Formal Methods for Security

Erik Poll

Digital Security group

Radboud University Nijmegen

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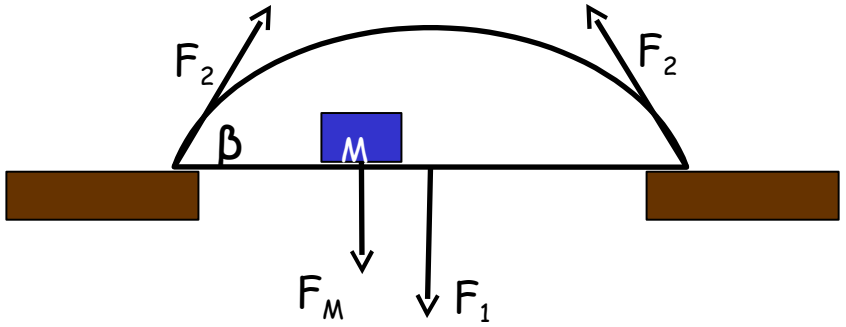
Overview

- Formal methods
  - in general and for security
- Case studies: formal methods for security protocols
  - to illustrate the different ways in formal methods can be used
  - based on our group's formal & informal investigations

Formal Methods for Structural Engineering



model

product

Formal methods involve **models** of which **properties** (eg bridge won't collapse) can be **specified** and **verified** (modulo modelling & abstraction errors) using some **methodology/theory**

$$F_1 + F_M = 2 * \sin \beta * F_2 \qquad F_1 = L * H * \rho \quad ....$$

Starting point for all: **specification**

- which for a bridge is very simple & unchanged for ages

Formal Methods for Software Engineering??

model??

properties??

specs

incl. functional requirements

security requirements

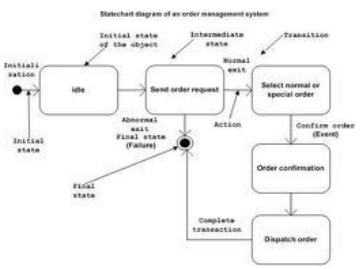
product,

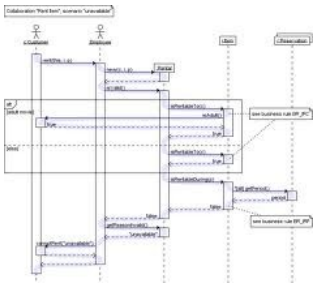
ie **code**

From specs to code

code itself is also possible formal model !

Control Name	ISO/IEC 27002:2007	Control Function					
		Deter	Avoid	Pre-test	De-tect	React	Re-cover
Security policy	5						
Information Security Policy	5.1						
Information security policy document	5.1.1	✓	✓	✓		✓	✓
Review of the information security policy	5.1.2	✓	✓	✓		✓	✓
Organisation and information security							
Internal organisation.	6.1						
Management commitment to information security.	6.1.1	✓	✓	✓		✓	✓
Information security co-ordination.	6.1.2		✓	✓		✓	✓
Allocation of information security responsibilities	6.1.3		✓	✓	✓	✓	✓
Authorisation process for information processing facilities	6.1.4		✓				
Confidentiality agreements	6.1.5		✓	✓			
Contact with authorities	6.1.6		✓			✓	
Contact with special interest groups	6.1.7		✓	✓	✓		
Independent review of information security	6.1.8		✓	✓	✓	✓	✓
External parties.	6.2						
Identification of risks related to external parties	6.2.1	✓	✓	✓			
Addressing security when dealing with customers	6.2.2	✓	✓	✓			
Addressing security in third party agreements	6.2.3	✓	✓	✓	✓	✓	✓
Asset management	7						
Responsibility for assets.	7.1						
Inventory of assets	7.1.1		✓	✓			✓
Ownership of assets	7.1.2		✓	✓	✓	✓	✓
Acceptable use of assets	7.1.3		✓	✓			
Information classification	7.2						





candidate formal models?

