Permission to Speak: An Access Control Logic

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Outline

1. Introduction and motivation
2. System Architecture
3. Inference component
4. Policies and conformance
5. Examples

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Background

Goal: analysis of regulated operations

- Bloodbanks (in the US, subject to FDA regulations)
- Medical records (in the US, subject to HIPAA)

Regulatory documents

- Natural language
  - Explicit references to connect sentences
  - Lots of exceptions
- Translate to logic one sentence at a time
  - Provide traceability
  - Reduce complexity

- This talk: access control

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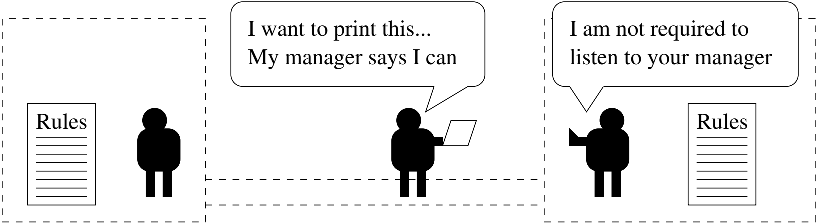
The problem

The problem of access control:

- Should a request be granted?



Questions to answer:

- which policies need to be consulted in granting access?
- which policies are violated and who is to blame?

Access control vs. conformance

Policy-based regulation

- A policy specifies what actions are permitted to happen and what are required to happen
- A policy is issued by an authority
  - A large system may have multiple sources of authority
- Possible actions include
  - Performing access
  - Delegating or authorizing access
  - Delegating the right to authorize access

- Access control is a special case of conformance checking

Deontic policies

Need a framework to combine

- Permission and obligation: deontic modalities
- "Saying": policy/credential introduction

Challenges

- Representation and authorization
- Positive and negative permissions
- Nested deontic modalities

Representation in access control

The **saying** modality

A says φ in the laws $I(A)$: $\mathrm{says}_{I(A)}\varphi$

Representation

- B speaks using the authority of A
  - Allows us to handle authorization and delegation
  - B should be able to make only authorized statements
    - Clear interplay with the notion of permission
- Many formalizations in access control literature
  - Hand-off axiom
  - Many pitfalls to avoid
  - No explicit representation of permissions

Representation: our approach

Axiom of representation

If A says that B is allowed to say φ, then if B says φ, A says φ

$$(\mathrm{says}_{I(A)}(\mathcal{P}_B \mathrm{says}_{I(B)}\varphi) \wedge \mathrm{says}_{I(B)}\varphi) \Rightarrow \mathrm{says}_{I(A)}\varphi$$

Advantages

- Decidable logic with complete semantics
- Hand-off and “speaking for” are obtained as a consequence
  - “speaking for” is representation on all formulas

Positive and negative permissions

A hospital H allows a patient A to access her records

$$\varphi = \mathrm{says}_{I(H)} \mathcal{P}_A(\mathrm{access}(A, A))$$

Suppose the patient listens to music. Is that permitted?

Permission as provability

- Positive permission:
  - Is $\varphi \Rightarrow \mathrm{says}_{I(H)}(\neg \mathcal{O}_A \neg \mathrm{music})$ provable?
- Negative permission:
  - Is $\varphi \Rightarrow \mathrm{says}_{I(H)} \mathcal{O}_A \neg \mathrm{music}$ not provable?

Nested deontic modalities

Parents (*A*) should not let their children (*B*) play by the road

Possible interpretations:

- Positive permission: *A* should not give permission to play
  - Too weak?
- Negative permission: *A* should tell *B* not to play
  - Arguably, adequate
- *A* should physically prevent *B* from playing
  - Too restrictive?

In the regulated setting

If *B* plays by the road, who is to blame: *A* or *B*?

Nested deontic modalities: our approach

Saying is crucial for the analysis

A hospital (H) permits patients (A) to permit their family (B) to access their information

- H says that A is *permitted to say* that B is permitted to access
  - $\mathrm{says}_{I(H)}\mathcal{P}_A\mathrm{says}_{I(A)}\mathcal{P}_B\mathrm{access}(A, B)$
- Now, when A gives permission
  - $\mathrm{says}_{I(A)}\mathcal{P}_B\mathrm{access}(A, B)$
- We should be able to infer that H permits access to B
  - $\mathrm{says}_{I(H)}\mathcal{P}_B\mathrm{access}(A, B)$
- In other words, A represents H on $\mathrm{access}(A, B)$.

