Lecture 23: Regular Expressions

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Announcements

- Lab11 due tomorrow
- Scheme Released
    - Checkpoint 1 due tomorrow, Tuesday, 8/1
    - Checkpoint 2 due Friday, 8/4
    - Whole project due next Tuesday 8/8. EC for submitting one day early 8/7.
- Please submit to the correct Scheme autograder!
- Hw05 recovery released (later today)!
- Final exam on 8/10 6-9 PM
    - Submit exam alteration form by Sunday 8/6

Regular Expressions

Declarative programming (again!!)

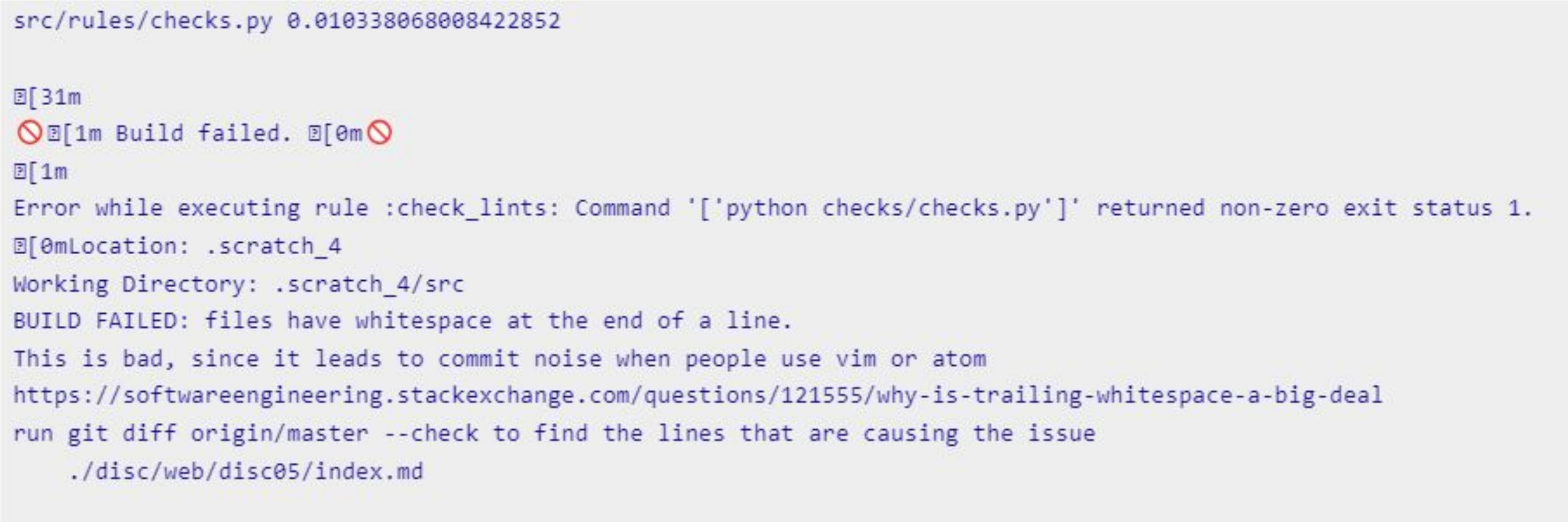
A **regular expression** (aka: **regex**) is a sequence of characters that specifies a **pattern**, usually utilized by string searching algorithms

Regular expressions, as they are typically used, are a great example of **declarative programming**

> —we can use a regular expression to specify a pattern that we want to find within a string, and then we give that pattern to a search algorithm to find the pattern for us

RegEx is *not* a programming language. It's a standard that is implemented within many modern programming languages (including Python!), because string search is a common problem

Motivation



```
src/rules/checks.py 0.010338068008422852

⍰[31m
🚫⍰[1m Build failed. ⍰[0m🚫
⍰[1m
Error while executing rule :check_lints: Command '['python checks/checks.py']' returned non-zero exit status 1.
⍰[0mLocation: .scratch_4
Working Directory: .scratch_4/src
BUILD FAILED: files have whitespace at the end of a line.
This is bad, since it leads to commit noise when people use vim or atom
https://softwareengineering.stackexchange.com/questions/121555/why-is-trailing-whitespace-a-big-deal
run git diff origin/master --check to find the lines that are causing the issue
    ./disc/web/disc05/index.md
```

RegEx allows us to systematically describe patterns for these kinds of problems, that we can then pass off to pre-implemented algorithms

Of all the topics we learn in this course, RegEx is probably the one I personally use most in my life

Matching exact strings

Regex is composed of characters that form a pattern

These characters match some strings

Let’s take a look at an example: https://regex101.com/

(Demo)

Matching exact strings - You try!

