Introduction to Computational and Algorithmic Thinking

NATURAL LANGUAGE PROCESSING AND REGULAR EXPRESSIONS

Announcements

This lecture: Natural Language Processing and Regular Expressions

Reading: Read Chapter 10 of Conery

Acknowledgement: Some of this lecture slides are based on CSE 101 lecture notes by Prof. Kevin McDonald at SBU

The Turing Test

- Alan Turing (1912-1954) was an English mathematician who laid some of the important theoretical groundwork of computer science

- In addition to other topics, Turing was interested in the idea of computers being able to think as human beings do

- He devised what he called the **imitation game**, now known as the **Turing test**

- A human judge (the interrogator) engages in an online chat with another person and a computer, but isn't told which is which

The Turing Test

- The interrogator asks the human being and the computer a series of questions to carry on a conversation
- If the interrogator cannot tell which is the person and which is the computer, then the computer has passed the Turing Test because it is simulating human intelligence
- So the Turing Test touches on two important areas of computer science: **artificial intelligence** and **natural language processing** (NLP)
- Google AI passes Turing test

ELIZA: The First (?) Chatbot

- ELIZA is a program first developed in the 1960s at MIT that attempts to converse in English with a human participant
  - More specifically, the program "pretends" to be a psychotherapist, so its responses often consist of questions that use words the user entered

- Based on an internal set of rules that analyze what the user types, the software attempts to simulate a natural conversation

- For example, one kind of rule will look for key words in the human's entry (H) and respond with generic sentences (C). Here's an example:
  - **H: My father wouldn't buy me a puppy.!**
  - **C: Tell me more about your family.!**

ELIZA: The First (?) Chatbot

- Since ELIZA is simulating a psychotherapist, its rules pay special attention to words like "dream" and various words that connote emotions:
  - **H: I'm sad I never got a puppy.!**
  - **C: Can you explain what made you sad you never got a puppy?!**

- These rules have limits. Consider the following exchange, which the software could generate:
  - **H: I'm sad we never had a chance to play fetch.!**
  - **C: I am sorry to hear you are sad we never had a chance to play fetch.!**

ELIZA: The First (?) Chatbot

- The software's intelligence is limited by its rules, or **script**
- The program should become better at conversing as more rules are added to its script
- The simplest rule would simply be that the program repeats or *echoes* the words entered by the user:

```
from PythonLabs.ElizaLab import Eliza
Eliza.run()
```

- Sample run:

```
H: hello!
C: hello!
H: are you imitating me?!
C: are you imitating me?!
bye!
```

ELIZA: The First (?) Chatbot

- To make things more interesting, let’s load the DOCTOR script, which simulates a psychotherapist.
- We could create our own scripts to simulate other kinds of conversations.

How do you do. Please tell me your problem.

H: I am afraid of spiders.

C: Is it because you are afraid of spiders that you came to me?

H: Yes, it is.

C: You seem quite positive.

H: I am very happy.

C: How have I helped you to be happy?

H: Just by chatting with me.

C: I am not sure I understand you fully.

H: You are not very smart.

C: What makes you think I am not very smart?

H: bye

Sentence Patterns

- To find key words in a sentence we need to search through strings
- The **find** method for strings will get the job done
- Given a string to search through and a target substring, the **find** method will return the index of the first character of the substring
- If the substring is not found, the method returns **–1**
- If the substring appears in several places, the **find** method
- returns the index of the first instance
- Example:

```
s1 = 'I was afraid of the cow.'
s1.find('cow') # returns 20
```

Sentence Patterns

- Now we will see that the method will return **-1** if we search for a substring that is not in the string:
- Example:

```
s1 = 'I am afraid of the dark.'!
s1.find('cow’)     # returns -1!
```

- Now let’s see what happens if we search for a substring that appears multiple times in a string:

```
s1 = 'I saw birds on the house, birds at school, birds everywhere!'
s1.find('birds') # returns 6
```

- See eliza_functions.py for these examples and other function calls on the next 20+ slides