Formal methods *at different levels*

- Formal methods for *programming languages*, eg
  - type system to rule out buffer overflows
  - static analysis to detect XSS vulnerabilities
- Formal methods for *abstract algorithms & protocols*, eg
  - prove that your shortest path algorithm is functionally correct
  - prove that HTTPS is secure
- Formal methods for *programs*, eg
  - prove that a program never throws a NullPointerException
  - prove that a program correctly implements HTTPS

security vs correctness

- A program is correct if it does what it should do
  - ie. *presence* of the *right* behaviour, under normal circumstances
- A program is secure if it is does not do what it should *not* do
  - ie. *absence* of *insecure* behaviour, under *any* circumstances
  - easy to overlook, and hard to check (eg by testing)
- A program also has to be correct for it to be secure?

Good news: some (generic) security requirements are independent of any detailed functional spec (eg absence of integer overflows)

Bad news: security requirements may be hard to pin down
(what does it mean for a system to be secure?)

Case studies: formal methods for (implementations of) security protocols

Security protocols

- Why security protocols?
  - they are security-critical components in systems
    - eg HTTPS, EMV (Chip & PIN), electronic passports, …
  - they are small but complex
  - they have clear security objectives

Note:

- forget about crypto, it's the protocols that matter!
- we can study the abstract protocols, or their concrete implementations

Potential problems in security protocols

1. using insecure cryptographic primitives *(eg. Oyster card)*
2. using default keys *(eg. lots of systems)*
3. using an buggy protocol. Security protocols are tricky to get right!
4. using an buggy implementation. Software bugs can break
   a) correctness
      Easy to detect, since the implementation won't work
   b) security, by erroneously accepting or crashing on
      - incorrect (malformed) message or
      - incorrect *order* of messages.

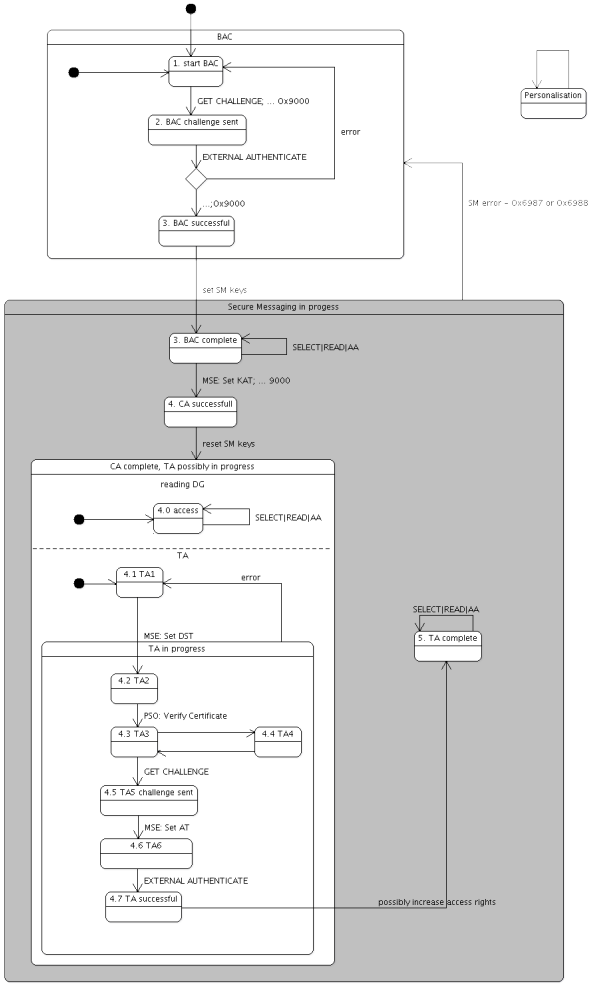
      This is harder to detect, since the implementation will work

Some example formal models for security protocols

Alice-Bob notation

1. A -> B: start session
2. B -> A: ok
3. A -> B: $Nonce_A$
4. B -> A: $encrypt_{KEY}(Nonce_A)$
5. A -> B: …
6. B -> A: …

state machines / automata



Such (partial) models capture different aspects and hence can be used for different goals and in different ways (see next slides)

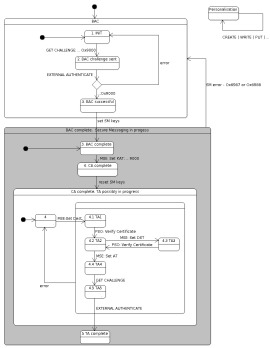
I. Security Protocol Analysis

- Given a formal description of the abstract security protocol, eg. in Alice-Bob notation, we can formally analyse some of its properties
  - possible using tool support

Eg next talk by Joeri de Ruiter, and plenty of others.

