FMICS 2003

A Case Study of a Formalized Security Architecture

Achim D. Brucker
ETH Zürich, Switzerland

Burkhart Wolff
Albert-Ludwigs Universität Freiburg, Germany

June 5, 2003

Our Problem

Practical Request: Provide a *secure* (and *safe*) CVS server, that

- conforms to our local network security policy (e.g. encryption, . . .)
- work reliably for at least 40 internal and external users
- migration of existing (local) repository (ca. 2GB of data)
- **provides an easy to maintain access control**
- **no need for a separated server (extra hardware)**

Our Proposal

A CVS server with cvsauth extension and a special setup, providing:

- **role based access control** (discussed in this talk)
- encrypted data transfer (via cvsauth, not discussed here)
- a (secure) anonymous access

Research Work/Challenges

- verify mapping of roles and users
- verify security/safety/access control properties

Research Work/Challenges

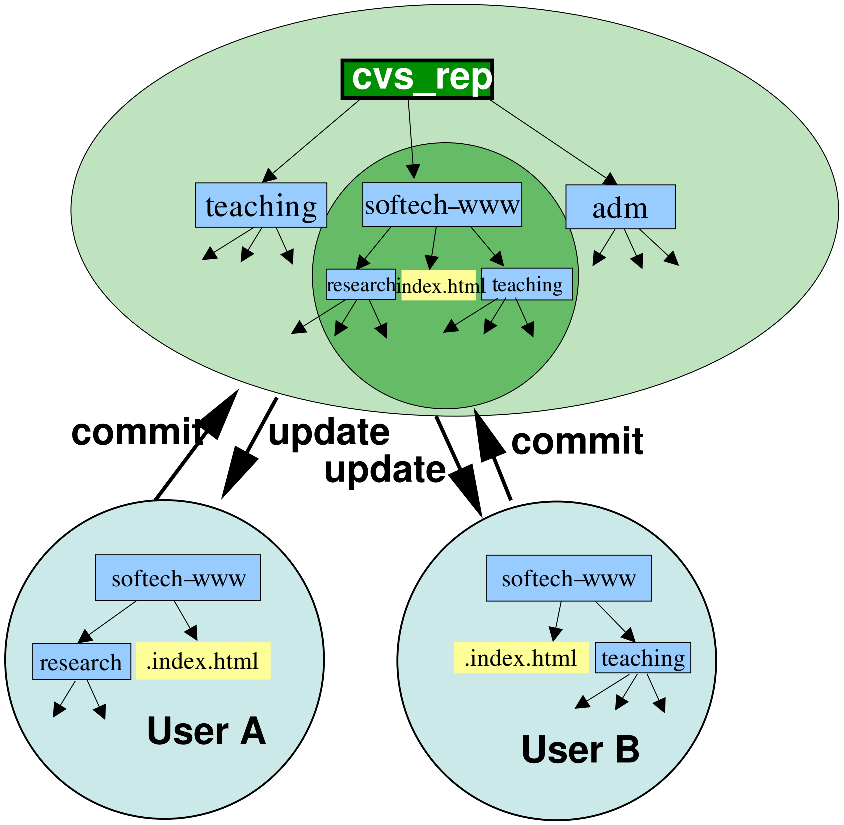
- verify mapping of roles and users
- verify security/safety/access control properties
- **We provide this using:**
  - standardized modeling language, namely Z
  - a compiler to Isabelle/HOL-Z
  - standard data refinement notions á la Spivey
  - special tactics for this type of proofs

Roadmap

- **Concepts of CVS**
- **CVS Server Refinement**
  - Example: Group Setup (Roles)
  - The CVS Server Architectures
- **Security as a Refinement Problem**
- **Security Analysis**

Concepts of CVS

- concurrent (and cooperative) versions management system
- provides a central database: the ***repository***
- provides merging for different versions of files (not discussed here)
- every client has a local copy: the ***working copy***



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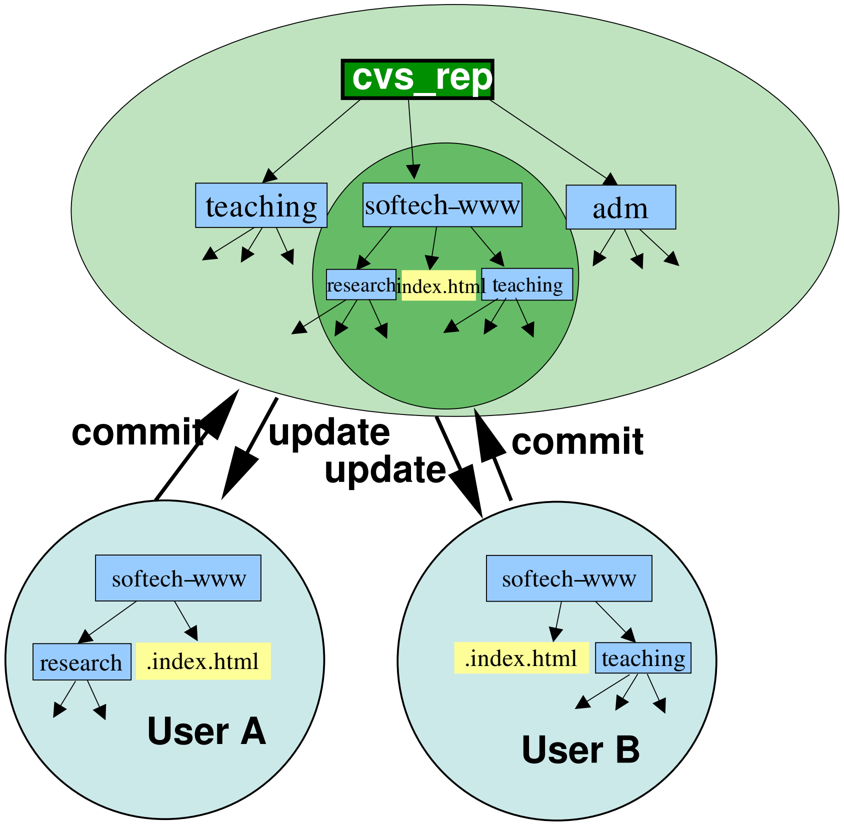

