Enabling and Achieving Self-Management for Large Scale Distributed Systems

Platform and Design Methodology for Self-Management

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Licentiate Seminar
April 9 2010

Outline

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The Autonomic Computing Initiative

Problem

All computing systems need to be managed

The Autonomic Computing Initiative

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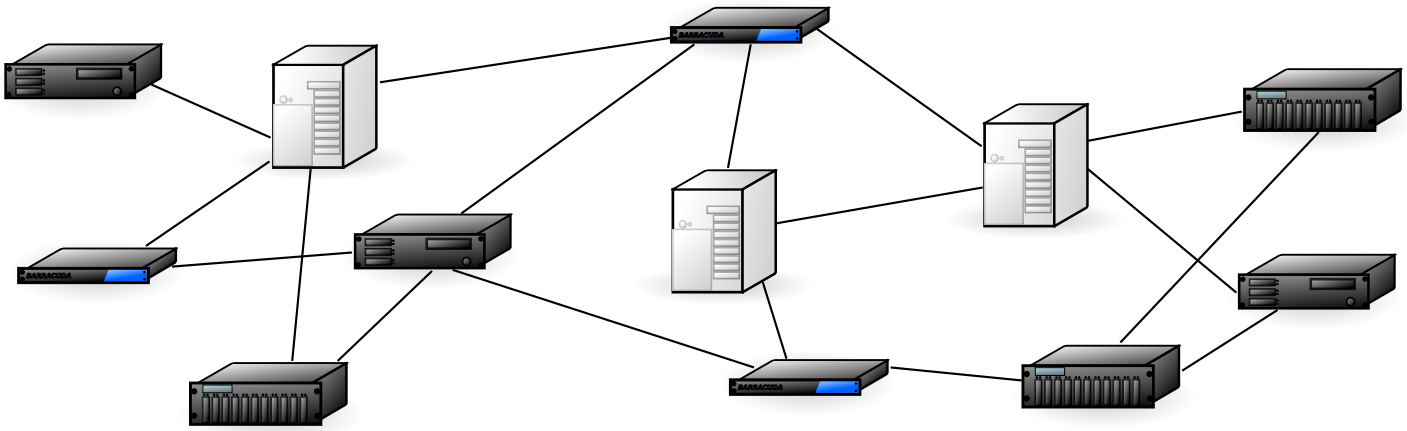
Problem

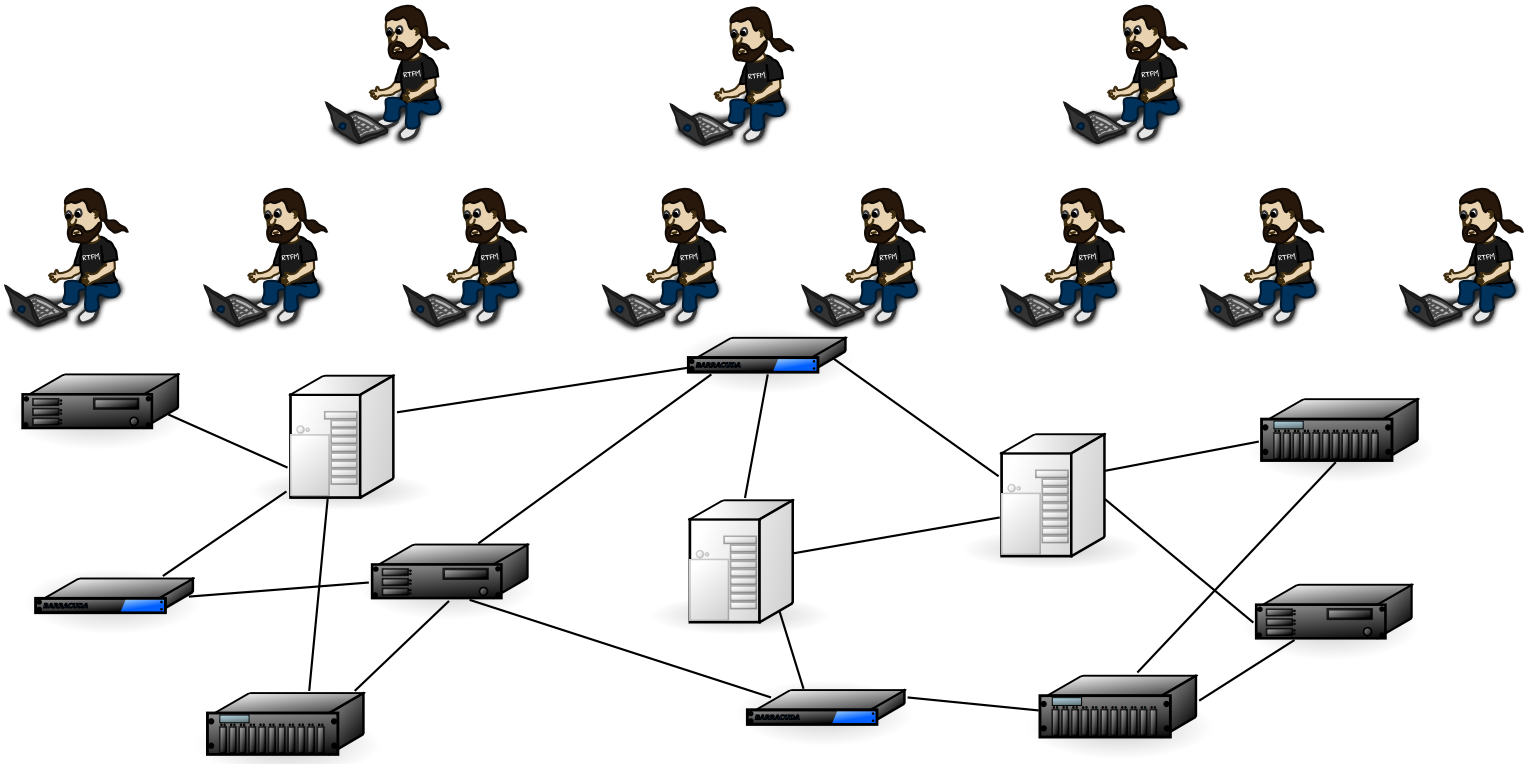
Computing systems are getting more and more complex



The Autonomic Computing Initiative

Problem

Complexity means higher administration overheads



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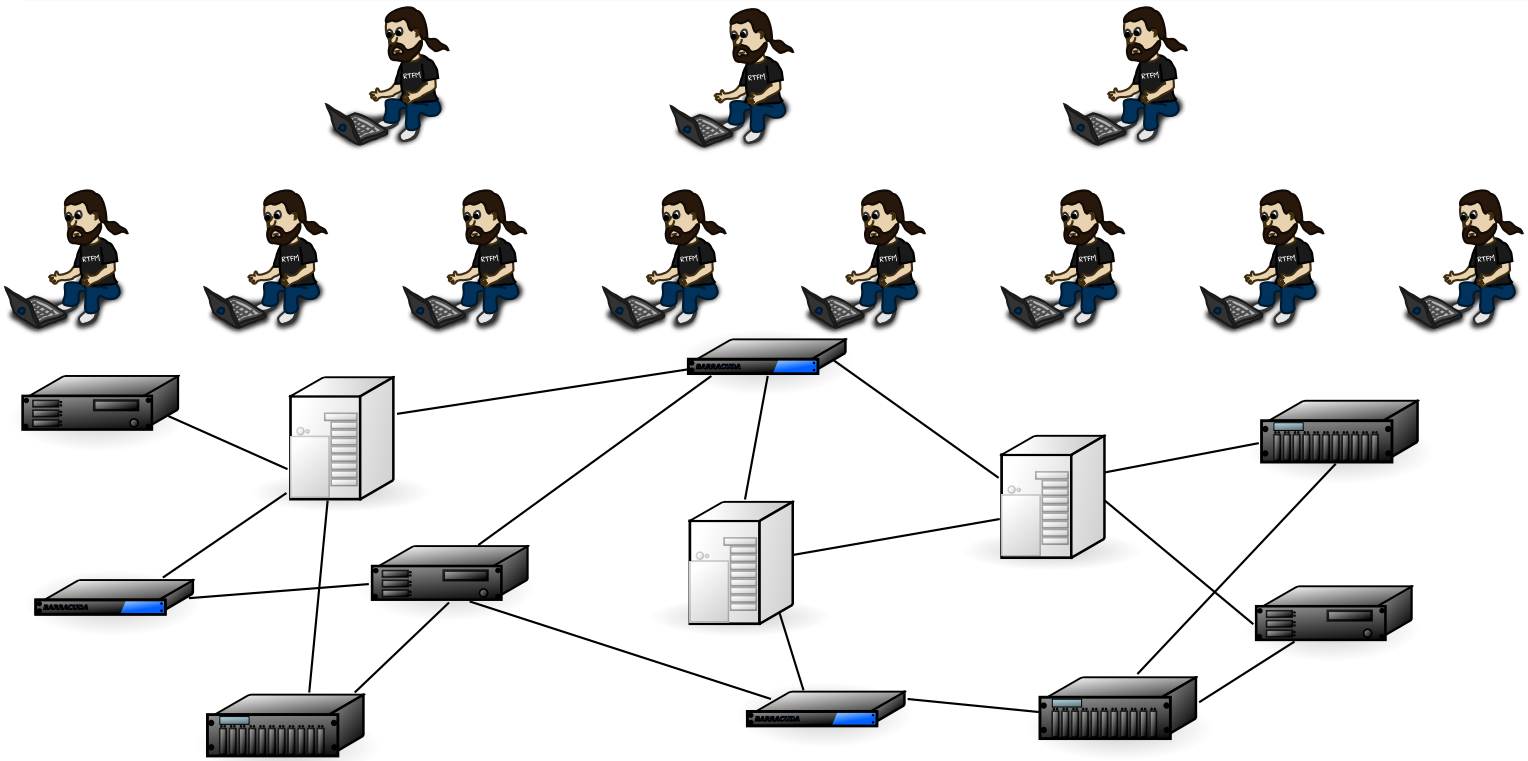
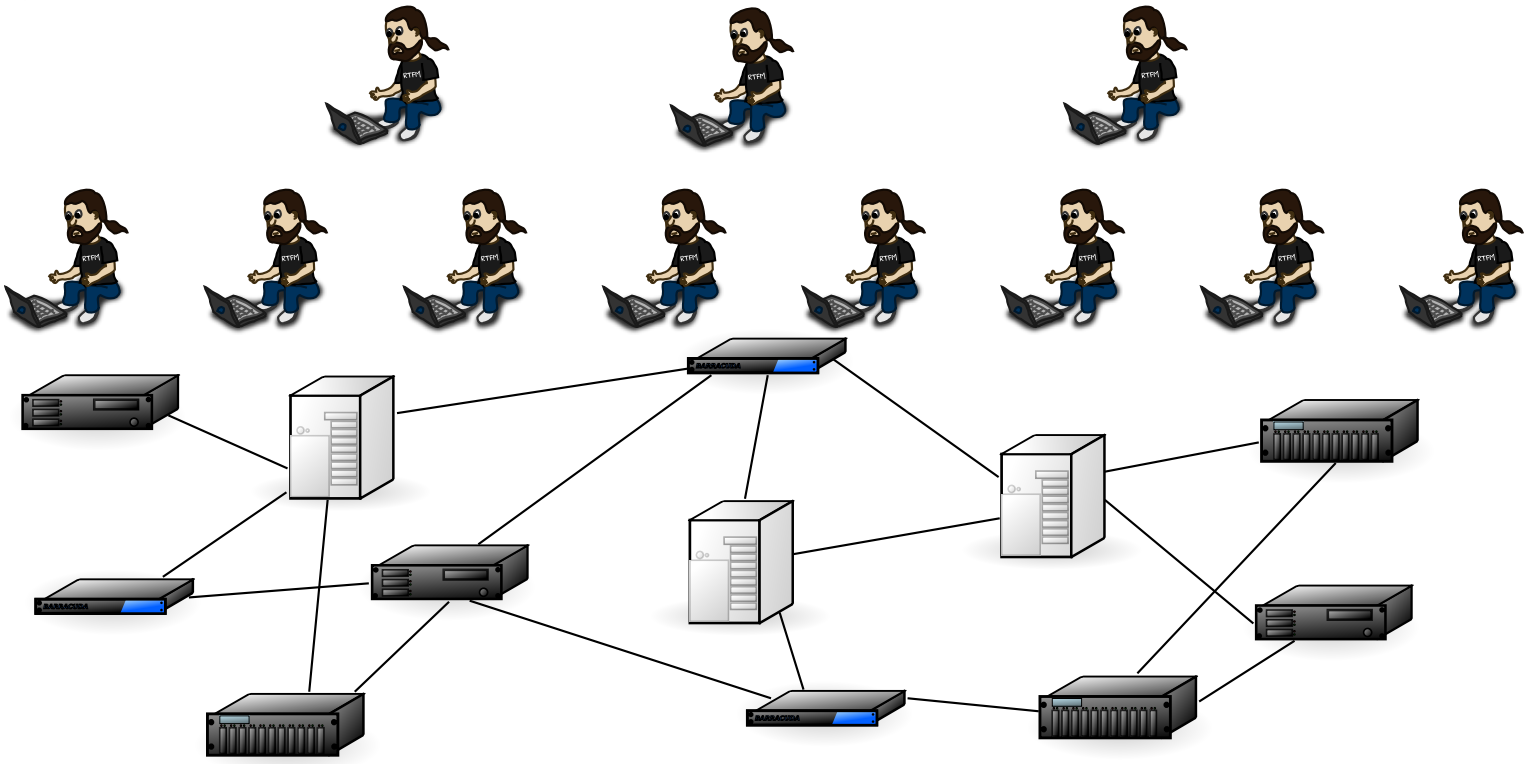
Complexity poses a barrier on further development



