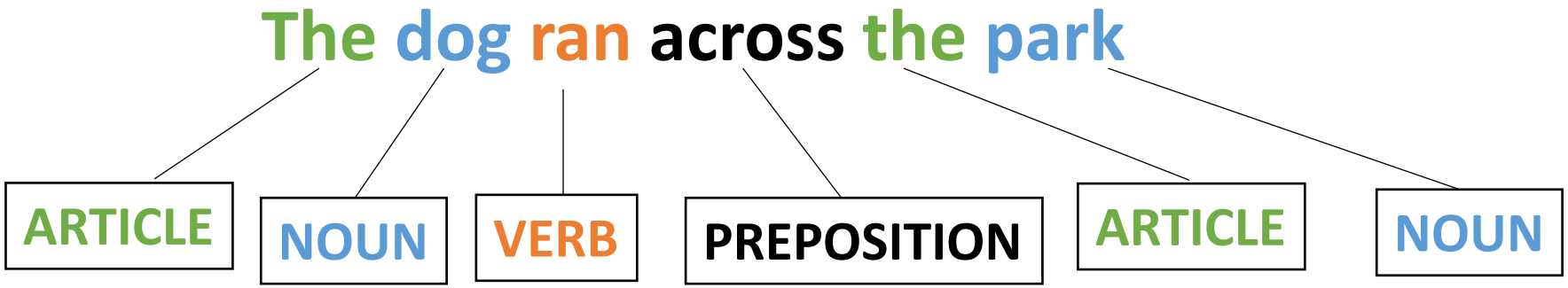
CSE110A: Compilers



- **Topics**:
  - *Lexical Analysis:*
    - Short comings of naïve scanner
  - ***Regular expressions**:*
    - Recursive definition
    - Syntactic sugar
    - groups

Review

Naïve implementation

- A scanner that implements

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
IGNORE = [“ “]
```

Naïve implementation

Building block:

```
class StringStream:
    def __init__(self, input_string):
        self.string = input_string


    def is_empty(self):
        return len(self.string) == 0


    def peek_char(self):
        if not self.is_empty():
            return self.string[0]
        return None


    def eat_char(self):
        self.string = self.string[1:]
```

Naïve implementation

Building block:

This class allows strings to be read as if we were doing I/O from a file.

So you are implementing with an abstraction that works both from a string or from a file.

```
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        return None

    def eat_char(self):
        self.string = self.string[1:]
```

Naïve implementation

First step in implementing the scanner

```
class NaiveScanner:

    def __init__(self, input_string):
        self.ss = StringStream(input_string)

    def token(self):

        while self.ss.peek_char() in IGNORE:
            self.ss.eat_char()

        if self.ss.is_empty():
            return None
```

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = "="
PLUS   = "+"
MULT   = "*"
IGNORE = [" "]
```

Naïve implementation

First step in implementing the scanner

```
class NaiveScanner:

    def token(self):
        ...
        if self.ss.peek_char() == "+":
            value = self.ss.peek_char()
            self.ss.eat_char()
            return ("ADD", value)

        if self.ss.peek_char() == "*":
            value = self.ss.peek_char()
            self.ss.eat_char()
            return ("MULT", value)
```

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = "="
PLUS   = "+"
MULT   = "*"
IGNORE = [" "]
```

Naïve implementation

First step in implementing the scanner

```
class NaiveScanner:

    def token(self):
        ...
        if self.ss.peek_char() in NUMS:
            value = ""
            while self.ss.peek_char() in NUMS:
                value += self.ss.peek_char()
                self.ss.eat_char()
            return ("NUM", value)
```

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = "="
PLUS   = "+"
MULT   = "*"
IGNORE = [" "]
```

Topics:

- Naïve Parser:
  - Code demo and discussion
- Regular expressions

Code Demo

Shortcomings of Naïve scanner

- Any thoughts?

Shortcomings of Naïve scanner

- IDs with numbers in them?
  - `x1, y1, etc.`
  - how would you solve?
- Numbers with a decimal point in them?
  - `4.5, 9999.99998`
  - how would you solve this?
- Two character operators:
  - `++, +=`
  - how would you solve this?

