There are many ways to get involved in Statistics at Carnegie Mellon: students, and undergraduates interact regularly. Faculty, graduate working environment and exceptional computing resources. Talented The Department augments all these strengths with a friendly, energetic accessible and are committed to involving undergraduates in research. Recent Statistics majors at Carnegie Mellon have taken jobs at leading companies in many fields, including the National Economic Research Association, Boeing, Morgan Stanley, Deloitte, Rosetta Marketing Group, Nielsen, Proctor and Gamble, Accenture, and Goldman Sachs. Other students have taken research positions at the National Security Agency, the U.S. Census Bureau, and the Science and Technology Policy Institute or worked for Teach for America. Many of our students have also gone on to graduate study at some of the top programs in the country including Carnegie Mellon, the Wharton School at the University of Pennsylvania, Johns Hopkins, University of Michigan, Stanford University, Harvard University, Duke University, Emory University, Yale University, Columbia University, and Georgia Tech.

The Department and Faculty
The Department of Statistics and Data Science at Carnegie Mellon University is world-renowned for its contributions to statistical theory and practice. Research in the department runs the gamut from pure mathematics to the hottest frontiers of science. Current research projects are helping make fundamental advances in neuroscience, cosmology, public policy, finance, and genetics. The faculty members are recognized around the world for their expertise and have garnered many prestigious awards and honors. (For example, three members of the faculty have been awarded the COPSS medal, the highest honor given by professional statistical societies.) At the same time, the faculty is firmly dedicated to undergraduate education. The entire faculty, junior and senior, teach courses at all levels. The faculty are accessible and are committed to involving undergraduates in research. The Department augments all these strengths with a friendly, energetic working environment and exceptional computing resources. Talented graduate students join the department from around the world, and add a unique dimension to the department's intellectual life. Faculty, graduate students, and undergraduates interact regularly.

How to Take Part
There are many ways to get involved in Statistics at Carnegie Mellon:

- The Bachelor of Science in Statistics and Machine Learning is a program housed in the Department of Statistics and Data Science and is jointly administered with the Department of Machine Learning. In this major, students take courses focused on skills in computing, mathematics, statistical theory, and the interpretation and display of complex data. The program is geared toward students interested in statistical computation, data science, and ‘big data’ problems.
- The Statistics Concentration and the Operations Research and Statistics Concentration in the Mathematical Sciences Major (see Department of Mathematical Sciences) are administered by the Department of Mathematical Sciences with input from the Department of Statistics and Data Science.
- There are several ongoing exciting research projects in the Department of Statistics and Data Science, and the department enthusiastically seeks to involve undergraduates in this work. Both majors and non-majors are welcome.
- Non-majors are eligible to take most of our courses, and indeed, they are required to do so by many programs on campus. Such courses offer one way to learn more about the Department of Statistics and Data Science and the field in general.

Curriculum
Statistics consists of two intertwined threads of inquiry: Statistical Theory and Data Analysis. The former uses probability theory to build and analyze mathematical models of data in order to devise methods for making effective predictions and decisions in the face of uncertainty. The latter involves techniques for extracting insights from complicated data, designs for accurate measurement and comparison, and methods for checking the validity of theoretical assumptions. Statistical Theory informs Data Analysis and vice versa. The Department of Statistics and Data Science curriculum follows both of these threads and helps the student develop the complementary skills required.

Throughout the sections of this catalog, we describe the requirements for the Major in Statistics and the different categories within our basic curriculum, followed by the requirements for the Major in Economics and Statistics, the Major in Statistics and Machine Learning, and the Minor in Statistics.

Note: We recommend that you use the information provided below as a general guideline, and then schedule a meeting with a Statistics Undergraduate Advisor (statadvising@stat.cmu.edu) to discuss the requirements in more detail, and build a program that is tailored to your strengths and interests.

B.S. in Statistics
Glenn Clune, Academic Advisor
Peter Freeman, Faculty Advisor
Location: Baker Hall 132
statadvising@stat.cmu.edu

Students in the Bachelor of Science program develop and master a wide array of skills in computing, mathematics, statistical theory, and the interpretation and display of complex data. In addition, Statistics majors gain experience in applying statistical tools to real problems in other fields and learn the nuances of interdisciplinary collaboration. The requirements for the Major in Statistics are detailed below and are organized by categories #1-#7.

Curriculum

1. Mathematical Foundations (Prerequisites)

29–39 units
Calculus*: Complete one of the following three sequences of mathematics courses at Carnegie Mellon, each of which provides sufficient preparation in calculus:

**Sequence 1**
21-111 Calculus I 10
21-112 Calculus II 10
and one of the following
21-256 Multivariate Analysis 9
21-259 Calculus in Three Dimensions 9

**Sequence 2**
21-120 Differential and Integral Calculus 10
and one of the following
21-256 Multivariate Analysis 9
21-259 Calculus in Three Dimensions 9

**Notes:**
- Passing the MSC 21-120 assessment test is an acceptable alternative to completing 21-120.
- It is recommended that students complete the calculus requirement during their freshman year.
- The linear algebra requirement needs to be completed before taking 36-401 Modern Regression.

Linear Algebra**: Complete one of the following three courses:
21-240 Matrix Algebra with Applications 10
21-241 Matrices and Linear Transformations 10
21-242 Matrix Theory 10

**2. Data Analysis: 36-45 units**

Data analysis is the art and science of extracting insight from data. The art lies in knowing which displays or techniques will reveal the most interesting features of a complicated data set. The science lies in understanding the various techniques and the assumptions on which they rely. Both aspects require practice to master.

