Lecture 24: Regular Expressions

Aug 2nd, 2021

Alex Kassil

Announcements

- Guest Lecture **Tuesday, August 3rd, 6pm-7pm Pacific Time.**
  - The guest lecturer is Igor Podkhodov, Senior Engineering Manager at Zoox! He has been working in the field of technology for nearly 20 years now, and has been a Software Engineer/Manager at companies like Samsung, Netflix, Google, Snapchat, and Facebook before Zoox.
  - Submit questions in advance here: https://links.cs61a.org/guest-lecture-questions
- Vitamin 10 due tomorrow 8am
- Vitamin 11 due tomorrow 8am
- Lab 11 due tomorrow 11:59pm
- HW 06 due Wednesday 11:59pm
- Scheme Project
  - submit with Questions 1-6 done by Tuesday, 8/3 (worth 1 pt), and
  - submit with Parts I and II complete (including passing all additional tests provided in `tests.scm`) by Friday, 8/6 (worth 1 pt), and
  - submit the entire project by Tuesday, 8/10. You will get an extra credit point for submitting the entire project by Monday, 8/9

Regular Expressions (Regex) Basics

Can be pronounced rejex or reggex. I think reggex is more right,
but rejex is easier for me to say and sounds better to me.

Pattern Matching

- Programs that manipulate text often have a need to search a string for things other than simple substrings.
- For example: “Find all numbers in this string” or “Find all Scheme tokens in this program text.”
- Another application might be to check input: “Does this user’s response have the proper form?” or “Did this user enter enough digits for their phone number?”
- We can think of this as a kind of declarative programming, because the programmer is saying, e.g., “find something that looks like this” rather than “search for the substring ‘(’, then look for a ’)’ after that” to check for a parenthesized expression.

What are Regular Expressions?

- One of the most widely available and useful mechanisms is the *regular expression*.
- Formally, regular expressions denote *sets of strings* that are called *regular languages*.
- But normally, we think of them as patterns that match certain strings.
- In Python, we denote them with strings and use them as patterns by means of functions and classes in the module `re`.
- We will spend some time building up to the example below that extracts information from a date string

```
>>> import re
>>> date = "January 1st, 1970 00:00:00"
>>> re.match(r"(\w+) (\d+\w+), (\d+) (\d+):(\d+):(\d+)", date).groups()
('January', '1st', '1970', '00', '00', '00')
```

Regular Expression Syntax

The four basic operations for regular expressions.

- Can technically do anything with just these basic four (albeit tediously).

operation	order	example	matches	does not match
concatenation	3	AABAAB	AABAAB	every other string

Regular Expression Syntax

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operation	order	example	matches	does not match
concatenation	3	AABAAB	AABAAB	every other string
or	4	AA | BAAB	AA BAAB	every other string

Regular Expression Syntax

The four basic operations for regular expressions.

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operation	order	example	matches	does not match
concatenation	3	AABAAB	AABAAB	every other string
or	4	AA|BAAB	AA BAAB	every other string
closure (zero or more)	2	AB*A	AA ABBBBBBA	AB ABABA

Regular Expression Syntax

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concatenation	3	AABAAB	AABAAB	every other string
or	4	AA|BAAB	AA BAAB	every other string
closure (zero or more)	2	AB*A	AA ABBBBBBA	AB ABABA
parenthesis	1	A(A|B)AAB	AAAAB ABAAB	every other string
		(AB)*A	A ABABABABA	AA ABBA

Regular Expression Syntax

AB*: A then zero or more copies of B: A, AB, ABB, ABBB
(AB)*: Zero or more copies of AB: ABABABAB, ABAB, AB,

Also matches the empty string!

operation	order	example	matches	does not match
concatenation	3	AABAAB	AABAAB	every other string
or	4	AA|BAAB	AA BAAB	every other string
closure (zero or more)	2	AB*A	AA ABBBBBBA	AB ABABA
parenthesis	1	A(A|B)AAB	AAAAB ABAAB	every other string
		(AB)*A	A ABABABABA	AA ABBA

regex101.com favorite tool for working with regex

Let’s write a regular expression that matches scheme with an odd number of e’s between sch and me.

Valid:

scheme, scheeeme, scheeeeeme, …

Not valid:

schme, scheeme, python, ...

regex101.com favorite tool for working with regex

Let’s write a regular expression that matches scheme with an odd number of e’s between sch and me.

