^[\s\u200c]+|[\s\u200c]+\$

The Parsing and Analysis of [rR]eg(ular)* *([eE]x(pression(s)*)*)*

Will Beddow, Antonia Ritter, Shiyue Zhang, Vicente Riquelme

The Challenges of Using Regexes

Why Aren't Regular Expressions a Lingua Franca? An Empirical Study on the Re-use and Portability of Regular Expressions



Malformed Stack Overflow Post Chokes Regex, Crashes Site



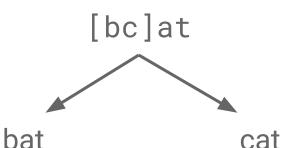
Blog/Article/Link Cloudflare outage caused by deploying bad regular expression that caused 100% CPU usage worldwide, dropping up to 82% of traffic (self.sysadmin) submitted 2 years ago by TyroPyro

Cloudflare Blog^[1]

275 comments source share save hide give award report crosspost hide all child comments

Regular Expressions

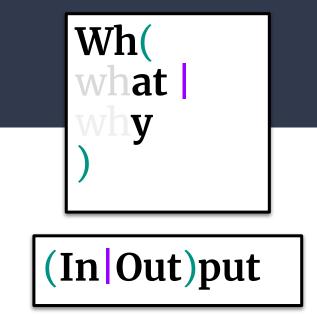
A regular expression (**regex**) is a pattern used to match particular strings

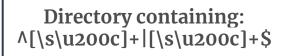


#?([\da-fA-F]{2})([\da-fA -F]{2})([\da-fA-F]{2}) Any hex code, for example #FF5733

