A Lingua Franca for Security by Design

Alexander van den Berghe, Koen Yskout, Riccardo Scandariato and Wouter Joosen

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DistriNet

"Improving software security should be an easy sell if your software has a significant number of users; the sheer cost of applying security updates makes it worth getting security, privacy, and reliability right early in the process rather than putting the burden on your customers to apply updates."

M. Howard and S. Lipner, The Security Development Lifecycle (2006)

How vicious can a security design flaw be?

Group Policy Remote Code Execution Vulnerability (CVE-2015-0008)[1]

Boils down to the improper use of DNS for authentication

- rated as critical
- impacted multiple Microsoft products
- fix required comprehensive architectural changes (1 year of development)
- older products are not patched due to impact on stability and compatibility

[1] https://docs.microsoft.com/en-us/security-updates/SecurityBulletins/2015/ms15-011

It seems beneficial to start tackling security early on

Requires the ability to create and reason about a high-level security view of the software

Intermezzo: What is a security view?

Requires the ability to create and reason about
a high-level security view of the software

ISO/IEC/IEEE 42010: Systems and software engineering — Architecture description

"architecture view
work product expressing the architecture of a system
from the perspective of specific system concerns"

A security view thus expresses only the security-relevant aspects of a system

It seems beneficial to start tackling security early on

Requires the ability to create and reason about a high-level security view of the software

Requires a modelling language “suitable” for security

What does this mean?

Who uses (security) views and for what?

ISO/IEC/IEEE 42010

- as basis for system design and development activities;
- as input to automated tools for simulation, system generation and analysis;
- communicating among parties involved in the development, production, deployment, operation and maintenance of a system;
- ...

Our observation is that

- specialised security teams are responsible to assess and harden the security of the designed software; and
- these teams communicate with architects, implementers, managers, ...

A security by design lingua franca needs to reconcile two contradicting forces

Communication to a broader audience

↓

Language that is easily comprehensible

↓

Currently used notations are often ad hoc and informal

Design and analysis of security solutions

↓

Language that is precise and expressive

↓

Proposed languages often go very formal and/or cover few security properties

So we developed our own security modelling language

It essentially consists of data manipulated by processes, which can collaborate by grouping them into networks, each of which can be further refined by assumptions

Our language is equipped with a graphical notation and is fully formalised using the Coq Proof Assistant

So we developed our own security modelling language

Built-in types for ciphertexts, cryptographic keys, credentials, . . .

It essentially consists of data manipulated by processes,
which can collaborate by grouping them into networks,
each of which can be further refined by assumptions

So we developed our own security modelling language

23 pre-defined types (Encrypter, Attacker, Fork, . . .)
Each exhibiting well-defined (non-deterministic) behaviour

It essentially consists of data manipulated by processes,
which can collaborate by grouping them into networks,
each of which can be further refined by assumptions

So we developed our own security modelling language

It essentially consists of data manipulated by processes, which can collaborate by grouping them into networks, each of which can be further refined by assumptions — Connected processes communicating data

So we developed our own security modelling language

It essentially consists of data manipulated by processes, which can collaborate by grouping them into networks, each of which can be further refined by assumptions

e.g. Attacker cannot obtain original data from a hash value

A security by design lingua franca needs to reconcile two contradicting forces

Communication to a broader audience

↓

Language that is easily comprehensible

Design and analysis of security solutions

↓

Language that is precise and expressive

Evaluating our language with respect to these two forces

Comprehension in the large	Creation in the large

Deals with real(istic) designs

Evaluating our language with respect to these two forces

Comprehension in the large	Creation in the large

Created a realistic model of password-based authentication

Evaluating our language with respect to these two forces

Comprehension in the large	Creation in the large
Comprehension in the small	Creation in the small

Deals with building blocks and small designs as a prerequisite

Evaluating our language with respect to these two forces

Comprehension in the large	Creation in the large
Comprehension in the small	Creation in the small

Performed a user study with master students in computer science

Evaluating our language with respect to these two forces

Comprehension in the large	Creation in the large
Comprehension in the small	Creation in the small

Software architecture course
105 participants
Security novice, junior software developers

Performed a user study with master students in computer science

Research questions

RQ1.1: Do participants comprehend the individual building blocks provided by the modelling language?

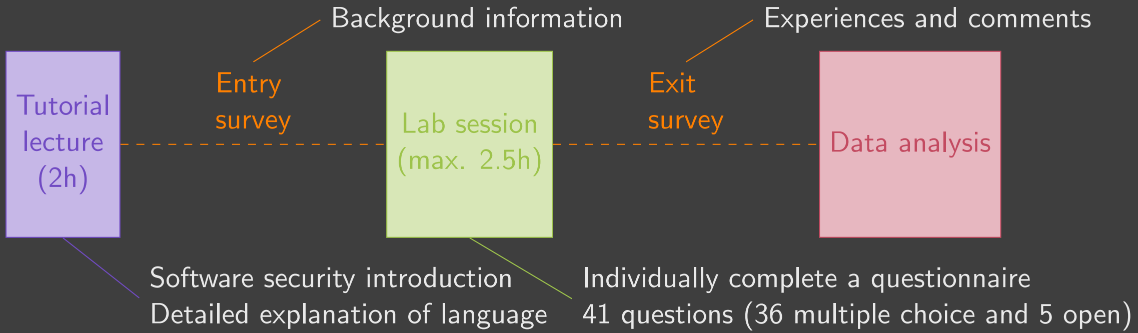
RQ1.2: Do participants comprehend models where multiple building blocks have been tied together?

