Corporate Technology

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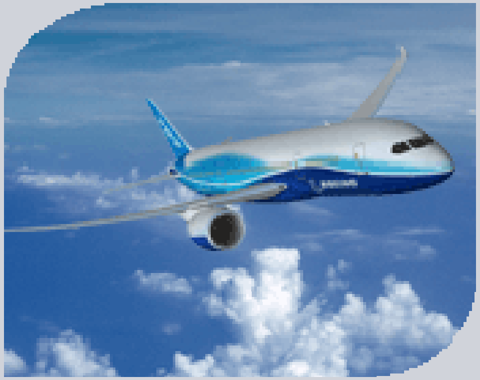
Formal security analysis and certification in industry, at the example of an AADS[1]



Dr. David von Oheimb
Siemens Corporate Technology

Guest lecture on invitation by Dr. Ricarda Weber at
CS department of TU Munich, Germany, 27 May 2008

http://www11.in.tum.de/Veranstaltungen/SecurityEngineering2008/

[1]**A**irplane **A**ssets **D**istribution **S**ystem

Overview

- **IT Security at Siemens CT**
- Software Distribution Systems
- Common Criteria certification
- Formal Security Analysis
- Alice-Bob protocol model
- Validation with AVISPA Tool
- Conclusion

Siemens Corporate Technology:
About 1,800 Researchers and Developers Worldwide …

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Security Applications & Methods

- **Secure Operating Systems, Trusted Platform Modules (TPM)**
- **General Purpose Security Mechanisms:**
  - Role / Policy Based Access Control (RBAC)
  - Public Key Infrastructure (PKI),
  - Single Sign-On (SSO)
- **Security of Service Oriented Architecture (SOA): Web Services etc.**
- **Application-level security: e-health, e-government, e-Commerce**
- **Digital Rights Management (DRM)**
- **Formal Methods and Certification**

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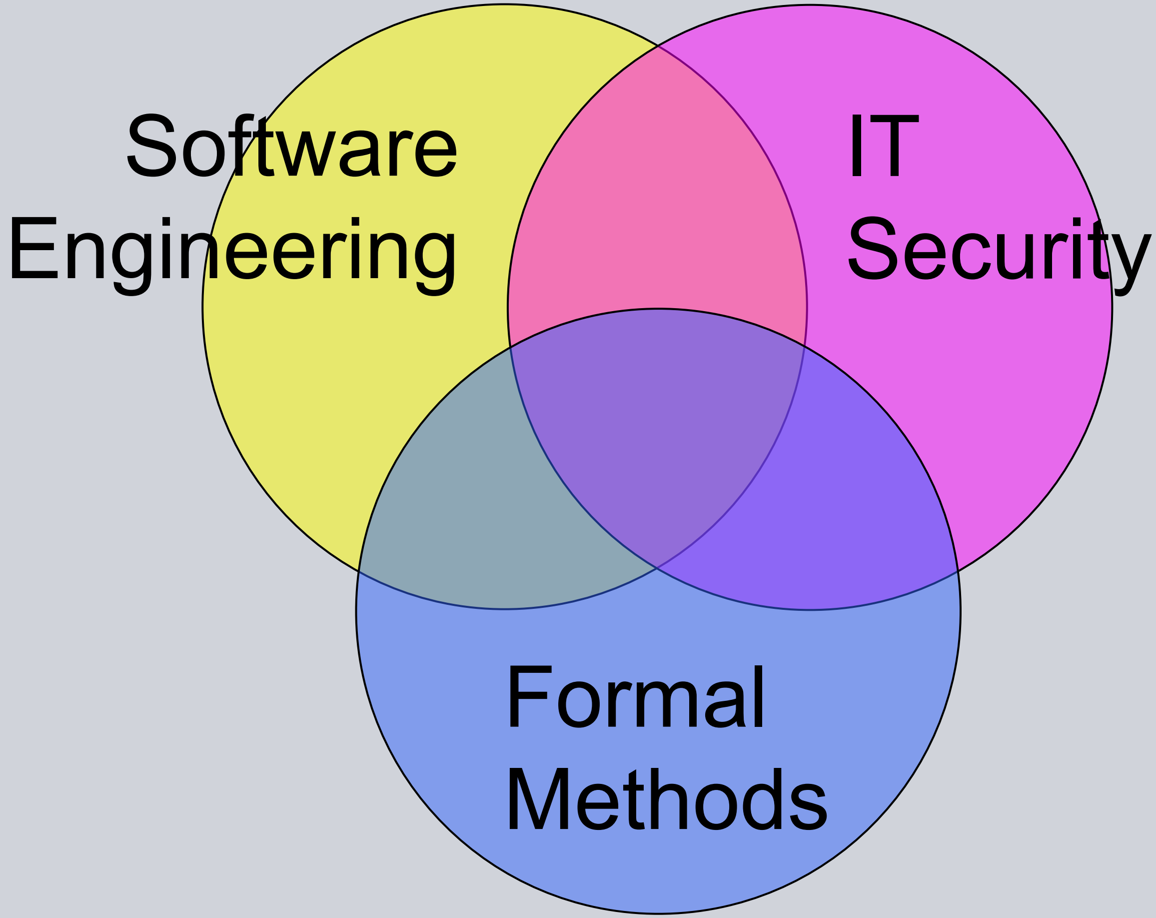
Fields



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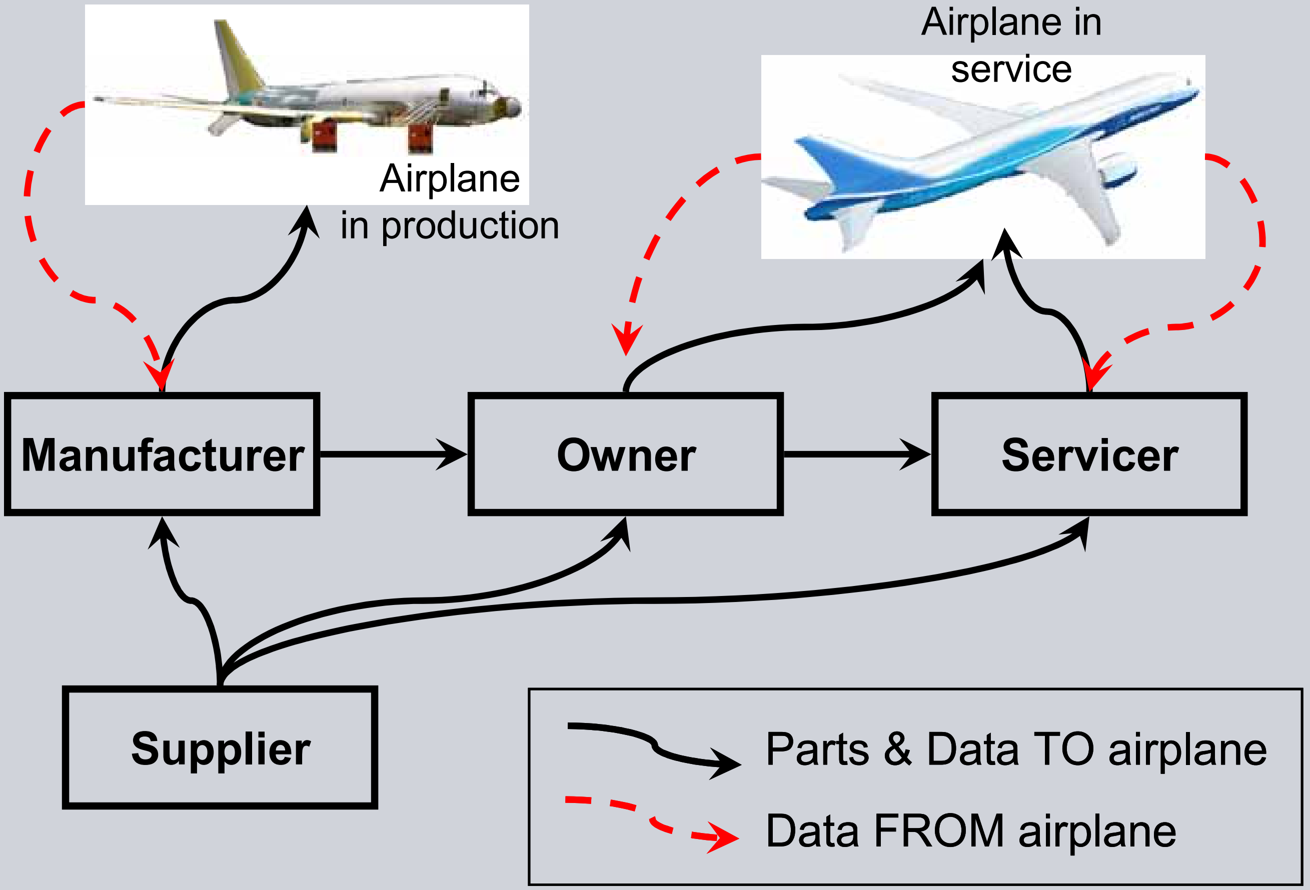
Airplane Assets Distribution System

