Python for scientific research

Pattern matching and text manipulation

Bram Kuijper

University of Exeter, Penryn Campus, UK

February 11, 2020

Basic features of strings

First, some basic features of working with strings of text in Python:

- Using quotes within strings:

```
1 str1 = "Text with 'embbeded' single quotes"
```

Basic features of strings

First, some basic features of working with strings of text in Python:

- Using quotes within strings:

```
1 str1 = "Text with 'embbeded' single quotes"
2 str2 = 'Text with "embedded" double quotes'
```

Basic features of strings

First, some basic features of working with strings of text in Python:

- Using quotes within strings:

```
1 str1 = "Text with 'embbeded' single quotes"
2 str2 = 'Text with "embedded" double quotes'
3 str3 = "Text with \"escaped\" double quotes" # Text
      with "escaped" double quotes
```

Basic features of strings

First, some basic features of working with strings of text in Python:

- Using quotes within strings:

```
1 str1 = "Text with 'embbeded' single quotes"
2 str2 = 'Text with "embedded" double quotes'
3 str3 = "Text with \"escaped\" double quotes" # Text
      with "escaped" double quotes
```

- Multiline strings demarcated by triple quotes

Basic features of strings

First, some basic features of working with strings of text in Python:

- Using quotes within strings:

```
1 str1 = "Text with 'embbeded' single quotes"
2 str2 = 'Text with "embedded" double quotes'
3 str3 = "Text with \"escaped\" double quotes" # Text
      with "escaped" double quotes
```

- Multiline strings demarcated by triple quotes

```
1 multiline = """This is a
2 multiline string"""
```

Basic features of strings

First, some basic features of working with strings of text in Python:

- Using quotes within strings:

```
1 str1 = "Text with 'embbeded' single quotes"
2 str2 = 'Text with "embedded" double quotes'
3 str3 = "Text with \"escaped\" double quotes" # Text
      with "escaped" double quotes
```

- Multiline strings demarcated by triple quotes

```
1 multiline = """This is a
2 multiline string"""
3 multiline2 = '''Another
4 multiline string'''
```

String literals

Different string literals identifying different types of string:

- By default, any string is *encoded* as UTF-8, allowing for international characters:

```
1 str_normal = "Let's go to Gijón!"
```

String literals

Different string literals identifying different types of string:

- By default, any string is *encoded* as UTF-8, allowing for international characters:

```
1 str_normal = "Let's go to Gijón!"
2 str_normal = u"Let's go to Gijón!" # u-prefix, now
      redundant (Python2)
```

String literals

Different string literals identifying different types of string:

- By default, any string is *encoded* as UTF-8, allowing for international characters:

```
1 str_normal = "Let's go to Gijón!"
2 str_normal = u"Let's go to Gijón!" # u-prefix, now
      redundant (Python2)
3 type(str_normal) # <class 'str'>
```

String literals

Different string literals identifying different types of string:

- By default, any string is *encoded* as UTF-8, allowing for international characters:

```
1 str_normal = "Let's go to Gijón!"
2 str_normal = u"Let's go to Gijón!" # u-prefix, now
      redundant (Python2)
3 type(str_normal) # <class 'str'>
```

- Byte strings (written as `b"..."`) only contain ASCII characters (no international characters):

```
1 str_ascii = b"Let's go to Gijón!" # Error
```

String literals

Different string literals identifying different types of string:

- By default, any string is *encoded* as UTF-8, allowing for international characters:

```
1 str_normal = "Let's go to Gijón!"
2 str_normal = u"Let's go to Gijón!" # u-prefix, now
      redundant (Python2)
3 type(str_normal) # <class 'str'>
```

- Byte strings (written as `b"..."`) only contain ASCII characters (no international characters):

```
1 str_ascii = b"Let's go to Gijón!" # Error
2 str_ascii = b"Let's go to Gijon!" # only ASCII
```

String literals

Different string literals identifying different types of string:

- By default, any string is *encoded* as UTF-8, allowing for international characters:

```
1 str_normal = "Let's go to Gijón!"
2 str_normal = u"Let's go to Gijón!" # u-prefix, now
      redundant (Python2)
3 type(str_normal) # <class 'str'>
```

- Byte strings (written as `b"..."`) only contain ASCII characters (no international characters):

```
1 str_ascii = b"Let's go to Gijón!" # Error
2 str_ascii = b"Let's go to Gijon!" # only ASCII
3 type(str_ascii) # <class 'bytes'>
```

String literals

Different string literals identifying different types of string:

- By default, any string is *encoded* as UTF-8, allowing for international characters:

```
1 str_normal = "Let's go to Gijón!"
2 str_normal = u"Let's go to Gijón!" # u-prefix, now
      redundant (Python2)
3 type(str_normal) # <class 'str'>
```

- Byte strings (written as `b"..."`) only contain ASCII characters (no international characters):

```
1 str_ascii = b"Let's go to Gijón!" # Error
2 str_ascii = b"Let's go to Gijon!" # only ASCII
3 type(str_ascii) # <class 'bytes'>
```

- UTF-8 and ASCII are encodings which specify how characters translate into 0s and 1s