The Beginning Data Analysis courses give a hands-on introduction to the art and science of data analysis. The courses cover similar topics but differ slightly in the examples they emphasize. 36-200 draws examples from many fields and satisfy the DC College Core Requirement in Statistical Reasoning. This course is therefore recommended for students in the College. (Note: A score of 4 or 5 on the Advanced Placement (AP) Exam in Statistics may be used to waive this requirement). Other courses emphasize examples in business (36-207), engineering and architecture (36-220), and the laboratory sciences (36-247).

The Intermediate Data Analysis courses build on the principles and methods covered in the introductory course, and more fully explore specific types of data analysis methods in more depth.

The Advanced Data Analysis courses draw on students’ previous experience with data analysis and understanding of statistical theory to develop advanced, more sophisticated methods. These courses involve extensive analysis of real data with emphasis on developing the oral and writing skills needed for communicating results.

**Sequence 1 (For students beginning their freshman or sophomore year)**

**Beginning*** Choose one of the following courses:
36-200 Reasoning with Data 9
36/70-207 Probability and Statistics for Business Applications 9
36-220 Engineering Statistics and Quality Control 9
36-247 Statistics for Lab Sciences 9

Note: Students who enter the program with 36-225 or 36-226 should discuss options with an advisor. Any 36-300 or 36-400 level course in Data Analysis that does not satisfy any other requirement for a Statistics Major and Minor may be counted as a Statistical Elective.

**Intermediate*** Choose one of the following courses:
36-202 Methods for Statistics & Data Science ** 9
36/70-208 Regression Analysis 9
36-309 Experimental Design for Behavioral & Social Sciences 9
36-290 Introduction to Statistical Research Methodology 9

* Or extra data analysis course in Statistics
** Must take prior to 36-401

**Advanced*** Choose one of the following courses:
36-303 Sampling, Survey and Society 9
36-315 Statistical Graphics and Visualization 9
36-311 Statistical Analysis of Networks 9
36-461 Special Topics: Statistical Methods in Epidemiology 9
36-462 Special Topics: Data Mining 9
36-463 Special Topics: Multilevel and Hierarchical Models 9
36-464 Special Topics: Applied Multivariate Methods 9
36-466 Special Topics: Statistical Methods in Finance 9
36-467 Special Topics: Data over Space & Time 9
36-468 Special Topics: Text Analysis 9
36-490 Undergraduate Research 9
36-497 Corporate Capstone Project 9

and take the following two courses:
36-401 Modern Regression 9
36-402 Advanced Methods for Data Analysis 9

Students can also take a second 36-46x (see section #5).

**Sequence 2 (For students beginning later in their college career)**

**Advanced*** Choose two of the following courses:
36-303 Sampling, Survey and Society 9
36-311 Statistical Analysis of Networks 9
36-315 Statistical Graphics and Visualization 9
36-461 Special Topics: Statistical Methods in Epidemiology 9
36-462 Special Topics: Data Mining 9
36-463 Special Topics: Multilevel and Hierarchical Models 9
36-464 Special Topics: Applied Multivariate Methods 9
36-466 Special Topics: Statistical Methods in Finance 9
36-467 Special Topics: Data over Space & Time 9
36-468 Special Topics: Text Analysis 9
36-490 Undergraduate Research 9
36-497 Corporate Capstone Project 9

**All Special Topics are not offered every semester, and new Special Topics are regularly added. See section 5 for details.

and take the following two courses:
36-401 Modern Regression 9
36-402 Advanced Methods for Data Analysis 9

**3. Probability Theory and Statistical Theory: 18 units**

The theory of probability gives a mathematical description of the randomness inherent in our observations. It is the language in which statistical models are stated, so an understanding of probability is essential for the study of statistical theory. Statistical theory provides a mathematical framework for making inferences about unknown quantities from data. The theory reduces statistical problems to their essential ingredients to help devise and evaluate inferential procedures. It provides a powerful and wide-ranging set of tools for dealing with uncertainty.

To satisfy the theory requirement take the following two courses:
36-225 Introduction to Probability Theory ** 9

and one of the following two courses:
36/70-208 Regression Analysis 9
36-202 Methods for Statistics & Data Science ** 9

**All Special Topics are not offered every semester, and new Special Topics are regularly added. See section 5 for details.**
7. Tracks*

Students should carefully check the course descriptions to determine if they qualify as well; consult with the Statistics Undergraduate Advisor.

*Note: Additional prerequisites are required for some of these courses. Students should carefully check the course descriptions to determine if additional prerequisites are necessary.

4. Statistical Computing: 9 units

36-350 Statistical Computing *

*In rare circumstances, a higher level Statistical Computing course, approved by your Statistics advisor, may be used as a substitute.

5. Special Topics 9 units

The Department of Statistics and Data Science offers advanced courses that focus on specific statistical applications or advanced statistical methods. These courses are numbered 36-46x (36-461, 36-462, etc.). Two of these courses will be offered every year, one per semester. Past topics included Statistical Learning, Data Mining, Statistics and the Law, Bayesian Statistics, Nonparametric Statistics, Statistical Genetics, Multilevel and Hierarchical Models, and Statistical Methods in Epidemiology. The objective of the course is to expose students to important topics in statistics and/or interesting applications which are not part of the standard undergraduate curriculum.

To satisfy the Special Topics requirement choose one of the 36-46x courses (which are 9 units).

Note: All 36-46x courses require 36-401 as a prerequisite or corequisite.

6. Statistical Elective: 9-10 units

Students are required to take one elective which can be within or outside the Department of Statistics and Data Science. Courses within Statistics can be any 300 or 400 level course (that is not used to satisfy any other requirement for the statistics major).

The following is a partial list of courses outside Statistics that qualify as electives as they provide intellectual infrastructure that will advance the student's understanding of statistics and its applications. Other courses may qualify as well; consult with the Statistics Undergraduate Advisor.