AADS is a system for storage and distribution of airplane assets, including *Loadable Software Airplane Parts* (LSAP) and airplane health data



AADS architecture

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A complex distributed store-and-forward middleware with OSS components

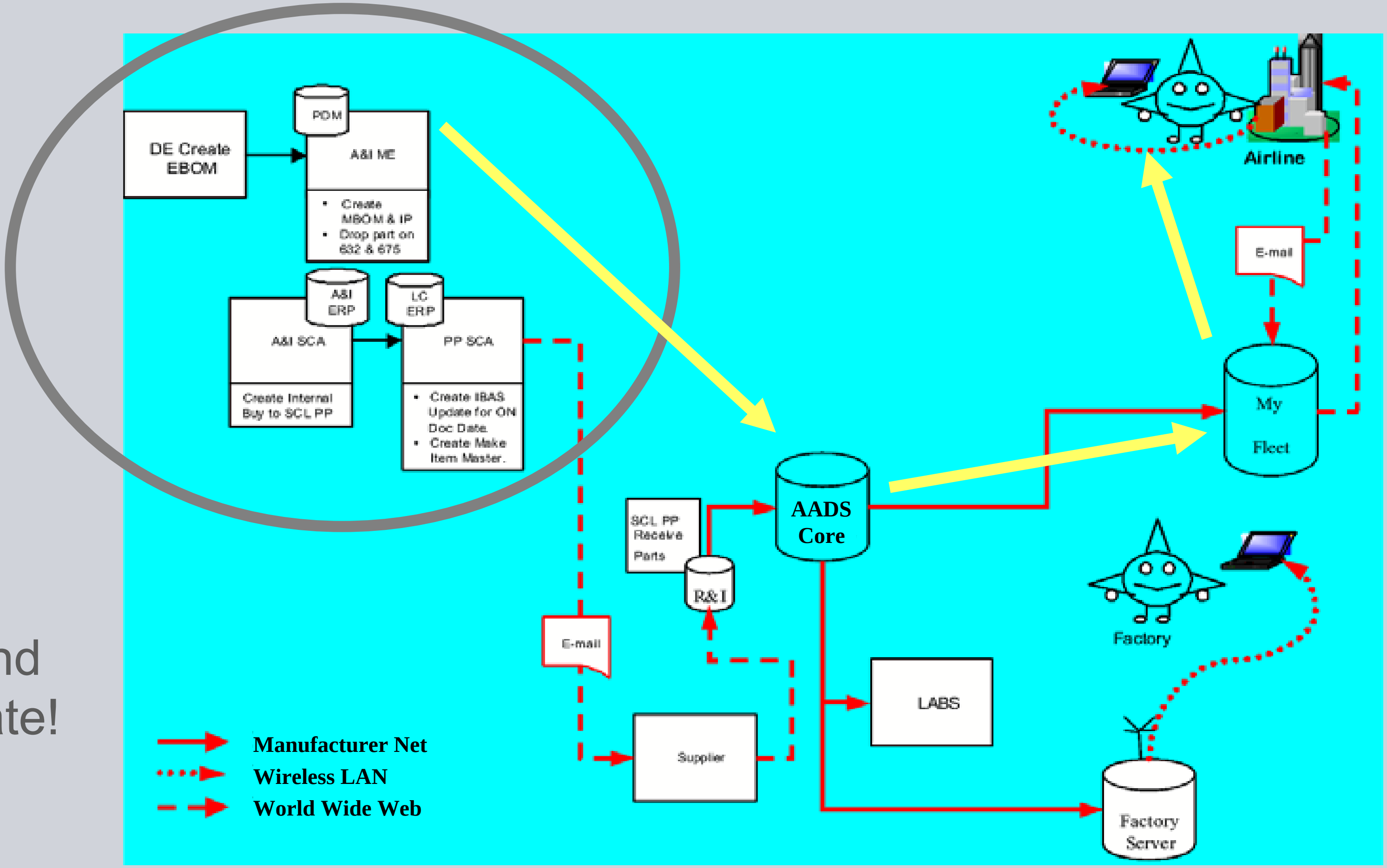
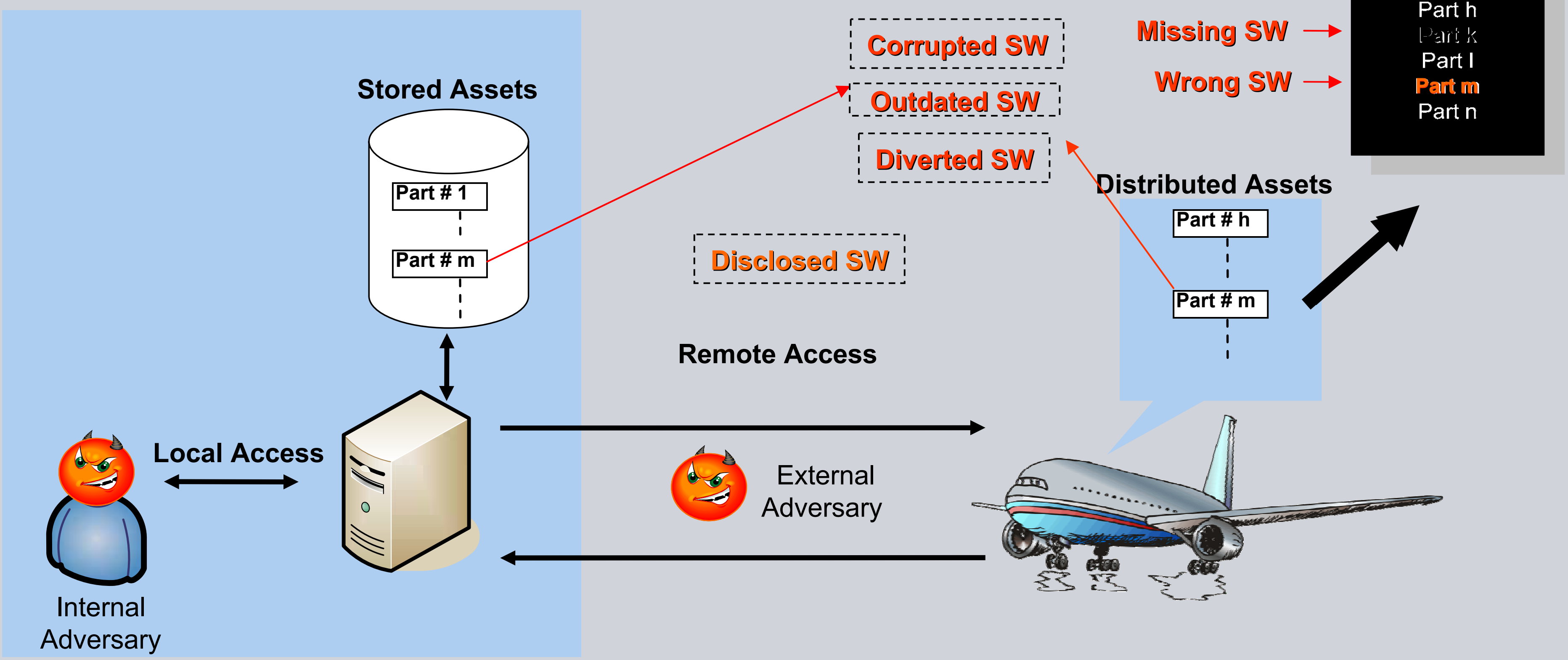


Figure is simplified and not up-to-date!