Concepts of CVS

- concurrent (and cooperative) versions management system
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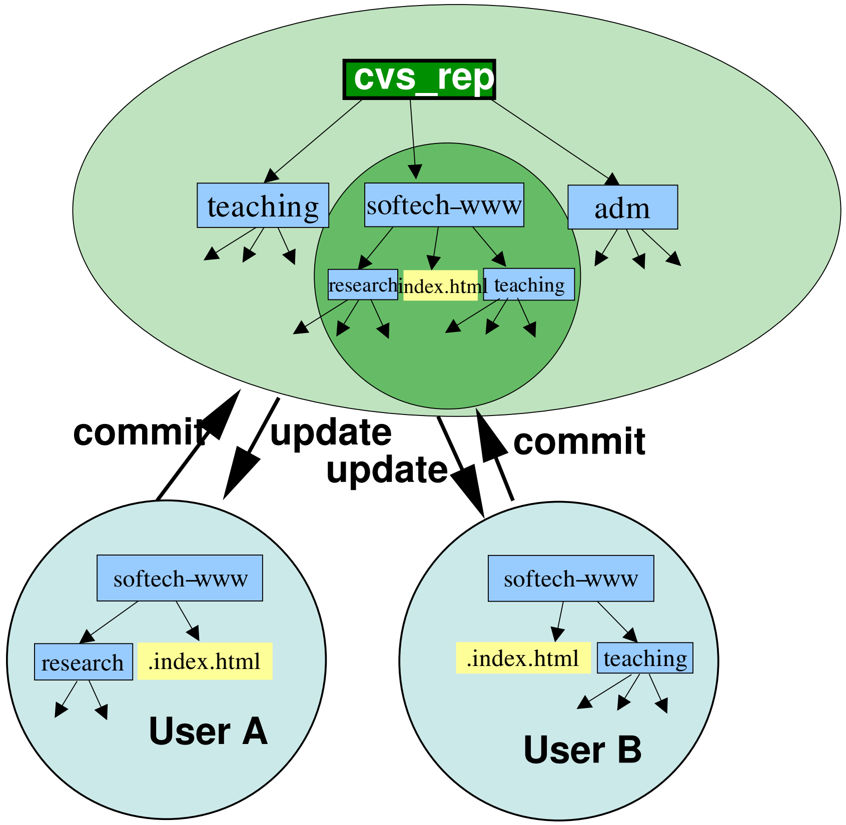
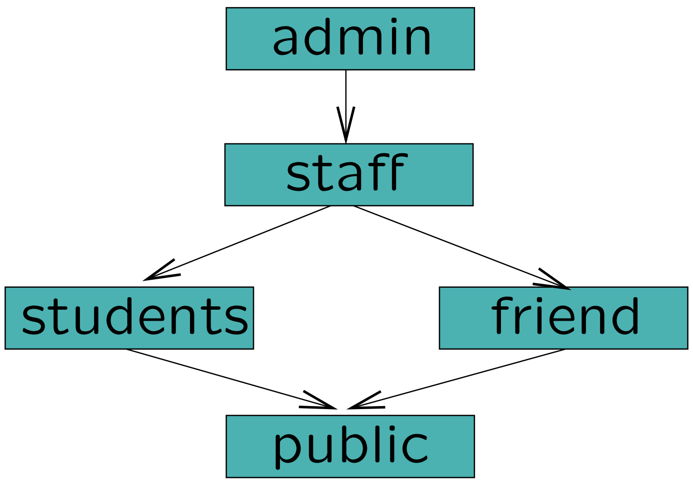
- **Problem**: limited access control via file system
- **Our extensions provide:** role-based access control over an insecure network (non-standard)



CVS Server Refinement: Group Setup

High-level request:	**Low-Level Implementation:** (/etc/group)



group	**users**				
admin	admin				
staff	admin	staff			
friend	admin	staff		friend	
students	admin	staff	students		
public	admin	staff	students	friend	public

- Who can write to a file with the following access attributes:

admin:owner	friend:group	other
r _ x	r _ x	_ w _

CVS Server Refinement: Group Setup

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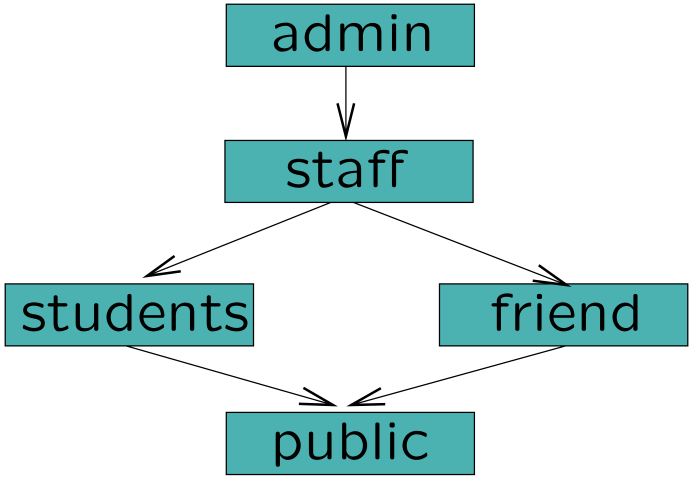
	see table below

group	users				
admin	admin				
staff	admin	staff			
friend	admin	staff		friend	
students	admin	staff	students		
public	admin	staff	students	friend	public

- Who can write to a file with the following access attributes:

admin:owner	friend:group	other
r _ x	r _ x	_ w _

- Only the users *students* and *public* can write to it.

