Model-based Security Testing Supporting Evolution

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3 Claims for this Talk

- Quality Assurance for security-critical systems is very difficult: some security properties cannot be established by conventional testing.
- To save effort, a security assurance approach needs to support system evolution.
- Model-based Security Testing can deal with these challenges.

Security: Some 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).

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.)

Testing Security-Critical Systems

Very challenging.

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

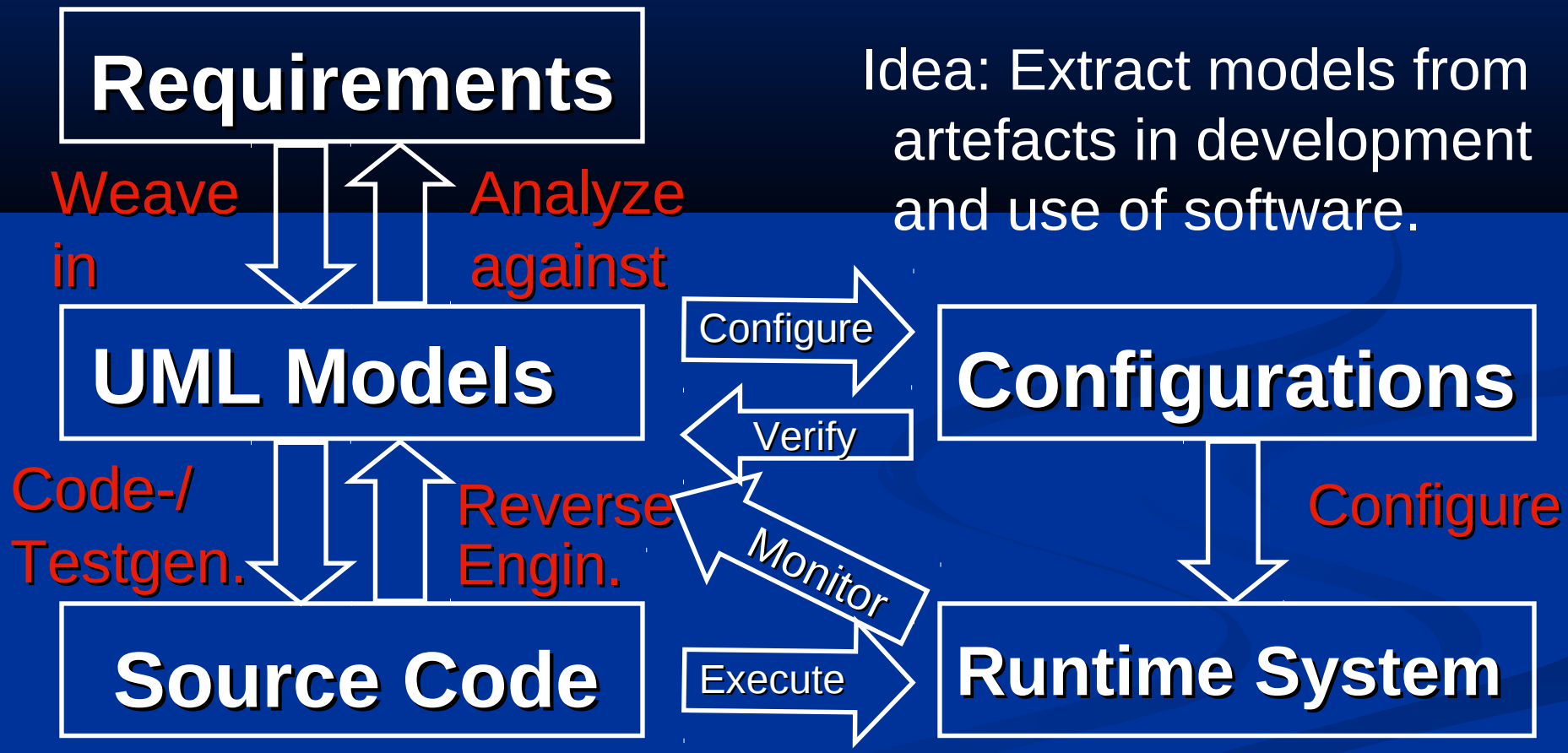
Usually infeasible (especially open systems).

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

Need to ask yourself:

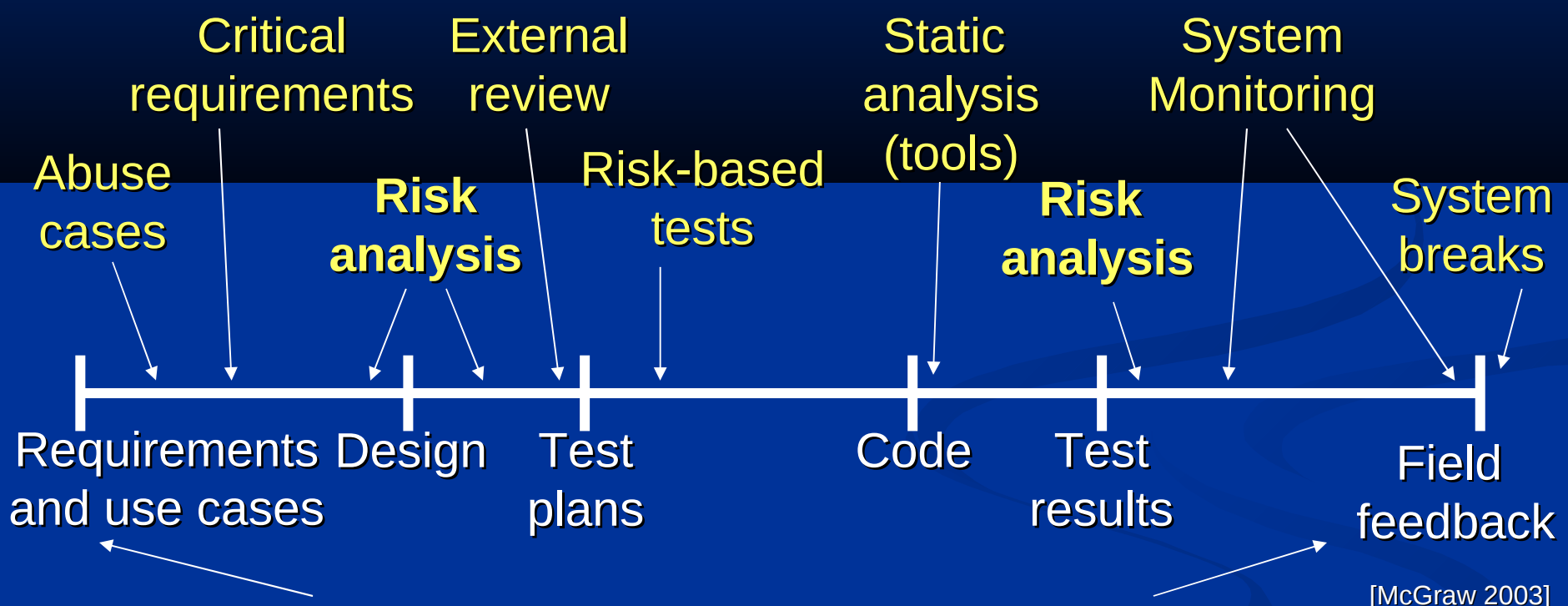
- How complete is the heuristic ?
- How can I validate it ?

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:

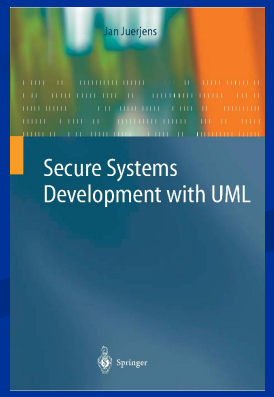
- construct interface spec model
- analyze interface spec for critical requirements
- verify that software satisfies interface spec

Important: to save effort need to automatically trace code evolution back to model level.
➔ Automatically reuse earlier tests.