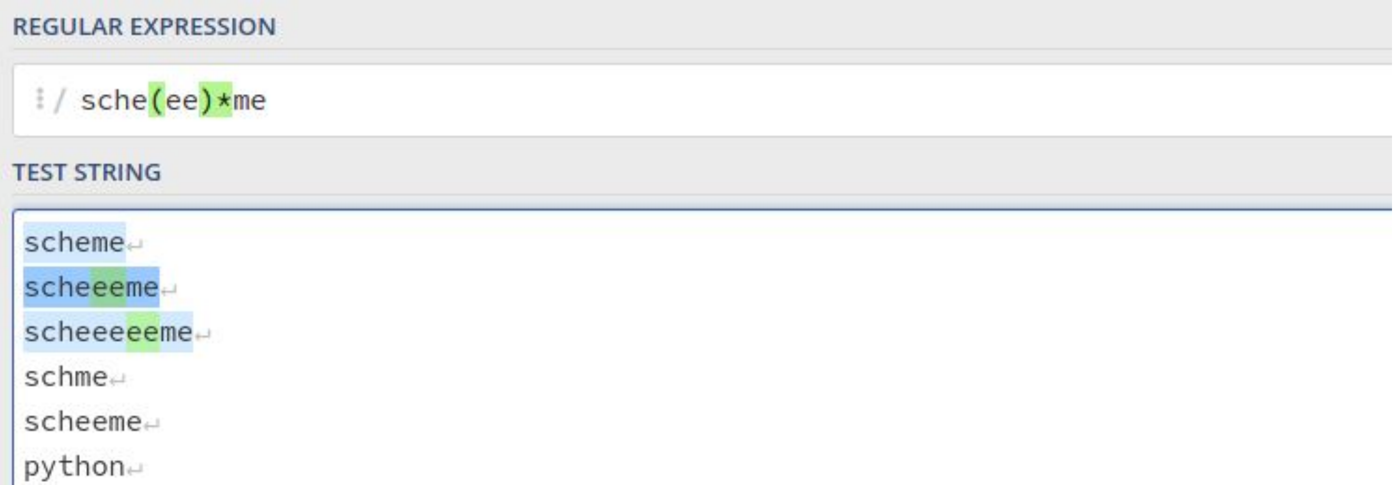
Valid:

scheme, scheeeme, scheeeeeme, …

Not valid:

schme, scheeme, python, …   solution:

https://r



REGULAR EXPRESSION

```
/ sche(ee)*me
```

TEST STRING

```
scheme
scheeeme
scheeeeeme
schme
scheeme
python
```

https://regex101.com/r/ApznBC/1 Your turn!

operation	order	example	matches	does not match
concatenation	3	AABAAB	AABAAB	every other string
or	4	AA|BAAB	AA BAAB	every other string
closure (zero or more)	2	AB*A	AA ABBBBBBA	AB ABABA
parenthesis	1	A(A|B)AAB	AAAAB ABAAB	every other string
		(AB)*A	A ABABABABA	AA ABBA

Write a regular expression that matches scheme with an odd number of e’s between sch and me or an even number of ea’s except zero.

Valid: scheme, scheeeme, scheame, scheaeame

Invalid: scheeme, schme, python, schame, schaeme

https://regex101.com/r/ekS1AC/1 Solution!

```
sch(e(ee)*|ea(ea)*)me
```

operation	order	example	matches	does not match
concatenation	3	AABAAB	AABAAB	every other string
or	4	AA|BAAB	AA BAAB	every other string
closure (zero or more)	2	AB*A	AA ABBBBBBA	AB ABABA
parenthesis	1	A(A|B)AAB	AAAAB ABAAB	every other string
		(AB)*A	A ABABABABA	AA ABBA

Write a regular expression that matches scheme with an odd number of e's between sch and me or an even number of ea's except zero.

