Access Control and Privacy Policies (5)

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Slides: KEATS (also homework is there)

Satan's Computer

Ross Anderson and Roger Needham wrote:

> In effect, our task is to program a computer which gives answers which are subtly and maliciously wrong at the most inconvenient possible moment... we hope that the lessons learned from programming Satan's computer may be helpful in tackling the more common problem of programming Murphy's.

Protocol Specifications

The Needham-Schroeder Protocol:

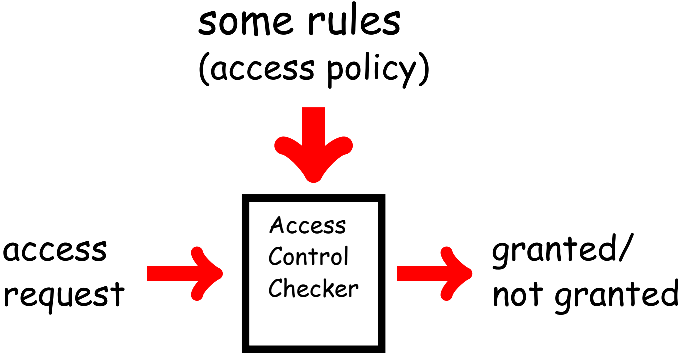
Message 1 $A \rightarrow S : A, B, N_A$
Message 2 $S \rightarrow A : \{N_A, B, K_{AB}, \{K_{AB}, A\}_{K_{BS}}\}_{K_{AS}}$
Message 3 $A \rightarrow B : \{K_{AB}, A\}_{K_{BS}}$
Message 4 $B \rightarrow A : \{N_B\}_{K_{AB}}$
Message 5 $A \rightarrow B : \{N_B - 1\}_{K_{AB}}$

Cryptographic Protocol Failures

Again Ross Anderson and Roger Needham wrote:

> A lot of the recorded frauds were the result of this kind of blunder, or from management negligence pure and simple. However, there have been a significant number of cases where the designers protected the right things, used cryptographic algorithms which were not broken, and yet found that their systems were still successfully attacked.

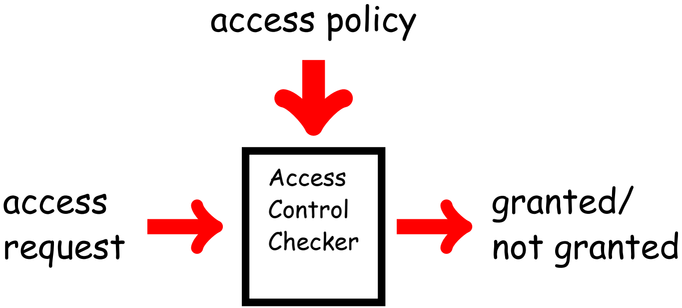
The Access Control Problem



Access Control Logic

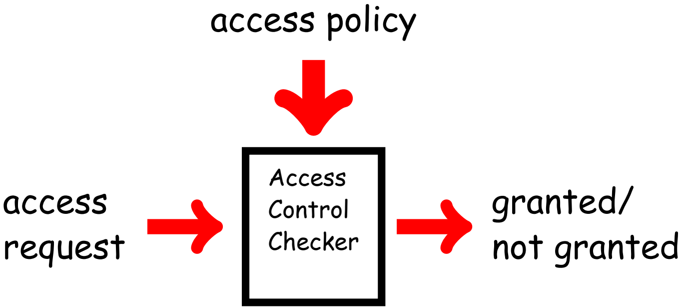
Ross Anderson about the use of Logic:

> Formal methods can be an excellent way of finding bugs in security protocol designs as they force the designer to make everything explicit and thus confront difficult design choices that might otherwise be fudged.



Assuming one file on my computer contains a virus.

Q: Given my access policy, can this file “infect” my whole computer?



Assuming one file on my computer contains a virus.

Q: Can my access policy prevent that my whole computer gets infected.

. . .
is_at_library (Christian)
is_student (a) $\wedge$ is_at_library (a) $\Rightarrow$ may_obtain_email (a)
is_staff (a) $\wedge$ is_at_library (a) $\Rightarrow$ may_obtain_email (a)

? may_obtain_email (Christian)

. . .