Shortcomings of Naïve scanner

- IDs with numbers in them?
  - `x1, y1, etc.`
  - how would you solve?
- Numbers with a decimal point in them?
  - `4.5, 9999.99998`
  - how would you solve this?
- Two character operators:
  - `++, +=`
  - how would you solve this?

Things get really hacky really quickly!

Creates a bad design that is not easily extended or maintained

How do we solve this?

A new token definition language:

- **Regular Expressions (RE)**
- Tokens will be defined using regular expressions
- Scanners can then utilize regular expression matchers

Benefits:

- Extensible design
  - easy to add new tokens, modify existing definitions
- Modular
  - Scanner can utilize common regex libraries

Cons:

How do we solve this?

A new token definition language:

- **Regular expressions**
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Benefits:

- Extensible design
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- Modular
  - Scanner can utilize common regex libraries

Cons:

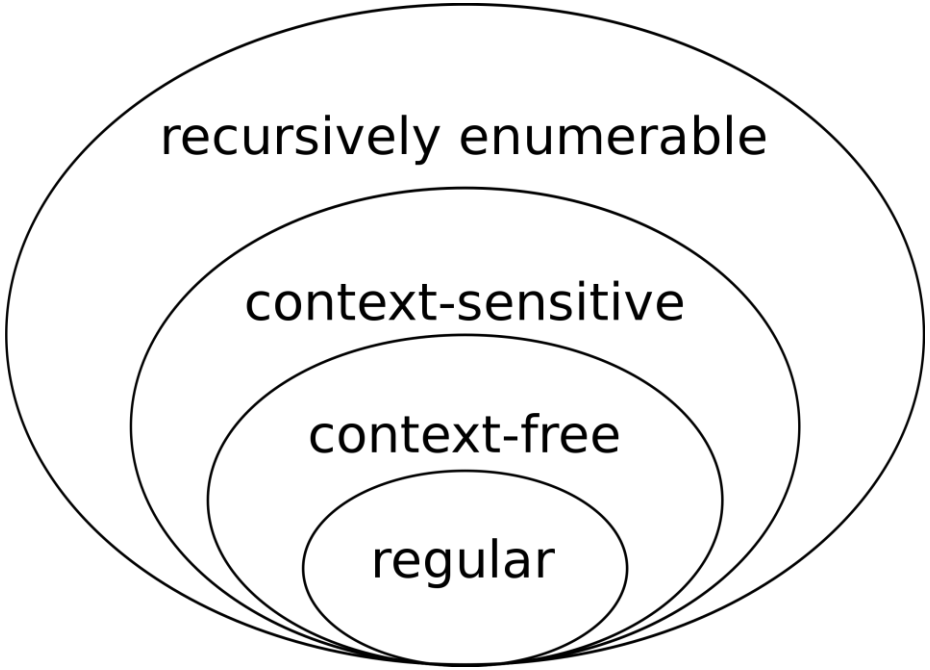
- Token definitions are restricted to regular languages
- Potentially slower
- Regular expression matchers are complicated

Regular expressions

Some theory:

- Given a language *L*, a string *s* is either part of that language or not
  - Integers are a language: “5”, “6”, “-7” is in the language. “abc” is not.
- Languages are grouped into families depending on how “hard” it is to determine if a string is part of that language.