Most characters in RegEx will match exactly the characters as they appear in the expression

(the highlighting doesn’t imply or mean anything other than it is easier for me to read)

Expression: `abcabc`

abcabc

abdabc

abcab

Matching exact strings

Most characters in RegEx will match exactly the characters as they appear in the expression

Expression: `abcabc`
Fully matched by: abcabc
Not fully matched by: abdabc, abcab

However, some characters in RegEx have reserved meanings, and so must be escaped with the backslash character if you're interested in the character itself: `\` `(` `)` `[` `]` `{` `}` `+` `*` `?` `|` `$` `^` `.`

Expression: `\{abc\}`
Fully matched by: {abc}

The dot character

In RegEx, the . character is a reserved character that will match any single character that is not a new line

Expression: `.a.a.a`

Fully matched by: `banana`, `aaaaaa`, `+a-a!a`

“Any non newline character followed by a lowercase ‘a’ followed by any non newline character followed by a lowercase ‘a’ followed by any non newline character followed by a lowercase ‘a’”

Custom Character Classes

Character classes match any of a set of characters—one instance of a character class will match exactly one character

Expression: `[ab]c[ab]c`
Fully matched by: `acac`, `bcac`, `acbc`, `bcbc`
Not fully matched by: `aacac`, `accc`

Expression: `[a-z][0-9]`
Fully matched by: `a0`, `b8`, `z0`, `g5`
“Any lowercase letter followed by any singular digit number”

Similar to this pseudo code:
Match if equal to exactly one of the characters in the bracket
Order matters

Common Character Classes

We have some shorthands for common character classes

`.` matches any non-newline character

`\d` matches digits, equivalent to `[0-9]`

`\w` matches "word characters", equivalent to `[A-Za-z0-9_]`

`\s` matches whitespace characters (spaces/tabs/line breaks)

`[^]` matches any character *except* whatever comes after `^`

`\D` matches any *non*-digit character (opposite of `\d`)
`\s` and `\w` also have `\S` and `\W` as opposites

Character classes: Examples

Expression: `[^ab]c`

Fully matched by: `cc`, `zc`, `!c`, ` c`

Not fully matched by: `ac`, `bc`

“Any singular character that is not an a or a b followed by a c”

Expression: `\(\d\d\d\) \d\d\d-\d\d\d\d`

Fully matched by: `(951) 262-3062`

“An open parenthesis followed by a digit, a digit, a digit, followed by a closed parenthesis, followed by a whitespace, a digit, a digit, a digit, a dash, a digit, a digit, a digit, and a digit”

Quantifiers

Quantifiers allow us to specify multiple occurrences of the same character or character class

`a*`	zero or more occurrences of `a`
`a+`	one or more occurrences of `a`
`a?`	zero or one occurences of `a`
`a{2}`	two occurrences of `a`
`a{2,4}`	two, three, or four occurrences of `a`
`a{2,}`	at least two occurrences of `a`

In my experience, of everything you see in this lecture, `+` and `*` are the ones I've used the most

Quantifiers: Examples

Expression: `a*b`

Fully matched by: `b`, `ab`, `aaaaaaaaaaaab`

“Zero or more lowercase a’s followed by a lowercase b”

Expression: `a+b`

Fully matched by: `ab`, `aaaaaaaaaaaab`

Not fully matched by: `b`

“At least one lowercase a followed by a lowercase b”

Expression: `\(\d{3}) \d{3}-\d{4}`

Fully matched by: `(951) 262-3062`

“An open parenthesis followed by 3 digits, a closed parenthesis, a whitespace, 3 digits, a dash, and 4 digits”

Combining patterns

The pipe `|` operator matches either the expression on its left or its right

Expression: `\d+|Inf`
Fully matched by: `78947892`, `Inf`
Not fully matched by: `78947892Inf`

“Either at least one digit, OR a capital I followed by a lowercase n and a lowercase f” → exclusive or

