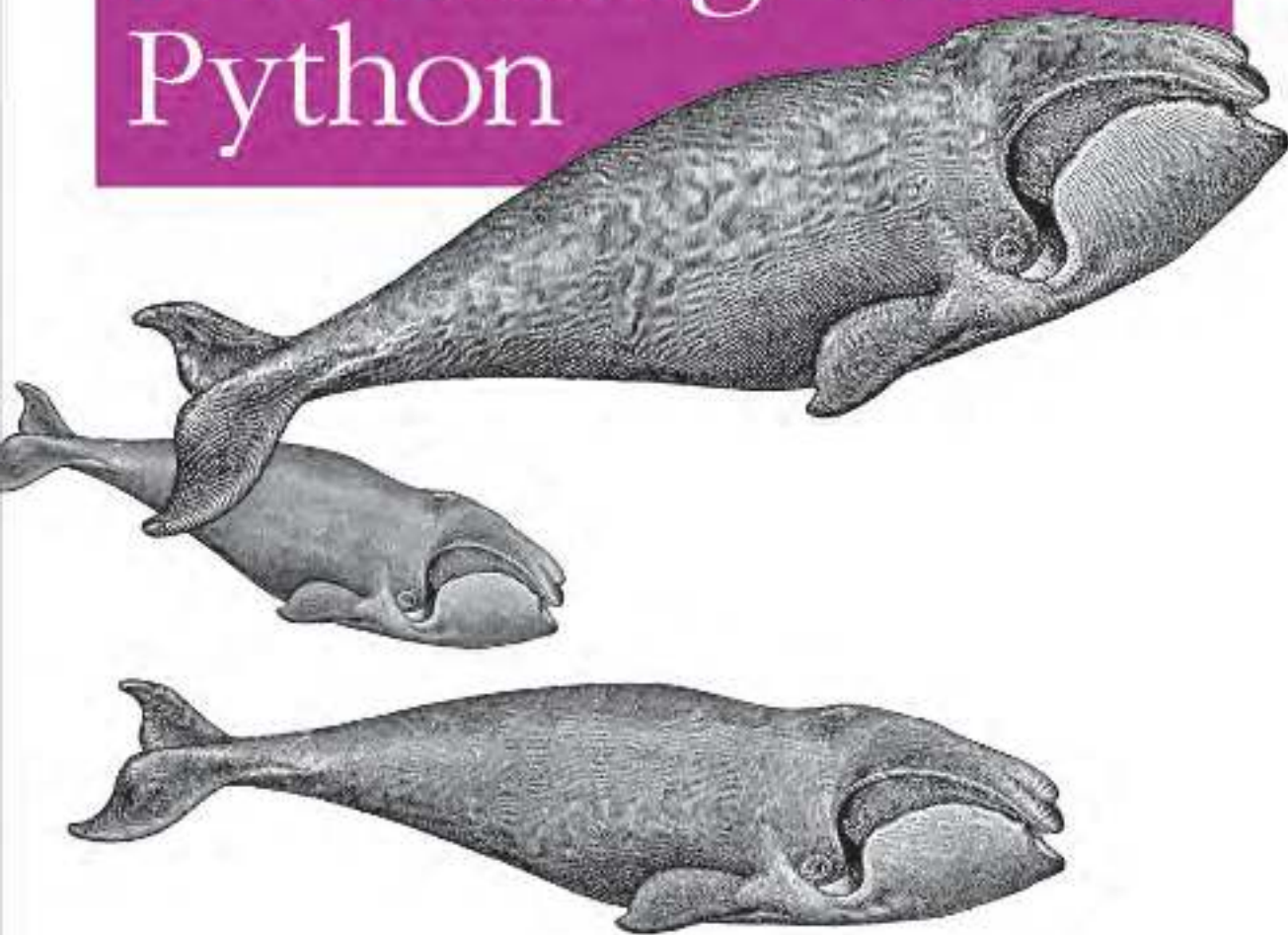


Natural Language Processing with Python



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Steven Bird, Ewan Klein & Edward Loper

Natural Language Processing with Python



This book offers a highly accessible introduction to natural language processing, the field that supports a variety of language technologies, from predictive text and email filtering to automatic summarization and translation. With it, you'll learn how to write Python programs that work with large collections of unstructured text. You'll access richly annotated datasets using a comprehensive range of linguistic data structures, and you'll understand the main algorithms for analyzing the content and structure of written communication.

