CS 6650: Computational Motion (Spring 2011)

Professor: **Doug James**
5146 Upson Hall
Office Hours: after class, or by appointment
djames 'at' cs.cornell.edu

Logistics: **Mon/Wed @ 2:55--4:10pm in (Room Change: Thurston 205)**
First Class: *Wednesday, Jan 26 (please attend for more information)*

Course Description: Covers computational aspects of motion, broadly construed. Topics include the computer representation, modeling, analysis, and simulation of motion, and its relationship to various areas, including computational geometry, mesh generation, physical simulation, computer animation, robotics, biology, computer vision, acoustics, and spatio-temporal databases. Students implement several of the algorithms covered in the course and complete a final project. *This Spring 2011 offering will also explore the special role of motion processing in physically based sound rendering*.

Prerequisites: Undergraduate-level understanding of algorithms, and some scientific computing.

Grade options: Letter or S/U

Credit hours: 4

Offered: Fall only

Cross-Listing: None

Grading Rubric:
- 30% Paper presentations, and submitted questions.
- 30% Written homeworks
- 05% Project: Written proposal
- 05% Project: Mid-course show-and-tell
- 05% Project: Final public presentation
- 25% Project: Final written report

Discussion Group: http://groups.google.com/group/cornellcs6650spring2011 (restricted access to students in course)

Class Schedule: (link to fall 2008 schedule)

DATE	TOPICS	MATERIALS
Wed Jan 26	**Introduction to Computational Motion**	*Slides:* PDF *Read for next class:* Agarwal, P. K., Guibas, L. J., Edelsbrunner, H., Erickson, J., Isard, M., Har-Peled, S., Hershberger, J., Jensen, C., Kavraki, L., Koehl, P., Lin, M., Manocha, D., Metaxas, D., Mirtich, B., Mount, D., Muthukrishnan, S., Pai, D., Sacks, E., Snoeyink, J., Suri, S., and Wolefson, O. 2002. **Algorithmic issues in modeling motion.** *ACM Comput. Surv.* 34, 4 (Dec. 2002), 550-572.

MonJan31 WedFeb2	**Euler-Lagrange Equations of Motion, and Computational Complexity** $$0 = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\mathbf{q}}}\right) - \frac{\partial L}{\partial \mathbf{q}}$$	**Discussion:** ***Algorithmic issues in modeling motion*** [Agarwal et al. 2002]. **References for Lagrangian dynamics:** • V.I. Arnold, **Mathematical Methods of Classical Mechanics**, Springer, 2nd edition, 1989. (more mathematical text) • H. Goldstein et al., **Classical Mechanics**, Addison Wesley, 3rd edition, 2001. (standard ugrad physics text) • S.T. Thornton and J.B. Marion, **Classical Dynamics of Particles and Systems**, Brooks Cole, 5th edition, 2003. (easier ugrad physics text) **Topics discussed:** • N-body problems (all-pairs complexity) • Reduced-coordinate deformable bodies (spatial/integration complexity) • 2D serial manipulator (recursive complexity) **Read for MonFeb7 class:** [Baraff & Witkin 1998] • Post discussion comments on group *before* class. **Assignment #1 for Wed Feb 9 (homework due in class):** Regarding the simplified N-body planar serial manipulator from class: Given joint angles and velocities, what is the complexity of naive evaluation of joint accelerations from the expanded Euler-Lagrange equations? Provide evidence to support your claim using the equations.

MonFeb7	**Deformable Models:**
	Cloth Motion
		Topics discussed:
		• Modeling cloth with energy terms
		• Implicit integration
		• *Tensor calculus recap:* Discussed differentiating the following quantities with respect to particle position vectors, p_i:
		  ◦ constant, c
		  ◦ position, p_j
		  ◦ vectors, (p_j-p_k)
		  ◦ distances, ‖p_j-p_k‖
		  ◦ distance powers, ‖p_j-p_k‖^n

- dot products, (p_1-p_0)^T (p_3-p_2)
- cross products
- ...

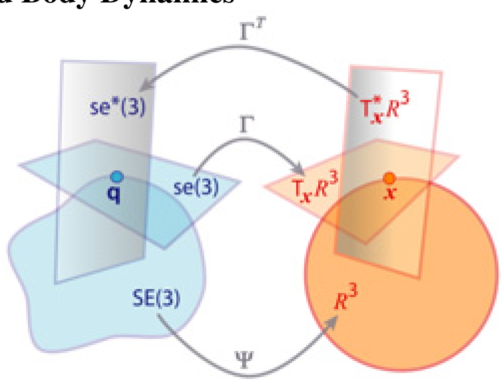
References:

- Baraff, D. and Witkin, A. 1998. **Large steps in cloth simulation.** In Proceedings of the 25th Annual Conference on Computer Graphics and interactive Techniques SIGGRAPH '98. ACM, New York, NY, 43-54.
- Jonathan Richard Shewchuk, ***An Introduction to the Conjugate Gradient Method Without the Agonizing Pain***, August 1994. **PDF (516k, 58 pages)**
- Discussion group posts

Assignment #2 for Mon Feb 21 class (homework due in class): Derive forces/Jacobians for [Baraff & Witkin 1998] (assignment (PDF)).

