Udacity cs101: Building a Search Engine

Unit 1: How to get started: your first program

Extracting a Link

Introducing the Web Crawler (Video: Web Crawler)

A **web crawler** is a program that collects content from the web. A web crawler finds web pages by starting from a seed page and following links to find other pages, and following links from the other pages it finds, and continuing to follow links until it has found many web pages.

Here is the process that a web crawler follows:

Start from one preselected page. We call the starting page the "seed" page.
Extract all the links on that page. (This is the part we will work on in this unit and Unit 2.)
Follow each of those links to find new pages.
Extract all the links from all of the new pages found.
Follow each of those links to find new pages.
Extract all the links from all of the new pages found.
…

This keeps going as long as there are new pages to find, or until it is stopped.

In this unit we will be writing a program to extract the first link from a given web page. In Unit 2, we will figure out how to extract all the links on a web page. In Unit 3, we will figure out how to keep the crawl going over many pages.

Quiz (Video: First Quiz)

What is the goal of Unit 1?

a. Get started programming.
b. Learn important computers science concepts.
c. Write code to extract a link from a web page.
d. Write code to rank web pages.

Programming (Video: Programming)

A **computer** is a machine that can execute a program. With the right program, a computer can do any mechanical computation you can imagine.

A **program** describes a very precise sequence of steps. Since the computer is just a machine, the program must give the steps in a way that can be executed mechanically. That is, the program can be followed without any thought.

A **programming language** is a language designed for producing computer programs. A good programming language makes it easy for humans to read and write programs that can be executed by a computer.

Python is a programming language. The programs that we write in the Python language will be the input to the Python interpreter, which is a program that runs on the computer. The Python interpreter reads our programs and executes them by following the rules of the Python language.

Quiz (Video: What is a Programming Language)

What is a programming language?

a. a language designed to be executed by computers
b. a language designed for describing programs
c. a language designed to be written by humans, and executed by computers
d. a language designed to be read by humans, and written by computers
e. a language designed to be read and written by humans, and executed by computers

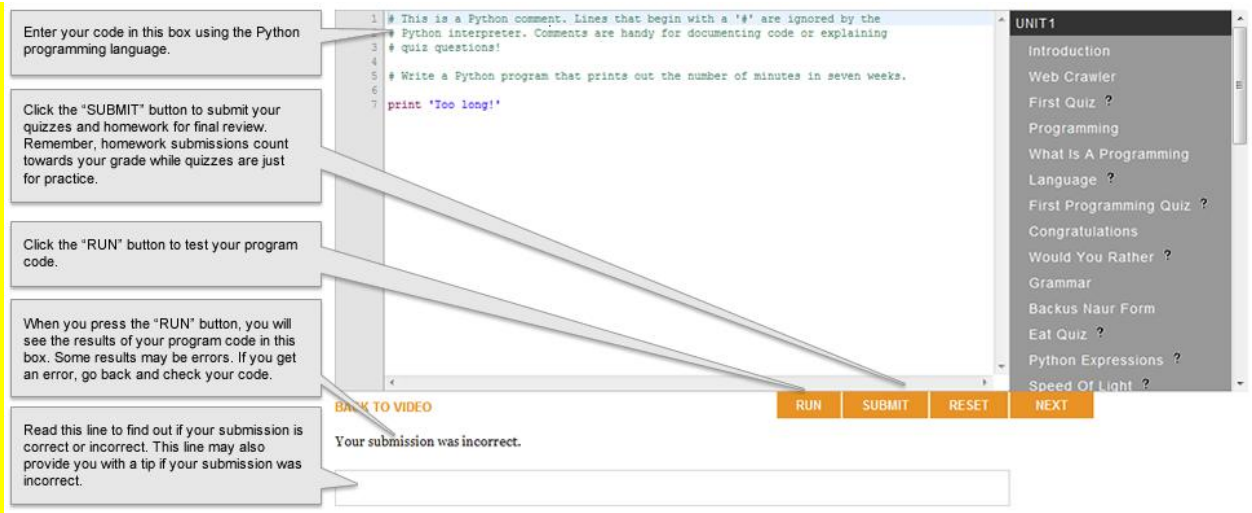
Getting Started with Python Programming

We have provided a way for you to run Python programs using your web browser. You do not need to install any extra programs to do this.

