Università degli Studi di Trento
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Monitoring and Diagnosing Malicious Attacks with Autonomic Software

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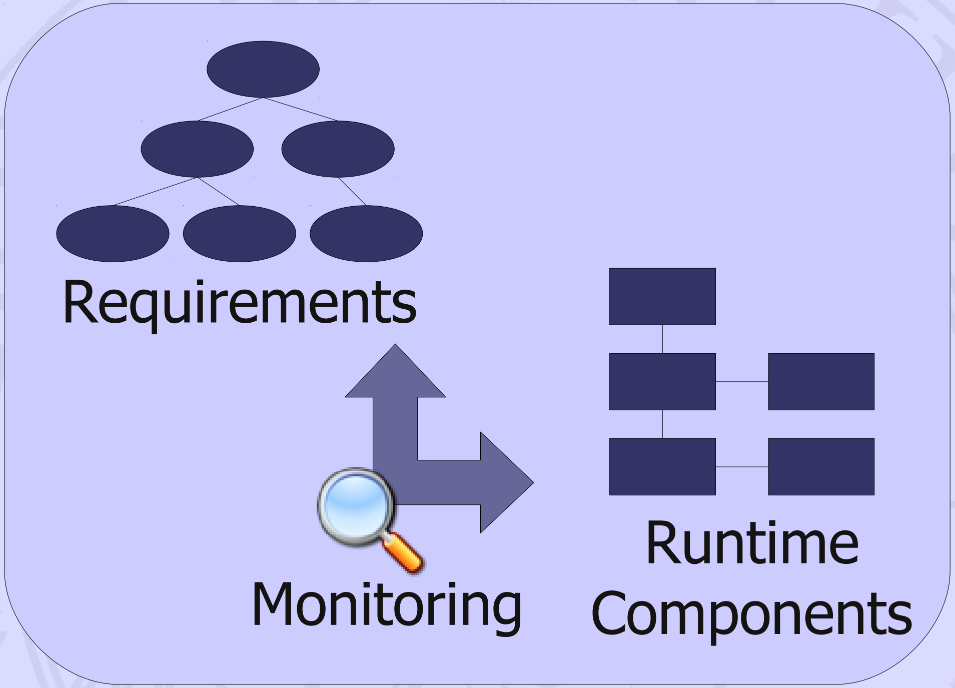
Agenda

- Motivation;
- A diagnosing framework;
- Proposed extensions for this framework:
  - Anti-goals;
  - Contextual variability;
- Evaluation;
- Conclusions.

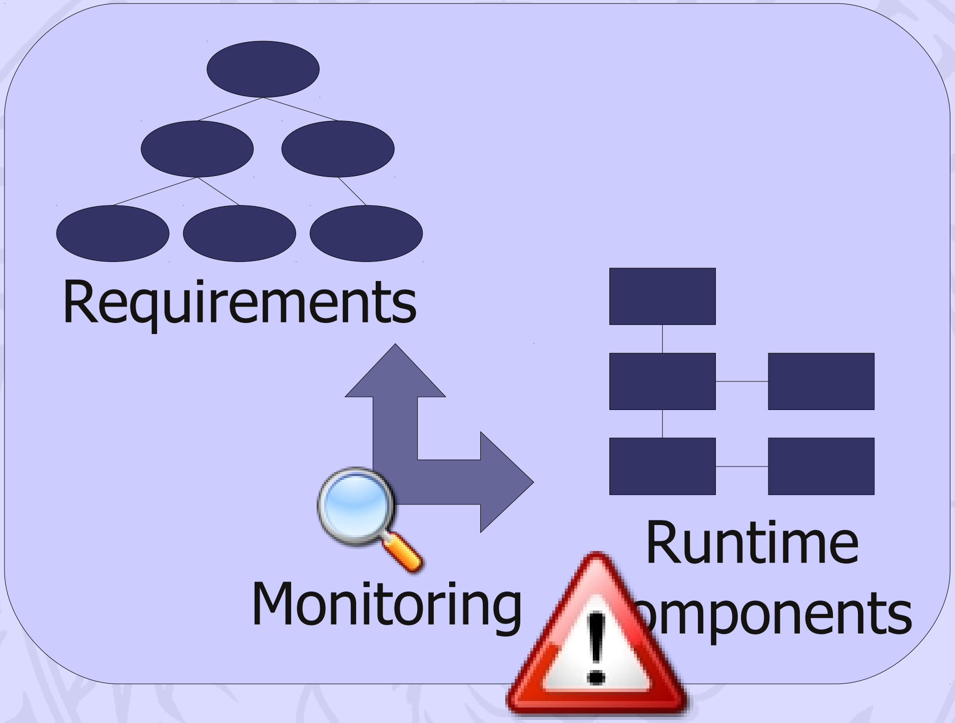
Motivation

- Monitoring and diagnosing against requirements:
  - Old problem (e.g. Fickas & Feather, 1995);
  - Considerable recent attention in the context of adaptive and autonomic software systems;
- Autonomic systems:
  - Operate on their own according to a set of rules;
  - Self-configuration, self-optimization, self-healing and self-protection;
  - Monitor (failures, sub-optimal behaviors, attacks, etc.) → diagnose → compensate.

Motivating Scenario (1)



Motivating Scenario (1)



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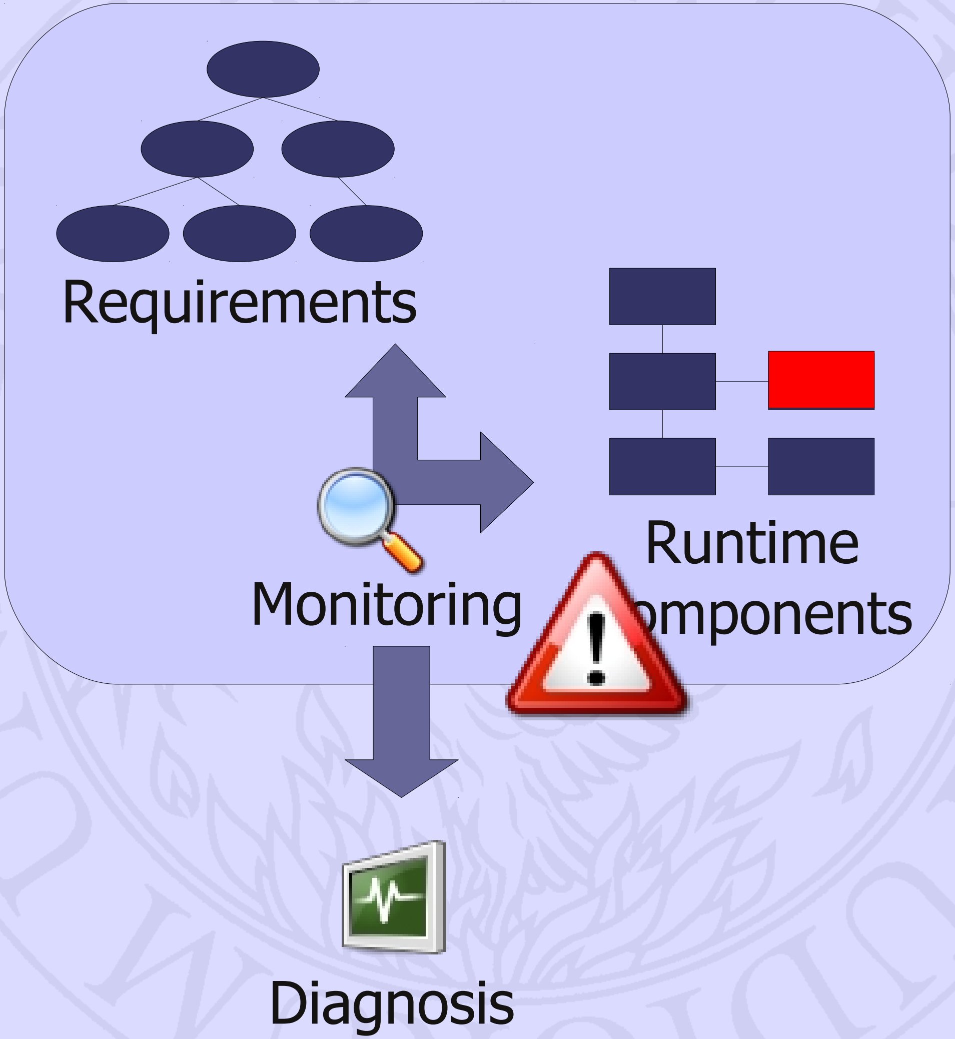