Project Overview

- Our tool evaluates:
 - Security
 - Understandability
 - Generalizability

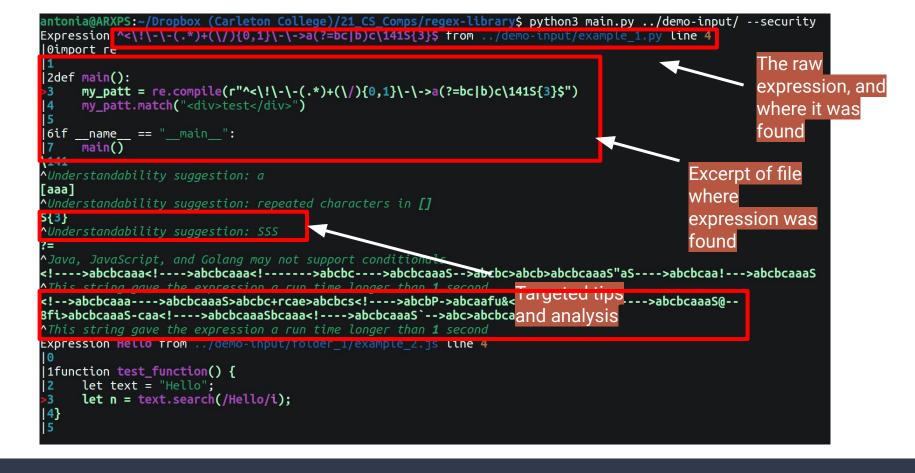






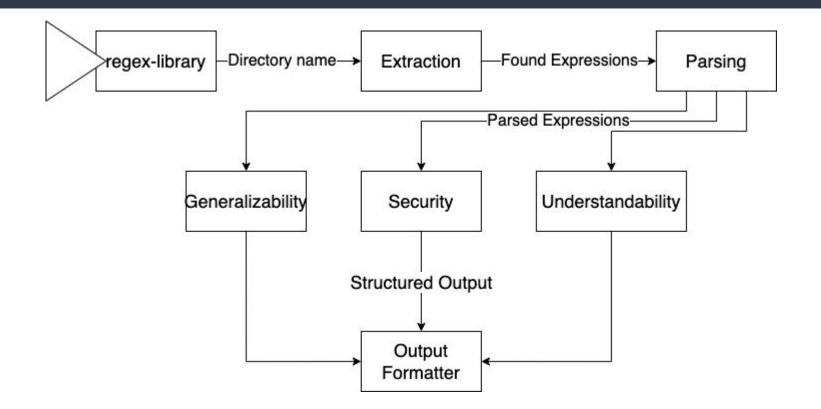


Analysis and Recommendations



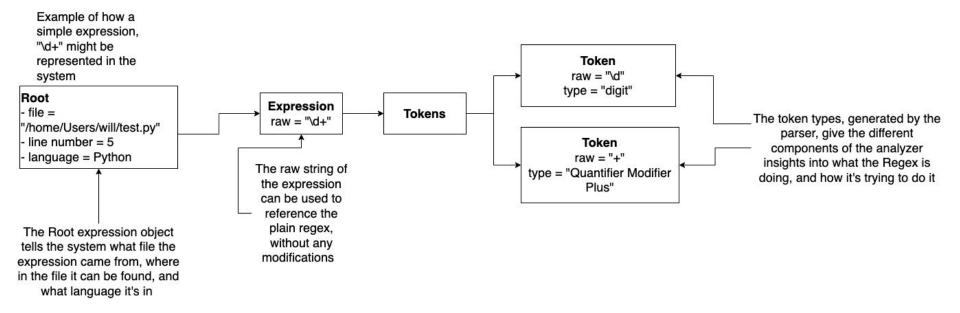
Output

Structure of the library



Data Format

Anatomy of an Expression Representation

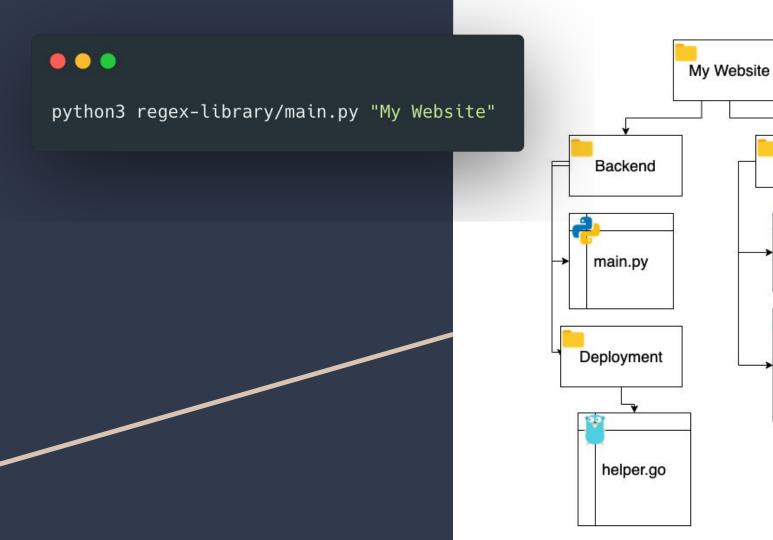


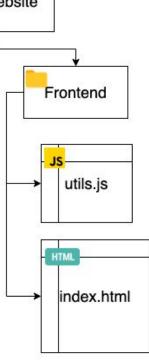
Brew

•••

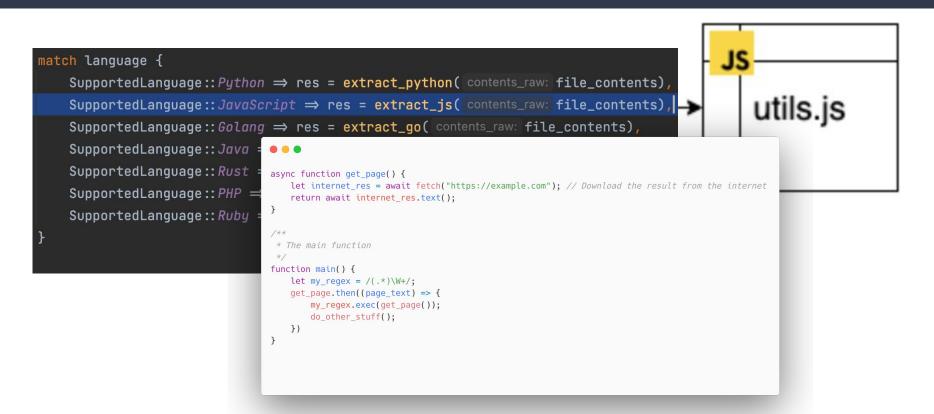
brew install zhangshyue/regexanalyzer/regexAnalyzer
regex-library [directory_path]



