Quality Assurance for Security-Critical Systems

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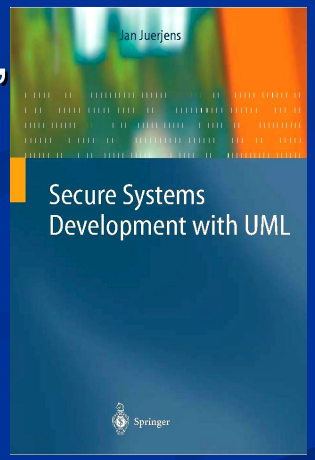
3 Key Points

- Quality Assurance for security-critical systems is very difficult
- Some specific security properties (e.g. wrt brute-force attacks) cannot be established using conventional testing methods
- Model-based Security Testing is a corner-stone of Security QA

Personal Introduction

- Senior Lecturer (comp. US Assoc. Prof.) at The Open University (British distance university)
- Prev. leading Competence Center for IT-Security at Software & Systems Engineering, TU Munich
- Extensive collaboration with industry (BMW, HypoVereinsbank, Munich Re, O2, Deutsche Bank, Siemens, Infineon, Allianz, …)
- PhD in Computer Science from Oxford Univ., Masters in Mathematics from Bremen Univ.
- Numerous publications incl. 2 books on the subject
- Founding Chair of GI WG on Formal Methods & Software Engineering for Safety & Security (FoMSESS)
- Extensive consulting on security and quality assurance



Testing Security-Critical Systems

Very challenging.

Given motivated adversary, would need full coverage (test every possible execution).

Usually infeasible (especially open systems).

Need heuristics for trade-off between development effort and reliability.

Need to ask yourself:

- How complete is the heuristic ?
- How can I validate it ?

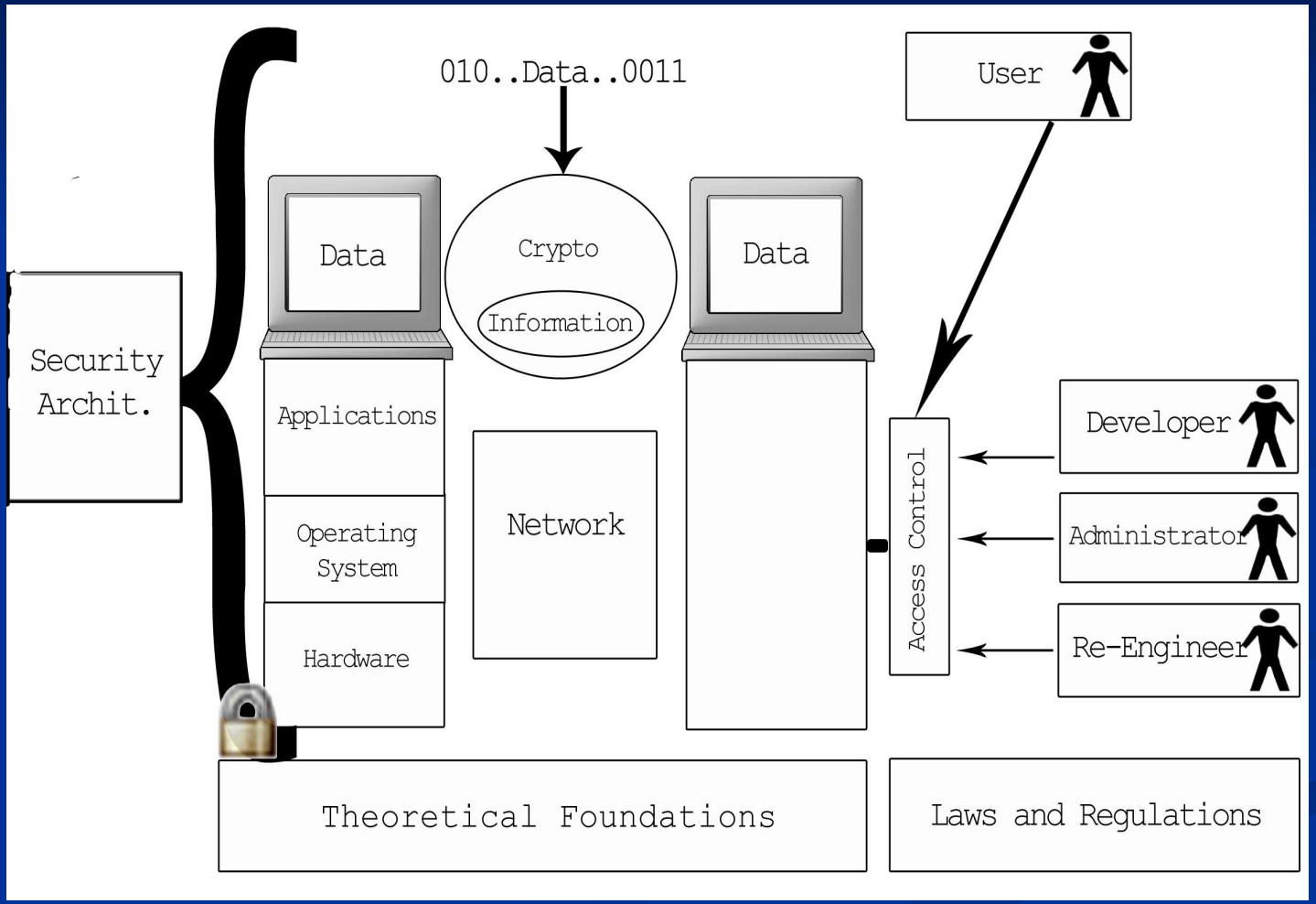
Security: Some Causes for Problems

„Blind“ use of security mechanisms:

- Security usually compromised by circumventing (rather than breaking) them.
- Assumptions on system context, physical environment.
- Attacker may use unintended/unnoticed functionality

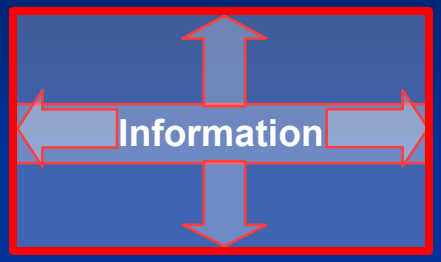
„Those who think that their problem can be solved by simply applying cryptography don`t understand cryptography and don`t understand their problem“ (R. Needham).