$is\_at\_library\ (Christian)$
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$HoD\ says\ is\_staff\ (a) \Rightarrow is\_staff\ (a)$
$HoD\ says\ is\_staff\ (Christian)$

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. . .

is_at_library (Christian)

is_student (a) $\wedge$ is_at_library (a) $\Rightarrow$ may_obtain_email (a)

is_staff (a) $\wedge$ is_at_library (a) $\Rightarrow$ may_obtain_email (a)

HoD says is_staff (a) $\Rightarrow$ is_staff (a)

HoD says is_staff (Christian)

may_obtain_email (a) $\wedge$ sending_spam (a) $\Rightarrow$ $\neg$ may_obtain_email (a)

? may_obtain_email (Christian)

There are two ways for tackling such problems:

- either you make up our own language in which you can describe the problem,
- or you use an existing language and represent the problem in this language.

Logic(s)

- Formulas

$$
\begin{array}{lcll}
F & ::= & \text{true} & \\
 & | & \text{false} & \\
 & | & F \wedge F & \\
 & | & F \vee F & \\
 & | & F \Rightarrow F & \text{implies} \\
 & | & \neg\, F & \text{negation} \\
 & | & p\,(t_1,\ldots,t_n) & \text{predicates}
\end{array}
$$

Terms $t ::= x \ldots \mid c \ldots$

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& | & p\,(t_1,\ldots,t_n) & \text{predicates} \\
& | & \forall\, x.\, F & \text{forall quantification} \\
& | & \exists\, x.\, F & \text{exists quantification}
\end{array}
$$

Terms $t ::= x \ldots \mid c \ldots$

```
abstract class Term
case class Var(s: String) extends Term
case class Consts(s: String) extends Term
case class Fun(s: String, ts: List[Term]) extends Term

abstract class Form
case object True extends Form
case object False extends Form
case class And(f1: Form, f2: Form) extends Form
case class Or(f1: Form, f2: Form) extends Form
case class Imp(f1: Form, f2: Form) extends Form
case class Neg(f: Form) extends Form
case class Pred(s: String, ts: List[Term]) extends Form
```

Judgements

$$\Gamma \vdash F$$

Γ is a collection of formulas, called the assumptions

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Γ is a collection of formulas, called the assumptions

- Example

$$\begin{array}{l} \text{is\_staff (Christian)}, \\ \text{is\_at\_library (Christian)}, \\ \forall x.\ \text{is\_at\_library}(x) \wedge \text{is\_staff}(x) \Rightarrow \text{may\_obtain\_email}(x) \end{array} \vdash \text{may\_obtain\_email (Christian)}$$

Judgements

$$\Gamma \vdash F$$

Γ is a collection of formulas, called the assumptions

- Example

$$\frac{\text{is\_staff (Christian)} \quad \text{is\_at\_library (Christian)} \quad \forall x.\ \text{is\_at\_library}(x) \wedge \text{is\_staff}(x) \Rightarrow \text{may\_obtain\_email}(x)}{\text{may\_obtain\_email (Christian)}}$$

Judgements

$$\Gamma \vdash F$$

Γ is a collection of formulas, called the assumptions

- Example

$$\frac{\begin{array}{l}\text{is\_staff (Alice)}\\ \text{is\_staff (Christian)}\\ \text{is\_at\_library (Christian)}\\ \forall x.\ \text{is\_at\_library}\ (x) \wedge \text{is\_staff}\ (x) \Rightarrow \text{may\_obtain\_email}\ (x)\end{array}}{\text{may\_obtain\_email (Alice)}}$$