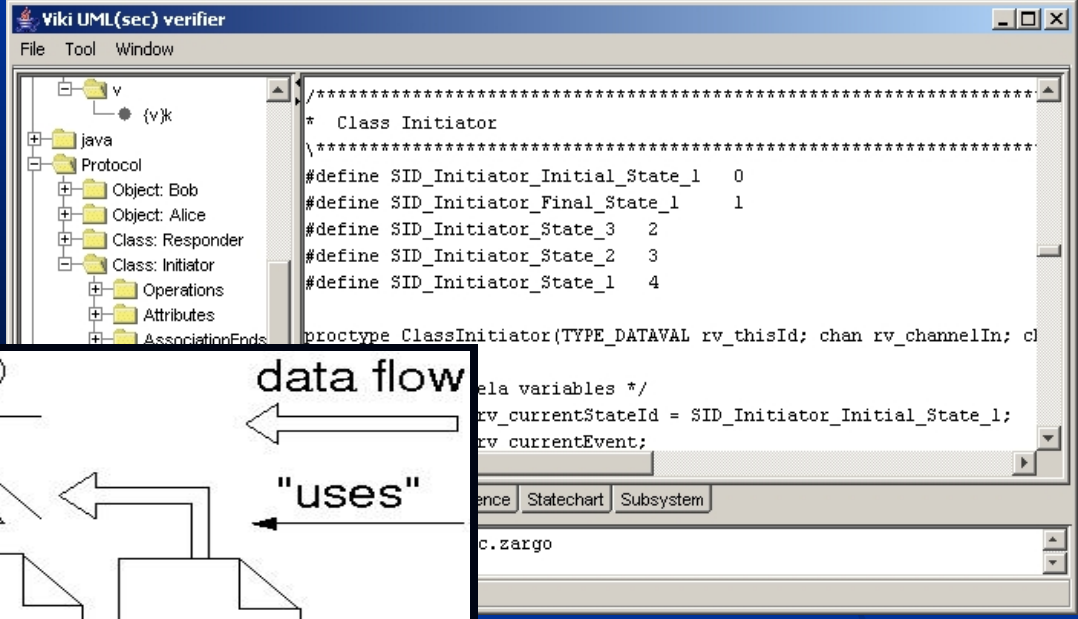
UMLsec

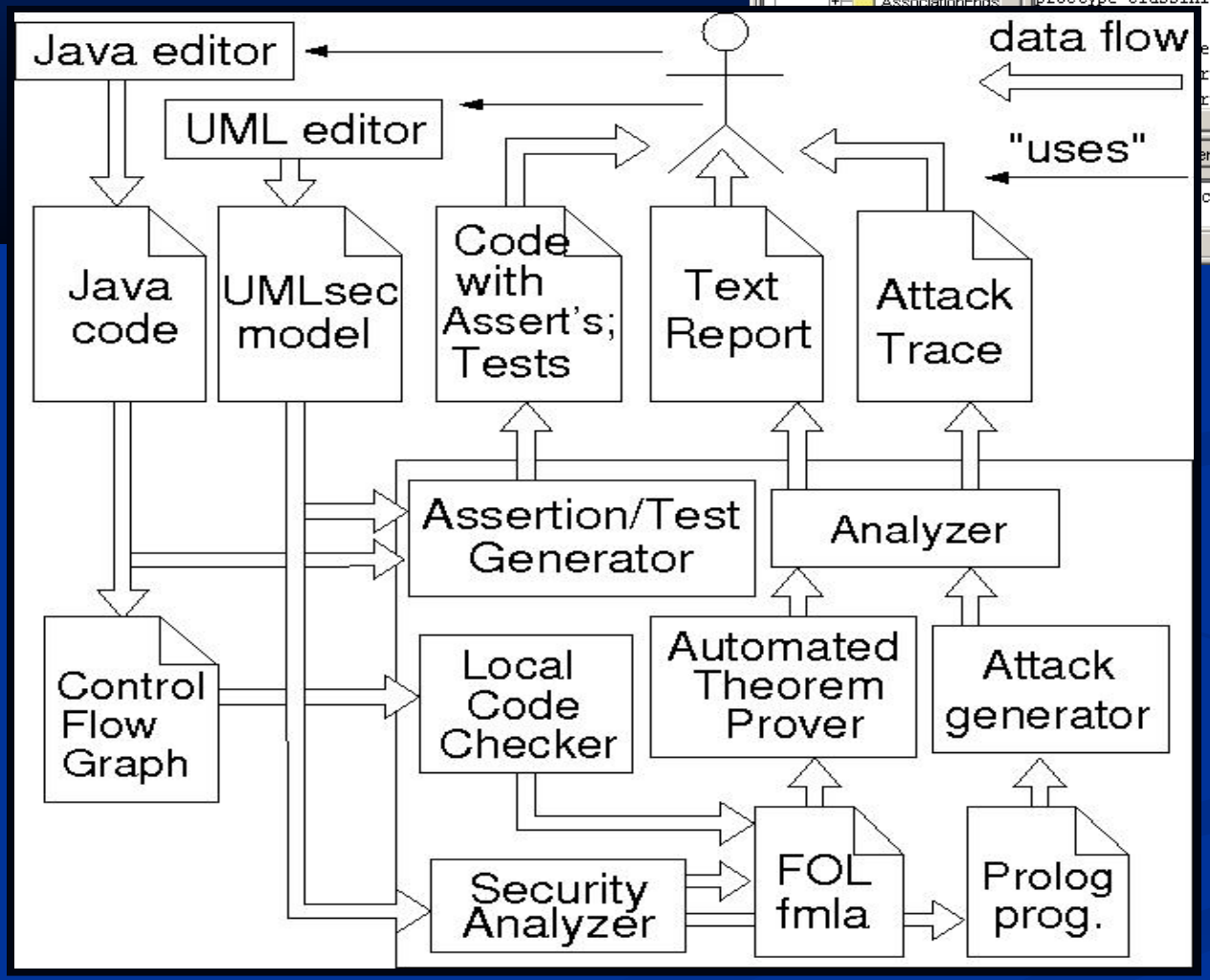
Extension for secure systems development.

- 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



Tool Support





Works also with C.

Model-based Testing Example: Protocols

Sent / received data

Testing

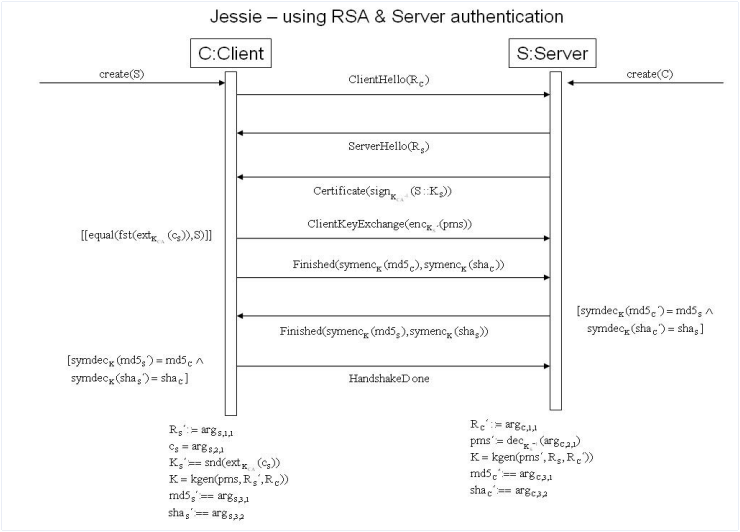
Test cases

Execute

Generate

Implementation

Correct Implementation ?



Model-based Security Testing: Strategies

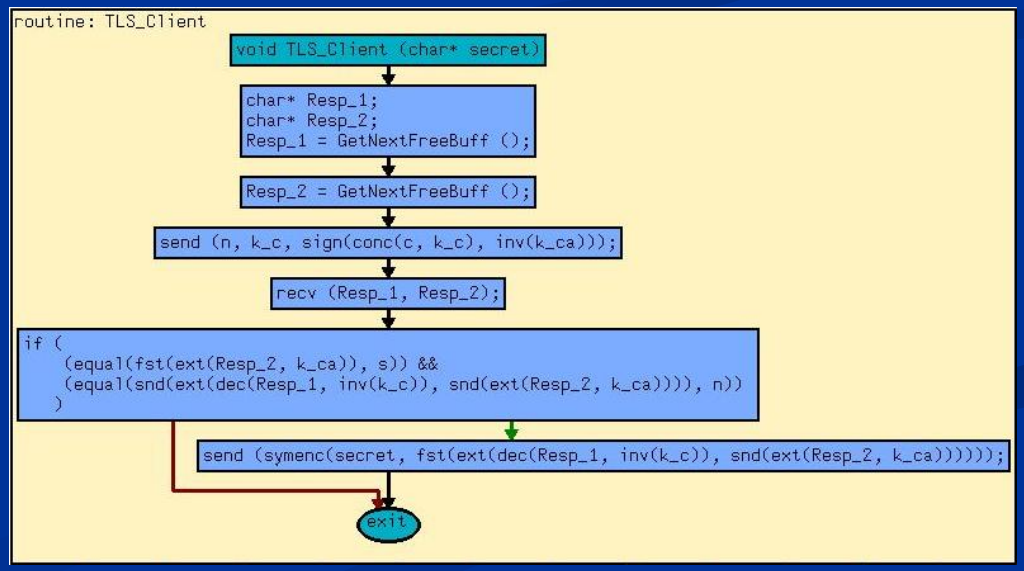
Internal: Ensure test-case selection from models does not miss critical cases: Select according to information on criticality / security.

