CMACS
Computational Modeling and Analysis for Complex Systems

CMACS Education Program

Complex systems and arrhythmias teaching module

Flavio H. Fenton

Department of Biomedical Sciences
College of Veterinary Medicine,
Cornell University, NY

NSF Expeditions in Computing CMACS, Site Review Meeting
Carnegie Mellon, Nov. 3-4, 2011

CMACS

Computational Modeling and Analysis for Complex Systems

In the CMACS proposal we promised that:

"At the core of the Education & Outreach initiative will be the formation of a new, highly ambitious and highly cross-discipline educational program called Complex Systems Science & Engineering (CSSE), with sub disciplines in:
BioSystems Science & Engineering (BSSE) and Embedded Systems Science & Engineering (ESSE)."

CMACS
Computational Modeling and Analysis for Complex Systems

Annual Workshops on Computational Modeling of Complex Systems

Teaching module on complex systems and arrhythmias

Atrial fibrillation Workshop

Nancy Griffeth and Flavio Fenton

January 3-21, 2011

Lehman College, Bronx, NY

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Computational Modeling and Analysis for Complex Systems

Workshop Objectives

- Disseminate project work among promising students
- Encourage enthusiasm for research and modeling complex systems
- Find good prospects for REU and graduate programs
- Encourage under-represented minorities to enter STEM fields (Science, Technology, Engineering and Mathematics).
- Encourage inter-disciplinary work
- Develop course materials

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2nd Workshop Students

17 undergraduate students

Ethnicity	Number	Major	Number
African-American	3	Math	6
Female	5	Bio	4
Hispanic	3	CS	7

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2nd Workshop Students

17 undergraduate students

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Workshop Outline

- Week 1: Biology and complex systems background. Lectures and lab experiments.
- Week 2: Mathematical biology and programming background. Lectures and exercises with cell models using Java applets.
- Week 3: Student Project.

Total cost ~$400.00 → $23.00 per student

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Week 1

- Complex Systems and Biological Background
  - CMACS and its goals
  - Chaos and complex systems
  - Experimental exercises with oscillators (Labs)
  - Relation between oscillators and cardiac cells
  - Mathematical modeling of cardiac cells
  - Cardiac arrhythmias and their study by computer simulations

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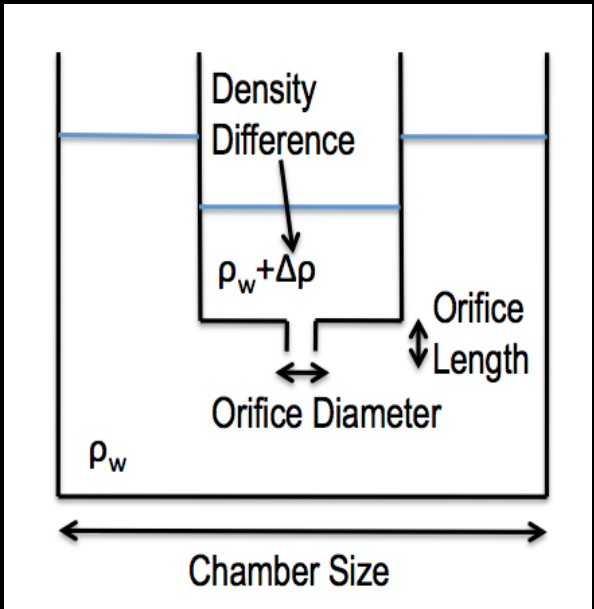
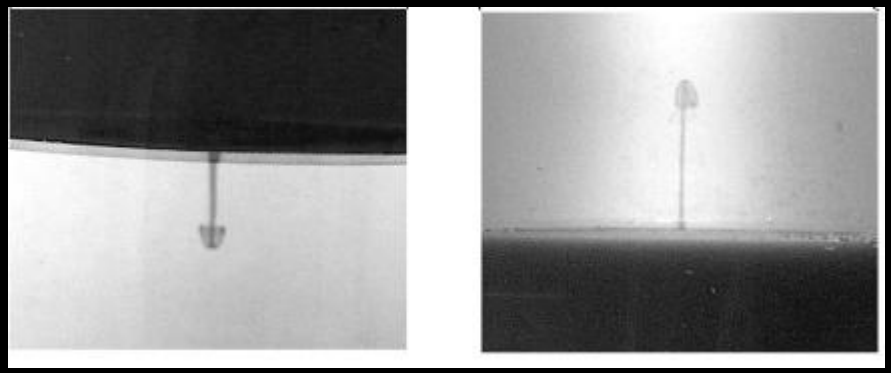
Computational Modeling and Analysis for Complex Systems

Week 1

Oscillators

- Saline Oscillator (5 cents experiment)





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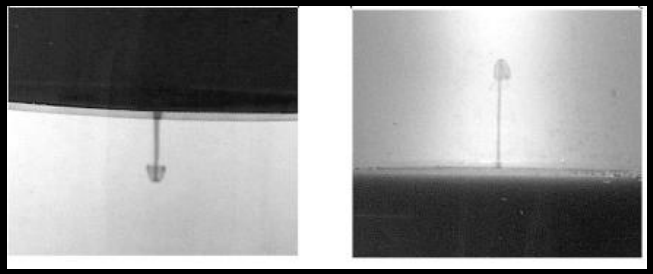

