Bioinformatics Graduate Program

PROGRAM DIRECTOR:
Shankar Subramaniam
Professor of Bioengineering and Chemistry and Biochemistry
Senior Fellow, San Diego Supercomputer Center

STUDENT AFFAIRS: (858) 822-4948
bioinfo@ucsd.edu
http:///www.bioinformatics.ucsd.edu

Participating Faculty

Department of Bioengineering

Shu Chien, *Professor*
Jeffrey Hasty, *Assistant Professor*
Xiaohua Huang, *Assistant Professor*
Trey Ideker, *Assistant Professor*
Andrew McCulloch, *Professor*
Bernhard Palsson, *Professor*
Shankar Subramaniam, *Professor*

Division of Biological Sciences

Russell Doolittle, *Professor Emeritus, Molecular Biology*
John Huelsenbeck, *Professor, Ecology, Behavior and Evolution*
Amy Kiger, *Assistant Professor, Cell and Developmental Biology*
William Loomis, *Professor, Cell and Developmental Biology*
Eduardo Macagno, *Atkinson Chair, Professor, Cell and Developmental Biology, Dean*
William McGinnis, *Professor, Cell and Developmental Biology*
James Posakony, *Professor, Cell and Developmental Biology*
Milton Saier, *Professor, Molecular Biology*
William Schafer, *Associate Professor, Neurobiology*
Julian Schroeder, *Professor, Cell and Developmental Biology*
Douglas Smith, *Professor Emeritus, Molecular Biology*
Suresh Subramani, *Professor, Molecular Biology*
Inder Verma, *Adjunct Professor*
Steven Wasserman, *Professor, Cell and Developmental Biology*

Biomedical Sciences Program

Joseph Adams, *Associate Professor, Pharmacology*
Philip Bourne, *Professor, Pharmacology*
Christopher Glass, *Professor, Cellular and Molecular Medicine*
Lawrence Goldstein, *Professor, Cellular and Molecular Medicine/Pharmacology*
Bing Ren, *Assistant Professor, Cellular and Molecular Medicine*
Palmer Taylor, *Professor/Dean, School of Pharmacy and Pharmaceutical Sciences*
Lynn Ten Eyck, *Adjunct Professor, Pharmacology*
Ron Thomas, *Professor, Family and Preventive Medicine*
Roger Tsien, *Professor, Pharmacology*
Robert Tukey, *Professor, Pharmacology*

Department of Chemistry and Biochemistry

Alexander Hoffmann, *Assistant Professor*
Patricia Jennings, *Professor*
Simpson Joseph, *Associate Professor*
Andrew McCammon, *Professor*
Susan Taylor, *Professor*
Lynn Ten Eyck, *Adjunct Professor*
Peter Van der Geer, *Assistant Professor*
Wei Wang, *Assistant Professor*
Peter Wolynes, *Professor*
John Wooley, *Adjunct Professor*

Department of Computer Science and Engineering

Scott B. Baden, *Professor*
Vineet Bafna, *Assistant Professor*
Richard Belew, *Professor*
Larry Carter, *Professor Emeritus*
Garrison Cottrell, *Professor*
Eleazar Eskin, *Assistant Professor (In-Residence)*
Charles Elkan, *Professor*
Pavel Pevzner, *Ronald R. Taylor Chair and Professor*
J. Benjamin Rosen, *Adjunct Professor*

Department of Mathematics

Ian Abramson, *Professor*
Michael Holst, *Professor*
Jeffery Remmel, *Professor*
Glenn Tesler, *Assistant Professor*
Ruth Williams, *Professor*

Department of Physics

Terence Hwa, *Professor*
Herbert Levine, *Professor*
José Onuchic, *Professor*

Department of Psychiatry

Nicholas Schork, *Professor*

School of Medicine

Jerrold M. Olefsky, *Professor*
Michael Rosenfeld, *Professor*

Program Focus

The Interdisciplinary Bioinformatics Graduate Program draws upon the expertise of affiliated faculty from the Division of Biological Sciences; Departments of Bioengineering, Chemistry and Biochemistry, Computer Science and Engineering, Mathematics, Physics, and Psychiatry; the Biomedical Sciences Graduate Program.