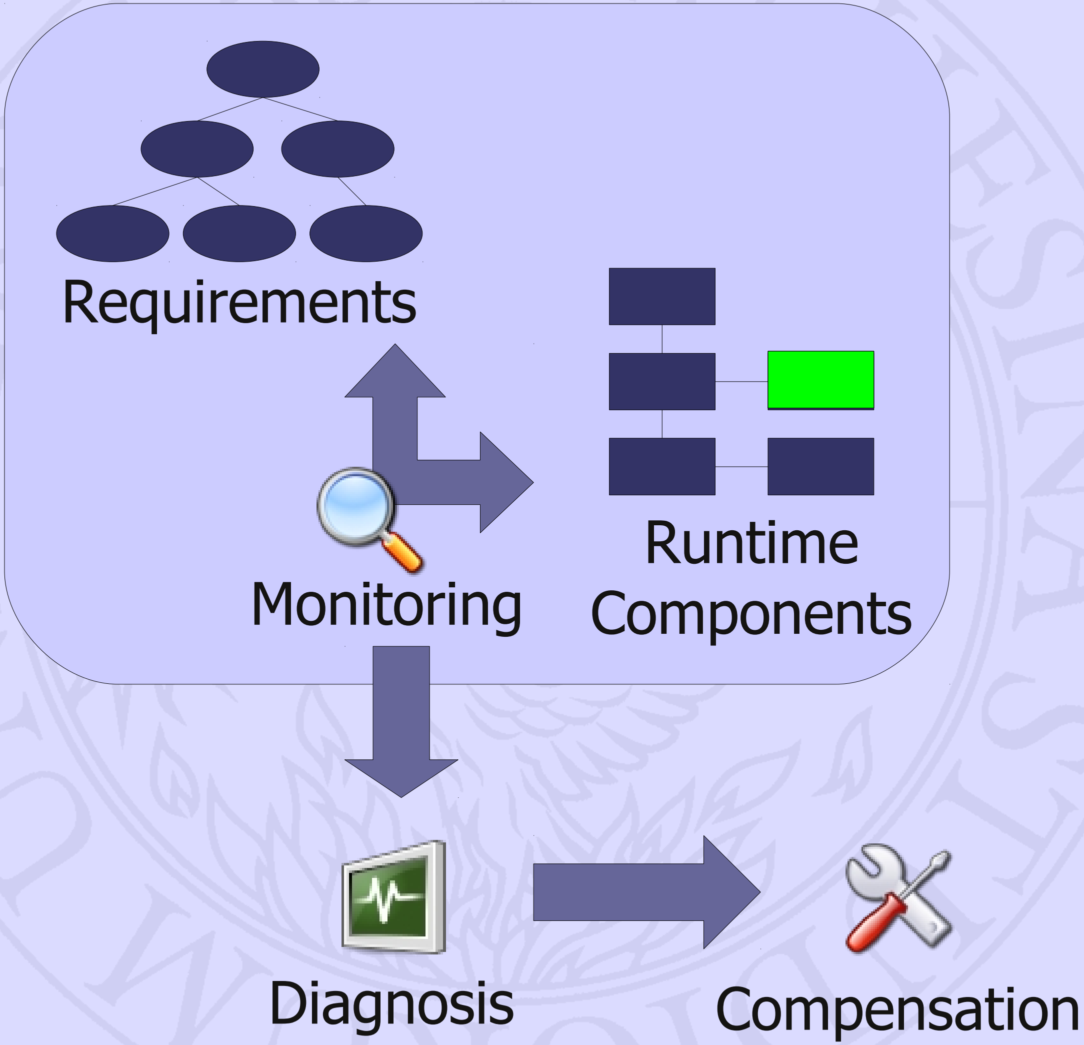
Requirements

Runtime
omponents

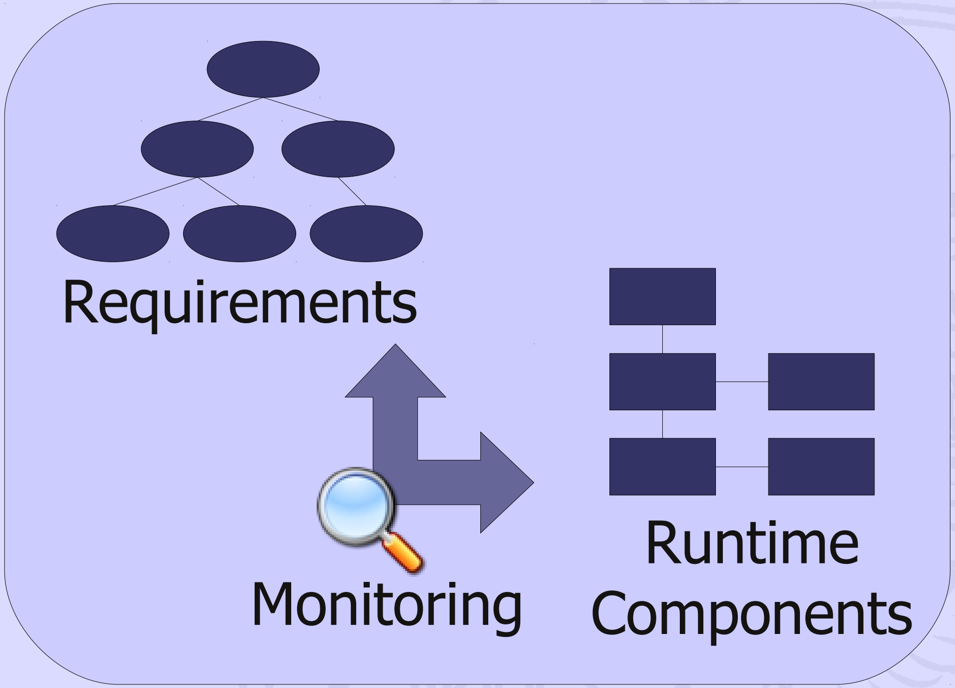
Monitoring

Diagnosis

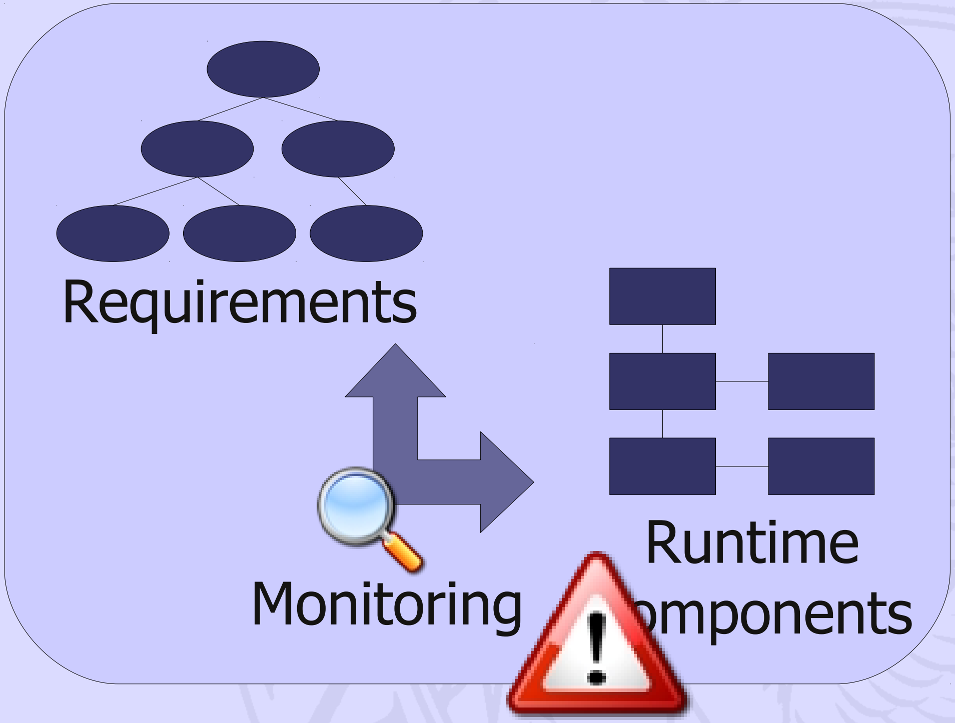
