Compensations and Runtime Monitoring

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Motivation

- More widespread use of SOA, dynamic service composition, long-lived transactions, system-of-systems architectures lead to greater need for **handling failure as part of a system's normal behaviour**.
- Catering for failure of components is becoming more important in various scenarios:
  - Systems built of separate components may not be able to trust the success of the constituent parts.
  - Components may be discovered, invoked at runtime, not knowing enough about them at compile time.
  - Invoking multiple services (for the same computation) and using the first result would require undoing the other partial transactions.

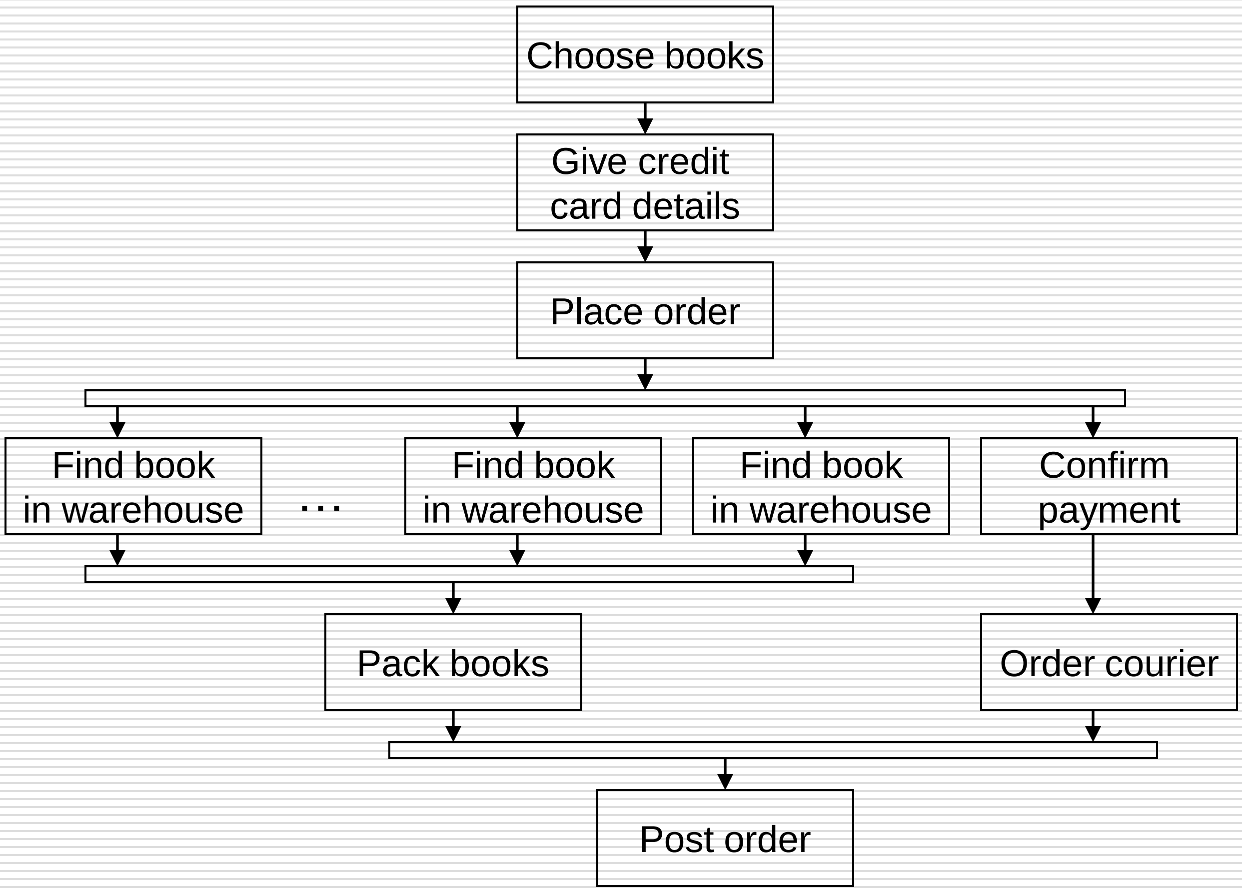
Compensation vs Reparation

- Reparation
  - Classical exception and error handling
  - What to do to make up for the fact that the current block has failed
  - Local by its very nature
- Compensation
  - What to do if something else fails later on and I have to 'undo' this block
  - Requires storing dynamic context