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case class Judgement(Gamma: List[Form], F: Form) {
  def lhs = Gamma
  def rhs = F
}
```

Inference Rules

$$\frac{\text{premise}_1 \quad \ldots \quad \text{premise}_n}{\text{conclusion}}$$

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$$\frac{\Gamma \vdash F_1 \quad \Gamma \vdash F_2}{\Gamma \vdash F_1 \wedge F_2}$$

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- Examples

$$\frac{\Gamma \vdash F_1 \quad \Gamma \vdash F_2}{\Gamma \vdash F_1 \wedge F_2}$$

$$\frac{\Gamma \vdash F_1}{\Gamma \vdash F_1 \vee F_2} \qquad \frac{\Gamma \vdash F_2}{\Gamma \vdash F_1 \vee F_2}$$

Implication

$$\frac{\Gamma, F_1 \vdash F_2}{\Gamma \vdash F_1 \Rightarrow F_2}$$

$$\frac{\Gamma \vdash F_1 \Rightarrow F_2 \quad \Gamma \vdash F_1}{\Gamma \vdash F_2}$$

Universal Quantification

$$\frac{\Gamma \vdash \forall x.\, F}{\Gamma \vdash F[x := t]}$$

Start Rules / Axioms

if $F \in \Gamma$

$$\overline{\Gamma \vdash F}$$

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Also written as:

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$$\frac{}{\Gamma \vdash F}$$

Also written as:

$$\frac{}{\Gamma, F \vdash F}$$

$$\frac{}{\Gamma \vdash \mathit{true}}$$

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$$\frac{\Gamma \vdash \text{is\_staff (Christian)} \qquad \Gamma \vdash \text{is\_at\_library (Christian)}}{\Gamma \vdash \text{is\_staff (Christian)} \wedge \text{is\_at\_library (Christian)}}$$

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$$\frac{\vdots \qquad\qquad \vdots}{\Gamma \vdash \text{may\_obtain\_email (Christian)}}$$

Access Control

$$\Gamma \vdash F$$

- If there is a proof $\Rightarrow$ yes (granted)
- If there isn't $\Rightarrow$ no (denied)

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$$\Gamma \nvdash may\_obtain\_email\ (Alice)$$

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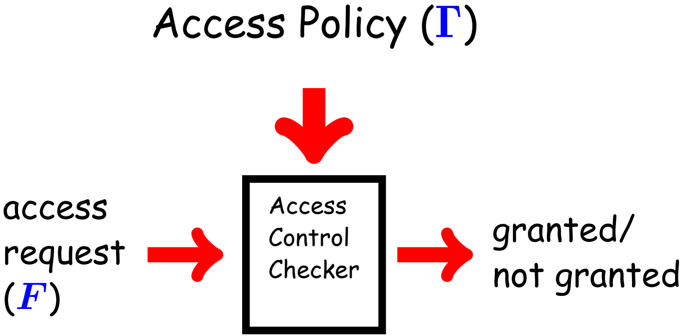

Bad News

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The problem is semi-decidable.

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where P ::= Alice, Bob, Christian, ... (principals)

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- HoD says is_staff (Christian)

Rules about Says

$$\frac{\Gamma \vdash F}{\Gamma \vdash P \text{ says } F}$$

$$\frac{\Gamma \vdash P \text{ says } (F_1 \Rightarrow F_2) \qquad \Gamma \vdash P \text{ says } F_1}{\Gamma \vdash P \text{ says } F_2}$$

$$\frac{\Gamma \vdash P \text{ says } (P \text{ says } F)}{\Gamma \vdash P \text{ says } F}$$

Consider the following scenario:

- If Admin says that $file_1$ should be deleted, then this file must be deleted.
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$$\Gamma \vdash \text{del\_file}_1$$

$$\frac{\Gamma \vdash F}{\Gamma \vdash P \text{ says } F}$$

$$\frac{\Gamma \vdash P \text{ says } (F_1 \Rightarrow F_2) \qquad \Gamma \vdash P \text{ says } F_1}{\Gamma \vdash P \text{ says } F_2}$$

$$\begin{array}{ll} & (\text{Admin says del\_file}_1) \Rightarrow \text{del\_file}_1, \\ \Gamma = & (\text{Admin says } ((\text{Bob says del\_file}_1) \Rightarrow \text{del\_file}_1)), \\ & \text{Bob says del\_file}_1 \end{array}$$

$$\Gamma \vdash \text{del\_file}_1$$

$$\underbrace{\dfrac{\overline{\Gamma \vdash \text{Bob says del\_file}}}{\Gamma \vdash \text{Admin says (Bob says del\_file)}}}_{X}$$

$$\underbrace{\dfrac{\overline{\Gamma \vdash \text{Admin says (Bob says del\_file} \Rightarrow \text{del\_file)}} \quad \begin{array}{c}\vdots\\ X\end{array}}{\Gamma \vdash \text{Admin says del\_file}}}_{Y}$$

$$\dfrac{\overline{\Gamma \vdash \text{(Admin says del\_file)} \Rightarrow \text{del\_file}} \quad \begin{array}{c}\vdots\\ Y\end{array}}{\Gamma \vdash \text{del\_file}}$$

