

Pensar en Python

Aprende a pensar como un informático

2da Edición, Versión 2.4.0

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La forma original de este libro es en código fuente de \LaTeX . Compilar esta fuente de \LaTeX tiene el efecto de generar una representación de un libro de texto independiente del dispositivo, el cual se puede convertir a otros formatos e imprimir.

La fuente de \LaTeX para este libro está disponible en <http://www.thinkpython2.com>

Título original: *Think Python: How to Think Like a Computer Scientist*

Traducción de Jorge Espinoza.

Prefacio

La extraña historia de este libro

En enero de 1999, me estaba preparando para enseñar un curso introductorio de programación en Java. Lo había enseñado tres veces y me estaba frustrando. La tasa de fracaso en el curso era muy alta y, aún para estudiantes que tenían éxito, el nivel general de logros era muy bajo.

Uno de los problemas que vi tenía relación con los libros. Eran muy grandes, con demasiados detalles innecesarios sobre Java, y no tenían suficiente orientación de alto nivel acerca de cómo programar. Y todos sufrían el efecto trampilla: comenzaban con facilidad, seguían gradualmente y luego, en algún lugar alrededor del Capítulo 5, se caían. Los estudiantes conseguían demasiado material nuevo, muy rápido, y yo ocupaba el resto del semestre recogiendo los pedazos.

Dos semanas antes del primer día de clases, decidí escribir mi propio libro. Mis objetivos eran:

- Que sea corto. Es mejor para los estudiantes leer 10 páginas que no leer 50 páginas.
- Tener cuidado con el vocabulario. Intenté minimizar la jerga y definir cada término en el primer uso.
- Construir de manera gradual. Para evitar trampillas, tomé los temas más difíciles y los dividí en series de pasos pequeños.
- Concentrarse en la programación, no en el lenguaje de programación. Incluí el mínimo subconjunto útil de Java y excluí el resto.

Necesitaba un título, así que por capricho escogí *Aprende a pensar como un informático*.

Mi primera versión fue áspera, pero funcionó. Los estudiantes hicieron la lectura y entendieron lo suficiente como para que yo pudiera ocupar el tiempo de la clase en los temas difíciles, los temas interesantes y (más importante) dejar a los estudiantes practicar.

Publiqué el libro bajo la Licencia de documentación libre de GNU, la cual permite a los usuarios copiar, modificar y distribuir el libro.

Lo que ocurrió después es la parte genial. Jeff Elkner, un profesor de escuela secundaria en Virginia, adoptó mi libro y lo tradujo a Python. Él me envió una copia de su traducción y yo tuve la experiencia inusual de aprender Python leyendo mi propio libro. Como Green Tea Press, publiqué la primera versión en Python en 2001.

En 2003 empecé a enseñar en el Olin College y tuve que enseñar Python por primera vez. El contraste con Java fue notable. Los estudiantes se esforzaban menos, aprendían más, trabajaban en más proyectos interesantes y generalmente se divertían mucho.

Desde entonces he continuado desarrollando el libro, corrigiendo errores, mejorando algunos de los ejemplos y agregando material, especialmente ejercicios.

El resultado es este libro, ahora con el título menos grandioso *Pensar en Python*. Algunos de los cambios son:

- Agregué una sección sobre depuración al final de cada capítulo. Estas secciones presentan técnicas generales para encontrar y evitar errores de programación y advertencias sobre trampas de Python.
- Agregué más ejercicios, que van desde pruebas cortas de comprensión hasta algunos proyectos sustanciales. La mayoría de los ejercicios incluye un enlace a mi solución.
- Agregué una serie de estudios de caso—ejemplos más largos con ejercicios, soluciones y discusión.
- Expandí la discusión de planes de desarrollo de programa y pautas de diseño básicas.
- Agregué apéndices acerca de depuración y análisis de algoritmos.

La segunda edición de *Pensar en Python* tiene nuevas características:

- El libro y todo el código de apoyo han sido actualizados a Python 3.
- Agregué unas pocas secciones, y más detalles en la web, para ayudar a los principiantes a empezar a ejecutar Python en un navegador, así que no tienes que lidiar con la instalación de Python hasta que tú quieras hacerlo.
- Para el Capítulo 4.1 cambié mi propio paquete de gráfica tortuga, llamado Swampy, por un módulo de Python más estándar, `turtle`, que es más fácil de instalar y más poderoso.
- Agregué un nuevo capítulo llamado “Trucos extra”, el cual introduce algunas características adicionales de Python que no son estrictamente necesarias, pero a veces son prácticas.

Espero que disfrutes trabajando con este libro y que te ayude a aprender a programar y a pensar como un informático, al menos un poco.

Allen B. Downey

Olin College

Agradecimientos

Muchas gracias a Jeff Elkner, quien tradujo mi libro de Java a Python, lo cual comenzó este proyecto y me presentó lo que ha resultado ser mi lenguaje favorito.

Gracias también a Chris Meyers, quien contribuyó a varias secciones de *How to Think Like a Computer Scientist*.

Gracias a la Free Software Foundation por desarrollar la Licencia de documentación libre de GNU, que me ayudó a hacer posible mi colaboración con Jeff y Chris, y a Creative Commons por la licencia que uso ahora.

Gracias a los editores de Lulu que trabajaron en *How to Think Like a Computer Scientist*.

Gracias a los editores de O'Reilly Media que trabajaron en *Think Python*.

Gracias a todos los estudiantes que trabajaron con las primeras versiones de este libro y a todos los colaboradores (nombrados a continuación) que enviaron correcciones y sugerencias.

Lista de colaboradores

Más de 100 lectores perspicaces y atentos han enviado sugerencias y correcciones en los últimos años. Sus contribuciones, y su entusiasmo por este proyecto, han sido una ayuda enorme.

Si tienes una sugerencia o corrección, por favor envía un email a feedback@thinkpython.com. Si hago un cambio basado en tu retroalimentación, te agregaré a la lista de colaboradores (a menos que pidas ser omitido).

Si incluyes al menos una parte de la oración en donde aparece el error, eso me facilita la búsqueda. Números de página y de sección están bien también, pero el trabajo no es tan fácil. ¡Gracias!

- Lloyd Hugh Allen envió una corrección a la Sección 8.4.
- Yvon Boulianne envió una corrección a un error semántico en el Capítulo 5.
- Fred Bremmer envió una corrección en la Sección 2.1.
- Jonah Cohen escribió los scripts de Perl que convierte la fuente de LaTeX para este libro en un hermoso HTML.
- Michael Conlon envió una corrección gramatical en el Capítulo 2 y una mejora de estilo en el Capítulo 1, e inició la discusión sobre los aspectos técnicos de los intérpretes.
- Benoît Girard envió una corrección a un error chistoso en la Sección 5.6.
- Courtney Gleason y Katherine Smith escribieron `horsebet.py`, que fue usado como un estudio de caso en una versión anterior del libro. Su programa encontrarse ahora en el sitio web.
- Lee Harr envió más correcciones de las que cabrían acá en una lista y, de hecho, debería aparecer como uno de los principales editores del texto.
- James Kaylin es un estudiante que usa el texto. Ha enviado numerosas correcciones.
- David Kershaw arregló la función rota `catTwice` en la Sección 3.10.
- Eddie Lam ha enviado numerosas correcciones a los Capítulos 1, 2 y 3. También arregló el Makefile para que cree un índice la primera vez que se ejecuta y nos ayudó a configurar un esquema de versionamiento.

- Man-Yong Lee envió una corrección al código de ejemplo en la Sección 2.4.
- David Mayo advirtió que la palabra “inconsciente” en el Capítulo 1 necesitaba ser cambiada a “subconsciente”.
- Chris McAloon envió muchas correcciones a las Secciones 3.9 y 3.10.
- Matthew J. Moelter ha sido un colaborador por mucho tiempo que envió numerosas correcciones y sugerencias al libro.
- Simon Dicon Montford informó una definición de función faltante y muchos errores tipográficos en el Capítulo 3. Además, encontró errores en la función `increment` en el Capítulo 13.
- John Ouzts corrigió la definición de “valor de retorno” en el Capítulo 3.
- Kevin Parks envió valiosos comentarios y sugerencias en cuanto a cómo mejorar la distribución del libro.
- David Pool envió un error tipográfico en el glosario del Capítulo 1, así como amables palabras de aliento.
- Michael Schmitt envió una corrección al capítulo de archivos y excepciones.
- Robin Shaw señaló un error en la Sección 13.1, donde la función `printTime` se usó en un ejemplo sin ser definida.
- Paul Sleight encontró un error en el Capítulo 7 y un error en el script de Perl de Jonah Cohen que genera HTML a partir de LaTeX.
- Craig T. Snyder está probando el texto en un curso en la Drew University. Ha aportado muchas sugerencias y correcciones valiosas.
- Ian Thomas y sus alumnos están usando el texto en un curso de programación. Ellos son los primeros en probar los capítulos de la segunda mitad del libro, y han hecho numerosas correcciones y sugerencias.
- Keith Verheyden envió una corrección en el Capítulo 3.
- Peter Winstanley nos hizo saber sobre un error en nuestro *Latin* que estuvo por mucho tiempo en el Capítulo 3.
- Chris Wrobel made corrections to the code in the chapter on file I/O and exceptions.
- Moshe Zadka ha hecho contribuciones invaluable a este proyecto. Además de escribir el primer borrador del capítulo de Diccionarios, proporcionó orientación continua en las primeras etapas del libro.
- Christoph Zwerschke envió muchas correcciones y sugerencias pedagógicas, y explicó la diferencia entre *gleich* y *selbe*.
- James Mayer nos envió una gran cantidad de errores de ortografía y tipográficos, incluyendo dos en la lista de colaboradores.
- Hayden McAfee encontró una inconsistencia potencialmente confusa entre dos ejemplos.
- Angel Arnal es parte de un equipo internacional de traductores trabajando en la versión en español del texto. Además, encontró muchos errores en la versión en inglés.
- Tauhidul Hoque y Lex Berezhny crearon las ilustraciones en el Capítulo 1 y mejoraron muchas de las otras ilustraciones.

- Dr. Michele Alzetta encontró un error en el Capítulo 8 y envió algunos comentarios pedagógicos interesantes y sugerencias sobre Fibonacci y Old Maid.
- Andy Mitchell encontró un error tipográfico en el Capítulo 1 y un ejemplo roto en el Capítulo 2.
- Kalin Harvey sugirió una aclaración en el Capítulo 7 y caught some typos.
- Christopher P. Smith encontró muchos errores tipográficos y nos ayudó a actualizar el libro para Python 2.2.
- David Hutchins encontró un error tipográfico en el Prólogo.
- Gregor Lingl está enseñando Python en una escuela secundaria en Vienna, Austria. Está trabajando en una traducción del libro al alemán y encontró un par de errores malos en el Capítulo 5.
- Julie Peters encontró un error tipográfico en el Prefacio.
- Florin Oprina envió una mejora a `makeTime`, una corrección a `printTime` y un buen error tipográfico.
- D. J. Webre sugirió una aclaración en el Capítulo 3.
- Ken encontró un puñado de errores en los Capítulos 8, 9 y 11.
- Ivo Wever encontró un error tipográfico en el Capítulo 5 y sugirió una aclaración en el capítulo 3.
- Curtis Yanko sugirió una aclaración en el Capítulo 2.
- Ben Logan envió una serie de errores tipográficos y problemas con la traducción del libro a HTML.
- Jason Armstrong vio la palabra perdida en el Capítulo 2.
- Louis Cordier notó un lugar en el Capítulo 16 donde el código no coincidía con el texto.
- Brian Cain sugirió varias aclaraciones en los Capítulos 2 y 3.
- Rob Black envió un montón de correcciones, incluyendo algunos cambios para Python 2.2.
- Jean-Philippe Rey de la École Centrale Paris envió una serie de parches, incluyendo algunas actualizaciones para Python 2.2 y otras mejoras para pensar.
- Jason Mader en la George Washington University hizo una serie de sugerencias y correcciones útiles.
- Jan Gundtofte-Bruun nos recordó que “a error” es un error.
- Abel David y Alexis Dinno nos recordaron que el plural de “matrix” es “matrices”, no “matrices”. Este error estuvo en el libro por años, pero dos lectores con las mismas iniciales lo informaron en el mismo día. Extraño.
- Charles Thayer nos animó a deshacernos de los punto y coma que habíamos puesto al final de algunas sentencias y a limpiar nuestro uso de “argumento” y “parámetro”.
- Roger Sperberg advirtió sobre una lógica retorcida en el Capítulo 3.
- Sam Bull advirtió sobre un párrafo confuso en el Capítulo 2.
- Andrew Cheung pointed out two instances of “use before def”.

- C. Corey Capel spotted the missing word in the Third Theorem of Debugging and a typo in Chapter 4.
- Alessandra ayudó a aclarar alguna confusión con Turtle.
- Wim Champagne found a brain-o in a dictionary example.
- Douglas Wright señaló un problema con la división entera en arco.
- Jared Spindor encontró algo de basura al final de una oración.
- Lin Peiheng envió una serie de sugerencias muy útiles.
- Ray Hagtvedt envió dos errores y un no tan error.
- Torsten Hübsch señaló una inconsistencia en Swampy.
- Inga Petuhhov corrigió un ejemplo en el Capítulo 14.
- Arne Babenhauserheide envió muchas correcciones útiles.
- Mark E. Casida es es bueno mirando palabras repetidas.
- Scott Tyler rellenó una que faltaba. Y envió un montón de correcciones.
- Gordon Shephard envió varias correcciones, todas en correos separados.
- Andrew Turner encontró un error en el Capítulo 8.
- Adam Hobart arregló un problema con la división entera en arco.
- Daryl Hammond y Sarah Zimmerman advirtieron que serví `math.pi` demasiado pronto. Y Zim vio un error tipográfico.
- George Sass encontró un error en una sección de Depuración.
- Brian Bingham sugirió el Ejercicio 11.5.
- Leah Engelbert-Fenton advirtió que usé `tuple` como un nombre de variable, contrario a mi propio consejo. Y luego encontró un montón de errores tipográficos y un “use before def”.
- Joe Funke vio un error tipográfico.
- Chao-chao Chen encontró una inconsistencia en el ejemplo de Fibonacci.
- Jeff Paine sabe la diferencia entre space y spam.
- Lubos Pintes envió un error tipográfico.
- Gregg Lind y Abigail Heithoff sugirieron el Ejercicio 14.3.
- Max Hailperin ha enviado una serie de correcciones y sugerencias. Max es uno de los autores del extraordinario *Concrete Abstractions*, que tal vez quieras leer cuando termines con este libro.
- Chotipat Pornavalai encontró un error en un mensaje de error.
- Stanislaw Antol envió una lista de sugerencias muy útiles.
- Eric Pashman envió una serie de correcciones para los Capítulos 4–11.
- Miguel Azevedo encontró algunos errores tipográficos.
- Jianhua Liu envió una larga lista de correcciones.

- Nick King encontró una palabra que faltaba.
- Martin Zuther envió una larga lista de sugerencias.
- Adam Zimmerman found an inconsistency in my instance of an “instance” and several other errors.
- Ratnakar Tiwari sugirió una nota al pie explicando los triángulos degenerados.
- Anurag Goel sugirió otra solución para `is_abecedarian` y envió algunas correcciones adicionales. Y sabe cómo deletrear Jane Austen.
- Kelli Kratzer vio uno de los errores tipográficos.
- Mark Griffiths señaló un ejemplo confuso en el Capítulo 3.
- Roydan Ongie encontró un error en mi método de Newton.
- Patryk Wolowiec me ayudó con un problema en la versión HTML.
- Mark Chonofsky me habló de una nueva palabra clave en Python 3.
- Russell Coleman me ayudó con mi geometría.
- Nam Nguyen found a typo and pointed out that I used the Decorator pattern but didn’t mention it by name.
- Stéphane Morin envió varias correcciones y sugerencias.
- Paul Stoop corrigió un error tipográfico en `uses_only`.
- Eric Bronner advirtió sobre una confusión en la discusión del orden de operaciones.
- Alexandros Gezerlis estableció un nuevo estándar para el número y la calidad de sugerencias que envió. ¡Estamos profundamente agradecidos!
- Gray Thomas knows his right from his left.
- Giovanni Escobar Sosa envió una larga lista de correcciones y sugerencias.
- Daniel Neilson corrigió un error sobre el orden de operaciones.
- Will McGinnis advirtió que `polyline` fue definida de manera diferente en dos lugares.
- Frank Hecker pointed out an exercise that was under-specified, and some broken links.
- Animesh B me ayudó a limpiar un ejemplo confuso.
- Martin Caspersen encontró dos errores de redondeo.
- Gregor Ulm envió varias correcciones y sugerencias.
- Dimitrios Tsirigkas me sugirió que aclarara un ejercicio.
- Carlos Tafur envió una página de correcciones y sugerencias.
- Martin Nordsletten encontró un error en una solución de un ejercicio.
- Sven Hoexter pointed out that a variable named `input` shadows a build-in function.
- Stephen Gregory advirtió el problema con `cmp` en Python 3.
- Ishwar Bhat corrigió mi enunciado del último teorema de Fermat.

- Andrea Zanella tradujo el libro al italiano y envió una serie de correcciones en el camino.
- Muchas, muchas gracias a Melissa Lewis y Luciano Ramalho por los excelentes comentarios y sugerencias sobre la segunda edición.
- Gracias a Harry Percival de PythonAnywhere por su ayuda al hacer que la gente comience ejecutando Python en un navegador.
- Xavier Van Aubel hizo muchas correcciones útiles en la segunda edición.
- William Murray corrigió mi definición de división entera.
- Per Starbäck me puso al día sobre nuevas líneas universales en Python 3.
- Laurent Rosenfeld y Mihaela Rotaru tradujeron este libro al francés. En el camino, me enviaron muchas correcciones y sugerencias.

Adicionalmente, las personas que vieron errores tipográficos o hicieron correcciones incluyen a Czeslaw Czapla, Dale Wilson, Francesco Carlo Cimini, Richard Fursa, Brian McGhie, Lokesh Kumar Makani, Matthew Shultz, Viet Le, Victor Simeone, Lars O.D. Christensen, Swarup Sahoo, Alix Etienne, Kuang He, Wei Huang, Karen Barber y Eric Ransom.

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Capítulo 1

El camino del programa

El objetivo de este libro es enseñarte a pensar como un informático. Esta forma de pensar combina algunas de las mejores características de las matemáticas, la ingeniería y las ciencias naturales. Al igual que los matemáticos, los informáticos usan lenguajes formales para denotar ideas (específicamente, computaciones). Al igual que los ingenieros, diseñan cosas, ensamblando componentes en sistemas y evaluando compensaciones entre alternativas. Al igual que los científicos, observan el comportamiento de sistemas complejos, a partir de hipótesis, y prueban predicciones.

La habilidad más importante de un informático es la **resolución de problemas**. La resolución de problemas supone la capacidad para formular problemas, pensar creativamente en soluciones y emitir una solución de manera clara y precisa. Como resultado, el proceso de aprender a programar es una excelente oportunidad para practicar habilidades de resolución de problemas. Es por eso que este capítulo se llama “El camino del programa”.

En un nivel, aprenderás a programar, una habilidad útil por sí misma. En otro nivel, usarás la programación como un medio para un fin. Mientras avancemos, ese fin se volverá más claro.

1.1. ¿Qué es un programa?

Un **programa** es una secuencia de instrucciones que especifica cómo realizar una computación. La computación puede ser algo matemático, tal como resolver un sistema de ecuaciones o encontrar las raíces de un polinomio, pero también puede ser una computación simbólica, tal como buscar y reemplazar texto en un documento, o algo gráfico, como procesar una imagen o reproducir un video.

Los detalles se ven diferentes en diferentes lenguajes, pero unas pocas instrucciones básicas aparecen en casi todos los lenguajes:

entrada: Obtener datos desde el teclado, un archivo, la red o algún otro dispositivo.

salida: Mostrar datos en la pantalla, guardarlos en un archivo, enviarlos a través de la red, etc.

matemáticas: Realizar operaciones matemáticas básicas como la suma y la multiplicación.

ejecución condicional: Verificar ciertas condiciones y ejecutar el código apropiado.

repetición: Realizar alguna acción repetidas veces, usualmente con alguna variación.

Lo creas o no, eso es prácticamente todo lo que hay. Cada programa que has usado, no importa cuán complicado, está compuesto de instrucciones que se parecen mucho a estas. Así que puedes pensar en la programación como el proceso de romper una tarea grande y compleja en subtarear cada vez más pequeñas, hasta que cada subtarea sea lo suficientemente simple para hacerla con una de estas instrucciones básicas.

1.2. Ejecutar Python

Uno de los desafíos de comenzar con Python es que quizás debas instalar Python y software relacionado en tu computador. Si estás familiarizado con tu sistema operativo, y especialmente si te sientes cómodo con la interfaz de línea de comandos, no tendrás problemas instalando Python. Sin embargo, puede ser doloroso para los principiantes aprender sobre administración del sistema y programación al mismo tiempo.

Para evitar ese problema, recomiendo que comiences ejecutando Python en un navegador. Después, cuando estés cómodo con Python, haré sugerencias para instalar Python en tu computador.

Hay una serie de páginas web que puedes usar para ejecutar Python. Si ya tienes una favorita, ve y úsala. De otra manera, recomiendo PythonAnywhere. En <http://tinyurl.com/thinkpython2e> proporciono instrucciones detalladas para comenzar.

Hay dos versiones de Python, llamadas Python 2 y Python 3. Son muy similares, así que si aprendes una, es fácil cambiar a la otra. De hecho, hay solo unas pocas diferencias que encontrarás como principiante. Este libro está escrito para Python 3, pero incluyo algunas notas sobre Python 2.

El **intérprete** de Python es un programa que lee y ejecuta código de Python. Dependiendo de tu entorno, puedes iniciar el intérprete haciendo clic en un ícono o escribiendo `python` en una línea de comandos. Cuando se inicia, deberías ver una salida como esta:

```
Python 3.4.0 (default, Jun 19 2015, 14:20:21)
[GCC 4.8.2] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

Las primeras tres líneas contienen información acerca del intérprete y el sistema operativo en el cual se está ejecutando, así que puede ser diferente para ti. Sin embargo, deberías verificar que el número de versión, que en este ejemplo es 3.4.0, comience con 3, el cual indica que estás ejecutando Python 3. Si comienza con 2, estás ejecutando (lo adivinaste) Python 2.

La última línea es un **prompt** que indica que el intérprete está listo para que introduzcas código. Si escribes una línea de código y presionas la tecla Enter, el intérprete muestra el resultado:

```
>>> 1 + 1
2
```

Ahora estás listo para comenzar. A partir de aquí, doy por sentado que sabes cómo iniciar el intérprete de Python y ejecutar código.

1.3. El primer programa

Tradicionalmente, el primer programa que escribes en un nuevo lenguaje de programación se llama “¡Hola, mundo!” porque todo lo que hace es mostrar las palabras “¡Hola, mundo!”. En Python, se ve así:

```
>>> print('¡Hola, mundo!')
```

Este es un ejemplo de una **sentencia print**, aunque en realidad no imprime nada en papel. Esta sentencia muestra un resultado en la pantalla. En este caso, el resultado es la frase

```
¡Hola, mundo!
```

Las comillas en el programa marcan el principio y el final del texto a visualizar; estas no aparecen en el resultado.

Los paréntesis indican que `print` es una función. Llegaremos a las funciones en el Capítulo 3.

En Python 2, la sentencia `print` es un poco diferente; no es una función, así que no usa paréntesis.

```
>>> print '¡Hola, mundo!'
```

Esta distinción tendrá más sentido pronto, pero eso es suficiente para comenzar.

1.4. Operadores aritméticos

Después de “Hola, mundo”, el siguiente paso es la aritmética. Python proporciona **operadores**, los cuales son símbolos especiales que representan computaciones como la suma y la multiplicación.

Los operadores `+`, `-` y `*` realizan sumas, restas y multiplicaciones, como en los siguientes ejemplos:

```
>>> 40 + 2
42
>>> 43 - 1
42
>>> 6 * 7
42
```

El operador `/` realiza divisiones:

```
>>> 84 / 2
42.0
```

Puedes preguntarte por qué el resultado es `42.0` en lugar de `42`. Lo explicaré en la sección siguiente.

Finalmente, el operador `**` realiza potenciaciones; es decir, eleva un número a una potencia:

```
>>> 6**2 + 6
42
```

En algunos otros lenguajes, `^` se usa para potenciación, pero en Python es un operador bit a bit llamado XOR. Si no estás familiarizado con los operadores bit a bit, el resultado te sorprenderá:

```
>>> 6 ^ 2
4
```

No cubriré operadores bit a bit en este libro, pero puedes leer sobre estos en <http://wiki.python.org/moin/BitwiseOperators>.

1.5. Valores y tipos

Un **valor** es una de las cosas básicas con las que funciona un programa, como una letra o un número. Algunos valores que hemos visto hasta ahora son 2, 42.0 y '¡Hola, mundo!'.

Estos valores pertenecen a diferentes **tipos**: 2 es un **entero** (en inglés, *integer*), 42.0 es un **número de coma flotante** (en inglés, *floating-point number*), y 'Hello, World!' es una **cadena** (en inglés, *string*), llamada así porque las letras que contiene están unidas.

Si no estás seguro de qué tipo tiene un valor, el intérprete te lo puede decir:

```
>>> type(2)
<class 'int'>
>>> type(42.0)
<class 'float'>
>>> type('¡Hola, mundo!')
<class 'str'>
```

En estos resultados, la palabra “class” se usa en el sentido de una categoría; un tipo es una categoría de valores.

Evidentemente, los enteros pertenecen al tipo `int`, las cadenas pertenecen al tipo `str` y los números de coma flotante pertenecen al tipo `float`.

¿Qué pasa con los valores como '2' y '42.0'? Se ven como números, pero están en comillas como cadenas.

```
>>> type('2')
<class 'str'>
>>> type('42.0')
<class 'str'>
```

Son cadenas.

Cuando escribes un entero grande, podrías estar tentado a usar comas entre grupos de dígitos, como en 1,000,000. No es un *entero* legal en Python, pero es legal:

```
>>> 1,000,000
(1, 0, 0)
```

¡Eso no es lo que esperábamos en absoluto! Python interpreta 1,000,000 como una secuencia de enteros separados por comas. Aprenderemos más sobre este tipo de secuencia más adelante.

1.6. Lenguajes formales y lenguajes naturales

Los **lenguajes naturales** son los lenguajes que hablan las personas, tales como el inglés, el español y el francés. No fueron diseñados por las personas (aunque las personas traten de imponerles algo de orden); evolucionan de manera natural.

Los **lenguajes formales** son lenguajes que están diseñados por personas para aplicaciones específicas. Por ejemplo, la notación que usan los matemáticos es un lenguaje formal que es particularmente bueno al denotar relaciones entre números y símbolos. Los químicos usan un lenguaje formal para representar la estructura química de las moléculas. Y más importante:

Los lenguajes de programación son lenguajes formales que han sido diseñados para expresar computaciones.

Los lenguajes formales tienden a tener reglas de **sintaxis** que gobiernan la estructura de las sentencias. Por ejemplo, en matemáticas la sentencia $3 + 3 = 6$ tiene sintaxis correcta, pero $3+ = 3\$6$ no la tiene. En química H_2O es una fórmula sintácticamente correcta, pero $_2Zz$ no.

Hay dos tipos de reglas de sintaxis, relacionadas con los **tokens** y la estructura. Los tokens son los elementos básicos del lenguaje, tales como palabras, números y elementos químicos. Uno de los problemas con $3+ = 3\$6$ es que \$ no es un token legal en matemáticas (al menos por lo que sé). Del mismo modo, $_2Zz$ no es legal porque no hay ningún elemento con la abreviatura Zz .

El segundo tipo de regla de sintaxis tiene relación con la manera en que los tokens están combinados. La ecuación $3 + /3$ es ilegal porque aunque + y / son tokens legales, no puedes tener uno justo después del otro. Del mismo modo, en una fórmula química el subíndice viene después del nombre del elemento, no antes.

Esta es una oración en español / bien estructurada con tokens inválidos. Esta oración todos los tokens válidos tiene, pero estructura inválida presenta.

Cuando lees una oración en español o una sentencia en un lenguaje formal, tienes que descifrar la estructura (aunque en un lenguaje natural lo haces de manera subconsciente). Este proceso se llama **análisis sintáctico** (en inglés, *parsing*).

Aunque los lenguajes formales y naturales tienen muchas características en común—tokens, estructura y sintaxis—existen algunas diferencias:

ambigüedad: Los lenguajes naturales están llenos de ambigüedad, con la cual las personas lidian mediante el uso de pistas contextuales y otra información. Los lenguajes formales están diseñados para ser casi o completamente inequívocos, lo cual significa que cualquier sentencia tiene exactamente un significado, sin importar el contexto.

redundancia: Para compensar la ambigüedad y reducir los malentendidos, los lenguajes naturales emplean mucha redundancia. Como consecuencia, a menudo son verbosos. Los lenguajes formales son menos redundantes y más concisos.

literalidad: Los lenguajes naturales están llenos de modismo y metáfora. Si yo digo “Cayó el centavo”, probablemente no hay ningún centavo ni nada cayendo (este modismo significa que alguien entendió algo después de un periodo de confusión). Los lenguajes formales expresan exactamente lo que dicen.

Debido a que todos crecemos hablando lenguajes naturales, a veces es difícil adaptarse a los lenguajes formales. La diferencia entre lenguaje formal y lenguaje natural es como la diferencia entre poesía y prosa, pero más aún:

Poesía: Las palabras se usan por su sonido tanto como por su significado y todo el poema junto crea un efecto o respuesta emocional. La ambigüedad no solo es común sino a menudo deliberada.

Prosa: El significado literal de las palabras es más importante y la estructura aporta más significado. La prosa es más susceptible de análisis que la poesía pero todavía a menudo ambigua.

Programas: El significado de un programa de computador es inequívoco y literal, y puede entenderse enteramente analizando los tokens y su estructura.

Los lenguajes formales son más densos que los lenguajes naturales, así que leerlos requiere más tiempo. Además, la estructura es importante, por lo que no siempre es mejor leer de arriba a abajo y de izquierda a derecha. En su lugar, hay que aprender a analizar sintácticamente el programa en tu cabeza, identificar los tokens e interpretar la estructura. Finalmente, los detalles importan. Pequeños errores en la ortografía y puntuación, que puedes cometer con los lenguajes naturales, pueden hacer una gran diferencia en un lenguaje formal.

1.7. Depuración

Los programadores cometen errores. Por razones caprichosas, los **errores de programación** se llaman *bugs* y el proceso de localizarlos se llama **depuración** (en inglés, *debugging*).

La programación, y especialmente la depuración, a veces provoca emociones fuertes. Si estás luchando con un error de programación difícil, podrías sentir ira, desánimo o vergüenza.

Hay evidencia de que las personas naturalmente responden a los computadores como si estos fueran personas. Cuando funcionan bien, pensamos en ellos como compañeros de equipo, y cuando son obstinados o rudos, respondemos a ellos de la misma manera que respondemos a las personas rudas y obstinadas (Reeves and Nass, *The Media Equation: How People Treat Computers, Television, and New Media Like Real People and Places*).

Prepararse para estas reacciones podría ayudarte a lidiar con ellas. Un enfoque es pensar en el computador como un empleado con ciertas fortalezas, como la velocidad y la precisión, y debilidades particulares, como la falta de empatía y la incapacidad para comprender el panorama general.

Tu trabajo es ser un buen jefe: encontrar maneras de aprovechar las fortalezas y mitigar las debilidades. Y encontrar maneras de usar tus emociones para abordar el problema, sin dejar que tus reacciones interfieran en tu capacidad de trabajar eficazmente.

Aprender a depurar puede ser frustrante, pero es una habilidad valiosa que es útil para muchas actividades más allá de la programación. Al final de cada capítulo hay una sección, como esta, con mis sugerencias para la depuración. ¡Espero que ayuden!

1.8. Glosario

resolución de problema: El proceso de formular un problema, encontrar una solución y expresarla.

lenguaje de alto nivel: Un lenguaje de programación como Python que está diseñado para que los humanos puedan leer y escribir fácilmente.

lenguaje de bajo nivel: Un lenguaje de programación que está diseñado para que sea fácil de ejecutar por un computador; también llamado “lenguaje de máquina” o “lenguaje ensamblador”.

portabilidad: Una propiedad de un programa que puede ejecutarse en más de un tipo de computador.

intérprete: Un programa que lee otro programa y lo ejecuta.

prompt: Caracteres mostrados por el intérprete que indican que está listo para recibir la entrada del usuario.

programa: Un conjunto de instrucciones que especifica una computación.

sentencia print: Una instrucción que hace que el intérprete de Python muestre un valor en la pantalla.

operador: Un símbolo especial que representa una computación simple como suma, multiplicación o concatenación de cadenas.

valor: Una de las unidades básicas de datos, como un número o una cadena, que manipula un programa.

tipo: Una categoría de valores. Los tipos que hemos visto hasta ahora son los enteros (tipo `int`), los números de coma flotante (tipo `float`) y cadenas (tipo `str`).

entero: Un tipo que representa números enteros.

coma flotante: Un tipo que representa números con partes fraccionarias.

cadena: Un tipo que representa secuencias de caracteres.

lenguaje natural: Cualquiera de los lenguajes que hablan las personas y que evolucionaron de manera natural.

lenguaje formal: Cualquiera de los lenguajes que las personas han diseñado para propósitos específicos, tales como representar ideas matemáticas o programas de computador; todos los lenguajes de programación son lenguajes formales.

token: Uno de los elementos básicos de la estructura sintáctica de un programa, análogo a una palabra en un lenguaje natural.

sintaxis: Las reglas que rigen la estructura de un programa.

análisis sintáctico (*parse*): Examinar un programa y analizar la estructura sintáctica.

error de programación (*bug*): Un error en un programa.

depuración (*debugging*): El proceso de encontrar y corregir errores de programación.

1.9. Ejercicios

Ejercicio 1.1. *Es una buena idea leer este libro en frente de un computador para que puedas probar los ejemplos mientras avanzas.*

Cada vez que experimentes con una nueva característica, deberías intentar cometer errores. Por ejemplo, en el programa “¡Hola, mundo!”, ¿qué ocurre si omites una de las comillas? ¿Y si omites ambas? ¿Qué ocurre si escribes `print` de manera incorrecta?

Este tipo de experimento te ayuda a recordar lo que leíste; también te ayuda cuando estás programando porque logras saber lo que significan los mensajes de error. Es mejor cometer errores ahora y a propósito que después y de manera accidental.

1. *En una sentencia `print`, ¿qué ocurre si omites uno de los paréntesis, o ambos?*
2. *Si estás intentando imprimir una cadena con `print`, ¿qué ocurre si omites una de las comillas, o ambas?*
3. *Puedes usar un signo menos para hacer un número negativo como `-2`. ¿Qué ocurre si pones un signo más antes de un número? ¿Qué pasa con `2++2`?*
4. *En notación matemática, los ceros a la izquierda están bien, como en `09`. ¿Qué ocurre si intentas esto en Python? ¿Qué pasa con `011`?*
5. *¿Qué ocurre si tienes dos valores sin operador entre ellos?*

Ejercicio 1.2. *Inicia el intérprete de Python y úsalo como una calculadora.*

1. *¿Cuántos segundos hay en 42 minutos con 42 segundos?*
2. *¿Cuántas millas hay en 10 kilómetros? Pista: hay 1.61 kilómetros en una milla.*
3. *Si corres una carrera de 10 kilómetros en 42 minutos con 42 segundos, ¿Cuál es tu ritmo promedio (tiempo por milla en minutos y segundos)? ¿Cuál es tu rapidez promedio en millas por hora?*

Capítulo 2

Variables, expresiones y sentencias

Una de las características más poderosas de un lenguaje de programación es la posibilidad de manipular **variables**. Una variable es un nombre que hace referencia a un valor.

2.1. Sentencias de asignación

Una **sentencia de asignación** crea una nueva variable y le da un valor:

```
>>> mensaje = 'Y ahora algo completamente diferente'
>>> n = 17
>>> pi = 3.1415926535897932
```

Este ejemplo hace tres asignaciones. La primera asigna una cadena a una nueva variable llamada `mensaje`; la segunda pone al entero 17 en `n`; la tercera asigna el valor (aproximado) de π a `pi`.

Una forma común de representar en papel las variables es escribir el nombre con una flecha apuntando a su valor. Este tipo de figura se llama **diagrama de estado** porque muestra en qué estado está cada una de las variables (piénsalo como el estado mental de la variable). La Figura 2.1 muestra el resultado del ejemplo anterior.

2.2. Nombres de variable

Los programadores generalmente escogen nombres para sus variables que sean significativos—documentan para qué se usa la variable.



```
mensaje —> 'Y ahora algo completamente diferente'
n —> 17
pi —> 3.1415926535897932
```

Figura 2.1: Diagrama de estado.

Los nombres de variable pueden ser tan largos como quieras. Pueden contener tanto letras como números, pero no pueden comenzar con un número. Es legal usar letras mayúsculas, pero es convencional usar solo minúsculas para los nombres de variables.

El guión bajo, `_`, puede aparecer en un nombre. A menudo se usa en nombres con varias palabras, tales como `tu_nombre` o `velocidad_de_golondrina_sin_carga`.

Si le das un nombre ilegal a una variable, obtendrás un error de sintaxis:

```
>>> 76trombones = 'gran desfile'
SyntaxError: invalid syntax
>>> mas@ = 1000000
SyntaxError: invalid syntax
>>> class = 'Cimología teórica avanzada'
SyntaxError: invalid syntax
```

76trombones es ilegal porque comienza con un número. mas@ es ilegal porque contiene un carácter ilegal, @. Sin embargo, ¿qué tiene de malo class?

Resulta que `class` es una de las **palabras clave** de Python. El intérprete usa las palabras clave para reconocer la estructura del programa y no se pueden usar como nombres de variable.

Python 3 tiene estas palabras clave:

False	class	finally	is	return
None	continue	for	lambda	try
True	def	from	nonlocal	while
and	del	global	not	with
as	elif	if	or	yield
assert	else	import	pass	
break	except	in	raise	

No tienes que memorizar esta lista. En la mayoría de los entornos de desarrollo, las palabras clave se muestran con un color diferente; si intentas usar una como un nombre de variable, lo sabrás.

2.3. Expresiones y sentencias

Una **expresión** es una combinación de valores, variables y operadores. Un valor por sí mismo es considerado una expresión, y por consiguiente es una variable, así que las siguientes son todas expresiones legales:

```
>>> 42
42
>>> n
17
>>> n + 25
42
```

Cuando escribes una expresión en el prompt, el intérprete lo **evalúa**, lo cual significa que encuentra el valor de la expresión. En este ejemplo, `n` tiene el valor 17 y `n + 25` tiene el valor 42.

Una **sentencia** es una unidad de código que tiene un efecto, como crear una variable o mostrar un valor.


```
>>> n = 17
>>> print(n)
```

La primera línea es una sentencia de asignación que le da un valor a `n`. La segunda línea es una sentencia `print` que muestra el valor de `n`.

Cuando escribes una sentencia, el intérprete la **ejecuta**, lo cual significa que hace lo que dice la sentencia. En general, las sentencias no tienen valores.

2.4. Modo Script

Hasta ahora hemos ejecutado Python en **modo interactivo**, lo cual significa que interactúas directamente con el intérprete. El modo interactivo es una buena manera de comenzar, pero si estás trabajando con más que unas pocas líneas de código, puede ser algo torpe.

La alternativa es guardar código en un archivo llamado un **script** y entonces usar el intérprete en **modo script** para ejecutar el script. Por convención, los scripts de Python tienen nombres que terminan con `.py`.

Si sabes cómo crear y ejecutar un script en tu computador, estás listo para seguir. De lo contrario, recomiendo de nuevo usar PythonAnywhere. He publicado instrucciones para usarlo en modo script en <http://tinyurl.com/thinkpython2e>.

Debido a que Python proporciona ambos modos, puedes probar pedazos de código en modo interactivo antes de ponerlos en un script. Sin embargo, hay diferencias entre el modo interactivo y el modo script que pueden confundir.

Por ejemplo, si usas Python como una calculadora, puedes escribir

```
>>> millas = 26.2
>>> millas * 1.61
42.182
```

La primera línea asigna un valor a `millas`, pero no tiene un efecto visible. La segunda línea es una expresión, por lo cual el intérprete la evalúa y muestra el resultado. Resulta que una maratón es de unos 42 kilómetros.

Sin embargo, si escribes el mismo código dentro de un script y lo ejecutas, no obtienes ninguna salida. En modo script una expresión, por sí misma, no tiene efecto visible. Python evalúa la expresión, pero no muestra el resultado. Para mostrar el resultado, necesitas una sentencia `print` como esta:

```
millas = 26.2
print(millas * 1.61)
```

Este comportamiento puede confundir al principio. Para comprobar tu comprensión, escribe las siguientes sentencias en el intérprete de Python y mira lo que hacen:

```
5
x = 5
x + 1
```

Ahora pon las mismas sentencias en un script y ejecútalo. ¿Cuál es la salida? Modifica el script transformando cada expresión en una sentencia `print` y luego ejecútalo de nuevo.

2.5. Orden de operaciones

Cuando una expresión contiene más de un operador, el orden de evaluación depende del **orden de operaciones**. Para operadores matemáticos, Python sigue la convención matemática. El acrónimo **PEMDAS** es una manera útil de recordar las reglas:

- Los **Paréntesis** tienen la mayor prioridad y se pueden usar para forzar una expresión a evaluar en el orden que tú quieras. Ya que las expresiones en paréntesis se evalúan primero, $2 * (3-1)$ es 4, y $(1+1)**(5-2)$ es 8. También puedes usar paréntesis para hacer una expresión más fácil de leer, como en $(\text{minuto} * 100) / 60$, incluso si no cambia el resultado.
- Los **Exponentes** de potencias tienen la siguiente prioridad, así que $1 + 2**3$ es 9, no 27, y $2 * 3**2$ es 18, no 36.
- La **Multiplicación** y la **División** tienen mayor prioridad que la **Adición** (suma) y la **Restra** (resta). Así que $2*3-1$ es 5, no 4, y $6+4/2$ es 8, no 5.
- Los operadores con la misma prioridad se evalúan de izquierda a derecha (excepto la potenciación). Así que en la expresión $\text{grados} / 2 * \pi$, la división ocurre primero y el resultado se multiplica por π . Para dividir por 2π , puedes usar paréntesis o escribir $\text{grados} / 2 / \pi$.

Yo no me esfuerzo mucho en recordar la prioridad de los operadores. Si no puedo saber mirando la expresión, uso paréntesis para hacerlo obvio.

2.6. Operaciones con cadenas

En general, no puedes realizar operaciones matemáticas con cadenas, incluso si las cadenas parecen números, por lo que las siguientes son ilegales:

```
'comida'-'china'      'huevos'/'fácil'      'tercero'*'un encanto'
```

Pero hay dos excepciones, $+$ y $*$.

El operador $+$ realiza una **concatenación**, lo cual significa que une las cadenas enlazándolas de extremo a extremo. Por ejemplo:

```
>>> primero = 'throat'
>>> segundo = 'warbler'
>>> primero + segundo
throatwarbler
```

El operador $*$ también funciona en cadenas; hace repetición. Por ejemplo, $\text{'Spam'}*3$ es 'SpamSpamSpam' . Si uno de los valores es una cadena, el otro tiene que ser un entero.

Este uso de $+$ y $*$ tiene sentido por analogía con la suma y la multiplicación. Tal como $4*3$ es equivalente a $4+4+4$, esperamos que $\text{'Spam'}*3$ sea lo mismo que $\text{'Spam'}+\text{'Spam'}+\text{'Spam'}$, y lo es. Por otro lado, hay una manera significativa en la que la concatenación y la repetición son diferentes de la suma y multiplicación de enteros. ¿Puedes pensar en una propiedad que tiene la suma que la concatenación no?

2.7. Comentarios

A medida que los programas se hacen más grandes y complicados, se vuelven más difíciles de leer. Los lenguajes formales son densos y a menudo es difícil mirar un pedazo de código y descifrar lo que hace, o por qué.

Por esta razón, es una buena idea añadir notas a tus programas para explicar en lenguaje natural lo que el programa hace. Estas notas se llaman **comentarios**, y comienzan con el símbolo #:

```
# calcular el porcentaje de la hora que ha transcurrido
porcentaje = (minuto * 100) / 60
```

En este caso, el comentario aparece en una línea por sí sola. Puedes también poner comentarios al final de una línea:

```
porcentaje = (minuto * 100) / 60      # porcentaje de una hora
```

Todo desde el # hasta el final de la línea es ignorado—no tiene efecto en la ejecución del programa.

Los comentarios son más útiles cuando documentan características no obvias del código. Es razonable asumir que el lector puede descifrar *qué* hace el código; es más útil explicar *por qué*.

Este comentario es redundante con el código e inútil:

```
v = 5      # asigna 5 a v
```

Este comentario contiene información útil que no está en el código:

```
v = 5      # velocidad en metros/segundos.
```

Los buenos nombres de variable pueden reducir la necesidad de comentarios, pero los nombres largos pueden hacer que las expresiones complejas sean difíciles de leer, así que hay una compensación.

2.8. Depuración

En un programa pueden ocurrir tres tipos de errores: errores de sintaxis, errores de tiempo de ejecución y errores semánticos. Es útil distinguir entre ellos para rastrearlos de manera más rápida.

Error de sintaxis: La “Sintaxis” se refiere a la estructura de un programa y las reglas sobre esa estructura. Por ejemplo, los paréntesis tienen que venir en pares que coincidan, por lo que `(1 + 2)` es legal, pero `8)` es un **error de sintaxis**.

Si hay un error de sintaxis en cualquier lugar de tu programa, Python muestra un mensaje de error y se detiene, y no podrás ejecutar el programa. Durante las primeras semanas de tu carrera de programación, podrías pasar mucho tiempo rastreando errores de sintaxis. A medida que ganes experiencia, cometerás menos errores y los encontrarás más rápido.

Error de tiempo de ejecución: El segundo tipo de error es un error de tiempo de ejecución, llamado así porque el error no aparece hasta después que el programa ha comenzado a ejecutarse. Estos errores también se llaman **excepciones** porque usualmente indican que algo excepcional (y malo) ha ocurrido.

Los errores de tiempo de ejecución son poco comunes en programas simples que verás en los primeros capítulos, así que puede pasar un tiempo antes de que encuentres uno.

Error semántico: El tercer tipo de error es “semántico”, lo cual significa que se relaciona con el significado. Si hay un error semántico en tu programa, se ejecutará sin generar mensajes de error, pero no hará lo correcto. Hará otra cosa. Específicamente, hará lo que le dijiste que hiciera.

Identificar errores semánticos puede ser complicado porque requiere que trabajes hacia atrás mirando la salida del programa e intentando averiguar lo que hace.

2.9. Glosario

variable: Un nombre que hace referencia a un valor.

asignación: Una sentencia que asigna un valor a una variable.

diagrama de estado: Una representación gráfica de un conjunto de variables y los valores a los cuales hacen referencia.

palabra clave: Una palabra reservada que se usa como parte de la sintaxis de un programa; no puedes usar palabras claves tales como `if`, `def` y `while` como nombres de variables.

operando: Uno de los valores en los cuales opera un operador.

expresión: Una combinación de variables, operadores y valores que representa un resultado único.

evaluar: Simplificar una expresión realizando las operaciones para obtener un valor único.

sentencia: Una sección de código que representa un comando o acción. Hasta aquí, las sentencias que hemos visto son asignaciones y sentencias `print`.

ejecutar: Llevar a efecto una sentencia y hacer lo que dice.

modo interactivo: Una manera de usar el intérprete de Python escribiendo código en el prompt.

modo script: Una manera de usar el intérprete de Python para leer código de un script y ejecutarlo.

script: Un programa almacenado en un archivo.

orden de operaciones: Reglas que gobiernan el orden en el cual se evalúan las expresiones que involucran múltiples operadores y operandos.

concatenar: Unir dos operandos de extremo a extremo.

comentario: Información en un programa que está destinada a otros programadores (o cualquiera que lea el código fuente) y no tiene efecto en la ejecución del programa.

error de sintaxis: Un error en un programa que hace imposible reconocer la estructura sintáctica (y por lo tanto imposible de interpretar).

excepción: Un error que es detectado mientras el programa se ejecuta.

semántica: El significado de un programa.

error semántico: Un error en un programa que supone hacer algo distinto a lo que el programador pretendía.

2.10. Ejercicios

Ejercicio 2.1. Repitiendo mi consejo del capítulo anterior, cuando aprendas una nueva característica, deberías intentar probarla en modo interactivo y cometer errores a propósito para ver qué sale mal.

- Hemos visto que $n = 42$ es legal. ¿Qué hay de $42 = n$?
- ¿Qué ocurre con $x = y = 1$?
- En algunos lenguajes cada sentencia termina con un punto y coma, `;`. ¿Qué ocurre si pones un punto y coma al final de una sentencia de Python?
- ¿Qué ocurre si pones un punto al final de una sentencia?
- En notación matemática puedes multiplicar x e y así: xy . ¿Qué ocurre si intentas eso en Python?

Ejercicio 2.2. Practica usando el intérprete de Python como una calculadora:

1. El volumen de una esfera con radio r es $\frac{4}{3}\pi r^3$. ¿Cuál es el volumen de una esfera con radio 5?
2. Supongamos que el precio original de un libro es \$24.95, pero las librerías obtienen un 40 % de descuento. El envío cuesta \$3 para la primera copia y 75 centavos por cada copia adicional. ¿Cuál es el costo al por mayor para 60 copias?
3. Si dejo mi casa a las 6:52 am y corro 1 milla a un ritmo fácil (8:15 por milla), luego 3 millas un poco más fuerte (7:12 por milla) y 1 milla a ritmo fácil de nuevo, ¿a qué hora llego a casa para el desayuno?

Capítulo 3

Funciones

En el contexto de la programación, una **función** es una secuencia de sentencias que realiza una computación y posee un nombre. Cuando defines una función, especificas el nombre y la secuencia de sentencias. Después, puedes “llamar” a la función por su nombre.

3.1. Llamadas a funciones

Ya hemos visto un ejemplo de una **llamada a función**:

```
>>> type(42)
<class 'int'>
```

El nombre de la función es `type`. La expresión en paréntesis se llama **argumento** de la función. El resultado, para esta función, es el tipo del argumento.

Es común decir que una función “toma” un argumento y “devuelve” un resultado. El resultado también se llama **valor de retorno** (en inglés, *return value*).

Python proporciona funciones que convierten valores de un tipo a otro. La función `int` toma cualquier valor y lo convierte en un entero, si puede, o de lo contrario reclama:

```
>>> int('32')
32
```

```
>>> int('Hola')
```

```
ValueError: invalid literal for int(): Hola
```

`int` puede convertir valores de coma flotante en enteros, pero no redondea; corta la parte de fracción:

```
>>> int(3.99999)
3
```

```
>>> int(-2.3)
-2
```

`float` convierte enteros y cadenas en números coma flotante:

```
>>> float(32)
32.0
```

```
>>> float('3.14159')
3.14159
```

Por último, `str` convierte su argumento en una cadena:

```
>>> str(32)
'32'
>>> str(3.14159)
'3.14159'
```

3.2. Funciones matemáticas

Python tiene un módulo matemático que proporciona la mayor parte de las funciones matemáticas conocidas. Un **módulo** es un archivo que contiene una colección de funciones relacionadas entre sí.

Antes de que podamos usar las funciones de un módulo, tenemos que importarlo con una **sentencia import**:

```
>>> import math
```

Esta sentencia crea un **objeto de módulo** llamado `math`. Si muestras el objeto de módulo en pantalla, obtienes información sobre este:

```
>>> math
<module 'math' (built-in)>
```

El objeto de módulo contiene las funciones y variables definidas en el módulo. Para tener acceso a una de las funciones, tienes que especificar el nombre del módulo y el nombre de la función, separados por un punto. Este formato se llama **notación de punto**.

