Synthesizing and Analyzing Attribute-Based Access Control Model Generated from Natural Language Policy Statements

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Motivation

- Security requirements are written in natural language
- Access requirements are manually extracted from these documents, represented by some access control model, and then enforced by security mechanisms
- Manual extraction can be tedious and error-prone
- Access control errors can have grave consequences
- *Can we automatically generate access control models from security requirements?*

Access Control Model

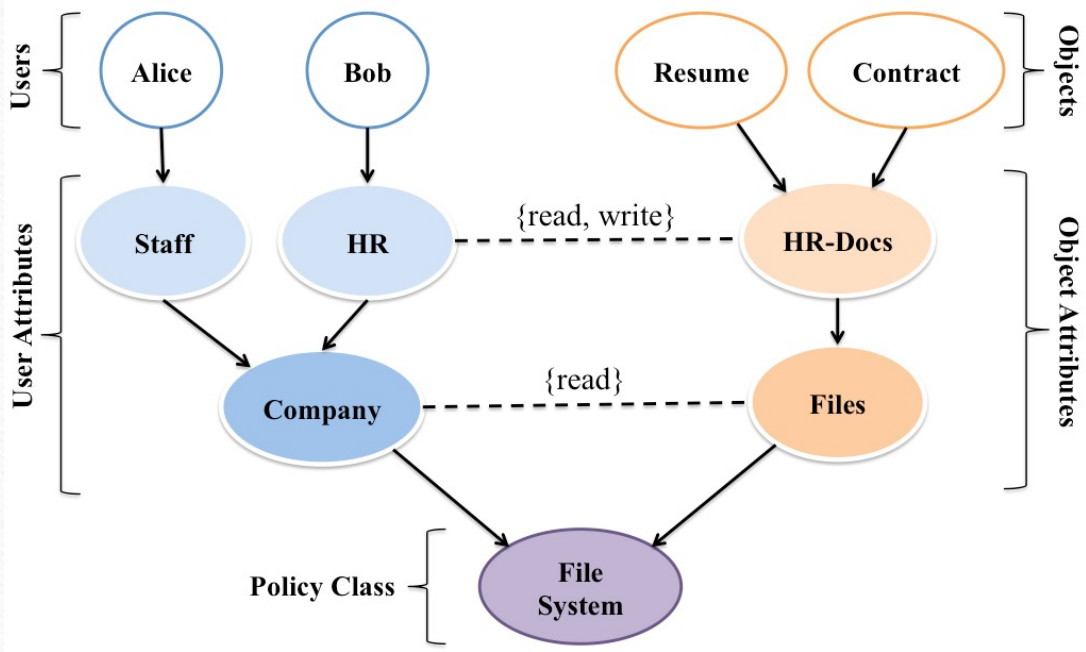
- We focus on NIST Next Generation Access Control Model
- Supports attribute-based access control
  - Entities: users, user attributes, objects, object attributes, policy classes
  - Relations: assignments, associations, prohibition, obligation
- Dynamic access control model: can change policies while they are deployed
- Example usage: situation monitoring applications, applications spanning multiple domains

NGAC Security Model Example

Human Resource File System

- 3 Users
- 2 Resources
- 3 User Attributes
- 2 Resource Attributes
- 1 Policy Class
- 9 Assignments
- 2 Association