There are two parts to the Python programming environment you will see in your web browser:

1. The top part is an editor, where you can write and edit code.
2. The bottom part is an output window, where you can see the results of running your code.

To try running your code, click the "Run" button avoid the editor.



We can see the value of something in Python by using `print` like this:

```
print 3
```

prints out the value `3`.
The expression after the print can be any value Python expression. Here are some examples:

`1 + 1`	addition
`2 - 1`	subtraction
`2 * 6`	multiplication

We can compose expressions to make more complicated expressions like,

```
52 * 3 +12 * 9
```

We can also use parentheses to group expressions:

```
(52 * 3) + (12 * 9)
```

is different from

```
52 * (3 + 12) * 9
```

For example, this code prints out the the number of hours in a day:

```
print 365 * 24 * 60 * 60
```

Quiz (Video: First Programming Quiz)

Write a Python program that prints out the number of minutes in seven weeks. You should enter your program in the editor window (top part), and then click "Run" to see the output in the bottom part.

Programming Languages (Video: Would_You_Rather)

Why do we need to invent and learn new languages, like Python, to program computers, rather than using natural languages like English or Mandarin?

There are many reasons why a designed language like Python is better for writing programs than a natural language like English. One problem with natural languages is that they are ambiguous. Hence, not everyone will interpret the same phrase the same way. To program computers, it is important that we know exactly what our programs mean, and that the computer will run them with the meaning we intended. Another problem with natural language is that they are very verbose. To say something with the level of precision needed for a computer to be able to follow it mechanically would require an awful lot of writing. We want our programs to be short so it is less work to write them, and so that it is easier to read and understand them.

Grammar (Video: Grammar)

Compared to a natural language, like English, programming languages like Python adhere to a strict grammatical structure. In English, even if a phrase is written or spoken incorrectly, it can still be understood with the help of context or other cues. On the other hand, in a programming language like Python, the code must match the language grammar exactly. The Python interpreter has no idea what to do with input that is not in the Python language, so it produces an error.

Basic English Grammar Rules:

Sentence → *Subject Verb Object*
Subject → *Noun*
Object → *Noun*
Verb → **Eat**
Verb → **Like**
Noun → **I**
Noun → **Python**
Noun → **Cookies**

When programming language grammar is not followed the interpreter will return a `"SyntaxError"` message. This means that the structure of the code is inconsistent with the rules of the programming language.

Backus-Naur Form (Video: Backus-Naur_Form)
The notation we used to describe the grammar is known as **Bakus-Naur Form**. It was introduced in the 1950s by John Backus, the lead designer of the Fortran programming language at IBM.

The purpose of Bakus-Naur Form is to describe a programming language in a simple and concise manner. The structure of this form is:

<Non-Terminal> → *replacement*

The replacement can be any sequence of zero or more non-terminals or terminals.

Terminals never appear on the left side of a rule. Once you get to a terminal there is nothing else you can replace it with. Here is an example showing to derive a sentence by following the replacement rules:

Sentence → *Subject* *Verb Object*
→ *Noun* *Verb Object*
→ **I** *Verb Object*
→ **I Like** *Object*
→ **I Like** *Noun*
→ **I Like Python**

The important thing about a replacement grammar is that we can describe an infinitely large language with a small set of precise rules.

Quiz (Video: Eat Quiz)

Which of these sentences can be produced from this grammar, starting from *sentence*?

a. **Python Eat Cookies**
b. **Python Eat Python**
c. **I Like Eat**

Python Grammar for Arithmetic Expressions (Video: Python Expressions)

An **expression** is something that has a value. Here are some examples of expressions in Python:

```
3
1 + 1
7 * 7 * 24 * 60
```

Here is one of the rules of the Python grammar for making expressions:

Expression → *Expression Operator Expression*

The *Expression* non-terminal that appears on the left side can be replaced by an *Expression*, followed by an *Operator*, followed by another *Expression*. For example, `1 + 1` is an *Expression Operator Expression*.