```
>>> relacion = potencia_sennal / potencia_ruido    # uso de 'nn' y no 'ñ'.
>>> decibeles = 10 * math.log10(relacion)
```

```
>>> radianes = 0.7
>>> altura = math.sin(radianes)
```

El primer ejemplo usa `math.log10` para calcular una relación señal/ruido en decibeles (suponiendo que `potencia_sennal` y `potencia_ruido` están definidas). El módulo `math` también proporciona `log`, el cual calcula logaritmos en base e .

El segundo ejemplo encuentra el seno de `radianes`. El nombre de la variable `radianes` es un indicio de que `sin` y las otras funciones trigonométricas (`cos`, `tan`, etc.) toman argumentos en radianes. Para convertir de grados a radianes, divide por 180 y multiplica por π :

```
>>> grados = 45
>>> radianes = grados / 180.0 * math.pi
>>> math.sin(radianes)
0.707106781187
```

La expresión `math.pi` obtiene la variable `pi` del módulo `math`. Su valor es una aproximación en coma flotante de π , con precisión de alrededor de 15 dígitos.

Si sabes trigonometría, puedes verificar los resultados anteriores comparándolos con la raíz cuadrada de dos, dividida por dos:

```
>>> math.sqrt(2) / 2.0
0.707106781187
```


3.3. Composición

Hasta aquí, hemos visto los elementos de un programa—variables, expresiones y sentencias—de forma aislada, sin hablar sobre cómo combinarlos.

Una de las características más útiles de los lenguajes de programación es su posibilidad de tomar pequeños bloques de construcción y **componerlos**. Por ejemplo, el argumento de una función puede ser cualquier tipo de expresión, incluyendo operadores aritméticos:

```
x = math.sin(grados / 360.0 * 2 * math.pi)
```

También llamadas a funciones:

```
x = math.exp(math.log(x+1))
```

Casi en cualquier lugar que puedes poner un valor, puedes poner una expresión arbitraria, con una excepción: el lado izquierdo de una sentencia de asignación tiene que ser un nombre de variable. Cualquier otra expresión en el lado izquierdo es un error de sintaxis (veremos excepciones a esta regla más tarde).

```
>>> minutos = horas * 60                # correcto
>>> horas * 60 = minutos                 # ¡incorrecto!
SyntaxError: can't assign to operator
```

3.4. Agregando nuevas funciones

Hasta aquí, solo hemos estado usando las funciones que vienen con Python, pero también es posible agregar nuevas funciones. Una **definición de función** especifica el nombre de una nueva función y la secuencia de sentencias que se ejecutan cuando la función es llamada.

Aquí hay un ejemplo:

```
def imprimir_letra():
    print("I'm a lumberjack, and I'm okay.")
    print("I sleep all night and I work all day.")
```

`def` es una palabra clave que indica que esta es una definición de función. El nombre de la función es `imprimir_letra`. Las reglas para los nombres de funciones son las mismas que para los nombres de variables: las letras, los números y el guión bajo son legales, pero el primer carácter no puede ser un número. No puedes usar una palabra clave como nombre de una función, y deberías evitar tener una variable y una función con el mismo nombre.

Los paréntesis vacíos después del nombre indican que esta función no toma ningún argumento.

La primera línea de la definición de función se llama **encabezado** (en inglés, *header*); el resto se llama **cuerpo** (en inglés, *body*). El encabezado debe terminar con el signo de dos puntos y el cuerpo debe tener sangría. Por convención, la sangría siempre se hace con cuatro espacios. El cuerpo puede contener cualquier número de sentencias.

Las cadenas en las sentencias `print` están encerradas en comillas dobles. Las comillas simples y las comillas dobles hacen lo mismo; la mayoría de la gente usa comillas simples excepto en casos como este donde una comilla simple (que también es un apóstrofe) aparece en la cadena.

Todas las comillas (simples y dobles) deben ser “comillas rectas”, usualmente ubicadas cerca de Enter en el teclado. Las “comillas tipográficas”, como las de esta oración, no son legales en Python.

Si escribes una definición de función en modo interactivo, el intérprete imprime puntos (...) que te hacen saber que la definición no está completa:

```
>>> def imprimir_letra():
...     print("I'm a lumberjack, and I'm okay.")
...     print("I sleep all night and I work all day.")
... 
```

Para terminar una función, tienes que insertar una línea vacía.

Al definir una función se crea un **objeto de función**, que tiene tipo `function`:

```
>>> print(imprimir_letra)
<function imprimir_letra at 0xb7e99e9c>
>>> type(imprimir_letra)
<class 'function'>
```

La sintaxis para llamar a la nueva función es la misma que para las funciones incorporadas:

```
>>> imprimir_letra()
I'm a lumberjack, and I'm okay.
I sleep all night and I work all day.
```

Una vez que hayas definido una función, puedes usarla dentro de otra función. Por ejemplo, para repetir el estribillo anterior, podríamos escribir una función llamada `repetir_letra`:

```
def repetir_letra():
    imprimir_letra()
    imprimir_letra()
```

Y luego llamar a `repetir_letra`:

```
>>> repetir_letra()
I'm a lumberjack, and I'm okay.
I sleep all night and I work all day.
I'm a lumberjack, and I'm okay.
I sleep all night and I work all day.
```

Pero así no es realmente como sigue la canción.

3.5. Definiciones y usos

Reuniendo los fragmentos de código de la sección anterior, el programa completo se ve así:

```
def imprimir_letra():
    print("I'm a lumberjack, and I'm okay.")
    print("I sleep all night and I work all day.")

def repetir_letra():
    imprimir_letra()
    imprimir_letra()

repetir_letra()
```

Este programa contiene dos definiciones de función: `imprimir_letra` y `repetir_letra`. Las definiciones de funciones se ejecutan al igual que otras sentencias, pero el efecto es crear objetos de función. Las sentencias dentro de la función no se ejecutan hasta que la función es llamada, y la definición de función no genera salida.

Como podrías esperar, tienes que crear la función antes de que puedas ejecutarla. En otras palabras, la definición de función tiene que efectuarse antes de que la función sea llamada.

Como ejercicio, mueve la última línea de este programa hasta el principio, así la llamada a la función aparece antes que las definiciones. Ejecuta el programa y mira qué mensaje de error obtienes.

Ahora regresa la llamada de función al final y mueve la definición de `imprimir_letra` a después de la definición de `repetir_letra`. ¿Qué ocurre cuando ejecutas este programa?

3.6. Flujo de ejecución

Para estar seguro de que una función está definida antes de su primer uso, tienes que conocer el orden en que se ejecutan las sentencias, el cual se llama **flujo de ejecución**.

La ejecución siempre comienza con la primera sentencia del programa. Las sentencias se ejecutan una a la vez, en orden de arriba a abajo.

Las definiciones de función no alteran el flujo de ejecución del programa, pero recuerda que las sentencias dentro de la función no se ejecutan hasta que la función es llamada.

Una llamada a función es como un desvío en el flujo de ejecución. En lugar de ir a la siguiente sentencia, el flujo salta al cuerpo de la función, ejecuta las sentencias que están allí y luego regresa para retomar donde lo había dejado.

Eso suena bastante simple, hasta que recuerdas que una función puede llamar a otra. Mientras está en el medio de una función, el programa podría tener que ejecutar las sentencias en otra función. Luego, mientras se ejecuta esa nueva función, ¡el programa podría tener que ejecutar otra función más!

Afortunadamente, Python es bueno haciendo seguimiento de dónde está, así que cada vez que se completa una función, el programa retoma donde lo había dejado en la función que la llamó. Cuando llega al final del programa, termina.

En resumen, cuando lees un programa, no siempre quieres leer de arriba a abajo. A veces tiene más sentido si sigues el flujo de ejecución.

3.7. Parámetros y argumentos

Algunas de las funciones que hemos visto requieren argumentos. Por ejemplo, cuando llamas a `math.sin` pasas un número como argumento. Algunas funciones toman más de un argumento: `math.pow` toma dos, la base y el exponente.

Dentro de la función, los argumentos son asignados a variables llamadas **parámetros**. Aquí hay una definición para una función que toma un argumento:

```
def impr_2veces(bruce):  
    print(bruce)  
    print(bruce)
```

Esta función asigna el argumento a un parámetro con nombre `bruce`. Cuando la función es llamada, esta imprime el valor del parámetro (sea lo que sea) dos veces.

Esta función puede usarse con cualquier valor que se pueda imprimir.

```
>>> impr_2veces('Spam')  
Spam  
Spam  
>>> impr_2veces(42)  
42  
42  
>>> impr_2veces(math.pi)  
3.14159265359  
3.14159265359
```

Las mismas reglas de composición que se aplican a las funciones incorporadas también se aplican a las funciones definidas por el programador, así que podemos usar cualquier tipo de expresión como un argumento para `impr_2veces`:

```
>>> impr_2veces('Spam '*4)  
Spam Spam Spam Spam  
Spam Spam Spam Spam  
>>> impr_2veces(math.cos(math.pi))  
-1.0  
-1.0
```

El argumento es evaluado antes de que se llame a la función, por lo que en los ejemplos las expresiones `'Spam '*4` y `math.cos(math.pi)` son evaluadas una sola vez.

También puedes usar una variable como un argumento:

```
>>> michael = 'Eric, the half a bee.'  
>>> impr_2veces(michael)  
Eric, the half a bee.  
Eric, the half a bee.
```

El nombre de la variable que pasamos como argumento (`michael`) no tiene nada que ver con el nombre del parámetro (`bruce`). No importa cómo se le llame al valor en su casa (en la llamadora); aquí en `impr_2veces`, a todos les llamamos `bruce`.

3.8. Las variables y los parámetros son locales

Cuando creas una variable dentro de una función, esta es **local**, lo cual significa que existe solamente dentro de la función. Por ejemplo:

```
def cat_2veces(parte1, parte2):  
    cat = parte1 + parte2  
    impr_2veces(cat)
```

Esta función toma dos argumentos, los concatena e imprime el resultado dos veces. Aquí hay un ejemplo que la usa:



Figura 3.1: Diagrama de pila.

```
>>> linea1 = 'Bing tiddle '      # evitar tildes en nombres de variables.
>>> linea2 = 'tiddle bang.'      # escribir 'linea' en lugar de 'línea'.
>>> cat_2veces(linea1, linea2)
Bing tiddle tiddle bang.
Bing tiddle tiddle bang.
```

Cuando `cat_2veces` termina, la variable `cat` se destruye. Si intentamos imprimirla, obtenemos una excepción:

```
>>> print(cat)
NameError: name 'cat' is not defined
```

Los parámetros también son locales. Por ejemplo, afuera de `impr_2veces`, no hay tal cosa como `bruce`.

3.9. Diagramas de pila

Para hacer un seguimiento de qué variables se pueden usar en qué lugar, a veces es útil dibujar un **diagrama de pila**. Al igual que los diagramas de estado, los diagramas de pila muestran el valor de cada variable, pero también muestran la función a la cual pertenece cada variable.

Cada función se representa por un **marco**. Un marco es un recuadro que tiene el nombre de una función al lado y los parámetros y variables de la función adentro. El diagrama de pila para el ejemplo anterior se muestra en la Figura 3.1.

Los marcos se organizan en una pila que indica cuál función llama a cuál, y así. En este ejemplo, `impr_2veces` fue llamado por `cat_2veces`, y `cat_2veces` fue llamado por `__main__`, el cual es un nombre especial para el marco más alto. Cuando creas una variable afuera de todas las funciones, esta pertenece a `__main__`.

Cada parámetro hace referencia al mismo valor que su argumento correspondiente. Así que, `parte1` tiene el mismo valor que `linea1`, `parte2` tiene el mismo valor que `linea2` y `bruce` tiene el mismo valor que `cat`.

Si ocurre un error durante una llamada de función, Python imprime el nombre de la función, el nombre de la función que la llamó y el nombre de la función que llamó a *esa*, todo el camino de vuelta a `__main__`.

Por ejemplo, si intentas acceder a `cat` desde adentro de `impr_2veces`, obtienes un `NameError`:

```
Traceback (innermost last):
  File "test.py", line 13, in __main__
    cat_2veces(linea1, linea2)
  File "test.py", line 5, in cat_2veces
    impr_2veces(cat)
  File "test.py", line 9, in impr_2veces
    print(cat)
```

NameError: name 'cat' is not defined

Esta lista de funciones se llama **rastreo** (en inglés, *traceback*). Te dice en qué archivo de programa ocurrió el error, y en qué línea, y qué funciones se estaban ejecutando en ese momento. Además, te muestra la línea de código que causó el error.

El orden de las funciones en el rastreo es el mismo que el orden de los marcos en el diagrama de pila. La función que se está ejecutando actualmente está al final.

3.10. Funciones productivas y funciones nulas

Algunas de las funciones que hemos usado, tales como las funciones matemáticas, devuelven resultados; por falta de un mejor nombre, las llamo **funciones productivas**. Otras funciones, como `impr_2veces`, realizan una acción pero no devuelven un valor. Son llamadas **funciones nulas**.

Cuando llamas a una función productiva, casi siempre quieres hacer algo con el resultado; por ejemplo, podrías asignarlo a una variable o usarlo como parte de una expresión:

```
x = math.cos(radianes)
dorado = (math.sqrt(5) + 1) / 2
```

Cuando llamas a una función en modo interactivo, Python muestra el resultado:

```
>>> math.sqrt(5)
2.2360679774997898
```

Pero en un script, si llamas a una función productiva por sí sola, ¡el valor de retorno se pierde para siempre!

```
math.sqrt(5)
```

Este script calcula la raíz cuadrada de 5, pero ya que no almacena ni muestra el resultado, no es muy útil.

Las funciones nulas podrían mostrar algo en la pantalla o tener algún otro efecto, pero no tienen un valor de retorno. Si asignas el resultado a una variable, obtienes un valor especial llamado `None`.

```
>>> resultado = impr_2veces('Bing')
Bing
Bing
>>> print(resultado)
None
```

El valor `None` no es lo mismo que la cadena `'None'`. Es un valor especial que tiene su propio tipo:

```
>>> type(None)
<class 'NoneType'>
```

Las funciones que hemos escrito hasta ahora son todas nulas. Comenzaremos a escribir funciones productivas en unos capítulos más adelante.

3.11. ¿Por qué funciones?

Puede que no esté claro por qué vale la pena el problema de dividir un programa en funciones. Hay muchas razones:

- Crear una nueva función te da la oportunidad de ponerle nombre a un grupo de sentencias, lo cual hace que tu programa sea más fácil de leer y depurar.
- Las funciones pueden hacer que un programa sea más pequeño al eliminar código repetitivo. Después, si quieres hacer un cambio, solo tienes que hacerlo en un lugar.
- Dividir un programa largo en funciones te permite depurar las partes una a la vez y luego reunir las partes en un todo funcional.
- Las funciones bien diseñadas son a menudo útiles para muchos programas. Una vez que escribes y depuras una, la puedes reusar.

3.12. Depuración

Una de las habilidades más importantes que adquirirás es la depuración. Aunque puede ser frustrante, la depuración es una de las partes más intelectualmente ricas, desafiantes e interesantes de la programación.

En algunas formas la depuración es como un trabajo de detective. Te enfrentas a pistas y tienes que inferir los procesos y eventos que te guían a los resultados que ves.

La depuración es también como una ciencia experimental. Una vez que tienes una idea sobre qué va mal, modificas tu programa e intentas de nuevo. Si tu hipótesis era correcta, puedes predecir el resultado de la modificación y das un paso más cerca hacia un programa que funcione. Si tu hipótesis era incorrecta, tienes que inventar una nueva. Como señaló Sherlock Holmes, “Una vez descartado lo imposible, lo que queda, por improbable que parezca, debe ser la verdad.” (A. Conan Doyle, *El signo de los cuatro*)

Para algunas personas, programar y depurar son lo mismo. Es decir, programar es el proceso de depurar gradualmente un programa hasta que haga lo que tú quieres. La idea es que deberías comenzar con un programa que funcione y hacer pequeñas modificaciones, depurándolas a medida que avanzas.

Por ejemplo, Linux es un sistema operativo que contiene millones de líneas de código, pero nació como un programa simple que Linus Torvalds usaba para explorar el chip Intel 80386. Según Larry Greenfield, “Uno de los proyectos anteriores de Linus era un programa que cambiaría entre imprimir AAAA y BBBB. Esto evolucionó más tarde a Linux.” (*The Linux Users' Guide Beta Version 1*).

3.13. Glosario

función: Una secuencia de sentencias que tiene nombre y realiza alguna operación útil. Las funciones pueden o no tomar argumentos y pueden o no producir un resultado.

definición de función: Una sentencia que crea una nueva función, especificando su nombre, parámetros y las sentencias que contiene.

objeto de función: Un valor creado por una definición de función. El nombre de la función es una variable que hace referencia a un objeto de función.

encabezado: La primera línea de una definición de función.

cuerpo: La secuencia de sentencias dentro de una definición de función.

parámetro: Un nombre usado dentro de una función para referirse al valor pasado como argumento.

llamada a función: Una sentencia que ejecuta una función. Consiste en el nombre de la función seguido de una lista de argumentos en paréntesis.

argumento: Un valor proporcionado a la función cuando la función es llamada. Este valor es asignado al parámetro correspondiente en la función.

variable local: Una variable definida dentro de una función. Una variable local solo puede usarse dentro de su función.

valor de retorno: El resultado de una función. Si una llamada a función se usa como expresión, el valor de retorno es el valor de la expresión.

función productiva: Una función que devuelve un valor.

función nula: Una función que siempre devuelve `None`.

`None`: Un valor especial devuelto por funciones nulas.

módulo: Un archivo que contiene una colección de funciones relacionadas entre sí y otras definiciones.

sentencia `import`: Una sentencia que lee un archivo de módulo y crea un objeto de módulo.

objeto de módulo: Un valor creado por una sentencia `import` que proporciona acceso a los valores definidos en el módulo.

notación de punto: La sintaxis para llamar a una función de otro módulo especificando el nombre del módulo, seguido de un punto y el nombre de la función.

composición: Usar una expresión como parte de una expresión más grande, o una sentencia como parte de una sentencia más grande.

flujo de ejecución: El orden en que las sentencias se ejecutan.

diagrama de pila: Una representación de una pila de funciones, sus variables y los valores a los que hacen referencia.

marco: Un recuadro en un diagrama de pila que representa una llamada a función. Contiene las variables locales y los parámetros de la función.

rastreo: Una lista de las funciones que se están ejecutando, impresas cuando ocurre una excepción.

3.14. Ejercicios

Ejercicio 3.1. Escribe una función con nombre `justificar_derecha` que tome una cadena con nombre `s` como parámetro e imprima la cadena con suficientes espacios al inicio de tal manera que la última letra de la cadena esté en la columna 70 de la pantalla.

```
>>> justificar_derecha('monty')
monty
```

Pista: usa la repetición de cadenas y la concatenación. Además, Python proporciona una función incorporada llamada `len` que devuelve la longitud de una cadena, por lo que el valor de `len('monty')` es 5.

Ejercicio 3.2. Un objeto de función es un valor que puedes asignar a una variable o pasarlo como argumento. Por ejemplo, `hacer_2veces` es una función que toma un objeto de función como argumento y lo llama dos veces:

```
def hacer_2veces(f):
    f()
    f()
```

Aquí hay un ejemplo que usa `hacer_2veces` para llamar a una función con nombre `imprimir_spam` dos veces.

```
def imprimir_spam():
    print('spam')
```

```
hacer_2veces(imprimir_spam)
```

1. Escribe este ejemplo en un script y pruébalo.
2. Modifica `hacer_2veces` para que tome dos argumentos, un objeto de función y un valor, y llame a la función dos veces, pasando al valor como argumento.
3. Copia la definición de `impr_2veces`, presentada previamente en este capítulo, a tu script.
4. Usa la versión modificada de `hacer_2veces` para llamar a `impr_2veces` dos veces, pasando a 'spam' como argumento.
5. Define una nueva función llamada `hacer_4veces` que tome un objeto de función y un valor y llame a la función cuatro veces, pasando al valor como parámetro. Debería haber solo dos sentencias en el cuerpo de esta función, no cuatro.

Solution: http://thinkpython2.com/code/do_four.py.

Ejercicio 3.3. Nota: Este ejercicio debería hacerse usando solo las sentencias y otras características que hemos aprendido hasta ahora.

1. Escribe una función que dibuje una cuadrícula como la siguiente:

```

+ - - - - + - - - - +
|           |           |
|           |           |
|           |           |
|           |           |
+ - - - - + - - - - +
|           |           |
|           |           |
|           |           |
|           |           |
+ - - - - + - - - - +

```

Pista: para imprimir más de un valor en una línea, puedes imprimir una secuencia de valores separada por comas:

```
print('+', '-')
```

Por defecto, print avanza a la siguiente línea, pero puedes anular ese comportamiento y poner un espacio al final, como esto:

```
print('+', end=' ')
print('-')
```

La salida de estas sentencias es '+ -' en la misma línea. La salida desde la siguiente sentencia print debería comenzar en la siguiente línea.

2. Escribe una función que dibuje una cuadrícula similar con cuatro filas y cuatro columnas.

Solución: <http://thinkpython2.com/code/grid.py>. Crédito: este ejercicio está basado en un ejercicio de Oualline, Practical C Programming, Third Edition, O'Reilly Media, 1997.

Capítulo 4

Estudio de caso: diseño de interfaz

Este capítulo presenta un estudio de caso que demuestra un proceso para diseñar funciones que interactúen entre sí.

Se presenta el módulo `turtle`, el cual te permite crear imágenes usando gráficas tortuga. El módulo `turtle` está incluido en la mayoría de las instalaciones de Python, pero si estás ejecutando Python usando PythonAnywhere, no podrás ejecutar los ejemplos de tortuga (al menos no podías cuando escribí esto).

Si ya has instalado Python en tu computador, deberías poder ejecutar los ejemplos. Si no, ahora es un buen momento para instalarlo. He publicado instrucciones en <http://tinyurl.com/thinkpython2e>.

Los códigos de ejemplo de este capítulo están disponibles en <http://thinkpython2.com/code/polygon.py>.

4.1. El módulo `turtle`

Para verificar si tienes el módulo `turtle`, abre el intérprete de Python y escribe

```
>>> import turtle
>>> bob = turtle.Turtle()
```

Cuando ejecutes este código, debería crearse una nueva ventana con una flecha pequeña que representa la tortuga. Cierra la ventana.

Crea un archivo con nombre `mipoligono.py` y escribe en él las siguientes líneas de código:

```
import turtle
bob = turtle.Turtle()
print(bob)
turtle.mainloop()
```

El módulo `turtle` (con 't' minúscula) proporciona una función llamada `Turtle` (con 'T' mayúscula) que crea un objeto `Turtle`, el cual asignamos a una variable con nombre `bob`. Al imprimir `bob` se muestra algo como:

```
<turtle.Turtle object at 0xb7bfbf4c>
```

Esto significa que bob hace referencia a un objeto con tipo `Turtle` como se define en el módulo `turtle`.

`mainloop` le dice a la ventana que espere a que el usuario haga algo, aunque en este caso no hay mucho que pueda hacer el usuario excepto cerrar la ventana.

Una vez que creas una tortuga, puedes llamar a un **método** para moverla alrededor de la ventana. Un método es similar a una función, pero este usa una sintaxis un poco diferente. Por ejemplo, para mover la tortuga adelante:

```
bob.fd(100)
```

El método, `fd` (*forward*), está asociado con el objeto tortuga que llamamos bob. Llamar a un método es como hacer una solicitud: le estás pidiendo a bob que se mueva hacia adelante.

El argumento de `fd` es una distancia en píxeles, por lo que el tamaño real depende de tu pantalla.

Otros métodos que puedes llamar en un objeto `Turtle` son `bk` (*backward*) para retroceder, `lt` (*left turn*) para girar a la izquierda y `rt` (*right turn*) para girar a la derecha. El argumento para `lt` y `rt` es un ángulo en grados.

Además, cada `Turtle` sostiene una pluma, que está arriba o abajo; si la pluma está abajo, la tortuga deja un rastro cuando se mueve. Los métodos `pu` y `pd` representan “*pen up*” y “*pen down*”.

Para dibujar un ángulo recto, agrega estas líneas al programa (después de crear a bob y antes de llamar a `mainloop`):

```
bob.fd(100)
bob.lt(90)
bob.fd(100)
```

Cuando ejecutes este programa, deberías ver a bob moverse al este y luego al norte, dejando dos segmentos de línea atrás.

Ahora modifica el programa para dibujar un cuadrado. ¡No continúes hasta que lo hayas hecho funcionar!

4.2. Repetición simple

Es probable que hayas escrito algo así:

```
bob.fd(100)
bob.lt(90)
```

```
bob.fd(100)
bob.lt(90)
```

```
bob.fd(100)
bob.lt(90)
```

```
bob.fd(100)
```

Podemos hacer lo mismo de manera más concisa con una sentencia `for`. Agrega este ejemplo a `mipoligono.py` y ejecútalo de nuevo:

```
for i in range(4):  
    print('¡Hola!')
```

Deberías ver algo como esto:

```
¡Hola!  
¡Hola!  
¡Hola!  
¡Hola!
```

Este es el uso más simple de una sentencia `for`; después veremos más. Pero eso debería ser suficiente para dejarte reescribir tu programa que dibuja cuadrados. No continúes hasta que lo hagas.

Aquí hay una sentencia `for` que dibuja un cuadrado:

```
for i in range(4):  
    bob.fd(100)  
    bob.lt(90)
```

La sintaxis de una sentencia `for` es similar a una definición de función. Tiene un encabezado que termina con el signo dos puntos y un cuerpo con sangría. El cuerpo puede contener cualquier número de sentencias.

Una sentencia `for` también es llamada **bucle** porque el flujo de ejecución recorre el cuerpo y luego vuelve hacia arriba. En este caso, recorre el cuerpo cuatro veces.

Esta versión es en realidad un poco diferente del código que dibuja cuadrados propuesto anteriormente porque hace otro giro después de dibujar el último lado del cuadrado. El giro extra toma más tiempo, pero simplifica el código si hacemos lo mismo en cada paso por el bucle. Esta versión también tiene el efecto de regresar a la tortuga a su posición inicial, apuntando a la dirección inicial.

4.3. Ejercicios

Lo siguiente es una serie de ejercicios que usan Turtle. Pretenden ser divertidos, pero también tienen un punto. Mientras trabajes en ellos, piensa cuál es el punto.

Las siguientes secciones tienen soluciones a los ejercicios, así que no mires hasta que hayas terminado (o al menos intentado).

1. Escribe una función llamada `cuadrado` que tome un parámetro con nombre `t`, que es una tortuga. Debería usar la tortuga para dibujar un cuadrado.
Escribe una llamada a función que pase a `bob` como argumento de `cuadrado`, y luego ejecuta el programa de nuevo.
2. Agrega otro parámetro, con nombre `longitud`, a `cuadrado`. Modifica el cuerpo para que la longitud de los lados sea `longitud`, y luego modifica la llamada a función para poner un segundo argumento. Ejecuta el programa de nuevo. Prueba tu programa con un rango de valores para `longitud`.
3. Haz una copia de `cuadrado` y cambia el nombre a `poligono`. Agrega otro parámetro con nombre `n` y modifica el cuerpo para que dibuje un polígono regular con `n` lados. Pista: los ángulos exteriores de un polígono regular con `n` lados son de $360/n$ grados.

4. Escribe una función llamada `circulo` que tome una tortuga, `t`, y radio, `r`, como parámetros y dibuje un círculo aproximado llamando a `poligono` con una longitud y número de lados apropiado. Prueba tu función con un rango de valores de `r`.
Pista: averigua cuál es el perímetro del círculo y asegúrate de que se cumpla que `longitud * n = perimetro`.
5. Haz una versión más general de `circulo` llamada `arco` que tome un parámetro adicional `angulo`, que determine qué fracción de un círculo dibujar. `angulo` está en grados, así que cuando `angulo=360`, `arco` debería dibujar un círculo completo.

4.4. Encapsulamiento

El primer ejercicio te pide poner tu código que dibuja cuadrados dentro de una definición de función y luego llamar a la función, pasando a la tortuga como parámetro. Aquí está la solución:

```
def cuadrado(t):
    for i in range(4):
        t.fd(100)
        t.lt(90)
```

```
cuadrado(bob)
```

Las sentencias de `más adentro`, `fd` y `lt`, tienen doble sangría para mostrar que están dentro del bucle `for`, el cual está dentro de la definición de función. La siguiente línea, `cuadrado(bob)`, está alineada con el margen izquierdo, lo cual indica el término tanto del bucle `for` como de la definición de función.

Dentro de la función, `t` hace referencia a la misma tortuga `bob`, por lo que `t.lt(90)` tiene el mismo efecto que `bob.lt(90)`. En ese caso, ¿por qué no llamar al parámetro `bob`? La idea es que `t` puede ser cualquier tortuga, no solo `bob`, así que podrías crear una segunda tortuga y pasarla como argumento a `cuadrado`:

```
alice = turtle.Turtle()
cuadrado(alice)
```

El acto de envolver un pedazo de código en una función se llama **encapsulamiento**. Uno de los beneficios del encapsulamiento es que adjunta un nombre al código, lo cual sirve como una especie de documentación. Otra ventaja es que si reutilizas el código, ¡es más conciso llamar a una función dos veces que copiar y pegar el cuerpo!

4.5. Generalización

El siguiente paso es agregar un parámetro `longitud` a `cuadrado`. Aquí hay una solución:

```
def cuadrado(t, longitud):
    for i in range(4):
        t.fd(longitud)
        t.lt(90)
```

```
cuadrado(bob, 100)
```

El acto de agregar un parámetro a una función se llama **generalización** porque hace que la función sea más general: en la versión anterior, el cuadrado tiene siempre el mismo tamaño; en esta versión puede ser cualquier tamaño.

El siguiente paso es también una generalización. En lugar de dibujar cuadrados, `poligono` dibuja polígonos regulares con cualquier número de lados. Aquí hay una solución:

```
def poligono(t, n, longitud):
    angulo = 360 / n
    for i in range(n):
        t.fd(longitud)
        t.lt(angulo)
```

```
poligono(bob, 7, 70)
```

Este ejemplo dibuja un polígono de 7 lados de longitud 70.

Si estás usando Python 2, el valor de `angulo` podría ser incorrecto debido a una división entera. Una solución simple es calcular `angulo = 360.0 / n`. Dado que el numerador es un número de coma flotante, el resultado es de coma flotante.

Cuando una función tiene más que unos pocos argumentos numéricos, es fácil olvidar qué son, o en qué orden deberían estar. En ese caso a menudo es una buena idea incluir los nombres de los parámetros en la lista de argumentos:

```
poligono(bob, n=7, longitud=70)
```

Estos se llaman **argumentos de palabra clave** porque incluyen a los nombres de parámetro tratándolos como “palabras clave” (no confundir con las palabras clave de Python como `while` y `def`).

Esta sintaxis hace que el programa sea más legible. Es también un recordatorio sobre cómo funcionan los argumentos y los parámetros: cuando llamas a una función, los argumentos son asignados a los parámetros.

4.6. Diseño de interfaz

El siguiente paso es escribir `circulo`, el cual toma un radio, `r`, como parámetro. Aquí hay una solución simple que usa a `poligono` para dibujar un polígono de 50 lados:

```
import math

def circulo(t, r):
    perimetro = 2 * math.pi * r
    n = 50
    longitud = perimetro / n
    poligono(t, n, longitud)
```

La primera línea calcula el perímetro de un círculo con radio `r` usando la fórmula $2\pi r$. Dado que usamos `math.pi`, tenemos que importar `math`. Por convención, las sentencias `import` usualmente están al comienzo del script.

`n` es el número de segmentos de línea en tu aproximación de un círculo, por lo que `longitud` es la longitud de cada segmento. Así, `poligono` dibuja un polígono de 50 lados que aproxima un círculo con radio `r`.

Una limitación de esta solución es que n es una constante, lo cual significa que para círculos muy grandes, los segmentos de línea son muy largos, y para círculos pequeños, ocupamos mucho tiempo dibujando segmentos muy pequeños. Una solución sería generalizar la función para que tome a n como parámetro. Esto le daría al usuario (quien llame a `circulo`) más control, pero la interfaz sería menos limpia.

La **interfaz** de una función es un resumen de cómo se usa: ¿cuáles son los parámetros? ¿Qué hace la función? ¿Y cuál es el valor de retorno? Una interfaz es “limpia” si permite a la llamadora hacer lo que quiere sin lidiar con detalles innecesarios.

En este ejemplo, r forma parte de la interfaz porque especifica el círculo a dibujar. n es menos apropiado porque pertenece a los detalles de *cómo* debería dibujarse el círculo.

En lugar de desordenar la interfaz, es mejor escoger un valor apropiado de n que dependa del perímetro:

```
def circulo(t, r):
    perimetro = 2 * math.pi * r
    n = int(perimetro / 3) + 3
    longitud = perimetro / n
    poligono(t, n, longitud)
```

Ahora, el número de segmentos es un entero cercano a $\text{perimetro}/3$, por lo que la longitud de cada segmento es aproximadamente 3, lo cual es suficientemente pequeño para que el círculo se vea bien, pero lo suficientemente grande para ser eficiente, y aceptable para cualquier tamaño de círculo.

Sumar 3 a n garantiza que el polígono tenga al menos 3 lados.

4.7. Refactorización

Cuando escribí `circulo`, fui capaz de reutilizar `poligono` porque un polígono de muchos lados es una buena aproximación de un círculo. Pero `arco` no es tan cooperativo; no podemos usar `poligono` o `circulo` para dibujar un arco.

Una alternativa es comenzar con una copia de `poligono` y transformarla en `arco`. El resultado podría verse así:

```
def arco(t, r, angulo):
    longitud_arco = 2 * math.pi * r * angulo / 360
    n = int(longitud_arco / 3) + 1
    longitud_paso = longitud_arco / n
    angulo_paso = angulo / n

    for i in range(n):
        t.fd(longitud_paso)
        t.lt(angulo_paso)
```

La segunda mitad de esta función se parece a `poligono`, pero no podemos reutilizar `poligono` sin cambiar la interfaz. Podríamos generalizar `poligono` para que tome un `angulo` como tercer argumento, ¡pero entonces `poligono` ya no sería un nombre apropiado! En cambio, llamemos `polilinea` a la función más general:


```
def polilinea(t, n, longitud, angulo):  
    for i in range(n):  
        t.fd(longitud)  
        t.lt(angulo)
```

Ahora podemos reescribir poligono y arco para que use a polilinea:

```
def poligono(t, n, longitud):  
    angulo = 360.0 / n  
    polilinea(t, n, longitud, angulo)  
  
def arco(t, r, angulo):  
    longitud_arco = 2 * math.pi * r * angulo / 360  
    n = int(longitud_arco / 3) + 1  
    longitud_paso = longitud_arco / n  
    angulo_paso = float(angulo) / n  
    polilinea(t, n, longitud_paso, angulo_paso)
```

Finalmente, podemos reescribir circulo para que use a arco:

```
def circulo(t, r):  
    arco(t, r, 360)
```

Este proceso—reorganizar un programa para mejorar las interfaces y facilitar la reutilización de código—se llama **refactorización**. En este caso, notamos que había código similar en arco y poligono, así que “lo factorizamos” en polilinea.

Si hubiéramos planificado con anticipación, podríamos haber escrito polilinea primero y evitar la refactorización, pero a menudo no sabes lo suficiente al comienzo de un proyecto para diseñar todas las interfaces. Una vez que comienzas a escribir código, entiendes mejor el problema. A veces la refactorización es una señal de que has aprendido algo.

4.8. Un plan de desarrollo

Un **plan de desarrollo** es un proceso para escribir programas. El proceso que usamos en este estudio de caso es “encapsulamiento y generalización”. Los pasos de este proceso son:

1. Comenzar escribiendo un programa pequeño sin definiciones de función.
2. Una vez que funciona el programa, identifica una parte coherente, encapsula la parte en una función y dale un nombre.
3. Generaliza la función agregando parámetros apropiados.
4. Repite los pasos 1–3 hasta que tengas un conjunto de funciones eficaces. Copia y pega código que funcione para evitar repetir (y volver a depurar).
5. Busca oportunidades para mejorar el programa refactorizando. Por ejemplo, si tienes código similar en muchos lugares, considera factorizarlo dentro de una función general apropiada.

Este proceso tiene algunos inconvenientes—más tarde veremos alternativas—pero puede ser útil si no sabes de antemano cómo dividir el programa en funciones. Este enfoque te permite diseñar a medida que avanzas.

4.9. docstring

Un **docstring** es una cadena al comienzo de una función que explica la interfaz (“doc” es la abreviatura de “documentation”). Aquí hay un ejemplo:

```
def polilinea(t, n, longitud, angulo):  
    """Dibuja n segmentos de línea con la longitud dada  
    y el ángulo (en grados) entre ellos. t es una tortuga.  
    """  
    for i in range(n):  
        t.fd(longitud)  
        t.lt(angulo)
```

Por convención, todos los docstrings son cadenas entre triple comillas, también conocidas como cadenas multilínea porque las triple comillas permiten expandir la cadena a más de una línea.

Es breve, pero contiene la información esencial que alguien necesitaría para usar esta función. Explica de manera concisa lo que hace la función (sin entrar en detalles sobre cómo lo hace). Explica qué efecto tiene cada parámetro en el comportamiento de la función y qué tipo debería ser cada parámetro (si no es obvio).

Escribir este tipo de documentación es una parte importante del diseño de la interfaz. Una interfaz bien diseñada debería ser simple de explicar; si tienes dificultades al explicar una de tus funciones, quizás la interfaz podría mejorar.

4.10. Depuración

Una interfaz es como un contrato entre una función y la llamadora. La llamadora acepta proporcionar ciertos parámetros y la función acepta hacer cierto trabajo.

Por ejemplo, `polilinea` requiere cuatro argumentos: `t` tiene que ser `Turtle`; `n` tiene que ser un entero; `longitud` debería ser un número positivo; y `angulo` tiene que ser un número, que se entiende que está en grados.

Estos requisitos se llaman **precondiciones** porque se supone que son verdaderos antes de que la función comience a ejecutarse. De forma opuesta, las condiciones al final de la función son **postcondiciones**. Las postcondiciones incluyen el efecto previsto de la función (como al dibujar segmentos de línea) y cualquier efecto secundario (como mover la tortuga o hacer otros cambios).

Las precondiciones son responsabilidad de la llamadora. Si la llamadora viola una precondición (¡debidamente documentada!) y la función no funciona de forma correcta, el error está en la llamadora, no en la función.

Si las precondiciones se satisfacen y las postcondiciones no, el error está en la función. Si tus pre y post condiciones están claras, pueden ayudar con la depuración.

4.11. Glosario

método: Una función que se asocia a un objeto y se llama usando notación de punto.



Figura 4.1: Flores de tortuga.

bucle: Una parte de un programa que puede ejecutarse de forma repetida.

encapsulamiento: El proceso de transformar una secuencia de sentencias en una definición de función.

generalización: El proceso de reemplazar algo innecesariamente específico (como un número) con algo apropiadamente general (como una variable o parámetro).

argumento de palabra clave: Un argumento que incluye el nombre del parámetro tratándolo como “palabra clave”.

interfaz: Una descripción de cómo usar una función, incluyendo el nombre y descripciones de los argumentos y el valor de retorno.

refactorización: El proceso de modificar un programa que funciona para mejorar las interfaces de funciones y otras cualidades del código.

plan de desarrollo: Un proceso para escribir programas.

docstring: Una cadena que aparece en la parte superior de una definición de función para documentar la interfaz de la función.

precondición: Un requisito que debería satisfacer la llamadora antes de que la función comience.

postcondición: Un requisito que debería satisfacer la función antes de que termine.

4.12. Ejercicios

Ejercicio 4.1. Descarga el código de este capítulo en <http://thinkpython2.com/code/polygon.py>.

1. Dibuja un diagrama de pila que muestre el estado del programa al ejecutar `circulo(bob, radio)`. Puedes hacer la aritmética a mano o agregar sentencias `print` al código.
2. La versión de `arco` en la Sección 4.7 no es muy precisa debido a que la aproximación lineal del círculo está siempre afuera del verdadero círculo. Como resultado, la tortuga termina a unos pocos píxeles de distancia del destino correcto. Mi solución muestra una manera de reducir el efecto de este error. Lee el código y ve si tiene sentido para ti. Si dibujas un diagrama, podrías ver cómo trabaja.

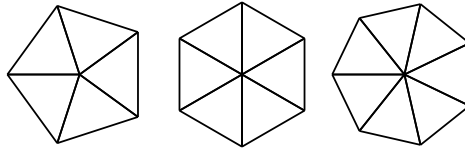


Figura 4.2: Pasteles de tortuga.

Ejercicio 4.2. Escribe un conjunto de funciones apropiadamente generales que puedan dibujar flores como en la Figura 4.1.

Solución: <http://thinkpython2.com/code/flower.py>, también requiere <http://thinkpython2.com/code/polygon.py>.

Ejercicio 4.3. Escribe un conjunto de funciones apropiadamente generales que puedan dibujar formas como en la Figura 4.2.

Solución: <http://thinkpython2.com/code/pie.py>.

Ejercicio 4.4. Las letras del alfabeto se pueden construir desde un número moderado de elementos básicos, como líneas verticales y horizontales y unas pocas curvas. Diseña un alfabeto que pueda dibujarse con un número mínimo de elementos básicos y luego escribe funciones que dibujen las letras.

Deberías escribir una función para cada letra, con nombres `dibujar_a`, `dibujar_b`, etc., y poner tus funciones en un archivo con nombre `letras.py`. Puedes descargar una “máquina de escribir tortuga” desde <http://thinkpython2.com/code/typewriter.py> para ayudarte a probar tu código.

Puedes obtener una solución en <http://thinkpython2.com/code/letters.py>; también requiere <http://thinkpython2.com/code/polygon.py>.

Ejercicio 4.5. Lee sobre espirales en <http://es.wikipedia.org/wiki/Espiral>; luego escribe un programa que dibuje una espiral arquimediana (o uno de los otros tipos). Solución: <http://thinkpython2.com/code/spiral.py>.

Capítulo 5

Condicionales y recursividad

El tema principal de este capítulo es la sentencia `if`, la cual ejecuta código diferente dependiendo del estado del programa. Pero primero quiero presentar dos operadores nuevos: división entera y módulo.

5.1. División entera y módulo

El operador **división entera**, `//`, divide dos números y redondea a un entero hacia abajo. Por ejemplo, supongamos que la duración de una película es 105 minutos. Quizás quieras saber cuánto dura en horas. La división convencional devuelve un número de coma flotante:

```
>>> minutos = 105
>>> minutos / 60
1.75
```

Pero normalmente no escribimos las horas con decimales. La división entera devuelve el número entero de horas, redondeando:

```
>>> minutos = 105
>>> horas = minutos // 60
>>> horas
1
```

Para obtener el resto, podrías restar una hora en minutos:

```
>>> resto = minutos - horas * 60
>>> resto
45
```

Una alternativa es usar el **operador de módulo**, `%`, el cual divide dos números y devuelve el resto.

