# Research Experiences for Math Majors at Arizona State University

Eric Kostelich

ARIZONA STATE UNIVERSITY
SCHOOL OF **MATHEMATICAL & STATISTICAL SCIENCES**

July 13, 2012

# Overall philosophy and rationale

- Mathematical themes: Uncertainty, prediction, simulation
- Applications: Biology, weather/climate, imaging, networks
- Goals: Provide a model for 21st Century mathematics curriculum and strengthen connections with other disciplines
- Professional concern: We must be able to give compelling reasons to invest in mathematics departments

# Fall 2005 CBMS report

- Fall enrollment growth: $+21\%$ at 4-year colleges & universities since 1990 (total: 1.6 million students)
- Math enrollment growth: $-2.3\%$
- All math/stat bachelors degrees: $-2\%$
- Number of bachelor's degrees awarded by doctoral department was up by $41\%$ over 2000 but those by master's & 4-year schools declined by 19–27%
- Fraction of 4-year colleges offering Advanced Engineering Mathematics once every 2 years: $7\%$ Advanced Calculus: $57\%$ Algebra: $52\%$

# The post-Sputnik problem

- Undergraduates see few applications of mathematics after 1950
  - Metropolis algorithm
  - Fast Fourier transform
  - Simplex algorithm
  - Public-key cryptography
  - Kalman-Bucy filter
  - Viterbi algorithm
  - Shotgun genome sequencing
  - etc.
- Resulting #1 FAQ: What can I do with a math degree?
- Students should get in-depth exposure to at least one of these topics in their baccalaureate program

# My interests and philosophy

- Professional goals: Create modern, high-impact programs for mathematics undergraduates that can serve as national models
- Courses and programs to educate mathematically literate scientists (not necessarily more mathematicians *per se*)
- Interdisciplinary collaboration is essential
- Double majors are not worthwhile
- Encourage combined BS/MA programs for strong undergraduates

# Undergraduate programs at ASU

- Current enrollment: 72,000 students on four campuses
- About 58,000 undergraduates
- Total mathematics enrollments: 16,000 students in fall, 14,000 in spring
- $\sim 40\%$ precalculus & below; $\sim 30\%$ business math; $\sim 30\%$ in engineering calculus & above
- Approximately 4,000 engineering majors, 550 math majors
- Transfer students, on-and-off enrollment are the rule

# The Computational Mathematical Sciences B.S. degree

- Goal: Create an interdisciplinary program that would appeal to good science and math students
- Must accommodate transfer students easily
- Encourages summer internships and undergraduate research experience
- Takes a broad view of "scientific computing"

# CMS core areas

- Mathematics: 3 semester calculus sequence, ordinary differential equations, linear algebra (18 credits total)
- Science: 2 one-year sequences in life/physical sciences (16 credits)
- Computing: 2 semesters of introductory programming and data structures plus Scientific Computing and Introduction to Numerical Methods (12 credits)
- Advanced courses: At least 3 in math/stat and 1 internship/research course (12 credits)
- Liberal studies: 5 courses in humanities/social sciences, 2 “science and society” courses (21 credits)

# The Scientific Computing course

- Audience: advanced undergraduate and beginning graduate students in mathematics and physical sciences
- Emphasis: Software development skills for scientific and high-performance computing
- Topics: Scripting (shell, Python, makefiles); Fortran 95/2003, C99, C++; OpenMP; LAPACK
- Prerequisites: At least 2 semesters of programming, differential equations and/or linear algebra
- The graduate version includes MPI, more on OpenMP, cache coherency, bandwidth issues, etc.

# The CSUMS program

- Computational Science Training for Undergraduates in the Mathematical Sciences
- Funded through Divisions of Mathematical Sciences and Undergraduate Education at the National Science Foundation
- Long-term research experiences for cohorts of at least six undergraduates
- From the solicitation: Projects must be genuine research experiences rather than rehearsals of research methods