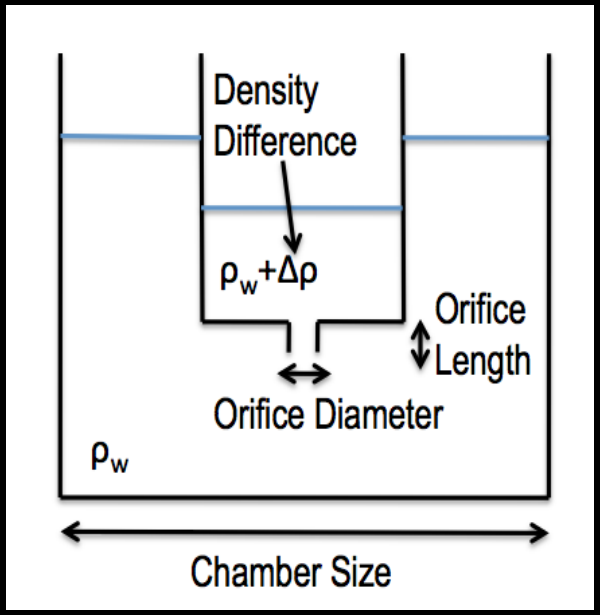

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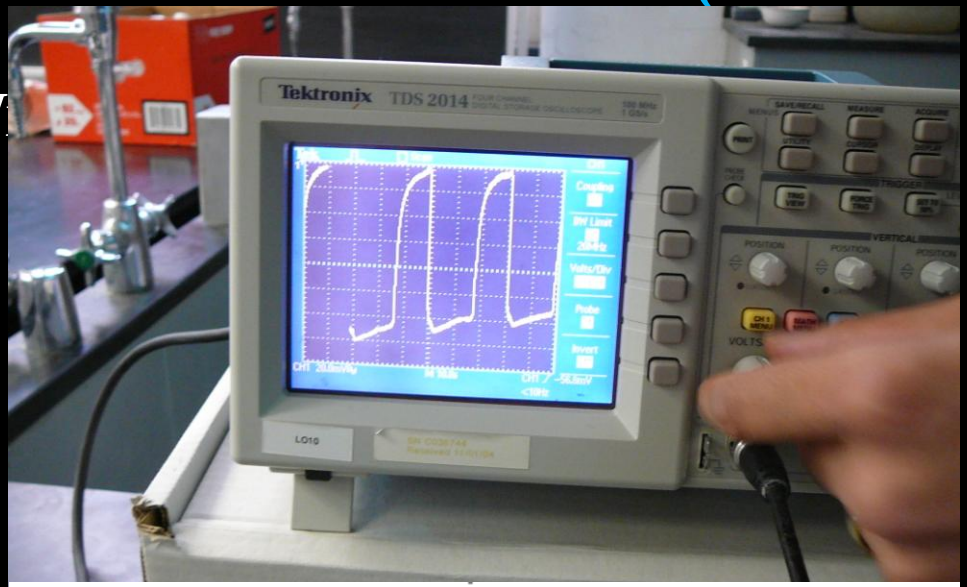

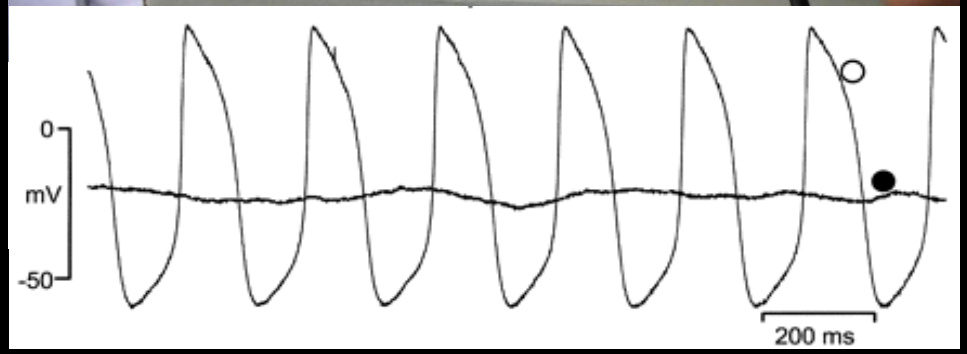

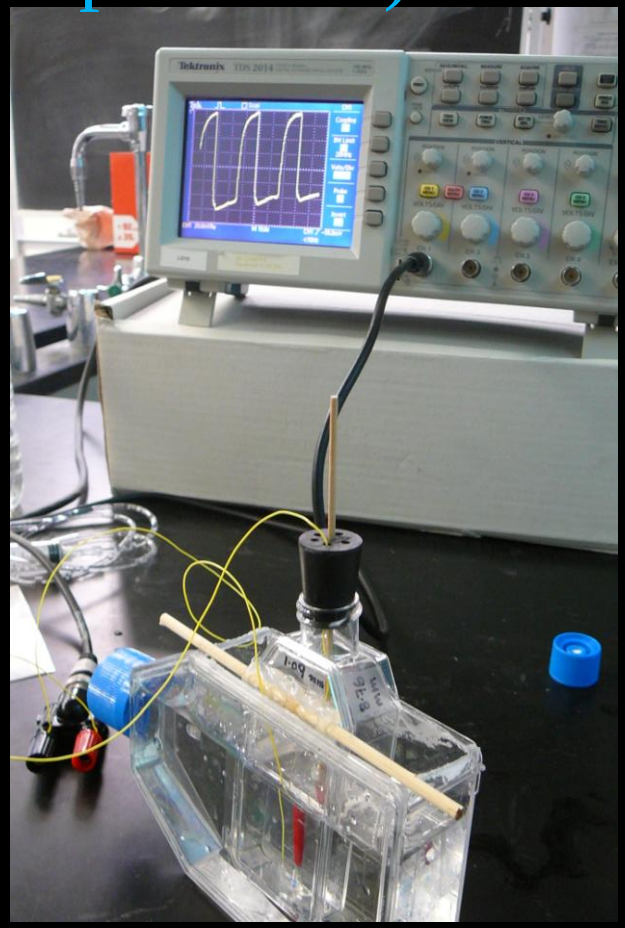

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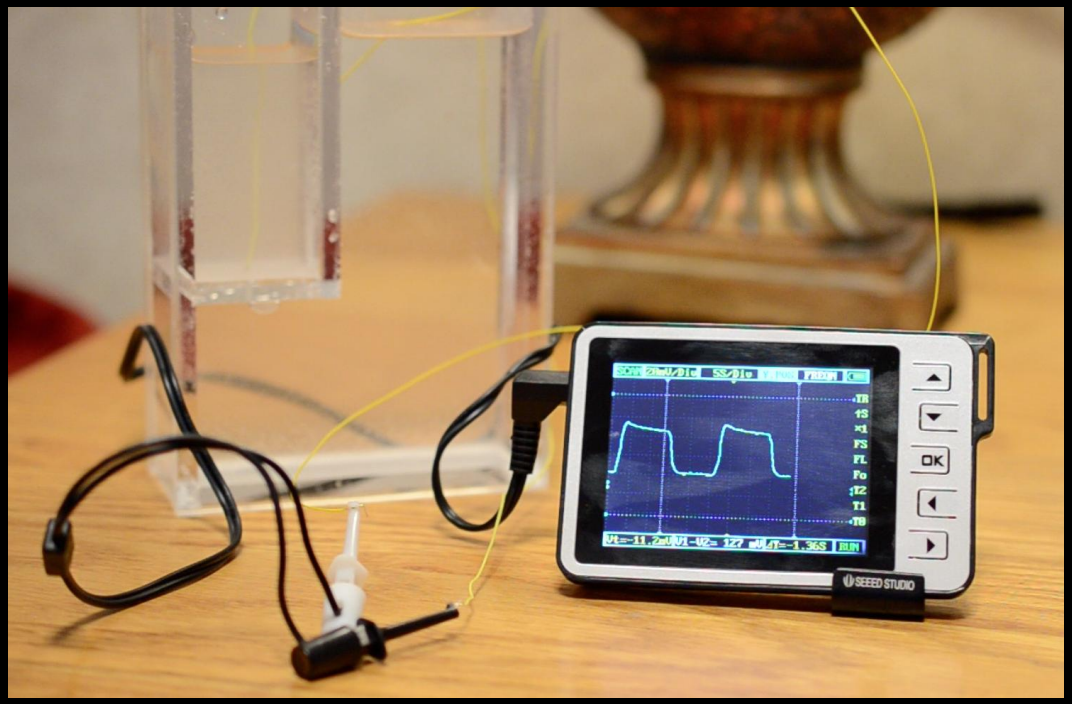
Week 1

Oscillators

- Saline Oscillator (5 cents experiment)

No oscilloscope, no problem!