Security threats at the airplane example

Attacker's objective: lower airplane safety margins
by tampering software that will be executed onboard an airplane

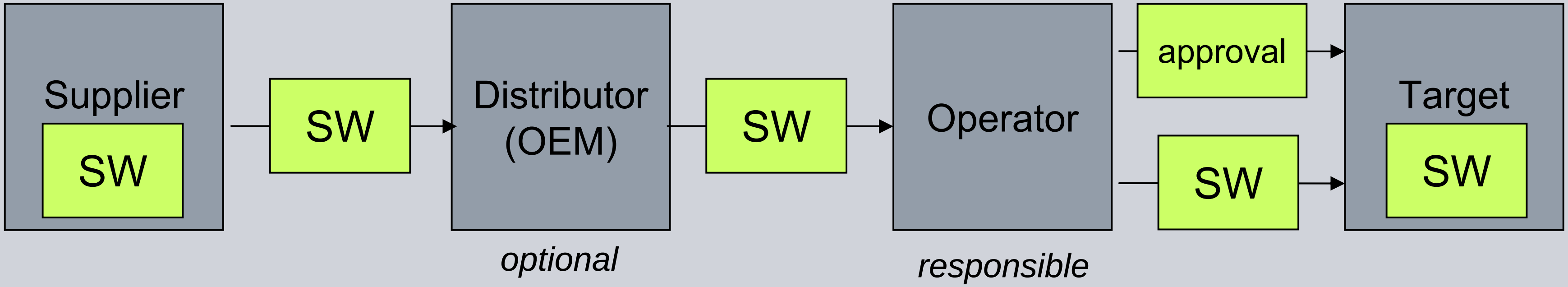


Corruption/Injection | **Wrong Version** | **Diversion** | **Disclosure**

Software Distribution System (SDS)

ICT systems with networked devices in the field performing safety-critical and/or security-critical tasks. Field devices require secure software update.

→ Software Distribution System (SDS):
System providing secure distribution of software (SW) from software supplier to target devices in the field

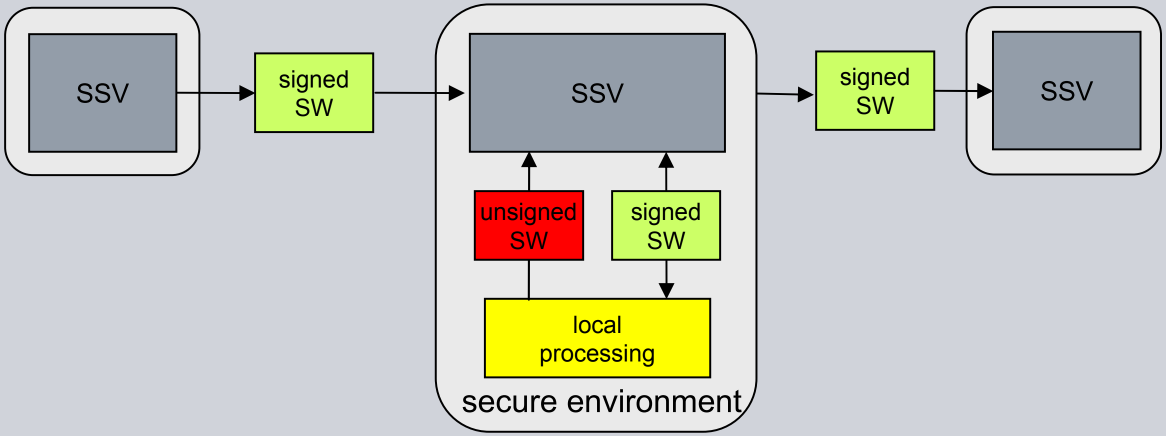


Transition from media-based (CD-ROMs etc.) to networked SW transport increases security risks due to transport over open, untrusted networks

Software Signer Verifier (SSV)

Each node in SDS runs an SSV instance, used for:

- Introducing unsigned software into the SDS, by digitally signing and optionally encrypting it
- Verifying the signature on software received from other SSVs, checking integrity, authenticity and authorization of the sender
- Approving software by adding an authorized signature
- Delivering software out of the SDS after successfully verifying it



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IT Security as a System Engineering Problem

- IT security aims at preventing, or at least detecting, unauthorized actions by agents in an IT system.

In the AADS context, security is a prerequisite of safety.

- Safety aims at the absence of accidents (→ airworthiness)

Situation: security loopholes in IT systems actively exploited

Objective: thwart attacks by eliminating vulnerabilities

Difficulty: IT systems are very complex. Security is interwoven with the whole system, so very hard to assess.

Remedy: evaluate system following the Common Criteria approach

- address security systematically in all development phases
- perform document & code reviews and tests
- for maximal assurance, use formal modeling and analysis

Common Criteria (CC) for IT security evaluation

Common Criteria

product-oriented methodology

for IT security assessment

ISO/IEC **standard** 15408

Current version: 3.1 of end-2006

Aim: gain confidence in the security of a system

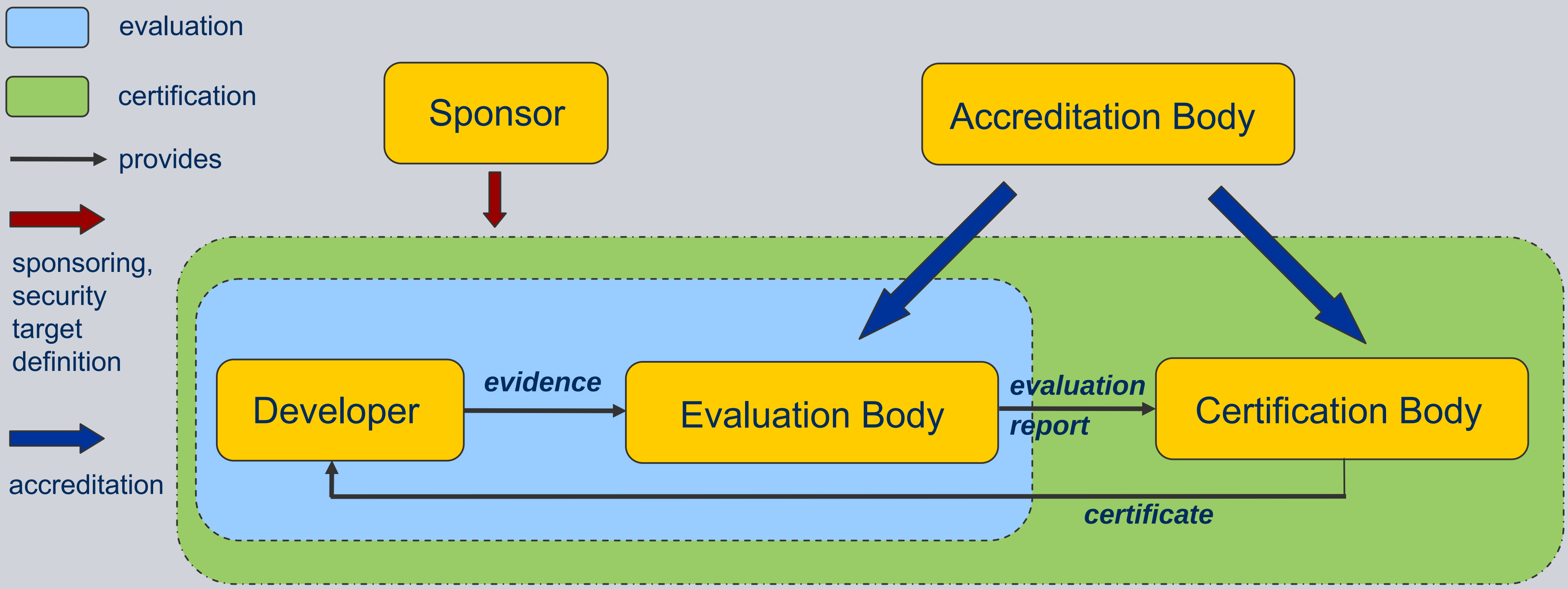
- What are the objectives the system should achieve?
- Are the measures employed appropriate to achieve them?
- Are the measures implemented and deployed correctly?