Motivating Scenario (1)



Motivating Scenario (2)



Motivating Scenario (2)



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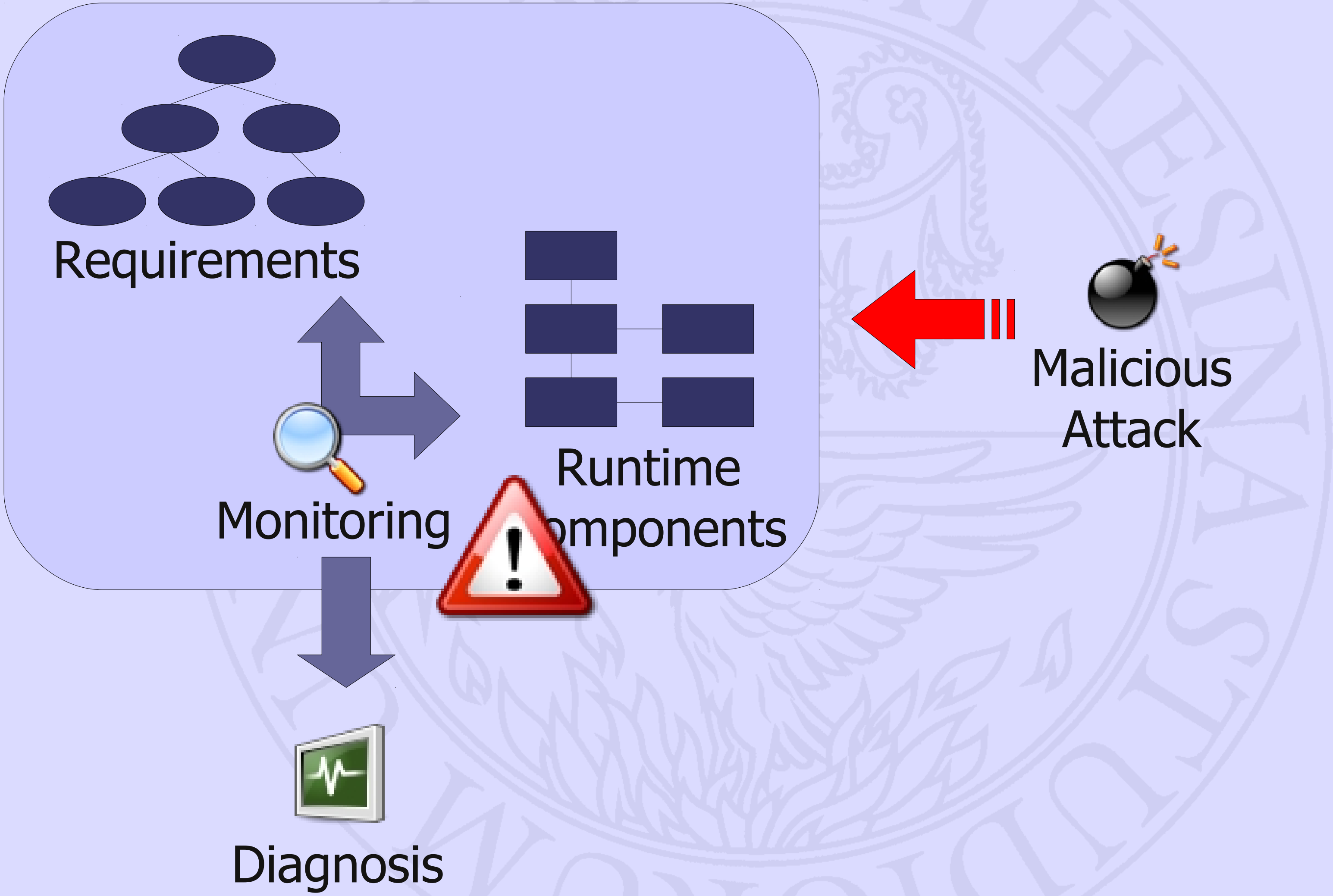

