

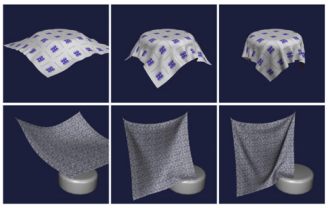
Guendelman, Bridson & Fedkiw
Nonconvex Rigid Bodies with Stacking
SIGGRAPH 2003



Cloth

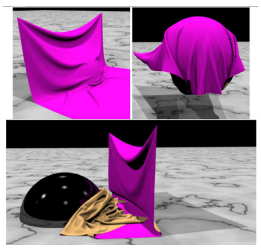
David Baraff & Andrew Witkin
Large Steps in Cloth Simulation
SIGGRAPH 1998

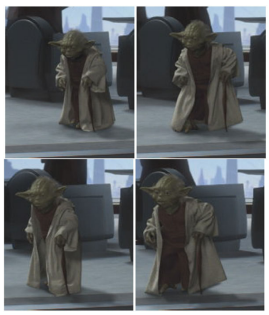
- Dynamic motion driven by animation



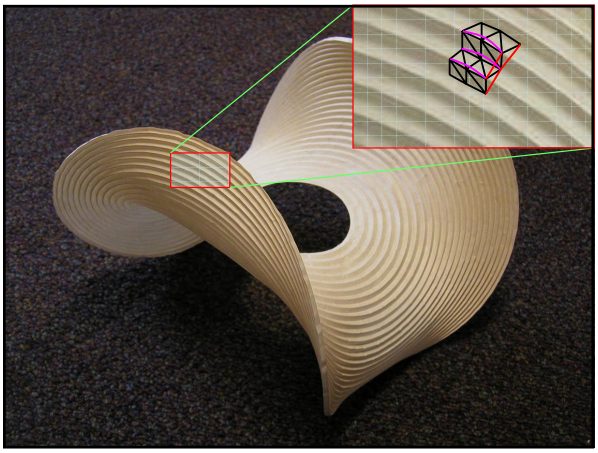
Collisions

Robert Bridson, Ronald Fedkiw & John Anderson
Robust Treatment of Collisions, Contact and Friction for Cloth Animation
SIGGRAPH 2002





- Approx 1 day to simulate (most time for collisions)



Simulations: Main Idea

- Engine: iterative solver
  - Euler, Runge-Kutta, implicit/explicit, …
  - particle systems / finite element method
  - collision detection / response
  - fracture / deformation
- Input:
  - initial conditions
  - forces
- Output:
  - animation / dynamics, frame by frame positions

- Related Graphics Research
  - dynamic simulations
  - optimizations & satisfying constraints
  - interactive vs. offline
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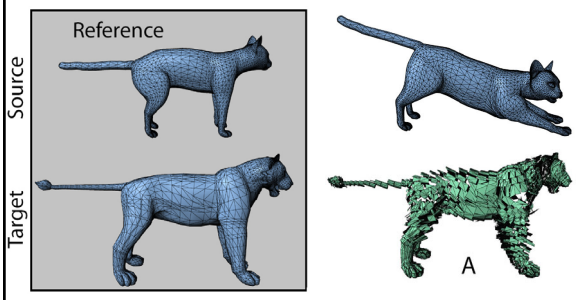
- Where does our problem fit?
  - Which aspects are most important?
  - Which things can be approximated or eliminated?

Optimization

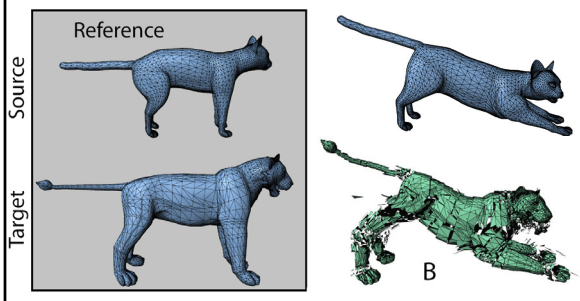
Bob Sumner & Jovan Popovic
Deformation Transfer for Triangle Meshes
SIGGRAPH 2004