WedFeb9
MonFeb14

Rigid Body Dynamics



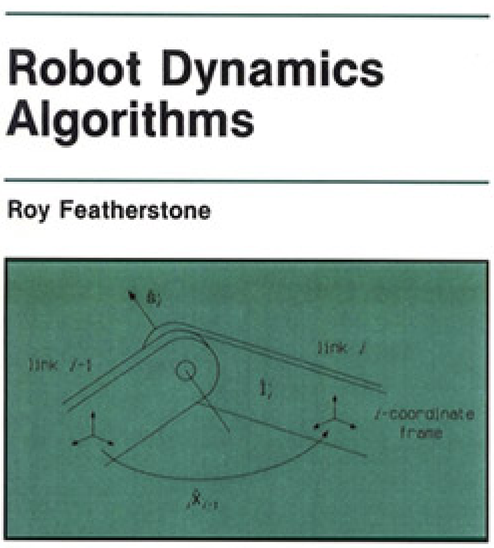
Topics discussed:

- Rotational and rigid motion; kinematics and dynamics
- SO(3), Special Orthogonal group in 3D
- SE(3), Special Euclidean group in 3D
- Rigid-body motion
- Spatial velocity vectors (contravariant twists); se(3); transformation
- Kinetic energy; inertia, principal axes
- Spatial forces (covariant wrenches); se*(3); transformation
- Velocity of contact points, and relation to twists
- Forces at contact points, and relation to wrenches
- Newton-Euler equations of motion
- Integrating rigid-body dynamics
- Deformable bodies; mode matrix, U; extensions to framework

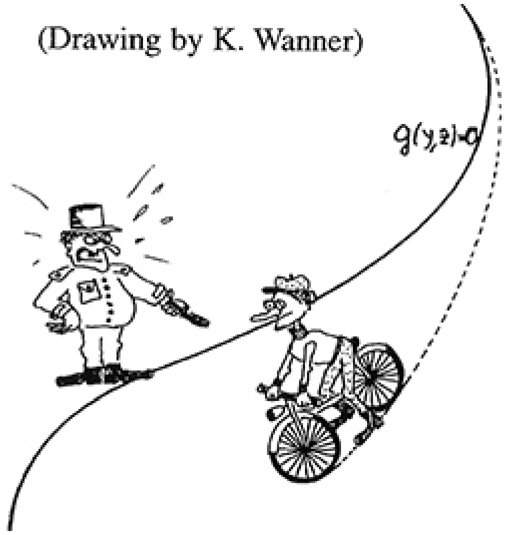
References:

- David Baraff and Andrew Witkin, **Physically Based Modeling**, Online SIGGRAPH 2001 Course Notes, 2001.
  - Rigid Body Simulation (slides)
- Murray, R. M., Sastry, S. S., and Zexiang, Li, **A Mathematical Introduction to**

		Robotic Manipulation. 1st. CRC Press, Inc., 1994. • See summary in appendix of: ◦ Danny M. Kaufman, Timothy Edmunds and Dinesh K. Pai, **Fast Frictional Dynamics for Rigid Bodies**, ACM Transactions on Graphics (SIGGRAPH 2005), 24(3), August 2005. • Ball's **screw theory** • Ahmed A. Shabana, **Dynamics of Multibody Systems**, Cambridge, 3rd ed, 2005.
	Discussion: **Parallel Rigid-Body Dynamics**	**Reference:** • Takahiro Harada, **Real-Time Rigid Body Simulation on GPUs**, GPU Gems 3, 2007. ◦ A simple parallel method for RB dynamics with penalty contact.

MonFeb14
WedFeb16
	Robot Dynamics Algorithms
	
		Topics discussed:
		• Algorithms overview
		  ◦ Forward and inverse kinematics
		  ◦ Inverse dynamics (control)
		  ◦ Forward dynamics (simulation)
		• Notation
		• Recurrence relations
		• Recursive Newton-Euler Algorithm (RNEA)
		  ◦ O(N) inverse dynamics
		• Composite-Rigid-Body Algorithm (CRBA)
		  ◦ O(n^2) mass matrix
		  ◦ Usage in O(N^3) forward dynamics (CRBA + RNEA + dense solve)
		• Articulated-Body Algorithm (ABA)
		  ◦ a.k.a. "Featherstone's algorithm"
		  ◦ O(N) forward dynamics
		• Closed-loop systems
		  ◦ Constraints and fast solution methods
		• Global analysis techniques
		  ◦ Fast robot algorithms as sparse matrix methods
		
		References:
		• Roy Featherstone and David Orin, **Robot Dynamics: Equations and Algorithms**, Proc. IEEE Int. Conf. Robotics & Automation, San Francisco, CA, 2000, pp.