Regular expressions



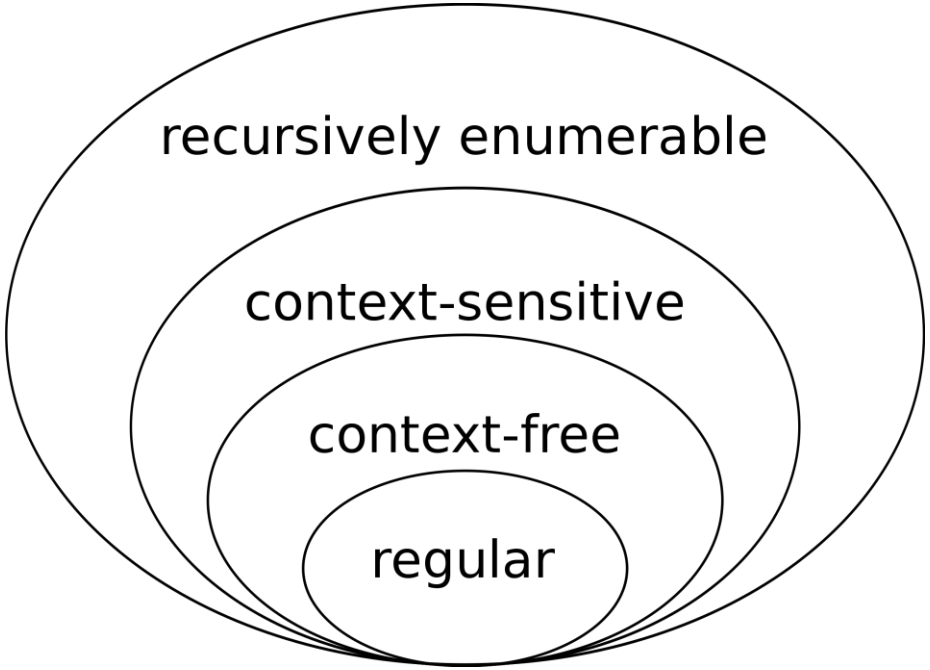
The simplest languages are regular. We will use regular languages as our token language.

We will use the next level: context-free, as the language for our parser.

Higher levels are interesting, but not as useful in compilers. Why?

image source: wikipedia

Regular expressions



The simplest languages are regular. We will use regular languages as our token language.

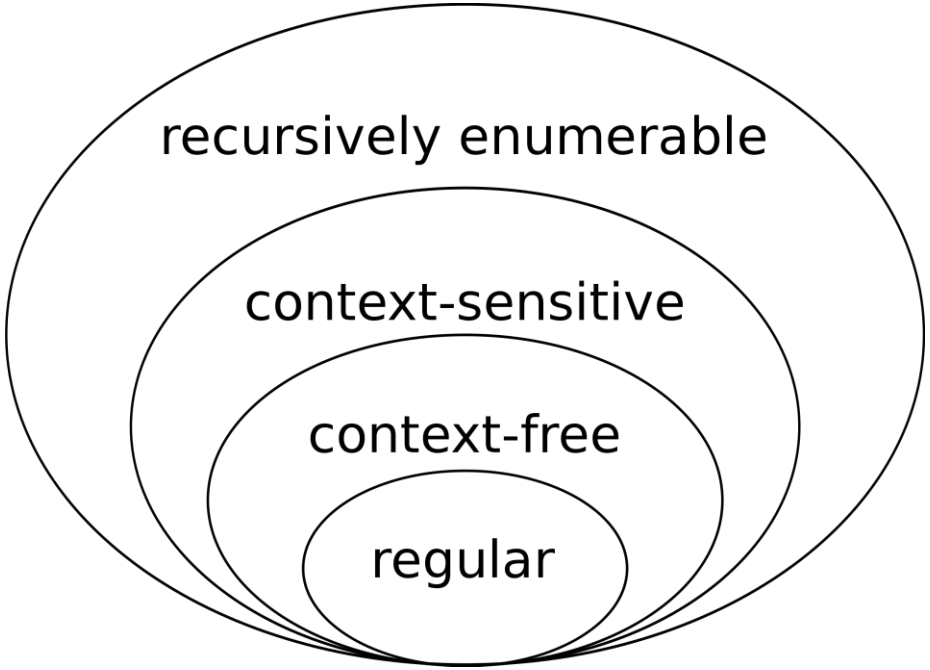
We will use the next level: context-free, as the language for our parser.

Higher levels are interesting, but not as useful in compilers. Why?