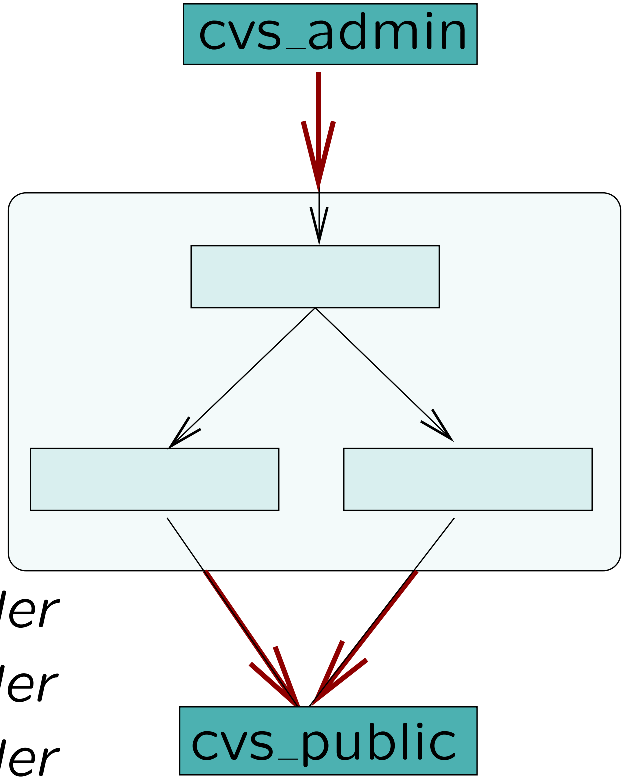
The System Architecture: Group Setup

- Abstract Data Type for Permissons

  $[Cvs\_Perm]$

- Permissions must be organized in a hierarchy

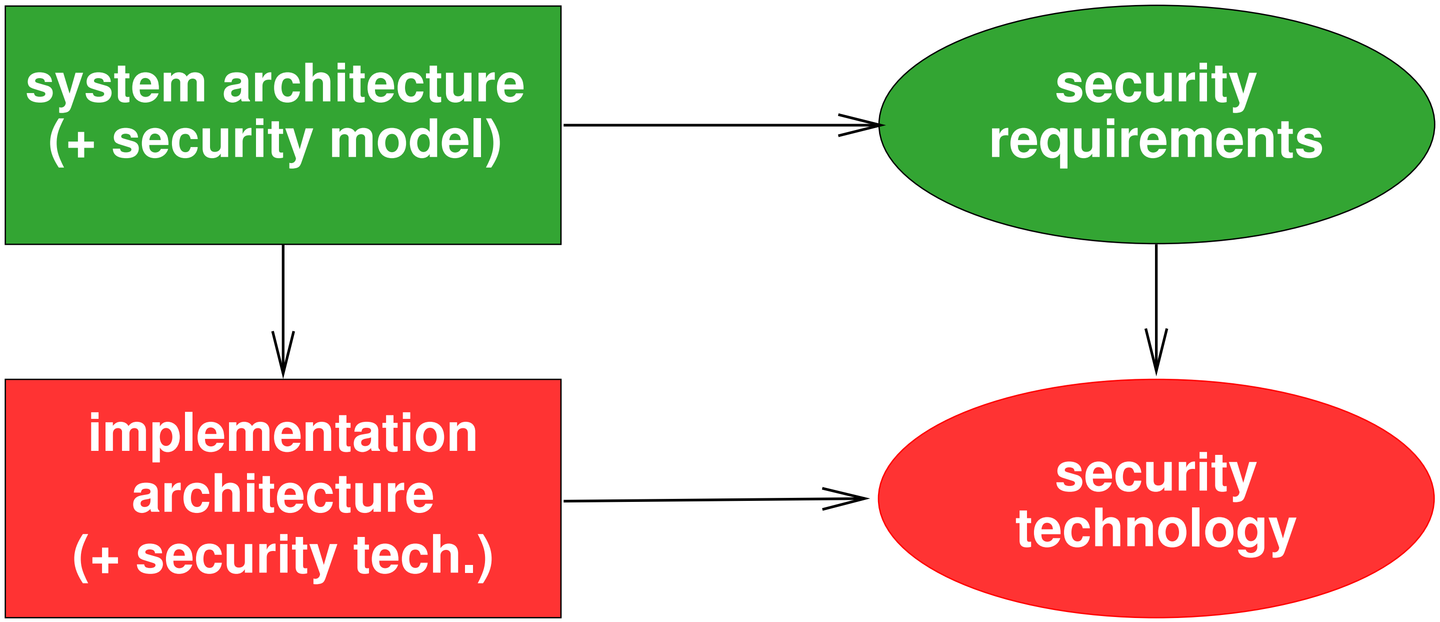
$$
\begin{array}{|l}
cvs\_admin, cvs\_public : Cvs\_Perm \\
cvs\_perm\_order : Cvs\_Perm \leftrightarrow Cvs\_Perm \\
\hline
cvs\_perm\_order = cvs\_perm\_order^{*} \\
\forall x : Cvs\_Perm \bullet (x, cvs\_admin) \in cvs\_perm\_order \\
\forall x : Cvs\_Perm \bullet (cvs\_public, x) \in cvs\_perm\_order \\
\forall x : Cvs\_Perm \bullet (cvs\_admin, x) \notin cvs\_perm\_order \\
\forall x : Cvs\_Perm \bullet (x, cvs\_public) \notin cvs\_perm\_order
\end{array}
$$