An Example of Compensations

- The bog-standard example: **A customer buying books from an on-line bookshop**
- The service proceeds as follows:
  - The customer commits an order
  - The bookshop gets payment from the customer
  - The bookshop orders a courier
  - The books are identified in the warehouse
  - The books are packed
  - The books are posted to the customer
- But errors may occur at various points in the process:
  - The bookshop realizes that one of the books is not in stock
  - The credit card payment may fail
  - The customer may cancel an order while still being processed

An Example of Compensations



The Question

- How can we use information about compensations in a system to support or strengthen runtime verification?

Further Motivation

- We are applying runtime verification techniques to an industrial case study system for financial transactions.
- Ixaris Systems Ltd are provide online payments solutions and virtual credit card provider.
- Their systems already include an implementation of compensable actions and rollbacks to handle long-lived transactions.

Challenges of Compensations

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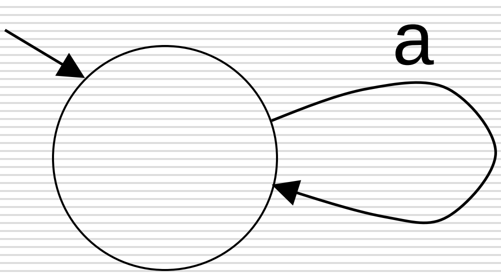

a^n

Challenges of Compensations

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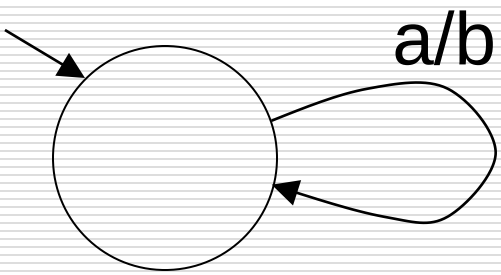

$a^n b^n$

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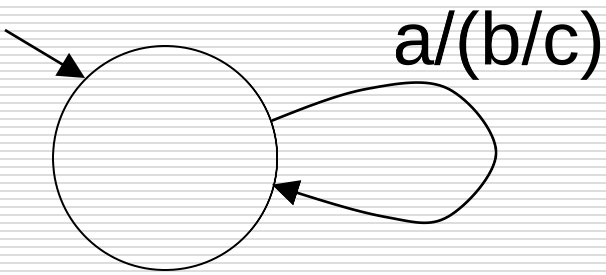


$a^n b^n c^n$

Challenges of Compensations

Actions performed before the failure occurs have to be "undone":

- Undoing actions may involve doing something other than the inverse of the forward action:
  - chargeAcct == charge(€1) / refund(95c)
- Compensations may be nested:
  - (…) / (destroyAcct / recreateBlacklistedAcct; …)
- Compensations may be overridden:
  - (createAcct; chargeAcct; makeOrder) / destroyAcct; verifyClient
- Compensations may be scoped:
  - payment; { advertisment }; delivery
- Parallelizing parts of the process makes compensation handling more involved