You can also use parentheses `(` `)` to group expressions

Expression: `(<3)+`
Fully matched by: `<3`, `<3<3<3<3<3`

Combining patterns

You can also use parentheses ( ) to group expressions

Expression: (<3)+

Fully matched by: <3, <3<3<3<3<3

(Demo)

Anchors

Anchors are unique in that they don't match characters—instead, they match positions in a string where an expression could land

`^` matches the beginning of a string

`$` matches the end of a string

`\b` matches a "word boundary" (whitespace, punctuation)

(Demo)

Note

Yes, “^” has 2 separate meanings in regex:

[^a] → inverse

^a → start of string

Regular Expressions in Python

The `re` module

Python has a module called `re` that supports regular expressions for strings!

This is common—many programming languages have some level of built-in support for regular expressions

```
>>> import re
>>> bool(re.search(r"\d+", "123 peeps"))
True
>>> bool(re.search(r"\d+", "So many peeps"))
False
```

Raw strings

Python has escape characters built in to string evaluation, such as the newline character

```
>>> print("hello\nthere!")
hello
there!
```

Regular expressions also use the backslash character, but we don't want the Python interpreter to treat these as Pythonic escape characters. Raw strings allow us to use backslashes without worrying about this

```
>>> print(r"hello\nthere!")
hello\nthere!
```

Evaluation rules for raw strings are confusing, and we won't test you on them—the important thing for you to know is that **if you're writing a regular expression, you should use a raw string rather than a regular string**

Match objects

The `re` module has methods that attempt to match a pattern to a string—if they find a match, they'll return a `Match` object (truthy), and if they don't, they'll return None (falsey)

`re.search(<pattern>, <string>)`

> Returns a `Match` object representing the first occurrence of `<pattern>` in `<string>`

`re.fullmatch(<pattern>, <string>)`

> Returns a `Match` object, requiring that `<pattern>` entirely match `<string>`

`re.match(<pattern>, <string>)`

> Returns a `Match` object, requiring that `<string>` must start with a substring that matches `<pattern>`

Match objects: Examples

```
>>> x = "This string contains 35 characters."
>>> mat = re.search(r'\d+', x)
>>> mat
<re.Match object ...>
>>> mat.group(0)
'35'
>>> mat2 = re.search(r'\d{3,}', x)
>>> mat2
>>> # Returned None :0
```

Capturing groups

When we use parentheses to group sub-expressions, they define **capture groups** that we can then access individually

```
>>> x = "There were 12 pence in a shilling and 20 
shillings in a pound."
>>> mat = re.search(r'(\d+)[a-z\s]+(\d+)', x)
>>> mat.group(0)
'12 pence in a shilling and 20'
>>> mat.group(1)
'12'
>>> mat.group(2)
'20'
>>> mat.groups()
('12', '20')
```

Capturing groups are super cool and helpful, but we won't test you on them in this class

Other `re` functions

These are functions from the `re` module that don't return match objects

`re.findall(<pattern>, <string>)`

    Returns a list of all substrings within `<string>` that match `<pattern>`, read from left to right

`re.sub(<pattern>, <repl>, <string>)`

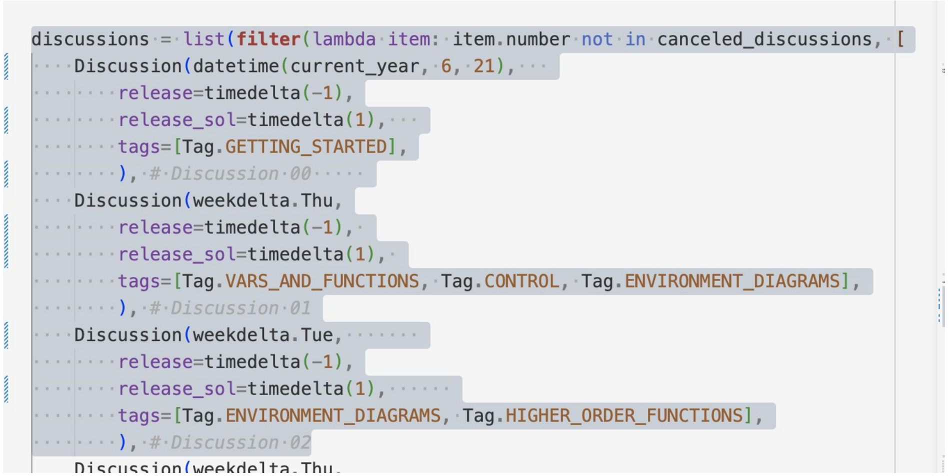
    Returns `<string>`, but with all instances of `<pattern>` replaced with `<repl>`

Examples!

