

# *RELIA: Accelerating the Analysis of Cloud Access Control Policies*

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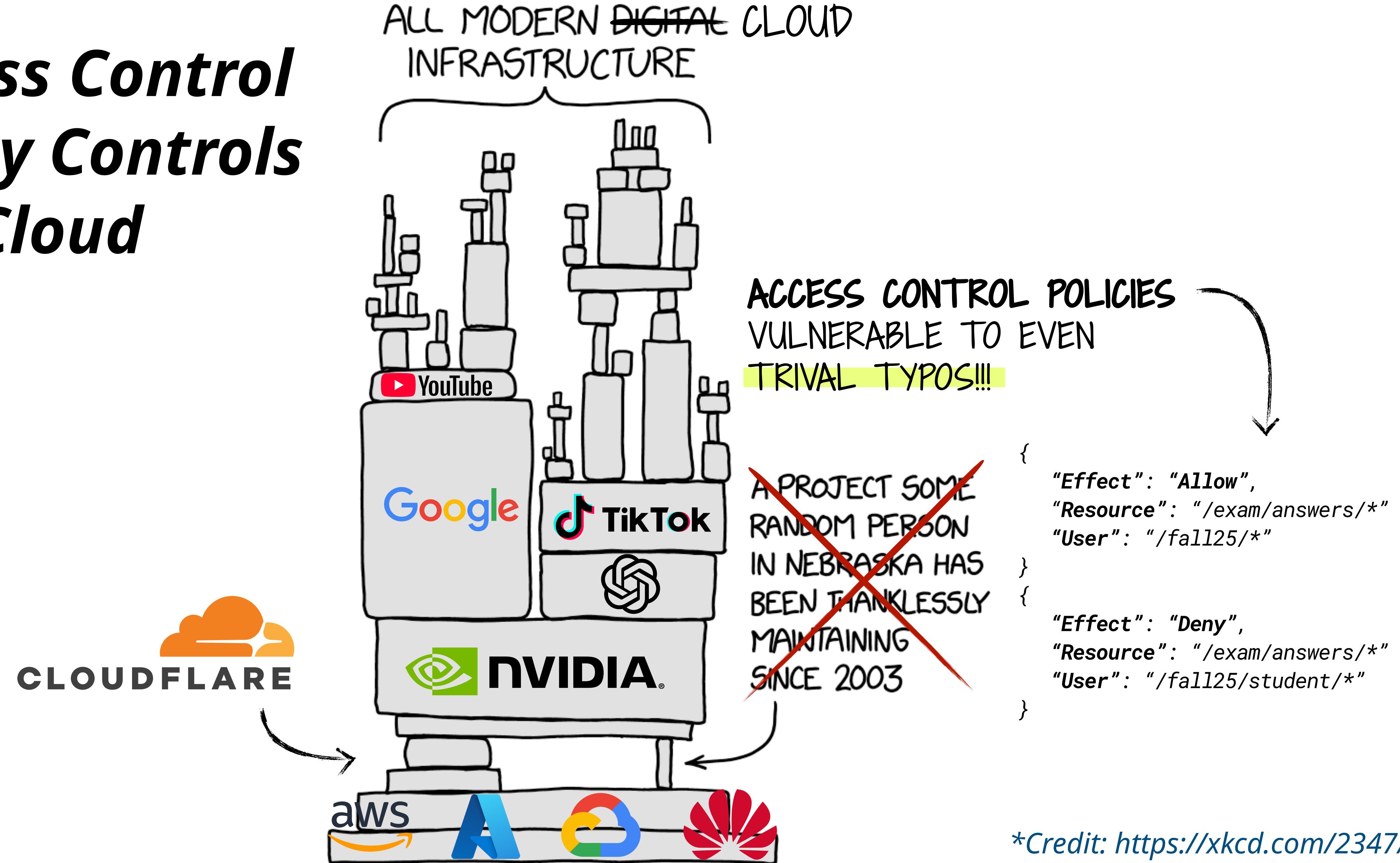


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# *Access Control Policy Controls the Cloud*



# *Cloud Access Control Policy Analyzers!*

**Analyzer:** Zelkova [FMCAD '18]



**Policies**

```
{  
    "Effect": "Allow",  
    "Resource": "/exam/answers/*"  
    "User": "/fall25/*"  
}
```

**"Allow the access  
of exam answers from  
all members of fall 2025 semester;**

```
{  
    "Effect": "Deny",  
    "Resource": "/exam/answers/*"  
    "User": "/fall25/student/*"  
}
```

**but do not allow  
the access from  
those who are students in fall 2025"**

# *Cloud Access Control Policy Analyzers!*

**Analyzer:** Zelkova [FMCAD '18]



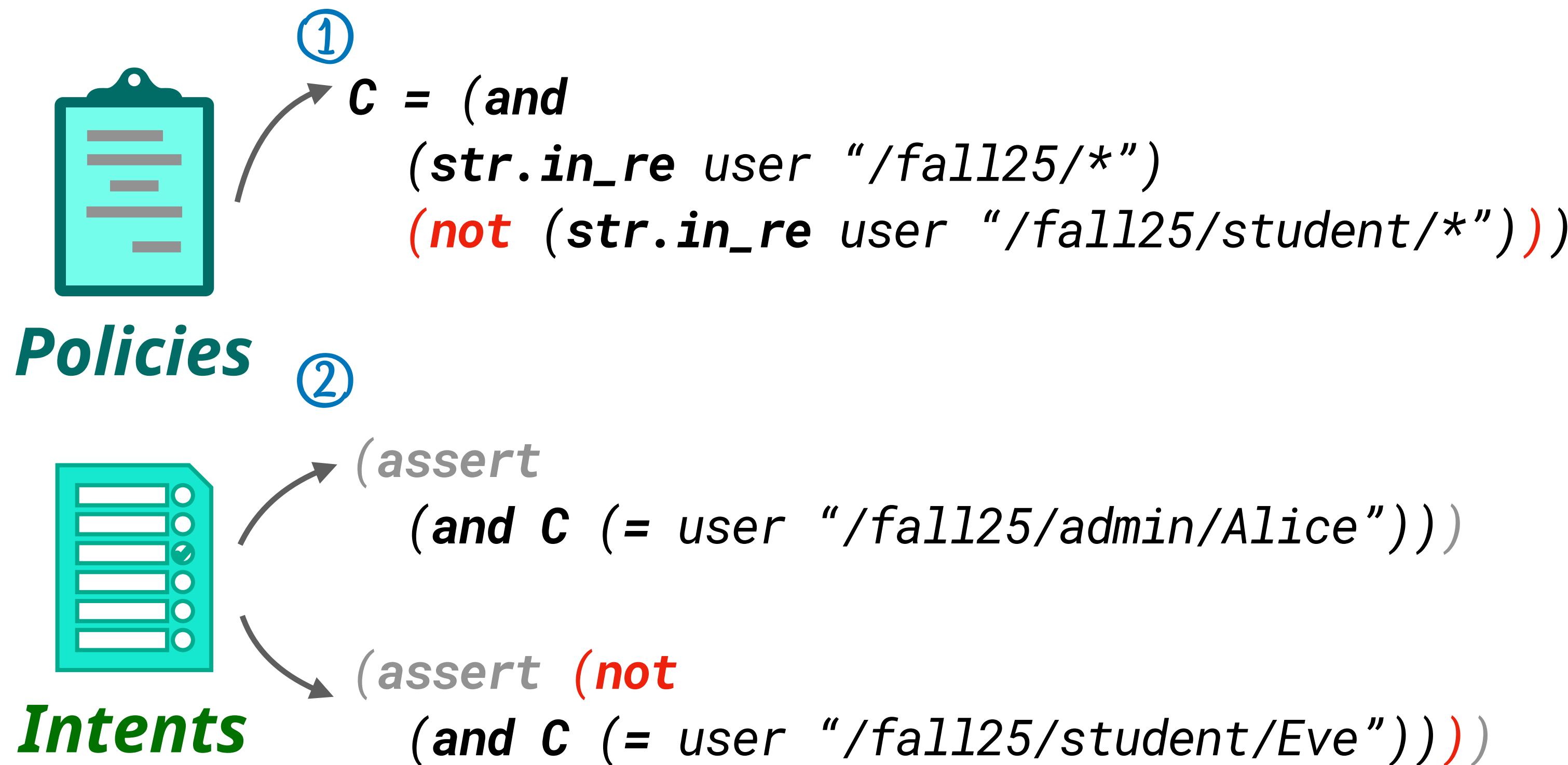
①

```
C = (and  
      (str.in_re user "/fall25/*")  
      (not (str.in_re user "/fall25/student/*"))))
```