Security: Need to Consider Complete Picture

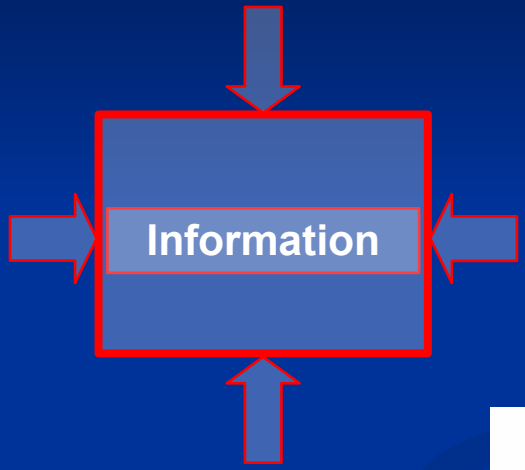


Basic Security Requirements

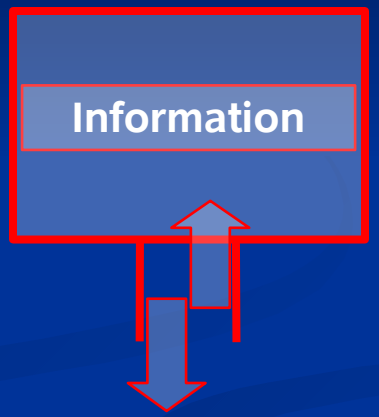
Secrecy

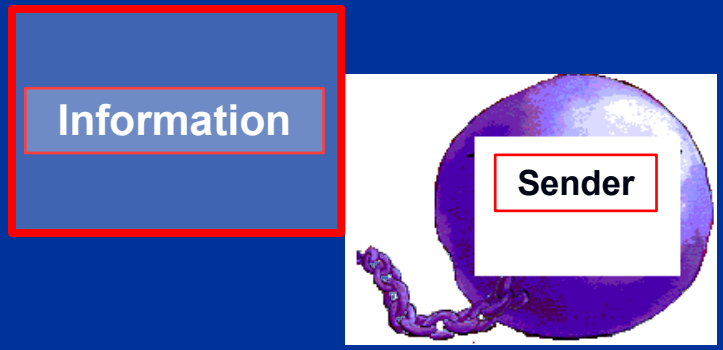


Integrity

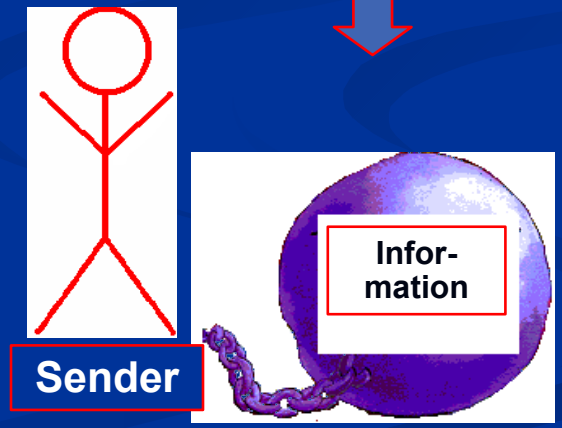


Availability





Authenticity



Nonrepudiability

Problem: Security is Elusive

- Classical weakness in old Unix systems: “wrong password” message at first wrong letter in password. Using timing attack, reduce password space from 26^n to 26*n (n = password length)
- More recent weakness on smart-card: reconstruct secret key by timed measurement of power consumption during crypto operations

➔ How do you find these weaknesses using classical testing ?

(You don't.)

Problem: Untrustworthy Programmer

- For security assurance, may not even trust the programmer of the code.
- May have intentionally built in back-door into code.
- May be impossible to find by random or black-box testing (e.g. hard-coded special password).
- Even worse when elusive weaknesses are used (previous slide).

➔ What is your precaution ?

(Probably none.)

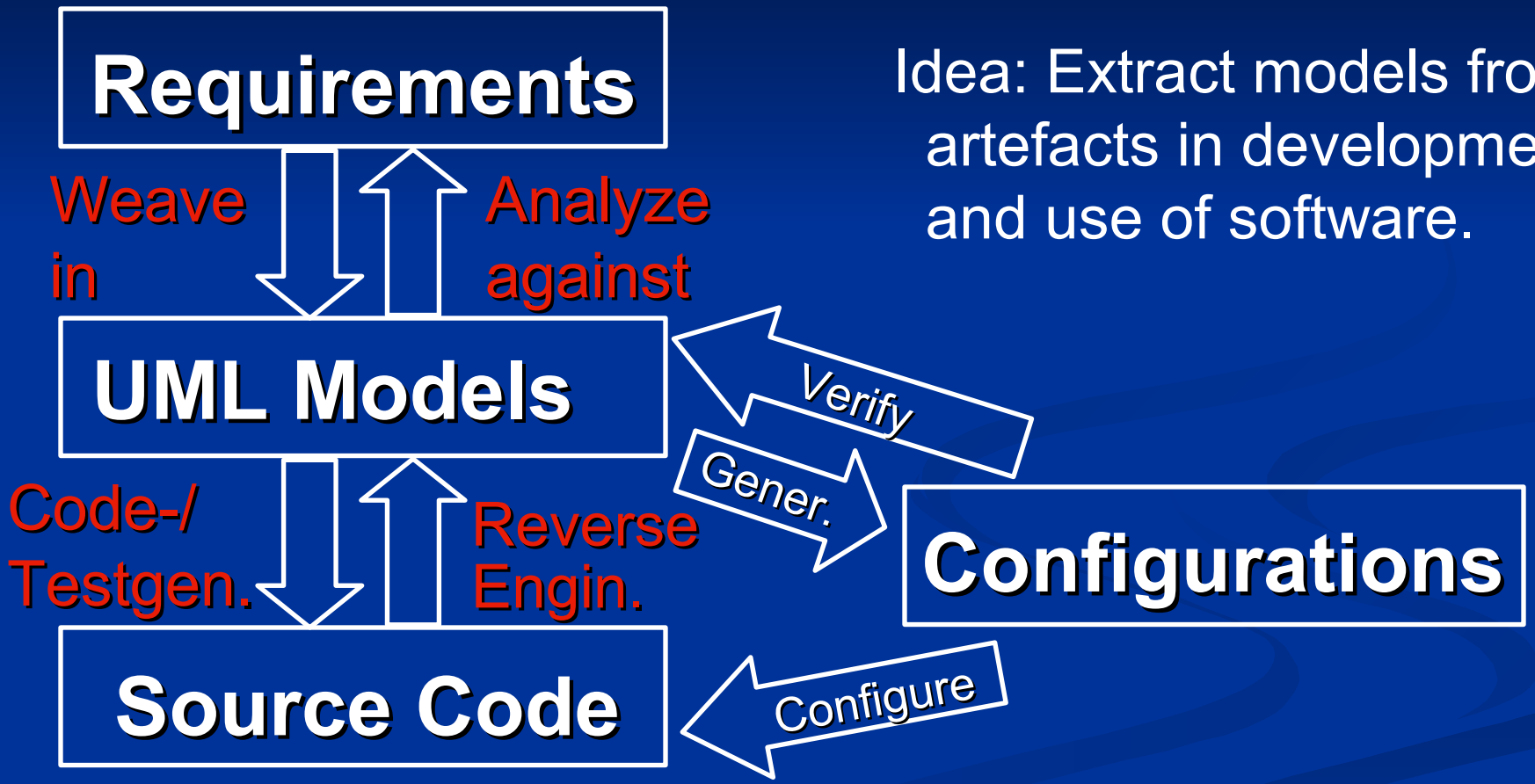
Special Problem: Crypto

- Cryptography plays important role in many security-critical applications
- By definition, needs to be secure against brute-force attacks
- Paradox: How do you get sufficient test coverage (for inputs accessible to a given attacker) of a system that needs to be secure against brute-force attacks on that input ?

➔ What`s your answer ?

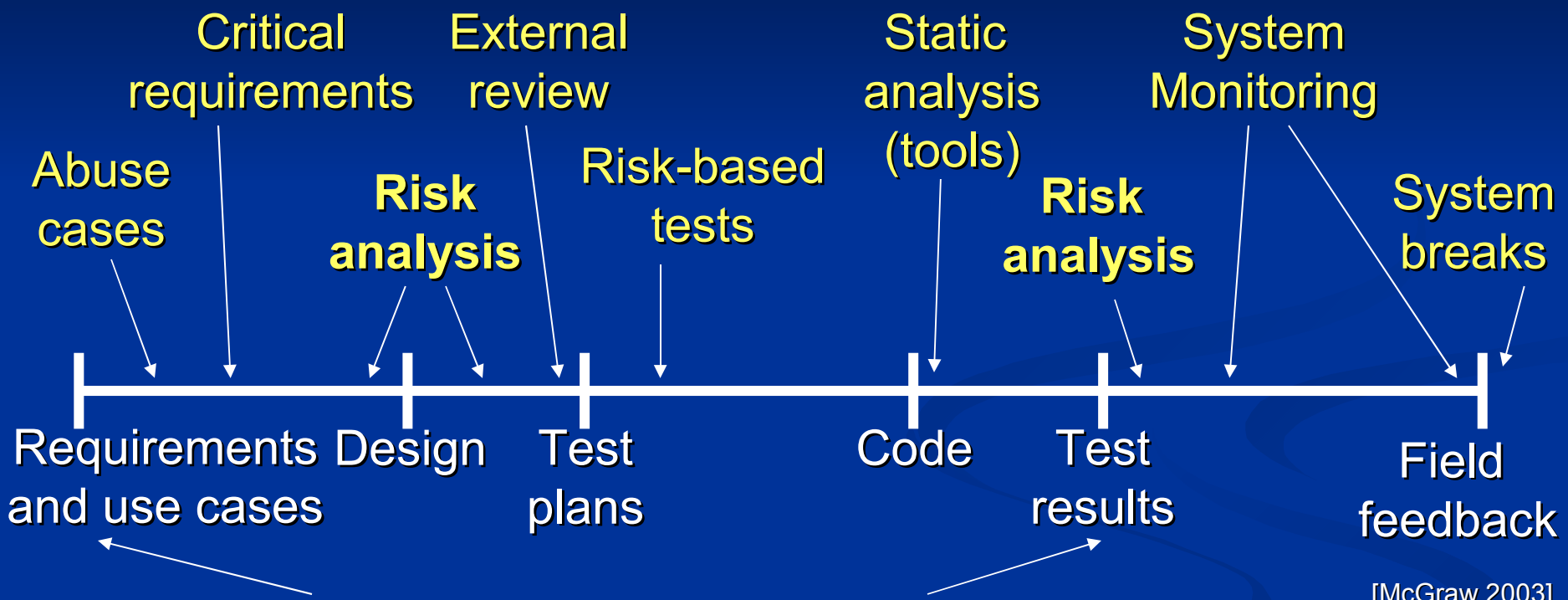
(Not using classical testing.)