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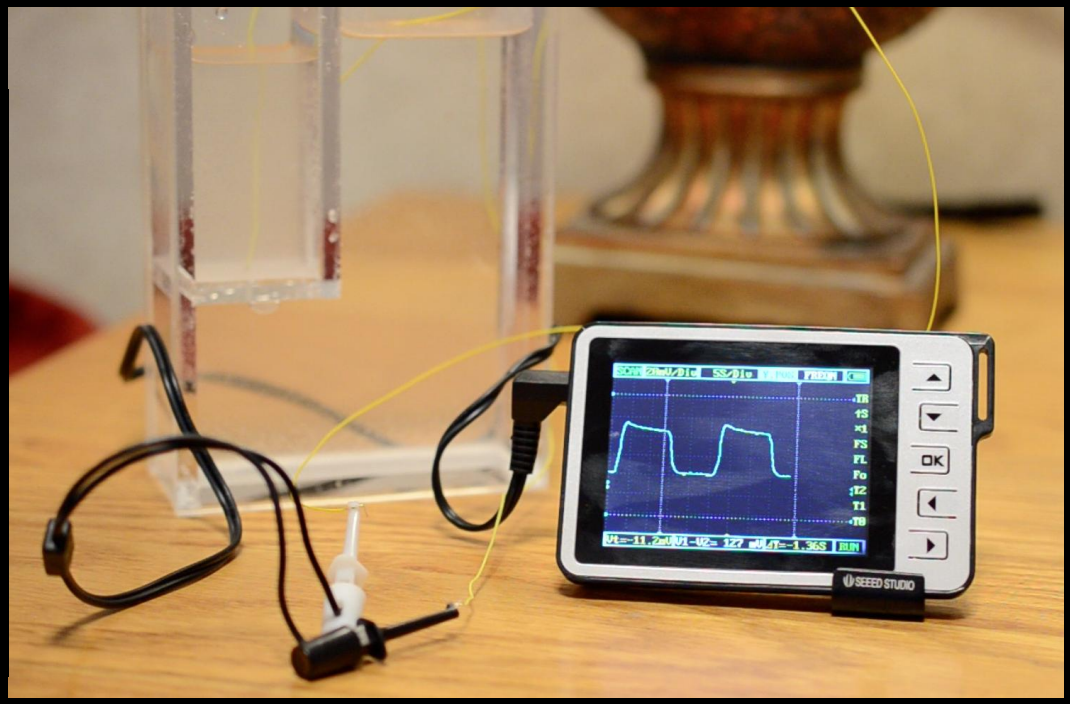

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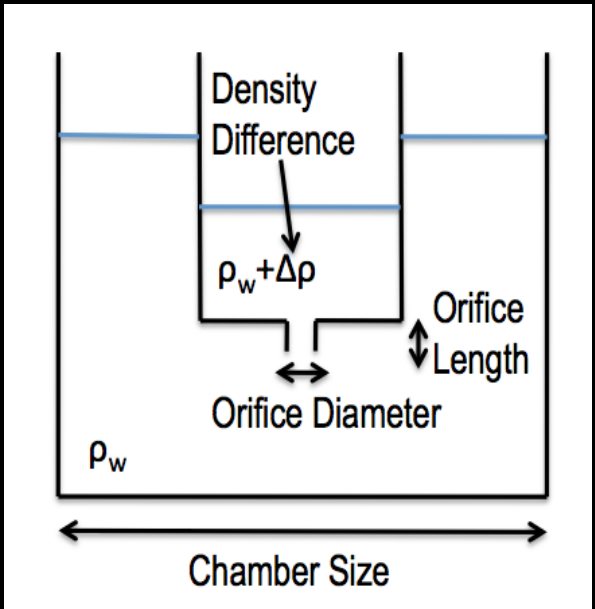
Week 1

Oscillators

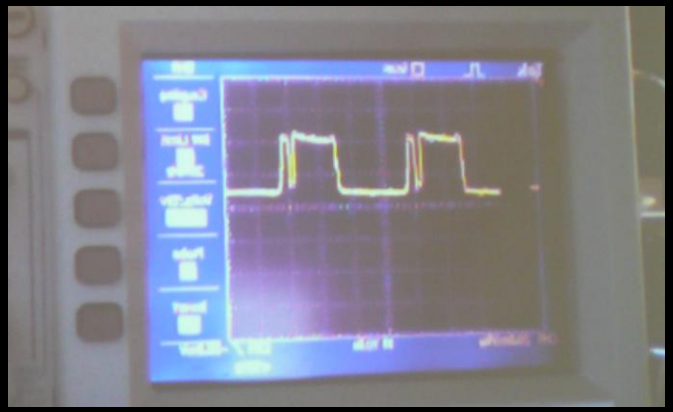
- Saline Oscillator (5 cents experiment)

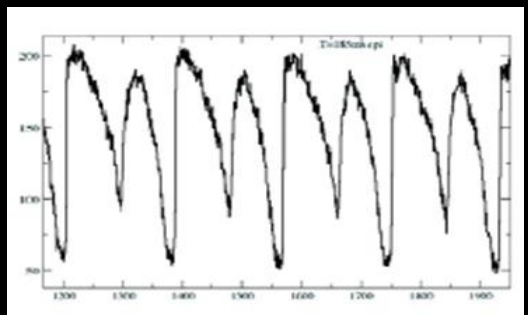
With a huge bang for the buck

Not only an oscillator but an excitable system!



- Paced
- Alternans
- Wenckebach
- Rhythms
- Chaos





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Week 1

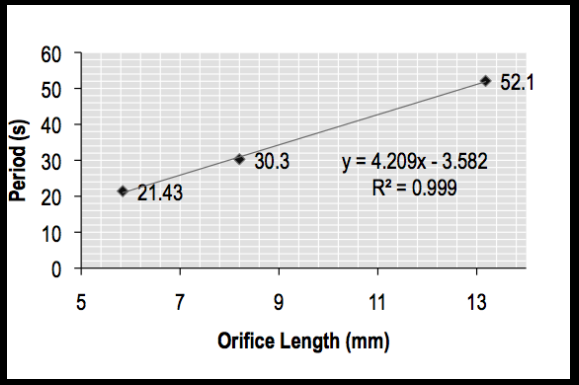
Oscillators

- Saline Oscillator (5 cents experiment)

With a huge bang for the buck

Exercises for the students

4 groups, 4 problems



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Week 1

Oscillators

- From 1 oscillator to many (Coupling and Diffusion)

Chemical oscillators (Briggs-Rauscher and Belousov-Zhabotinsky).

