Computation in Particle Physics

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What kind of computing { do we / should we } include in the Vassar curriculum?

Who?
What?
Where?
When?
Why?

Why teach computation to physics students?

- Computational methods are used in all branches of physics research, for both experimentation and theoretical calculations. [More later...]
- Computation can enable useful ways to teach particular topics. (eg "Computer" problems, graphics)
- Students with proper computational background have a better chance at summer research opportunities (eg CERN REU)
- Preparation for more advanced study (grad school)
- General knowledge

Computing is a part of a complete, well rounded education

... in physics

... in the sciences

... in general!

Why teach computation? (II)

It is becoming as necessary as Calculus (or Algebra in Maria's day)

I. In physics classes we want students to know how to compute derivatives and integrals, and what they mean

II In math class students learn not just how to calculate, but why it works, when it doesent, and the reasons

Physics students need I, but profit from having been through II.

Without some background and fundamental reasons, students just treat calculus as a black box and turn the crank without knowing why it works.

The same is true for numerical methods.

"Physics is to Mathematics
as Sex is to Masturbation"

– Richard Feynman

Physicists view computation as a useful tool but not as an end in itself

eg Taylor's Theorem

$$f(x_0+\Delta x) = f(x_0) + \left.\frac{df}{dx}\right|_{x_0}(\Delta x)$$

$$+ \left.\frac{d^2f}{dx^2}\right|_{x_0}(\Delta x)^2 + \ldots$$

$$= \sum_{n=0}^{N} \left.\frac{d^nf}{dx^n}\right|_{x_0}(\Delta x)^n + R$$

Physicists will use this to evaluate $f(x)$ or manipulate f, assuming R is negligible or $N \to \infty$

Mathematicians are more interested in the properties of R that let us do this

Both views important!

What computational topics or numerical methods should be taught?

Those useful for particle physics

Who am I? a "particle physicist"

Particle physics asks fundamental questions:

- **what** is everything made of?
- **how** do these constituents interact?
- **where** did it all come from?

Particle physics is also "High Energy" physics because particles behave like waves:

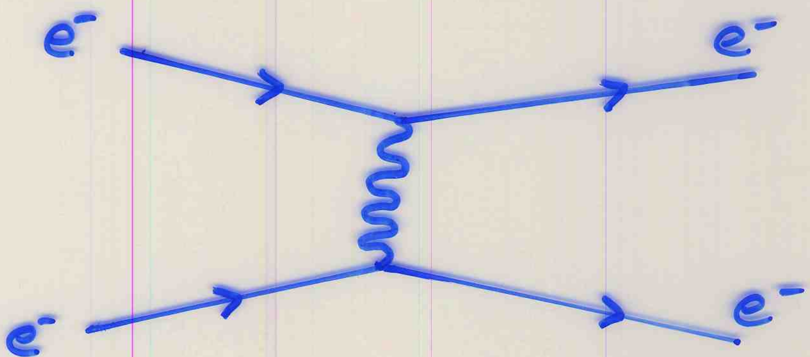
$$\lambda = \frac{h}{p}$$ (de Broglie's hypothesis)

To probe shorter distances (smaller λ) we need larger momenta (bigger $p = mv$) and hence higher energies

eg "Tevatron" at Fermilab $\leq$ 1.96 TeV

LHC at CERN $\approx$ 14 TeV
($\approx$ 2007)

Particle physics is also "Particles and Fields" because relativistic particles and their interactions are described by Quantum Field Theories (QFT)



Maxwell's Equations lead to QED ("Quantum Electrodynamics") for photon field

Extended to "Electroweak" Theory for $W^{\pm}, Z^{0}$, which carry "weak" force

Extended to QCD ("Quantum Chromodynamics") where "gluons" carry the "strong" force

Einstein's Equations in GR should be the classical limit of a Quantum Field Theory of gravitation (and "gravitons")

open area of research

"Particle" physicists divide themselves into:

"Theorists" ⟷ "Experimentalists"

I am proud to have worked on both sides:

- Started out as a theorist, working on particle interactions and gravitation
- Worked summers on nuclear, cosmic ray, and particle experiments
- Worked on many kinds of theoretical simulations: lattice gauge theory (QCD), cosmic strings, flux vortices in superconductor, magnetic materials, self-ordered criticality, lattice quantum gravity, DNA branch migration
- Spent last 2 years before Vassar working on DØ at Fermilab and ATLAS at CERN LHC for Univ. of Michigan (primarily computing)

I'm currently interested in an opportunity to mix experiment and theory : LIGO

Laser Interferometer Gravity wave Observatory

Goals:

1. detection of gravity waves, as predicted by GR

2. use gravity waves as a new spectrum for astronomical observation

My contributions:

1. "distributed" computing for LIGO data analysis, using "GRID" computing and "cluster" computing

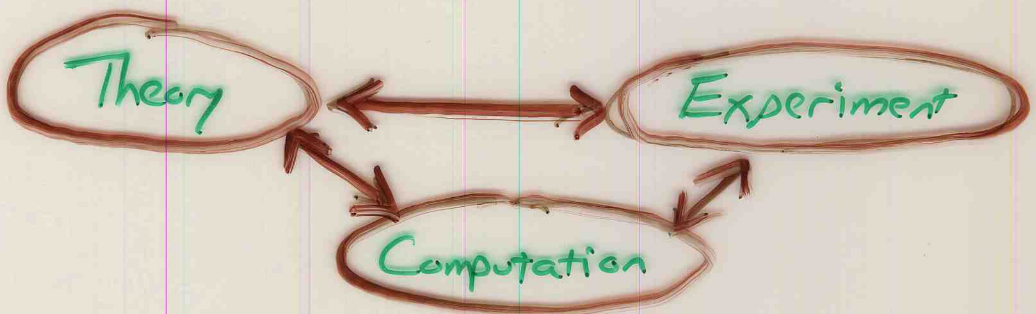
2. Source modeling for gravity waves

   a) absorbing boundary conditions for lattice simulations

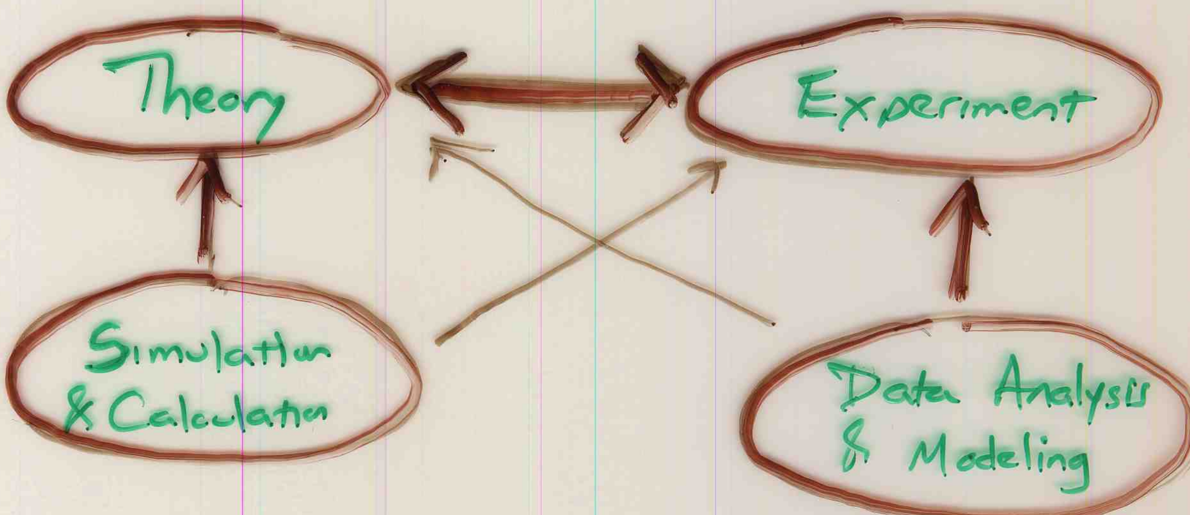
   b) compute gravity waves produced by intercommuting cosmic strings

What is "Computational" Physics?

Proponents suggest it is a new division of physics (eg APS-DCOMP):



I disagree. I think it's more like:



What topics to teach?

Which tools, which methods?

TOOLS ("Give someone a fish...")