Model-based Security Assurance



Idea: Extract models from artefacts in development and use of software.

Secure System Lifecycle



[McGraw 2003]

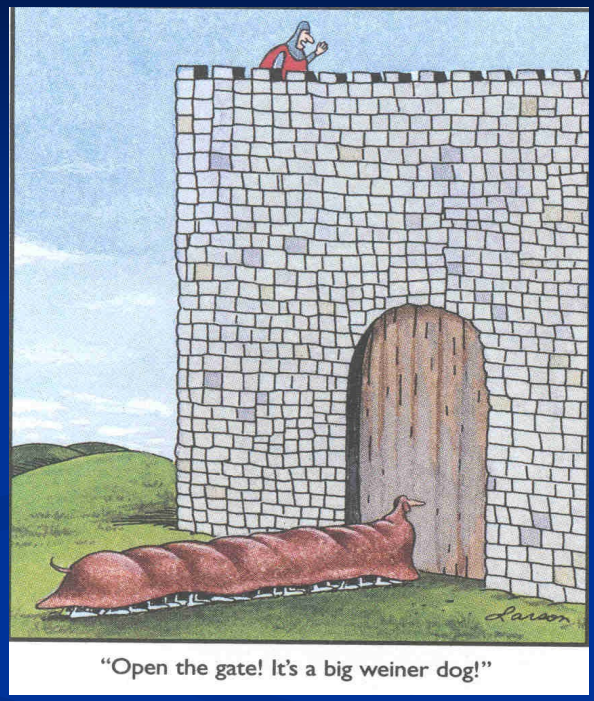
Model-based Security Assurance

Security Assurance: Model vs Code

Model:

+ earlier (less expensive to fix flaws)

+ more abstract ➔ more efficient



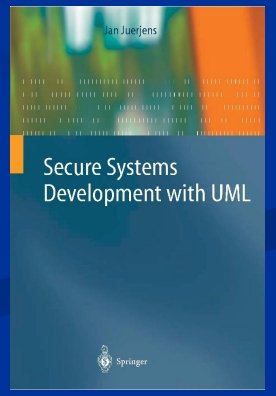
➔ Analyze both model and code:

- construct interface spec model
- analyze interface spec for critical requirements
- verify that software satisfies interface spec

UMLsec

Extension for secure systems development.

- evaluate UML specifications for weaknesses in design
- encapsulate established rules of prudent secure engineering as checklist
- make available to developers not specialized in secure systems
- consider security requirements from early design phases, in system context
- make certification cost-effective

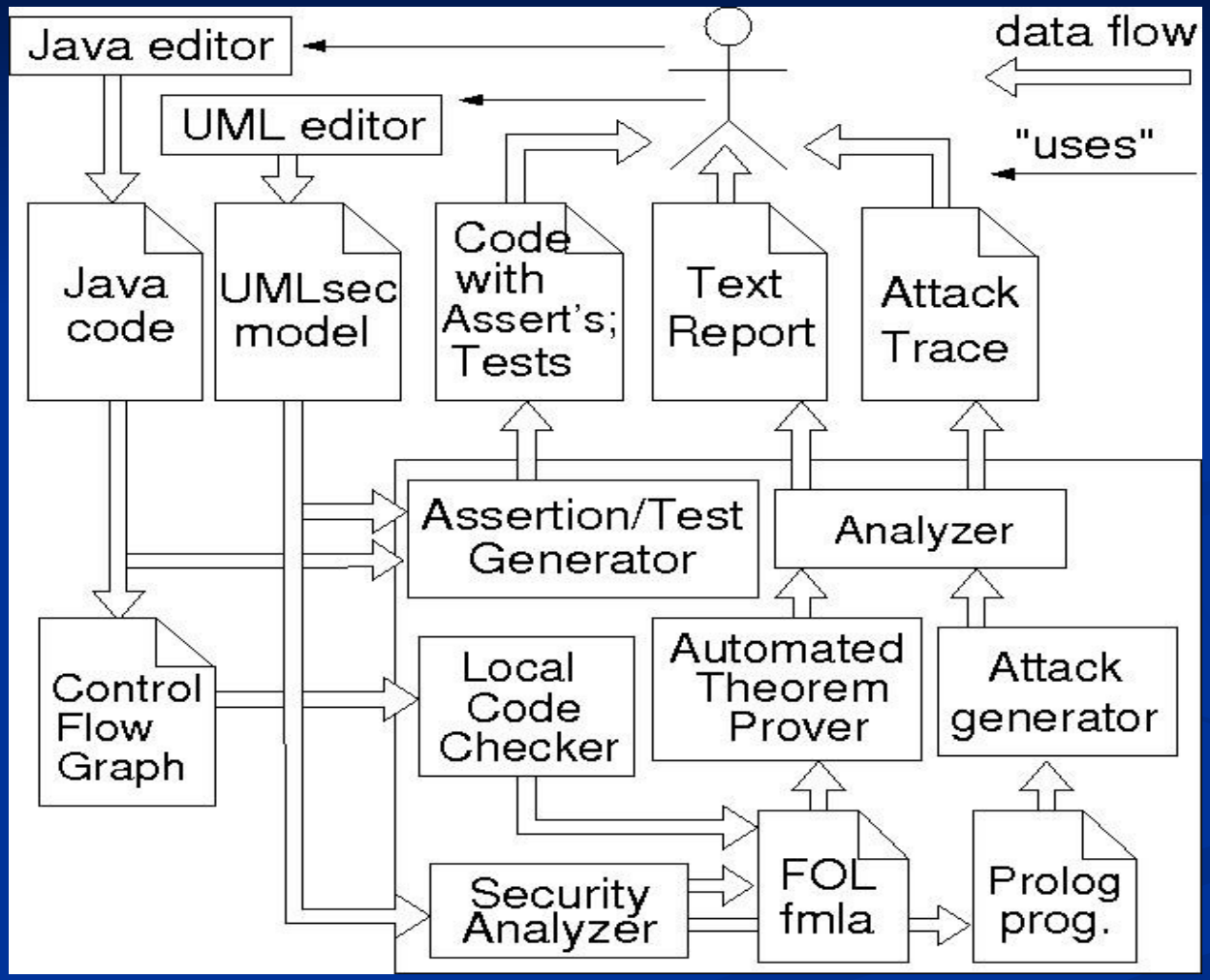


UMLsec Tool Support

For example:

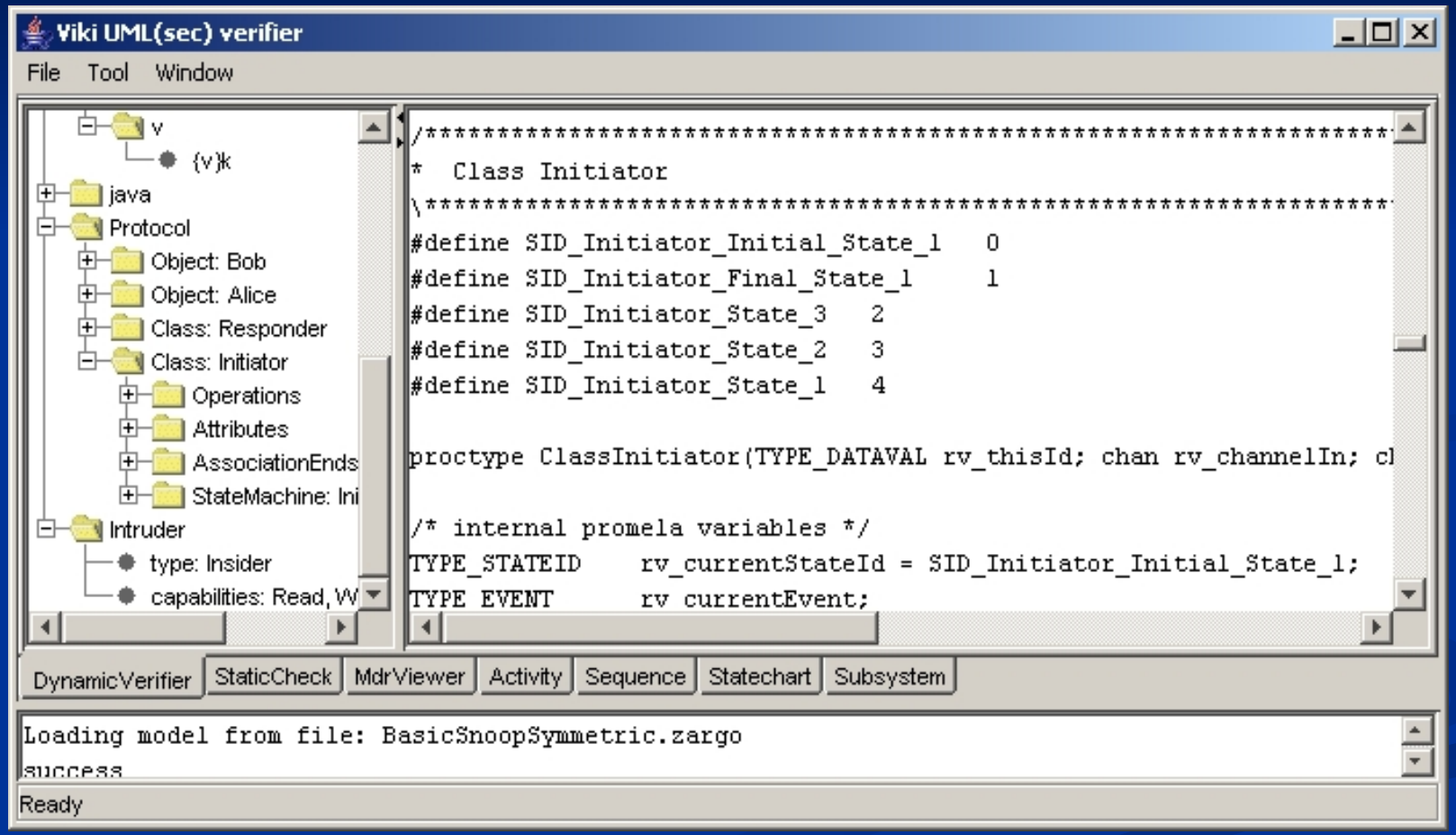
- consistency checks
- automated analysis of complicated requirements on model level (bindings to model-checkers, constraint solvers, automated theorem provers, …)
- code generation
- test-sequence generation
- configuration data analysis against models.

Tool Architecture

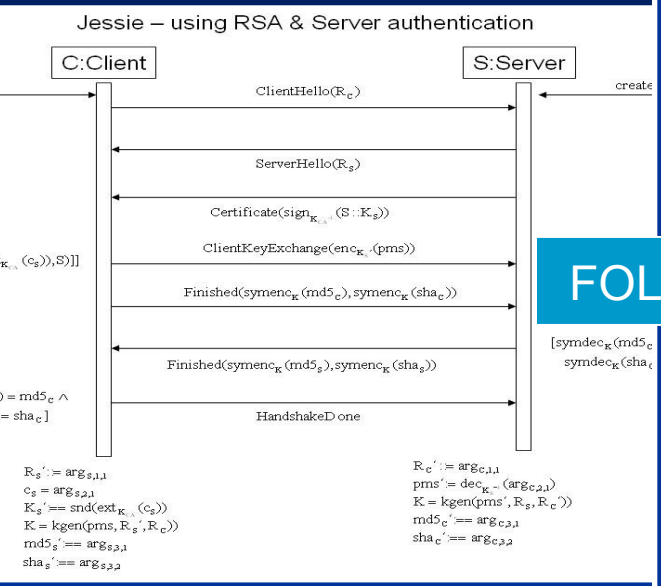


Works also with C.

Snapshot


Viki UML(sec) verifier
File Tool Window
v
{v}k
java
Protocol
Object: Bob
Object: Alice
Class: Responder
Class: Initiator
Operations
Attributes
AssociationEnds
StateMachine: Ini
Intruder
type: Insider
capabilities: Read, W
/**********
* Class Initiator
****
#define SID_Initiator_Initial_State_1 0
#define SID_Initiator_Final_State_1 1
#define SID_Initiator_State_3 2
#define SID_Initiator_State_2 3
#define SID_Initiator_State_1 4
proctype ClassInitiator(TYPE_DATAVAL rv_thisId; chan rv_channelIn; cl
/* internal promela variables */
TYPE_STATEID rv_currentStateId = SID_Initiator_Initial_State_1;
TYPE_EVENT rv_currentEvent;
DynamicVerifier
StaticCheck
MdrViewer
Activity
Sequence
Statechart
Subsystem
Loading model from file: BasicSnoopSymmetric.zargo
success
Ready

Model Verification



FOL

```
...
((
  knows(ArgC_3)
  & (equal(fst(ArgC_3), type_serverkeyexchange))
  & (equal(snd(ext(snd(snd(ArgC_3)), k_ca)), skey))
  & (equal(snd(ext(snd(ArgC_2), k_ca)), fst(snd(ArgC_3))))
)
=>(
  ((knows(ArgC_4_1)
    & equal(ArgC_4_1, type_serverhellodone))
    =>(
  ( ( true & equal(ClientKeyExchange, enc(premasterkey, skey))
)
...
```

```
%------------------------ Conjecture --

input_formula(attack,conjecture,(
   knows(mastersecret) )).
```

ATP

```
analyzing results ...
model found/total failure
time limit information: 19 total / 18 strategy
(leaving wrapper).
task myUML_PID1491 on atbroy1 has status SUCCESS
(model found by strategy 300) consuming 1 seconds
deleting temporary files.
e-SETHEO done. exiting
```