CC General Approach

Approach: assessment of system + documents by neutral experts

- Gaining understanding of the system's security functionality
- Checking evidence that the functionality is correctly implemented
- Checking evidence that the system integrity is maintained

CC Process Scheme



Certification according to the Common Criteria is a rather complex, time consuming and expensive process.

A successful, approved evaluation is awarded a certificate.

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CC: Security Targets

Security Target (ST): defines extent and depth of the evaluation

for a specific product called *Target of Evaluation (TOE)*

Protection Profile (PP): defines extent and depth of the evaluation

for a whole class of products, i.e. firewalls

STs and PPs may inherit (‘*claim*’) other PPs.

ST and PP specifications use **generic** “construction kit”:

- Building blocks for defining *Security Functional Requirements (SFRs)*
- Scalable in depth and rigor: *Security Assurance Requirements (SARs)*

layered as *Evaluation Assurance Levels (EALs)*

AADS Security Specification: CC Protection Profile (1)

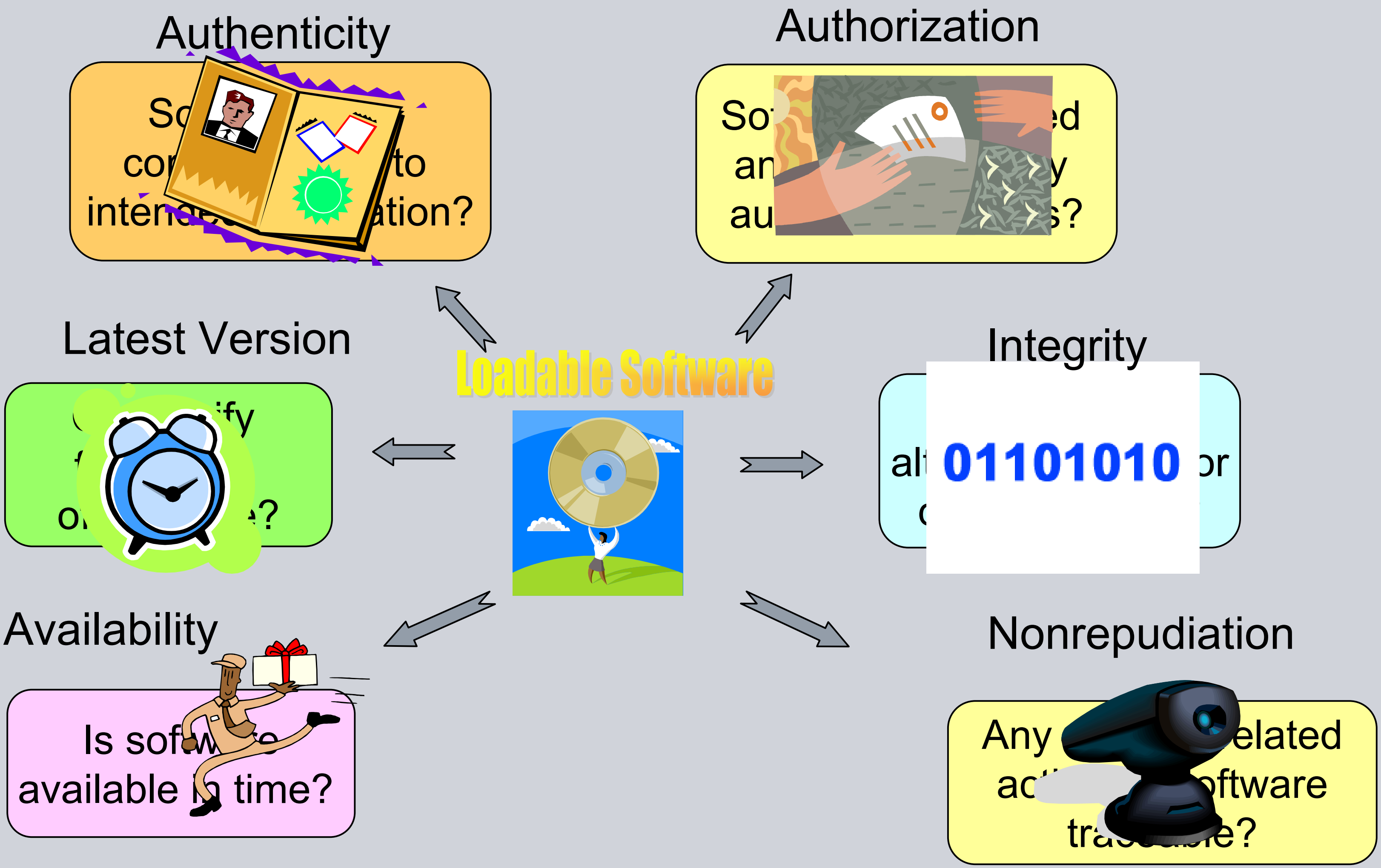
1. Introduction
2. System Description - Target of Evaluation (TOE)
3. Security Environment

   - Assets and Related Actions
   - Threats
   - Required Assurance Level
   - Assumptions

4. Security Objectives

   - …
   - Rationale

Security Objectives for AADS



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Threats Addressed by the AADS Security Objectives

Objectives	Threats	Safety-relevant				Business-relevant			
		Corruption	Misconfiguration	Diversion	Staleness	Unavailability	Late Detection	False Alarm	Repudiation
Safety-relevant	Integrity	√							
	Correct Destination			√					
	Latest Version				√				
	Authentication	√	√						√
	Authorization	√	√						
	Timeliness				√				
Business-Relevant	Availability					√			
	Early Detection						√		
	Correct Status							√	
	Traceability	√	√						√
	Nonrepudiation								√
Environment	Part_Coherence	√	√	√					
	Loading_Interlocks	√	√	√					
	Protective_Channels	√							
	Network_Protection				√	√			
	Host_Protection	√							√
Assumptions	Adequate_Signing	√							
	Configuration		√						
	Development	√	√	√	√	√	√	√	√
	Management	√	√						√

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AADS Security Specification: CC Protection Profile (2)

1. Introduction
2. System Description
3. Security Environment

   - Assets and Related Actions
   - Threats
   - Required Assurance Level
   - Assumptions

4. Security Objectives

   - …
   - Rationale

5. Security Functional Requirements

   - …
   - Rationale

CC: Security Functional Requirements (SFRs) overview

FAU: Security audit

- Security audit automatic response (FAU_ARP)
- Security audit data generation (FAU_GEN)
- Security audit analysis (FAU_SAA)
- Security audit review (FAU_SAR)
- Security audit event selection (FAU_SEL)
- Security audit event storage (FAU_STG)