So Many Logics, So Little Time

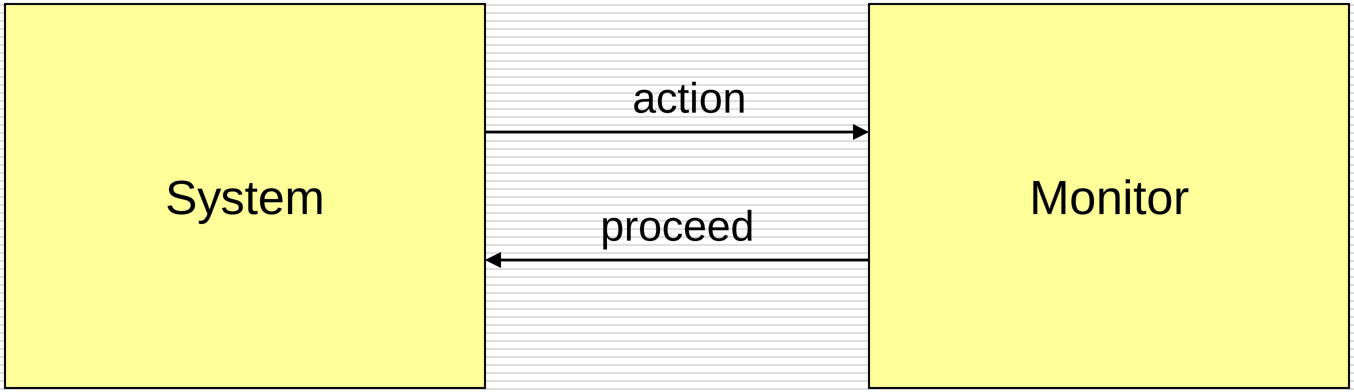
- There are various flavours of compensations:
  - Process calculus style (CSP, pi-calculus based)
  - Petri net based
  - Language-based approaches
  - Deontic logics

Remember the Question?

- How can we use information about compensations in a system to support or strengthen runtime verification?

Online Runtime Verification

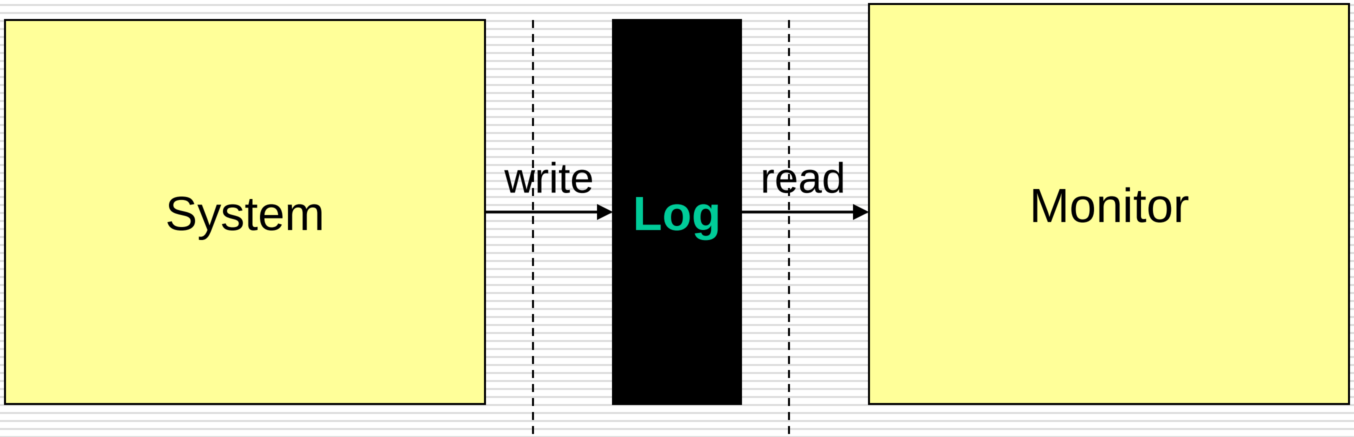
Online monitoring



- Instrumented code of the monitor *M* is added within the running system *S*, sharing the same address space.
- Running synchronously with the system.
- As soon as a problem is identified, mitigation may occur without the system running further.
- But, we are effectively monitoring *S* || *M*, not *S*.
- The overheads and interaction with the system are not always acceptable in an industrial setting.

