

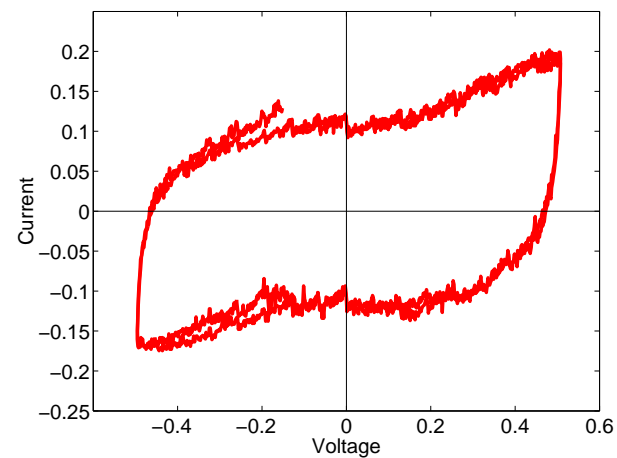
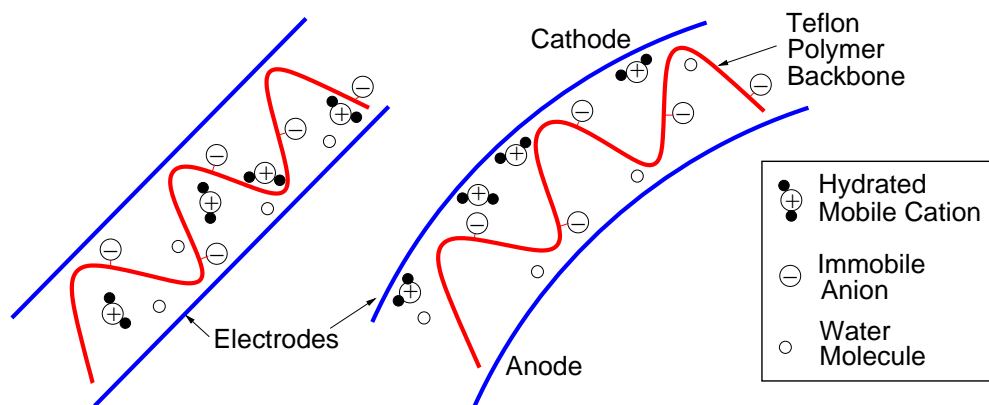
APPLIED MATHEMATICS AT NCSU

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Department of Mathematics

Center for Research in Scientific Computation

North Carolina State University



APPLIED MATHEMATICS AT NCSU

Question: What is applied mathematics??

- This is not so easy to answer!!
- For example, algebraic number theory can be very pure and yet has extremely important applications — e.g., cryptography.
- Some people like the designation “applicable mathematics” ... but even this is pretty vague!

First Thought: A major strength of this department is synergy between pure and applied math

Second Thought: Emerging applications can motivate entire new areas of analysis!

- Examples to follow!

RESEARCH AREAS AT NCSU

1. Mathematical Modeling of Physical Processes

Banks, Buche, Campbell, Gremaud, Ito, Kelley, Meyer, Scroggs, Smith, Tran

2. Math Biology

Banks, Franke, Haider, Lloyd, Lubkin, Olufsen, Selgrade, Tran

3. Probability, Stochastic Processes and Financial Math

Buche, Ito, Kang, Koev, Meyer, Pang, Silverstein

4. Ordinary and Partial Differential Equations

Banks, Campbell, Chu, Franke, Gremaud, Ito, Kelley, Li, Lin, Martin, Medhin, Olufsen, Schechter, Scroggs, Selgrade, Smith, Tran, Tsynkov, Zenkov

5. Numerical Analysis and Analysis

Campbell, Chertock, Chu, Gremaud, Haider, Ipsen, Ito, Kelley, Labate, Li, Meyer, Scroggs, Siewert, Smith, Tsynkov