FCO: Communication

FCS: Cryptographic support

FDP: User data protection

FIA : Identification and authentication

FMT: Security management

FPR: Privacy

FPT: Protection of the TSF

FRU: Resource utilization

FTA: TOE access

FTP: Trusted path/channels

CC: EALs

Security Assurance Requirements (SARs)

grouped as

Evaluation Assurance Levels (EALs)

Assurance class	Assurance Family	Assurance Components by Evaluation Assurance Level						
		EAL1	EAL2	EAL3	EAL4	EAL5	EAL6	EAL7
Development	ADV_ARC		**1**	1	1	1	1	1
	ADV_FSP	**1**	**2**	**3**	**4**	**5**	5	**6**
	ADV_IMP				**1**	1	**2**	2
	ADV_INT					**2**	**3**	3
	ADV_SPM						**1**	1
	ADV_TDS		**1**	**2**	**3**	**4**	**5**	**6**
Guidance documents	AGD_OPE	**1**	1	1	1	1	1	1
	AGD_PRE	**1**	1	1	1	1	1	1
Life-cycle support	ALC_CMC	**1**	**2**	**3**	**4**	4	**5**	5
	ALC_CMS	**1**	**2**	**3**	**4**	**5**	5	5
	ALC_DEL		**1**	1	1	1	1	1
	ALC_DVS			**1**	1	1	**2**	2
	ALC_FLR							
	ALC_LCD			**1**	1	1	1	**2**
	ALC_TAT				**1**	**2**	**3**	3
Security Target evaluation	ASE_CCL	**1**	1	1	1	1	1	1
	ASE_ECD	**1**	1	1	1	1	1	1
	ASE_INT	**1**	1	1	1	1	1	1
	ASE_OBJ	**1**	**2**	2	2	2	2	2
	ASE_REQ	**1**	**2**	2	2	2	2	2
	ASE_SPD		**1**	1	1	1	1	1
	ASE_TSS	**1**	1	1	1	1	1	1
Tests	ATE_COV		**1**	**2**	2	2	**3**	3
	ATE_DPT			**1**	**2**	**3**	3	**4**
	ATE_FUN		**1**	1	1	1	**2**	2
	ATE_IND	**1**	**2**	2	2	2	2	**3**
Vulnerability assessment	AVA_VAN	**1**	**2**	2	**3**	**4**	**5**	5

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CC: Evaluation Assurance Level 2

Development	ADV_ARC.1 Security architecture description ADV_FSP.2 Security-enforcing functional specification ADV_TDS.1 Basic design
Guidance documents	AGD_OPE.1 Operational user guidance AGD_PRE.1 Preparative procedures
Life-cycle support	ALC_CMC.2 Use of a CM system ALC_CMS.2 Parts of the TOE CM coverage ALC_DEL.1 Delivery procedures
Security Target Eval.	ASE_XXX *(6 families of components)*
Tests	ATE_COV.1 Evidence of coverage ATE_FUN.1 Functional testing ATE_IND.2 Independent testing - sample
Vulnerability analysis	AVA_VAN.2 Vulnerability analysis

CC: Evaluation Assurance Level 4

Development	ADV_FSP.4 **Complete** functional specification
	ADV_IMP.1 Implementation representation of the TSF
	ADV_TDS.**3** Basic **modular** design
Guidance documents	
Life-cycle support	ALC_CMC.**4 Production support, acceptance procedures and automation**
	ALC_CMS.**4 Problem tracking** CM coverage
	ALC_DVS.1 Identification of security measures
	ALC_LCD.1 Developer defined life-cycle model
	ALC_TAT.1 Well-defined development tools
Security Target Eval.	
Tests	ATE_COV.**2 Analysis** of coverage
	ATE_DPT.2 Testing: security enforcing modules
Vulnerability analysis	AVA_VAN.**3 Focused** vulnerability analysis

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CC: Evaluation Assurance Level 6

Development	ADV_FSP.**5** Complete semi-formal functional spec. **with additional error information**
	ADV_IMP.**2 Implementation** of the TSF
	ADV_INT.3 Minimally complex internals
	ADV_SPM.1 Formal **TOE security policy model**
	ADV_TDS.**5 Complete semiformal** modular design
Guidance documents	
Life-cycle support	ALC_CMC.**5 Advanced** support
	ALC_CMS.**5 Development tools** CM coverage
	ALC_DVS.**2 Sufficiency** of security measures
	ALC_TAT.**3 Compliance with implementation standards – all parts**
Security Target Eval.	
Tests	ATE_COV.**3 Rigorous** analysis of coverage
	ATE_DPT.**3** Testing: **modular design**
	ATE_FUN.2 Ordered functional testing
Vulnerability analysis	AVA_VAN.**5 Advanced methodical** vulnerability analysis

CC: Factors determining the evaluation effort

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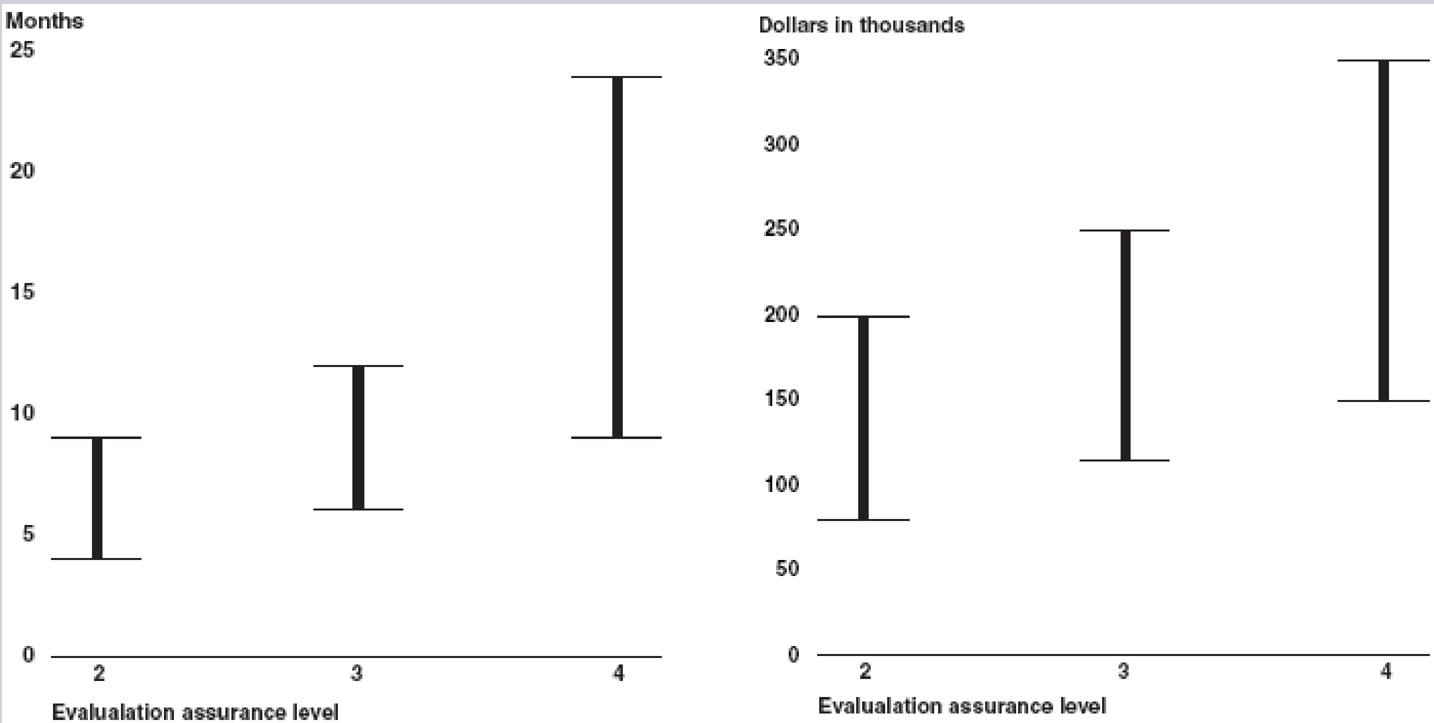
- Definition of TOE vs. TOE environment
- Definition of Treats and Security Objectives for the TOE
- Definition of Security Functional Requirements (SFRs)
- Selection of Evaluation Assurance Level (EAL)



Source: GAO analysis of data provided by laboratories.