The Autonomic Computing Initiative

Solution

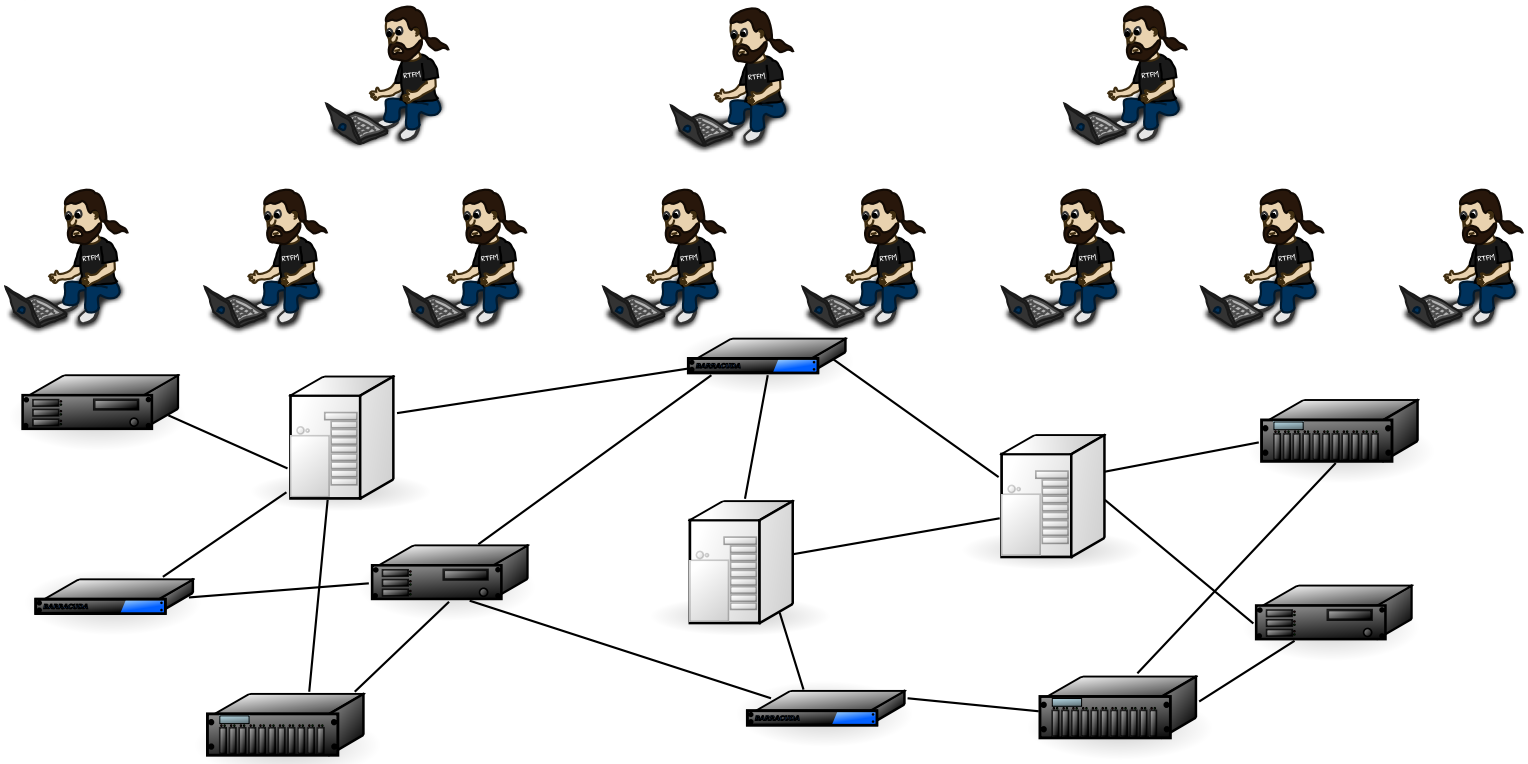
The Autonomic Computing initiative by IBM



The Autonomic Computing Initiative

Solution

Self-Management: Systems capable of managing themselves



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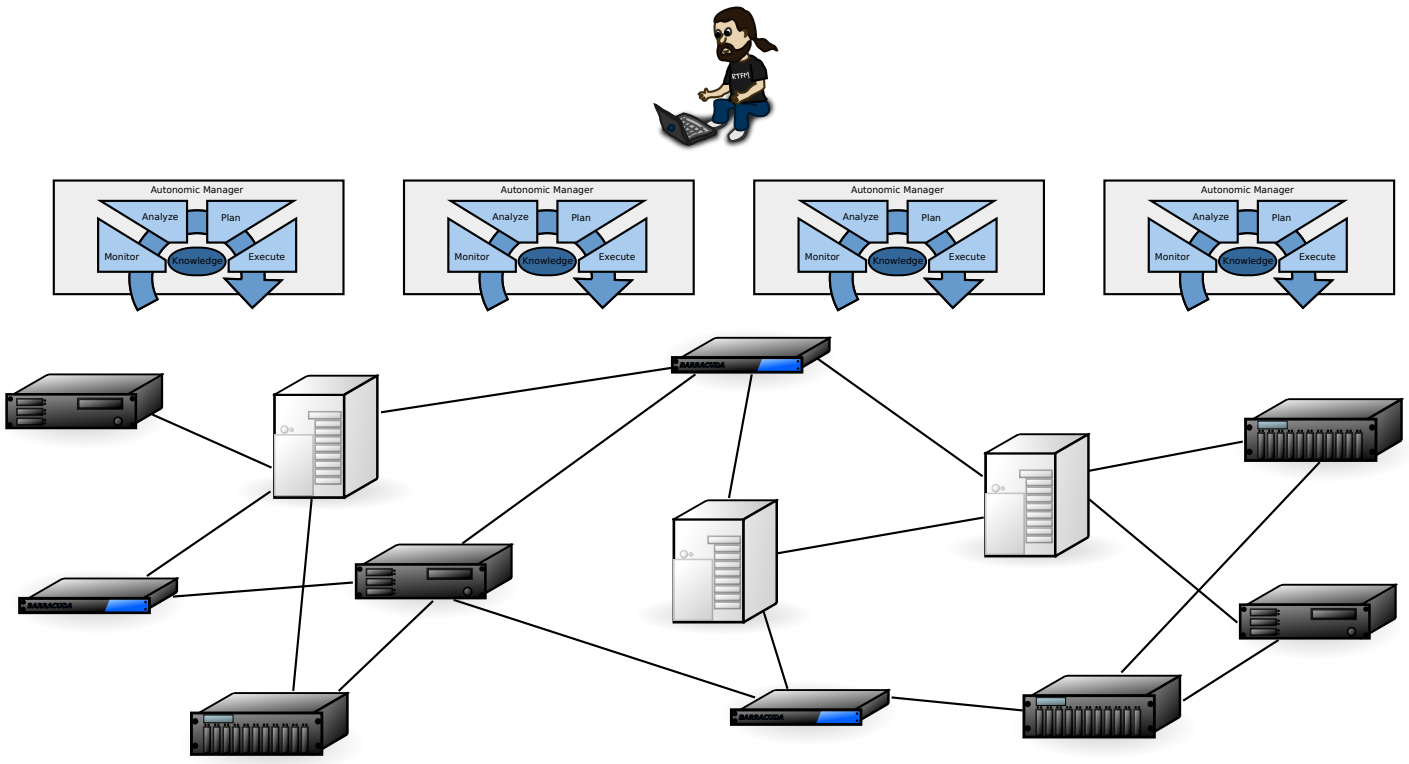
Solution