**Policies**

# Cloud Access Control Policy Analyzers!

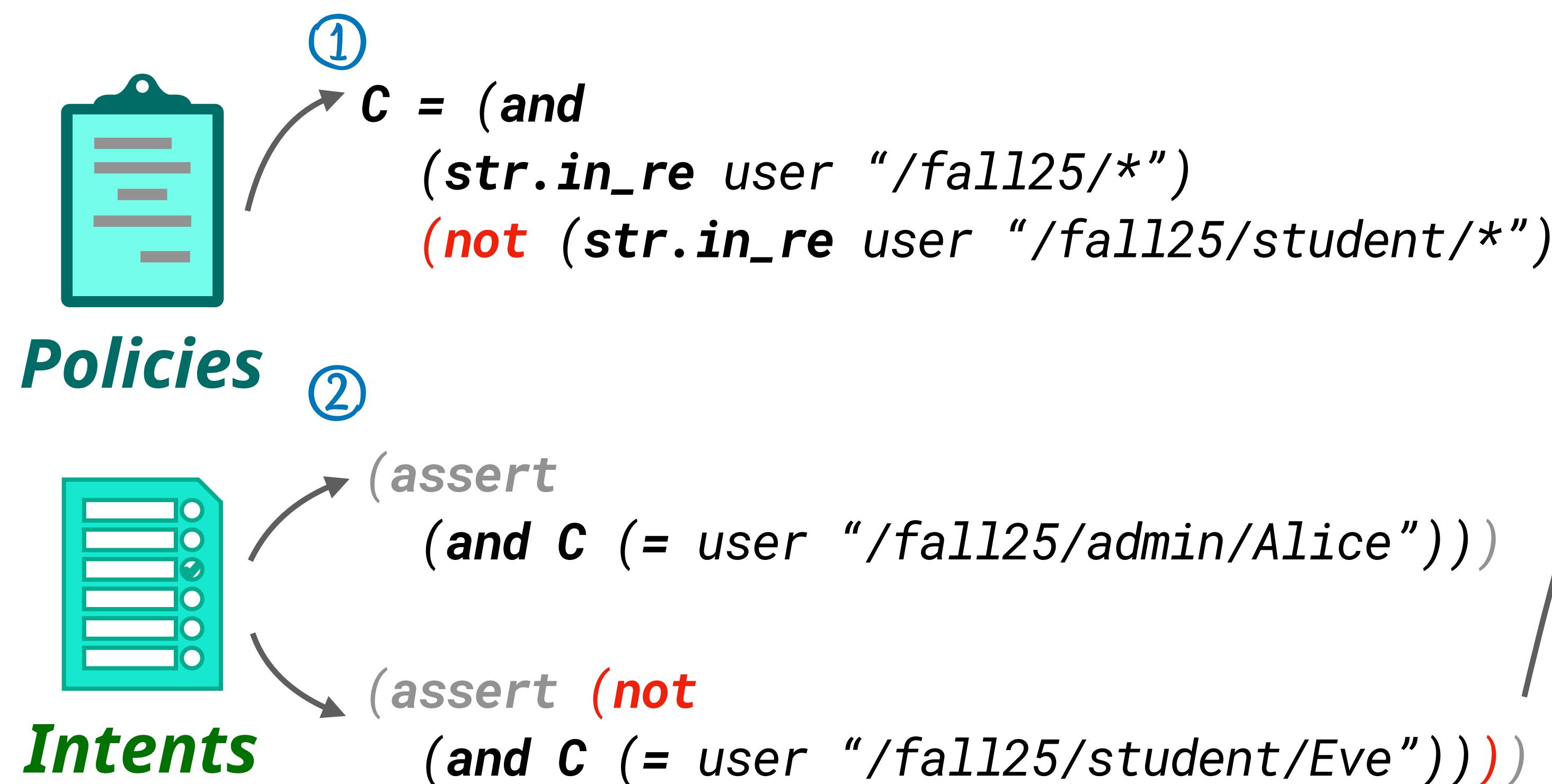
Analyzer: Zelkova [FMCAD '18]



Findings: AccessSummary [CAV '20]

# Cloud Access Control Policy Analyzers!

Analyzer: Zelkova [FMCAD '18]

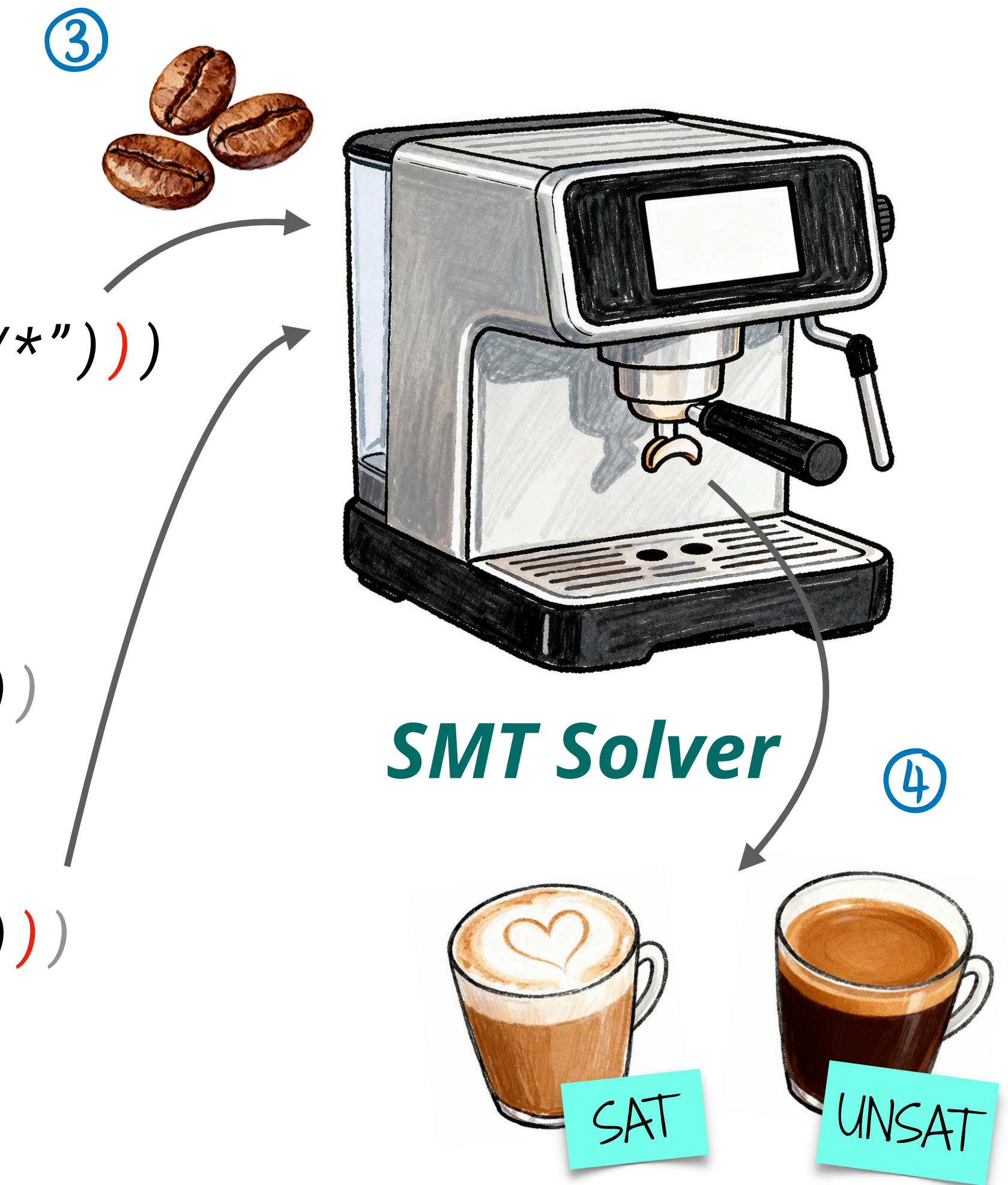
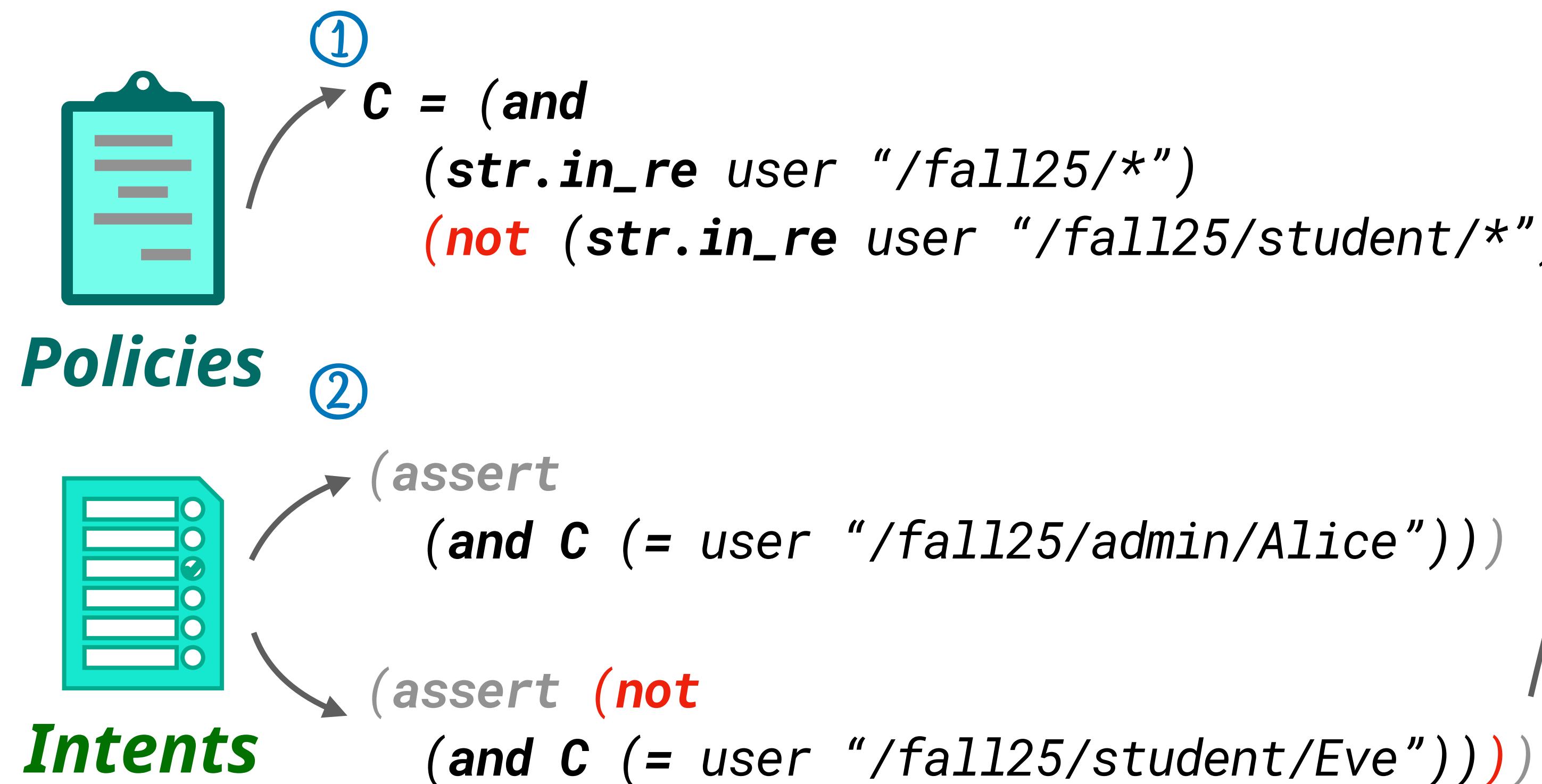