Refinement and Security

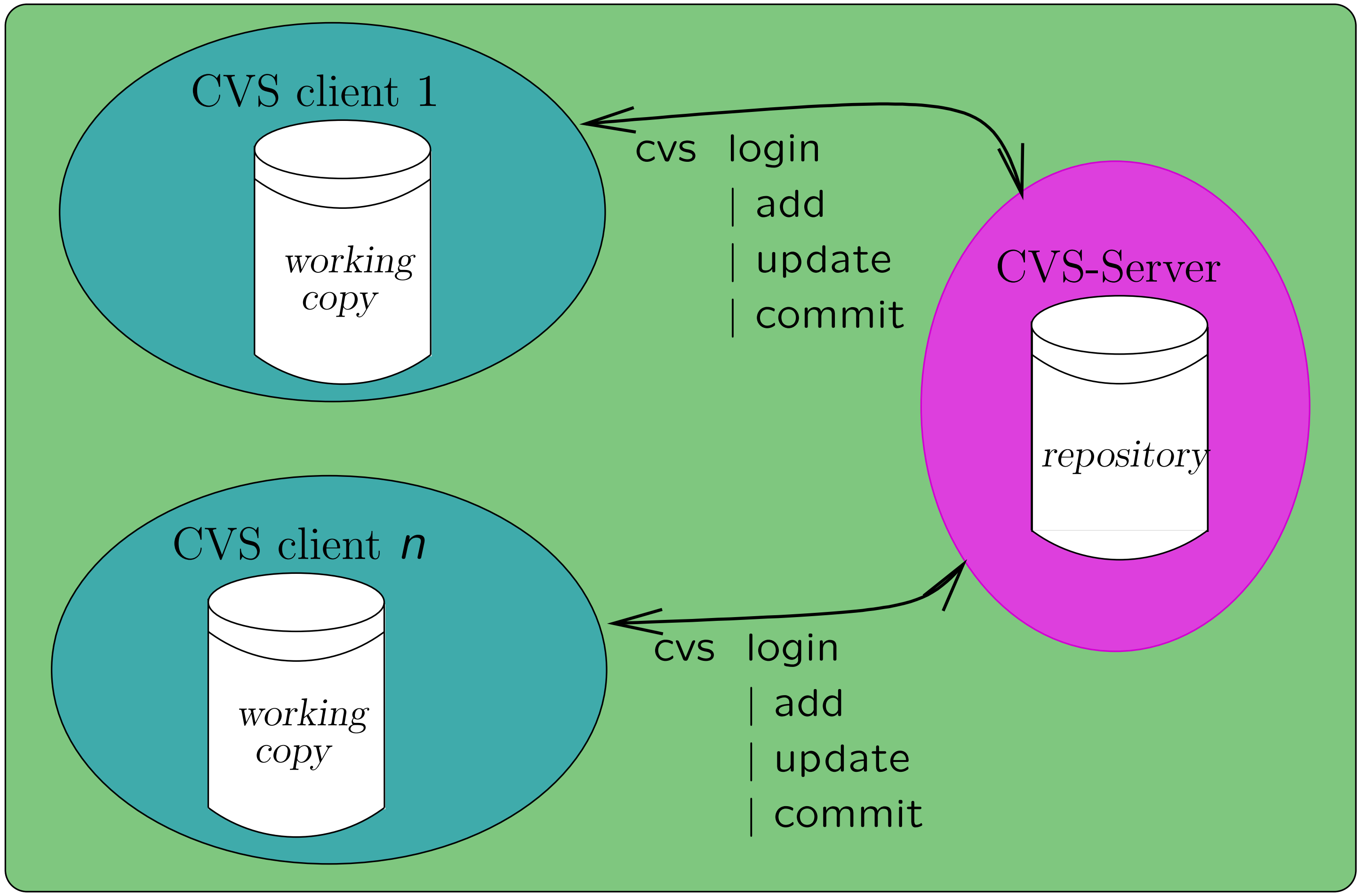
e.g.
hierarchic
role–based
access control