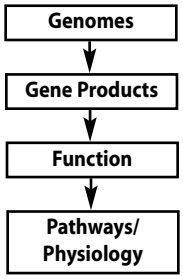
The University of California, San Diego is a premier research institution that has fostered interdisciplinary research since its inception. Specifically, bioengineering (at the interface of biology, medicine, and engineering), neuroscience (at the interface of biology and medicine), biophysics (at the interface of chemistry, biology, and physics), and cognitive science (at the interface of medicine and computer science) are all nationally ranked interdisciplinary graduate research programs. This has led to growth and innovation in many new areas of science and engineering research and the training of an exceptionally high caliber of graduate and postdoctoral students.

In recent years, bioinformatics has been identified by the UCSD administration as one of the most important growth areas for the campus. Several recent new faculty hires have been targeted in bioinformatics-related fields. UCSD has also seen a significant increase in the research activity associated with bioinformatics across the traditional disciplines.

Development of the Field and Departmental Strength in the Field

We are witnessing the birth of a new era in biology. The ability to decipher the genetic code of living organisms is dramatically changing our understanding of the natural world and promises to improve substantially the quality of human life. Recent advances in technology have led to the creation of a new interdisciplinary science—genomics. In simple terms, genomics is the reading and understanding of the blueprints for life. Understanding how genomes work requires sophisticated computer-based information handling tools *(bioinformatics)*, and new high throughput technologies for understanding the function of genes on a genome-wide scale *(functional genomics)*.

Bioinformatics characterizes the flow of information in living systems and can be schematically represented by the following:



The most pressing problem in the post-genome sequencing era will be to understand the integrated functions of thousands of genes. Dealing with this problem will require an interdisciplinary research structure dedicated to developing intellectual and human capital in bioinformatics and genome science. Due to the complexity of this new paradigm in biology, i.e., understanding the organization, evolution, and function of whole genomes rather than single genes, entirely new sets of tools and human resources will be necessary. Thus, future developments in genomics, and the applications that derive from genomics, will be dependent upon the scientific progress at the interface of three major disciplines—biology, engineering, and computer science. In addition to the scientific advances required to understand the functions of genomes, the accelerated growth of modern biology warrants revolutionary changes in academic curricula.

Each department represented in this program participates in various interdisciplinary graduate programs in addition to providing very strong intradisciplinary graduate training. One example is the La Jolla Interfaces in Science program (LJIS), a campus- and mesa-wide fellowship opportunity sponsored by the Burroughs Wellcome Fund. LJIS supports exploration of interfaces between the biological and biomedical sciences and the physical, computer, and mathematical sciences at UCSD, The Scripps Research Institute (TSRI), the Salk Institute, and the San Diego Supercomputer Center.

Bioengineering, consistently ranked among the top three programs nationally by *U.S. News and World Report*, has several new faculty hires in the area of bioinformatics and computational biology and has identified bioinformatics as a major area of focus.

Biological Sciences, a premier division at UCSD, will spearhead the interdisciplinary, undergraduate specialization in bioinformatics and is planning to hire new faculty in bioinformatics fields.

Biomedical Sciences, is an interdisciplinary Ph.D. program, based in the School of Medicine, with tracks in pharmacology, physiology, and cellular and molecular medicine. It will be closely linked to the planned new School of Pharmacy and Pharmaceutical Sciences. In addition to a strong computational biology presence amongst its faculty, there are plans to hire more faculty whose main interests are in computational pharmacogenomics and bioinformatics.

Chemistry and Biochemistry, the home of the Molecular Biophysics Training Grant, is highly recognized for its strong computational biology program with plans to further expand in chemo and bioinformatics areas.

Computer Science and Engineering is unique in having a critical mass of faculty whose research interests focus on biology. These faculty have very strong collaborative research interactions with biology, chemistry, and engineering researchers. CSE is currently recruiting for a senior faculty member with computational biology expertise.

Mathematics has expressed strong interest in building in the area of bioinformatics with emphasis on statistics and probability. This focus is one of fundamental importance for the future of bioinformatics, and the department is committed to both hiring new faculty and launching new courses in statistics pertinent to bioinformatics.