		826–834. (an excellent review) • Roy Featherstone, **Robot Dynamics Algorithms**, Kluwer Academic Publishers, 1987. (classic book--highly readable) • Roy Featherstone, **A Divide-and-Conquer Articulated-Body Algorithm for Parallel O(log(n)) Calculation of Rigid-Body Dynamics. Part 1: Basic Algorithm**, The International Journal of Robotics Research, Vol. 18, No. 9, 867-875, 1999. (has good appendix on spatial notation) • Roy Featherstone, **Rigid Body Dynamics Algorithms**, Boston: Springer, 2007. • E. Kokkevis, **Practical Physics for Articulated Characters**, Proc. of Game Developers Conference (GDC), 2004. (good overview of system integration issues for ABA, e.g., handling contact and constraints) • David Baraff, **Linear-Time Dynamics using Lagrange Multipliers**, Proceedings of SIGGRAPH 96, Computer Graphics Proceedings, Annual Conference Series, August 1996, pp. 137-146. • Robot dynamics, Scholarpedia page. • D.K. Pai, **STRANDS: Interactive Simulation of Thin Solids using Cosserat Models**, Computer Graphics Forum, 21(3), pp. 347-352, 2002.
MonFeb21	**Discussion:** **Articulated Body Algorithm (ABA)**	**Reference:** • E. Kokkevis, **Practical Physics for Articulated Characters**, Proc. of Game Developers Conference (GDC), 2004. (good overview of system integration issues for ABA, e.g., handling contact and constraints)
MonFeb21	**Constrained Dynamics and Differential-Algebraic Equations (DAEs)**	**References for Differential-Algebraic Equations (DAEs):** • U.M. Ascher and L.R. Petzold, **Computer Methods for Ordinary Differential Equations and Differential-Algebraic Equations**, SIAM. • E. Hairer and G. Wanner, **Solving Ordinary Differential Equations II: Stiff and Differential-Algebraic Problems**, 2nd edition, Springer, 1996. ◦ See Chapter VII.(1-2) Differential-Algebraic Equations of Higher



Index

Topics discussed:

- **Constrained Lagrangian dynamics (CLD)**
  - Holonomic constraints
  - Constraint-augmented Lagrangian
  - Examples, e.g., pendulum
- **DAE systems**
  - Differentiation index
  - Structure of index-1, -2, and -3 DAE systems
  - Index reduction by differentiation
  - Drift-off phenomena

WedFeb23

Integrating Constrained Dynamics

$$\begin{aligned} \dot{y} &= f(y, z) \\ 0 &= g(y) \\ &\Downarrow \\ y_1 &= y_0 + h f(y_0, z_0) \\ 0 &= g(y_1) \end{aligned}$$

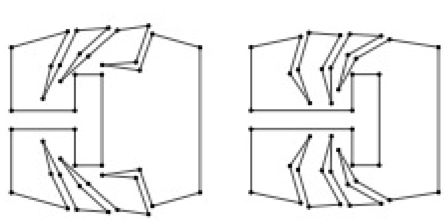
Topics discussed:

- Constrained Lagrangian dynamics in index-1, -2, -3 and GGL DAE forms
- Solving for Lagrange multiplier from index-1 form.
- Constraint stabilization:
  - Baumgarte's method; modified Lagrange multiplier
  - Projection (position, velocity)
- Implicit integration of DAEs (for stiff problems)
  - General DAEs, and semi-explicit index-1 DAEs
  - Backwards Euler
  - BDF and multistep methods
- Half-explicit Runge-Kutta methods
- Methods for ODEs on manifolds
  - Poststabilization
  - Coordinate projection (c.f. coordinate resetting)
  - Hamiltonian dynamics; energy conservation
  - Symplectic integrators w/ constraints (SHAKE & RATTLE)

Additional CLD reference:
David Baraff and Andrew Witkin, **Physically Based Modeling**, Online SIGGRAPH 2001 Course Notes, 2001.