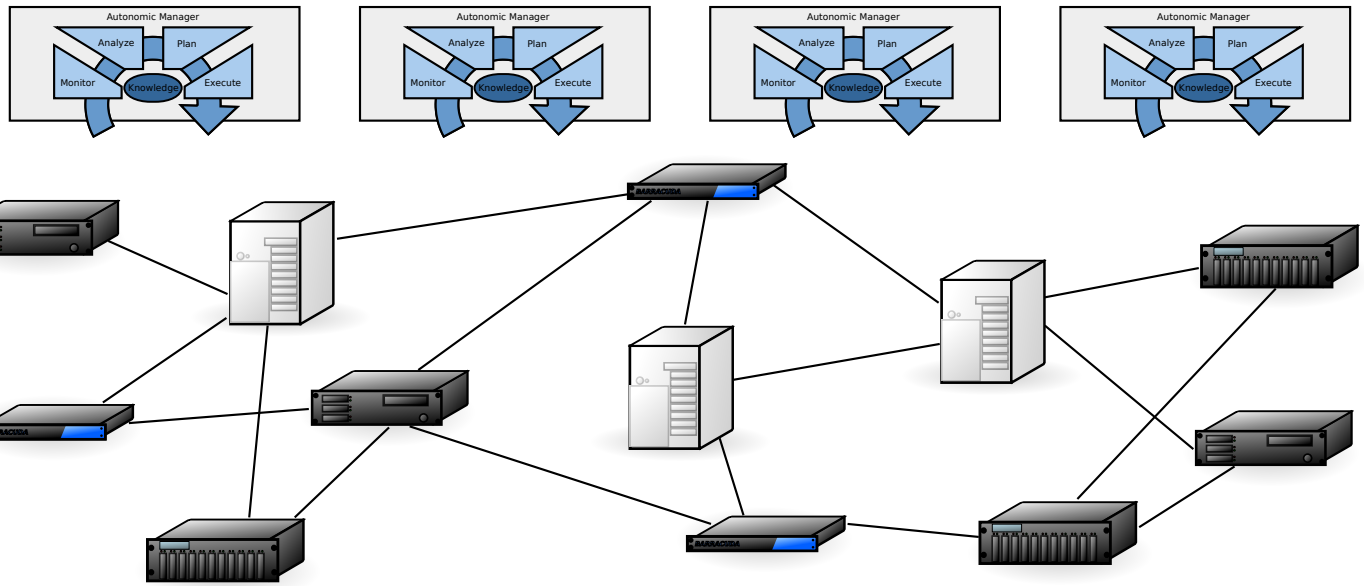
Use Autonomic Managers



The Autonomic Computing Initiative

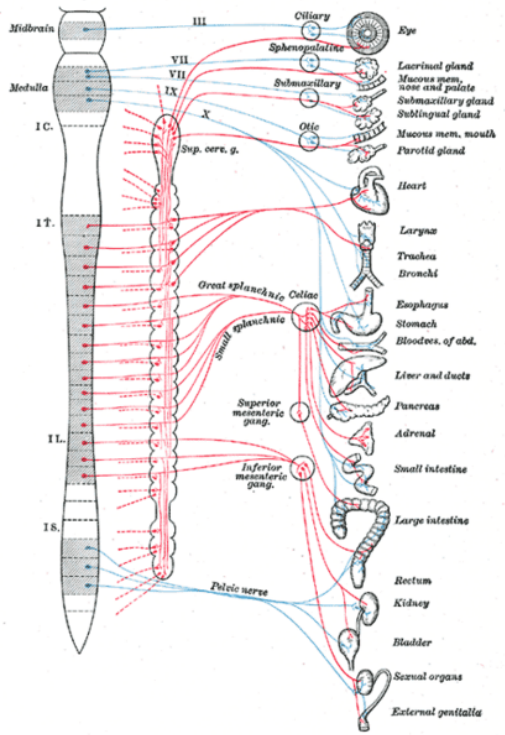
Open Question

How to achieve Self-Management?



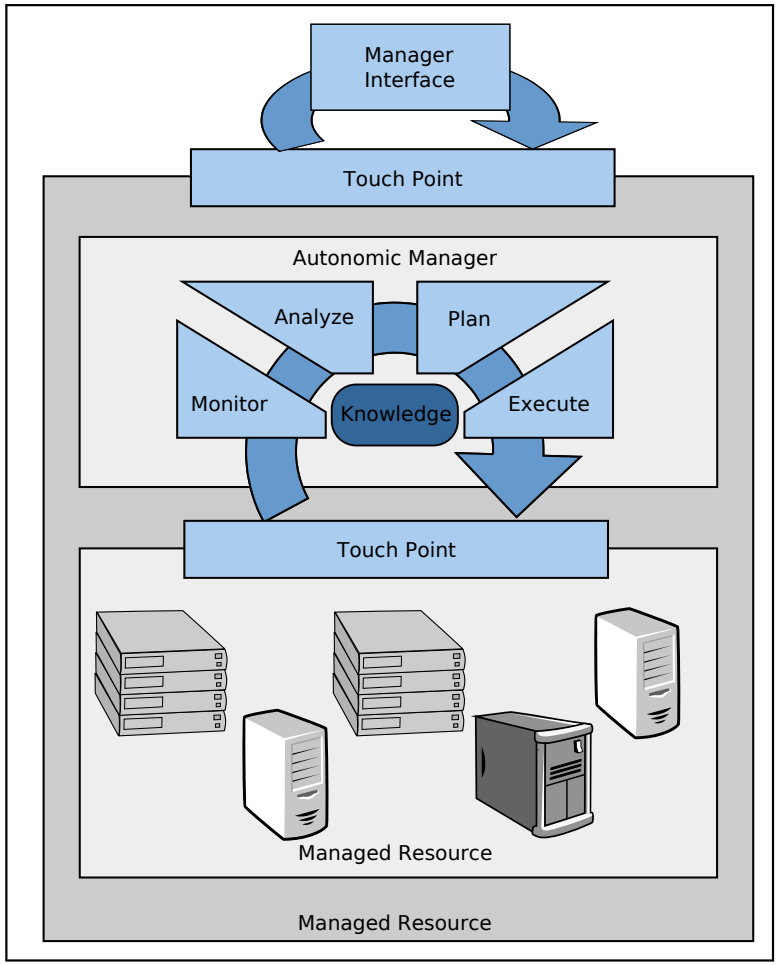
Self-* Properties

- Inspired by the autonomic nervous system of the human body
- Control loops from Control Theory
- Self-management along four main axes (self-* properties):
  - self-configuration
  - self-optimization
  - self-healing
  - self-protection



The Autonomic Computing Architecture

- Managed Resource
- Touchpoint (Sensors & Actuators)
- Autonomic Manager
  - Monitor
  - Analyze
  - Plan
  - Execute
- Knowledge Source
- Communication
- Manager Interface



Problem Statement

Large-scale distributed systems

- Complex and require self-management
- May run on unreliable resources
- Major sources of complexity:
  - Scale (resources, events, users, . . .)
  - Dynamism (resource churn, load changes, . . .)

Goal

- A platform (concepts, abstractions, algorithms. . .) that facilitates development of self-managing applications in large-scale and/or dynamic distributed environment.
- A methodology that help us to achieve self-management.

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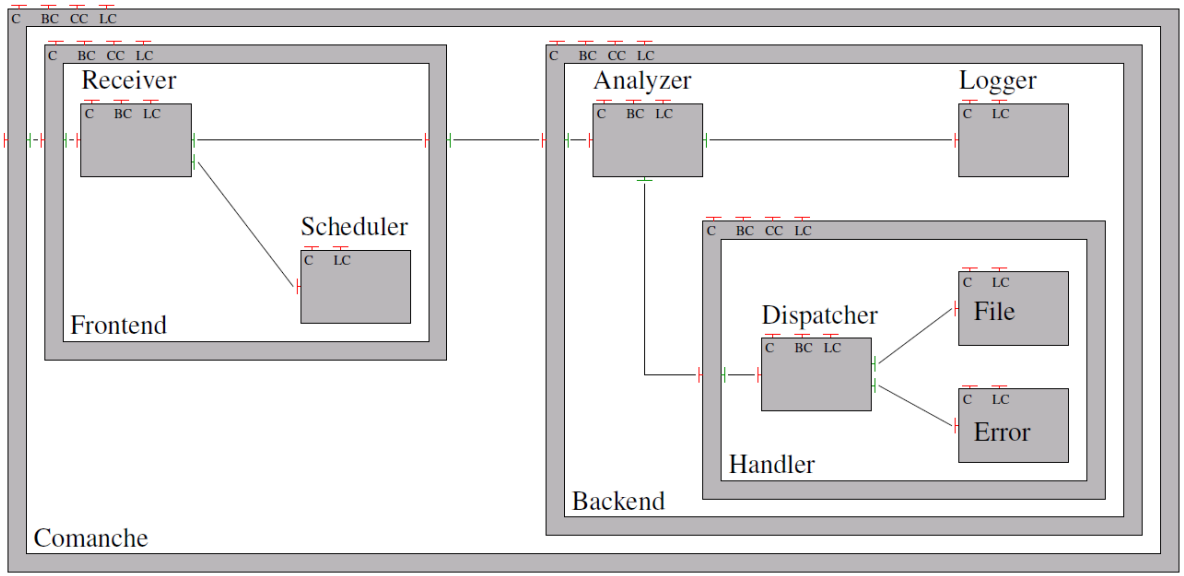
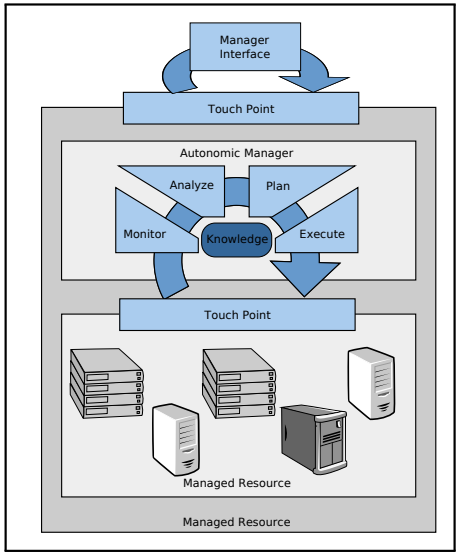
Component Model

- Architectural approach to autonomic computing
- Applications built of components
- Improved manageability through introspection and reconfiguration
- The Fractal component model



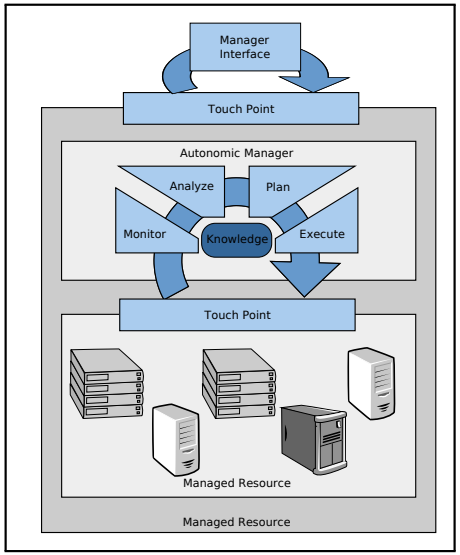
Niche

- Niche is a Distributed Component Management System
- Niche implements the Autonomic Computing Architecture
- Niche targets large-scale and dynamic distributed environment and applications
  - Resources and components are distributed
  - Autonomic managers are distributed network of Management Elements (MEs)
  - Sensors and Actuators are distributed