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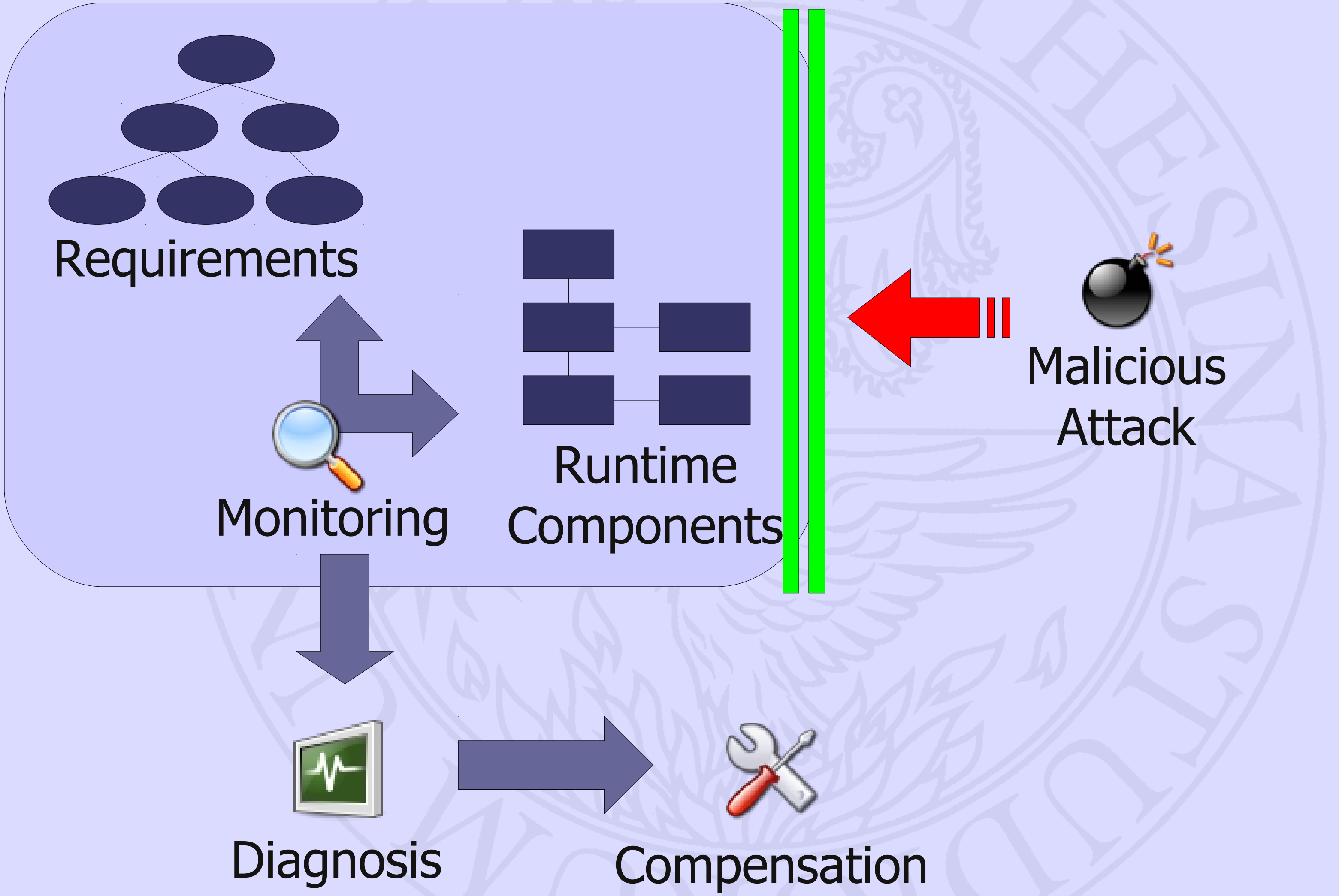