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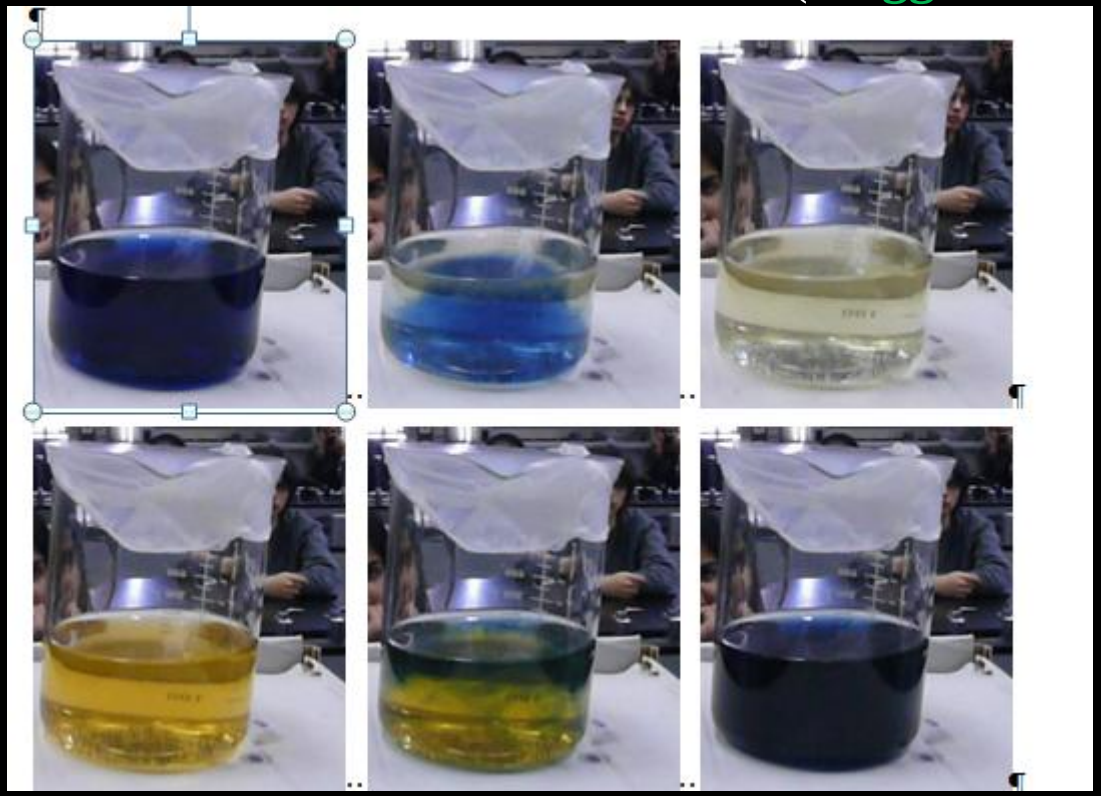
- From 1 oscillator to many (Coupling and Diffusion)

Chemical oscillators (**Briggs-Rauscher** and Belousov-Zhabotinsky).



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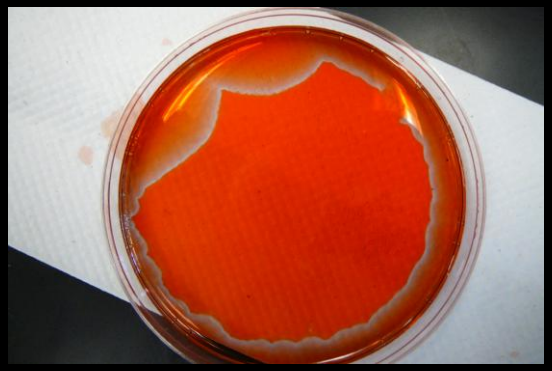
- From 1 oscillator to many (Coupling and Diffusion)

Chemical oscillators (Briggs-Rauscher and **Belousov-Zhabotinsky**).



Week 2

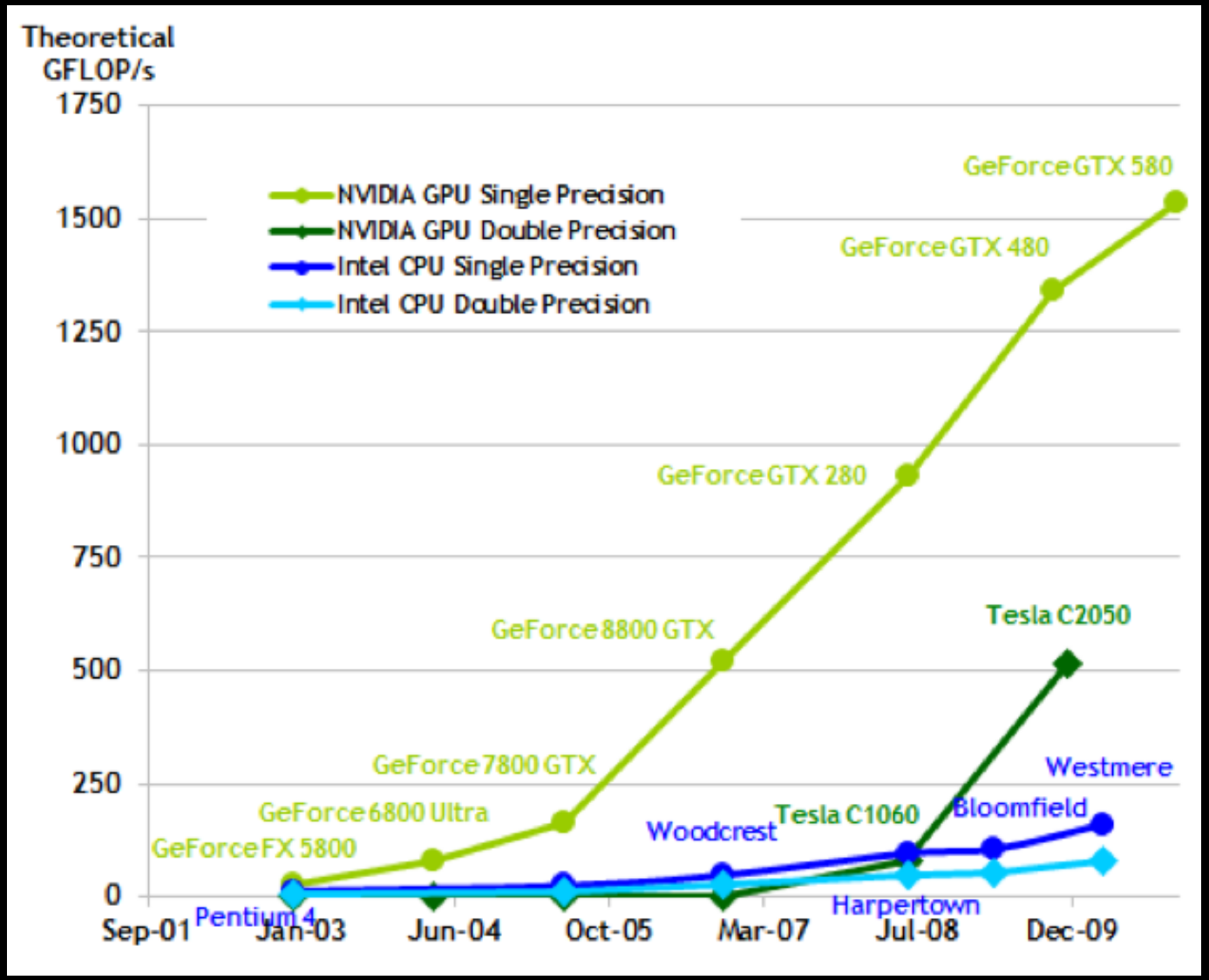
- Mathematical preliminaries

  – Modeling exercise and differential equations
  – Numerical integration
  – Java applets with exercises in cell dynamics
    http://TheVirtualHeart.org