Sentence Patterns

- The **find** method takes an optional argument that indicates at what index the search should begin
- For example, the first instance of “birds” in the string below is at index 6.
- If we start the search at index 7, the **find** method will find the next instance of “birds” in the string, which starts at index 26:

```
s1 = 'I saw birds on the house, birds at school, birds everywhere!'
s1.find('birds', 7) # returns 26
```

Sentence Patterns

- One issue with **find** is that does not have any notion of *words*
- For example, the letters of “cow” appear in the word “scowl”, among others
  - If we were trying to build a chatbot to have conversations about farm animals, it might incorrectly see the word “scowl” and think that the person had typed “cow”
- So to extract key words from a user’s entry, we actually need to look for *words*, not simply substrings
- To help address this problem we will use **regular expressions**, also called **regexes**, for short

Regular Expressions

- Regular expressions give us a formal ways of expressing **patterns** of characters we want to find in an input string
- The simplest kind of regular expression looks for a particular substring in an input string
- Initially we will not look at the details of how to write regular expressions, but rather use some capabilities from the ElizaLab
- The **Pattern** class in ElizaLab lets us create regular expressions using a user-friendly notation
- The **Pattern** object below can be used to detect when a sentence contains the word “cow”:

```
from PythonLabs.ElizaLab import Pattern
p = Pattern('cow’)
```

Regular Expressions

- Given a **Pattern** object, we can then provide possible responses the chatbot might produce when it sees a sentence that matches the pattern:

```
p.add_response('Tell me more about your farm')
p.add_response('Go on’)
```

- We can also give a list of responses when we create the **Pattern** object, instead of doing it later:

```
p = Pattern('lamb', ['I love lambs’, 'How cute’])
```

Regular Expressions

- To see if a sentence matches the pattern, we call the **apply** method of the **Pattern** object
  - If the match is successful, a response string is returned
  - If not, the method returns **None**

- An example:

  p.apply('I milked the cow and fed the chickens.')

  - Return value:

    'Tell me more about your farm’

Regular Expressions

- The **apply** method is “smart” enough to look for words, not simply substrings

- For the example below, “scowled” will not trigger a match for the word “cow”, so **None** is returned:

```
p.apply('I scowled at the horse yesterday.')
```

Regular Expressions

- Regular expressions let us define patterns that will match several different words
  - We separate the words by vertical bars to form a **group**
  - This means we don't have to make a separate pattern for each word

- Below is a pattern that could be applied to any sentence containing “cow”, “pig” or “horse”:

```
p = Pattern('cow|pig|horse', ['Really?’, 'Go on'])
p.apply('The horse jumped the fence.’)
```

- For this input, **apply** returns **'Really?'**

Decomposing Sentences into Parts

- Finding individual words in a sentence is useful, but it's not enough to understand the context of the word
- We need some way of decomposing a sentence into parts
- First, we will need to somehow save the part of the sentence that matches a group in pattern so it can be used later to make the response
- Each group in a pattern has an associated variable name, with **$1** identifying the first group, **$2** for the second group, and so on
- We can then use these variable names in responses
- This is easiest to understand by example (next slide)

Decomposing Sentences into Parts

```
p = Pattern('cow|pig|horse')
p.add_response('You had a $1?')
p.add_response('How many $1s were on the farm?’)
```

- Now, call the **apply** method to try the new pattern:

```
p.apply('The horse jumped the fence.’)
```

- Return value: **'You had a horse?’**

Decomposing Sentences into Parts

- We can start to build up pretty complex patterns that contain multiple groups, as in this example:

```
p = Pattern('I (like|love|adore) my
                    (cat|dog|ducks)')
p.add_response('Why do you $1 your $2?')
p.add_response('What about your $2 do you $1?')
```

- Call the **apply** method to try the new pattern:
- **p.apply('I adore my cat.’)**
- Return value: **'Why do you adore your cat?’**

Decomposing Sentences into Parts

- This approach looks pretty good, but we would have to list every word we are interested in
- What if we wanted to write a pattern to anticipate everything a person might be afraid of?
  - We really couldn't list everything
- We could write a pattern containing one or more wildcards that match any piece of text
- A wildcard is written using a period followed by an asterisk

