CYBER-Alaska: Training Tomorrow's Engineers in Cyber-Physical Systems

Dr. Seta Bogosyan   Dr. Orion Sky Lawlor

University of Alaska Fairbanks, College of Engineering and Mines

Start with Laplace's equation, the steady-state heat equation:

$$\nabla^2 f = 0$$

Expand partials for a 2D grid, familiar to Calculus 2 students:

$$\frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} = 0$$

Discretize via centered differences, now reaching Calculus 1:

$$\frac{f(x+h,y) - 2f(x,y) + f(x-h,y)}{h^2} + \frac{f(x,y+h) - 2f(x,y) + f(x,y-h)}{h^2} = 0$$

Cancel h^2 and collect terms, now reaching Algebra students:

$$-4f(x,y) + f(x+h,y) + f(x-h,y) + f(x,y+h) + f(x,y-h) = 0$$

Solve for new f, now reaching something computationally useful:

$$f(x,y) = \frac{1}{4}(f(x+h,y) + f(x-h,y) + f(x,y+h) + f(x,y-h))$$

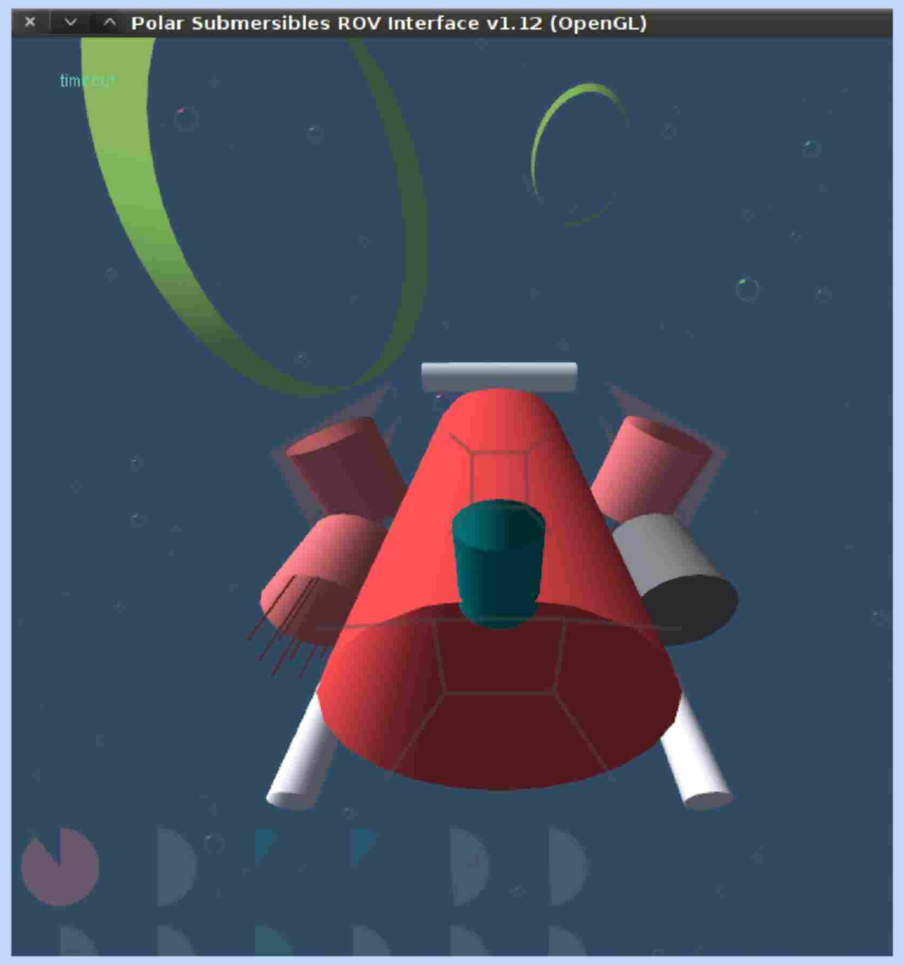
Giving labels to the neighboring values of f, we have:

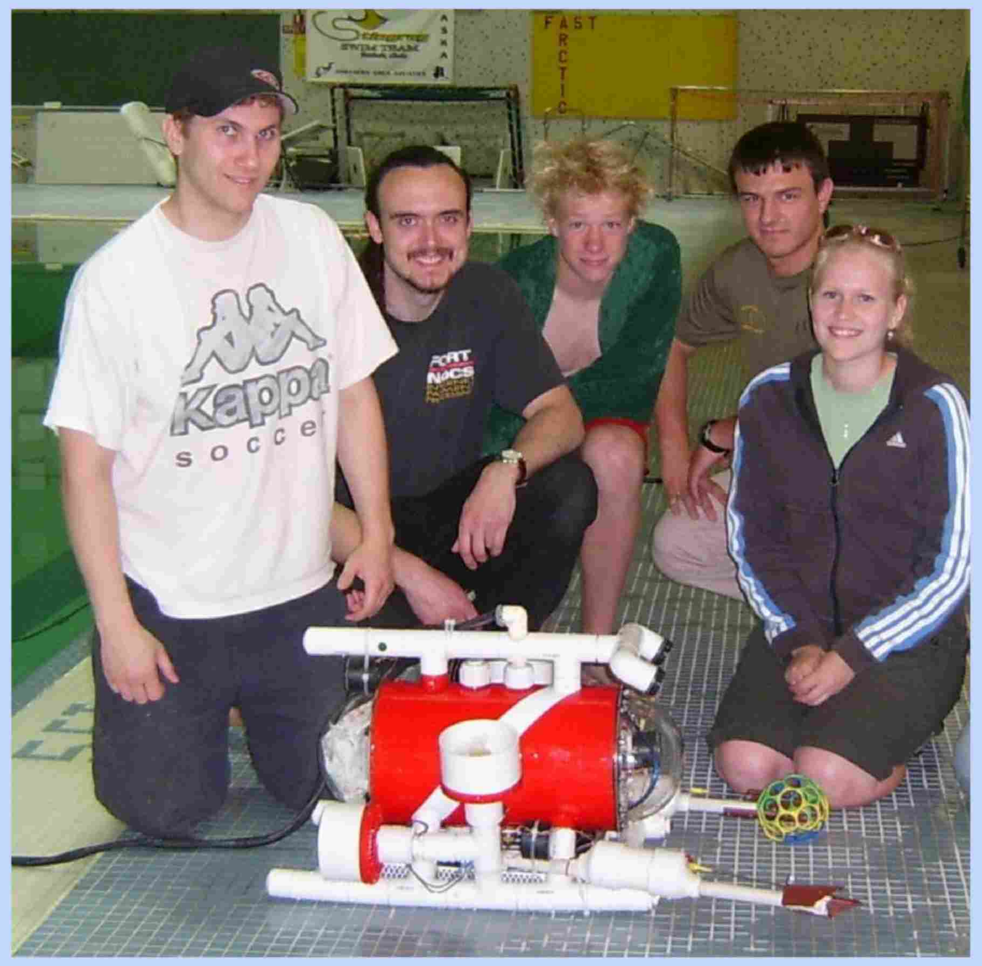
$$\text{temperature} = \frac{1}{4}\,(\text{right} + \text{left} + \text{top} + \text{bottom})$$

Or for middle school, heat flow means:

your temperature = average temperature of your neighbors

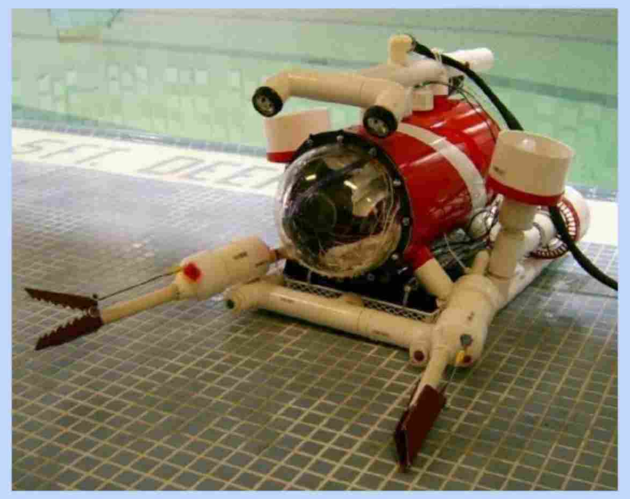
Online Physical & Virtual Coupled Robot Simulation





As shown by the MATE ROV competition and MIT SeaPerch projects, even middle school students are capable of constructing underwater remotely operated vehicles (ROVs). UAF undergraduate students and Alaska middle and high school students have competed in the MATE ROV contest international finals in 2007, 2008, and 2010, mentored by Co-PI Lawlor. Typically, a control PC sends commands over a USB or serial link to an onboard microcontroller, which drives the thrusters and reads the vehicle's sensors. The pilot sits at the PC watching a video feed from the ROV, and commands the vehicle using a joystick or gamepad.

We have found it useful to provide the pilot with a real-time simulation of the ROV, driven from the same control inputs, where a simple Newtonian physics model integrates the linear force and angular torques from the virtual thrusters. This linked real-time simulation provides the pilot with a "bird's eye view" of the ROV's position and orientation, and displays sensor data from the ROV. In particular, for reorienting servo-pointed video cameras, it is much easier to use the simulated view frustum than the controlled video feed, which by definition is pointing in the wrong direction! This interrelationship between physical and virtual robots helps naturally deliver CPS concepts to high school students.