Offline Runtime Verification

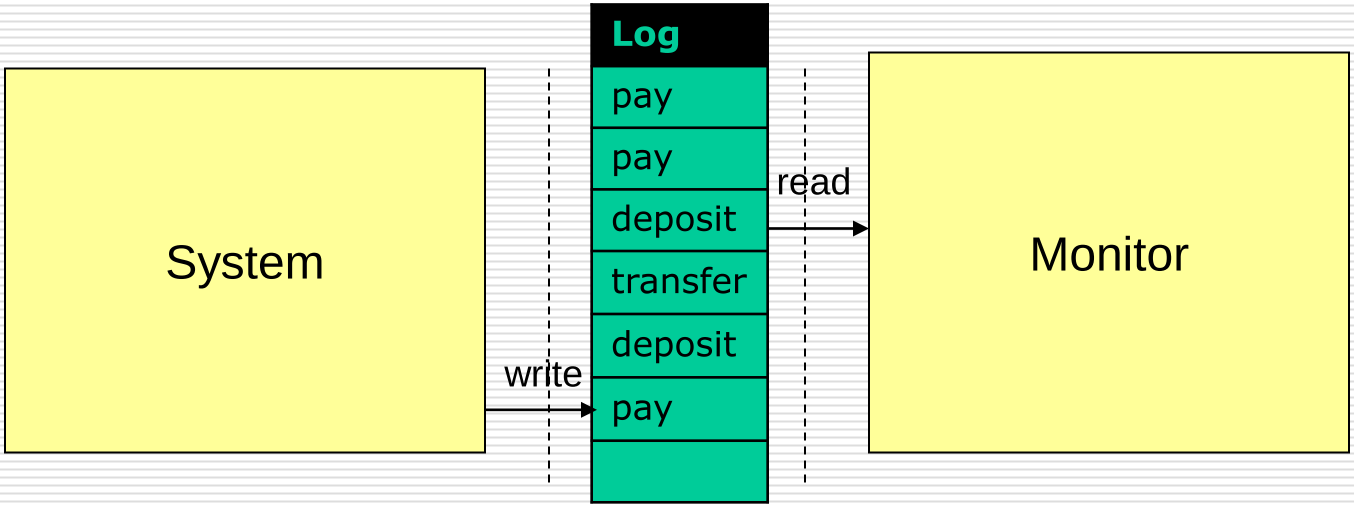
Offline monitoring



- The system produces a log to run the verification code on at a later stage.
- Running asynchronously with the system.
- Verification much more acceptable and faithful since the logging code is typically much more lightweight than the monitoring code.
- But by the time a problem is identified it may already been too late.