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Selection of Evaluation Assurance Level (EAL) for AADS

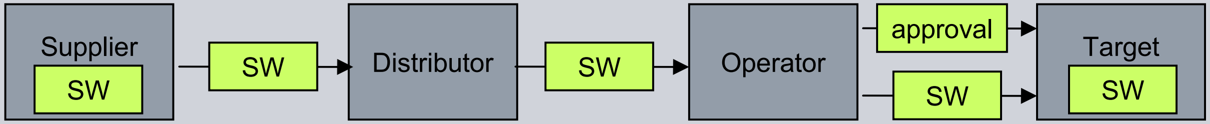
	Flight safety	Airline business
Threat Level assume sophisticated adversary with moderate resources who is willing to take XXX risk	**T5**: XXX = significant e.g. intl. terrorists	**T4**: XXX = little e.g. organized crime, sophisticated hackers, intl. corporations
Information Value violation of the protection policy would cause YYY damage to the security, safety, financial posture, or infrastructure of the organization	**V5**: YYY= exceptionally grave Risk: loss of lives	**V4**: YYY = serious Risk: airplanes out of service, or damage airline reputation
Evaluation Assurance Level for the given Treat Level and Information Value	**EAL 6**: semiformally verified design and tested	**EAL 4**: methodically designed, tested, and reviewed

Evaluating the whole AADS at EAL 6 would be extremely costly.
Currently available Public Key Infrastructure (PKI) certified only at EAL 4.

Two-level approach: evaluate only LSAP integrity & authenticity at EAL6.

Hybrid security assessment

- Highest CC evaluation assurance levels (EAL 6-7) require formal analysis
- SDS usually are complex distributed systems with many components



General problems:

- Highly critical system, but (complete) formal analysis too costly
- CC offer only limited support ("CAP") for modular system evaluation

Pragmantic approach:

- Define confined security kernel with generic component: SSV
- Software Signer Verifier (SSV) handles digital signatures at each node
- Evaluate SSV according to Common Criteria EAL4 (non-formal)
- Analyze the interaction of SSVs in a formal way (→ crypto protocol)

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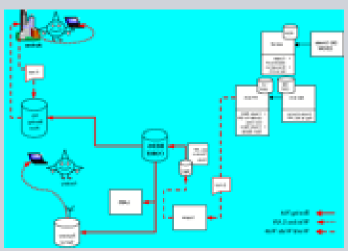
Formal Security Analysis: Approach and Benefits

Mission: security analysis with maximal precision
Approach: formal modeling and verification

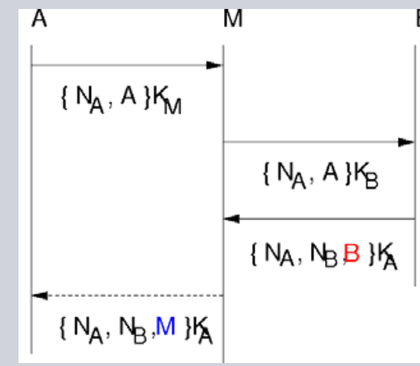
Spec.

Impl.



Abstraction

Interpretation



Improving the quality of the system specification

High-Level Protocol Spec. Language
- Model checkers (AVISPA tools)

Checking for the existence of security loopholes

Interacting State Machines
- Interactive theorem prover (Isabelle)

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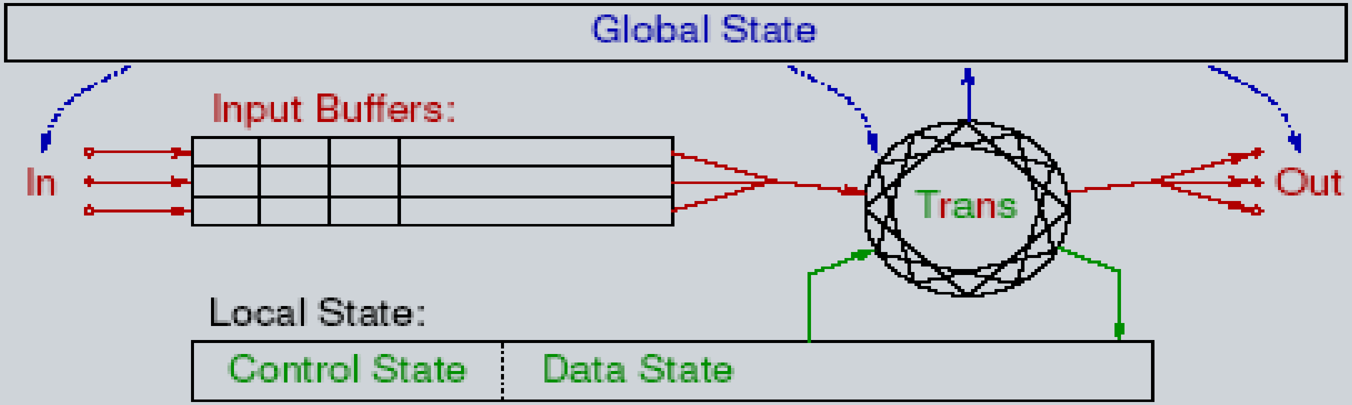
Security Models

- A security policy defines what is allowed (actions, data flow, ...) typically by a relationship between subjects and objects.
- A security model is a (+/- formal) description
  of a policy and enforcing mechanisms,
  usually in terms of system states or state sequences (traces).
- Security verification proves that mechanisms enforce policy.
- Models focus on specific characteristics of the reality (policies).
- Types of formal security models
  - Automata models
  - Access Control models
  - Information Flow models
  - Cryptoprotocol models

Interacting State Machines (ISMs)

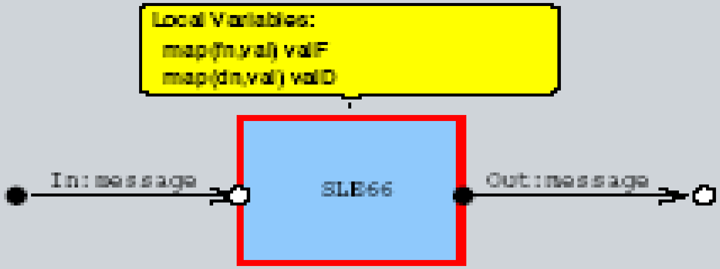
Automata with (nondeterministic) state transitions + buffered I/O, simultaneously on multiple connections.