Requirements

Monitoring

Runtime Components

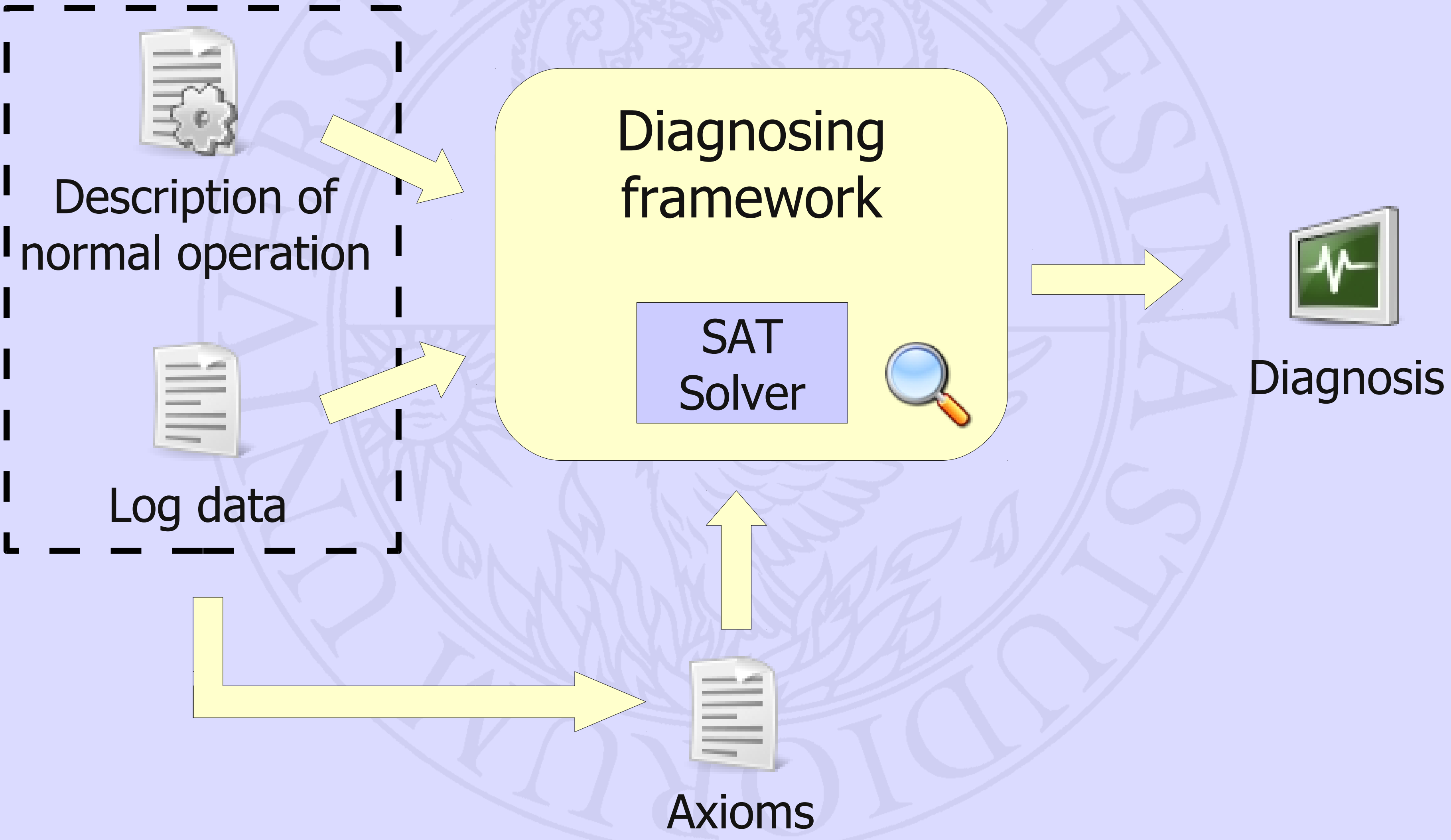
Malicious Attack

Diagnosis

Compensation

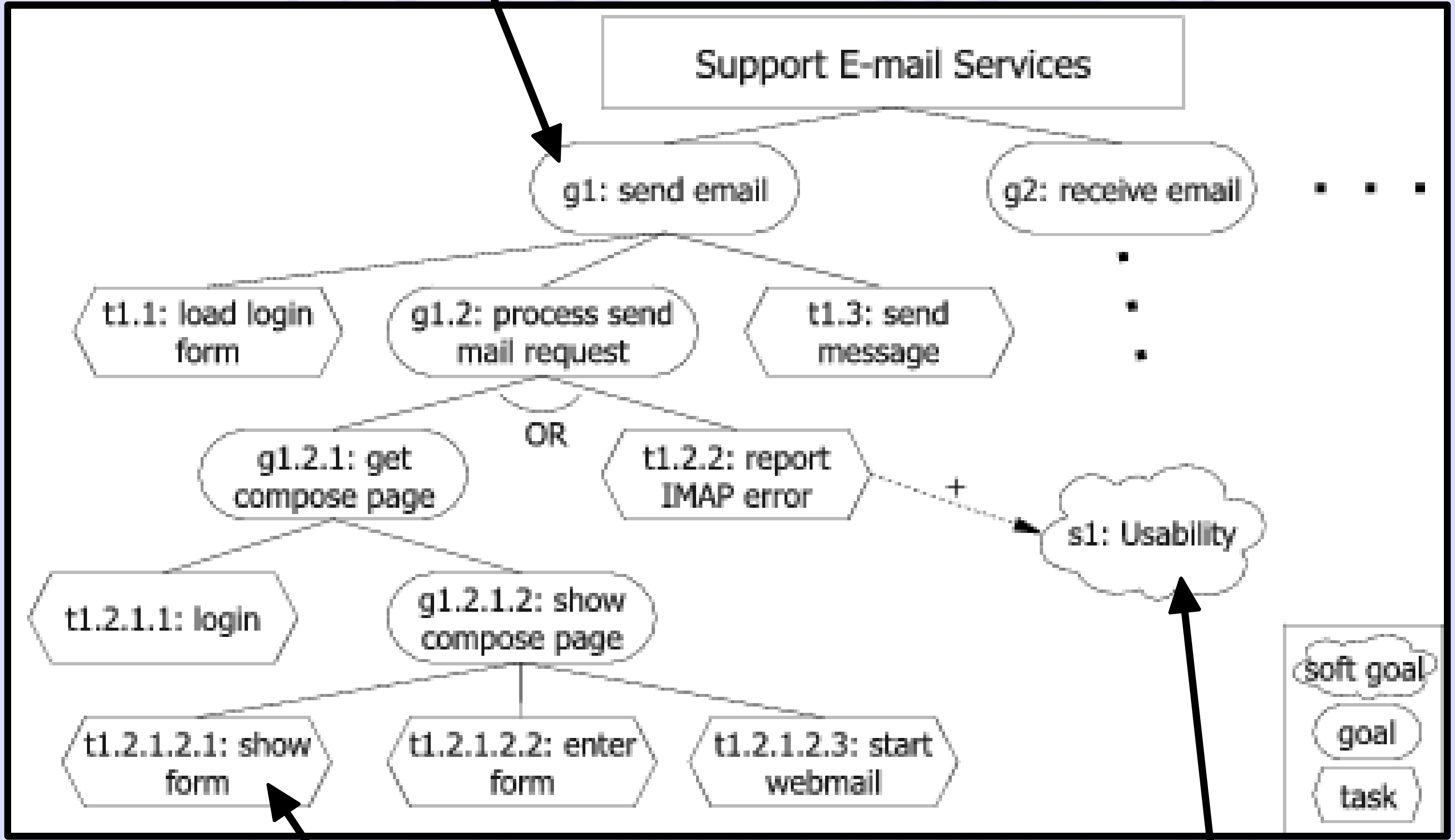
A diagnosing framework

- Based on Wang et. al.



Requirements are goal models

Main goals of the application



A monitorable piece of the software

Non-functional requirements

Diagnosing

- Based on requirements and an execution log:

**url_entered(1), occ(t1.1, 2), correct_form(3),
~ wrong_imap(4), occ(t1.2.1.1, 5), correct_key(6),
occ(t1.2.1.2.1, 7), occ(t1.2.1.2.2, 8), occ(t1.2.1.2.3, 9),
~ webmail_started(10), occ(t1.3, 11), ~ email_sent(12)**

- The framework produces:
  - Facts;
  - Propagation axioms;
  - Contribution axioms;
  - Deniability axioms.

fd(t1.2.1.1); fd(t1.3)
fd(t1.2.1.2); fd(t1.3)
fd(t1.2.1.3); fd(t1.3)

- The SAT solver then derives the diagnosis.