Example encoding: ASCII

USASCII code chart

b_7 b_6 b_5 → / Bits ↓	0 0 0	0 0 1	0 1 0	0 1 1	1 0 0	1 0 1	1 1 0	1 1 1
b_4 b_3 b_2 b_1 / Row ↓ Column →	0	1	2	3	4	5	6	7
0 0 0 0	0	NUL	DLE	SP	0	@	P	`	p
0 0 0 1	1	SOH	DC1	!	1	A	Q	a	q
0 0 1 0	2	STX	DC2	"	2	B	R	b	r
0 0 1 1	3	ETX	DC3	#	3	C	S	c	s
0 1 0 0	4	EOT	DC4	$	4	D	T	d	t
0 1 0 1	5	ENQ	NAK	%	5	E	U	e	u
0 1 1 0	6	ACK	SYN	&	6	F	V	f	v
0 1 1 1	7	BEL	ETB	'	7	G	W	g	w
1 0 0 0	8	BS	CAN	(	8	H	X	h	x
1 0 0 1	9	HT	EM	)	9	I	Y	i	y
1 0 1 0	10	LF	SUB	*	:	J	Z	j	z
1 0 1 1	11	VT	ESC	+	;	K	[	k	{
1 1 0 0	12	FF	FS	,	<	L	\	l	|
1 1 0 1	13	CR	GS	-	=	M	]	m	}
1 1 1 0	14	SO	RS	.	>	N	^	n	~
1 1 1 1	15	SI	US	/	?	O	_	o	DEL

String literals continued

- International characters sometimes problematic, think web adresses or old filesystems/databases

String literals continued

- International characters sometimes problematic, think web adresses or old filesystems/databases
- To overcome this, you can use `str.encode()` to encode into bytes

```
1 str_var = "Let's go to Gijón!" # utf-8 string
```

String literals continued

- International characters sometimes problematic, think web adresses or old filesystems/databases
- To overcome this, you can use `str.encode()` to encode into bytes

```
1 str_var = "Let's go to Gijón!" # utf-8 string
2 str_ascii = str_var.encode() # bytes
```

String literals continued

- International characters sometimes problematic, think web adresses or old filesystems/databases
- To overcome this, you can use `str.encode()` to encode into bytes

```
1 str_var = "Let's go to Gijón!" # utf-8 string
2 str_ascii = str_var.encode() # bytes
3 # b"Let's go to Gij\xc3\xb3n!"
```

String literals continued

- International characters sometimes problematic, think web adresses or old filesystems/databases
- To overcome this, you can use `str.encode()` to encode into bytes

```
1 str_var = "Let's go to Gijón!" # utf-8 string
2 str_ascii = str_var.encode() # bytes
3 # b"Let's go to Gij\xc3\xb3n!"
```

- Here, `\xc3` and `\xb3` are escape sequences that together encode ç as a hex number (see UTF-8 tool)

String literals continued

- International characters sometimes problematic, think web adresses or old filesystems/databases
- To overcome this, you can use `str.encode()` to encode into bytes

```
1 str_var = "Let's go to Gijón!" # utf-8 string
2 str_ascii = str_var.encode() # bytes
3 # b"Let's go to Gij\xc3\xb3n!"
```

- Here, `\xc3` and `\xb3` are escape sequences that together encode ç as a hex number (see UTF-8 tool)
- The original UTF-8 string can be recovered from `bytes.decode()`

```
1 back_2_utf8 = str_ascii.decode('utf-8') # back to UTF-8
2 # "Let's go to Gijón!"
```

Escaping the escape sequences

- Sometimes we do not want \ to be interpreted as an escape sequence:

```
1 windows_path = "C:\new_file.csv"
2 # C:
3 # ew_file.csv
```

Escaping the escape sequences

- Sometimes we do not want \ to be interpreted as an escape sequence:

```
1 windows_path = "C:\new_file.csv"
2 # C:
3 # ew_file.csv
```

- \n is interpreted as a newline character

Escaping the escape sequences

- Sometimes we do not want \ to be interpreted as an escape sequence:

```
1 windows_path = "C:\new_file.csv"
2 # C:
3 # ew_file.csv
```

- \n is interpreted as a newline character
- We can prevent this by writing another backslash:

```
1 windows_path = "C:\\new_file.csv"
2 # C:\new_file.csv
```

Escaping the escape sequences

- Sometimes we do not want `\` to be interpreted as an escape sequence:

```
1 windows_path = "C:\new_file.csv"
2 # C:
3 # ew_file.csv
```

- `\n` is interpreted as a newline character
- We can prevent this by writing another backslash:

```
1 windows_path = "C:\\new_file.csv"
2 # C:\new_file.csv
```

- or by using a raw string literal (prefix: `r"..."`)

```
1 windows_path = r"C:\new_file.csv"
2 # C:\new_file.csv
```

Various string methods

- Lots of string methods available. Some examples:

Various string methods

- Lots of string methods available. Some examples:
  - Split strings in words

```
1 string1 = "Split this string up"
2 string1.split()
3 #["Split","this","string","up"]
```

Various string methods

- Lots of string methods available. Some examples:
  - Split strings in words

```
1 string1 = "Split this string up"
2 string1.split()
3 #["Split","this","string","up"]
```

  - Join a list of words

```
1 list_of_words = ["Join","me","together!"]
2 "--".join(list_of_words)
3 # Join--me--together!
```

Various string methods

- Lots of string methods available. Some examples:
  - Split strings in words

```
string1 = "Split this string up"
string1.split()
#["Split","this","string","up"]
```

  - Join a list of words

```
list_of_words = ["Join","me","together!"]
"--".join(list_of_words)
# Join--me--together!
```

  - Find/replace substrings

```
str_subject = "Great rockpools at Swanpool beach"
str_subject.find("pool") # 10
str_subject.rfind("pool") # 23
str_subject.replace("pool","puddle")  # "Great
    rockpuddles at Swanpuddle beach"
```