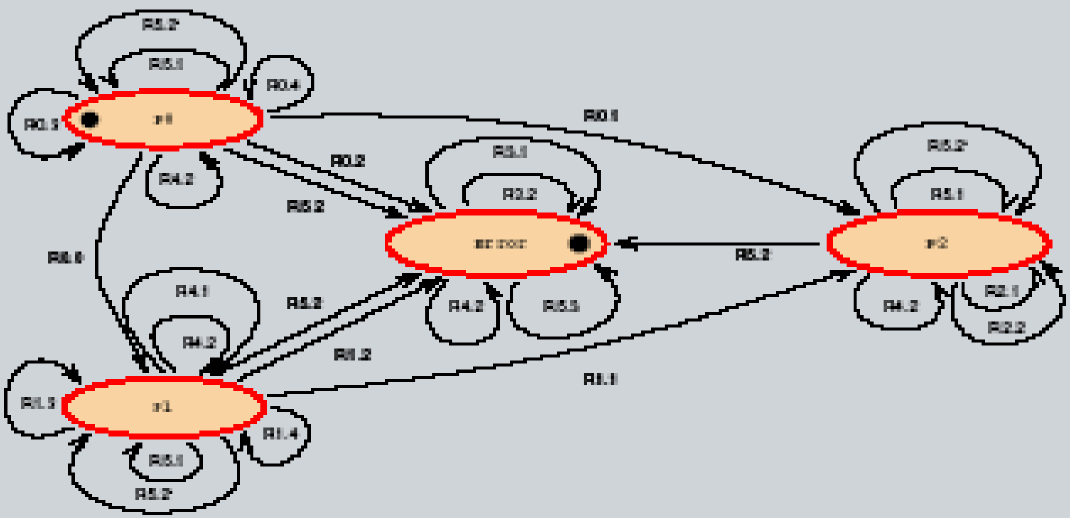
Transitions definable in executable and/or axiomatic style.
An ISM system may have changing global state.
Applicable to a large variety of reactive systems.
By now, not much verification support (theory, tools).

Model of Infineon SLE 66 Smart Card Processor

System Structure Diagram:



State Transition Diagram (abstracted):



First higher-level (EAL5) certification for a smart card processor!

RBAC of Complex Information System

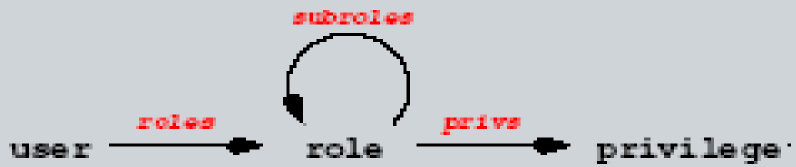
Is the security design (with emergency access etc.) sound?

Privileges:

$roles \subseteq \mathtt{user} \times \mathtt{role}$

$subroles \subseteq \mathtt{role} \times \mathtt{role}$

$privs \subseteq \mathtt{role} \times \mathtt{privilege}$



$(u, p) \in roles \circ subroles^* \circ privs$

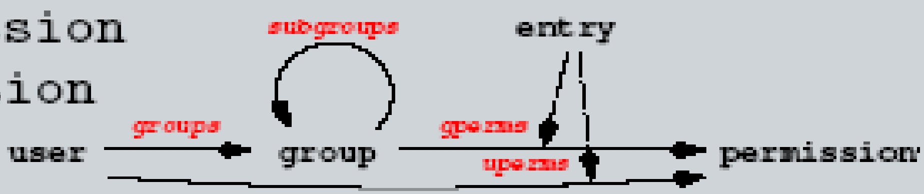
Permissions:

$groups \subseteq \mathtt{user} \times \mathtt{group}$

$subgroups \subseteq \mathtt{group} \times \mathtt{group}$

$gperms \subseteq \mathtt{group} \times \mathtt{permission}$

$uperms \subseteq \mathtt{user} \times \mathtt{permission}$



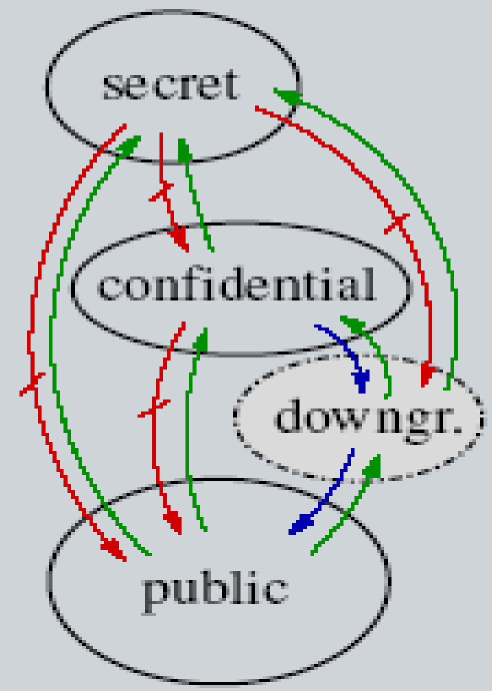
$(u, p) \in (groups \circ subgroups^* \circ gperms(e)) \;\cup\; uperms(e)$

"nagging questions" $\leadsto$ clarifications improving specification quality.

Open issue: relation between model and implementation ($\leadsto$ testing).

Information Flow Models

- Identify knowledge/information domains
- Specify allowed flow between domains
- Check the observations that can be made about state and/or actions
- Consider also indirect and partial flow



- Classical model: Noninterference (Goguen & Meseguer)
- Many variants: Non-deducability, Restrictiveness, Non-leakage, ...

Very strong, but rarely used in practice

In progress: connection with ISMs

Language-based Information Flow Security

Policy: no assignments of high-values to low-variables, enforced by type system

Semantically: take (x, y) as elements of the state space with high-level data (on left) and low-level data (on right).

Step function $S(x, y) = (S_H(x, y), S_L(x, y))$ does not leak information from high to low if $S_L(x_1, y) = S_L(x_2, y)$ (functional independence).

Observational equivalence $(x, y) \overset{L}{\sim} (x', y') \;:\longleftrightarrow\; y = y'$ allows re-formulation:

$$s \overset{L}{\sim} t \longrightarrow S(s) \overset{L}{\sim} S(t) \quad (\text{preservation of } \overset{L}{\sim})$$