apply local rotation & scale

Optimization

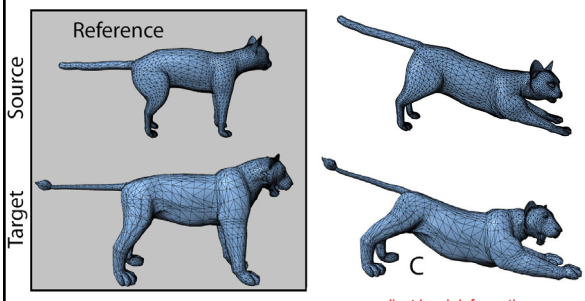
Bob Sumner & Jovan Popovic
Deformation Transfer for Triangle Meshes
SIGGRAPH 2004



apply global translation

Optimization

Bob Sumner & Jovan Popovic
Deformation Transfer for Triangle Meshes
SIGGRAPH 2004

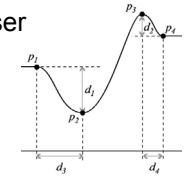


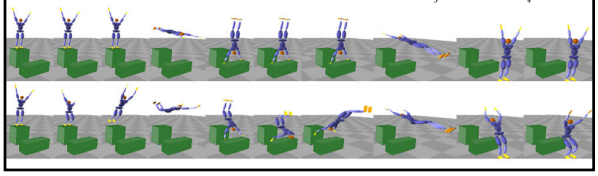
adjust local deformation
to maintain connectivity

Optimization

C. Karen Liu & Zoran Popovic
Synthesis of Complex Dynamic Character Motion from Simple Animations
SIGGRAPH 2002

- Minimal keyframes from user
- Common patterns of angular momentum (biomechanics data)

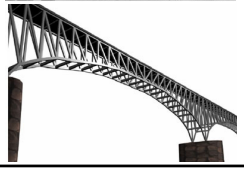




Optimization

Jeffrey Smith, Jessica Hodgins & Irving Oppenheim
Creating Models of Truss Structures with Optimization
SIGGRAPH 2002

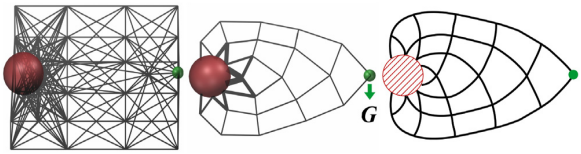
- Cross sectional, topology & geometry optimization



Optimization

Jeffrey Smith, Jessica Hodgins & Irving Oppenheim
Creating Models of Truss Structures with Optimization
SIGGRAPH 2002

- Constraints: loads, anchors, empty volumes
  - Intelligent placement of free joints can speed up convergence
- Object Function: minimize total mass



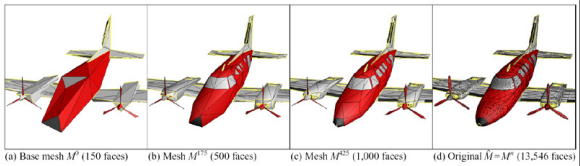
Optimization: Main Idea

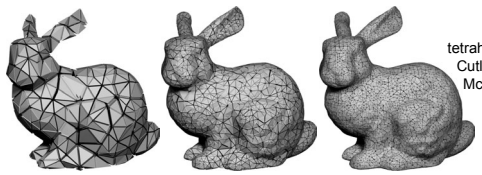
- Engine: constraints solver
  - solving is easier if system is in a particular form (e.g. linear constraints)
- Specify constraints
  - floors should be horizontal, …
- Minimize the objective/cost function
  - material, manufacturing, transportation, installation costs, …

- Related Graphics Research
  - dynamic simulations
  - optimizations & satisfying constraints
  - interactive vs. offline
  - high vs. low resolution models
  - procedural modeling
  - surface vs. volume representations
- Where does our problem fit?
  - Which aspects are most important?
  - Which things can be approximated or eliminated?