The interesting thing about this rule is that it has *Expresison* on both the left and right sides! This looks circular, and would be, except we also have other rules for *Expresison* that do not include *Expression* on the right side. This is an example of a **recursive definition**. To make a good recursive definition you need at least two rules:

1. A rule to that defines something in terms of itself.
   Expression → *Expression Operator Expression*
2. A rule to that defines that thing in terms of something else that we already know.
   Expression → *Number*

Recursive definitions are a very powerful idea in computer science. They allow us to define infinitely many things using a few simple rules. We will talk about this a lot more in Unit 6.

Here are some of the Python grammar rules for arithmetic expressions:

Expression → *Expression Operator Expression*
Expression → *Number*
Operator → **+**
Operator → *****
Number → **0**, **1**, ...

Here is an example derivation using this grammar:

Expression → *Expression* *Operator* *Expression*
→ *Expression* **+** *Expression*
→ *Expression* **+** *Number*
→ *Expression* **+ 1**
→ *Expression* *Operator Expression* **+ 1**
→ *Number* *Operator Expression* **+ 1**
→ **2** *Operator* *Expression* **+ 1**
→ **2 *** *Expression* **+ 1**
→ **2 *** *Expression* *Operator Expression* **+ 1**
→ **2 *** *Number* *Operator Expression* **+ 1**
→ **2 * 3** *Operator* *Expression* **+ 1**
→ **2 * 3 *** *Expression* **+ 1**
→ **2 * 3 *** *Number* **+ 1**
→ **2 * 3 * 3 + 1**

(Note: the example here is slightly different than the one in the video. The `3+3` expression has been changed to `3*3`, since the precedence rules in Python would have grouped `2 * 3 + 3 + 1` as `(2 * 3) + 3 + 1`, so it would not be interpreted as shown in the derivation.)

We need to add one more rule to our expression grammar to be able to produce all of the expressions we have used so far:

Expression → **(***Expression***)**

Quiz (Video: Python Expressions)

Which of the following are valid Python expressions that can be produced starting from *Expression*? There may be more than one.

a. `3`
b. `((3)`
c. `(1 * (2 * (3 * 4)))`
d. `+ 3 3`
e. `(((7)))`

Quiz (Video: Speed of Light)

Write Python code to print out how far light travels in centimeters after one nanosecond using the multiplication operator.

The speed of light is 299792458 meters per second.
One meter is 100 centimeters.
One nanosecond is one billionth (1/1000000000) of a second.

The reason for computing this is because the distance light travels in a nanosecond really matters in computing! A typical computer today executes billions of steps every second. The processor I am

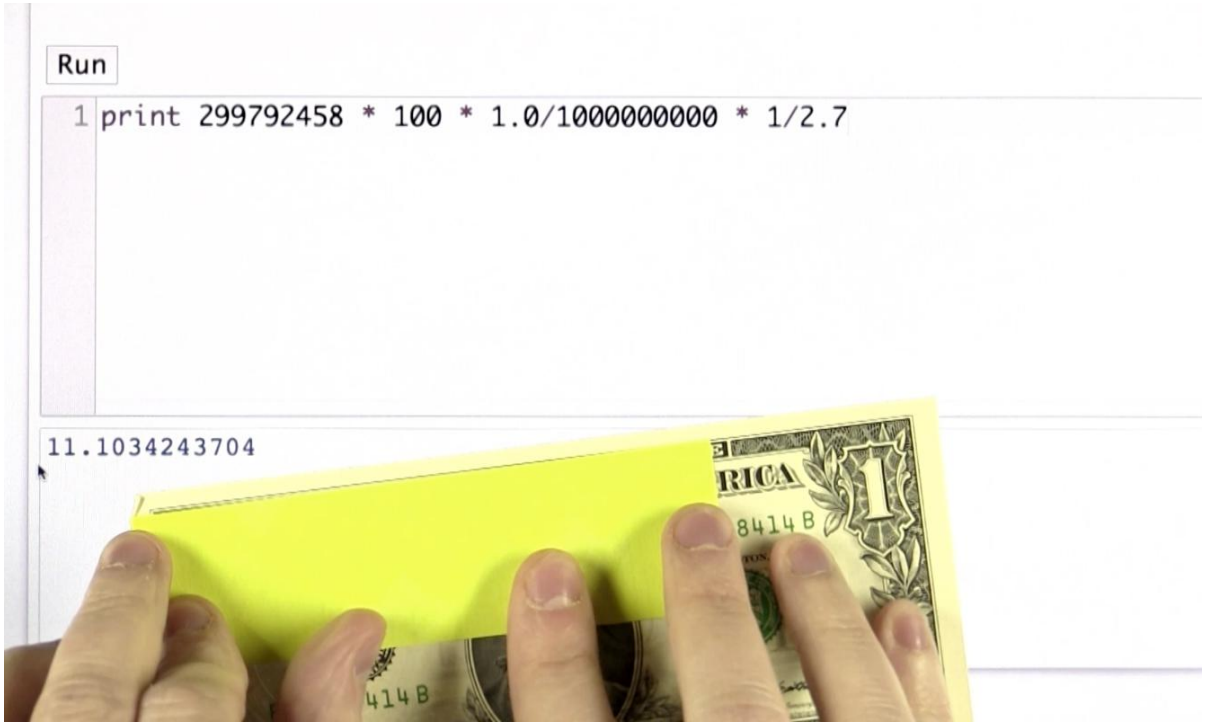
using is a *2.7 GHz* processor. The GHz means gigahertz which is a billion cycles per second. So, the computer executes 2700000000 cycles per second.