```
>>> resto = minutos % 60
>>> resto
45
```

El operador de módulo es más útil de lo que parece. Por ejemplo, puedes verificar si un número es divisible por otro—si $x \% y$ es cero, entonces x es divisible por y .

Además, puedes extraer el dígito de más a la derecha o más dígitos de un número. Por ejemplo, $x \% 10$ entrega el dígito de más a la derecha de x (en base 10). De manera similar, $x \% 100$ entrega los dos últimos dígitos.

Si estás usando Python 2, la división funciona diferente. El operador división, $/$, realiza una división entera si ambos operandos son enteros, y la división de coma flotante si cualquiera de los dos operandos es un `float`.

5.2. Expresión booleana

Una **expresión booleana** es una expresión que es verdadera o falsa. Los siguientes ejemplos usan el operador `==`, el cual compara dos operandos y produce `True` si son iguales y `False` si no lo son:

```
>>> 5 == 5
True
>>> 5 == 6
False
```

`True` y `False` son valores especiales que pertenecen al tipo `bool`; no son cadenas:

```
>>> type(True)
<class 'bool'>
>>> type(False)
<class 'bool'>
```

El operador `==` es uno de los **operadores relacionales**; los otros son:

<code>x != y</code>	# x no es igual a y
<code>x > y</code>	# x es mayor que y
<code>x < y</code>	# x es menor que y
<code>x >= y</code>	# x es mayor o igual que y
<code>x <= y</code>	# x es menor o igual que y

Aunque estas operaciones probablemente sean familiares para ti, los símbolos de Python son diferentes a los símbolos matemáticos. Un error común es usar el signo igual simple (`=`) en lugar de un signo igual doble (`==`). Recuerda que `=` es un operador de asignación y `==` es un operador relacional. No hay tal cosa como `=< o =>`.

5.3. Operadores lógicos

Existen tres **operadores lógicos**: `and`, `or` y `not`. La semántica (significado) de estos operadores es similar a su significado en inglés. Por ejemplo, $x > 0$ and $x < 10$ es verdadera solo si x es mayor que 0 y menor que 10.

$n \% 2 == 0$ or $n \% 3 == 0$ es verdadera si *cualquiera o ambas* condiciones son verdaderas, es decir, si el número es divisible por 2 o 3.

Finalmente, el operador `not` niega una expresión booleana, por lo que `not (x > y)` es verdadera si $x > y$ es falsa, es decir, si x es menor o igual que y .

Estrictamente hablando, los operandos de los operadores lógicos deberían ser expresiones booleanas, pero Python no es muy estricto. Cualquier número distinto de cero es interpretado como True:

```
>>> 42 and True
True
```

Esta flexibilidad puede ser útil, pero hay algunas sutilezas que podrían ser confusas. Podrías querer evitar esto (a menos que sepas lo que estás haciendo).

5.4. Ejecución condicional

Para escribir programas útiles, casi siempre necesitamos la capacidad de verificar las condiciones y cambiar el comportamiento del programa como corresponde. Las **sentencias condicionales** nos dan esta capacidad. La forma más simple es la sentencia if:

```
if x > 0:
    print('x es positivo')
```

La expresión booleana después de if se llama **condición**. Si es verdadera, se ejecutan las sentencias con sangría. Si no, no pasa nada.

Las sentencias if tienen la misma estructura que las definiciones de función: un encabezado seguido de un cuerpo con sangrías. Las sentencias como esta se llaman **sentencias compuestas**.

No hay límite en el número de sentencias que pueden aparecer en el cuerpo, pero tiene que haber al menos una. A veces, es útil tener un cuerpo sin sentencias (usualmente para reservar lugar a código que no has escrito todavía). En ese caso, puedes usar la sentencia pass, la cual no hace nada.

```
if x < 0:
    pass                # PENDIENTE: ¡falta manejar los valores negativos!
```

5.5. Ejecución alternativa

Una segunda forma de la sentencia if es la “ejecución alternativa”, en la cual hay dos posibilidades y la condición determina cuál se ejecuta. La sintaxis se ve así:

```
if x % 2 == 0:
    print('x es par')
else:
    print('x es impar')
```

Si el resto de dividir x por 2 es 0, entonces sabemos que x es par y el programa muestra un mensaje correspondiente. Si la condición es falsa, se ejecuta el segundo conjunto de sentencias. Dado que la condición debe ser verdadera o falsa, se ejecutará exactamente una de las alternativas. Las alternativas se llaman **ramas**, porque son ramas en el flujo de ejecución.

5.6. Condicionales encadenados

A veces hay más de dos posibilidades y necesitamos más de dos ramas. Una manera de expresar una computación como esa es un **condicional encadenado**:

```
if x < y:
    print('x es menor que y')
elif x > y:
    print('x es mayor que y')
else:
    print('x e y son iguales')
```

`elif` es una abreviación de “else if”. De nuevo, se ejecutará exactamente una rama. No hay límite en el número de sentencias `elif`. Si hay una cláusula `else`, tiene que estar al final, pero no tiene que haber una.

```
if opcion == 'a':
    dibujar_a()
elif opcion == 'b':
    dibujar_b()
elif opcion == 'c':
    dibujar_c()
```

Cada condición es verificada en orden. Si la primera es falsa, se verifica la siguiente, y así. Si una de ellas es verdadera, se ejecuta la rama correspondiente y la sentencia termina. Incluso si más de una condición es verdadera, solo se ejecuta la primera rama verdadera.

5.7. Condicionales anidados

Un condicional puede también estar anidado dentro de otro. Podríamos haber escrito el ejemplo de la sección anterior de esta forma:

```
if x == y:
    print('x e y son iguales')
else:
    if x < y:
        print('x es menor que y')
    else:
        print('x es mayor que y')
```

El condicional de más afuera contiene dos ramas. La primera rama contiene una sentencia simple. La segunda rama contiene otra sentencia `if`, la cual tiene dos ramas propias. Aquellas dos ramas son sentencias simples, aunque también podrían haber sido sentencias condicionales.

A pesar de que la sangría de las sentencias hacen evidente la estructura, los **condicionales anidados** se vuelven difíciles de leer rápidamente. Es una buena idea evitarlos cuando puedas.

Los operadores lógicos a menudo proporcionan una manera de simplificar las sentencias condicionales anidadas. Por ejemplo, podemos reescribir el siguiente código usando un único condicional:

```
if 0 < x:
    if x < 10:
        print('x es un número positivo de un dígito.')
```


La sentencia `print` solo se ejecuta si pasamos por los dos condicionales, así que podemos obtener el mismo efecto con el operador `and`:

```
if 0 < x and x < 10:
    print('x es un número positivo de un dígito.')
```

Para este tipo de condición, Python proporciona una opción más concisa:

```
if 0 < x < 10:
    print('x es un número positivo de un dígito.')
```

5.8. Recursividad

Es legal para una función llamar a otra; es legal también para una función llamarse a sí misma. Puede que no sea obvio por qué eso es una buena idea, pero resulta ser una de las cosas más mágicas que puede hacer un programa. Por ejemplo, mira la siguiente función:

```
def cuenta_reg(n):
    if n <= 0:
        print('¡Despegue!')
    else:
        print(n)
        cuenta_reg(n-1)
```

Si `n` es 0 o negativo, muestra la palabra, “¡Despegue!” De lo contrario, muestra `n` y luego llama a la función con nombre `cuenta_reg`—a sí misma—pasando a `n-1` como argumento.

¿Qué ocurre si llamamos a esta función así?

```
>>> cuenta_reg(3)
```

La ejecución de `cuenta_reg` comienza con `n=3`, y dado que `n` es mayor que 0, muestra el valor 3 y se llama a sí misma...

La ejecución de `cuenta_reg` comienza con `n=2`, y dado que `n` es mayor que 0, muestra el valor 2 y se llama a sí misma...

La ejecución de `cuenta_reg` comienza con `n=1`, y dado que `n` es mayor que 0, muestra el valor 1 y se llama a sí misma...

La ejecución de `cuenta_reg` comienza con `n=0`, y dado que `n` no es mayor que 0, muestra la palabra “¡Despegue!” y luego vuelve.

La `cuenta_reg` que obtuvo `n=1` vuelve.

La `cuenta_reg` que obtuvo `n=2` vuelve.

La `cuenta_reg` que obtuvo `n=3` vuelve.

Y luego estás de regreso en `__main__`. Por lo tanto, la salida completa se ve así:

```
3
2
1
¡Despegue!
```

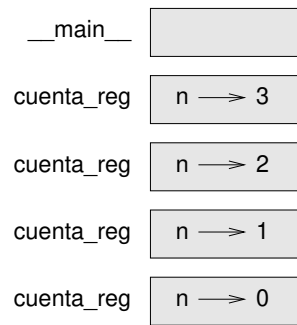


Figura 5.1: Diagrama de pila.

Una función que se llama a sí misma es **recursiva**; el proceso de ejecutarla se llama **recursividad**.

Como otro ejemplo, podemos escribir una función que imprima una cadena n veces.

```
def imprimir_n(s, n):
    if n <= 0:
        return
    print(s)
    imprimir_n(s, n-1)
```

Si $n \leq 0$ la **sentencia return** hace que se salga de la función. El flujo de ejecución vuelve inmediatamente a la llamadora y las líneas restantes de la función no se ejecutan.

El resto de la función es similar a `cuenta_reg`: muestra s y luego se llama a sí misma para mostrar s otras $n - 1$ veces. Entonces el número de líneas de salida es $1 + (n - 1)$, lo cual suma n .

Para ejemplos simples como este, probablemente es más fácil usar un bucle `for`. Pero más adelante veremos ejemplos que son difíciles de escribir con un bucle `for` y fáciles de escribir con recursividad, así que es bueno comenzar pronto.

5.9. Diagramas de pila para funciones recursivas

En la Sección 3.9, usamos un diagrama de pila para representar el estado de un programa durante una llamada a función. El mismo tipo de diagrama puede ayudar a interpretar una función recursiva.

Cada vez que una función es llamada, Python crea un marco que contiene las variables locales y los parámetros de la función. Para una función recursiva, podría haber más de un marco en la pila al mismo tiempo.

La Figura 5.1 muestra un diagrama de pila para `cuenta_reg` llamada con $n = 3$.

Como siempre, la parte de arriba de la pila es el marco para `__main__`. Está vacío porque no creamos variables en `__main__` ni le pasamos argumentos.

Los cuatro marcos de `cuenta_reg` tienen valores diferentes para el parámetro n . La parte de abajo de la pila, donde $n=0$, se llama **caso base**. No hace una llamada recursiva, por lo que no hay más marcos.

Como ejercicio, dibuja un diagrama de pila para `imprimir_n` llamada con `s = 'Hola'` y `n=2`. Luego escribe una función llamada `hacer_n` que tome una objeto de función y un número, `n`, como argumentos, y que llame a dicha función `n` veces.

5.10. Recursividad infinita

Si una recursividad nunca llega a un caso base, sigue haciendo llamadas recursivas por siempre y el programa nunca termina. Esto se conoce como **recursividad infinita** y en general no es una buena idea. Aquí hay un programa mínimo con una recursividad infinita:

```
def recursivo():  
    recursivo()
```

En la mayoría de los entornos de programación, un programa con recursividad infinita no se ejecuta realmente por siempre. Python entrega un mensaje de error cuando la recursividad alcanza la profundidad máxima:

```
File "<stdin>", line 2, in recursivo  
File "<stdin>", line 2, in recursivo  
File "<stdin>", line 2, in recursivo  
.  
.  
.  
File "<stdin>", line 2, in recursivo  
RuntimeError: Maximum recursion depth exceeded
```

Este rastreo es un poco más grande del que vimos en el capítulo anterior. Cuando el error ocurre, ¡hay 1000 marcos de recursivo en la pila!

Si encuentras una recursividad infinita por accidente, revisa tu función para confirmar que hay un caso base que no hace una llamada recursiva. Y si hay un caso base, verifica si tienes garantizado alcanzarlo.

5.11. Entrada de teclado

Los programas que hemos escrito hasta ahora no admiten entradas del usuario. Simplemente hacen siempre lo mismo.

Python proporciona una función incorporada llamada `input` que detiene el programa y espera a que el usuario escriba algo. Cuando el usuario presiona Return o Enter, el programa continúa e `input` devuelve lo que el usuario escribió como una cadena. En Python 2, la misma función se llama `raw_input`.

```
>>> texto = input()  
¿Qué estás esperando?  
>>> texto  
'¿Qué estás esperando?'
```

Antes de obtener la entrada del usuario, es una buena idea imprimir un mensaje que le diga al usuario qué escribir. `input` puede tomar un mensaje como argumento:

```
>>> nombre = input('¿Cuál...es tu nombre?\n')
¿Cuál...es tu nombre?
¿Arturo, Rey de los Britones!
>>> nombre
'¿Arturo, Rey de los Britones!'
```

La secuencia `\n` al final del mensaje representa una **nueva línea**, la cual es un carácter especial que provoca un salto de línea. Esa es la razón por la cual la entrada del usuario aparece debajo del mensaje.

Si esperas que el usuario escriba un entero, puedes intentar convertir el valor de retorno a `int`:

```
>>> mensaje = '¿Cuál...es la velocidad media de una golondrina sin carga?\n'
>>> velocidad = input(mensaje)
¿Cuál...es la velocidad media de una golondrina sin carga?
42
>>> int(velocidad)
42
```

Pero si el usuario escribe algo distinto a una cadena de dígitos, obtienes un error:

```
>>> velocidad = input(mensaje)
¿Cuál...es la velocidad media de una golondrina sin carga?
¿De qué especie, de la africana o de la europea?
>>> int(velocidad)
ValueError: invalid literal for int() with base 10
```

Más adelante veremos cómo tratar este tipo de error.

5.12. Depuración

Cuando ocurre un error de sintaxis o de tiempo de ejecución, el mensaje de error contiene mucha información, pero esto puede ser abrumador. Las partes más útiles suelen ser:

- Qué tipo de error fue y
- Dónde ocurrió.

Los errores de sintaxis son generalmente fáciles de encontrar, pero hay algunas trampas. Los errores de espacio en blanco pueden ser complicados porque los espacios y las sangrías son invisibles y estamos acostumbrados a ignorarlos.

```
>>> x = 5
>>> y = 6
File "<stdin>", line 1
    y = 6
    ^
```

`IndentationError: unexpected indent`

En este ejemplo, el problema es que la segunda línea está desajustada por un espacio. Pero el mensaje de error señala a `y`, lo cual es engañoso. En general, los mensajes de error indican dónde fue descubierto el problema, pero el error real podría estar antes en el código, a veces en una línea anterior. Lo mismo ocurre con los errores de tiempo de ejecución.

Supongamos que estás intentando calcular una relación señal/ruido en decibels. La fórmula es $RSR_{db} = 10 \log_{10}(P_{señal} / P_{ruido})$. En Python, podrías escribir algo así:

```
import math
potencia_senal = 9
potencia_ruido = 10
relacion = potencia_senal // potencia_ruido
decibeles = 10 * math.log10(relacion)
print(decibeles)
```

Cuando ejecutas este programa, obtienes una excepción:

```
Traceback (most recent call last):
  File "snr.py", line 5, in ?
    decibeles = 10 * math.log10(relacion)
ValueError: math domain error
```

El mensaje de error indica la línea 5, pero no hay nada malo con esa línea. Para encontrar el error real, podría ser útil imprimir el valor de `relacion`, el cual resulta ser 0. El problema está en la línea 4, la cual usa división entera en lugar de división de coma flotante.

Deberías tomarte el tiempo de leer cuidadosamente los mensajes de error, pero no supongas que todo lo que dice es correcto.

5.13. Glosario

división entera: Un operador, denotado por `//`, que divide dos números y redondea a un entero hacia abajo (en sentido hacia el infinito negativo).

operador de módulo: Un operador, denotado con un signo de porcentaje (`%`), que trabaja con enteros y revuelve el resto de dividir un número por otro.

expresión booleana: Una expresión cuyo valor es `True` o `False`.

operador relacional: Uno de los operadores que comprara sus operandos: `==`, `!=`, `>`, `<`, `>=` y `<=`.

operador lógico: Uno de los operadores que combina expresiones booleanas: `and`, `or` y `not`.

sentencia condicional: Una sentencia que controla el flujo de ejecución dependiendo de una condición.

condición: La expresión booleana en una sentencia condicional que determina cuál rama se ejecuta.

sentencia compuesta: Una sentencia que consiste en un encabezado y un cuerpo. El encabezado termina con un signo de dos puntos (`:`). El cuerpo tiene sangrías relativas al encabezado.

rama: Una de las secuencias de sentencias alternativas en una sentencia condicional.

condicional encadenado: Una sentencia condicional con una serie de ramas alternativas.

condicional anidado: Una sentencia condicional que aparece en una de las ramas de otra sentencia condicional.

sentencia return: Una sentencia que provoca que una función termine inmediatamente y vuelva a la llamadora.

recursividad: El proceso de llamar a la función que ya se está ejecutando.

caso base: Una rama condicional de una función recursiva que no hace una llamada recursiva.

recursividad infinita: Una recursividad que no tiene un caso base, o nunca lo alcanza. Eventualmente, una recursividad infinita provoca un error de tiempo de ejecución.

5.14. Ejercicios

Ejercicio 5.1. El módulo `time` proporciona una función, con el mismo nombre `time`, que devuelve el tiempo transcurrido desde la Hora Media de Greenwich (GMT) en “la época” (epoch), la cual es un momento arbitrario usado como punto de referencia. En sistemas UNIX, la época es el 1 de enero de 1970.

```
>>> import time
>>> time.time()
1437746094.5735958
```

Escribe un script que lea el tiempo actual y lo convierta a una hora del día en horas, minutos y segundos, además del número de días desde la época.

Ejercicio 5.2. El Último Teorema de Fermat dice que no hay enteros positivos a , b y c tales que

$$a^n + b^n = c^n$$

para cualquier valor de n mayor que 2.

1. Escribe una función con nombre `comprobar_fermat` que tome cuatro parámetros— a , b , c y n —y compruebe si se cumple el teorema de Fermat. Si n es mayor que 2 y

$$a^n + b^n = c^n$$

el programa debería imprimir “¡Ay caramba, Fermat se equivocó!”. De lo contrario, el programa debería imprimir “No, eso no funciona.”

2. Escribe una función que permita al usuario ingresar valores para a , b , c y n , los convierta a enteros y use a `comprobar_fermat` para comprobar si violan el teorema de Fermat.

Ejercicio 5.3. Si te dan tres palos, podrías ser capaz o no de formar un triángulo. Por ejemplo, si uno de los palos mide 12 pulgadas y los otros dos miden una pulgada, no serás capaz de hacer que los palos cortos se encuentren en el medio. Para tres longitudes cualesquiera, hay una prueba simple para ver si es posible formar un triángulo:

Si cualquiera de las tres longitudes es mayor que la suma de las otras dos, entonces no puedes formar un triángulo. De lo contrario, sí puedes. (Si la suma de dos longitudes es igual a la tercera, forman lo que llaman un triángulo “degenerado”).

1. Escribe una función con nombre `es_triángulo` que tome tres enteros como argumentos e imprima “Sí” o “No”, dependiendo de si puedes o no formar un triángulo con palos cuyas longitudes sean los enteros dados.
2. Escribe una función que permita al usuario ingresar tres longitudes de palos, los convierta a enteros y use a `es_triángulo` para comprobar si los palos con las longitudes dadas pueden formar un triángulo.

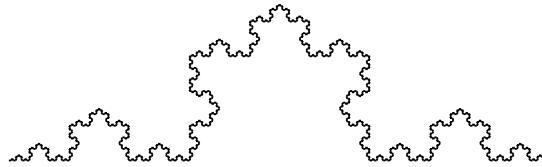


Figura 5.2: Una curva de Koch.

Ejercicio 5.4. *¿Cuál es la salida del siguiente programa? Dibuja un diagrama de pila que muestre el estado del programa cuando imprime el resultado.*

```
def recursivo(n, s):
    if n == 0:
        print(s)
    else:
        recursivo(n-1, n+s)

recursivo(3, 0)
```

1. *¿Qué ocurriría si llamas a esta función así: `recursivo(-1, 0)`?*
2. *Escribe un docstring que explique todo lo que alguien necesitaría saber para usar esta función (y nada más).*

Los siguientes ejercicios usan el módulo `turtle`, descrito en el Capítulo 4:

Ejercicio 5.5. *Lee la siguiente función y mira si puedes averiguar lo que hace (mira los ejemplos en el Capítulo 4). Luego ejecútala y mira si la entendiste bien.*

```
def dibujar(t, longitud, n):
    if n == 0:
        return
    angulo = 50
    t.fd(longitud*n)
    t.lt(angulo)
    dibujar(t, longitud, n-1)
    t.rt(2*angulo)
    dibujar(t, longitud, n-1)
    t.lt(angulo)
    t.bk(longitud*n)
```

Ejercicio 5.6. *La curva de Koch es un fractal que se ve algo como la Figura 5.2. Para dibujar una curva de Koch con longitud x , todo lo que tienes que hacer es*

1. *Dibujar una curva de Koch con longitud $x/3$.*
2. *Girar 60 grados a la izquierda.*
3. *Dibujar una curva de Koch con longitud $x/3$.*
4. *Girar 120 grados a la derecha.*
5. *Dibujar una curva de Koch con longitud $x/3$.*
6. *Girar 60 grados a la izquierda.*

7. Dibujar una curva de Koch con longitud $x/3$.

La excepción es si x es menor que 3: en ese caso, puedes simplemente dibujar una línea recta con longitud x .

1. Escribe una función llamada `koch` que tome una tortuga y una longitud como parámetros y que use a la tortuga para dibujar una curva de Koch con la longitud dada.
2. Escribe una función llamada `copo_de_nieve` que dibuje tres curvas de Koch que hagan el contorno de un copo de nieve.

Solución: <http://thinkpython2.com/code/koch.py>.

3. La curva de Koch se puede generalizar en muchas formas. Mira http://en.wikipedia.org/wiki/Koch_snowflake para ejemplos e implementa tu favorito.

Capítulo 6

Fruitful functions

Many of the Python functions we have used, such as the math functions, produce return values. But the functions we've written are all void: they have an effect, like printing a value or moving a turtle, but they don't have a return value. In this chapter you will learn to write fruitful functions.

6.1. Return values

Calling the function generates a return value, which we usually assign to a variable or use as part of an expression.

```
e = math.exp(1.0)
height = radius * math.sin(radians)
```

The functions we have written so far are void. Speaking casually, they have no return value; more precisely, their return value is `None`.

In this chapter, we are (finally) going to write fruitful functions. The first example is `area`, which returns the area of a circle with the given radius:

```
def area(radius):
    a = math.pi * radius**2
    return a
```

We have seen the `return` statement before, but in a fruitful function the `return` statement includes an expression. This statement means: "Return immediately from this function and use the following expression as a return value." The expression can be arbitrarily complicated, so we could have written this function more concisely:

```
def area(radius):
    return math.pi * radius**2
```

On the other hand, **temporary variables** like `a` can make debugging easier.

Sometimes it is useful to have multiple return statements, one in each branch of a conditional:

```
def absolute_value(x):
    if x < 0:
        return -x
    else:
        return x
```

Since these return statements are in an alternative conditional, only one runs.

As soon as a return statement runs, the function terminates without executing any subsequent statements. Code that appears after a return statement, or any other place the flow of execution can never reach, is called **dead code**.

In a fruitful function, it is a good idea to ensure that every possible path through the program hits a return statement. For example:

```
def absolute_value(x):
    if x < 0:
        return -x
    if x > 0:
        return x
```

This function is incorrect because if x happens to be 0, neither condition is true, and the function ends without hitting a return statement. If the flow of execution gets to the end of a function, the return value is `None`, which is not the absolute value of 0.

```
>>> print(absolute_value(0))
None
```

By the way, Python provides a built-in function called `abs` that computes absolute values.

As an exercise, write a `compare` function that takes two values, x and y , and returns 1 if $x > y$, 0 if $x == y$, and -1 if $x < y$.

6.2. Incremental development

As you write larger functions, you might find yourself spending more time debugging.

To deal with increasingly complex programs, you might want to try a process called **incremental development**. The goal of incremental development is to avoid long debugging sessions by adding and testing only a small amount of code at a time.

As an example, suppose you want to find the distance between two points, given by the coordinates (x_1, y_1) and (x_2, y_2) . By the Pythagorean theorem, the distance is:

$$\text{distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

The first step is to consider what a `distance` function should look like in Python. In other words, what are the inputs (parameters) and what is the output (return value)?

In this case, the inputs are two points, which you can represent using four numbers. The return value is the distance represented by a floating-point value.

Immediately you can write an outline of the function:

```
def distance(x1, y1, x2, y2):
    return 0.0
```

Obviously, this version doesn't compute distances; it always returns zero. But it is syntactically correct, and it runs, which means that you can test it before you make it more complicated.

To test the new function, call it with sample arguments:

```
>>> distance(1, 2, 4, 6)
0.0
```

I chose these values so that the horizontal distance is 3 and the vertical distance is 4; that way, the result is 5, the hypotenuse of a 3-4-5 triangle. When testing a function, it is useful to know the right answer.

At this point we have confirmed that the function is syntactically correct, and we can start adding code to the body. A reasonable next step is to find the differences $x_2 - x_1$ and $y_2 - y_1$. The next version stores those values in temporary variables and prints them.

```
def distance(x1, y1, x2, y2):
    dx = x2 - x1
    dy = y2 - y1
    print('dx is', dx)
    print('dy is', dy)
    return 0.0
```

If the function is working, it should display `dx is 3` and `dy is 4`. If so, we know that the function is getting the right arguments and performing the first computation correctly. If not, there are only a few lines to check.

Next we compute the sum of squares of `dx` and `dy`:

```
def distance(x1, y1, x2, y2):
    dx = x2 - x1
    dy = y2 - y1
    dsquared = dx**2 + dy**2
    print('dsquared is: ', dsquared)
    return 0.0
```

Again, you would run the program at this stage and check the output (which should be 25). Finally, you can use `math.sqrt` to compute and return the result:

```
def distance(x1, y1, x2, y2):
    dx = x2 - x1
    dy = y2 - y1
    dsquared = dx**2 + dy**2
    result = math.sqrt(dsquared)
    return result
```

If that works correctly, you are done. Otherwise, you might want to print the value of `result` before the return statement.

The final version of the function doesn't display anything when it runs; it only returns a value. The print statements we wrote are useful for debugging, but once you get the function working, you should remove them. Code like that is called **scaffolding** because it is helpful for building the program but is not part of the final product.

When you start out, you should add only a line or two of code at a time. As you gain more experience, you might find yourself writing and debugging bigger chunks. Either way, incremental development can save you a lot of debugging time.

The key aspects of the process are:

1. Start with a working program and make small incremental changes. At any point, if there is an error, you should have a good idea where it is.
2. Use variables to hold intermediate values so you can display and check them.
3. Once the program is working, you might want to remove some of the scaffolding or consolidate multiple statements into compound expressions, but only if it does not make the program difficult to read.

As an exercise, use incremental development to write a function called `hypotenuse` that returns the length of the hypotenuse of a right triangle given the lengths of the other two legs as arguments. Record each stage of the development process as you go.

6.3. Composition

As you should expect by now, you can call one function from within another. As an example, we'll write a function that takes two points, the center of the circle and a point on the perimeter, and computes the area of the circle.

Assume that the center point is stored in the variables `xc` and `yc`, and the perimeter point is in `xp` and `yp`. The first step is to find the radius of the circle, which is the distance between the two points. We just wrote a function, `distance`, that does that:

```
radius = distance(xc, yc, xp, yp)
```

The next step is to find the area of a circle with that radius; we just wrote that, too:

```
result = area(radius)
```

Encapsulating these steps in a function, we get:

```
def circle_area(xc, yc, xp, yp):
    radius = distance(xc, yc, xp, yp)
    result = area(radius)
    return result
```

The temporary variables `radius` and `result` are useful for development and debugging, but once the program is working, we can make it more concise by composing the function calls:

```
def circle_area(xc, yc, xp, yp):
    return area(distance(xc, yc, xp, yp))
```

6.4. Boolean functions

Functions can return booleans, which is often convenient for hiding complicated tests inside functions. For example:

```
def is_divisible(x, y):
    if x % y == 0:
        return True
    else:
        return False
```

It is common to give boolean functions names that sound like yes/no questions; `is_divisible` returns either `True` or `False` to indicate whether `x` is divisible by `y`.

Here is an example:

```
>>> is_divisible(6, 4)
False
>>> is_divisible(6, 3)
True
```

The result of the `==` operator is a boolean, so we can write the function more concisely by returning it directly:

```
def is_divisible(x, y):
    return x % y == 0
```

Boolean functions are often used in conditional statements:

```
if is_divisible(x, y):
    print('x is divisible by y')
```

It might be tempting to write something like:

```
if is_divisible(x, y) == True:
    print('x is divisible by y')
```

But the extra comparison is unnecessary.

As an exercise, write a function `is_between(x, y, z)` that returns `True` if $x \leq y \leq z$ or `False` otherwise.

6.5. More recursion

We have only covered a small subset of Python, but you might be interested to know that this subset is a *complete* programming language, which means that anything that can be computed can be expressed in this language. Any program ever written could be rewritten using only the language features you have learned so far (actually, you would need a few commands to control devices like the mouse, disks, etc., but that's all).

Proving that claim is a nontrivial exercise first accomplished by Alan Turing, one of the first computer scientists (some would argue that he was a mathematician, but a lot of early computer scientists started as mathematicians). Accordingly, it is known as the Turing Thesis. For a more complete (and accurate) discussion of the Turing Thesis, I recommend Michael Sipser's book *Introduction to the Theory of Computation*.

To give you an idea of what you can do with the tools you have learned so far, we'll evaluate a few recursively defined mathematical functions. A recursive definition is similar to a circular definition, in the sense that the definition contains a reference to the thing being defined. A truly circular definition is not very useful:

vorpal: An adjective used to describe something that is vorpal.

If you saw that definition in the dictionary, you might be annoyed. On the other hand, if you looked up the definition of the factorial function, denoted with the symbol `!`, you might get something like this:

$$0! = 1$$

$$n! = n(n-1)!$$

This definition says that the factorial of 0 is 1, and the factorial of any other value, n , is n multiplied by the factorial of $n - 1$.

So $3!$ is 3 times $2!$, which is 2 times $1!$, which is 1 times $0!$. Putting it all together, $3!$ equals 3 times 2 times 1 times 1, which is 6.

If you can write a recursive definition of something, you can write a Python program to evaluate it. The first step is to decide what the parameters should be. In this case it should be clear that `factorial` takes an integer:

```
def factorial(n):
```

If the argument happens to be 0, all we have to do is return 1:

```
def factorial(n):
    if n == 0:
        return 1
```

Otherwise, and this is the interesting part, we have to make a recursive call to find the factorial of $n - 1$ and then multiply it by n :

```
def factorial(n):
    if n == 0:
        return 1
    else:
        recurse = factorial(n-1)
        result = n * recurse
        return result
```

The flow of execution for this program is similar to the flow of `countdown` in Section 5.8. If we call `factorial` with the value 3:

Since 3 is not 0, we take the second branch and calculate the factorial of $n-1$...

Since 2 is not 0, we take the second branch and calculate the factorial of $n-1$...

Since 1 is not 0, we take the second branch and calculate the factorial of $n-1$...

Since 0 equals 0, we take the first branch and return 1 without making any more recursive calls.

The return value, 1, is multiplied by n , which is 1, and the result is returned.

The return value, 1, is multiplied by n , which is 2, and the result is returned.

The return value (2) is multiplied by n , which is 3, and the result, 6, becomes the return value of the function call that started the whole process.

Figure 6.1 shows what the stack diagram looks like for this sequence of function calls.

The return values are shown being passed back up the stack. In each frame, the return value is the value of `result`, which is the product of `n` and `recurse`.

In the last frame, the local variables `recurse` and `result` do not exist, because the branch that creates them does not run.

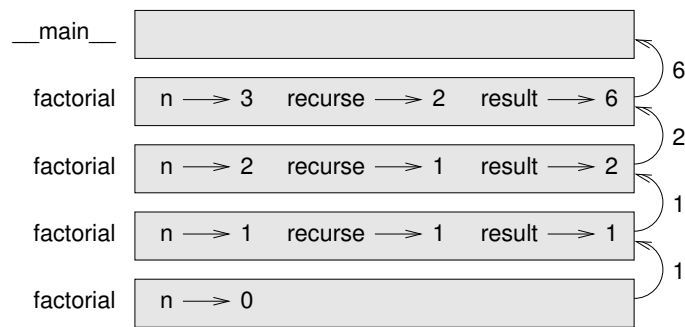


Figura 6.1: Stack diagram.

6.6. Leap of faith

Following the flow of execution is one way to read programs, but it can quickly become overwhelming. An alternative is what I call the “leap of faith”. When you come to a function call, instead of following the flow of execution, you *assume* that the function works correctly and returns the right result.

In fact, you are already practicing this leap of faith when you use built-in functions. When you call `math.cos` or `math.exp`, you don’t examine the bodies of those functions. You just assume that they work because the people who wrote the built-in functions were good programmers.

The same is true when you call one of your own functions. For example, in Section 6.4, we wrote a function called `is_divisible` that determines whether one number is divisible by another. Once we have convinced ourselves that this function is correct—by examining the code and testing—we can use the function without looking at the body again.

The same is true of recursive programs. When you get to the recursive call, instead of following the flow of execution, you should assume that the recursive call works (returns the correct result) and then ask yourself, “Assuming that I can find the factorial of $n - 1$, can I compute the factorial of n ?” It is clear that you can, by multiplying by n .

Of course, it’s a bit strange to assume that the function works correctly when you haven’t finished writing it, but that’s why it’s called a leap of faith!

6.7. One more example

After `factorial`, the most common example of a recursively defined mathematical function is `fibonacci`, which has the following definition (see http://en.wikipedia.org/wiki/Fibonacci_number):

$$\begin{aligned}
 \text{fibonacci}(0) &= 0 \\
 \text{fibonacci}(1) &= 1 \\
 \text{fibonacci}(n) &= \text{fibonacci}(n - 1) + \text{fibonacci}(n - 2)
 \end{aligned}$$

Translated into Python, it looks like this:

```
def fibonacci(n):
    if n == 0:
        return 0
    elif n == 1:
        return 1
    else:
        return fibonacci(n-1) + fibonacci(n-2)
```

If you try to follow the flow of execution here, even for fairly small values of n , your head explodes. But according to the leap of faith, if you assume that the two recursive calls work correctly, then it is clear that you get the right result by adding them together.

6.8. Checking types

What happens if we call `factorial` and give it 1.5 as an argument?

```
>>> factorial(1.5)
RuntimeError: Maximum recursion depth exceeded
```

It looks like an infinite recursion. How can that be? The function has a base case—when $n == 0$. But if n is not an integer, we can *miss* the base case and recurse forever.

In the first recursive call, the value of n is 0.5. In the next, it is -0.5. From there, it gets smaller (more negative), but it will never be 0.

We have two choices. We can try to generalize the `factorial` function to work with floating-point numbers, or we can make `factorial` check the type of its argument. The first option is called the gamma function and it's a little beyond the scope of this book. So we'll go for the second.

We can use the built-in function `isinstance` to verify the type of the argument. While we're at it, we can also make sure the argument is positive:

```
def factorial(n):
    if not isinstance(n, int):
        print('Factorial is only defined for integers.')
        return None
    elif n < 0:
        print('Factorial is not defined for negative integers.')
        return None
    elif n == 0:
        return 1
    else:
        return n * factorial(n-1)
```

The first base case handles nonintegers; the second handles negative integers. In both cases, the program prints an error message and returns `None` to indicate that something went wrong:

```
>>> print(factorial('fred'))
Factorial is only defined for integers.
None
>>> print(factorial(-2))
Factorial is not defined for negative integers.
None
```


If we get past both checks, we know that n is a non-negative integer, so we can prove that the recursion terminates.

This program demonstrates a pattern sometimes called a **guardian**. The first two conditionals act as guardians, protecting the code that follows from values that might cause an error. The guardians make it possible to prove the correctness of the code.

In Section 11.4 we will see a more flexible alternative to printing an error message: raising an exception.

6.9. Debugging

Breaking a large program into smaller functions creates natural checkpoints for debugging. If a function is not working, there are three possibilities to consider:

- There is something wrong with the arguments the function is getting; a precondition is violated.
- There is something wrong with the function; a postcondition is violated.
- There is something wrong with the return value or the way it is being used.

To rule out the first possibility, you can add a `print` statement at the beginning of the function and display the values of the parameters (and maybe their types). Or you can write code that checks the preconditions explicitly.

If the parameters look good, add a `print` statement before each `return` statement and display the return value. If possible, check the result by hand. Consider calling the function with values that make it easy to check the result (as in Section 6.2).

If the function seems to be working, look at the function call to make sure the return value is being used correctly (or used at all!).

Adding `print` statements at the beginning and end of a function can help make the flow of execution more visible. For example, here is a version of `factorial` with `print` statements:

```
def factorial(n):
    space = ' ' * (4 * n)
    print(space, 'factorial', n)
    if n == 0:
        print(space, 'returning 1')
        return 1
    else:
        recurse = factorial(n-1)
        result = n * recurse
        print(space, 'returning', result)
        return result
```

`space` is a string of space characters that controls the indentation of the output. Here is the result of `factorial(4)` :

```

        factorial 4
      factorial 3
    factorial 2
  factorial 1
factorial 0
returning 1
  returning 1
    returning 2
      returning 6
        returning 24

```

If you are confused about the flow of execution, this kind of output can be helpful. It takes some time to develop effective scaffolding, but a little bit of scaffolding can save a lot of debugging.

6.10. Glossary

temporary variable: A variable used to store an intermediate value in a complex calculation.

dead code: Part of a program that can never run, often because it appears after a return statement.

incremental development: A program development plan intended to avoid debugging by adding and testing only a small amount of code at a time.

scaffolding: Code that is used during program development but is not part of the final version.

guardian: A programming pattern that uses a conditional statement to check for and handle circumstances that might cause an error.

6.11. Exercises

Ejercicio 6.1. Draw a stack diagram for the following program. What does the program print?

```

def b(z):
    prod = a(z, z)
    print(z, prod)
    return prod

def a(x, y):
    x = x + 1
    return x * y

def c(x, y, z):
    total = x + y + z
    square = b(total)**2
    return square

```

```
x = 1
y = x + 1
print(c(x, y+3, x+y))
```

Ejercicio 6.2. The Ackermann function, $A(m, n)$, is defined:

$$A(m, n) = \begin{cases} n + 1 & \text{if } m = 0 \\ A(m - 1, 1) & \text{if } m > 0 \text{ and } n = 0 \\ A(m - 1, A(m, n - 1)) & \text{if } m > 0 \text{ and } n > 0. \end{cases}$$

See http://en.wikipedia.org/wiki/Ackermann_function. Write a function named `ack` that evaluates the Ackermann function. Use your function to evaluate `ack(3, 4)`, which should be 125. What happens for larger values of `m` and `n`? Solution: <http://thinkpython2.com/code/ackermann.py>.

Ejercicio 6.3. A palindrome is a word that is spelled the same backward and forward, like “noon” and “redivider”. Recursively, a word is a palindrome if the first and last letters are the same and the middle is a palindrome.

The following are functions that take a string argument and return the first, last, and middle letters:

```
def first(word):
    return word[0]

def last(word):
    return word[-1]

def middle(word):
    return word[1:-1]
```

We'll see how they work in Chapter 8.

1. Type these functions into a file named `palindrome.py` and test them out. What happens if you call `middle` with a string with two letters? One letter? What about the empty string, which is written `''` and contains no letters?
2. Write a function called `is_palindrome` that takes a string argument and returns `True` if it is a palindrome and `False` otherwise. Remember that you can use the built-in function `len` to check the length of a string.

Solution: http://thinkpython2.com/code/palindrome_soln.py.

Ejercicio 6.4. A number, a , is a power of b if it is divisible by b and a/b is a power of b . Write a function called `is_power` that takes parameters `a` and `b` and returns `True` if `a` is a power of `b`. Note: you will have to think about the base case.

Ejercicio 6.5. The greatest common divisor (GCD) of a and b is the largest number that divides both of them with no remainder.

One way to find the GCD of two numbers is based on the observation that if r is the remainder when a is divided by b , then $\text{gcd}(a, b) = \text{gcd}(b, r)$. As a base case, we can use $\text{gcd}(a, 0) = a$.

Write a function called `gcd` that takes parameters `a` and `b` and returns their greatest common divisor.

Credit: This exercise is based on an example from Abelson and Sussman's *Structure and Interpretation of Computer Programs*.

Capítulo 7

Iteration

This chapter is about iteration, which is the ability to run a block of statements repeatedly. We saw a kind of iteration, using recursion, in Section 5.8. We saw another kind, using a `for` loop, in Section 4.2. In this chapter we'll see yet another kind, using a `while` statement. But first I want to say a little more about variable assignment.

7.1. Reassignment

As you may have discovered, it is legal to make more than one assignment to the same variable. A new assignment makes an existing variable refer to a new value (and stop referring to the old value).

```
>>> x = 5
>>> x
5
>>> x = 7
>>> x
7
```

The first time we display `x`, its value is 5; the second time, its value is 7.

Figure 7.1 shows what **reassignment** looks like in a state diagram.

At this point I want to address a common source of confusion. Because Python uses the equal sign (`=`) for assignment, it is tempting to interpret a statement like `a = b` as a mathematical proposition of equality; that is, the claim that `a` and `b` are equal. But this interpretation is wrong.

First, equality is a symmetric relationship and assignment is not. For example, in mathematics, if $a = 7$ then $7 = a$. But in Python, the statement `a = 7` is legal and `7 = a` is not.

Also, in mathematics, a proposition of equality is either true or false for all time. If $a = b$ now, then a will always equal b . In Python, an assignment statement can make two variables equal, but they don't have to stay that way:

```
>>> a = 5
>>> b = a    # a and b are now equal
```

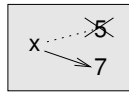


Figura 7.1: State diagram.

```
>>> a = 3    # a and b are no longer equal
>>> b
5
```

The third line changes the value of `a` but does not change the value of `b`, so they are no longer equal.

Reassigning variables is often useful, but you should use it with caution. If the values of variables change frequently, it can make the code difficult to read and debug.

7.2. Updating variables

A common kind of reassignment is an **update**, where the new value of the variable depends on the old.