Because deciding if a string is in a recursively enumerable language is undecidable.

image source: wikipedia

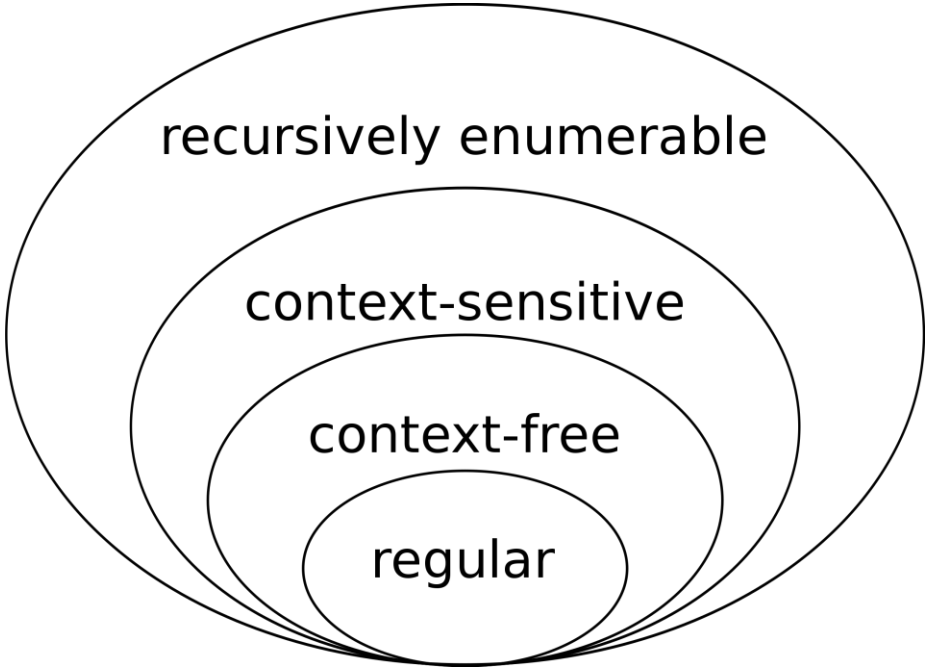
Regular expressions



What is a regular language?

image source: wikipedia

Regular expressions

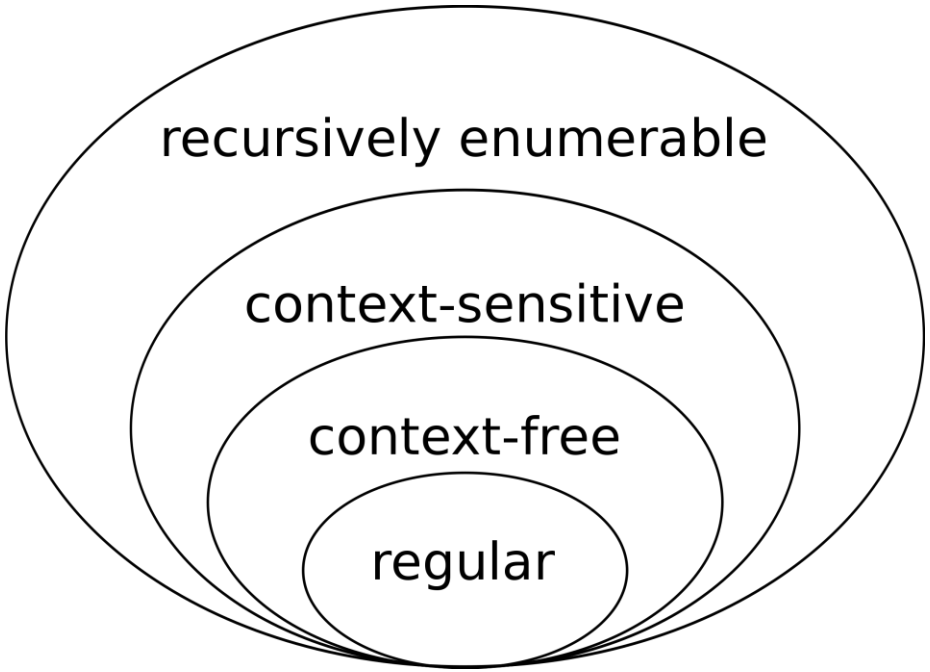


What is a regular language?

For this class: *A regular language is a language that can be expressed as a regular expression.*

image source: wikipedia

Regular expressions



What is a regular language?