Controls

- $P \text{ controls } F \equiv (P \text{ says } F) \Rightarrow F$
- its meaning "P is entitled to do F"
- if P controls F and P says F then F

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$$\frac{\Gamma \vdash \mathsf{P\ controls\ F} \quad \Gamma \vdash \mathsf{P\ says\ F}}{\Gamma \vdash \mathsf{F}}$$

$$\frac{\Gamma \vdash (\mathsf{P\ says\ F}) \Rightarrow \mathsf{F} \quad \Gamma \vdash \mathsf{P\ says\ F}}{\Gamma \vdash \mathsf{F}}$$

Speaks For

- $P \mapsto Q \equiv \forall F.\ (P \text{ says } F) \Rightarrow (Q \text{ says } F)$
- its meaning "P speaks for Q"

$$\frac{\Gamma \vdash P \mapsto Q \quad \Gamma \vdash P \text{ says } F}{\Gamma \vdash Q \text{ says } F}$$

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$$\frac{\Gamma \vdash P \mapsto Q \quad \Gamma \vdash P \text{ says } F}{\Gamma \vdash Q \text{ says } F}$$

$$\frac{\Gamma \vdash P \mapsto Q \quad \Gamma \vdash Q \text{ controls } F}{\Gamma \vdash P \text{ controls } F}$$

$$\frac{\Gamma \vdash P \mapsto Q \quad \Gamma \vdash Q \mapsto R}{\Gamma \vdash P \mapsto R}$$

Tickets

- Tickets control access to restricted objects.

  Example: Permitted (Bob, enter_flight) ?

- Bob says Permitted (Bob, enter_flight)
  (access request)

- Ticket says (Bob controls Permitted (Bob, enter_flight))

- Airline controls (Bob controls Permitted (Bob, enter_flight))
  (access policy)

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- Airline controls (Bob controls Permitted (Bob, enter_flight))
  (access policy)
- Ticket $\mapsto$ Airline
  (trust assumption)

Tickets

1. $\text{Bob says Permitted (Bob, enter\_flight)}$
2. $\text{Ticket says (Bob controls Permitted (Bob, enter\_flight))}$
3. $\text{Airline controls (Bob controls Permitted (Bob, enter\_flight))}$
4. $\text{Ticket} \mapsto \text{Airline}$

Is $\Gamma \vdash \text{Permitted (Bob, enter\_flight)}$ derivable ?

$$\frac{\Gamma \vdash P \text{ controls } F \quad \Gamma \vdash P \text{ says } F}{\Gamma \vdash F} \qquad \frac{\Gamma \vdash P \mapsto Q \quad \Gamma \vdash P \text{ says } F}{\Gamma \vdash Q \text{ says } F}$$

Tickets

- Access Request:

  Person says Object

- Ticket:

  Ticket says (Person controls Object)

- Access policy:

  Authority controls (Person controls Object)

- Trust assumption:

  Ticket $\mapsto$ Authority

Derived Rule for Tickets

$$\frac{\begin{array}{l}\text{Authority controls (Person controls F)}\\ \text{Ticket says (Person controls F)}\\ \text{Ticket} \mapsto \text{Authority}\\ \text{Person says F}\end{array}}{\text{F}}$$

$$\frac{\Gamma \vdash \text{P controls F} \quad \Gamma \vdash \text{P says F}}{\Gamma \vdash \text{F}} \qquad \frac{\Gamma \vdash \text{P} \mapsto \text{Q} \quad \Gamma \vdash \text{P says F}}{\Gamma \vdash \text{Q says F}}$$

Security Levels

- Top secret (TS)
- Secret (S)
- Public (P)

$$slev(P) < slev(S) < slev(TS)$$

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- Top secret (TS)
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- Bob has a clearance for "secret"
- Bob can read documents that are public or sectret, but not top secret

Reading a File

$$\frac{\text{Bob controls Permitted (File, read)} \quad \text{Bob says Permitted (File, read)}}{\text{Permitted (File, read)}}$$

Reading a File

$$\frac{\begin{array}{l} slev(\mathsf{File}) < slev(\mathsf{Bob}) \Rightarrow \\ \qquad\qquad \text{Bob controls Permitted (File, read)} \\ \text{Bob says Permitted (File, read)} \\ slev(\mathsf{File}) < slev(\mathsf{Bob}) \end{array}}{\text{Permitted (File, read)}}$$

Reading a File

$slev(\text{File}) < slev(\text{Bob}) \Rightarrow$