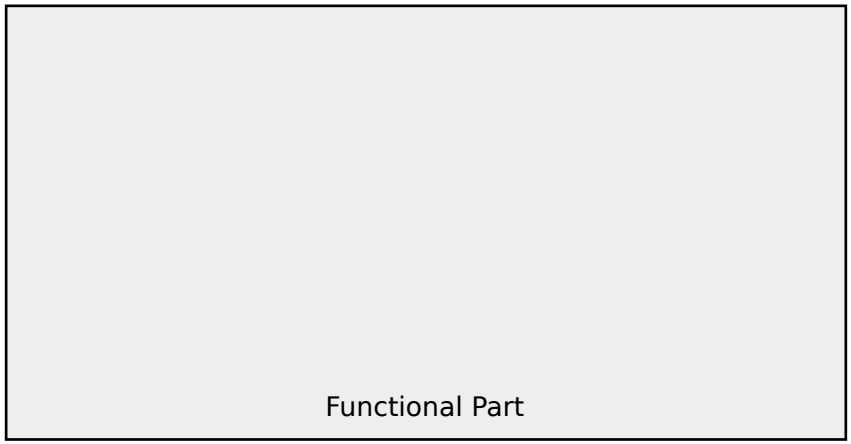
Niche

- Niche leverages Structured Overlay Networks (SONs) for communication and for provisioning of basic services
  - Name based communication and bindings
  - DHT, Publish/Subscribe, Groups, ...
- Niche separates functional part from management part of the application



Functional Part

- Components, Interfaces, and Bindings
- System wide identification
- Support for mobility
- Component groups
- One-to-all and one-to-any bindings
- Dynamic group membership
- Deployment using ADL



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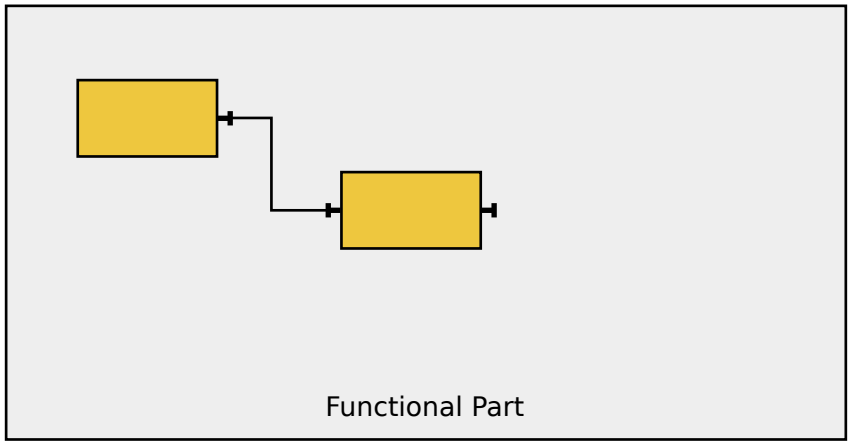

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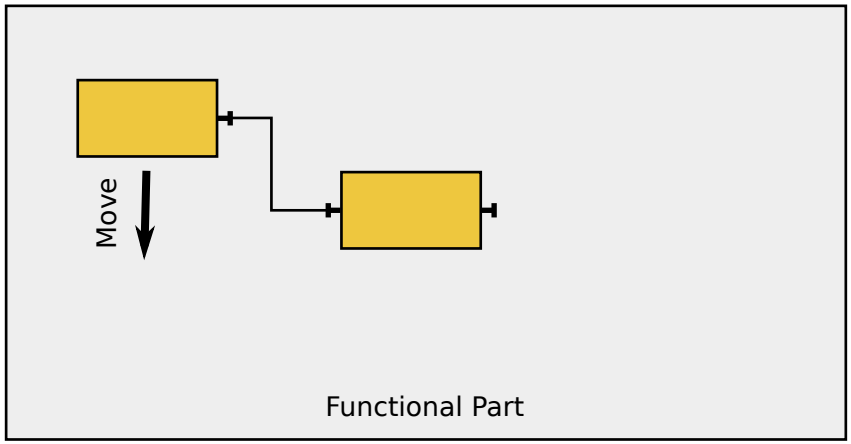

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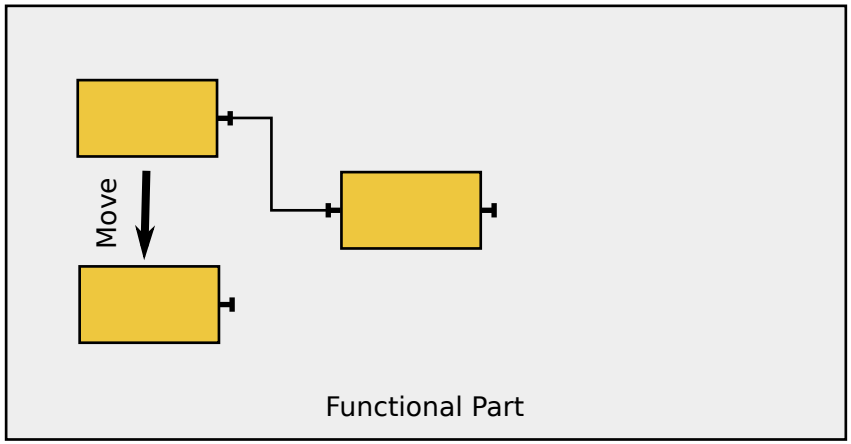

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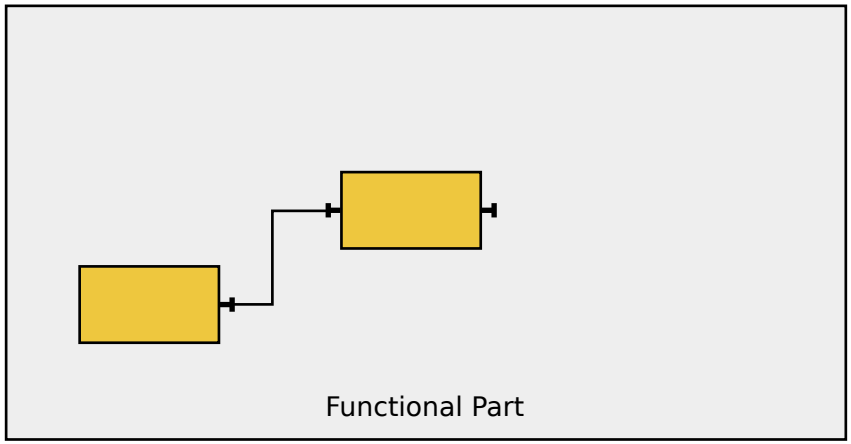

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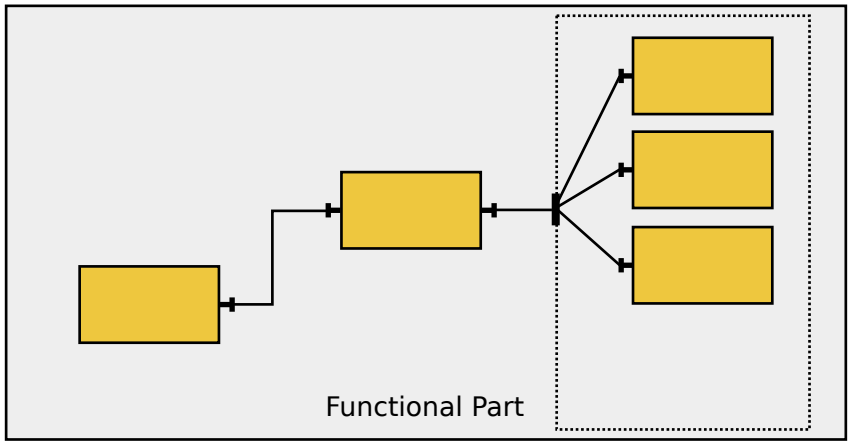

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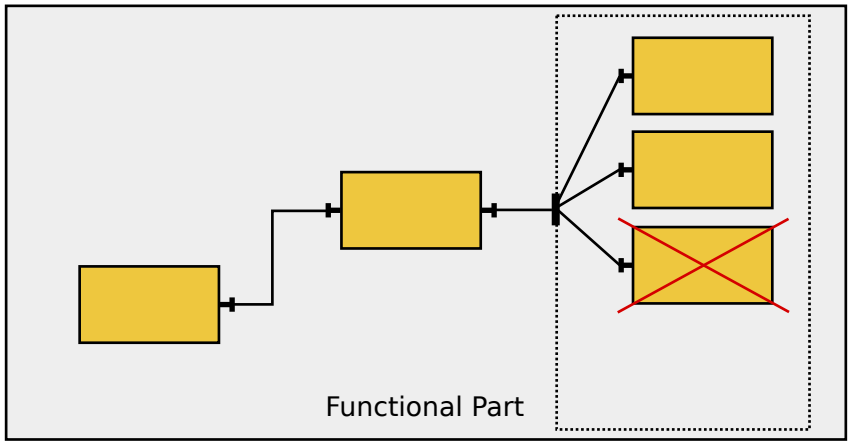

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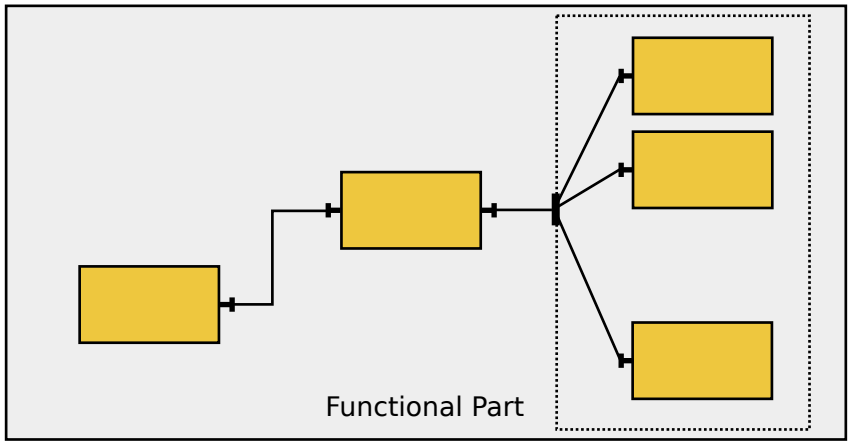