Simplification

Hughes Hoppe
Progressive Meshes
SIGGRAPH 1996



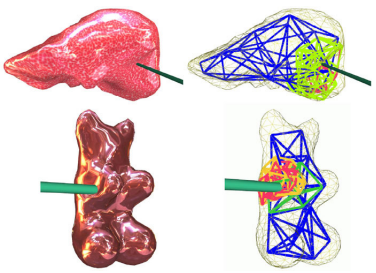


tetrahedral models:
Cutler, Dorsey & McMillan 2004

Level of Detail

Gilles Debunne , Mathieu Desbrun, Marie-Paule Cani, & Alan H. Barr
Dynamic Real-Time Deformations using Space & Time Adaptive Sampling
SIGGRAPH 2001

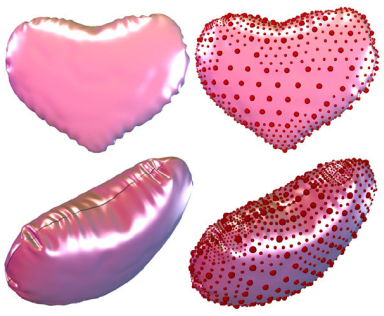
- Use high-resolution model only in areas of extreme deformation



Level of Detail

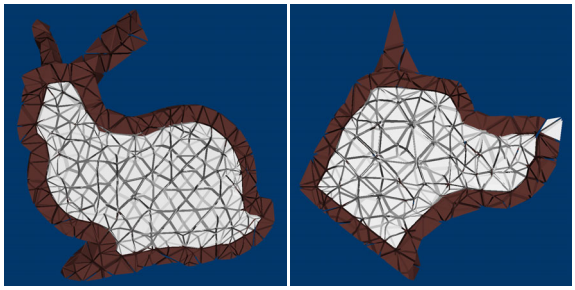
Eitan Grinspun, Petr Krysl, & Peter Schroder
CHARMS: A Simple Framework for Adaptive Simulation
SIGGRAPH 2002

- Use high-resolution where needed to get sharp creases



Simplified Physics

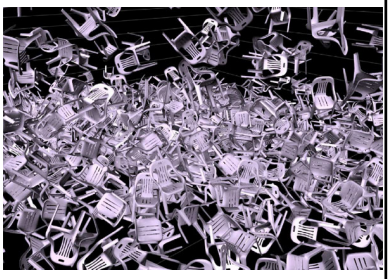
Mueller, Dorsey, McMillan, Jagnow, & Cutler
Stable Real-Time Deformations
Symposium on Computer Animation 2002



Reduced Deformation

Doug L. James & Dinesh K. Pai
BD-Tree: Output-Sensitive Collision Detection for Reduced Deformable Models
SIGGRAPH 2004

- Collisions are expensive
- Deformation is expensive
- This is a lot of geometry!
- Simplify the simulation model



Level of Detail: Main Idea

- Target Application
  - model resolution
  - level of interaction / resposiveness
- Approximation in Representation / Solver
  - acceptable errors / inaccuracies?
  - prototyping / exploration / education *vs.* final construction documents

- Related Graphics Research
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By Example

Funkhouser, Kazhdan, Shilane, Min, Kiefer, Tal, Rusinkiewicz & Dobkin
Modeling by Example
SIGGRAPH 2004

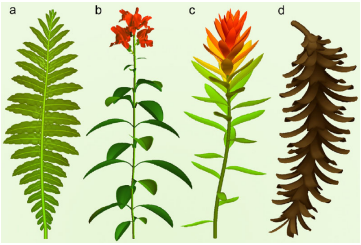
- User Interface
- Grab parts from other objects
- Connect together

L-Systems

Prusinkiewicz & team at University of Calgary
Algorithmic Botany

SIGRRAPH 1994, 1996, 1998, 2001

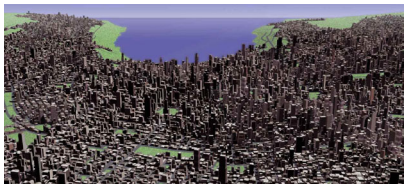
- Describe variations algorithmically
  - color
  - size
  - angle
  - density
  - shape
  - etc.