You can think of each cycle as executing a very small instruction step. If you are using a Mac, you can see how fast your processor is by selecting the Apple menu and choosing *About this Mac*. If you are using a Windows 7 machine, open the *Control Panel* and select *System and Security*, then under *System* select *View amount of RAM and processor speed*.

We can compute how far light travels in the time it takes for the computer to complete one cycle:

```
print 299792458 * 100 * 1.0/1000000000 *1/2.7
```
11.1034243704

This is approximately 3/4 of the length of a dollar bill.



A **processor** is the part of the computer that carries out the steps specified in a computer program. Sometimes people call the processor the "central processing unit" or CPU.

A processor has to be small to execute programs quickly. If your computer's processor were any larger than the size of a dollar bill, then you couldn't even send light from one end of the processor to the other before finishing the execution of a single step in a program.

Admiral Grace Hopper (1906- 1992) (Video: Grace Hopper)

Grace Hopper was a pioneer in computing who was known for walking around with *nanosticks*. Nanosticks are pieces of wire that are the length light travels in a nanosecond, about 30 cm.

Hopper wrote one of the first programming languages, COBOL, which was for a long time the world's most widely used programming language. Hopper built the first compiler. A **compiler** is a program that takes as input a program in a programming language easy for humans to write and outputs a program in another language that is easier for computers to execute. The difference between a compiler and an interpreter like Python is that a compiler does all the work at once and runs a new program, whereas, the interpreter converts the source code one step at a time as the program runs.

When Grace Hopper started building the first compiler, most people did not believe it was possible for a computer program to produce other computer programs: "Nobody believed that I had a running compiler and nobody would touch it. They told me computers could only do arithmetic."

Variables (Video: Variables)

A **variable** is a name refers to a value. In Python, we can use any sequence of letters and numbers and underscores (_) we want to make a variable name, so long as it does not start with a number. Here are some examples of valid variable names:

```
processor_speed
n
Dorina
item73
```

To introduce a new variable, we use an **assignment statement**:

Name = *Expression*

After executing an assignment expression, the name refers to the value of the expression on the right side of the assignment:

```
speed_of_light = 299792458
```

We can use the variable name anywhere we want and it means the same things as the value it refers to. Here is an expression using the name to print out the speed of light in centimeters:

```
print speed_of_light * 100
```

You can create new variables to keep track of values in programs. Here is an expression to find the length of the nanostick in centimeters:

```
speed_of_light = 299792458
billionth = 1.0 / 1000000000
nanostick = speed_of_light * billionth * 100
print nanostick
```

Quiz (Video: Variables)

Given the variables defined below, write Python code that prints out the distance, in meters, that light travels in one processor cycle. We use the hash mark (**#**) to introduce a comment. After the hash, we can write anything we want. The rest of the line is treated as a comment. The comment is not interpreted by the Python interpreter, but it is useful for humans reading the code.

Compute this by dividing the speed of light by the number of cycles per second.

```
speed_of_light = 299792458 # meters per second
cycles_per_second = 27000000000. # 2.7GHz
```

Variables Can Vary (Video: Variables Can Vary)

The value a variable refers to can change. When a variable name is used, it always refers to the last value assigned to that variable.