e.g.
configuration of
POSIX groups,
users, and
file permissions



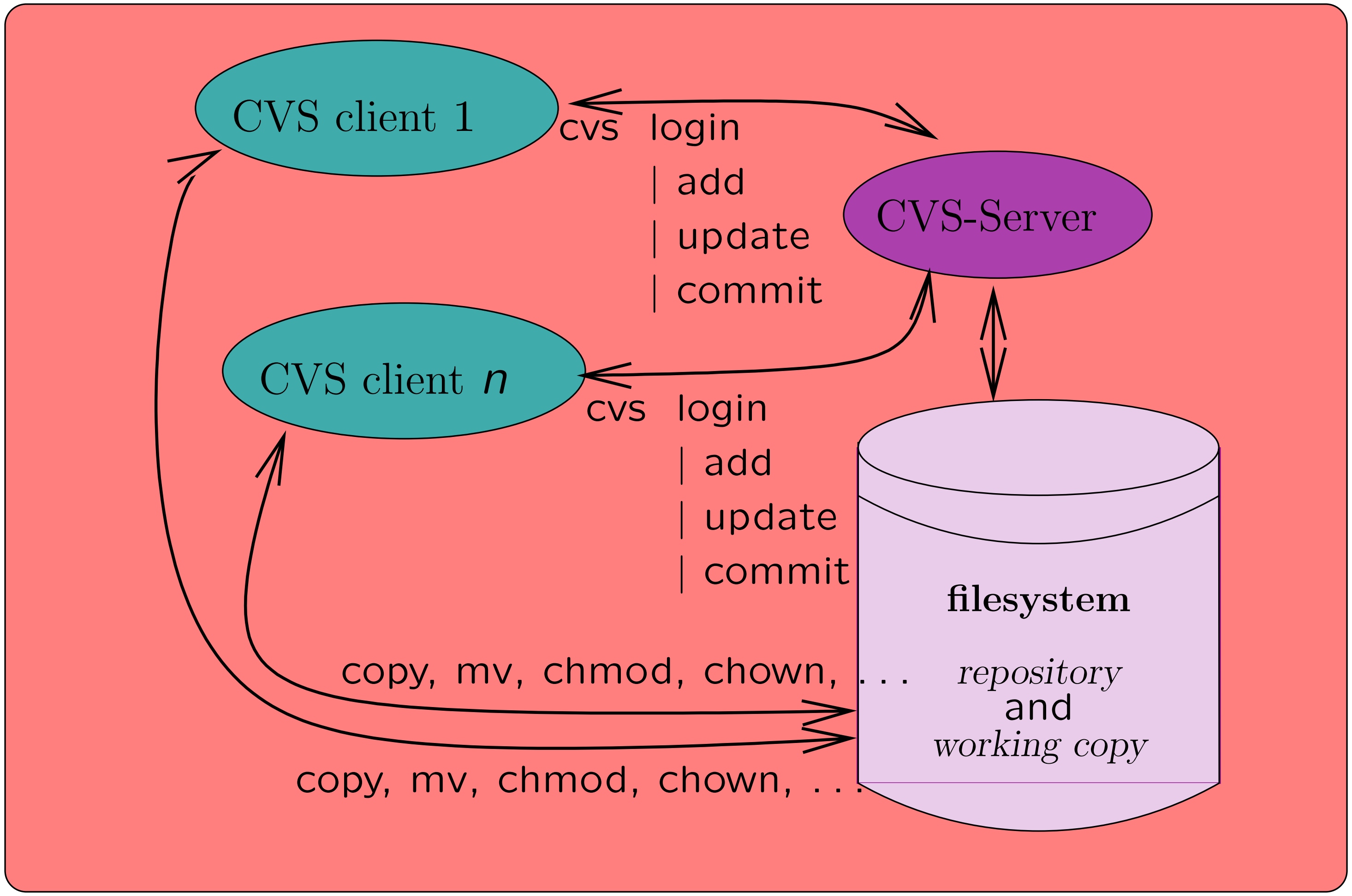
CVS-Server: High-Level Architecture

Security Properties: access control, authentication, non-repudiation

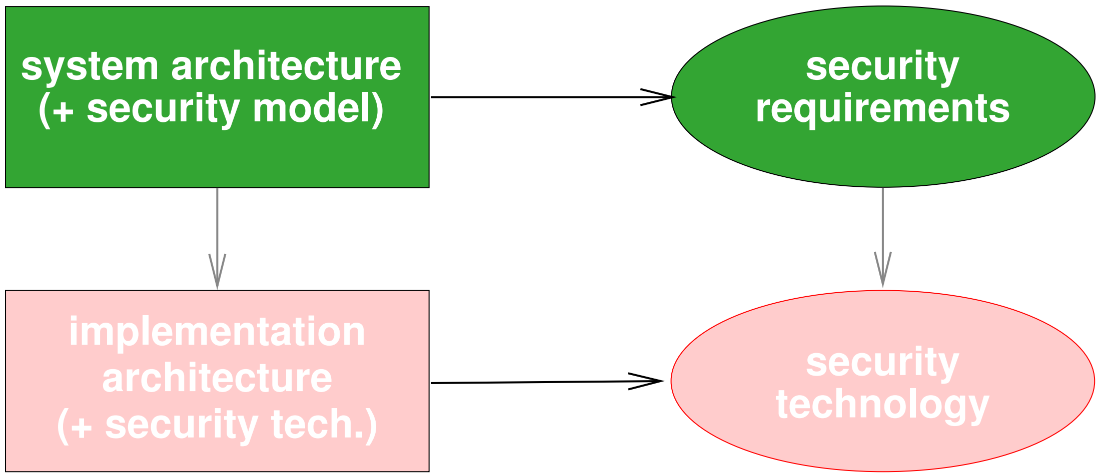


CVS-Server: Low-Level Architecture

Security Properties: access control



The Abstract CVS-Server Model



- **Data:**
  - clients with their states (a table of files)
  - server with its state
  - roles, authentication, permissions
  - role hierarchies
- **Abstract Operations:**
  - login
  - commit
  - update
  - checkout

The System Architecture

- names and data
  $[Abs\_Name, Abs\_Data]$

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  $[Abs\_Name, Abs\_Data]$

- modeling the working copy

  $ABS\_DATATAB == Abs\_Name \pfun Abs\_Data$

  $ABS\_ROLETAB == Abs\_Name \pfun Cvs\_Perm$

The System Architecture

- names and data

  $[Abs\_Name, Abs\_Data]$

- modeling the working copy

  $ABS\_DATATAB == Abs\_Name \pfun Abs\_Data$

  $ABS\_ROLETAB == Abs\_Name \pfun Cvs\_Perm$

- modeling the client state (the *security context*):

  ClientState

  $wfiles : \mathbb{P}\, Abs\_Name$

  $wc : ABS\_DATATAB$

  $wc\_uidtab : ABS\_UIDTAB$

  $abs\_passwd : PASSWD\_TAB$

The System Architecture: Operations

abs_up

$\Delta ClientState$

$\Xi RepositoryState$

$files? : \mathbb{P}\, Abs\_Name$

$wc' = wc \oplus \{n : wfiles \cap files? \mid n \in \mathrm{dom}\, rep \land n \in \mathrm{dom}\, wc\_uidtab$

$\quad \land (wc\_uidtab(n), abs\_passwd(wc\_uidtab\, n))\ \mathsf{is\_valid\_in}\ rep\} \lhd rep)$

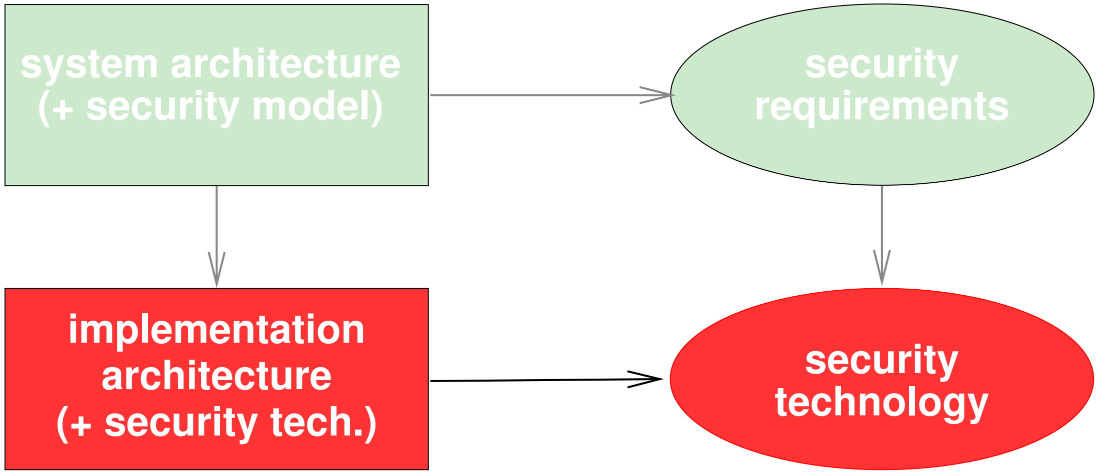
$wc\_uidtab' = wc\_uidtab \cup \{n : wfiles \cap files? \mid n \in \mathrm{dom}\, rep$