AR= {read, write}

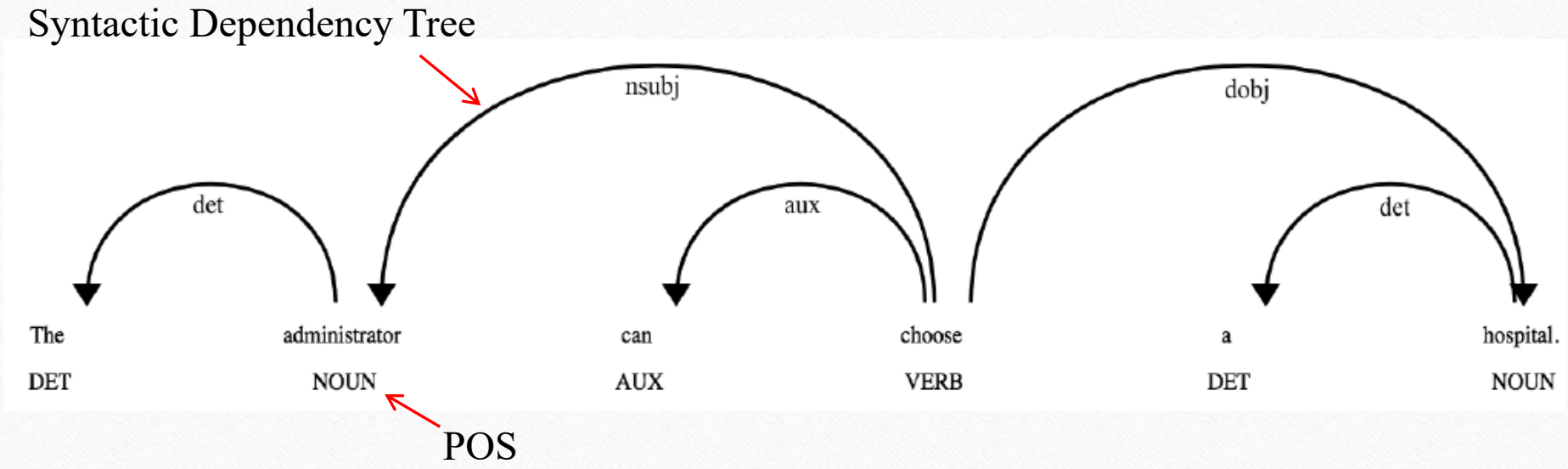


SpaCy Model: Linguistic Features

- **Tokenization:** splits texts into words, punctuation marks etc. (tokens)
- **Part-of-speech (POS) Tagging:** labels tokens as noun, verb, adjective etc.
- **Lemmatization:** assigns the base forms of the word
- **Dependency Parsing:** parses the tokens, generates a syntactic dependency tree, and assigns relations to the links
- **Named Entity Recognition (NER):** identifies various named and numeric entities

SpaCy Model Cont.

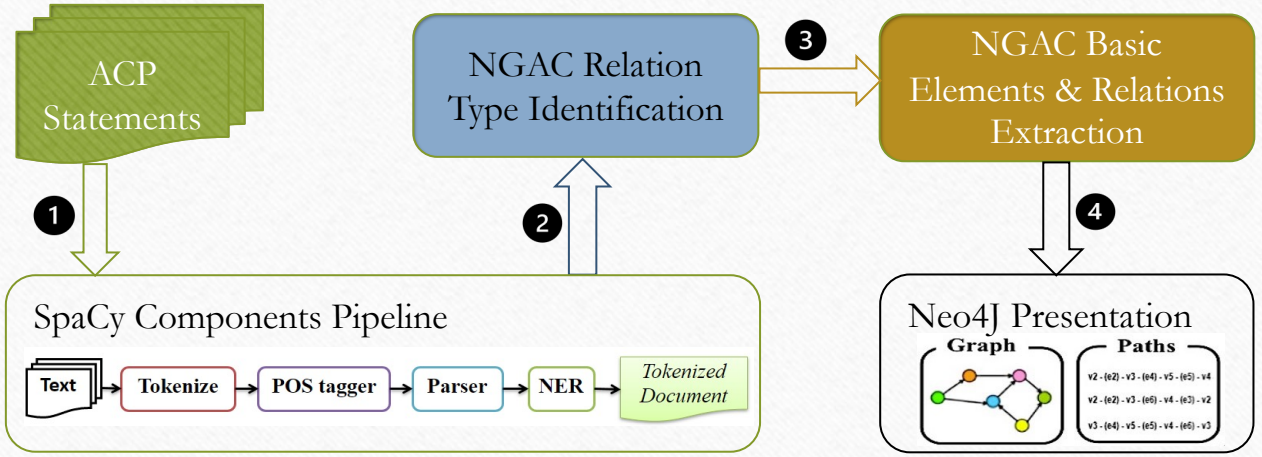
- Example: "The administrator can choose a hospital."