II. Model based testing

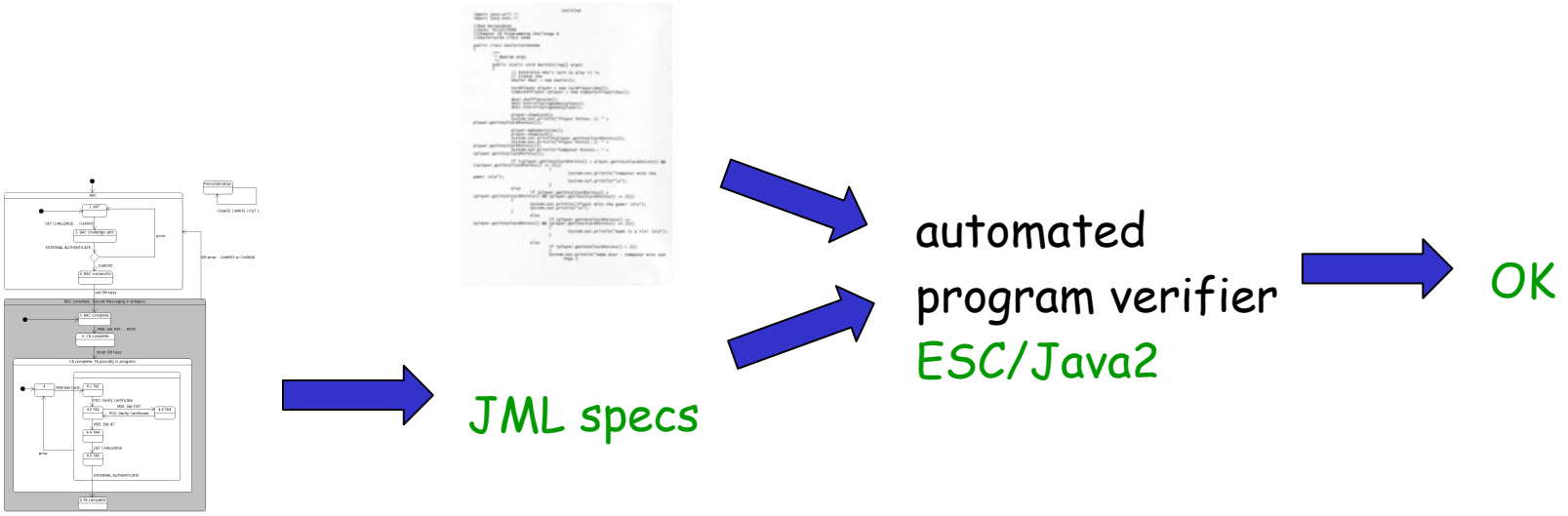
- We automatically test if implementation conforms to the model
  - we feed randomly generated inputs to both model and code, and check if they behave the same
  - the model is used as test oracle
    - possibly also for generating tests & measuring test coverage
- by aggressively testing many (all?) possible sequences we can test for security as well as correctness – "state-based" fuzzing
- *Eg we have done this for the electronic passport.* [W.Mostowski et al, FMICS 2009]



TorXakis tool

III. Program verification

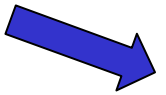
- A more rigorous form of checking compliance of code & model: formal verification (with mathematical proof) that the code conforms to the model
- *Eg for a Java implementation of SSH [E.Poll and A.Schubert, WITS 2007]*

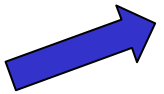


A formal model can also be used, informally, by a human code reviewer

III. Program verification

- Even without any formal model, we can use formal verification to verify that the code meets some security property





automated
program verifier
eg ESC/Java2

OK

security property
eg in JML

Problem: what do we want to verify anyway?