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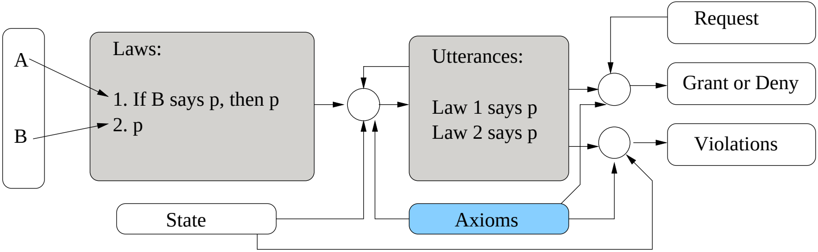
System architecture



Utterances and conformance

- Evaluation of policies yields a set of utterances
- Access control: is a request permitted by utterances?
- Conformance: do actions satisfy obligations in utterances?

Logic of saying and obligation

Syntax of L

$$\varphi \quad ::= \quad \alpha \mid \varphi \wedge \varphi \mid \neg\varphi \mid \text{says}_{Id}\psi \mid \text{says}_{I(y)}\psi$$
$$\psi \quad ::= \quad \varphi \mid \psi \wedge \psi \mid \neg\psi \mid \mathcal{O}_y\varphi$$

- Atomic predicates: $\alpha = p(y_1, \ldots, y_j)$
  - Predicates are applied to objects or variables: $y_i \in X \cup O$
  - E.g. $\text{access}(A, B)$ - access of A's medical records by B
- Saying is parameterized on a set of laws
- Syntax enforces alternation between saying and obligation

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Axiomatization

A1 All substitution instances of propositional tautologies.

A2 $\mathcal{Q}(\varphi \Rightarrow \psi) \Rightarrow (\mathcal{Q}(\varphi) \Rightarrow \mathcal{Q}(\psi))$ (for all modalities $\mathcal{Q}$)

A3 $\mathrm{says}_{Id}\varphi \Rightarrow \mathrm{says}_{Id'}\varphi$ (for all $Id \subseteq Id'$)

A4 $\mathcal{O}_A\varphi \Rightarrow \mathcal{P}_A\varphi$ (for all $A \in O$)

A5 $\mathrm{says}_{Id_A}(\mathcal{P}_B \mathrm{says}_{Id_B}\varphi) \Rightarrow (\mathrm{says}_{Id_B}\varphi \Rightarrow \mathrm{says}_{Id_A}\varphi)$ (for all $\{A, B\} \subseteq O$, $Id_A \subseteq I(A)$, and $Id_B \subseteq I(B)$)

A6 $\mathrm{says}_{Id_A}(\mathcal{P}_B \mathrm{says}_{Id_A}\varphi) \Rightarrow \mathrm{says}_{Id_A}\varphi$ (for all $\{A, B\} \subseteq O$, and $Id_A \subseteq I(A)$)

R1 From $\vdash \varphi \Rightarrow \psi$ and $\vdash \varphi$, infer $\vdash \psi$

R2 From $\vdash \varphi$, infer $\vdash \mathcal{Q}(\varphi)$ (for all modalities $\mathcal{Q}$)

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Decidability

Provability is decidable for the propositional case

For all $\varphi \in L$, $\vdash \varphi$ is decidable

Complexity

- Satisfiability checking is NEXPTIME-complete
- A variant of axioms **A5**, **A6** allows PSPACE satisfiability
  - A strictly larger set of formulas is provable
  - Open question: is it adequate in access control applications?

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Policies

Logic programming framework

- A policy is a collection of statements

$$(id)\ \varphi \mapsto \psi$$

- Each statement has a unique *id*
- Preconditions $\varphi \in L_\varphi$
  - Obligations must be in the scope of saying
- True preconditions must have true postconditions
  - Postconditions may make more preconditions true

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States and assignments

State

- Objects known to the system
- Interpretation of predicates w.r.t. objects
- Example:
  - Objects: A, B, C, d
  - Predicates: $\text{patient}(A)$, $\text{patient}(B)$, $\text{relative}(A, C)$, $\text{access}(B, C)$, $\text{test}(B, d)$

Evaluation of ground formulas

- Policies are evaluated in a given state
- Assignments map variables in the formula to objects

Utterances

- The first step in checking conformance is to determine what has been said.