Decomposing Sentences into Parts

- Example of a wildcard expression:

```
p = Pattern('I am afraid of .*')
p.add_response('Why are you afraid of $1?')
p.apply('I am afraid of little green men’)
```

- Return value:

```
'Why are you afraid of little green men?’
```

- This looks pretty good, but it can lead to some nonsensical results, as we’ll see in the next example

Response Pre-/Post-processing

- The patterns we just wrote use a basic copy-and-paste strategy to transfer a string fragment from the input to the response, but can lead to silly responses:

```
p = Pattern('I am (.*)', ['Are you really $1?'])
p.apply('I am happy to see you')
```

- Return value:

```
'Are you really happy to see you?’
```

- What we need to do after matching the input is to do some **postprocessing** to replace some words or phrases
- For example, the response above really should have been “Are you really happy to see *me*?”

Response Pre-/Post-processing

- Let’s create a dictionary that will provide substitutions for pronouns that should be made for a pattern:

```
pronouns = { 'I': 'you', 'your': 'my' }
```

- Now let’s try a few examples:

```
p.apply('I am sorry I dropped your
computer', post=pronouns)
```

- Return value:

```
'Are you really sorry you dropped my computer?’
```

- Another example:

```
p.apply("I'm happy I lost", post=pronouns)
```

- Return value: **None** (uh-oh! What happened?)

Response Pre-/Post-processing

- The **apply** function can match **"I"**, but not **"I'm"**
- Let’s define a dictionary that can recognize contractions
- We will use it to perform **preprocessing** on the input string before we attempt to make a match:

```
contractions = { "I'm": "I am" }
p.apply("I'm happy I lost",
               pre=contractions, post=pronouns)
```

- Return value:

```
'Are you really happy you lost?’
```

Response Pre-/Post-processing

- When ElizaLab is used to load a script, the preprocessing and postprocessing dictionaries are available via **Eliza.pre** and **Eliza.post**, respectively:

- **Eliza.pre** has the value:

```
{"can't": 'can not', "don't": 'do not', "i'm": 'I
am', "won't": 'will not', "you're": 'you are’}
```

- **Eliza.post** has the value:

```
{'am': 'are', 'are': 'am', 'i': 'you', 'me':
'you', 'my': 'your', 'myself': 'yourself', 'you':
'I', 'your': 'my', 'yourself': 'myself'}
```

Algorithm for Having a Conversation

- The summary so far:
  - A **`Pattern`** object is defined by a string that has a key word, groups of words, or wildcards
  - We can specify any number of response strings, and the object's **`apply`** method will return one of these strings if a sentence matches its pattern
  - Pattern-matching variables (**`$1`**, **`$2`**, etc.) along with preprocessing and postprocessing help the **`apply`** method extract parts of the input sentence and reuse them as part of the response

- Now, we need to take this functionality and develop an algorithm for carrying on a conversation

Algorithm for Having a Conversation

- One simple approach is to try patterns until we find one that matches an input sentence, but this means that patterns will always be applied in the same order
- To solve this problem we can assign a priority to each word
  - The creator of ELIZA anticipated that people would ask questions like “Are you a computer?” so he gave higher priority to words like “computer” and “machine” than others
- Another problem is that the same word (like **"I"**) can appear in multiple patterns - which one should be applied?
  - In ElizaLab, this problem is addressed by creating a **Rule** object, which is a collection of patterns that pertain to a particular word

Algorithm for Having a Conversation

- The **rule_for** method tells us which rules (if any) pertain to a particular word:

```
Eliza.rule_for('remember')
```

- Return value:

```
PythonLabs.ElizaLab.Rule [5]
   'I remember (.*)’
   'do you remember (.*)'
```