For this class: *A regular language is a language that can be expressed as a regular expression.*

What is a regular expression?

image source: wikipedia

Regular expressions

- We will define regular expressions (RE) recursively
- We will show examples at each step.
- And show to match them in Python
  - *A string matches an RE if it belongs to the regular language defined by the RE*
  - Python has a great RE matching library

Regular expressions in Python

```
# import the library
import re

# pattern is a string representing the RE
# the function reports whether string matches RE
re.fullmatch(pattern, string)
```

Regular expressions

- **We will define regular expressions (RE) recursively**

- Like any recursive function, we can start with the base case:

a regular expression can be a single character or the empty string

Regular expressions

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- Like any recursive function, we can start with the base case:

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Example:

```
ASSIGN = “=“
PLUS   = ”+”
```

Python:

```
import re
re.fullmatch(“=“, “=“)

re.fullmatch(“+”, “+”) # what happens here?
```

Regular expressions

- When we define regular expressions, some characters are special.
  - They are operators in the regular expression language
  - If we want to use them as a character, then we need to ”escape them” with a \
  - “+” happens to be one of those characters

https://riptutorial.com/regex/example/15848/what-characters-need-to-be-escaped-

Python:

```
import re
re.fullmatch(“=“, “=“)

re.fullmatch(“\+”, “+”) # what happens here?
```

Regular expressions

- **We will define regular expressions (RE) recursively**

- Like any recursive function, we can start with the base case:

  a regular expression can be a single character or the empty string

Python:

```
import re
re.fullmatch("", "")
```

Not super useful for us, but useful for the theory

Regular expressions

- First recursive case: **concatenation**

- Two REs can be concatenated by simply writing them in sequence:
  - RE1 = ”a”, RE2 = “b”
  - concatenated it is: RE12 = “ab”

- This allows us to build words

Example:

```
FOR   = “for“
WHILE = ”while”
```

Python:

```
import re
re.fullmatch(“for“, “for“)
re.fullmatch(“a+b”, “a+b”) # what happens here?
```

Can we define these tokens yet?

Tokens		Tokens Definitions
• ARTICLE	=	{The, A, My, Your}
• NOUN	=	{Dog, Car, Computer}
• VERB	=	{Ran, Crashed, Accelerated}
• ADJECTIVE	=	{Purple, Spotted, Old}

Can we define these tokens yet? No, we need one more operator

Tokens		Tokens Definitions
• ARTICLE	=	{The, A, My, Your}
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Regular expressions

- Second recursive operator: **choice** (sometimes called ”union”, or “or”)

- Two REs can be choiced together using the “|” operator
  - RE1 = “a”, RE2 = “b”
  - The choice is: RE1|2 = “a|b”
  - Matches either

Example:

```
OP   = "*|+"
CMP  = "==|<=|>="
```

Python:

```
import re
re.fullmatch("*|+", "+")
re.fullmatch("==|<=|>=", "==")
```

Can we define these tokens yet?

Tokens		Tokens Definitions
• ARTICLE	=	{The, A, My, Your}
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Can we define these tokens yet? Yes!

Tokens		Tokens Definitions
• ARTICLE	=	“The|A|Mine|Your”
• NOUN	=	“Dog|Car|Computer”
• VERB	=	“Ran|Crashed|Accelerated”
• ADJECTIVE	=	“Purple|Spotted|Old”

Can we define these tokens yet?

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
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MULT   = “*”
IGNORE = [“ “]
```

Can we define these tokens yet? No!

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
IGNORE = [“ “]
```

Regular expressions

- Last recursive operator: **Repeat**

- Unary operator: *
  - RE1 = “a”
  - Repeat RE1 zero or more times: ”a*”

Example:

```
RE1   = “a*“
RE2   = “a*|b*”
RE3   = ”a|b*
```

Python:

```
import re
re.fullmatch(“a*|b*“, “aaa“)
re.fullmatch(“a*|b*”, “”)
```

Regular expressions

- Last recursive operator: **Repeat**

- Unary operator: *
  - RE1 = “a”
  - Repeat RE1 zero or more times: ”a*”

Example:

```
RE1   = “a*“
RE2   = “a*|b*”
RE3   = ”a|b*
```

Precedence?