Valid: scheme, scheeeme, scheame, scheaeame

Invalid: scheeme, schme, python, schame, schaeme

Order of Operations in Regexes

`sch(e(ee)*|ea(ea)*)me`

- Matches starting with sch and ending with me, with either of the following in the middle:
  - `e(ee)*`
  - `ea(ea)*`

Match examples:

```
scheme
scheeeme
scheame
scheaeame
```

Order of Operations in Regexes

`sch(e(ee)*|ea(ea)*)me`

- Matches starting with sch and ending with me, with either of the following in the middle:
  - `e(ee)*`
  - `ea(ea)*`

Match examples:

```
scheme
scheeeme
scheame
scheaeame
```

`sch(e(ee)*)|(ea(ea)*)me`

- Matches either of the following
  - `sch` followed by `e(ee)*`
  - `ea(ea)*` followed by `me`

Match examples:

```
sche
sche
eame
eaeame
```

https://regex101.com/r/oyjGnW/1

In regexes | comes last.

https://regex101.com/r/ApznBC/1 Your turn!

operation	order	example	matches	does not match
concatenation	3	AABAAB	AABAAB	every other string
or	4	AA|BAAB	AA BAAB	every other string
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parenthesis	1	A(A|B)AAB	AAAAB ABAAB	every other string
		(AB)*A	A ABABABABA	AA ABBA

Write a regular expression that matches scheme with an odd number of e's between sch and me or an even number of ea's except zero.

Valid: scheme, scheeeme, scheame, scheaeame

Invalid: scheeme, schme, python, schame, schaeme

Matching some CS Lower Divs

Write a regular expression that matches strings that start with CS61 and end with a capital letter

Valid: CS61A, CS61B, CS61C, CS61D, ..., CS61Z

Not valid: CS70, CS10, CS611, EECS16A, ...

```
(CS61A|CS61B|CS61C|CS61D|CS61E|CS61F|CS61G|CS61H|CS61I|CS61J|CS61K|CS61L|CS61M|CS61N|CS61O|CS61P|CS61Q|CS61R|CS61S|CS61T|CS61U|CS61V|CS61W|CS61X|CS61Y|CS61Z)
```

```
CS61(A|B|C|D|E|F|G|H|I|J|K|L|M|N|O|P|Q|R|S|T|U|V|W|X|Y|Z)
```

Writing such long expressions is a little tedious

Expanded Regex Syntax

operation	example	matches	does not match
any character (except newline)	`.A.A.A.`	`BANANAS` `AAAAAAA`	`ALABAMA` `AAAAAA`

Expanded Regex Syntax

operation	example	matches	does not match
any character (except newline)	`.A.A.A.`	`BANANAS` `AAAAAAA`	`ALABAMA` `AAAAAA`

character class	`[A-Za-z][a-z]*`	`word`
		`Capitalized`
			`camelCase`
			`4illegal`

Expanded Regex Syntax

operation	example	matches	does not match
any character (except newline)	.A.A.A.	BANANAS AAAAAAA	ALABAMA AAAAAA
character class	[A-Za-z][a-z]*	word Capitalized	camelCase 4illegal
inverse character class	[^A-Za-z]*	12345 ?!*%3	word BANANAS

Expanded Regex Syntax

operation	example	matches	does not match
any character (except newline)	.A.A.A.	BANANAS AAAAAAA	ALABAMA AAAAAA
character class	[A-Za-z][a-z]*	word Capitalized	camelCase 4illegal
inverse character class	[^A-Za-z]*	12345 ?!*%3	word BANANAS
at least one	jo+hn	john joooooohn	jhn jjohn

Expanded Regex Syntax

operation	example	matches	does not match
any character (except newline)	.A.A.A.	BANANAS AAAAAAA	ALABAMA AAAAAA
character class	[A-Za-z][a-z]*	word Capitalized	camelCase 4illegal
inverse character class	[^A-Za-z]*	12345 ?!*%3	word BANANAS
at least one	jo+hn	john joooooohn	jhn jjohn
zero or one	joh?n	jon john	any other string

Expanded Regex Syntax

operation	example	matches	does not match
any character (except newline)	.A.A.A.	BANANAS AAAAAAA	ALABAMA AAAAAA
character class	[A-Za-z][a-z]*	word Capitalized	camelCase 4illegal
inverse character class	[^A-Za-z]*	12345 ?!*%3	word BANANAS
at least one	jo+hn	john jooooooohn	jhn jjohn
zero or one	joh?n	jon john	any other string
repeated exactly {a} times	j[aeiou]{3}hn	jaoehn jooohn	jhn jaeiouhn

Expanded Regex Syntax

operation	example	matches	does not match
any character (except newline)	.A.A.A.	BANANAS AAAAAAA	ALABAMA AAAAAA
character class	[A-Za-z][a-z]*	word Capitalized	camelCase 4illegal
inverse character class	[^A-Za-z]*	12345 ?!*%3	word BANANAS
at least one	jo+hn	john jooooohn	jhn jjohn
zero or one	joh?n	jon john	any other string
repeated exactly {a} times	j[aeiou]{3}hn	jaoehn jooohn	jhn jaeiouhn
repeated from a to b times: {a,b}	j[ou]{1,2}hn	john juohn	jhn jooohn