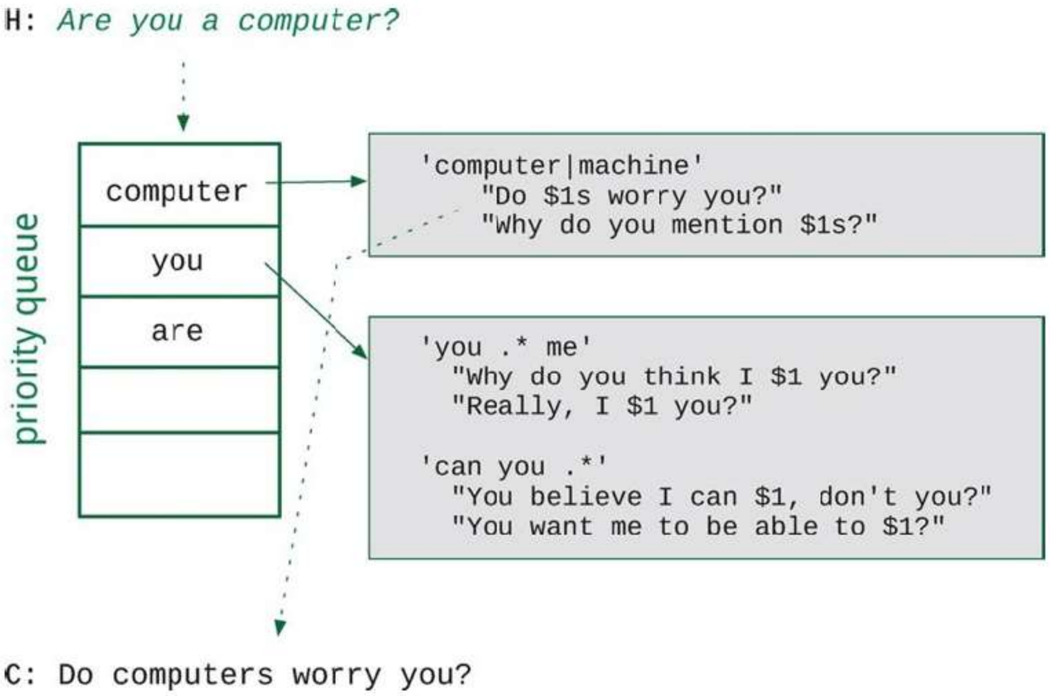
- The **5** indicates that this rule has high priority (higher number à higher priority)
- We can use a priority queue (from our study of Huffman coding) to keep track of the highest-priority rules

Algorithm for Having a Conversation

- A complete algorithm for transforming an input sentence into a response has three steps:
  1. initialization
  2. tokenization (borrowed from the SpamLab) and insertion of rules into priority queue
  3. rule processing

Algorithm for Having a Conversation

- The priority queue and rules relevant to this sentence are depicted in the figure below



H: *Are you a computer?*

priority queue

computer

you

are

```
'computer|machine'
    "Do $1s worry you?"
    "Why do you mention $1s?"
```

```
'you .* me'
  "Why do you think I $1 you?"
  "Really, I $1 you?"

'can you .*'
  "You believe I can $1, don't you?"
  "You want me to be able to $1?"
```

C: Do computers worry you?

Algorithm for Having a Conversation

```
from PythonLabs.Tools import tokenize
from PythonLabs.ElizaLab import *

def transform(sentence):
    queue = PriorityQueue()
    sentence = Eliza.preprocess(sentence, Eliza.pre)

    for word in tokenize(sentence):
        rule = Eliza.rule_for(word)
        if rule is not None:
            queue.insert(rule)

    while len(queue) > 0:
        rule = queue.pop()
        response = rule.apply(sentence, post=Eliza.post)
        if response is not None:
            return response

return None
```

See eliza_transform.py

Algorithm for Having a Conversation

- Let’s call the **transform** function a few times:

```
transform('Are you a computer?’)
```

- Sample return values:

```
Do computers worry you?
Why do you mention computers?
What do you think computers have to do
   with your problem?
Don't you think computers can help
   people?
What about computers worries you?
```

ELIZA and the Turing Test

- Can a chatbot like ELIZA pass the Turing Test?
- One challenge in developing natural language processing systems is algorithmically assigning meanings to words in a sentence. This is the problem of **semantics**.
- Consider the following exchange:

  H: That cow was huge.