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

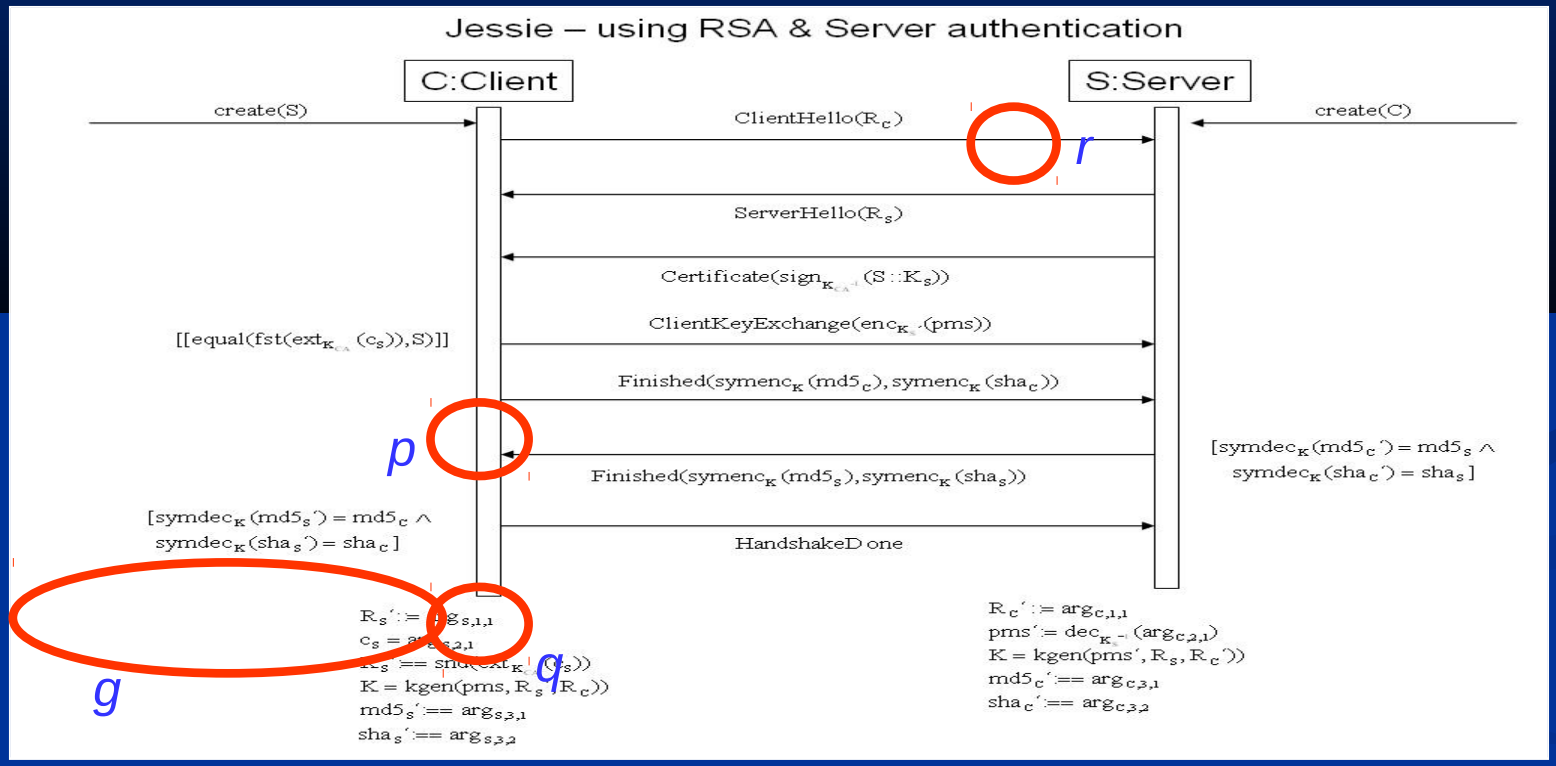
Model-based Security Testing: Some technical details

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 by mutation testing.