Trimming whitespace

This is based on something real that one of our staff members had to do lol

For formatting reasons, programmers tend to not like whitespace on the end of lines



```
discussions·=·list(filter(lambda·item:·item.number·not·in·canceled_discussions,·[
····Discussion(datetime(current_year,·6,·21),···
········release=timedelta(-1),
········release_sol=timedelta(1),···
········tags=[Tag.GETTING_STARTED],
········),·#·Discussion·00·····
····Discussion(weekdelta.Thu,
········release=timedelta(-1),·
········release_sol=timedelta(1),·
········tags=[Tag.VARS_AND_FUNCTIONS,·Tag.CONTROL,·Tag.ENVIRONMENT_DIAGRAMS],
········),·#·Discussion·01
····Discussion(weekdelta.Tue,·······
········release=timedelta(-1),
········release_sol=timedelta(1),······
········tags=[Tag.ENVIRONMENT_DIAGRAMS,·Tag.HIGHER_ORDER_FUNCTIONS],
········),·#·Discussion·02
    Discussion(weekdelta.Thu,
```

Our website base actually has a built-in check that won't let you commit edits if there's trailing whitespace, which is the source of much pain for our content team

Trimming whitespace

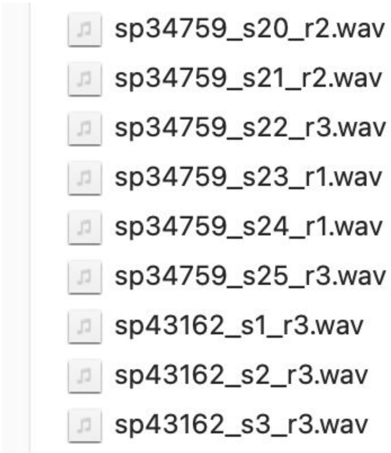
```python
import re

in_f = open('example.txt', 'r')
lines = in_f.readlines()
# ^ reads in lines of a file as a list of strings
lines = [re.sub(r'\s+$', '', l) for l in lines]
out_f = open('fixed.txt', 'w')
out_f.writelines(['\n' + l for l in lines])
in_f.close()
out_f.close()
```

This is a script that trims whitespace, but we can also do it with find + replace in VS Code!

Batch processing files

This is also a real example from Cooper’s thesis! They had a bunch of files that looked like this:



```
sp34759_s20_r2.wav
sp34759_s21_r2.wav
sp34759_s22_r3.wav
sp34759_s23_r1.wav
sp34759_s24_r1.wav
sp34759_s25_r3.wav
sp43162_s1_r3.wav
sp43162_s2_r3.wav
sp43162_s3_r3.wav
```

Every file name is of the format

```
sp<speaker_id>_s<sentence_id>_r<rep_#>.wav
```

Where that file is a recording of speaker <speaker_id> reading sentence <sentence_id>, and it's their <rep_#> iteration reading it (which doesn't matter very much)

Batch processing files

```
import glob
import re
from parselmouth import Sound

wav_files = glob.glob("*.wav")
# ^ generates a list of all file names that end in .wav
sounds_by_id = {}
for w in wav_files:
    mat = re.fullmatch(r"sp(\d{5})_s(\d{1,2})_r\d\.wav", w)
    assert mat is not None, "Must match file format"
    speaker_id, sentence_id = mat.groups()
    if speaker_id not in files_by_id:
        files_by_id[speaker_id] = {}
    sounds_by_id[speaker_id][sentence_id] = Sound(w)
```

Formal Language Theory

Center embedding

Try to write a regular expression to match these strings:

b

abc

aabcc

aaabccc

aaaaaaaaaabcccccccccc

I.e., there are n a's, then one b, and then exactly n c's

Context-free grammars (CFGs)

That problem is actually technically impossible, at least with regex

You can formally prove it, but you need to use some math that we're not really going to talk about in this class