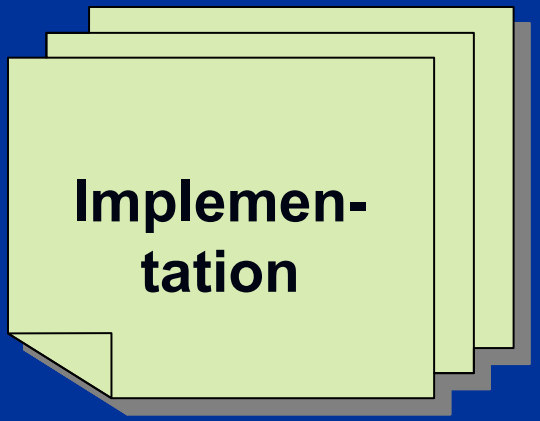
Model vs. Implementation

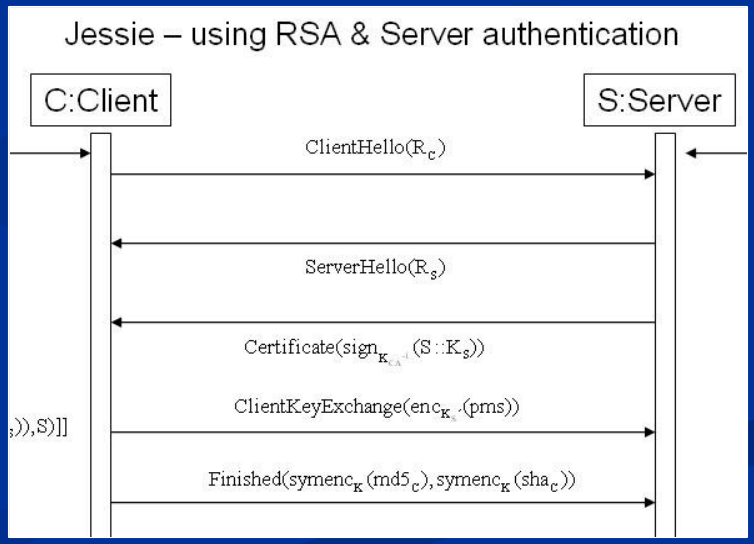
Sent / received data

Test cases

Trace

Generate





Model-based Security Testing: Strategies

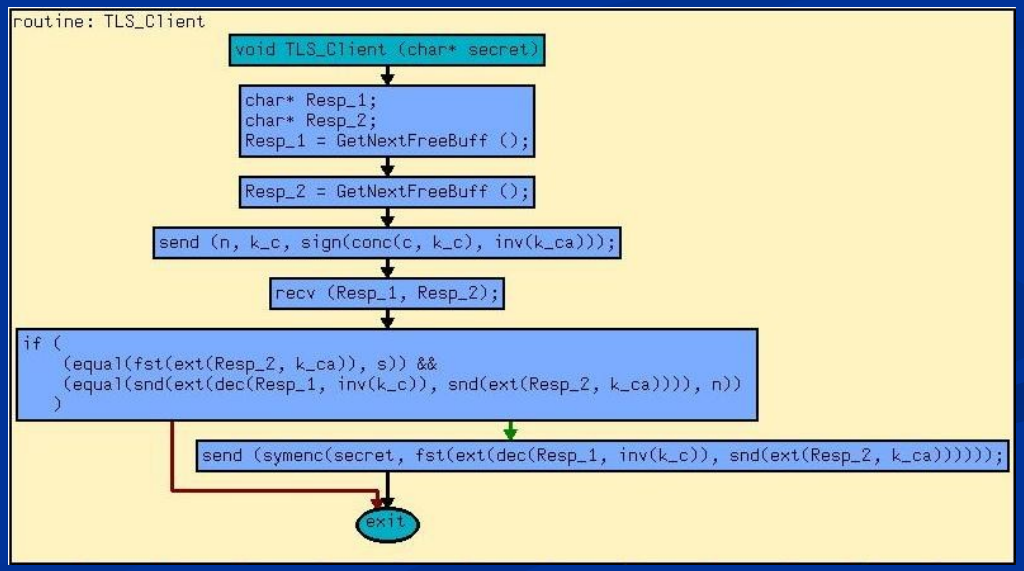
Internal: Ensure test-case selection from models does not miss critical cases: Select according to information on criticality / security.

External: Test code against possible environment interaction generated from parts of the model (e.g. deployment diagram with information on physical environment).

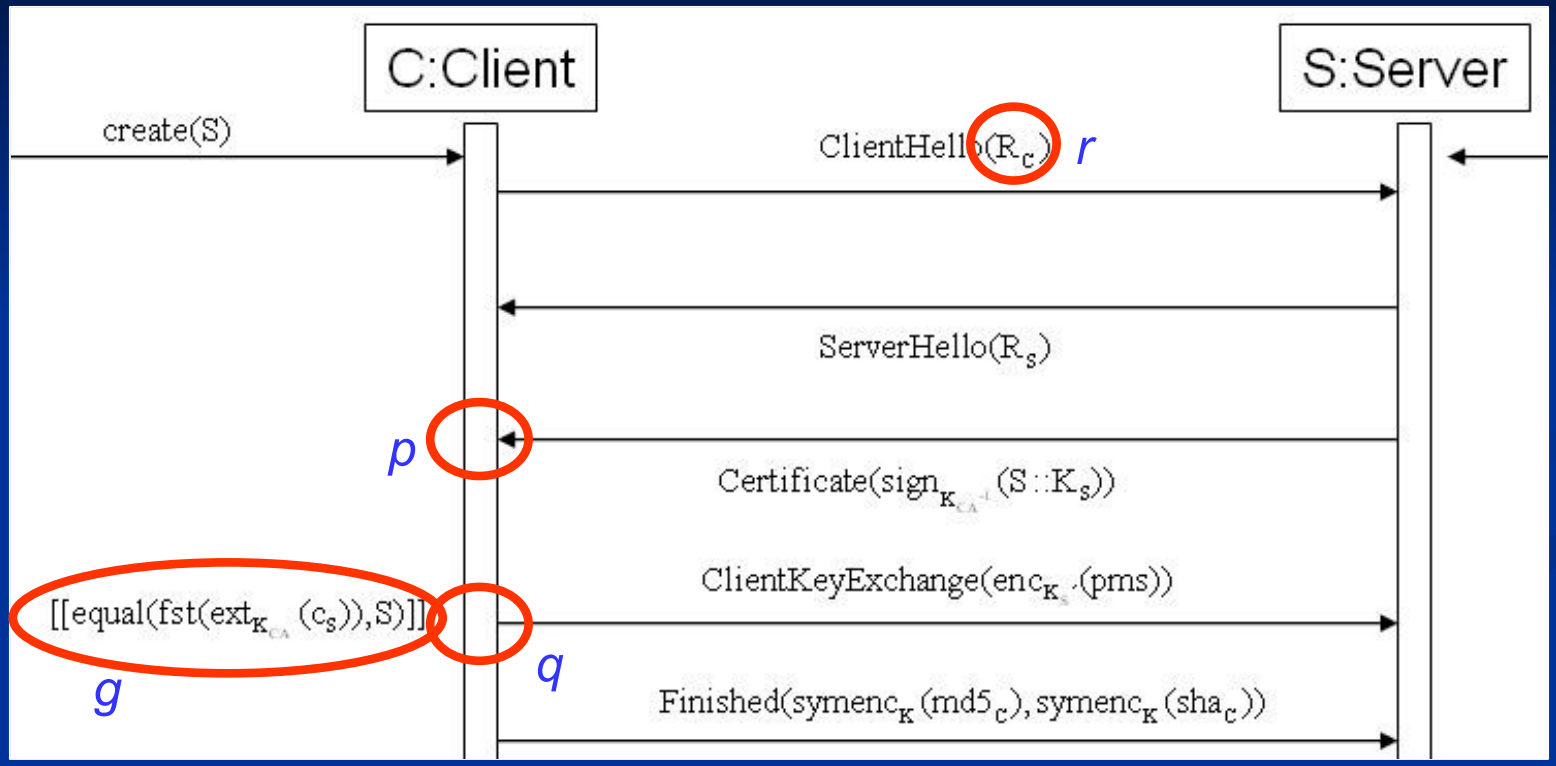
Model-based Security Testing: Some technical details

To address problems mentioned earlier, test cases generation needs to be informed by actual code.

- Generate control flow graph.
- Analyze for criticality requirements (e.g. security).
- Use to generate critical test-cases.



Example: SSL

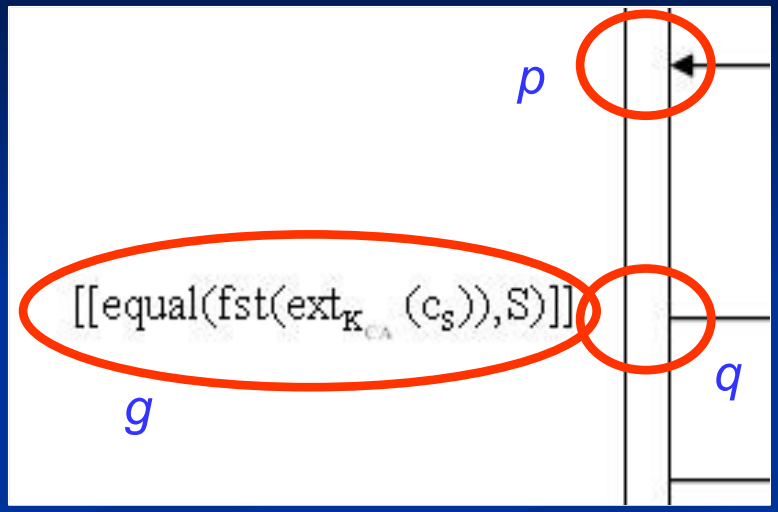


I) Identify program points:
value (*r*), receive (*p*), guard (*g*), send (*q*)