NGAC Security Model Extraction

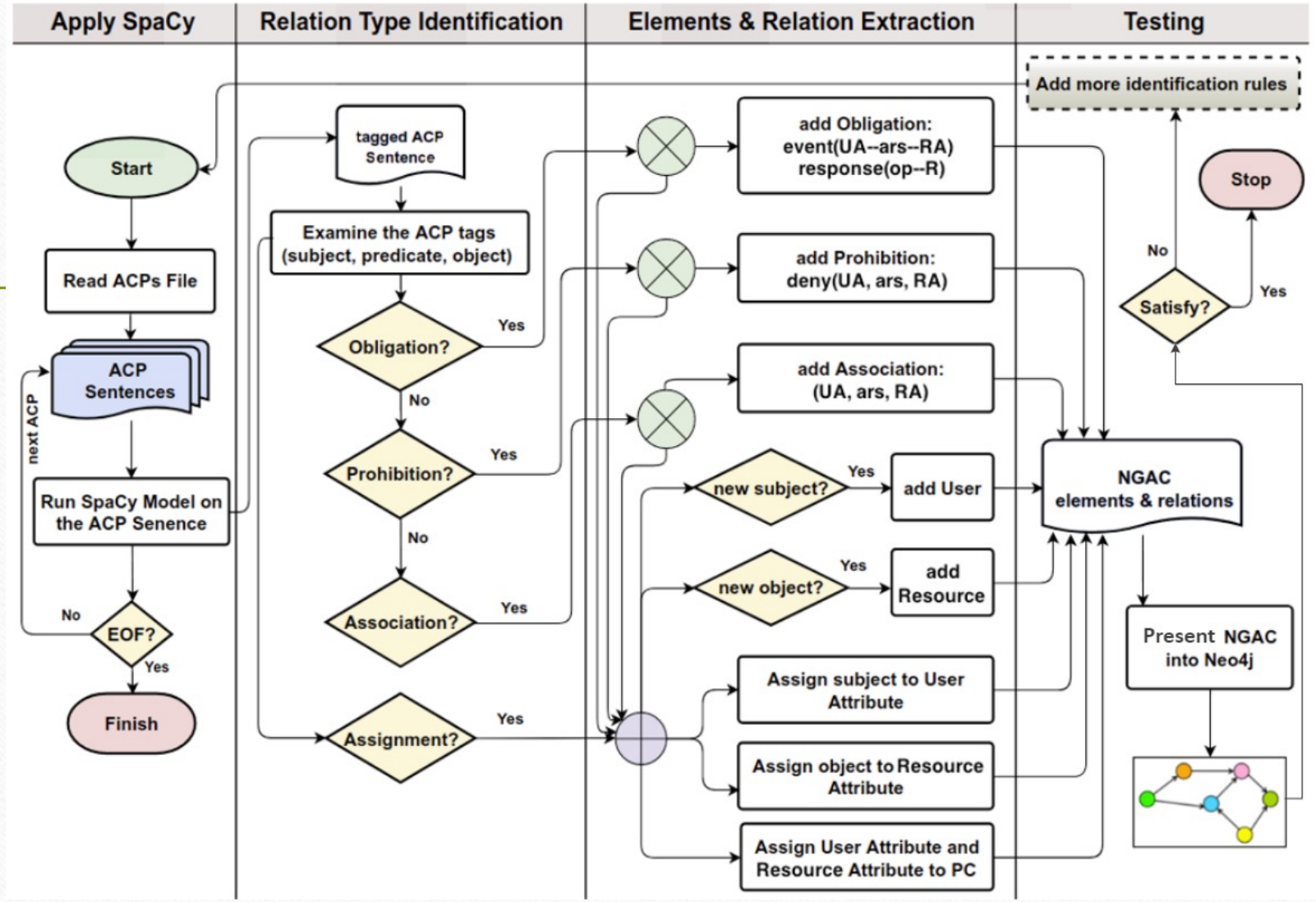
- **Extraction Framework:**

1) Apply NLP to each ACP statement
2) Define the relation type
3) Extract the elements and form them into NGAC relation
4) Present the elements and the relations into Neo4j as graph