Packed with examples and exercises, *Natural Language Processing with Python* will help you:

- Extract information from unstructured text, either to guess the topic or identify "named entities"
- Analyze linguistic structure in text, including parsing and semantic analysis
- Access popular linguistic databases, including WordNet and treebanks
- Integrate techniques drawn from fields as diverse as linguistics and artificial intelligence

This book will help you gain practical skills in natural language processing using the Python programming language and the Natural Language Toolkit (NLTK) open source library. If you're interested in developing web applications, analyzing multilingual news sources, or documenting endangered languages—or if you're simply curious to have a programmer's perspective on how human language works—you'll find *Natural Language Processing with Python* both fascinating and immensely useful.

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"Rarely does a book tackle such a difficult computing subject with such a clear approach and with such beautifully clean code.... This is the book from which to learn natural language processing."

—Ken Getz,
Senior Consultant,
MCW Technologies

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Natural Language Processing with Python

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Steven Bird, Ewan Klein, and Edward Loper

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Natural Language Processing with Python

by Steven Bird, Ewan Klein, and Edward Loper

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Preface

This is a book about Natural Language Processing. By “natural language” we mean a language that is used for everyday communication by humans; languages such as English, Hindi, or Portuguese. In contrast to artificial languages such as programming languages and mathematical notations, natural languages have evolved as they pass from generation to generation, and are hard to pin down with explicit rules. We will take Natural Language Processing—or NLP for short—in a wide sense to cover any kind of computer manipulation of natural language. At one extreme, it could be as simple as counting word frequencies to compare different writing styles. At the other extreme, NLP involves “understanding” complete human utterances, at least to the extent of being able to give useful responses to them.

Technologies based on NLP are becoming increasingly widespread. For example, phones and handheld computers support predictive text and handwriting recognition; web search engines give access to information locked up in unstructured text; machine translation allows us to retrieve texts written in Chinese and read them in Spanish. By providing more natural human-machine interfaces, and more sophisticated access to stored information, language processing has come to play a central role in the multilingual information society.

This book provides a highly accessible introduction to the field of NLP. It can be used for individual study or as the textbook for a course on natural language processing or computational linguistics, or as a supplement to courses in artificial intelligence, text mining, or corpus linguistics. The book is intensely practical, containing hundreds of fully worked examples and graded exercises.

The book is based on the Python programming language together with an open source library called the *Natural Language Toolkit* (NLTK). NLTK includes extensive software, data, and documentation, all freely downloadable from <http://www.nltk.org/>. Distributions are provided for Windows, Macintosh, and Unix platforms. We strongly encourage you to download Python and NLTK, and try out the examples and exercises along the way.

Audience

NLP is important for scientific, economic, social, and cultural reasons. NLP is experiencing rapid growth as its theories and methods are deployed in a variety of new language technologies. For this reason it is important for a wide range of people to have a working knowledge of NLP. Within industry, this includes people in human-computer interaction, business information analysis, and web software development. Within academia, it includes people in areas from humanities computing and corpus linguistics through to computer science and artificial intelligence. (To many people in academia, NLP is known by the name of “Computational Linguistics.”)

This book is intended for a diverse range of people who want to learn how to write programs that analyze written language, regardless of previous programming experience:

New to programming?

The early chapters of the book are suitable for readers with no prior knowledge of programming, so long as you aren’t afraid to tackle new concepts and develop new computing skills. The book is full of examples that you can copy and try for yourself, together with hundreds of graded exercises. If you need a more general introduction to Python, see the list of Python resources at <http://docs.python.org/>.

New to Python?