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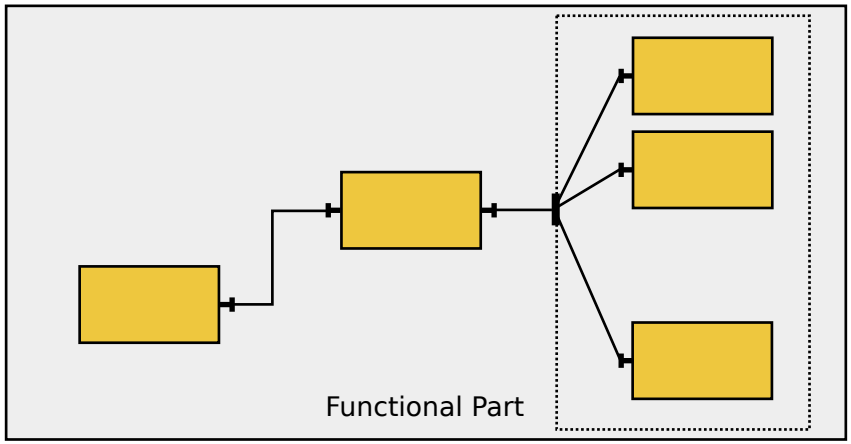
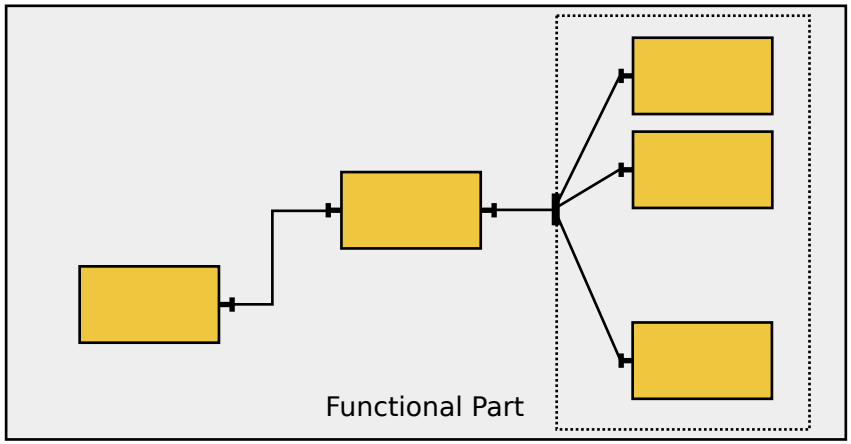


Management Part

- Management Elements
  - Watchers
  - Aggregators
  - Managers
  - Executors
- Communicate through events
- Publish/Subscribe
- Autonomic Managers (control loops) built as network of MEs



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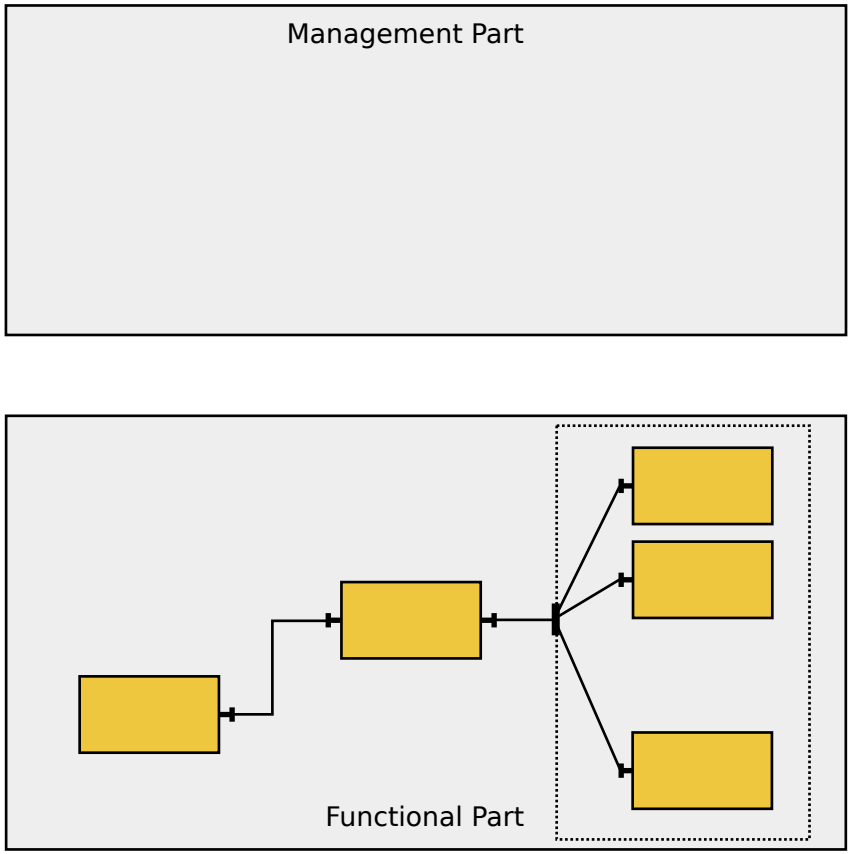

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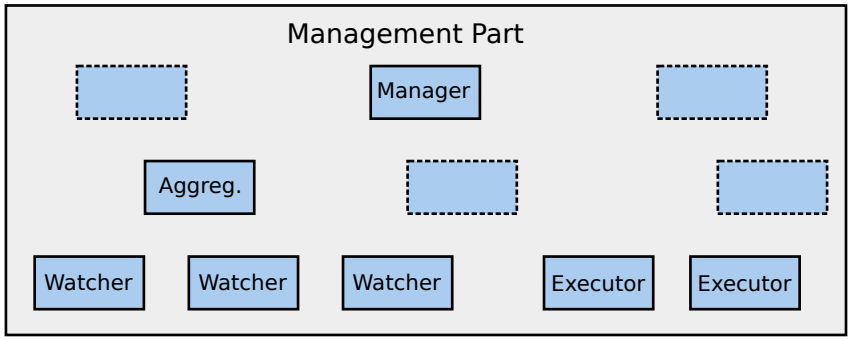

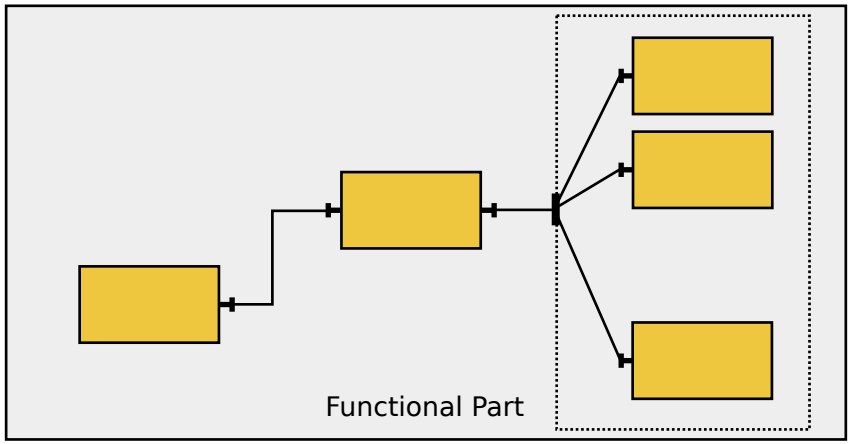

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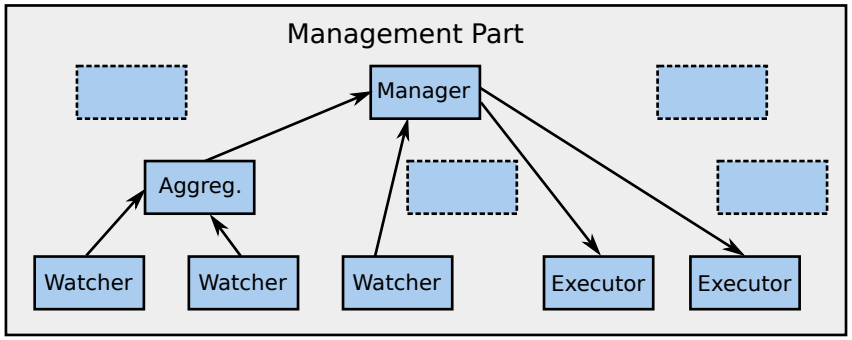