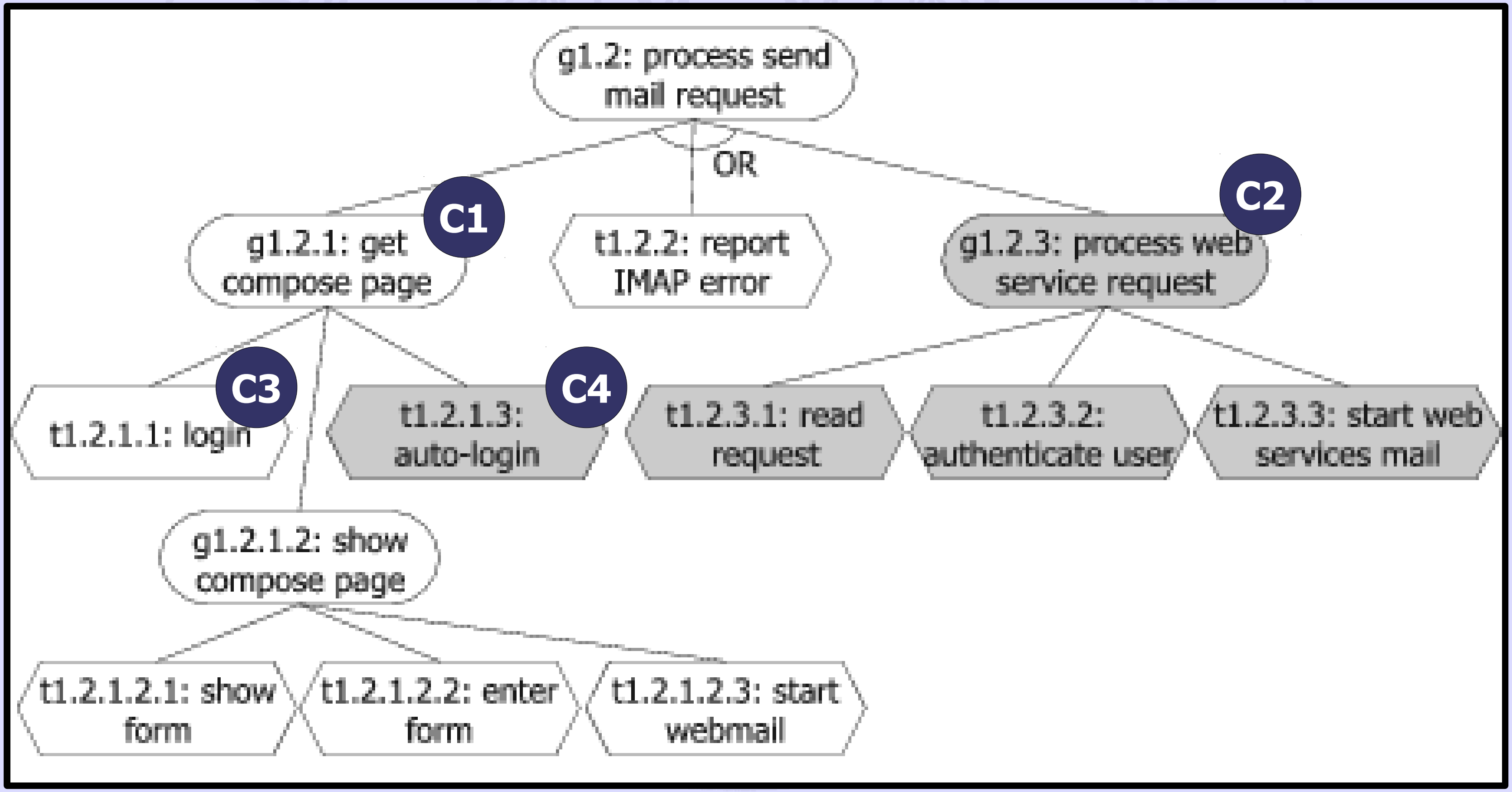
Proposed extensions for the framework

- Goal: to monitor and diagnose malicious attacks;
- Add support for anti-goals[1]:
  - Software components are not faulty;
  - Problem caused by an external agent;
- Add support for contextual variability[2]:
  - Attacks are notoriously context-dependent;
  - Richer goal model.

[1] – Based on anti-goals proposal by Lamsweerde et al.;
[2] – Based on contextual variability proposed by Lapouchnian.

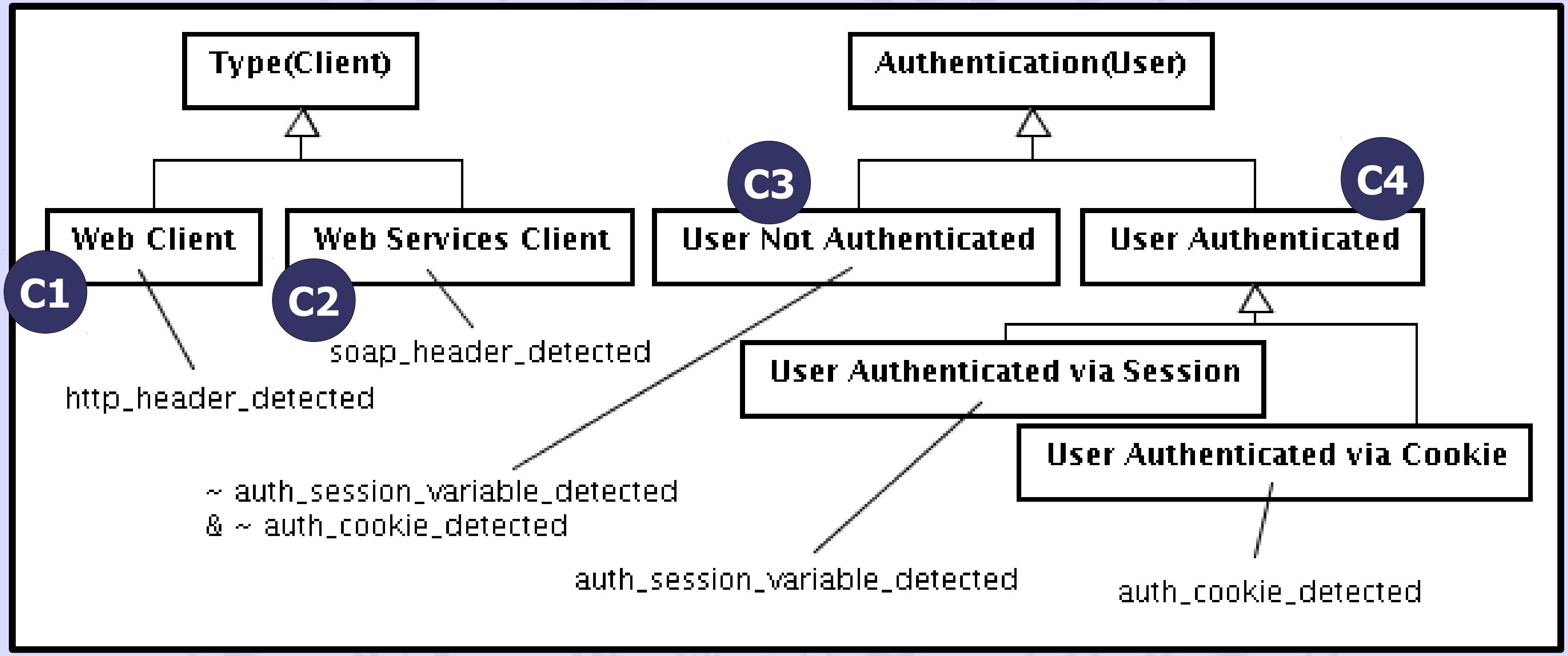
Support for contextual variability

- Goals and tasks can be annotated with context;
- Instrumented code logs data needed to identify active context.


g1.2: process send mail request
OR
C1
g1.2.1: get compose page
t1.2.2: report IMAP error
C2
g1.2.3: process web service request
C3
t1.2.1.1: login
C4
t1.2.1.3: auto-login
t1.2.3.1: read request
t1.2.3.2: authenticate user
t1.2.3.3: start web services mail
g1.2.1.2: show compose page
t1.2.1.2.1: show form
t1.2.1.2.2: enter form
t1.2.1.2.3: start webmail

Support for contextual variability

- Contexts can form hierarchies:



- A context is active if:
  - A sub-context is active;
  - Its formula evaluates to true.

Support for contextual variability

- Contextual information affect:
  - Satisfiability propagation (an AND goal is satisfied iff all its children **with active context** are satisfied);
  - Task/goal occurrence – tasks and goals cannot occur when their context is inactive:
    - Instrumented code not logging context information;
    - Software not according to specifications.