Experienced programmers can quickly learn enough Python using this book to get immersed in natural language processing. All relevant Python features are carefully explained and exemplified, and you will quickly come to appreciate Python’s suitability for this application area. The language index will help you locate relevant discussions in the book.

Already dreaming in Python?

Skim the Python examples and dig into the interesting language analysis material that starts in [Chapter 1](#). You’ll soon be applying your skills to this fascinating domain.

Emphasis

This book is a **practical** introduction to NLP. You will learn by example, write real programs, and grasp the value of being able to test an idea through implementation. If you haven’t learned already, this book will teach you **programming**. Unlike other programming books, we provide extensive illustrations and exercises from NLP. The approach we have taken is also **principled**, in that we cover the theoretical underpinnings and don’t shy away from careful linguistic and computational analysis. We have tried to be **pragmatic** in striking a balance between theory and application, identifying the connections and the tensions. Finally, we recognize that you won’t get through this unless it is also **pleasurable**, so we have tried to include many applications and examples that are interesting and entertaining, and sometimes whimsical.

Note that this book is not a reference work. Its coverage of Python and NLP is selective, and presented in a tutorial style. For reference material, please consult the substantial quantity of searchable resources available at <http://python.org/> and <http://www.nltk.org/>.

This book is not an advanced computer science text. The content ranges from introductory to intermediate, and is directed at readers who want to learn how to analyze text using Python and the Natural Language Toolkit. To learn about advanced algorithms implemented in NLTK, you can examine the Python code linked from <http://www.nltk.org/>, and consult the other materials cited in this book.

What You Will Learn

By digging into the material presented here, you will learn:

- How simple programs can help you manipulate and analyze language data, and how to write these programs
- How key concepts from NLP and linguistics are used to describe and analyze language
- How data structures and algorithms are used in NLP
- How language data is stored in standard formats, and how data can be used to evaluate the performance of NLP techniques

Depending on your background, and your motivation for being interested in NLP, you will gain different kinds of skills and knowledge from this book, as set out in [Table P-1](#).

Table P-1. Skills and knowledge to be gained from reading this book, depending on readers' goals and background

Goals	Background in arts and humanities	Background in science and engineering
Language analysis	Manipulating large corpora, exploring linguistic models, and testing empirical claims.	Using techniques in data modeling, data mining, and knowledge discovery to analyze natural language.
Language technology	Building robust systems to perform linguistic tasks with technological applications.	Using linguistic algorithms and data structures in robust language processing software.

Organization

The early chapters are organized in order of conceptual difficulty, starting with a practical introduction to language processing that shows how to explore interesting bodies of text using tiny Python programs (Chapters 1–3). This is followed by a chapter on structured programming ([Chapter 4](#)) that consolidates the programming topics scattered across the preceding chapters. After this, the pace picks up, and we move on to a series of chapters covering fundamental topics in language processing: tagging, classification, and information extraction (Chapters 5–7). The next three chapters look at

ways to parse a sentence, recognize its syntactic structure, and construct representations of meaning (Chapters 8–10). The final chapter is devoted to linguistic data and how it can be managed effectively (Chapter 11). The book concludes with an Afterword, briefly discussing the past and future of the field.

Within each chapter, we switch between different styles of presentation. In one style, natural language is the driver. We analyze language, explore linguistic concepts, and use programming examples to support the discussion. We often employ Python constructs that have not been introduced systematically, so you can see their purpose before delving into the details of how and why they work. This is just like learning idiomatic expressions in a foreign language: you’re able to buy a nice pastry without first having learned the intricacies of question formation. In the other style of presentation, the programming language will be the driver. We’ll analyze programs, explore algorithms, and the linguistic examples will play a supporting role.

Each chapter ends with a series of graded exercises, which are useful for consolidating the material. The exercises are graded according to the following scheme: ○ is for easy exercises that involve minor modifications to supplied code samples or other simple activities; ◐ is for intermediate exercises that explore an aspect of the material in more depth, requiring careful analysis and design; ● is for difficult, open-ended tasks that will challenge your understanding of the material and force you to think independently (readers new to programming should skip these).