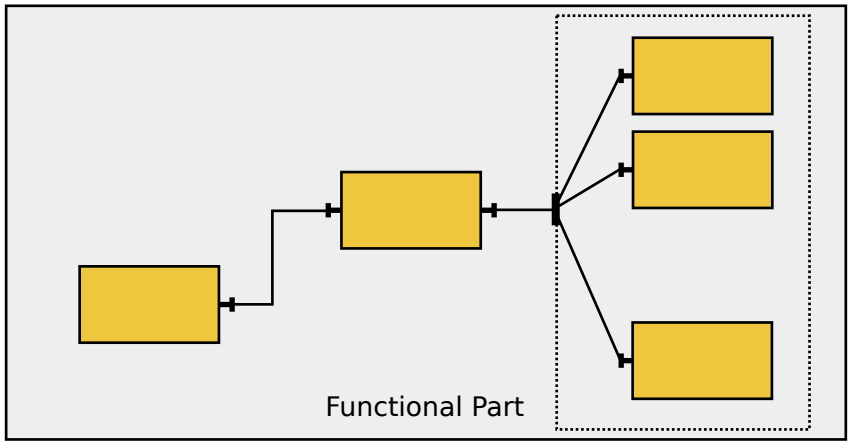

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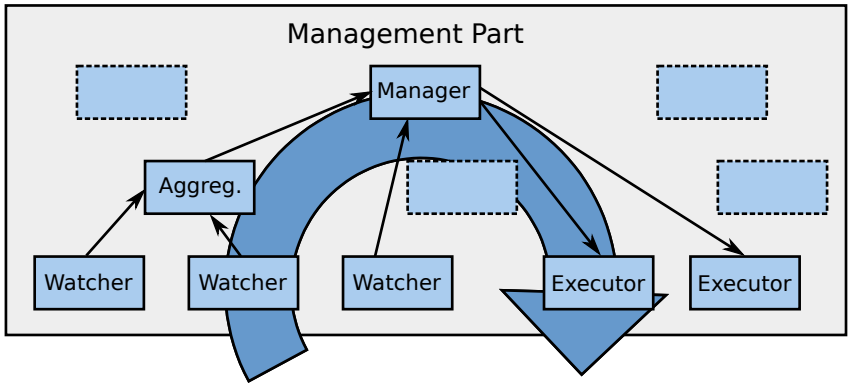
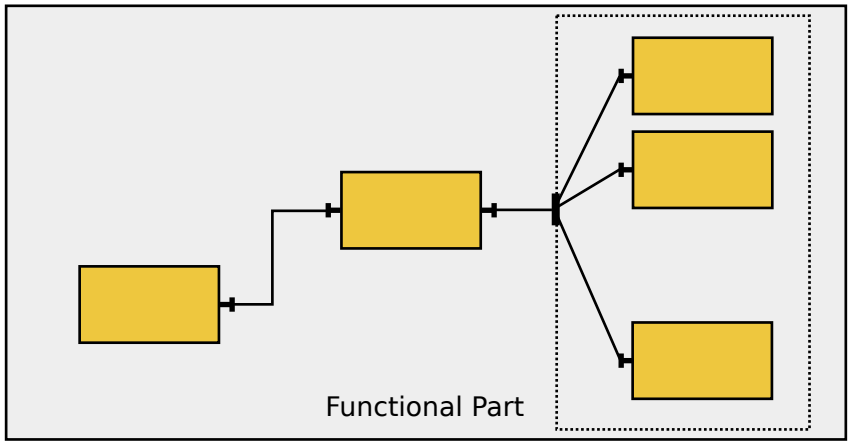
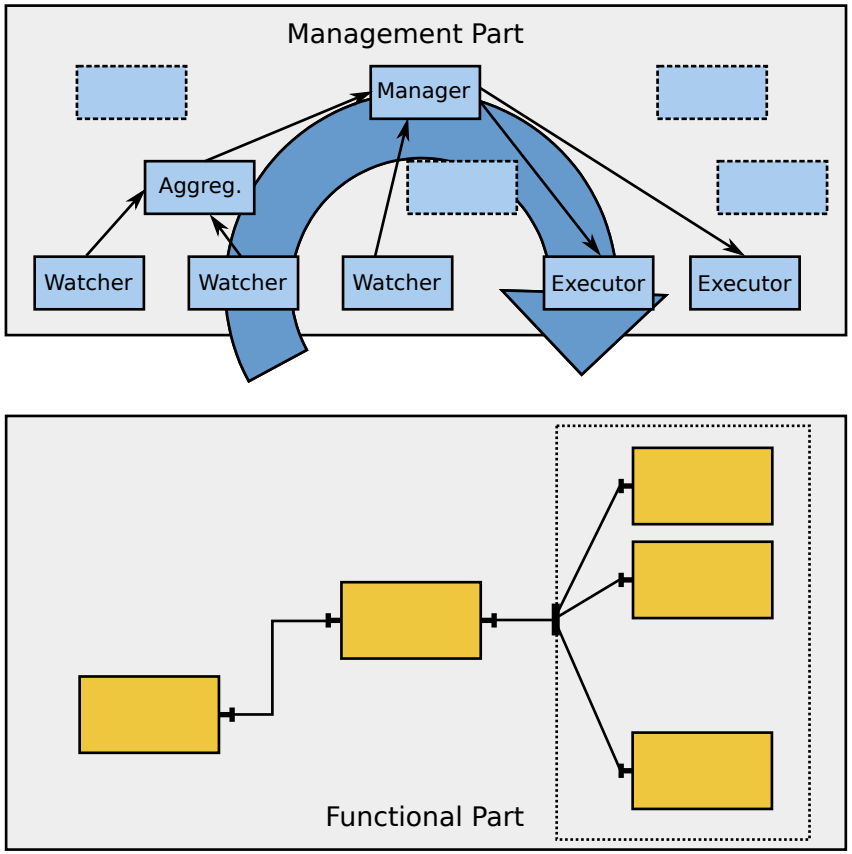




Touchpoints

- Sensors and Actuators
- For Components and Groups
- Automatically install sensors/actuators on group members
- Predefined events (failures, group creation, . . .)
- API (bind, start/stop, create group, discover, . . .)



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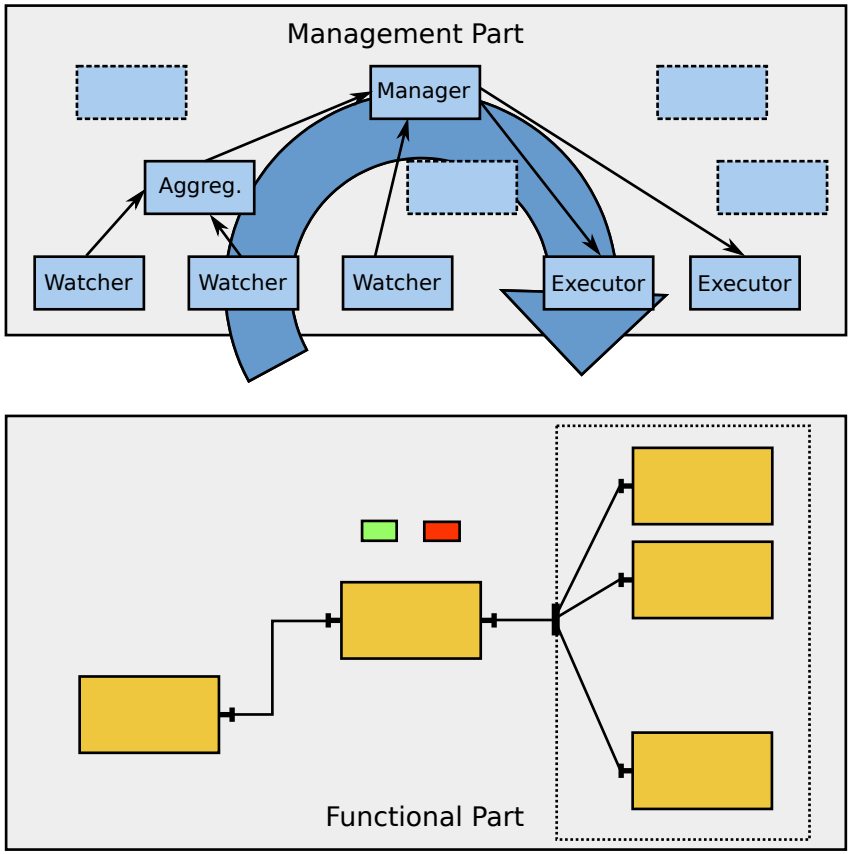

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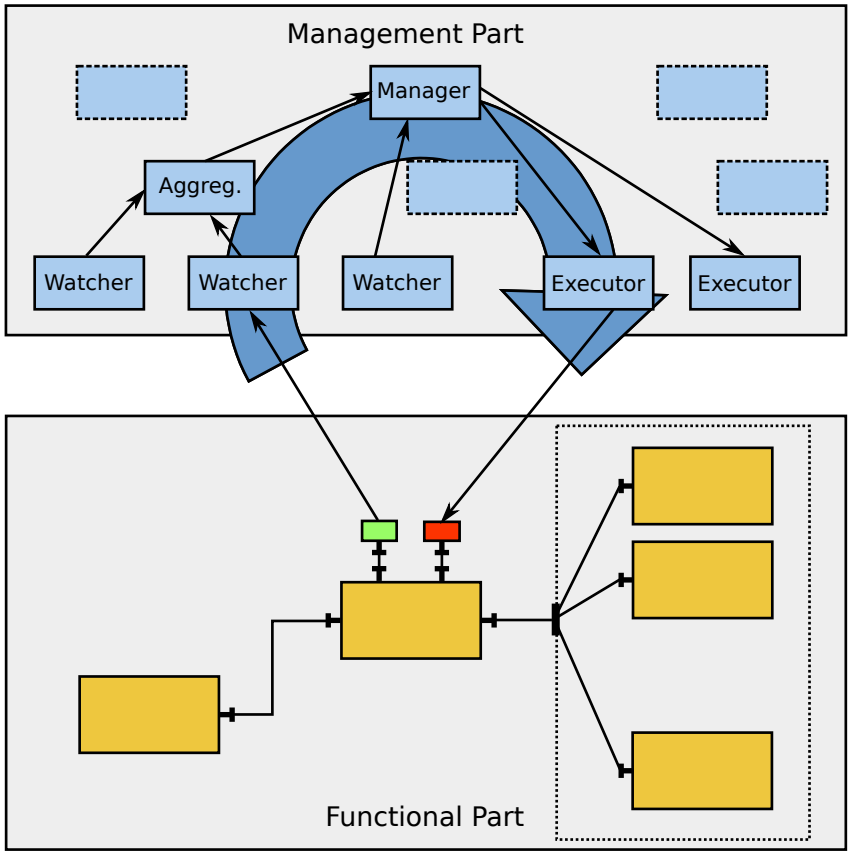

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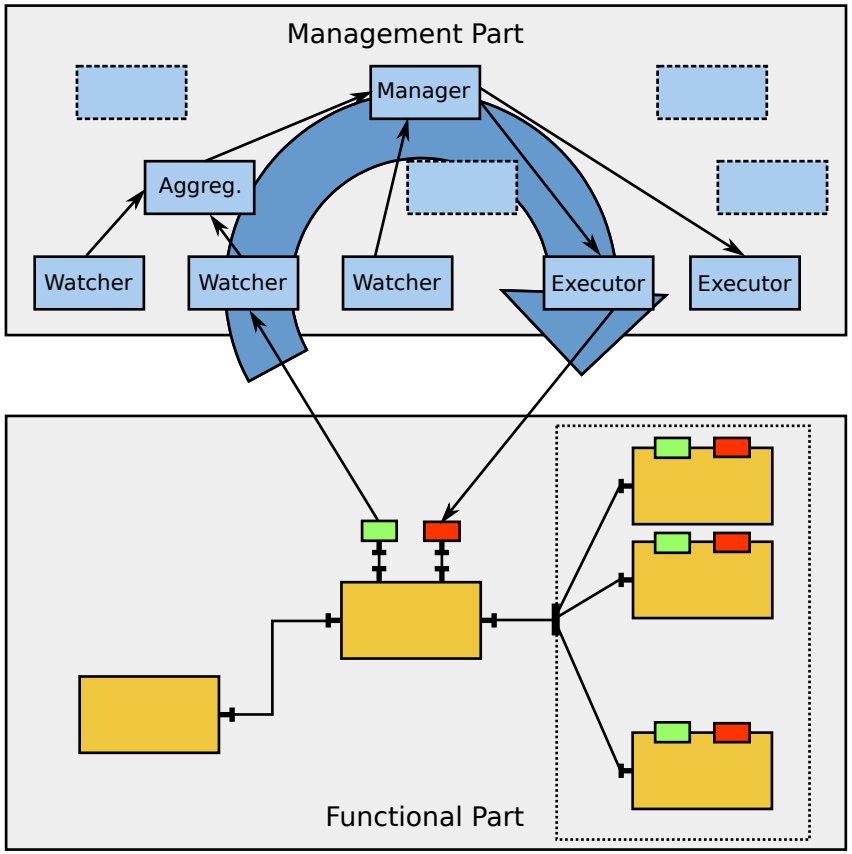

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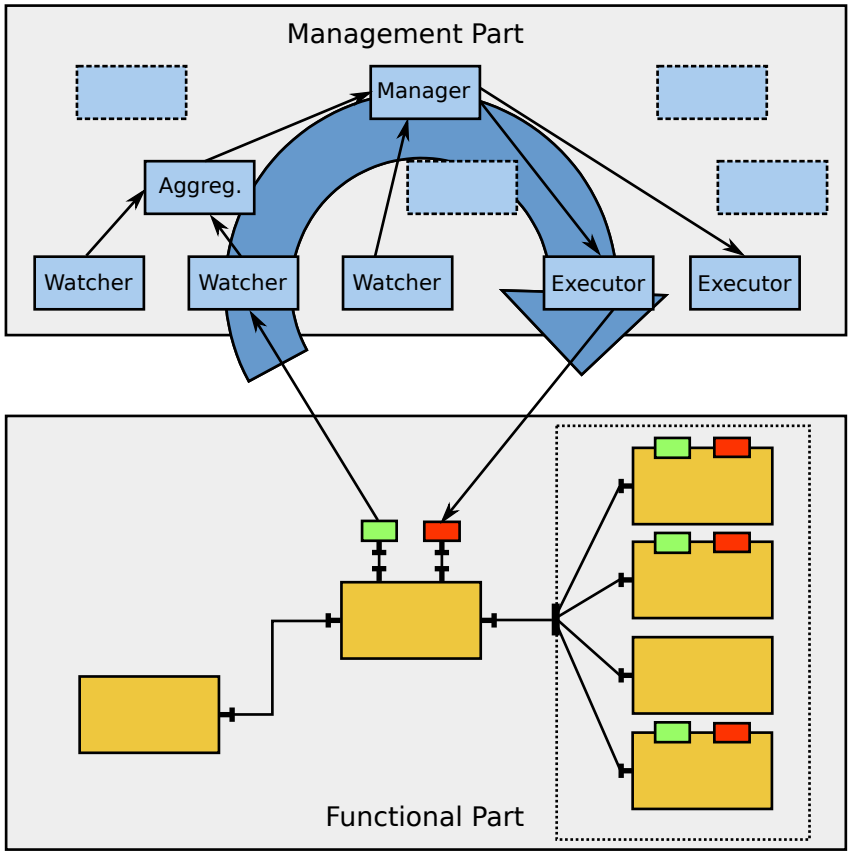