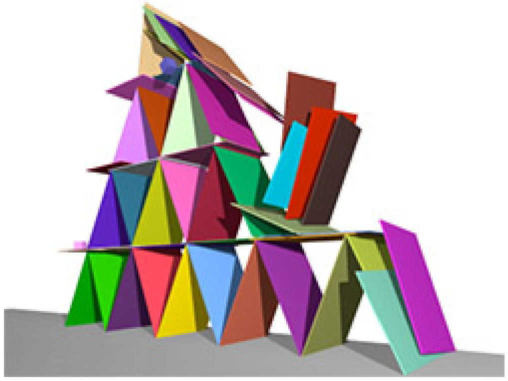
WedFeb23

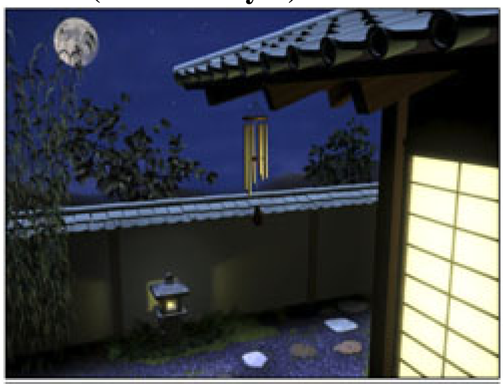
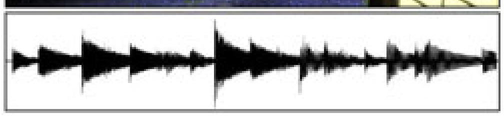
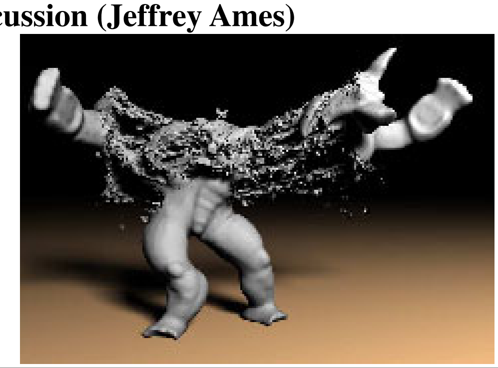
Discussion (Andrew Spielberg)



Reference:

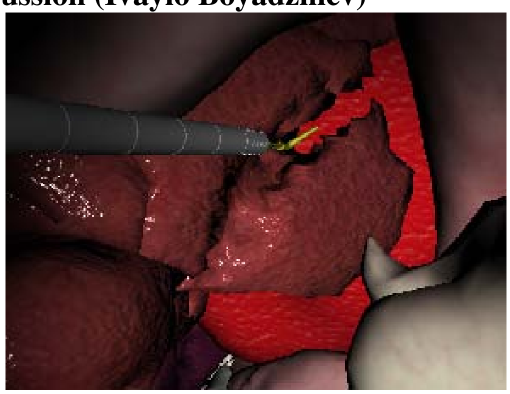
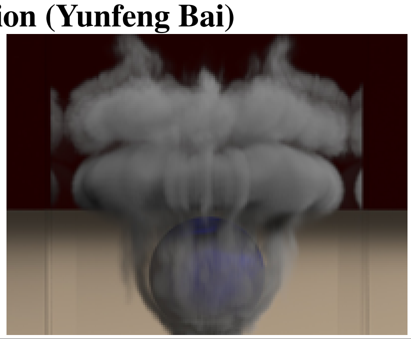
- Hayley N. Iben, James F. O'Brien, and Erik D. Demaine. **"Refolding Planar Polygons"**. *Discrete and Computational Geometry*, 41(3):444–460, April 2009.

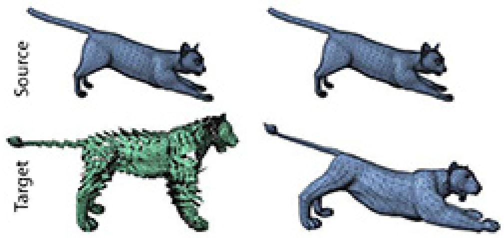
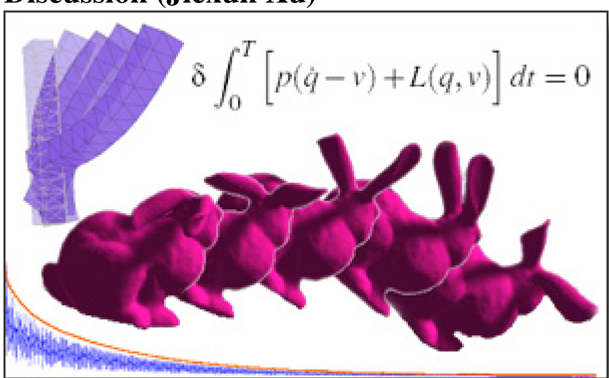
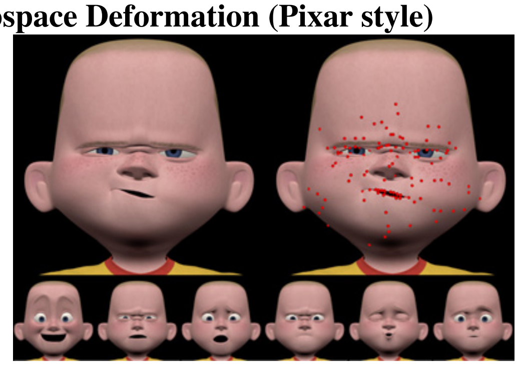
MonFeb28	**Frictional Contact** 	**Topics discussed:**
		• Impact models; restitution coefficient
		• Nonpenetration constraints
		• Linear complementarity problems (LCP); QP formulations; Dantzig's algorithm
		• Friction
		• Painleve's paradox; frictional indeterminacy; frictional inconsistency; the importance of impulses
		• Velocity-level contact formulation
		• The myth of "contact points"; distributed friction forces; planar sliding; center of friction
		• Contacting multibody systems
		  ◦ Nonpenetration constraints; Signorini-Fichera condition
		  ◦ Maximal dissipation principle
		• "Staggered Projections" contact algorithm
		• Iterative solvers; projected Gauss-Seidel methods
		