NGAC Security Model Extraction

Cross-functional Flowchart



NGAC Extraction: Assignment Rules

- Proper noun subject converted to user
- Common noun subject converted to user attribute
- Proper noun object converted to resource
- Common noun object converted to resource attribute
- User to user attribute relation created
- Resource to resource created

NGAC Extraction: Prohibition Rules

- Syntactic dependency contains a negation pattern
  - a user **cannot** view, or a user is **not allowed** to view an object)
- Root verb is checked against a list of prohibition words
  - prohibit, deny, disallow, forbid, prevent, inhibit

HCP is **prevented** to view the patient's security question and password

$$Prohibition(deny(HCP - \{view\} - security\ question))$$
$$Prohibition(deny(HCP - \{view\} - password))$$

NGAC Extraction: Obligation Rules

- Syntactic dependency has an adverbial clause as (event and response)
- Independent clause represents the response
- Conditional clause corresponds to the event

Whenever the HCP changes the patients' data, an email must be sent to the administrator

$$Obligation(Event : (HCP - \{change\} - patient\ record) \rightarrow Response : (send(email) - administrator))$$

NGAC Extraction: Association Rules

- If the ACP sentence is not obligation or prohibition, is it association?
- Syntactic dependency is used to identify association relation
  - **(subject, predicate, object)**

The administrator can choose a hospital

$$Association(administrator - \{choose\} - hospital)$$

Represent NGAC Elements & Relations in Neo4j

1. Association Statement (UA -[AR]-RA):

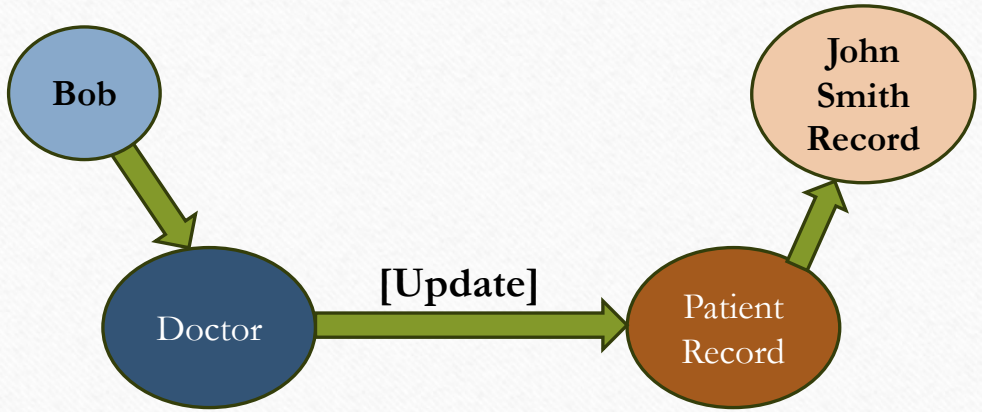
Doctor can **update** the **patient record**