Week 2

- Mathematical preliminaries
  - GPUs (Graphical processors units)

GPU vs CPU


Theoretical GFLOP/s
1750
1500
1250
1000
750
500
250
0
NVIDIA GPU Single Precision
NVIDIA GPU Double Precision
Intel CPU Single Precision
Intel CPU Double Precision
GeForce GTX 580
GeForce GTX 480
GeForce GTX 280
GeForce 8800 GTX
GeForce 7800 GTX
GeForce 6800 Ultra
GeForce FX 5800
Tesla C2050
Tesla C1060
Westmere
Bloomfield
Woodcrest
Harpertown
Pentium 4
Sep-01
Jan-03
Jun-04
Oct-05
Mar-07
Jul-08
Dec-09

Tesla C1060

30 Multiprocessors
240 Cores
Processor core clock: 1.296 GHz
933 Gigaflops (Single precision)
78 Gigaflops (Double Precision)
Max Bandwidth(102 Gigabytes/sec)
4 GB of DRAM

Cost: $**1000**

Fermi C2070

14 Multiprocessors
448 Cores
Processor core clock: 1.15 GHz
1030 Gigaflops (Single precision)
515 Gigaflops (Double precision)
Max Bandwidth (144 GBytes/sec)
6 GB of DRAM

Cost: $**3200**

Week 3

- Student Project
  - Students worked in 5 groups.
  - Each group used a CUDA program for a cardiac cell model that ran near-real time.
  - Physiological parameters were changed to study their effects on dynamics in 2D.

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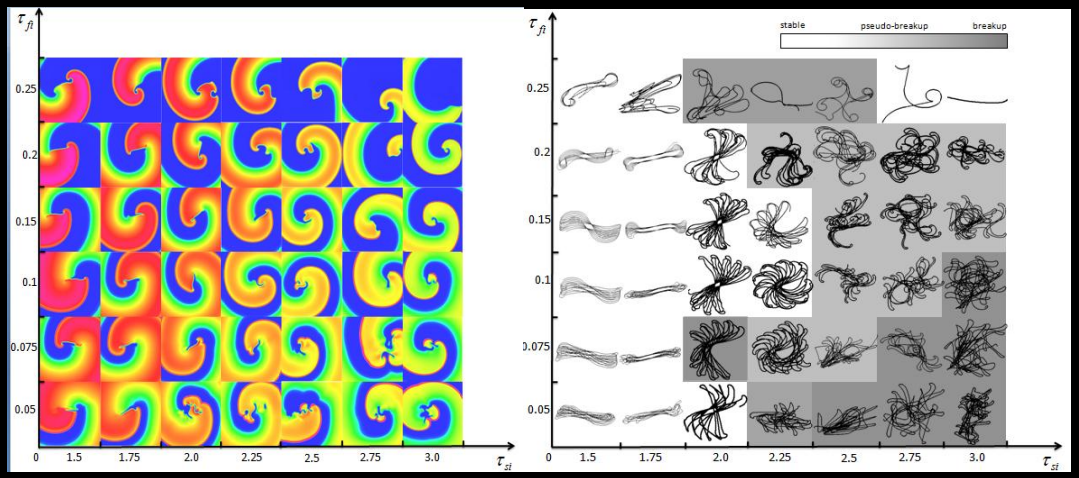
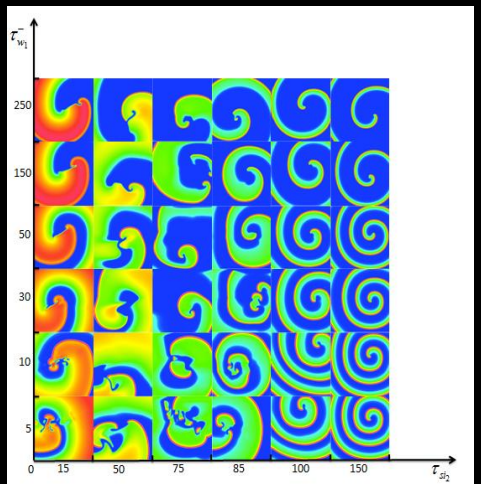
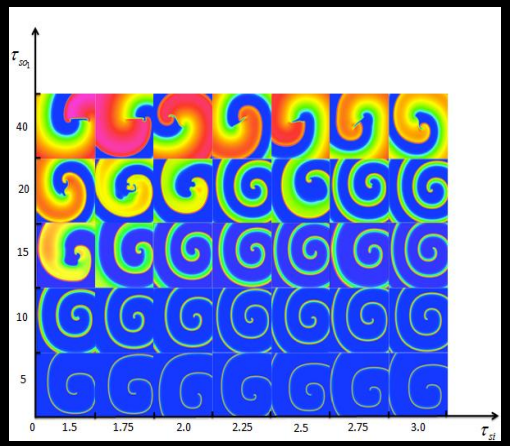
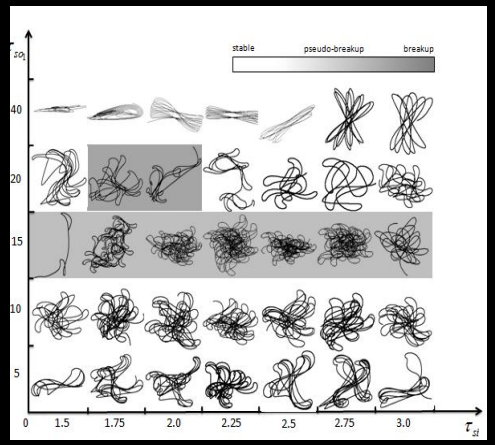
Week 3

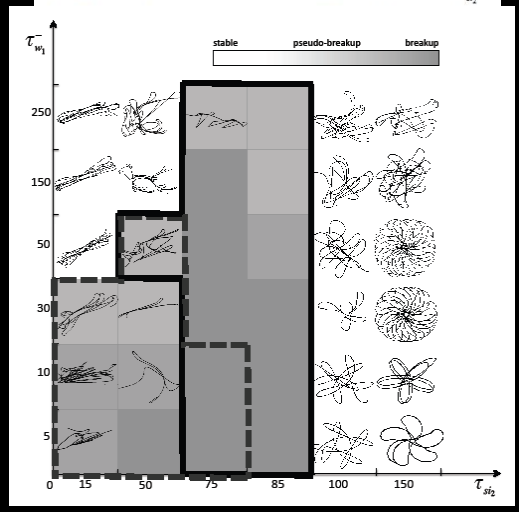
- Student Results











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Student Results

Advances in Physiology Education

Teaching cardiac electrophysiology modeling to undergraduate students: Lab exercises and GPU programming for the study of arrhythmias and spiral wave dynamics