15-110 Principles of Computing
15-112 Fundamentals of Programming and Computer Science
15-121 Introduction to Data Structures
15-122 Principles of Imperative Computation
10-301 Introduction to Machine Learning (Undergrad)
10-315 Introduction to Machine Learning (SCS Majors)
15-388 Practical Data Science
21-127 Concepts of Mathematics
21-260 Differential Equations
21-292 Operations Research I
21-301 Combinatorics
21-355 Principles of Real Analysis I
80-220 Philosophy of Science
80-221 Philosophy of Social Science
80-310 Formal Logic
85-310 Research Methods in Cognitive Psychology
85-320 Research Methods in Developmental Psychology
85-340 Research Methods in Social Psychology
88-223 Decision Analysis
88-302 Behavioral Decision Making

Self-Defined Concentration Area (with advisor's approval) 36 units

The power of Statistics, and much of the fun, is that it can be applied to answer such a wide variety of questions in so many different fields. A critical part of statistical practice is understanding the questions being asked so that appropriate methods of analysis can be used. Hence, a critical part of statistical training is to gain experience applying the abstract tools to real problems.

The Concentration Area is a set of four related courses outside of Statistics that prepares the student to deal with statistical aspects of problems that arise in another field. These courses are usually drawn from a single discipline the student seeks to specialize in and must be approved by the Statistics Undergraduate Advisor. While these courses may not be Statistics, the concentration area must complement the overall Statistics degree.

For example, students intending to pursue careers in the health or biomedical sciences could take further courses in Biology or Chemistry, or students intending to pursue graduate work in Statistics could take further courses in advanced Mathematics.

The concentration area can be fulfilled with a minor or additional major, but not all minors and additional majors fulfill this requirement. Please make sure to consult the Undergraduate Statistics Advisor prior to pursuing courses for the concentration area. Once the concentration area is approved, any changes made to the previously agreed upon coursework requires re-approval by the Undergraduate Advisor.

Concentration Approval Process

- Submit the below materials to the Undergraduate Statistics Advisor
- List of possible coursework to fulfill the concentration*
- 150–200 word essay describing how the proposed courses complement the Statistics degree.

* These courses can be amended later, but must be re-approved by the Statistics Undergraduate Advisor if amended.

* Note: The concentration/track requirement is only for students whose primary major is statistics and have no other additional major or minor. The requirement does not apply for students who pursue an additional major in statistics.

Mathematical Statistics Track 46–52 units

21-127 Concepts of Mathematics 10
21-355 Principles of Real Analysis I 9
36-410 Introduction to Probability Modeling 9

And two of the following:

36-700 Probability and Mathematical Statistics 12
or 36-705 Intermediate Statistics
21-228 Discrete Mathematics 9
21-257 Models and Methods for Optimization 9
21-292 Operations Research I 9
21-301 Combinatorics 9
21-356 Principles of Real Analysis II 9

Statistics and Neuroscience Track 45–54 units

85-211 Cognitive Psychology 9
85-219 Biological Foundations of Behavior 9

And three electives (at least one from Methodology and Analysis and at least one from Neuroscientific Background):

Methodology and Analysis

36-700 Probability and Mathematical Statistics 12
or 36-705 Intermediate Statistics
10-301 Introduction to Machine Learning (Undergrad) 12
18-290 Signals and Systems 12
85-314 Cognitive Neuroscience Research Methods 9
42/86-631 Neural Data Analysis 9

Neuroscience Background

03-362 Cellular Neuroscience 9
03-363 Systems Neuroscience 9
15-386 Neural Computation 9
85-414 Cognitive Neuropsychology 9
85-419 Introduction to Parallel Distributed Processing 9
Recommendations

Students in the College of Humanities and Social Sciences who wish to major or minor in Statistics are advised to complete both the calculus requirement (one Mathematical Foundations calculus sequence) and the Beginning Data Analysis course 36-200 by the end of their Freshman year.

The linear algebra requirement is a prerequisite for the course 36-401. It is therefore essential to complete this requirement during your junior year at the latest.

Recommendations for Prospective PhD Students

Students interested in pursuing a PhD in Statistics or Biostatistics (or related programs) after completing their undergraduate degree are strongly recommended to pursue the Mathematical Statistics Track.

Additional Major in Statistics

Students who elect Statistics as a second or third major must fulfill all Statistics degree requirements except for the Concentration Area requirement. Majors in many other programs would naturally complement a Statistics Major, including Tepper’s undergraduate business program, Social and Decision Sciences, Policy and Management, and Psychology.

With respect to double-counting courses, it is departmental policy that students must have at least five statistics courses that do not count for their primary major. If students do not have at least five, they typically take additional advanced data analysis electives.

Students are advised to begin planning their curriculum (with appropriate advisors) as soon as possible. This is particularly true if the other major has a complex set of requirements and prerequisites or when many of the other major’s requirements overlap with the requirements for a Major in Statistics.

Many departments require Statistics courses as part of their Major or Minor programs. Students seeking transfer credit for those requirements from substitute courses (at Carnegie Mellon or elsewhere) should seek permission from their advisor in the department setting the requirement. The final authority in such decisions rests there. The Department Statistics does not provide approval or permission for substitution or waiver of another department’s requirements.

If a waiver or substitution is made in the home department, it is not automatically approved in the Department of Statistics and Data Science. In many of these cases, the student will need to take additional courses to satisfy the Statistics major requirements. Students should discuss this with a Statistics advisor when deciding whether to add an additional major in Statistics.

Research

One goal of the Statistics program is to give students experience with statistical research. The department gives students research experience through various courses focused on real world experiences and application. There is a variety of research projects in the department as well, and students who would like to pursue working on a project with faculty will need to contact that faculty directly to discuss that possibility.

Before graduation, students are encouraged to participate in a research project under faculty supervision. Students mostly do this through projects in specific courses, such as 36-290, 36-303, 36-490, and/or 36-497. Students can also pursue an independent study, or a summer research position.