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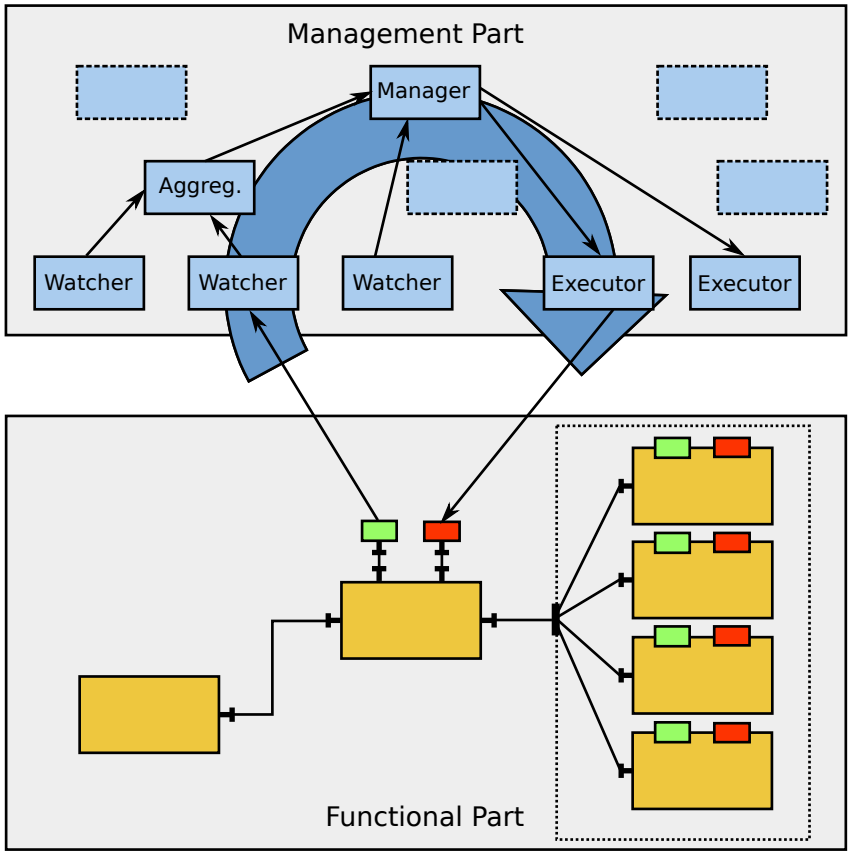

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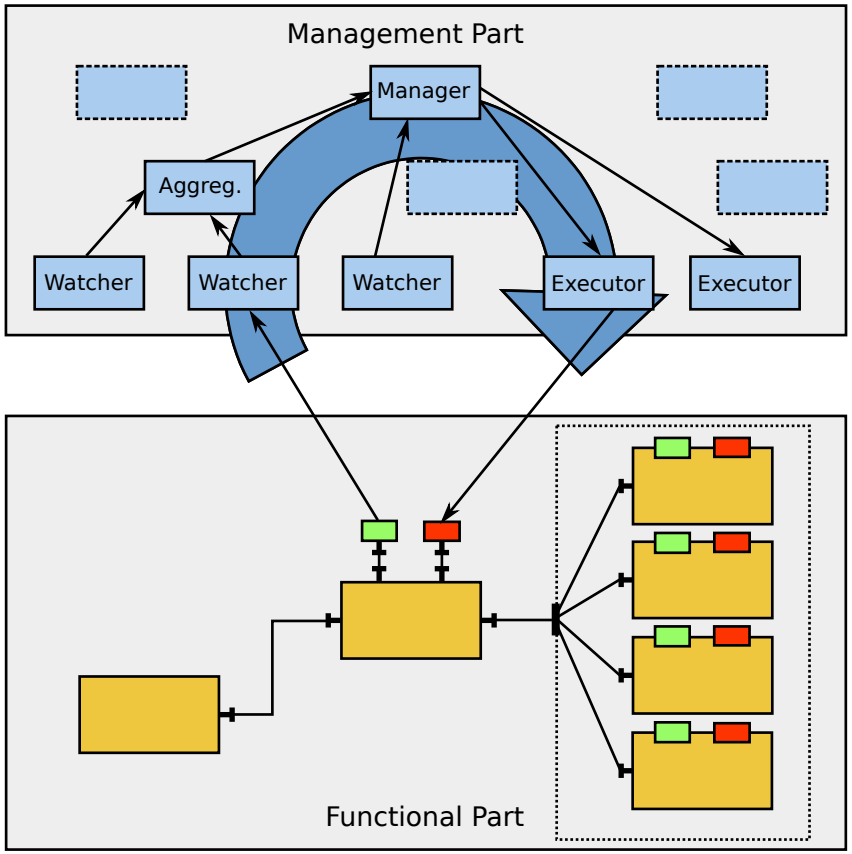
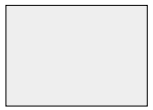


Runtime Environment

- Containers that host components and MEs
- Use a Structured Overlay Network (SON) for communication
- Provide overlay services
  - Resource Discovery
  - Initial deployment
  - Dynamic runtime reconfiguration
  - Publish/subscribe
  - DHT-based registry of identifiable entities such as components, groups, and bindings



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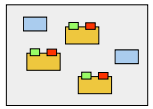
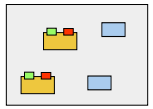
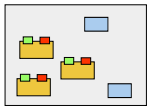
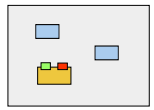

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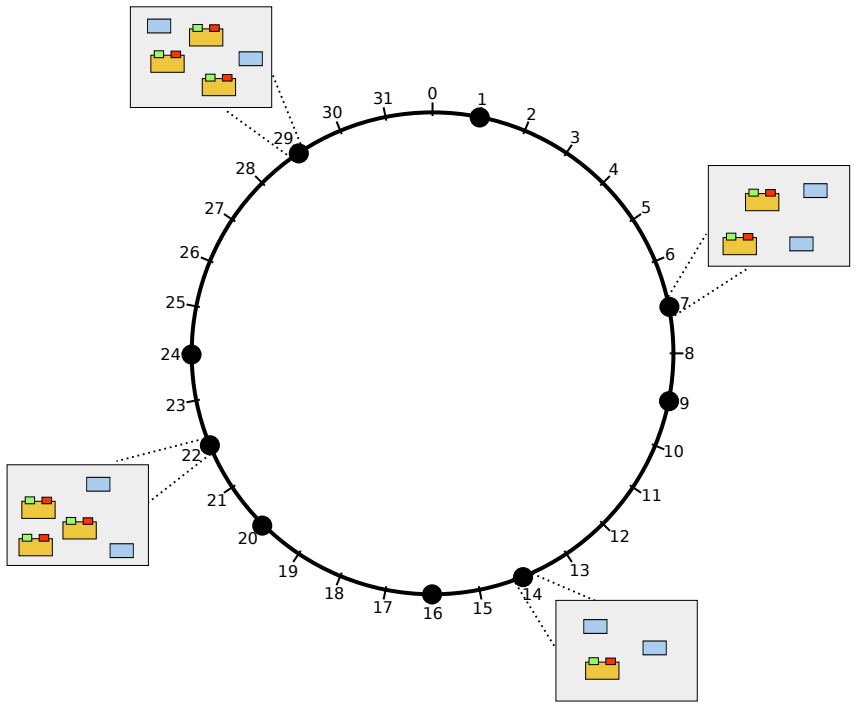

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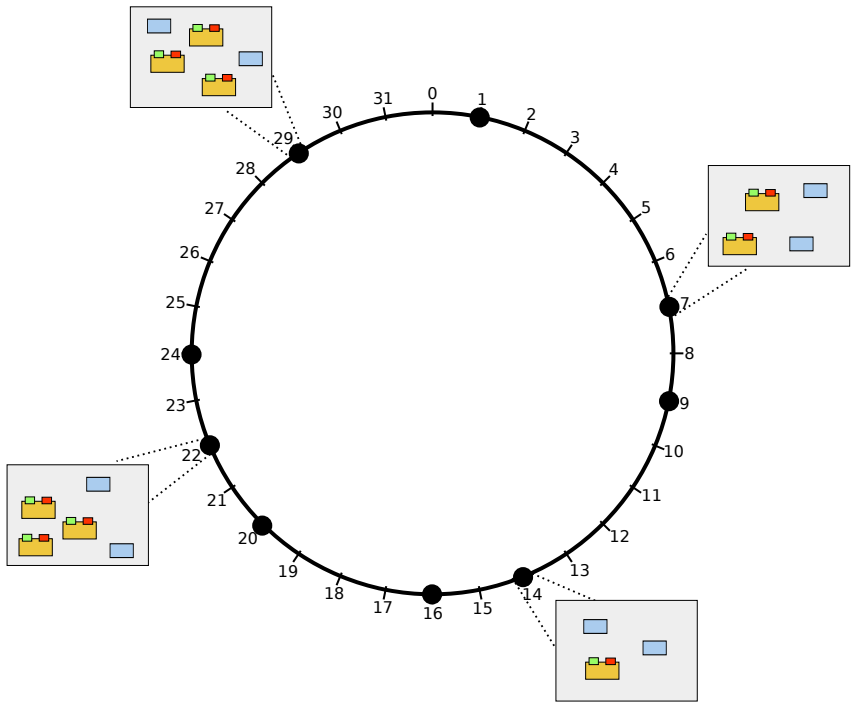

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Distributed Management

- In distributed environments we advocate for distribution of management functions among several cooperative managers
- Multiple managers are needed for scalability, robustness, and performance and also useful for reflecting separation of concerns
- Need guidance on how to design distributed management