$\quad \land n \notin \mathrm{dom}\, wc\_uidtab \bullet n \mapsto choose\_valid\_rolename(rep\_permtab, n)\}$

$abs\_passwd' = abs\_passwd \land wfiles' = wfiles$

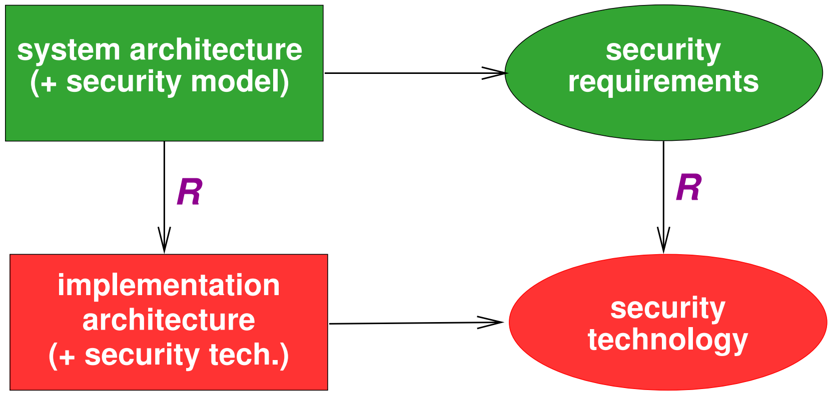
- client needs sufficient permissions
- non-blocking, files to which the client has no permissions are ignored
- the permission table in the working copy is updated

Concrete CVS-Server Model



- **The POSIX Layer:**
  - names, paths
  - POSIX permissions (DAC model)
  - state of a filesystem
  - state of the process
  - operations cd, mkdir, chmod, umask, cp, . . .
- **The CVS-Server Layer:**
  - Operation cvs_login
  - Operation cvs_ci
  - Operation cvs_up
  - Operation cvs_co

The Refinement



- **The concrete state:**
  System invariant describing allowable UNIX permissions on the user accounts and the repository. (formalizing 'the administrators job')

- **Abstraction relation** R**:**
  - abstract client state *are mapped onto* files with suitable file permissions
  - roles *are mapped onto* UNIX configurations (groups, unique uid's, sticky bits, ...)

System Architecture: Security Properties

Any sequence of CVS operations starting from an empty working copy does not lead to a working copy with data to which the client has no permission (unless he was able to “invent” it).

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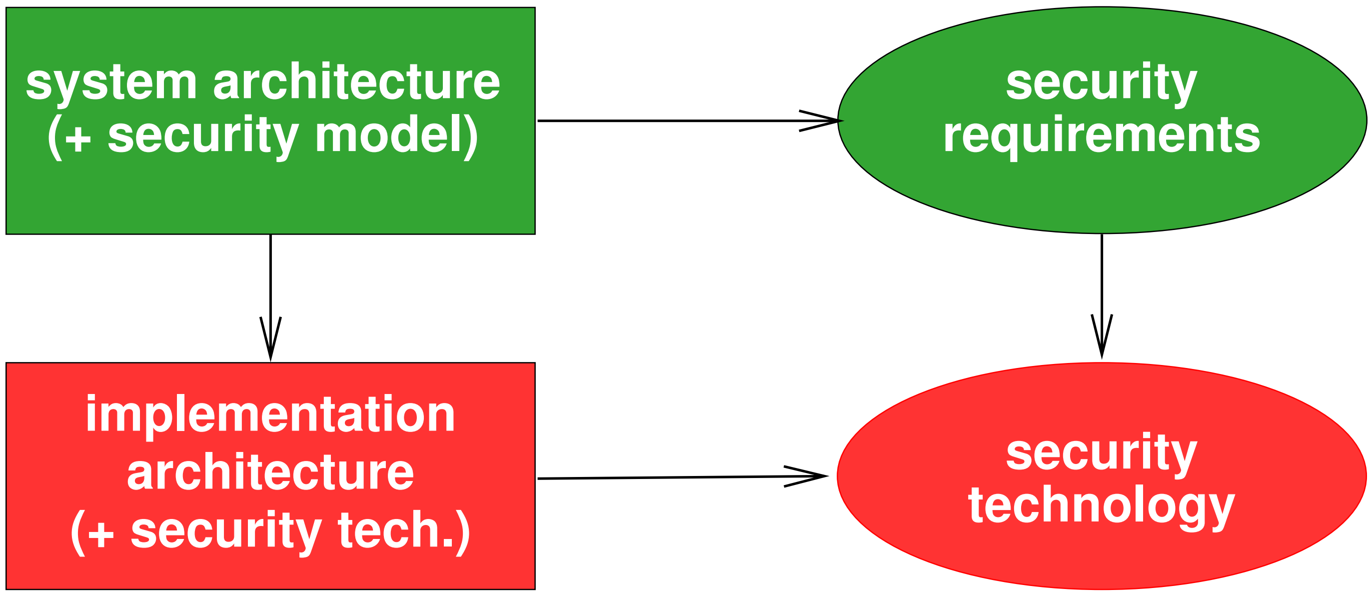
$$
\begin{aligned}
&\mathit{InitAbsState}1 == \mathit{AbsState} \land [\mathit{wc} : \mathit{ABS\_DATATAB} \mid \mathit{wc} = \varnothing]\\
&\mathit{ReachableStates} == \mathit{AtransR}(\!|\mathit{InitAbsState}1|\!)\\
&\mathit{ReadAccess} == \forall\, \mathit{ReachableStates} \bullet \mathit{ClientState} \land \mathit{RepositoryState}\\
&\qquad \land\ [\mathit{wc} : \mathit{ABS\_DATATAB};\\
&\qquad\quad \mathit{rep} : \mathit{ABS\_DATATAB};\\
&\qquad\quad \mathit{rep\_permtab} : \mathit{ABS\_PERMTAB} \mid\\
&\qquad\qquad \forall\, n : \mathrm{dom}\, \mathit{wc} \bullet (n, \mathit{wc}(n)) \in \mathit{Ainvents} \lor\\
&\qquad\qquad\quad ((\mathit{wc}(n) = \mathit{rep}(n)) \land (\exists\, m : \mathit{Aknows} \bullet\\
&\qquad\qquad\qquad (\mathit{rep\_permtab}(n), \mathit{authtab}(\mathit{rep})(m)) \in\\
&\qquad\qquad\qquad\quad \mathit{cvs\_perm\_order}))]
\end{aligned}
$$