Each chapter has a further reading section and an online “extras” section at <http://www.nltk.org/>, with pointers to more advanced materials and online resources. Online versions of all the code examples are also available there.

Why Python?

Python is a simple yet powerful programming language with excellent functionality for processing linguistic data. Python can be downloaded for free from <http://www.python.org/>. Installers are available for all platforms.

Here is a five-line Python program that processes *file.txt* and prints all the words ending in *ing*:

```
>>> for line in open("file.txt"):
...     for word in line.split():
...         if word.endswith('ing'):
...             print word
```

This program illustrates some of the main features of Python. First, whitespace is used to *nest* lines of code; thus the line starting with `if` falls inside the scope of the previous line starting with `for`; this ensures that the `ing` test is performed for each word. Second, Python is *object-oriented*; each variable is an entity that has certain defined attributes and methods. For example, the value of the variable `line` is more than a sequence of characters. It is a string object that has a “method” (or operation) called `split()` that

we can use to break a line into its words. To apply a method to an object, we write the object name, followed by a period, followed by the method name, i.e., `line.split()`. Third, methods have *arguments* expressed inside parentheses. For instance, in the example, `word.endswith('ing')` had the argument 'ing' to indicate that we wanted words ending with *ing* and not something else. Finally—and most importantly—Python is highly readable, so much so that it is fairly easy to guess what this program does even if you have never written a program before.

We chose Python because it has a shallow learning curve, its syntax and semantics are transparent, and it has good string-handling functionality. As an interpreted language, Python facilitates interactive exploration. As an object-oriented language, Python permits data and methods to be encapsulated and re-used easily. As a dynamic language, Python permits attributes to be added to objects on the fly, and permits variables to be typed dynamically, facilitating rapid development. Python comes with an extensive standard library, including components for graphical programming, numerical processing, and web connectivity.

Python is heavily used in industry, scientific research, and education around the world. Python is often praised for the way it facilitates productivity, quality, and maintainability of software. A collection of Python success stories is posted at <http://www.python.org/about/success/>.

NLTK defines an infrastructure that can be used to build NLP programs in Python. It provides basic classes for representing data relevant to natural language processing; standard interfaces for performing tasks such as part-of-speech tagging, syntactic parsing, and text classification; and standard implementations for each task that can be combined to solve complex problems.

NLTK comes with extensive documentation. In addition to this book, the website at <http://www.nltk.org/> provides API documentation that covers every module, class, and function in the toolkit, specifying parameters and giving examples of usage. The website also provides many HOWTOs with extensive examples and test cases, intended for users, developers, and instructors.

Software Requirements

To get the most out of this book, you should install several free software packages. Current download pointers and instructions are available at <http://www.nltk.org/>.

Python

The material presented in this book assumes that you are using Python version 2.4 or 2.5. We are committed to porting NLTK to Python 3.0 once the libraries that NLTK depends on have been ported.

NLTK

The code examples in this book use NLTK version 2.0. Subsequent releases of NLTK will be backward-compatible.

NLTK-Data

This contains the linguistic corpora that are analyzed and processed in the book.

NumPy (recommended)

This is a scientific computing library with support for multidimensional arrays and linear algebra, required for certain probability, tagging, clustering, and classification tasks.

Matplotlib (recommended)

This is a 2D plotting library for data visualization, and is used in some of the book's code samples that produce line graphs and bar charts.

NetworkX (optional)

This is a library for storing and manipulating network structures with nodes and edges. For visualizing semantic networks, also install the Graphviz library.

Prover9 (optional)

This is an automated theorem prover for first-order and equational logic, used to support inference in language processing.

Natural Language Toolkit (NLTK)

NLTK was originally created in 2001 as part of a computational linguistics course in the Department of Computer and Information Science at the University of Pennsylvania. Since then it has been developed and expanded with the help of dozens of contributors. It has now been adopted in courses in dozens of universities, and serves as the basis of many research projects. [Table P-2](#) lists the most important NLTK modules.