2007 UAF underwater robot
MATE ROV finals
in St. Johns, Newfoundland

2008 UAF underwater robot
MATE ROV finals: San Diego, California
"Inspiration for Future Engineers" Award

2010 UAF underwater robot
MATE ROV finals: Hilo, Hawaii
"Biggest Bang for the Buck" Award

"Trashbot" video
analysis demo (2008)

"SmartWheels"
video tracker (2009)

Tracked LIDAR platform
(2009)

"Sun Dog" Solar Powered
RADAR platform (2010+)

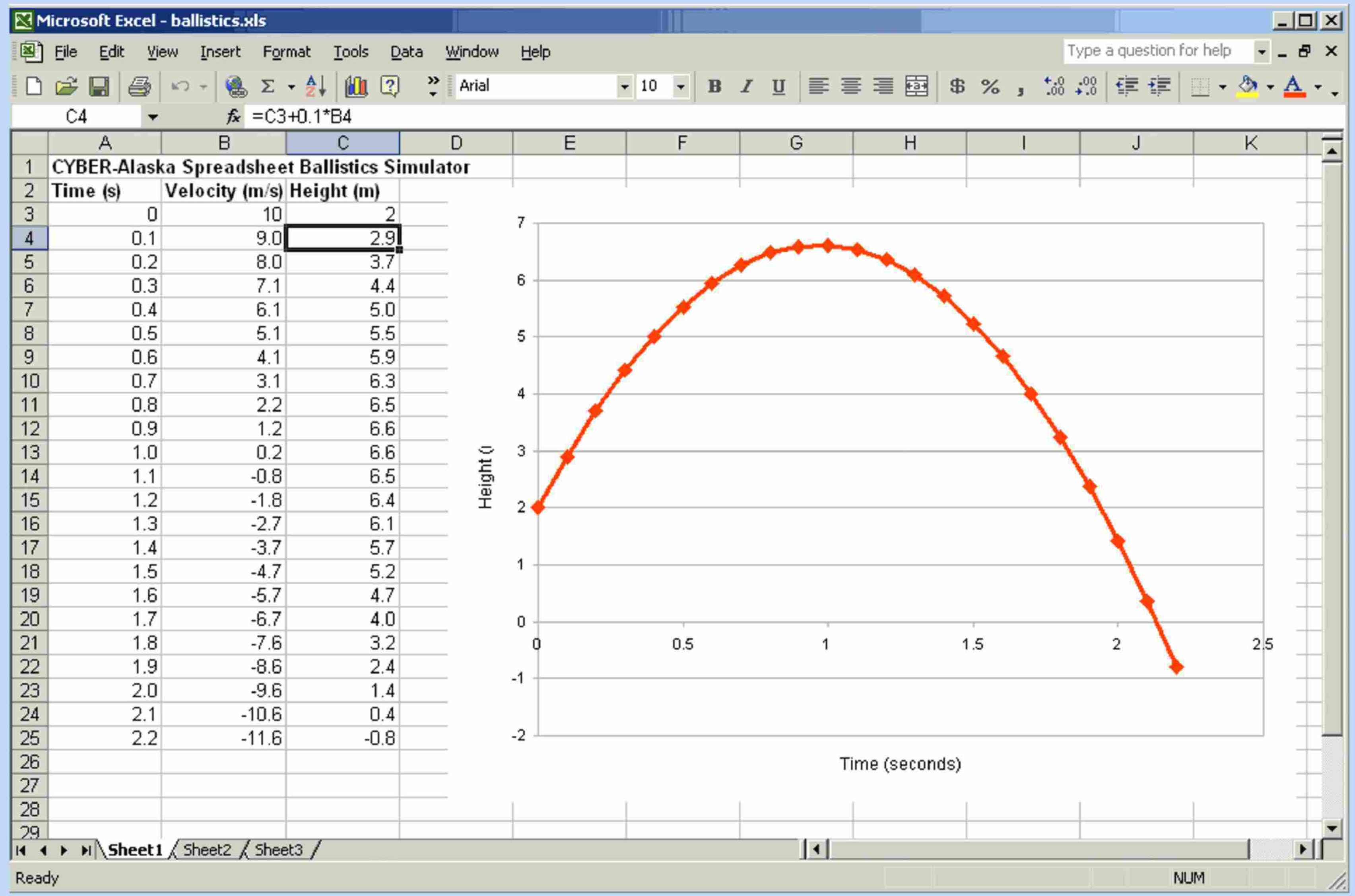
Overall Project Goals

For Graduate Students: Teaching, supervising and communicating their research to a less technically savvy audience in inquiry-based classes and projects not only will improve their communication, team building and leadership skills, but will also result in a better understanding of their research theme, and understanding of other CPS elements, hence contributing to their expertise in CPS.

