APPLIED & COMPUTATIONAL MATHEMATICS (ACME)

A NEW DEGREE FOR 21ST CENTURY DISCOVERY AND INNOVATION

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What is ACME?

- **Math and computation for data and information**
  - Lock-step core
  - Theory and practice of math and computation—**unified**!
  - NOT just data science, but good prep for data science jobs
- **Cross-disciplinary**
  - Concentration in another discipline
  - Labs applying the theory to a wide range of applications
- **Capstone Experience**
  - Research or an internship
  - Senior projects

Program Overview

- Freshman & Sophomore Years
  - General Education Requirements
  - Math Minor (3 Calculus, Proofs, Linear Algebra, ODE)
  - Intro Computer Programming (C++)
  - First Semester of Real Analysis (Abbott/Blue Rudin)
- Junior Year
  - Linear and Nonlinear Analysis
  - **Algorithms, Approximation, Optimization**
  - Concentration classes
- Senior Year
  - Modeling with Uncertainty & Data
    (Probability, Statistics, & Machine Learning)
  - Modeling with Dynamics and Control
    (Diff EQ, Dynamical Systems, Optimal Control)
  - Concentration projects

CORE PROGRAM

First Year (Junior) Sequences

Mathematical Analysis

- Vector Spaces
- Linear Transformations
- Inner Product Spaces
- Spectral Theory
- Metric Topology
- Differentiation
- Contraction Mappings
- Integration
- Integration on Manifolds
- Complex Analysis
- Adv. Spectral Theory
- Arnoldi & GMRES
- Pseudospectrum

Algorithm Design & Optimization

- Intro to Algorithms
- Data Structures
- Combinatorial Optimization
- Graph Algorithms
- Probability, Sampling, & Estimation
- Harmonic Analysis
- Interpolation and Approximation
- Numerical computation
- Unconstrained Optimization
- Linear Optimization
- Nonlinear Optimization
- Convex Optimization
- Dynamic Optimization
- Markov Decision Processes

First Year (Junior) Labs

Mathematical Analysis

- Introduction to Python
- Linear Transformations
- Linear Systems
- QR Decomposition
- Least Squares and Computing Eigenvalues
- Image Segmentation
- The SVD and Image Compression
- Facial Recognition
- Differentiation
- Newton's Method
- Conditioning and Stability
- Monte Carlo Integration
- Visualizing Complex-valued Functions
- PageRank Algorithm
- Drazin Inverse
- Iterative Solvers
- The Arnoldi Iteration
- GMRES

Algorithm Design & Optimization

- Linked Lists
- Binary Search Trees
- Nearest Neighbor Search
- Breadth-first Search
- Markov Chains
- The Discrete Fourier Transform
- Convolution and Filtering
- Wavelets
- Polynomial Interpolation
- Gaussian Quadrature
- One-dimensional Optimization
- Gradient Descent Methods
- The Simplex Method
- OpenGym AI
- CVXOPT
- Interior Point 1: Linear Programs
- Interior Point 2: Quadratic Programs
- Dynamic Optimization
- Policy Iteration

Second Year (Senior) Sequences

Modeling with Uncertainty & Data

- Random Spaces & Variables
- Distributions & Expectation
- Markov Processes
- Information Theory
- Linear and Logistic Regression
- Kalman Filtering & Time-Series
- Principal Components
- Clustering
- Bayesian Statistics (MCMC)
- Random Forests & Boosted Trees
- Support Vector Machines
- Deep Neural Networks

Modeling with Dynamics & Control

- ODE Existence & Uniqueness
- Linear ODE
- Nonlinear Stability
- Boundary-Value Problems
- Hyperbolic PDE
- Parabolic PDE
- Elliptic PDE
- Calculus of Variations
- Optimal Control
- Stochastic Control