**SMT Solver**

Findings: AccessSummary [CAV '20]

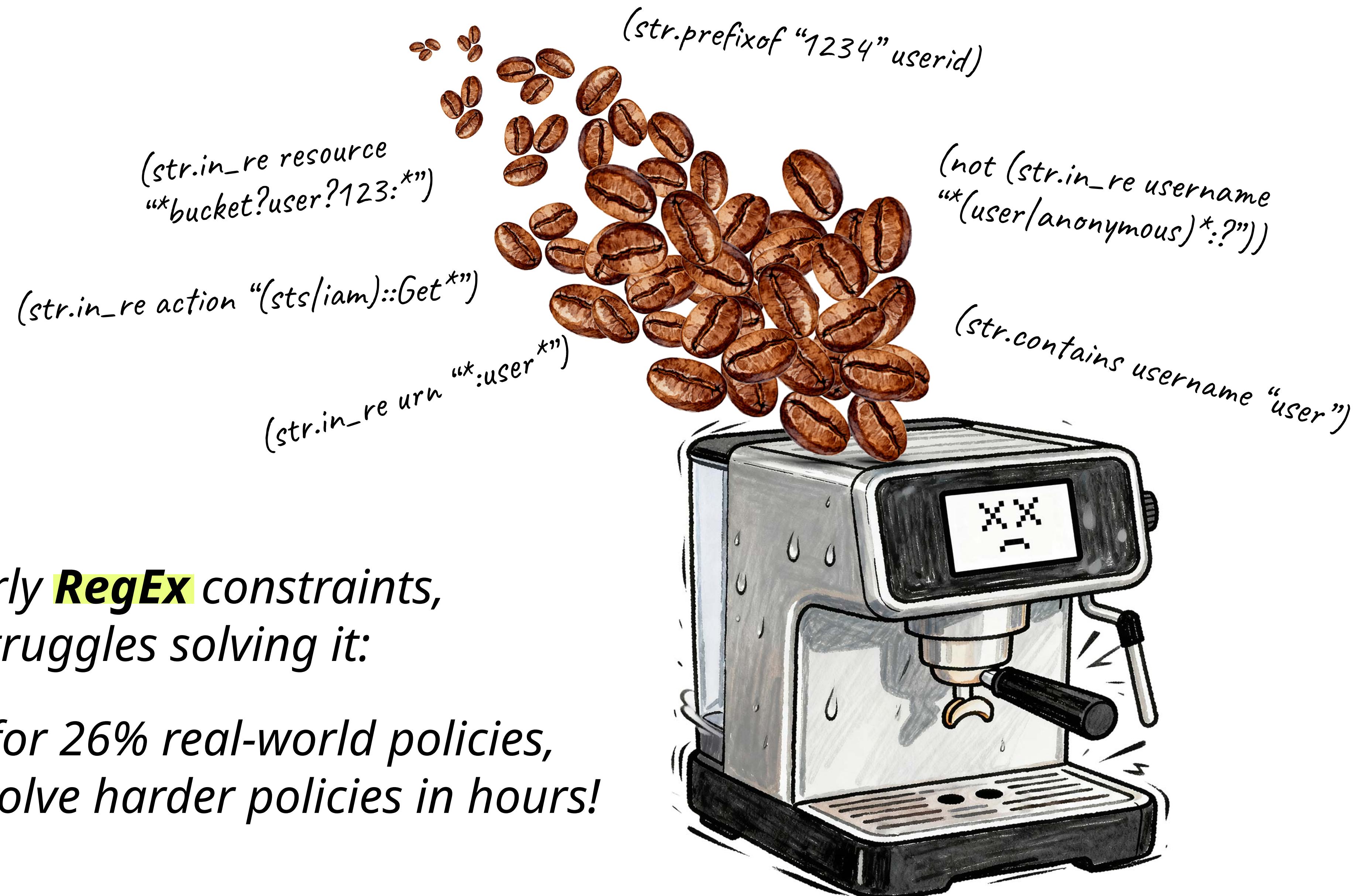
# Cloud Access Control Policy Analyzers!

Analyzer: Zelkova [FMCAD '18]



Findings: AccessSummary [CAV '20]

# However...



ACP are majorly **RegEx** constraints,  
SMT solvers struggles solving it:

Z3 timed out for 26% real-world policies,  
Cvc5 cannot solve harder policies in hours!

# *Insight: Infinite Space of Strings*

Solvers “search” the **whole string space** to find answers, but the space is huge:

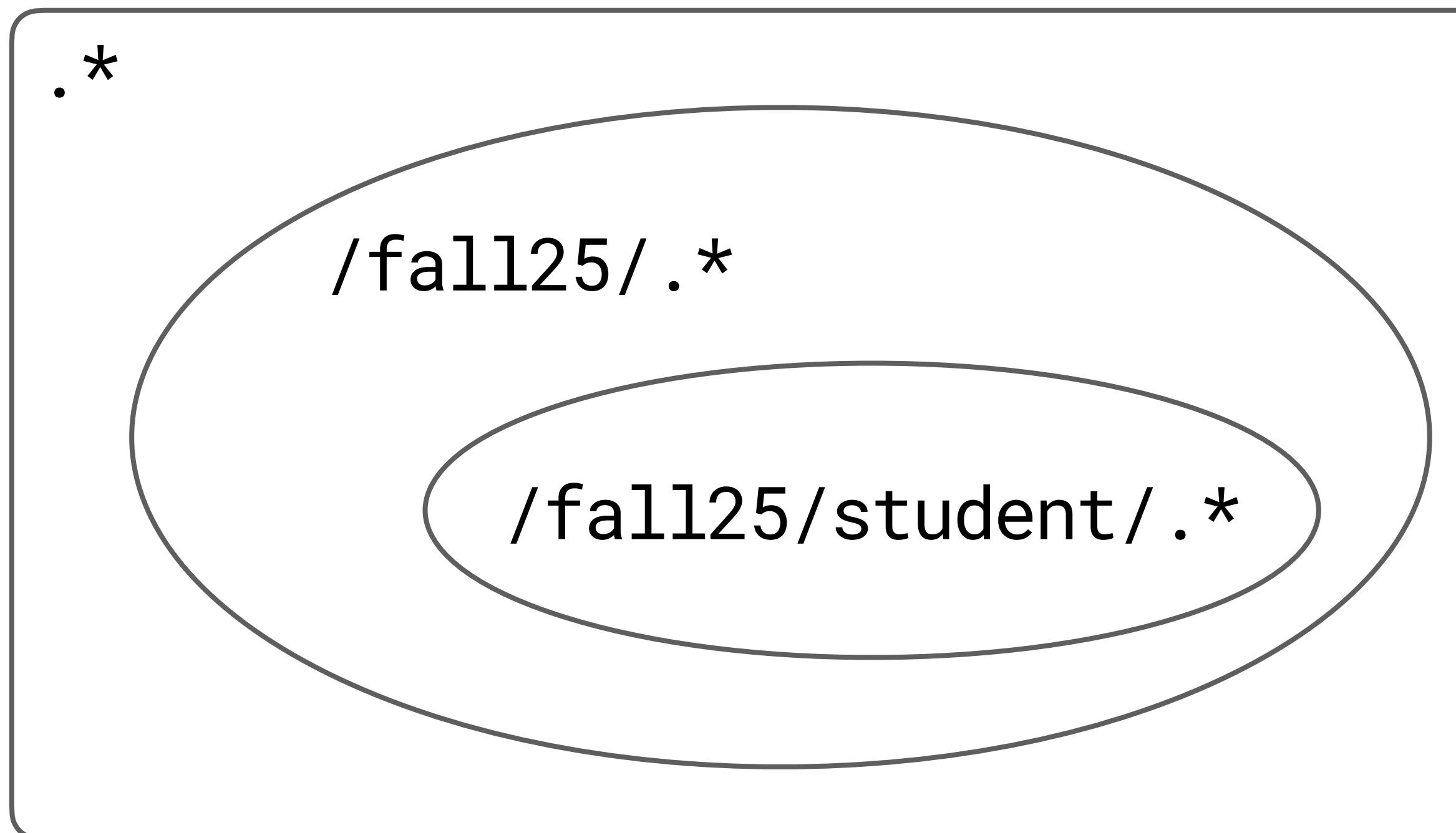
A paper strip with every ascii string **≤5 characters** circles around the Earth **5 times!**

Strings in Cloud Access Control Policies are typically **a lot longer**.

a ab abc Relia hello world alpha ase 2025 a81C\_ s1827 zcs98 ss8a7 dd asbse regex what next wycs never when I see you again who do we talk about if it's the same as a 4 byte string or a 16 byte string or a 32 byte string or a 64 byte string or a 128 byte string or a 256 byte string or a 512 byte string or a 1024 byte string or a 2048 byte string or a 4096 byte string or a 8192 byte string or a 16384 byte string or a 32768 byte string or a 65536 byte string or a 131072 byte string or a 262144 byte string or a 524288 byte string or a 1048576 byte string or a 2097152 byte string or a 4194304 byte string or a 8388608 byte string or a 16777216 byte string or a 33554432 byte string or a 67108864 byte string or a 134217728 byte string or a 268435456 byte string or a 536870912 byte string or a 1073741824 byte string or a 2147483648 byte string or a 4294967296 byte string or a 8589934592 byte string or a 17179869184 byte string or a 34359738368 byte string or a 68719476736 byte string or a 137438953472 byte string or a 274877906944 byte string or a 549755813888 byte string or a 1099511627776 byte string or a 2199023255552 byte string or a 4398046511104 byte string or a 8796093022208 byte string or a 17592186044416 byte string or a 35184372088832 byte string or a 70368744177664 byte string or a 140737488355328 byte string or a 281474976710656 byte string or a 562949953421312 byte string or a 1125899906842624 byte string or a 2251799813685248 byte string or a 4503599627370496 byte string or a 9007199254740992 byte string or a 18014398509481984 byte string or a 36028797018963968 byte string or a 72057594037927936 byte string or a 144115188075855872 byte string or a 288230376151711744 byte string or a 576460752303423488 byte string or a 1152921504606846976 byte string or a 2305843009213693952 byte string or a 4611686018427387904 byte string or a 9223372036854775808 byte string or a 18446744073709551616 byte string or a 36893488147419103232 byte string or a 73786976294838206464 byte string or a 147573952589676412928 byte string or a 295147905179352825856 byte string or a 590295810358705651712 byte string or a 1180591620717411303424 byte string or a 2361183241434822606848 byte string or a 4722366482869645213696 byte string or a 9444732965739290427392 byte string or a 18889465931478580854784 byte string or a 37778931862957161609568 byte string or a 75557863725914323219136 byte string or a 151115727458286466438272 byte string or a 302231454916572932876544 byte string or a 604462909833145865753088 byte string or a 1208925819666291731506176 byte string or a 2417851639332583463012352 byte string or a 4835703278665166926024704 byte string or a 9671406557330333852049408 byte string or a 1934281311466066770409816 byte string or a 3868562622932133540819632 byte string or a 7737125245864267081639264 byte string or a 15474250491728534163278528 byte string or a 30948500983457068326557056 byte string or a 61897001966914136653114112 byte string or a 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23384026196738155479280440710476431097600 byte string or a 46768052393476310958560881420952862195200 byte string or a 93536104786952621917121762841855724384000 byte string or a 18707220957390524383424332568371144768000 byte string or a 37414441914781048766848665136742289536000 byte string or a 74828883829562097533697330273484578872000 byte string or a 14965776765912419506739466054696915764000 byte string or a 29931553531824838513478932109393831528000 byte string or a 59863107063649677026957864218787663056000 byte string or a 119726214127293354053915728437575326112000 byte string or a 239452428254586708107831456875150652224000 byte string or a 478904856509173416215662913750301304448000 byte string or a 957809713018346832431325827500602608896000 byte string or a 1915619426036693664862651655001205217792000 byte string or a 383123885207338732972530331000241043588000 byte string or a 766247770414677465945060662000482087176000 byte string or a 1532495540829354931890121324000964174352000 byte 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32910091145639560746222045957235108415317894896000 byte string or a 65820182291279121492444091914470216826655789792000 byte string or a 131640364582558242984881838288940433653115775584000 byte string or a 263280729165116485969763676577880867316231551168000 byte string or a 526561458330232971939527353155761734632463102336000 byte string or a 105312291666046594387905470631152346866486204672000 byte string or a 210624583332093188775810941262304693732972409344000 byte string or a 421249166664186377551621882524609387465944818688

# *Insight: Finite Space of String Equivalence Classes*

```
(assert (str.in_re user "/fall25/*"))
(assert (not
(str.in_re user "/fall25/student/*")))
```

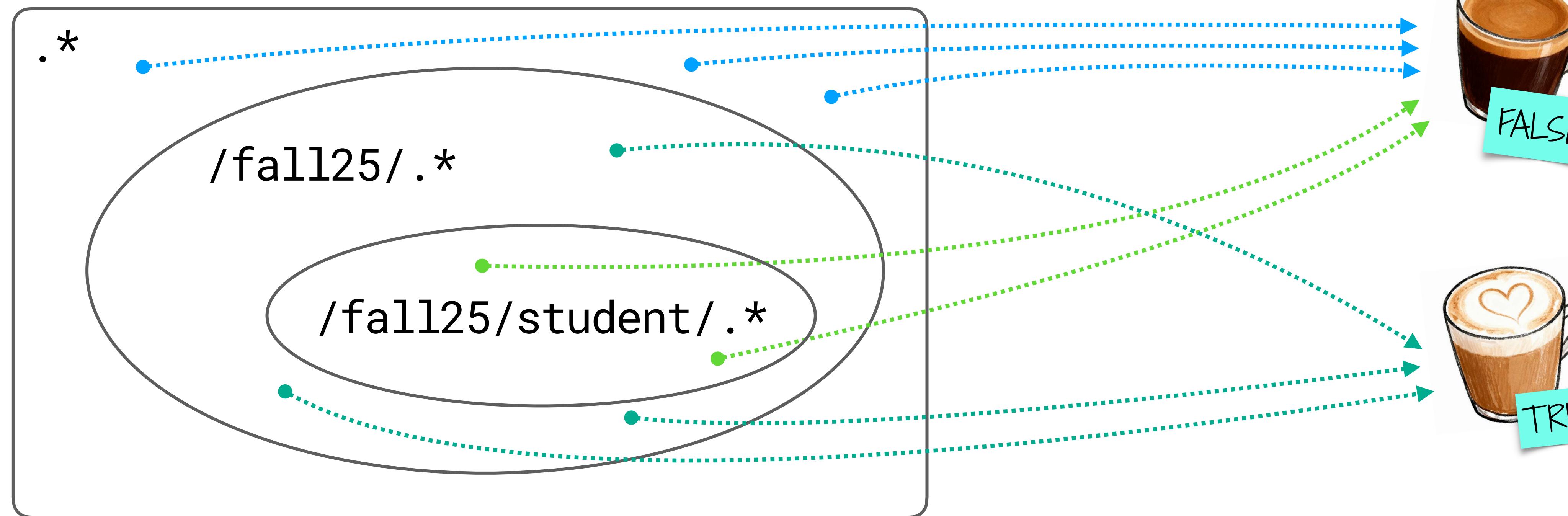


If a variable **s** only has RegEx constraints,  
Equivalence classes about the  
**RegExes that s belongs to**  
can be constructed.