Table P-2. Language processing tasks and corresponding NLTK modules with examples of functionality

Language processing task	NLTK modules	Functionality
Accessing corpora	<code>nltk.corpus</code>	Standardized interfaces to corpora and lexicons
String processing	<code>nltk.tokenize</code> , <code>nltk.stem</code>	Tokenizers, sentence tokenizers, stemmers
Collocation discovery	<code>nltk.collocations</code>	t-test, chi-squared, point-wise mutual information
Part-of-speech tagging	<code>nltk.tag</code>	n-gram, backoff, Brill, HMM, TnT
Classification	<code>nltk.classify</code> , <code>nltk.cluster</code>	Decision tree, maximum entropy, naive Bayes, EM, k-means
Chunking	<code>nltk.chunk</code>	Regular expression, n-gram, named entity
Parsing	<code>nltk.parse</code>	Chart, feature-based, unification, probabilistic, dependency
Semantic interpretation	<code>nltk.sem</code> , <code>nltk.inference</code>	Lambda calculus, first-order logic, model checking
Evaluation metrics	<code>nltk.metrics</code>	Precision, recall, agreement coefficients
Probability and estimation	<code>nltk.probability</code>	Frequency distributions, smoothed probability distributions
Applications	<code>nltk.app</code> , <code>nltk.chat</code>	Graphical concordancer, parsers, WordNet browser, chatbots
Linguistic fieldwork	<code>nltk.toolbox</code>	Manipulate data in SIL Toolbox format

NLTK was designed with four primary goals in mind:

Simplicity

To provide an intuitive framework along with substantial building blocks, giving users a practical knowledge of NLP without getting bogged down in the tedious house-keeping usually associated with processing annotated language data

Consistency

To provide a uniform framework with consistent interfaces and data structures, and easily guessable method names

Extensibility

To provide a structure into which new software modules can be easily accommodated, including alternative implementations and competing approaches to the same task

Modularity

To provide components that can be used independently without needing to understand the rest of the toolkit

Contrasting with these goals are three non-requirements—potentially useful qualities that we have deliberately avoided. First, while the toolkit provides a wide range of functions, it is not encyclopedic; it is a toolkit, not a system, and it will continue to evolve with the field of NLP. Second, while the toolkit is efficient enough to support meaningful tasks, it is not highly optimized for runtime performance; such optimizations often involve more complex algorithms, or implementations in lower-level programming languages such as C or C++. This would make the software less readable and more difficult to install. Third, we have tried to avoid clever programming tricks, since we believe that clear implementations are preferable to ingenious yet indecipherable ones.

For Instructors

Natural Language Processing is often taught within the confines of a single-semester course at the advanced undergraduate level or postgraduate level. Many instructors have found that it is difficult to cover both the theoretical and practical sides of the subject in such a short span of time. Some courses focus on theory to the exclusion of practical exercises, and deprive students of the challenge and excitement of writing programs to automatically process language. Other courses are simply designed to teach programming for linguists, and do not manage to cover any significant NLP content. NLTK was originally developed to address this problem, making it feasible to cover a substantial amount of theory and practice within a single-semester course, even if students have no prior programming experience.

A significant fraction of any NLP syllabus deals with algorithms and data structures. On their own these can be rather dry, but NLTK brings them to life with the help of interactive graphical user interfaces that make it possible to view algorithms step-by-

step. Most NLTK components include a demonstration that performs an interesting task without requiring any special input from the user. An effective way to deliver the materials is through interactive presentation of the examples in this book, entering them in a Python session, observing what they do, and modifying them to explore some empirical or theoretical issue.

This book contains hundreds of exercises that can be used as the basis for student assignments. The simplest exercises involve modifying a supplied program fragment in a specified way in order to answer a concrete question. At the other end of the spectrum, NLTK provides a flexible framework for graduate-level research projects, with standard implementations of all the basic data structures and algorithms, interfaces to dozens of widely used datasets (corpora), and a flexible and extensible architecture. Additional support for teaching using NLTK is available on the NLTK website.