Qualified students are also encouraged to participate in an advanced research project through 36-490 Undergraduate Research or 36-497 Corporate Capstone Project. Note that both of these courses require an application. Students who maintain a quality point average of 3.25 overall may also apply to participate in the Dietrich College Senior Honors Program (http:// coursecatalog.web.cmu.edu/dietrichcollegeofhumanitiesandsocialsciences/ #collegeservicesandprograms).

Sample Programs

The following sample programs illustrate three (of many) ways to satisfy the requirements of the Statistics Major. However, keep in mind that the program is flexible enough to support many other possible schedules and to emphasize a wide variety of interests.

The first schedule uses calculus sequence 1.

The second schedule is an example of the case when a student enters the program through 36-225 and 36-226 (and therefore skips the beginning data analysis sequence). This schedule has more emphasis on statistical theory and probability.

The third schedule is an example of the Mathematical Statistics track.

In these schedules, C.A. refers to Concentration Area courses.

Schedule 1

<table>
<thead>
<tr>
<th>Freshman</th>
<th>Sophomore</th>
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<tbody>
<tr>
<td><strong>Fall</strong></td>
<td><strong>Spring</strong></td>
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<tr>
<td>36-200 Reasoning with Data</td>
<td>36-202 Methods for Statistics &amp; Data Science</td>
</tr>
<tr>
<td>21-111 Calculus I</td>
<td>21-112 Calculus II</td>
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Schedule 2

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<th>Freshman</th>
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<tbody>
<tr>
<td><strong>Fall</strong></td>
<td><strong>Spring</strong></td>
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<tr>
<td>21-120 Differential and Integral Calculus</td>
<td>21-256 Multivariate Analysis</td>
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<tr>
<td>36-200 Reasoning with Data</td>
<td>21-260 Differential Equations</td>
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</table>

Schedule 3 - Mathematics Track Only

<table>
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<tr>
<th>Freshman</th>
<th>Sophomore</th>
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<td><strong>Fall</strong></td>
<td><strong>Spring</strong></td>
</tr>
<tr>
<td>21-120 Differential and Integral Calculus</td>
<td>21-256 Multivariate Analysis</td>
</tr>
<tr>
<td>21-260 Differential Equations</td>
<td>C.A.</td>
</tr>
</tbody>
</table>

B.S. in Economics and Statistics

Samantha Nielsen, Statistics & Data Science Lead Academic Advisor
Kathleen Conway, Economics Senior Academic Advisor
Rebecca Nugent and Edward Kennedy, Faculty Advisors
Carol Goldburg, Executive Director, Undergraduate Economics Program

Statistics & Data Science Location: Baker Hall 132
statadvising@stat.cmu.edu
The B.S. in Economics and Statistics is jointly advised by the Department of Statistics and Data Science and the Undergraduate Economics Program.

The Major in Economics and Statistics provides an interdisciplinary course of study aimed at students with a strong interest in the empirical analysis of economic data. With joint curriculum from the Department of Statistics and Data Science and the Undergraduate Economics Program, the major provides students with a solid foundation in the theories and methods of both fields. Students in this major are trained to advance the understanding of economic issues through the analysis, synthesis and reporting of data using the advanced empirical research methods of statistics and econometrics. Graduates are well positioned for admission to competitive graduate programs, including those in statistics, economics and management, as well as for employment in positions requiring strong analytic and conceptual skills—especially those in economics, finance, education, and public policy.

All economics courses counting towards an economics degree must be completed with a grade of 'C' or higher.

The requirements for the B.S. in Economics and Statistics are the following:

I. Prerequisites 38-39 units

1. Mathematical Foundations 38-39 units

Calculus
21-120 Differential and Integral Calculus 10
and one of the following:
21-256 Multivariate Analysis 9
21-259 Calculus in Three Dimensions 9

Note: Passing the MSC 21-120 assessment test is an acceptable alternative to completing 21-120.

Linear Algebra
One of the following three courses:
21-240 Matrix Algebra with Applications 10
21-241 Matrices and Linear Transformations 10
21-242 Matrix Theory 10

Note: 21-241 and 21-242 are intended only for students with a very strong mathematical background.

II. Foundations 18-36 units

2. Economics Foundations 18 units
73-102 Principles of Microeconomics 9
73-103 Principles of Macroeconomics 9

3. Statistical Foundations 9-18 units

Sequence 1 (For students beginning their freshman or sophomore year)

Beginning*

Choose one of the following courses:
36-200 Reasoning with Data 9
36/70-207 Probability and Statistics for Business Applications 9
36-220 Engineering Statistics and Quality Control 9
36-247 Statistics for Lab Sciences 9

Note: Students who enter the program with 36-225 or 36-226 should discuss options with an advisor. Any 36-300 or 36-400 level course in Data Analysis that does not satisfy any other requirement for the Economics and Statistics Major may be counted as a Statistical Elective.

Intermediate*

Choose one of the following courses:
36-202 Methods for Statistics & Data Science 9
36-208 Regression Analysis 9
36-290 Introduction to Statistical Research Methodology 9

36-309 Experimental Design for Behavioral & Social Sciences 9

* Or extra data analysis course in Statistics
** Must take prior to 36-401 Modern Regression.