Example: SSL



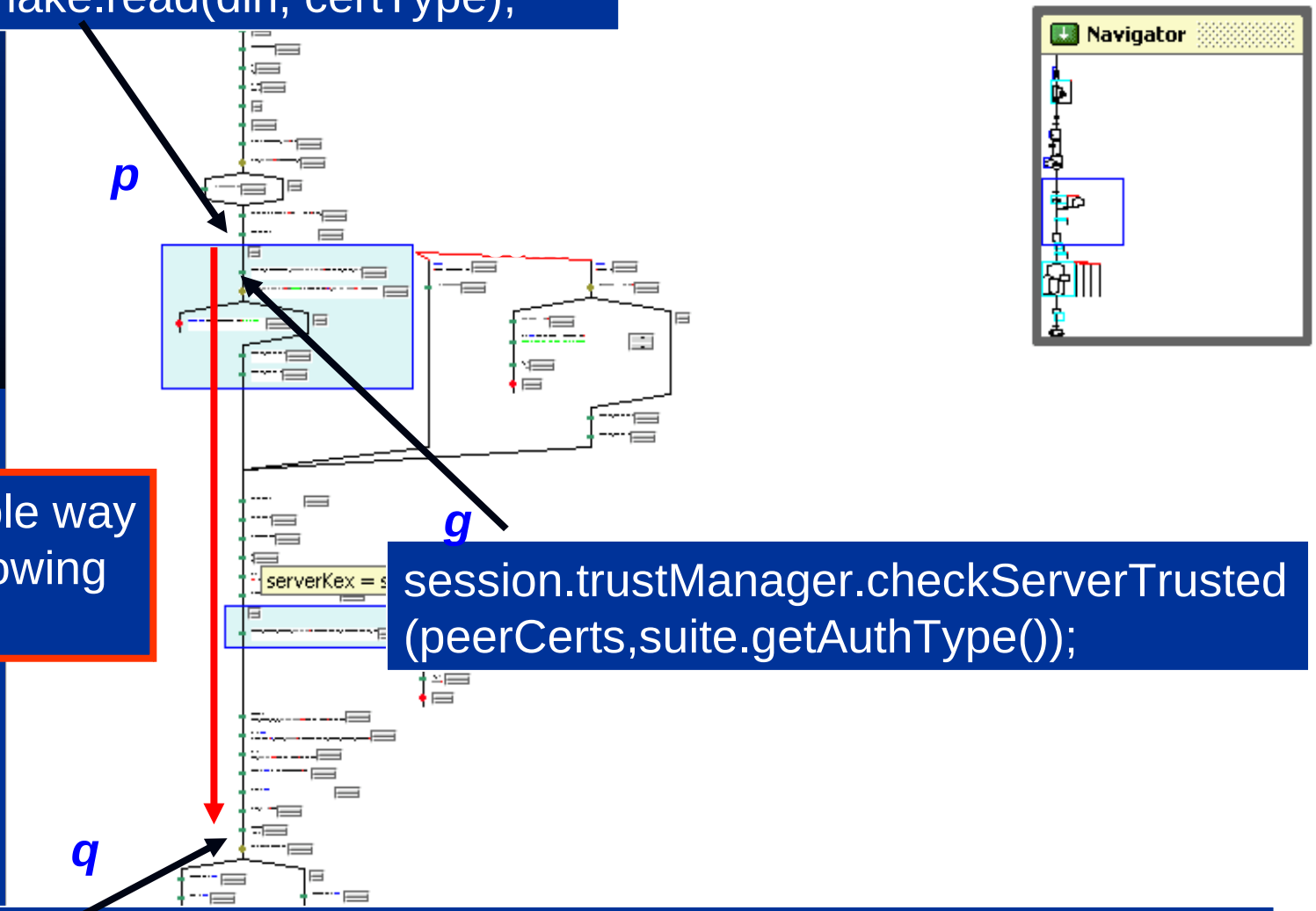
I) Identify program points:

value (*r*), receive (*p*), guard (*g*), send (*q*)

II) Check guards enforced

Execution Path Diagram for method SSLSocket.doClientHandshake()

msg = Handshake.read(din, certType);



only possible way without throwing exception

session.trustManager.checkServerTrusted (peerCerts,suite.getAuthType());

msg = new Handshake(Handshake.Type.CLIENT_KEY_EXCHANGE, ckex);
msg.write (dout, version);

Maintaining Traceability under Evolution

Code evolution can potentially multiply testing effort.

Need to re-verify code parts that changed, re-do integration testing etc.

Particular problem when testing for sophisticated properties (such as security) since requires particular effort.

➔ Want to automatically trace code evolution to model level so can automatically reuse earlier tests.

[Bauer, Jurjens, Yu 09]

Model-Code Co-Evolution

Basic observation: Most system changes can be reduced to two kinds:

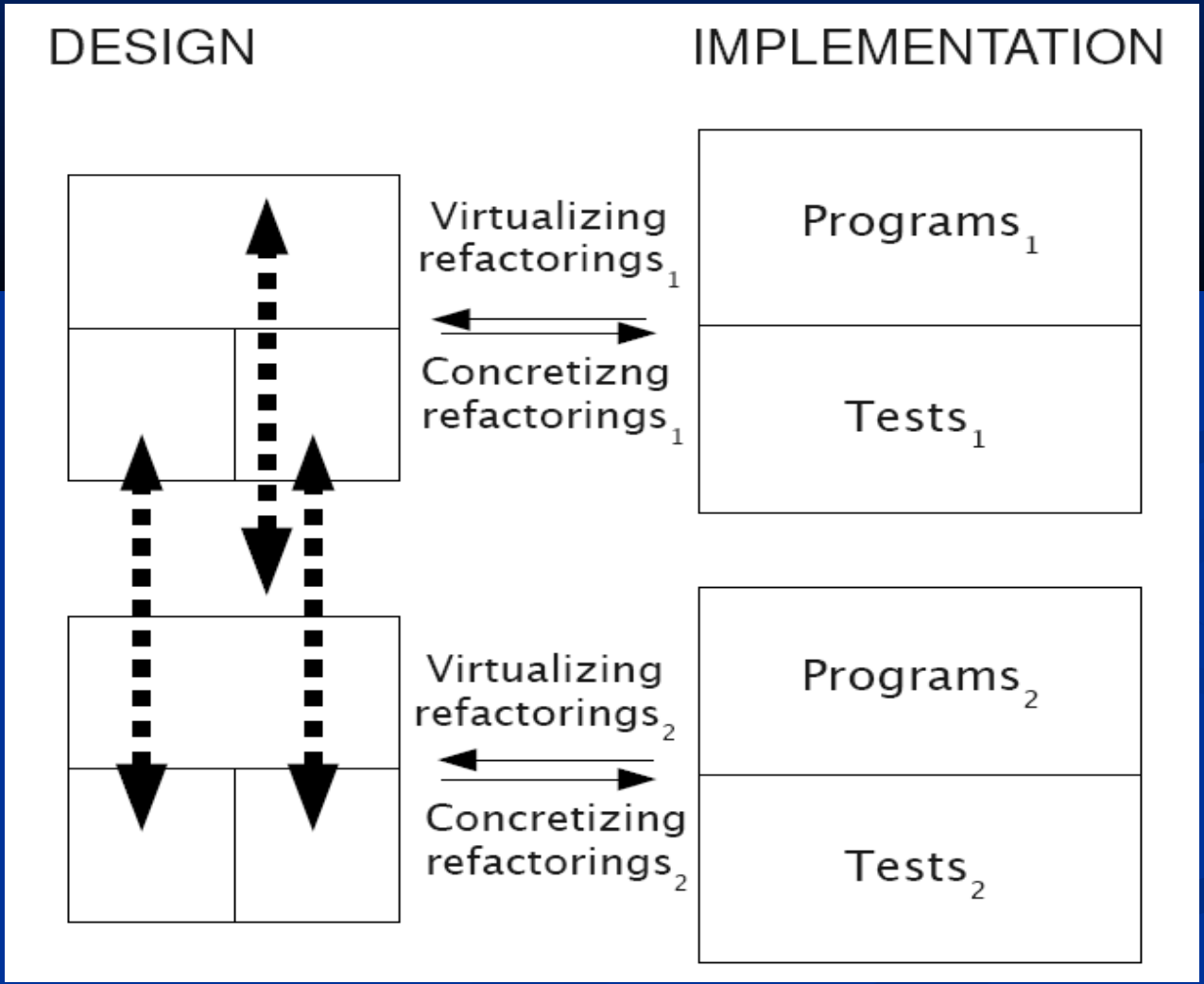
- Adding / removing parts of the system.
- Basic refactoring operations to hold system parts together despite changes.

When adding / removing code parts we need to assume that the corresponding models are also added / removed.

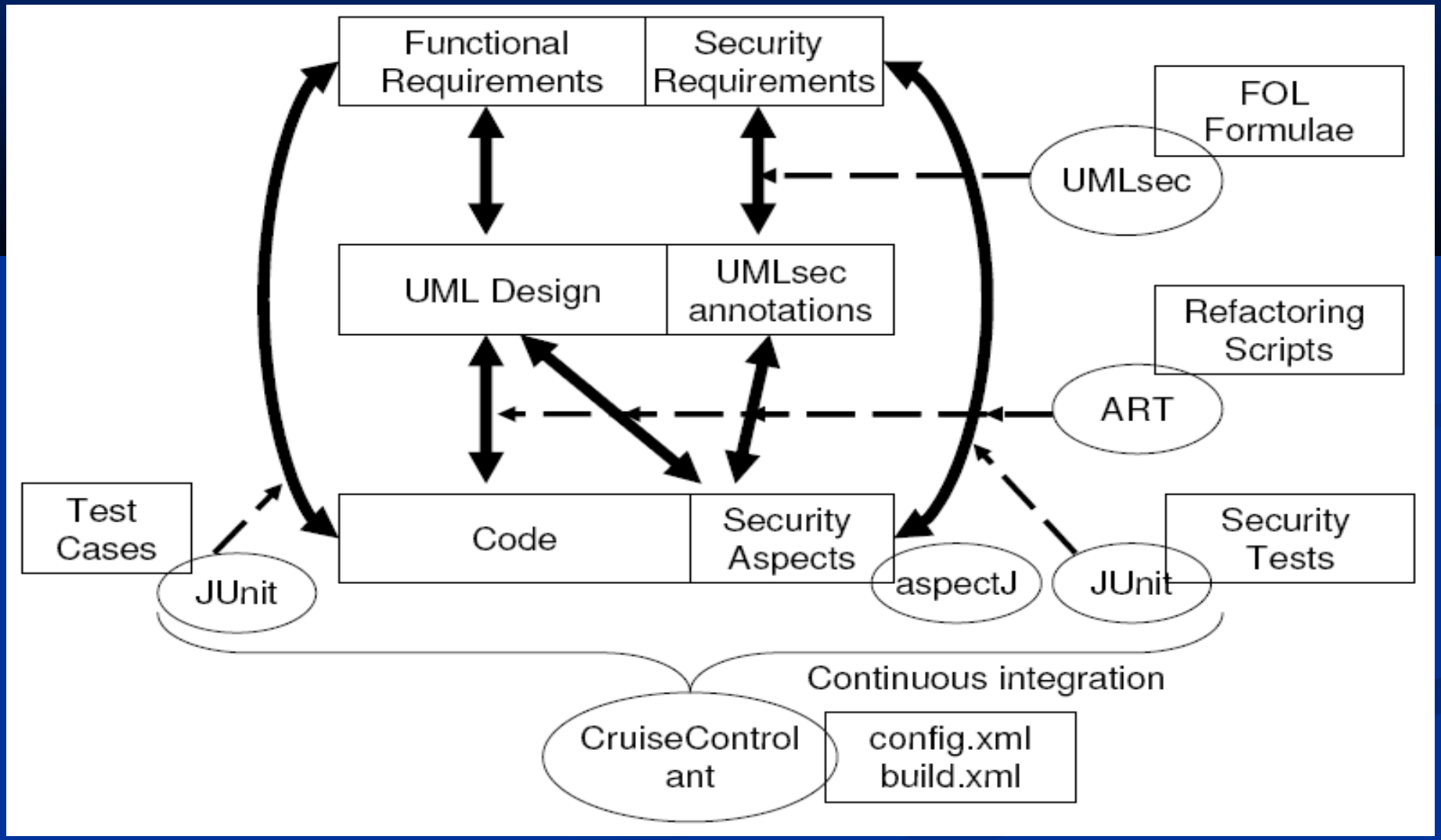
For evolution by refactoring can achieve automated model-code traceability e.g. using Eclipse Refactoring Language Toolkit (LTK) / XML based refactoring scripts.

