Dynamic Event-Based Runtime Monitoring of Real-Time and Contextual Properties

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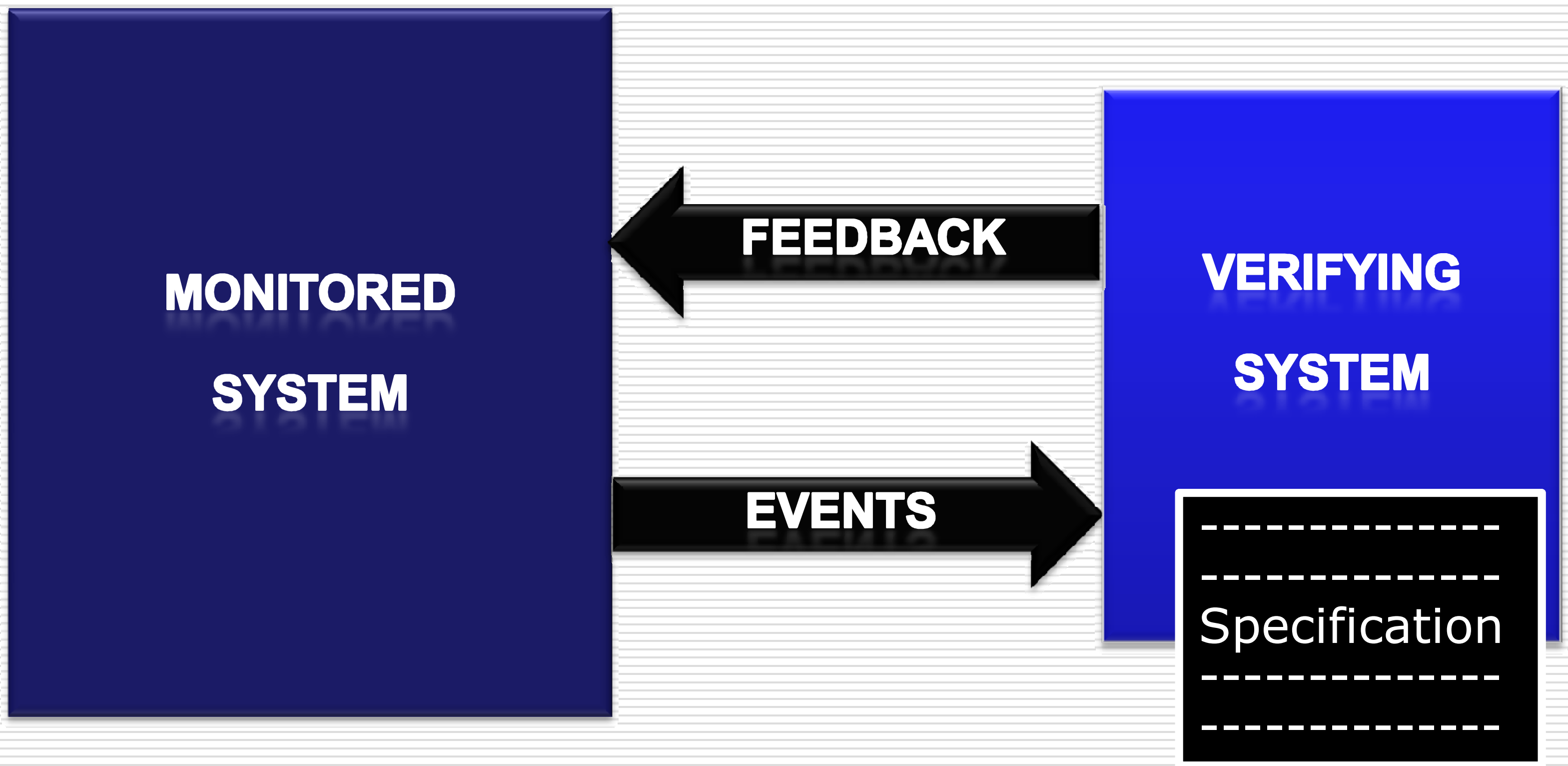
Why Runtime Verification?

- In security-critical systems we cannot afford to fail!
- Model checking is not scalable.
- Testing lacks coverage.
- Runtime verification is a good compromise.
- There is a great gap between the design and the implementation.

General Architecture



Simple Examples

- Ensuring that only authorised users access reserved areas in the system.
- Checking that a train gate which started closing has indeed closed after a number of seconds.
- Monitoring the life-cycle of an object (such as a transaction), ensuring it goes through its stages properly.