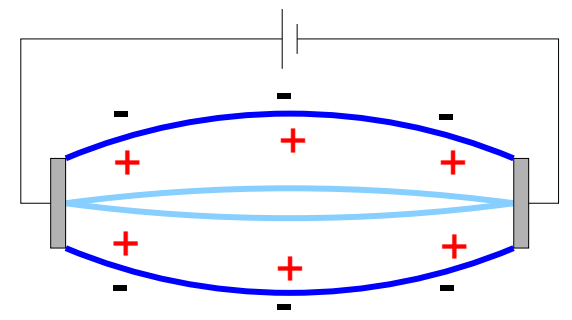
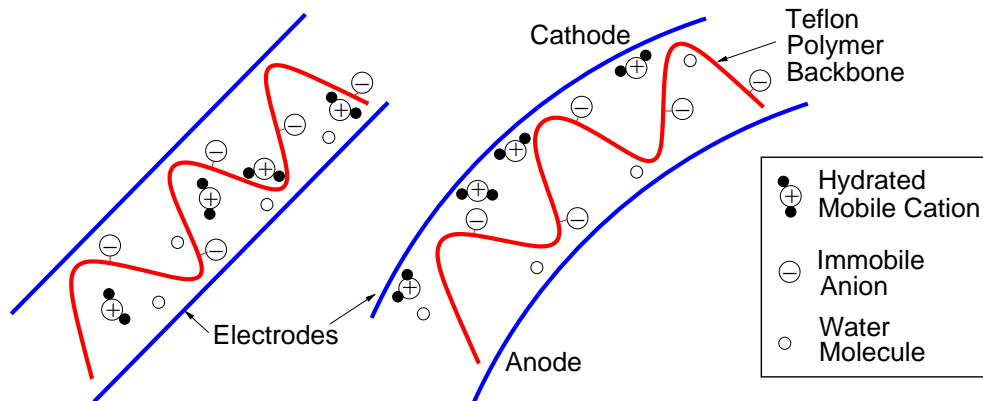
6. Symbolic Computation

Helminck, Hong, Kaltofen, Singer, Szanto

7. Control and Optimization

Banks, Campbell, Ito, Kelley, Medhin, Sivaramakrishnan, Smith, Tran, Zenkov

MATHEMATICAL MODELING OF PHYSICAL PROCESSES



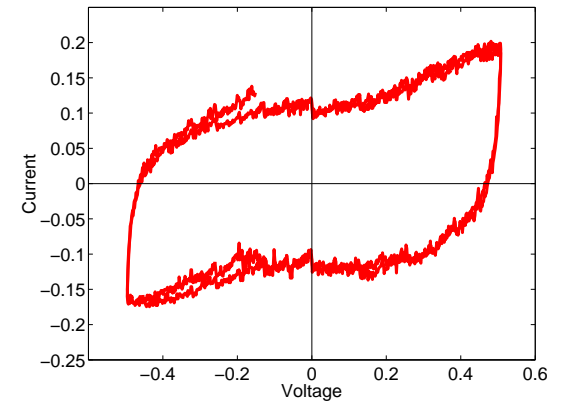
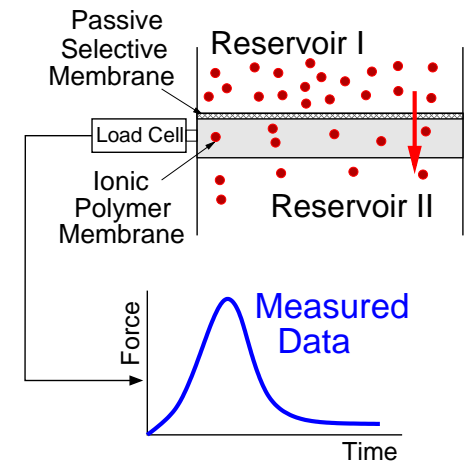
Ionic Polymer-Metal Composites (IPMCs):

- Low voltages (4-7 V) ; PZT (1-1600 V)
- Large displacements (>10 %) ; PZT (0.1-0.3%)
- Chemical/biological sensing
- Related technology – Fuel cells

Holy Grail:

- Custom design materials to achieve specific design or control capabilities.