# The CSUMS project at ASU

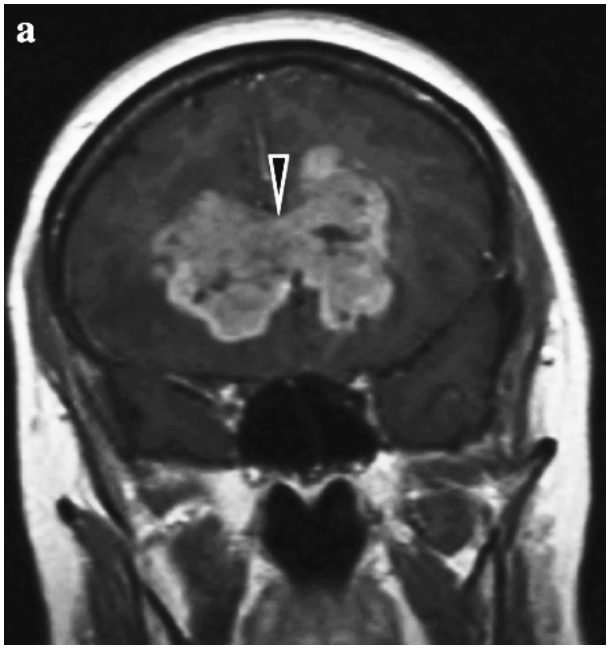
- 65 students in overlapping cohorts since Jan. 2008
- Basic requirements: Math major with 3.5+ GPA, differential equations, linear algebra, 1+ semester of programming
- Year 1: Weekly pizza seminar
- Summer 1: 8-week research projects
- Year 2: Weekly pizza seminar, conference, paper, graduation
- Option: Continue to BS/MA program
- Conference presentation, possibly an honors thesis or paper

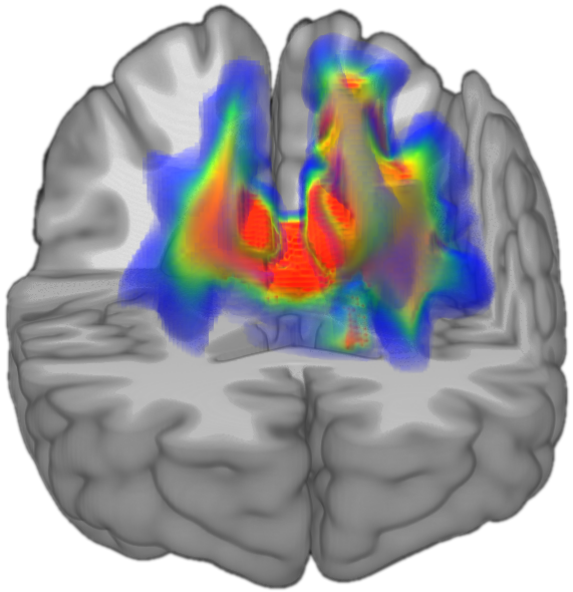
# The CSUMS project at ASU, 2

- Sliding window of 12 faculty participants
- 43 CSUMS students have graduated, 18 to PhD programs, 6 masters, 5 BS/MA program, 3 to medical school, 1 to law school
- 20 women, 8 minority, 18 first-generation college students; ages 15–32
- 2 Goldwater Scholars, 1 NSF Graduate Research Fellowship, 3 finalists, 10 local scholarships

# Modeling of glioblastomas (John Ingraham)

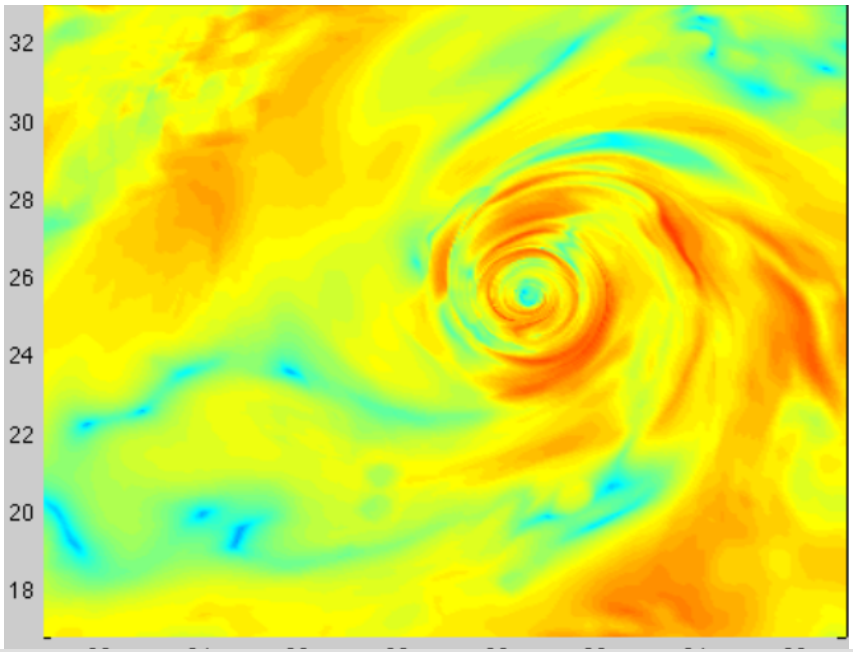
- Swanson/Murray model: $g_t = \nabla \cdot (D \nabla g) + \alpha g(1-g)$
- Use diffusion tensor imaging data to estimate anisotropy