Specifying Properties

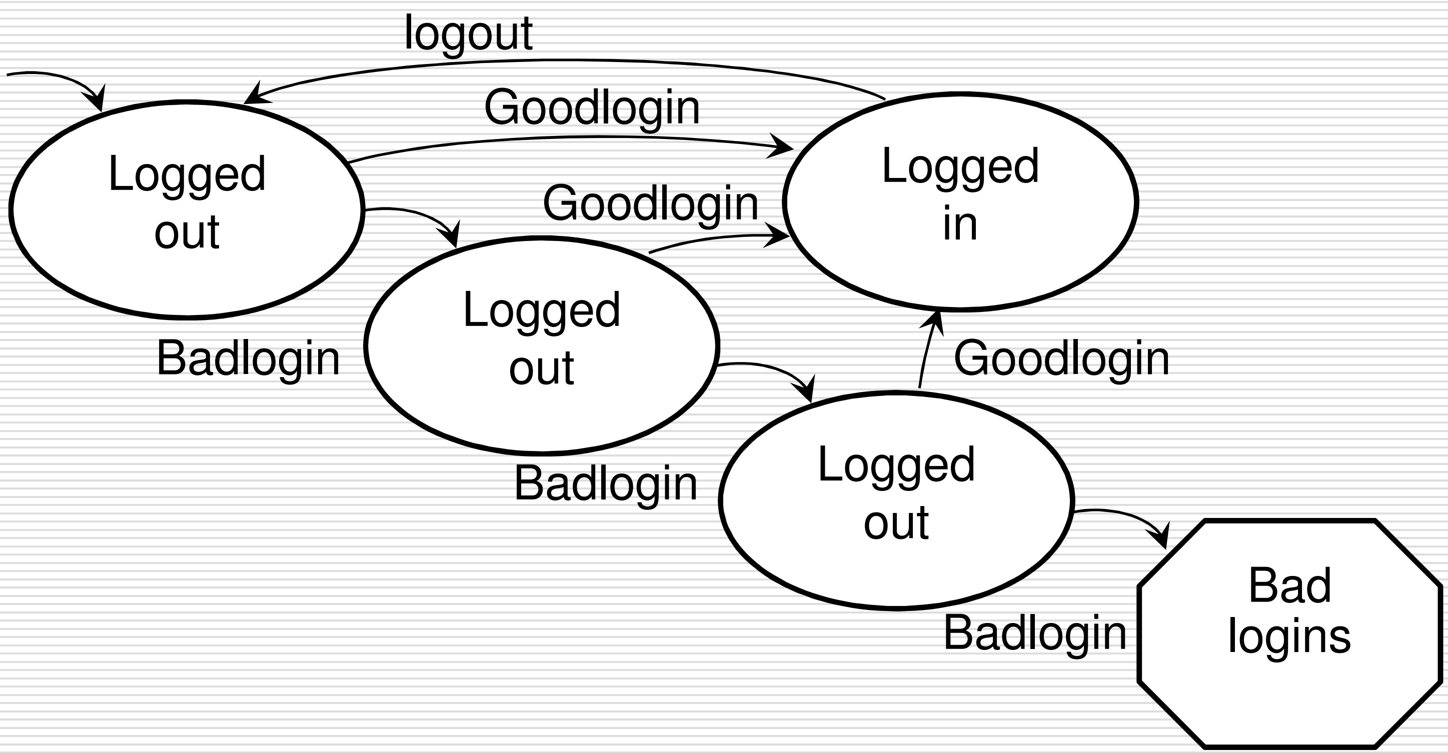
- Intuitive, clear and succinct logic.
- Understandable and useable by developers.
- Includes all the required expressive power.
- Automatically instrumentable in the target system.
- Low overheads (eg. Determinism)

Dynamic Automata with Timers & Events (DATE)

- Communicating symbolic automata enriched with **events** and **timers**.
- Automata are automatically replicated according to context: hence **dynamic**.
- Supports:
  - Conditions and actions on transitions
  - Real-time
  - Communication between automata