We believe this book is unique in providing a comprehensive framework for students to learn about NLP in the context of learning to program. What sets these materials apart is the tight coupling of the chapters and exercises with NLTK, giving students—even those with no prior programming experience—a practical introduction to NLP. After completing these materials, students will be ready to attempt one of the more advanced textbooks, such as *Speech and Language Processing*, by Jurafsky and Martin (Prentice Hall, 2008).

This book presents programming concepts in an unusual order, beginning with a non-trivial data type—lists of strings—then introducing non-trivial control structures such as comprehensions and conditionals. These idioms permit us to do useful language processing from the start. Once this motivation is in place, we return to a systematic presentation of fundamental concepts such as strings, loops, files, and so forth. In this way, we cover the same ground as more conventional approaches, without expecting readers to be interested in the programming language for its own sake.

Two possible course plans are illustrated in [Table P-3](#). The first one presumes an arts/humanities audience, whereas the second one presumes a science/engineering audience. Other course plans could cover the first five chapters, then devote the remaining time to a single area, such as text classification (Chapters 6 and 7), syntax (Chapters 8 and 9), semantics ([Chapter 10](#)), or linguistic data management ([Chapter 11](#)).

Table P-3. Suggested course plans; approximate number of lectures per chapter

Chapter	Arts and Humanities	Science and Engineering
Chapter 1, Language Processing and Python	2–4	2
Chapter 2, Accessing Text Corpora and Lexical Resources	2–4	2
Chapter 3, Processing Raw Text	2–4	2
Chapter 4, Writing Structured Programs	2–4	1–2
Chapter 5, Categorizing and Tagging Words	2–4	2–4
Chapter 6, Learning to Classify Text	0–2	2–4

Chapter	Arts and Humanities	Science and Engineering
Chapter 7, <i>Extracting Information from Text</i>	2	2–4
Chapter 8, <i>Analyzing Sentence Structure</i>	2–4	2–4
Chapter 9, <i>Building Feature-Based Grammars</i>	2–4	1–4
Chapter 10, <i>Analyzing the Meaning of Sentences</i>	1–2	1–4
Chapter 11, <i>Managing Linguistic Data</i>	1–2	1–4
Total	18–36	18–36

Conventions Used in This Book

The following typographical conventions are used in this book:

Bold

Indicates new terms.

Italic

Used within paragraphs to refer to linguistic examples, the names of texts, and URLs; also used for filenames and file extensions.

Constant width

Used for program listings, as well as within paragraphs to refer to program elements such as variable or function names, statements, and keywords; also used for program names.

Constant width italic

Shows text that should be replaced with user-supplied values or by values determined by context; also used for metavariables within program code examples.



This icon signifies a tip, suggestion, or general note.



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Royalties

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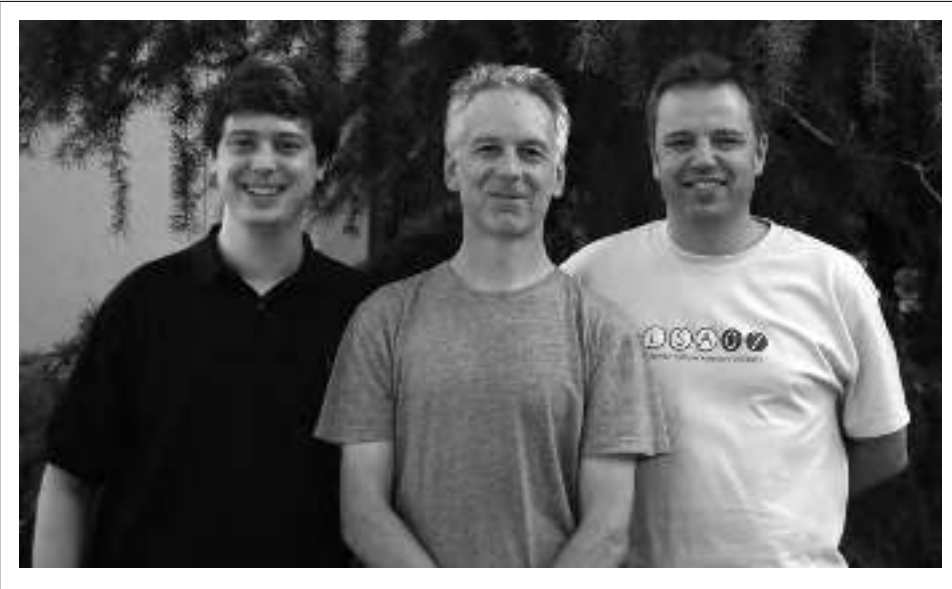