# *Insight: Finite Space of String Equivalence Classes*

```
(assert (str.in_re user "/fall25/*"))
(assert (not
(str.in_re user "/fall25/student/*")))
```

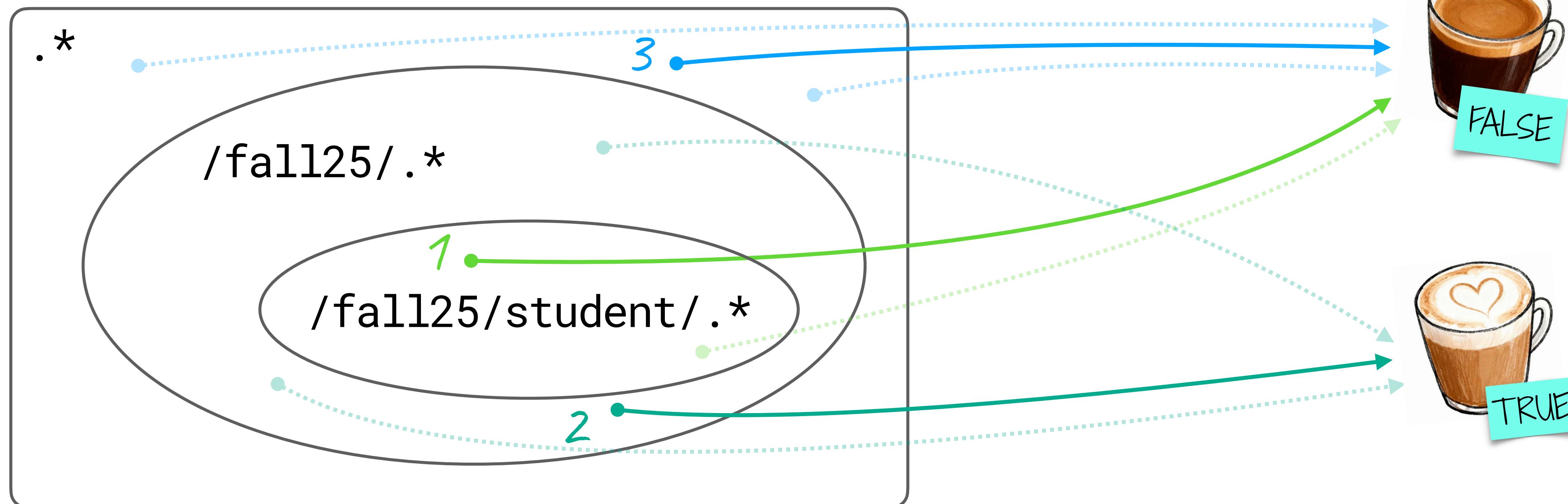
**Same behavior**  
in the same SEC!



# *Insight: Finite Space of String Equivalence Classes*

```
(assert (str.in_re user "/fall25/*"))
(assert (not
(str.in_re user "/fall25/student/*")))
```

Only consider  
the 3 SECs!



# *Our Idea: RELIA*

(str.in\_re user "/fall25/.<sup>\*</sup>")  
(str.in\_re user  
"/fall25/student.<sup>\*</sup>")

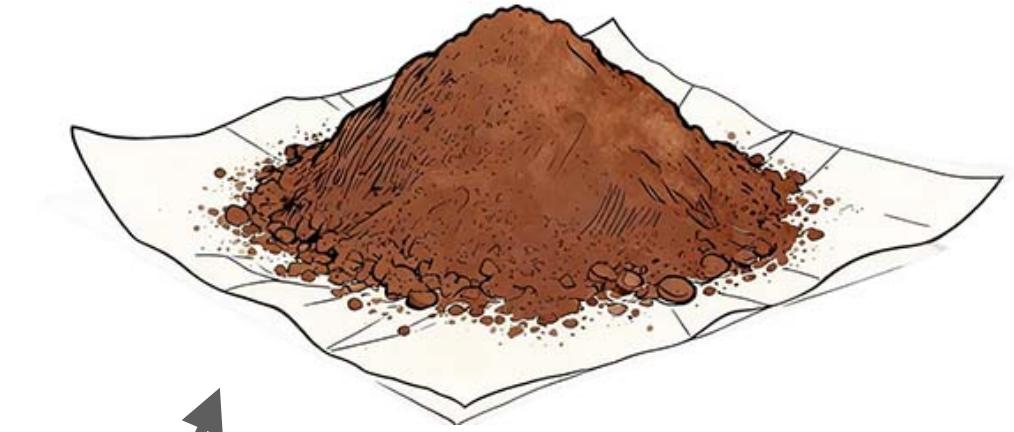


**RE** constraints  
over strings



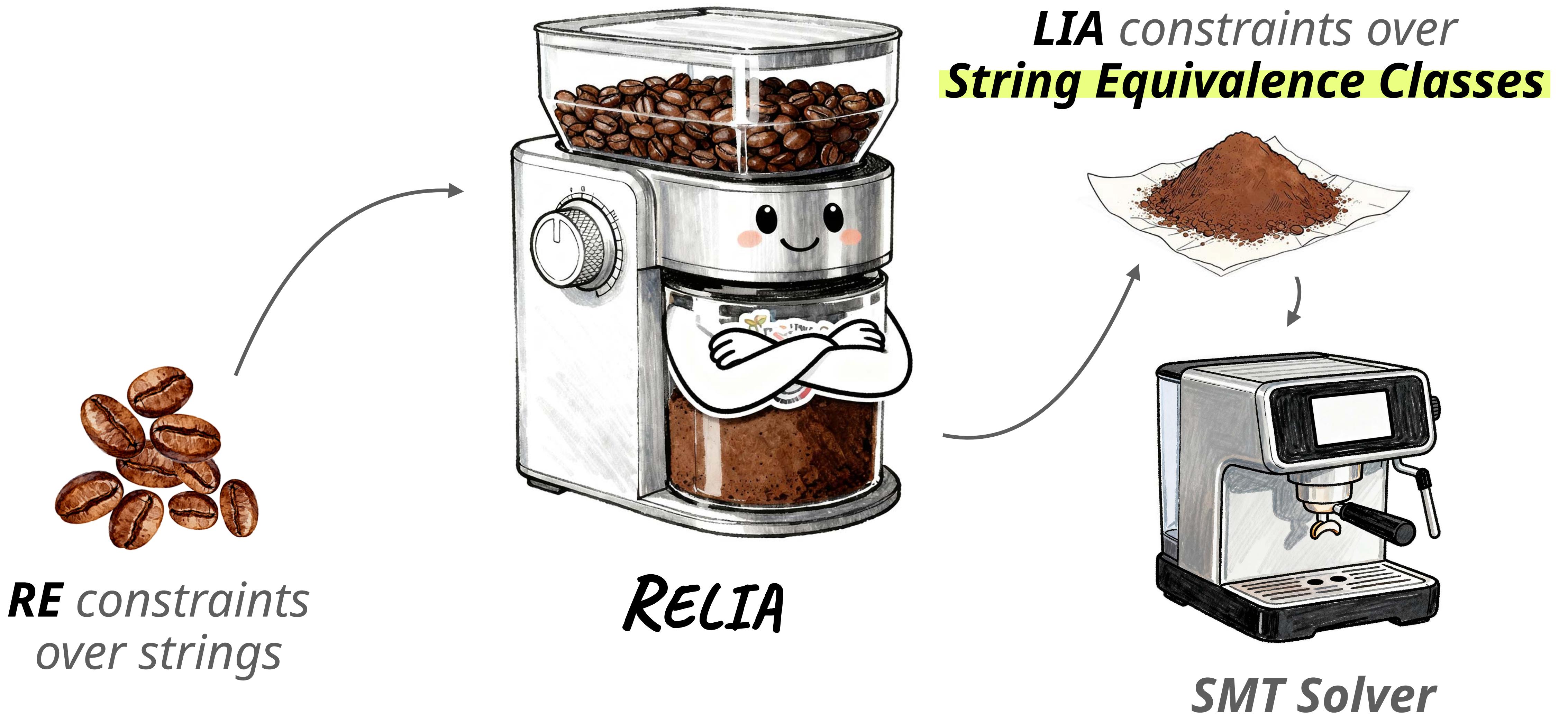
**RELIA**

**LIA** constraints over  
**String Equivalence Classes**



(or (= user 1) (= user 2))  
 (= user 2)  
(and ( $\geq$  user 1) ( $\leq$  user 3)))