Advanced

Choose two of the following courses:
36-303 Sampling, Survey and Society 9
36-311 Statistical Analysis of Networks 9
36-315 Statistical Graphics and Visualization 9
36-461 Special Topics: Statistical Methods in Epidemiology 9
36-462 Special Topics: Data Mining 9
36-463 Special Topics: Multilevel and Hierarchical Models 9
36-464 Special Topics: Applied Multivariate Methods 9
36-466 Special Topics: Statistical Methods in Finance 9
36-467 Special Topics: Data over Space & Time 9
36-468 Special Topics: Text Analysis 9
36-490 Undergraduate Research 9
36-497 Corporate Capstone Project 9

Sequence 2 (For students beginning later in their college career)

Advanced

Choose three of the following courses:
36-303 Sampling, Survey and Society 9
36-311 Statistical Analysis of Networks 9
36-315 Statistical Graphics and Visualization 9
36-461 Special Topics: Statistical Methods in Epidemiology 9
36-462 Special Topics: Data Mining 9
36-463 Special Topics: Multilevel and Hierarchical Models 9
36-464 Special Topics: Applied Multivariate Methods 9
36-466 Special Topics: Statistical Methods in Finance 9
36-467 Special Topics: Data over Space & Time 9
36-468 Special Topics: Text Analysis 9
36-490 Undergraduate Research 9
36-497 Corporate Capstone Project 9

**All Special Topics are not offered every semester, and new Special Topics are regularly added. See section 5 for details.

III. Disciplinary Core 126 units

1. Economics Core 45 units
73-230 Intermediate Microeconomics 9
73-240 Intermediate Macroeconomics 9
73-270 Professional Communication for Economists 9
73-265 Economics and Data Science 9
73-274 Econometrics I 9
73-374 Econometrics II 9

2. Statistics Core 36 units
36-225 Introduction to Probability Theory 9
and one of the following courses:
36-226 Introduction to Statistical Inference 9
36-326 Mathematical Statistics (Honors) 9
and both of the following courses:
36-401 Modern Regression 9
36-402 Advanced Methods for Data Analysis 9

*In order meet the prerequisite requirements for the major, a grade of C or better is required in 36-225 (or equivalents), 36-226 or 36-326 and 36-401.

**It is possible to substitute 36-217, 36-218, or 31-235 for 36-225 36-226 36-22536-225 36-22536-225. (36-225 36-226 36-22536-225 is the standard introduction to probability, 36-217 is tailored for engineers and computer scientists, 36-218 is a more mathematically rigorous class for Computer Science students and more mathematically advanced Statistics students (Statistics students need advisor approval to enroll), and 31-235 31-235 31-23521-325
is a rigorous Probability Theory course offered by the Department of Mathematics.)

3. Computing  
36-350 Statistical Computing 9 units

*In rare circumstances, a higher level Statistical Computing course, approved by your Statistics advisor, may be used as a substitute.

4. Advanced Electives 36 units

Students must take two advanced Economics elective courses (numbered 73-300 through 73-495, excluding 73-374) and two (or three - depending on previous coursework, see Section 3) advanced Statistics elective courses (numbered 36-303, 36-311, 36-315, 36-46X, 36-490, or 36-497).

Students pursuing a degree in Economics and Statistics also have the option of earning a concentration area (https://www.cmu.edu/tepper/programs/undergraduate-economics/curriculum/concentrations/) by completing a set of interconnected electives. While a concentration area is not required for this degree, it is an additional option that allows students to explore a group of aligned topics and/or develop a specialized and advanced skill set appropriate for a desired career path. The electives required for this degree may count towards your concentration area. To fulfill a concentration, students must take four courses from the designated set of electives. Please make sure to consult an advisor when choosing these courses.

| Total number of units for the major | 191-201 units |
| Total number of units for the degree | 360 units |

Professional Development

Students are strongly encouraged to take advantage of professional development opportunities and/or coursework. One option is 73-210 Economics Colloquium I, a fall-only course that provides information about careers in Economics, job search strategies, and research opportunities. The Department of Statistics and Data Science also offers a series of workshops pertaining to resume preparation, graduate school applications, careers in the field, among other topics. Students should also take advantage of the Career and Professional Development Center.

Additional Major in Economics and Statistics

Students who elect Economics and Statistics as a second or third major must fulfill all Economics and Statistics degree requirements. Majors in many other programs would naturally complement an Economics and Statistics Major, including Tepper’s undergraduate business program, Social and Decision Sciences, Policy and Management, and Psychology.

With respect to double-counting courses, it is departmental policy that students must have at least six courses (three Economics and three Statistics) that do not count for their primary major. If students do not have at least six, they typically take additional advanced data analysis or economics electives, depending on where the double counting issue is.

Students are advised to begin planning their curriculum (with appropriate advisors) as soon as possible. This is particularly true if the other major has a complex set of requirements and prerequisites or when many of the other major’s requirements overlap with the requirements for a Major in Economics and Statistics.

Many departments require Statistics courses as part of their Major or Minor programs. Students seeking transfer credit for those requirements from substitute courses (at Carnegie Mellon or elsewhere) should seek permission from their advisor in the department setting the requirement. The final authority in such decisions rests there. The Department of Statistics and Data Science does not provide approval or permission for substitution or waiver of another department’s requirements.

If a waiver or substitution is made in the home department, it is not automatically approved in the Department of Statistics and Data Science. In many of these cases, the student will need to take additional courses to satisfy the Economics and Statistics major requirements. Students should discuss this with a Statistics advisor when deciding whether to add an additional major in Economics and Statistics.

Sample Program

The following sample program illustrates one way to satisfy the requirements of the Economics and Statistics Major. Keep in mind that the program is flexible and can support other possible schedules (see footnotes below the schedule).

<table>
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<th>Freshman</th>
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<td><strong>Fall</strong></td>
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<tr>
<td>21-120 Differential and Integral Calculus</td>
<td>36-202 Methods for Statistics &amp; Data Science</td>
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<tr>
<td>36-200 Reasoning with Data</td>
<td>21-256 Multivariate Analysis</td>
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<tr>
<td>73-103 Principles of Microeconomics</td>
<td>73-103 Principles of Microeconomics</td>
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<tr>
<td>73-060 Economics: BaseCamp * Not required*</td>
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<th>Junior</th>
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<tr>
<td><strong>Fall</strong></td>
<td><strong>Spring</strong></td>
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<tr>
<td>36-401 Modern Regression</td>
<td>73-270 Professional Communication for Economists</td>
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<td>73-374 Econometrics II</td>
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*In each semester, ---- represents other courses (not related to the major) which are needed in order to complete the 360 units that the degree requires.