Generalization to action sequences α and arbitrary policies $\leadsto$

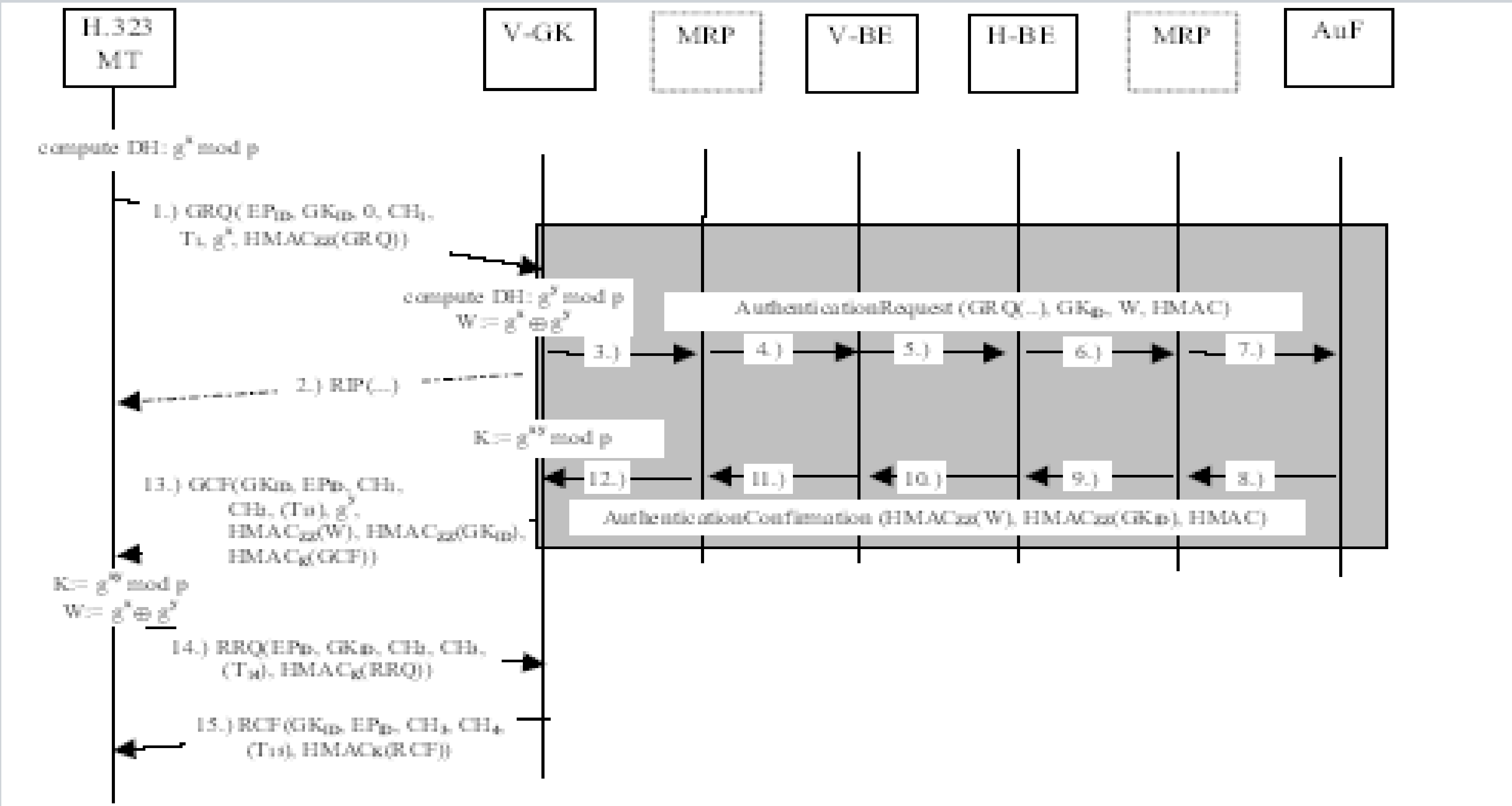
Cryptoprotocol models

- Describe message exchange between processes or principals

- Take cryptographic operations as perfect primitives
- Describe system with specialized modeling languages
- State secrecy, authentication, . . . goals
- Verify (mostly) automatically using model-checkers

EU project AVISPA , ...

H.530 Mobile Roaming Authentication



Two vulnerabilities found and corrected. Solution standardized.

Shaping a Formal Model

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Formality Level: should be adequate:

- the more formal, the more precise,
- but requires deeper mastering of formal methods

Choice of Formalism: dependent on ...

- application domain, modeler's experience, tool availability, ...
- formalism should be simple, expressive, flexible, mature

Abstraction Level: should be ...

- high enough to achieve clarity and limit the effort
- low enough not to loose important detail

refinement allows for both high-level and detailed description

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Development Phases and the Benefits of Formal Analysis

Requirements analysis:

understanding the security issues

- abstraction: concentration on essentials, to keep overview
- genericity: standardized patterns simplify the analysis

Design, documentation:

quality of specifications

- enforces preciseness and completeness

Implementation:

effectiveness of security functionality

- formal model as precise reference for testing and verification

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Formal modeling: Alice-Bob notation

```
SUP - {Asset.{h(Asset).DIS}_inv(KSUP).CertSUP}_KDIS -> DIS
DIS - {Asset.{h(Asset).DIS}_inv(KSUP).CertSUP
            .{h(Asset).OP }_inv(KDIS).CertDIS}_KOP  -> OP
OP  - {Asset.{h(Asset).DIS}_inv(KSUP).CertSUP
            .{h(Asset).OP }_inv(KDIS).CertDIS
            .{h(Asset).TD }_inv(KOP ).CertOP }_KTD  -> TD
```

`A - M -> B`	message M sent from A to B
`Asset`	a software item including its identity
`h(M)`	the hash value (i.e. crypto checksum) of content M
`M.N`	the concatenated contents of M and N
`{M}_inv(K)`	content M digitally signed with private key K
`{M}_K`	content M encrypted with public key K

Formal modeling: SDS protocol structure

```
SUP - {Asset.{h(Asset).DIS}_inv(KSUP).CertSUP}_KDIS -> DIS
DIS - {Asset.{h(Asset).DIS}_inv(KSUP).CertSUP
            .{h(Asset).OP }_inv(KDIS).CertDIS}_KOP  -> OP
OP  - {Asset.{h(Asset).DIS}_inv(KSUP).CertSUP
            .{h(Asset).OP }_inv(KDIS).CertDIS
            .{h(Asset).TD }_inv(KOP ).CertOP }_KTD  -> TD
```

SUP: software supplier with private key `inv(KSUP)`

DIS: software distributor with private key `inv(KDIS)`

OP : target operator with private key `inv(KOP)`

TD : target device with private key `inv(KTD)`

Signatures comprise hash value of asset and identity of intended receiver

Signatures are applied in parallel (rather than nested or discarded)

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Formal modeling: SDS approvals and certificates

```
SUP - {Asset.{h(Asset).DIS}_inv(KSUP).CertSUP}_KDIS -> DIS
DIS - {Asset.{h(Asset).DIS}_inv(KSUP).CertSUP
            .{h(Asset).OP }_inv(KDIS).CertDIS}_KOP  -> OP
OP  - {Asset.{h(Asset).DIS}_inv(KSUP).CertSUP
            .{h(Asset).OP }_inv(KDIS).CertDIS
            .{h(Asset).TD }_inv(KOP ).CertOP }_KTD  -> TD
```

- Approval information partially modelled: **operator** determines **target**
- Certificate of a node relates its identity with its public key,
  e.g. certificate of supplier SUP: `CertSUP = {SUP.KSUP}_inv(KCA)`
- Certificate authority (CA) with private key `inv(KCA)`
- Certificates are self-signed or signed by CA
- Locally stored sets of public keys of trusted SSVs and CAs

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Overview

- IT Security at Siemens CT
- **S**oftware **D**istribution **S**ystems
- Common Criteria certification
- Formal Security Analysis
- Alice-Bob protocol model
- Validation with AVISPA Tool
- Conclusion

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Verification goals

Show asset authenticity & integrity (end-to-end) and confidentiality:

- assets accepted by target have indeed been sent by the supplier
- assets accepted by target have not been modified during transport
- assets remain secret among the SSV instances

Proved asset authenticity & integrity also hop-by-hop

Correct destination covered:

- Name of the intended receiver in signed part, checked by target.
  Signature of the operator acts as installation approval statement

Correct version not modelled:

- Integrity of version info, *checks delegated* to SSV local environment

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Formal Verification

- Alice-Bob notation not detailed and precise enough
- Use the specification language of the AVISPA Tool: HLPSL
- Software Signer Verifier (SSV) as parameterized role (node class)
- SDS as communication protocol linking different SSV instances
- Multiple protocol sessions describing individual SW transports

- Modelcheckers at their complexity limits, due to
  - parallel signatures, only the latest one being checked
  - multiple instances of central nodes (e.g. manufacturer)
  - …?

Overview

- IT Security at Siemens CT
- **S**oftware **D**istribution **S**ystems
- Hybrid security assessment
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Conclusion (1)

- Challenges for AADS development
  - pioneering system design and architecture
  - complex, heterogeneous, distributed system
  - security is critical for both safety and business
- Common Criteria offer adequate methodology for assessment
- Systematic approach, in particular formal analysis, enhances
  - understanding of the security issues
  - quality of specifications and documentation
  - confidence (of Boeing, customers, FAA, etc.) in the security solutions

Conclusion (2)

- Experience with SDS evaluation
  - Common Criteria most widely accepted methodology
  - Problem of compositional security evaluation not solved
  - Use formal analysis where cost/benefit ratio is best
  - Highly precise design and documentation:
    assumptions, requirements
  - Shape system architecture to support security evaluation

- Future steps
  - Key management aspects:
    Public Key Infrastructure (PKI) components
  - Configuration management
    with installation instructions and reports