Physics is the home of leaders in the field of computational statistical mechanics applied to biology and provides the foundation for sophisticated modeling of complex biological systems. Physics also plans to recruit new faculty members whose research focus will be on development of information/theory-based models of biological systems.

Admissions Requirements

Admission is in accordance with the general requirements of the graduate division. Candidates will have an interdisciplinary persuasion to work across computers, biology, medicine, and engineering; with an undergraduate degree majoring in any of the disciplines in biological science, physical science, computer science, mathematics, or engineering with a strong background in quantitative sciences and biology.

Admission review will be on a competitive basis based on the applicants' undergraduate track record, Graduate Record Examination General Test (GRE) scores, and other scholastic achievements. Attention will also be given to the motivation and career plans of the applicant candidates. Special attention will be given to the quantitative and analytical section scores of the GRE. The applications will be screened and evaluated by the Admissions Committee with input from all program faculty. In addition, applicants must submit a completed UCSD Application for Graduate Admission (use major code BF75), official transcripts (English translation must accompany official transcript written in other languages), TOEFL scores (required ONLY for all international applicants whose native language is not English and whose undergraduate education was conducted in a language other than English), and three letters of recommendation from individuals who can attest to the academic competence and to the depth of the candidates' interest in pursuing graduate study.

Acceptance letters to incoming students will indicate academic areas in which the Admissions Committee believe the individual is deficient and suggestions for remedial materials to be examined prior to the fall quarter may be provided.

For further admission information and/or to request an application packet, students should contact the bioinformatics graduate coordinator via email at bioinfo@ucsd.edu or at (858) 822-4948. You may also visit our Web site at http:///www.bioinformatics.ucsd.edu.

Foreign Language Requirement

Competence in one or more foreign languages is encouraged but not required.

Curriculum

Specific fields of emphasis:

- biological data and analysis tools
- sequence analysis
- genomic analysis
- statistical methods for bioinformatics

The Interdisciplinary Bioinformatics Graduate Program is organized around a formal course requirement consisting of three quarters of course work, with enrollment in four four-unit courses each quarter. One four-unit course in each quarter

will be a research rotation in the laboratory of a program faculty mentor. The remaining nine courses will include four compulsory core courses and five courses to be chosen from a list of electives approved by the Course Committee.

The electives are intended to maximize the flexibility of the program, but at least one course must be chosen from the biology field and one from the computer science and engineering field. The faculty adviser(s) will pay particular attention to deficits in the background of each student and will assist in making appropriate course choices from the elective fields. Students electing to take any of the undergraduate courses listed in these fields will receive an additional course component in order to make it equivalent to a graduate level course. Students have the option to test out of a field by passing an exam designed by the faculty committee. This exam will fulfill one of the breadth requirements of the program.

It is the general policy of the program to be as adaptable as possible to the needs of the individual student. The faculty advisory committee will work closely with students to identify what might be lacking in a particular curriculum program.

Core Training Courses

- Bioinformatics I: Biological Data and Analysis Tools (Pharm 201)
- Bioinformatics II: Sequence and Structure Analysis—Methods and Applications (BENG 202/CSE 257A)
- Bioinformatics III: Genomic Analysis (BENG 203)
- Bioinformatics IV: Statistical Methods in Bioinformatics (Math 283)

PROGRAM ELECTIVES

(Each student will select from five of the eight elective fields below. One must be from the biology field and one from the computer science field. For each elective, multiple course options currently available are listed).

Elective 1: Biochemistry

BENG 230:	Biochemistry
BIBC 100:	Structural Biochemistry
CHEM 114A:	Biochemical Structure and Function
CHEM 213:	Chemistry of Macromolecules
CHEM 218:	Macromolecular Biochemistry

Elective 2: Data Structures

CSE 100:	Data Structures
CSE 200:	Computability and Complexity
Math 176A:	Computer Implementation of Data Structures

Elective 3: Algorithms

CSE 101:	(also Math 188) Design and Analysis of Algorithms
Math 173:	Mathematical Software Scientific Programming

Elective 4: Information Retrieval, Databases and Data Mining

CSE 132A:	Database System Principles
CSE 133:	Information Retrieval
CSE 254:	Machine Learning