```
>>> x = x + 1
```

This means “get the current value of `x`, add one, and then update `x` with the new value.”

If you try to update a variable that doesn’t exist, you get an error, because Python evaluates the right side before it assigns a value to `x`:

```
>>> x = x + 1
NameError: name 'x' is not defined
```

Before you can update a variable, you have to **initialize** it, usually with a simple assignment:

```
>>> x = 0
>>> x = x + 1
```

Updating a variable by adding 1 is called an **increment**; subtracting 1 is called a **decrement**.

7.3. The while statement

Computers are often used to automate repetitive tasks. Repeating identical or similar tasks without making errors is something that computers do well and people do poorly. In a computer program, repetition is also called **iteration**.

We have already seen two functions, `countdown` and `print_n`, that iterate using recursion. Because iteration is so common, Python provides language features to make it easier. One is the `for` statement we saw in Section 4.2. We’ll get back to that later.

Another is the `while` statement. Here is a version of `countdown` that uses a `while` statement:

```
def countdown(n):
    while n > 0:
        print(n)
        n = n - 1
    print('Blastoff!')
```

You can almost read the while statement as if it were English. It means, “While *n* is greater than 0, display the value of *n* and then decrement *n*. When you get to 0, display the word Blastoff!”

More formally, here is the flow of execution for a while statement:

1. Determine whether the condition is true or false.
2. If false, exit the while statement and continue execution at the next statement.
3. If the condition is true, run the body and then go back to step 1.

This type of flow is called a loop because the third step loops back around to the top.

The body of the loop should change the value of one or more variables so that the condition becomes false eventually and the loop terminates. Otherwise the loop will repeat forever, which is called an **infinite loop**. An endless source of amusement for computer scientists is the observation that the directions on shampoo, “Lather, rinse, repeat”, are an infinite loop.

In the case of countdown, we can prove that the loop terminates: if *n* is zero or negative, the loop never runs. Otherwise, *n* gets smaller each time through the loop, so eventually we have to get to 0.

For some other loops, it is not so easy to tell. For example:

```
def sequence(n):
    while n != 1:
        print(n)
        if n % 2 == 0:          # n is even
            n = n / 2
        else:                  # n is odd
            n = n*3 + 1
```

The condition for this loop is *n* != 1, so the loop will continue until *n* is 1, which makes the condition false.

Each time through the loop, the program outputs the value of *n* and then checks whether it is even or odd. If it is even, *n* is divided by 2. If it is odd, the value of *n* is replaced with *n**3 + 1. For example, if the argument passed to sequence is 3, the resulting values of *n* are 3, 10, 5, 16, 8, 4, 2, 1.

Since *n* sometimes increases and sometimes decreases, there is no obvious proof that *n* will ever reach 1, or that the program terminates. For some particular values of *n*, we can prove termination. For example, if the starting value is a power of two, *n* will be even every time through the loop until it reaches 1. The previous example ends with such a sequence, starting with 16.

The hard question is whether we can prove that this program terminates for *all* positive values of *n*. So far, no one has been able to prove it *or* disprove it! (See http://en.wikipedia.org/wiki/Collatz_conjecture.)

As an exercise, rewrite the function `print_n` from Section 5.8 using iteration instead of recursion.

7.4. break

Sometimes you don't know it's time to end a loop until you get half way through the body. In that case you can use the `break` statement to jump out of the loop.

For example, suppose you want to take input from the user until they type `done`. You could write:

```
while True:
    line = input('> ')
    if line == 'done':
        break
    print(line)
```

```
print('Done!')
```

The loop condition is `True`, which is always true, so the loop runs until it hits the `break` statement.

Each time through, it prompts the user with an angle bracket. If the user types `done`, the `break` statement exits the loop. Otherwise the program echoes whatever the user types and goes back to the top of the loop. Here's a sample run:

```
> not done
not done
> done
Done!
```

This way of writing `while` loops is common because you can check the condition anywhere in the loop (not just at the top) and you can express the stop condition affirmatively ("stop when this happens") rather than negatively ("keep going until that happens").

7.5. Square roots

Loops are often used in programs that compute numerical results by starting with an approximate answer and iteratively improving it.

For example, one way of computing square roots is Newton's method. Suppose that you want to know the square root of a . If you start with almost any estimate, x , you can compute a better estimate with the following formula:

$$y = \frac{x + a/x}{2}$$

For example, if a is 4 and x is 3:

```
>>> a = 4
>>> x = 3
>>> y = (x + a/x) / 2
>>> y
2.16666666667
```


The result is closer to the correct answer ($\sqrt{4} = 2$). If we repeat the process with the new estimate, it gets even closer:

```
>>> x = y
>>> y = (x + a/x) / 2
>>> y
2.00641025641
```

After a few more updates, the estimate is almost exact:

```
>>> x = y
>>> y = (x + a/x) / 2
>>> y
2.00001024003
>>> x = y
>>> y = (x + a/x) / 2
>>> y
2.00000000003
```

In general we don't know ahead of time how many steps it takes to get to the right answer, but we know when we get there because the estimate stops changing:

```
>>> x = y
>>> y = (x + a/x) / 2
>>> y
2.0
>>> x = y
>>> y = (x + a/x) / 2
>>> y
2.0
```

When `y == x`, we can stop. Here is a loop that starts with an initial estimate, `x`, and improves it until it stops changing:

```
while True:
    print(x)
    y = (x + a/x) / 2
    if y == x:
        break
    x = y
```

For most values of `a` this works fine, but in general it is dangerous to test float equality. Floating-point values are only approximately right: most rational numbers, like $1/3$, and irrational numbers, like $\sqrt{2}$, can't be represented exactly with a float.

Rather than checking whether `x` and `y` are exactly equal, it is safer to use the built-in function `abs` to compute the absolute value, or magnitude, of the difference between them:

```
if abs(y-x) < epsilon:
    break
```

Where `epsilon` has a value like `0.0000001` that determines how close is close enough.

7.6. Algorithms

Newton's method is an example of an **algorithm**: it is a mechanical process for solving a category of problems (in this case, computing square roots).

To understand what an algorithm is, it might help to start with something that is not an algorithm. When you learned to multiply single-digit numbers, you probably memorized the multiplication table. In effect, you memorized 100 specific solutions. That kind of knowledge is not algorithmic.

But if you were “lazy”, you might have learned a few tricks. For example, to find the product of n and 9, you can write $n - 1$ as the first digit and $10 - n$ as the second digit. This trick is a general solution for multiplying any single-digit number by 9. That’s an algorithm!

Similarly, the techniques you learned for addition with carrying, subtraction with borrowing, and long division are all algorithms. One of the characteristics of algorithms is that they do not require any intelligence to carry out. They are mechanical processes where each step follows from the last according to a simple set of rules.

Executing algorithms is boring, but designing them is interesting, intellectually challenging, and a central part of computer science.

Some of the things that people do naturally, without difficulty or conscious thought, are the hardest to express algorithmically. Understanding natural language is a good example. We all do it, but so far no one has been able to explain *how* we do it, at least not in the form of an algorithm.

7.7. Debugging

As you start writing bigger programs, you might find yourself spending more time debugging. More code means more chances to make an error and more places for bugs to hide.

One way to cut your debugging time is “debugging by bisection”. For example, if there are 100 lines in your program and you check them one at a time, it would take 100 steps.

Instead, try to break the problem in half. Look at the middle of the program, or near it, for an intermediate value you can check. Add a `print` statement (or something else that has a verifiable effect) and run the program.

If the mid-point check is incorrect, there must be a problem in the first half of the program. If it is correct, the problem is in the second half.

Every time you perform a check like this, you halve the number of lines you have to search. After six steps (which is fewer than 100), you would be down to one or two lines of code, at least in theory.

In practice it is not always clear what the “middle of the program” is and not always possible to check it. It doesn’t make sense to count lines and find the exact midpoint. Instead, think about places in the program where there might be errors and places where it is easy to put a check. Then choose a spot where you think the chances are about the same that the bug is before or after the check.

7.8. Glossary

reassignment: Assigning a new value to a variable that already exists.

update: An assignment where the new value of the variable depends on the old.

initialization: An assignment that gives an initial value to a variable that will be updated.

increment: An update that increases the value of a variable (often by one).

decrement: An update that decreases the value of a variable.

iteration: Repeated execution of a set of statements using either a recursive function call or a loop.

infinite loop: A loop in which the terminating condition is never satisfied.

algorithm: A general process for solving a category of problems.

7.9. Exercises

Ejercicio 7.1. Copy the loop from Section 7.5 and encapsulate it in a function called `mysqrt` that takes `a` as a parameter, chooses a reasonable value of `x`, and returns an estimate of the square root of `a`.

To test it, write a function named `test_square_root` that prints a table like this:

<code>a</code>	<code>mysqrt(a)</code>	<code>math.sqrt(a)</code>	<code>diff</code>
1.0	1.0	1.0	0.0
2.0	1.41421356237	1.41421356237	2.22044604925e-16
3.0	1.73205080757	1.73205080757	0.0
4.0	2.0	2.0	0.0
5.0	2.2360679775	2.2360679775	0.0
6.0	2.44948974278	2.44948974278	0.0
7.0	2.64575131106	2.64575131106	0.0
8.0	2.82842712475	2.82842712475	4.4408920985e-16
9.0	3.0	3.0	0.0

The first column is a number, `a`; the second column is the square root of `a` computed with `mysqrt`; the third column is the square root computed by `math.sqrt`; the fourth column is the absolute value of the difference between the two estimates.

Ejercicio 7.2. The built-in function `eval` takes a string and evaluates it using the Python interpreter. For example:

```
>>> eval('1 + 2 * 3')
7
>>> import math
>>> eval('math.sqrt(5)')
2.2360679774997898
>>> eval('type(math.pi)')
<class 'float'>
```

Write a function called `eval_loop` that iteratively prompts the user, takes the resulting input and evaluates it using `eval`, and prints the result.

It should continue until the user enters 'done', and then return the value of the last expression it evaluated.

Ejercicio 7.3. The mathematician Srinivasa Ramanujan found an infinite series that can be used to generate a numerical approximation of $1/\pi$:

$$\frac{1}{\pi} = \frac{2\sqrt{2}}{9801} \sum_{k=0}^{\infty} \frac{(4k)!(1103 + 26390k)}{(k!)^4 396^{4k}}$$

Write a function called `estimate_pi` that uses this formula to compute and return an estimate of π . It should use a `while` loop to compute terms of the summation until the last term is smaller than `1e-15` (which is Python notation for 10^{-15}). You can check the result by comparing it to `math.pi`.

Solution: <http://thinkpython2.com/code/pi.py>.

Capítulo 8

Strings

Strings are not like integers, floats, and booleans. A string is a **sequence**, which means it is an ordered collection of other values. In this chapter you'll see how to access the characters that make up a string, and you'll learn about some of the methods strings provide.

8.1. A string is a sequence

A string is a sequence of characters. You can access the characters one at a time with the bracket operator:

```
>>> fruit = 'banana'
>>> letter = fruit[1]
```

The second statement selects character number 1 from `fruit` and assigns it to `letter`.

The expression in brackets is called an **index**. The index indicates which character in the sequence you want (hence the name).

But you might not get what you expect:

```
>>> letter
'a'
```

For most people, the first letter of `'banana'` is `b`, not `a`. But for computer scientists, the index is an offset from the beginning of the string, and the offset of the first letter is zero.

```
>>> letter = fruit[0]
>>> letter
'b'
```

So `b` is the 0th letter (“zero-eth”) of `'banana'`, `a` is the 1th letter (“one-eth”), and `n` is the 2th letter (“two-eth”).

As an index you can use an expression that contains variables and operators:

```
>>> i = 1
>>> fruit[i]
'a'
>>> fruit[i+1]
'n'
```

But the value of the index has to be an integer. Otherwise you get:

```
>>> letter = fruit[1.5]
TypeError: string indices must be integers
```

8.2. len

`len` is a built-in function that returns the number of characters in a string:

```
>>> fruit = 'banana'
>>> len(fruit)
6
```

To get the last letter of a string, you might be tempted to try something like this:

```
>>> length = len(fruit)
>>> last = fruit[length]
IndexError: string index out of range
```

The reason for the `IndexError` is that there is no letter in 'banana' with the index 6. Since we started counting at zero, the six letters are numbered 0 to 5. To get the last character, you have to subtract 1 from `length`:

```
>>> last = fruit[length-1]
>>> last
'a'
```

Or you can use negative indices, which count backward from the end of the string. The expression `fruit[-1]` yields the last letter, `fruit[-2]` yields the second to last, and so on.

8.3. Traversal with a for loop

A lot of computations involve processing a string one character at a time. Often they start at the beginning, select each character in turn, do something to it, and continue until the end. This pattern of processing is called a **traversal**. One way to write a traversal is with a `while` loop:

```
index = 0
while index < len(fruit):
    letter = fruit[index]
    print(letter)
    index = index + 1
```

This loop traverses the string and displays each letter on a line by itself. The loop condition is `index < len(fruit)`, so when `index` is equal to the length of the string, the condition is false, and the body of the loop doesn't run. The last character accessed is the one with the index `len(fruit)-1`, which is the last character in the string.

As an exercise, write a function that takes a string as an argument and displays the letters backward, one per line.

Another way to write a traversal is with a `for` loop:

```
for letter in fruit:
    print(letter)
```

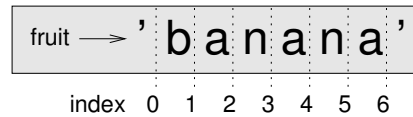


Figura 8.1: Slice indices.

Each time through the loop, the next character in the string is assigned to the variable `letter`. The loop continues until no characters are left.

The following example shows how to use concatenation (string addition) and a `for` loop to generate an abecedarian series (that is, in alphabetical order). In Robert McCloskey's book *Make Way for Ducklings*, the names of the ducklings are Jack, Kack, Lack, Mack, Nack, Ouack, Pack, and Quack. This loop outputs these names in order:

```
prefixes = 'JKLMNOPQ'
suffix = 'ack'

for letter in prefixes:
    print(letter + suffix)
```

The output is:

```
Jack
Kack
Lack
Mack
Nack
Oack
Pack
Qack
```

Of course, that's not quite right because "Ouack" and "Quack" are misspelled. As an exercise, modify the program to fix this error.

8.4. String slices

A segment of a string is called a **slice**. Selecting a slice is similar to selecting a character:

```
>>> s = 'Monty Python'
>>> s[0:5]
'Monty'
>>> s[6:12]
'Python'
```

The operator `[n:m]` returns the part of the string from the "n-eth" character to the "m-eth" character, including the first but excluding the last. This behavior is counterintuitive, but it might help to imagine the indices pointing *between* the characters, as in Figure 8.1.

If you omit the first index (before the colon), the slice starts at the beginning of the string. If you omit the second index, the slice goes to the end of the string:

```
>>> fruit = 'banana'
>>> fruit[:3]
```

```
'ban'
>>> fruit[3:]
'ana'
```

If the first index is greater than or equal to the second the result is an **empty string**, represented by two quotation marks:

```
>>> fruit = 'banana'
>>> fruit[3:3]
''
```

An empty string contains no characters and has length 0, but other than that, it is the same as any other string.

Continuing this example, what do you think `fruit[:]` means? Try it and see.

8.5. Strings are immutable

It is tempting to use the `[]` operator on the left side of an assignment, with the intention of changing a character in a string. For example:

```
>>> greeting = 'Hello, world!'
>>> greeting[0] = 'J'
TypeError: 'str' object does not support item assignment
```

The “object” in this case is the string and the “item” is the character you tried to assign. For now, an object is the same thing as a value, but we will refine that definition later (Section 10.10).

The reason for the error is that strings are **immutable**, which means you can’t change an existing string. The best you can do is create a new string that is a variation on the original:

```
>>> greeting = 'Hello, world!'
>>> new_greeting = 'J' + greeting[1:]
>>> new_greeting
'Jello, world!'
```

This example concatenates a new first letter onto a slice of `greeting`. It has no effect on the original string.

8.6. Searching

What does the following function do?

```
def find(word, letter):
    index = 0
    while index < len(word):
        if word[index] == letter:
            return index
        index = index + 1
    return -1
```


In a sense, `find` is the inverse of the `[]` operator. Instead of taking an index and extracting the corresponding character, it takes a character and finds the index where that character appears. If the character is not found, the function returns `-1`.

This is the first example we have seen of a `return` statement inside a loop. If `word[index] == letter`, the function breaks out of the loop and returns immediately.

If the character doesn't appear in the string, the program exits the loop normally and returns `-1`.

This pattern of computation—traversing a sequence and returning when we find what we are looking for—is called a **search**.

As an exercise, modify `find` so that it has a third parameter, the index in `word` where it should start looking.

8.7. Looping and counting

The following program counts the number of times the letter `a` appears in a string:

```
word = 'banana'
count = 0
for letter in word:
    if letter == 'a':
        count = count + 1
print(count)
```

This program demonstrates another pattern of computation called a **counter**. The variable `count` is initialized to 0 and then incremented each time an `a` is found. When the loop exits, `count` contains the result—the total number of `a`'s.

As an exercise, encapsulate this code in a function named `count`, and generalize it so that it accepts the string and the letter as arguments.

Then rewrite the function so that instead of traversing the string, it uses the three-parameter version of `find` from the previous section.

8.8. String methods

Strings provide methods that perform a variety of useful operations. A method is similar to a function—it takes arguments and returns a value—but the syntax is different. For example, the method `upper` takes a string and returns a new string with all uppercase letters.

Instead of the function syntax `upper(word)`, it uses the method syntax `word.upper()`.

```
>>> word = 'banana'
>>> new_word = word.upper()
>>> new_word
'BANANA'
```

This form of dot notation specifies the name of the method, `upper`, and the name of the string to apply the method to, `word`. The empty parentheses indicate that this method takes no arguments.

A method call is called an **invocation**; in this case, we would say that we are invoking `upper` on `word`.

As it turns out, there is a string method named `find` that is remarkably similar to the function we wrote:

```
>>> word = 'banana'
>>> index = word.find('a')
>>> index
1
```

In this example, we invoke `find` on `word` and pass the letter we are looking for as a parameter.

Actually, the `find` method is more general than our function; it can find substrings, not just characters:

```
>>> word.find('na')
2
```

By default, `find` starts at the beginning of the string, but it can take a second argument, the index where it should start:

```
>>> word.find('na', 3)
4
```

This is an example of an **optional argument**; `find` can also take a third argument, the index where it should stop:

```
>>> name = 'bob'
>>> name.find('b', 1, 2)
-1
```

This search fails because `b` does not appear in the index range from 1 to 2, not including 2. Searching up to, but not including, the second index makes `find` consistent with the slice operator.

8.9. The `in` operator

The word `in` is a boolean operator that takes two strings and returns `True` if the first appears as a substring in the second:

```
>>> 'a' in 'banana'
True
>>> 'seed' in 'banana'
False
```

For example, the following function prints all the letters from `word1` that also appear in `word2`:

```
def in_both(word1, word2):
    for letter in word1:
        if letter in word2:
            print(letter)
```

With well-chosen variable names, Python sometimes reads like English. You could read this loop, “for (each) letter in (the first) word, if (the) letter (appears) in (the second) word, print (the) letter.”

Here’s what you get if you compare apples and oranges:

```
>>> in_both('apples', 'oranges')
a
e
s
```

8.10. String comparison

The relational operators work on strings. To see if two strings are equal:

```
if word == 'banana':
    print('All right, bananas.')
```

Other relational operations are useful for putting words in alphabetical order:

```
if word < 'banana':
    print('Your word, ' + word + ', comes before banana.')
elif word > 'banana':
    print('Your word, ' + word + ', comes after banana.')
else:
    print('All right, bananas.')
```

Python does not handle uppercase and lowercase letters the same way people do. All the uppercase letters come before all the lowercase letters, so:

Your word, Pineapple, comes before banana.

A common way to address this problem is to convert strings to a standard format, such as all lowercase, before performing the comparison. Keep that in mind in case you have to defend yourself against a man armed with a Pineapple.

8.11. Debugging

When you use indices to traverse the values in a sequence, it is tricky to get the beginning and end of the traversal right. Here is a function that is supposed to compare two words and return True if one of the words is the reverse of the other, but it contains two errors:

```
def is_reverse(word1, word2):
    if len(word1) != len(word2):
        return False

    i = 0
    j = len(word2)

    while j > 0:
        if word1[i] != word2[j]:
            return False
        i = i+1
```

```
j = j-1
```

```
return True
```

The first if statement checks whether the words are the same length. If not, we can return False immediately. Otherwise, for the rest of the function, we can assume that the words are the same length. This is an example of the guardian pattern in Section 6.8.

i and j are indices: i traverses word1 forward while j traverses word2 backward. If we find two letters that don't match, we can return False immediately. If we get through the whole loop and all the letters match, we return True.

If we test this function with the words "pots" and "stop", we expect the return value True, but we get an IndexError:

```
>>> is_reverse('pots', 'stop')
...
File "reverse.py", line 15, in is_reverse
    if word1[i] != word2[j]:
IndexError: string index out of range
```

For debugging this kind of error, my first move is to print the values of the indices immediately before the line where the error appears.

```
while j > 0:
    print(i, j)          # print here

    if word1[i] != word2[j]:
        return False
    i = i+1
    j = j-1
```

Now when I run the program again, I get more information:

```
>>> is_reverse('pots', 'stop')
0 4
...
IndexError: string index out of range
```

The first time through the loop, the value of j is 4, which is out of range for the string 'pots'. The index of the last character is 3, so the initial value for j should be len(word2)-1.

If I fix that error and run the program again, I get:

```
>>> is_reverse('pots', 'stop')
0 3
1 2
2 1
True
```

This time we get the right answer, but it looks like the loop only ran three times, which is suspicious. To get a better idea of what is happening, it is useful to draw a state diagram. During the first iteration, the frame for is_reverse is shown in Figure 8.2.

I took some license by arranging the variables in the frame and adding dotted lines to show that the values of i and j indicate characters in word1 and word2.

Starting with this diagram, run the program on paper, changing the values of i and j during each iteration. Find and fix the second error in this function.

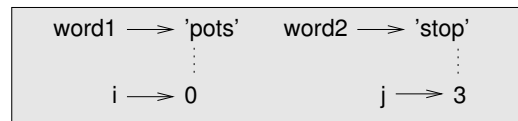


Figura 8.2: State diagram.

8.12. Glossary

object: Something a variable can refer to. For now, you can use “object” and “value” interchangeably.

sequence: An ordered collection of values where each value is identified by an integer index.

item: One of the values in a sequence.

index: An integer value used to select an item in a sequence, such as a character in a string. In Python indices start from 0.

slice: A part of a string specified by a range of indices.

empty string: A string with no characters and length 0, represented by two quotation marks.

immutable: The property of a sequence whose items cannot be changed.

traverse: To iterate through the items in a sequence, performing a similar operation on each.

search: A pattern of traversal that stops when it finds what it is looking for.

counter: A variable used to count something, usually initialized to zero and then incremented.

invocation: A statement that calls a method.

optional argument: A function or method argument that is not required.

8.13. Exercises

Ejercicio 8.1. Read the documentation of the string methods at <http://docs.python.org/3/library/stdtypes.html#string-methods>. You might want to experiment with some of them to make sure you understand how they work. `strip` and `replace` are particularly useful.

The documentation uses a syntax that might be confusing. For example, in `find(sub[, start[, end]])`, the brackets indicate optional arguments. So `sub` is required, but `start` is optional, and if you include `start`, then `end` is optional.

Ejercicio 8.2. There is a string method called `count` that is similar to the function in Section 8.7. Read the documentation of this method and write an invocation that counts the number of `a`'s in `'banana'`.

Ejercicio 8.3. A string slice can take a third index that specifies the “step size”; that is, the number of spaces between successive characters. A step size of 2 means every other character; 3 means every third, etc.

```
>>> fruit = 'banana'
>>> fruit[0:5:2]
'bnn'
```

A step size of -1 goes through the word backwards, so the slice `[::-1]` generates a reversed string.

Use this idiom to write a one-line version of `is_palindrome` from Exercise 6.3.

Ejercicio 8.4. The following functions are all intended to check whether a string contains any lowercase letters, but at least some of them are wrong. For each function, describe what the function actually does (assuming that the parameter is a string).

```
def any_lowercase1(s):
    for c in s:
        if c.islower():
            return True
        else:
            return False

def any_lowercase2(s):
    for c in s:
        if 'c'.islower():
            return 'True'
        else:
            return 'False'

def any_lowercase3(s):
    for c in s:
        flag = c.islower()
    return flag

def any_lowercase4(s):
    flag = False
    for c in s:
        flag = flag or c.islower()
    return flag

def any_lowercase5(s):
    for c in s:
        if not c.islower():
            return False
    return True
```

Ejercicio 8.5. A Caesar cypher is a weak form of encryption that involves “rotating” each letter by a fixed number of places. To rotate a letter means to shift it through the alphabet, wrapping around to the beginning if necessary, so ‘A’ rotated by 3 is ‘D’ and ‘Z’ rotated by 1 is ‘A’.

To rotate a word, rotate each letter by the same amount. For example, “cheer” rotated by 7 is “jolly” and “melon” rotated by -10 is “cubed”. In the movie 2001: A Space Odyssey, the ship computer is called HAL, which is IBM rotated by -1.

Write a function called `rotate_word` that takes a string and an integer as parameters, and returns a new string that contains the letters from the original string rotated by the given amount.

You might want to use the built-in function `ord`, which converts a character to a numeric code, and

`chr`, which converts numeric codes to characters. Letters of the alphabet are encoded in alphabetical order, so for example:

```
>>> ord('c') - ord('a')
2
```

Because 'c' is the two-eth letter of the alphabet. But beware: the numeric codes for upper case letters are different.

Potentially offensive jokes on the Internet are sometimes encoded in ROT13, which is a Caesar cypher with rotation 13. If you are not easily offended, find and decode some of them. Solution: <http://thinkpython2.com/code/rotate.py>.

Capítulo 9

Case study: word play

This chapter presents the second case study, which involves solving word puzzles by searching for words that have certain properties. For example, we'll find the longest palindromes in English and search for words whose letters appear in alphabetical order. And I will present another program development plan: reduction to a previously solved problem.

9.1. Reading word lists

For the exercises in this chapter we need a list of English words. There are lots of word lists available on the Web, but the one most suitable for our purpose is one of the word lists collected and contributed to the public domain by Grady Ward as part of the Moby lexicon project (see http://wikipedia.org/wiki/Moby_Project). It is a list of 113,809 official crosswords; that is, words that are considered valid in crossword puzzles and other word games. In the Moby collection, the filename is `113809of.fic`; you can download a copy, with the simpler name `words.txt`, from <http://thinkpython2.com/code/words.txt>.

This file is in plain text, so you can open it with a text editor, but you can also read it from Python. The built-in function `open` takes the name of the file as a parameter and returns a **file object** you can use to read the file.

```
>>> fin = open('words.txt')
```

`fin` is a common name for a file object used for input. The file object provides several methods for reading, including `readline`, which reads characters from the file until it gets to a newline and returns the result as a string:

```
>>> fin.readline()
'aa\n'
```

The first word in this particular list is “aa”, which is a kind of lava. The sequence `\n` represents the newline character that separates this word from the next.

The file object keeps track of where it is in the file, so if you call `readline` again, you get the next word:

```
>>> fin.readline()
'aah\n'
```

The next word is “aah”, which is a perfectly legitimate word, so stop looking at me like that. Or, if it’s the newline character that’s bothering you, we can get rid of it with the string method `strip`:

```
>>> line = fin.readline()
>>> word = line.strip()
>>> word
'aahed'
```

You can also use a file object as part of a for loop. This program reads `words.txt` and prints each word, one per line:

```
fin = open('words.txt')
for line in fin:
    word = line.strip()
    print(word)
```

9.2. Exercises

There are solutions to these exercises in the next section. You should at least attempt each one before you read the solutions.

Ejercicio 9.1. Write a program that reads `words.txt` and prints only the words with more than 20 characters (not counting whitespace).

Ejercicio 9.2. In 1939 Ernest Vincent Wright published a 50,000 word novel called *Gadsby* that does not contain the letter “e”. Since “e” is the most common letter in English, that’s not easy to do.

In fact, it is difficult to construct a solitary thought without using that most common symbol. It is slow going at first, but with caution and hours of training you can gradually gain facility.

All right, I’ll stop now.

Write a function called `has_no_e` that returns `True` if the given word doesn’t have the letter “e” in it.

Write a program that reads `words.txt` and prints only the words that have no “e”. Compute the percentage of words in the list that have no “e”.

Ejercicio 9.3. Write a function named `avoids` that takes a word and a string of forbidden letters, and that returns `True` if the word doesn’t use any of the forbidden letters.

Write a program that prompts the user to enter a string of forbidden letters and then prints the number of words that don’t contain any of them. Can you find a combination of 5 forbidden letters that excludes the smallest number of words?

Ejercicio 9.4. Write a function named `uses_only` that takes a word and a string of letters, and that returns `True` if the word contains only letters in the list. Can you make a sentence using only the letters `acefhlo`? Other than “Hoe alfalfa”?

Ejercicio 9.5. Write a function named `uses_all` that takes a word and a string of required letters, and that returns `True` if the word uses all the required letters at least once. How many words are there that use all the vowels `aeiou`? How about `aeiouy`?

Ejercicio 9.6. Write a function called `is_abecedarian` that returns `True` if the letters in a word appear in alphabetical order (double letters are ok). How many abecedarian words are there?

9.3. Search

All of the exercises in the previous section have something in common; they can be solved with the search pattern we saw in Section 8.6. The simplest example is:

```
def has_no_e(word):
    for letter in word:
        if letter == 'e':
            return False
    return True
```

The for loop traverses the characters in word. If we find the letter “e”, we can immediately return False; otherwise we have to go to the next letter. If we exit the loop normally, that means we didn’t find an “e”, so we return True.

You could write this function more concisely using the in operator, but I started with this version because it demonstrates the logic of the search pattern.

avoids is a more general version of has_no_e but it has the same structure:

```
def avoids(word, forbidden):
    for letter in word:
        if letter in forbidden:
            return False
    return True
```

We can return False as soon as we find a forbidden letter; if we get to the end of the loop, we return True.

uses_only is similar except that the sense of the condition is reversed:

```
def uses_only(word, available):
    for letter in word:
        if letter not in available:
            return False
    return True
```

Instead of a list of forbidden letters, we have a list of available letters. If we find a letter in word that is not in available, we can return False.

uses_all is similar except that we reverse the role of the word and the string of letters:

```
def uses_all(word, required):
    for letter in required:
        if letter not in word:
            return False
    return True
```

Instead of traversing the letters in word, the loop traverses the required letters. If any of the required letters do not appear in the word, we can return False.

If you were really thinking like a computer scientist, you would have recognized that uses_all was an instance of a previously solved problem, and you would have written:

```
def uses_all(word, required):
    return uses_only(required, word)
```

This is an example of a program development plan called **reduction to a previously solved problem**, which means that you recognize the problem you are working on as an instance of a solved problem and apply an existing solution.

9.4. Looping with indices

I wrote the functions in the previous section with `for` loops because I only needed the characters in the strings; I didn't have to do anything with the indices.

For `is_abecedarian` we have to compare adjacent letters, which is a little tricky with a `for` loop:

```
def is_abecedarian(word):
    previous = word[0]
    for c in word:
        if c < previous:
            return False
        previous = c
    return True
```

An alternative is to use recursion:

```
def is_abecedarian(word):
    if len(word) <= 1:
        return True
    if word[0] > word[1]:
        return False
    return is_abecedarian(word[1:])
```

Another option is to use a `while` loop:

```
def is_abecedarian(word):
    i = 0
    while i < len(word)-1:
        if word[i+1] < word[i]:
            return False
        i = i+1
    return True
```

The loop starts at `i=0` and ends when `i=len(word)-1`. Each time through the loop, it compares the i th character (which you can think of as the current character) to the $i + 1$ th character (which you can think of as the next).

If the next character is less than (alphabetically before) the current one, then we have discovered a break in the abecedarian trend, and we return `False`.

If we get to the end of the loop without finding a fault, then the word passes the test. To convince yourself that the loop ends correctly, consider an example like 'flossy'. The length of the word is 6, so the last time the loop runs is when `i` is 4, which is the index of the second-to-last character. On the last iteration, it compares the second-to-last character to the last, which is what we want.

Here is a version of `is_palindrome` (see Exercise 6.3) that uses two indices; one starts at the beginning and goes up; the other starts at the end and goes down.

```
def is_palindrome(word):
    i = 0
    j = len(word)-1

    while i < j:
        if word[i] != word[j]:
```

```
        return False
    i = i+1
    j = j-1

    return True
```

Or we could reduce to a previously solved problem and write:

```
def is_palindrome(word):
    return is_reverse(word, word)
```

Using `is_reverse` from Section 8.11.

9.5. Debugging

Testing programs is hard. The functions in this chapter are relatively easy to test because you can check the results by hand. Even so, it is somewhere between difficult and impossible to choose a set of words that test for all possible errors.

Taking `has_no_e` as an example, there are two obvious cases to check: words that have an ‘e’ should return `False`, and words that don’t should return `True`. You should have no trouble coming up with one of each.

Within each case, there are some less obvious subcases. Among the words that have an “e”, you should test words with an “e” at the beginning, the end, and somewhere in the middle. You should test long words, short words, and very short words, like the empty string. The empty string is an example of a **special case**, which is one of the non-obvious cases where errors often lurk.

In addition to the test cases you generate, you can also test your program with a word list like `words.txt`. By scanning the output, you might be able to catch errors, but be careful: you might catch one kind of error (words that should not be included, but are) and not another (words that should be included, but aren’t).

In general, testing can help you find bugs, but it is not easy to generate a good set of test cases, and even if you do, you can’t be sure your program is correct. According to a legendary computer scientist:

Program testing can be used to show the presence of bugs, but never to show their absence!

— Edsger W. Dijkstra

9.6. Glossary

file object: A value that represents an open file.

reduction to a previously solved problem: A way of solving a problem by expressing it as an instance of a previously solved problem.

special case: A test case that is atypical or non-obvious (and less likely to be handled correctly).

9.7. Exercises

Ejercicio 9.7. This question is based on a Puzzler that was broadcast on the radio program Car Talk (<http://www.cartalk.com/content/puzzlers>):

Give me a word with three consecutive double letters. I'll give you a couple of words that almost qualify, but don't. For example, the word committee, c-o-m-m-i-t-t-e-e. It would be great except for the 'i' that sneaks in there. Or Mississippi: M-i-s-s-i-s-s-i-p-p-i. If you could take out those i's it would work. But there is a word that has three consecutive pairs of letters and to the best of my knowledge this may be the only word. Of course there are probably 500 more but I can only think of one. What is the word?

Write a program to find it. Solution: <http://thinkpython2.com/code/cartalk1.py>.

Ejercicio 9.8. Here's another Car Talk Puzzler (<http://www.cartalk.com/content/puzzlers>):

"I was driving on the highway the other day and I happened to notice my odometer. Like most odometers, it shows six digits, in whole miles only. So, if my car had 300,000 miles, for example, I'd see 3-0-0-0-0-0.

"Now, what I saw that day was very interesting. I noticed that the last 4 digits were palindromic; that is, they read the same forward as backward. For example, 5-4-4-5 is a palindrome, so my odometer could have read 3-1-5-4-4-5.

"One mile later, the last 5 numbers were palindromic. For example, it could have read 3-6-5-4-5-6. One mile after that, the middle 4 out of 6 numbers were palindromic. And you ready for this? One mile later, all 6 were palindromic!

"The question is, what was on the odometer when I first looked?"

Write a Python program that tests all the six-digit numbers and prints any numbers that satisfy these requirements. Solution: <http://thinkpython2.com/code/cartalk2.py>.

Ejercicio 9.9. Here's another Car Talk Puzzler you can solve with a search (<http://www.cartalk.com/content/puzzlers>):

"Recently I had a visit with my mom and we realized that the two digits that make up my age when reversed resulted in her age. For example, if she's 73, I'm 37. We wondered how often this has happened over the years but we got sidetracked with other topics and we never came up with an answer.

"When I got home I figured out that the digits of our ages have been reversible six times so far. I also figured out that if we're lucky it would happen again in a few years, and if we're really lucky it would happen one more time after that. In other words, it would have happened 8 times over all. So the question is, how old am I now?"

Write a Python program that searches for solutions to this Puzzler. Hint: you might find the string method `zfill` useful.

Solution: <http://thinkpython2.com/code/cartalk3.py>.

Capítulo 10

Lists

This chapter presents one of Python's most useful built-in types, lists. You will also learn more about objects and what can happen when you have more than one name for the same object.

10.1. A list is a sequence

Like a string, a **list** is a sequence of values. In a string, the values are characters; in a list, they can be any type. The values in a list are called **elements** or sometimes **items**.

There are several ways to create a new list; the simplest is to enclose the elements in square brackets ([and]):

```
[10, 20, 30, 40]
['crunchy frog', 'ram bladder', 'lark vomit']
```

The first example is a list of four integers. The second is a list of three strings. The elements of a list don't have to be the same type. The following list contains a string, a float, an integer, and (lo!) another list:

```
['spam', 2.0, 5, [10, 20]]
```

A list within another list is **nested**.

A list that contains no elements is called an empty list; you can create one with empty brackets, [].

As you might expect, you can assign list values to variables:

```
>>> cheeses = ['Cheddar', 'Edam', 'Gouda']
>>> numbers = [42, 123]
>>> empty = []
>>> print(cheeses, numbers, empty)
['Cheddar', 'Edam', 'Gouda'] [42, 123] []
```

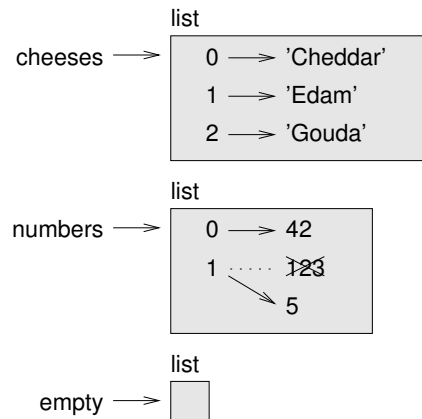


Figura 10.1: State diagram.

10.2. Lists are mutable

The syntax for accessing the elements of a list is the same as for accessing the characters of a string—the bracket operator. The expression inside the brackets specifies the index. Remember that the indices start at 0:

```
>>> cheeses[0]
'Cheddar'
```

Unlike strings, lists are mutable. When the bracket operator appears on the left side of an assignment, it identifies the element of the list that will be assigned.

```
>>> numbers = [42, 123]
>>> numbers[1] = 5
>>> numbers
[42, 5]
```

The one-eth element of `numbers`, which used to be 123, is now 5.

Figure 10.1 shows the state diagram for `cheeses`, `numbers` and `empty`:

Lists are represented by boxes with the word “list” outside and the elements of the list inside. `cheeses` refers to a list with three elements indexed 0, 1 and 2. `numbers` contains two elements; the diagram shows that the value of the second element has been reassigned from 123 to 5. `empty` refers to a list with no elements.

List indices work the same way as string indices:

- Any integer expression can be used as an index.
- If you try to read or write an element that does not exist, you get an `IndexError`.
- If an index has a negative value, it counts backward from the end of the list.

The `in` operator also works on lists.

```
>>> cheeses = ['Cheddar', 'Edam', 'Gouda']
>>> 'Edam' in cheeses
True
>>> 'Brie' in cheeses
False
```


10.3. Traversing a list

The most common way to traverse the elements of a list is with a `for` loop. The syntax is the same as for strings:

```
for cheese in cheeses:
    print(cheese)
```

This works well if you only need to read the elements of the list. But if you want to write or update the elements, you need the indices. A common way to do that is to combine the built-in functions `range` and `len`:

```
for i in range(len(numbers)):
    numbers[i] = numbers[i] * 2
```

This loop traverses the list and updates each element. `len` returns the number of elements in the list. `range` returns a list of indices from 0 to $n - 1$, where n is the length of the list. Each time through the loop `i` gets the index of the next element. The assignment statement in the body uses `i` to read the old value of the element and to assign the new value.

A `for` loop over an empty list never runs the body:

```
for x in []:
    print('This never happens.')
```

Although a list can contain another list, the nested list still counts as a single element. The length of this list is four:

```
['spam', 1, ['Brie', 'Roquefort', 'Pol le Veq'], [1, 2, 3]]
```

10.4. List operations

The `+` operator concatenates lists:

```
>>> a = [1, 2, 3]
>>> b = [4, 5, 6]
>>> c = a + b
>>> c
[1, 2, 3, 4, 5, 6]
```

The `*` operator repeats a list a given number of times:

```
>>> [0] * 4
[0, 0, 0, 0]
>>> [1, 2, 3] * 3
[1, 2, 3, 1, 2, 3, 1, 2, 3]
```

The first example repeats `[0]` four times. The second example repeats the list `[1, 2, 3]` three times.

10.5. List slices

The slice operator also works on lists:

```
>>> t = ['a', 'b', 'c', 'd', 'e', 'f']
>>> t[1:3]
['b', 'c']
>>> t[:4]
['a', 'b', 'c', 'd']
>>> t[3:]
['d', 'e', 'f']
```

If you omit the first index, the slice starts at the beginning. If you omit the second, the slice goes to the end. So if you omit both, the slice is a copy of the whole list.

```
>>> t[:]
['a', 'b', 'c', 'd', 'e', 'f']
```

Since lists are mutable, it is often useful to make a copy before performing operations that modify lists.

A slice operator on the left side of an assignment can update multiple elements:

```
>>> t = ['a', 'b', 'c', 'd', 'e', 'f']
>>> t[1:3] = ['x', 'y']
>>> t
['a', 'x', 'y', 'd', 'e', 'f']
```

10.6. List methods

Python provides methods that operate on lists. For example, `append` adds a new element to the end of a list:

```
>>> t = ['a', 'b', 'c']
>>> t.append('d')
>>> t
['a', 'b', 'c', 'd']
```

`extend` takes a list as an argument and appends all of the elements:

```
>>> t1 = ['a', 'b', 'c']
>>> t2 = ['d', 'e']
>>> t1.extend(t2)
>>> t1
['a', 'b', 'c', 'd', 'e']
```

This example leaves `t2` unmodified.

`sort` arranges the elements of the list from low to high:

```
>>> t = ['d', 'c', 'e', 'b', 'a']
>>> t.sort()
>>> t
['a', 'b', 'c', 'd', 'e']
```

Most list methods are void; they modify the list and return `None`. If you accidentally write `t = t.sort()`, you will be disappointed with the result.

10.7. Map, filter and reduce

To add up all the numbers in a list, you can use a loop like this:

```
def add_all(t):
    total = 0
    for x in t:
        total += x
    return total
```

`total` is initialized to 0. Each time through the loop, `x` gets one element from the list. The `+=` operator provides a short way to update a variable. This **augmented assignment statement**,

```
total += x
```

is equivalent to

```
total = total + x
```

As the loop runs, `total` accumulates the sum of the elements; a variable used this way is sometimes called an **accumulator**.

Adding up the elements of a list is such a common operation that Python provides it as a built-in function, `sum`:

```
>>> t = [1, 2, 3]
>>> sum(t)
6
```

An operation like this that combines a sequence of elements into a single value is sometimes called **reduce**.

Sometimes you want to traverse one list while building another. For example, the following function takes a list of strings and returns a new list that contains capitalized strings:

```
def capitalize_all(t):
    res = []
    for s in t:
        res.append(s.capitalize())
    return res
```

`res` is initialized with an empty list; each time through the loop, we append the next element. So `res` is another kind of accumulator.

An operation like `capitalize_all` is sometimes called a **map** because it “maps” a function (in this case the method `capitalize`) onto each of the elements in a sequence.

Another common operation is to select some of the elements from a list and return a sublist. For example, the following function takes a list of strings and returns a list that contains only the uppercase strings:

```
def only_upper(t):
    res = []
    for s in t:
        if s.isupper():
            res.append(s)
    return res
```

`isupper` is a string method that returns `True` if the string contains only upper case letters.

An operation like `only_upper` is called a **filter** because it selects some of the elements and filters out the others.

Most common list operations can be expressed as a combination of `map`, `filter` and `reduce`.

10.8. Deleting elements

There are several ways to delete elements from a list. If you know the index of the element you want, you can use `pop`:

```
>>> t = ['a', 'b', 'c']
>>> x = t.pop(1)
>>> t
['a', 'c']
>>> x
'b'
```

`pop` modifies the list and returns the element that was removed. If you don't provide an index, it deletes and returns the last element.

If you don't need the removed value, you can use the `del` operator:

```
>>> t = ['a', 'b', 'c']
>>> del t[1]
>>> t
['a', 'c']
```

If you know the element you want to remove (but not the index), you can use `remove`:

```
>>> t = ['a', 'b', 'c']
>>> t.remove('b')
>>> t
['a', 'c']
```

The return value from `remove` is `None`.

To remove more than one element, you can use `del` with a slice index:

```
>>> t = ['a', 'b', 'c', 'd', 'e', 'f']
>>> del t[1:5]
>>> t
['a', 'f']
```

As usual, the slice selects all the elements up to but not including the second index.

10.9. Lists and strings

A string is a sequence of characters and a list is a sequence of values, but a list of characters is not the same as a string. To convert from a string to a list of characters, you can use `list`:

```
>>> s = 'spam'
>>> t = list(s)
>>> t
['s', 'p', 'a', 'm']
```

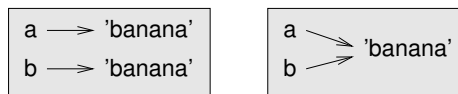


Figura 10.2: State diagram.

Because `list` is the name of a built-in function, you should avoid using it as a variable name. I also avoid `l` because it looks too much like `1`. So that's why I use `t`.

The `list` function breaks a string into individual letters. If you want to break a string into words, you can use the `split` method:

```
>>> s = 'pining for the fjords'
>>> t = s.split()
>>> t
['pining', 'for', 'the', 'fjords']
```

An optional argument called a **delimiter** specifies which characters to use as word boundaries. The following example uses a hyphen as a delimiter:

```
>>> s = 'spam-spam-spam'
>>> delimiter = '-'
>>> t = s.split(delimiter)
>>> t
['spam', 'spam', 'spam']
```

`join` is the inverse of `split`. It takes a list of strings and concatenates the elements. `join` is a string method, so you have to invoke it on the delimiter and pass the list as a parameter:

```
>>> t = ['pining', 'for', 'the', 'fjords']
>>> delimiter = ' '
>>> s = delimiter.join(t)
>>> s
'pining for the fjords'
```

In this case the delimiter is a space character, so `join` puts a space between words. To concatenate strings without spaces, you can use the empty string, `' '`, as a delimiter.

10.10. Objects and values

If we run these assignment statements:

```
a = 'banana'
b = 'banana'
```

We know that `a` and `b` both refer to a string, but we don't know whether they refer to the *same* string. There are two possible states, shown in Figure 10.2.

In one case, `a` and `b` refer to two different objects that have the same value. In the second case, they refer to the same object.

To check whether two variables refer to the same object, you can use the `is` operator.

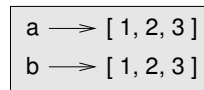


Figura 10.3: State diagram.

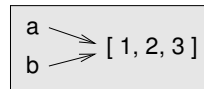


Figura 10.4: State diagram.