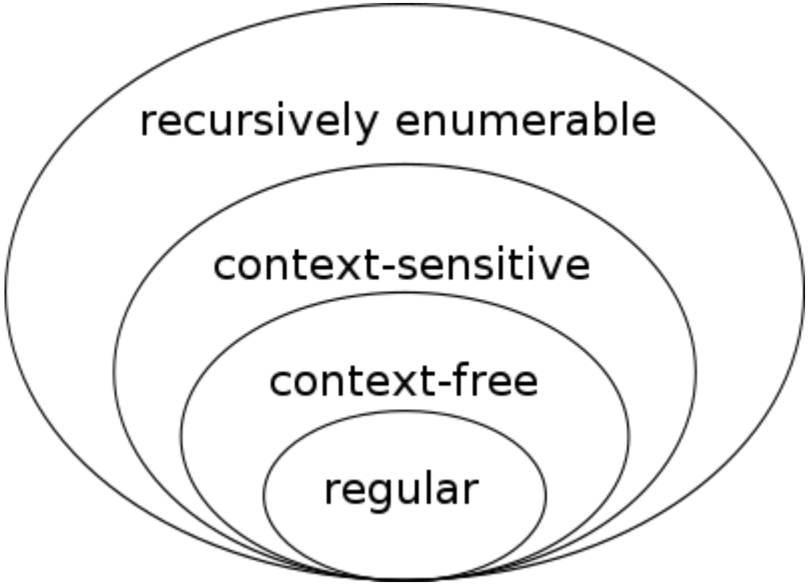
Basically, regular expressions don't have "memory"—if I match 10 instances of the letter a, regular expressions don't have a way to remember that so that it can then match exactly 10 instances of the letter c

We can, however, do this with a different kind of pattern called a **context-free grammar**:

```
START ==>  ABC
ABC   ==>  "a" + ABC + "c"
ABC   ==>  "b"
```

The Chomsky Hierarchy

The Chomsky Hierarchy is an idea in **formal language** theory that we can use to classify what are called **formal grammars**



At the very bottom are **regular grammars**, like regular expressions, and context-free grammars are one step up from these

At the top are **recursively enumerable grammars**, which can fully model the behavior of a computer

BNF

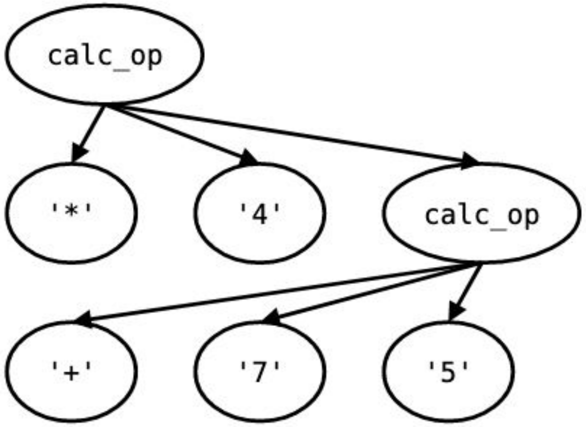
Although you need a recursively enumerable grammar to fully model computation, you can specify syntax for programming languages using a CFG!

Backaus-Naur Form is a schema designed specifically for describing the syntax of programming languages using context-free grammars

BNF has been taught formally in previous iterations of this class, but it's out of scope this semester dw

BNF for (part of) Calculator

```
?start: calc_expr
?calc_expr: NUMBER | calc_op
calc_op: "(" OPERATOR calc_expr* ")"
OPERATOR: "+" | "-" | "*" | "/"
```