Maintain model-code synchrony using continuous integration scripts (with CruiseControl / Apache Ant).

Evolution as Code Refactoring



Refactoring: Tool Supports



Java Secure Sockets Extension

Applied our approach to a series of implementations of the Java Secure Sockets Extension library:

- Jessie 1.0.0
- Jessie 1.0.1
- JSSE 1.6

Demonstrated that our model-code co-evolution approach is robust even across major software changes.

Refactoring JSSE

Symbols	Program entities	Identif.	Refactoring op.
1. C	clientHello	C	rename.type
2. S	serverHello	S	rename.type
3. P_{ver}	session.protocol version	P_ver	extract.temp
4. R_C R_S	clientRandom serverRandom	R_C R_S	rename.local.variable rename.local.variable
5. S_{id}	sessionId sessionId	S_id S_id	rename.field rename.local.variable
6. Ciph[ ]	session.enabledSuites	Ciph	extract.temp
7. Comp[ ]	comp	Comp	extract.temp
8. Veri	Lines 1518–1557	Veri	extract.method

Refactoring: Performance

Messages in sequence	op.	diff	Time (sec)
S1: $C \rightarrow S : (P_{\text{ver}}, R_C, S_{\text{id}}, \text{Ciph}[\,], \text{Comp}[\,])$	7	31	13.891
S2. $S \rightarrow C : (P_{\text{ver}}, R_S, S_{\text{id}}, \text{Ciph}[\,], \text{Comp}[\,])$	5	20	9.437
S3. $S \rightarrow C : \text{Certificate}[\text{X509Cert}_s]$	2	2	1.474
S4. $C : \text{Veri}(\text{X509Cert}_s)$	2	2	3.854
...	...	...	...
Total of 7 messages and 3 checks	27	86	40.303

Vulnerability in SSL implementation

Analyzed open-source Java implementation Jessie of SSL protocol.

- According to SSL specification, a certificate with (issuedDate, expiredDate) should be checked whenever a message is received.
- 4 call sites of certificate() were found in the code.
- Only 3 of them call the Veri() function.
- Test cases were constructed to reveal the vulnerability.
- Fix of the vulnerability can be done using AOP techniques.

Note similar bug to this was recently found in widely used C implementation openSSL.

Some other Applications

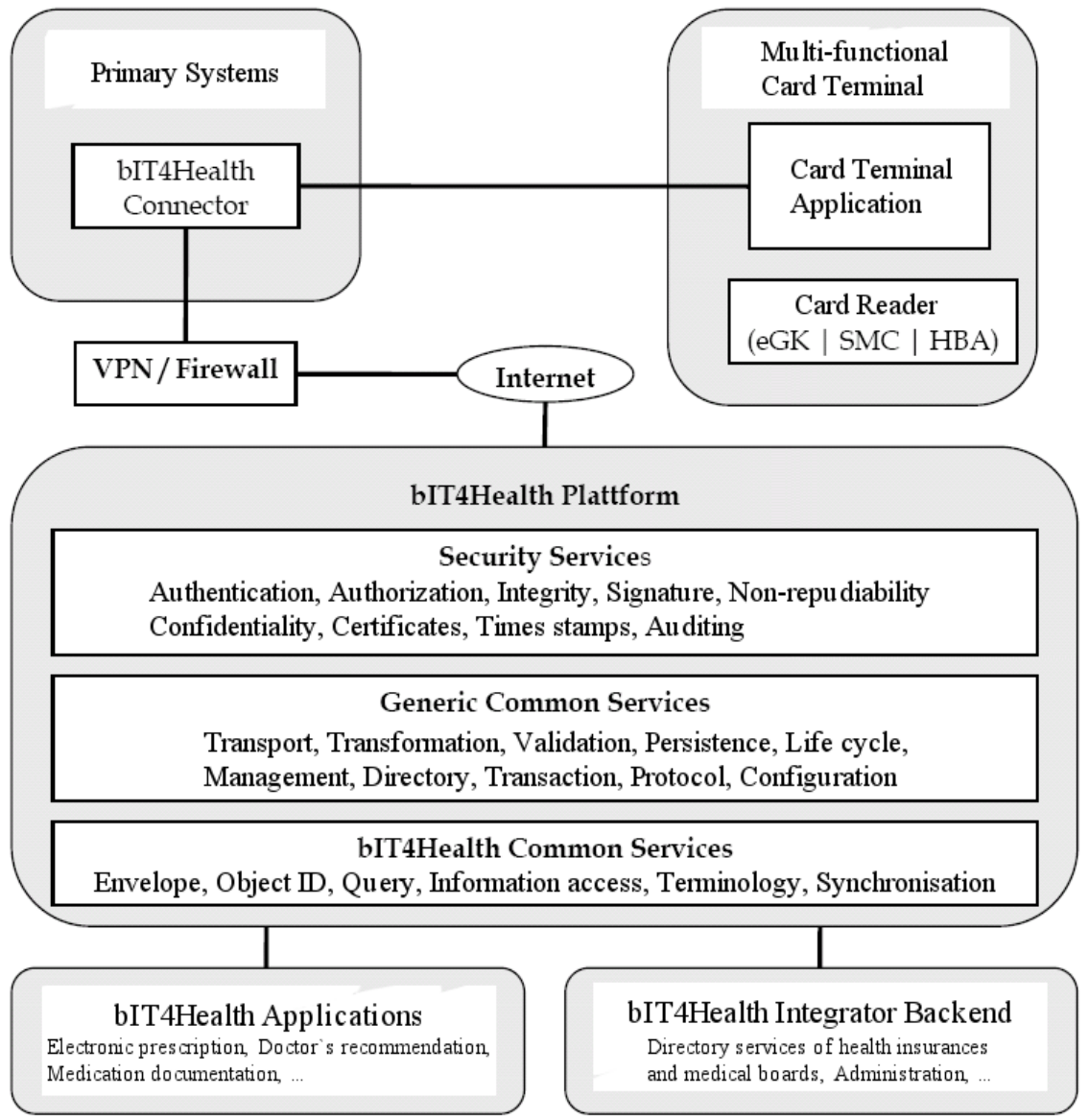
Analyzed designs / implementations / configurations e.g. for