Security Analysis



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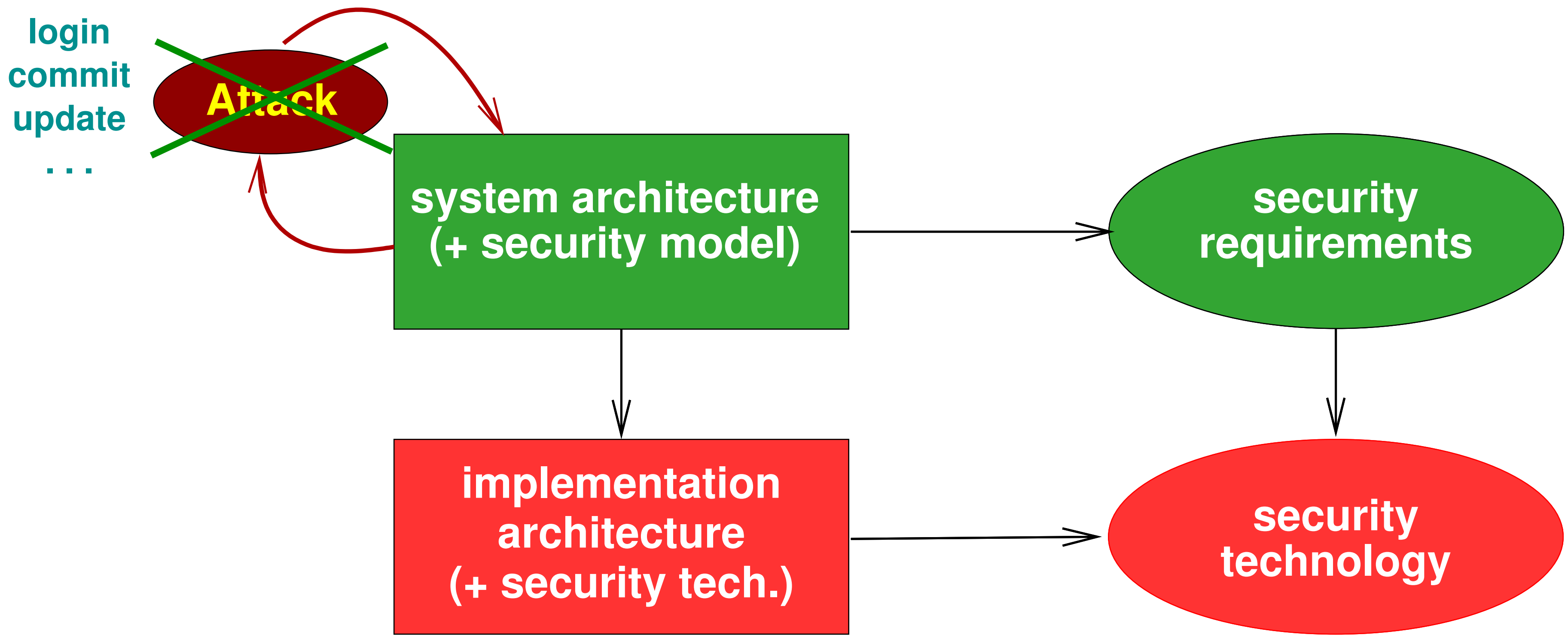

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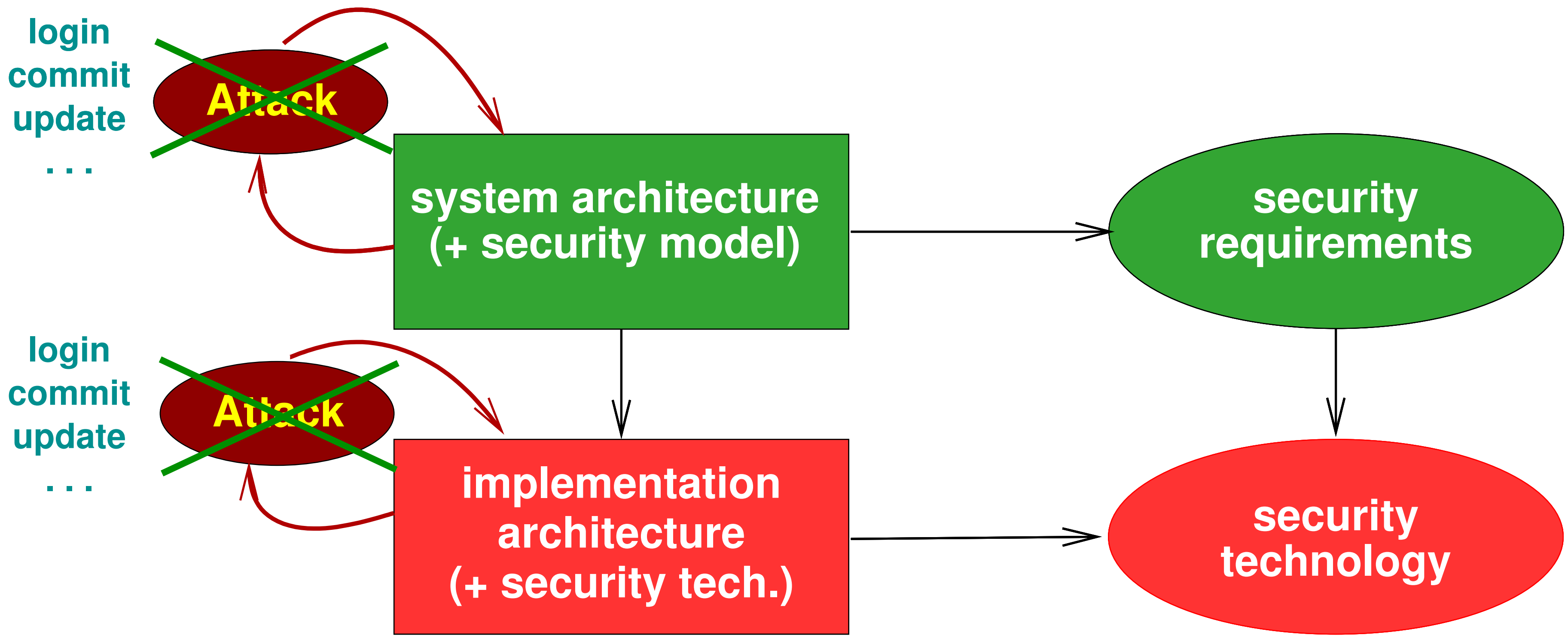