II) Check guards enforced

Checking Guards

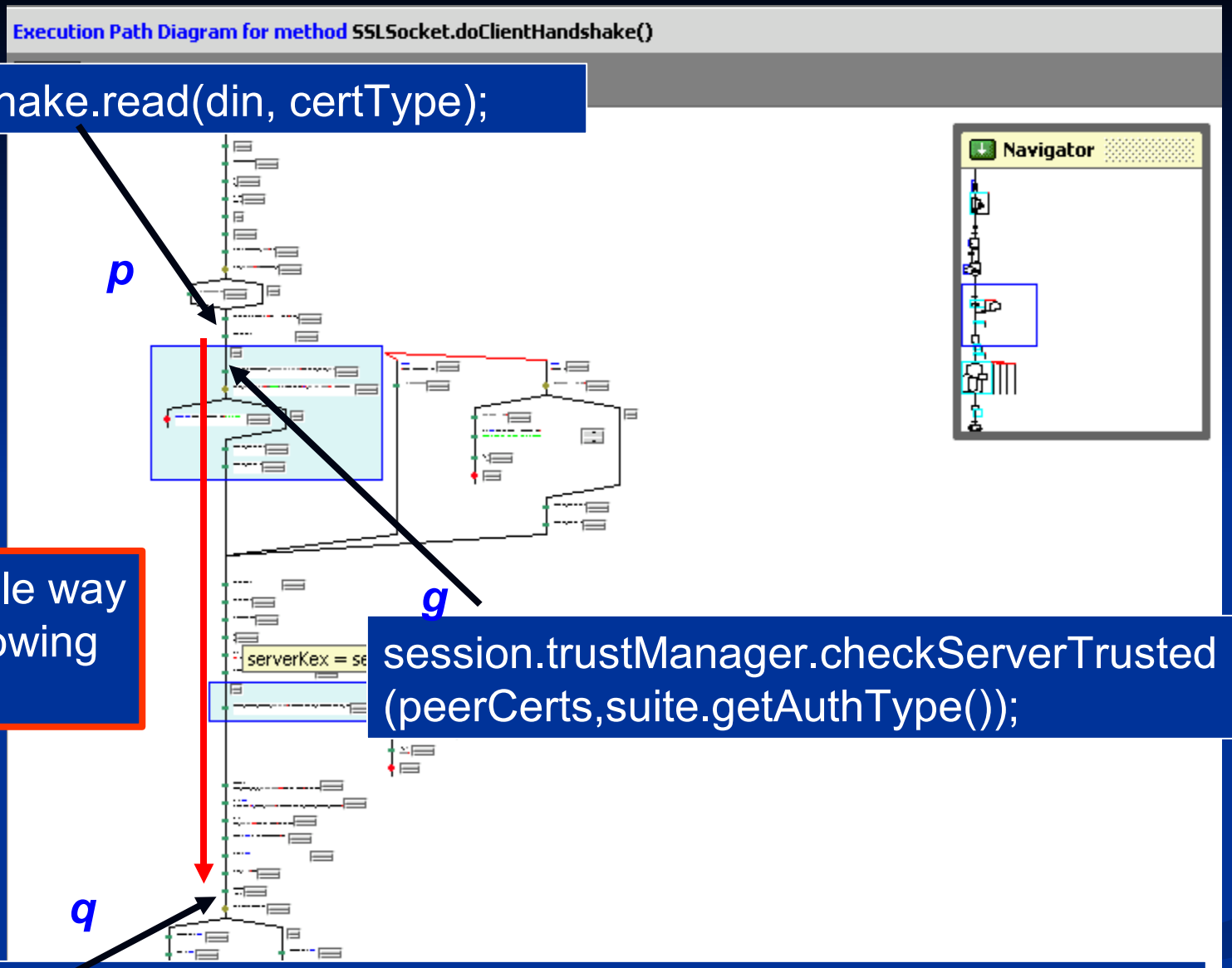
Guard *g* enforced by code?



b) Generate runtime check for *g* at *q* from diagram: simple + effective, but performance penalty.

c) Testing against checks (symbolic abstractions for crypto).

d) Automated formal local verification: conditionals between *p* and *q* logically imply *g* (uses Prolog).


Execution Path Diagram for method SSLSocket.doClientHandshake()
msg = Handshake.read(din, certType);
p
Navigator
only possible way without throwing exception
g
session.trustManager.checkServerTrusted (peerCerts,suite.getAuthType());
serverKex = se
q
msg = new Handshake(Handshake.Type.CLIENT_KEY_EXCHANGE, ckex);
msg.write (dout, version);

Some Applications

Analyzed designs / implementations / configurations e.g. for

- Biometry- or smart-card-based identification
- authentication (crypto protocols)
- authorization (user permissions, e.g. SAP systems)

Analyzed security policies, e.g. for privacy regulations.

Allianz

Deutsche Bank

HypoVereinsbank

CEPS™

BMW Group

Münchener Rück
Munich Re Group

Bundesministerium für Bildung und Forschung

Bundesministerium für Wirtschaft und Technologie

O2

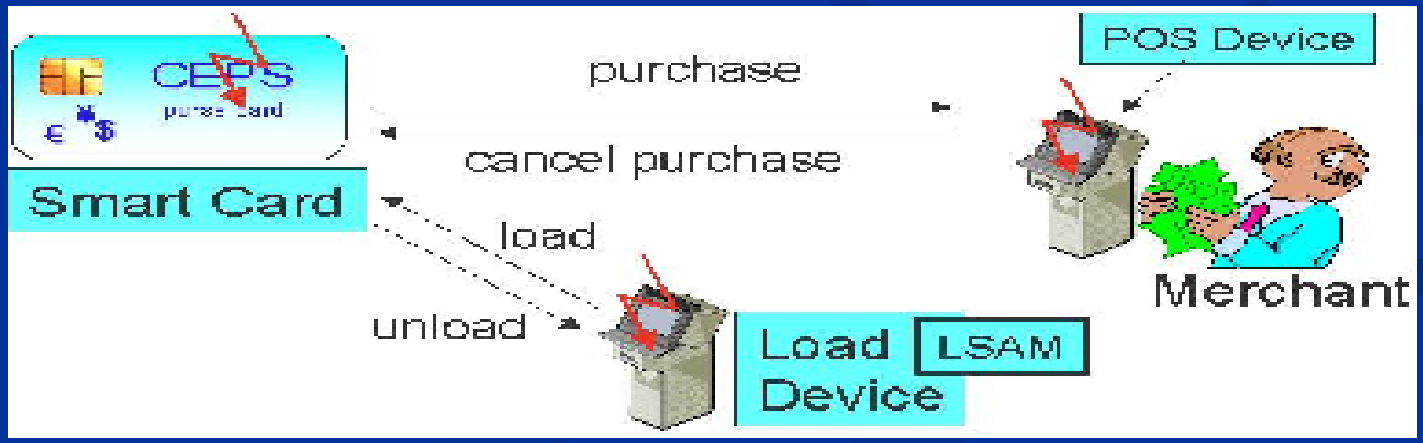
infineon

Common Electronic Purse Spec.

Global elec. purse standard (Visa, 90% market).

Smart card contains account balance, performs crypto operations securing each transaction.

Formal analysis of load and purchase protocols: three significant weaknesses: purchase redirection, fraud bank vs. load device owner.



Biometric Authentication System

In development by company in joint project.

Uses bio-reference template on smart-card.

Analyze given UML spec.

Discovered three major weaknesses in subsequently improved versions (misuse counter circumvented by dropping / replaying messages, smart-card insufficiently authenticated by mixing sessions).

Finally developed version secure by our analysis.

Bank Application

Security analysis of web-based banking application, to be put to commercial use (clients fill out and sign digital order forms).

Layered security protocol (first layer: SSL protocol, second layer: client authentication protocol)

Security requirements: confidentiality, authenticity

Successfully verified using model-based security.

Intranet Information System

MetaSearch Engine: Personalized search in company intranet (including password protected).

Some documents highly security-critical.

