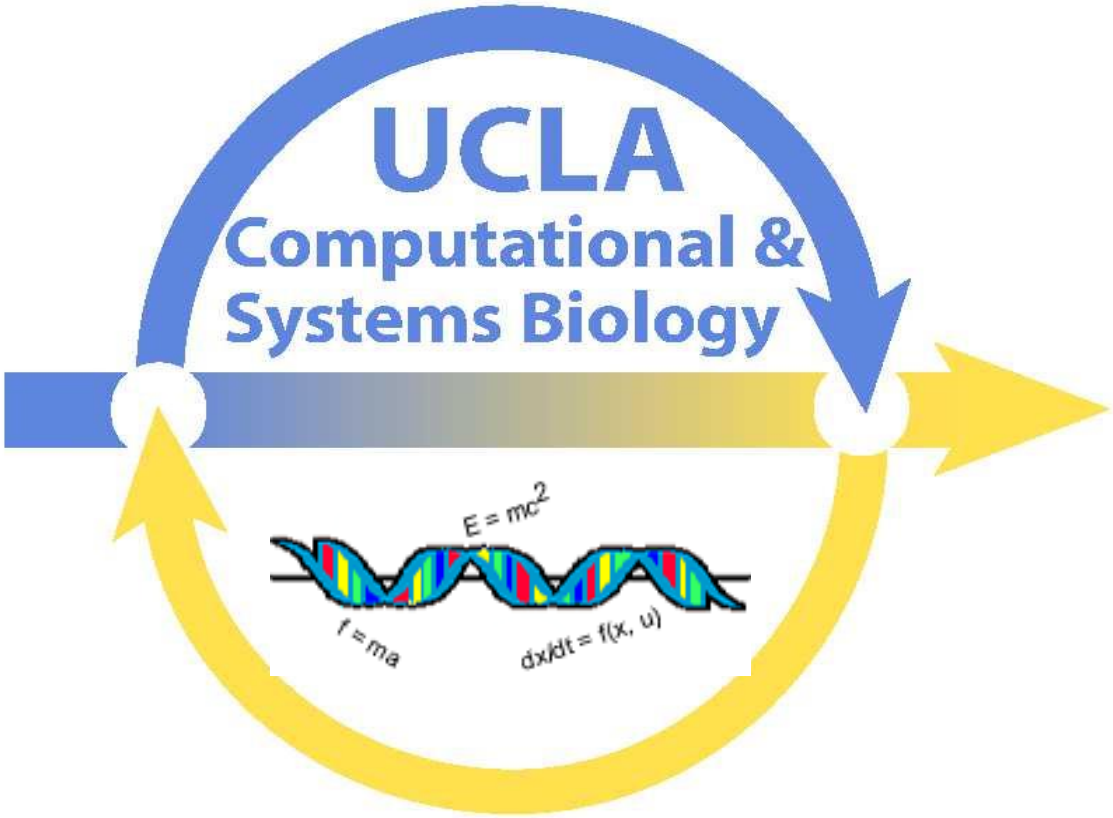
*2016 Academic Program**



University of California, Los Angeles

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Vice Chair: Grace Xiao, Dept. of Integrative Biology & Physiology
Program Counselor/Administrator: Edward Olano (eolano@cs.ucla.edu)
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(310) 825-7482
http://www.cs.ucla.edu/C&SB

***Formerly the **Cybernetics**
Interdepartmental Program

Updated September 21, 2016

Computational & Systems Biology is one of 24 interdepartmental majors in the College of Letters and Science (L&S). Completion of the curriculum leads to a Bachelor of Science degree. The Major, called Cybernetics until Fall '06, was established in the early 1970s, with faculty participation from several departments of L&S, the Henry Samueli School of Engineering and Applied Science (HSSEAS) and the School of Medicine (MEDICINE). Faculty for 2016-2017 are:

FACULTY

Prof. Chris Anderson	Mathematics (L&S)	anderson@math.ucla.edu
Prof. Tom Chou	Biomathematics & Mathematics (MEDICINE & L&S)	tomchou@ucla.edu
Prof. Marc Cohen	Psychiatry & Behavioral Sci (MED)	marc.cohen@va.gov
Prof. Joseph DiStefano III	Computer Science, Medicine & Biomed Engr (HSSEAS & MEDICINE)	joed@cs.ucla.edu
Prof. Dino Di Carlo	Bioengineering (HSEAS)	dicarlo@seas.ucla.edu
Prof. Michael Dyer	Computer Science (HSSEAS)	dyer@cs.ucla.edu
Prof. Eleazar Eskin	Computer Science & Human Genetics (HSSEAS & MEDICINE)	eeskin@cs.ucla.edu
Prof. Leah Fitzgerald	School of Nursing (NURSING)	lfitzger@sonnet.ucla.edu
Prof. Mark Frye	Integrative Biology & Physiology (L&S)	frye@ucla.edu
Prof. Thomas Graeber	Molecular & Medical Pharmacology (MEDICINE)	tgraeber@mednet.ucla.edu
Prof. Alex Hoffmann		ahoffmann@ucla.edu
Prof. Henry Huang	Molecular & Medical Pharmacology (MEDICINE)	hhuang@mednet.ucla.edu
Prof. teD Iwasaki	Mech & Aero Engr (HSSEAS)	iwasaki@seas.ucla.edu
Prof. Daniel Kamei	Bioengineering (HSSEAS)	kamei@seas.ucla.edu
Prof. Ken Lange	Human Genetics/Biomath (MED)	klange@ucla.edu
Prof. Elliot Landaw	Biomathematics (MEDICINE)	elandaw@biomath.ucla.edu
Prof. Chris Lee	Chemistry/Biochemistry, Computer Science (L&S and HSSEAS)	leec@chem.ucla.edu
Prof. James Liao	Chemical Engineering (HSSEAS)	liaoj@ucla.edu
Prof. Mayank R. Mehta	Physics & Astronomy (L&S)	MayankMehta@ucla.edu
Prof. Stott Parker	Computer Science (HSSEAS)	stott@cs.ucla.edu
Prof. Matteo Pellegrini	Molecular, Cell & Devel Biol, Computer Science (L&S)	matteop@mcdb.ucla.edu
Prof. Wendie Robbins	School of Nursing (NURSING)	wrobbins@sonnet.ucla.edu
Prof. Marcus Roper	Mathematics (L&S)	mroper@math.ucla.edu
Prof. Van Savage, Chair	Biomathematics (MEDICINE)	vsavage@ucla.edu
Prof. Mary Sehl	Division of Hem & Oncol (MEDICINE)	msehl@mednet.ucla.edu
Prof. Jamie Lloyd-Smith	Ecology & Evolutionary Biology (L&S)	jlloydsmith@ucla.edu
Prof. Jason Speyer	Mech & Aero Engr (HSSEAS)	speyer@seas.ucla.edu
Prof. Stefano Soatto	Computer Science (HSSEAS)	soatto@cs.ucla.edu
Prof. Victoria Sork	Ecology & Evolutionary Biology (L&S)	vlsork@ucla.edu
Prof. Marc Suchard	Human Genetics, Biomathematics (MEDICINE) & Biostatistics (Public Health)	msuchard@ucla.edu
Prof. Ren Sun	Medicine and Biomedical Engineering	rsun@mednet.ucla.edu
Prof. Ben Wu	Bioengineering & Material Sciences Engineering (HSSEAS)	benwu@ucla.edu
Prof. Grace Xiao, Vice Chair	Integrative Biology & Physiology (L&S)	gxxiao@ucla.edu
Prof. Todd Yeates	Chemistry & Biochemistry (L&S)	yeates@chem.ucla.edu
Prof. Alan Yuille	Statistics, Computer Science (L&S and HSSEAS)	yuille@stat.ucla.edu
Prof. Jie Zheng	Ophthamology (MEDICINE)	jzheng@jsei.ucla.edu
Prof. Z. Hong Zhou	Microbiology, Immunology & Molecular Genetics (L&S)	Hong.Zhou@ucla.edu