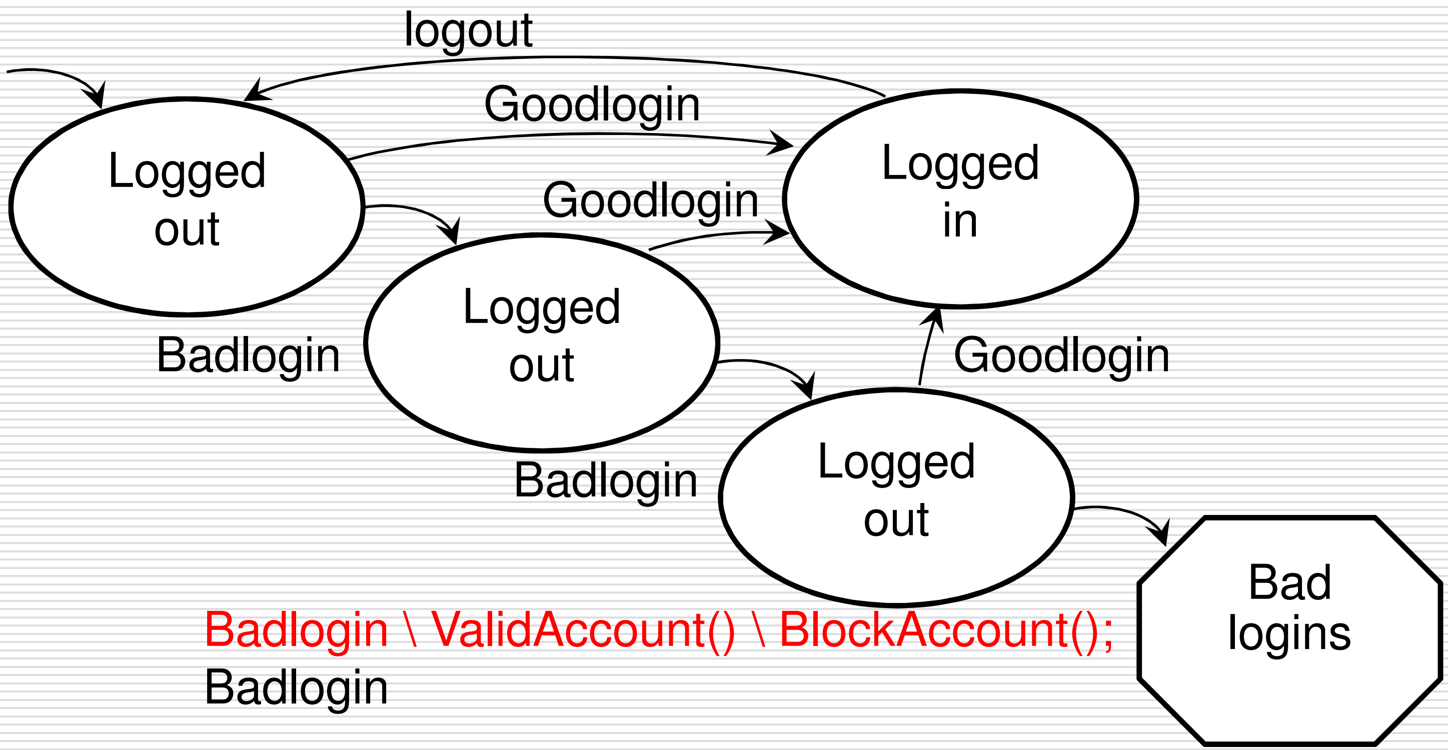
A Scenario - Events

No 3 successive bad logins

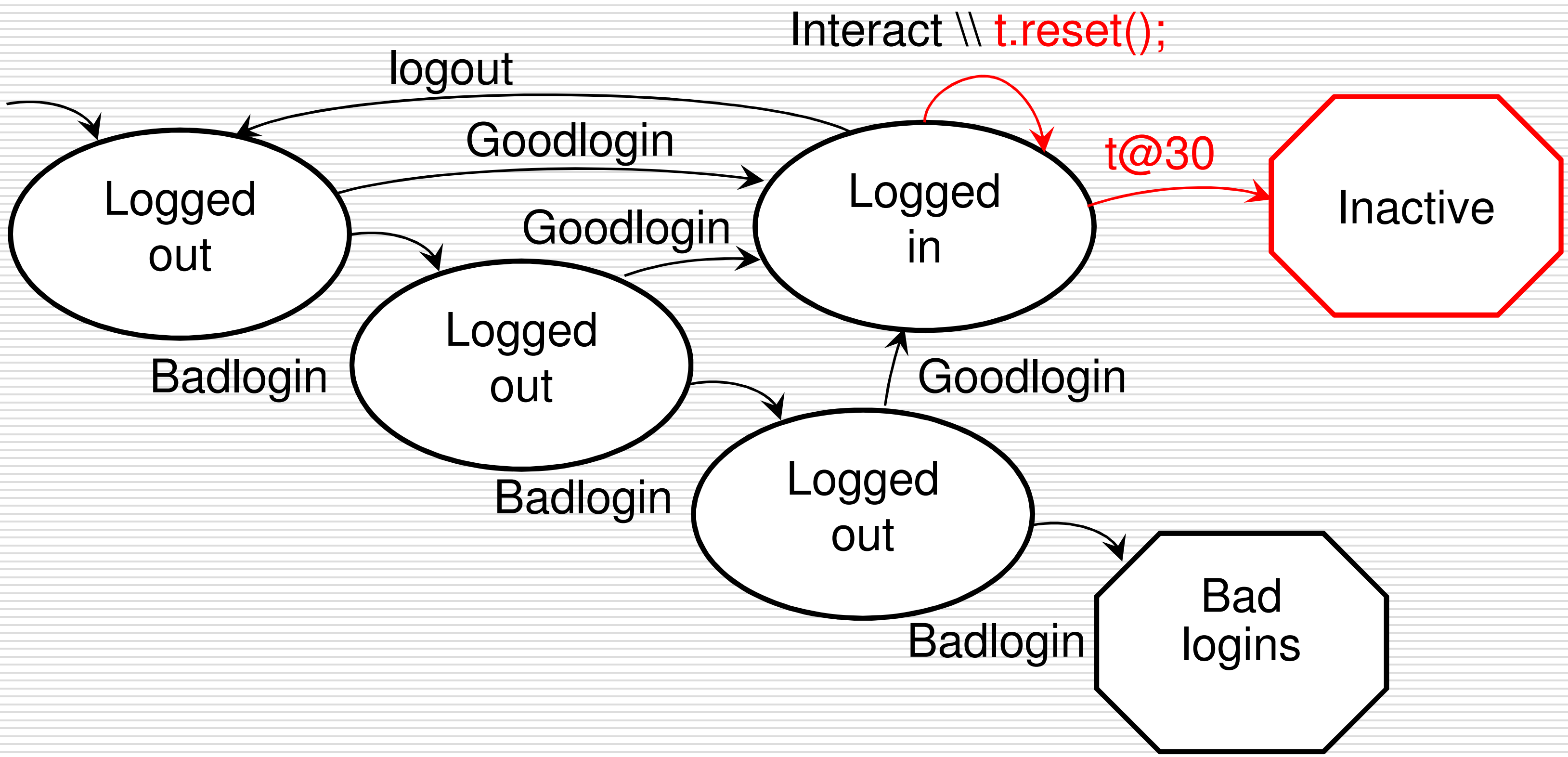


A Scenario – Conditions & Actions

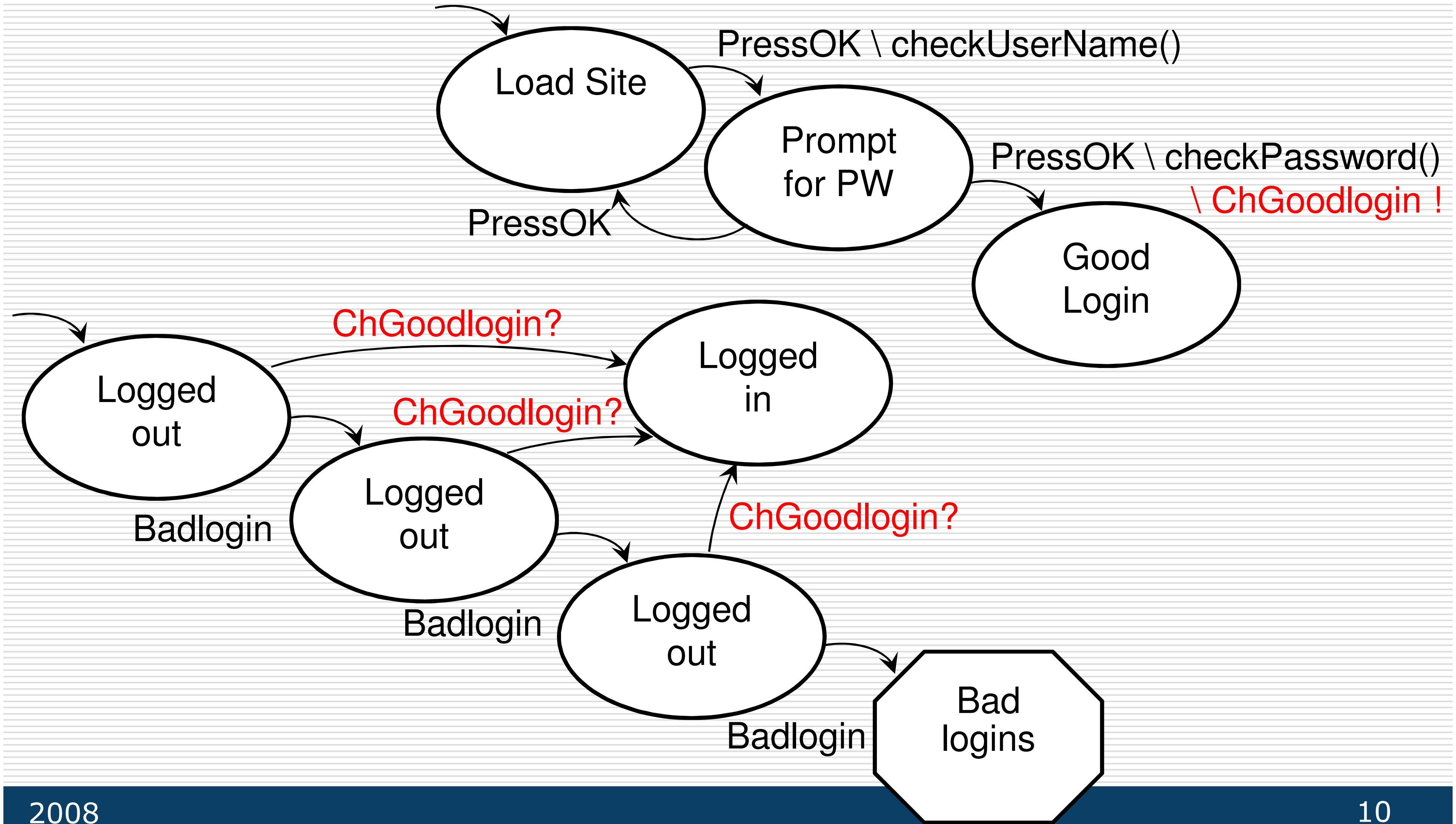
No 3 successive bad logins



A Scenario - Clocks



A Scenario – Channels



