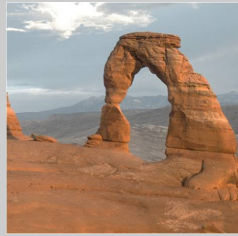


# Practical Issues with Formal Specifications

Lessons Learned from an Industrial Case Study



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## Agenda



- 1 Introduction & Motivation
- 2 Case Study: Distributed Object Management
- 3 Lessons Learned and Conclusion

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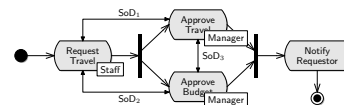
## Modern Business Software

A Target for Formal Methods?



### Modern business software is

- complex  
 (large code base, various programming languages)
- parallel  
 (distributed, service-oriented implementation, multi-tenancy)



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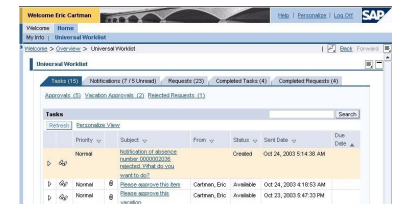
## Modern Business Software

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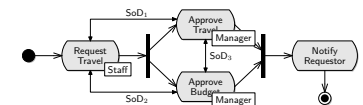
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### Modern business software has to be

- correct,  
 (correct and compliant processes)
- reliable, and  
 (no crashes, guaranteed availability)
- fast  
 (response times, virtualization)



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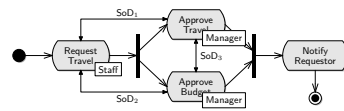
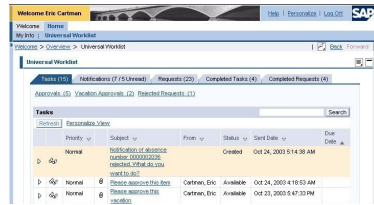


# Modern Business Software

A Target for Formal Methods?



- Modern business software is
  - complex (large code base, various programming languages)
  - parallel (distributed, service-oriented implementation, multi-tenancy)
- Modern business software has to be
  - correct, (correct and compliant processes)
  - reliable, and (no crashes, guaranteed availability)
  - fast (response times, virtualization)
- Can formal methods/specifications help?



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## The Problem:

Consistent Distributed Object Management



“ Ensure the *correctness* of our rule-engine.

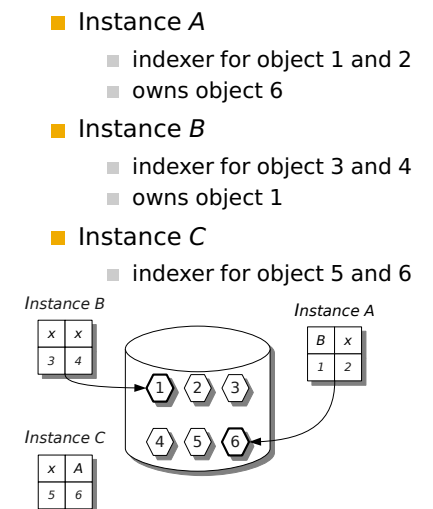
- Implementation of an event-condition-action **rule engine**:
  - events** are represented as object state changes,
  - conditions** are formulated as expressions on object, attributes
  - actions** may change the object state.
- The implementation is **multi-threaded** and **multi-clustered**:
  - multiple application instances are running on different server nodes
  - application instances may start or stop during the life-time of the cluster
- Thus, we need to
  - coordinate object access across different application instances
  - deal with variations in the cluster topology, especially in the case of unexpected changes due to application or cluster node failures.

## The Solution:

Object Ownership and Cluster Failover Management



- Guarantee **exclusive** object ownership
- Each application instance
  - manages the **ownership** of some objects
  - authoritative **indexer** for these objects
- Acquiring ownership of an object:
  - contacts the indexer of that object
  - only two messages required
  - indexer can be computed locally
- Topology changes requires updates
- Ownership via restructuring protocol
  - 1 all instances agree on the same view
  - 2 each instance knows the ownership
- A dedicated **master** instance provides the current view to joining instances.



## The Solution:

### Object Ownership and Cluster Failover Management

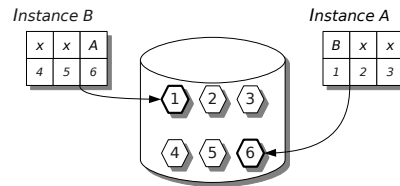


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  - 1 all instances agree on the same view
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- A dedicated *master* instance provides the current view to joining instances.

After instance C has left

- Instance A and B agree
  - on cluster size 2
  - A indexer for 1, 2, 3
  - B indexer for 4, 5, 6

- B is informed that A owns 6



## Implementation Constraints

### Industrial software development does not happen in isolation



- Avoid additional functionality by reusing existing frameworks
  - no specialized runtime
  - named communication channels using JNDI
- Minimize central knowledge while avoiding redundancy
  - existing infrastructure does not provide redundancy/replication
  - only local meta information (i. e., object ownership) per instance
  - needs to be synchronized whenever the cluster topology changes
- Global synchronization via locks
  - one global lock for all instances
  - master election: ability to acquire global master lock
- Synchronous mode of operation
  - synchronous communication via RMI
- Continuous operation during restructuring
  - restructuring should not block regular operation