  C: How big was it?
- This kind of response is not possible with a rule-based algorithm like Eliza’s because the software doesn't understand that “huge” and “big” have similar definitions.
- So we could give the program a dictionary and/or thesaurus

ELIZA and the Turing Test

- Giving the program a dictionary of word definitions is not enough, however. Consider the following exchange:

  H: The cow fell into the canal.

  C: Was it able to get out?

- Having the definitions of all the words in the human being's sentence will not empower a computer to draw conclusions, make inferences, and apply other kinds of "real-world knowledge" or "common sense"
- So, although natural language processing systems have been deployed successfully in systems like airline reservation systems and other interactive telephone-based systems, there is still a long way to go before a computer could consistently pass the Turing Test

Regular Expressions

“Real” Regular Expressions

- As we have seen, part of string processing in real applications (e.g., online forms in websites) often involves ensuring that a string matches a particular format, called a **pattern**
- We have been expressing patterns using the ElizaLab module, but these aren’t “real” regular expressions (although they are pretty close)
- Now, we will look at how regular expressions are actually defined and see briefly how we can write Python programs that use them

Simplest Regular Expressions

- The simplest regular expressions are those that just contain exactly the characters you are looking for

- So, suppose you want to see if the letters “CSE” appear in a string

- The regular expression in this case would simply be: CSE

- It would match the occurrences of “CSE” in these strings:
  - **CSE**
  - **CSE 101**
  - **I am taking CSE 101**

Digits

- The notation **`\d`** represents a single digit
- So a generic Social Security Number could be expressed as **`\d\d\d-\d\d-\d\d\d\d`** using regexes
- But, this is a little cumbersome, so we can use curly braces instead to denote repetition. For example, **{3}** would mean to repeat something 3 times. Let's rewrite our regex:
- **`\d{3}-\d{2}-\d{4}`**
- Any SSN would ***match*** the above pattern
- This is a nifty website that will let you try out regular expressions to see which strings they will match: http://regex101.com
- We will use it throughout this lesson

The Dot Metacharacter

- A period by itself matches any character

- So **.{5}** would match a 5-character sequence of any characters:
  - **12345**
  - **abcde**
  - **a&c(9**
  - **1 3 4** Yes, spaces are matched too!

- If you want to match an actual period, you ***escape it***: **\.**
- **\d{3}\.\d{3}\.\d{4}** will match phone numbers written in a form like **010.777.1223**

Matching Specific Characters

- Sometimes the dot metacharacter is too “powerful” because it can match any character

- We can match specific characters using regular expressions, by defining them inside square brackets

- For example, the pattern **`[abc]`** will only match a single **a**, **b**, or **c** letter and nothing else

Excluding Specific Characters

- In some cases, we might know that there are specific characters that we don't want to match

- For example, we might only want to match phone numbers that are *not* from the area code 880

- To exclude specific characters we use the square brackets and the **^** (hat) character

- For example, the pattern **[^abc]** will match any single character except for the letters **a**, **b**, or **c**

Character Ranges

- We can match a character from a list of sequential characters by using the dash to indicate a character range
- For example, the pattern **[0-6]** will only match any single digit character from zero to six, and nothing else
- **[^n-p]** will only match any single character except for letters **n** through **p**
- Multiple character ranges can also be used in the same set of brackets
- **[A-Za-z0-9_]** is often used to match characters in English text

Alphanumeric Characters

- The notation **\w** denotes any word character: **a-z**, **A-Z**, **0-9** and the underscore (_)

- So the regex **\w{3}\d{4}** would match any string containing three alphanumeric characters followed by any four digits
  - **abc1234**
  - **ABC1234**
  - **1AB7892**
  - **1234567**

- Related is the **\W** notation, which matches any non-alphanumeric character

Repetitions

- We saw that the notation **{m}** means to match the character *m* times
- We can also use the repetition notation with the square bracket notation
- For example, **[wxy]{5}** would match five characters, each of which can be a **w**, **x**, or **y**
- The notation **{m,n}** means we want to match a pattern from **m** to **n** times, inclusive of **m** and **n**
- For example, **.{2,6}** would match from two to six consecutive copies of any character, inclusive
- Another example: **[a-z]{3-7}** would match from three to seven lowercase letters, inclusive