```

>>> a = 'banana'
>>> b = 'banana'
>>> a is b
True

```

In this example, Python only created one string object, and both `a` and `b` refer to it. But when you create two lists, you get two objects:

```

>>> a = [1, 2, 3]
>>> b = [1, 2, 3]
>>> a is b
False

```

So the state diagram looks like Figure 10.3.

In this case we would say that the two lists are **equivalent**, because they have the same elements, but not **identical**, because they are not the same object. If two objects are identical, they are also equivalent, but if they are equivalent, they are not necessarily identical.

Until now, we have been using “object” and “value” interchangeably, but it is more precise to say that an object has a value. If you evaluate `[1, 2, 3]`, you get a list object whose value is a sequence of integers. If another list has the same elements, we say it has the same value, but it is not the same object.

10.11. Aliasing

If `a` refers to an object and you assign `b = a`, then both variables refer to the same object:

```

>>> a = [1, 2, 3]
>>> b = a
>>> b is a
True

```

The state diagram looks like Figure 10.4.

The association of a variable with an object is called a **reference**. In this example, there are two references to the same object.

An object with more than one reference has more than one name, so we say that the object is **aliased**.

If the aliased object is mutable, changes made with one alias affect the other:

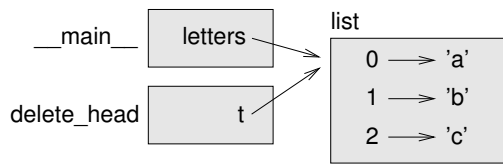


Figura 10.5: Stack diagram.

```

>>> b[0] = 42
>>> a
[42, 2, 3]

```

Although this behavior can be useful, it is error-prone. In general, it is safer to avoid aliasing when you are working with mutable objects.

For immutable objects like strings, aliasing is not as much of a problem. In this example:

```

a = 'banana'
b = 'banana'

```

It almost never makes a difference whether `a` and `b` refer to the same string or not.

10.12. List arguments

When you pass a list to a function, the function gets a reference to the list. If the function modifies the list, the caller sees the change. For example, `delete_head` removes the first element from a list:

```

def delete_head(t):
    del t[0]

```

Here's how it is used:

```

>>> letters = ['a', 'b', 'c']
>>> delete_head(letters)
>>> letters
['b', 'c']

```

The parameter `t` and the variable `letters` are aliases for the same object. The stack diagram looks like Figure 10.5.

Since the list is shared by two frames, I drew it between them.

It is important to distinguish between operations that modify lists and operations that create new lists. For example, the `append` method modifies a list, but the `+` operator creates a new list.

Here's an example using `append`:

```

>>> t1 = [1, 2]
>>> t2 = t1.append(3)
>>> t1
[1, 2, 3]
>>> t2
None

```

The return value from `append` is `None`.

Here's an example using the `+` operator:

```
>>> t3 = t1 + [4]
>>> t1
[1, 2, 3]
>>> t3
[1, 2, 3, 4]
```

The result of the operator is a new list, and the original list is unchanged.

This difference is important when you write functions that are supposed to modify lists. For example, this function *does not* delete the head of a list:

```
def bad_delete_head(t):
    t = t[1:]          # WRONG!
```

The slice operator creates a new list and the assignment makes `t` refer to it, but that doesn't affect the caller.

```
>>> t4 = [1, 2, 3]
>>> bad_delete_head(t4)
>>> t4
[1, 2, 3]
```

At the beginning of `bad_delete_head`, `t` and `t4` refer to the same list. At the end, `t` refers to a new list, but `t4` still refers to the original, unmodified list.

An alternative is to write a function that creates and returns a new list. For example, `tail` returns all but the first element of a list:

```
def tail(t):
    return t[1:]
```

This function leaves the original list unmodified. Here's how it is used:

```
>>> letters = ['a', 'b', 'c']
>>> rest = tail(letters)
>>> rest
['b', 'c']
```

10.13. Debugging

Careless use of lists (and other mutable objects) can lead to long hours of debugging. Here are some common pitfalls and ways to avoid them:

1. Most list methods modify the argument and return `None`. This is the opposite of the string methods, which return a new string and leave the original alone.

If you are used to writing string code like this:

```
word = word.strip()
```

It is tempting to write list code like this:


```
t = t.sort()          # WRONG!
```

Because `sort` returns `None`, the next operation you perform with `t` is likely to fail.

Before using list methods and operators, you should read the documentation carefully and then test them in interactive mode.

2. Pick an idiom and stick with it.

Part of the problem with lists is that there are too many ways to do things. For example, to remove an element from a list, you can use `pop`, `remove`, `del`, or even a slice assignment.

To add an element, you can use the `append` method or the `+` operator. Assuming that `t` is a list and `x` is a list element, these are correct:

```
t.append(x)
t = t + [x]
t += [x]
```

And these are wrong:

```
t.append([x])          # WRONG!
t = t.append(x)         # WRONG!
t + [x]                 # WRONG!
t = t + x               # WRONG!
```

Try out each of these examples in interactive mode to make sure you understand what they do. Notice that only the last one causes a runtime error; the other three are legal, but they do the wrong thing.

3. Make copies to avoid aliasing.

If you want to use a method like `sort` that modifies the argument, but you need to keep the original list as well, you can make a copy.

```
>>> t = [3, 1, 2]
>>> t2 = t[:]
>>> t2.sort()
>>> t
[3, 1, 2]
>>> t2
[1, 2, 3]
```

In this example you could also use the built-in function `sorted`, which returns a new, sorted list and leaves the original alone.

```
>>> t2 = sorted(t)
>>> t
[3, 1, 2]
>>> t2
[1, 2, 3]
```

10.14. Glossary

list: A sequence of values.

element: One of the values in a list (or other sequence), also called items.

nested list: A list that is an element of another list.

accumulator: A variable used in a loop to add up or accumulate a result.

augmented assignment: A statement that updates the value of a variable using an operator like +=.

reduce: A processing pattern that traverses a sequence and accumulates the elements into a single result.

map: A processing pattern that traverses a sequence and performs an operation on each element.

filter: A processing pattern that traverses a list and selects the elements that satisfy some criterion.

object: Something a variable can refer to. An object has a type and a value.

equivalent: Having the same value.

identical: Being the same object (which implies equivalence).

reference: The association between a variable and its value.

aliasing: A circumstance where two or more variables refer to the same object.

delimiter: A character or string used to indicate where a string should be split.

10.15. Exercises

You can download solutions to these exercises from http://thinkpython2.com/code/list_exercises.py.

Ejercicio 10.1. Write a function called `nested_sum` that takes a list of lists of integers and adds up the elements from all of the nested lists. For example:

```
>>> t = [[1, 2], [3], [4, 5, 6]]
>>> nested_sum(t)
21
```

Ejercicio 10.2. Write a function called `cumsum` that takes a list of numbers and returns the cumulative sum; that is, a new list where the *i*th element is the sum of the first *i* + 1 elements from the original list. For example:

```
>>> t = [1, 2, 3]
>>> cumsum(t)
[1, 3, 6]
```

Ejercicio 10.3. Write a function called `middle` that takes a list and returns a new list that contains all but the first and last elements. For example:

```
>>> t = [1, 2, 3, 4]
>>> middle(t)
[2, 3]
```

Ejercicio 10.4. Write a function called `chop` that takes a list, modifies it by removing the first and last elements, and returns `None`. For example:

```
>>> t = [1, 2, 3, 4]
>>> chop(t)
>>> t
[2, 3]
```

Ejercicio 10.5. Write a function called `is_sorted` that takes a list as a parameter and returns `True` if the list is sorted in ascending order and `False` otherwise. For example:

```
>>> is_sorted([1, 2, 2])
True
>>> is_sorted(['b', 'a'])
False
```

Ejercicio 10.6. Two words are anagrams if you can rearrange the letters from one to spell the other. Write a function called `is_anagram` that takes two strings and returns `True` if they are anagrams.

Ejercicio 10.7. Write a function called `has_duplicates` that takes a list and returns `True` if there is any element that appears more than once. It should not modify the original list.

Ejercicio 10.8. This exercise pertains to the so-called Birthday Paradox, which you can read about at http://en.wikipedia.org/wiki/Birthday_paradox.

If there are 23 students in your class, what are the chances that two of you have the same birthday? You can estimate this probability by generating random samples of 23 birthdays and checking for matches. Hint: you can generate random birthdays with the `randint` function in the `random` module.

You can download my solution from <http://thinkpython2.com/code/birthday.py>.

Ejercicio 10.9. Write a function that reads the file `words.txt` and builds a list with one element per word. Write two versions of this function, one using the `append` method and the other using the idiom `t = t + [x]`. Which one takes longer to run? Why?

Solution: <http://thinkpython2.com/code/wordlist.py>.

Ejercicio 10.10. To check whether a word is in the word list, you could use the `in` operator, but it would be slow because it searches through the words in order.

Because the words are in alphabetical order, we can speed things up with a bisection search (also known as binary search), which is similar to what you do when you look a word up in the dictionary (the book, not the data structure). You start in the middle and check to see whether the word you are looking for comes before the word in the middle of the list. If so, you search the first half of the list the same way. Otherwise you search the second half.

Either way, you cut the remaining search space in half. If the word list has 113,809 words, it will take about 17 steps to find the word or conclude that it's not there.

Write a function called `in_bisect` that takes a sorted list and a target value and returns `True` if the word is in the list and `False` if it's not.

Or you could read the documentation of the `bisect` module and use that! Solution: <http://thinkpython2.com/code/inlist.py>.

Ejercicio 10.11. Two words are a “reverse pair” if each is the reverse of the other. Write a program that finds all the reverse pairs in the word list. Solution: http://thinkpython2.com/code/reverse_pair.py.

Ejercicio 10.12. Two words “interlock” if taking alternating letters from each forms a new word. For example, “shoe” and “cold” interlock to form “schooled”. Solution: <http://thinkpython2.com/code/interlock.py>.

com/code/interlock.py. Credit: This exercise is inspired by an example at <http://puzzlers.org>.

- 1. Write a program that finds all pairs of words that interlock. Hint: don't enumerate all pairs!*
- 2. Can you find any words that are three-way interlocked; that is, every third letter forms a word, starting from the first, second or third?*

Capítulo 11

Dictionaries

This chapter presents another built-in type called a dictionary. Dictionaries are one of Python's best features; they are the building blocks of many efficient and elegant algorithms.

11.1. A dictionary is a mapping

A **dictionary** is like a list, but more general. In a list, the indices have to be integers; in a dictionary they can be (almost) any type.

A dictionary contains a collection of indices, which are called **keys**, and a collection of values. Each key is associated with a single value. The association of a key and a value is called a **key-value pair** or sometimes an **item**.

In mathematical language, a dictionary represents a **mapping** from keys to values, so you can also say that each key “maps to” a value. As an example, we'll build a dictionary that maps from English to Spanish words, so the keys and the values are all strings.

The function `dict` creates a new dictionary with no items. Because `dict` is the name of a built-in function, you should avoid using it as a variable name.

```
>>> eng2sp = dict()
>>> eng2sp
{}
```

The squiggly-brackets, `{}`, represent an empty dictionary. To add items to the dictionary, you can use square brackets:

```
>>> eng2sp['one'] = 'uno'
```

This line creates an item that maps from the key `'one'` to the value `'uno'`. If we print the dictionary again, we see a key-value pair with a colon between the key and value:

```
>>> eng2sp
{'one': 'uno'}
```

This output format is also an input format. For example, you can create a new dictionary with three items:

```
>>> eng2sp = {'one': 'uno', 'two': 'dos', 'three': 'tres'}
```

But if you print `eng2sp`, you might be surprised:

```
>>> eng2sp
{'one': 'uno', 'three': 'tres', 'two': 'dos'}
```

The order of the key-value pairs might not be the same. If you type the same example on your computer, you might get a different result. In general, the order of items in a dictionary is unpredictable.

But that's not a problem because the elements of a dictionary are never indexed with integer indices. Instead, you use the keys to look up the corresponding values:

```
>>> eng2sp['two']
'dos'
```

The key `'two'` always maps to the value `'dos'` so the order of the items doesn't matter.

If the key isn't in the dictionary, you get an exception:

```
>>> eng2sp['four']
KeyError: 'four'
```

The `len` function works on dictionaries; it returns the number of key-value pairs:

```
>>> len(eng2sp)
3
```

The `in` operator works on dictionaries, too; it tells you whether something appears as a *key* in the dictionary (appearing as a value is not good enough).

```
>>> 'one' in eng2sp
True
>>> 'uno' in eng2sp
False
```

To see whether something appears as a value in a dictionary, you can use the method `values`, which returns a collection of values, and then use the `in` operator:

```
>>> vals = eng2sp.values()
>>> 'uno' in vals
True
```

The `in` operator uses different algorithms for lists and dictionaries. For lists, it searches the elements of the list in order, as in Section 8.6. As the list gets longer, the search time gets longer in direct proportion.

Python dictionaries use a data structure called a **hashtable** that has a remarkable property: the `in` operator takes about the same amount of time no matter how many items are in the dictionary. I explain how that's possible in Section B.4, but the explanation might not make sense until you've read a few more chapters.

11.2. Dictionary as a collection of counters

Suppose you are given a string and you want to count how many times each letter appears. There are several ways you could do it:

1. You could create 26 variables, one for each letter of the alphabet. Then you could traverse the string and, for each character, increment the corresponding counter, probably using a chained conditional.

2. You could create a list with 26 elements. Then you could convert each character to a number (using the built-in function `ord`), use the number as an index into the list, and increment the appropriate counter.
3. You could create a dictionary with characters as keys and counters as the corresponding values. The first time you see a character, you would add an item to the dictionary. After that you would increment the value of an existing item.

Each of these options performs the same computation, but each of them implements that computation in a different way.

An **implementation** is a way of performing a computation; some implementations are better than others. For example, an advantage of the dictionary implementation is that we don't have to know ahead of time which letters appear in the string and we only have to make room for the letters that do appear.

Here is what the code might look like:

```
def histogram(s):
    d = dict()
    for c in s:
        if c not in d:
            d[c] = 1
        else:
            d[c] += 1
    return d
```

The name of the function is `histogram`, which is a statistical term for a collection of counters (or frequencies).

The first line of the function creates an empty dictionary. The `for` loop traverses the string. Each time through the loop, if the character `c` is not in the dictionary, we create a new item with key `c` and the initial value 1 (since we have seen this letter once). If `c` is already in the dictionary we increment `d[c]`.

Here's how it works:

```
>>> h = histogram('brontosaurus')
>>> h
{'a': 1, 'b': 1, 'o': 2, 'n': 1, 's': 2, 'r': 2, 'u': 2, 't': 1}
```

The histogram indicates that the letters 'a' and 'b' appear once; 'o' appears twice, and so on.

Dictionaries have a method called `get` that takes a key and a default value. If the key appears in the dictionary, `get` returns the corresponding value; otherwise it returns the default value. For example:

```
>>> h = histogram('a')
>>> h
{'a': 1}
>>> h.get('a', 0)
1
>>> h.get('c', 0)
0
```

As an exercise, use `get` to write `histogram` more concisely. You should be able to eliminate the `if` statement.

11.3. Looping and dictionaries

If you use a dictionary in a `for` statement, it traverses the keys of the dictionary. For example, `print_hist` prints each key and the corresponding value:

```
def print_hist(h):
    for c in h:
        print(c, h[c])
```

Here's what the output looks like:

```
>>> h = histogram('parrot')
>>> print_hist(h)
a 1
p 1
r 2
t 1
o 1
```

Again, the keys are in no particular order. To traverse the keys in sorted order, you can use the built-in function `sorted`:

```
>>> for key in sorted(h):
...     print(key, h[key])
a 1
o 1
p 1
r 2
t 1
```

11.4. Reverse lookup

Given a dictionary `d` and a key `k`, it is easy to find the corresponding value `v = d[k]`. This operation is called a **lookup**.

But what if you have `v` and you want to find `k`? You have two problems: first, there might be more than one key that maps to the value `v`. Depending on the application, you might be able to pick one, or you might have to make a list that contains all of them. Second, there is no simple syntax to do a **reverse lookup**; you have to search.

Here is a function that takes a value and returns the first key that maps to that value:

```
def reverse_lookup(d, v):
    for k in d:
        if d[k] == v:
            return k
    raise LookupError()
```

This function is yet another example of the search pattern, but it uses a feature we haven't seen before, `raise`. The **raise statement** causes an exception; in this case it causes a `LookupError`, which is a built-in exception used to indicate that a lookup operation failed.

If we get to the end of the loop, that means `v` doesn't appear in the dictionary as a value, so we raise an exception.

Here is an example of a successful reverse lookup:


```
>>> h = histogram('parrot')
>>> key = reverse_lookup(h, 2)
>>> key
'r'
```

And an unsuccessful one:

```
>>> key = reverse_lookup(h, 3)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "<stdin>", line 5, in reverse_lookup
LookupError
```

The effect when you raise an exception is the same as when Python raises one: it prints a traceback and an error message.

When you raise an exception, you can provide a detailed error message as an optional argument. For example:

```
>>> raise LookupError('value does not appear in the dictionary')
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
LookupError: value does not appear in the dictionary
```

A reverse lookup is much slower than a forward lookup; if you have to do it often, or if the dictionary gets big, the performance of your program will suffer.

11.5. Dictionaries and lists

Lists can appear as values in a dictionary. For example, if you are given a dictionary that maps from letters to frequencies, you might want to invert it; that is, create a dictionary that maps from frequencies to letters. Since there might be several letters with the same frequency, each value in the inverted dictionary should be a list of letters.

Here is a function that inverts a dictionary:

```
def invert_dict(d):
    inverse = dict()
    for key in d:
        val = d[key]
        if val not in inverse:
            inverse[val] = [key]
        else:
            inverse[val].append(key)
    return inverse
```

Each time through the loop, `key` gets a key from `d` and `val` gets the corresponding value. If `val` is not in `inverse`, that means we haven't seen it before, so we create a new item and initialize it with a **singleton** (a list that contains a single element). Otherwise we have seen this value before, so we append the corresponding key to the list.

Here is an example:

```
>>> hist = histogram('parrot')
>>> hist
```



Figura 11.1: State diagram.

```

{'a': 1, 'p': 1, 'r': 2, 't': 1, 'o': 1}
>>> inverse = invert_dict(hist)
>>> inverse
{1: ['a', 'p', 't', 'o'], 2: ['r']}

```

Figure 11.1 is a state diagram showing `hist` and `inverse`. A dictionary is represented as a box with the type `dict` above it and the key-value pairs inside. If the values are integers, floats or strings, I draw them inside the box, but I usually draw lists outside the box, just to keep the diagram simple.

Lists can be values in a dictionary, as this example shows, but they cannot be keys. Here's what happens if you try:

```

>>> t = [1, 2, 3]
>>> d = dict()
>>> d[t] = 'oops'
Traceback (most recent call last):
  File "<stdin>", line 1, in ?
TypeError: list objects are unhashable

```

I mentioned earlier that a dictionary is implemented using a hashtable and that means that the keys have to be **hashable**.

A **hash** is a function that takes a value (of any kind) and returns an integer. Dictionaries use these integers, called hash values, to store and look up key-value pairs.

This system works fine if the keys are immutable. But if the keys are mutable, like lists, bad things happen. For example, when you create a key-value pair, Python hashes the key and stores it in the corresponding location. If you modify the key and then hash it again, it would go to a different location. In that case you might have two entries for the same key, or you might not be able to find a key. Either way, the dictionary wouldn't work correctly.

That's why keys have to be hashable, and why mutable types like lists aren't. The simplest way to get around this limitation is to use tuples, which we will see in the next chapter.

Since dictionaries are mutable, they can't be used as keys, but they *can* be used as values.

11.6. Memos

If you played with the `fibonacci` function from Section 6.7, you might have noticed that the bigger the argument you provide, the longer the function takes to run. Furthermore, the run time increases quickly.

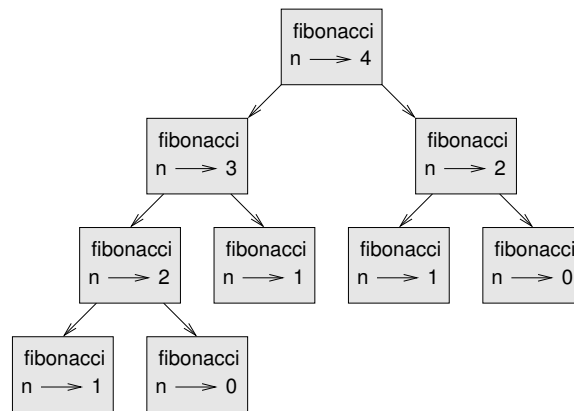


Figura 11.2: Call graph.

To understand why, consider Figure 11.2, which shows the **call graph** for `fibonacci` with `n=4`:

A call graph shows a set of function frames, with lines connecting each frame to the frames of the functions it calls. At the top of the graph, `fibonacci` with `n=4` calls `fibonacci` with `n=3` and `n=2`. In turn, `fibonacci` with `n=3` calls `fibonacci` with `n=2` and `n=1`. And so on.

Count how many times `fibonacci(0)` and `fibonacci(1)` are called. This is an inefficient solution to the problem, and it gets worse as the argument gets bigger.

One solution is to keep track of values that have already been computed by storing them in a dictionary. A previously computed value that is stored for later use is called a **memo**. Here is a “memoized” version of `fibonacci`:

```
known = {0:0, 1:1}

def fibonacci(n):
    if n in known:
        return known[n]

    res = fibonacci(n-1) + fibonacci(n-2)
    known[n] = res
    return res
```

`known` is a dictionary that keeps track of the Fibonacci numbers we already know. It starts with two items: 0 maps to 0 and 1 maps to 1.

Whenever `fibonacci` is called, it checks `known`. If the result is already there, it can return immediately. Otherwise it has to compute the new value, add it to the dictionary, and return it.

If you run this version of `fibonacci` and compare it with the original, you will find that it is much faster.

11.7. Global variables

In the previous example, `known` is created outside the function, so it belongs to the special frame called `__main__`. Variables in `__main__` are sometimes called **global** because they can be accessed from any function. Unlike local variables, which disappear when their function ends, global variables persist from one function call to the next.

It is common to use global variables for **flags**; that is, boolean variables that indicate (“flag”) whether a condition is true. For example, some programs use a flag named `verbose` to control the level of detail in the output:

```
verbose = True

def example1():
    if verbose:
        print('Running example1')
```

If you try to reassign a global variable, you might be surprised. The following example is supposed to keep track of whether the function has been called:

```
been_called = False

def example2():
    been_called = True          # WRONG
```

But if you run it you will see that the value of `been_called` doesn’t change. The problem is that `example2` creates a new local variable named `been_called`. The local variable goes away when the function ends, and has no effect on the global variable.

To reassign a global variable inside a function you have to **declare** the global variable before you use it:

```
been_called = False

def example2():
    global been_called
    been_called = True
```

The **global statement** tells the interpreter something like, “In this function, when I say `been_called`, I mean the global variable; don’t create a local one.”

Here’s an example that tries to update a global variable:

```
count = 0

def example3():
    count = count + 1          # WRONG
```

If you run it you get:

```
UnboundLocalError: local variable 'count' referenced before assignment
```

Python assumes that `count` is local, and under that assumption you are reading it before writing it. The solution, again, is to declare `count` global.

```
def example3():
    global count
    count += 1
```

If a global variable refers to a mutable value, you can modify the value without declaring the variable:

```
known = {0:0, 1:1}
```

```
def example4():  
    known[2] = 1
```

So you can add, remove and replace elements of a global list or dictionary, but if you want to reassign the variable, you have to declare it:

```
def example5():  
    global known  
    known = dict()
```

Global variables can be useful, but if you have a lot of them, and you modify them frequently, they can make programs hard to debug.

11.8. Debugging

As you work with bigger datasets it can become unwieldy to debug by printing and checking the output by hand. Here are some suggestions for debugging large datasets:

Scale down the input: If possible, reduce the size of the dataset. For example if the program reads a text file, start with just the first 10 lines, or with the smallest example you can find. You can either edit the files themselves, or (better) modify the program so it reads only the first *n* lines.

If there is an error, you can reduce *n* to the smallest value that manifests the error, and then increase it gradually as you find and correct errors.

Check summaries and types: Instead of printing and checking the entire dataset, consider printing summaries of the data: for example, the number of items in a dictionary or the total of a list of numbers.

A common cause of runtime errors is a value that is not the right type. For debugging this kind of error, it is often enough to print the type of a value.

Write self-checks: Sometimes you can write code to check for errors automatically. For example, if you are computing the average of a list of numbers, you could check that the result is not greater than the largest element in the list or less than the smallest. This is called a “sanity check” because it detects results that are “insane”.

Another kind of check compares the results of two different computations to see if they are consistent. This is called a “consistency check”.

Format the output: Formatting debugging output can make it easier to spot an error. We saw an example in Section 6.9. Another tool you might find useful is the `pprint` module, which provides a `pprint` function that displays built-in types in a more human-readable format (`pprint` stands for “pretty print”).

Again, time you spend building scaffolding can reduce the time you spend debugging.

11.9. Glossary

mapping: A relationship in which each element of one set corresponds to an element of another set.

dictionary: A mapping from keys to their corresponding values.

key-value pair: The representation of the mapping from a key to a value.

item: In a dictionary, another name for a key-value pair.

key: An object that appears in a dictionary as the first part of a key-value pair.

value: An object that appears in a dictionary as the second part of a key-value pair. This is more specific than our previous use of the word “value”.

implementation: A way of performing a computation.

hashtable: The algorithm used to implement Python dictionaries.

hash function: A function used by a hashtable to compute the location for a key.

hashable: A type that has a hash function. Immutable types like integers, floats and strings are hashable; mutable types like lists and dictionaries are not.

lookup: A dictionary operation that takes a key and finds the corresponding value.

reverse lookup: A dictionary operation that takes a value and finds one or more keys that map to it.

raise statement: A statement that (deliberately) raises an exception.

singleton: A list (or other sequence) with a single element.

call graph: A diagram that shows every frame created during the execution of a program, with an arrow from each caller to each callee.

memo: A computed value stored to avoid unnecessary future computation.

global variable: A variable defined outside a function. Global variables can be accessed from any function.

global statement: A statement that declares a variable name global.

flag: A boolean variable used to indicate whether a condition is true.

declaration: A statement like `global` that tells the interpreter something about a variable.

11.10. Exercises

Ejercicio 11.1. Write a function that reads the words in `words.txt` and stores them as keys in a dictionary. It doesn't matter what the values are. Then you can use the `in` operator as a fast way to check whether a string is in the dictionary.

If you did Exercise 10.10, you can compare the speed of this implementation with the list `in` operator and the bisection search.

Ejercicio 11.2. Read the documentation of the dictionary method `setdefault` and use it to write a more concise version of `invert_dict`. Solution: http://thinkpython2.com/code/invert_dict.py.

Ejercicio 11.3. Memoize the Ackermann function from Exercise 6.2 and see if memoization makes it possible to evaluate the function with bigger arguments. Hint: no. Solution: http://thinkpython2.com/code/ackermann_memo.py.

Ejercicio 11.4. If you did Exercise 10.7, you already have a function named `has_duplicates` that takes a list as a parameter and returns `True` if there is any object that appears more than once in the list.

Use a dictionary to write a faster, simpler version of `has_duplicates`. Solution: http://thinkpython2.com/code/has_duplicates.py.

Ejercicio 11.5. Two words are “rotate pairs” if you can rotate one of them and get the other (see `rotate_word` in Exercise 8.5).

Write a program that reads a wordlist and finds all the rotate pairs. Solution: http://thinkpython2.com/code/rotate_pairs.py.

Ejercicio 11.6. Here’s another Puzzler from Car Talk (<http://www.cartalk.com/content/puzzlers>):

This was sent in by a fellow named Dan O’Leary. He came upon a common one-syllable, five-letter word recently that has the following unique property. When you remove the first letter, the remaining letters form a homophone of the original word, that is a word that sounds exactly the same. Replace the first letter, that is, put it back and remove the second letter and the result is yet another homophone of the original word. And the question is, what’s the word?

Now I’m going to give you an example that doesn’t work. Let’s look at the five-letter word, ‘wrack.’ W-R-A-C-K, you know like to ‘wrack with pain.’ If I remove the first letter, I am left with a four-letter word, ‘R-A-C-K.’ As in, ‘Holy cow, did you see the rack on that buck! It must have been a nine-pointer!’ It’s a perfect homophone. If you put the ‘w’ back, and remove the ‘r,’ instead, you’re left with the word, ‘wack,’ which is a real word, it’s just not a homophone of the other two words.

But there is, however, at least one word that Dan and we know of, which will yield two homophones if you remove either of the first two letters to make two, new four-letter words. The question is, what’s the word?

You can use the dictionary from Exercise 11.1 to check whether a string is in the word list.

To check whether two words are homophones, you can use the CMU Pronouncing Dictionary. You can download it from <http://www.speech.cs.cmu.edu/cgi-bin/cmudict> or from <http://thinkpython2.com/code/c06d> and you can also download <http://thinkpython2.com/code/pronounce.py>, which provides a function named `read_dictionary` that reads the pronouncing dictionary and returns a Python dictionary that maps from each word to a string that describes its primary pronunciation.

Write a program that lists all the words that solve the Puzzler. Solution: <http://thinkpython2.com/code/homophone.py>.

Capítulo 12

Tuples

This chapter presents one more built-in type, the tuple, and then shows how lists, dictionaries, and tuples work together. I also present a useful feature for variable-length argument lists, the gather and scatter operators.

One note: there is no consensus on how to pronounce “tuple”. Some people say “tuh-ple”, which rhymes with “supple”. But in the context of programming, most people say “too-ple”, which rhymes with “quadruple”.

12.1. Tuples are immutable

A tuple is a sequence of values. The values can be any type, and they are indexed by integers, so in that respect tuples are a lot like lists. The important difference is that tuples are immutable.

Syntactically, a tuple is a comma-separated list of values:

```
>>> t = 'a', 'b', 'c', 'd', 'e'
```

Although it is not necessary, it is common to enclose tuples in parentheses:

```
>>> t = ('a', 'b', 'c', 'd', 'e')
```

To create a tuple with a single element, you have to include a final comma:

```
>>> t1 = 'a',  
>>> type(t1)  
<class 'tuple'>
```

A value in parentheses is not a tuple:

```
>>> t2 = ('a')  
>>> type(t2)  
<class 'str'>
```

Another way to create a tuple is the built-in function `tuple`. With no argument, it creates an empty tuple:

```
>>> t = tuple()  
>>> t  
()
```

If the argument is a sequence (string, list or tuple), the result is a tuple with the elements of the sequence:

```
>>> t = tuple('lupins')
>>> t
('l', 'u', 'p', 'i', 'n', 's')
```

Because `tuple` is the name of a built-in function, you should avoid using it as a variable name.

Most list operators also work on tuples. The bracket operator indexes an element:

```
>>> t = ('a', 'b', 'c', 'd', 'e')
>>> t[0]
'a'
```

And the slice operator selects a range of elements.

```
>>> t[1:3]
('b', 'c')
```

But if you try to modify one of the elements of the tuple, you get an error:

```
>>> t[0] = 'A'
TypeError: object doesn't support item assignment
```

Because tuples are immutable, you can't modify the elements. But you can replace one tuple with another:

```
>>> t = ('A',) + t[1:]
>>> t
('A', 'b', 'c', 'd', 'e')
```

This statement makes a new tuple and then makes `t` refer to it.

The relational operators work with tuples and other sequences; Python starts by comparing the first element from each sequence. If they are equal, it goes on to the next elements, and so on, until it finds elements that differ. Subsequent elements are not considered (even if they are really big).

```
>>> (0, 1, 2) < (0, 3, 4)
True
>>> (0, 1, 2000000) < (0, 3, 4)
True
```

12.2. Tuple assignment

It is often useful to swap the values of two variables. With conventional assignments, you have to use a temporary variable. For example, to swap `a` and `b`:

```
>>> temp = a
>>> a = b
>>> b = temp
```

This solution is cumbersome; **tuple assignment** is more elegant:

```
>>> a, b = b, a
```

The left side is a tuple of variables; the right side is a tuple of expressions. Each value is assigned to its respective variable. All the expressions on the right side are evaluated before any of the assignments.

The number of variables on the left and the number of values on the right have to be the same:

```
>>> a, b = 1, 2, 3
ValueError: too many values to unpack
```

More generally, the right side can be any kind of sequence (string, list or tuple). For example, to split an email address into a user name and a domain, you could write:

```
>>> addr = 'monty@python.org'
>>> uname, domain = addr.split('@')
```

The return value from `split` is a list with two elements; the first element is assigned to `uname`, the second to `domain`.

```
>>> uname
'monty'
>>> domain
'python.org'
```

12.3. Tuples as return values

Strictly speaking, a function can only return one value, but if the value is a tuple, the effect is the same as returning multiple values. For example, if you want to divide two integers and compute the quotient and remainder, it is inefficient to compute x/y and then $x\%y$. It is better to compute them both at the same time.

The built-in function `divmod` takes two arguments and returns a tuple of two values, the quotient and remainder. You can store the result as a tuple:

```
>>> t = divmod(7, 3)
>>> t
(2, 1)
```

Or use tuple assignment to store the elements separately:

```
>>> quot, rem = divmod(7, 3)
>>> quot
2
>>> rem
1
```

Here is an example of a function that returns a tuple:

```
def min_max(t):
    return min(t), max(t)
```

`max` and `min` are built-in functions that find the largest and smallest elements of a sequence. `min_max` computes both and returns a tuple of two values.

12.4. Variable-length argument tuples

Functions can take a variable number of arguments. A parameter name that begins with ***gatherers** arguments into a tuple. For example, `printall` takes any number of arguments and prints them:

```
def printall(*args):
    print(args)
```

The gather parameter can have any name you like, but `args` is conventional. Here's how the function works:

```
>>> printall(1, 2.0, '3')
(1, 2.0, '3')
```

The complement of gather is **scatter**. If you have a sequence of values and you want to pass it to a function as multiple arguments, you can use the `*` operator. For example, `divmod` takes exactly two arguments; it doesn't work with a tuple:

```
>>> t = (7, 3)
>>> divmod(t)
TypeError: divmod expected 2 arguments, got 1
```

But if you scatter the tuple, it works:

```
>>> divmod(*t)
(2, 1)
```

Many of the built-in functions use variable-length argument tuples. For example, `max` and `min` can take any number of arguments:

```
>>> max(1, 2, 3)
3
```

But `sum` does not.

```
>>> sum(1, 2, 3)
TypeError: sum expected at most 2 arguments, got 3
```

As an exercise, write a function called `sum_all` that takes any number of arguments and returns their sum.

12.5. Lists and tuples

`zip` is a built-in function that takes two or more sequences and interleaves them. The name of the function refers to a zipper, which interleaves two rows of teeth.

This example zips a string and a list:

```
>>> s = 'abc'
>>> t = [0, 1, 2]
>>> zip(s, t)
<zip object at 0x7f7d0a9e7c48>
```

The result is a **zip object** that knows how to iterate through the pairs. The most common use of `zip` is in a `for` loop:

```
>>> for pair in zip(s, t):
...     print(pair)
...
('a', 0)
('b', 1)
('c', 2)
```

A zip object is a kind of **iterator**, which is any object that iterates through a sequence. Iterators are similar to lists in some ways, but unlike lists, you can't use an index to select an element from an iterator.

If you want to use list operators and methods, you can use a zip object to make a list:

```
>>> list(zip(s, t))
[('a', 0), ('b', 1), ('c', 2)]
```

The result is a list of tuples; in this example, each tuple contains a character from the string and the corresponding element from the list.

If the sequences are not the same length, the result has the length of the shorter one.

```
>>> list(zip('Anne', 'Elk'))
[('A', 'E'), ('n', 'l'), ('n', 'k')]
```

You can use tuple assignment in a for loop to traverse a list of tuples:

```
t = [('a', 0), ('b', 1), ('c', 2)]
for letter, number in t:
    print(number, letter)
```

Each time through the loop, Python selects the next tuple in the list and assigns the elements to `letter` and `number`. The output of this loop is:

```
0 a
1 b
2 c
```

If you combine `zip`, `for` and tuple assignment, you get a useful idiom for traversing two (or more) sequences at the same time. For example, `has_match` takes two sequences, `t1` and `t2`, and returns `True` if there is an index `i` such that `t1[i] == t2[i]`:

```
def has_match(t1, t2):
    for x, y in zip(t1, t2):
        if x == y:
            return True
    return False
```

If you need to traverse the elements of a sequence and their indices, you can use the built-in function `enumerate`:

```
for index, element in enumerate('abc'):
    print(index, element)
```

The result from `enumerate` is an `enumerate` object, which iterates a sequence of pairs; each pair contains an index (starting from 0) and an element from the given sequence. In this example, the output is

```
0 a
1 b
2 c
```

Again.

12.6. Dictionaries and tuples

Dictionaries have a method called `items` that returns a sequence of tuples, where each tuple is a key-value pair.

```
>>> d = {'a':0, 'b':1, 'c':2}
>>> t = d.items()
>>> t
dict_items([('c', 2), ('a', 0), ('b', 1)])
```

The result is a `dict_items` object, which is an iterator that iterates the key-value pairs. You can use it in a `for` loop like this:

```
>>> for key, value in d.items():
...     print(key, value)
...
c 2
a 0
b 1
```

As you should expect from a dictionary, the items are in no particular order.

Going in the other direction, you can use a list of tuples to initialize a new dictionary:

```
>>> t = [('a', 0), ('c', 2), ('b', 1)]
>>> d = dict(t)
>>> d
{'a': 0, 'c': 2, 'b': 1}
```

Combining `dict` with `zip` yields a concise way to create a dictionary:

```
>>> d = dict(zip('abc', range(3)))
>>> d
{'a': 0, 'c': 2, 'b': 1}
```

The dictionary method `update` also takes a list of tuples and adds them, as key-value pairs, to an existing dictionary.

It is common to use tuples as keys in dictionaries (primarily because you can't use lists). For example, a telephone directory might map from last-name, first-name pairs to telephone numbers. Assuming that we have defined `last`, `first` and `number`, we could write:

```
directory[last, first] = number
```

The expression in brackets is a tuple. We could use tuple assignment to traverse this dictionary.

```
for last, first in directory:
    print(first, last, directory[last,first])
```

This loop traverses the keys in `directory`, which are tuples. It assigns the elements of each tuple to `last` and `first`, then prints the name and corresponding telephone number.

There are two ways to represent tuples in a state diagram. The more detailed version shows the indices and elements just as they appear in a list. For example, the tuple `('Cleese', 'John')` would appear as in Figure 12.1.

But in a larger diagram you might want to leave out the details. For example, a diagram of the telephone directory might appear as in Figure 12.2.

Here the tuples are shown using Python syntax as a graphical shorthand. The telephone number in the diagram is the complaints line for the BBC, so please don't call it.

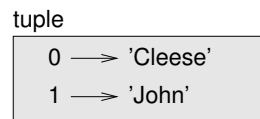


Figura 12.1: State diagram.

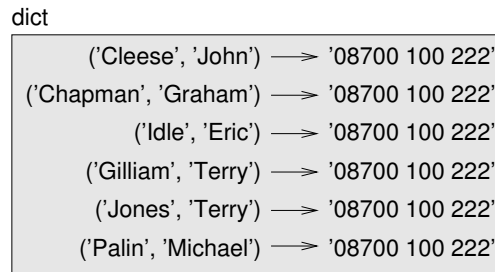


Figura 12.2: State diagram.

12.7. Sequences of sequences

I have focused on lists of tuples, but almost all of the examples in this chapter also work with lists of lists, tuples of tuples, and tuples of lists. To avoid enumerating the possible combinations, it is sometimes easier to talk about sequences of sequences.

In many contexts, the different kinds of sequences (strings, lists and tuples) can be used interchangeably. So how should you choose one over the others?

To start with the obvious, strings are more limited than other sequences because the elements have to be characters. They are also immutable. If you need the ability to change the characters in a string (as opposed to creating a new string), you might want to use a list of characters instead.

Lists are more common than tuples, mostly because they are mutable. But there are a few cases where you might prefer tuples:

1. In some contexts, like a return statement, it is syntactically simpler to create a tuple than a list.
2. If you want to use a sequence as a dictionary key, you have to use an immutable type like a tuple or string.
3. If you are passing a sequence as an argument to a function, using tuples reduces the potential for unexpected behavior due to aliasing.

Because tuples are immutable, they don't provide methods like `sort` and `reverse`, which modify existing lists. But Python provides the built-in function `sorted`, which takes any sequence and returns a new list with the same elements in sorted order, and `reversed`, which takes a sequence and returns an iterator that traverses the list in reverse order.

12.8. Debugging

Lists, dictionaries and tuples are examples of **data structures**; in this chapter we are starting to see compound data structures, like lists of tuples, or dictionaries that contain tuples as keys and lists as values. Compound data structures are useful, but they are prone to what I call **shape errors**; that is, errors caused when a data structure has the wrong type, size, or structure. For example, if you are expecting a list with one integer and I give you a plain old integer (not in a list), it won't work.

To help debug these kinds of errors, I have written a module called `structshape` that provides a function, also called `structshape`, that takes any kind of data structure as an argument and returns a string that summarizes its shape. You can download it from <http://thinkpython2.com/code/structshape.py>

Here's the result for a simple list:

```
>>> from structshape import structshape
>>> t = [1, 2, 3]
>>> structshape(t)
'list of 3 int'
```

A fancier program might write "list of 3 ints", but it was easier not to deal with plurals. Here's a list of lists:

```
>>> t2 = [[1,2], [3,4], [5,6]]
>>> structshape(t2)
'list of 3 list of 2 int'
```

If the elements of the list are not the same type, `structshape` groups them, in order, by type:

```
>>> t3 = [1, 2, 3, 4.0, '5', '6', [7], [8], 9]
>>> structshape(t3)
'list of (3 int, float, 2 str, 2 list of int, int)'
```

Here's a list of tuples:

```
>>> s = 'abc'
>>> lt = list(zip(t, s))
>>> structshape(lt)
'list of 3 tuple of (int, str)'
```

And here's a dictionary with 3 items that map integers to strings.

```
>>> d = dict(lt)
>>> structshape(d)
'dict of 3 int->str'
```

If you are having trouble keeping track of your data structures, `structshape` can help.

12.9. Glossary

tuple: An immutable sequence of elements.

tuple assignment: An assignment with a sequence on the right side and a tuple of variables on the left. The right side is evaluated and then its elements are assigned to the variables on the left.

gather: An operation that collects multiple arguments into a tuple.

scatter: An operation that makes a sequence behave like multiple arguments.

zip object: The result of calling a built-in function `zip`; an object that iterates through a sequence of tuples.

iterator: An object that can iterate through a sequence, but which does not provide list operators and methods.

data structure: A collection of related values, often organized in lists, dictionaries, tuples, etc.

shape error: An error caused because a value has the wrong shape; that is, the wrong type or size.

12.10. Exercises

Ejercicio 12.1. Write a function called `most_frequent` that takes a string and prints the letters in decreasing order of frequency. Find text samples from several different languages and see how letter frequency varies between languages. Compare your results with the tables at http://en.wikipedia.org/wiki/Letter_frequencies. Solution: http://thinkpython2.com/code/most_frequent.py.

Ejercicio 12.2. More anagrams!

1. Write a program that reads a word list from a file (see Section 9.1) and prints all the sets of words that are anagrams.

Here is an example of what the output might look like:

```
['deltas', 'desalt', 'lasted', 'salted', 'slated', 'staled']
['retainers', 'ternaries']
['generating', 'greatening']
['resmelts', 'smelters', 'termless']
```

Hint: you might want to build a dictionary that maps from a collection of letters to a list of words that can be spelled with those letters. The question is, how can you represent the collection of letters in a way that can be used as a key?

2. Modify the previous program so that it prints the longest list of anagrams first, followed by the second longest, and so on.
3. In Scrabble a “bingo” is when you play all seven tiles in your rack, along with a letter on the board, to form an eight-letter word. What collection of 8 letters forms the most possible bingos?

Solution: http://thinkpython2.com/code/anagram_sets.py.

Ejercicio 12.3. Two words form a “metathesis pair” if you can transform one into the other by swapping two letters; for example, “converse” and “conserve”. Write a program that finds all of the metathesis pairs in the dictionary. Hint: don’t test all pairs of words, and don’t test all possible swaps. Solution: <http://thinkpython2.com/code/metathesis.py>. Credit: This exercise is inspired by an example at <http://puzzlers.org>.

Ejercicio 12.4. Here's another Car Talk Puzzler (<http://www.cartalk.com/content/puzzlers>):

What is the longest English word, that remains a valid English word, as you remove its letters one at a time?

Now, letters can be removed from either end, or the middle, but you can't rearrange any of the letters. Every time you drop a letter, you wind up with another English word. If you do that, you're eventually going to wind up with one letter and that too is going to be an English word—one that's found in the dictionary. I want to know what's the longest word and how many letters does it have?

I'm going to give you a little modest example: Sprite. Ok? You start off with sprite, you take a letter off, one from the interior of the word, take the r away, and we're left with the word spite, then we take the e off the end, we're left with spit, we take the s off, we're left with pit, it, and I.

Write a program to find all words that can be reduced in this way, and then find the longest one.

This exercise is a little more challenging than most, so here are some suggestions:

1. You might want to write a function that takes a word and computes a list of all the words that can be formed by removing one letter. These are the “children” of the word.
2. Recursively, a word is reducible if any of its children are reducible. As a base case, you can consider the empty string reducible.
3. The wordlist I provided, `words.txt`, doesn't contain single letter words. So you might want to add “I”, “a”, and the empty string.
4. To improve the performance of your program, you might want to memoize the words that are known to be reducible.

Solution: <http://thinkpython2.com/code/reducible.py>.

Capítulo 13

Case study: data structure selection

At this point you have learned about Python's core data structures, and you have seen some of the algorithms that use them. If you would like to know more about algorithms, this might be a good time to read Chapter B. But you don't have to read it before you go on; you can read it whenever you are interested.

This chapter presents a case study with exercises that let you think about choosing data structures and practice using them.

13.1. Word frequency analysis

As usual, you should at least attempt the exercises before you read my solutions.

Ejercicio 13.1. *Write a program that reads a file, breaks each line into words, strips whitespace and punctuation from the words, and converts them to lowercase.*

Hint: The `string` module provides a string named `whitespace`, which contains space, tab, newline, etc., and `punctuation` which contains the punctuation characters. Let's see if we can make Python swear:

```
>>> import string
>>> string.punctuation
'!"#$%&\'()*+,-./:;<=>?@[\\]^_`{|}~'
```

Also, you might consider using the string methods `strip`, `replace` and `translate`.

Ejercicio 13.2. *Go to Project Gutenberg (<http://gutenberg.org>) and download your favorite out-of-copyright book in plain text format.*

Modify your program from the previous exercise to read the book you downloaded, skip over the header information at the beginning of the file, and process the rest of the words as before.

Then modify the program to count the total number of words in the book, and the number of times each word is used.

Print the number of different words used in the book. Compare different books by different authors, written in different eras. Which author uses the most extensive vocabulary?

Ejercicio 13.3. *Modify the program from the previous exercise to print the 20 most frequently used words in the book.*

Ejercicio 13.4. *Modify the previous program to read a word list (see Section 9.1) and then print all the words in the book that are not in the word list. How many of them are typos? How many of them are common words that should be in the word list, and how many of them are really obscure?*

13.2. Random numbers

Given the same inputs, most computer programs generate the same outputs every time, so they are said to be **deterministic**. Determinism is usually a good thing, since we expect the same calculation to yield the same result. For some applications, though, we want the computer to be unpredictable. Games are an obvious example, but there are more.

Making a program truly nondeterministic turns out to be difficult, but there are ways to make it at least seem nondeterministic. One of them is to use algorithms that generate **pseudorandom** numbers. Pseudorandom numbers are not truly random because they are generated by a deterministic computation, but just by looking at the numbers it is all but impossible to distinguish them from random.

The `random` module provides functions that generate pseudorandom numbers (which I will simply call “random” from here on).

The function `random` returns a random float between 0.0 and 1.0 (including 0.0 but not 1.0). Each time you call `random`, you get the next number in a long series. To see a sample, run this loop:

```
import random

for i in range(10):
    x = random.random()
    print(x)
```

The function `randint` takes parameters `low` and `high` and returns an integer between `low` and `high` (including both).

