An Authorization Logic with Explicit Time

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Computer Security Foundations 2008
June 24, 2008

Outline

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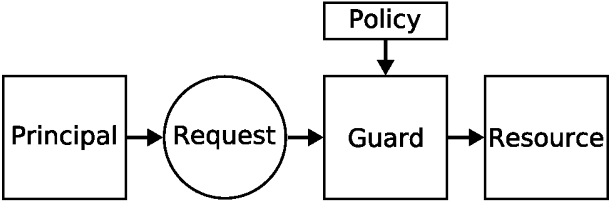
The Problem of Access Control



Source: [Lampson *et al.* '92]

- Problem
  - Restrict access to a resource according to *policy*.
- Approach
  - Specify (and enforce) policies using an *authorization logic*.

Logic for Access Control

Policies are expressed as logical theories. [LABW ’92]

Benefits:

- Precision
  - Logical specifications are more precise than natural language.
- Flexibility
  - Can incorporate user-defined predicates.
  - Can easily change policies without changing the system.
- Enforcement via PCA [AF ’99, Bauer ’03]
  - Allow access to a resource if and only if a formal proof of access is presented.
- Policy Analysis
  - Consequence of proof-theory.
  - E.g., non-interference theorems. [GP ’06, Abadi ’06]

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Motivating Example: Office Entry

Setting:

- admin, who controls entry to academic offices.
- Alice, a professor.
- Bob, a graduate student of Alice.

Policy:

- During 2007–2008, the admin allows a person K_1 to enter an office owned by a person K_2, provided that K_2 has authorized K_1 to enter.

Dilemma:

- Alice is at CSF this week.
- Bob needs a book from Alice's office.

A Traditional Approach to Time-Dependent Policies

Traditional approach:

- Ignore time-dependencies in the logical formulation of the policy.
- Policy:

$$\mathrm{admin}\ \textsf{says}\ (\forall K_1.\forall K_2.((K_2\ \textsf{says}\ \texttt{may\_enter}(K_1, K_2)) \supset \texttt{may\_enter}(K_1, K_2)))$$

- Alice signs a certificate allowing Bob to enter during the week 6/23/08–6/30/08.

$$\mathrm{Alice}\ \textsf{says}\ \texttt{may\_enter}(\mathrm{Bob}, \mathrm{Alice})$$

- Bob tries to enter at 1pm 6/24/08. He must prove:

$$\mathrm{admin}\ \textsf{says}\ \texttt{may\_enter}(\mathrm{Bob}, \mathrm{Alice})$$

- Credentials used in the proof are checked for expiration.

Drawbacks:

- Correct proofs might be rejected because of expired credentials.
- Cannot analyze time using logical methods.

A Better Approach to Time-Dependent Policies

Better approach:

- Include time in the logic.
- Policy:

$$(\mathrm{admin}\ \textsf{says}\ (\forall K_1.\forall K_2.((K_2\ \textsf{says}\ \texttt{may\_enter}(K_1, K_2)) \supset \texttt{may\_enter}(K_1, K_2)))) \ @\ [2007, 2008]$$

- Alice signs a certificate allowing Bob to enter during the week 6/23/08–6/30/08.

$$(\mathrm{Alice}\ \textsf{says}\ \texttt{may\_enter}(\mathrm{Bob}, \mathrm{Alice}))\ @\ [6/23/08, 6/30/08]$$

- Bob tries to enter at 1pm 6/24/08. He must prove:

$$(\mathrm{admin}\ \textsf{says}\ \texttt{may\_enter}(\mathrm{Bob}, \mathrm{Alice}))\ @\ [\text{1pm } 6/24/08, \text{1pm } 6/24/08]$$

Benefits:

- Proof construction is accurate with respect to time.
- Analysis of time-dependent policies.

Purpose of the Paper

- Design an authorization logic (for use with PCA) in which time-dependent policies can be specified and enforced.
- Hence, we propose η logic (explicit time authorization logic).

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Key Ideas of η Logic

Key Ideas:

- Intuitionistic sequent calculus.
- All truths and statements are relativized to a set of time points.
- Authorization policies use *absolute, specific* sets of time.
  - Temporal logic seems inadequate.
  - For convenience, sets of time are called “intervals”.
- Model explicit time with hybrid @.
  - Hybrid logic: modal logic where worlds may appear in formulas.
  - Worlds $\cong$ intervals.
- Abstract away from “implementation” of times and sets of time.
  - Require only a partial order of inclusion on intervals.
- Constraints for modeling the usual inclusion ordering on intervals.

Syntax and Basic Judgments

Syntax:

$$A, B ::= K \text{ says } A \mid A \mathbin{@} I \mid P \mid A \supset B \mid \forall x{:}s.A \mid \ \ldots$$

Martin-Löf: Judgments are the objects of knowledge and evidenced by proofs. Propositions are the subjects of judgments.