2. User Assignment (U-UA):

Bob is a **doctor**

3. Resource Assignment (R-RA):

John Smith Record is a **patient record**



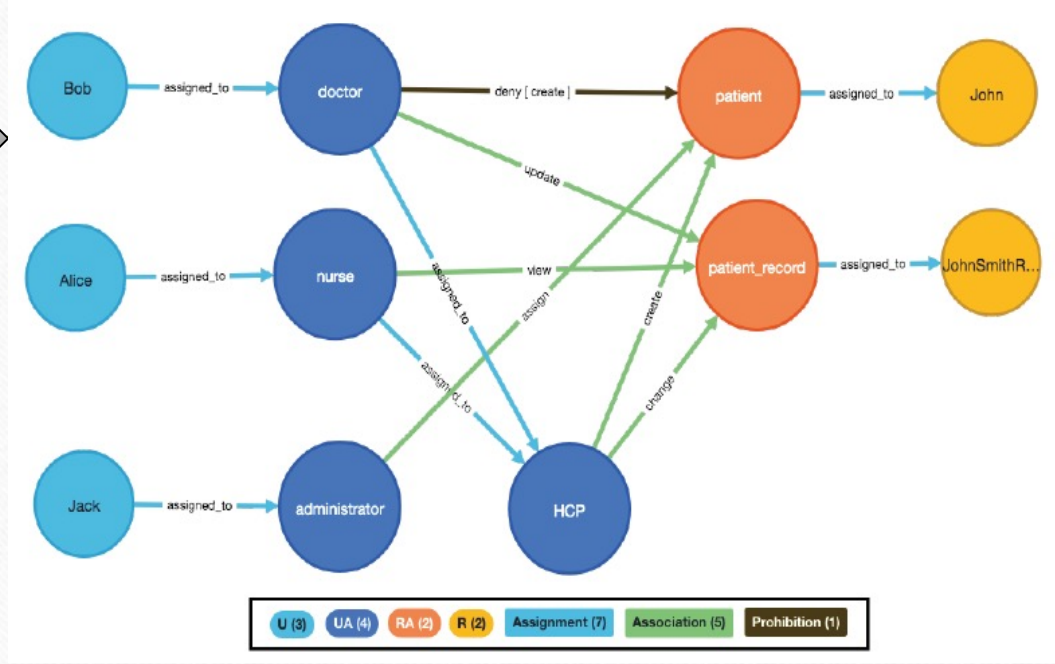
Represent NGAC Elements & Relations in Neo4j

iTrust: Access Control Policies	
1	An HCP creates patients.
2	Doctor is an HCP.
3	Nurse is an HCP.
4	A doctor is prohibited from creating patients.
5	Doctors can update the patient record.
6	Nurses can only view the patient record.
7	Whenever a HCP changes a patient record, an email must be sent to the administrator.
8	The administrator can assign a patient.
Users	
9	Bob is a doctor.
10	Alice is a nurse.
11	Jack is an administrator.
Resources	
12	JohnSmithRecord is a patient record.
13	John is a patient.