```
>>> random.randint(5, 10)
5
>>> random.randint(5, 10)
9
```

To choose an element from a sequence at random, you can use `choice`:

```
>>> t = [1, 2, 3]
>>> random.choice(t)
2
>>> random.choice(t)
3
```

The `random` module also provides functions to generate random values from continuous distributions including Gaussian, exponential, gamma, and a few more.

Ejercicio 13.5. *Write a function named `choose_from_hist` that takes a histogram as defined in Section 11.2 and returns a random value from the histogram, chosen with probability in proportion to frequency. For example, for this histogram:*

```
>>> t = ['a', 'a', 'b']
>>> hist = histogram(t)
>>> hist
{'a': 2, 'b': 1}
```

your function should return 'a' with probability 2/3 and 'b' with probability 1/3.

13.3. Word histogram

You should attempt the previous exercises before you go on. You can download my solution from http://thinkpython2.com/code/analyze_book1.py. You will also need <http://thinkpython2.com/code/emma.txt>.

Here is a program that reads a file and builds a histogram of the words in the file:

```
import string

def process_file(filename):
    hist = dict()
    fp = open(filename)
    for line in fp:
        process_line(line, hist)
    return hist

def process_line(line, hist):
    line = line.replace('-', ' ')

    for word in line.split():
        word = word.strip(string.punctuation + string.whitespace)
        word = word.lower()
        hist[word] = hist.get(word, 0) + 1

hist = process_file('emma.txt')
```

This program reads `emma.txt`, which contains the text of *Emma* by Jane Austen.

`process_file` loops through the lines of the file, passing them one at a time to `process_line`. The histogram `hist` is being used as an accumulator.

`process_line` uses the string method `replace` to replace hyphens with spaces before using `split` to break the line into a list of strings. It traverses the list of words and uses `strip` and `lower` to remove punctuation and convert to lower case. (It is a shorthand to say that strings are “converted”; remember that strings are immutable, so methods like `strip` and `lower` return new strings.)

Finally, `process_line` updates the histogram by creating a new item or incrementing an existing one.

To count the total number of words in the file, we can add up the frequencies in the histogram:

```
def total_words(hist):
    return sum(hist.values())
```

The number of different words is just the number of items in the dictionary:

```
def different_words(hist):
    return len(hist)
```

Here is some code to print the results:

```
print('Total number of words:', total_words(hist))
print('Number of different words:', different_words(hist))
```

And the results:

```
Total number of words: 161080
Number of different words: 7214
```

13.4. Most common words

To find the most common words, we can make a list of tuples, where each tuple contains a word and its frequency, and sort it.

The following function takes a histogram and returns a list of word-frequency tuples:

```
def most_common(hist):
    t = []
    for key, value in hist.items():
        t.append((value, key))

    t.sort(reverse=True)
    return t
```

In each tuple, the frequency appears first, so the resulting list is sorted by frequency. Here is a loop that prints the ten most common words:

```
t = most_common(hist)
print('The most common words are:')
for freq, word in t[:10]:
    print(word, freq, sep='\t')
```

I use the keyword argument `sep` to tell `print` to use a tab character as a “separator”, rather than a space, so the second column is lined up. Here are the results from *Emma*:

The most common words are:

```
to      5242
the     5205
and     4897
of      4295
i       3191
a       3130
it      2529
her     2483
was     2400
she     2364
```

This code can be simplified using the `key` parameter of the `sort` function. If you are curious, you can read about it at <https://wiki.python.org/moin/HowTo/Sorting>.

13.5. Optional parameters

We have seen built-in functions and methods that take optional arguments. It is possible to write programmer-defined functions with optional arguments, too. For example, here is a function that prints the most common words in a histogram

```
def print_most_common(hist, num=10):
    t = most_common(hist)
    print('The most common words are:')
    for freq, word in t[:num]:
        print(word, freq, sep='\t')
```

The first parameter is required; the second is optional. The **default value** of `num` is 10.

If you only provide one argument:

```
print_most_common(hist)
```

`num` gets the default value. If you provide two arguments:

```
print_most_common(hist, 20)
```

`num` gets the value of the argument instead. In other words, the optional argument **overrides** the default value.

If a function has both required and optional parameters, all the required parameters have to come first, followed by the optional ones.

13.6. Dictionary subtraction

Finding the words from the book that are not in the word list from `words.txt` is a problem you might recognize as set subtraction; that is, we want to find all the words from one set (the words in the book) that are not in the other (the words in the list).

`subtract` takes dictionaries `d1` and `d2` and returns a new dictionary that contains all the keys from `d1` that are not in `d2`. Since we don't really care about the values, we set them all to `None`.

```
def subtract(d1, d2):
    res = dict()
    for key in d1:
        if key not in d2:
            res[key] = None
    return res
```

To find the words in the book that are not in `words.txt`, we can use `process_file` to build a histogram for `words.txt`, and then `subtract`:

```
words = process_file('words.txt')
diff = subtract(hist, words)

print("Words in the book that aren't in the word list:")
for word in diff:
    print(word, end=' ')
```

Here are some of the results from *Emma*:

```
Words in the book that aren't in the word list:
rencontre jane's blanche woodhouses disingenuousness
friend's venice apartment ...
```

Some of these words are names and possessives. Others, like “rencontre”, are no longer in common use. But a few are common words that should really be in the list!

Ejercicio 13.6. Python provides a data structure called `set` that provides many common set operations. You can read about them in Section 19.5, or read the documentation at <http://docs.python.org/3/library/stdtypes.html#types-set>.

Write a program that uses set subtraction to find words in the book that are not in the word list.
Solution: http://thinkpython2.com/code/analyze_book2.py.

13.7. Random words

To choose a random word from the histogram, the simplest algorithm is to build a list with multiple copies of each word, according to the observed frequency, and then choose from the list:

```
def random_word(h):
    t = []
    for word, freq in h.items():
        t.extend([word] * freq)

    return random.choice(t)
```

The expression `[word] * freq` creates a list with `freq` copies of the string `word`. The `extend` method is similar to `append` except that the argument is a sequence.

This algorithm works, but it is not very efficient; each time you choose a random word, it rebuilds the list, which is as big as the original book. An obvious improvement is to build the list once and then make multiple selections, but the list is still big.

An alternative is:

1. Use keys to get a list of the words in the book.
2. Build a list that contains the cumulative sum of the word frequencies (see Exercise 10.2). The last item in this list is the total number of words in the book, n .
3. Choose a random number from 1 to n . Use a bisection search (See Exercise 10.10) to find the index where the random number would be inserted in the cumulative sum.
4. Use the index to find the corresponding word in the word list.

Ejercicio 13.7. Write a program that uses this algorithm to choose a random word from the book.
Solution: http://thinkpython2.com/code/analyze_book3.py.

13.8. Markov analysis

If you choose words from the book at random, you can get a sense of the vocabulary, but you probably won't get a sentence:

this the small regard harriet which knightley's it most things

A series of random words seldom makes sense because there is no relationship between successive words. For example, in a real sentence you would expect an article like "the" to be followed by an adjective or a noun, and probably not a verb or adverb.

One way to measure these kinds of relationships is Markov analysis, which characterizes, for a given sequence of words, the probability of the words that might come next. For example, the song *Eric, the Half a Bee* begins:

Half a bee, philosophically,
 Must, ipso facto, half not be.
 But half the bee has got to be
 Vis a vis, its entity. D'you see?

But can a bee be said to be
 Or not to be an entire bee
 When half the bee is not a bee
 Due to some ancient injury?

In this text, the phrase “half the” is always followed by the word “bee”, but the phrase “the bee” might be followed by either “has” or “is”.

The result of Markov analysis is a mapping from each prefix (like “half the” and “the bee”) to all possible suffixes (like “has” and “is”).

Given this mapping, you can generate a random text by starting with any prefix and choosing at random from the possible suffixes. Next, you can combine the end of the prefix and the new suffix to form the next prefix, and repeat.

For example, if you start with the prefix “Half a”, then the next word has to be “bee”, because the prefix only appears once in the text. The next prefix is “a bee”, so the next suffix might be “philosophically”, “be” or “due”.

In this example the length of the prefix is always two, but you can do Markov analysis with any prefix length.

Ejercicio 13.8. *Markov analysis:*

1. Write a program to read a text from a file and perform Markov analysis. The result should be a dictionary that maps from prefixes to a collection of possible suffixes. The collection might be a list, tuple, or dictionary; it is up to you to make an appropriate choice. You can test your program with prefix length two, but you should write the program in a way that makes it easy to try other lengths.
2. Add a function to the previous program to generate random text based on the Markov analysis. Here is an example from *Emma* with prefix length 2:

He was very clever, be it sweetness or be angry, ashamed or only amused, at such a stroke. She had never thought of Hannah till you were never meant for me?I cannot make speeches, Emma:”he soon cut it all himself.

For this example, I left the punctuation attached to the words. The result is almost syntactically correct, but not quite. Semantically, it almost makes sense, but not quite.

What happens if you increase the prefix length? Does the random text make more sense?
3. Once your program is working, you might want to try a mash-up: if you combine text from two or more books, the random text you generate will blend the vocabulary and phrases from the sources in interesting ways.

Credit: This case study is based on an example from Kernighan and Pike, The Practice of Programming, Addison-Wesley, 1999.

You should attempt this exercise before you go on; then you can download my solution from <http://thinkpython2.com/code/markov.py>. You will also need <http://thinkpython2.com/code/emma.txt>.

13.9. Data structures

Using Markov analysis to generate random text is fun, but there is also a point to this exercise: data structure selection. In your solution to the previous exercises, you had to choose:

- How to represent the prefixes.
- How to represent the collection of possible suffixes.
- How to represent the mapping from each prefix to the collection of possible suffixes.

The last one is easy: a dictionary is the obvious choice for a mapping from keys to corresponding values.

For the prefixes, the most obvious options are string, list of strings, or tuple of strings.

For the suffixes, one option is a list; another is a histogram (dictionary).

How should you choose? The first step is to think about the operations you will need to implement for each data structure. For the prefixes, we need to be able to remove words from the beginning and add to the end. For example, if the current prefix is “Half a”, and the next word is “bee”, you need to be able to form the next prefix, “a bee”.

Your first choice might be a list, since it is easy to add and remove elements, but we also need to be able to use the prefixes as keys in a dictionary, so that rules out lists. With tuples, you can’t append or remove, but you can use the addition operator to form a new tuple:

```
def shift(prefix, word):  
    return prefix[1:] + (word,)
```

`shift` takes a tuple of words, `prefix`, and a string, `word`, and forms a new tuple that has all the words in `prefix` except the first, and `word` added to the end.

For the collection of suffixes, the operations we need to perform include adding a new suffix (or increasing the frequency of an existing one), and choosing a random suffix.

Adding a new suffix is equally easy for the list implementation or the histogram. Choosing a random element from a list is easy; choosing from a histogram is harder to do efficiently (see Exercise 13.7).

So far we have been talking mostly about ease of implementation, but there are other factors to consider in choosing data structures. One is run time. Sometimes there is a theoretical reason to expect one data structure to be faster than other; for example, I mentioned that the `in` operator is faster for dictionaries than for lists, at least when the number of elements is large.

But often you don’t know ahead of time which implementation will be faster. One option is to implement both of them and see which is better. This approach is called **benchmarking**. A practical alternative is to choose the data structure that is easiest to implement, and then see if it is fast enough for the intended application. If so, there is no need to go on. If not, there are tools, like the `profile` module, that can identify the places in a program that take the most time.

The other factor to consider is storage space. For example, using a histogram for the collection of suffixes might take less space because you only have to store each word once, no

matter how many times it appears in the text. In some cases, saving space can also make your program run faster, and in the extreme, your program might not run at all if you run out of memory. But for many applications, space is a secondary consideration after run time.

One final thought: in this discussion, I have implied that we should use one data structure for both analysis and generation. But since these are separate phases, it would also be possible to use one structure for analysis and then convert to another structure for generation. This would be a net win if the time saved during generation exceeded the time spent in conversion.

13.10. Debugging

When you are debugging a program, and especially if you are working on a hard bug, there are five things to try:

Reading: Examine your code, read it back to yourself, and check that it says what you meant to say.

Running: Experiment by making changes and running different versions. Often if you display the right thing at the right place in the program, the problem becomes obvious, but sometimes you have to build scaffolding.

Ruminating: Take some time to think! What kind of error is it: syntax, runtime, or semantic? What information can you get from the error messages, or from the output of the program? What kind of error could cause the problem you're seeing? What did you change last, before the problem appeared?

Rubberducking: If you explain the problem to someone else, you sometimes find the answer before you finish asking the question. Often you don't need the other person; you could just talk to a rubber duck. And that's the origin of the well-known strategy called **rubber duck debugging**. I am not making this up; see https://en.wikipedia.org/wiki/Rubber_duck_debugging.

Retreating: At some point, the best thing to do is back off, undoing recent changes, until you get back to a program that works and that you understand. Then you can start rebuilding.

Beginning programmers sometimes get stuck on one of these activities and forget the others. Each activity comes with its own failure mode.

For example, reading your code might help if the problem is a typographical error, but not if the problem is a conceptual misunderstanding. If you don't understand what your program does, you can read it 100 times and never see the error, because the error is in your head.

Running experiments can help, especially if you run small, simple tests. But if you run experiments without thinking or reading your code, you might fall into a pattern I call "random walk programming", which is the process of making random changes until the program does the right thing. Needless to say, random walk programming can take a long time.

You have to take time to think. Debugging is like an experimental science. You should have at least one hypothesis about what the problem is. If there are two or more possibilities, try to think of a test that would eliminate one of them.

But even the best debugging techniques will fail if there are too many errors, or if the code you are trying to fix is too big and complicated. Sometimes the best option is to retreat, simplifying the program until you get to something that works and that you understand.

Beginning programmers are often reluctant to retreat because they can't stand to delete a line of code (even if it's wrong). If it makes you feel better, copy your program into another file before you start stripping it down. Then you can copy the pieces back one at a time.

Finding a hard bug requires reading, running, ruminating, and sometimes retreating. If you get stuck on one of these activities, try the others.

13.11. Glossary

deterministic: Pertaining to a program that does the same thing each time it runs, given the same inputs.

pseudorandom: Pertaining to a sequence of numbers that appears to be random, but is generated by a deterministic program.

default value: The value given to an optional parameter if no argument is provided.

override: To replace a default value with an argument.

benchmarking: The process of choosing between data structures by implementing alternatives and testing them on a sample of the possible inputs.

rubber duck debugging: Debugging by explaining your problem to an inanimate object such as a rubber duck. Articulating the problem can help you solve it, even if the rubber duck doesn't know Python.

13.12. Exercises

Ejercicio 13.9. The “rank” of a word is its position in a list of words sorted by frequency: the most common word has rank 1, the second most common has rank 2, etc.

Zipf's law describes a relationship between the ranks and frequencies of words in natural languages (http://en.wikipedia.org/wiki/Zipf's_law). Specifically, it predicts that the frequency, f , of the word with rank r is:

$$f = cr^{-s}$$

where s and c are parameters that depend on the language and the text. If you take the logarithm of both sides of this equation, you get:

$$\log f = \log c - s \log r$$

So if you plot $\log f$ versus $\log r$, you should get a straight line with slope $-s$ and intercept $\log c$.

Write a program that reads a text from a file, counts word frequencies, and prints one line for each word, in descending order of frequency, with $\log f$ and $\log r$. Use the graphing program of your choice to plot the results and check whether they form a straight line. Can you estimate the value of s ?

Solution: <http://thinkpython2.com/code/zipf.py>. To run my solution, you need the plotting module `matplotlib`. If you installed Anaconda, you already have `matplotlib`; otherwise you might have to install it.

Capítulo 14

Files

This chapter introduces the idea of “persistent” programs that keep data in permanent storage, and shows how to use different kinds of permanent storage, like files and databases.

14.1. Persistence

Most of the programs we have seen so far are transient in the sense that they run for a short time and produce some output, but when they end, their data disappears. If you run the program again, it starts with a clean slate.

Other programs are **persistent**: they run for a long time (or all the time); they keep at least some of their data in permanent storage (a hard drive, for example); and if they shut down and restart, they pick up where they left off.

Examples of persistent programs are operating systems, which run pretty much whenever a computer is on, and web servers, which run all the time, waiting for requests to come in on the network.

One of the simplest ways for programs to maintain their data is by reading and writing text files. We have already seen programs that read text files; in this chapter we will see programs that write them.

An alternative is to store the state of the program in a database. In this chapter I will present a simple database and a module, `pickle`, that makes it easy to store program data.

14.2. Reading and writing

A text file is a sequence of characters stored on a permanent medium like a hard drive, flash memory, or CD-ROM. We saw how to open and read a file in Section 9.1.

To write a file, you have to open it with mode `'w'` as a second parameter:

```
>>> fout = open('output.txt', 'w')
```

If the file already exists, opening it in write mode clears out the old data and starts fresh, so be careful! If the file doesn't exist, a new one is created.

`open` returns a file object that provides methods for working with the file. The `write` method puts data into the file.

```
>>> line1 = "This here's the wattle,\n"
>>> fout.write(line1)
24
```

The return value is the number of characters that were written. The file object keeps track of where it is, so if you call `write` again, it adds the new data to the end of the file.

```
>>> line2 = "the emblem of our land.\n"
>>> fout.write(line2)
24
```

When you are done writing, you should close the file.

```
>>> fout.close()
```

If you don't close the file, it gets closed for you when the program ends.

14.3. Format operator

The argument of `write` has to be a string, so if we want to put other values in a file, we have to convert them to strings. The easiest way to do that is with `str`:

```
>>> x = 52
>>> fout.write(str(x))
```

An alternative is to use the **format operator**, `%`. When applied to integers, `%` is the modulus operator. But when the first operand is a string, `%` is the format operator.

The first operand is the **format string**, which contains one or more **format sequences**, which specify how the second operand is formatted. The result is a string.

For example, the format sequence `'%d'` means that the second operand should be formatted as a decimal integer:

```
>>> camels = 42
>>> '%d' % camels
'42'
```

The result is the string `'42'`, which is not to be confused with the integer value 42.

A format sequence can appear anywhere in the string, so you can embed a value in a sentence:

```
>>> 'I have spotted %d camels.' % camels
'I have spotted 42 camels.'
```

If there is more than one format sequence in the string, the second argument has to be a tuple. Each format sequence is matched with an element of the tuple, in order.

The following example uses `'%d'` to format an integer, `'%g'` to format a floating-point number, and `'%s'` to format a string:

```
>>> 'In %d years I have spotted %g %s.' % (3, 0.1, 'camels')
'In 3 years I have spotted 0.1 camels.'
```


The number of elements in the tuple has to match the number of format sequences in the string. Also, the types of the elements have to match the format sequences:

```
>>> '%d %d %d' % (1, 2)
TypeError: not enough arguments for format string
>>> '%d' % 'dollars'
TypeError: %d format: a number is required, not str
```

In the first example, there aren't enough elements; in the second, the element is the wrong type.

For more information on the format operator, see <https://docs.python.org/3/library/stdtypes.html#printf-style-string-formatting>. A more powerful alternative is the string format method, which you can read about at <https://docs.python.org/3/library/stdtypes.html#str.format>.

14.4. Filenames and paths

Files are organized into **directories** (also called “folders”). Every running program has a “current directory”, which is the default directory for most operations. For example, when you open a file for reading, Python looks for it in the current directory.

The `os` module provides functions for working with files and directories (“`os`” stands for “operating system”). `os.getcwd` returns the name of the current directory:

```
>>> import os
>>> cwd = os.getcwd()
>>> cwd
'/home/dinsdale'
```

`cwd` stands for “current working directory”. The result in this example is `/home/dinsdale`, which is the home directory of a user named `dinsdale`.

A string like `'/home/dinsdale'` that identifies a file or directory is called a **path**.

A simple filename, like `memo.txt` is also considered a path, but it is a **relative path** because it relates to the current directory. If the current directory is `/home/dinsdale`, the filename `memo.txt` would refer to `/home/dinsdale/memo.txt`.

A path that begins with `/` does not depend on the current directory; it is called an **absolute path**. To find the absolute path to a file, you can use `os.path.abspath`:

```
>>> os.path.abspath('memo.txt')
'/home/dinsdale/memo.txt'
```

`os.path` provides other functions for working with filenames and paths. For example, `os.path.exists` checks whether a file or directory exists:

```
>>> os.path.exists('memo.txt')
True
```

If it exists, `os.path.isdir` checks whether it's a directory:

```
>>> os.path.isdir('memo.txt')
False
>>> os.path.isdir('/home/dinsdale')
True
```

Similarly, `os.path.isfile` checks whether it's a file.

`os.listdir` returns a list of the files (and other directories) in the given directory:

```
>>> os.listdir(cwd)
['music', 'photos', 'memo.txt']
```

To demonstrate these functions, the following example “walks” through a directory, prints the names of all the files, and calls itself recursively on all the directories.

```
def walk(dirname):
    for name in os.listdir(dirname):
        path = os.path.join(dirname, name)

        if os.path.isfile(path):
            print(path)
        else:
            walk(path)
```

`os.path.join` takes a directory and a file name and joins them into a complete path.

The `os` module provides a function called `walk` that is similar to this one but more versatile. As an exercise, read the documentation and use it to print the names of the files in a given directory and its subdirectories. You can download my solution from <http://thinkpython2.com/code/walk.py>.

14.5. Catching exceptions

A lot of things can go wrong when you try to read and write files. If you try to open a file that doesn't exist, you get an `IOError`:

```
>>> fin = open('bad_file')
IOError: [Errno 2] No such file or directory: 'bad_file'
```

If you don't have permission to access a file:

```
>>> fout = open('/etc/passwd', 'w')
PermissionError: [Errno 13] Permission denied: '/etc/passwd'
```

And if you try to open a directory for reading, you get

```
>>> fin = open('/home')
IsADirectoryError: [Errno 21] Is a directory: '/home'
```

To avoid these errors, you could use functions like `os.path.exists` and `os.path.isfile`, but it would take a lot of time and code to check all the possibilities (if “Errno 21” is any indication, there are at least 21 things that can go wrong).

It is better to go ahead and try—and deal with problems if they happen—which is exactly what the `try` statement does. The syntax is similar to an `if...else` statement:

```
try:
    fin = open('bad_file')
except:
    print('Something went wrong.')
```

Python starts by executing the `try` clause. If all goes well, it skips the `except` clause and proceeds. If an exception occurs, it jumps out of the `try` clause and runs the `except` clause.

Handling an exception with a `try` statement is called **catching** an exception. In this example, the `except` clause prints an error message that is not very helpful. In general, catching an exception gives you a chance to fix the problem, or try again, or at least end the program gracefully.

14.6. Databases

A **database** is a file that is organized for storing data. Many databases are organized like a dictionary in the sense that they map from keys to values. The biggest difference between a database and a dictionary is that the database is on disk (or other permanent storage), so it persists after the program ends.

The module `dbm` provides an interface for creating and updating database files. As an example, I'll create a database that contains captions for image files.

Opening a database is similar to opening other files:

```
>>> import dbm
>>> db = dbm.open('captions', 'c')
```

The mode `'c'` means that the database should be created if it doesn't already exist. The result is a database object that can be used (for most operations) like a dictionary.

When you create a new item, `dbm` updates the database file.

```
>>> db['cleese.png'] = 'Photo of John Cleese.'
```

When you access one of the items, `dbm` reads the file:

```
>>> db['cleese.png']
b'Photo of John Cleese.'
```

The result is a **bytes object**, which is why it begins with `b`. A bytes object is similar to a string in many ways. When you get farther into Python, the difference becomes important, but for now we can ignore it.

If you make another assignment to an existing key, `dbm` replaces the old value:

```
>>> db['cleese.png'] = 'Photo of John Cleese doing a silly walk.'
>>> db['cleese.png']
b'Photo of John Cleese doing a silly walk.'
```

Some dictionary methods, like `keys` and `items`, don't work with database objects. But iteration with a `for` loop works:

```
for key in db:
    print(key, db[key])
```

As with other files, you should close the database when you are done:

```
>>> db.close()
```

14.7. Pickling

A limitation of `dbm` is that the keys and values have to be strings or bytes. If you try to use any other type, you get an error.

The `pickle` module can help. It translates almost any type of object into a string suitable for storage in a database, and then translates strings back into objects.

`pickle.dumps` takes an object as a parameter and returns a string representation (`dumps` is short for “dump string”):

```
>>> import pickle
>>> t = [1, 2, 3]
>>> pickle.dumps(t)
b'\x80\x03q\x00(K\x01K\x02K\x03e.'
```

The format isn’t obvious to human readers; it is meant to be easy for `pickle` to interpret. `pickle.loads` (“load string”) reconstitutes the object:

```
>>> t1 = [1, 2, 3]
>>> s = pickle.dumps(t1)
>>> t2 = pickle.loads(s)
>>> t2
[1, 2, 3]
```

Although the new object has the same value as the old, it is not (in general) the same object:

```
>>> t1 == t2
True
>>> t1 is t2
False
```

In other words, pickling and then unpickling has the same effect as copying the object.

You can use `pickle` to store non-strings in a database. In fact, this combination is so common that it has been encapsulated in a module called `shelve`.

14.8. Pipes

Most operating systems provide a command-line interface, also known as a **shell**. Shells usually provide commands to navigate the file system and launch applications. For example, in Unix you can change directories with `cd`, display the contents of a directory with `ls`, and launch a web browser by typing (for example) `firefox`.

Any program that you can launch from the shell can also be launched from Python using a **pipe object**, which represents a running program.

For example, the Unix command `ls -l` normally displays the contents of the current directory in long format. You can launch `ls` with `os.popen`¹:

```
>>> cmd = 'ls -l'
>>> fp = os.popen(cmd)
```

¹`popen` is deprecated now, which means we are supposed to stop using it and start using the `subprocess` module. But for simple cases, I find `subprocess` more complicated than necessary. So I am going to keep using `popen` until they take it away.

The argument is a string that contains a shell command. The return value is an object that behaves like an open file. You can read the output from the `ls` process one line at a time with `readline` or get the whole thing at once with `read`:

```
>>> res = fp.read()
```

When you are done, you close the pipe like a file:

```
>>> stat = fp.close()
```

```
>>> print(stat)
```

```
None
```

The return value is the final status of the `ls` process; `None` means that it ended normally (with no errors).

For example, most Unix systems provide a command called `md5sum` that reads the contents of a file and computes a “checksum”. You can read about MD5 at <http://en.wikipedia.org/wiki/Md5>. This command provides an efficient way to check whether two files have the same contents. The probability that different contents yield the same checksum is very small (that is, unlikely to happen before the universe collapses).

You can use a pipe to run `md5sum` from Python and get the result:

```
>>> filename = 'book.tex'
```

```
>>> cmd = 'md5sum ' + filename
```

```
>>> fp = os.popen(cmd)
```

```
>>> res = fp.read()
```

```
>>> stat = fp.close()
```

```
>>> print(res)
```

```
1e0033f0ed0656636de0d75144ba32e0  book.tex
```

```
>>> print(stat)
```

```
None
```

14.9. Writing modules

Any file that contains Python code can be imported as a module. For example, suppose you have a file named `wc.py` with the following code:

```
def linecount(filename):
    count = 0
    for line in open(filename):
        count += 1
    return count
```

```
print(linecount('wc.py'))
```

If you run this program, it reads itself and prints the number of lines in the file, which is 7. You can also import it like this:

```
>>> import wc
```

```
7
```

Now you have a module object `wc`:

```
>>> wc
```

```
<module 'wc' from 'wc.py'>
```

The module object provides `linecount`:

```
>>> wc.linecount('wc.py')
7
```

So that's how you write modules in Python.

The only problem with this example is that when you import the module it runs the test code at the bottom. Normally when you import a module, it defines new functions but it doesn't run them.

Programs that will be imported as modules often use the following idiom:

```
if __name__ == '__main__':
    print(linecount('wc.py'))
```

`__name__` is a built-in variable that is set when the program starts. If the program is running as a script, `__name__` has the value `'__main__'`; in that case, the test code runs. Otherwise, if the module is being imported, the test code is skipped.

As an exercise, type this example into a file named `wc.py` and run it as a script. Then run the Python interpreter and `import wc`. What is the value of `__name__` when the module is being imported?

Warning: If you import a module that has already been imported, Python does nothing. It does not re-read the file, even if it has changed.

If you want to reload a module, you can use the built-in function `reload`, but it can be tricky, so the safest thing to do is restart the interpreter and then import the module again.

14.10. Debugging

When you are reading and writing files, you might run into problems with whitespace. These errors can be hard to debug because spaces, tabs and newlines are normally invisible:

```
>>> s = '1 2\t 3\n 4'
>>> print(s)
1 2 3
4
```

The built-in function `repr` can help. It takes any object as an argument and returns a string representation of the object. For strings, it represents whitespace characters with backslash sequences:

```
>>> print(repr(s))
'1 2\t 3\n 4'
```

This can be helpful for debugging.

One other problem you might run into is that different systems use different characters to indicate the end of a line. Some systems use a newline, represented `\n`. Others use a return character, represented `\r`. Some use both. If you move files between different systems, these inconsistencies can cause problems.

For most systems, there are applications to convert from one format to another. You can find them (and read more about this issue) at <http://en.wikipedia.org/wiki/Newline>. Or, of course, you could write one yourself.

14.11. Glossary

persistent: Pertaining to a program that runs indefinitely and keeps at least some of its data in permanent storage.

format operator: An operator, %, that takes a format string and a tuple and generates a string that includes the elements of the tuple formatted as specified by the format string.

format string: A string, used with the format operator, that contains format sequences.

format sequence: A sequence of characters in a format string, like %d, that specifies how a value should be formatted.

text file: A sequence of characters stored in permanent storage like a hard drive.

directory: A named collection of files, also called a folder.

path: A string that identifies a file.

relative path: A path that starts from the current directory.

absolute path: A path that starts from the topmost directory in the file system.

catch: To prevent an exception from terminating a program using the try and except statements.

database: A file whose contents are organized like a dictionary with keys that correspond to values.

bytes object: An object similar to a string.

shell: A program that allows users to type commands and then executes them by starting other programs.

pipe object: An object that represents a running program, allowing a Python program to run commands and read the results.

14.12. Exercises

Ejercicio 14.1. Write a function called `sed` that takes as arguments a pattern string, a replacement string, and two filenames; it should read the first file and write the contents into the second file (creating it if necessary). If the pattern string appears anywhere in the file, it should be replaced with the replacement string.

If an error occurs while opening, reading, writing or closing files, your program should catch the exception, print an error message, and exit. Solution: <http://thinkpython2.com/code/sed.py>.

Ejercicio 14.2. If you download my solution to Exercise 12.2 from http://thinkpython2.com/code/anagram_sets.py, you'll see that it creates a dictionary that maps from a sorted string of letters to the list of words that can be spelled with those letters. For example, 'opst' maps to the list ['opts', 'post', 'pots', 'spot', 'stop', 'tops'].

Write a module that imports `anagram_sets` and provides two new functions: `store_anagrams` should store the anagram dictionary in a "shelf"; `read_anagrams` should look up a word and return a list of its anagrams. Solution: http://thinkpython2.com/code/anagram_db.py.

Ejercicio 14.3. *In a large collection of MP3 files, there may be more than one copy of the same song, stored in different directories or with different file names. The goal of this exercise is to search for duplicates.*

1. *Write a program that searches a directory and all of its subdirectories, recursively, and returns a list of complete paths for all files with a given suffix (like `.mp3`). Hint: `os.path` provides several useful functions for manipulating file and path names.*
2. *To recognize duplicates, you can use `md5sum` to compute a “checksum” for each files. If two files have the same checksum, they probably have the same contents.*
3. *To double-check, you can use the Unix command `diff`.*

Solution: http://thinkpython2.com/code/find_duplicates.py.

Capítulo 15

Classes and objects

At this point you know how to use functions to organize code and built-in types to organize data. The next step is to learn “object-oriented programming”, which uses programmer-defined types to organize both code and data. Object-oriented programming is a big topic; it will take a few chapters to get there.

Code examples from this chapter are available from <http://thinkpython2.com/code/Point1.py>; solutions to the exercises are available from http://thinkpython2.com/code/Point1_soln.py.

15.1. Programmer-defined types

We have used many of Python’s built-in types; now we are going to define a new type. As an example, we will create a type called `Point` that represents a point in two-dimensional space.

In mathematical notation, points are often written in parentheses with a comma separating the coordinates. For example, $(0,0)$ represents the origin, and (x,y) represents the point x units to the right and y units up from the origin.

There are several ways we might represent points in Python:

- We could store the coordinates separately in two variables, `x` and `y`.
- We could store the coordinates as elements in a list or tuple.
- We could create a new type to represent points as objects.

Creating a new type is more complicated than the other options, but it has advantages that will be apparent soon.

A programmer-defined type is also called a **class**. A class definition looks like this:

```
class Point:
    """Represents a point in 2-D space."""
```

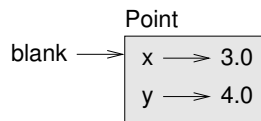


Figura 15.1: Object diagram.

The header indicates that the new class is called `Point`. The body is a docstring that explains what the class is for. You can define variables and methods inside a class definition, but we will get back to that later.

Defining a class named `Point` creates a **class object**.

```
>>> Point
<class '__main__.Point'>
```

Because `Point` is defined at the top level, its “full name” is `__main__.Point`.

The class object is like a factory for creating objects. To create a `Point`, you call `Point` as if it were a function.

```
>>> blank = Point()
>>> blank
<__main__.Point object at 0xb7e9d3ac>
```

The return value is a reference to a `Point` object, which we assign to `blank`.

Creating a new object is called **instantiation**, and the object is an **instance** of the class.

When you print an instance, Python tells you what class it belongs to and where it is stored in memory (the prefix `0x` means that the following number is in hexadecimal).

Every object is an instance of some class, so “object” and “instance” are interchangeable. But in this chapter I use “instance” to indicate that I am talking about a programmer-defined type.

15.2. Attributes

You can assign values to an instance using dot notation:

```
>>> blank.x = 3.0
>>> blank.y = 4.0
```

This syntax is similar to the syntax for selecting a variable from a module, such as `math.pi` or `string.whitespace`. In this case, though, we are assigning values to named elements of an object. These elements are called **attributes**.

As a noun, “AT-trib-ute” is pronounced with emphasis on the first syllable, as opposed to “a-TRIB-ute”, which is a verb.

Figure 15.1 is a state diagram that shows the result of these assignments. A state diagram that shows an object and its attributes is called an **object diagram**.

The variable `blank` refers to a `Point` object, which contains two attributes. Each attribute refers to a floating-point number.

You can read the value of an attribute using the same syntax:

```
>>> blank.y
4.0
>>> x = blank.x
>>> x
3.0
```

The expression `blank.x` means, “Go to the object `blank` refers to and get the value of `x`.” In the example, we assign that value to a variable named `x`. There is no conflict between the variable `x` and the attribute `x`.

You can use dot notation as part of any expression. For example:

```
>>> '(%g, %g)' % (blank.x, blank.y)
'(3.0, 4.0)'
>>> distance = math.sqrt(blank.x**2 + blank.y**2)
>>> distance
5.0
```

You can pass an instance as an argument in the usual way. For example:

```
def print_point(p):
    print('(%g, %g)' % (p.x, p.y))
```

`print_point` takes a point as an argument and displays it in mathematical notation. To invoke it, you can pass `blank` as an argument:

```
>>> print_point(blank)
(3.0, 4.0)
```

Inside the function, `p` is an alias for `blank`, so if the function modifies `p`, `blank` changes.

As an exercise, write a function called `distance_between_points` that takes two `Points` as arguments and returns the distance between them.

15.3. Rectangles

Sometimes it is obvious what the attributes of an object should be, but other times you have to make decisions. For example, imagine you are designing a class to represent rectangles. What attributes would you use to specify the location and size of a rectangle? You can ignore angle; to keep things simple, assume that the rectangle is either vertical or horizontal.

There are at least two possibilities:

- You could specify one corner of the rectangle (or the center), the width, and the height.
- You could specify two opposing corners.

At this point it is hard to say whether either is better than the other, so we'll implement the first one, just as an example.

Here is the class definition:

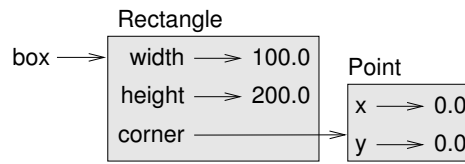


Figura 15.2: Object diagram.

```

class Rectangle:
    """Represents a rectangle.

    attributes: width, height, corner.
    """

```

The docstring lists the attributes: width and height are numbers; corner is a Point object that specifies the lower-left corner.

To represent a rectangle, you have to instantiate a Rectangle object and assign values to the attributes:

```

box = Rectangle()
box.width = 100.0
box.height = 200.0
box.corner = Point()
box.corner.x = 0.0
box.corner.y = 0.0

```

The expression `box.corner.x` means, “Go to the object box refers to and select the attribute named corner; then go to that object and select the attribute named x.”

Figure 15.2 shows the state of this object. An object that is an attribute of another object is **embedded**.

15.4. Instances as return values

Functions can return instances. For example, `find_center` takes a Rectangle as an argument and returns a Point that contains the coordinates of the center of the Rectangle:

```

def find_center(rect):
    p = Point()
    p.x = rect.corner.x + rect.width/2
    p.y = rect.corner.y + rect.height/2
    return p

```

Here is an example that passes box as an argument and assigns the resulting Point to center:

```

>>> center = find_center(box)
>>> print_point(center)
(50, 100)

```

15.5. Objects are mutable

You can change the state of an object by making an assignment to one of its attributes. For example, to change the size of a rectangle without changing its position, you can modify the values of width and height:

```
box.width = box.width + 50
box.height = box.height + 100
```

You can also write functions that modify objects. For example, `grow_rectangle` takes a `Rectangle` object and two numbers, `dwidth` and `dheight`, and adds the numbers to the width and height of the rectangle:

```
def grow_rectangle(rect, dwidth, dheight):
    rect.width += dwidth
    rect.height += dheight
```

Here is an example that demonstrates the effect:

```
>>> box.width, box.height
(150.0, 300.0)
>>> grow_rectangle(box, 50, 100)
>>> box.width, box.height
(200.0, 400.0)
```

Inside the function, `rect` is an alias for `box`, so when the function modifies `rect`, `box` changes.

As an exercise, write a function named `move_rectangle` that takes a `Rectangle` and two numbers named `dx` and `dy`. It should change the location of the rectangle by adding `dx` to the `x` coordinate of `corner` and adding `dy` to the `y` coordinate of `corner`.

15.6. Copying

Aliasing can make a program difficult to read because changes in one place might have unexpected effects in another place. It is hard to keep track of all the variables that might refer to a given object.

Copying an object is often an alternative to aliasing. The `copy` module contains a function called `copy` that can duplicate any object:

```
>>> p1 = Point()
>>> p1.x = 3.0
>>> p1.y = 4.0

>>> import copy
>>> p2 = copy.copy(p1)
```

`p1` and `p2` contain the same data, but they are not the same `Point`.

```
>>> print_point(p1)
(3, 4)
>>> print_point(p2)
(3, 4)
>>> p1 is p2
False
```

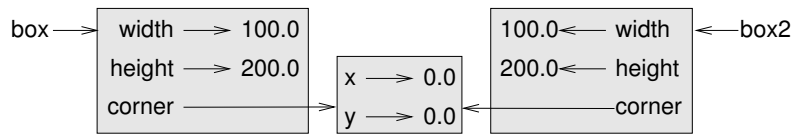


Figura 15.3: Object diagram.

```
>>> p1 == p2
False
```

The `is` operator indicates that `p1` and `p2` are not the same object, which is what we expected. But you might have expected `==` to yield `True` because these points contain the same data. In that case, you will be disappointed to learn that for instances, the default behavior of the `==` operator is the same as the `is` operator; it checks object identity, not object equivalence. That's because for programmer-defined types, Python doesn't know what should be considered equivalent. At least, not yet.

If you use `copy.copy` to duplicate a `Rectangle`, you will find that it copies the `Rectangle` object but not the embedded `Point`.

```
>>> box2 = copy.copy(box)
>>> box2 is box
False
>>> box2.corner is box.corner
True
```

Figure 15.3 shows what the object diagram looks like. This operation is called a **shallow copy** because it copies the object and any references it contains, but not the embedded objects.

For most applications, this is not what you want. In this example, invoking `grow_rectangle` on one of the `Rectangles` would not affect the other, but invoking `move_rectangle` on either would affect both! This behavior is confusing and error-prone.

Fortunately, the `copy` module provides a method named `deepcopy` that copies not only the object but also the objects it refers to, and the objects *they* refer to, and so on. You will not be surprised to learn that this operation is called a **deep copy**.

```
>>> box3 = copy.deepcopy(box)
>>> box3 is box
False
>>> box3.corner is box.corner
False
```

`box3` and `box` are completely separate objects.

As an exercise, write a version of `move_rectangle` that creates and returns a new `Rectangle` instead of modifying the old one.

15.7. Debugging

When you start working with objects, you are likely to encounter some new exceptions. If you try to access an attribute that doesn't exist, you get an `AttributeError`:

```
>>> p = Point()
>>> p.x = 3
>>> p.y = 4
>>> p.z
AttributeError: Point instance has no attribute 'z'
```

If you are not sure what type an object is, you can ask:

```
>>> type(p)
<class '__main__.Point'>
```

You can also use `isinstance` to check whether an object is an instance of a class:

```
>>> isinstance(p, Point)
True
```

If you are not sure whether an object has a particular attribute, you can use the built-in function `hasattr`:

```
>>> hasattr(p, 'x')
True
>>> hasattr(p, 'z')
False
```

The first argument can be any object; the second argument is a *string* that contains the name of the attribute.

You can also use a `try` statement to see if the object has the attributes you need:

```
try:
    x = p.x
except AttributeError:
    x = 0
```

This approach can make it easier to write functions that work with different types; more on that topic is coming up in Section 17.9.

15.8. Glossary

class: A programmer-defined type. A class definition creates a new class object.

class object: An object that contains information about a programmer-defined type. The class object can be used to create instances of the type.

instance: An object that belongs to a class.

instantiate: To create a new object.

attribute: One of the named values associated with an object.

embedded object: An object that is stored as an attribute of another object.

shallow copy: To copy the contents of an object, including any references to embedded objects; implemented by the `copy` function in the `copy` module.

deep copy: To copy the contents of an object as well as any embedded objects, and any objects embedded in them, and so on; implemented by the `deepcopy` function in the `copy` module.

object diagram: A diagram that shows objects, their attributes, and the values of the attributes.

15.9. Exercises

Ejercicio 15.1. Write a definition for a class named `Circle` with attributes `center` and `radius`, where `center` is a `Point` object and `radius` is a number.

Instantiate a `Circle` object that represents a circle with its center at (150,100) and radius 75.

Write a function named `point_in_circle` that takes a `Circle` and a `Point` and returns `True` if the `Point` lies in or on the boundary of the circle.

Write a function named `rect_in_circle` that takes a `Circle` and a `Rectangle` and returns `True` if the `Rectangle` lies entirely in or on the boundary of the circle.

Write a function named `rect_circle_overlap` that takes a `Circle` and a `Rectangle` and returns `True` if any of the corners of the `Rectangle` fall inside the circle. Or as a more challenging version, return `True` if any part of the `Rectangle` falls inside the circle.

Solution: <http://thinkpython2.com/code/Circle.py>.

Ejercicio 15.2. Write a function called `draw_rect` that takes a `Turtle` object and a `Rectangle` and uses the `Turtle` to draw the `Rectangle`. See Chapter 4 for examples using `Turtle` objects.

Write a function called `draw_circle` that takes a `Turtle` and a `Circle` and draws the `Circle`.

Solution: <http://thinkpython2.com/code/draw.py>.

Capítulo 16

Classes and functions

Now that we know how to create new types, the next step is to write functions that take programmer-defined objects as parameters and return them as results. In this chapter I also present “functional programming style” and two new program development plans.

Code examples from this chapter are available from <http://thinkpython2.com/code/Time1.py>. Solutions to the exercises are at http://thinkpython2.com/code/Time1_soln.py.

16.1. Time

As another example of a programmer-defined type, we’ll define a class called `Time` that records the time of day. The class definition looks like this:

```
class Time:
    """Represents the time of day.

    attributes: hour, minute, second
    """
```

We can create a new `Time` object and assign attributes for hours, minutes, and seconds:

```
time = Time()
time.hour = 11
time.minute = 59
time.second = 30
```

The state diagram for the `Time` object looks like Figure 16.1.

As an exercise, write a function called `print_time` that takes a `Time` object and prints it in the form `hour:minute:second`. Hint: the format sequence `‘%.2d’` prints an integer using at least two digits, including a leading zero if necessary.

Write a boolean function called `is_after` that takes two `Time` objects, `t1` and `t2`, and returns `True` if `t1` follows `t2` chronologically and `False` otherwise. Challenge: don’t use an `if` statement.

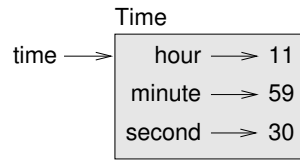


Figura 16.1: Object diagram.

16.2. Pure functions

In the next few sections, we'll write two functions that add time values. They demonstrate two kinds of functions: pure functions and modifiers. They also demonstrate a development plan I'll call **prototype and patch**, which is a way of tackling a complex problem by starting with a simple prototype and incrementally dealing with the complications.

Here is a simple prototype of `add_time`:

```
def add_time(t1, t2):
    sum = Time()
    sum.hour = t1.hour + t2.hour
    sum.minute = t1.minute + t2.minute
    sum.second = t1.second + t2.second
    return sum
```

The function creates a new `Time` object, initializes its attributes, and returns a reference to the new object. This is called a **pure function** because it does not modify any of the objects passed to it as arguments and it has no effect, like displaying a value or getting user input, other than returning a value.

To test this function, I'll create two `Time` objects: `start` contains the start time of a movie, like *Monty Python and the Holy Grail*, and `duration` contains the run time of the movie, which is one hour 35 minutes.

`add_time` figures out when the movie will be done.