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

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

German Health Card Architecture

- Analyzed architecture against security requirements using UMLsec
- Investigated potential security weaknesses in the architecture



[Meth. Inform. Medicine 08]

Intranet Information System

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

Some documents highly security-critical.

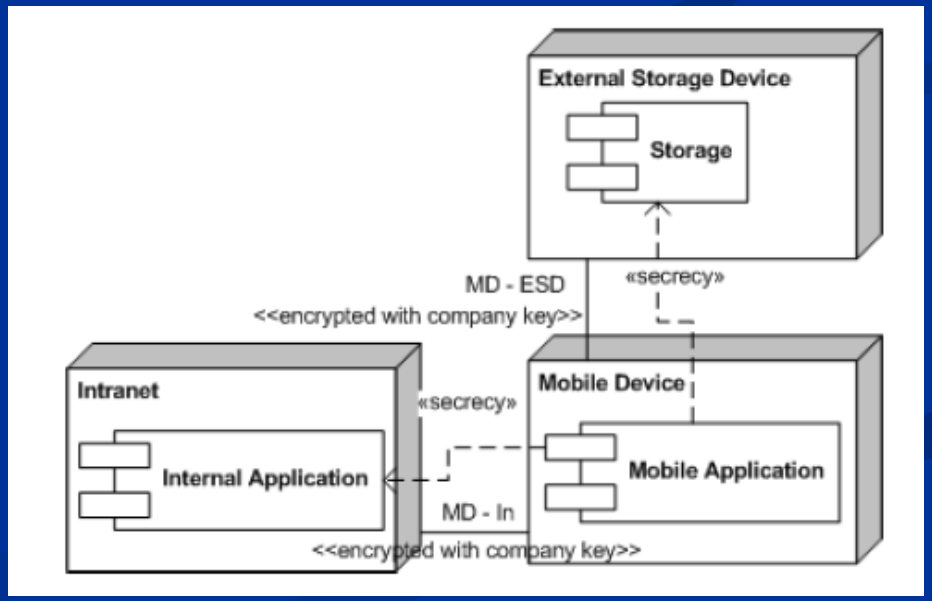
More than 1,000 potential users, index 280,000 documents, allow 20,000 queries per day.

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



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

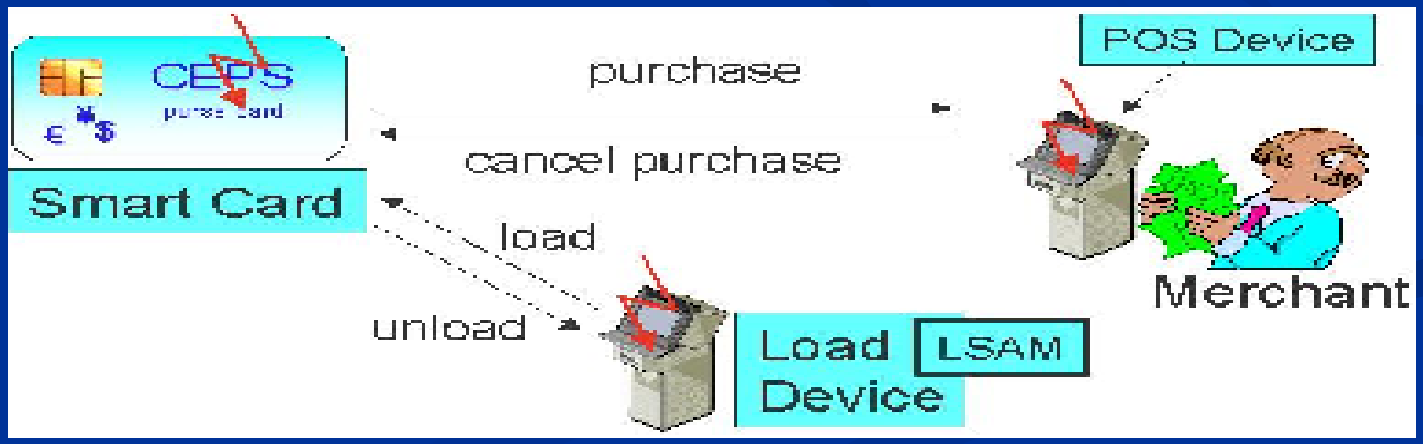
Successfully verified using model-based security.

Common Electronic Purse Spec.

Global elec. purse standard (Visa et al., 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.

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 Take Away

- Quality Assurance for security-critical systems is very difficult: some security properties cannot be established by conventional testing.
- To save effort, a security assurance approach needs to support system evolution.
- Model-based Security Testing can deal with these challenges.

More information: www.umlsec.de

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