# *RELIA: RegEx to LIA (Linear Integer Arithmetic)*



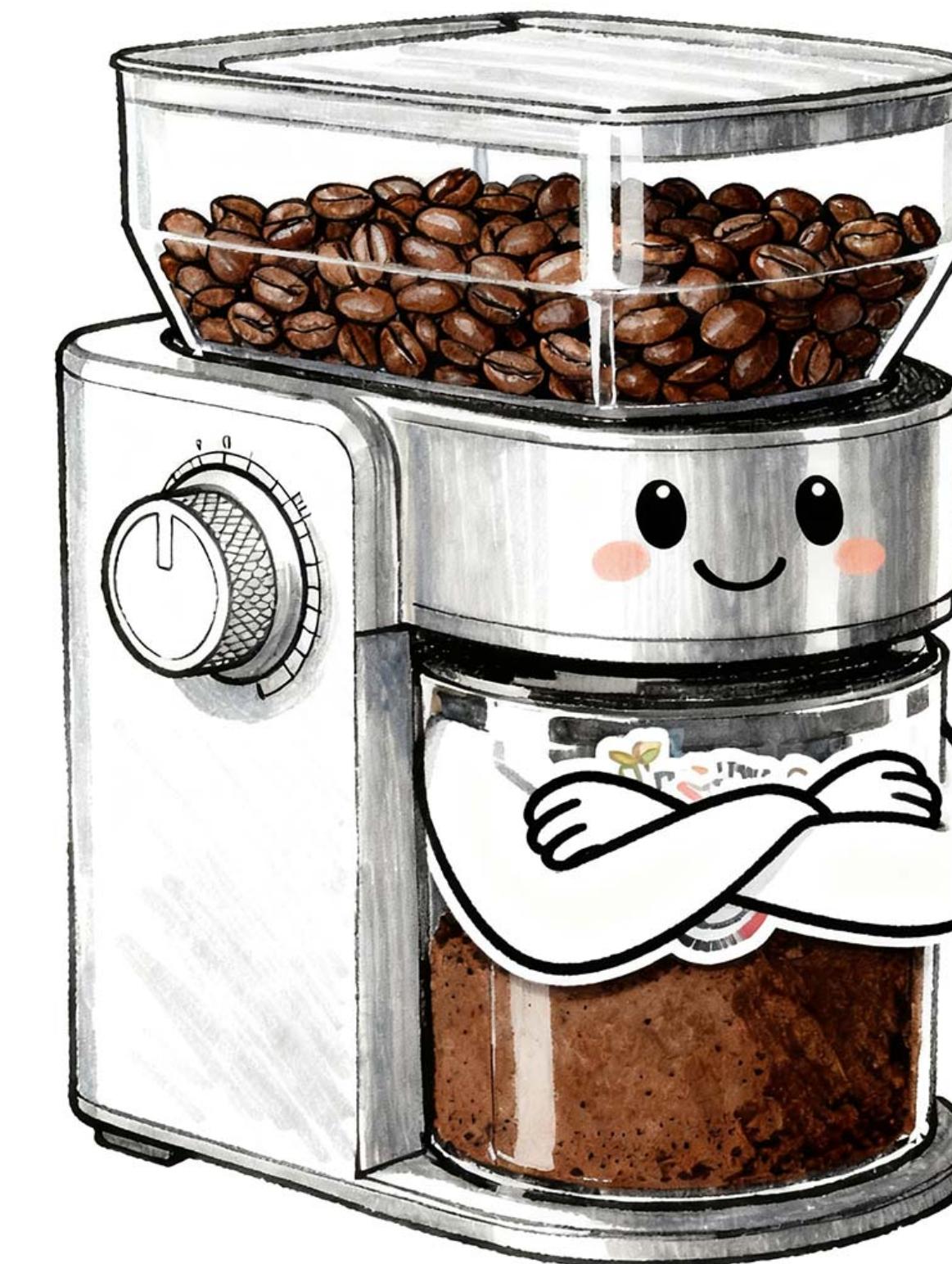
# ***RELIA: RegEx to LIA (Linear Integer Arithmetic)***