ADVISORY COMMITTEE (*effective July 1, 2016*)

Prof. Joseph DiStefano III
Prof. Elliot Landaw
Prof. Chris Anderson
Prof. Ken Lange
Prof. Eleazar Eskin
Prof. Matteo Pellegrini
Prof. Marc Suchard
Prof. Tom Chou
Prof. Xinshu Grace Xiao, Vice Chair
Prof. teD Iwasaki
Prof. Van Savage, Chair
Prof. Alex Hoffmann
Prof. Jamie Lloyd-Smith
Vikash Singh, C&SB Student Rep.

COMPUTATIONAL & SYSTEMS BIOLOGY AT UCLA

The *Computational & Systems Biology (C&S Bio)* major is designed primarily for highly motivated students interested in interdisciplinary studies in life sciences, behavioral sciences, and the computational, control, communication and information branches of engineering and computer sciences. Primary emphasis is on integrative computational and systems biology studies. Preparation for the Major consists of a broad foundation in basic sciences - chemistry, biology, physics and mathematics, plus an introduction to computer science. The Major itself provides foundations in mathematical modeling, simulation, computational and information analysis, with emphasis on quantitative ideas, integrative systems concepts and methodologies. Mathematical, computational and other analytical skills are central to the Major. *C&S Bio* majors have several options for in-depth studies: a coherent integration of courses selected from one of five designated Concentrations: *Systems Biology, Bioinformatics, Neurosystems, Biomedical Systems, Computers & Biosystems;* or a well-justified combination of courses from these concentrations.

Undergraduate research is emphasized throughout the program. The major prepares student for graduate studies, research or employment in any of these areas, with emphasis on interdisciplinary activities. It is also appropriate preparation for professional school studies in medicine, public health, management, dentistry and engineering. For example, degree recipients have been admitted to the country's top-ranking medical, dental and engineering schools. Local industry also has been receptive to our graduates. Some have become members of the professional technical staff in systems analysis or computer-related activities, and others have found work in the health sciences, biotechnology and bioengineering industry.

ADMISSION TO THE PROGRAM

Students entering UCLA directly from high school or first quarter transfer students who declare the Computational & Systems Biology Premajor at the time of application are automatically admitted. Current UCLA students need to file a petition with the undergraduate advising office, 4436 Boelter Hall.

All students are identified as Premajors until they (1) satisfy the preparation for the Major requirments by achieving a **minimum 2.7 GPA in all Premajor math courses, a minimum 2.7 GPA in all Premajor courses** and, and a minimum grade of C in all Premajor courses, and (2) file a petition to declare the Computational and Systems Biology Major. Premajor courses (PIC 10B + 10C) or CS 32, which are additionally required for students following the *Computer Systems* Concentration or the *Bioinformatics* Concentration, do **not** have to be completed prior to admission into the Major and are **not** calculated into the pre-major GPA.

All courses for the Premajor and Major must be taken for a letter grade and all courses in the Major must be completed with a grade of C or higher.

OTHER IMPORTANT INFORMATION

STUDENTS ARE SUBJECT TO ANY REQUIREMENT CHANGES IN THE PREMAJOR AND MAJOR UNTIL THEY ARE OFFICIALLY ADMITTED TO THE MAJOR.