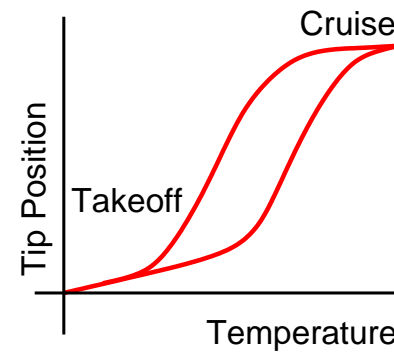
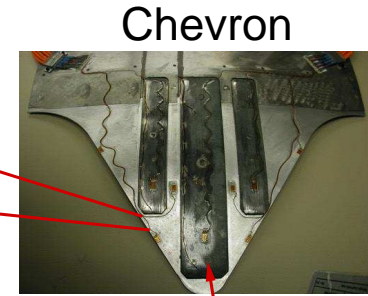
Model Strategy: Combined deterministic/stochastic analysis (SAMSI — More Details Later)



MATHEMATICAL MODELING OF PHYSICAL PROCESSES

Jet Noise Reduction:

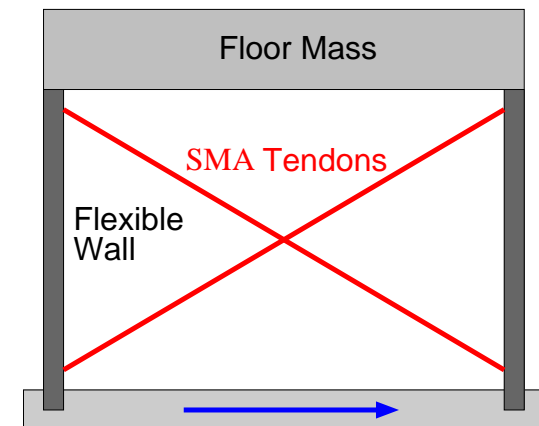
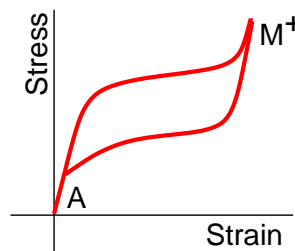
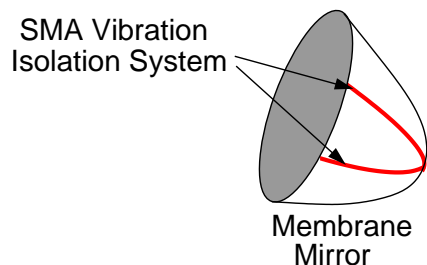
- Employ chevrons to improve mixing and decrease jet noise
- Boeing experiments demonstrate 4 dB noise reduction
 - 3 dB reduction if 1 of 2 engines turned off
- Requires 2-D and 3-D SMA models



SMA Strips

Vibration Attenuation:

- Passive or active damping for aerospace structures (e.g., Flexible mirrors – Kirtland AFB)
- Maximize hysteresis to maximize damping!



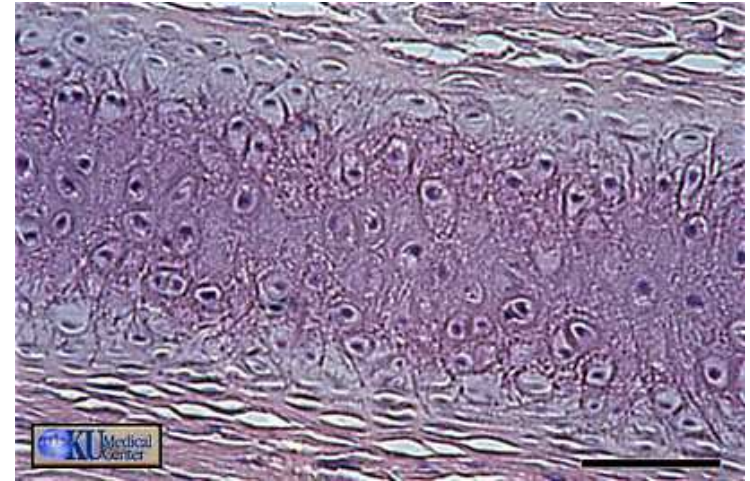
- Vibration attenuation in civil structures (e.g., buildings, bridges)

Later Presentation: [Ryan Siskind](#)

MATH BIOLOGY

Cartilage:

- Characterize the functional properties of cartilage as initial step toward repair and treatment of degenerative diseases
- [Haider, Ward, Lada, Smith — NCSU]
[Setton - Duke Medical Center]



Note: There is an increasing emphasis on synergy between biological modeling and control theory.