For example, we can change the value of `cycles_per_second`. Suppose we have a faster processor:

```
speed_of_light = 299792458 # meters per second
cycles_per_second = 27000000000. # 2.7GHz
cycle_distance = speed_of_light / cycles_per_second
cycle_per_second = 2800000000. # 2.8 GHz

print cycle_distance
```
0.111.34243704

```
cycle_distance = speed_of_light/ cycles_per_second
print cycle_distance
```
0.107068735

Since the value that a variable refers to can change, the same exact expression can have different values at the different times it is executed.

This gets more interesting when we use the same variable on both sides of an assignment. The right side is evaluated first, using the current value of the variable. Then the assignment is done using that value. In the following expressions, the value of `days` changes from 49 to 48 and then to 47 as the expression changes:

```
days = 7 * 7      # after the assignment, days refers to 49
days = 48         # after the assignment, days refers to 48
days = days - 1   # after the assignment, days refers to 47
days = days - 1   # after the assignment, days refers to 46
```

It is important to remember that although we use = for assignment it does not mean equality. You should think of the **=** sign in Python as an arrow, ←, showing that the value the right side evaluates to is being assigned to the variable name on the left side.

Quiz (Video: Varying Variables Quiz 1)

What is the value of `hours` after running this code:

```
hours = 9
hours = hours + 1
hours = hours * 2
```

a. *9*
b. *10*
c. *18*
d. *20*
e. *22*
f. Error

Quiz (Video: Varying Variables Quiz 2)

What is the value of `seconds` after running this code:

```
minutes = minutes + 1
seconds = minutes * 60
```

a. *0*
b. *60*
c. *120*
d. Error

For Python to be able to output a result, we need to always define a variable by assigning a value to it before using it.

```
minutes = 30
minutes = minutes +1
seconds + minutes * 60
print seconds
1860
```

Quiz (Video: Spirit Age)

Write Python code that defines the variable `age` to be your age in years, and then prints out the number of days you have been alive. If you don't want to use your real age, feel free to use your age in spirit instead.

```
age = 26
days_per_year = 365
days_alive = age * days_per_year
print days_alive
```
9490

Strings (Video: Strings)

A **string** is a sequence of characters surrounded by quotes; either single or double.

```
'I am a string!'
```

The only requirement is that the string must start and end with the same kind of quote.

```
"I prefer double quotes!"
```

This allows you to include quotes inside of quotes as a character in the string.

```
"I'm happy I started with a double quote!"
```

Using the interpreter, notice how the color of the input changes before and after you put quotes on both sides of the string.

What happens when you do not include any quotes:

```
print Hello
```

Without the quotes, Python reads Hello as a variable that is undefined:

```
NameError: name 'Hello' is not defined
```

As we saw above, Python will not print an undefined variable, which is why we get the name error.

Quiz (Video: Valid Strings)

Which of the following are valid strings in Python?

a. `"Ada"`
b. `'Ada"`
c. `"Ada`
d. `Ada`
e. `'"Ada'`

August Ada King (Video: Ada)

August Ada King, Countess of Lovelace, 1815-1852, was arguably the world's first computer programmer. Grace Hopper wasn't the first person to think about using computers to do things other than arithmetic, but Ada probably was. In her 1843 notes on programming the Analytical Engine, she writes:

> *It might act upon other things besides number, were objects found whose mutual fundamental relations could be expressed by those of the abstract science of operations, and which should be also susceptible of adaptations to the action of the operating notation and mechanism of the engine…*

The *It* King is referring to is the Analytical Engine, a mechanical programmable computer that Charles Babbage designed. Although he did not succeed in building it in the 1840s, he did have a design for it, which Ada was thinking about programming to compose music.

Quiz (Video: Hello!!!)

Define a variable, `name`, and assign to it a string that is your name.

Using Operators on Strings (Video: Strings and Numbers)

We can also use the plus operator (**+**) on strings, but it has a different meaning from when it is used on numbers. With string, plus means **concatenation**.

<*string*> **+** <*string*> outputs the concatenation of the two strings

Try concatenating the string `'Hello'` to `name`.