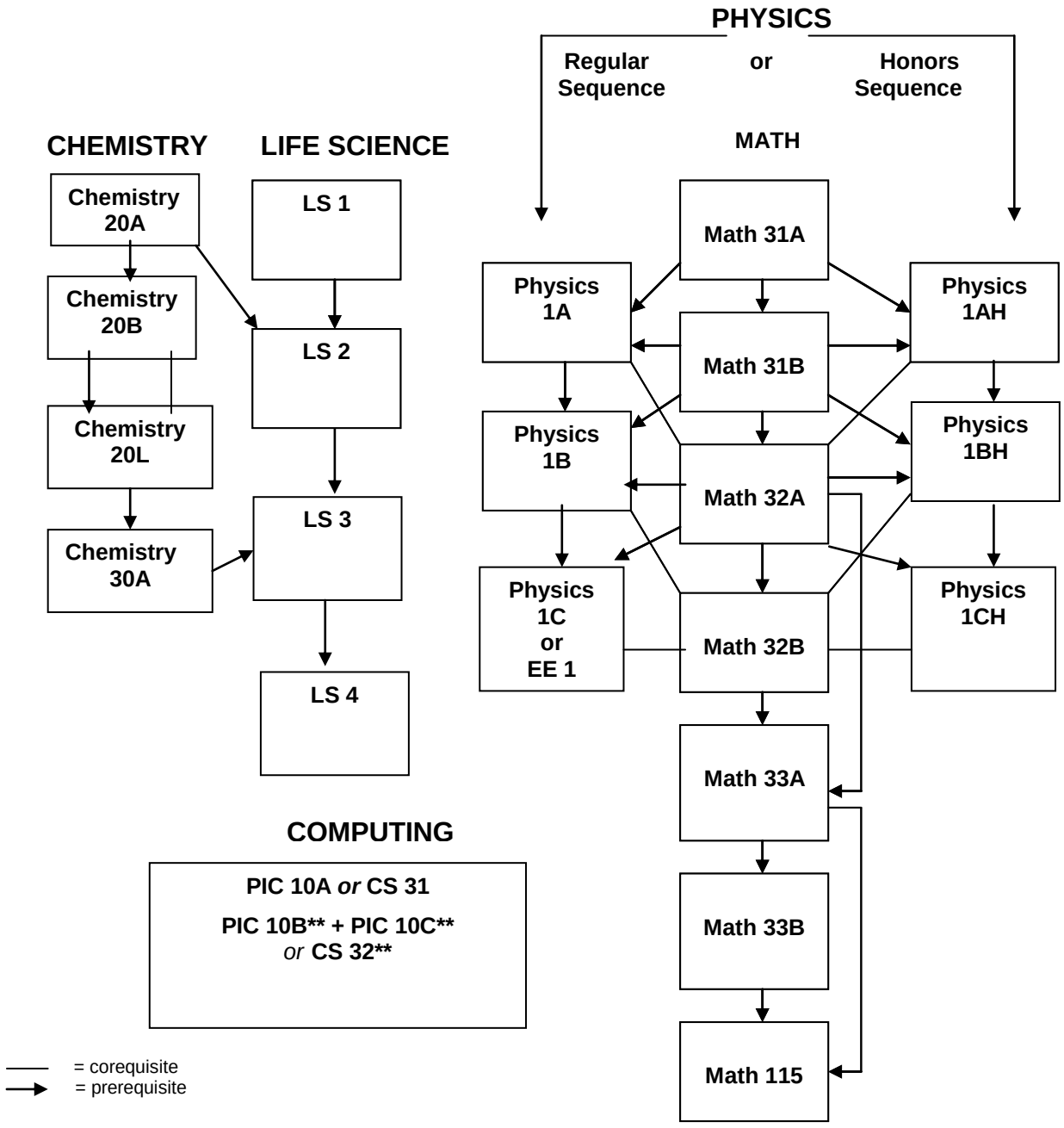
*USUAL SCHEDULE OF COURSE OFFERINGS INDICATED FOR MANY PROGRAM COURSES LISTED IN THIS BROCHURE. THESE ARE SUBJECT TO CHANGE. PLEASE CONSULT THE QUARTERLY SCHEDULE OF CLASSES FOR ACTUAL OFFERING TIMES.

DEPARTMENTAL HONORS AT GRADUATION

Eligibility Requirements

- A 3.0 minimum GPA in all university-level coursework (including Pre- Major courses).
- A 3.5 minimum GPA in coursework required for the Major (excluding Pre-Major courses).
- Faculty sponsor recommendation for excellence of the Senior Thesis.
- For Highest Honors, student must complete an extraordinary Senior Thesis, as judged by the faculty sponsor and IDP Advisory Committee, and it must be prepared in a format for peer-reviewed publication.

PREPARATION FOR THE MAJOR (PRE-MAJOR REQUIREMENTS)
19 Courses Required – 81 to 83 units*



*Total units depends on Physics series taken (Physics 1A, 1B, 1C or Physics 1A, 1B, EE1) and Computing course taken (PIC 10A or CS 31)

**Premajor courses PIC 10B + 10C, or CS 32 required for the Computers & Biosystems and for the Bioinformatics Concentration, but do not have to be completed prior to admission to the Major. Also, the CS series requires fewer total units.

PREMAJOR COURSE DESCRIPTIONS

(Normally offered F, W, Sp unless otherwise noted)

MATH

31A	Differential and Integral Calculus	4 units
31B	Integration and Infinite Series	4 units
32A	Calculus of Several Variables	4 units
32B	Calculus of Several Variables	4 units
33A	Linear Algebra and Applications	4 units
33B	Differential Equations	4 units
115A	Linear Algebra (Intermediate Level)	5 units

CHEMISTRY

20A	Chemical Structure	4 units
20B	Chemical Energetics and Change	4 units
20L	General Chemistry Laboratory I	3 units
30A	Introduction to Organic Chemistry	4 units

PHYSICS

Physics 1A, 1B, 1C or EE 1 - Physics for Scientists and Engineers

1A or 1AH	Mechanics	5 units
1B or 1BH	Oscillations, Waves, Electric and Magnetic Fields	5 units
1C or 1CH	Electrodynamics, Optics and Special Relativity	5 units
or EE1	Electrical Engineering Physics I	4 units

LIFE SCIENCES

1	Evolution, Ecology and Biodiversity	5 units
2	Cells, Tissues and Organs	5 units
3	Introduction to Molecular Biology	4 units
4	Genetics	5 units