- Blood flow control when going from sitting to standing
- Control strategies for HIV treatment
- Aeronautic control systems motivated by dragonfly flight

Later Presentations: H.T. Banks, **Jimena Davis**, Mette Olufsen

PROBABILITY, STOCHASTIC PROCESSES AND FINANCIAL MATH

Random Matrices and Multivariate Statistical Analysis:

- Mathematical statistics (e.g., applied to wireless communications)
- Spectral properties of large-dimensional random matrices
- Highly efficient numerical methods for random matrix applications

Financial Mathematics and Control Theory:

- Stochastic optimization in financial models
- Stochastic control and approximation (e.g., wireless, internet)

Interacting Random Systems and Martingale Theory

- Stochastic partial differential equations
 - e.g., Application to statistical physics, phase transitions in physical systems
- Dynamical stochastic systems with random interactions

ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS

Example: Model development for granular flow

- Civil and industrial applications: Grain hoppers
- Food products: cereal, sugar, pasta
- Snow avalanches, mudslides
- Solid state physics

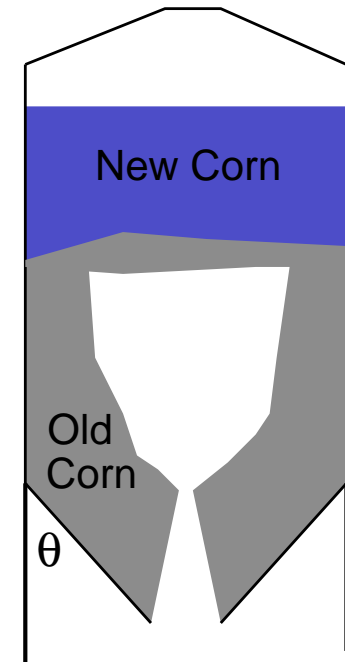
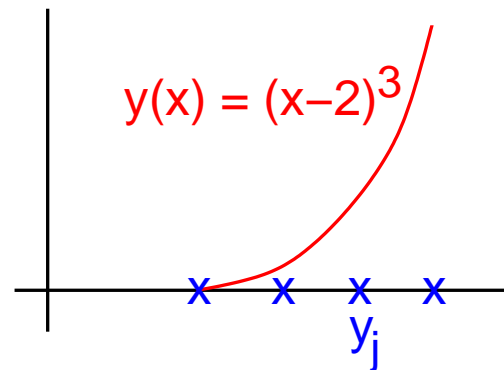