RQ1.3: Do participants comprehend models where security mechanisms and an attacker are intertwined?

RQ2.1: Can participants use the language to express an informally described situation?

Not covered in this presentation

Study Design



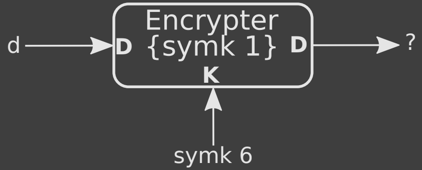
Multiple choice questions

3. What is valid output data for this Encrypter process?

Sometimes we ask to provide rationale

Multiple correct options

- ◯ d
- ◯ symk 1
- ◯ enc d (symk 1)
- ◯ enc d (symk 6)
- ◯ Nothing
- ◯ Don't know



Differentiate blank answers from those a participant does not know

Remarks: Optional (unless selected "Don't know")

Difficulty: ◯ Very difficult ◯ Rather difficult ◯ Rather easy ◯ Very easy

Asses perceived difficulty

The data we measured

Scored each answer to multiple choice questions

Correctly selected options — Incorrectly selected options

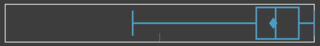
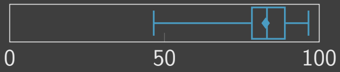
$$score = \max\left(0, \frac{S^+ - S^-}{N^+}\right) \times 100\%$$

Total number of correct options

Rationale is manually analysed and coded

A code can, for example, indicate the presence of a common error

Resulting scores

RQ	Topic	Score (%) Min.	Mean	Max.	Box plot
RQ1.1	Individual building blocks	41	**87**	100	
RQ1.2	Combined building blocks	33	**79**	100	
RQ1.3	Security aspects	50	**77**	100	
RQ1		47	**83**	97	

What were the recurring problems?

Non-determinism

Attacker omnipotence

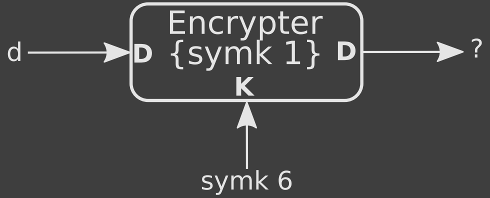
(Complex processes)

(Data equality)

Non-deterministically processing inputs

Roughly 50% of the participants prefer processes to deal with multiple inputs in a certain order

Significant majority of these participants prefer that "configuration" precedes "functionality"



Among the participants
40% do not prefer order (correct answer)
48% configure key before encrypting
5% encrypt before configuring key

The challenge of an omnipotent attacker

Our Attacker process can *guess* any data as well as *derive* any data from other data it already knows, unless explicitly constrained using assumptions

What data can be obtained by a given, unconstrained Attacker?

Attacker
{plain 2 5, cred 6, id 5, sid 9, hashed (cred 1), enc (cred 1) (symk 3)}

Replies by 36% of the participants indicate they implicitly constrain the attacker's guessing and derivation abilities

Such implicit assumptions are problematic

They remain unchecked with respect to the software under design

Potentially allowing possible attacks to go unnoticed

So what have we learned from this?

We now know what the shortcomings are

Building blocks and small models seem fairly easy to comprehend

- given limited training (2h)
- without going into the formal specification

Underlying formal machinery does seem necessary to cover all possibilities

- e.g. make assumptions on attacker's abilities explicit

Evaluating our language with respect to these two forces

Comprehension in the large	Creation in the large

Created a realistic model of password-based authentication

What we modelled

Modelled features

- Username-password authentication
- User registration
- Two-factor authentication
- Sessions
- Change password
- Reset password

Followed OWASP's best practices

Resulted in a large, complex model containing 200+ processes

I won't dive into it here, excerpts can be found in paper and full model is available online

Experience

- ✗ Model quickly grows in size and complexity
- ✗ Defining a comprehensive set of assumptions is laborious
- ✗ Some processes get cumbersome to work with
- ✗ Expressing time-based aspects is clumsy

- ✓ Pre-defined building blocks to fall back on
- ✓ Existing set of process types was sufficient
- ✓ Revealed some possibilities we did not think of up-front
  e.g. use of password reset to reactivate an account

Wrapping up

It is advantageous to tackle security issues early on in the software development cycle

This requires a suitable security modelling language

- Comprehensible by a broad audience
- Allows security experts to design and analyse security solutions

We evaluated our proposed modelling language with respect to these forces

At least to some extend

User study to assess comprehensibility of the building blocks and small models for security novice, junior software developers

Modelled a realistic version of username-password based authentication to assess expressivity

Results are promising and have shown us what the current shortcomings are

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