Your turn! https://regex101.com/r/07v7K1/1

operation	example	matches	does not match
any character (except newline)	.A.A.A.	BANANAS AAAAAAA	ALABAMA AAAAAA
character class	[A-Za-z][a-z]*	word Capitalized	camelCase 4illegal
inverse character class	[^A-Za-z]*	12345 ?!*%3	word BANANAS
at least one	jo+hn	john joooooohn	jhn jjohn
zero or one	joh?n	jon john	any other string
repeated exactly {a} times	j[aeiou]{3}hn	jaoehn jooohn	jhn jaeiouhn
repeated from a to b times: {a,b} {a,} means a or more	j[ou]{1,2}hn	john juohn	jhn jooohn

Match social security numbers, example 111-11-1111

Your turn! https://regex101.com/r/07v7K1/1

operation	example	matches	does not match
any character (except newline)	`.A.A.A.`	`BANANAS` `AAAAAAA`	`ALABAMA` `AAAAAA`

character class	`[A-Za-z][a-z]*`	`word`
		`Capitalized`
			`camelCase`
			`4illegal`

inverse character class	`[^A-Za-z]*`	`12345`
		`?!*%3`
			`word`
			`BANANAS`

at least one	`jo+hn`	`john` `joooooohn`	`jhn` `jjohn`
zero or one	`joh?n`	`jon` `john`	`any other string`
repeated exactly {a} times	`j[aeiou]{3}hn`	`jaoehn` `jooohn`	`jhn` `jaeiouhn`
repeated from a to b times: {a,b} {a,} means a or more	`j[ou]{1,2}hn`	`john` `juohn`	`jhn` `jooohn`

Match social security numbers, example 111-11-1111
Solution: `[0-9]{3}-[0-9]{2}-[0-9]{4}`

Simple Email Address Regex

Let’s write a regular expression that matches email addresses of the form:

letters@letters.exactly 3 letters

Valid: alex@gmail.com, gmail@alex.com, alexkassil@berkeley.edu

Not valid: alex@gmail, gmail+org@gmail.com, ALEXKASSIL@BERKELEY.EDU

Simple Email Address Regex

Let’s write a regular expression that matches email addresses of the form:

letters@letters.exactly 3 letters

Valid: alex@gmail.com, gmail@alex.com, alexkassil@berkeley.edu

Not valid: alex@gmail, gmail+org@gmail.com, ALEXKASSIL@BERKELEY.EDU

Solution: `[a-z]+@[a-z]+\.[a-z]{3}`

Email Address Regular Expression (a probably bad idea)

The regular expression for email addresses (for the Perl programming language):

```
(?:(?:\r\n)?[ \t])*(?:(?:(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?: \r\n)?[
\t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[
\t])*))*@(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\ ](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[
\t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?: (?:\r\n)?[ \t])*))*|(?:[^()<>@,;:\\".\[\]
\000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n) ?[ \t])*)*\<(?:(?:\r\n)?[ \t])*(?:@(?:[^()<>@,;:\\".\[\]
\000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t] )*))*(?:,@(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])* )(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
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\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r \n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t ]))*"(?:(?:\r\n)?[ \t])*))*@(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
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\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]| \\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|" (?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*))*@(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
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\t])+|\Z|(?=[\["()<>@,;:\\".\[ \]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*))*|(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|( ?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*)*\<(?:(?:\r\n)?[ \t])*(?:@(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([ ^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
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\t])+|\Z|(?=[\["()<>@,;:\\".\[\] ]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*))*\>(?:(?:\r\n)?[ \t])*)(?:,\s*(?:(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
\t])+|\Z|(?=[\["()<>@,;:\\ ".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[
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])+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|
\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*))*|(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".\[\
]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*)*\<(?:(?:\r\n)?[ \t])*(?:@(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["
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@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*))*(?:,@(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,
;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\
".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*))*)*:(?:(?:\r\n)?[ \t])*)?(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\["()<>@,;:\\".
\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z|(?=[\[
"()<>@,;:\\".\[\]]))|"(?:[^\"\r\\]|\\.|(?:(?:\r\n)?[ \t]))*"(?:(?:\r\n)?[ \t])*))*@(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])
+|\Z|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*)(?:\.(?:(?:\r\n)?[ \t])*(?:[^()<>@,;:\\".\[\] \000-\031]+(?:(?:(?:\r\n)?[ \t])+|\Z
|(?=[\["()<>@,;:\\".\[\]]))|\[([^\[\]\r\\]|\\.)*\](?:(?:\r\n)?[ \t])*))*\>(?:(?:\r\n)?[ \t])*))*)?;\s*)
```