BMW Group

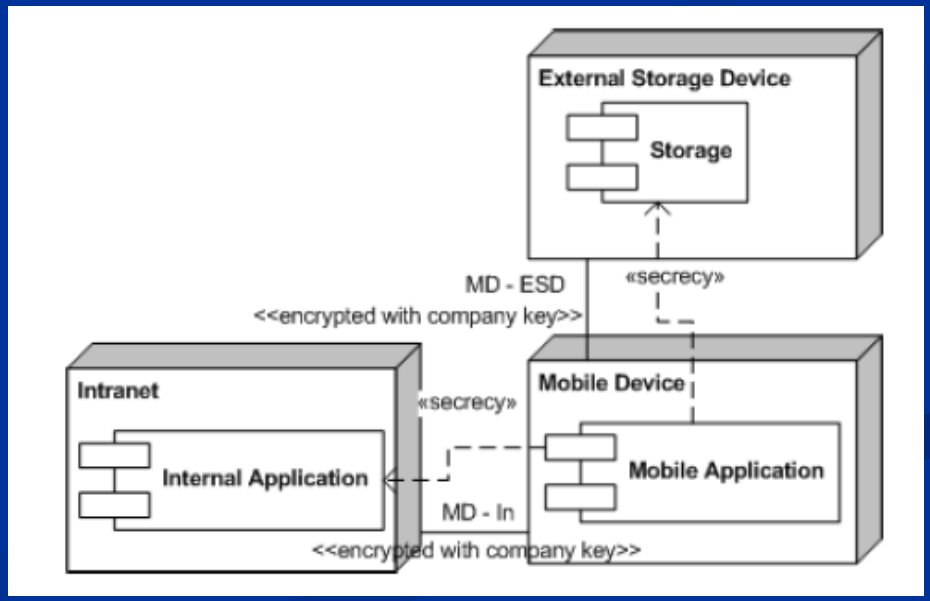
More than 1,000 potential users, index 280,000 documents, allow 20,000 queries per day.

Seamlessly integrated in enterprise-wide security reference architecture. Provides security services to applications, including user authentication, role-based access control, global single-sign-on and hook-up of new security apps.

Successfully analyzed using model-based security.

Mobile Communications

- Application of Model-based Security Assurance at Mobile Communication Systems at O2 (Germany)
- All 62 relevant security requirements derived from the security policy could successfully be established using the approach



How does it compare ?

- Empirical study to compare classical vs. model-based testing: embedded software / Automotive (window controller). In cooperation with colleagues from BMW / Elektrobit. From the comparison:

Modelchecking
Examines an abstract model
Cheap and early verification (without setting up complex in-the-loop-test environments)
Proof of correctness of properties possible
Uses selected user specific properties

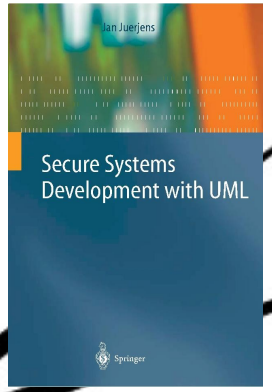
Testing
Examines a physical or concrete system
In-the-loop-tests take place in an environment near to the real one
No proof of correctness of properties possible
Uses often many, superficial test cases

3 Things to Remember

- Quality Assurance for security-critical systems is very difficult
- Some specific security properties (e.g. wrt brute-force attacks) cannot be established using conventional testing methods
- Model-based Security Testing based on UMLsec is a corner-stone of Security QA

… don`t get lost in the security maze…

Overview



Security Engineering

- Patterns
- Services
- Components
- Layers
- Architectures
- Aspects
- Requirements
- Processes
- Models
  - UMLsec
  - Formal Semantics
  - Analysis Framework
  - Model Checking
  - Autom. Theorem Proving
  - Refinement
- Applications
  - CEPS
  - Biometry
  - Cryptokey
  - Jessie
  - TLS variant
  - Wiesncard
- Code
  - Runtime Checks
  - Model-based Testing
  - Autom. Theorem Proving
- Foundations

Dependable Systems Development

- Fault-tolerance
- Reliability
- Real-time
- Security
  - Engineering
  - Management
    - Risk Assessment
    - Permissions
    - Business Processes
    - Security Investment
    - Firewall Configurations

More information:
www.umlsec.org
Questions ?
J.Jurjens@open.ac.uk

Backup

CEPS Load Protocol

- Unlinked, cash-based load transaction (on-line).
- Load value onto card using cash at load device.
- Load device contains Load Security Application Module (LSAM): secure data processing and storage.
- Card account balance adjusted; transaction data logged and sent to issuer for financial settlement.
- Uses symmetric cryptography.

Load «data security»

Card «critical»

{secrecy={K_{CI}}}
{integrity={K_{CI},cep,nt,rc_{nt}}}

cep, nt, rc_{nt} : Data; K_{CI} : Keys

Init(lda,m)
Credit(s2,rl)

LSAM «critical»

{secrecy={K_{LI}}}
{integrity={K_{LI},lda,n,rl_n,$r2l_n$,r_n,m_n}}

lda, n, rl_n, $r2l_n$, m_n : Data
K_{LI}, r_n : Keys

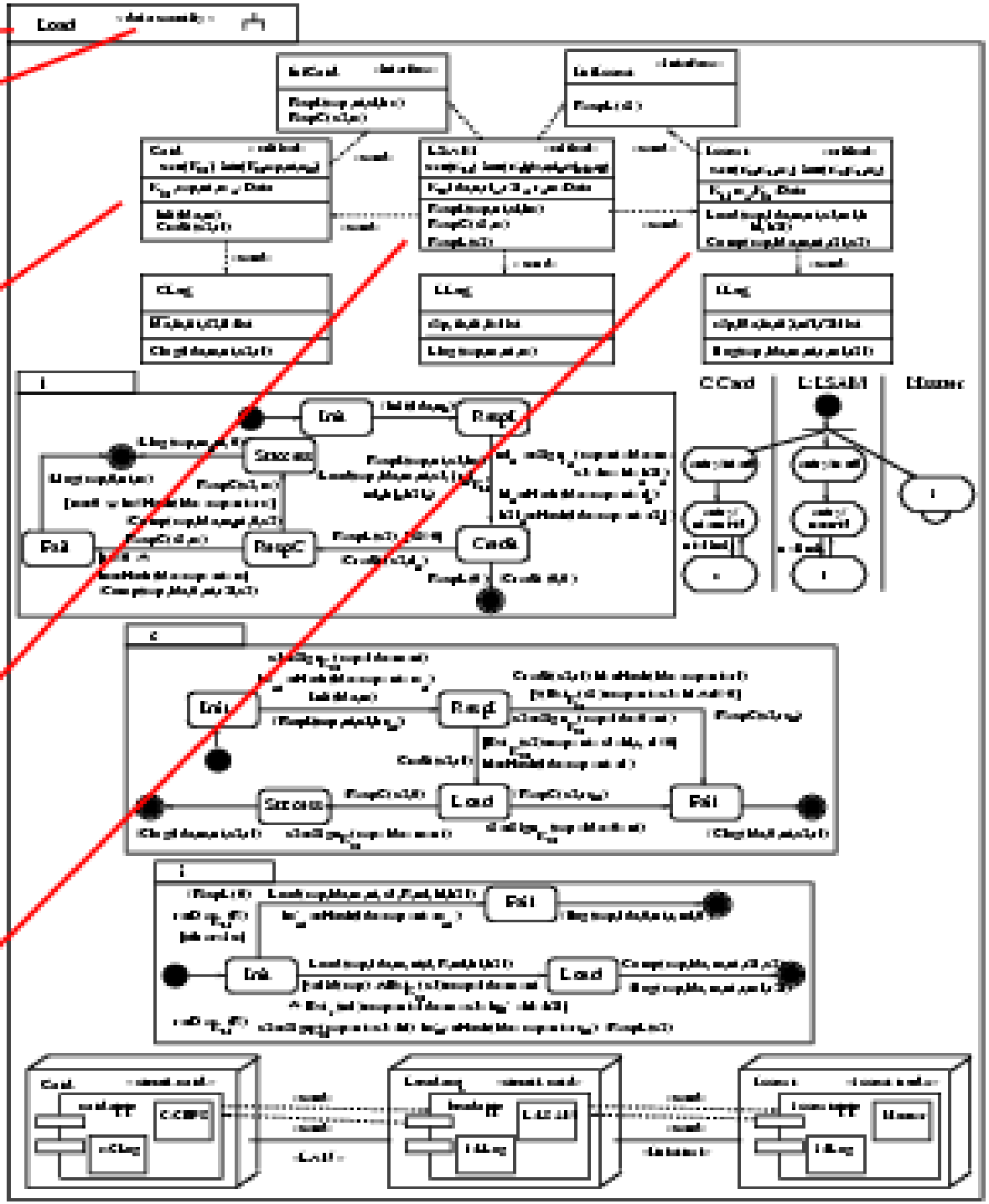
RespI(cep,nt,sl,hc)
RespC(s3,rc)
RespL(s2)

Issuer «critical»

{secrecy={K_{CI},K_{LI},rc_{nt}}}
{integrity={K_{CI},K_{LI},rc_{nt}}}

rc_{nt} : Data; K_{LI}, K_{CI} : Keys

Load(cep,lda,m,nt,s1,ml,h hl,h2l)
Comp(cep,lda,m,nt,r2l,s3)



Audit Security

No direct communication between card and cardholder. Manipulate load device display.