```
>>> start = Time()
>>> start.hour = 9
>>> start.minute = 45
>>> start.second = 0

>>> duration = Time()
>>> duration.hour = 1
>>> duration.minute = 35
>>> duration.second = 0

>>> done = add_time(start, duration)
>>> print_time(done)
10:80:00
```

The result, 10:80:00 might not be what you were hoping for. The problem is that this function does not deal with cases where the number of seconds or minutes adds up to more than sixty. When that happens, we have to “carry” the extra seconds into the minute column or the extra minutes into the hour column.

Here's an improved version:

```
def add_time(t1, t2):
    sum = Time()
    sum.hour = t1.hour + t2.hour
    sum.minute = t1.minute + t2.minute
    sum.second = t1.second + t2.second

    if sum.second >= 60:
        sum.second -= 60
        sum.minute += 1

    if sum.minute >= 60:
        sum.minute -= 60
        sum.hour += 1

    return sum
```

Although this function is correct, it is starting to get big. We will see a shorter alternative later.

16.3. Modifiers

Sometimes it is useful for a function to modify the objects it gets as parameters. In that case, the changes are visible to the caller. Functions that work this way are called **modifiers**.

`increment`, which adds a given number of seconds to a `Time` object, can be written naturally as a modifier. Here is a rough draft:

```
def increment(time, seconds):
    time.second += seconds

    if time.second >= 60:
        time.second -= 60
        time.minute += 1

    if time.minute >= 60:
        time.minute -= 60
        time.hour += 1
```

The first line performs the basic operation; the remainder deals with the special cases we saw before.

Is this function correct? What happens if `seconds` is much greater than sixty?

In that case, it is not enough to carry once; we have to keep doing it until `time.second` is less than sixty. One solution is to replace the `if` statements with `while` statements. That would make the function correct, but not very efficient. As an exercise, write a correct version of `increment` that doesn't contain any loops.

Anything that can be done with modifiers can also be done with pure functions. In fact, some programming languages only allow pure functions. There is some evidence that programs that use pure functions are faster to develop and less error-prone than programs that use modifiers. But modifiers are convenient at times, and functional programs tend to be less efficient.

In general, I recommend that you write pure functions whenever it is reasonable and resort to modifiers only if there is a compelling advantage. This approach might be called a **functional programming style**.

As an exercise, write a “pure” version of `increment` that creates and returns a new `Time` object rather than modifying the parameter.

16.4. Prototyping versus planning

The development plan I am demonstrating is called “prototype and patch”. For each function, I wrote a prototype that performed the basic calculation and then tested it, patching errors along the way.

This approach can be effective, especially if you don’t yet have a deep understanding of the problem. But incremental corrections can generate code that is unnecessarily complicated—since it deals with many special cases—and unreliable—since it is hard to know if you have found all the errors.

An alternative is **designed development**, in which high-level insight into the problem can make the programming much easier. In this case, the insight is that a `Time` object is really a three-digit number in base 60 (see <http://en.wikipedia.org/wiki/Sexagesimal>.)! The second attribute is the “ones column”, the minute attribute is the “sixties column”, and the hour attribute is the “thirty-six hundreds column”.

When we wrote `add_time` and `increment`, we were effectively doing addition in base 60, which is why we had to carry from one column to the next.

This observation suggests another approach to the whole problem—we can convert `Time` objects to integers and take advantage of the fact that the computer knows how to do integer arithmetic.

Here is a function that converts `Times` to integers:

```
def time_to_int(time):
    minutes = time.hour * 60 + time.minute
    seconds = minutes * 60 + time.second
    return seconds
```

And here is a function that converts an integer to a `Time` (recall that `divmod` divides the first argument by the second and returns the quotient and remainder as a tuple).

```
def int_to_time(seconds):
    time = Time()
    minutes, time.second = divmod(seconds, 60)
    time.hour, time.minute = divmod(minutes, 60)
    return time
```

You might have to think a bit, and run some tests, to convince yourself that these functions are correct. One way to test them is to check that `time_to_int(int_to_time(x)) == x` for many values of `x`. This is an example of a consistency check.

Once you are convinced they are correct, you can use them to rewrite `add_time`:

```
def add_time(t1, t2):
    seconds = time_to_int(t1) + time_to_int(t2)
    return int_to_time(seconds)
```

This version is shorter than the original, and easier to verify. As an exercise, rewrite `increment` using `time_to_int` and `int_to_time`.

In some ways, converting from base 60 to base 10 and back is harder than just dealing with times. Base conversion is more abstract; our intuition for dealing with time values is better.

But if we have the insight to treat times as base 60 numbers and make the investment of writing the conversion functions (`time_to_int` and `int_to_time`), we get a program that is shorter, easier to read and debug, and more reliable.

It is also easier to add features later. For example, imagine subtracting two `Times` to find the duration between them. The naive approach would be to implement subtraction with borrowing. Using the conversion functions would be easier and more likely to be correct.

Ironically, sometimes making a problem harder (or more general) makes it easier (because there are fewer special cases and fewer opportunities for error).

16.5. Debugging

A `Time` object is well-formed if the values of `minute` and `second` are between 0 and 60 (including 0 but not 60) and if `hour` is positive. `hour` and `minute` should be integral values, but we might allow `second` to have a fraction part.

Requirements like these are called **invariants** because they should always be true. To put it a different way, if they are not true, something has gone wrong.

Writing code to check invariants can help detect errors and find their causes. For example, you might have a function like `valid_time` that takes a `Time` object and returns `False` if it violates an invariant:

```
def valid_time(time):
    if time.hour < 0 or time.minute < 0 or time.second < 0:
        return False
    if time.minute >= 60 or time.second >= 60:
        return False
    return True
```

At the beginning of each function you could check the arguments to make sure they are valid:

```
def add_time(t1, t2):
    if not valid_time(t1) or not valid_time(t2):
        raise ValueError('invalid Time object in add_time')
    seconds = time_to_int(t1) + time_to_int(t2)
    return int_to_time(seconds)
```

Or you could use an **assert statement**, which checks a given invariant and raises an exception if it fails:

```
def add_time(t1, t2):
    assert valid_time(t1) and valid_time(t2)
    seconds = time_to_int(t1) + time_to_int(t2)
    return int_to_time(seconds)
```

`assert` statements are useful because they distinguish code that deals with normal conditions from code that checks for errors.

16.6. Glossary

prototype and patch: A development plan that involves writing a rough draft of a program, testing, and correcting errors as they are found.

designed development: A development plan that involves high-level insight into the problem and more planning than incremental development or prototype development.

pure function: A function that does not modify any of the objects it receives as arguments. Most pure functions are fruitful.

modifier: A function that changes one or more of the objects it receives as arguments. Most modifiers are void; that is, they return `None`.

functional programming style: A style of program design in which the majority of functions are pure.

invariant: A condition that should always be true during the execution of a program.

assert statement: A statement that check a condition and raises an exception if it fails.

16.7. Exercises

Code examples from this chapter are available from <http://thinkpython2.com/code/Time1.py>; solutions to the exercises are available from http://thinkpython2.com/code/Time1_soln.py.

Ejercicio 16.1. Write a function called `mul_time` that takes a `Time` object and a number and returns a new `Time` object that contains the product of the original `Time` and the number.

Then use `mul_time` to write a function that takes a `Time` object that represents the finishing time in a race, and a number that represents the distance, and returns a `Time` object that represents the average pace (time per mile).

Ejercicio 16.2. The `datetime` module provides `time` objects that are similar to the `Time` objects in this chapter, but they provide a rich set of methods and operators. Read the documentation at <http://docs.python.org/3/library/datetime.html>.

1. Use the `datetime` module to write a program that gets the current date and prints the day of the week.
2. Write a program that takes a birthday as input and prints the user's age and the number of days, hours, minutes and seconds until their next birthday.
3. For two people born on different days, there is a day when one is twice as old as the other. That's their *Double Day*. Write a program that takes two birth dates and computes their *Double Day*.
4. For a little more challenge, write the more general version that computes the day when one person is *n* times older than the other.

Solution: <http://thinkpython2.com/code/double.py>

Capítulo 17

Classes and methods

Although we are using some of Python's object-oriented features, the programs from the last two chapters are not really object-oriented because they don't represent the relationships between programmer-defined types and the functions that operate on them. The next step is to transform those functions into methods that make the relationships explicit.

Code examples from this chapter are available from <http://thinkpython2.com/code/Time2.py>, and solutions to the exercises are in http://thinkpython2.com/code/Point2_soln.py.

17.1. Object-oriented features

Python is an **object-oriented programming language**, which means that it provides features that support object-oriented programming, which has these defining characteristics:

- Programs include class and method definitions.
- Most of the computation is expressed in terms of operations on objects.
- Objects often represent things in the real world, and methods often correspond to the ways things in the real world interact.

For example, the `Time` class defined in Chapter 16 corresponds to the way people record the time of day, and the functions we defined correspond to the kinds of things people do with times. Similarly, the `Point` and `Rectangle` classes in Chapter 15 correspond to the mathematical concepts of a point and a rectangle.

So far, we have not taken advantage of the features Python provides to support object-oriented programming. These features are not strictly necessary; most of them provide alternative syntax for things we have already done. But in many cases, the alternative is more concise and more accurately conveys the structure of the program.

For example, in `Time1.py` there is no obvious connection between the class definition and the function definitions that follow. With some examination, it is apparent that every function takes at least one `Time` object as an argument.

This observation is the motivation for **methods**; a method is a function that is associated with a particular class. We have seen methods for strings, lists, dictionaries and tuples. In this chapter, we will define methods for programmer-defined types.

Methods are semantically the same as functions, but there are two syntactic differences:

- Methods are defined inside a class definition in order to make the relationship between the class and the method explicit.
- The syntax for invoking a method is different from the syntax for calling a function.

In the next few sections, we will take the functions from the previous two chapters and transform them into methods. This transformation is purely mechanical; you can do it by following a sequence of steps. If you are comfortable converting from one form to another, you will be able to choose the best form for whatever you are doing.

17.2. Printing objects

In Chapter 16, we defined a class named `Time` and in Section 16.1, you wrote a function named `print_time`:

```
class Time:
    """Represents the time of day."""

def print_time(time):
    print('%.2d:%.2d:%.2d' % (time.hour, time.minute, time.second))
```

To call this function, you have to pass a `Time` object as an argument:

```
>>> start = Time()
>>> start.hour = 9
>>> start.minute = 45
>>> start.second = 00
>>> print_time(start)
09:45:00
```

To make `print_time` a method, all we have to do is move the function definition inside the class definition. Notice the change in indentation.

```
class Time:
    def print_time(time):
        print('%.2d:%.2d:%.2d' % (time.hour, time.minute, time.second))
```

Now there are two ways to call `print_time`. The first (and less common) way is to use function syntax:

```
>>> Time.print_time(start)
09:45:00
```

In this use of dot notation, `Time` is the name of the class, and `print_time` is the name of the method. `start` is passed as a parameter.

The second (and more concise) way is to use method syntax:

```
>>> start.print_time()
09:45:00
```


In this use of dot notation, `print_time` is the name of the method (again), and `start` is the object the method is invoked on, which is called the **subject**. Just as the subject of a sentence is what the sentence is about, the subject of a method invocation is what the method is about.

Inside the method, the subject is assigned to the first parameter, so in this case `start` is assigned to `time`.

By convention, the first parameter of a method is called `self`, so it would be more common to write `print_time` like this:

```
class Time:
    def print_time(self):
        print('%02d:%02d:%02d' % (self.hour, self.minute, self.second))
```

The reason for this convention is an implicit metaphor:

- The syntax for a function call, `print_time(start)`, suggests that the function is the active agent. It says something like, “Hey `print_time`! Here’s an object for you to print.”
- In object-oriented programming, the objects are the active agents. A method invocation like `start.print_time()` says “Hey `start`! Please print yourself.”

This change in perspective might be more polite, but it is not obvious that it is useful. In the examples we have seen so far, it may not be. But sometimes shifting responsibility from the functions onto the objects makes it possible to write more versatile functions (or methods), and makes it easier to maintain and reuse code.

As an exercise, rewrite `time_to_int` (from Section 16.4) as a method. You might be tempted to rewrite `int_to_time` as a method, too, but that doesn’t really make sense because there would be no object to invoke it on.

17.3. Another example

Here’s a version of `increment` (from Section 16.3) rewritten as a method:

```
# inside class Time:

    def increment(self, seconds):
        seconds += self.time_to_int()
        return int_to_time(seconds)
```

This version assumes that `time_to_int` is written as a method. Also, note that it is a pure function, not a modifier.

Here’s how you would invoke `increment`:

```
>>> start.print_time()
09:45:00
>>> end = start.increment(1337)
>>> end.print_time()
10:07:17
```

The subject, `start`, gets assigned to the first parameter, `self`. The argument, `1337`, gets assigned to the second parameter, `seconds`.

This mechanism can be confusing, especially if you make an error. For example, if you invoke `increment` with two arguments, you get:

```
>>> end = start.increment(1337, 460)
TypeError: increment() takes 2 positional arguments but 3 were given
```

The error message is initially confusing, because there are only two arguments in parentheses. But the subject is also considered an argument, so all together that's three.

By the way, a **positional argument** is an argument that doesn't have a parameter name; that is, it is not a keyword argument. In this function call:

```
sketch(parrot, cage, dead=True)
```

`parrot` and `cage` are positional, and `dead` is a keyword argument.

17.4. A more complicated example

Rewriting `is_after` (from Section 16.1) is slightly more complicated because it takes two `Time` objects as parameters. In this case it is conventional to name the first parameter `self` and the second parameter `other`:

```
# inside class Time:

    def is_after(self, other):
        return self.time_to_int() > other.time_to_int()
```

To use this method, you have to invoke it on one object and pass the other as an argument:

```
>>> end.is_after(start)
True
```

One nice thing about this syntax is that it almost reads like English: “end is after start?”

17.5. The `init` method

The `init` method (short for “initialization”) is a special method that gets invoked when an object is instantiated. Its full name is `__init__` (two underscore characters, followed by `init`, and then two more underscores). An `init` method for the `Time` class might look like this:

```
# inside class Time:

    def __init__(self, hour=0, minute=0, second=0):
        self.hour = hour
        self.minute = minute
        self.second = second
```

It is common for the parameters of `__init__` to have the same names as the attributes. The statement

```
self.hour = hour
```

stores the value of the parameter `hour` as an attribute of `self`.

The parameters are optional, so if you call `Time` with no arguments, you get the default values.

```
>>> time = Time()
>>> time.print_time()
00:00:00
```

If you provide one argument, it overrides `hour`:

```
>>> time = Time(9)
>>> time.print_time()
09:00:00
```

If you provide two arguments, they override `hour` and `minute`.

```
>>> time = Time(9, 45)
>>> time.print_time()
09:45:00
```

And if you provide three arguments, they override all three default values.

As an exercise, write an `init` method for the `Point` class that takes `x` and `y` as optional parameters and assigns them to the corresponding attributes.

17.6. The `__str__` method

`__str__` is a special method, like `__init__`, that is supposed to return a string representation of an object.

For example, here is a `str` method for `Time` objects:

```
# inside class Time:

    def __str__(self):
        return '%.2d:%.2d:%.2d' % (self.hour, self.minute, self.second)
```

When you print an object, Python invokes the `str` method:

```
>>> time = Time(9, 45)
>>> print(time)
09:45:00
```

When I write a new class, I almost always start by writing `__init__`, which makes it easier to instantiate objects, and `__str__`, which is useful for debugging.

As an exercise, write a `str` method for the `Point` class. Create a `Point` object and print it.

17.7. Operator overloading

By defining other special methods, you can specify the behavior of operators on programmer-defined types. For example, if you define a method named `__add__` for the `Time` class, you can use the `+` operator on `Time` objects.

Here is what the definition might look like:

```
# inside class Time:
```

```
def __add__(self, other):
    seconds = self.time_to_int() + other.time_to_int()
    return int_to_time(seconds)
```

And here is how you could use it:

```
>>> start = Time(9, 45)
>>> duration = Time(1, 35)
>>> print(start + duration)
11:20:00
```

When you apply the + operator to Time objects, Python invokes `__add__`. When you print the result, Python invokes `__str__`. So there is a lot happening behind the scenes!

Changing the behavior of an operator so that it works with programmer-defined types is called **operator overloading**. For every operator in Python there is a corresponding special method, like `__add__`. For more details, see <http://docs.python.org/3/reference/datamodel.html#specialnames>.

As an exercise, write an add method for the Point class.

17.8. Type-based dispatch

In the previous section we added two Time objects, but you also might want to add an integer to a Time object. The following is a version of `__add__` that checks the type of `other` and invokes either `add_time` or `increment`:

```
# inside class Time:
```

```
def __add__(self, other):
    if isinstance(other, Time):
        return self.add_time(other)
    else:
        return self.increment(other)

def add_time(self, other):
    seconds = self.time_to_int() + other.time_to_int()
    return int_to_time(seconds)

def increment(self, seconds):
    seconds += self.time_to_int()
    return int_to_time(seconds)
```

The built-in function `isinstance` takes a value and a class object, and returns True if the value is an instance of the class.

If `other` is a Time object, `__add__` invokes `add_time`. Otherwise it assumes that the parameter is a number and invokes `increment`. This operation is called a **type-based dispatch** because it dispatches the computation to different methods based on the type of the arguments.

Here are examples that use the + operator with different types:

```
>>> start = Time(9, 45)
>>> duration = Time(1, 35)
>>> print(start + duration)
11:20:00
>>> print(start + 1337)
10:07:17
```

Unfortunately, this implementation of addition is not commutative. If the integer is the first operand, you get

```
>>> print(1337 + start)
TypeError: unsupported operand type(s) for +: 'int' and 'instance'
```

The problem is, instead of asking the `Time` object to add an integer, Python is asking an integer to add a `Time` object, and it doesn't know how. But there is a clever solution for this problem: the special method `__radd__`, which stands for “right-side add”. This method is invoked when a `Time` object appears on the right side of the `+` operator. Here's the definition:

```
# inside class Time:

    def __radd__(self, other):
        return self.__add__(other)
```

And here's how it's used:

```
>>> print(1337 + start)
10:07:17
```

As an exercise, write an `add` method for `Points` that works with either a `Point` object or a tuple:

- If the second operand is a `Point`, the method should return a new `Point` whose x coordinate is the sum of the x coordinates of the operands, and likewise for the y coordinates.
- If the second operand is a tuple, the method should add the first element of the tuple to the x coordinate and the second element to the y coordinate, and return a new `Point` with the result.

17.9. Polymorphism

Type-based dispatch is useful when it is necessary, but (fortunately) it is not always necessary. Often you can avoid it by writing functions that work correctly for arguments with different types.

Many of the functions we wrote for strings also work for other sequence types. For example, in Section 11.2 we used `histogram` to count the number of times each letter appears in a word.

```
def histogram(s):
    d = dict()
    for c in s:
        if c not in d:
            d[c] = 1
```

```

    else:
        d[c] = d[c]+1
    return d

```

This function also works for lists, tuples, and even dictionaries, as long as the elements of `s` are hashable, so they can be used as keys in `d`.

```

>>> t = ['spam', 'egg', 'spam', 'spam', 'bacon', 'spam']
>>> histogram(t)
{'bacon': 1, 'egg': 1, 'spam': 4}

```

Functions that work with several types are called **polymorphic**. Polymorphism can facilitate code reuse. For example, the built-in function `sum`, which adds the elements of a sequence, works as long as the elements of the sequence support addition.

Since `Time` objects provide an `add` method, they work with `sum`:

```

>>> t1 = Time(7, 43)
>>> t2 = Time(7, 41)
>>> t3 = Time(7, 37)
>>> total = sum([t1, t2, t3])
>>> print(total)
23:01:00

```

In general, if all of the operations inside a function work with a given type, the function works with that type.

The best kind of polymorphism is the unintentional kind, where you discover that a function you already wrote can be applied to a type you never planned for.

17.10. Debugging

It is legal to add attributes to objects at any point in the execution of a program, but if you have objects with the same type that don't have the same attributes, it is easy to make mistakes. It is considered a good idea to initialize all of an object's attributes in the `init` method.

If you are not sure whether an object has a particular attribute, you can use the built-in function `hasattr` (see Section 15.7).

Another way to access attributes is the built-in function `vars`, which takes an object and returns a dictionary that maps from attribute names (as strings) to their values:

```

>>> p = Point(3, 4)
>>> vars(p)
{'y': 4, 'x': 3}

```

For purposes of debugging, you might find it useful to keep this function handy:

```

def print_attributes(obj):
    for attr in vars(obj):
        print(attr, getattr(obj, attr))

```

`print_attributes` traverses the dictionary and prints each attribute name and its corresponding value.

The built-in function `getattr` takes an object and an attribute name (as a string) and returns the attribute's value.

17.11. Interface and implementation

One of the goals of object-oriented design is to make software more maintainable, which means that you can keep the program working when other parts of the system change, and modify the program to meet new requirements.

A design principle that helps achieve that goal is to keep interfaces separate from implementations. For objects, that means that the methods a class provides should not depend on how the attributes are represented.

For example, in this chapter we developed a class that represents a time of day. Methods provided by this class include `time_to_int`, `is_after`, and `add_time`.

We could implement those methods in several ways. The details of the implementation depend on how we represent time. In this chapter, the attributes of a `Time` object are `hour`, `minute`, and `second`.

As an alternative, we could replace these attributes with a single integer representing the number of seconds since midnight. This implementation would make some methods, like `is_after`, easier to write, but it makes other methods harder.

After you deploy a new class, you might discover a better implementation. If other parts of the program are using your class, it might be time-consuming and error-prone to change the interface.

But if you designed the interface carefully, you can change the implementation without changing the interface, which means that other parts of the program don't have to change.

17.12. Glossary

object-oriented language: A language that provides features, such as programmer-defined types and methods, that facilitate object-oriented programming.

object-oriented programming: A style of programming in which data and the operations that manipulate it are organized into classes and methods.

method: A function that is defined inside a class definition and is invoked on instances of that class.

subject: The object a method is invoked on.

positional argument: An argument that does not include a parameter name, so it is not a keyword argument.

operator overloading: Changing the behavior of an operator like `+` so it works with a programmer-defined type.

type-based dispatch: A programming pattern that checks the type of an operand and invokes different functions for different types.

polymorphic: Pertaining to a function that can work with more than one type.

17.13. Exercises

Ejercicio 17.1. Download the code from this chapter from <http://thinkpython2.com/code/Time2.py>. Change the attributes of `Time` to be a single integer representing seconds since midnight. Then modify the methods (and the function `int_to_time`) to work with the new implementation. You should not have to modify the test code in `main`. When you are done, the output should be the same as before. Solution: http://thinkpython2.com/code/Time2_soln.py.

Ejercicio 17.2. This exercise is a cautionary tale about one of the most common, and difficult to find, errors in Python. Write a definition for a class named `Kangaroo` with the following methods:

1. An `__init__` method that initializes an attribute named `pouch_contents` to an empty list.
2. A method named `put_in_pouch` that takes an object of any type and adds it to `pouch_contents`.
3. A `__str__` method that returns a string representation of the `Kangaroo` object and the contents of the pouch.

Test your code by creating two `Kangaroo` objects, assigning them to variables named `kanga` and `roo`, and then adding `roo` to the contents of `kanga`'s pouch.

Download <http://thinkpython2.com/code/BadKangaroo.py>. It contains a solution to the previous problem with one big, nasty bug. Find and fix the bug.

If you get stuck, you can download <http://thinkpython2.com/code/GoodKangaroo.py>, which explains the problem and demonstrates a solution.

Capítulo 18

Inheritance

The language feature most often associated with object-oriented programming is **inheritance**. Inheritance is the ability to define a new class that is a modified version of an existing class. In this chapter I demonstrate inheritance using classes that represent playing cards, decks of cards, and poker hands.

If you don't play poker, you can read about it at <http://en.wikipedia.org/wiki/Poker>, but you don't have to; I'll tell you what you need to know for the exercises.

Code examples from this chapter are available from <http://thinkpython2.com/code/Card.py>.

18.1. Card objects

There are fifty-two cards in a deck, each of which belongs to one of four suits and one of thirteen ranks. The suits are Spades, Hearts, Diamonds, and Clubs (in descending order in bridge). The ranks are Ace, 2, 3, 4, 5, 6, 7, 8, 9, 10, Jack, Queen, and King. Depending on the game that you are playing, an Ace may be higher than King or lower than 2.

If we want to define a new object to represent a playing card, it is obvious what the attributes should be: `rank` and `suit`. It is not as obvious what type the attributes should be. One possibility is to use strings containing words like 'Spade' for suits and 'Queen' for ranks. One problem with this implementation is that it would not be easy to compare cards to see which had a higher rank or suit.

An alternative is to use integers to **encode** the ranks and suits. In this context, “encode” means that we are going to define a mapping between numbers and suits, or between numbers and ranks. This kind of encoding is not meant to be a secret (that would be “encryption”).

For example, this table shows the suits and the corresponding integer codes:

Spades	↦	3
Hearts	↦	2
Diamonds	↦	1
Clubs	↦	0

This code makes it easy to compare cards; because higher suits map to higher numbers, we can compare suits by comparing their codes.

The mapping for ranks is fairly obvious; each of the numerical ranks maps to the corresponding integer, and for face cards:

```
Jack    ↦ 11
Queen   ↦ 12
King    ↦ 13
```

I am using the \mapsto symbol to make it clear that these mappings are not part of the Python program. They are part of the program design, but they don't appear explicitly in the code.

The class definition for `Card` looks like this:

```
class Card:
    """Represents a standard playing card."""

    def __init__(self, suit=0, rank=2):
        self.suit = suit
        self.rank = rank
```

As usual, the `init` method takes an optional parameter for each attribute. The default card is the 2 of Clubs.

To create a `Card`, you call `Card` with the suit and rank of the card you want.

```
queen_of_diamonds = Card(1, 12)
```

18.2. Class attributes

In order to print `Card` objects in a way that people can easily read, we need a mapping from the integer codes to the corresponding ranks and suits. A natural way to do that is with lists of strings. We assign these lists to **class attributes**:

inside class `Card`:

```
suit_names = ['Clubs', 'Diamonds', 'Hearts', 'Spades']
rank_names = [None, 'Ace', '2', '3', '4', '5', '6', '7',
               '8', '9', '10', 'Jack', 'Queen', 'King']

def __str__(self):
    return '%s of %s' % (Card.rank_names[self.rank],
                        Card.suit_names[self.suit])
```

Variables like `suit_names` and `rank_names`, which are defined inside a class but outside of any method, are called class attributes because they are associated with the class object `Card`.

This term distinguishes them from variables like `suit` and `rank`, which are called **instance attributes** because they are associated with a particular instance.

Both kinds of attribute are accessed using dot notation. For example, in `__str__`, `self` is a `Card` object, and `self.rank` is its rank. Similarly, `Card` is a class object, and `Card.rank_names` is a list of strings associated with the class.

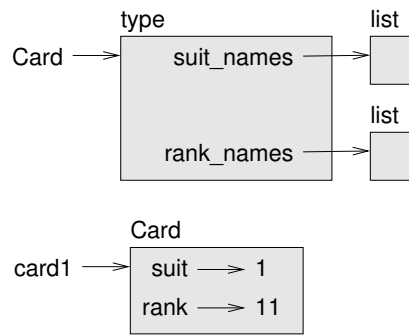


Figura 18.1: Object diagram.

Every card has its own suit and rank, but there is only one copy of `suit_names` and `rank_names`.

Putting it all together, the expression `Card.rank_names[self.rank]` means “use the attribute `rank` from the object `self` as an index into the list `rank_names` from the class `Card`, and select the appropriate string.”

The first element of `rank_names` is `None` because there is no card with rank zero. By including `None` as a place-keeper, we get a mapping with the nice property that the index 2 maps to the string '2', and so on. To avoid this tweak, we could have used a dictionary instead of a list.

With the methods we have so far, we can create and print cards:

```
>>> card1 = Card(2, 11)
>>> print(card1)
Jack of Hearts
```

Figure 18.1 is a diagram of the `Card` class object and one `Card` instance. `Card` is a class object; its type is `type`. `card1` is an instance of `Card`, so its type is `Card`. To save space, I didn't draw the contents of `suit_names` and `rank_names`.

18.3. Comparing cards

For built-in types, there are relational operators (`<`, `>`, `==`, etc.) that compare values and determine when one is greater than, less than, or equal to another. For programmer-defined types, we can override the behavior of the built-in operators by providing a method named `__lt__`, which stands for “less than”.

`__lt__` takes two parameters, `self` and `other`, and returns `True` if `self` is strictly less than `other`.

The correct ordering for cards is not obvious. For example, which is better, the 3 of Clubs or the 2 of Diamonds? One has a higher rank, but the other has a higher suit. In order to compare cards, you have to decide whether rank or suit is more important.

The answer might depend on what game you are playing, but to keep things simple, we'll make the arbitrary choice that suit is more important, so all of the Spades outrank all of the Diamonds, and so on.

With that decided, we can write `__lt__`:

```
# inside class Card:

    def __lt__(self, other):
        # check the suits
        if self.suit < other.suit: return True
        if self.suit > other.suit: return False

        # suits are the same... check ranks
        return self.rank < other.rank
```

You can write this more concisely using tuple comparison:

```
# inside class Card:

    def __lt__(self, other):
        t1 = self.suit, self.rank
        t2 = other.suit, other.rank
        return t1 < t2
```

As an exercise, write an `__lt__` method for Time objects. You can use tuple comparison, but you also might consider comparing integers.

18.4. Decks

Now that we have Cards, the next step is to define Decks. Since a deck is made up of cards, it is natural for each Deck to contain a list of cards as an attribute.

The following is a class definition for Deck. The `init` method creates the attribute `cards` and generates the standard set of fifty-two cards:

```
class Deck:

    def __init__(self):
        self.cards = []
        for suit in range(4):
            for rank in range(1, 14):
                card = Card(suit, rank)
                self.cards.append(card)
```

The easiest way to populate the deck is with a nested loop. The outer loop enumerates the suits from 0 to 3. The inner loop enumerates the ranks from 1 to 13. Each iteration creates a new Card with the current suit and rank, and appends it to `self.cards`.

18.5. Printing the deck

Here is a `__str__` method for Deck:

```
#inside class Deck:

    def __str__(self):
        res = []
```

```

        for card in self.cards:
            res.append(str(card))
        return '\n'.join(res)

```

This method demonstrates an efficient way to accumulate a large string: building a list of strings and then using the string method `join`. The built-in function `str` invokes the `__str__` method on each card and returns the string representation.

Since we invoke `join` on a newline character, the cards are separated by newlines. Here's what the result looks like:

```

>>> deck = Deck()
>>> print(deck)
Ace of Clubs
2 of Clubs
3 of Clubs
...
10 of Spades
Jack of Spades
Queen of Spades
King of Spades

```

Even though the result appears on 52 lines, it is one long string that contains newlines.

18.6. Add, remove, shuffle and sort

To deal cards, we would like a method that removes a card from the deck and returns it. The list method `pop` provides a convenient way to do that:

```

#inside class Deck:

    def pop_card(self):
        return self.cards.pop()

```

Since `pop` removes the *last* card in the list, we are dealing from the bottom of the deck.

To add a card, we can use the list method `append`:

```

#inside class Deck:

    def add_card(self, card):
        self.cards.append(card)

```

A method like this that uses another method without doing much work is sometimes called a **veneer**. The metaphor comes from woodworking, where a veneer is a thin layer of good quality wood glued to the surface of a cheaper piece of wood to improve the appearance.

In this case `add_card` is a “thin” method that expresses a list operation in terms appropriate for decks. It improves the appearance, or interface, of the implementation.

As another example, we can write a `Deck` method named `shuffle` using the function `shuffle` from the `random` module:

```

# inside class Deck:

    def shuffle(self):
        random.shuffle(self.cards)

```

Don't forget to import random.

As an exercise, write a Deck method named `sort` that uses the list method `sort` to sort the cards in a Deck. `sort` uses the `__lt__` method we defined to determine the order.

18.7. Inheritance

Inheritance is the ability to define a new class that is a modified version of an existing class. As an example, let's say we want a class to represent a "hand", that is, the cards held by one player. A hand is similar to a deck: both are made up of a collection of cards, and both require operations like adding and removing cards.

A hand is also different from a deck; there are operations we want for hands that don't make sense for a deck. For example, in poker we might compare two hands to see which one wins. In bridge, we might compute a score for a hand in order to make a bid.

This relationship between classes—similar, but different—lends itself to inheritance. To define a new class that inherits from an existing class, you put the name of the existing class in parentheses:

```
class Hand(Deck):
    """Represents a hand of playing cards."""
```

This definition indicates that `Hand` inherits from `Deck`; that means we can use methods like `pop_card` and `add_card` for Hands as well as Decks.

When a new class inherits from an existing one, the existing one is called the **parent** and the new class is called the **child**.

In this example, `Hand` inherits `__init__` from `Deck`, but it doesn't really do what we want: instead of populating the hand with 52 new cards, the `init` method for Hands should initialize cards with an empty list.

If we provide an `init` method in the `Hand` class, it overrides the one in the `Deck` class:

```
# inside class Hand:

    def __init__(self, label=''):
        self.cards = []
        self.label = label
```

When you create a `Hand`, Python invokes this `init` method, not the one in `Deck`.

```
>>> hand = Hand('new hand')
>>> hand.cards
[]
>>> hand.label
'new hand'
```

The other methods are inherited from `Deck`, so we can use `pop_card` and `add_card` to deal a card:

```
>>> deck = Deck()
>>> card = deck.pop_card()
>>> hand.add_card(card)
>>> print(hand)
King of Spades
```

A natural next step is to encapsulate this code in a method called `move_cards`:

```
#inside class Deck:
```

```
def move_cards(self, hand, num):
    for i in range(num):
        hand.add_card(self.pop_card())
```

`move_cards` takes two arguments, a `Hand` object and the number of cards to deal. It modifies both `self` and `hand`, and returns `None`.

In some games, cards are moved from one hand to another, or from a hand back to the deck. You can use `move_cards` for any of these operations: `self` can be either a `Deck` or a `Hand`, and `hand`, despite the name, can also be a `Deck`.

Inheritance is a useful feature. Some programs that would be repetitive without inheritance can be written more elegantly with it. Inheritance can facilitate code reuse, since you can customize the behavior of parent classes without having to modify them. In some cases, the inheritance structure reflects the natural structure of the problem, which makes the design easier to understand.

On the other hand, inheritance can make programs difficult to read. When a method is invoked, it is sometimes not clear where to find its definition. The relevant code may be spread across several modules. Also, many of the things that can be done using inheritance can be done as well or better without it.

18.8. Class diagrams

So far we have seen stack diagrams, which show the state of a program, and object diagrams, which show the attributes of an object and their values. These diagrams represent a snapshot in the execution of a program, so they change as the program runs.

They are also highly detailed; for some purposes, too detailed. A class diagram is a more abstract representation of the structure of a program. Instead of showing individual objects, it shows classes and the relationships between them.

There are several kinds of relationship between classes:

- Objects in one class might contain references to objects in another class. For example, each `Rectangle` contains a reference to a `Point`, and each `Deck` contains references to many `Cards`. This kind of relationship is called **HAS-A**, as in, “a `Rectangle` has a `Point`.”
- One class might inherit from another. This relationship is called **IS-A**, as in, “a `Hand` is a kind of a `Deck`.”
- One class might depend on another in the sense that objects in one class take objects in the second class as parameters, or use objects in the second class as part of a computation. This kind of relationship is called a **dependency**.

A **class diagram** is a graphical representation of these relationships. For example, Figure 18.2 shows the relationships between `Card`, `Deck` and `Hand`.

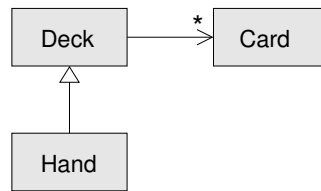


Figura 18.2: Class diagram.

The arrow with a hollow triangle head represents an IS-A relationship; in this case it indicates that Hand inherits from Deck.

The standard arrow head represents a HAS-A relationship; in this case a Deck has references to Card objects.

The star (*) near the arrow head is a **multiplicity**; it indicates how many Cards a Deck has. A multiplicity can be a simple number, like 52, a range, like 5..7 or a star, which indicates that a Deck can have any number of Cards.

There are no dependencies in this diagram. They would normally be shown with a dashed arrow. Or if there are a lot of dependencies, they are sometimes omitted.

A more detailed diagram might show that a Deck actually contains a *list* of Cards, but built-in types like list and dict are usually not included in class diagrams.

18.9. Debugging

Inheritance can make debugging difficult because when you invoke a method on an object, it might be hard to figure out which method will be invoked.

Suppose you are writing a function that works with Hand objects. You would like it to work with all kinds of Hands, like PokerHands, BridgeHands, etc. If you invoke a method like `shuffle`, you might get the one defined in Deck, but if any of the subclasses override this method, you'll get that version instead. This behavior is usually a good thing, but it can be confusing.

Any time you are unsure about the flow of execution through your program, the simplest solution is to add print statements at the beginning of the relevant methods. If `Deck.shuffle` prints a message that says something like `Running Deck.shuffle`, then as the program runs it traces the flow of execution.

As an alternative, you could use this function, which takes an object and a method name (as a string) and returns the class that provides the definition of the method:

```
def find_defining_class(obj, meth_name):
    for ty in type(obj).mro():
        if meth_name in ty.__dict__:
            return ty
```

Here's an example:

```
>>> hand = Hand()
>>> find_defining_class(hand, 'shuffle')
<class '__main__.Deck'>
```


So the `shuffle` method for this `Hand` is the one in `Deck`.

`find_defining_class` uses the `mro` method to get the list of class objects (types) that will be searched for methods. “MRO” stands for “method resolution order”, which is the sequence of classes Python searches to “resolve” a method name.

Here’s a design suggestion: when you override a method, the interface of the new method should be the same as the old. It should take the same parameters, return the same type, and obey the same preconditions and postconditions. If you follow this rule, you will find that any function designed to work with an instance of a parent class, like a `Deck`, will also work with instances of child classes like a `Hand` and `PokerHand`.

If you violate this rule, which is called the “Liskov substitution principle”, your code will collapse like (sorry) a house of cards.

18.10. Data encapsulation

The previous chapters demonstrate a development plan we might call “object-oriented design”. We identified objects we needed—like `Point`, `Rectangle` and `Time`—and defined classes to represent them. In each case there is an obvious correspondence between the object and some entity in the real world (or at least a mathematical world).

But sometimes it is less obvious what objects you need and how they should interact. In that case you need a different development plan. In the same way that we discovered function interfaces by encapsulation and generalization, we can discover class interfaces by **data encapsulation**.

Markov analysis, from Section 13.8, provides a good example. If you download my code from <http://thinkpython2.com/code/markov.py>, you’ll see that it uses two global variables—`suffix_map` and `prefix`—that are read and written from several functions.

```
suffix_map = {}
prefix = ()
```

Because these variables are global, we can only run one analysis at a time. If we read two texts, their prefixes and suffixes would be added to the same data structures (which makes for some interesting generated text).

To run multiple analyses, and keep them separate, we can encapsulate the state of each analysis in an object. Here’s what that looks like:

```
class Markov:

    def __init__(self):
        self.suffix_map = {}
        self.prefix = ()
```

Next, we transform the functions into methods. For example, here’s `process_word`:

```
def process_word(self, word, order=2):
    if len(self.prefix) < order:
        self.prefix += (word,)
    return
```

```

try:
    self.suffix_map[self.prefix].append(word)
except KeyError:
    # if there is no entry for this prefix, make one
    self.suffix_map[self.prefix] = [word]

self.prefix = shift(self.prefix, word)

```

Transforming a program like this—changing the design without changing the behavior—is another example of refactoring (see Section 4.7).

This example suggests a development plan for designing objects and methods:

1. Start by writing functions that read and write global variables (when necessary).
2. Once you get the program working, look for associations between global variables and the functions that use them.
3. Encapsulate related variables as attributes of an object.
4. Transform the associated functions into methods of the new class.

As an exercise, download my Markov code from <http://thinkpython2.com/code/markov.py>, and follow the steps described above to encapsulate the global variables as attributes of a new class called Markov. Solution: <http://thinkpython2.com/code/markov2.py>.

18.11. Glossary

encode: To represent one set of values using another set of values by constructing a mapping between them.

class attribute: An attribute associated with a class object. Class attributes are defined inside a class definition but outside any method.

instance attribute: An attribute associated with an instance of a class.

veneer: A method or function that provides a different interface to another function without doing much computation.

inheritance: The ability to define a new class that is a modified version of a previously defined class.

parent class: The class from which a child class inherits.

child class: A new class created by inheriting from an existing class; also called a “subclass”.

IS-A relationship: A relationship between a child class and its parent class.

HAS-A relationship: A relationship between two classes where instances of one class contain references to instances of the other.

dependency: A relationship between two classes where instances of one class use instances of the other class, but do not store them as attributes.

class diagram: A diagram that shows the classes in a program and the relationships between them.

multiplicity: A notation in a class diagram that shows, for a HAS-A relationship, how many references there are to instances of another class.

data encapsulation: A program development plan that involves a prototype using global variables and a final version that makes the global variables into instance attributes.

18.12. Exercises

Ejercicio 18.1. *For the following program, draw a UML class diagram that shows these classes and the relationships among them.*

```
class PingPongParent:
    pass

class Ping(PingPongParent):
    def __init__(self, pong):
        self.pong = pong

class Pong(PingPongParent):
    def __init__(self, pings=None):
        if pings is None:
            self.pings = []
        else:
            self.pings = pings

    def add_ping(self, ping):
        self.pings.append(ping)

pong = Pong()
ping = Ping(pong)
pong.add_ping(ping)
```

Ejercicio 18.2. *Write a Deck method called `deal_hands` that takes two parameters, the number of hands and the number of cards per hand. It should create the appropriate number of Hand objects, deal the appropriate number of cards per hand, and return a list of Hands.*

Ejercicio 18.3. *The following are the possible hands in poker, in increasing order of value and decreasing order of probability:*

pair: *two cards with the same rank*

two pair: *two pairs of cards with the same rank*

three of a kind: *three cards with the same rank*

straight: *five cards with ranks in sequence (aces can be high or low, so Ace-2-3-4-5 is a straight and so is 10-Jack-Queen-King-Ace, but Queen-King-Ace-2-3 is not.)*

flush: *five cards with the same suit*

full house: *three cards with one rank, two cards with another*

four of a kind: *four cards with the same rank*

straight flush: *five cards in sequence (as defined above) and with the same suit*

The goal of these exercises is to estimate the probability of drawing these various hands.

1. Download the following files from <http://thinkpython2.com/code/>:
`Card.py` : A complete version of the `Card`, `Deck` and `Hand` classes in this chapter.
`PokerHand.py` : An incomplete implementation of a class that represents a poker hand, and some code that tests it.
2. If you run `PokerHand.py`, it deals seven 7-card poker hands and checks to see if any of them contains a flush. Read this code carefully before you go on.
3. Add methods to `PokerHand.py` named `has_pair`, `has_twopair`, etc. that return `True` or `False` according to whether or not the hand meets the relevant criteria. Your code should work correctly for “hands” that contain any number of cards (although 5 and 7 are the most common sizes).
4. Write a method named `classify` that figures out the highest-value classification for a hand and sets the `label` attribute accordingly. For example, a 7-card hand might contain a flush and a pair; it should be labeled “flush”.
5. When you are convinced that your classification methods are working, the next step is to estimate the probabilities of the various hands. Write a function in `PokerHand.py` that shuffles a deck of cards, divides it into hands, classifies the hands, and counts the number of times various classifications appear.
6. Print a table of the classifications and their probabilities. Run your program with larger and larger numbers of hands until the output values converge to a reasonable degree of accuracy. Compare your results to the values at http://en.wikipedia.org/wiki/Hand_rankings.

Solution: <http://thinkpython2.com/code/PokerHandSoln.py>.

Capítulo 19

The Goodies

One of my goals for this book has been to teach you as little Python as possible. When there were two ways to do something, I picked one and avoided mentioning the other. Or sometimes I put the second one into an exercise.

Now I want to go back for some of the good bits that got left behind. Python provides a number of features that are not really necessary—you can write good code without them—but with them you can sometimes write code that’s more concise, readable or efficient, and sometimes all three.

19.1. Conditional expressions

We saw conditional statements in Section 5.4. Conditional statements are often used to choose one of two values; for example:

```
if x > 0:
    y = math.log(x)
else:
    y = float('nan')
```

This statement checks whether `x` is positive. If so, it computes `math.log`. If not, `math.log` would raise a `ValueError`. To avoid stopping the program, we generate a “NaN”, which is a special floating-point value that represents “Not a Number”.

We can write this statement more concisely using a **conditional expression**:

```
y = math.log(x) if x > 0 else float('nan')
```

You can almost read this line like English: “`y` gets `log-x` if `x` is greater than 0; otherwise it gets NaN”.

Recursive functions can sometimes be rewritten using conditional expressions. For example, here is a recursive version of `factorial`:

```
def factorial(n):
    if n == 0:
        return 1
    else:
        return n * factorial(n-1)
```

We can rewrite it like this:

```
def factorial(n):
    return 1 if n == 0 else n * factorial(n-1)
```

Another use of conditional expressions is handling optional arguments. For example, here is the `init` method from `GoodKangaroo` (see Exercise 17.2):

```
def __init__(self, name, contents=None):
    self.name = name
    if contents == None:
        contents = []
    self.pouch_contents = contents
```

We can rewrite this one like this:

```
def __init__(self, name, contents=None):
    self.name = name
    self.pouch_contents = [] if contents == None else contents
```

In general, you can replace a conditional statement with a conditional expression if both branches contain simple expressions that are either returned or assigned to the same variable.

19.2. List comprehensions

In Section 10.7 we saw the `map` and `filter` patterns. For example, this function takes a list of strings, maps the string method `capitalize` to the elements, and returns a new list of strings:

```
def capitalize_all(t):
    res = []
    for s in t:
        res.append(s.capitalize())
    return res
```

We can write this more concisely using a **list comprehension**:

```
def capitalize_all(t):
    return [s.capitalize() for s in t]
```

The bracket operators indicate that we are constructing a new list. The expression inside the brackets specifies the elements of the list, and the `for` clause indicates what sequence we are traversing.

The syntax of a list comprehension is a little awkward because the loop variable, `s` in this example, appears in the expression before we get to the definition.

List comprehensions can also be used for filtering. For example, this function selects only the elements of `t` that are upper case, and returns a new list:

```
def only_upper(t):
    res = []
    for s in t:
        if s.isupper():
            res.append(s)
    return res
```

We can rewrite it using a list comprehension

```
def only_upper(t):  
    return [s for s in t if s.isupper()]
```

List comprehensions are concise and easy to read, at least for simple expressions. And they are usually faster than the equivalent for loops, sometimes much faster. So if you are mad at me for not mentioning them earlier, I understand.

But, in my defense, list comprehensions are harder to debug because you can't put a print statement inside the loop. I suggest that you use them only if the computation is simple enough that you are likely to get it right the first time. And for beginners that means never.

19.3. Generator expressions

Generator expressions are similar to list comprehensions, but with parentheses instead of square brackets:

```
>>> g = (x**2 for x in range(5))  
>>> g  
<generator object <genexpr> at 0x7f4c45a786c0>
```

The result is a generator object that knows how to iterate through a sequence of values. But unlike a list comprehension, it does not compute the values all at once; it waits to be asked. The built-in function `next` gets the next value from the generator:

```
>>> next(g)  
0  
>>> next(g)  
1
```

When you get to the end of the sequence, `next` raises a `StopIteration` exception. You can also use a `for` loop to iterate through the values:

```
>>> for val in g:  
...     print(val)  
4  
9  
16
```

The generator object keeps track of where it is in the sequence, so the `for` loop picks up where `next` left off. Once the generator is exhausted, it continues to raise `StopIteration`:

```
>>> next(g)  
StopIteration
```

Generator expressions are often used with functions like `sum`, `max`, and `min`:

```
>>> sum(x**2 for x in range(5))  
30
```

19.4. any and all

Python provides a built-in function, `any`, that takes a sequence of boolean values and returns `True` if any of the values are `True`. It works on lists:

```
>>> any([False, False, True])
True
```

But it is often used with generator expressions:

```
>>> any(letter == 't' for letter in 'monty')
True
```

That example isn't very useful because it does the same thing as the `in` operator. But we could use `any` to rewrite some of the search functions we wrote in Section 9.3. For example, we could write `avoids` like this:

```
def avoids(word, forbidden):
    return not any(letter in forbidden for letter in word)
```

The function almost reads like English, “word avoids forbidden if there are not any forbidden letters in word.”

Using `any` with a generator expression is efficient because it stops immediately if it finds a `True` value, so it doesn't have to evaluate the whole sequence.

Python provides another built-in function, `all`, that returns `True` if every element of the sequence is `True`. As an exercise, use `all` to re-write `uses_all` from Section 9.3.

19.5. Sets

In Section 13.6 I use dictionaries to find the words that appear in a document but not in a word list. The function I wrote takes `d1`, which contains the words from the document as keys, and `d2`, which contains the list of words. It returns a dictionary that contains the keys from `d1` that are not in `d2`.