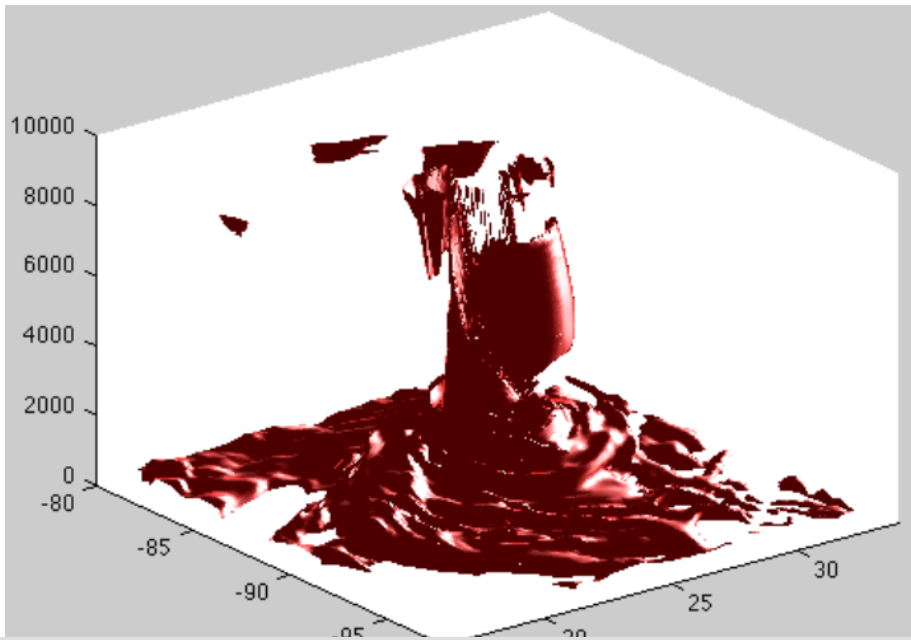


# Chaotic saddles in Hurricane Katrina (Chris Wake, Angelica Deibel)

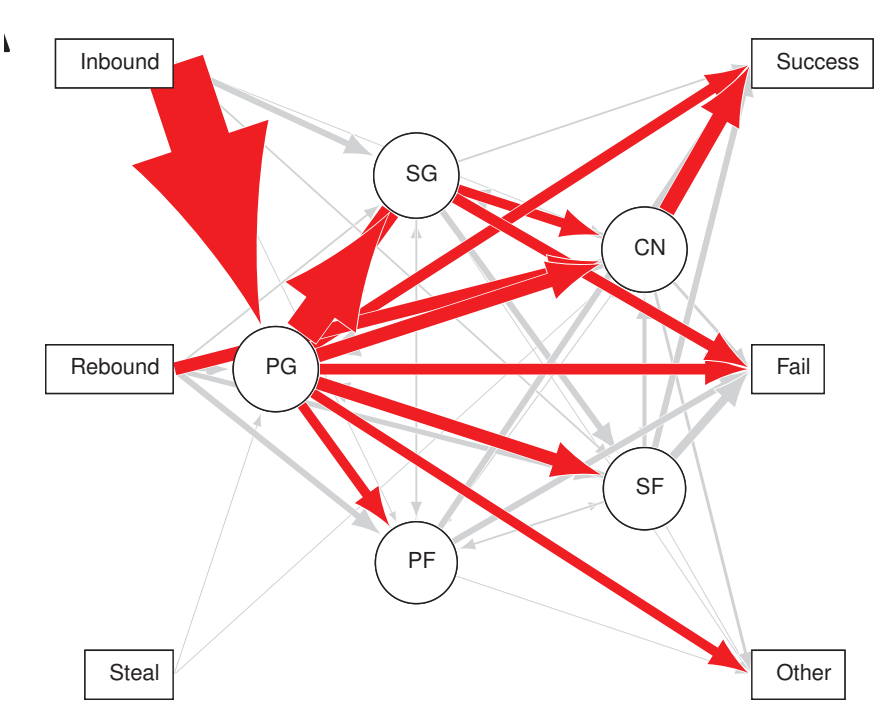
- Weather Research and Forecast model on 128 processors
- Initialized with atmospheric analyses from Aug. 27–29, 2005