		References:
		• D.E. Stewart, **Rigid-Body Dynamics with Friction and Impact**, SIAM Review, 42(1), pp. 3-39, 2000.
		• D. Baraff, **Fast contact force computation for nonpenetrating rigid bodies**, Computer Graphics Proceedings, Annual Conference Series: 23-34, 1994. *(cover's Dantzig's algorithm)*
		• D. Baraff, **Coping with friction for non-penetrating rigid body simulation**, Computer Graphics 25(4): 31-40, 1991. *(cover's frictional indeterminacy & inconsistency)*
		• Danny M. Kaufman, Shinjiro Sueda, Doug L. James and Dinesh K. Pai, **Staggered Projections for Frictional Contact in Multibody Systems**, ACM Trans. Graph. (Proc. SIGGRAPH Asia), 27, 2008.
		• Brian Mirtich, **Impulse-based Dynamic Simulation of Rigid Body Systems**, Ph.D. thesis, UC Berkeley, 1996.
		• Eran Guendelman , Robert Bridson , Ronald Fedkiw, **Nonconvex rigid bodies with stacking**, ACM Transactions on Graphics (TOG), v.22 n.3, July 2003 [doi>10.1145/882262.882358] *(good example of a velocity-level iterative contact solver)*
		• Kenny Erleben, **Velocity-based shock propagation for multibody dynamics**

		animation, ACM Transactions on Graphics, 26(2), June 2007, pp. 12:1-12:20. *(good summary of a velocity-level projected Gauss-Seidel contact solver)* • Christopher D. Twigg, Doug L. James, **Backward Steps in Rigid Body Simulation**, ACM Transactions on Graphics, 27(3), August 2008, pp. 25:1-25:10. *(see for summary of velocity-level contact problem)*
MonFeb28	**Discussion (Chuck Moyes)**  	**Reference:** • James F. O'Brien , Chen Shen , Christine M. Gatchalian, Synthesizing sounds from rigid-body simulations, Proceedings of the 2002 ACM SIGGRAPH/Eurographics symposium on Computer animation, July 21-22, 2002, San Antonio, Texas
WedMar2	**Frictional Contact (cont'd)**	
WedMar2	**Discussion (Jeffrey Ames)** 	**Reference:** • Molino, N., Bao, Z. and Fedkiw, R., "A Virtual Node Algorithm for Changing Mesh Topology During Simulation", SIGGRAPH 2004, ACM TOG 23, 385-392 (2004).
MonMar7	**No class (PhD Visit Day)** **--> Project planning day**	**Work on project proposals:** • **Hand in proposal in Wednesday Feb 9 class.** • **Get feedback then get cracking.**
WedMar9	**Course Project Discussion**	**Agenda:** • Discussion of [Parker and O'Brien 2009] • Submit project proposals • Informal discussion of proposed course projects; revisions • BOOM Showcase at 4pm

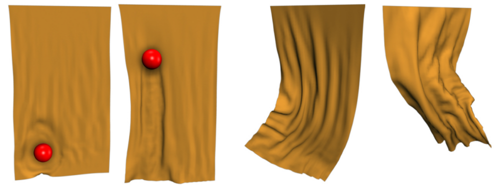
WedMar9	**Discussion (Himanshu Bhatia & Jonathan Hirschberg)** 	**Reference:** • Eric G. Parker and James F. O'Brien. "**Real-Time Deformation and Fracture in a Game Environment**". In *Proceedings of the ACM SIGGRAPH/Eurographics Symposium on Computer Animation*, pages 156–166, August 2009.
MonMar14	**Friction Contact (cont'd): Staggered Projections**	
WedMar16 MonMar28 WedMar30	**Incompressible Flow** 	**Topics discussed:** • Advection; upwind differencing; ENO schemes • Incompressibility constraint • Navier-Stokes equation • MAC grid discretization; interpolation and averaging; upwinding • Time-stepping schemes (Eulerian, and semi-Lagrangian) • Projection to divergence-free velocity • Poisson equation; discretization; compatibility condition; PCG solution • DAE view of incompressible flow • Higher-order semi-Lagrangian schemes; monotone interpolation; BFECC; CIP and USCIP **Reference:** • S. Osher and R. Fedkiw, **Level Set Methods and Dynamic Implicit Surfaces**, Applied Mathematical Sciences, volume 153, Springer-Verlag, 2003. • U.M. Ascher and L.R. Petzold, **Computer Methods for Ordinary Differential Equations and Differential-Algebraic Equations**, SIAM. • Jos Stam, **Stable Fluids**, Proceedings of SIGGRAPH 99, Computer Graphics Proceedings, Annual Conference Series, August 1999, pp. 121-128. ◦ Slides and notes • Ronald Fedkiw, Jos Stam, Henrik Wann Jensen, **Visual Simulation of Smoke**, Proceedings of ACM SIGGRAPH 2001, Computer Graphics Proceedings, Annual Conference Series, August 2001, pp. 15-22. (introduces *vorticity confinement* forces)

