Protocol Verification Techniques - Theorem Provers

Design and Verification of Security Protocols and Security Ceremonies

Programa de Pós-Graduacão em Ciências da Computacão
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Attention!

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This topic will be divided into two lectures. One will deal with automatic theorem provers using FOL and the second will deal with theorem provers using HOL

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- HOL is any predicate logic that has greater order than Second-Order Logic;

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- Higher-order logic admits quantification over sets that are nested arbitrarily deeply.

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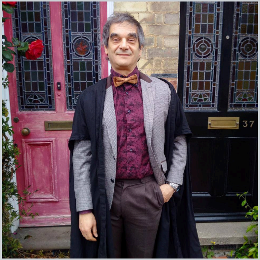
- This is the definition of the set of Natural Numbers.

Lawrence Charles Paulson - Larry



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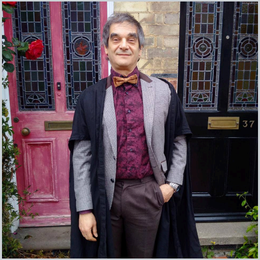

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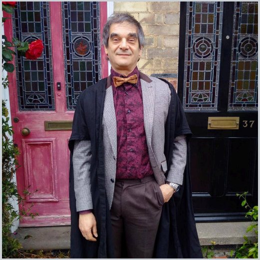

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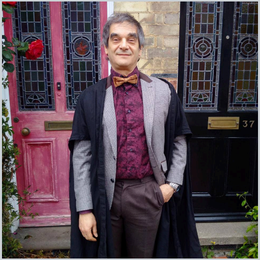

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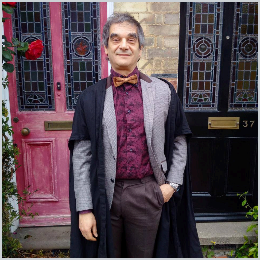

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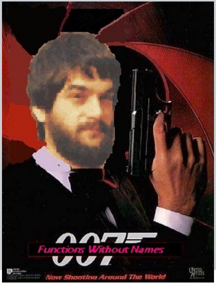

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- Last work published in 2015: "Verifying multicast-based security protocols using the inductive method. Martina, J.E., Paulson, L.C."

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- Out of that we extract:
  - An inductive abstract trace model;
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- We state the goals ad theorems and lemmas;
- We prove the theorems inductively to demonstrate correctness.

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  - Main point: these proofs are big, uninteresting, and better left to machines;
  - Use a theorem prover (Isabelle)to write the proofs.

Isabelle

- Automated support for proof development, which supports:

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- Strong support for inductive definitions.

Inductive Method Support in Isabelle

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  - *Public.thy* which inherits from *Event.thy*, which despite the narrowly chosen name, accounts for the specification of symmetric and asymmetric cryptographic primitives;
  - We also have some other specialised theories for Smart-Cards, Threshold Cryptography and Multicast communication.

Inductive Method Details - Agents

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Agent datatype definition

datatype

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        | Server
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- Finally we have the attacker, which is categorised separately.

Inductive Method Details - Cryptographic Keys

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shrK function definition

consts

```
  shrK :: "agent => key"
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specification (shrK)

```
  inj_shrK: "inj shrK"
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- A shared key is specified as an injective function taking an agent and returning a key.

Inductive Method Details - Cryptographic Keys

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invKey function definition

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specification (invKey)
  invKey [simp]: "invKey (invKey K) = K"
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symKeys set definition

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- By stating $K \in symKeys \wedge K \notin range\ shrK$ we can create a second class of symmetric keys that are not long-term so that it represents sessions keys in our protocols being verified.