Elective 5: Molecular Genetics

BICD 100:	Genetics
BIMM 100:	Molecular Biology
BIBC 116:	Evolution of Genes and Proteins
BGGN 220:	Advanced Molecular Biology
BGGN 223:	Advanced Genetics

Elective 6: Cell Biology

BICD 110:	Cell Biology
BICD 130:	Embryos, Genes, and Development
BIOMED 210:	Cellular Biology
BIOMED 212:	Cellular and Molecular Pharmacology
BGGN 222:	Advanced Cell Biology

Elective 7: Physics and Engineering

BENG 253:	Biomedical Transport Phenomena
BENG 275:	Computational Biomechanics
PHYS 210A:	Equilibrium Statistical Mechanics or higher

Elective 8: Mathematics and Statistics

Math 174:	Numerical Methods in Science and Engineering
Math 181E:	Mathematical Statistics
Math 280A:	Probability Theory

EXAMPLE 1–SAMPLE PROGRAM (YEAR 1)

A student with an undergraduate background in biology might make the following course selections:

YEAR 1

FALL	WINTER	SPRING
Bioinformatics I	Bioinformatics II	Bioinformatics III
		Bioinformatics IV
	CSE 100	CSE 101
Test out– Chem. 114A	BENG 275	Test out– BICD 110
Elective	Elective	Elective
	Research Rotation	Research Rotation

EXAMPLE 2–SAMPLE PROGRAM (YEAR 1)

A sample program for a student with an undergraduate degree in computer science and engineering might be structured as follows:

YEAR 1

FALL	WINTER	SPRING
Bioinformatics I	Bioinformatics II	Bioinformatics III
		Bioinformatics IV
	BIOMED 210	Chem. 213
Test out – CSE 101	Math 280A	Elective
Elective	Elective	Test out – CSE 132A
	Research Rotation	Research Rotation

YEAR 2

All students, regardless of their background and elective track, will be expected to begin working in the laboratory of their choice by the second year. Additionally in Year 2, students will begin preparing for their qualifying examination and will participate in advanced seminar courses and journal clubs identified by program faculty.

End of Year 2 through 5

Spring of Year 2: Qualifying Examination

Spring of Year 3: Advance to Candidacy

End of Year 5: Ph.D.

In summary, in addition to three quarters of research rotations, students must complete the four compulsory bioinformatics core courses; and, either test out of, or select at least five courses from the eight elective areas.

Research Rotations

Each student in the graduate program will participate in three research rotations, at least two of which will be in the laboratory of mentors other than the thesis directors. The purpose of the research rotation will be to train the students in research methodology in specific bioinformatics areas. At the end of the research rotation period, the student will submit a written report that will be evaluated by the faculty mentor in whose laboratory the project was carried out. The report will also be sent to the Qualifying

Examination Committee who will take this into consideration in the assessment of the student for admission to candidacy.

Seminars, Informal Courses, Group Meetings, and Symposia

As well as formally structured courses and research rotations, graduate students will have access to seminars, group meetings, and informal sessions during which they will have frequent opportunities to interact closely with faculty mentors and to present their research plans, problems, and findings. In addition to weekly bioinformatics seminars, the graduate program will launch monthly student/faculty meetings at which students can present their research findings and discuss their progress. Graduate students will also be expected to organize an annual symposium where they will invite leading researchers to UCSD for one-day talks and discussions.

Besides the activities noted above, UCSD as a premier research institution has many excellent seminar programs sponsored by each research department and organized research group. Several interdisciplinary programs facilitate research meetings. Notable ones include the La Jolla Interfaces in Sciences (LJIS) Program, the Neurosciences Program, the Molecular Biophysics Program, the Whitaker Institute for Biomedical Engineering, the San Diego Supercomputer Center, and the Structural Genomics Program. LJIS, for example, is an extremely successful interdisciplinary program sponsoring stimulating and state-of-the-art seminars. LJIS recently sponsored a well- received symposium on Post-Genomic Bioinformatics. Many program faculty are involved in several of the areas mentioned above, and the bioinformatics graduate program benefits from all of these additional programs and symposia.

Research Training

Students, upon completion of the appropriate course work, will be given research orientation lectures by the bioinformatics program faculty. Each graduate student will participate in a research experience in the laboratory he or she selects to carry out the research rotation. During this period students will become acquainted with scientific methodology for designing experiments, analyzing the results, organizing the data, conducting research in a responsible manner, preparing oral and poster presentations of research results, and writing scientific papers.