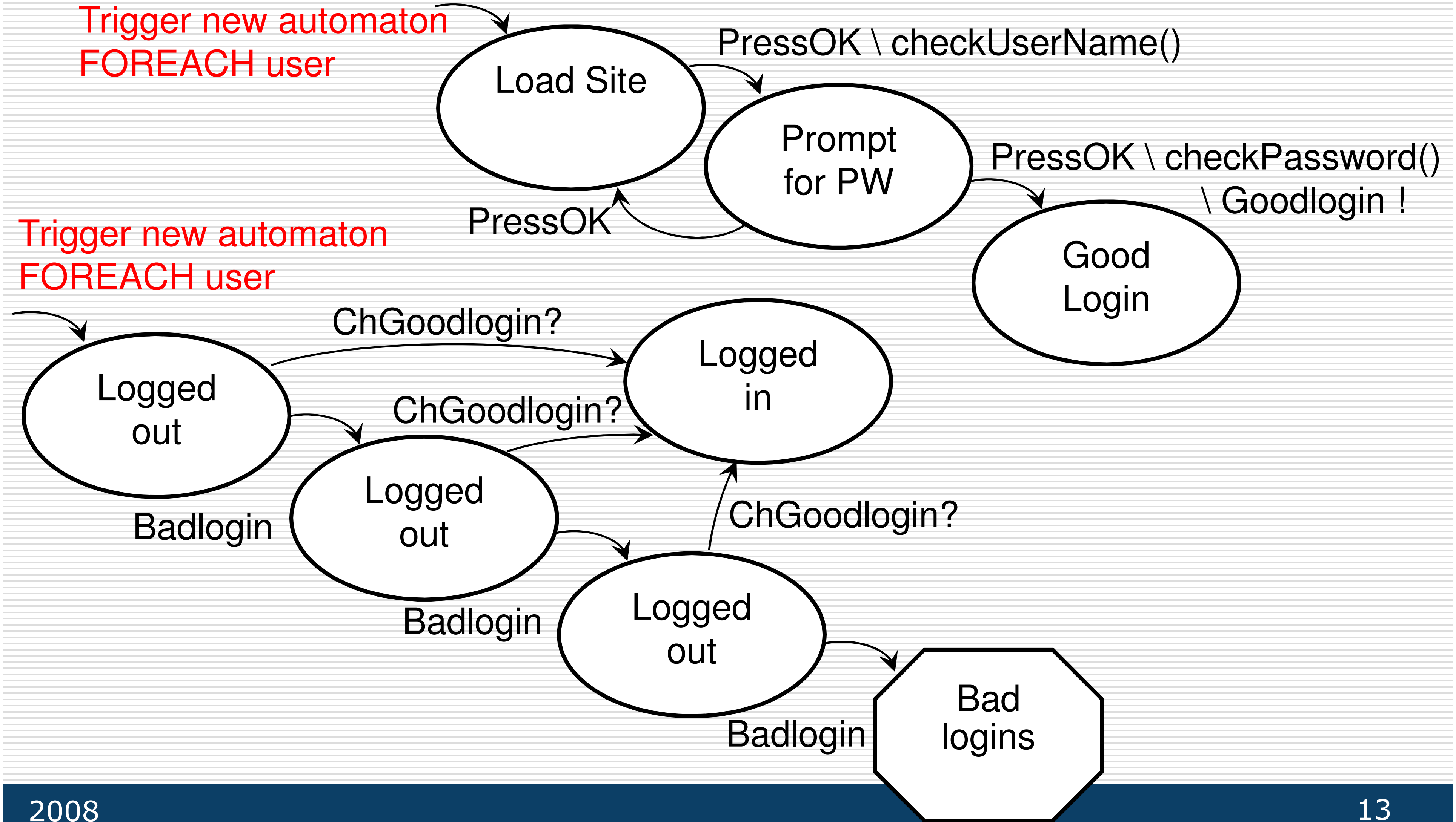
A Scenario – Dynamic Triggers

- Imagine we need to check login/logout for each user.
- We have to **trigger** an automaton for every user, to keep track whether each user is logged in or not.
- Use method parameters to get **context**.