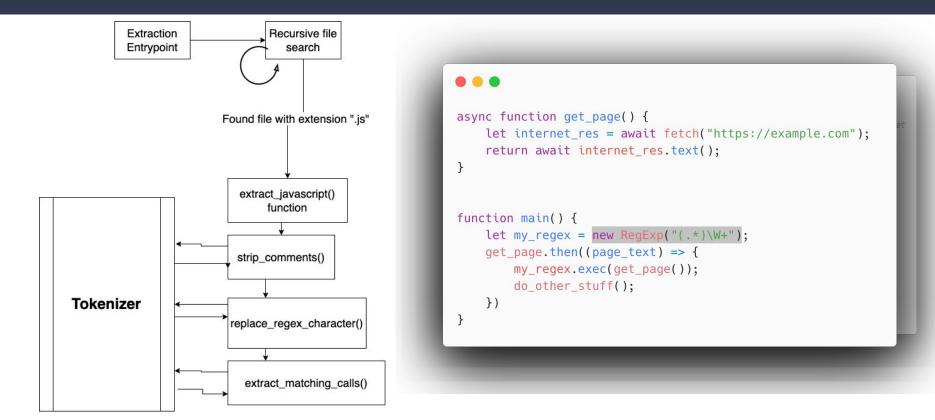




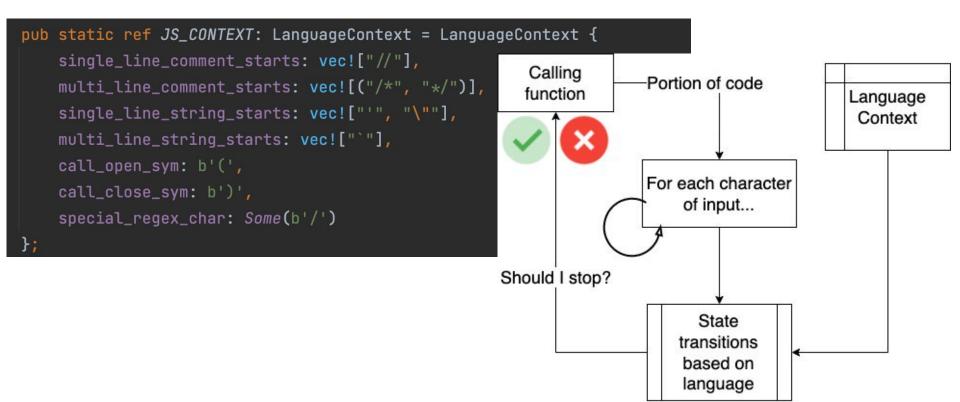
Finding Regular Expressions in Files



Extraction Process Overview



General Purpose Tokenizer: A Finite State Machine



Parsing

•••

```
message Token {
    string token = 8;
    TokenType type = 9;
```

```
oneof sub_type {
    FlagType flag = 10;
    SubstitutionType substitution = 11;
    QuantifierModifierType quantifiermodifier = 12;
    AnchorType anchor = 13;
    string character = 14;
    LookaroundType lookaround = 15;
    EscapeType escape = 16;
    GroupReferenceType groupref = 17;
    CharacterClassType characterclass = 18;
}
```

token: "g" type: Flag flag: Global

token: "\t" type: Escape escape: Tab

Parsing



expression { raw: "(.*)\\\#+" tokens { token: "(" type: GroupReference groupref: OpenCapture tokens { token: "." type: CharacterClass characterclass: Dot nce 3 tokens { oture token: "*" type: OuantifierModifier quantifiermodifier: Star tokens { token: ")" SS type: GroupReference groupref: CloseCapture tokens { token: "\\W" type: CharacterClass characterclass: NotWord tokens { token: "+" type: QuantifierModifier quantifiermodifier: Plus

4. token: ")"
type: GroupReference
groupref: CloseCapture
5. token: "\W"
type: CharacterClass
characterclass: NotWord
6. token: "+"

difier type: QuantifierModifier Star quantifiermodifier: Plus

Understandability Component

- Single bounded class:
 S{3} = SSS = S{3,3}
- Lower bounded class:
 A{2,} = AAA* = AA+

- Carl Chapman, Peipei Wang, and Kathryn T. Stolee. 2017. Exploring regular expression comprehension.
- Custom Character class:
 [0-9a] = [\da] = [0123456789a]
- Literal class:

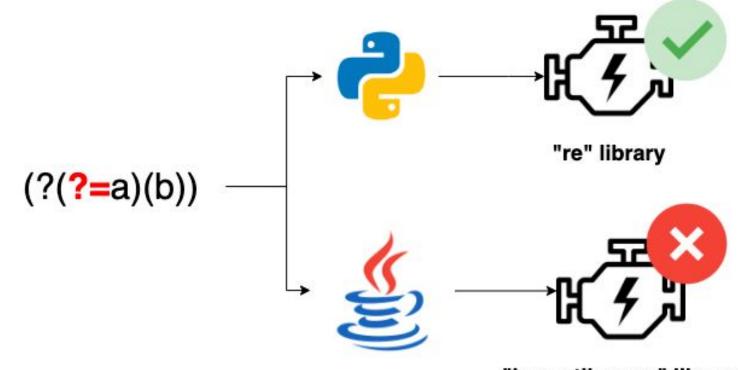
$$a\ = \a[\] = \x61\x24 = \141\044$$

Understandability Component

 $\frac{x61[0-9]}{2}$



Generalizability Component: Regex Engines



"java.util.regex" library

Generalizability Component: Functionality

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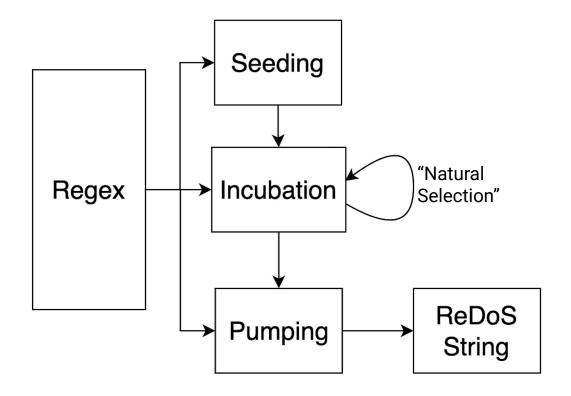
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Language feature comparison (part 1)

Security Component

- What is a ReDoS attack?
 - "Regex Denial of Service"
 - Error when a certain input string takes a regex exponential time to match
- Example:
 - o regex = "^(([a-z])+.)+[A-Z]([a-z])+\$"

ReScue Algorithm



Input: Regex Output: ReDoS String

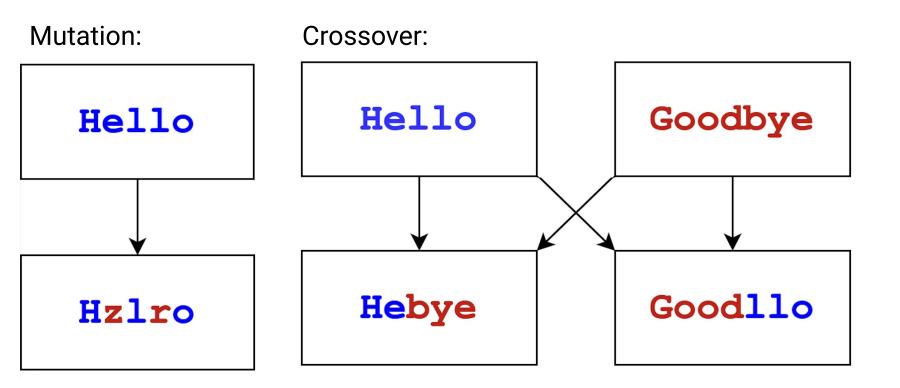
- Genetic algorithm for incubation.
- Most desirable strings kept each generation

"ReScue: Crafting Regular Expression DoS Attacks" Yuju Shen et al., Nanjing University

Seeding (Phase 1)

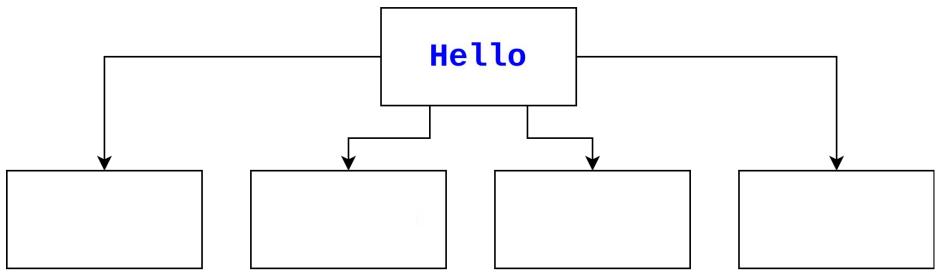
- Regex = "hello. {1, 10}goodbye"
- Extract tokens from expression:
 - "hello"
 - "goodbye"
- Make seeds from the tokens, mixing in random characters:
 - o "goodbyeYY7goodbye6qL<GWhellogoodbye2>hello"
 - "hellogoodbyehellogoodbyeQhellogoodbye#K(goodbye \\\\fXhellohello4hellogoodbye"