Inductive Method Details - Cryptographic Keys

Definition

Axiom for symmetric usage of shared keys

axioms

```
  sym_shrK [iff]: "shrK X ∈ symKeys"
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Inductive Method Details - Cryptographic Keys

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Axiom for symmetric usage of shared keys

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- Establishes that our long-term keys are symmetric with an axiom.

Inductive Method Details - Cryptographic Keys

Definition

publicKey definition

```
datatype
  keymode = Signature | Encryption

consts
  publicKey :: "[keymode,agent] => key"

specification (publicKey)
  injective_publicKey:
   "publicKey b A = publicKey c A' ==> b=c & A=A'"
```

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privateKey axiom definition

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privateKey_neq_publicKey [iff]:
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Inductive Method Details - Cryptographic Keys

Definition

Public Key abbreviations

abbreviation

```
pubEK :: "agent => key" where
"pubEK == publicKey Encryption"
pubSK :: "agent => key" where
"pubSK == publicKey Signature"
privateKey :: "[keymode, agent] => key" where
"privateKey b A == invKey (publicKey b A)"
priEK :: "agent => key" where
"priEK A == privateKey Encryption A"
priSK :: "agent => key" where
"priSK A == privateKey Signature A"
```

Inductive Method Details - Compromised Agents

Definition

bad set definition

consts

```
  bad :: "agent set"
```

specification *(bad)*

```
  Spy_in_bad [iff]: "Spy ∈ bad"
  Server_not_bad [iff]: "Server ∉ bad"
```

Inductive Method Details - Messages

Definition

msg datatype definition

datatype

```
msg = Agent agent
    | Number nat
    | Nonce nat
    | Key key
    | MPair msg msg
    | Hash msg
    | Crypt key msg
```

Inductive Method Details - Events

Definition

event datatype definition

datatype

```
  event = Says agent agent msg
        | Gets agent msg
        | Notes agent msg
```

Inductive Method Details - Initial Knowledge

Definition

initState definition

consts

```
  initState :: "agent => msg set"
```

Inductive Method Details - Initial Knowledge

Definition

Spy agent initial knowledge definition

primrec

```
  initState_Spy:
    "initState Spy =
    (Key ` invKey ` pubEK ` bad) ∪
    (Key ` invKey ` pubSK ` bad) ∪
    (Key ` shrK ` bad) ∪
    (Key ` range pubEK) ∪ (Key ` range pubSK)"
```

Inductive Method Details - Knows

Definition

knows function definition

```
consts   knows :: "agent => event list => msg set"

primrec
  knows_Nil: "knows A [] = initState A"
  knows_Cons:
    "knows A (ev # evs) =
    (if A = Spy then
    (case ev of
      Says A' B X => insert X (knows Spy evs)
      | Gets A' X => knows Spy evs
      | Notes A' X =>
        if A' ∈ bad then insert X (knows Spy evs)
          else knows Spy evs)
```

Inductive Method Details - Knows

Definition

knows function definition

consts

```
    else
    (case ev of
      Says A' B X =>
        if A'=A then insert X (knows A evs) else knows
A evs
      | Gets A' X =>
        if A'=A then insert X (knows A evs) else knows
A evs
      | Notes A' X =>
        if A'=A then insert X (knows A evs) else knows
A evs))"
```

Inductive Method Details - Operators

Definition

parts inductive set definition

inductive_set

```
  parts :: "msg set => msg set"
  for H :: "msg set"
  where
      Inj [intro]: "X ∈ H ==> X ∈ parts H"
      | Fst: "{|X,Y|} ∈ parts H ==> X ∈ parts H"
      | Snd: "{|X,Y|} ∈ parts H ==> Y ∈ parts H"
      | Body: "Crypt K X ∈ parts H ==> X ∈ parts H"
```

Inductive Method Details - Operators

Definition

analz inductive set definition

inductive_set

```
  analz :: "msg set => msg set"
  for H :: "msg set"
  where
      Inj [intro,simp] : "X ∈ H ==> X ∈ analz H"
      | Fst: "{|X,Y|} ∈ analz H ==> X ∈ analz H"
      | Snd: "{|X,Y|} ∈ analz H ==> Y ∈ analz H"
      | Decrypt [dest]:
         "[|Crypt K X ∈ analz H; Key(invKey K): analz
H|] ==>
        X ∈ analz H"
```

Inductive Method Details - Operators

Definition

synth inductive set definition

inductive_set