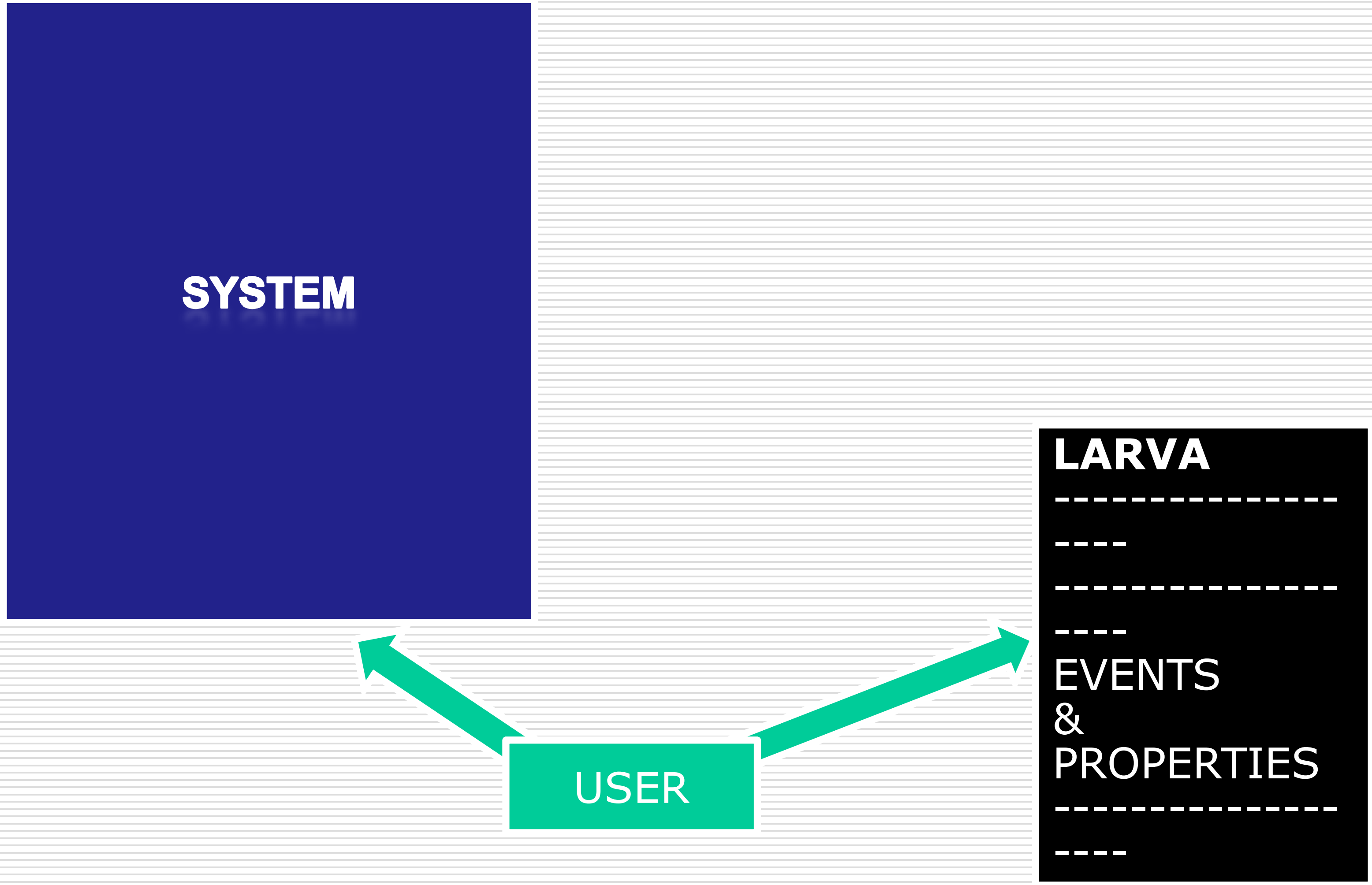
Specifying Context

- Actions and conditions on transitions can access the context (User).
- A context can be nested to have a more specific context within it:
  - Eg: Check login for each **site** of each individual **user**.