8 ACP Sentences from iTrust Dataset

+

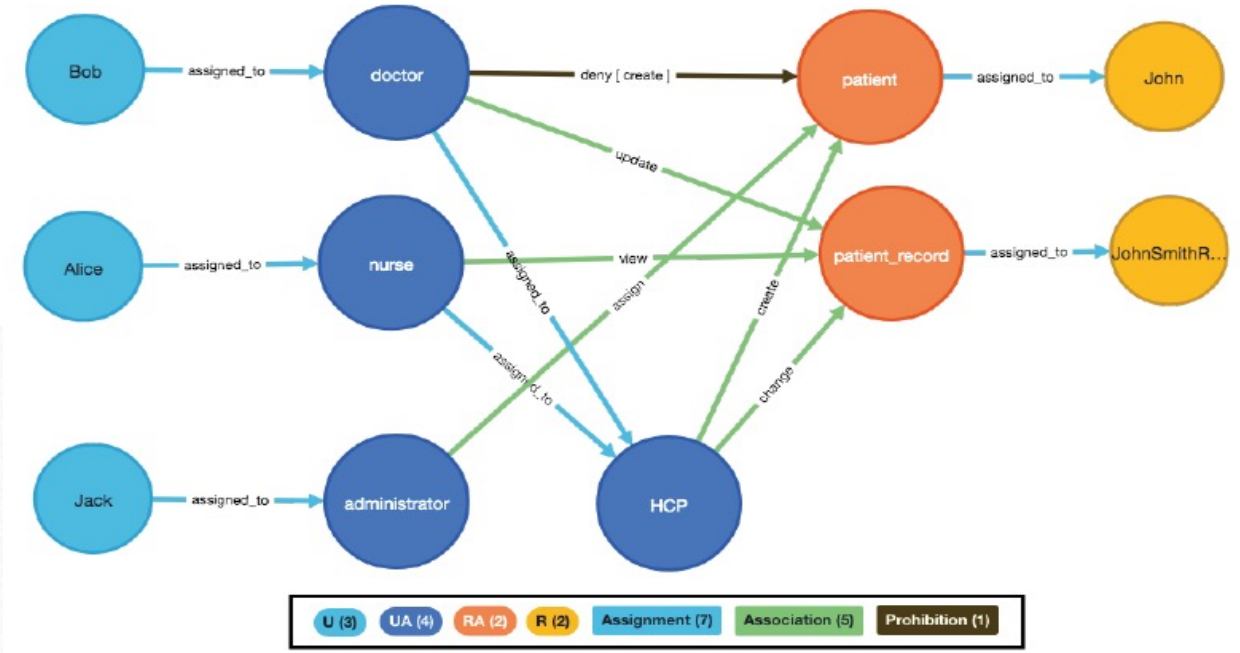
3 Users and 2 Resources



NGAC Graph

Generate Paths from Neo4j Graph

- Use Neo4j Cypher to generate paths
- Each path represents access of user to resource
- 8 Paths that cover the graph from Users to Resources.

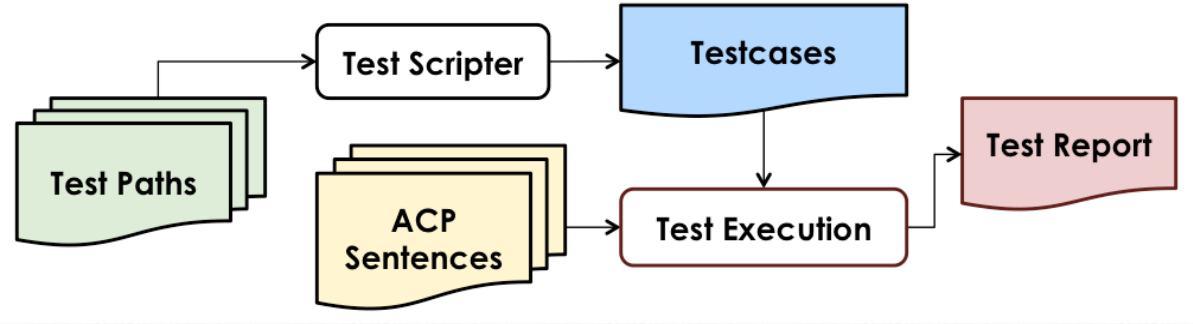


Example of two paths:

1) [{name:"**Bob**"},{assign:"assigned_to"},{name:"**doctor**"},{name:"doctor"},{ars:"**update**"},{name:"patient record"},{name:"**patient record**"}, {assign:"assigned_to"}, {name:"**John Smith Record**"}].

2) [{name:"**Alice**"},{assign:"assigned_to"},{name:"**nurse**"},{name:"nurse"},{ars:"**view**"},{name:"patient record"}, {name:"**patient record**"}, {assign:"assigned_to"},{name:"**John Smith Record**"}].