- Graphics and Visualization — pro Fit, Mathematica, MatLAB
- Symbolic Manipulation — Mathematica
- Numerical Manipulation — MATLab
- Data Acquisition (DAQ) — Lab View
- Technical Typesetting — TEX

METHODS ("Teach someone to fish...")

! PROGRAMMING ! (The difference between riding and driving yourself)

FORTRAN, C, C++, Python, Perl, MATLab, Unix (use and admin)

basics: arithmetic, flow control, algorithms

specialized methods: Lattice QCD, SPH, Monte Carlo simulation, Molecular Dynamics

general methods: Numerical Analysis

Tools may die, but Methods live on

Numerical Analysis

- Accuracy, precision, & rounding errors
- Evaluation of functions / special functions
- Solving linear systems of equations
- Eigenvector / Eigenvalue methods (QM!)
- Solution of non-linear equations
- Interpolation and Approximation
- Numerical Integration and Differentiation
- Numerical solution of ODE's
- Optimization (max/min)
- Random Numbers / Monte Carlo methods
- Sorting
- Fourier Transforms & Spectral methods
- Wavelets
- Statistical descriptions of data
- Modeling of data
- Numerical solution of PDE's
- Chaos and complex systems

VASSAR COLLEGE
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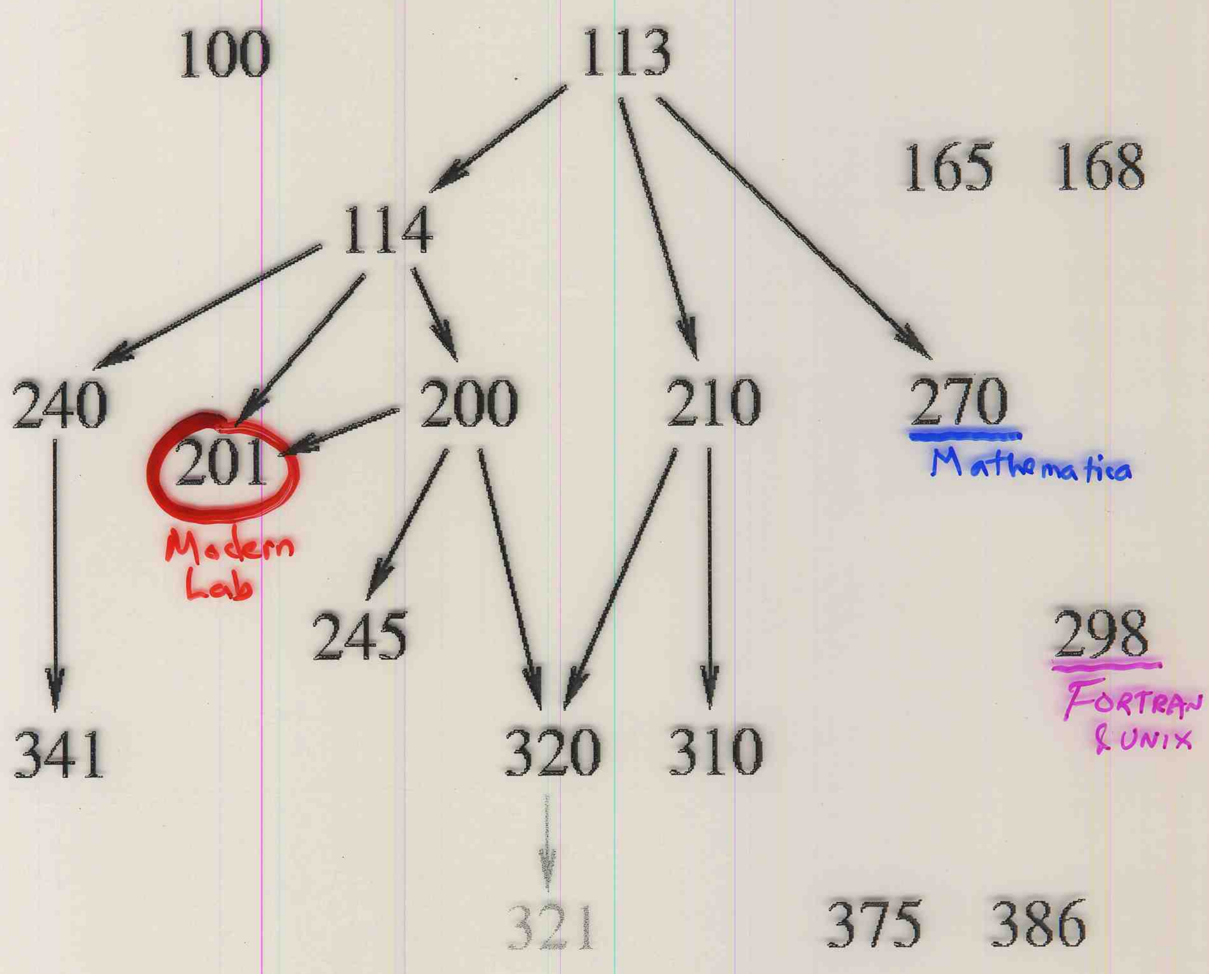
Department of Physics and Astronomy