Ezio Bartocci[1], Rupinder Singh[2], Frederick B. von Stein[3], Avessie Amedome[4], Alan Joseph J. Caceres[4], Juan Castillo[4], Evan Closser[4], Gabriel Deards[4], Andriy Goltsev[4], Roumwelle Sta. Ines[4], Cem Isbilir[4], Joan K. Marc[4], Diquan Moore[4], Dana Pardi[4], Sandeep Sadhu[4], Samuel Sanchez[4], Pooja Sharma[4], Anoopa Singh[4], Joshua Rogers[4], Aron Wolinetz[4], Terri Grosso-Applewhite[4], Kai Zhao[4], Andrew B. Filipski[5], Robert F. Gilmour Jr[3], Radu Grosu[5], James Glimm[1], Scott A Smolka[5], Elizabeth M. Cherry[3,7], Edmund M. Clarke[8], Nancy Griffeth[4], Flavio H. Fenton[3]

[1]Department of Applied Mathematics and Statistics, Stony Brook University, NY. [2]Department of Biomedical Engineering, Cornell University, Ithaca, NY. [3]Department of Biomedical Sciences, Cornell University, NY. [4]The City University of New York. [5]Department of Software Engineering, Rochester Institute of Technology, NY. [6]Department of Computer Science, Stony Brook University, NY. [7]Department of Applied Mathematics, Rochester Institute of Technology, NY. [8]Computer Science Department, Carnegie Mellon University, PA

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Reviewer Comments

Reviewer 1. The student workshops that this manuscript discusses sound fascinating. I support the idea and I am certain the students benefited immensely from the experience. I wish I had attended such a workshop in high school.

Reviewer 2. This is an extremely well written report of an outstanding, 3-week long undergraduate workshop. The material covered in the workshop is at a very advanced level and addresses a very important subject

John D. Griffin
Editor's comments,
We are very interested in accepting this manuscript for publication. If you could respond to the additional comments of the reviewer, we will provide an expedited review process …….

Student Comments

Best things about workshop…

- Learning experience
  - A ground-up exposure to the process of formulating a model
  - Running the Simulations of the Spiral waves on the CUDA GPU
  - Learning how heart fibrillation works
  - Learning about the resources and technology … necessary for … research
  - Applications of parallel computation to simulate the human heart
- Collaboration
  - The opportunity to collaborate with other peers in different disciplines
  - Seeing how every area of science (Biology, Math) work together to solve the real world problems from very distinguished professors
- Future plans
  - This workshop inspired me to pursue information outside of my own discipline.
  - Getting a sense that I am capable of doing similar research

What is Next?

Expand the teaching module :

- More Java applet exercises
- More GPU interactive codes (HTML 5)
- CUDA and 3D physiological heart structures

What is Next?

Tailor the teaching module for:

- Middle/High School Students

CLIMB (Cornell's Learning Initiative in Medicine and Bioengineering) connected with a teacher in Ernie Davis Middle School, NY (4 classes, 20-30 students each, Nov. 21-25)

- Undergraduate Students
- Graduate Students

In collaboration with University Campus Biomedico of Rome (60 students class, Nov. 28 – Dec. 2)

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What is Next?

Tailor the teaching module for:

- Middle/High School Students
- Undergraduate Students
- Graduate Students

Make available all the information for downloading online.

For further dissemination: Submit to *Science* Prize for Inquiry-Based Instruction (highlight outstanding "modules" for teaching introductory college science courses that can readily spread to other settings and schools)

Write and answer this part:

•To what extent does this Expedition inspire (and will continue to inspire) students to pursue careers in computer science, information science and computer engineering?

What are the education/outreach-related accomplishments?
How well does the project integrate research with education?
Does the implementation of educational/outreach activities differ significantly from the original plan?
    If so, what were the reasons for the change?
How appropriate are the project's future goals and plans with respect to educational and outreach activities?
How well does the project broaden the participation of underrepresented groups (e.g. gender, ethnicity, disability, geographic, etc.)?

Course Modules
Flavio Fenton and **Rupinder Singh**, Atrial fibrillation module, also supported in part by NSF xxx, used wholly or in part at:
    Università Campus Bio-Medico, 60 masters level students
    Lehman College, 8 high school students
    Ernie Davis Middle School, Rochester, NY, 15 middle school students
I added the tutorial and the middle school for Kelly Clement. Is the title ok? I thought more specific would be better. And we can get in the other grant this way.

•
In the original proposal we promised to do this:
"At the core of the Education&Outreach initiative will be the formation of a new, highly ambitious and highly cross-discipline educational program called Complex Systems Science & Engineering (CSSE), with subdisciplines in BioSystems Science & Engineering (BSSE) and Embedded Systems Science & Engineering (ESSE)."

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Collaborators

Ezio Bartocci[1], Rupinder Singh[2], Frederick B. von Stein[3], Avessie Amedome[4], Alan Joseph J. Caceres[4], Juan Castillo[4], Evan Closser[4], Gabriel Deards[4], Andriy Goltsev[4], Roumwelle Sta. Ines[4], Cem Isbilir[4], Joan K. Marc[4], Diquan Moore[4], Dana Pardi[4], Sandeep Sadhu[4], Samuel Sanchez[4], Pooja Sharma[4], Anoopa Singh[4], Joshua Rogers[4], Aron Wolinetz[4], Terri Grosso-Applewhite[4], Kai Zhao[4], Andrew B. Filipski[5], Robert F. Gilmour Jr[3], Radu Grosu[5], James Glimm[1], Scott A Smolka[5], Elizabeth M. Cherry[3,7], Edmund M. Clarke[8], Nancy Griffeth[4], Flavio H. Fenton[3]