Various string methods

- Lots of string methods available. Some examples:
  - Split strings in words

```
string1 = "Split this string up"
string1.split()
#["Split","this","string","up"]
```

  - Join a list of words

```
list_of_words = ["Join","me","together!"]
"--".join(list_of_words)
# Join--me--together!
```

  - Find/replace substrings

```
str_subject = "Great rockpools at Swanpool beach"
str_subject.find("pool") # 10
str_subject.rfind("pool") # 23
str_subject.replace("pool","puddle")  # "Great
    rockpuddles at Swanpuddle beach"
```

String `isX` methods

- Identifying string contents using various `str.isX()` functions

String `isX` methods

- Identifying string contents using various `str.isX()` functions
  - All characters in the string are numeric

```
1 string1 = "899898"
2 string1.isnumeric() # True
```

String `isX` methods

- Identifying string contents using various `str.isX()` functions
  - All characters in the string are numeric

```
1 string1 = "899898"
2 string1.isnumeric() # True
3 string2 = "8998.98"
4 string2.isnumeric() # False
```

String `isX` methods

- Identifying string contents using various `str.isX()` functions
  - All characters in the string are numeric

```
string1 = "899898"
string1.isnumeric() # True
string2 = "8998.98"
string2.isnumeric() # False
```

  - All characters in the string are alphabetic

```
string1 = "Thisisallalphabetic"
string1.isalpha() # True
```

String `isX` methods

- Identifying string contents using various `str.isX()` functions
  - All characters in the string are numeric

```
1 string1 = "899898"
2 string1.isnumeric() # True
3 string2 = "8998.98"
4 string2.isnumeric() # False
```

  - All characters in the string are alphabetic

```
1 string1 = "Thisisallalphabetic"
2 string1.isalpha() # True
3 string2 = "Now with whitespace"
4 string2.isalpha() # False
```

String `isX` methods

- Identifying string contents using various `str.isX()` functions
  - All characters in the string are numeric

```
1 string1 = "899898"
2 string1.isnumeric() # True
3 string2 = "8998.98"
4 string2.isnumeric() # False
```

  - All characters in the string are alphabetic

```
1 string1 = "Thisisallalphabetic"
2 string1.isalpha() # True
3 string2 = "Now with whitespace"
4 string2.isalpha() # False
```

  - Lots of other `str.isX()` functions available. As we see later, however, regular expressions often preferable to search for patterns in text

Finding patterns of text without regular expressions

- Imagine one wants to convert various date formats to YYYY-MM-DD

Finding patterns of text without regular expressions

- Imagine one wants to convert various date formats to YYYY-MM-DD

```
1 s = "23.01.1980,08.09.1990,15-03-2019"
```

Finding patterns of text without regular expressions

- Imagine one wants to convert various date formats to YYYY-MM-DD

```
1 s = "23.01.1980,08.09.1990,15-03-2019"
2
3 for i in range(len(s)):
4
5     if i + 10 <= len(s):
6         if s[i:i+2].isdigit() and s[i+2] in ".-" and s[
              i+3:i+5].isdigit() and s[i+5] in ".-" and s[
              i+6:i+10].isdigit():
```

Finding patterns of text without regular expressions

- Imagine one wants to convert various date formats to YYYY-MM-DD

```
1  s = "23.01.1980,08.09.1990,15-03-2019"
2
3  for i in range(len(s)):
4
5      if i + 10 <= len(s):
6          if s[i:i+2].isdigit() and s[i+2] in ".-" and s[
               i+3:i+5].isdigit() and s[i+5] in ".-" and s[
               i+6:i+10].isdigit():
7              day = s[i:i+2]
8              month = s[i+3:i+5]
9              year = s[i+6:i+10]
10             print(year + "-" + month + "-" + day)
```

Finding patterns of text without regular expressions

- Imagine one wants to convert various date formats to YYYY-MM-DD

```
1  s = "23.01.1980,08.09.1990,15-03-2019"
2
3  for i in range(len(s)):
4
5      if i + 10 <= len(s):
6          if s[i:i+2].isdigit() and s[i+2] in ".-" and s[
               i+3:i+5].isdigit() and s[i+5] in ".-" and s[
               i+6:i+10].isdigit():
7              day = s[i:i+2]
8              month = s[i+3:i+5]
9              year = s[i+6:i+10]
10             print(year + "-" + month + "-" + day)
```

- Gets complicated quickly
- Breaks down for single digit months/days, e.g., `8.9.1980`

Finding patterns of text with regular expressions

```
1 # load the regular expression module
2 import re
```

Finding patterns of text with regular expressions

```
1 # load the regular expression module
2 import re
3
4 # text with dates (with single digit days and months)
5 s = "23.01.1980,8.9.1990,15-03-2019"
```

Finding patterns of text with regular expressions

```
1 # load the regular expression module
2 import re
3
4 # text with dates (with single digit days and months)
5 s = "23.01.1980,8.9.1990,15-03-2019"
6
7 # regular expression (given as a r"" [raw literal] string)
8 all_dates = re.findall(r"(\d{1,2})[-.](\d{1,2})[-.](\d{4})",
      s)
```

Finding patterns of text with regular expressions

```
1  # load the regular expression module
2  import re
3
4  # text with dates (with single digit days and months)
5  s = "23.01.1980,8.9.1990,15-03-2019"
6
7  # regular expression (given as a r"" [raw literal] string)
8  all_dates = re.findall(r"(\d{1,2})[-.](\d{1,2})[-.](\d{4})",
       s)
9
10 # print the result
11 for date in all_dates:
12     print(date[2] + "-" + date[1].zfill(2) + "-" + date[0].
           zfill(2))
```

What is a regular expression?