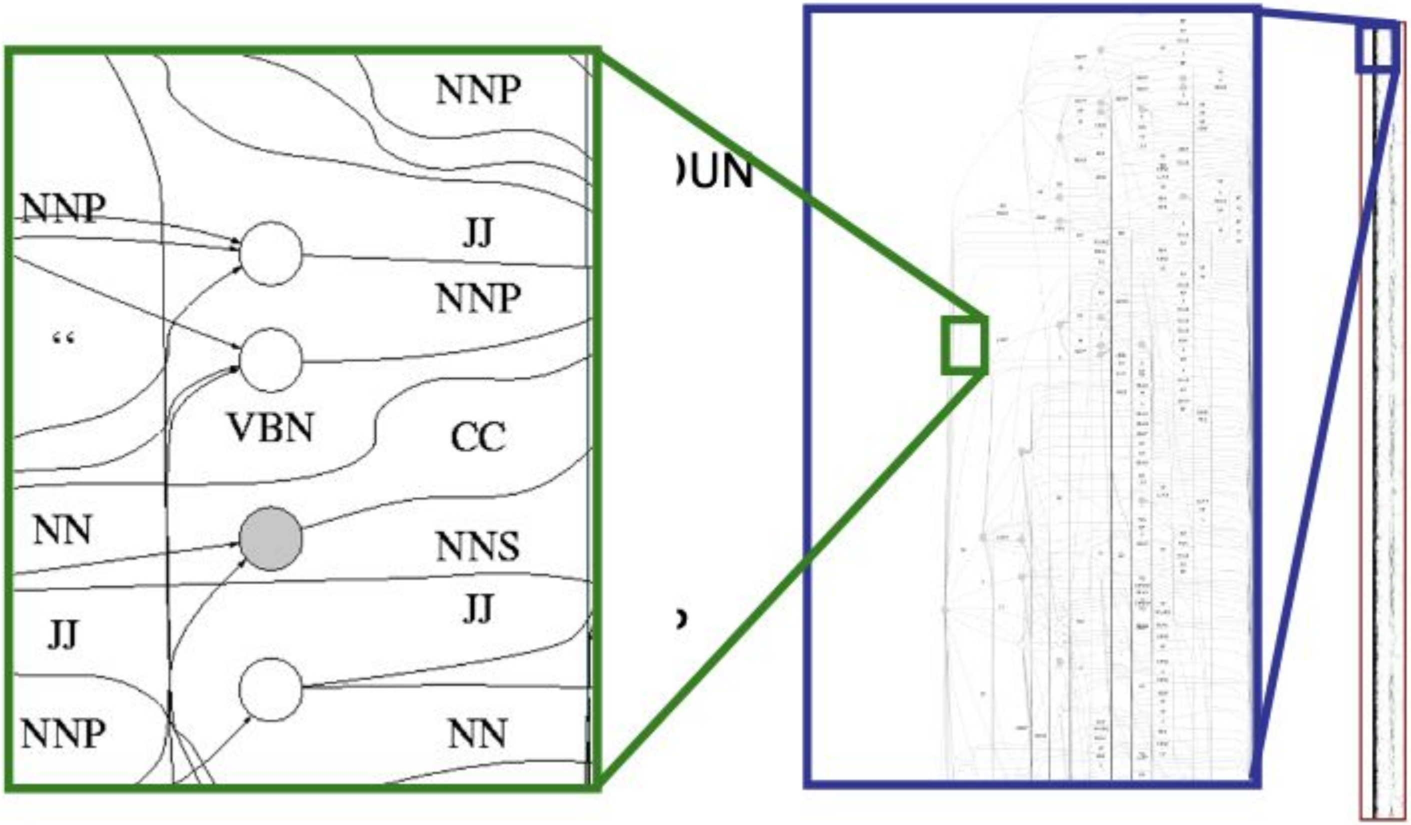


If I make a really good CFG for the Scheme language, I can actually pass a BNF grammar into an algorithm to make my parser, which would have saved you a lot of work in Lab 9

BNF for (part of) English

```
?start: sentence
sentence: noun_phrase verb
noun: NOUN
noun_phrase: article noun
article : | ARTICLE
verb: VERB
NOUN: "horse" | "dog" | "hamster"
ARTICLE: "a" | "the"
VERB: "stands" | "walks" | "jumps"
%ignore /\s+/
```

Really big CFGs :0



(From CS 288 lecture slides)

Review

Regular expressions are a way to define patterns that allow us to match strings in specified ways

Python has an `re` module that you can use to employ regular expressions in the language

You can't do everything with regex—there are, however, more powerful grammars that can specify more complex forms

In this class, you only need to worry about a couple of things:

- How to write a regular expression to match a given pattern
- How to read a regex and know whether it matches a string
- How to read Python code that uses regular expressions

Tips

Do not memorize everything—have the docs in front of you, and as you use them with practice you'll get comfortable finding where things are

RegEx can be really hard to debug—make sure you're being methodical, and breaking a bigger problem up into smaller pieces (just like any other kind of programming!) is often a great strategy

If you use RegEx in the real world, be wary of long and complicated regular expressions—these can be hard to read for other developers, and often can have sinister bugs or edge cases

Also, keep in mind that there's no guarantee of any level of efficiency with pre-packaged RegEx algorithms