Basic Judgments:

1. $A[I]$: A is true on I.
   - Judgmental form of $A \mathbin{@} I$.
2. (K affirms A) at I: During I, K affirms that A is true on I.
   - Judgmental form of (K says A) $\mathbin{@} I$.

Hypothetical Judgments

Hypotheses:

- Ψ contains $I \supseteq I'$ constraint hypotheses
- Γ contains $A[I]$ hypotheses

Hypothetical Judgments:

1. $\Psi \models I \supseteq I'$
2. $\Psi; \Gamma \Longrightarrow A[I]$
3. $\Psi; \Gamma \Longrightarrow (K \text{ affirms } A) \text{ at } I$

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Inference Rules: Hypothetical Judgments

$$\frac{\Psi \models I \supseteq I' \quad (P \text{ atomic})}{\Psi; \Gamma, P[I] \Longrightarrow P[I']}\ \text{init}$$

Inference Rules: @ as a Hybrid Connective

$$\frac{\Psi ; \Gamma \Longrightarrow A[I]}{\Psi ; \Gamma \Longrightarrow (A \mathbin{@} I)[I']}\ @R \qquad \frac{\Psi ; \Gamma, (A \mathbin{@} I)[I'], A[I] \Longrightarrow \gamma}{\Psi ; \Gamma, (A \mathbin{@} I)[I'] \Longrightarrow \gamma}\ @L$$

Admissible properties:

- Write $\vdash A$ if $\cdot ; \cdot \Longrightarrow A[I'']$ for all I'' and all instantiations of the propositional variables. Write $\nvdash A$ otherwise.

1. $\nvdash (A \mathbin{@} I) \supset (A \mathbin{@} I')$ (in general)
2. $\vdash (A \mathbin{@} I) \supset (A \mathbin{@} I')$ if $\cdot \models I \supseteq I'$
3. $\vdash (A \mathbin{@} I \mathbin{@} I') \equiv (A \mathbin{@} I)$

Inference Rules: $\supset$

$$\frac{\Psi, I \supseteq i; \Gamma, A[i] \Longrightarrow B[i] \quad (i \text{ fresh})}{\Psi; \Gamma \Longrightarrow (A \supset B)[I]} \supset R$$

$$\frac{\Psi \models I \supseteq I' \quad \Psi; \Gamma, (A \supset B)[I] \Longrightarrow A[I'] \quad \Psi; \Gamma, (A \supset B)[I], B[I'] \Longrightarrow \gamma}{\Psi; \Gamma, (A \supset B)[I] \Longrightarrow \gamma} \supset L$$

1. $\vdash ((A \supset B) @ I) \supset ((A @ I) \supset (B @ I))$
2. $\not\vdash ((A @ I) \supset (B @ I)) \supset ((A \supset B) @ I)$

Inference Rules: says as a K-Indexed Monad

$$\frac{\Psi;\Gamma \Longrightarrow A[I]}{\Psi;\Gamma \Longrightarrow (K \text{ affirms } A) \text{ at } I}\ \text{affirms}$$

$$\frac{\Psi;\Gamma \Longrightarrow (K \text{ affirms } A) \text{ at } I}{\Psi;\Gamma \Longrightarrow (K \text{ says } A)[I]}\ \text{says}R$$

$$\frac{\Psi;\Gamma,(K \text{ says } A)[I], A[I] \Longrightarrow (K \text{ affirms } B) \text{ at } I' \quad \Psi \models I \supseteq I'}{\Psi;\Gamma,(K \text{ says } A)[I] \Longrightarrow (K \text{ affirms } B) \text{ at } I'}\ \text{says}L$$

1. $\vdash A \supset (K \text{ says } A)$
2. $\vdash (K \text{ says } (A \supset B)) \supset ((K \text{ says } A) \supset (K \text{ says } B))$
3. $\vdash (K \text{ says } (K \text{ says } A)) \supset (K \text{ says } A)$
4. $\not\vdash (K \text{ says } A) \supset A$
5. $\not\vdash ((K \text{ says } A) \mathbin{@} I) \supset (K \text{ says } (A \mathbin{@} I))$
6. $\not\vdash (K \text{ says } (A \mathbin{@} I)) \supset ((K \text{ says } A) \mathbin{@} I)$

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Meta-theory

Theorem (Admissibility of Cut)

If $\Psi; \Gamma \Longrightarrow A[I]$ *and* $\Psi; \Gamma, A[I] \Longrightarrow \gamma$, *then* $\Psi; \Gamma \Longrightarrow \gamma$.

- Entails the subformula property.
- Consequently, the connectives are defined *entirely* by their left and right rules.