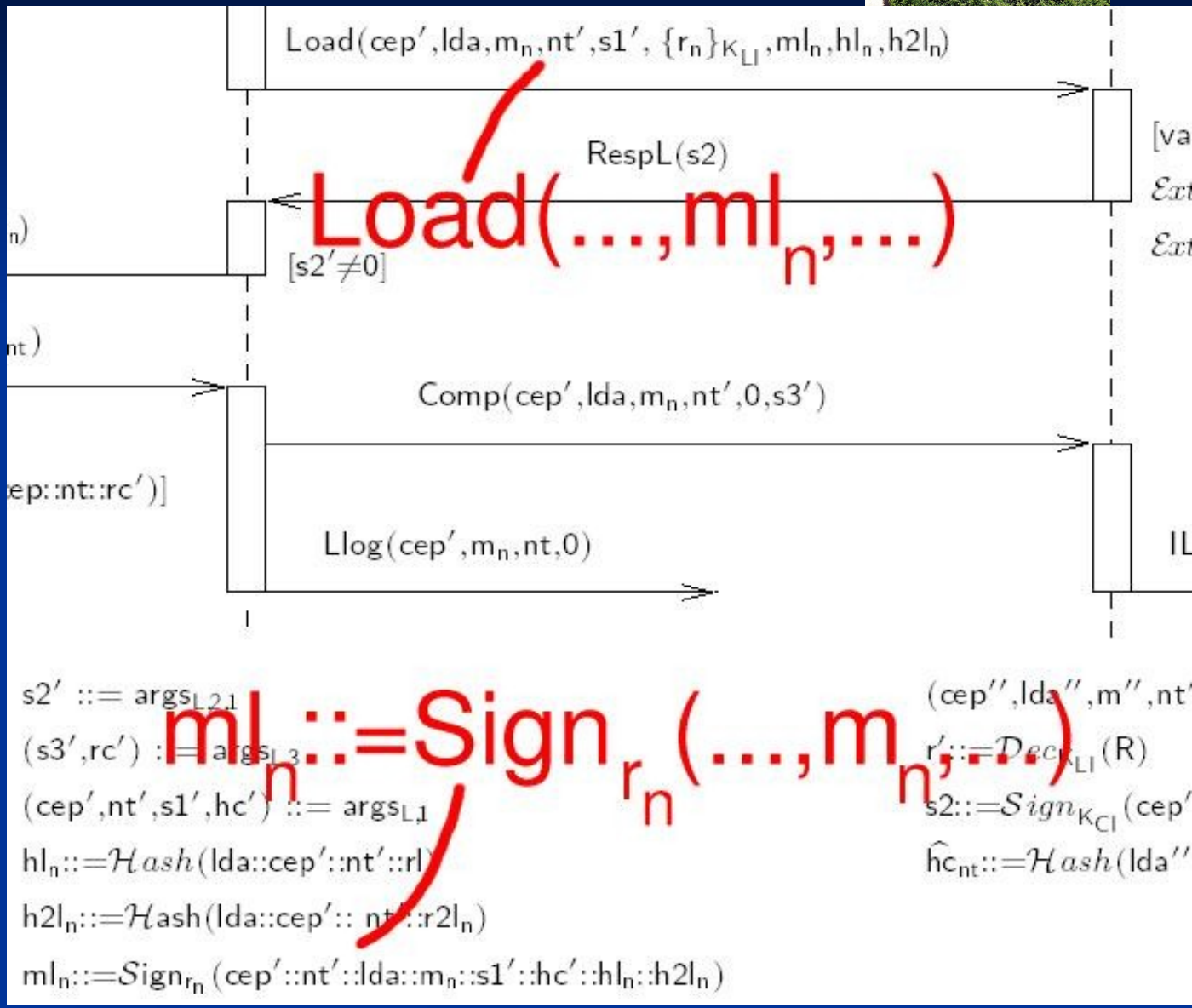
Use post-transaction settlement scheme.

Relies on secure auditing.

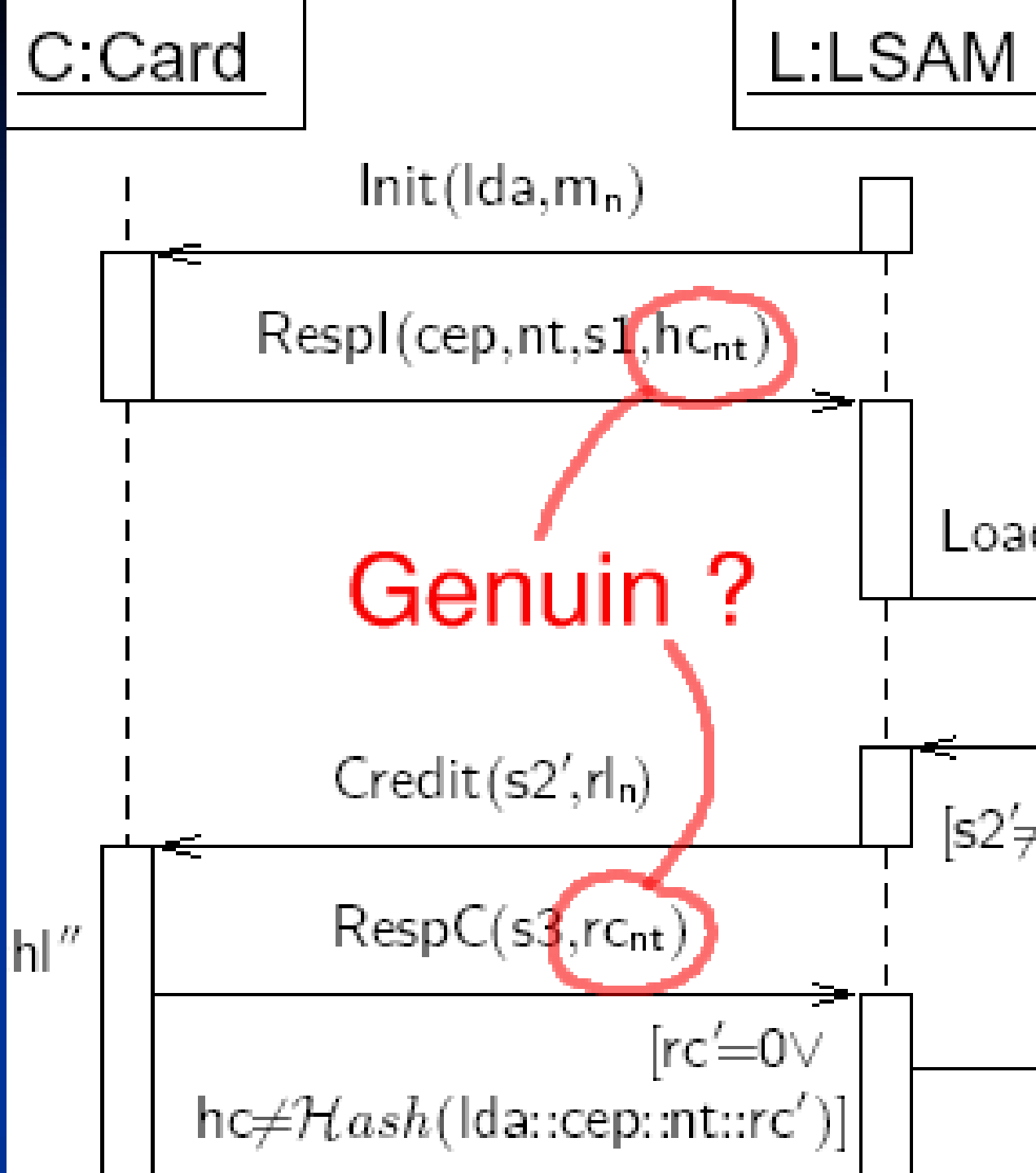
Verify this here (only executions completed without exception).

Flaw I

ml_n: „Proof“ for bank that load machine received money.
But: r_n shared between bank and load machine.



Flaw II

rc_{nt}: „Proof“ for LSAM that load device received only amount m_n.

But: LSAM cannot prove validity of rc_{nt}.