Analysis: Existence, uniqueness and behavior of solutions

- Super-easy example: $\frac{\partial y}{\partial x} = 3y^{2/3}$ with $y(2) = 0$

Solution: $y(x) = (x - 2)^3$

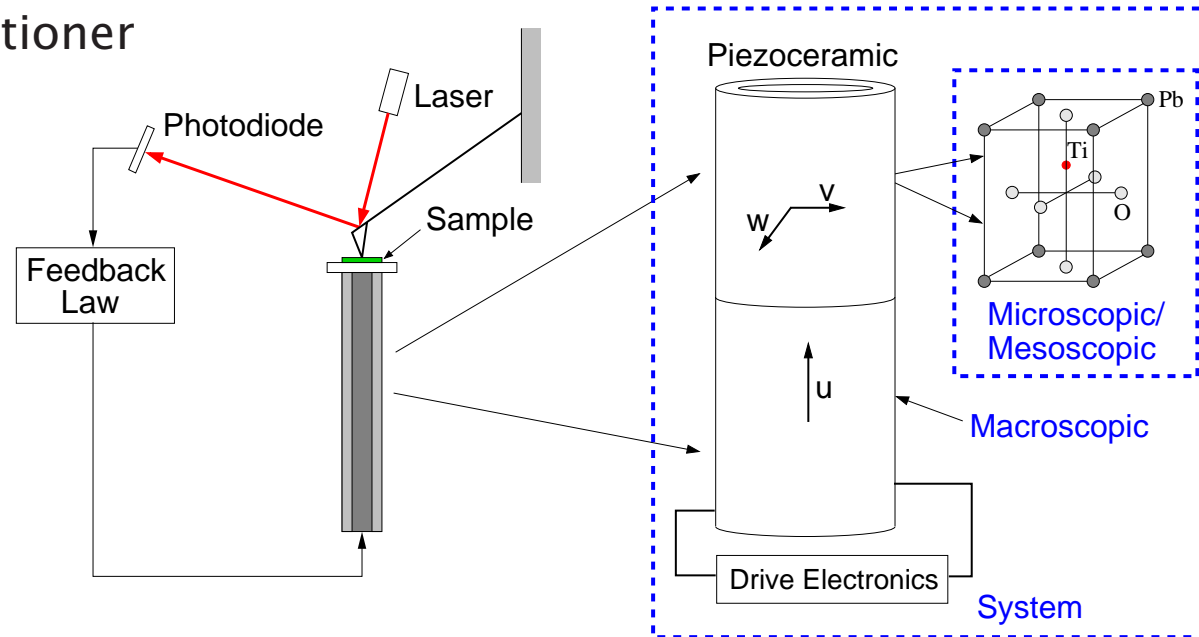
Euler's Method: $y_{j+1} = y_j + 3hy_j^{2/3}$



Later Presentation: **Ryan Siskind**

NUMERICAL ANALYSIS AND ANALYSIS

Example: Nanopositioner



Shell Model:

$$R\rho h \frac{\partial^2 u}{\partial t^2} - R \frac{\partial N_x}{\partial x} - \frac{\partial N_{\theta x}}{\partial \theta} = Rg_x + \frac{2RE_{pe}h_{pe}}{1 - \nu_{pe}} \frac{\partial e_{pe}}{\partial x}$$

$$R\rho h \frac{\partial^2 v}{\partial t^2} - \frac{\partial N_{\theta}}{\partial \theta} - R \frac{N_{x\theta}}{\partial x} = Rg_{\theta} + \frac{2E_{pe}h_{pe}}{1 - \nu_{pe}} \frac{\partial e_{pe}}{\partial \theta}$$

$$R\rho h \frac{\partial^2 w}{\partial t^2} - R \frac{\partial^2 M_x}{\partial x^2} - \frac{1}{R} \frac{\partial^2 M_{\theta}}{\partial \theta^2} - 2 \frac{\partial^2 M_{x\theta}}{\partial x \partial \theta} + N_{\theta} = Rg_n$$

Note: High fidelity and low-order numerical methods required to approximate solns

Later Presentations: **Corey Winton** and Tim Kelley

SYMBOLIC COMPUTATION (COMPUTER ALGEBRA)

Example: Maple or Mathematica

Research Areas:

- Symbolic integration
- Closed form solution of ODE and PDE
- Solution of overdetermined systems
- Cryptography – algebraic theory of polynomial rings, finite fields, elliptic curves
 - Some of these applications have produced renaissance in the field

Note: Strong synergy between applied and pure research

Later Presentations: Agnes Szanto

CONTROL AND OPTIMIZATION

Example: Consider the spring model

$$m \frac{d^2 y}{dt^2} + c \frac{dy}{dt} + ky = f(t)$$

- Control problem: Determine input $f(t)$ which yields specific displacement $y(t)$

High Speed, High Accuracy Tracking:

- Magnetic system (Unified model)
- 10% sensor noise s at 60 Hz
- Delay due to hysteretic actuator



Analogy: “Bad” shower

- Low speeds: use feedback based on measurements — e.g., shower adjustment
- High speeds: delays can cause instabilities
- Control must be robust with regard to random uncertainties

New Fields: Quantum systems — Heisenberg states that sensing changes system!