From: http://www.ex-parrot.com/~pdw/Mail-RFC822-Address.html

Built in Character Classes

pattern	explanation	matches
\d	`Any single digit, [0-9]`	1 2

Built in Character Classes

pattern	explanation	matches
\d	Any single digit, [0-9]	1 2
\w	Any single letter, digit or underscore, [A-Za-z0-9_]	A _

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\d	Any single digit, [0-9]	1 2
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\W	Anything \w doesn’t match, [^A-Za-z0-9_]	! φ
\s	Any single whitespace character: space, tab, newline, carriage return, "\f", or "\v"	
\S	Any single character that is not whitespace	A φ

Regex Makeover!

Let's make a regular expression to match 24-hour times of the format `HH:MM`.

First draft: `[0-2]\d:\d\d`

What not valid times would that match?

```
25:99
```

How do we fix minutes?

```
[0-2]\d:[0-5]\d
```

How do we fix hours?

```
(2[0-3]|[0-1]\d):[0-5]\d
```

Anchors

A few patterns match the empty string, but only at certain places.

pattern	explanation	example	matches	does not match
`^`	`Matches the empty string at the beginning of a string.`	`^hello`	**hello** **hello** there	why hello

Anchors

A few patterns match the empty string, but only at certain places.

pattern	explanation	example	matches	does not match

`^`	`Matches the empty string at the beginning of a string.`	`^hello`	**`hello`**
			`hello` `there`
				`why hello`

`$`	`Matches the empty string at the end of a string.`	`hello$`	**`hello`**
			`why` **`hello`**
				`hello there`

Anchors

A few patterns match the empty string, but only at certain places.

pattern	explanation	example	matches	does not match
^	Matches the empty string at the beginning of a string.	^hello	**hello** **hello** there	why hello
$	Matches the empty string at the end of a string.	hello$	**hello** why **hello**	hello there
\b	Matches the empty string at the beginning or end of a word (composed of matches to \w).	\b4\b	44 pieces of a4 is **4**$	44 pieces of a4

Anchors

A few patterns match the empty string, but only at certain places.

pattern	explanation	example	matches	does not match
^	Matches the empty string at the beginning of a string.	^hello	**hello** **hello** there	why hello
$	Matches the empty string at the end of a string.	hello$	**hello** why **hello**	hello there
\b	Matches the empty string at the beginning or end of a word (composed of matches to \w).	\b4\b	44 pieces of a4 is **4**$	44 pieces of a4
\B	Matches the empty string where \b does not match.	\B4\b	4**4** pieces of a**4** is 4 dollars	4a 4

Your Turn! https://regex101.com/r/3x1lsx/1

pattern	explanation	example	matches	does not match
^	Matches the empty string at the beginning of a string.	^hello	**hello** **hello** there	why hello
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Make a regular expression that matches all the lowercase words ending with ing

Your Turn! https://regex101.com/r/D6MkkM/1

pattern	explanation	example	matches	does not match
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$	Matches the empty string at the end of a string.	hello$	**hello** why **hello**	hello there
\b	Matches the empty string at the beginning or end of a word (composed of matches to \w).	\b4\b	44 pieces of a4 is **4**$	44 pieces of a4
\B	Matches the empty string where \b does not match.	\B4\b	4**4** pieces of a**4** is 4 dollars	4a 4

Make a regular expression that matches all the lowercase words ending with ing

Solution: `\b[a-z]+ing\b`

Escaping Characters

- Recap: Patterns that don’t contain any of the special characters

  ```
  \ ( ) [ ] { } + * ? | $ ^ .
  ```

  simply match themselves
- Example: `Berkeley, CA 94720` matches exactly the string or substring `Berkeley, CA 94720`
- To match one of the special characters above, precede with a backslash
- Example: `\(1\+3\)` matches exactly `(1+3)`