Quasi-Online Runtime Verification

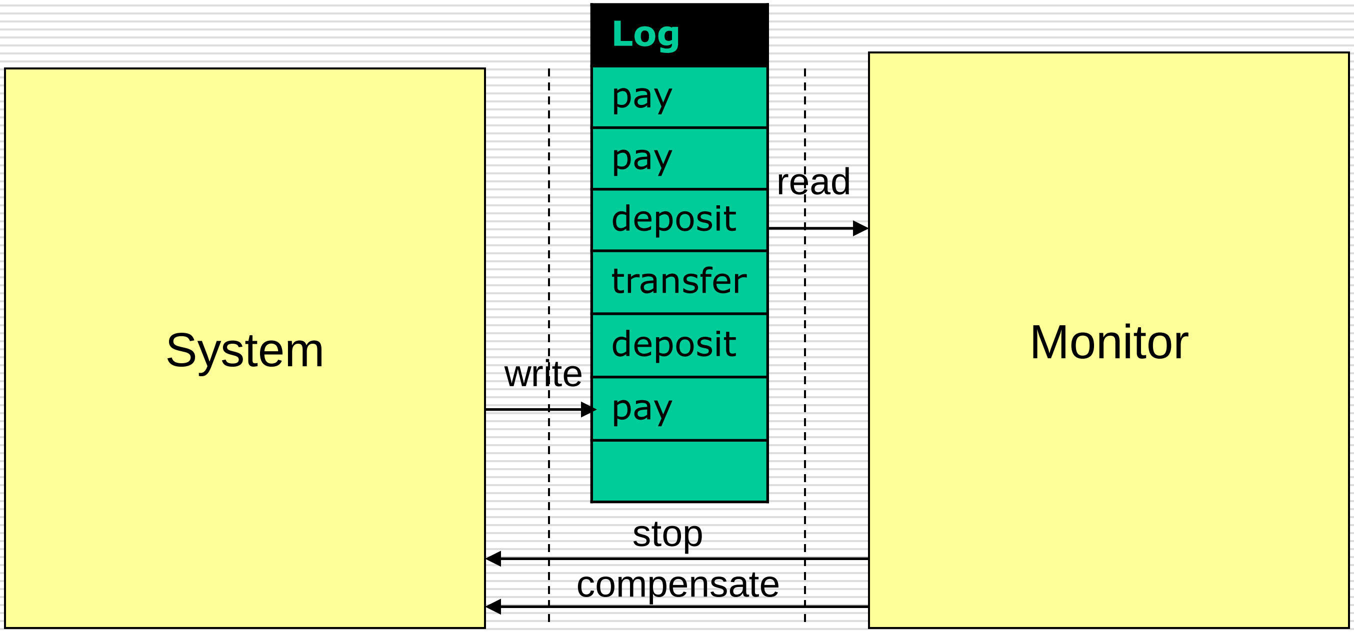
Quasi-online monitoring



- Monitoring is identical to offline monitoring:
  - The system produces a log at runtime.
  - The monitors run concurrently but on separate address spaces.
  - May not be in sync.

Quasi-Online Runtime Verification

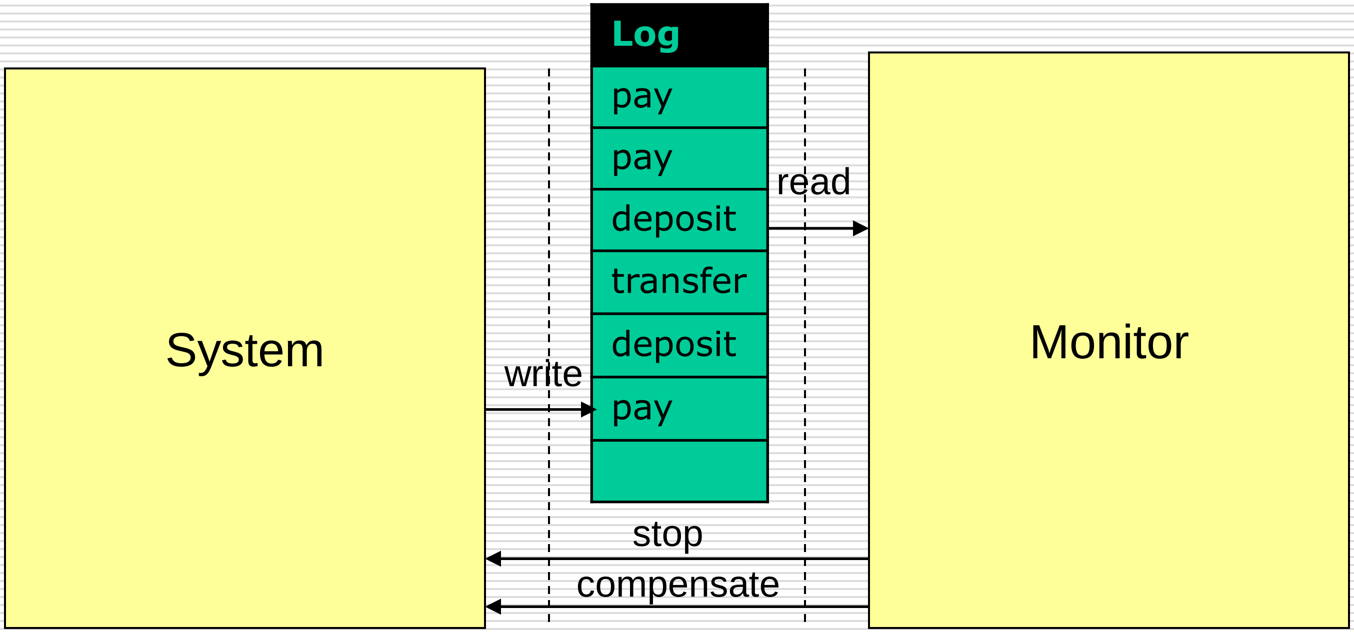
Quasi-online monitoring



- But when a problem is identified:
  - The monitor may stop the system, and
  - Use compensations to undo the actions performed by the system in the meantime.