Upon successful completion of the Qualifying Examination (described in the following section), graduate students will choose their research project from the many possibilities offered in the program and begin to work on a research problem with their faculty advisers. In consultation with their mentors, students will formulate the research activity that will lead to their dissertation. Graduate students will have the opportunity to do internships in the local bioinformatics/biotechnology industry if the thesis project is of mutual interest to a corporate sponsor and the thesis advisers. The research program is designed with two key objectives in mind: (1) to provide a truly interdisciplinary research training at the interface area between biology and computer science and engineering; and (2) to address fundamentally strong research problems that will lead to the advancement of the field of bioinformatics. We anticipate that every graduating student will emerge as a highly trained bioinformatician who can either pursue an academic career by choosing optimal postdoctoral research positions or enter the next generation biotechnology/biopharmaceutical industry.

It is our belief that active research under proper tutelage is the best means of training and that the foundations of a good graduate training program rest on an outstanding faculty group, an excellent student body, and a strong and well-coordinated research program. Each of the faculty members in this program has expertise and interests that will contribute importantly to the Interdisciplinary Bioinformatics Graduate Program. Participating faculty have pooled their resources in terms of laboratories, and the knowledge and experience to ensure the success of the program. Through daily contact with faculty and other research colleagues, students will learn to develop critical and creative thinking skills, scientific methodology, and a sound knowledge of research problems.

Second-Year Qualifying Examination

The Bioinformatics Second-Year Qualifying Examination (BQE) is designed in an innovative manner to test the ability of students to think analytically and in an interdisciplinary manner. This method was suggested by students of the program during the first two years after inception.

Students are expected to come up with a research problem different from the one he or she may have been working on with a faculty adviser and write a proposal that can be defended at the oral examination to a faculty committee appointed by the chair of BQE. The written document is expected to be in the form of a proposal to NSF or NIH, where the student provides the specific aims of the project, the background for and significance of the problem chosen, some preliminary results and/or observations and specific details on the design of the research. The student is tested on his or her ability to formulate and design the problem as well as on the interdisciplinary nature of the approach. Once the student passes the oral portion of the exam, the student is deemed to be qualified for advancing into Ph.D. thesis research in bioinformatics. The student can schedule this examination at any time of the year, but with two provisions. First, the student should have completed all the required and most of the elective courses assigned, and second, the examination should be taken before the student completes his or her second year in the program. At the time of BQE, the student should have decided on his or her two mentors/research advisers, and should have discussed with them about joining their laboratories and obtaining guaranteed funding for the duration of research as long as he or she is in good academic standing. The BQE Oral Examination Committee will discuss these specifics and other program requirements with the students at the oral examination.

Advancement to Ph.D. Candidacy

Upon completion of formal course requirements, each student will be required to take a written and oral qualifying examination that will admit the student to the candidacy of the Ph.D. program. In advance of the qualifying examination, each student, in consultation with his or her faculty adviser(s), will establish a dissertation committee of five faculty members. The committee will consist of three faculty, at least two of whom are affiliated with the bioinformatics program, and two other faculty from departments affiliated with the program, or who are themselves members of the program faculty. At least two of the five committee members must be from a department other than the committee chair's department and at least one of these two must be tenured. The thesis advisers will have the major responsibility for the student's research and dissertation.

It is anticipated that each student will complete the qualifying examination before the end of the second year of his or her tenure, but no

later than the end of the third year. The student is expected to join a research laboratory for completing a thesis dissertation no later than the beginning of the second year of tenure.