Testing Process



- Test Scripter loads the generated paths and converts them into testcases
- Test Executor runs the testcases against each ACP, reports the result (pass or fail)
- Applies to 7 Datasets collected from the Web
- Verify the well-formedness properties: Completeness, Consistency, and Minimality

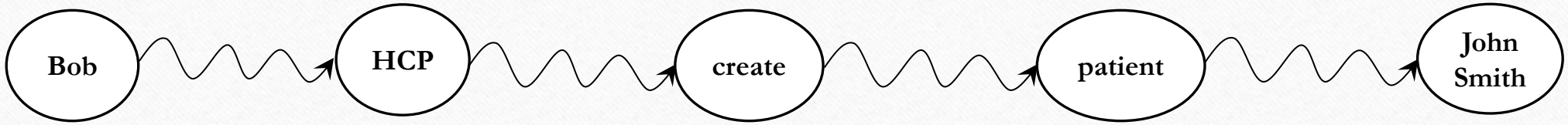
Testing Process Cont.

- **Use Regular Expression to Script Testcases**

  e.g., ACP Sentences: 1) **HCP** can **create patient**
  2) **Bob is HCP**
  3) **John Smith is** a **patient**

Path:

[**{name:"Bob"}**,{assign:"assigned_to"},{name:"**HCP**"},{name:"HCP"},**{ars:"create"}**,{name:"**patient**"},{name:"patient"},{assign:"assigned_to"},**{name:"John"}**]



Regular Expression Pattern = '[{name:"**Bob**".*{name:"**HCP**".*{ars:"**create**".*{name:"**patient**".*{name:"**John Smith**"}]'

Testing Process Cont.

- **Completeness:** Awkward sentences, unnecessary words, incorrect statements

Institute	Dataset Name	# of ACPs
University of Massachusetts Amherst	MA	2
University of Arizona	AZ	9
Georgia State University	GA	20
Colorado State University	CSU	62
New York University	NYU	83
University of Denver	DU	105
Harvard University	Harvard	249

Dataset	# of TCs	# of TCs Passed	Accuracy(%)
MA	16	14	87.50
AZ	31	23	74.19
GA	248	234	94.35
CSU	162	146	90.12
NYU	271	215	79.34
DU	440	388	88.18
Harvard	509	359	70.53

Avg. 83.5%

Testing Process for Consistency

- **Consistency** (Paths-conflict): grant and deny a user for the same resource
  - HCP can create a patient
  - Doctor cannot create a patient
  - Bob is a doctor and HCP.
  - John Smith is a patient.

Two paths conflict:

1) [{name:"**Bob**"},{assign:"assigned_to"},{name:"**doctor**"},{name:"doctor"},{**Deny**:"**create**"},{name:"patient"}, {name:"**patient**"}, {assign:"assigned_to"}, {name:"**John Smith**"}].

2) [{name:"**Bob**"},{assign:"assigned_to"},{name:"**HCP**"},{name:"HCP"},{ars:"**create**"},{name:"patient"}, {nam e:"**patient**"}, {assign:"assigned_to"},{name:"**John Smith**"}].

Testing Process for Minimality

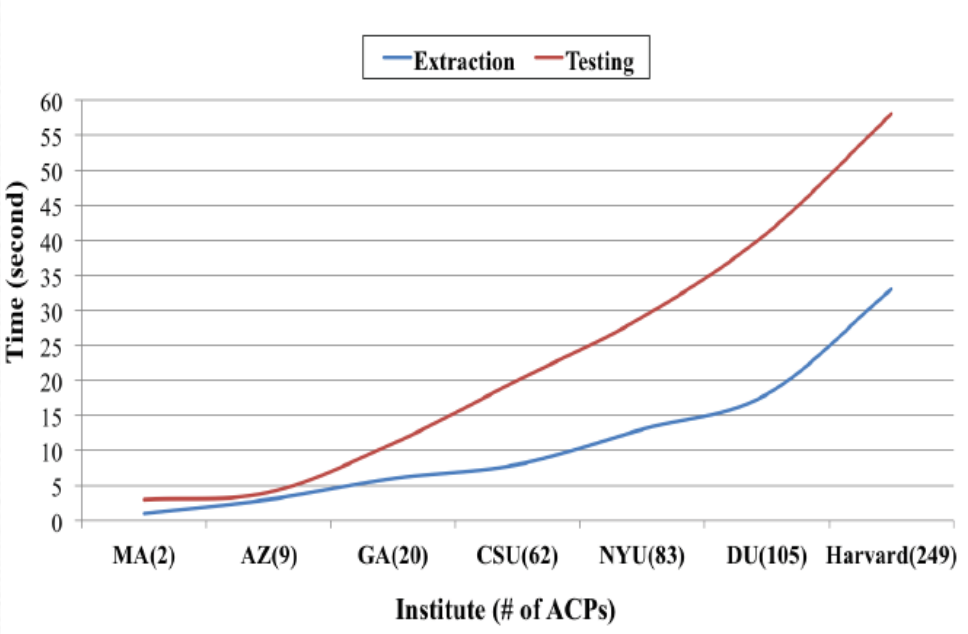
- **Minimality** (Non-redundancy): repeated access right for the same user in various ACP
  - HCP can create a patient
  - Bob is HCP.
  - Bob can create a patient.
  - John Smith is a patient.