```
def subtract(d1, d2):
    res = dict()
    for key in d1:
        if key not in d2:
            res[key] = None
    return res
```

In all of these dictionaries, the values are `None` because we never use them. As a result, we waste some storage space.

Python provides another built-in type, called a `set`, that behaves like a collection of dictionary keys with no values. Adding elements to a set is fast; so is checking membership. And sets provide methods and operators to compute common set operations.

For example, set subtraction is available as a method called `difference` or as an operator, `-`. So we can rewrite `subtract` like this:

```
def subtract(d1, d2):
    return set(d1) - set(d2)
```

The result is a set instead of a dictionary, but for operations like iteration, the behavior is the same.

Some of the exercises in this book can be done concisely and efficiently with sets. For example, here is a solution to `has_duplicates`, from Exercise 10.7, that uses a dictionary:


```
def has_duplicates(t):
    d = {}
    for x in t:
        if x in d:
            return True
        d[x] = True
    return False
```

When an element appears for the first time, it is added to the dictionary. If the same element appears again, the function returns True.

Using sets, we can write the same function like this:

```
def has_duplicates(t):
    return len(set(t)) < len(t)
```

An element can only appear in a set once, so if an element in `t` appears more than once, the set will be smaller than `t`. If there are no duplicates, the set will be the same size as `t`.

We can also use sets to do some of the exercises in Chapter 9. For example, here's a version of `uses_only` with a loop:

```
def uses_only(word, available):
    for letter in word:
        if letter not in available:
            return False
    return True
```

`uses_only` checks whether all letters in `word` are in `available`. We can rewrite it like this:

```
def uses_only(word, available):
    return set(word) <= set(available)
```

The `<=` operator checks whether one set is a subset of another, including the possibility that they are equal, which is true if all the letters in `word` appear in `available`.

As an exercise, rewrite `avoids` using sets.

19.6. Counters

A Counter is like a set, except that if an element appears more than once, the Counter keeps track of how many times it appears. If you are familiar with the mathematical idea of a **multiset**, a Counter is a natural way to represent a multiset.

Counter is defined in a standard module called `collections`, so you have to import it. You can initialize a Counter with a string, list, or anything else that supports iteration:

```
>>> from collections import Counter
>>> count = Counter('parrot')
>>> count
Counter({'r': 2, 't': 1, 'o': 1, 'p': 1, 'a': 1})
```

Counters behave like dictionaries in many ways; they map from each key to the number of times it appears. As in dictionaries, the keys have to be hashable.

Unlike dictionaries, Counters don't raise an exception if you access an element that doesn't appear. Instead, they return 0:

```
>>> count['d']
0
```

We can use Counters to rewrite `is_anagram` from Exercise 10.6:

```
def is_anagram(word1, word2):
    return Counter(word1) == Counter(word2)
```

If two words are anagrams, they contain the same letters with the same counts, so their Counters are equivalent.

Counters provide methods and operators to perform set-like operations, including addition, subtraction, union and intersection. And they provide an often-useful method, `most_common`, which returns a list of value-frequency pairs, sorted from most common to least:

```
>>> count = Counter('parrot')
>>> for val, freq in count.most_common(3):
...     print(val, freq)
r 2
p 1
a 1
```

19.7. defaultdict

The `collections` module also provides `defaultdict`, which is like a dictionary except that if you access a key that doesn't exist, it can generate a new value on the fly.

When you create a `defaultdict`, you provide a function that's used to create new values. A function used to create objects is sometimes called a **factory**. The built-in functions that create lists, sets, and other types can be used as factories:

```
>>> from collections import defaultdict
>>> d = defaultdict(list)
```

Notice that the argument is `list`, which is a class object, not `list()`, which is a new list. The function you provide doesn't get called unless you access a key that doesn't exist.

```
>>> t = d['new key']
>>> t
[]
```

The new list, which we're calling `t`, is also added to the dictionary. So if we modify `t`, the change appears in `d`:

```
>>> t.append('new value')
>>> d
defaultdict(<class 'list'>, {'new key': ['new value']})
```

If you are making a dictionary of lists, you can often write simpler code using `defaultdict`. In my solution to Exercise 12.2, which you can get from http://thinkpython2.com/code/anagram_sets.py, I make a dictionary that maps from a sorted string of letters to the list of words that can be spelled with those letters. For example, `'opst'` maps to the list `['opts', 'post', 'pots', 'spot', 'stop', 'tops']`.

Here's the original code:

```
def all_anagrams(filename):
    d = {}
    for line in open(filename):
        word = line.strip().lower()
        t = signature(word)
        if t not in d:
            d[t] = [word]
        else:
            d[t].append(word)
    return d
```

This can be simplified using `setdefault`, which you might have used in Exercise 11.2:

```
def all_anagrams(filename):
    d = {}
    for line in open(filename):
        word = line.strip().lower()
        t = signature(word)
        d.setdefault(t, []).append(word)
    return d
```

This solution has the drawback that it makes a new list every time, regardless of whether it is needed. For lists, that's no big deal, but if the factory function is complicated, it might be.

We can avoid this problem and simplify the code using a `defaultdict`:

```
def all_anagrams(filename):
    d = defaultdict(list)
    for line in open(filename):
        word = line.strip().lower()
        t = signature(word)
        d[t].append(word)
    return d
```

My solution to Exercise 18.3, which you can download from <http://thinkpython2.com/code/PokerHandSoln.py>, uses `setdefault` in the function `has_straightflush`. This solution has the drawback of creating a `Hand` object every time through the loop, whether it is needed or not. As an exercise, rewrite it using a `defaultdict`.

19.8. Named tuples

Many simple objects are basically collections of related values. For example, the `Point` object defined in Chapter 15 contains two numbers, `x` and `y`. When you define a class like this, you usually start with an `init` method and a `str` method:

```
class Point:

    def __init__(self, x=0, y=0):
        self.x = x
        self.y = y

    def __str__(self):
        return '(%g, %g)' % (self.x, self.y)
```

This is a lot of code to convey a small amount of information. Python provides a more concise way to say the same thing:

```
from collections import namedtuple
Point = namedtuple('Point', ['x', 'y'])
```

The first argument is the name of the class you want to create. The second is a list of the attributes Point objects should have, as strings. The return value from `namedtuple` is a class object:

```
>>> Point
<class '__main__.Point'>
```

Point automatically provides methods like `__init__` and `__str__` so you don't have to write them.

To create a Point object, you use the Point class as a function:

```
>>> p = Point(1, 2)
>>> p
Point(x=1, y=2)
```

The `init` method assigns the arguments to attributes using the names you provided. The `str` method prints a representation of the Point object and its attributes.

You can access the elements of the named tuple by name:

```
>>> p.x, p.y
(1, 2)
```

But you can also treat a named tuple as a tuple:

```
>>> p[0], p[1]
(1, 2)
```

```
>>> x, y = p
>>> x, y
(1, 2)
```

Named tuples provide a quick way to define simple classes. The drawback is that simple classes don't always stay simple. You might decide later that you want to add methods to a named tuple. In that case, you could define a new class that inherits from the named tuple:

```
class Pointier(Point):
    # add more methods here
```

Or you could switch to a conventional class definition.

19.9. Gathering keyword args

In Section 12.4, we saw how to write a function that gathers its arguments into a tuple:

```
def printall(*args):
    print(args)
```

You can call this function with any number of positional arguments (that is, arguments that don't have keywords):

```
>>> printall(1, 2.0, '3')
(1, 2.0, '3')
```

But the `*` operator doesn't gather keyword arguments:

```
>>> printall(1, 2.0, third='3')
TypeError: printall() got an unexpected keyword argument 'third'
```

To gather keyword arguments, you can use the `**` operator:

```
def printall(*args, **kwargs):
    print(args, kwargs)
```

You can call the keyword gathering parameter anything you want, but `kwargs` is a common choice. The result is a dictionary that maps keywords to values:

```
>>> printall(1, 2.0, third='3')
(1, 2.0) {'third': '3'}
```

If you have a dictionary of keywords and values, you can use the scatter operator, `**` to call a function:

```
>>> d = dict(x=1, y=2)
>>> Point(**d)
Point(x=1, y=2)
```

Without the scatter operator, the function would treat `d` as a single positional argument, so it would assign `d` to `x` and complain because there's nothing to assign to `y`:

```
>>> d = dict(x=1, y=2)
>>> Point(d)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: __new__() missing 1 required positional argument: 'y'
```

When you are working with functions that have a large number of parameters, it is often useful to create and pass around dictionaries that specify frequently used options.

19.10. Glossary

conditional expression: An expression that has one of two values, depending on a condition.

list comprehension: An expression with a `for` loop in square brackets that yields a new list.

generator expression: An expression with a `for` loop in parentheses that yields a generator object.

multiset: A mathematical entity that represents a mapping between the elements of a set and the number of times they appear.

factory: A function, usually passed as a parameter, used to create objects.

19.11. Exercises

Ejercicio 19.1. *The following is a function computes the binomial coefficient recursively.*

```
def binomial_coeff(n, k):  
    """Compute the binomial coefficient "n choose k".  
  
    n: number of trials  
    k: number of successes  
  
    returns: int  
    """  
    if k == 0:  
        return 1  
    if n == 0:  
        return 0  
  
    res = binomial_coeff(n-1, k) + binomial_coeff(n-1, k-1)  
    return res
```

Rewrite the body of the function using nested conditional expressions.

One note: this function is not very efficient because it ends up computing the same values over and over. You could make it more efficient by memoizing (see Section 11.6). But you will find that it's harder to memoize if you write it using conditional expressions.

Apéndice A

Debugging

When you are debugging, you should distinguish among different kinds of errors in order to track them down more quickly:

- Syntax errors are discovered by the interpreter when it is translating the source code into byte code. They indicate that there is something wrong with the structure of the program. Example: Omitting the colon at the end of a `def` statement generates the somewhat redundant message `SyntaxError: invalid syntax`.
- Runtime errors are produced by the interpreter if something goes wrong while the program is running. Most runtime error messages include information about where the error occurred and what functions were executing. Example: An infinite recursion eventually causes the runtime error “maximum recursion depth exceeded”.
- Semantic errors are problems with a program that runs without producing error messages but doesn’t do the right thing. Example: An expression may not be evaluated in the order you expect, yielding an incorrect result.

The first step in debugging is to figure out which kind of error you are dealing with. Although the following sections are organized by error type, some techniques are applicable in more than one situation.

A.1. Syntax errors

Syntax errors are usually easy to fix once you figure out what they are. Unfortunately, the error messages are often not helpful. The most common messages are `SyntaxError: invalid syntax` and `SyntaxError: invalid token`, neither of which is very informative.

On the other hand, the message does tell you where in the program the problem occurred. Actually, it tells you where Python noticed a problem, which is not necessarily where the error is. Sometimes the error is prior to the location of the error message, often on the preceding line.

If you are building the program incrementally, you should have a good idea about where the error is. It will be in the last line you added.

If you are copying code from a book, start by comparing your code to the book's code very carefully. Check every character. At the same time, remember that the book might be wrong, so if you see something that looks like a syntax error, it might be.

Here are some ways to avoid the most common syntax errors:

1. Make sure you are not using a Python keyword for a variable name.
2. Check that you have a colon at the end of the header of every compound statement, including `for`, `while`, `if`, and `def` statements.
3. Make sure that any strings in the code have matching quotation marks. Make sure that all quotation marks are "straight quotes", not "curly quotes".
4. If you have multiline strings with triple quotes (single or double), make sure you have terminated the string properly. An unterminated string may cause an invalid token error at the end of your program, or it may treat the following part of the program as a string until it comes to the next string. In the second case, it might not produce an error message at all!
5. An unclosed opening operator—`(`, `{`, or `[`—makes Python continue with the next line as part of the current statement. Generally, an error occurs almost immediately in the next line.
6. Check for the classic `=` instead of `==` inside a conditional.
7. Check the indentation to make sure it lines up the way it is supposed to. Python can handle space and tabs, but if you mix them it can cause problems. The best way to avoid this problem is to use a text editor that knows about Python and generates consistent indentation.
8. If you have non-ASCII characters in the code (including strings and comments), that might cause a problem, although Python 3 usually handles non-ASCII characters. Be careful if you paste in text from a web page or other source.

If nothing works, move on to the next section...

A.1.1. I keep making changes and it makes no difference.

If the interpreter says there is an error and you don't see it, that might be because you and the interpreter are not looking at the same code. Check your programming environment to make sure that the program you are editing is the one Python is trying to run.

If you are not sure, try putting an obvious and deliberate syntax error at the beginning of the program. Now run it again. If the interpreter doesn't find the new error, you are not running the new code.

There are a few likely culprits:

- You edited the file and forgot to save the changes before running it again. Some programming environments do this for you, but some don't.
- You changed the name of the file, but you are still running the old name.

- Something in your development environment is configured incorrectly.
- If you are writing a module and using `import`, make sure you don't give your module the same name as one of the standard Python modules.
- If you are using `import` to read a module, remember that you have to restart the interpreter or use `reload` to read a modified file. If you import the module again, it doesn't do anything.

If you get stuck and you can't figure out what is going on, one approach is to start again with a new program like "Hello, World!", and make sure you can get a known program to run. Then gradually add the pieces of the original program to the new one.

A.2. Runtime errors

Once your program is syntactically correct, Python can read it and at least start running it. What could possibly go wrong?

A.2.1. My program does absolutely nothing.

This problem is most common when your file consists of functions and classes but does not actually invoke a function to start execution. This may be intentional if you only plan to import this module to supply classes and functions.

If it is not intentional, make sure there is a function call in the program, and make sure the flow of execution reaches it (see "Flow of Execution" below).

A.2.2. My program hangs.

If a program stops and seems to be doing nothing, it is "hanging". Often that means that it is caught in an infinite loop or infinite recursion.

- If there is a particular loop that you suspect is the problem, add a `print` statement immediately before the loop that says "entering the loop" and another immediately after that says "exiting the loop".

Run the program. If you get the first message and not the second, you've got an infinite loop. Go to the "Infinite Loop" section below.

- Most of the time, an infinite recursion will cause the program to run for a while and then produce a "RuntimeError: Maximum recursion depth exceeded" error. If that happens, go to the "Infinite Recursion" section below.

If you are not getting this error but you suspect there is a problem with a recursive method or function, you can still use the techniques in the "Infinite Recursion" section.

- If neither of those steps works, start testing other loops and other recursive functions and methods.
- If that doesn't work, then it is possible that you don't understand the flow of execution in your program. Go to the "Flow of Execution" section below.

Infinite Loop

If you think you have an infinite loop and you think you know what loop is causing the problem, add a `print` statement at the end of the loop that prints the values of the variables in the condition and the value of the condition.

For example:

```
while x > 0 and y < 0 :
    # do something to x
    # do something to y

    print('x: ', x)
    print('y: ', y)
    print("condition: ", (x > 0 and y < 0))
```

Now when you run the program, you will see three lines of output for each time through the loop. The last time through the loop, the condition should be `False`. If the loop keeps going, you will be able to see the values of `x` and `y`, and you might figure out why they are not being updated correctly.

Infinite Recursion

Most of the time, infinite recursion causes the program to run for a while and then produce a `Maximum recursion depth exceeded error`.

If you suspect that a function is causing an infinite recursion, make sure that there is a base case. There should be some condition that causes the function to return without making a recursive invocation. If not, you need to rethink the algorithm and identify a base case.

If there is a base case but the program doesn't seem to be reaching it, add a `print` statement at the beginning of the function that prints the parameters. Now when you run the program, you will see a few lines of output every time the function is invoked, and you will see the parameter values. If the parameters are not moving toward the base case, you will get some ideas about why not.

Flow of Execution

If you are not sure how the flow of execution is moving through your program, add `print` statements to the beginning of each function with a message like “entering function `foo`”, where `foo` is the name of the function.

Now when you run the program, it will print a trace of each function as it is invoked.

A.2.3. When I run the program I get an exception.

If something goes wrong during runtime, Python prints a message that includes the name of the exception, the line of the program where the problem occurred, and a traceback.

The traceback identifies the function that is currently running, and then the function that called it, and then the function that called *that*, and so on. In other words, it traces the

sequence of function calls that got you to where you are, including the line number in your file where each call occurred.

The first step is to examine the place in the program where the error occurred and see if you can figure out what happened. These are some of the most common runtime errors:

NameError: You are trying to use a variable that doesn't exist in the current environment. Check if the name is spelled right, or at least consistently. And remember that local variables are local; you cannot refer to them from outside the function where they are defined.

TypeError: There are several possible causes:

- You are trying to use a value improperly. Example: indexing a string, list, or tuple with something other than an integer.
- There is a mismatch between the items in a format string and the items passed for conversion. This can happen if either the number of items does not match or an invalid conversion is called for.
- You are passing the wrong number of arguments to a function. For methods, look at the method definition and check that the first parameter is `self`. Then look at the method invocation; make sure you are invoking the method on an object with the right type and providing the other arguments correctly.

KeyError: You are trying to access an element of a dictionary using a key that the dictionary does not contain. If the keys are strings, remember that capitalization matters.

AttributeError: You are trying to access an attribute or method that does not exist. Check the spelling! You can use the built-in function `vars` to list the attributes that do exist.

If an `AttributeError` indicates that an object has `NoneType`, that means that it is `None`. So the problem is not the attribute name, but the object.

The reason the object is `None` might be that you forgot to return a value from a function; if you get to the end of a function without hitting a `return` statement, it returns `None`. Another common cause is using the result from a list method, like `sort`, that returns `None`.

IndexError: The index you are using to access a list, string, or tuple is greater than its length minus one. Immediately before the site of the error, add a `print` statement to display the value of the index and the length of the array. Is the array the right size? Is the index the right value?

The Python debugger (`pdb`) is useful for tracking down exceptions because it allows you to examine the state of the program immediately before the error. You can read about `pdb` at <https://docs.python.org/3/library/pdb.html>.

A.2.4. I added so many `print` statements I get inundated with output.

One of the problems with using `print` statements for debugging is that you can end up buried in output. There are two ways to proceed: simplify the output or simplify the program.

To simplify the output, you can remove or comment out print statements that aren't helping, or combine them, or format the output so it is easier to understand.

To simplify the program, there are several things you can do. First, scale down the problem the program is working on. For example, if you are searching a list, search a *small* list. If the program takes input from the user, give it the simplest input that causes the problem.

Second, clean up the program. Remove dead code and reorganize the program to make it as easy to read as possible. For example, if you suspect that the problem is in a deeply nested part of the program, try rewriting that part with simpler structure. If you suspect a large function, try splitting it into smaller functions and testing them separately.

Often the process of finding the minimal test case leads you to the bug. If you find that a program works in one situation but not in another, that gives you a clue about what is going on.

Similarly, rewriting a piece of code can help you find subtle bugs. If you make a change that you think shouldn't affect the program, and it does, that can tip you off.

A.3. Semantic errors

In some ways, semantic errors are the hardest to debug, because the interpreter provides no information about what is wrong. Only you know what the program is supposed to do.

The first step is to make a connection between the program text and the behavior you are seeing. You need a hypothesis about what the program is actually doing. One of the things that makes that hard is that computers run so fast.

You will often wish that you could slow the program down to human speed, and with some debuggers you can. But the time it takes to insert a few well-placed print statements is often short compared to setting up the debugger, inserting and removing breakpoints, and "stepping" the program to where the error is occurring.

A.3.1. My program doesn't work.

You should ask yourself these questions:

- Is there something the program was supposed to do but which doesn't seem to be happening? Find the section of the code that performs that function and make sure it is executing when you think it should.
- Is something happening that shouldn't? Find code in your program that performs that function and see if it is executing when it shouldn't.
- Is a section of code producing an effect that is not what you expected? Make sure that you understand the code in question, especially if it involves functions or methods in other Python modules. Read the documentation for the functions you call. Try them out by writing simple test cases and checking the results.

In order to program, you need a mental model of how programs work. If you write a program that doesn't do what you expect, often the problem is not in the program; it's in your mental model.

The best way to correct your mental model is to break the program into its components (usually the functions and methods) and test each component independently. Once you find the discrepancy between your model and reality, you can solve the problem.

Of course, you should be building and testing components as you develop the program. If you encounter a problem, there should be only a small amount of new code that is not known to be correct.

A.3.2. I've got a big hairy expression and it doesn't do what I expect.

Writing complex expressions is fine as long as they are readable, but they can be hard to debug. It is often a good idea to break a complex expression into a series of assignments to temporary variables.

For example:

```
self.hands[i].addCard(self.hands[self.findNeighbor(i)].popCard())
```

This can be rewritten as:

```
neighbor = self.findNeighbor(i)
pickedCard = self.hands[neighbor].popCard()
self.hands[i].addCard(pickedCard)
```

The explicit version is easier to read because the variable names provide additional documentation, and it is easier to debug because you can check the types of the intermediate variables and display their values.

Another problem that can occur with big expressions is that the order of evaluation may not be what you expect. For example, if you are translating the expression $\frac{x}{2\pi}$ into Python, you might write:

```
y = x / 2 * math.pi
```

That is not correct because multiplication and division have the same precedence and are evaluated from left to right. So this expression computes $x\pi/2$.

A good way to debug expressions is to add parentheses to make the order of evaluation explicit:

```
y = x / (2 * math.pi)
```

Whenever you are not sure of the order of evaluation, use parentheses. Not only will the program be correct (in the sense of doing what you intended), it will also be more readable for other people who haven't memorized the order of operations.

A.3.3. I've got a function that doesn't return what I expect.

If you have a return statement with a complex expression, you don't have a chance to print the result before returning. Again, you can use a temporary variable. For example, instead of:

```
return self.hands[i].removeMatches()
```

you could write:

```
count = self.hands[i].removeMatches()  
return count
```

Now you have the opportunity to display the value of `count` before returning.

A.3.4. I'm really, really stuck and I need help.

First, try getting away from the computer for a few minutes. Computers emit waves that affect the brain, causing these symptoms:

- Frustration and rage.
- Superstitious beliefs (“the computer hates me”) and magical thinking (“the program only works when I wear my hat backward”).
- Random walk programming (the attempt to program by writing every possible program and choosing the one that does the right thing).

If you find yourself suffering from any of these symptoms, get up and go for a walk. When you are calm, think about the program. What is it doing? What are some possible causes of that behavior? When was the last time you had a working program, and what did you do next?

Sometimes it just takes time to find a bug. I often find bugs when I am away from the computer and let my mind wander. Some of the best places to find bugs are trains, showers, and in bed, just before you fall asleep.

A.3.5. No, I really need help.

It happens. Even the best programmers occasionally get stuck. Sometimes you work on a program so long that you can't see the error. You need a fresh pair of eyes.

Before you bring someone else in, make sure you are prepared. Your program should be as simple as possible, and you should be working on the smallest input that causes the error. You should have `print` statements in the appropriate places (and the output they produce should be comprehensible). You should understand the problem well enough to describe it concisely.

When you bring someone in to help, be sure to give them the information they need:

- If there is an error message, what is it and what part of the program does it indicate?
- What was the last thing you did before this error occurred? What were the last lines of code that you wrote, or what is the new test case that fails?
- What have you tried so far, and what have you learned?

When you find the bug, take a second to think about what you could have done to find it faster. Next time you see something similar, you will be able to find the bug more quickly.

Remember, the goal is not just to make the program work. The goal is to learn how to make the program work.

Apéndice B

Analysis of Algorithms

This appendix is an edited excerpt from *Think Complexity*, by Allen B. Downey, also published by O'Reilly Media (2012). When you are done with this book, you might want to move on to that one.

Analysis of algorithms is a branch of computer science that studies the performance of algorithms, especially their run time and space requirements. See http://en.wikipedia.org/wiki/Analysis_of_algorithms.

The practical goal of algorithm analysis is to predict the performance of different algorithms in order to guide design decisions.

During the 2008 United States Presidential Campaign, candidate Barack Obama was asked to perform an impromptu analysis when he visited Google. Chief executive Eric Schmidt jokingly asked him for “the most efficient way to sort a million 32-bit integers.” Obama had apparently been tipped off, because he quickly replied, “I think the bubble sort would be the wrong way to go.” See http://www.youtube.com/watch?v=k4RRi_ntQc8.

This is true: bubble sort is conceptually simple but slow for large datasets. The answer Schmidt was probably looking for is “radix sort” (http://en.wikipedia.org/wiki/Radix_sort)¹.

The goal of algorithm analysis is to make meaningful comparisons between algorithms, but there are some problems:

- The relative performance of the algorithms might depend on characteristics of the hardware, so one algorithm might be faster on Machine A, another on Machine B. The general solution to this problem is to specify a **machine model** and analyze the number of steps, or operations, an algorithm requires under a given model.
- Relative performance might depend on the details of the dataset. For example, some sorting algorithms run faster if the data are already partially sorted; other algorithms

¹ But if you get a question like this in an interview, I think a better answer is, “The fastest way to sort a million integers is to use whatever sort function is provided by the language I’m using. Its performance is good enough for the vast majority of applications, but if it turned out that my application was too slow, I would use a profiler to see where the time was being spent. If it looked like a faster sort algorithm would have a significant effect on performance, then I would look around for a good implementation of radix sort.”

run slower in this case. A common way to avoid this problem is to analyze the **worst case** scenario. It is sometimes useful to analyze average case performance, but that's usually harder, and it might not be obvious what set of cases to average over.

- Relative performance also depends on the size of the problem. A sorting algorithm that is fast for small lists might be slow for long lists. The usual solution to this problem is to express run time (or number of operations) as a function of problem size, and group functions into categories depending on how quickly they grow as problem size increases.

The good thing about this kind of comparison is that it lends itself to simple classification of algorithms. For example, if I know that the run time of Algorithm A tends to be proportional to the size of the input, n , and Algorithm B tends to be proportional to n^2 , then I expect A to be faster than B, at least for large values of n .

This kind of analysis comes with some caveats, but we'll get to that later.

B.1. Order of growth

Suppose you have analyzed two algorithms and expressed their run times in terms of the size of the input: Algorithm A takes $100n + 1$ steps to solve a problem with size n ; Algorithm B takes $n^2 + n + 1$ steps.

The following table shows the run time of these algorithms for different problem sizes:

Input size	Run time of Algorithm A	Run time of Algorithm B
10	1 001	111
100	10 001	10 101
1 000	100 001	1 001 001
10 000	1 000 001	100 010 001

At $n = 10$, Algorithm A looks pretty bad; it takes almost 10 times longer than Algorithm B. But for $n = 100$ they are about the same, and for larger values A is much better.

The fundamental reason is that for large values of n , any function that contains an n^2 term will grow faster than a function whose leading term is n . The **leading term** is the term with the highest exponent.

For Algorithm A, the leading term has a large coefficient, 100, which is why B does better than A for small n . But regardless of the coefficients, there will always be some value of n where $an^2 > bn$, for any values of a and b .

The same argument applies to the non-leading terms. Even if the run time of Algorithm A were $n + 1000000$, it would still be better than Algorithm B for sufficiently large n .

In general, we expect an algorithm with a smaller leading term to be a better algorithm for large problems, but for smaller problems, there may be a **crossover point** where another algorithm is better. The location of the crossover point depends on the details of the algorithms, the inputs, and the hardware, so it is usually ignored for purposes of algorithmic analysis. But that doesn't mean you can forget about it.

If two algorithms have the same leading order term, it is hard to say which is better; again, the answer depends on the details. So for algorithmic analysis, functions with the same leading term are considered equivalent, even if they have different coefficients.

An **order of growth** is a set of functions whose growth behavior is considered equivalent. For example, $2n$, $100n$ and $n + 1$ belong to the same order of growth, which is written $O(n)$ in **Big-Oh notation** and often called **linear** because every function in the set grows linearly with n .

All functions with the leading term n^2 belong to $O(n^2)$; they are called **quadratic**.

The following table shows some of the orders of growth that appear most commonly in algorithmic analysis, in increasing order of badness.

Order of growth	Name
$O(1)$	constant
$O(\log_b n)$	logarithmic (for any b)
$O(n)$	linear
$O(n \log_b n)$	linearithmic
$O(n^2)$	quadratic
$O(n^3)$	cubic
$O(c^n)$	exponential (for any c)

For the logarithmic terms, the base of the logarithm doesn't matter; changing bases is the equivalent of multiplying by a constant, which doesn't change the order of growth. Similarly, all exponential functions belong to the same order of growth regardless of the base of the exponent. Exponential functions grow very quickly, so exponential algorithms are only useful for small problems.

Ejercicio B.1. Read the Wikipedia page on Big-Oh notation at http://en.wikipedia.org/wiki/Big_O_notation and answer the following questions:

1. What is the order of growth of $n^3 + n^2$? What about $1000000n^3 + n^2$? What about $n^3 + 1000000n^2$?
2. What is the order of growth of $(n^2 + n) \cdot (n + 1)$? Before you start multiplying, remember that you only need the leading term.
3. If f is in $O(g)$, for some unspecified function g , what can we say about $af + b$, where a and b are constants?
4. If f_1 and f_2 are in $O(g)$, what can we say about $f_1 + f_2$?
5. If f_1 is in $O(g)$ and f_2 is in $O(h)$, what can we say about $f_1 + f_2$?
6. If f_1 is in $O(g)$ and f_2 is in $O(h)$, what can we say about $f_1 \cdot f_2$?

Programmers who care about performance often find this kind of analysis hard to swallow. They have a point: sometimes the coefficients and the non-leading terms make a real difference. Sometimes the details of the hardware, the programming language, and the characteristics of the input make a big difference. And for small problems, order of growth is irrelevant.

But if you keep those caveats in mind, algorithmic analysis is a useful tool. At least for large problems, the "better" algorithm is usually better, and sometimes it is *much* better. The difference between two algorithms with the same order of growth is usually a constant factor, but the difference between a good algorithm and a bad algorithm is unbounded!

B.2. Analysis of basic Python operations

In Python, most arithmetic operations are constant time; multiplication usually takes longer than addition and subtraction, and division takes even longer, but these run times don't depend on the magnitude of the operands. Very large integers are an exception; in that case the run time increases with the number of digits.

Indexing operations—reading or writing elements in a sequence or dictionary—are also constant time, regardless of the size of the data structure.

A for loop that traverses a sequence or dictionary is usually linear, as long as all of the operations in the body of the loop are constant time. For example, adding up the elements of a list is linear:

```
total = 0
for x in t:
    total += x
```

The built-in function `sum` is also linear because it does the same thing, but it tends to be faster because it is a more efficient implementation; in the language of algorithmic analysis, it has a smaller leading coefficient.

As a rule of thumb, if the body of a loop is in $O(n^a)$ then the whole loop is in $O(n^{a+1})$. The exception is if you can show that the loop exits after a constant number of iterations. If a loop runs k times regardless of n , then the loop is in $O(n^a)$, even for large k .

Multiplying by k doesn't change the order of growth, but neither does dividing. So if the body of a loop is in $O(n^a)$ and it runs n/k times, the loop is in $O(n^{a+1})$, even for large k .

Most string and tuple operations are linear, except indexing and `len`, which are constant time. The built-in functions `min` and `max` are linear. The run-time of a slice operation is proportional to the length of the output, but independent of the size of the input.

String concatenation is linear; the run time depends on the sum of the lengths of the operands.

All string methods are linear, but if the lengths of the strings are bounded by a constant—for example, operations on single characters—they are considered constant time. The string method `join` is linear; the run time depends on the total length of the strings.

Most list methods are linear, but there are some exceptions:

- Adding an element to the end of a list is constant time on average; when it runs out of room it occasionally gets copied to a bigger location, but the total time for n operations is $O(n)$, so the average time for each operation is $O(1)$.
- Removing an element from the end of a list is constant time.
- Sorting is $O(n \log n)$.

Most dictionary operations and methods are constant time, but there are some exceptions:

- The run time of `update` is proportional to the size of the dictionary passed as a parameter, not the dictionary being updated.
- `keys`, `values` and `items` are constant time because they return iterators. But if you loop through the iterators, the loop will be linear.

The performance of dictionaries is one of the minor miracles of computer science. We will see how they work in Section B.4.

Ejercicio B.2. Read the Wikipedia page on sorting algorithms at http://en.wikipedia.org/wiki/Sorting_algorithm and answer the following questions:

1. What is a “comparison sort?” What is the best worst-case order of growth for a comparison sort? What is the best worst-case order of growth for any sort algorithm?
2. What is the order of growth of bubble sort, and why does Barack Obama think it is “the wrong way to go?”
3. What is the order of growth of radix sort? What preconditions do we need to use it?
4. What is a stable sort and why might it matter in practice?
5. What is the worst sorting algorithm (that has a name)?
6. What sort algorithm does the C library use? What sort algorithm does Python use? Are these algorithms stable? You might have to Google around to find these answers.
7. Many of the non-comparison sorts are linear, so why does Python use an $O(n \log n)$ comparison sort?

B.3. Analysis of search algorithms

A **search** is an algorithm that takes a collection and a target item and determines whether the target is in the collection, often returning the index of the target.

The simplest search algorithm is a “linear search”, which traverses the items of the collection in order, stopping if it finds the target. In the worst case it has to traverse the entire collection, so the run time is linear.

The `in` operator for sequences uses a linear search; so do string methods like `find` and `count`.

If the elements of the sequence are in order, you can use a **bisection search**, which is $O(\log n)$. Bisection search is similar to the algorithm you might use to look a word up in a dictionary (a paper dictionary, not the data structure). Instead of starting at the beginning and checking each item in order, you start with the item in the middle and check whether the word you are looking for comes before or after. If it comes before, then you search the first half of the sequence. Otherwise you search the second half. Either way, you cut the number of remaining items in half.

If the sequence has 1,000,000 items, it will take about 20 steps to find the word or conclude that it’s not there. So that’s about 50,000 times faster than a linear search.

Bisection search can be much faster than linear search, but it requires the sequence to be in order, which might require extra work.

There is another data structure, called a **hashtable** that is even faster—it can do a search in constant time—and it doesn’t require the items to be sorted. Python dictionaries are implemented using hashtables, which is why most dictionary operations, including the `in` operator, are constant time.

B.4. Hashtables

To explain how hashtables work and why their performance is so good, I start with a simple implementation of a map and gradually improve it until it's a hashtable.

I use Python to demonstrate these implementations, but in real life you wouldn't write code like this in Python; you would just use a dictionary! So for the rest of this chapter, you have to imagine that dictionaries don't exist and you want to implement a data structure that maps from keys to values. The operations you have to implement are:

`add(k, v)`: Add a new item that maps from key `k` to value `v`. With a Python dictionary, `d`, this operation is written `d[k] = v`.

`get(k)`: Look up and return the value that corresponds to key `k`. With a Python dictionary, `d`, this operation is written `d[k]` or `d.get(k)`.

For now, I assume that each key only appears once. The simplest implementation of this interface uses a list of tuples, where each tuple is a key-value pair.

```
class LinearMap:
```

```
    def __init__(self):
        self.items = []

    def add(self, k, v):
        self.items.append((k, v))

    def get(self, k):
        for key, val in self.items:
            if key == k:
                return val
        raise KeyError
```

`add` appends a key-value tuple to the list of items, which takes constant time.

`get` uses a for loop to search the list: if it finds the target key it returns the corresponding value; otherwise it raises a `KeyError`. So `get` is linear.

An alternative is to keep the list sorted by key. Then `get` could use a bisection search, which is $O(\log n)$. But inserting a new item in the middle of a list is linear, so this might not be the best option. There are other data structures that can implement `add` and `get` in log time, but that's still not as good as constant time, so let's move on.

One way to improve `LinearMap` is to break the list of key-value pairs into smaller lists. Here's an implementation called `BetterMap`, which is a list of 100 `LinearMaps`. As we'll see in a second, the order of growth for `get` is still linear, but `BetterMap` is a step on the path toward hashtables:

```
class BetterMap:
```

```
    def __init__(self, n=100):
        self.maps = []
        for i in range(n):
            self.maps.append(LinearMap())
```

```

def find_map(self, k):
    index = hash(k) % len(self.maps)
    return self.maps[index]

def add(self, k, v):
    m = self.find_map(k)
    m.add(k, v)

def get(self, k):
    m = self.find_map(k)
    return m.get(k)

```

`__init__` makes a list of n `LinearMaps`.

`find_map` is used by `add` and `get` to figure out which map to put the new item in, or which map to search.

`find_map` uses the built-in function `hash`, which takes almost any Python object and returns an integer. A limitation of this implementation is that it only works with hashable keys. Mutable types like lists and dictionaries are unhashable.

Hashable objects that are considered equivalent return the same hash value, but the converse is not necessarily true: two objects with different values can return the same hash value.

`find_map` uses the modulus operator to wrap the hash values into the range from 0 to `len(self.maps)`, so the result is a legal index into the list. Of course, this means that many different hash values will wrap onto the same index. But if the hash function spreads things out pretty evenly (which is what hash functions are designed to do), then we expect $n/100$ items per `LinearMap`.

Since the run time of `LinearMap.get` is proportional to the number of items, we expect `BetterMap` to be about 100 times faster than `LinearMap`. The order of growth is still linear, but the leading coefficient is smaller. That's nice, but still not as good as a hashtable.

Here (finally) is the crucial idea that makes hashtables fast: if you can keep the maximum length of the `LinearMaps` bounded, `LinearMap.get` is constant time. All you have to do is keep track of the number of items and when the number of items per `LinearMap` exceeds a threshold, resize the hashtable by adding more `LinearMaps`.

Here is an implementation of a hashtable:

```

class HashMap:

    def __init__(self):
        self.maps = BetterMap(2)
        self.num = 0

    def get(self, k):
        return self.maps.get(k)

    def add(self, k, v):
        if self.num == len(self.maps.maps):

```

```

        self.resize()

    self.maps.add(k, v)
    self.num += 1

def resize(self):
    new_maps = BetterMap(self.num * 2)

    for m in self.maps.maps:
        for k, v in m.items:
            new_maps.add(k, v)

    self.maps = new_maps

__init__ creates a BetterMap and initializes num, which keeps track of the number of items.

```

`get` just dispatches to `BetterMap`. The real work happens in `add`, which checks the number of items and the size of the `BetterMap`: if they are equal, the average number of items per `LinearMap` is 1, so it calls `resize`.

`resize` make a new `BetterMap`, twice as big as the previous one, and then “rehashes” the items from the old map to the new.

Rehashing is necessary because changing the number of `LinearMaps` changes the denominator of the modulus operator in `find_map`. That means that some objects that used to hash into the same `LinearMap` will get split up (which is what we wanted, right?).

Rehashing is linear, so `resize` is linear, which might seem bad, since I promised that `add` would be constant time. But remember that we don’t have to `resize` every time, so `add` is usually constant time and only occasionally linear. The total amount of work to run `add` n times is proportional to n , so the average time of each `add` is constant time!

To see how this works, think about starting with an empty `HashTable` and adding a sequence of items. We start with 2 `LinearMaps`, so the first 2 `adds` are fast (no resizing required). Let’s say that they take one unit of work each. The next `add` requires a `resize`, so we have to rehash the first two items (let’s call that 2 more units of work) and then add the third item (one more unit). Adding the next item costs 1 unit, so the total so far is 6 units of work for 4 items.

The next `add` costs 5 units, but the next three are only one unit each, so the total is 14 units for the first 8 `adds`.

The next `add` costs 9 units, but then we can add 7 more before the next `resize`, so the total is 30 units for the first 16 `adds`.

After 32 `adds`, the total cost is 62 units, and I hope you are starting to see a pattern. After n `adds`, where n is a power of two, the total cost is $2n - 2$ units, so the average work per `add` is a little less than 2 units. When n is a power of two, that’s the best case; for other values of n the average work is a little higher, but that’s not important. The important thing is that it is $O(1)$.

Figure B.1 shows how this works graphically. Each block represents a unit of work. The columns show the total work for each `add` in order from left to right: the first two `adds` cost 1 unit each, the third costs 3 units, etc.

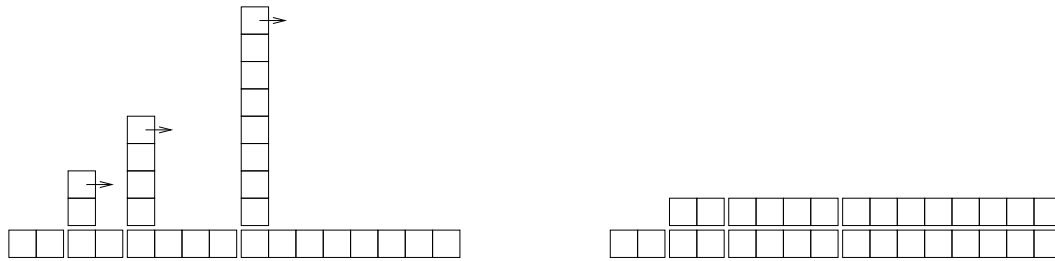


Figura B.1: The cost of a hashtable add.

The extra work of rehashing appears as a sequence of increasingly tall towers with increasing space between them. Now if you knock over the towers, spreading the cost of resizing over all adds, you can see graphically that the total cost after n adds is $2n - 2$.

An important feature of this algorithm is that when we resize the HashTable it grows geometrically; that is, we multiply the size by a constant. If you increase the size arithmetically—adding a fixed number each time—the average time per add is linear.

You can download my implementation of HashMap from <http://thinkpython2.com/code/Map.py>, but remember that there is no reason to use it; if you want a map, just use a Python dictionary.

B.5. Glossary

analysis of algorithms: A way to compare algorithms in terms of their run time and/or space requirements.

machine model: A simplified representation of a computer used to describe algorithms.

worst case: The input that makes a given algorithm run slowest (or require the most space).

leading term: In a polynomial, the term with the highest exponent.

crossover point: The problem size where two algorithms require the same run time or space.

order of growth: A set of functions that all grow in a way considered equivalent for purposes of analysis of algorithms. For example, all functions that grow linearly belong to the same order of growth.

Big-Oh notation: Notation for representing an order of growth; for example, $O(n)$ represents the set of functions that grow linearly.

linear: An algorithm whose run time is proportional to problem size, at least for large problem sizes.

quadratic: An algorithm whose run time is proportional to n^2 , where n is a measure of problem size.

search: The problem of locating an element of a collection (like a list or dictionary) or determining that it is not present.

hashtable: A data structure that represents a collection of key-value pairs and performs search in constant time.

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