- Bridson, R., Fedkiw, R., and Muller-Fischer, M. 2006. **Fluid simulation: SIGGRAPH 2006 course notes**, In ACM SIGGRAPH 2006 Courses (Boston, Massachusetts, July 30 - August 03, 2006). SIGGRAPH '06. ACM Press, New York, NY, 1-87. [Slides]
- Foster, N. and Fedkiw, R., **Practical Animation of Liquids**, SIGGRAPH 2001, 15-22 (2001).
- Enright, D., Marschner, S. and Fedkiw, R., **Animation and Rendering of Complex Water Surfaces**, SIGGRAPH 2002, ACM TOG 21, 736-744 (2002).
- Yongning Zhu , Robert Bridson, **Animating sand as a fluid**, ACM Transactions on Graphics (TOG), v.24 n.3, July 2005. (Discusses PIC and FLIP hybrid particle/grid methods)
- Higher-order advection schemes:
    - BFECC and MacCormack methods:
        - Byungmoon Kim, Yingjie Liu, Ignacio Llamas, Jarek Rossignac, ***Advections with Significantly Reduced Dissipation and Diffusion***, IEEE Transactions on Visualization and Computer Graphics, Volume 13, Issue 1, Pages 135-144, 2007. video(DivX)
        - Selle, A., Fedkiw, R., Kim, B., Liu, Y., and Rossignac, J. 2008. An **Unconditionally Stable MacCormack Method**. *J. Sci. Comput*. 35, 2-3 (Jun. 2008), 350-371.
    - Methods with small stencils (constrained interpolation profile (CIP)):
        - Doyub Kim, Oh-young Song, Hyeong-Seok Ko, **A Semi-Lagrangian CIP Fluid Solver without Dimensional Splitting**, Computer Graphics Forum, 27(2), April 2008, pp. 467-475. (**project page** with videos)
- A projection method to approximate complex boundaries:
    - Jeroen Molemaker, Jonathan M. Cohen, Sanjit Patel, Jun-yong Noh. **Low Viscosity Flow Simulations**

		for Animation. Symposium on Computer Animation 2008. [video (mpeg4)] • Multigrid Poisson solver ◦ A. McAdams, E. Sifakis, J. Teran, ***A Parallel Multigrid Poisson Solver for Fluids Simulation on Large Grids***, ACM SIGGRAPH/Eurographics Symposium on Computer Animation (SCA) edited by M. Otaduy and Z. Popovic, pp.1-10, 2010. [PDF] [Video+Code] • A coarse-grid Poisson solver ◦ Lentine, M., Zheng, W., and Fedkiw, R., **A Novel Algorithm for Incompressible Flow Using Only A Coarse Grid Projection**, SIGGRAPH 2010, ACM TOG 29, 4 (2010). [**Video**]
MonMar21 WedMar23	**Spring Break (No classes)**	
MonMar28	**Discussion (Ivaylo Boyadzhiev)** 	Hadrien Courtecuisse, Hoeryong Jung, Jérémie Allard, Christian Duriez, Doo Yong Lee, Stéphane Cotin, **GPU-based Real-Time Soft Tissue Deformation with Cutting and Haptic Feedback,** Progress in Biophysics and Molecular Biology 103, 2-3, pages 159–168 - December 2010, doi:10.1016/j.pbiomolbio.2010.09.016, Special Issue on Soft Tissue Modelling • PDF: GPU-based Real-Time Soft Tissue Deformation with Cutting and Haptic Feedback
WedMar30	**Discussion (Yunfeng Bai)** 	Lentine, M., Zheng, W., and Fedkiw, R., **A Novel Algorithm for Incompressible Flow Using Only A Coarse Grid Projection**, SIGGRAPH 2010, ACM TOG 29, 4 (2010). [**Video**]
Mon4Apr	**Project Updates**	**Description:** • Each project group will give a short 5-minute presentation on their project topic, current results/progress, and goals for the remaining month.