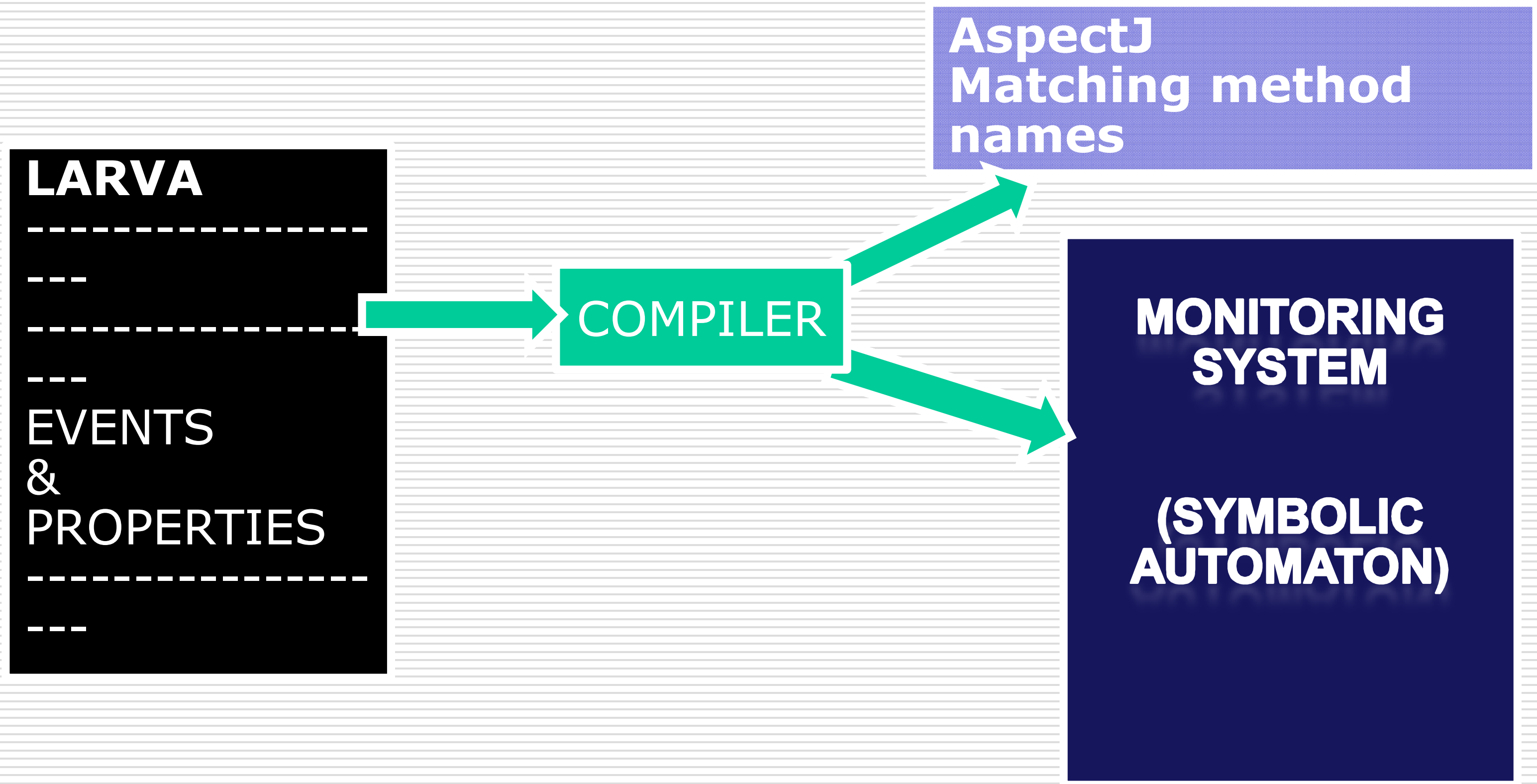
A Scenario – Context



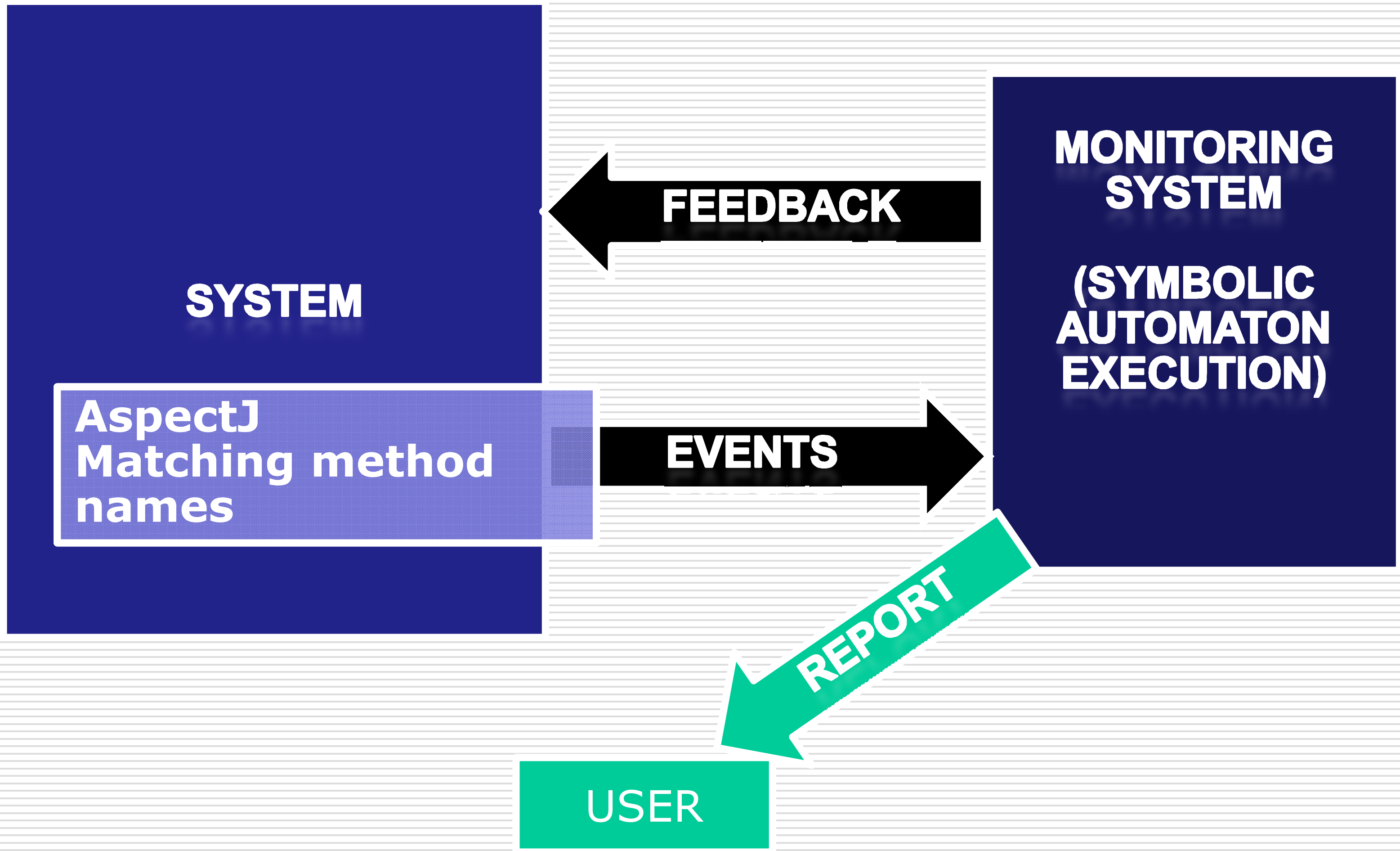