- A tiny, highly specialized programming language within Python

What is a regular expression?

- A tiny, highly specialized programming language within Python
- Made available in the `re` module

What is a regular expression?

- A tiny, highly specialized programming language within Python
- Made available in the `re` module
- Specifies the rules to match (and replace) patterns in text

What is a regular expression?

- A tiny, highly specialized programming language within Python
- Made available in the `re` module
- Specifies the rules to match (and replace) patterns in text
- One line of regex can replace 100s of lines of procedural code

What is a regular expression?

- A tiny, highly specialized programming language within Python
- Made available in the `re` module
- Specifies the rules to match (and replace) patterns in text
- One line of regex can replace 100s of lines of procedural code
- More portable across different programming languages than `str` methods

What is a regular expression?

- A tiny, highly specialized programming language within Python
- Made available in the `re` module
- Specifies the rules to match (and replace) patterns in text
- One line of regex can replace 100s of lines of procedural code
- More portable across different programming languages than `str` methods
- Easy to create using trial and error, for example on `https://regex101.com`

What is a regular expression?

- A tiny, highly specialized programming language within Python
- Made available in the `re` module
- Specifies the rules to match (and replace) patterns in text
- One line of regex can replace 100s of lines of procedural code
- More portable across different programming languages than `str` methods
- Easy to create using trial and error, for example on https://regex101.com
- A simple example:

```
1 import re
```

What is a regular expression?

- A tiny, highly specialized programming language within Python
- Made available in the `re` module
- Specifies the rules to match (and replace) patterns in text
- One line of regex can replace 100s of lines of procedural code
- More portable across different programming languages than `str` methods
- Easy to create using trial and error, for example on https://regex101.com
- A simple example:

```
1 import re
2 str_to_match = "Factors: 1foo, 2foo, foo, 4bar"
```

What is a regular expression?

- A tiny, highly specialized programming language within Python
- Made available in the `re` module
- Specifies the rules to match (and replace) patterns in text
- One line of regex can replace 100s of lines of procedural code
- More portable across different programming languages than `str` methods
- Easy to create using trial and error, for example on https://regex101.com
- A simple example:

```
1 import re
2 str_to_match = "Factors: 1foo, 2foo, foo, 4bar"
3 # regex that matches '1foo', '2foo' etc but not 'foo'
```

What is a regular expression?

- A tiny, highly specialized programming language within Python
- Made available in the `re` module
- Specifies the rules to match (and replace) patterns in text
- One line of regex can replace 100s of lines of procedural code
- More portable across different programming languages than `str` methods
- Easy to create using trial and error, for example on https://regex101.com
- A simple example:

```
1 import re
2 str_to_match = "Factors: 1foo, 2foo, foo, 4bar"
3 # regex that matches '1foo', '2foo' etc but not 'foo'
4 regex = r"\dfoo"
```

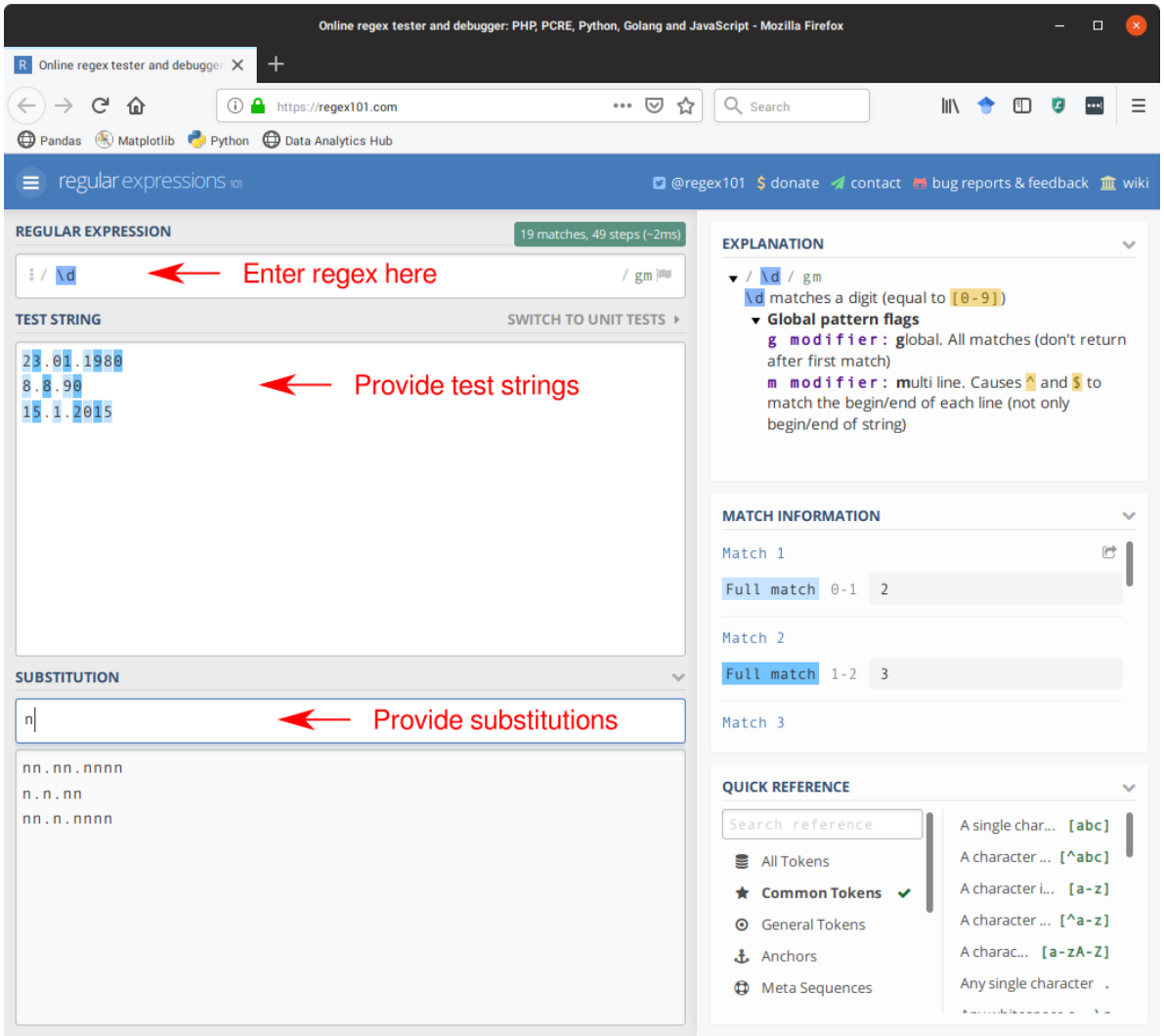
What is a regular expression?