You can create a space between the strings by adding a space to one of the strings. You can also continue to add strings as many times as you need.

```
name = 'Dave'
print 'Hello ' + name + '!' + '!' + '!'
```
Hello Dave!!!

However, you cannot use the plus operator to combine strings and integers, as in the case of:

```
print 'My name is ' + 9
```

When you run this program you should see an error message like this:

```
TypeError: cannot concatenate 'str' and 'int' objects.
```

It is a bit surprising that you can multiply strings and integers!

```
print '!' * 12
```
!!!!!!!!!!!!

This program multiplies the string by the integer to return 12 exclamation points!

Indexing Strings (Video: Indexing Strings)

When you want to select sub-sequences from a string, it is called **indexing**. Use the square brackets `[]` to specify which part of the string you want to select.

<*string*>`[`<*expression*>`]`

For example, if we have the string `'udacity'` and we want to select the character in the zero position (that is, the first character), we would write:

```
'udacity'[0]
```

The positions in a string are numbered starting with `0`, so this evaluates to `'u'`.

Indexing strings is the most useful when the string is given using a variable:

```
'udacity'[0] → 0
'udacity'[1 +1 ] → 'a'
name = 'Dave'
name[0] → 'D'
```

When you use negative numbers in the index it starts counting from the back of the string:

```
name = 'Dave'
print name[-1]
e
```

or,

```
name='Dave'
print name[-2]
v
```

When you try to index a character in a position where there is none, Python produces an error indicating that the index is out of range:

```
name = 'Dave'
print name[4]
IndexError: string index out of range
```

Quiz (Video: Same Value)

Given the variable,

```
s = '<any string>'
```

which of these pairs are two things with the exact same value?

a. `s[3]`, `s[1+1+1]`
b. `s[0]`, `(s+s)[0]`
c. `s[0] + s[1]`, `s[0+1]`
d. `s[1]`, `(s + 'ity') [1]`
e. `s[-1]`, `(s + s)[-1]`

Selecting Sub-Sequences from String (Video: Selecting Sub-Sequences)

You can select a sub-sequence of a string by designating a starting position and an end position. Python reads the characters positions starting at 0, so that if we consider the string `'udacity'` that has 7 characters, there are 6 positions with `'u'` being in the 0 position.

<*string*>`[`<*expression*>`]` → a one-character string

<*string*>`[`<*start expression*>`:`<*stop expression*>`]` → a string that is a sub-sequence of the characters in the string, from the start position up to the character before the stop position. If the start expression is missing, the sub-sequence starts from the beginning of the string; if the stop expression is missing, the sub-sequence goes to the end of the string.

Examples:

```
word = 'assume'
print word[3]
u
print word[4:6]
me
print word[4:]
me
print word[:2]
as
print word[:]
assume
```

Quiz (Video: Capital Udacity)

Write Python code that prints out *Udacity* (with a capital *U*), given the definition

```
s = 'audacity'
```

Quiz (Video: Understanding Selection)

For any string,

```
s= '<any string>'
```

which of these is *always* equivalent to `s`:

a. `s[:]`
b. `s + s[0:-1 +1]`
c. `s[0:]`
d. `s[:-1]`
e. `s[:3] + s[3:]`

Finding Strings in Strings (Video: Finding Strings in Strings)

The **find method** is a built in operation, or method, provided by Python, that operates on strings. The output of find is the position of the string where the specified sub-string is found.

```
<search string>.find(<target string>)
```

If the *target string* is not found anywhere in the *search string*, then the output will be `-1`.

Here are some examples (try them yourself in the interpreter):

```
pythagoras = 'There is geometry in the humming of the strings, there is
music in the spacing of the spheres. '

print pythagoras.find('string')
40
print pythagoras[40:]
strings, there is music in the spacing of the spheres.
print pythagoras.find('T')
0
print pythagoras.find('sphere')
86
print pythagoras[86:]
spheres
print pythagoras.find('algebra')
-1
```

Quiz (Video: Testing)

Which of the following evaluate to `-1`:

a. `'test'.find('t')`
b. `"test".find('st')`
c. `"Test".find('te')`
d. `'west'.find('test')`

Quiz (Video: Testing)

For any string,

```
s = '<any string>'
```

which of the following always has the value `0`?

a. `s.find(s)`
b. `s.find('s')`
c. `'s'.find('s')`
d. `s.find('')`
e. `s.find(s + '!!!') +1`

Using find with Numbers (Video: Finding with Numbers)

In addition to passing in a target string to `find`, we can also pass in a number:

```
<search string>.find(<target string>, <number>)
```

The *number* input is the position in the *search string* where find will start looking for the *target string*. So, the output is a number giving the position of the first occurrence of the target string in the search string at or after the number input position. If there is no occurrence at or after that position, the output is `-1`.