Second Year (Senior) Labs

Modeling with Uncertainty & Data

- Unix Shell
- SQL and relational databases
- Regular Expressions
- Web Scraping and Crawling
- Pandas & Geopandas
- MongoDB / NoSQL
- Parallel Computing and MPI
- Apache Spark
- Kalman Filtering for Time Series
- Scikit-Learn
- Naïve Bayes and Spam filtering
- HMMs for speech recognition
- Gibbs Sampling and LDA
- Metropolis Hastings
- Clustering with k-means
- Random Forests and Boosted Trees
- Deep Neural Networks

Modeling with Dynamics & Control

- Harmonic Oscillators and Resonance
- Weightloss Models
- Predator-Prey Models
- Shooting Methods and Applications
- Compartmental Models (SIR)
- Pseudospectral methods for BVP
- Lyapunov Exponents and Lorenz Attractors
- Hysteresis in population models
- Conservation Laws and Heat Flow
- Anisotropic diffusion
- Poisson equation, finite difference
- Nonlinear Waves
- Finite Volume Methods
- Finite Element Methods
- Scattering Problems
- PID Control
- LQR and LQG Control
- Guided Missiles
- Merton Model in Finance

Growing list of Concentrations

- Biology
- Business Management
- Chemical Engineering
- Chemistry
- Computer Science
- Cryptography
- **Data Science**
- Economics
- Electrical and Computer Engineering: Circuits
- Electromagnetics
- Finance
- Geological Sciences
- **Machine Learning**
- Mechanical Engineering: Dynamic Systems
- Mechanical Engineering: Fluids and Thermodynamics
- **Linguistics (Natural Language Processing)**
- Physics
- Political Science
- Signals and Systems
- Statistics

ACME Successes

- Reputation as the Hardest major on campus
  - Students learn a LOT of math and computing
- Very popular
  - 15 students in 2013,
  - 250 students in 2020 (2/3 of all math majors)
- Graduates in high demand
  - They win competitions
  - Employers are eager to offer high-salary positions
  - Excellent grad school placement in many different disciplines
- Alumni are very loyal

ACME Successes

The material is so interesting.

Very challenging, but it is all worth it.

I chose ACME because it challenges me.

The program is very exciting...awesome.

The most engaging and exhausting mental challenge of my life—I love it!

ACME Successes

"No other major will satisfy my desire to learn"
—C. Herrera

Job Placement

- Amazon, Apple, Facebook, Google, Microsoft
- Goldman Sachs, Capital One, Wells Fargo, Tanius
- Oracle, Fast Enterprises, Domo, Innosight, Vicarious
- Intermountain Health Care, United Health, Recursion Analytics, Tula Health, Owlet
- Raytheon, MITRE
- NSA, USAF, NASA, Los Alamos, Sandia, Livermore

Grad School Placement

- Berkeley: Math Education
- Chicago: Marketing
- Columbia: Electrical Engineering
- Duke: Computational Biology, Biostatistics
- Georgia Tech: CS (Machine Learning)
- Rice: CS, Geology
- Michigan: Applied Math
- Stanford: Economics
- UCLA: Math
- UT Austin: Computational Engineering / Applied Math
- Texas A&M: Petroleum Eng. & Math
- Yale: CS (Machine Learning)

Key Takeaways

- Rethink your curriculum, but don't give up on rigor
- Ensure your degree will endure beyond the hype cycle
- Unify the math and computing, theory and practice
- Require/encourage capstone experiences
- Lock-step cohort is powerful
- Students can do more than you think, if you **show you believe in them**

Additional Advice

- Find (and talk to) industrial partners
- Advertising matters:
  - To students
  - To Employers
  - To your administration
- When people do something 50–60 hours per week for 2 years, they get really good at it.
- Leverage your alumni base

More Information About ACME

- Program website:

  acme.byu.edu

- Labs and other course materials

  foundations-of-applied-mathematics.github.io/

- Textbooks from SIAM

  Foundations of Applied Mathematics

  Volume 1: Mathematical Analysis

  Volume 2: Algorithms, Approximation, Optimization