COMPUTING COURSES

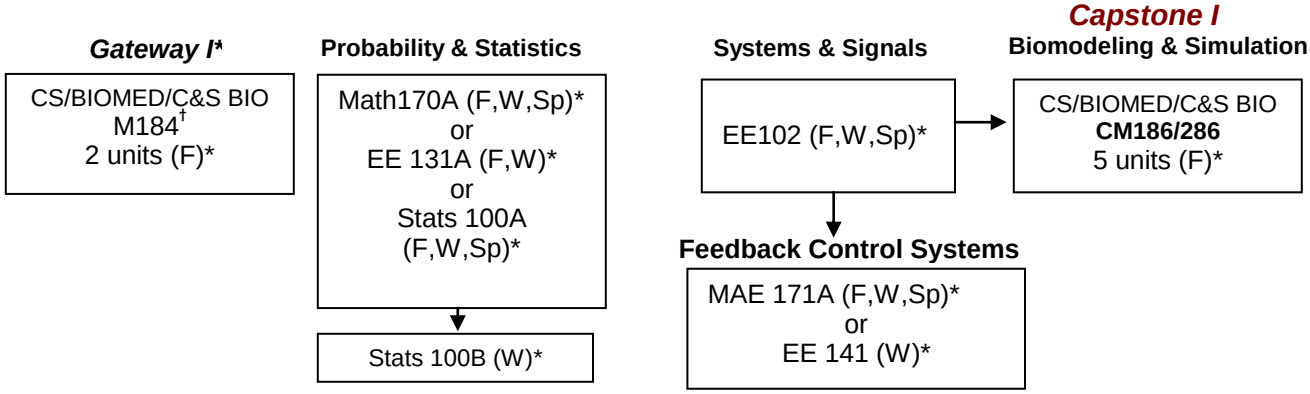
PIC 10A	Introduction to Programming (C++)	5 units
PIC10B*	Intermediate Programming	5 units (W,Sp)[1]
PIC 10C*	Advanced Programming	5 units (Sp)
CS 31	Introduction to Computer Science I	4 units
CS 32*	Introduction to Computer Science II	4 units

* Only for Bioinformatics and Computers and Biosystems Concentration majors

MAJOR FIELD REQUIREMENTS

I. METHODOLOGY *CORE & Capstone I*

(6 courses – 23 units)



†**Gateway I** course must be completed by the Sophomore year.
See pages 8 & 9 for courses descriptions.

II. RESEARCH COURSEWORK

***Gateway II* course (185)** should be taken in sophomore or (no later than) junior year, following the requisite 186 Core course in Fall.

***Capstone II* course (187) is required** and should be taken in the junior or senior year.

III. CONCENTRATION AREAS of STUDY

We offer five Concentration Areas of Study (abbrev: Concentrations). The synergy for all is integrative systems, information and computational modeling sciences in biology. The focus is primarily quantitative, as mastery of advanced quantitative skills is essential for multidisciplinary understanding. Each Concentration emphasizes different systems or modalities, and computational or modeling approaches. Students normally choose one, but because the Concentration areas have substantial methodologic overlap, well-justified combinations are also possible.

Systems Biology

This Concentration is designed for students who want to understand biological systems holistically and quantitatively, and pursue research with an emphasis on *systems* and integrative principles in biology. The curriculum in this Concentration imparts an understanding of systems biology (often called the new physiology) using dynamical systems, control, computer simulation and other computational methods – integrated with the biology. For example, at the cellular level, systems biologists integrate transcriptomic, proteomic, lipidomic and/or metabolomic information into a more complete systems picture of living organisms. The methodologies include single-scale and multiscale modeling for enhancing understanding of regulatory biomechanisms at any or all levels, including molecular, cellular, organ and/or whole-organism levels. Population and ecosystems applications as well systems-level problems in medicine and pharmacology are included.

Bioinformatics

This Concentration is designed for students interested in computational discovery and management of biological *data*, primarily genomic, proteomic or metabolomic data. Bioinformatics concentration studies emphasize computational, statistical and other mathematical approaches for depicting (modeling) and analyzing high-throughput biological data, and the inherent structure of biological information. Example research problems include finding statistical patterns that reveal genomic or evolutionary or developmental information, or how regulatory sequences give rise to programs of gene expression.

Neurosystems

This Concentration is designed for students interested primarily in the nervous system, or quantitative neurophysiology, with emphasis on neural system networks that control behavior – at molecular, cellular as well as whole-organism levels, neural information and control systems, and systems electrophysiology and neural electronic systems for controlling prostheses. Example research problems include analysis of (real) neural networks in normal and abnormal brain function; design of prosthetic systems for hearing (cochlear implant) and walking (spinal cord stimulation) recovery, and MEMS-based brain-machine interface devices.

Computers & Biosystems

This Concentration is designed for student interested primarily in systems and computational aspects of data management, data representation, graph theory, artificial intelligence, computer hardware or software applications in biological sciences, medicine or pharmacology. Research problems include computational algorithms for managing -omics data; development of knowledge-based systems (KBS) for delivering patient education; and KBS for automating complex biosystem modeling or data representation tasks.

Biomedical Systems

For student interested primarily in medical system studies, the systems aspects of biomedical, surgical, or other biomedical-engineering system devices, including MEMS or nanoscale system devices, as well as use of dynamic biosystem modeling for optimizing or developing new clinical diagnostic or therapeutic protocols. Example research problems include feedback biocontrol system model development for imaging-based medical diagnosis; and optimal control of therapeutic drug delivery.

GROUND RULES FOR DESIGNING THE CONCENTRATION

1. Courses **are selected** from the approved lists (below) **in consultation with a faculty mentor.** They should form a coherent grouping.

2. Courses **must be approved beforehand by the Interdepartmental Chair. NO EXCEPTIONS.** Approval is based upon a written statement, submitted by the student to the Interdepartmental Chair at the time of application to the Major, explaining the relevance and coherence of the courses selected to the student's overall C&S Bio Program.

   With appropriate justification, approved programs can be revised by petition. These same prior-approval rules apply to the revised program.

3. Students may choose courses from more than one concentration area if the course selection is well justified. The coherence and relevance of the courses to the Major and to student goals must be addressed in the written statement.

4. **No 199** Special Studies courses are permissible in the Major Concentration Area.

5. **All courses** in the Concentration Area must be upper division, unless specifically listed in the Approved List.

6. **All concentration courses** must be taken for a letter grade.

