Formal Analysis of Security Policies

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Security Workshop

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Development of an Access Control System

1) Authentication

2) Security Policies

3) Security Mechanisms

Security Policy

"A set of norms regulating the modalities – obligation, permission, interdiction – for a set of agents on some action "

Inconsistencies

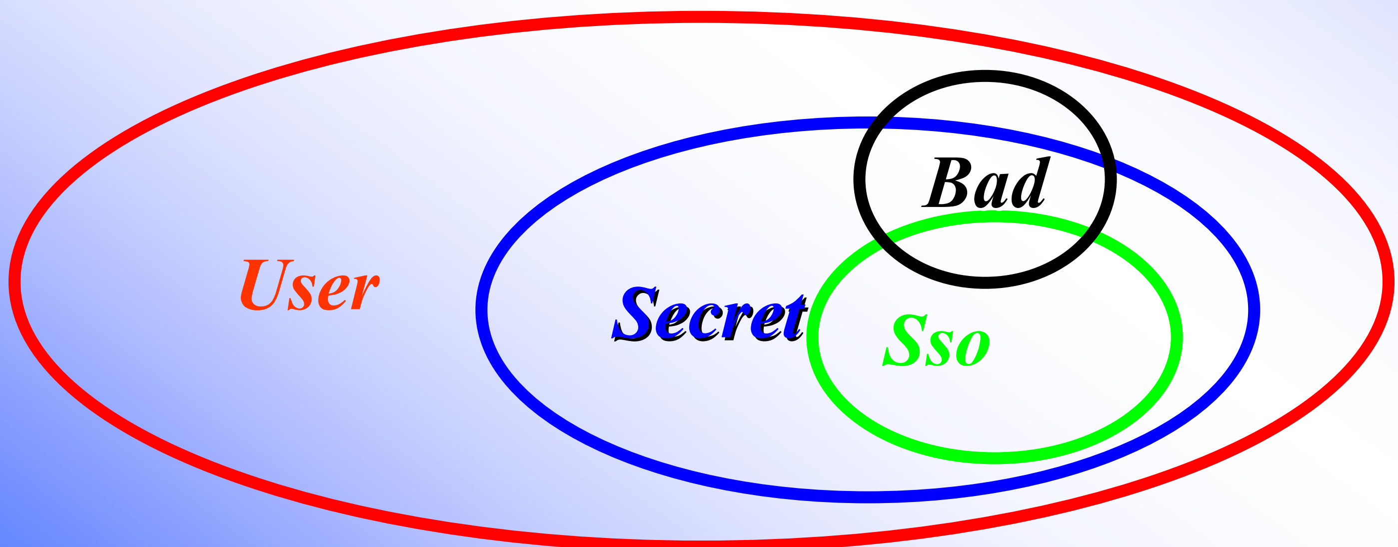
- **Contradiction:**

  "forbidden smoke" and "obligatory smoke"!

- **Dilemma:**

  "forbidden smoke" and "forbidden no smoke"!

Roles



Example Policy

11 Norms

4 Roles

```
N1: if play(a,User) and public(f)
    then Perm(Read(a,f))

N2: if play(a,User) and public(f) and owner(f,a)
    then Perm(Write(a,f))

N3: if play(a,User)
    then Forb(Downgrade(a,f))

N4: if play(a,User) and password(a,p) and old(p)
    then Obl(Change_Psswd(a))
```

Example Policy

```
N5: if play(a,Secret) and not(public(f))
    then Perm(Read(a,f))

N6: if play(a,Secret) and not(public(f))
        and owner(f,a)
    then Perm(Write(a,f))

N7: if play(a,Sso)

    then Perm(Downgrade(a,f))
```

Example Policy

```
N8:  if play(a,Bad)
     then Forb(Read(a,f))

N9:  if play(a,Bad)
     then Forb(Write(a,f))

N10: if play(a,Bad)
     then Forb(Downgrade(a,f))

N11: if play(a,Bad)
     then Forb(Change_Psswd(a))
```