Quasi-Online Runtime Verification

Quasi-online monitoring

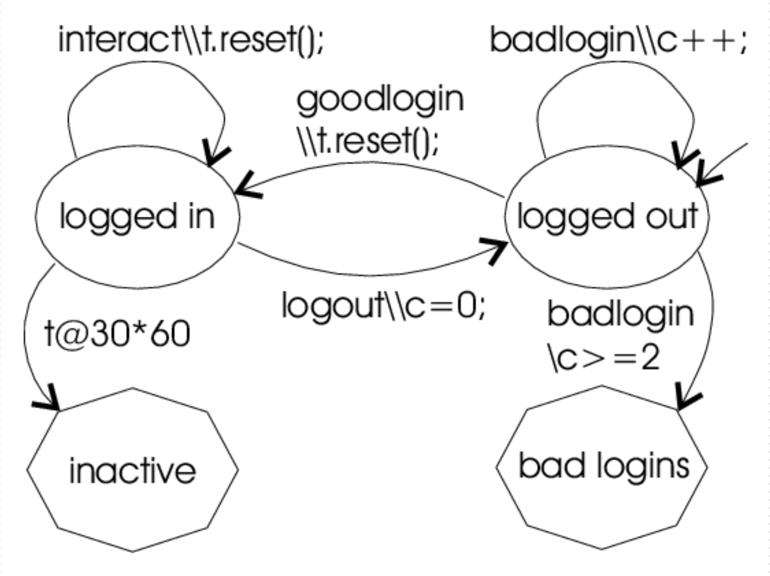


- In this example we would want to perform a compensation for:
  - transfer; deposit; pay

Quasi-Online Runtime Verification

- Compensate for actions:
  - up to the point which the system reached,
  - regressing back to just before or after the error.
- Compensations may be specified by either:
  - the system, or
  - as part of the properties themselves.
- The major challenge is resuming the system from the point where it was ‘rewound’ to.

Runtime Verification and LARVA

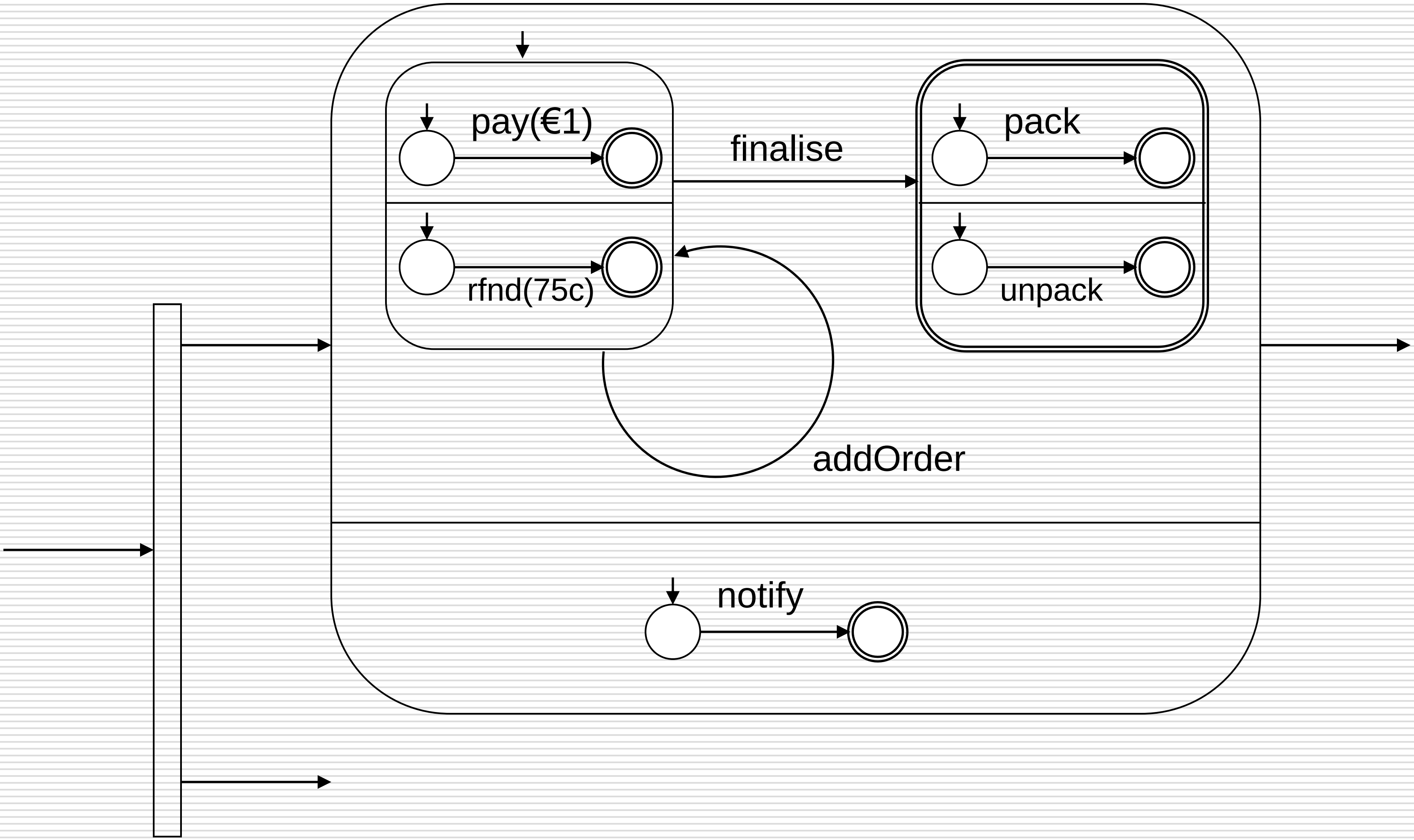



```
GLOBAL {
 VARIABLES { Clock t; int c = 0; }
 EVENTS {
  interact() = {*.action()}
  t30() = {t@30*60}
  ...
 }
 PROPERTY users {
  STATES {
   BAD { inactive badlogins }
   NORMAL { loggedin }
   STARTING { loggedout }
  }
  TRANSITIONS {
   loggedout -> loggedin  [goodlogin\\t.reset();]
   loggedout -> loggedout [badlogin\\c++;]
   ...
}}}
```