COURSE DESCRIPTIONS – C&S BIO METHODOLOGY CORE

GATEWAY I

COMPUTER SCIENCE M184 - Introduction to Cybernetics, Biomodeling & Biomedical Computing (Same as Biomed Eng M184 and C&S Bio M184)
Survey course designed as an introduction to topics in computational and systems biology (cybernetics), biomodeling, biocomputing and related bioengineering disciplines. Lectures presented by faculty currently performing research in these areas. *2 units (Pass/No Pass). Requisites: Math 31A, 31B, PIC 10A or equivalent.* ***This course must be completed in the first year of admission to the major.*** *Offered Fall Quarter only.*

GATEWAY II

COMPUTER SCIENCE M185 – Thesis Research Opportunities in Computational and Systems Biology (Same as Biomed Eng M185 and C&S Bio M185)
This course introduces students to research opportunities in computational and systems biology. Prepares students for active engagement in research. Faculty present projects and students visit laboratories, participate in ongoing projects and attend regular laboratory meetings. 2 *units (Pass/No Pass). Requisites: C&S Bio CM 186, Math 31-33 series, LS 2, 3, and 4. Offered Winter or Spring Quarter.*

PROBABILITY AND STATISTICS

MATH 170A - Probability Theory
Probability distributions, random variables and vectors, expectation. *4 units. Requisites: Math 32B. Offered Fall, Winter and Spring Quarter.*

Or **ELECTRICAL ENGR. 131A - Probability**
Introduction to basic concepts of probability, including random variables and vectors, distributions and densities, moments, characteristic functions and limit theorems. Applications to communication, control and signal processing. Introduction to computer simulation and generation of random events. *4 units. Requisites: EE 102, Math 32B and 33B. Offered Fall and Winter Quarter.*

Or **STATISTICS 100A - Introduction to Probability**
Probability distributions, random variables, vectors and expectation. *4 units. Requisites: Math 32B and 33A. Offered Fall, Winter and Spring Quarter; sometimes offered Summer Quarter.*

And **STATISTICS 100B – Introduction to Mathematical Statistics**
Survey sampling, estimation, testing, data summary, one- and two-sample problems. *4 units. Requisite: Math 170A or Statistics 100A. Offered Winter Quarter only.*

SYSTEMS, SIGNALS, FEEDBACK & CONTROL

ELECTRICAL ENGR. 102 - Systems and Signals
Elements of differential equations, first- and second-order equations, variation of parameters method and method of undetermined coefficients, existence and uniqueness. Systems: input-output description, linearity, time-invariance and causality. Impulse response functions, superposition and convolution integrals. Laplace transforms and system functions. Fourier series and transforms. Frequency responses, responses of systems to periodic signals. Sampling theorem. *4 units. Requisites: EE 1 or Physics 1C, Math 33A, 33B. Offered Fall, Winter, and Spring Quarter.*

And **ELECTRICAL ENGR. 141 - Principles of Feedback Control**
Mathematical modeling of physical control systems in form of differential equations and transfer functions. Design problems, system performance indices of feedback control systems via classical

techniques, root-locus and frequency-domain methods. Computer-aided solution of design problems from real world. *4 units. Requisite: EE 102. Offered Winter Quarter only.*

Or **MAE 171A - Introduction to Feedback and Control Systems: Dynamic Systems Control I**
Introduction to feedback principles, control systems design and system stability. Modeling of physical systems in engineering and other fields; transform methods; controller design using Nyquist, Bode and root locus methods; compensation; computer-aided analysis and design. *4 units. Requisites: MAE 181A or MAE 182A or MAE 107L or equivalent. Offered Fall, Winter and Spring Quarter; sometimes offered Summer Quarter.*

CAPSTONE I: BIOMODELING AND SIMULATION

COMPUTER SCIENCE CM186/286 –Computational Systems Biology: Modeling and Simulation of Biological Systems (Same as Biomed Eng CM186/286 and C&S BIO CM186/286)
Dynamic biosystems modeling and computer simulation methods for studying biological/biomedical processes and systems at multiple levels of organization. Control system, multicompartmental, predator-prey, pharmacokinetic (PK), pharmacodynamic (PD), and other structural modeling methods applied to life sciences problems at molecular, cellular (biochemical pathways/networks), organ and organismic levels. Both theory- and data-driven modeling, with focus on translating biomodeling goals and data into mathematics models and implementing them for simulation and analysis. Basics of numerical simulation algorithms, with modeling software exercises in class and PC laboratory assignments. *5 units. (Co)requisite: EE 102 or equivalent. Offered Fall Quarter only.*

CAPSTONE II: THESIS RESEARCH AND RESEARCH COMMUNICATION WORKSHOP

COMPUTER SCIENCE CM187 – Thesis Research & Research Communication in Computational and Systems Biology (Same as Biomed Eng CM187 and C&S Bio CM187)
Closely directed, interactive, and real research experience in active quantitative systems biology research laboratory. Direction on how to focus on topics of current interest in the scientific community, appropriate to student interests and capabilities. Critiques of oral presentations and written progress reports explain how to proceed with search for research results. Major emphasis on effective research reporting, both oral and written. 4 *units. Requisite: C&S Bio CM186. Offered Winter or Spring Quarter.*

CONCENTRATION SPECIALIZATION AREAS

Systems Biology (SB)

This Concentration is designed for students who want to understand biological systems holistically and quantitatively, and pursue research with an emphasis on *systems* and integrative principles in biology. The curriculum in this Concentration imparts an understanding of systems biology (often called the new physiology) using dynamical systems, control, computer simulation and other computational methods – integrated with the biology. For example, at the cellular level, systems biologists integrate transcriptomic, proteomic, lipidomic and/or metabolomic information into a more complete systems picture of living organisms. The methodologies include single-scale and multiscale modeling for enhancing understanding of regulatory biomechanisms at any or all levels, including molecular, cellular, organ and/or whole-organism levels. Population and ecosystems applications as well systems-level problems in medicine and pharmacology are included.

I. Required CORE - Courses in Molecular and Cellular Biology and Physiology

1. MCDB M140: Cell Biology: Cell Cycle (5) (Spring)*
OR
MCDB 144: Molecular Biology (5) (Fall & Spring)*

2. Phy Sci 125: Molecular Systems Biology (4) (Spring)*
OR
MCDB 172: Genomics and Bioinformatics (5) (Winter)*

3. Phy Sci 166: Animal Physiology (6) (Summer only)*
OR
EEB 170: Animal Environmental Physiology (6) (Fall)*
OR
Biomed CM102 and CM103: Basic Human Biology for Biomedical Engineers I & II (4+4=8) (Fall, Winter sequence)*

II. **Two additional courses** selected from the following list, in consultation with an SB mentor, justified as coherent in the proposal submitted when applying to the Major, and approved by the Program Chair.