Thesis and/or Dissertation

Each graduate student in the program will work on a bioinformatics thesis project under dual mentorship of the program faculty. At UCSD, the University Qualifying "Candidacy/Senate" Examination is a requirement for a graduate student to complete satisfactorily, once a thesis project has been decided upon and the student has established a thesis committee in consultation with his or her faculty research advisers. It is deemed after this examination that the student is formally advanced to Ph.D. candidacy and eligible to graduate provided he or she completes his or her dissertation. It is strongly recommended except in special circumstances that the student complete this examination prior to the end of the first three years in the program. The format for this examination is consistent with the highest standards held by peer universities. The student should write a detailed candidacy report in the format of NIH proposals where it is expected that each specific aim will approximately form a chapter in the dissertation. The student should ensure that there is initial progress and the research design and methods are spelled out unambiguously. While the size of this document may vary, it is expected to be at least twenty-five to thirty pages. Any publications/supplementary material may be attached. The student should form the examination committee in consultation with his or her faculty research advisers, and the committee should be in a position to advise the student on his or her dissertation topic. The committee constitution shall be in accordance with the rules of the program and UCSD. The student is advised to choose a committee whose members will be in the best position to advise and will serve arguably as the toughest, albeit constructive, critics of the research so as to maximize the quality of the dissertation. The report should be interdisciplinary and should have input from both thesis advisers. The format for the report should conform to the Bioinformaticcs Program requirements and not those of the parent department(s) of the mentor(s)/faculty research adviser(s). It is expected that the student will meet at least annually with the committee to update the members on his or her progress. As a partial fulfillment for the Ph.D. degree, the student will submit a complete dissertation to be evaluated by a doctoral committee chosen by his or her mentors in consultation with the bioinformatics steering committee. The doctoral dissertation will be submitted to each member of the doctoral committee at least four weeks before the final examination. The student will defend his or her final thesis after the committee's evaluation and will pass or fail depending on the committee's decision. The entire graduate program is expected to be completed within the proposed timeline of the program.

Final Examination

Bioinformatics graduate students will defend their thesis in a final oral examination. The exam will consist of (1) a presentation of the thesis by the graduate student, (2) questioning by the general audience, and (3) closed door questioning by the thesis committee. The student will be informed of the exam result at the completion of all three parts of the oral examination. The final report of the doctoral committee will be signed by all members of the committee and the final version of the dissertation will conform to the procedures outlined in the publication, *Instructions for the Preparation and Submission of Doctoral and Master's Theses*.

Teaching Requirement

Each graduate student admitted to the Ph.D. program in bioinformatics is mandated to serve as a teaching assistant (TA) for at least two quarters. This will aid in preparing the students for a teaching career. In addition, each student will make periodic research presentations to the graduate program students/faculty. Students will also discuss their progress at the annual program meeting to be held each year. It is anticipated these formal presentations will serve as valuable training in preparing the student for a teaching career.

Bioinformatics graduate students will also participate in additional TA training provided by the Office of Graduate Studies and Research through the Center for Teaching Development (CTD).

Financial Support

It is expected that all students admitted into the Ph.D. program in bioinformatics will receive financial assistance subject to their continuance and performance in the program. The assistance will be provided from (1) departmental financial commitments, (2) university financial commitments, (3) teaching assistantships, (4) research assistantships, and (5) NIH-funded graduate training grant.

Employment Prospects

There is enormous demand from industry for trained professionals in bioinformatics. The pharmaceutical industry, agrobusiness, and biotechnology companies often look to academia for people with the appropriate interdisciplinary skills. There is also a great need for academic faculty who have broad, interdisciplinary training, because much of the success of the next generation of undergraduate and graduate students will depend on their ability to master materials in several disciplines. Competition for people skilled in bioinformatics is so intense that salary offers are being driven sky-high and there is concern that the universities—few of which are training students in the field—are rapidly being depleted of the best researchers.

A report from the Working Group of Biomedical Computing of the NIH recognized the shortage of biologists with appropriate computing expertise and called for strong NIH support of cross-disciplinary education and training.

Ph.D. Degrees with a Specialization in Bioinformatics

Currently, UCSD offers Ph.D. degrees with a specialization in bioinformatics from the participating departments listed in this section. Students are admitted into one of the departmental graduate programs and satisfy the requirements of both the departmental and the interdisciplinary bioinformatics graduate program. If you are interested in the Ph.D. degree with a specialization in bioinformatics, please consult with the Student Affairs Office of the department you are interested in to obtain further information on admission and individual program requirements.

Further Information

For further information please visit our Web site at http:///www.bioinformatics.ucsd.edu, or contact the bioinformatics student affairs office at (858) 822-4948, bioinfo@ucsd.edu.