Two paths are redundant:

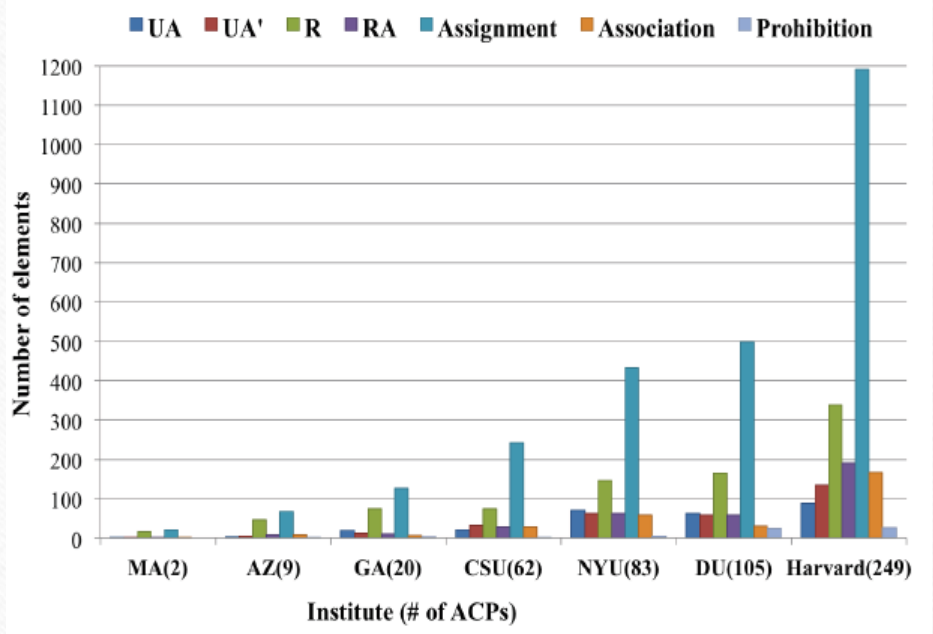
1) [{name:"**Bob**"},{assign:"assigned_to"},{name:"**HCP**"},{name:"HCP"},{ars:"**create**"},{name:"patient"}, {name:"**patient**"}, {assign:"assigned_to"},{name:"**John Smith**"}].

2) [{name:"**Bob**"},{assign:"assigned_to"},{name:"**HCP**"},{name:"HCP"},{ars:"**create**"},{name:"patient"}, {name:"**patient**"}, {assign:"assigned_to"},{name:"**John Smith**"}].

Scalability: Time and Space Complexity



Quadratic Time Complexity



Only Assignment Relations Reached 1200 Nodes for 249 ACP Statements

Future Work

- Clean ACP Datasets
- Multiple levels of hierarchy
- Use graph properties for efficient verification
- Comparision to other NLP models BERT and GPT-3
- Use formal methods to verify whether use case and misuse case scenarios generated from software and security specification complies with the policies