*ACP  
Analyzer*

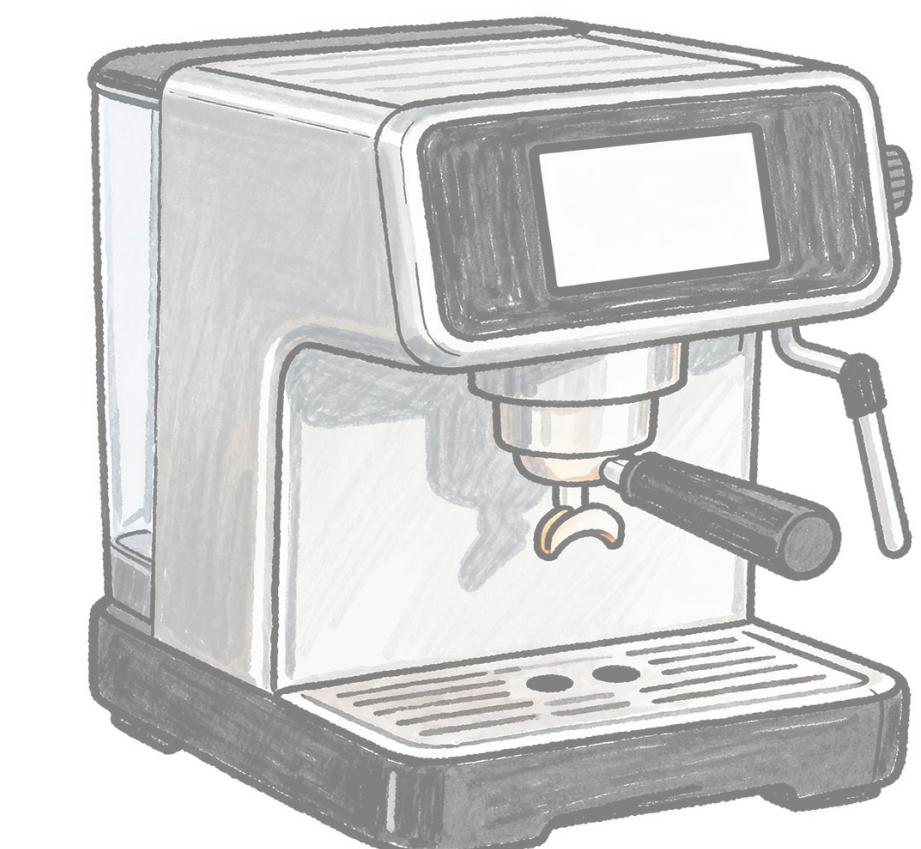


*RE constraints  
over strings*



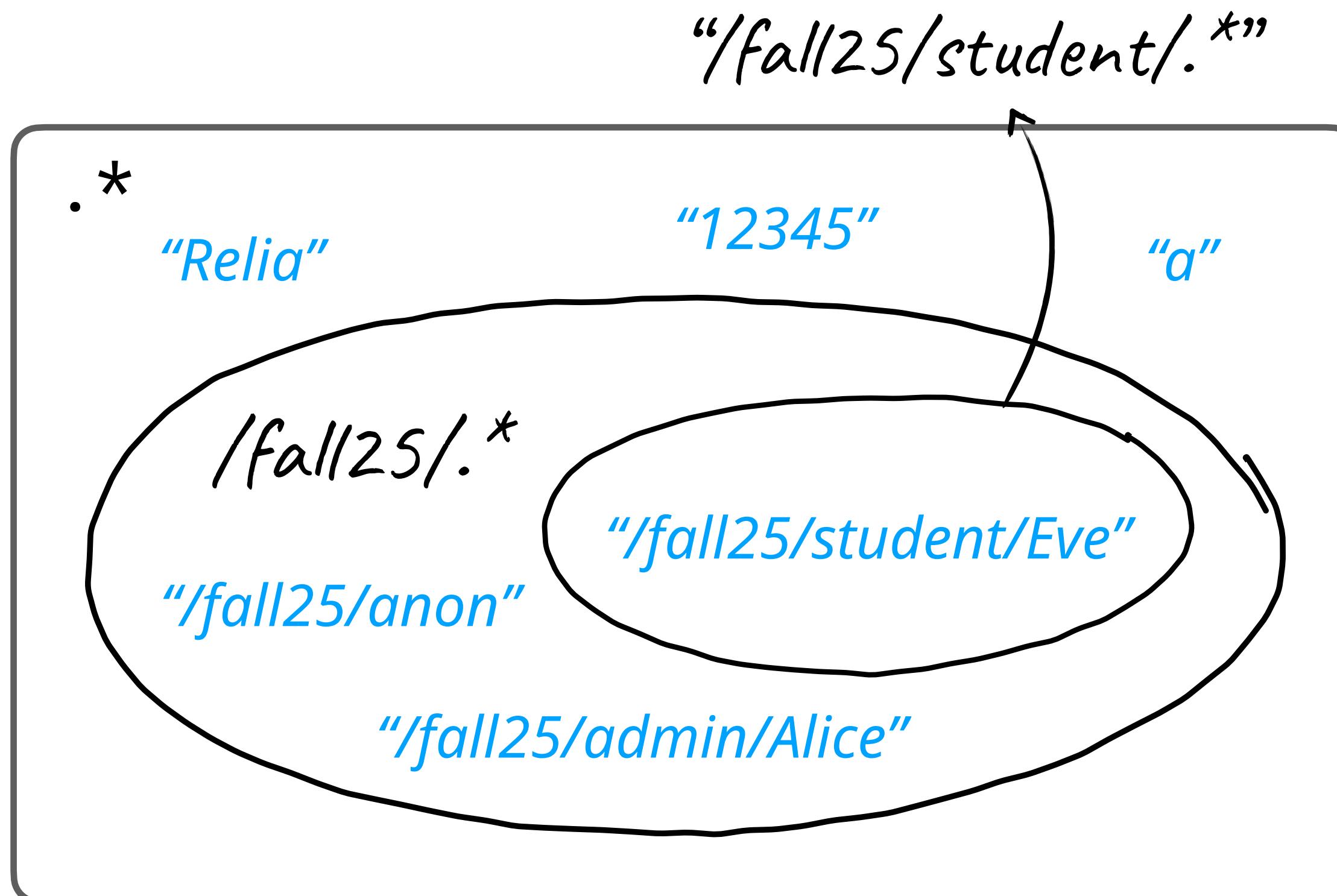
***RELIA***

*LIA constraints over  
**String Equivalence Classes***



*SMT Solver*

# Compute SECs



**Constraints:** { “/fall25/.<sup>\*</sup>”,  
“/fall25/student/.<sup>\*</sup>” }

**SECs:** ① “/fall25/”    ② “/fall25/  
student/.<sup>\*</sup>”     $\neg(\text{student}/).<sup>*</sup>”$

③ “ $\neg(\text{/fall25}/).<sup>*</sup>”$

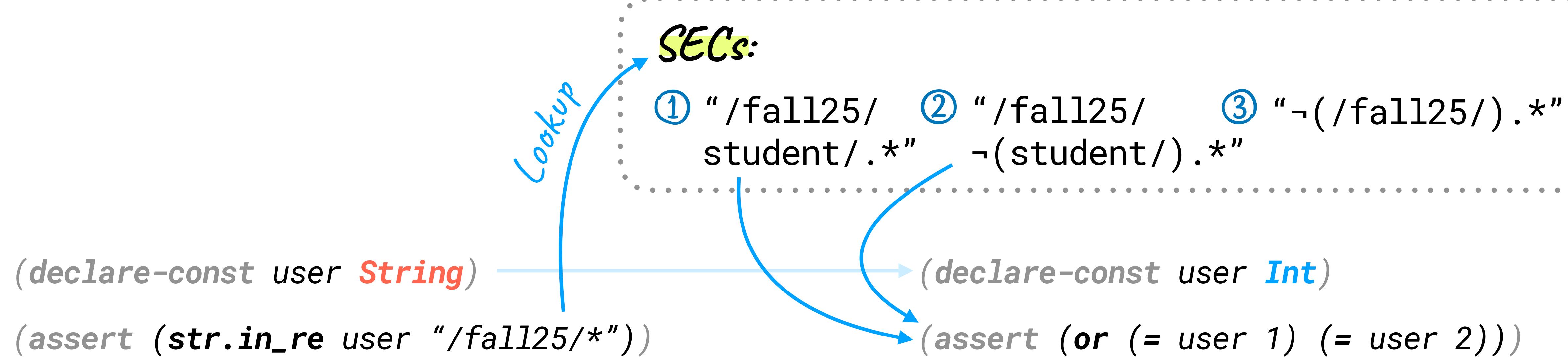
# Convert Constraints

SECs:

- ① “/fall125/ student/. $*$ ”
- ② “/fall125/  $\neg$ (student/. $*$ )”
- ③ “ $\neg$ (/fall125/). $*$ ”

*(declare-const user String)* ————— *convert type to Int* ————— *(declare-const user Int)*

# Convert Constraints



# Convert Constraints

SECs:

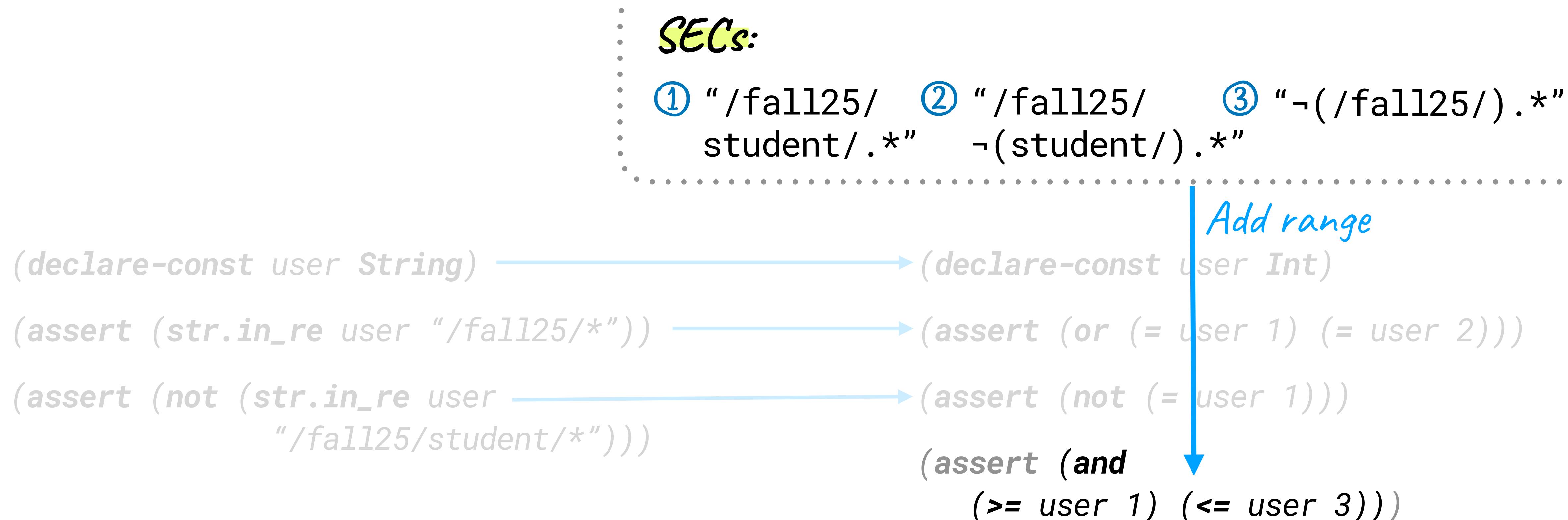
- ① “/fall125/ student/. $*$ ”
- ② “/fall125/  $\neg$ (student/. $*$ )”
- ③ “ $\neg$ (/fall125/). $*$ ”

*(declare-const user String)* → *(declare-const user Int)*

*(assert (str.in\_re user “/fall125/\*”))* → *(assert (or (= user 1) (= user 2)))*

*(assert (not (str.in\_re user “/fall125/student/\*”)))* → *(assert (not (= user 1)))*

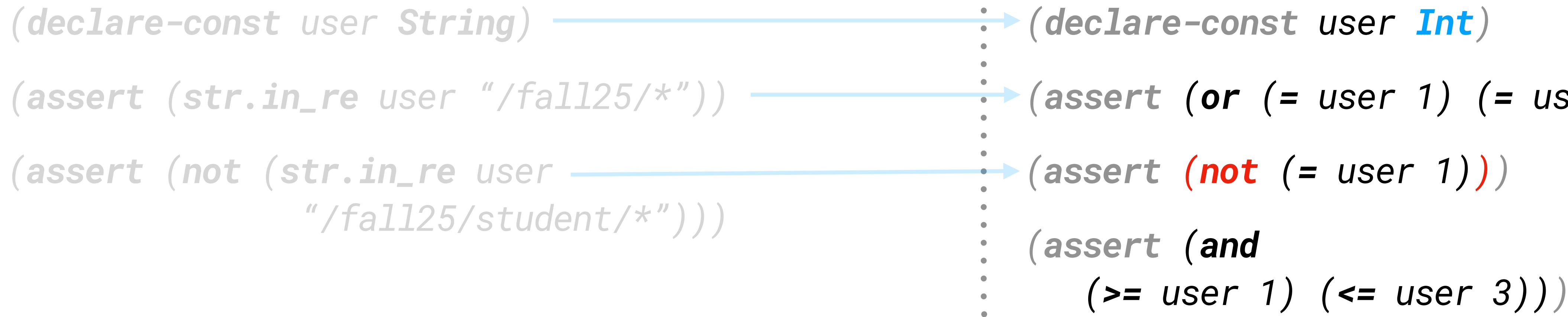
# Convert Constraints



# Convert Constraints

SECs:

- ① “/fall125/”
  - ② “/fall125/”
  - ③ “ $\neg(/fall125/).*$ ”
- student/. $*$ ”       $\neg(\text{student}/).*$ ”