- A tiny, highly specialized programming language within Python
- Made available in the `re` module
- Specifies the rules to match (and replace) patterns in text
- One line of regex can replace 100s of lines of procedural code
- More portable across different programming languages than `str` methods
- Easy to create using trial and error, for example on https://regex101.com
- A simple example:

```
1 import re
2 str_to_match = "Factors: 1foo, 2foo, foo, 4bar"
3 # regex that matches '1foo', '2foo' etc but not 'foo'
4 regex = r"\dfoo"
5 print(re.findall(regex, str_to_match)) # ['1foo','2foo
      ']
```

Testing regular expressions

- Practice regular expressions at `https://regex101.com/`



Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit

Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit
- `\D` matches any character that is not a digit

Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit
- `\D` matches any character that is not a digit
- `\s` matches any whitespace character (e.g., a space, a tab, a newline)

Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit
- `\D` matches any character that is not a digit
- `\s` matches any whitespace character (e.g., a space, a tab, a newline)
- `\S` matches any character that is not a whitespace

Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit
- `\D` matches any character that is not a digit
- `\s` matches any whitespace character (e.g., a space, a tab, a newline)
- `\S` matches any character that is not a whitespace
- `\b` matches a word boundary

Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit
- `\D` matches any character that is not a digit
- `\s` matches any whitespace character (e.g., a space, a tab, a newline)
- `\S` matches any character that is not a whitespace
- `\b` matches a word boundary

```
1 str_to_match = "Factor levels are snafoo, foosna and
      foo"
```

Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit
- `\D` matches any character that is not a digit
- `\s` matches any whitespace character (e.g., a space, a tab, a newline)
- `\S` matches any character that is not a whitespace
- `\b` matches a word boundary

```
1 str_to_match = "Factor levels are snafoo, foosna and
      foo"
2 regex = r"\bfoo\b" # regex
```

Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit
- `\D` matches any character that is not a digit
- `\s` matches any whitespace character (e.g., a space, a tab, a newline)
- `\S` matches any character that is not a whitespace
- `\b` matches a word boundary

```
1 str_to_match = "Factor levels are snafoo, foosna and
      foo"
2 regex = r"\bfoo\b" # regex
3 m = re.search(regex, str_to_match) # Factor levels are
      snafoo, foosna and bar
```

Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit
- `\D` matches any character that is not a digit
- `\s` matches any whitespace character (e.g., a space, a tab, a newline)
- `\S` matches any character that is not a whitespace
- `\b` matches a word boundary

```
1 str_to_match = "Factor levels are snafoo, foosna and
      foo"
2 regex = r"\bfoo\b" # regex
3 m = re.search(regex, str_to_match) # Factor levels are
      snafoo, foosna and bar
4 m.group(0) # obtain the complete match
```

Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit
- `\D` matches any character that is not a digit
- `\s` matches any whitespace character (e.g., a space, a tab, a newline)
- `\S` matches any character that is not a whitespace
- `\b` matches a word boundary

```
1 str_to_match = "Factor levels are snafoo, foosna and
      foo"
2 regex = r"\bfoo\b" # regex
3 m = re.search(regex, str_to_match) # Factor levels are
      snafoo, foosna and bar
4 m.group(0) # obtain the complete match
5 m.start() # Match position in string: 37
```

Regular expressions: syntax

The syntax for different patterns:

- `\d` matches any character that is a digit
- `\D` matches any character that is not a digit
- `\s` matches any whitespace character (e.g., a space, a tab, a newline)
- `\S` matches any character that is not a whitespace
- `\b` matches a word boundary

```
1 str_to_match = "Factor levels are snafoo, foosna and
      foo"
2 regex = r"\bfoo\b" # regex
3 m = re.search(regex, str_to_match) # Factor levels are
      snafoo, foosna and bar
4 m.group(0) # obtain the complete match
5 m.start() # Match position in string: 37
```

- `\B` does not match a word boundary

Regular expressions: syntax II

The syntax for different patterns:

- . matches any character (except a newline)

Regular expressions: syntax II

The syntax for different patterns:

- . matches any character (except a newline)
- ^ matches the start of a string

Regular expressions: syntax II

The syntax for different patterns:

- . matches any character (except a newline)
- ^ matches the start of a string

```
1 str1 = "foo snafoo funfoo"
2 regex = r"^foo" # regex matching the first foo
```

Regular expressions: syntax II

The syntax for different patterns:

- . matches any character (except a newline)
- ^ matches the start of a string

```
1 str1 = "foo snafoo funfoo"
2 regex = r"^foo" # regex matching the first foo
3 m = re.search(regex, str1)
4 m.start() # match position in string: 0
```

Regular expressions: syntax II

The syntax for different patterns:

- . matches any character (except a newline)
- ^ matches the start of a string

```
str1 = "foo snafoo funfoo"
regex = r"^foo" # regex matching the first foo
m = re.search(regex, str1)
m.start() # match position in string: 0
```

- $ matches end of a string

```
str1 = "foo snafoo funfoo"
regex = r"foo$" # regex matching the last foo
```

Regular expressions: syntax II

The syntax for different patterns:

- . matches any character (except a newline)
- ^ matches the start of a string

```
1 str1 = "foo snafoo funfoo"
2 regex = r"^foo" # regex matching the first foo
3 m = re.search(regex, str1)
4 m.start() # match position in string: 0
```

- $ matches end of a string

```
1 str1 = "foo snafoo funfoo"
2 regex = r"foo$" # regex matching the last foo
3 m = re.search(regex, str1)
4 m.start() # match position in string: 14
```

Regular expressions: syntax II

The syntax for different patterns:

- . matches any character (except a newline)
- ^ matches the start of a string

```
1 str1 = "foo snafoo funfoo"
2 regex = r"^foo" # regex matching the first foo
3 m = re.search(regex, str1)
4 m.start() # match position in string: 0
```

- $ matches end of a string

```
1 str1 = "foo snafoo funfoo"
2 regex = r"foo$" # regex matching the last foo
3 m = re.search(regex, str1)
4 m.start() # match position in string: 14
```

Regular expressions: syntax III

The syntax for different patterns:

- `[...]` matches a range of characters

```
1 str1 = "the number 60 is larger than 59"
2 regex = r"[0-5][0-9]" # matches 00 to 59
```

Regular expressions: syntax III

The syntax for different patterns:

- `[...]` matches a range of characters

```
str1 = "the number 60 is larger than 59"
regex = r"[0-5][0-9]" # matches 00 to 59
m = re.search(regex, str1)
m.group(0) # '59'
```

- `[^...]` matches characters not in the range

```
seq1 = "cccgggtaacccg"
```

Regular expressions: syntax III

The syntax for different patterns:

- `[...]` matches a range of characters

```
str1 = "the number 60 is larger than 59"
regex = r"[0-5][0-9]" # matches 00 to 59
m = re.search(regex, str1)
m.group(0) # '59'
```

- `[^...]` matches characters not in the range

```
seq1 = "cccgggtaacccg"
regex = r"[^cg]" # do not match c or g
```

Regular expressions: syntax III

The syntax for different patterns:

- `[...]` matches a range of characters

```
str1 = "the number 60 is larger than 59"
regex = r"[0-5][0-9]" # matches 00 to 59
m = re.search(regex, str1)
m.group(0) # '59'
```

- `[^...]` matches characters not in the range

```
seq1 = "cccgggtaacccg"
regex = r"[^cg]" # do not match c or g
m = re.search(regex, seq1)
m.group(0)  # 't', first match when using re.search()
```

Regular expressions: repetitions

Specify number of times patterns are matched

Regular expressions: repetitions

Specify number of times patterns are matched

- $*$ matches preceding regex 0 or more times

Regular expressions: repetitions

Specify number of times patterns are matched

- $*$ matches preceding regex 0 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d*" # matches 0 or more occurrences of
      numbers
```

Regular expressions: repetitions

Specify number of times patterns are matched

- $*$ matches preceding regex 0 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d*" # matches 0 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['', '', '', '', '', '', '',
      '', '60', '', '500', '', '', '', '', '', '3000', '']
```

Regular expressions: repetitions

Specify number of times patterns are matched

- $*$ matches preceding regex 0 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d*" # matches 0 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['', '', '', '', '', '', '',
      '', '60', '', '500', '', '', '', '', '', '3000', '']
```

- $+$ matches preceding regex 1 or more times

Regular expressions: repetitions

Specify number of times patterns are matched

- * matches preceding regex 0 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d*" # matches 0 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['', '', '', '', '', '', '',
      '', '60', '', '500', '', '', '', '', '', '3000', '']
```

- + matches preceding regex 1 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d+" # matches 1 or more occurrences of
      numbers
```

Regular expressions: repetitions

Specify number of times patterns are matched

- $*$ matches preceding regex 0 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d*" # matches 0 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['', '', '', '', '', '', '',
      '', '60', '', '500', '', '', '', '', '', '3000', '']
```

- $+$ matches preceding regex 1 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d+" # matches 1 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['60', '500', '3000']
```

Regular expressions: repetitions

Specify number of times patterns are matched

- * matches preceding regex 0 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d*" # matches 0 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['', '', '', '', '', '', '',
      '', '60', '', '500', '', '', '', '', '', '3000', '']
```

- + matches preceding regex 1 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d+" # matches 1 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['60', '500', '3000']
```

- ? matches preceding regex 0 or 1 times

Regular expressions: repetitions

Specify number of times patterns are matched

- * matches preceding regex 0 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d*" # matches 0 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['', '', '', '', '', '', '',
      '', '60', '', '500', '', '', '', '', '', '3000', '']
```