Python:

```
import re
re.fullmatch(“a*|b*“, “aaa“)
re.fullmatch(“a*|b*”, ““)
```

Regular expressions

- These are the theoretical foundational operators.
- Most languages give syntactic sugar to make common cases easier
- Most languages also break the theory
  - Perl regexes are extremely complicated
    - https://www.perlmonks.org/?node_id=809842
  - Python regexes (with recursion) are can capture context free languages
    - https://www.npopov.com/2012/06/15/The-true-power-of-regular-expressions.html#matching-context-free-languages

Regular expressions

- strict repeat operator: +
- one or more repeats (the * operator is 0 or more repeats)
- derivation: “r+” = “rr*”

Regular expressions

- Ranges:
  - digits [0-9]
  - alpha [a-z], [A-Z]
- Derivation: [0-9] = ”1|2|3|4|5|6|7|8|9|0”
- Lets try C style IDs: [a-zA-Z_][a-zA-Z_0-9]*
- Hexadecimal numbers:

Regular expressions

- Ranges:
  - digits [0-9]
  - alpha [a-z], [A-Z]
- Derivation: [0-9] = ”1|2|3|4|5|6|7|8|9”
- Lets try C style IDs: “[a-zA-Z][0-9a-zA-Z]*”
- Hexadecimal numbers: “0x[0-9a-fA-F]+”

Regular expressions

- optional operator ?
  - optional characters

- “r?” = “|r”

- Example: “ab?”

Regular expressions

- optional operator ?
  - optional characters
- “r?” = “|r”
- Example: “ab?”
- Let’s do simple floating-point numbers:

Regular expressions

- optional operator ?
  - optional characters

- “r?” = “|r”

- Example: “ab?”

- Let’s do simple floating-point numbers: “[0-9]+(\.[0-9]+)?”

Regular expressions

- any character ‘.’

- example using email (this is probably too general!)

Regular expressions

- any character ‘.’
- example using email (this is probably too general!)
- ”.*@.*\.com”

Using REs

- What if we want to extract the domain or user name from the email?
- We can use groups!
  - use ()s to delimitate groups
- ”(.*)@(.*\.com)”
- Index the resulting object with [1] and [2] to get to the user name and domain respectively

Using REs

- you can give groups id names rather than using indices

- “(?P<name>.+)@(?P<domain>.+\.com)”

Example Using RE groups

- you can give groups id names rather than using indices

  “(?P<name>.+)@(?P<domain>.+\.com)”

```
import re
pattern = r"(?P<name>.+)@(?P<domain>.+\.com)"
email = "johndoe@example.com"
match = re.match(pattern, email) # apply pattern
if match:
    name = match.group("name") # extract user name
    domain = match.group("domain") # extract domain
    print(f"Name: {name}, Domain: {domain}")
else:
    print("No match found.")
```

REs are good for?

- Scanning large amounts of documents quickly, looking for:
  - Websites
  - Email
  - Profiling numbers
  - Variable usages
  - **What else?**

RE examples

- **What can REs not do?**

- Nested structures, such as parenthesis matching:
  - Try doing arithmetic expressions
  - You will not be able to match ()s

- Classical example: REs cannot capture same number of repeats:
  - A{N}B{N}

- REs cannot parse HTML!!!
  - One of the most upvoted answers on stackoverflow!
  - https://stackoverflow.com/questions/1732348/regex-match-open-tags-except-xhtml-self-contained-tags/1732454#1732454

For your homework

- You'll need to write tokens for a simple programming language, including:

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = "="
PLUS   = "+"
MULT   = "*"
IGNORE = [" "]
```

How to implement an RE matcher?

- Overview: first you have to parse the RE...
  - Chicken and egg problem
  - The language of REs is not a regular language. It is context sensitive (because it has ()s)

  - But once you can parse the RE, there are several options

How to implement an RE matcher?

- parsing with derivatives
  - We discuss this in CSE211
  - Elegant solution, but difficult to make fast

- Convert to an automata
  - Learn more about this CSE103
  - A cool website
  - https://ivanzuzak.info/noam/webapps/fsm_simulator/

How to use REs in a scanner implementation?

- Will be the next topic of discussion.