Zero or More Repetitions

- The * symbol (the **Kleene star**) means that we want to match 0 or
- more repetitions of the character or group of characters that it
- Follows

- The **+** symbol (the **Kleene plus**) matches 1 or more repetitions of the character or group of characters that it follows

- **`\d*`** would match any number of digits
- **`\d+`** would match one or more digits
- **`[abc]+`** would match one or more of any **`a`**, **`b`**, or **`c`** character in any combination

Optional Characters

- The **?** (question mark) metacharacter denotes optionality

- For example, the pattern **`ab?c`** will match either the strings **`abc`** or **`ac`** because the **`b`** is considered optional

- If you want to match an actual question mark, you ***escape it***: **`\?`**

- The **?** can also be used with groups of characters. More on groups a little later.

Any Whitespace

- Real-world input contains a lot of **whitespace**: spaces, tabs, and newlines

- The whitespace special character **\s** will match any of the specific whitespaces

- Similarly, **\S** will match any non-whitespace character

Starting and Ending Patterns

- We can define a pattern that describes both the start and the end of the line using the special **^** (hat) and **$** (dollar sign) metacharacters
  - Note that **^** is used in a different context here; when used in square brackets it means to exclude characters

- **^success** would match only a line that begins with the word **success**

- **target$** would match only a line that ends with the word **target**

Match Groups

- We can use groups of characters and capturing them using the parentheses metacharacters

- For example, imagine that you had a command line tool to list all the PNG image files you have stored on a computer that start with the letters “IMG”

- You could then use a pattern such as **`^(IMG\d+\.png)$`** to capture and extract the full filename

Conditional Matches

- When using groups, you can use the **|** (logical OR, a.k.a. the **pipe**) to denote different possible sets of characters

- We could write the pattern

  Buy more (milk|bread|juice) to match only the strings “Buy more milk”, “Buy more bread”, or “Buy more juice”

- You can use any sequence of characters or metacharacters in a condition

- For example, **([cb]ats*|[dh]ogs?)** would match “cats”, “cat”, “batsssss”, “dog”, “hogs” and many other strings

Regexes in Python

- Python offers some advanced capabilities for working with regexes, but this simple example gives the basics. The `r` character indicates we are using a **raw string**:

```
import re
phone = '123-456-7890'
pattern = r'^\d{3}-\d{3}-\d{4}$'
if re.search(pattern, phone):
   print('The string matches the pattern.')
else:
   print('The string does not match.')
```

Regexes in Python

- Groups are numbered starting with 1 and can be identified by **\1**, **\2**, etc.
- The **sub** function lets us perform replacements in a string
- **sub** takes three arguments:
  - A regex that describes the input string
  - A regex that describes what substitutions to perform
  - The input string itself
- A simple example that replaces **dog** with **fox**:

```
line = 'the dog and cat'
result = re.sub(r'(.*)(dog)(.*)',
                r'\1fox\3', line)
```

- **result** will be **'the fox and cat'**

Regexes in Python

- Another example, which reformats a date given in **MM-DD-YY** as **YYYY-MM-DD**:

```
date = '12/25/05'
result = re.sub(r'(\d\d)/(\d\d)/(\d\d)’,
                  r'20\3-\1-\2', date)
```

- **result** will be '2005-12-25'

Example: Match Filenames

- If you use the Linux or Mac OS terminal frequently, you are often dealing with lists of files
- Most files have a filename component as well as an extension, but in Linux, it is also common to have hidden files that have no filename
  - A hidden file starts with a period
- Let’s write a regex to match filenames of only image files (jpg, png, gif) that are not hidden
- Note that the filenames must *end* with one of these three file name extensions
- A regular expression that will match these file names:
- **`\w+\.(png|gif|jpg)`**

Example: Match Filenames

- Test cases (green strings match, red ones don't match):

  photo1.jpg

  fun_times.png

  baby22.gif

  1.png

  schooljpg

  .jpg

  ..png

Example: Match Credit Cards

- A credit card number is a sequence of 13 to 16 digits, with a few specific digits at the start that identify the card issuer
- Visa card numbers start with a 4 and have 16 digits
- MasterCard numbers start with the numbers 51 through 55 and have 16 digits
- American Express card numbers start with 34 or 37 and have 15 digits
- A single regular expression to match all three kinds of credit cards (Visa, MC, AmEx):
- **`(4\d{15})|(5[1-5]\d{14})|(3[47]\d{13})`**