Compensation Automata

- Extends automata with compensations using hierarchical automata with three structuring elements:
  - **Compensation declaration** to enact a compensation of an automaton.
  - **Deviation** to redirect compensations.
  - **Scoping** of compensations.

Compensation Automata



Compensations in Financial Transaction Systems

- We are exploring the use of LARVA with compensations to monitor transactions handled by the systems built at Ixaris.
- Using compensations as specifications of expected behaviour and to specify recovery actions can already be done by translating into base LARVA.
- We are exploring the *quasi-online approach*, in which we use the compensations already built in the system. Major challenges are:
  - *Resuming the system after recovery (easy on a transaction by transaction system, but tough otherwise).*
  - *Making sure that rollbacks induced by the monitors do not interfere with rollbacks induced by the system.*

Reactivity and Compensations

- How can compensation be encoded in a reactive setting?
- If the monitor lags behind the system by at most n time units, compensation handling uses bounded space
- What if this is not the case?
  - Enable the monitor to pause the system
  - Skim over parts of the trace
  - Breaking loops and/or using additional properties (eg idempotency of certain compensations)

Conclusions and Future Directions

- The system is up and running at Ixaris – monitoring for properties and compensations but still working on the quasi-online approach.
- Naïve implementation of compensations may induce unbounded overhead.
- Investigating adding real-time.

Auxiliary Slides

Monitoring of Financial Transaction Systems

- Life cycle
  - Frozen or reclaimed credit cards cannot be used in financial transactions.
  - The states in the life-cycle of an entity (eg. user, credit card) are correctly traversed, i.e. in the correct order.
- Real-time
  - After six months (but not before) of user inactivity, the user should be put in a dormant state.
  - After a year (but not before) of user inactivity, the user should be removed from the system.
- Access rights
  - A user must have the necessary right before loading money onto the credit card.
  - A user must have the necessary right before transferring money from a card to another.
- Amounts
  - The number of times a user loads money to a credit card should not exceed the stipulated amount for a day or a month.
  - The total sum of money loaded should not exceed the stipulated limit for a day or for a month.