- + matches preceding regex 1 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d+" # matches 1 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['60', '500', '3000']
```

- ? matches preceding regex 0 or 1 times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d?" # matches 0 or 1 occurrences of numbers
```

Regular expressions: repetitions

Specify number of times patterns are matched

- * matches preceding regex 0 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d*" # matches 0 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['', '', '', '', '', '', '',
      '', '60', '', '500', '', '', '', '', '', '3000', '']
```

- + matches preceding regex 1 or more times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d+" # matches 1 or more occurrences of
      numbers
3 re.findall(str1,regex) #  ['60', '500', '3000']
```

- ? matches preceding regex 0 or 1 times

```
1 str1 = "numbers 60, 500 and 3000"
2 regex = r"\d?" # matches 0 or 1 occurrences of numbers
3 re.findall(str1,regex) # ['', '', '', '', '', '', '',
      '', '6', '0', '', '', '5', '0', '0', '', '', '', '',
       '', '3', '0', '0', '0', '']
```

Regular expressions: repetitions continued

Specify number of times patterns are matched (continued)

Regular expressions: repetitions continued

Specify number of times patterns are matched (continued)

- `{n}` match preceding regex exactly n times

Regular expressions: repetitions continued

Specify number of times patterns are matched (continued)

- `{n}` match preceding regex exactly n times
- `{n,m}` match preceding regex minimally n and maximally m times

Regular expressions: repetitions continued

Specify number of times patterns are matched (continued)

- `{n}` match preceding regex exactly n times
- `{n,m}` match preceding regex minimally n and maximally m times

```
1 str1 = "numbers 5, 60, 500, 3000, 50000"
2 regex = r"\d{2,4}" # matches numbers of 2 to 4 digits
```

Regular expressions: repetitions continued

Specify number of times patterns are matched (continued)

- `{n}` match preceding regex exactly n times
- `{n,m}` match preceding regex minimally n and maximally m times

```
1 str1 = "numbers 5, 60, 500, 3000, 50000"
2 regex = r"\d{2,4}" # matches numbers of 2 to 4 digits
3 re.findall(str1,regex) # ['60', '500', '3000', '5000']
```

Regular expressions: repetitions continued

Specify number of times patterns are matched (continued)

- `{n}` match preceding regex exactly n times
- `{n,m}` match preceding regex minimally n and maximally m times

```
1 str1 = "numbers 5, 60, 500, 3000, 50000"
2 regex = r"\d{2,4}" # matches numbers of 2 to 4 digits
3 re.findall(str1,regex) # ['60', '500', '3000', '5000']
```

- `*?`, `+?`, `??`, `{m,n}?` minimize the number of times a pattern matches

Regular expressions: repetitions continued

Specify number of times patterns are matched (continued)

- `{n}` match preceding regex exactly n times
- `{n,m}` match preceding regex minimally n and maximally m times

```
1 str1 = "numbers 5, 60, 500, 3000, 50000"
2 regex = r"\d{2,4}" # matches numbers of 2 to 4 digits
3 re.findall(str1,regex) # ['60', '500', '3000', '5000']
```

- `*?`, `+?`, `??`, `{m,n}?` minimize the number of times a pattern matches

```
1 str1 = "numbers 5, 60, 500, 3000, 50000"
2 regex = r"\d{2,4}?" # matches numbers of 2 to 4 digits,
      favoring minimal numbers
```

Regular expressions: repetitions continued

Specify number of times patterns are matched (continued)

- `{n}` match preceding regex exactly n times
- `{n,m}` match preceding regex minimally n and maximally m times

```
1 str1 = "numbers 5, 60, 500, 3000, 50000"
2 regex = r"\d{2,4}" # matches numbers of 2 to 4 digits
3 re.findall(str1,regex) # ['60', '500', '3000', '5000']
```

- `*?`, `+?`, `??`, `{m,n}?` minimize the number of times a pattern matches

```
1 str1 = "numbers 5, 60, 500, 3000, 50000"
2 regex = r"\d{2,4}?" # matches numbers of 2 to 4 digits,
      favoring minimal numbers
3 re.findall(str1,regex) # ['60', '50', '30', '00', '50',
      '00']
```

Regular expressions: repetitions continued

Specify number of times patterns are matched (continued)

- `{n}` match preceding regex exactly n times
- `{n,m}` match preceding regex minimally n and maximally m times

```
1 str1 = "numbers 5, 60, 500, 3000, 50000"
2 regex = r"\d{2,4}" # matches numbers of 2 to 4 digits
3 re.findall(str1,regex) # ['60', '500', '3000', '5000']
```

- `*?`, `+?`, `??`, `{m,n}?` minimize the number of times a pattern matches

```
1 str1 = "numbers 5, 60, 500, 3000, 50000"
2 regex = r"\d{2,4}?" # matches numbers of 2 to 4 digits,
      favoring minimal numbers
3 re.findall(str1,regex) # ['60', '50', '30', '00', '50',
      '00']
```

Regular expressions: functions

- `re.compile()` compiles a regular expression before applying it. Speeds things up when same regex is used a lot of times

Regular expressions: functions

- `re.compile()` compiles a regular expression before applying it. Speeds things up when same regex is used a lot of times
- `re.findall()` matches all occurrences of a pattern

Regular expressions: functions

- `re.compile()` compiles a regular expression before applying it. Speeds things up when same regex is used a lot of times
- `re.findall()` matches all occurrences of a pattern
- `re.search()` matches the first occurrence of a pattern