Inductive Approach

- **Trace**: list of admissible norms induced by policy
- **Model of Policy**: set of all possible trace of norms that the policy admits
  - Mechanized with the proof assistant: PVS or Isabelle
- Properties of the model proved with the correspondent inductive principle

Inductive Definition of Policy

"Set of all possible trace of norms that the policy admits"

Base case

```
[] ∈ Policy
```

Inductive case

```
trace ∈ Policy ⇒ nm # trace ∈ Policy
```

Types

```
typedecl Agent

typedecl File

typedecl Psswd


datatype Role = User | Sso | Secret | Bad
```

Functions

```
consts
  play     :: "[Agent, Role]    ⇒ bool"
  owner    :: "[File, Agent]    ⇒ bool"
  password :: "[Agent, Psswd]   ⇒ bool"
  public   :: "File             ⇒ bool"
  old      :: "Psswd            ⇒ bool"
```

Constraints on Roles

```
axioms
 Secret_User [simp] : "play a Secret → play a User"
 Sso_Secret  [simp] : "play a Sso → play a Secret"
 Bad_User    [simp] : "play a Bad → play a User"

lemma Transitivity_Sso_User [simp] :
  " ∀ (a::Agent). play a Sso → play a User"
```

Operations

```
datatype operation =
    Read          Agent File
  | Write         Agent File
  | Change_Psswd  Agent
  | Downgrade     Agent File
  | Not_op        operation   ("¬o")

axioms
  Not_op_idemp [simp] : "¬o (¬o oper) = oper"
```

Norms

```
datatype norma =
    Obl          operation
  | Perm         operation
  | Forb         operation
  | Waived       operation
  | Not_norma norma          ("¬n")
```

Axioms for Norms

```
axioms

 Not_norma_idemp [simp]: "¬n (¬n nm) = nm"

 Perm_Obl [simp]: "Perm oper = ¬n (Obl (¬o oper))"

 Forb_Obl [simp]: "Forb oper   = Obl (¬o oper)"
```

Mechanization with Isabelle

```
types trace = “norma list”

consts Policy :: "trace set"

inductive "Policy"

intros

Empty : “[] ∈ Policy”

Norma_1 : “[|tr1 ∈ Policy; play a User;
         public f|]
            ⇒ Perm (Read a f) # tr1 ∈ Policy”
```

Inconsistencies

Contradiction

$$(\text{Obligatory}(op) \wedge \neg\, \text{Obligatory}(op))$$
$$\vee$$
$$(\text{Obligatory}(\neg\, op) \wedge \neg\, \text{Obligatory}(\neg\, op)$$

Dilemma

$$\text{Obligatory}(op) \wedge \text{Obligatory}(\neg\, op)$$
$$\vee$$
$$(\neg\, \text{Obligatory}(op) \wedge \neg\, \text{Obligatory}\ (\neg\, op))$$

Contradiction in Isabelle

```
consts Contradiction :: “norma ⇒ norma“

axioms Contradiction_1 [simp] :
“Contradiction (Obl oper) = ¬n (Obl oper)“

axioms Contradiction_2 [simp] :
“Contradiction (¬n (Obl oper)) = Obl oper”
```

Dilemma in Isabelle

```
consts Dilemma :: "norma ⇒ norma"

axioms Dilemma_1 [simp] :

"Dilemma (Obl oper) = Obl (¬o oper)"
```

Absence of Contradictions and of Dilemmas

```
theorem No_Contradiction :
  “[|nm ∈ set tr; tr ∈ Policy|] ⇒
   Contradiction nm ∉ set tr“
```

```
theorem No_Dilemma :
  “[|nm ∈ set tr;tr ∈ Policy|] ⇒
   Dilemma nm ∉ set tr”
```

Proof - step 1

```
tr ∈ Policy ⇒
        nm ∈ set tr → Contradiction nm → set tr
```

```
erule
Policy.induct
```

12 subgoal!!!