<table>
<tr><td>Wed6Apr
Mon11Apr</td><td>Gradient-Domain Shape and Deformable Motion Modeling

</td><td>References:
Robert W. Sumner, Jovan Popović, Deformation transfer for triangle meshes, ACM Transactions on Graphics, 23(3), August 2004, pp. 399-405.
Robert W. Sumner, Matthias Zwicker, Craig Gotsman, Jovan Popović, Mesh-based Inverse Kinematics, ACM Transactions on Graphics, 24(3), August 2005, pp. 488-495.</td></tr>
<tr><td>Wed6Apr</td><td>Discussion (Jiexun Xu)

</td><td>Geometric, Variational Integrators for Computer Animation
L. Kharevych, Weiwei, Y. Tong, E. Kanso, J. E. Marsden, P. Schröder, and Mathieu Desbrun
ACM/EG Symposium on Computer Animation 2006, pp. 43-51</td></tr>
<tr><td>Mon11Apr</td><td>Subspace Deformation (Pixar style)
</td><td>References:
Mark Meyer, John Anderson, Key Point Subspace Acceleration and Soft Caching, ACM Transactions on Graphics, 26(3), July 2007, pp. 74:1-74:8.
Pushkar Joshi, Mark Meyer, Tony DeRose, Brian Green, Tom Sanocki, Harmonic Coordinates for Character Articulation, ACM Transactions on Graphics, 26(3), July 2007, pp. 71:1-71:9.</td></tr>
<tr><td>Wed13Apr
Mon18Apr</td><td>Collision Detection, and
Subspace Deformation Bounds
</td><td>Topics discussed:
Bounding volumes (spheres, boxes, k-DOPs, etc)
Separating axis theorem
Space-time bounds
Bounding moving points
Bounding subspace deformations;
Bounded Deformation Trees
O(r) and O(1) updates
Spheres, boxes, k-DOPs
Translational and affine/rotational models
References:</td></tr>
</table>

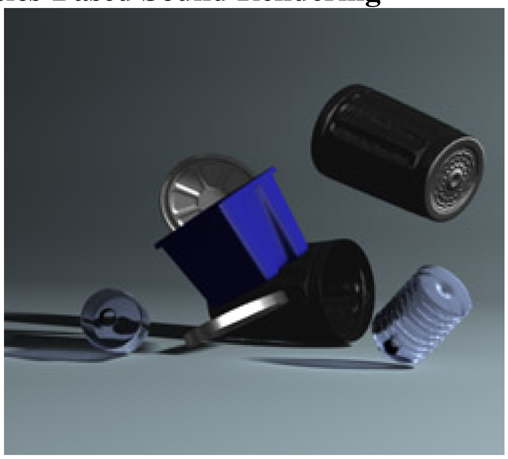
		• Philip M. Hubbard. 1996. **Approximating polyhedra with spheres for time-critical collision detection**. *ACM Trans. Graph.* 15, 3 (July 1996), 179-210. DOI=10.1145/231731.231732 http://doi.acm.org/10.1145/231731.231732 • B. Gaertner, **Fast and Robust Smallest Enclosing Balls**, Lecture Notes in Computer Science, Springer, pp. 325-338, 1999. • **Miniball software**, Smallest Enclosing Balls of Points - Fast and Robust in C++. • Doug L. James, Dinesh K. Pai, **BD-Tree: Output-sensitive collision detection for reduced deformable models**, ACM Transactions on Graphics, 23(3), August 2004, pp. 393-398. [SIGGRAPH Talk] • M. Teschner et al., **Collision Detection for Deformable Objects**, Eurographics State-of-the-Art Report (EG-STAR), Eurographics Association, pages 119-139, 2004. • Jernej Barbič and Doug L. James, **Six-DoF haptic rendering of contact between geometrically complex reduced deformable models**, IEEE Transactions on Haptics, 1(1):39–52, 2008. [Project page] **Assignment for Mon May 9:** Building on the affine motion model (described for spheres in class), propose a tight 6-DOP deformation bound that supports large rotations (is affine invariant) and has an O(r) update cost for r displacement modes.
Wed13Apr	**Discussion (Kevin Matzen)** **http://graphics.stanford.edu/projects/pbaepmo-04/image.gif**	M. Müller, R. Keiser, A. Nealen, M. Pauly, M. Gross, M. Alexa, **Point Based Animation of Elastic, Plastic and Melting Objects**, SCA 2004. http://graphics.ethz.ch/disclaimer.php?dlurl=/Downloads/Publications/Papers/2004/Mue04c/Mue04c.pdf **Videos**: http://graphics.ethz.ch/Downloads/Publications/PaperVideos/2004/Mue04c%20Matthias_Mueller%20-%20PBA_Elatsic_Plastic_Melting%20-%20SCA04.avi http://graphics.ethz.ch/Downloads/Publications/PaperVideos/2004/Mue04c%20Matthias_Mueller%20-%20PBA_Elatsic_Plastic_Melting2%20-%20SCA04.avi
Mon18Apr	**Discussion (Nathan Lloyd & Greg Sadowski)**	Oktar Ozgen, Marcelo Kallmann, Lynnette Es Ramirez, Carlos Fm Coimbra, **Underwater cloth simulation with fractional derivatives**,



ACM Transactions on Graphics, 29(3), June 2010, pp. 23:1-23:9.