Later Presentation: [Adam Attarian](#)

COURSES

Courses: 59 regularly scheduled graduate courses plus special topics

Example Schedule: PhD student interested in Modeling, Control, PDE or Numerical

	Fall	Spring
Year 1	MA 531* Dyn Sys and Control I MA 580* Numerical Analysis I MA 573 Mathematical Models I	MA 731* Dyn Sys and Control II MA 780* Numerical Analysis II MA 574 Mathematical Models II
Year 2	MA 515* Analysis I MA 534* PDE I MA 584 Finite Differences	MA 715* Analysis II MA 734* PDE II MA 585 Finite Elements

* Qualifying exam sequence

QUALIFYING EXAMS

Qualifying Exams:

- Analysis
- Applied Matrix Theory
- Applied Probability and Stochastic Processes
- Computer Algebra
- Linear Algebra and Lie Algebra
- Numerical Analysis
- Ordinary Differential Equations
- Partial Differential Equations
- Systems and Control

WHERE STUDENTS ARE NOW

Departments:

- Clemson University
- University of Graz, Austria,
- University of Colorado
- Clarkson University

Postdocs:

- EPA
- University of Michigan
- Florida State University
- IMA

Nonacademic Positions:

- The Boeing Corporation
- MIT Lincoln Labs
- Sandia National Laboratories
- SAS
- National Security Agency

SAMSI

What: Statistical and Applied Mathematical Sciences Institute

Where: Research Triangle Park (about 5 miles from airport)

When: Started in 2002

Goal: Investigate problems having both stochastic and deterministic components

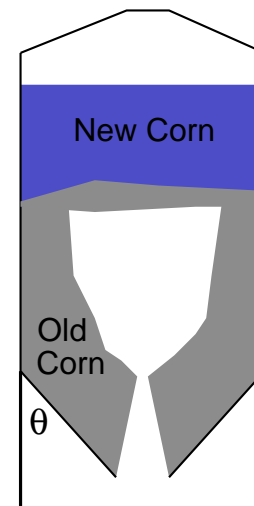
Structure: NSF Institute: Partnership between **NCSU**, **UNC**, **Duke** and NISS

Programs in 2008–2009:

- Algebraic Methods in Systems Biology and Statistics
- Sequential Monte Carlo Methods

Opportunities for Graduate Students:

- Support for 1 year
- Highly interdisciplinary research topics (e.g., potential dissertation)
- Industrial Mathematical and Statistical Modeling Workshop (IMSM)

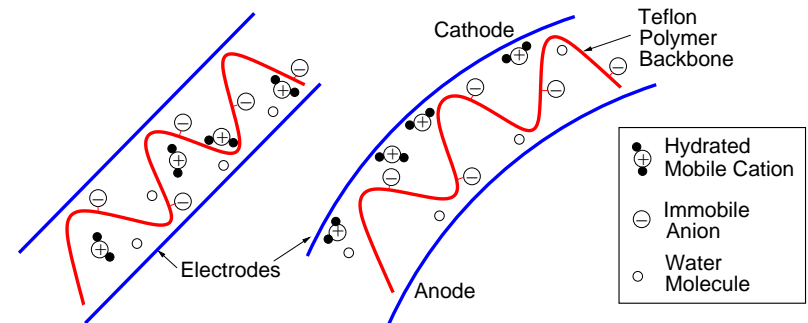


RESEARCH TRAINING GROUP (RTG)

MATHEMATICS OF MATERIALS

Research Topics:

- Multifunctional and Smart Materials
- Orthopaedic Biomaterials
- Dynamics of Thin Material Layers
- Material Behavior for Laser Welding
- Polymers and Composites including Carbon Nanotubes



Support: \$25,000/year plus \$1500/year travel support

Mathematical Areas:

- Model development, numerical approximation, analysis, parameter estimation, and control design in the context of materials

FINAL THOUGHTS

Ask lots of questions and have a great visit!!