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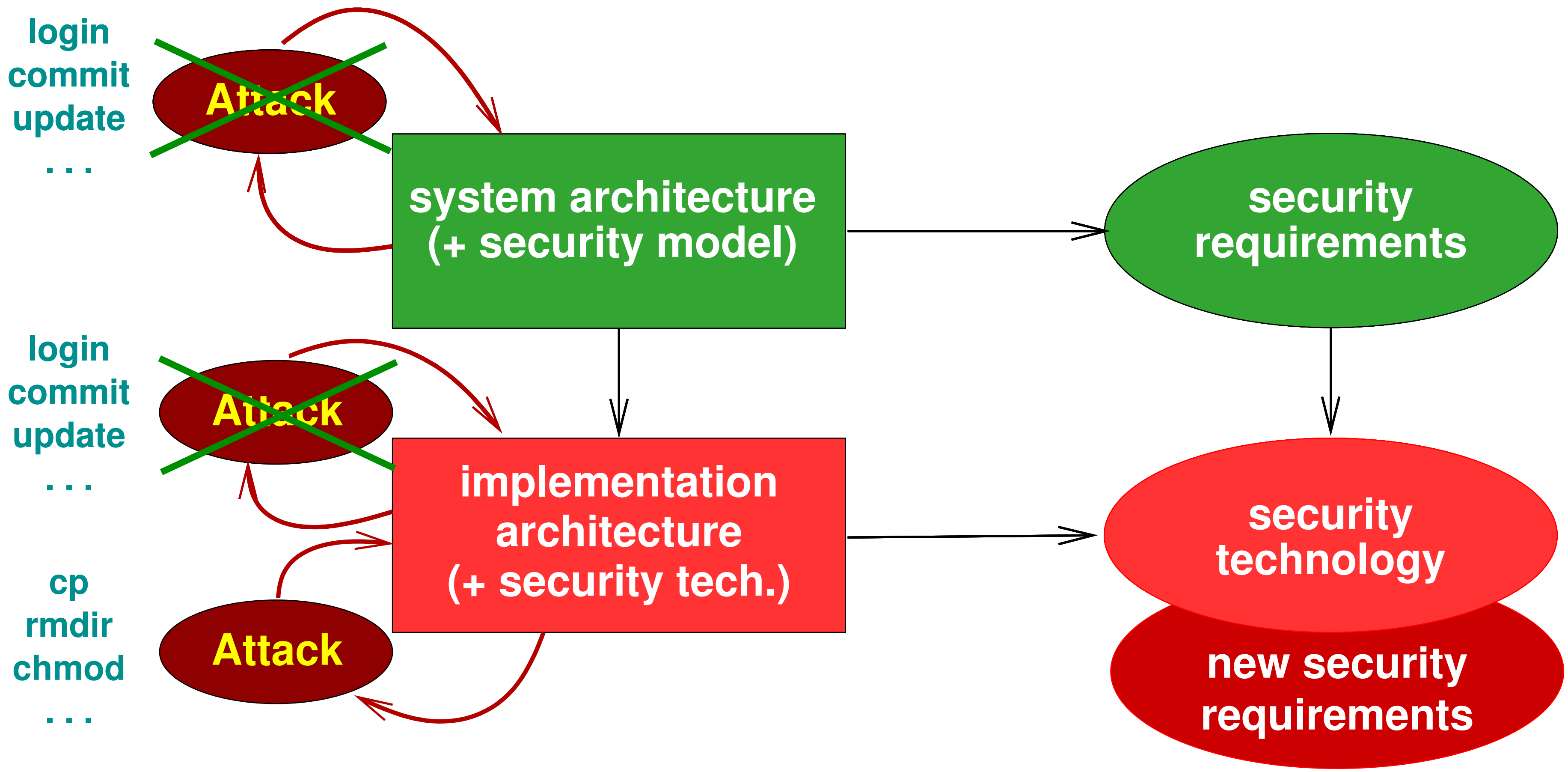

Security Analysis

We study two levels of possible attacks:

- Attacks against the **abstract model**:

  $$trans = (login \vee add \vee commit \vee update)^*$$

  (change data in wc only to invent data)

- Attacks against the **concrete model** (POSIX):

  $$\begin{aligned} trans = (&login \vee add \vee commit \vee update \\ &\vee chmod \vee umask \vee cp \vee \ldots)^* \end{aligned}$$

  (not being root)

Summary

- Architecture modeling is an important abstraction level in security analysis: we investigate security models and their relation (and not code)

- . . . technique to analyze tricky system administration issues formally

- POSIX/Unix-model reusable, (validated against POSIX and Linux)

- Method applicable for a wide range of practical security problems

Practical relevance (Application)

- over 80 users in 5 different roles
- over 3 GB of versioned data
- used on a daily basis (in mission critical projects)
- used for over two year without problems