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, handwriting recognition.
- 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, Campbell, Gremaud, Ito, Kelley, Meyer, Shearer, Smith, Tran

2. Math Biology
   Banks, Franke, Haider, Lloyd, Lubkin, Olufsen, Selgrade, Sullivant, Tran

3. Probability, Stochastics, Financial Math, Uncertainty Quantification
   Ito, Kang, Meyer, Pang, Silverstein, Smith

4. Ordinary and Partial Differential Equations
   Banks, Campbell, Chu, Franke, Gremaud, Ito, Harlim, Hoefer, Kelley, Li, Lin,
   Medhin, Schecter, Scroggs, Selgrade, Shearer, Smith, Tran, Tsynkov, Zenkov

5. Numerical Analysis and Analysis
   Campbell, Chertock, Chu, Gremaud, Haider, Ipsen, Ito, Kelley, Li,
   Meyer, Scroggs, Siewert, Smith, Tsynkov

6. Symbolic Computation
   Hauenstein, Helminck, Hong, Kaltofen, Singer, Szanto

7. Control and Optimization
   Banks, Campbell, Ito, Kelley, Medhin, Smith, Tran, Zenkov
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)
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

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 Presentations: H.T. Banks, Nakeya Williams, Rachael Gordon-Wright
MATH BIOLOGY

Cartilage:

- Characterize the functional properties of cartilage as initial step toward repair and treatment of degenerative diseases

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 vaccination programs
- Aeronautic control systems motivated by dragonfly flight

Note: A second evolving field involves synergy between algebra, statistics and biology.

Later Presentations: H.T. Banks, Sharon Lubkin, Hien Tran, Angelean Hendrix, Nakeya Williams
STOCHASTICS, FINANCIAL MATH, UNCERTAINTY QUANTIFICATION

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)

Uncertainty Quantification for Complex Systems
- Requires synthesis of mathematics, statistics and applications
  - e.g., Consortium for Advanced Simulation of Light Water Reactors (CASL)
  - Collaboration between Oak Ridge, Sandia, NCSU, MIT, Michigan, ...
  - DOE Secretary Steven Chu: Commented that CASL was a great model for how to design a successful HUB.
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: \( y_{j+1} = y_j + 3h y_j^{2/3} \)

Later Presentation: Xiao-Bao Lin, Anna Meade, Angelean Hendrix, Justin Wright
Example: Nanopositioner

Shell Model:

\[
\begin{align*}
R\rho h \frac{\partial^2 u}{\partial t^2} - R \frac{\partial N_x}{\partial x} - \frac{\partial N_{\theta x}}{\partial \theta} &= Rg_x + \frac{2RE_{pe}h_{pe}e_{pe}}{1 - \nu_{pe}} \frac{\partial e_{pe}}{\partial x}
\end{align*}
\]

\[
\begin{align*}
R\rho h \frac{\partial^2 v}{\partial t^2} - \frac{\partial N_{\theta}}{\partial \theta} - R \frac{N_{x\theta}}{\partial x} &= Rg_{\theta} + \frac{2E_{pe}h_{pe}e_{pe}}{1 - \nu_{pe}} \frac{\partial e_{pe}}{\partial \theta}
\end{align*}
\]

\[
\begin{align*}
R\rho h \frac{\partial^2 w}{\partial t^2} - R \frac{\partial^2 M_x}{\partial x^2} - \frac{1}{R} \frac{\partial^2 M_{\theta}}{\partial \theta^2} - 2 \frac{\partial^2 M_{x\theta}}{\partial x \partial \theta} + N_{\theta} &= Rg_n
\end{align*}
\]

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

Later Presentations: C.T. Kelley, Anna Meade, John Holodnak, Nick Lowman, Rachael Gordon-Wright, Justin Wright
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
Example: Consider the spring model

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

- 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:** H.T. Banks, H.T. Tran
COURSES

Courses: 59 regularly scheduled graduate courses plus special topics

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

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<th>Year 1</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
<td></td>
<td>MA 531* Dyn Sys and Control I</td>
<td>MA 731* Dyn Sys and Control II</td>
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<td>MA 580* Numerical Analysis I</td>
<td>MA 780* Numerical Analysis II</td>
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<tr>
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<td>MA 573* Mathematical Models I</td>
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<td></td>
<td>MA 534* PDE I</td>
<td>MA 734* PDE II</td>
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<td>MA 584 Finite Differences</td>
<td>MA 585 Finite Elements</td>
</tr>
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</table>

* 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
- Mathematical Modeling
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
- NOAA’s National Climatic Data Center
- 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 2013–2014:

• Program on Low-Dimensional Structure in High Dimensional Systems
• Program on Computational Methods in Social Sciences

Opportunities for Graduate Students:

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

• Several opportunities for Applied Math students
  – Applied Mathematics Graduate Student Seminar (AMGSS)
  – Applied Math Club
  – Research Training Modules (RTM)

Ask lots of questions and have a great visit!!