Map of courses for the Vassar Physics Major

Requirements for a Physics Major: 9 units above the introductory level, including the 6 core courses 200, 201, 210, 240, 245 and 320; and 3 additional units in Physics or Astronomy (above the 100 level), at least 2 of which must be at the 300 level.



http://noether.vassar.edu/physastro/PhysicsMap...

Physics ~~298~~ 272

Fortran and Unix for Physics and Astronomy

http://noether.vassar.edu/~myers/fortran/

A reading course to learn computer programming for scientific coursework and research.

This is the Home Page for the independent study reading course in Fortran and Unix for Physics and Astronomy students at Vassar College.

Textbook Info	Instructor/Mentor	Exercises	Schedule

Introduction

Computer programming is an important skill for experimental, observational and theoretical scientific work, and Fortran is (still!) one of the most important computer languages used for such work. Similarly, the Unix operating system is now in use on most scientific computer systems, ranging from PC's and workstations to supercomputers and computer clusters. The purpose of this course is to introduce students to programming in Fortran 77, while at the same time familiarizing them with the Unix operating system and many of the programming tools available in the Unix environment, including the emacs editor and the Revision Control System (RCS).

The only real way to learn to program is by writing programs, so the course is structured around a set of simple exercises. Each exercise requires that you learn one or more new programming concepts in order to complete that exercise. Once your program works correctly, you can move on to the next exercise.

Why Fortran 77? Why not C or C++?

> *The latest version of Fortran is Fortran 90, so why does this course use Fortran 77?*

First of all, Fortran 90 includes Fortran 77 as a subset, so by learning Fortran 77 you are actually learning the basics of Fortran 90 too. But Fortran 90 also includes extra language elements for manipulating arrays and matrices, and new control structures. These are useful, especially for problems which have to be run on the latest supercomputers, but they can also be confusing for beginners. It is better to start with simpler ideas and work your way up. So you should start by learning Fortran 77, and then later learn the more powerful and specialized constructs of Fortran 90.

Suggested Schedule

Unless you are very organized and diligent it is easy to fall behind in an independent study course. The suggested schedule below should help you keep up the proper pace. It is suggested that you print out this page and fill in the "Date" column so that you can better keep track of where you should be throughout the semester. You can also check off the lessons you have completed, to track your progress.

Week	Date	Lesson(s)
Week 1		Lesson 1 - Getting Started Lesson 2 - How to send E-mail Lesson 3 - Compling a Fortran Program Lesson 4 - Entering and Editing Programs
Week 2		Lesson 5 - Aircraft Weight and Balance
Week 3		Lesson 6 - The IF Statement
Week 4		Lesson 7 - The DO Loop
Week 5		Lesson 8 - The REAL DO Loop
Week 6		Lesson 9 - Nested DO Loops
Week 7		Lesson 10 - The Flour Bomb Program - I
Week 8		Lesson 10 - The Flour Bomb Program - II
Week 9		Lesson 11 - The Bubble Sort
Week 10		Lesson 12 - The Selection Sort
Week 11		Lesson 13 - The Heapsort Subroutine
Week 12		Lesson 14 - Functions and COMMON blocks
Week 13		Lesson 15 - System Libraries and Computer Graphics