Figure P-1. Edward Loper, Ewan Klein, and Steven Bird, Stanford, July 2007

Language Processing and Python

It is easy to get our hands on millions of words of text. What can we do with it, assuming we can write some simple programs? In this chapter, we'll address the following questions:

1. What can we achieve by combining simple programming techniques with large quantities of text?
2. How can we automatically extract key words and phrases that sum up the style and content of a text?
3. What tools and techniques does the Python programming language provide for such work?
4. What are some of the interesting challenges of natural language processing?

This chapter is divided into sections that skip between two quite different styles. In the “computing with language” sections, we will take on some linguistically motivated programming tasks without necessarily explaining how they work. In the “closer look at Python” sections we will systematically review key programming concepts. We'll flag the two styles in the section titles, but later chapters will mix both styles without being so up-front about it. We hope this style of introduction gives you an authentic taste of what will come later, while covering a range of elementary concepts in linguistics and computer science. If you have basic familiarity with both areas, you can skip to [Section 1.5](#); we will repeat any important points in later chapters, and if you miss anything you can easily consult the online reference material at <http://www.nltk.org/>. If the material is completely new to you, this chapter will raise more questions than it answers, questions that are addressed in the rest of this book.

1.1 Computing with Language: Texts and Words

We're all very familiar with text, since we read and write it every day. Here we will treat text as *raw data* for the programs we write, programs that manipulate and analyze it in a variety of interesting ways. But before we can do this, we have to get started with the Python interpreter.

Getting Started with Python

One of the friendly things about Python is that it allows you to type directly into the interactive **interpreter**—the program that will be running your Python programs. You can access the Python interpreter using a simple graphical interface called the Interactive DeveLopment Environment (IDLE). On a Mac you can find this under Applications→MacPython, and on Windows under All Programs→Python. Under Unix you can run Python from the shell by typing `idle` (if this is not installed, try typing `python`). The interpreter will print a blurb about your Python version; simply check that you are running Python 2.4 or 2.5 (here it is 2.5.1):

```
Python 2.5.1 (r251:54863, Apr 15 2008, 22:57:26)
[GCC 4.0.1 (Apple Inc. build 5465)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>>
```



If you are unable to run the Python interpreter, you probably don't have Python installed correctly. Please visit <http://python.org/> for detailed instructions.

The `>>>` prompt indicates that the Python interpreter is now waiting for input. When copying examples from this book, don't type the "`>>>`" yourself. Now, let's begin by using Python as a calculator:

```
>>> 1 + 5 * 2 - 3
8
>>>
```

Once the interpreter has finished calculating the answer and displaying it, the prompt reappears. This means the Python interpreter is waiting for another instruction.



Your Turn: Enter a few more expressions of your own. You can use asterisk (*) for multiplication and slash (/) for division, and parentheses for bracketing expressions. Note that division doesn't always behave as you might expect—it does integer division (with rounding of fractions downwards) when you type `1/3` and “floating-point” (or decimal) division when you type `1.0/3.0`. In order to get the expected behavior of division (standard in Python 3.0), you need to type: `from __future__ import division`.

The preceding examples demonstrate how you can work interactively with the Python interpreter, experimenting with various expressions in the language to see what they do. Now let's try a non-sensical expression to see how the interpreter handles it:

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