Bob controls Permitted (File, read)
Bob says Permitted (File, read)
$slev(\text{File}) = P$
$slev(\text{Bob}) = S$
$slev(P) < slev(S)$

Permitted (File, read)

Substitution Rule

$$\frac{\Gamma \vdash slev(P) = l_1 \quad \Gamma \vdash slev(Q) = l_2 \quad \Gamma \vdash l_1 < l_2}{\Gamma \vdash slev(P) < slev(Q)}$$

Substitution Rule

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- $slev(\mathsf{Bob}) = S$
- $slev(\mathsf{File}) = P$
- $slev(P) < slev(S)$

Reading a File

$$\frac{\begin{array}{l} slev(\text{File}) < slev(\text{Bob}) \Rightarrow \\ \qquad\qquad \text{Bob controls Permitted (File, read)} \\ \text{Bob says Permitted (File, read)} \\ slev(\text{File}) = P \\ slev(\text{Bob}) = TS \\ ? \end{array}}{\text{Permitted (File, read)}}$$

Reading a File

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Transitivity Rule

$$\frac{\Gamma \vdash l_1 < l_2 \qquad \Gamma \vdash l_2 < l_3}{\Gamma \vdash l_1 < l_3}$$

- $slev(P) < slev(S)$
- $slev(S) < slev(TS)$

  $slev(P) < slev(TS)$

Reading Files

- Access policy for reading

$$\forall f.\ slev(f) < slev(\text{Bob}) \Rightarrow$$
$$\text{Bob controls Permitted } (f, \text{read})$$

$$\dfrac{\begin{array}{l}\forall f.\ slev(f) < slev(\text{Bob}) \Rightarrow \\ \qquad\qquad \text{Bob controls Permitted } (f, \text{read}) \\ \text{Bob says Permitted (File, read)} \\ slev(\text{File}) = P \\ slev(\text{Bob}) = TS \\ slev(P) < slev(S) \\ slev(S) < slev(TS)\end{array}}{\text{Permitted (File, read)}}$$

Reading Files

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$$\text{Bob controls Permitted } (f, \text{read})$$
$$\text{Bob says Permitted (File, read)}$$
$$slev(\text{File}) = TS$$
$$slev(\text{Bob}) = TS$$
$$slev(P) < slev(S)$$
$$slev(S) < slev(TS)$$

$$\text{Permitted (File, read)}$$

Writing Files

- Access policy for writing

$$\frac{\begin{array}{l}\forall f.\, slev(\text{Bob}) \leq slev(f) \Rightarrow \\ \qquad\qquad \text{Bob controls Permitted}\ (f, \text{write}) \\ \text{Bob says Permitted (File, write)} \\ slev(\text{File}) = TS \\ slev(\text{Bob}) = S \\ slev(P) < slev(S) \\ slev(S) < slev(TS)\end{array}}{\text{Permitted (File, write)}}$$

Bell-LaPadula

- Read Rule: A principal P can read an object O if and only if P's security level is at least as high as O's.
- Write Rule: A principal P can write an object O if and only if O's security level is at least as high as P's.
- Meta-Rule: All principals in a system should have a sufficiently high security level in order to access an object.

This restricts information flow $\Rightarrow$ military

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Bell-LaPadula: **'no read up'** - **'no write down'**

Principle of Least Privilege

A principal should have as few privileges as possible to access a resource.

- Bob (TS) and Alice (S) want to communicate

  $\Rightarrow$ Bob should lower his security level

Biba Policy

Data Integrity (rather than data confidentiality)

- Biba: **'no read down'** - **'no write up'**
- Read Rule: A principal P can read an object O if and only if P's security level is lower or equal than O's.
- Write Rule: A principal P can write an object O if and only if O's security level is lower or equal than P's.

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E.g. Generals write orders to officers; officers write oders to solidiers
Firewall: you can read from inside the firewall, but not from outside
Phishing: you can look at an approved PDF, but not one from a random email

Point to Take Home

- Formal methods can be an excellent way of finding bugs as they force the designer to make everything explicit and thus confront difficult design choices that might otherwise be fudged.