For example:

```
danton = "De l'audace, encore de l'audace, toujours de l'audace."
print danton.find('audace')
5
print danton.find('audace', 0)
5
print danton.find('audace', 5)
5
print danton.find('audace', 6)
25
print danton.find('audace', 25)
25
print danton.find('audace', 48)
47
```

Quiz (Video: Finding with Numbers Quiz)

For any variables `s` and `t` that are strings, and `i` that is a number:

```
s = '<any string>'
t = '<any string>'
i = <any number>
```

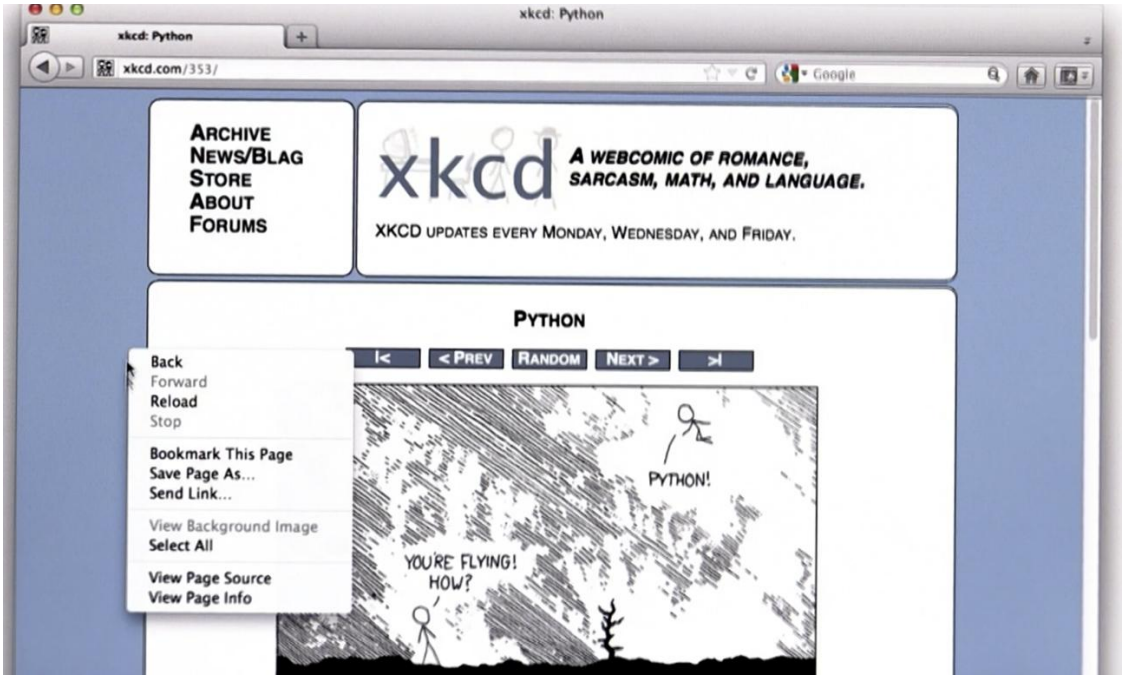
which of these are equivalent to `s.find(t,i)`:

a. `s[i: ].find(t)`
b. `s.find(t)[ :i]`
c. `s[i: ].find(t) + i`
d. `s[i: ].find(t[i: ])`

Extracting Links (Video: Extracting Links)