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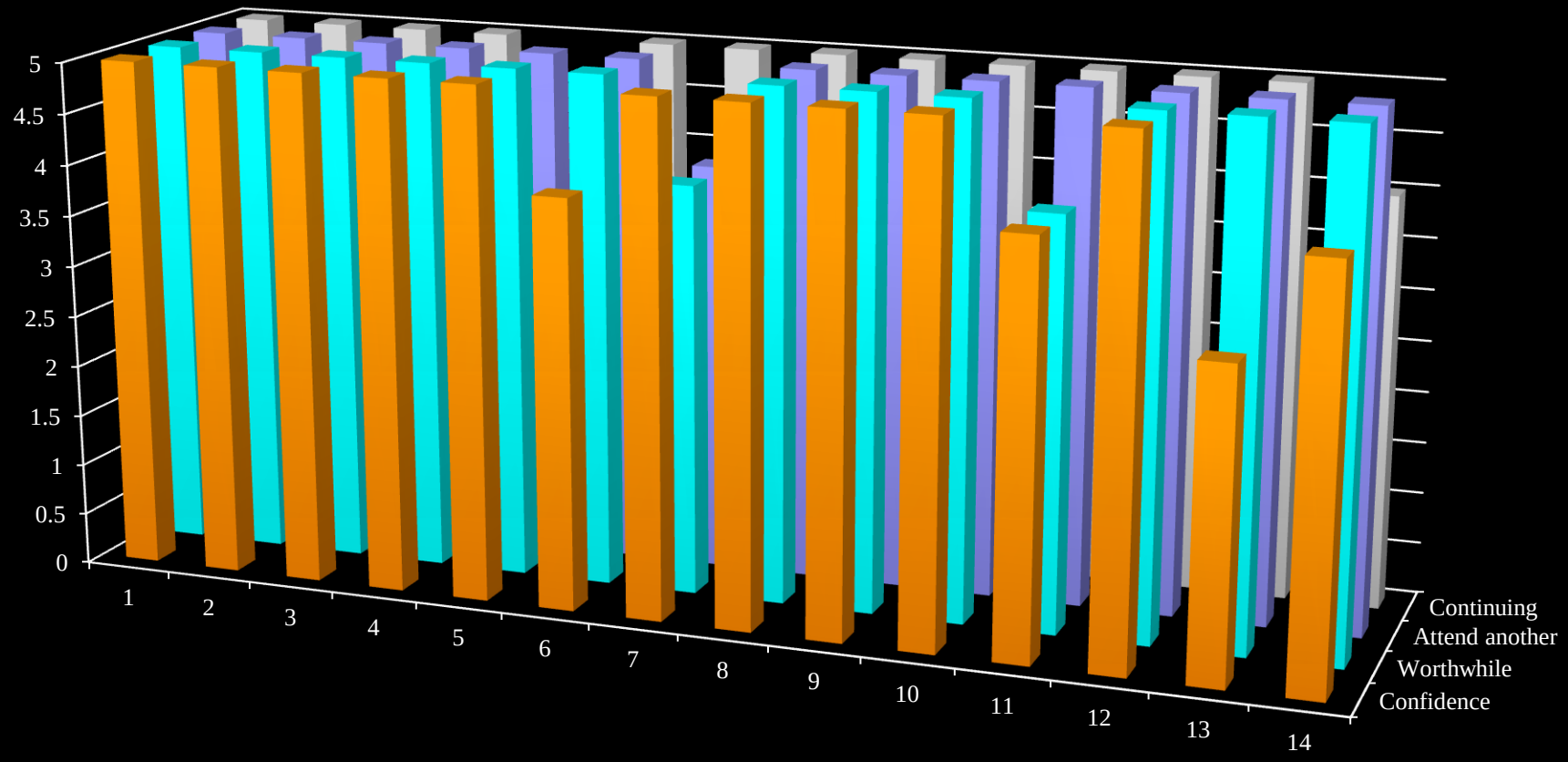
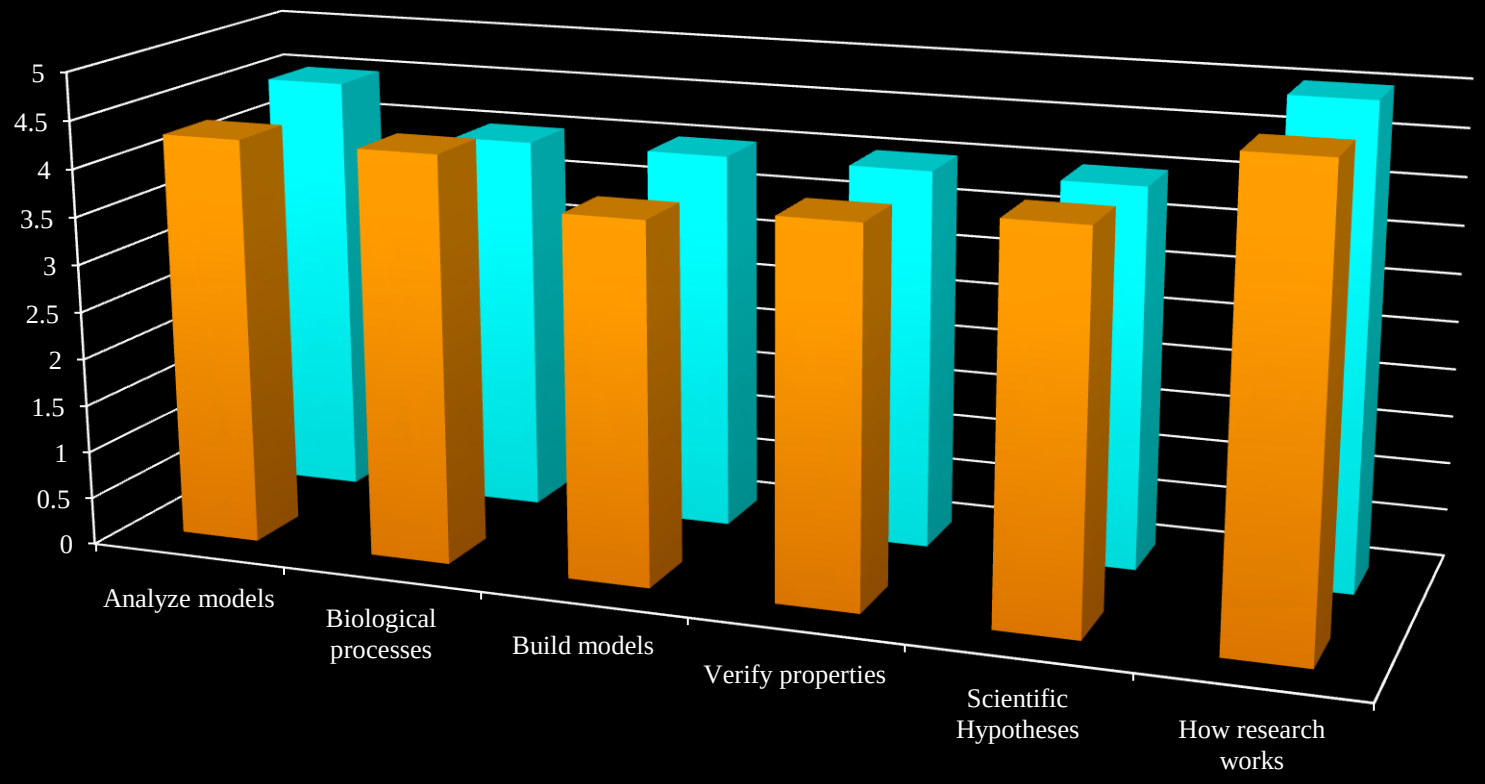
- END
- The rest is for other things.