III. Program specification: what to verify?

Typical easy properties to begin specifying:

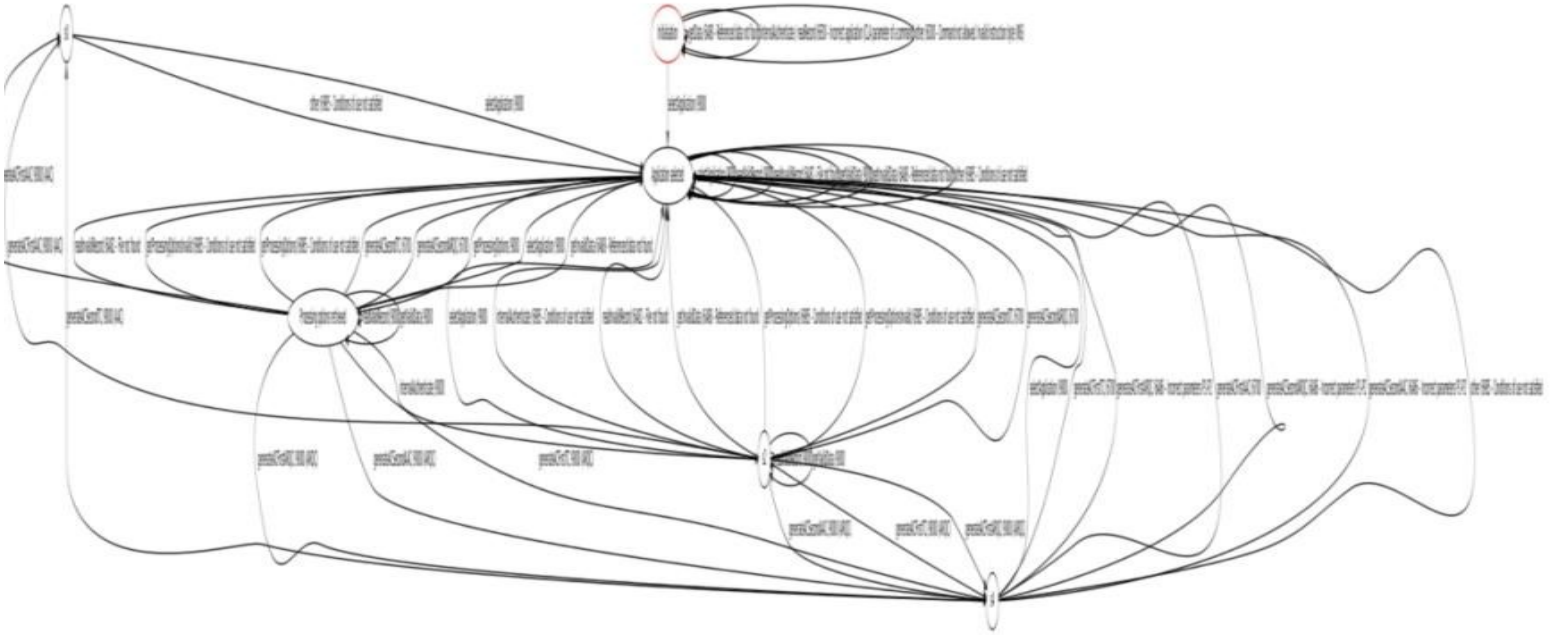
(i) important invariants (ii) absence of runtime exceptions

plus the additional preconditions and invariants this requires.

```
public class ElectronicPurse extends javacard.framework.Applet {

  private int balance;  //@ invariant  0 <= balance;


 //@ requires  buffer != null && 0 <= offset && offset+length <=
   buffer.length;

 public static void install (byte[] buffer, short offset, byte length) {

 ....}
```

IV. Model extraction

- Automated learning techniques can be used (in combination with model-based testing) to infer an automaton for an implementation's behaviour



Automaton learned from a Dutch EMV bankcard
[Fides Aarts et al, ISoLA'10]

Conclusions

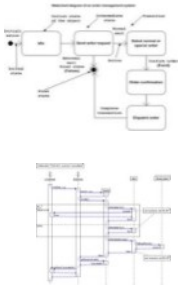
- Central challenges
  - does code meet the specs?
  - do specs & code not overlook
    or introduce security problems?

?

specs code

- Formal models & methods can help in different ways

specs



models

compare, by
- testing
- code review
- verification

code

extract

analyse

generate

analyse