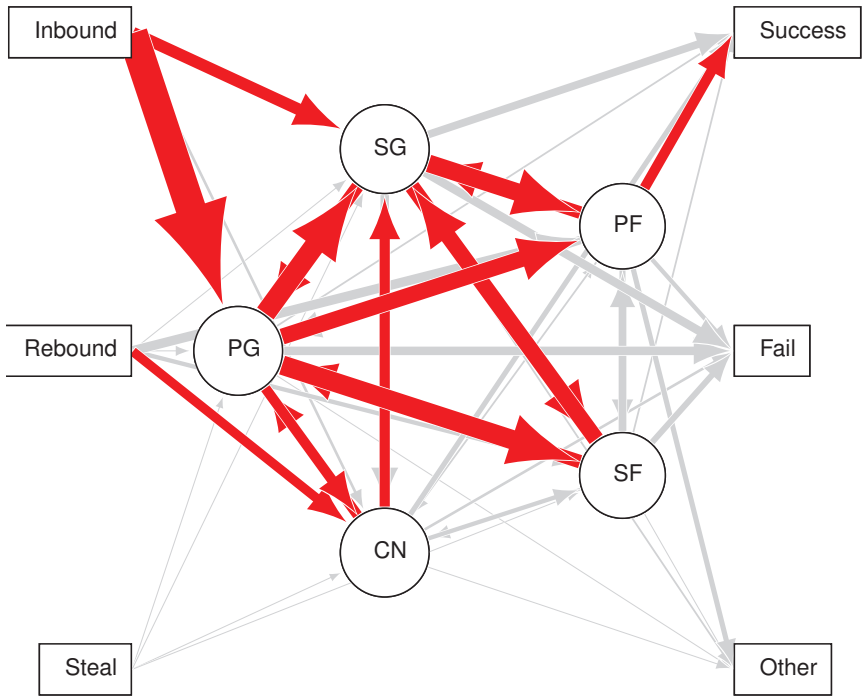


# Netball: Bulls & Lakers (John Ingraham, Alex Petersen)

- Analyzed every possession of 2010 NBA playoffs
- Passes, inbounds, etc. are links in a graph



# Others

- Edge detection from noisy Fourier data
- Financial mathematics (Black-Scholes & variants)
- Rabies epizootics in Arizona and Texas
- Lagrangian dynamics of radioactive particles from Fukushima
- Inverse problems in biofuels
- Astrophysical jets

# The MCTP program—beginning July 16

- Partnership with the Maricopa Community College District (141,000 students) and ASU
- MCCCD enrollments: 5,000 students in precalculus & engineering calculus (up 36% in the last 5 years)
- 3-week, half-day summer enrichment programs at Scottsdale Community College for 20 students
- Summer 1 program: Students with Calc I: time value of money, Monte Carlo simulation, logistic growth, Lotka-Volterra models, WFF'n Proof
- Summer 2 program: Students with Calc II–III: symmetry & groups, numerical methods, statistical analysis of biological data

# MCTP at ASU

- 8-week summer research experience
- Rotating set of "project seminar" courses during the academic year for 18–25 students
- Mathematics and Climate
- Mathematics and Cancer
- Graphs and Networks
- Mathematics and Imaging
- Prerequisites: calculus, linear algebra, differential equations
- Expose students to modern applications of mathematics and provide rationale for the advanced courses

# Scaling up

- Jennifer Widom: infolab.stanford.edu/∼widom
- 100,000 students signed up for her Introduction to Databases course
- 25,000 submitted assignments, 6,500 finished with a strong score
- Similar effort by Sebastian Thrun for Artificial Intelligence
- Auto-generated multiple-choice tests & Web forums for the masses
- Hand-graded assignments, programming project, written exams, etc. for Stanford students

# Why not adopt the Stanford model for CS&E?

- Create a course for 100,000 K–12 teachers on applied math and computational science
- NSF could fund the creation of the initial infrastructure, including semester-long buyouts for faculty at 20–30 colleges & universities to prepare
- The course could be team-taught or be a series of videos by one or two “star” professors
- The format could be adapted for many purposes

# The Stanford model, continued

- Each college agrees to offer course credit and charges its regular tuition to cover local expenses for tutoring, homework & exam grading, etc., for those who need contining ed credits
- "Certificates of completion" could be offered for everyone else who finishes the online portion
- The "textbook" could be a Wiki and sold for 99 cents a chapter (to cover expenses) through iTunes with embedded demos and programmed exercises on an iPad

# Acknowledgments

Thanks to:

- National Science Foundation
- ASU College of Liberal Arts and Sciences
- School of Mathematical and Statistical Sciences, ASU