Wed20Apr

Subspace Dynamics;
Physics-Based Sound Rendering



Topics discussed:

- Dimensional model reduction
  - linear & nonlinear dynamics
  - linear integration; IIR digital filter
  - generalized eigenvalue problem; mass normalization
- Newmark integration
  - full vs subspace
  - explicit & implicit
- Reduced-order deformation force models
  - exact reductions (linear, StVK)
  - approximations (cubature)
- Reduced-order fluids
- Sound rendering
  - rigid bodies
  - nonlinear thin shells; mode coupling

References:

- S. R. Idelsohn and A. Cardona, **A Reduction Method for Nonlinear Structural Dynamic Analysis**, Computer Methods in Applied Mechanics and Engineering 49, 253-279, 1985.
- A. A. Shabana, **Theory of Vibration (Volume II: Discrete and Continuous Systems)**, Springer-Verlag, New York, NY, 1990.
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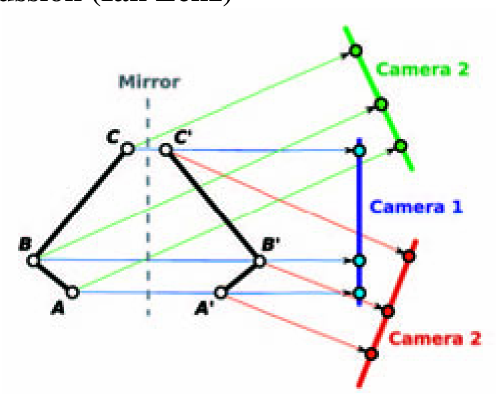
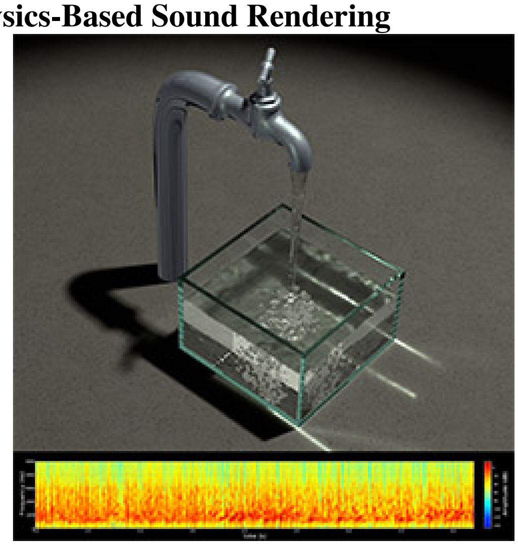
Wed20Apr	**Discussion (Ian Lenz)** 	Ozden, K.E.; Schindler, K.; Van Gool, L.; **Multibody Structure-from-Motion in Practice**, *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol.32, no.6, pp.1134-1141, June 2010.

Mon25Apr	**Physics-Based Sound Rendering**
	
		Topics Discussed:
		• Sound rendering problems
		• Acoustic radiation problems
		  ◦ Sound waves
		  ◦ Derivation of wave equation
		  ◦ Approximation
		• Application to solids and fluids
		  ◦ Case study: Harmonic Fluids
		
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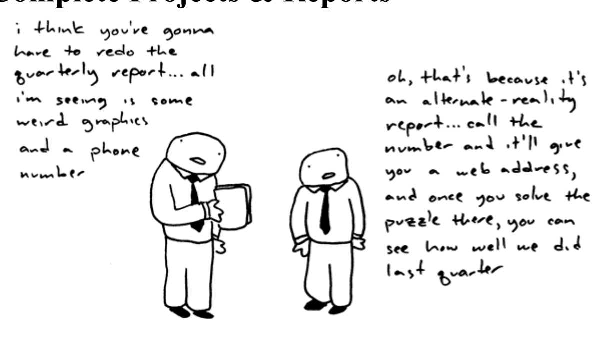
		• Changxi Zheng and Doug L. James, **Toward High-Quality Modal Contact Sound**, SIGGRAPH 2011 (to appear)
Mon25Apr	**Discussion (Albert Liu)**	Huamin Wang, Gavin Miller and Greg Turk. 2007. "Solving General Shallow Wave Equations on Surfaces". In *Proceedings of ACM SIGGRAPH/Eurographics Symposium on Computer Animation (**SCA**) 2007*, pp. 229 -- 238, San Diego, USA. [PDF 2.3MB], [AVI in DivX 46MB] [BibTex]
Wed27Apr	**Computational Motion** **Project Presentations (Part I)**	**Presentations:** • Kevin & Ivo • Greg & Nathan • Albert • Chuck & Mark • Himanshu & Jonathan
Mon2May	**Computational Motion** **Project Presentations (Part II)**	**Presentations:** • Jeff • Andy • Ian • Yunfeng • Jiexun
Wed4May	**No class**	
Wed18May Due Date	**Complete Projects & Reports** 	Submit (via CMS) by Wed May 18.
	End of classes!	