LARVA - Architecture



LARVA - Architecture (2)



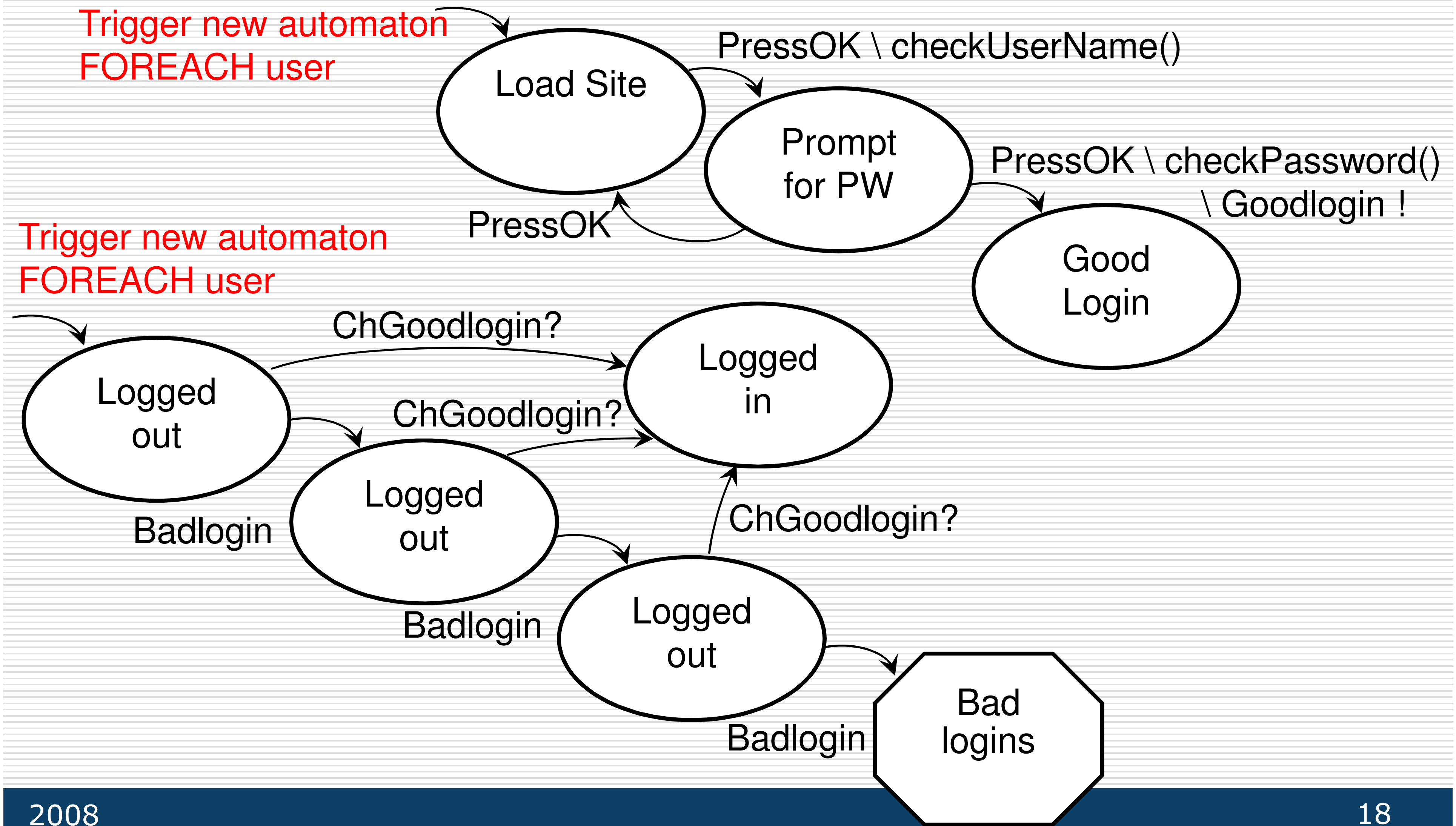
LARVA - Architecture (3)