Information and Control in Biosystems

These courses are suggested for students interested in information theoretic or control aspects within and among biological or physiological systems at organ, whole-organism or environmental levels.

Bioeng 180	System Integration in Biology, Engineering and Medicine I (4)
Bioeng 180L	System Integration in Biology, Engineering and Medicine I Laboratory (3)
Bioeng 181	System Integration in Biology, Engineering and Medicine II (4)
Bioeng 181L	System Integration in Biology, Engineering and Medicine II Laboratory (3)
Biomath 106	Introduction to Celluar Modeling (4)
Biomath 108	Introduction to Modeling in Neurobiology (4)
Biomath 206	Introduction to Mathematical Oncology (4)
Biomath 220	Kinetic and Steady State Models in Pharmacology and Physiology
CS M296D	Computational Cardiology (4) (*same as Biomed Eng M296D*)
Neurosci M148	Neuronal Signaling in Brain (4) (*same as Phy Sci M148*)
Neurosci 205	Systems Neuroscience (4)
Physiol Sci 107	Systems Anatomy (5)
Physiol Sci C144	Neural Control of Physiological Systems (5)
Physiol Sci M145	Neural Mechanisms Controlling Movement (5)
Physiol Sci M173	Anatomy and Physiology of Sense Organs (4)

Molecular and Cellular Biosystems

These courses are suggested for students interested in regulation, control, informational or pharmaceutical aspects of biosystems, at mechanistic molecular or cell signaling levels.

Biomath 106	Introduction to Cellular Modeling (4)
Bioeng 110	Biotransport and Bioreaction Processes (4)
Chem 153A/153AH	Biochemistry: Introduction to Structure, Enzymes and Metabolism (4)
MCDB CM156/CM256	Human Genetics (4)
MCDB CM160/CM252	Biological Catalysis (4) (*same as Chem CM155*)
MCDB 165A	Biology of Cells (5)
MCDB 165B	Molecular Biology of Cell Nucleus (5)
MCDB CM169/CM223A	Cell Biology (4) (*same as Biological Chem CM169 and Human Genetics CM169*)
Psych 119A	Neuropsychopharmacology (4)
Psych 119D	Behavioral Neuropharmacology (4)

Methodology Pertinent to Both Subareas

These courses can be included in either S1 or S2, to make up the additional units for the total 28 units required in the concentration (* recommended).

Chem 110A	Physical Chemistry: Chemical Thermodynamics (4)
Chem C160A/CM260A	Introduction to Bioinformatics and Genomics (4)
Chem C160B/C260B	Algorithms in Bioinformatics and Systems Biology (4)
Chem 156	Physical Biochemistry (4)
Chem Eng CM145	Molecular Biotechnology for Engineers (4) (*same as Biomed Eng CM145*)
CS M296B	Optimal Parameter Estimation and Experiment Design for Biomedical Systems (4) (*same as Biomath M270, Biomed Eng M296B and Medicine M270D*)
EE 131B	Introduction to Stochastic Processes (4)
EE 136	Introduction to Engineering Optimization Techniques (4)
EE 142	Linear Systems: State-Space Approach (4)
MAE 105A	Introduction to Engineering Thermodynamics (4)
Math 134*	Linear and Nonlinear Systems of Differential Equations (4)
Math 136*	Partial Differential Equations (4)
Math 151A*	Applied Numerical Methods I (4)
Math 151B	Applied Numerical Methods II (4)
Math 171	Stochastic Processes (4)
Physics 105A	Analytic Mechanics (4)
Physics 112	Thermodynamics (4)

Systems Biology Graduate-Level Courses

Biomath M203	Stochastic Models in Biology (4)
Biomath 204	Biomedical Data Analysis (4)
Biomath 207A	Theoretical Genetic Modeling (4)
Biomath M211	Mathematical and Statistical Phylogenetics (4)
Biomath 220	Kinetic and Steady State Models in Pharmacology and Physiology (4)
Biomath M230	Computed Tomography: Theory and Applications (4) (*same as Biomed Physics M230*)
Biomath M271	Statistical Methods in Computational Biology (4) (*same as Stats M254*)
Biostats 200A	Biostatistics (4)
Biostats M234	Applied Bayesian Inference (4) (*same as Biomath M234*)
Chem Eng 246	Systems Biology: Intracellular Network Identification and Analysis (4)

Bioinformatics (BI)

This Concentration is designed for students interested in computational discovery and management of biological *data*, primarily genomic, proteomic or metabolomic data. Bioinformatics concentration studies emphasize computational, statistical and other mathematical approaches for depicting (modeling) and analyzing high-throughput biological data, and the inherent structure of biological information. Example research problems include finding statistical patterns that reveal genomic or evolutionary or developmental information, or how regulatory sequences give rise to programs of gene expression.

I. **Two premajor** PIC courses, PIC 10B and 10C (10 units) ***OR*** one premajor CS course: CS 32 (4 units).

II. Required CORE Courses

1. MCDB M140: Cell Biology: Cell Cycle (5) (Spring)*
OR
MCDB 144: Molecular Biology (5) (Fall & Spring)*

2. Phy Sci 125: Molecular Systems Biology (4) (Spring)*
OR
MCDB 172: Genomics and Bioinformatics (5) (Winter)*

3. Chem C160A/CM260A: Introduction to Bioinformatics and Genomics (4) (Fall)*

4. Comp Sci CM124: Computational Genetics (4) (Spring)*

III. **One additional course** selected from the following subarea groups, chosen in consultation with a BI mentor, justified as coherent in the proposal submitted when applying to the Major, and approved by the Program Chair.