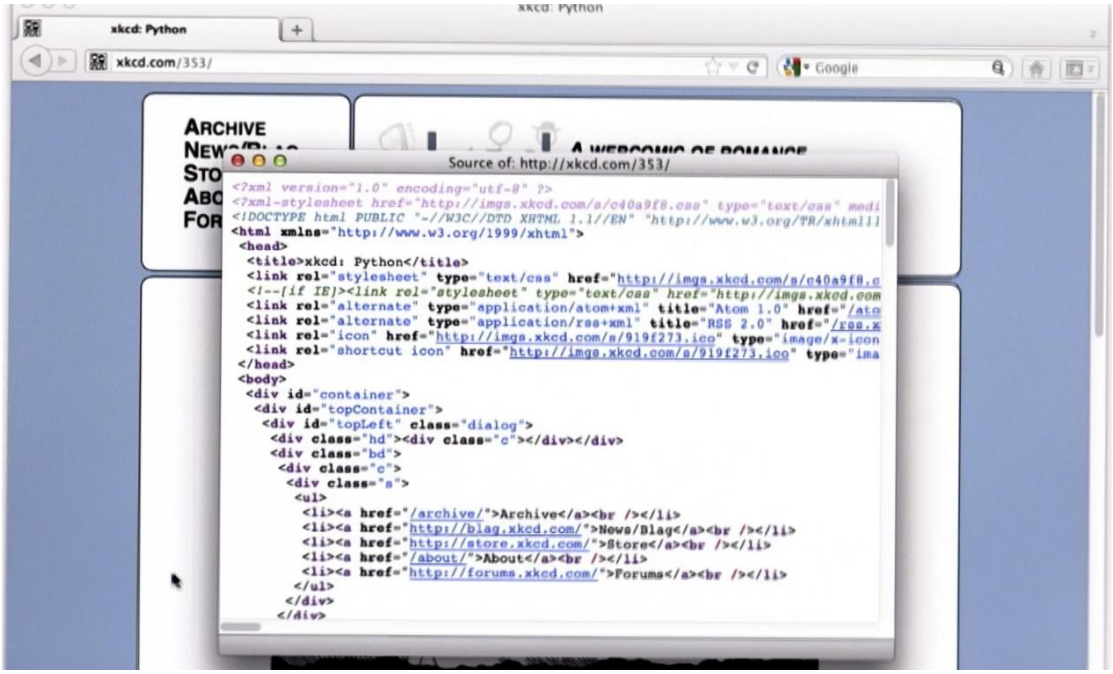
A **web page** is really just a long string of characters. Your **browser** renders the web page in a way that looks more attractive than just the string of characters. You can view the string of characters for any web page in your browser. How to do this depends on the browser you are using. For Chrome and Firefox, right-click anywhere on the page that is not a link and select "View Page Source". For Internet Explorer, right-click and select "View Source".

Here's what this looks like in Chrome:



Select **View Page Source** from the menu.

The raw string for the web page pops up in a new window:



For our web crawler, the important thing is to find the links to other web pages in the page. We can find those links by looking for the anchor tags that match this structure:

```
<a href="<url>">
```

For example, here is a link to the **News/Blag** page:

```
<a href=http://blag.xkcd.com/>
```

To build our crawler, for each web page we want to find all the link target URLs on the page. We want to keep track of them and follow them to find more content on the web.

For this unit, we will do the first step which is to extract the first target URL from the page. In Unit 2, we will see how to keep going to get all the link targets, and in Unit 3, we will see how to keep track of them to be able to crawl the target pages.

For now, our goal is to take the text from a web request and find the first link target in that text. We can do this by finding the anchor tag, `<a href="`, and then extract from that tag the URL that is found between the double quotes.

We will assume that with the page's contents in a variable, `page`.

Quiz (Video: Extracting Links)

Write Python code that initializes the variable `start_link` to be the value of the position where the first `'<a href='` occurs in the string `page` refers to.

Quiz (Video: Final Quiz)

Write Python code that assigns to the variable `url` a string that is the value of the first URL that appears in a link tag in the string page.

For the example page used in the test code, your code should end up with `url` having the value `'http://udacity.com'`.

```
page = <contents of a web page>
start_link = page.find('<a href= ')

[ your code here ]

print url
http://udacity.com
```

Yay! You did it and are off to a great start!

You've learned about programs, variables, expressions, and strings, and a well on your way to building a web crawler. Next unit, we will learn some big ideas in computer science that will make this code more useful and enable us to get all the links on the page, not just the first one.