Regular Expressions in Python

Small Preliminary: Raw Strings

- Traditionally, the backslash character (\) is often used in patterns.
- This can conflict with the usual Python string escape sequences (which begin with backslashes), like \n for newline
- So early on, Python introduced raw strings, which have an ‘r’ or ‘R’ in front of the quotes, as in `r"\n"`.
- In these strings, backslashes are just backslashes (except, annoyingly, that they cannot appear alone at the end of a string.)
- So generally, we use raw strings to denote patterns in Python that have backslashes.
- Reminder, strings in python prefixed by ‘f’ are formatted strings, which allow variables enclosed in { } to be evaluated and inserted into the string

Raw String Examples

```
>>> "\n"
'\n'
>>> r"\n"
'\\n'
>>> print("I have\na newline in me.")
I have
a newline in me
>>> print(r"I have\na newline in me.")
I have\na newline in me.
```

Using Patterns in Python

- Need to import the re module `import re`
- The methods `re.match`, `re.search`, and `re.fullmatch` all take a string containing a regular expression and a string of text. They return either a *match object* or, if there is no match, None.
- Match objects are ‘true’ values as far as Python is concerned, so one can use the results of these functions as True/False values:

```
>>> import re
>>> for x in ["jack", "25", "-5", "aardvark"]:
...   if re.fullmatch(r'-?\d+', x):
...     print(f"{x} is a number")
25 is a number
-5 is a number
>>> bool(re.fullmatch(r'-?\d+', '123'))
True
>>> bool(re.fullmatch(r'-?\d+', '123 people'))
False
```

The Matching Methods

- `re.fullmatch` requires that the pattern match the entire searched string
- `re.match` does not require that the whole string be matched, but does require that the matching string occur at the beginning of the string
- `re.search` finds the first occurrence of the pattern anywhere in the string

```
>>> import re
>>> x = "Structure and Interpretation of Computer Programs"
>>> bool(re.match("Structure", x))
True
>>> bool(re.fullmatch("Structure", x))
False
>>> bool(re.fullmatch("Structure.*Programs", x))
True
>>> bool(re.match("and", x))
False
>>> bool(re.search("and", x))
True
```

Write a function that checks if input string is a float

```
import re
def is_float(x):
    """ Return whether a string x is a float
    >>> is_float("0.0")
    True
    >>> is_float("0")
    False
    >>> is_float("-1234.5678")
    True
    >>> is_float("Chapter 2.1")
    False
    >>> is_float("1.1.1")
    False
    """
    pattern = r"_______"
    return bool(re._______(pattern, x))
```

Write a function that checks if input string is a float

```
import re
def is_float(x):
    """ Return whether a string x is a float
    >>> is_float("0.0")
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    False
    """
    pattern = r"-?\d+\.\d+"
    return bool(re._______(pattern, x))
```

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    False
    >>> is_float("-1234.5678")
    True
    >>> is_float("Chapter 2.1")
    False
    >>> is_float("1.1.1")
    False
    """
    pattern = r"-?\d+\.\d+"
    return bool(re.fullmatch(pattern, x))
```

Retrieving Matched Text

- Match objects also carry information about what has been matched. The `.group()` method allows you to retrieve it
- Furthermore, if there are parenthesized expressions in the pattern, you can retrieve them as well by indexing `.group()` or calling `.groups()`

```
>>> x = "This string contains 35 characters."
>>> mat = re.search(r'\d+', x)
>>> mat.group()
'35'
>>> x = "There were 12 pence in a shilling and 20 shillings in a pound."
>>> mat = re.search(r'(\d+).*(\d+)', x)
>>> mat.group(0) # Same as mat.group()
'12 pence in a shilling and 20'
>>> mat.group(1)
'12'
>>> mat.group(2)
'20'
>>> mat.groups() # All parenthesized groups
('12', '20')
```

For more information

- Sp21 Intro to Regex Slides
- Sp21 Review: Regular Expressions + BNF (Ignore the BNF part)
- https://regexone.com/ Online tutorial
- https://regex101.com/ platform for experimenting with regular expressions
- https://regexr.com/ online tool to learn, build, & test Regular Expressions
- https://regexcrossword.com/ Fun games to learn regex
- http://www.regular-expressions.info/
- https://projects.lukehaas.me/regexhub/
- Fa20 Data 100 Regex Reference
- Data 100 Textbook Section on Regex
- Sp21 Data 100 Regular Expressions Lecture