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
```

Regular expressions: functions

- `re.compile()` compiles a regular expression before applying it. Speeds things up when same regex is used a lot of times
- `re.findall()` matches all occurrences of a pattern
- `re.search()` matches the first occurrence of a pattern

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
2 # pattern that matches '1foo', '2foo' etc but not 'foo'
3 regex = r"\dfoo" # regex
```

Regular expressions: functions

- `re.compile()` compiles a regular expression before applying it. Speeds things up when same regex is used a lot of times
- `re.findall()` matches all occurrences of a pattern
- `re.search()` matches the first occurrence of a pattern

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
2 # pattern that matches '1foo', '2foo' etc but not 'foo'
3 regex = r"\dfoo" # regex
4 m = re.search(regex, str_to_match) # returns a Match
      object
```

Regular expressions: functions

- `re.compile()` compiles a regular expression before applying it. Speeds things up when same regex is used a lot of times
- `re.findall()` matches all occurrences of a pattern
- `re.search()` matches the first occurrence of a pattern

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
2 # pattern that matches '1foo', '2foo' etc but not 'foo'
3 regex = r"\dfoo" # regex
4 m = re.search(regex, str_to_match) # returns a Match
      object
5
6 m.group(0) # '1foo'
7
8 regex = r"\dbar" # another regex which does not match
```

Regular expressions: functions

- `re.compile()` compiles a regular expression before applying it. Speeds things up when same regex is used a lot of times
- `re.findall()` matches all occurrences of a pattern
- `re.search()` matches the first occurrence of a pattern

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
2 # pattern that matches '1foo', '2foo' etc but not 'foo'
3 regex = r"\dfoo" # regex
4 m = re.search(regex, str_to_match) # returns a Match
      object
5
6 m.group(0) # '1foo'
7
8 regex = r"\dbar" # another regex which does not match
9 re.search(regex, str_to_match) # None
```

Regular expressions: functions II

- `re.sub()` replaces occurrences of patterns in a string

Regular expressions: functions II

- `re.sub()` replaces occurrences of patterns in a string

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
```

Regular expressions: functions II

- `re.sub()` replaces occurrences of patterns in a string

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
2 # pattern that matches '1foo', '2foo' etc but not 'foo'
3 # and remembers the digit using a group ()
4 regex = r"(\d)foo" # regex
```

Regular expressions: functions II

- `re.sub()` replaces occurrences of patterns in a string

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
2 # pattern that matches '1foo', '2foo' etc but not 'foo'
3 # and remembers the digit using a group ()
4 regex = r"(\d)foo" # regex
5 # replace foo by bar but keep the digit
6 replacement = r"\1bar" # regex
```

Regular expressions: functions II

- `re.sub()` replaces occurrences of patterns in a string

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
2 # pattern that matches '1foo', '2foo' etc but not 'foo'
3 # and remembers the digit using a group ()
4 regex = r"(\d)foo" # regex
5 # replace foo by bar but keep the digit
6 replacement = r"\1bar" # regex
7 re.sub(regex, replacement, str_to_match) # Factor
      levels are 1bar, 2bar and foo
```

Regular expressions: functions II

- `re.sub()` replaces occurrences of patterns in a string

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
2 # pattern that matches '1foo', '2foo' etc but not 'foo'
3 # and remembers the digit using a group ()
4 regex = r"(\d)foo" # regex
5 # replace foo by bar but keep the digit
6 replacement = r"\1bar" # regex
7 re.sub(regex, replacement, str_to_match) # Factor
      levels are 1bar, 2bar and foo
```

- Everything within `()` (a group) is stored in memory

Regular expressions: functions II

- `re.sub()` replaces occurrences of patterns in a string

```
1 str_to_match = "Factor levels are 1foo, 2foo and foo"
2 # pattern that matches '1foo', '2foo' etc but not 'foo'
3 # and remembers the digit using a group ()
4 regex = r"(\d)foo" # regex
5 # replace foo by bar but keep the digit
6 replacement = r"\1bar" # regex
7 re.sub(regex, replacement, str_to_match) # Factor
      levels are 1bar, 2bar and foo
```

- Everything within `()` (a group) is stored in memory
- Group contents can be recalled in the replacement, using \1,\2,\3, etc

Regex exercise

- Use https://regex101.com/ to write dates in `"23.01.1980,29-03-2019"` as `"1980-01-23,2019-03-29"`

Regex exercise

- Use https://regex101.com/ to write dates in `"23.01.1980,29-03-2019"` as `"1980-01-23,2019-03-29"`
- Then try to do it in Python

Regex exercise

- Use https://regex101.com/ to write dates in "23.01.1980,29-03-2019" as "1980-01-23,2019-03-29"
- Then try to do it in Python
- In Python, that is:

```
two_dates = "23.01.1980,29-03-2019"
date_regex = r"(\d{1,2})[.-](\d{1,2})[.-](\d{2,4})"
date_substitution = r"\3-\2-\1"
re.sub(date_regex, date_substitution, two_dates)
# 23-01-1980,29-3-2019
```

Another regex exercise

- Use https://regex101.com/ to match the words 'pit', 'spot', 'spate', but not 'pt', 'Pot', 'peat', 'part' |

Another regex exercise

- Use https://regex101.com/ to match the words 'pit', 'spot', 'spate', but not 'pt', 'Pot', 'peat', 'part' | |

```
regex = r"s?p(i|o|a)te?"
```