Utterance is a nugget of saying

$$v(\mathrm{says}_{\{id\}}\psi, S)$$

- Policy contains $(id)\ \varphi \mapsto \psi$
- S is a state, v is an assignment

Utterance pairs (U, U')

- Utterance set U corresponds to true preconditions
- Utterance set U' corresponds to non-false preconditions

Computing utterances (I)

Evaluation of preconditions

- Evaluation is up to an utterance pair: $\mathbf{tv}_{(U,U')}(\varphi, S, v)$
- Interesting case: the saying modality

$$\mathbf{tv}_{(U,U')}(\mathrm{says}_{Id}\psi, S, v) = \begin{cases} \top \text{ if } U \vdash v(\mathrm{says}_{Id}\psi, S) \\ \bot \text{ if } U' \not\vdash v(\mathrm{says}_{Id}\psi, S) \\ ? \text{ otherwise} \end{cases}$$

Consistent utterance pair $U \subseteq U'$

For all policy statements $(id)\ \varphi \mapsto \psi$

- If $v(\mathrm{says}_{\{id\}}\psi, S) \in U$, $\mathbf{tv}_{(U,U')}(\varphi, S, v) = \top$
- If $v(\mathrm{says}_{\{id\}}\psi, S) \notin U'$, $\mathbf{tv}_{(U,U')}(\varphi, S, v) = \bot$

Computing utterances (II)

Fixed point computation

- Initialization: $U = \emptyset$, $U' =$ utterances for all postconditions
- Computation step:
  - Compute $\mathbf{tv}(U, U')$ for all preconditions
  - Add utterances whose preconditions evaluate to $\top$ to U
  - Remove utterances whose preconditions evaluate to $\perp$ from U'
- Stop when fixed point is reached

Correctness

- The partially ordered set of consistent utterances has a least fixed point
- Computation is monotonic

Conformance

Conformance is satisfaction of obligations

- A conforms to the laws Id:

$$\text{If } S \models_{(U,U')} \mathrm{says}_{Id} \mathcal{O}_A \varphi, \text{ then } S \models_{(U,U')} \varphi$$

Access control is permission by the laws of the owner

- A can perform an action p controlled by B

$$S \models_{(U,U')} \mathrm{says}_{I(B)} \mathcal{P}_A p$$

Conformance with nested deontic modalities

Example

- Owners of parking lots must forbid parking by lot entrance
- Our interpretation:
  - Owners of parking lots must introduce rules that forbid parking near lot entrance
  - (P) $\mathrm{owner}(x) \wedge \mathrm{driver}(y) \mapsto \mathcal{O}_x \mathrm{says}_{l(x)} \mathcal{O}_y \neg \mathrm{pk}(y, x)$

Conformance

- If an owner A does not introduce any rules and $\mathrm{pk}(B, A)$
  - B conforms to (P) but A does not conform to (P)
- If A introduces $\mathrm{driver}(y) \mapsto \mathcal{O}_y \neg \mathrm{pk}(y, A)$
  - A conforms to (P) but B does not conform to (P)

A more elaborate example

Health Insurance Portability and Accountability Act (HIPAA)

- Regulates the uses and disclosures of health information
- Hospitals have local policies, must be HIPAA compliant
- Users give written consent, also part of the regulation

1. An individual **has a right** to access her PHI, except for:
   i. Psychotherapy notes;
   ii. PHI compiled for a legal proceeding; or
   ...

What is a right?

Formalization

Our interpretation

1 An individual **is permitted to require the hospital to permit** to access her PHI, except for:

- i Psychotherapy notes;
- ii PHI compiled for a legal proceeding; or
- ...

- Let $\varphi(x, y, z) = \mathrm{ind}(x) \wedge \mathrm{says}_{I(HIPAA)}\mathrm{ce}(y) \wedge \mathrm{info}(z, x, y)$

(1) $\varphi(x, y, z) \wedge \neg\mathrm{says}_{\{i,ii\}}\mathrm{list}(z) \mapsto \mathcal{P}_x\mathrm{says}_{I(x)}\mathcal{O}_y\mathrm{says}_{I(y)}\mathcal{P}_x\mathrm{access}(x, z)$

Hospital and user policies

Conformant policies

- A permissive hospital: $\top \mapsto \mathcal{P}_A \mathrm{access}(A, r)$
- A hospital who only wants to give access when HIPAA requires it:
  - $\top \mapsto \mathcal{P}_{HIPAA} \mathrm{says}_{I(HIPAA)} \mathcal{O}_H \mathrm{says}_{I(H)} \mathcal{P}_A \mathrm{access}(A, r)$
  - *H* permits *HIPAA* to require it to permit *A* to access.

HIPAA consent forms

- $\top \mapsto \mathcal{O}_H \mathrm{says}_{I(H)} \mathcal{P}_A \mathrm{access}(A, r)$
- Registrars care only about obligations imposed by the hospital

Happy end: $\mathrm{says}_{I(H)} \mathcal{P}_A \mathrm{access}(A, r)$ is derived

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Conclusions

- Logic to represent regulatory documents
  - permission, obligation, cross-referencing
  - multiple sources of authority
- Aimed at checking conformance
  - conformance is decidable and reasonably efficient in practice
- Cross-references can be compiled away for acyclic regulation
  - lose traceability (counterexample generation)
- Designed with NLP in mind
  - Parser is work in progress

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