## Writing Formal Specifications



- Formalization of an existing implementation
  - reverse-engineer the implementation into an executable specification
  - focus on robustness of the protocol against communication failures
- We followed a two-staged approach:
  - A high-level abstract specification on paper:
    - initial starting point
    - primary communication and discussion medium with the development team
    - clarification of the overall system architecture
  - An executable specification
    - as soon as possible, we refined the abstract specification
    - using *asynchronous multi-agent ASM* in CoreASM
  - Both specifications updated in parallel
  - At the end: ca. 3200 lines of formal specification

## Cluster Protocol Invariants

### Stable Cluster States



```
derived IndicesInSync =
  forall node in RunningNodes() holds IndexInSync(node)

derived IndicesAreValid =
  forall node in RunningNodes() holds IndexIsValid(node)

derived IndexInSync(node) =
  forall oid in [1..OID_MAX] holds SlotInSync(node, oid)

derived SlotInSync(node, oid) =
  node = authIndexer(oid, node) implies
  OWNER(OWNER(node, oid), oid) = OWNER(node, oid)

derived IndexIsValid(node) =
  forall oid in [1..OID_MAX] holds SlotIsValid(node, oid)

derived SlotIsValid(node, oid) =
  node = authIndexer(oid, node) implies
  OWNER(node, oid) memberof RunningNodes()
```

## Simulation Results



- The original implementation was based on a wrong assumption:
  - notifications in the case of failure are always sent immediately
  - this should be ensured by the runtime environment
- Assume a delayed notification while a new node is starting up:
  - the new node becomes master of new cluster
  - if delayed notification is received, the old nodes will
    - try to become master and fail
    - do nothing and wait for restructuring
  - resulting in an inconsistent state (IndicesInSync does not hold)
- Initialize cluster with two active nodes and an inactive one:

```
nodeList = ["N1", "N2"]  
newMasterNode = "N3"
```

## Simulation Results



- The original implementation was based on a wrong assumption:
  - notifications in the case of failure are always sent immediately
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    - try to become master and fail
    - do nothing and wait for restructuring
  - resulting in an inconsistent state (IndicesInSync does not hold)
- Deactivate node failure detection

```
SuspendNodeFailureHandlers()  
clusterIsStable := true
```

## Simulation Results



- The original implementation was based on a wrong assumption:
  - notifications in the case of failure are always sent immediately
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- Assume a delayed notification while a new node is starting up:
  - the new node becomes master of new cluster
  - if delayed notification is received, the old nodes will
    - try to become master and fail
    - do nothing and wait for restructuring
  - resulting in an inconsistent state (IndicesInSync does not hold)
- Shutdown the current master node

```
killedMaster := MasterNode()  
remove NodeID(MasterNode()) from nodeList  
SignalNodeShutdown(MasterNode(), true)  
clusterIsStable := false
```

## Simulation Results



- The original implementation was based on a wrong assumption:
  - notifications in the case of failure are always sent immediately
  - this should be ensured by the runtime environment
- Assume a delayed notification while a new node is starting up:
  - the new node becomes master of new cluster
  - if delayed notification is received, the old nodes will
    - try to become master and fail
    - do nothing and wait for restructuring
  - resulting in an inconsistent state (IndicesInSync does not hold)
- Start inactive node

```
if (NodeIsDown(killedMaster)) then {  
  AddNode()  
  add newMasterID to nodeList  
}
```

## Simulation Results



- The original implementation was based on a wrong assumption:
  - notifications in the case of failure are always sent immediately
  - this should be ensured by the runtime environment
- Assume a delayed notification while a new node is starting up:
  - the new node becomes master of new cluster
  - if delayed notification is received, the old nodes will
    - try to become master and fail
    - do nothing and wait for restructuring
  - resulting in an inconsistent state (IndicesInSync does not hold)
- Re-activate handling of node failures

```
if (MasterNode() != undef
    and HasJoinedCluster(newMasterID)) then {
  ResumeElemLossHandlers()
}
```

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## Lessons Learned



- Missing scope for locations
- Missing tool support for “Refinements”
- Reusables specification modules
- Insufficient support for literate specifications
- Debugging support
- Combining formal and semi-formal development processes
- Lack of commercially applicable tools
- Think twice before you decide for a specific (set of) method(s)
- There are places for interactive and for automated Methods

## Conclusion



- Well-know facts:
  - already writing a formal specification can reveal problems
  - Fully automated tools can be used by non-experts in formal methods
- We used the “consultancy model” also in other formal method projects
  - requiring an formal methods exports for the (interactive) analysis is fine
  - non-experts in formal methods should be able to
    - write specifications
    - type-check and animate (execute) specifications
    - write (simple) properties that should be verified
- Business applications can be worthwhile targets for formal methods
- Formal methods are applied, if there is there is a business case

# Thank you!



## Specification



Table: An overview of the modules of the ASM specification

Module	Lines	Rules	Functions
Control ASM States	50	0	1
Cluster Master	161	12	10
Protocol Messages	138	0	25
Cluster Membership and Object Management	1 796	114	159
Object Requests	128	10	3
Cluster Environment (Notification)	328	19	31
Lock Management	141	7	19
Message Passing	362	12	56
Control Flow	88	10	5
Control State Handling	63	5	9
<b>Total</b>	<b>3 255</b>	<b>189</b>	<b>318</b>

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In Stefan Kowalewski and Marco Roveri, editors, *International Workshop on Formal Methods for Industrial Critical Systems (FMICS)*, number 6371 in Lecture Notes in Computer Science, pages 17–32. Springer-Verlag, 2010.

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