BI Methodology

Phy Sci 125	Molecular Systems Biology (5)
MCDB 172	Genomics and Bioinformatics (5)
Chem C160B/C260B	Algorithms in Bioinformatics and Systems Biology (4)
Stats M254/Biomath M271	Statistical Methods in Computational Biology (4)
Human Genetics C144	Genomic Technology (4)
Human Genetics M207A	Theoretical Genetic Modeling (4) (*same as Biomath M207A, Biostats M272; really rigorous complement to BI, for the strong at heart only*)
Human Genetics M207B	Applied Genetic Modeling (4) (*same as Biomath M207B, Biostats M237); more applied, less rigorous, still substantive. Requires Biostats 110A, 110B*)
Biomath M211	Statistical and Mathematical Phylogenetics

BI Computer Science

Math 157	Software Techniques for Scientific Computation (4)
PIC 60	Data Structure and Algorithms (4)
PIC 110	Parallel and Distributed Computing (5)
CS 130	Software Engineering (4)
CS 143	Database Systems (4)
CS 170A	Mathematical Modeling and Methods for Computer Science (4)
CS M171L	Data Communication Systems Lab (2 to 4) (*same as EE M171L*)
CS 180	Introduction to Algorithms and Complexity (4)
CS 181	Introduction to Formal Languages and Automata Theory (4)

BI Molecular & Cellular Biochemistry

MCDB CM156	Human Genetics (4) (*same as Human Genetics CM156 and MIMG CM156*)
MIMG 101	Introductory Microbiology (4)
MIMG C106/C206	Molecular and Genetic Basis of Bacterial Infections (4)
MIMG 168	Molecular Parasitology (4) (*good biological systems analysis course*)
MIMG 185A	Immunology (5)
Chem 110A	Physical Chemistry: Chemical Thermodynamics (4)
Chem 110B	Physical Chemistry: Intro to Statistical Mechanics and Kinetics (4)
Chem 125	Computers in Chemistry (4)
Chem 153A/153AH	Biochemistry: Introduction to Structure, Enzymes & Metabolism (4)
Chem 153B/153BH	Biochemistry: DNA, RNA and Protein Synthesis (4)
Chem 153C/153CH	Biochemistry: Biosynthetic and Energy Metabolism and Its Regulation (4)
Chem CM153G/CM253G	Macromolecular Structure (4) (*same as Biological Chem CM153G and Human Genetics CM153G*)
Chem 156	Physical Biochemistry (4)
Biological Chemistry CM169	Cell Biology (*same as Human Genetics CM169 and MCDB CM169*)

Graduate-Level Courses

Stats M254	Statistical Methods in Computational Biology (4) (*same as Biomath M271*)
Biomath 204	Biomedical Data Analysis
Biomath 207AB	Genetic Modeling
Biomath 211	Statistical and Mathematical Phylogenetics
Biostats 200A	Regression
Biostats 234	Bayesian Methods

Neurosystems (NS)

This Concentration is designed for students interested primarily in the nervous system, or quantitative neurophysiology, with emphasis on neural system networks that control behavior – at molecular, cellular as well as whole-organism levels, neural information and control systems, and systems electrophysiology and neural electronic systems for controlling prostheses. Example research problems include analysis of (real) neural networks in normal and abnormal brain function; design of prosthetic systems for hearing (cochlear implant) and walking (spinal cord stimulation) recovery, and MEMS-based brain-machine interface devices.

I. Required CORE Courses

1. Neurosci M101A: Cellular and Systems Neuroscience (5) (Fall)*

2. Neurosci M101B: Molecular and Developmental Neuroscience (5) (Winter)*

3. Neurosci 102: Introduction to Functional Anatomy of Central Nervous Systems (4) (Fall)*

OR

EE 113: Digital Signal Processing (4) (Fall)*

OR

Math 155: Mathematical Imaging (4) (Spring)*

OR

Neurosci M203: Structure and Function of the Nervous System (4) (Winter)*

II. **Two additional courses** selected from the following Subarea groups, chosen in consultation with an NS mentor, justified as coherent in the proposal submitted when applying to the Major, and approved by the Program Chair.

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Neural-Electronic and Electrophysiological Systems Methodology

These courses are suggested for students interested in the neural-electronic interface, e.g. to design and simulate the physical interface between neurons and electronics. Lab sections 1xxL should be included with each 1xx chosen (e.g. 110 and 110L).

EE 110	Circuit Analysis II (4)
EE 110L	Circuit Measurements Laboratory (2)
EE 113	Digital Signal Processing (4)
EE 113D	Digital Signal Processing Design (2)
EE 115A	Analog Electronic Circuits I (4)
EE 115AL	Analog Electronics Laboratory I (2)
EE CM150/CM250A	Introduction to Micromachining and Microelectromechanical Systems (MEMS) (4)
EE CM150L	Introduction to Micromachining and Microelectromechanical Systems (MEMS) Laboratory (2)
Psych 119F	Neural Basis of Behavior (4)
Physiol Sci C144	Neural Control of Physiological Systems (5)
Physiol Sci M145	Neural Mechanisms Controlling Movement (5)
Neurosci CM204	Synapses, Cells and Circuits (4)

Neural Information and Control Systems

These courses are suggested for students interested in information theoretic or the control aspects of neural or neurophysiological systems and devices.

Biomath 108	Introduction to Modeling in Neurobiology (4)
Chem Eng CM145/CM245	Molecular Biotechnology for Engineers (4) (*same as Biomed Eng CM145*)
EE 131B	Introduction to Stochastic Processes (4) (*take EE 131A instead of Stats 100A / Math 170A as prereq*)
EE 132A	Introduction to Communication Systems (4)
EE 136	Introduction to Engineering Optimization Techniques (4)
Neurosci M101C	Behavioral and Cognitive Neuroscience (5) (*same as MCDB M175C, Phy Sci M180C and Psych M117C*)
Neurosci M204	Synapses, Cells and Circuits (4) (*same as Neurobio M200A*)
Neurosci 205	Systems Neuroscience (4)
Physiol Sci M145	Neural Mechanisms Controlling Movement (5) (*same as Neurosci M145*)
Physiol Sci 173	Anatomy and Physiology of Sense Organs (4)
Psych 119F	Neural Basis of Behavior (4)

Molecular and Cellular Neurosystems

These courses are suggested for students interested in regulation, control, informational or pharmaceutical aspects of neurosystems, at mechanistic molecular or cellular levels.