Genetic Algorithm Mutations (Phase 2)

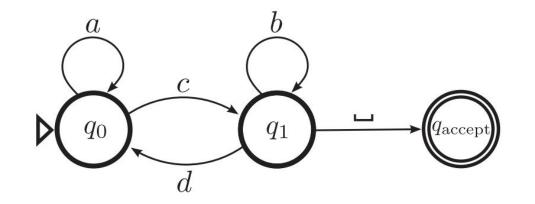


Genetic Algorithm Mutations (Phase 2)

Randomized Mutation:



Regex as Finite State Machines



State diagram for regex: (a*cb*d)* a*cb*

- Any regex can be described as a Finite State Machine
- Match steps are graph dependent
- Implications for fitness functions and timing

Timing as a Fitness Function

- Slower strings = fitter
- Kept fittest strings in each generation
- RESCUE finds fittest strings by calculating matching steps per character
 - Essentially O(match(regex, input))

• This requires a regex engine



Timing as a Fitness Function

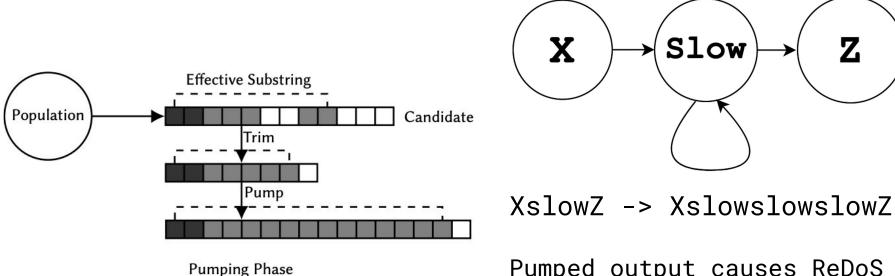
• Instead we use time(match(regex, input))

$$f_{fitness}(s) = rac{| au(s)|}{|s|} o f_{fitness}(s) = t(s)$$

- s = input string
- τ(s) = matching steps of s
 - t(s) = time to match s

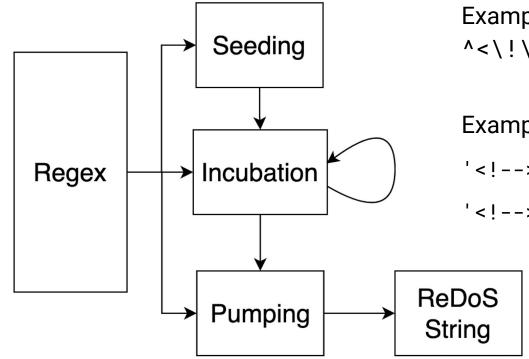
- Matching steps $\tau(s)$ > process time t(s)
- Multiprocessing to allow for timeouts

Pumping (Phase 3)



Pumped output causes ReDoS attack if used as input

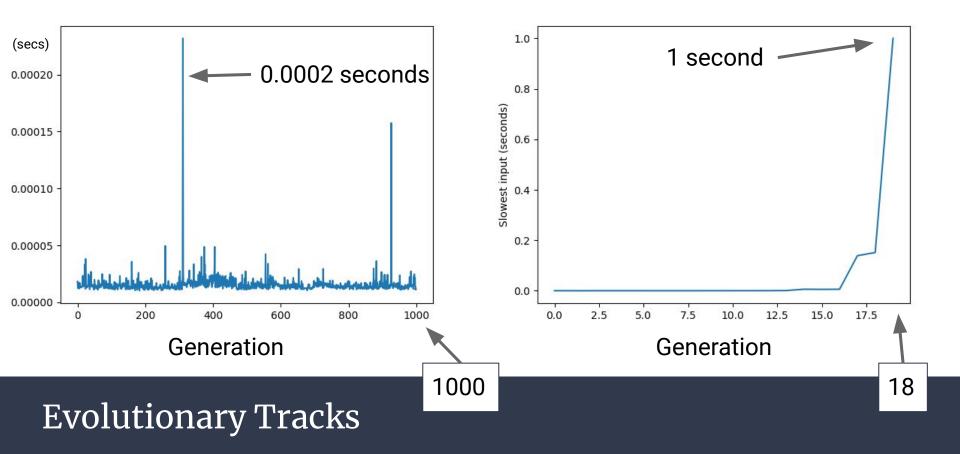
ReScue Algorithm



Example Regex: ^<\!\-\-(.*)+(\/){0,1}\-\->\$

Example Output:

(4m)



Output

?=

^Java, JavaScript, and Golang may not support conditionals

antonia@ARXPS:~/Dropbox (carleton ege)/21_CS_Comps/regex-library\$ python3 main.py/demo-input/security
Expression ^<\!\-\-(.*)+(\/){0,1}} & (?=bc b)c\1415{3}\$ from/demo-input/example_1.py line 4
0inport re
/ Zdef main():
<pre>3 my_patt = re.complig(n"<<!--!-(.*)+(\/){0,1}\-->a(?=bc b)c\1415{3}\$")</pre>
4 my_patt.match(" <di></di> test")
6ifname == "nain":
7 main() \141
li≄i ∧Understandal⊾lity suggestion: a
laaa
AUnderst indability suggestion: repeated characters in []
s{3}
^Und#rstandability suggestion: SSS
/= ·
^Java, JavaScript, and Golang may not support conditionals abcbcaaa abcbcaaa abcbc>abcbc>abcbcaaaS>abcbc>abcb>abcbcaaaS"aS>abcbcaaa!>abcbcaaaS
A This string gave the expression a run time longer than 1 second
abcbcaaa>abcbcaaaS>abcbc+rcae>abcbcs abcbP->abcaafu& abcbcaaaS>abcbcaaaS@
8fi>abcbcaaaS-caa abcbcaaaSbcaaa abcbcaaaS`>abcbca>abcbca
^This string gave the expression a run time longer than 1 second
Expression Hello from/demo-input/folder_1/example_2.js line 4
0 1function test_function() {
2 let text = "Hello";
<pre>>3 Let n = text.search(/Hello/i);</pre>
4}

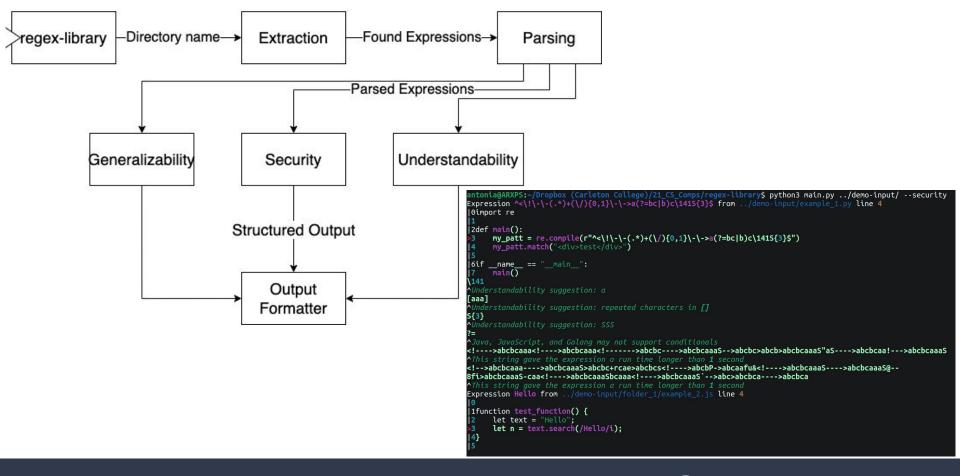
Annotation Fields

- Note
- One of
 - Token
 - Expression
 - Entity



References

- Yuju Shen, Yanyan Jiang, Chang Xu, Ping Yu, Xiaoxing Ma, and Jian Lu. 2018. ReScue: crafting regular expression DoS attacks. Proceedings of the 33rd ACM/IEEE International Conference on Automated Software Engineering. Association for Computing Machinery, New York, NY, USA, 225-235. DOI: <u>https://doi.org/10.1145/3238147.3238159</u>
- Carl Chapman, Peipei Wang, and Kathryn T. Stolee. 2017. Exploring regular expression comprehension. In Proceedings of the 32nd IEEE/ACM International Conference on Automated Software Engineering (ASE 2017). IEEE Press, 405-416.



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