# Handle Concatenation

$id = "/" + semester + "/" + role$

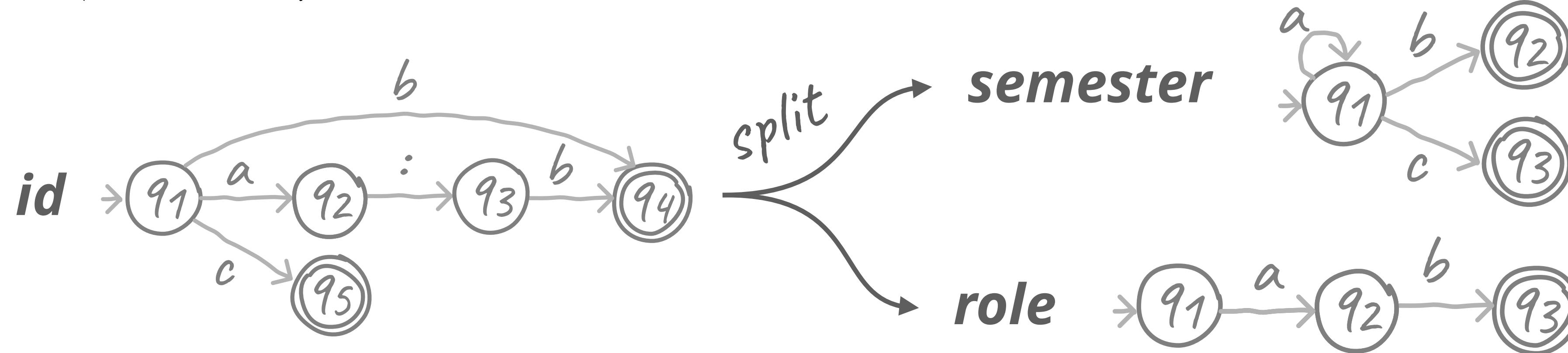
$id \in "/(fall.*|spring.*/(admin|professor)"$

$semester \in ???$

$role \in ???$

We use a **novel FA algorithm** to deal with **string concatenations**.

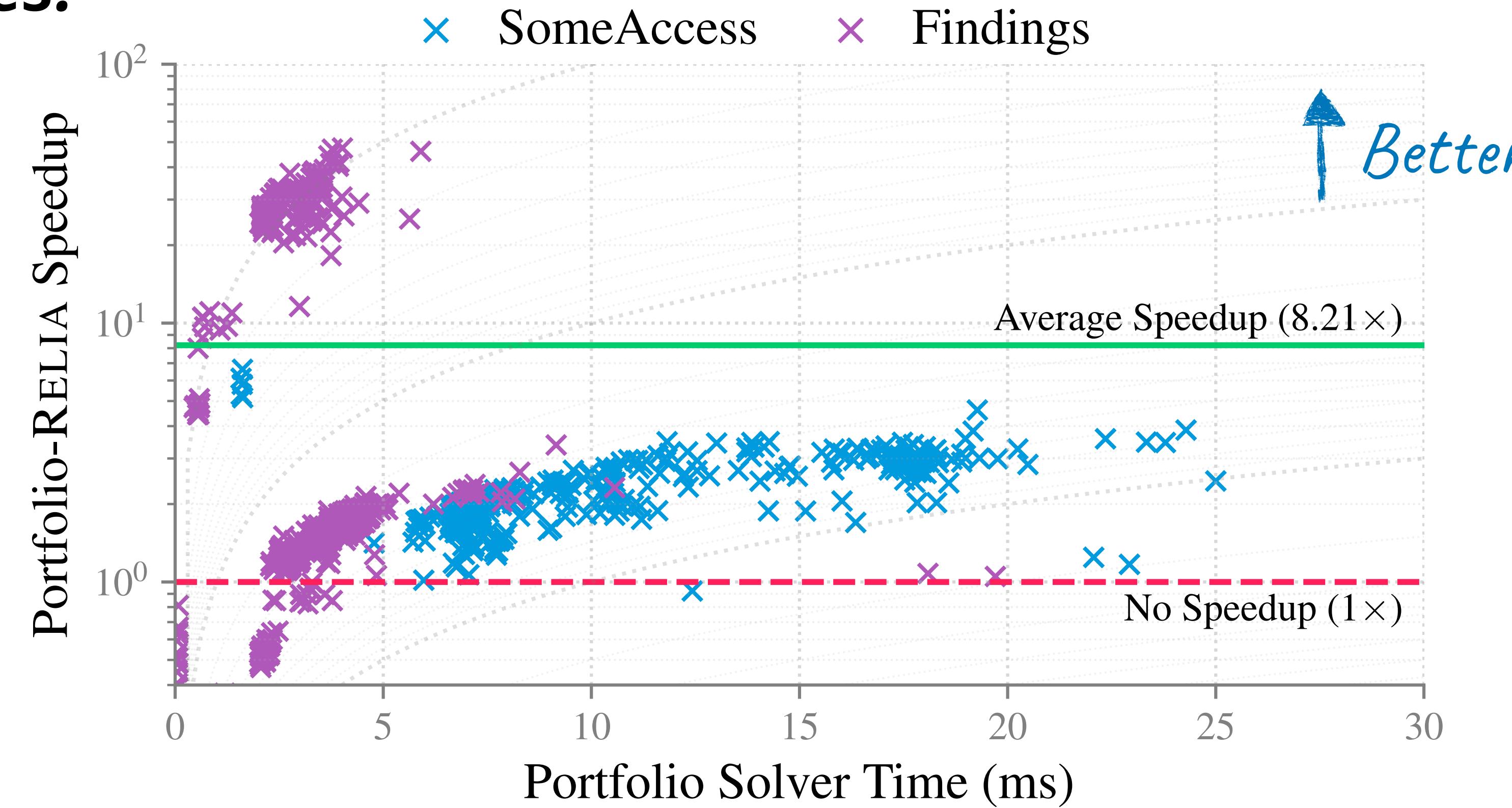
Go to our poster / paper for more!



\*not the actual algorithm, for illustration only

# Evaluations

*Real policies:*



*Speed up the analysis of real policies from Huawei Cloud tenants by **8.21x***

# Evaluations

*Hard policies:*

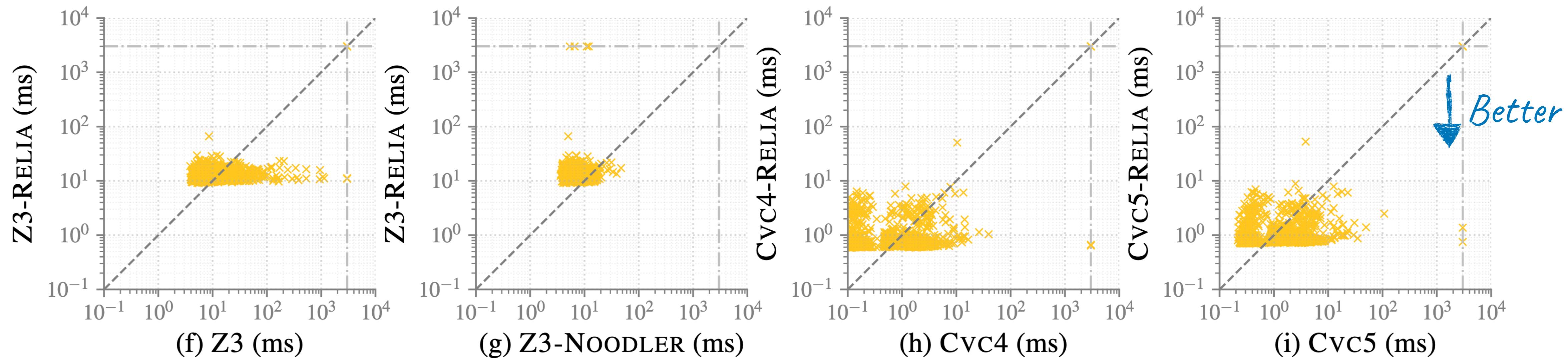
#Cases solved in time	Z3	Cvc4	Cvc5	Z3- Noodler	Cvc5- RELIA
10ms	0	0	0	0	1
100ms	0	0	0	2	4
1s	0	0	0	5	7
10s	1	0	0	5	8

Solve **8/10** hard policies in seconds while Z3 / Cvc5 cannot solve most in hours!

**View our dataset:** <https://zenodo.org/records/17236980>

# *Evaluations*

*We can also accelerate some general SMT string solving!*



*View more results in our poster / paper!*

# Conclusion

1. **Access Control Policies** are essential in Cloud, but analyzing them are slow due to difficulty of solving **string constraints** in SMT.
2. We propose *RELIA*, a tool to bypass string solving by utilizing **String Equivalence Classes**.
3. *RELIA* can accelerate **ACP** analyzers along with some **general** SMT string problems.



# *Happy to take your questions!*

## *RELIA: Accelerating the Analysis of Cloud Access Control Policies*

*NetVerify, ANTS, Xi'an Jiaotong University; Huawei Cloud*

\*Illustrations in the slides are generated using Doubao AI.