LARVA - Compilation into Java

- AOP to capture events.
- A hierarchy of classes: one for each context.
- Each class has a reference to its parent context. (E.g. The account context, have access to the user context.)
- A hashmap to keep track of the distinct objects which we are checking.

Recall Scenario



LARVA – Script

```
GLOBAL { FOREACH (User u) {
 VARIABLES { Channel gl; }
 EVENTS {
  goodlogin() = {gl.receive(User u1)} where {u = u1;}
  pressOK() = {*.pressedOK(u1)} where {u = u1;}
  badlogin() = {*.loginTry(u1)} where {u = u1;}
 }
 PROPERTY one {
  STATES {
   BAD { badlogins }
   NORMAL { loggedout2 loggedout3 loggedin }
   STARTING { loggedout1 }
  }
  TRANSITIONS {
   loggedout1 -> loggedin   [goodlogin]
   loggedout2 -> loggedin   [goodlogin]
   loggedout3 -> loggedin   [goodlogin]
   loggedout1 -> loggedout2 [badlogin]
   loggedout2 -> loggedout3 [badlogin]
   loggedout3 -> badlogins  [badlogin]
  }
 }
  PROPERTY two {
   STATES {
     NORMAL { promptPW goodlogin }
     STARTING { loadsite }
   }
   TRANSITIONS {
     loadsite   -> promptPW
[PressOK\checkUserName()]
     promptPW   -> goodlogin
[PressOK\checkPassword()\gl.send(u);]
     promptPW   -> loadsite   [PressOK]
   }
  }
} }
METHODS {
  boolean checkUserName(){return true;}
  boolean checkPassword(){return true;}
}
```

Case-Study (1): Credit Card System

- Relatively large system (>26 kloc)
- Great security implications
- Challenges:
  - Communication with 3rd party systems
  - Although deployed, the system had no proper documented specification

Case-Study (2): Properties

- Logging of credit card numbers – no risk of exposing sensitive information.
- Execution of transactions – correct progress through states.
- Authorisation transaction – transaction consistency.
- Backlog – retries in case of failure.

Case-Study (3): - Experience

- A lot of interesting properties are relatively simple.
- Intuitive definition of properties.
- Identified shortcomings of Larva and it was extended.
- RV helps in clearly identifying requirements.
- Integration in system life cycle.

Benchmark – Expressivity

Table 1. Expressivity features of various tools.

Tool	LARVA	ConSpec	Java-MOP	Java-MaC	Hawk	Lola
Scope	*Sess./Obj.*	✓[a]	*Sess./Obj.*	*Sess.*	*Sess.*	*Sess.*
Exceptions	✓	✓	×	×	×	×
Temporal Logics	×	×	✓	×	✓	✓
Real-Time	✓	×	×	✓[b]	✓[c]	×
Mobile Application Policies	×	✓	×	×	×	×
Invariants	✓	×	✓	✓	×	×
Feedback	✓	*Stop.*	✓	✓	×	×
Conditions	✓	✓	✓[d]	✓	×	×
Numerical Queries	×	×	×	×	×	✓

[a] in specification it supports all the mentioned scopes but currently only *session* is supported
[b] restricted (cannot trigger clock events)
[c] can be extended to support real-time
[d] restricted to implementing conditions in violation/validation handling method

Benchmark – Performance

- Dummy transaction processing system (4 properties – 2 real-time)
- Memory and time required is considerable but linear to the number of objects being monitored (replication of automata).
- Compares well with Java-MOP which is the most similar work available for usage.

Ongoing Work

- Translation from other logics to DATEs
- Guaranteeing time and memory upperbounds
  - Going through Lustre
  - Starting from a subset of QDDC
- Guaranteeing effect of runtime verification on real-time properties upon adding/removing monitors

Conclusions

- Mathematical framework – DATE
- Implemented useable tool – LARVA
- Highly expressive (incl. real-time)
- Used in an industrial case-study
- Evolving theory with practical guarantees

Questions

- ?