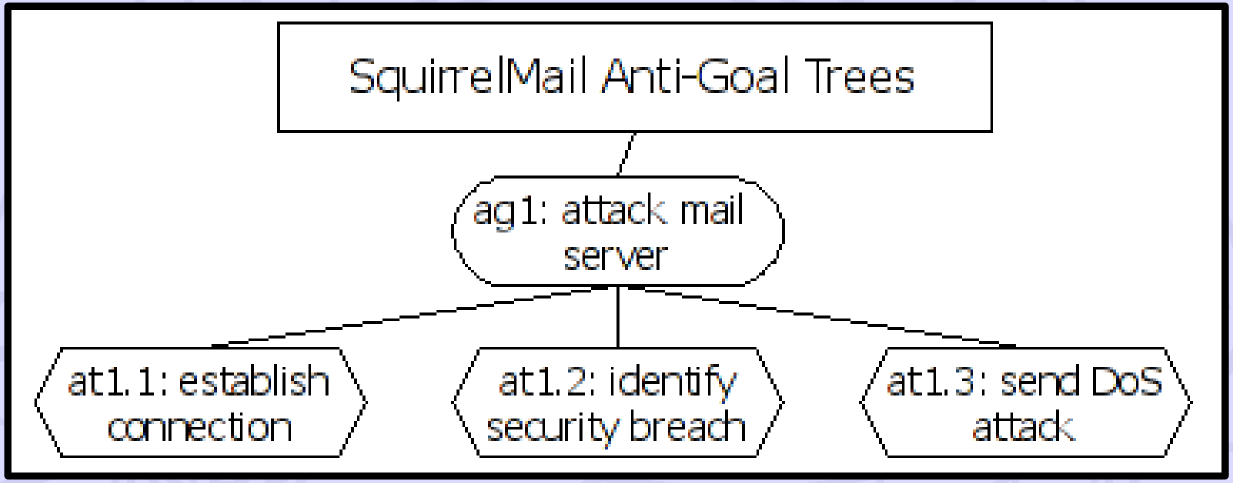
$$occ(g,t_s,t_e) \land \neg context\_formula(g,t_s) \rightarrow iocc(g,s)$$

$$occ(a,t_{occ}) \land \neg context\_formula(a,t_{occ}) \rightarrow iocc(a,s)$$

Context formula is built navigating context hierarchy depth-first and joining the leaf-contexts in a disjunction.

Support for anti-goals

- Goal models can include anti-goal trees;

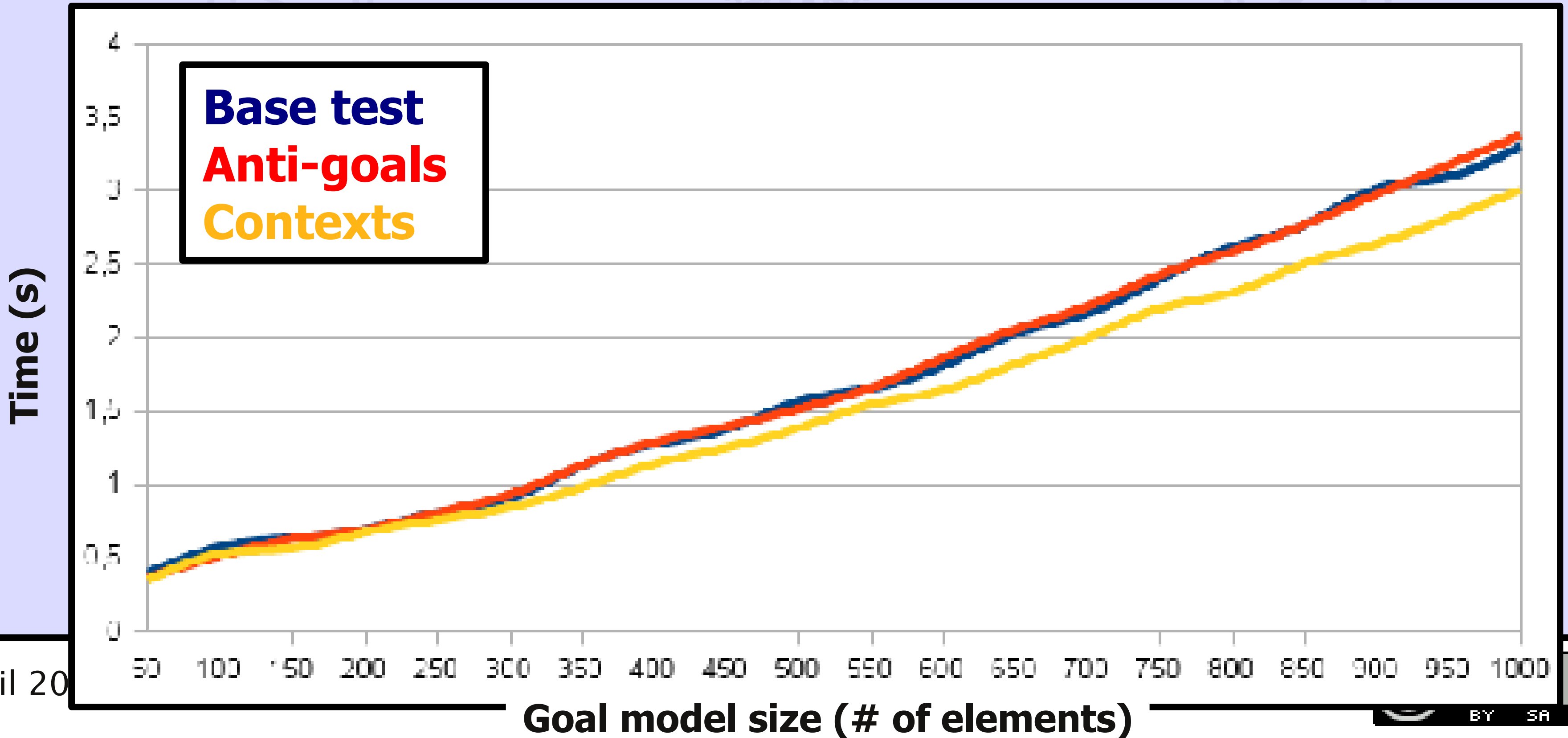

SquirrelMail Anti-Goal Trees
ag1: attack mail server
at1.1: establish connection
at1.2: identify security breach
at1.3: send DoS attack

- Anti-goals and tasks have sets of targets;
- Attack detection software produces log information on anti-goals;
- Anti-goal satisfiability axioms are produced:

$$\forall e \in \{e_1, e_2, \ldots, e_n\} : occ(a, t_s, t_e) \wedge fd(e, s) \rightarrow fs(a, s)$$

Performance evaluation

- Used the ATM Simulation by R. C. Bjork;
  - Goal model and log files are replicated in different sizes (from 100 to 1000);
  - New features maintain framework scalability:



Conclusions

- Contributions:
  - Novel approach for M&D malicious attacks;
  - Support for goal models enriched with contexts;
  - Preliminary feasibility and scalability tests.
- Future work:
  - Study of possible compensating mechanisms;
  - Complementing the diagnostic reasoner with probabilistic techniques;
  - Further research on autonomic computing, with emphasis on self-protection.