For Schools: Bringing CPS related computer science and engineering concepts to grade 7-12 students and their teachers will provide an understanding of and interest in CPS, will help them understand why they need to learn math and science to be a part of the state-of-the-art technologies they enjoy, and may help create motivation for careers in computer science and engineering.

Selected graduate students at UAF, performing CPS related research, will teach and mentor grade 7-12 students and teachers in urban and rural Alaska via course material and simple project models to be developed related to their research. We will take the students through the whole development process of the project kits (i.e. modeling, simulation, mechanical design, control, and networking steps) in a level-appropriate manner, using an inquiry-based approach. The fellows will bring their research to classrooms primarily through the in-class development of simpler dynamic simulations or models--both physical and virtual--of the actual systems related to their research. Such an interactive model of the actual system acts like an "elevator speech" intro for the field, can help convey the fundamental principles of the field, and most importantly transforms vague and nebulous talk into concrete, tangible activity. The developed courses and project kits, both software and hardware, will be made accessible on the internet for use by other students, researchers, and general public.

Simulations for Grades 7-12



Microsoft Excel - ballistics.xls

C4 =C3+0.1*B4

CYBER-Alaska Spreadsheet Ballistics Simulator

Time (s)	Velocity (m/s)	Height (m)
0	10	2
0.1	9.0	2.9
0.2	8.0	3.7
0.3	7.1	4.4
0.4	6.1	5.0
0.5	5.1	5.5
0.6	4.1	5.9
0.7	3.1	6.3
0.8	2.2	6.5
0.9	1.2	6.6
1.0	0.2	6.6
1.1	-0.8	6.5
1.2	-1.8	6.4
1.3	-2.7	6.1
1.4	-3.7	5.7
1.5	-4.7	5.2
1.6	-5.7	4.7
1.7	-6.7	4.0
1.8	-7.6	3.2
1.9	-8.6	2.4
2.0	-9.6	1.4
2.1	-10.6	0.4
2.2	-11.6	-0.8

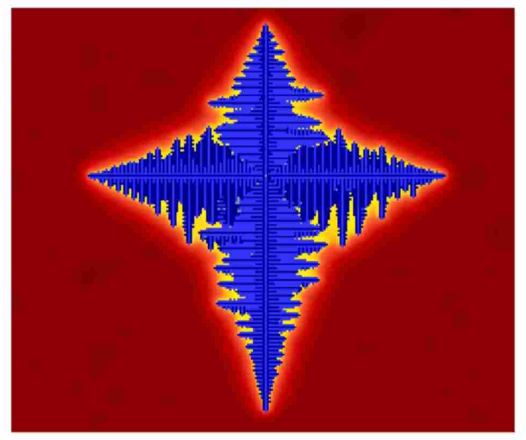
Useful simulations can be built from very simple addition and multiplication in a spreadsheet, with "fill down" propagating the simulation through time. This ballistics simulation spreadsheet can be built and understood by students a single class session, or the same spreadsheet could form the foundation for a multi-year discussion of the details of the underlying parabola, quadratic equation root finding, air resistance, boundary conditions and rebound, a full discussion of differential equations, higher order solutions, predictor-corrector methods, numerical stability, experimental validation, data exchange over the network, ad infinitum. With today's powerful computational tools, and some creativity and showmanship, modern science really can be scaled down to small appetizing pieces.

Smart Buildings & Roads via Online Simulation

The thermostat of a future energy-efficient house might combine sensor measurements of interior and exterior temperature with predicted weather, a detailed online simulation, and variety of passive and active actuators such as solar reflectors and heat pumps. As the coldest US state, and one with among the highest fuel prices, Alaskan children have a deep and intimate familiarity with the importance of energy-efficient heating systems, and the benefits of intelligently reducing energy consumption.

We will build upon a house model which has been used at UAF for several years, where the house's central heater is emulated using an incandescent light bulb and a small fan. We will add microprocessor controlled sensors & actuators linked to a PC, allowing us to plot temperatures, run experiments to measure transient and steady-state heating effects, run simple data fusion algorithms, and compare the physical kit measurements with various simulations. Because heat flow rates are a linear function of temperature difference, high school students should be able to construct useful models to predict energy use given interior and exterior temperatures. Based on these models, students can then construct heating control systems using CPS concepts, such as a smart thermostat that integrates sparse measurements with a linked simulation.

"Little House in Alaska"
building heat flow model



Heat flow & ice solidification /
dendritic growth simulator

PI Dr. Seta Bogosyan
sbogosyan@alaska.edu
Department of Electrical &
Computer Engineering

Co-PI Dr. Orion Sky Lawlor
lawlor@alaska.edu
Department of Computer Science

http://www.cs.uaf.edu/2011/research/cyberalaska/

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