Procedural Modeling

Yoav Parish & Pascal Müller
Procedural Modeling of Cities
SIGGRAPH 2001

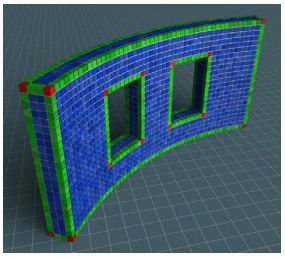
- Describe variations algorithmically
  - street layout
  - density
  - height
  - texture

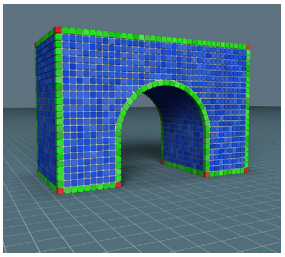


Modeling

Justin Legakis, Julie Dorsey & Steven Gortler
Feature-Based Cellular Texturing of Architectural Models
SIGGRAPH 2001

- Automatically label corners, edges, & faces

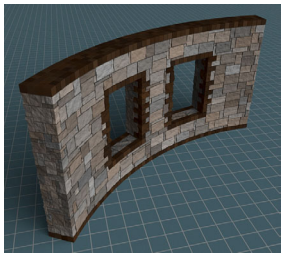


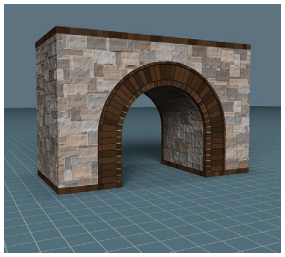


Modeling

Justin Legakis, Julie Dorsey & Steven Gortler
Feature-Based Cellular Texturing of Architectural Models
SIGGRAPH 2001

- Texture by orientation (vertical/horizontal/arch)
- Correctly wrap texture between features





Modeling

Cutler Dorsey, McMillan, Mueller & Jagnow
A Procedural Approach to Authoring Solid Models
SIGGRAPH 2002

```
STRIPED_CANDY = volume {
  distance_field = surface_mesh {
    file = "candy.obj" }
  interior_layers = {
    layer {
      material = CHOCOLATE
      thickness = fill } }
  exterior_layers = {
    layer {
      material = WHITE_CHOCOLATE
      thickness = 1.0 }
    layer {
      material = STRIPED_CHOCOLATE
      thickness = 1.0 } } }
```

Modeling: Main Idea

- User Interface
  - Modeling by example
- Procedural Modeling
  - Identify patterns / similarities
  - Develop a parameterized model

An aside: what's "Generative"?

- Procedural Modeling: Capture pattern
  - simple description → lots of complexity
- Optimization: Goal Driven
  - reverse engineer to discover proper inputs

- Related Graphics Research
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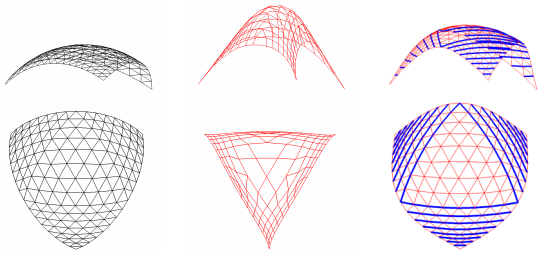
  - Which things can be approximated or eliminated?

Do We Need Dynamics?

- In many cases, we only want the *static equilibrium*, (which we can find more efficiently for larger models)



Desired Shape | Compression | Compression & Tension

When might we want Dynamics?

- (Other than "because it's fun")
- Teaching tool: builds intuition about general physics/structural principles
- To understand a particular structure
- To understand our representation, assumptions & simulation (& figure out where it's incorrect/incomplete)
- ?

Thoughts on a User Interface?

- Discuss SodaPlay?
- Where do the models come from?
  - Created with other applications?
  - How much editing do we want to support?
- What (expensive) tasks can we do offline?
- ?