Theorem (Subsumption)

If $\Psi; \Gamma \Longrightarrow A[I]$ *and* $\Psi \models I \supseteq I'$, *then* $\Psi; \Gamma \Longrightarrow A[I']$.

- Verifies desirable behavior of intervals.
- Verifies a proper fit between constraint and logical reasoning.

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PCA with η Logic

Principals state policies by digitally signing certificates.

When a principal requests access to a resource:

1. The certificates are converted to logical assumptions Γ; validity bounds I are converted to $@\, I$ in Γ.
2. The principal must submit a proof of
$$\cdot; \Gamma \Longrightarrow A_{\text{access}}[\text{now}, \text{now} + \epsilon]$$
where:
   - A_{access} is the required formula to access the resource
   - (By subsumption, it is sufficient to prove
   $$\cdot; \Gamma \Longrightarrow A_{\text{access}}[I]$$
   for any I such that $\cdot \models I \supseteq [\text{now}, \text{now} + \epsilon]$.)
3. Access is granted if and only if the proof is correct.

Proof construction is now correct with respect to time.

Modeling Consumable Credentials

Problem:

- As presented in this talk, η logic cannot model consumable credentials.
- Alice probably wants Bob to enter *at most once* during the week 6/23/08–6/30/08.

Solution:

- In our paper, η logic incorporates linear logic to express "use-once" authorizations.
  - Follows previous work on linear authorization logics (without time). [GBBPR '06, CCDEdHL '06, BM '06]
- Example, inference rules, admissible properties, and meta-theory all easily extend to the linear case (see paper).

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Future Work and Summary

Future work:

- Formal comparison of η logic to other logics and languages.
- Implementation of a PCA architecture based on η logic.
- Extend non-interference theorems to η logic. [GP '06, Abadi '06]

Summary:

- Using logic for access control provides several benefits.
- If the logic does not include time, benefits cannot apply to time.
- Therefore, we propose η logic.
  - Incorporates time internally using a hybrid @ connective.
  - Possesses "nice" meta-theoretic properties such as admissibility of cut.
  - Can be extended to model consumable credentials.

Thank you!

Questions?

Intuitionistic vs. Classical Logic

- Keep the logic constructive to make evidence as direct as possible.
  - Key role of proofs in the system.
- In classical logic, $\neg\neg A \supset A$ holds.
  - If there is no proof of access denial ($\neg\neg A$), then there is a proof of access (A).
  - Risky for security purposes: a proof of denial might have been overlooked.
- In constructive logic, $\neg\neg A \supset A$ is not provable.

Adding Linearity

Refine basic judgments:

1. $A[I]$: *Single-use* resource A is true on I.
2. $A[\![I]\!]$: *Multi-use* fact A is true on I.
3. (K affirms A) at I: During I, K affirms that *single-use* resource A is true on I.

Refine hypothetical judgments:

1. $\Psi; \Gamma; \Delta \Longrightarrow A[I]$
2. $\Psi; \Gamma; \Delta \Longrightarrow (K \text{ affirms } A) \text{ at } I$

$$\frac{\Psi \models I \supseteq I'}{\Psi; \Gamma; P[I] \Longrightarrow P[I']}\ \text{init} \qquad \frac{\Psi; \Gamma, A[\![I]\!]; \Delta, A[I] \Longrightarrow \gamma}{\Psi; \Gamma, A[\![I]\!]; \Delta \Longrightarrow \gamma}\ \text{copy}$$

Inference Rules: $\wedge$

$$\frac{\Psi; \Gamma \Longrightarrow A[I] \quad \Psi; \Gamma \Longrightarrow B[I]}{\Psi; \Gamma \Longrightarrow (A \wedge B)[I]} \wedge R$$

$$\frac{\Psi; \Gamma, (A \wedge B)[I], A[I] \Longrightarrow \gamma}{\Psi; \Gamma, (A \wedge B)[I] \Longrightarrow \gamma} \wedge L_1 \qquad \frac{\Psi; \Gamma, (A \wedge B)[I], B[I] \Longrightarrow \gamma}{\Psi; \Gamma, (A \wedge B)[I] \Longrightarrow \gamma} \wedge L_2$$

1. $\vdash ((A \wedge B) @ I) \equiv ((A @ I) \wedge (B @ I))$

Meta-theory: Identity

Theorem (Identity)

For all A, if $\Psi \models I \supseteq I'$, then $\Psi; \Gamma, A[I] \Longrightarrow A[I']$.

- Generalizes the init rule to compound propositions.

Generic Non-Interference Theorem

- If $\Psi;\Gamma, A[I] \Longrightarrow B[I']$ and $\langle$some criteria on Ψ, Γ, A, I, B, $I'\rangle$, then $\Psi;\Gamma \Longrightarrow B[I']$.