Prospective PhD students might add 21-127 fall of sophomore year, replace 21-240 with 21-241, add 21-260 in spring of junior year and 21-355 in fall of senior year.

B.S. in Statistics and Machine Learning

Samantha Nielsen, Academic Advisor  
Ryan Tibshirani and Ann Lee, Faculty Advisors  
Location: Baker Hall 132  
statadvising@stat.cmu.edu

Students in the Statistics and Machine Learning program develop and master a wide array of skills in computing, mathematics, statistical theory, and the interpretation and display of complex data. In addition, Statistics and Machine Learning majors gain experience in applying statistical tools to real problems in other fields and learn the nuances of interdisciplinary collaboration. This program is geared towards students interested in statistical computation, data science, or “Big Data” problems. The requirements for the Major in Statistics and Machine Learning are detailed below and are organized by categories.

Curriculum

1. Mathematical Foundations (Prerequisites)  
49-59 units

Mathematics is the language in which statistical models are described and analyzed, so some experience with basic calculus and linear algebra is an important component for anyone pursuing a program of study in Statistics and Machine Learning.

Calculus*:  
Complete one of the following sequences of mathematics courses at Carnegie Mellon, each of which provides sufficient preparation in calculus:

**Sequence 1**

| 21-111 | 10 |
| 21-112 | 10 |

and one of the following:

| 21-256 | 9 |
| 21-259 | 9 |
### Sequence 2

21-120 Differential and Integral Calculus  
and one of the following:
21-256 Multivariate Analysis  
21-259 Calculus in Three Dimensions

### Notes:
- Passing the Mathematical Sciences 21-120 assessment test is an acceptable alternative to completing 21-120

### Integration and Approximation
21-122 Integration and Approximation  

### Linear Algebra**:
Complete one of the following three courses:
21-240 Matrix Algebra with Applications  
21-241 Matrices and Linear Transformations  
21-242 Matrix Theory
* It is recommended that students complete the calculus requirement during their freshman year.
**The linear algebra requirement needs to be completed before taking 36-401 Modern Regression.
21-241 and 21-242 are intended only for students with a very strong mathematical background.

### Mathematical Theory:
21-127 Concepts of Mathematics  

### 2. Data Analysis 45–54 units

Data analysis is the art and science of extracting insight from data. The art lies in knowing which displays or techniques will reveal the most interesting features of a complicated data set. The science lies in understanding the various techniques and the assumptions on which they rely. Both aspects require practice to master.

The Beginning Data Analysis courses give a hands-on introduction to the art and science of data analysis. The courses cover similar topics but differ slightly in the examples they emphasize. 36-200 draws examples from many fields and satisfies the Dietrich College Core Requirement in Statistical Reasoning. One of these courses is therefore recommended for students in the College. (Note: A score of 4 or 5 on the Advanced Placement (AP) Exam in Statistics may be used to waive this requirement). Other courses emphasize examples in business (36-207), engineering and architecture (36-220), and the laboratory sciences (36-247).

The Intermediate Data Analysis courses build on the principles and methods covered in the introductory course, and more fully explore specific types of data analysis methods in more depth.

The Advanced Data Analysis courses draw on students’ previous experience with data analysis and understanding of statistical theory to develop advanced, more sophisticated methods. These core courses involve extensive analysis of real data with emphasis on developing the oral and writing skills needed for communicating results.

### Sequence 1
#### Beginning*
Choose one of the following courses:
36-200 Reasoning with Data  
36/70-207 Probability and Statistics for Business Applications  
36-220 Engineering Statistics and Quality Control  
36-247 Statistics for Lab Sciences

Note: Students who enter the program with 36-225 or 36-226 should discuss options with an advisor. Any 36-300 or 36-400 level course in Data Analysis that does not satisfy any other requirement for a Statistics Major and Minor may be counted as a Statistical Elective.

#### Intermediate*
Choose one of the following courses:
36-202 Methods for Statistics & Data Science**  
36/70-208 Regression Analysis

### Sequence 2
#### Advanced
Choose three of the following courses:
36-208 Topics: Experimental Design for Behavioral & Social Sciences  
36-290 Introduction to Statistical Research Methodology  
*Or extra data analysis course in Statistics
**Must take prior to 36-401

### 3. Probability Theory and Statistical Theory 18 units

The theory of probability gives a mathematical description of the randomness inherent in our observations. It is the language in which statistical models are stated, so an understanding of probability is essential for the study of statistical theory. Statistical theory provides a mathematical framework for making inferences about unknown quantities from data. The theory reduces statistical problems to their essential ingredients to help devise and evaluate inferential procedures. It provides a powerful and wide-ranging set of tools for dealing with uncertainty.

To satisfy the theory requirement take the following two courses**:
36-225 Introduction to Probability Theory  
36-226 Introduction to Statistical Inference  
or 36-326 Mathematical Statistics (Honors)

**It is possible to substitute 36-217, 36-218, or 21-325 for 36-225. (36-225 is the standard introduction to probability, 36-217 is tailored for engineers and computer scientists, 36-218 is a more mathematically rigorous class for Computer Science students and more mathematically advanced Statistics
students (Statistics students need advisor approval to enroll, and 21-325 is a rigorous Probability Theory course offered by the Department of Mathematics.) 36-326 Mathematical Statistics (Honors) can be substituted for 36-226 Introduction to Statistical Inference and is considered an honors course.