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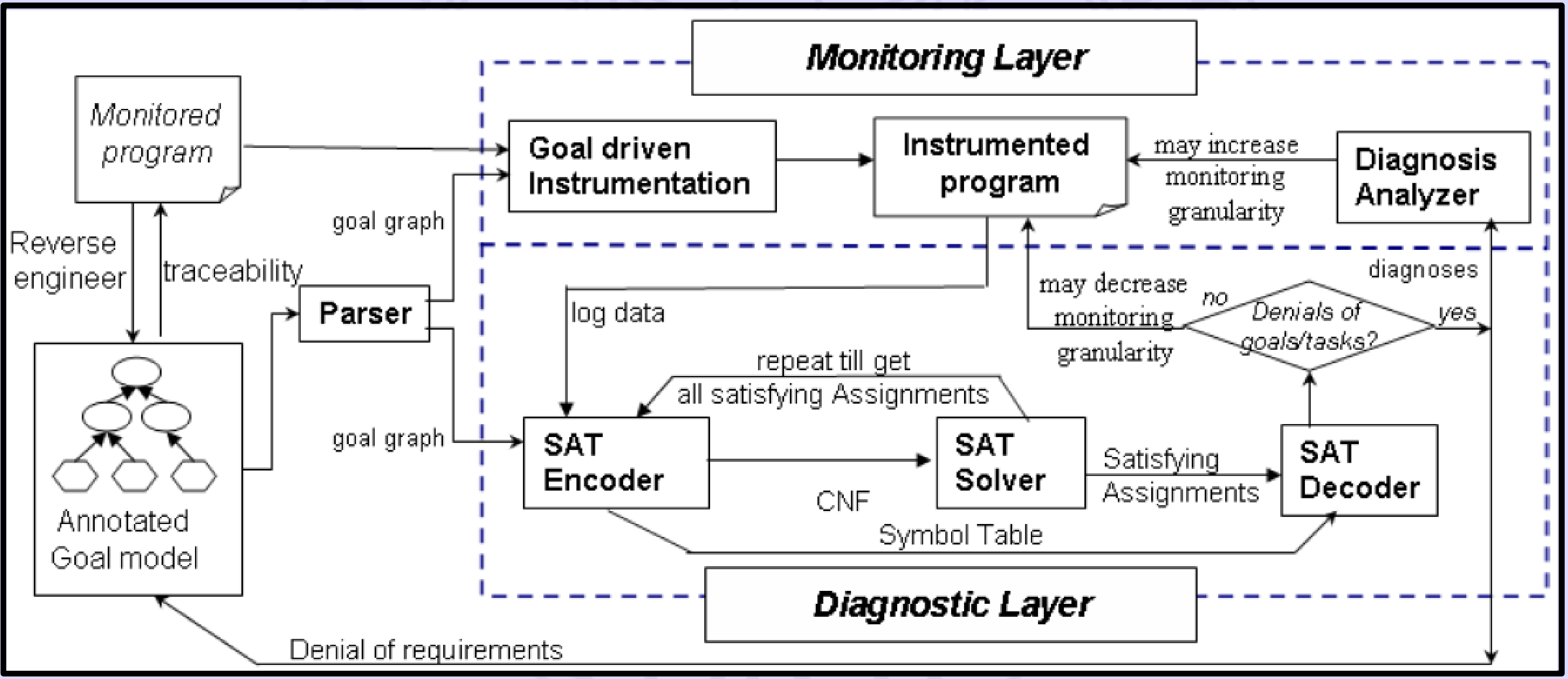
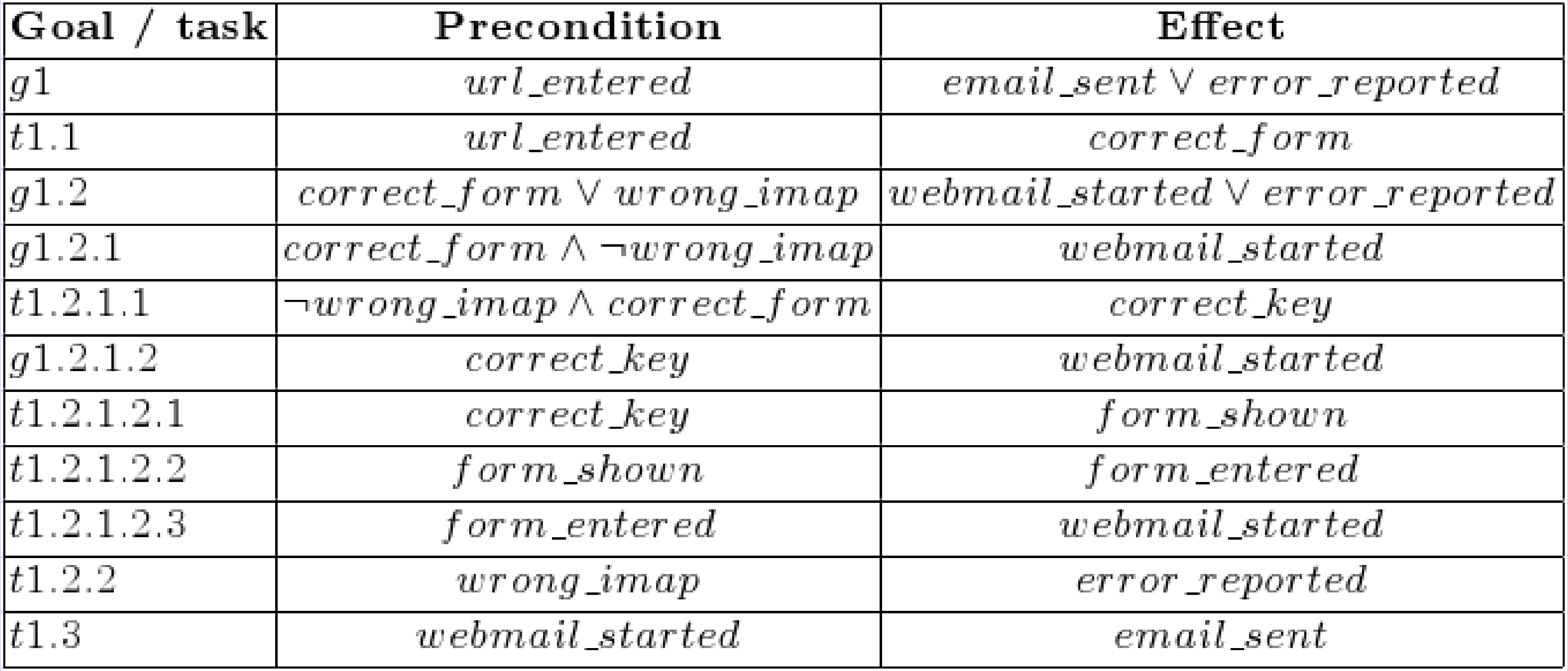
Diagnosing framework by Wang et al.

A general monitoring framework, paired with a SAT-based diagnostic reasoner adapted from Artificial Intelligence (AI) theories of action and diagnosis.



Monitoring the specification



Goal / task	Precondition	Effect
$g1$	$url\_entered$	$email\_sent \lor error\_reported$
$t1.1$	$url\_entered$	$correct\_form$
$g1.2$	$correct\_form \lor wrong\_imap$	$webmail\_started \lor error\_reported$
$g1.2.1$	$correct\_form \land \neg wrong\_imap$	$webmail\_started$
$t1.2.1.1$	$\neg wrong\_imap \land correct\_form$	$correct\_key$
$g1.2.1.2$	$correct\_key$	$webmail\_started$
$t1.2.1.2.1$	$correct\_key$	$form\_shown$
$t1.2.1.2.2$	$form\_shown$	$form\_entered$
$t1.2.1.2.3$	$form\_entered$	$webmail\_started$
$t1.2.2$	$wrong\_imap$	$error\_reported$
$t1.3$	$webmail\_started$	$email\_sent$

Can turn monitoring on or off

Must be true before a task is executed or a goal is satisfied

Must be true after a task is executed or a goal is satisfied