Proof – step 2

```
[|tr1 ∈ Policy; play a User; public f;
   nm ∈ set tr1 → Contradiction nm ∉ set tr1|]
⇒ nm ∈ set (Perm (Read a f) # tr1) →
  Contradiction nm ∉ set (Perm(Read a f) # tr1)
```

simp del: “Perm_Obl”

Proof – step 3

```
[| tr1 ∈ Policy; play a User; public f;
  nm ∈ set tr1 → Contradiction nm ∉ set tr1 |]
⇒ (nm = Perm (Read a f) →
  Contradiction (Perm (Read a f)) ≠ Perm (Read a f) ∧
  Contradiction (Perm (Read a f)) ∉ set tr1)
  ∧ (nm ∈ set tr1→ Contradiction nm ≠ Perm(Read a f))
```

```
subgoal_tac
"Contradiction(Perm(Read a f))
 ∉ set tr1"
```

Proof – step 4

```
[| tr1 ∈ Policy; play a User; public f;
   nm ∈ set tr1→ Contradiction nm ∉ set tr1 |]
⇒ Contradiction (Perm (Read a f)) ∉ set tr1
```

```
erule
Policy.induct
```

Proof – step 5

```
[| tr1 ∈ Policy; play a User; public f;
   nm ∈ set tr1 → Contradiction nm ∉ set tr1;
   Contradiction (Perm (Read a f)) ∉ set tr1|]
⇒ (nm = Perm(Read a f) →
   Contradiction(Perm(Read a f)) ≠ Perm(Read a f) ∧
   Contradiction(Perm(Read a f)) ∉ set tr1)
∧ (nm ∈ set tr1→ Contradiction nm ≠ Perm(Read a f))
```

rule conjI

Proof – step 6

```
[| tr1 ∈ Policy; play a User; public f;
   nm ∈ set tr1 → Contradiction nm ∉ set tr1;
   Contradiction(Perm(Read a f)) ∉ set tr1|]
⇒ nm = Perm(Read a f) →
  Contradiction(Perm(Read a f)) ≠ Perm(Read a f)
  ∧ Contradiction(Perm(Read a f)) ∉ set tr1
```

simp

Proof – step 7

```
[| tr1 ∈ Policy; play a User; public f;
   nm ∈ set tr1 → Contradiction nm ∉ set tr1;
   Contradiction (Perm (Read a f)) ∉ set tr1|]
⇒ nm ∈ set tr1 → Contradiction nm ≠ Perm(Read a f)
```

```
erule
Policy.induct
```

Proof – step 8

auto

```
⋀ a f tr8 tr1.[| play a Bad; tr1 ∈ Policy;
  public f; ¬n (Obl (¬o (Read a f))) ∉ set tr8;
  ¬n (Obl (¬o (Read a f))) ∉ set tr1|]
  ⇒ False
```

Policy Inconsistencies

6 Contradictions:

N7 – N3: "A system security officer is both permitted and forbidden to downgrade a public file"

N8 – N1: "A bad user is both forbidden and permitted to read a public file"

N8 – N5: "A bad user is both forbidden and permitted to read a not public file"

N9 – N2: "A bad user is both forbidden and permitted to write on a public file he owns"

N9 – N6: "A bad user is both forbidden and permitted to write on a not public file he owns"

N10 – N7: "A bad user is both forbidden and permitted to downgrade a file"

1 Dilemma:

N11 – N4 : "A bad user is both forbidden and obliged to change his password"

Conclusions

- Developed the first inductive approach to prove security policy correctness
- Mechanized the approach with the proof assistant *Isabelle*
- Verified presence of many inconsistence in the example policy: proof script of 500 lines

Next steps…

- To simplify proof demonstration strategy
- Search of alternative formalization, if possible without trace
- Application to widest study case
- Extension to union of more policy

Thanks!!!