MCDB 140	Cell Biology: Cell Cycle (5)
Physiol Sci 125	Molecular Systems Biology (4)
OR	
MCDB 172	Genomics and Bioinformatics (5)
Neurosci M101C	Behavioral and Cognitive Neuroscience (5) (*same as MCDB M175C, Phy Sci M180C and Psych M117C*)
Neurosci 102	Introduction to Functional Anatomy of Central Nervous Systems (4*)*
Psych 119D	Behavioral Neuropharmacology (4)
Chem Eng CM145/CM245	Molecular Biotechnology for Engineers (4) (*same as Biomed Eng CM145*)

Computers & Biosystems (CB)

This Concentration is designed for student interested primarily in systems and computational aspects of data management, data representation, graph theory, artificial intelligence, computer hardware or software applications in biological sciences, medicine or pharmacology. Research problems include computational algorithms for managing -omics data; development of knowledge-based systems (KBS) for delivering patient education; and KBS for automating complex biosystem modeling or data representation tasks.

I. **Two premajor** PIC courses, PIC 10B and 10C (10 units) ***OR*** one premajor CS course CS 32 (4 units). See page 5 for course descriptions and tentative schedules.

II. **REQUIRED CORE Courses**

1. Math 151A Applied Numerical Methods (4) (Fall, Winter, Spring)*
OR
EE 103 Applied Numerical Computing (4) (Fall, Spring)*
OR
CS 170A Mathematical Modeling and Methods for Computer Science (4) (Spring)*

2. CS 180 Introduction to Algorithms and Complexity (4) (Fall, Winter, Spring)*

3. MCDB M140 Cell Biology: Cell Cycle (5) (Spring)*
OR
MCDB 144 Molecular Biology (5) (Fall & Spring)*
OR
Phy Sci 166: Animal Physiology (6) (Summer only)*
OR
BME CM102 Basic Human Biology for Biomedical Engineers I (4) (Fall)*
OR
BME CM103 Basic Human Biology for Biomedical Engineers II (4) (Fall)*

III. **Two additional courses** selected from the following list, in consultation with a CB mentor, justified as coherent in the proposal submitted when applying to the Major, and approved by the Program Chair.

CS 111	Operating Systems Principles (4)
CS 112	Computer Science Modeling Fundamentals (4)
CS M117	Computer Networks: Physical Layer (6) (*same as EE M117*)
CS 118	Computer Network Fundamentals (4)
CS CM121	Introduction to Bioinformatics (4)
CS CM122	Algorithms in Bioinformatics and Systems Biology (4)
CS CM124	Computational Genetics (4)
CS 130	Software Engineering (4)
CS 131	Programming Languages (4)
CS 132	Compiler Construction (4)
CS 133	Parallel and Distributed Computing (4)
CS 143	Database Systems (4)
CS M151B/EE M116	Computer Systems Architecture (4)
CS 151C	Design of Digital Systems (4)
CS M152A/EE M116L	Introductory Digital Design Laboratory (2)
CS 152B	Digital Design Project Laboratory (4)
CS 161	Fundamentals of Artificial Intelligence (4)
CS 170A	Mathematical Modeling and Methods for Computer Science (4)

CS M171L	Data Communication Systems Laboratory (2 to 4)
CS 174A	Introduction to Computer Graphics (4)
CS 180	Introduction to Algorithms and Complexity (4)
CS 181	Introduction to Formal Languages and Automata Theory (4)
CS M296B	Optimal Parameter Estimation and Experiment Design for Biomedical Systems (*same as Biomath M270B, Biomed Eng M296B and Medicine M270D*)
CS M296D	Introduction to Computational Cardiology (4) (*same as Biomed Eng M296D*)
Math 180	Combinatorics (4)
Math 149	Mathematics of Computer Graphics (4)
Math 151B	Applied Numerical Methods (4)
Stats 101B	Introduction to Data Analysis and Regression (4)
Stats 101C	Introduction to Regression and Data Mining (4)
Stats 201A	Research Design, Sampling and Data Mining (4)
Stats 201B	Regression Analysis: Model Building, Fitting and Criticism (4)
Stats 201C	Advanced Modeling and Data Mining (4)

Biomedical Systems (BMS)

For student interested primarily in computationally-oriented medical system studies, e.g. systems aspects of computational model-based biomedical, surgical or other biomedical-engineering system devices, including MEMS or nanoscale system devices; use of dynamic biosystem/computational modeling methods for optimizing or developing new clinical diagnostic or therapeutic protocols; feedback biocontrol system model development for imaging-based medical diagnosis; and optimal control of therapeutic drug delivery.

I. Required Core Courses

1. BME CM102/CM202 - Basic Human Biology for Biomedical Engineers I (4) (Fall)*

2. BME CM103/CM203 - Basic Human Biology for Biomedical Engineers II (4) (Fall)*

3. Math 151A Applied Numerical Methods (4) (Fall, Winter, Spring)*

OR

EE 103 Applied Numerical Computing (4) (Fall, Spring)*

II. **Two additional courses** selected from the following list, in consultation with a BMS mentor, justified as coherent in the proposal submitted when applying to the Major, and approved by the Program Chair.

BE 110	Biotransport and Bioreaction Processes (4)
BE 120	Biomedical Transducers (4)
BME M248	Intro to Biological Imaging (4) (*same as Biomed Phys M248 & Pharm M248*)
BME M259H	Biomechanics of Traumatic Injury (4) (same as EHS M259H)
BME M260	Neuroengineering (4) (*same as Neurosci M206*)
BME M296B	Optimal Parameter Estimation and Experiment Design for Biomedical Systems (4) (*same as Biomath M270, CS M296B and Medicine M270D*)
BME 296D	Introduction to Computational Cardiology (4) (*same as CS M296D*)
Biomath 106	Introduction to Cellular Modeling (4)
Biomath 220	Kinetic and Steady State Models in Pharmacology and Physiology (4)
Biomath M230	Computed Tomography: Theory and Applications (4)
Math 134	Linear and Nonlinear Systems of Differential Equations (4)
Math 136	Partial Differential Equations (4)
Math 151B	Applied Numerical Methods (4)
Math 164	Optimization (4)
Math 171	Stochastic Processes (4)
Stats 101B	Introduction to Data Analysis and Regression (4)
Stats 101C	Introduction to Regression and Data Mining (4)