Example: Match Credit Cards

- Test cases (green strings match, red ones don’t match):

  4829193238102932

  481729382312323

  5180129380293232

  5484128379172212

  5698274398734598

  348282019492392

  379187239817298

  359820938023232

Example: Match ISBN-10

- Suppose a 10-digit ISBN can be written in any of the following sample formats:
  - ISBN 0 93028 923 4
  - ISBN 1-56389-668-0
  - ISBN 1-56389-016-X
- The first digit must be a 0 or 1 can the last symbol can be a digit (0-9) or the capital letter X
- Let’s construct a regular expression for matching ISBNs:
- **ISBN [01][\s-]\d{5}[\s-]\d{3}[\s-][0-9X]**

Example: Match ISBN-10

- The regex isn’t perfect because it will match strings that mix dashes
- and spaces, such as **ISBN 0-83923 823-0**
- The solution here would be to combine regexes with string processing methods and functions
- More on this issue a little later
- Test cases (green strings match, red ones don’t match):

  ISBN 0-82918-392-0

  ISBN 1 99238 123 X

  ISBN 0-83923 823-6

  isbn 0-82918-392-0

  ISBN-1-33223-233-X

Example: Match Decimal Numbers

- Our goal is to match numbers like these:
  - **3.14529**
  - **-255.34**
  - **128**
  - **1.9e10**
  - **123,340.00**
- As with programming, it's best NOT to try to solve the entire problem in one shot
- How might we solve this problem in an incremental fashion (akin to successive prototyping)?
- What kinds of numbers would be easiest to match first?

Example: Match Decimal Numbers

- Here is how we might try to piece together the regular expression:

```
\d+
-?\d+
-?\d+(,\d{3})*
-?\d+(,\d{3})*(\.\d+)?
-?\d+(,\d{3})*(\.\d+)?(e-?\d+)?
```

Example: Match Decimal Numbers

- Test cases (green strings match, red ones don't match):

```
3.14529
-255.34
128
1.9e10
1.9e-10
-3.1e8
123,340.00
2,55.3
,213.6
.241
```

Example: Match Phone Numbers

- Suppose we wanted to match phone numbers that could be written in a variety of forms:
  - 1416-555-3456
  - 14165553456
  - 1416 555 3456
  - 1(416) 555-3456
  - 1(416)555-3456
  - 1 416 555 9292
  - 1-416-555-9292
  - 1 (416) 555-3456
  - How could we build a single regular expression that will eventually match all these forms (and possibly more)?

- Here is how we might try to piece together the regular expression:

```
1\d{3}-\d{3}-\d{4}
1\d{3}-?\d{3}-?\d{4}
1\d{3}[\s-]?\d{3}[\s-]?\d{4}
1[\s-]?\d{3}[\s-]?\d{3}[\s-]?\d{4}
1[\s-]?\(?\d{3}\)?[\s-]?\d{3}[\s-]?\d{4}
1[\s-]?\(?\d{3}\)?[\s-]?\d{3}[\s-]?\d{4}
```

Example: Match Phone Numbers

- Test cases (green strings match, red ones don’t match):

  1416-555-3456

  14165553456

  1416 555 3456

  1(416) 555-3456

  1(416)555-3456

  1 416 555 9292

  1-416-555-9292

  1 (416) 555-3456

  (416) 555-3456

Example: Match Phone Numbers

- This is not a perfect solution. For example, this regex would accept a phone number like **1(800)-5552468.**
- Sometimes a regular expression that matches only the correct input is very, very complicated.
- In such cases it is usually advisable to use a simpler regex in concert with string processing functions and methods
- In the phone number example, we could ensure that dashes are present or absent in the correct combinations, for instance
- Then we could avoid problems like accepting the phone number at the top of this slide

Questions?