Comments:
(i) In order to meet the prerequisite requirements, a grade of at least a C is required in 36-225, 36-226 and 36-401.

4. Statistical Computing

9 units

36-350 Statistical Computing

*In rare circumstances, a higher level Statistical Computing course, approved by your Statistics advisor, may be used as a substitute.

5. Machine Learning/Computer Science

46-48 units

Statistical modeling in practice nearly always requires computation in one way or another. Computational algorithms are sometimes treated as “black-boxes”, whose innards the statistician need not pay attention to. But this attitude is becoming less and less prevalent, and today there is much to be gained from a strong working knowledge of computational tools. Understanding the strengths and weaknesses of various methods allows the data analyst to select the right tool for the job; understanding how they can be adapted to work in new settings greatly extends the realm of problems that he/she can solve. While all Majors in Statistics are given solid grounding in computation, extensive computational training is really what sets the Major in Statistics and Machine Learning apart.

15-112 Fundamentals of Programming and Computer Science 12
15-122 Principles of Imperative Computation 10
15-351 Algorithms and Advanced Data Structures 12
10-301 Introduction to Machine Learning (Undergrad) 12
or 10-315 Introduction to Machine Learning (SCS Majors)
and take one of the following Machine Learning Advanced Electives:

10-405 Machine Learning with Large Datasets (Undergraduate) 12
10-605 Machine Learning with Large Datasets 12
10-703 Deep Reinforcement Learning & Control 12
10-707 Advanced Deep Learning 12
11-411 Natural Language Processing 12
11-441 Machine Learning for Text Mining 9
11-661 Language and Statistics 12
15-386 Neural Computation 9
15-387 Computational Perception 9
16-311 Introduction to Robotics 12
16-385 Computer Vision 12
16-720 Computer Vision 12
11-761 Language and Statistics 12
*PhD level ML course as approved by Statistics advisor
** Independent research with an ML faculty member

Sample Programs

The following sample program illustrates one way to satisfy the requirements of the Statistics and Machine Learning program. Keep in mind that the program is flexible and can support other possible schedules (see footnotes below the schedule). Sample program 1 is for students who have not satisfied the basic calculus requirements. Sample program 2 is for students who have satisfied the basic calculus requirements and choose option 2 for their data analysis courses (see section #2)

Schedule 1

<table>
<thead>
<tr>
<th>Fall</th>
<th>Spring</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>36-200 Reasoning with Data</td>
<td>36-202 Methods for Statistics &amp; Data Science</td>
<td>36-225 Introduction to Probability Theory</td>
<td>36-226 Introduction to Statistical Inference</td>
</tr>
<tr>
<td>21-120 Differential and Integral Calculus</td>
<td>21-256 Multivariate Analysis</td>
<td>21-122 Integration and Approximation</td>
<td>21-241 Matrices and Linear Transformations</td>
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</tbody>
</table>
**The Minor in Statistics**

Glenn Clune, Academic Advisor  
Peter Freeman, Faculty Advisor  
Location: Baker Hall 132M  
statadvising@stat.cmu.edu

The Minor in Statistics develops skills that complement major study in other disciplines. The program helps the student master the basics of statistical theory and advanced techniques in data analysis. This is a good choice for deepening understanding of statistical ideas and for strengthening research skills.

In order to get a minor in Statistics a student must satisfy all of the following requirements:

1. **Mathematical Foundations (Prerequisites)**  
   **29–39 units**

   Calculus:*: Complete one of the following two sequences of mathematics courses at Carnegie Mellon, each of which provides sufficient preparation in calculus:

   **Sequence 1**
   - 21-111 Calculus I  
   - 21-112 Calculus II  

   and one of the following:
   - 21-256 Multivariate Analysis  
   - 21-259 Calculus in Three Dimensions

   **Sequence 2**
   - 21-120 Differential and Integral Calculus  

   *Or extra data analysis course in Statistics

**Note:** Students who enter the program with 36-225 or 36-226 should discuss options with an advisor. Any 36-300 or 36-400 level course in Data Analysis that does not satisfy any other requirement for a Statistics Major and Minor may be counted as a Statistical Elective.

**Intermediate Data Analysis***

Choose one of the following courses:
- 36-202 Methods for Statistics & Data Science **  
- 36-208 Regression Analysis  
- 36-290 Introduction to Statistical Research Methodology  
- 36-309 Experimental Design for Behavioral & Social Sciences

*Or extra data analysis course in Statistics

**Note:** Must take prior to 36-401

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**Schedule 2**

<table>
<thead>
<tr>
<th>Freshman</th>
<th>Sophomore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>Spring</td>
</tr>
<tr>
<td>36-305 Statistical Computing</td>
<td>36-402 Advanced Methods for Data Analysis</td>
</tr>
<tr>
<td>36-306 Modern Regression</td>
<td>10-301 Introduction to Machine Learning (undergrad)</td>
</tr>
<tr>
<td>36-307 Introduction to Statistical Inference</td>
<td>36-401 Modern Regression</td>
</tr>
</tbody>
</table>

*In each semester, **** represents other courses (not related to the major) which are needed in order to complete the 360 units that the degree requires.

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**2. Data Analysis**  
**36 units**

Data analysis is the art and science of extracting insight from data. The art lies in knowing which displays or techniques will reveal the most interesting features of a complicated data set. The science lies in understanding the various techniques and the assumptions on which they rely. Both aspects require practice to master.

The Beginning Data Analysis courses give a hands-on introduction to the art and science of data analysis. The courses cover similar topics but differ slightly in the examples they emphasize. 36-200 draws examples from many fields and satisfies the DC College Core Requirement in Statistical Reasoning. One of these courses is therefore recommended for students in the College. (Note: A score of 4 or 5 on the Advanced Placement (AP) Exam in Statistics may be used to waive this requirement). Other courses emphasize examples in business (36-207 ), engineering and architecture (36-220 ), and the laboratory sciences (36-247 ).