Student Evaluations – General Objectives



Student Evaluations – Specific Learning Objectives



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- Future plans
  - This workshop inspired me to pursue information outside of my own discipline.
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Suggested improvements

- More of the biological background relevant to our models. I really enjoyed Robert Gilmore's presentation … it would have been more helpful to begin with [it].
- [Topics], whether biology, math, or programming, [were] first presented in a complex manner and then more simply.
- More time to working on projects and presentations
- I would do the Math first.
- [More on] how to construct a basic differential equation that describes some simple behavior
- **Week one**: general introductions of the concept to students of all majors.
  Week two: separate students by majors and provide more intense learning in the field related to each group
  Week three: final project

Planned 2012 Workshop

- Challenge problem: Pancreatic Cancer
- Collaborators: Jim Faeder, Ed Clarke, …

Flavio H. Fenton and Robert Gilmour

Department of Biomedical Sciences
College of Veterinary Medicine,
Cornell University, NY

Collaborators
Scott A Smolka, Radu Grosu, Ezio Bartocci and James Glimm
Stony Brook University

NSF Expeditions in Computing CMACS PI Review Meeting University of Maryland, April 28-29 2011

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CMACS Education Program

Complex systems and arrhythmias module

Flavio H. Fenton

CMACS
Educational Reach

Postdoctoral fellows

- **Haijun Gong**, Carnegie Mellon University, Edmund Clarke

- **Paolo Zuliani**, Carnegie Mellon University, Edmund Clarke
Ping Hou, Carnegie Mellon University, Edmund Clarke

- **Ezio Bartocci**, Stony Brook University, James Glimm, Radu Grosu, and Scott Smolka

- **Andreas Witzel**, New York University, Bud Mishra

Doctoral Students

- **Sicun Gao**, Carnegie Mellon University, Edmund Clarke
- **David Henriques**, Carnegie Mellon University, Edmund Clarke
- **William Klieber,** Carnegie Mellon University, Edmund Clarke
- **Anvesh Komuravelli,** Carnegie Mellon University, Edmund Clarke
- **Soon Ho Kong**, Carnegie Mellon University, Edmund Clarke
- **Samir Sapra,** Carnegie Mellon University, Edmund Clarke
- **Qinsi Wang,** Carnegie Mellon University, Edmund Clarke
- **Ying-Chih Wang,** Carnegie Mellon University, Edmund Clarke

- To add to the cardiac future studies
- I'm still struggling to understand where we could use probablistic model checking and I'm skeptical that this will really scale to something useful. It wasn't clear what real problems this is being applied to.
- Purkinje fibers.
- Add the karma and sobbie studies good enough solutions.

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Educational Reach

Doctoral Students

- **David Renshaw**, Carnegie Mellon University, Andre Platzer
- **Sarah Loos**, Carnegie Mellon University, Andre Platzer
- **Peter Fontana**, University of Maryland, Rance Cleaveland
- **Sam Huang**, University of Maryland, Rance Cleaveland
- **Christoph Schulze,** University of Maryland, Rance Cleaveland
- **Ilya Korsunsky,** New York University, Bud Mishra
- **Justin Jee**, New York University, Bud Mishra
- **Loes Olde Loohuis**, New York University, Bud Mishra
- **Andrew Sundstrom**, New York University, Bud Mishra

Doctoral Students

- **James Ferlez**, University of Maryland, Steve Marcus
- **Yongqiang Wang**, University of Maryland, Steve Marcus
- **Kun Lin**, University of Maryland, Steve Marcus
- **Terri Grosso-Applewhite,** Lehman College, Nancy Griffeth
- **Kai Zhao**, Lehman College, Nancy Griffeth
- **Fred Von Stein**, Cornell University, Flavio Fenton
- **Rupinder Singh**, Cornell University, Flavio Fenton
- **Alessio Gizzi**, University campus biomedico of Rome, Flavio Fenton

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Educational Reach

Master's Students

- **Fred Dieckamp**, Hunter College, supporting NSF CMACS Workshop
- **Aron Wolinetz**, Lehman College, supporting NSF CMACS Workshop
- **Joshua Rogers**, Lehman College, supporting NSF CMACS Workshop
- **Athena Shi**, New York University, Bud Mishra

Undergraduate Students
Individual Mentoring

- **Ilya Korsunsky**, Carnegie Mellon University, intern with Edmund Clarke and James Faeder
- **Mate Nagy**, Carnegie Mellon University, intern with Edmund Clarke and James Faeder
-

Undergraduate Students
Individual Mentoring

- **Jingyi Ni**, Carnegie Mellon University, Andre Platzer
- **Mohammed Mehdi Premjee**, Cornell University, Flavio Fenton
- **Jeffrey Shieh Fitch**, Cornell University, Flavio Fenton
- **Andrew Filipski,** Rochester Institute of Technology, Elizabeth Cherry

CIMACS Workshop Students
2010

- **Hyukin Kwon**, Stony Brook University
- **Tamara Schillin**, Lehman College
- **Ann Marie Alcocer,** Lehman College
- **Jinnie Lee**, Lehman College
- **Daniele Ippolito**, Lehman College

CMACS
Educational Reach

CMACS Workshop Students
2010

- **Samantha Daley**, Lehman College
- **Truong Le Ngo**, Lehman College
- **Victor Nnah**, Lehman College
- **Elzara Kimalova**, Hunter College
- **Ilya Korsunsky**, Hunter College
- **Jason Fitzsimmons**, Hunter College
- **Alexander Smith,** Hunter College
- **Jesse Lopez**, Brooklyn College
- **Adiba Ishak**, Brooklyn College
- **Mate Nagy**, Brooklyn College

High School Teachers

- **Kelly Clement**, Cornell University, Flavio Fenton

CMACS Workshop Students
2010

- **Dana Pardi**, Brooklyn College
- **Roumwelle Ines**, Brooklyn College
- **Avessie Amedome,** Hunter College
- **Anoopa Singh**, Hunter College
- **Cem Isbiller,** Hunter College
- **Andriy Goltsev**, Hunter College
- **Gabriel Deards**, Hunter College
- **Joan K. Marc**, Hunter College
- **Sandeep Sadhu**, Lehman College
- **Alan Caceres,** Lehman College
- **Diquan Moore**, Lehman College
- **Juan Castillo,** Lehman College
- **Pooja Sharma**, Queens College
- **Jonathan Hernandez,** Queens College
- **Samuel Sanchez**, Queens College
- **Evan Closser,** Queens College

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Other Educational activities

Tutorials

- **Howard Barringer and Klaus Havelund.** Internal versus External DSLs for Trace Analysis, 2nd International Conference on RUNTIME VERIFICATION RV 2011, September 27 - September 30, 2011

- **Klaus Havelund and Martin Luecker**, Runtime Verification, at SEFM School, November 7-11, 2011, Montevideo, Uruguay

- **Flavio H Fenton** Caos, espirales y la dinámica del corazón XII escuela de Otono en biologia Matematica y VI Encuentro Nacional de Biologia Matematica Pachuca Mexico, Octubre 18-22, 2010

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Other Educational activities

Workshops

•Formally Verified Distributed Car Control Sytem, to 30 high school students, by Sarah Loos in Andrew's Leap at Carnegie Mellon University
•(Need title) 15 high school students (of Kelly)
•(Need title) 60 master students (University campus biomedico of Rome)
•Saline oscillator and BZ reaction exercises, for 8 high school students in summer program at Lehman College, by Nancy Griffeth
•College Courses
•Logical analysis of hybrid systems, new course at Carnegie Mellon University based on techniques developed in Expedition (Andre Platzer)
•Simulation and Modeling of Biological Systems, new course at Lehman College based on NSF CMACS winter workshops (Nancy Griffeth)
•Abstract interpretation added to model-checking courses at Carnegie Mellon University (Edmund Clarke)
•College Programs
•New minor in Quantitative and Systems Biology is in approval process at Lehman College.