```
  synth :: "msg set => msg set"
  for H :: "msg set"
  where
      Inj [intro]: "X ∈ H ==> X ∈ synth H"
      | Agent [intro]: "Agent agt ∈ synth H"
      | Number [intro]: "Number n ∈ synth H"
      | Hash [intro]: "X ∈ synth H ==> Hash X ∈ synth
H"
      | MPair [intro]: "[|X ∈ synth H; Y ∈ synth H|]
==>
        {|X,Y|} ∈ synth H"
```

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Inductive Method Details - Operators

Definition

used function definition

consts

```
  used :: "event list => msg set"
```

primrec

```
  used_Nil: "used [] = (UN B. parts (initState B))"
  used_Cons: "used (ev # evs) =
    (case ev of
      Says A B X => parts {X} ∪ used evs
      | Gets A X => used evs
      | Notes A X => parts {X} ∪ used evs)"
```

Dummy Protocol

$$\boxed{\begin{array}{llclcc} 1. & A & \rightarrow & B & : & \{|A, B, Na|\}_{K_B} \\ 2. & B & \rightarrow & A & : & \{|Na, Nb, K_{AB}|\}_{K_A} \\ 3. & A & \rightarrow & B & : & \{|Nb\}_{K_{AB}} \end{array}}$$

Figure: Example protocol

Dummy Protocol Specification

Definition

inductive definition of example protocol

```
inductive_set example :: "event list set"
where
    Nil: "[] ∈ example"

    |Fake:"[|evsf ∈ example; X ∈ synth(analz (knows
Spy evsf))|]
     ⇒ Says Spy B X # evsf ∈ example"

    |EX1: "[|evs1 ∈ example; Nonce NA ∉ used evs1|]
     ⇒Says A B (Crypt (pubK B){|Agent A, Agent B,
Nonce NA|}) #
     evs1 ∈ example"
```

Dummy Protocol Specification

Definition

```
|EX2: "[|evs2 ∈ example; Nonce NB ∉ used evs2;
    Key AB ∉ used evs1
    Says A' B (Crypt (pubK B){|Agent A, Agent B,
Nonce NA|})
    ∈ set evs2|]
  ⇒Says B A (Crypt (pubK A) {| Nonce NA, Nonce NB,
Key AB|})
  # evs2 ∈ example"
```

Dummy Protocol Specification

Definition

```
    |EX3: "[|evs3 ∈ example;
       Says A B (Crypt (pubK B){|Agent A, Agent B,
Nonce NA|})
       ∈ set evs3;
       Says B A (Crypt (pubK A) {| Nonce NA, Nonce NB,
Key AB|})
       ∈ set evs3 |]
     ⇒Says A B (Crypt (Key AB){| Nonce NB|}) # evs3 ∈
example"
```

Dummy Protocol Specification

Definition

```
    |Oops: "[|evso ∈ example;
     Says B A (Crypt (pubK A) {| Nonce NA, Nonce NB,
Key AB|})
     ∈ set evso|]
     ⇒ Notes Spy {|Nonce NA, Nonce NB, Key AB|}# evso
∈ example"
```

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- We describe the protocol goals as Theorems and Lemmas;
- We prove these inductively with the assistance of Isabelle;
- Proof tactics are known for most of the usual goals;
- The problem starts when you want to prove a new goal....

Problems with the Inductive Method

- Training someone to use it proficiently takes 2 years;

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Problems with the Inductive Method

- Training someone to use it proficiently takes 2 years;
- Understanding Isabelle cryptic messages is painful
- The person carrying the verification need to be clever and seasoned with the tool, otherwise there will be pain;
- Too much freedom and power are sometimes difficult to use.

Discussion

- What else can you foresee modelled using this strategy?

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Discussion

- What else can you foresee modelled using this strategy?
- Can this be extended?
- What this strategy can not do?

Questions????

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