The Intermediate Data Analysis courses build on the principles and methods covered in the introductory course, and more fully explore specific types of data analysis methods in more depth.

The Advanced Data Analysis courses draw on students’ previous experience with data analysis and understanding of statistical theory to develop advanced, more sophisticated methods. These core courses involve extensive analysis of real data with emphasis on developing the oral and writing skills needed for communicating results.

**Sequence 1** (For students beginning their freshman or sophomore year)

**Beginning Data Analysis***

Choose one of the following courses:
- 36-200 Reasoning with Data  
- 36-70-207 Probability and Statistics for Business  
- 36-220 Engineering Statistics and Quality Control  
- 36-247 Statistics for Lab Sciences

**Intermediate Data Analysis***

Choose one of the following courses:
- 36-202 Methods for Statistics & Data Science **  
- 36-70-208 Regression Analysis  
- 36-290 Introduction to Statistical Research Methodology  
- 36-309 Experimental Design for Behavioral & Social Sciences

*Or extra data analysis course in Statistics

**Note:** Must take prior to 36-401

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Advanced Data Analysis and Methodology

Take the following course:

36-401 Modern Regression  9

and one of the following courses:

36-402 Advanced Methods for Data Analysis  9
36-410 Introduction to Probability Modeling  9
36-461 Special Topics: Statistical Methods in Epidemiology  9
36-462 Special Topics: Data Mining  9
36-463 Special Topics: Multilevel and Hierarchical Models  9
36-464 Special Topics: Applied Multivariate Methods  9
36-465 Special Topics: An Introduction to Bayesian Inference  9
36-466 Special Topics: Statistical Methods in Finance  9
36-467 Special Topics: Data over Space & Time  9
36-468 Special Topics: Text Analysis  9
36-490 Undergraduate Research  9
36-497 Corporate Capstone Project  9

Special Topics rotate and new ones are regularly added.

Sequence 2 (For students beginning later in their college career)

Advanced Data Analysis and Methodology

Take the following course:

36-401 Modern Regression  9

and take two of the following courses (one of which must be 400-level):

36-303 Sampling, Survey and Society  9
36-315 Statistical Analysis of Networks  9
36-402 Advanced Methods for Data Analysis  9
36-410 Introduction to Probability Modeling  9
36-461 Special Topics: Statistical Methods in Epidemiology  9
36-462 Special Topics: Data Mining  9
36-463 Special Topics: Multilevel and Hierarchical Models  9
36-464 Special Topics: Applied Multivariate Methods  9
36-465 Special Topics: An Introduction to Bayesian Inference  9
36-466 Special Topics: Statistical Methods in Finance  9
36-467 Special Topics: Data over Space & Time  9
36-468 Special Topics: Text Analysis  9
36-490 Undergraduate Research  9
36-497 Corporate Capstone Project  9

Special Topics rotate and new ones are regularly added.

3. Probability Theory and Statistical Theory  18 units

To satisfy the theory requirement take the following two courses:

36-225 Introduction to Probability Theory  9
36-226 Introduction to Statistical Inference  9

or 36-326 Mathematical Statistics (Honors)  9

**It is possible to substitute 36-217, 36-218 or 21-325 for 36-225. (36-225 is the standard introduction to probability, 36-217 is tailored for engineers and computer scientists, 36-218 is a more mathematically rigorous class for Computer Science students and more mathematically advanced Statistics students. (Statistics students need advisor approval to enroll), and 21-325 is a rigorous Probability Theory course offered by the Department of Mathematics.) 36-326 Mathematical Statistics (Honors) can be substituted for 36-226 Introduction to Statistical Inference and is considered an honors course.

Comments:

(i) In order to be a Major or a Minor in good standing, a grade of at least a C is required in 36-225, 36-226 and 401. In particular, a grade of C or higher is required in order to be able to continue in the major.
DAVID CHOI, Assistant Professor of Statistics and Information Systems – Ph.D., Stanford University; Carnegie Mellon, 2004–
ALEXANDRA CHOULDECHOVA, Assistant Professor of Statistics and Public Policy – Ph.D., Stanford University; Carnegie Mellon, 2014–
PETER FREEMAN, Assistant Teaching Faculty – Ph.D., University of Chicago; Carnegie Mellon, 2004–
MAX G’SELL, Assistant Professor – Ph.D., Stanford University; Carnegie Mellon, 2014–
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JIASHUN JIN, Professor of Statistics – Ph.D., Stanford University; Carnegie Mellon, 2007–
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COSMA SHALIZI, Associate Professor – Ph.D., University of Wisconsin, Madison; Carnegie Mellon, 2005–
YUTING WEI, Assistant Professor – Ph.D., University of California; Carnegie Mellon, 2019–

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DALENE STANGL, Teaching Professor – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2017–

Adjunct Faculty

OLGA CHILINA, Lecturer – MS, University of Toronto; Carnegie Mellon, 2016–
APRIL GALYARDT – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2017–
CHRISTOPHER PETER MAKRIS, Adjunct Lecturer – MSP, Carnegie Mellon University; Carnegie Mellon, 2018–
ROSS O’CONNELL – Ph.D., University of Michigan; Carnegie Mellon, 2016–
GORDON WEINBERG, Senior Lecturer – M.A. Mathematics, University of Pittsburgh; Carnegie Mellon, 2004–

Special Faculty

ROBIN MEJIA

Affiliated Faculty

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BERNIE DEVLIN – Ph.D., Pennsylvania State University; Carnegie Mellon, 1994–
SAM VENTURA – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2015–

Emeriti Faculty

GEORGE T. DUNCAN, Professor of Statistics and Public Policy – Ph.D., University of Minnesota; Carnegie Mellon, 1974–