High Level Design Steps

A self-managing application

- Functional part
- Management part
- Touchpoints

Iterative steps to distribute management

- Management objectives
- Decomposition
- Assignment
- Orchestration
- Mapping

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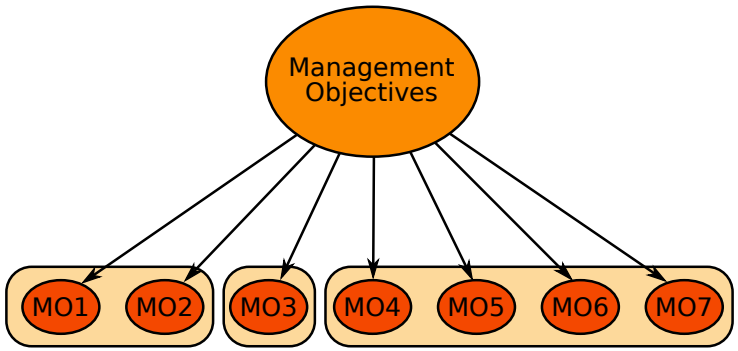

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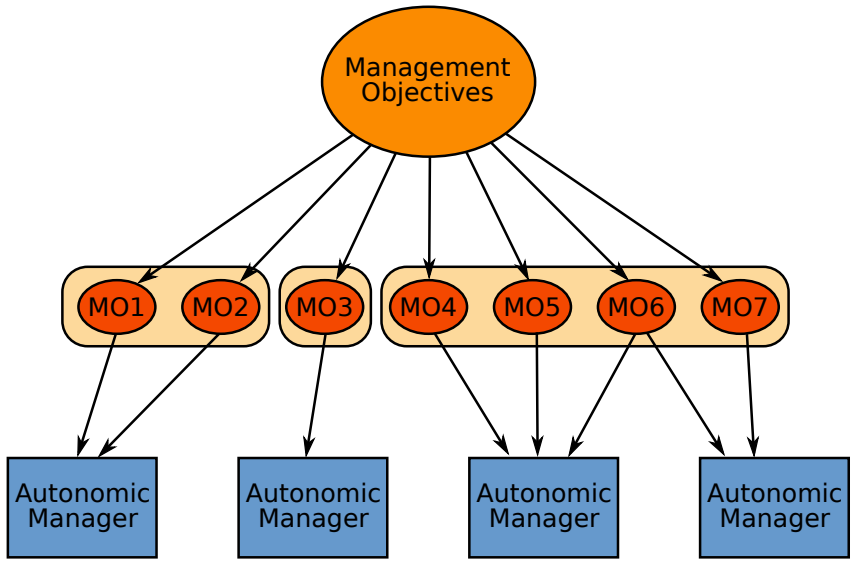

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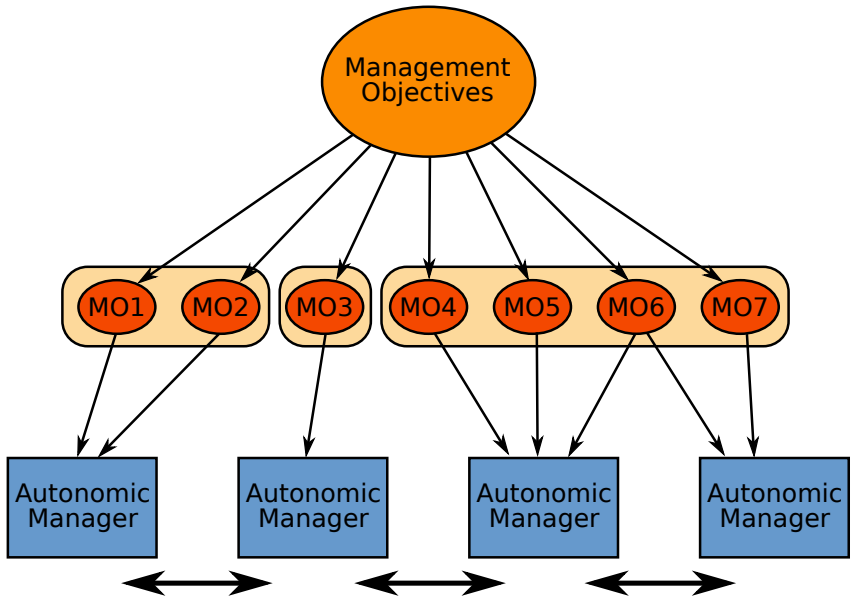

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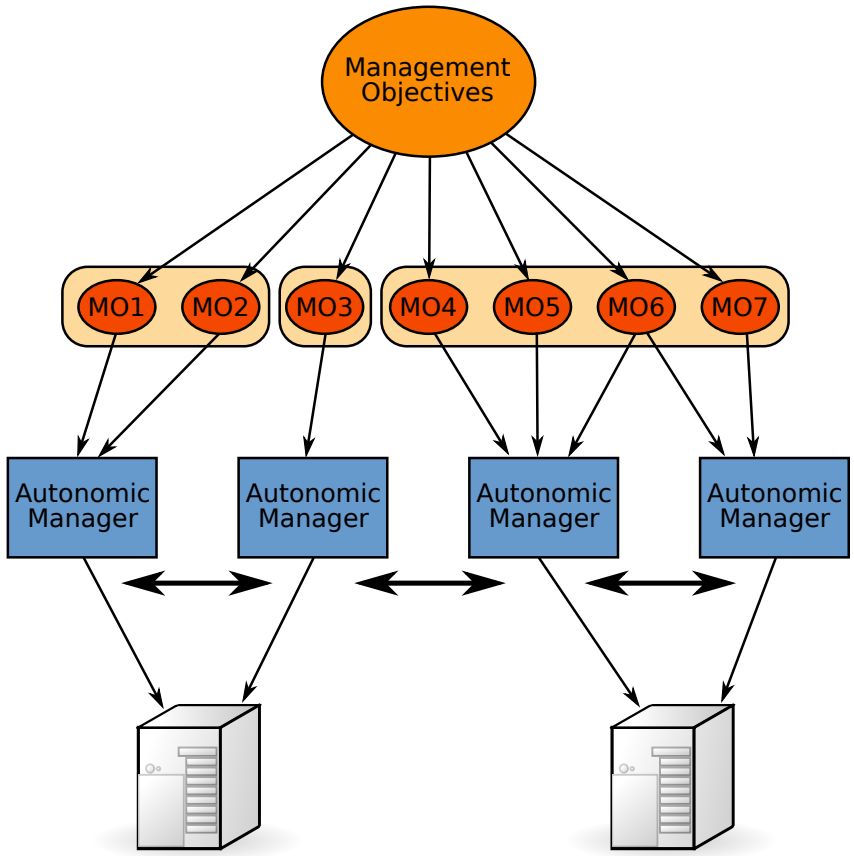
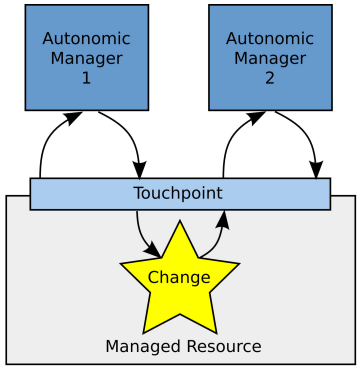
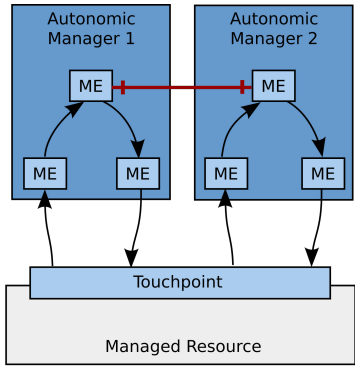


Design Space for Management Interaction

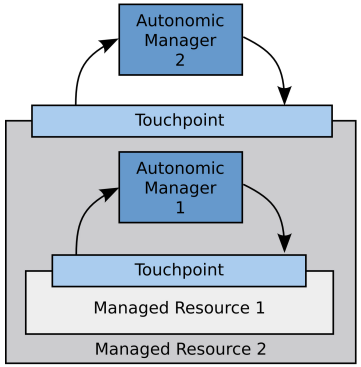
- Stigmergy
- Hierarchical
- Direct Interaction
- Sharing of MEs



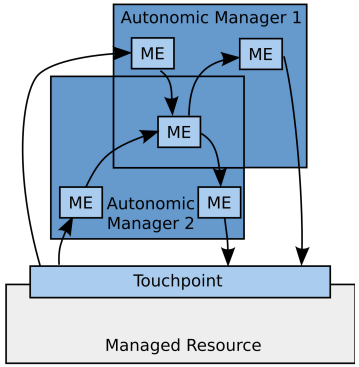
a. The stigmergy effect.



b. Direct interaction.



c. Hierarchical management.



d. Shared Management Elements.

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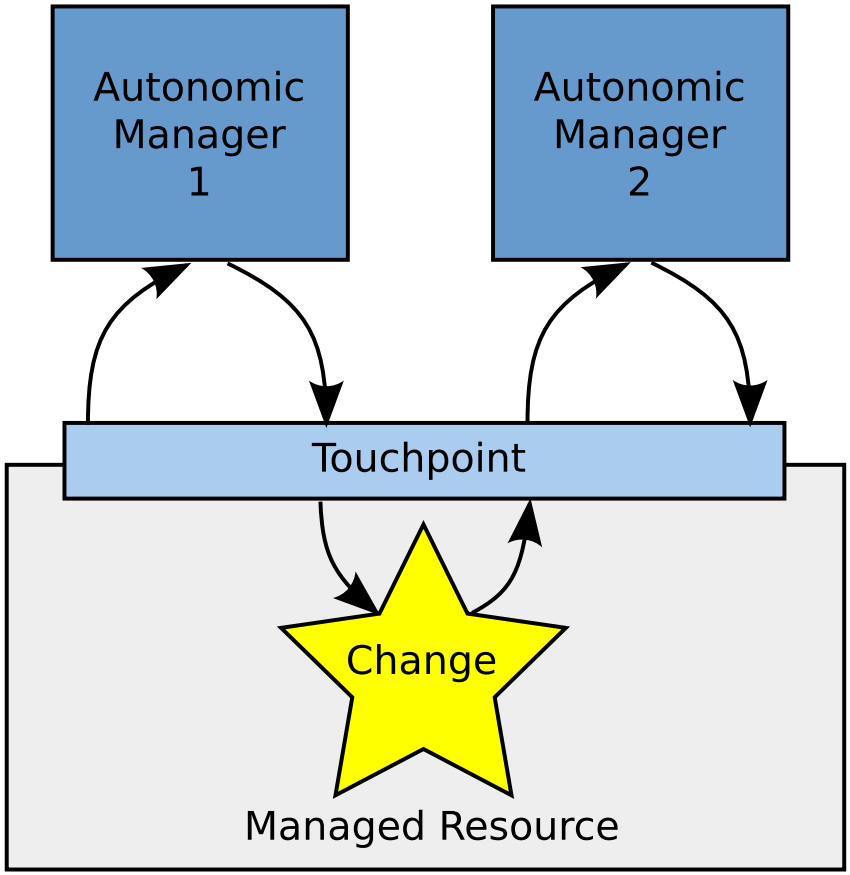

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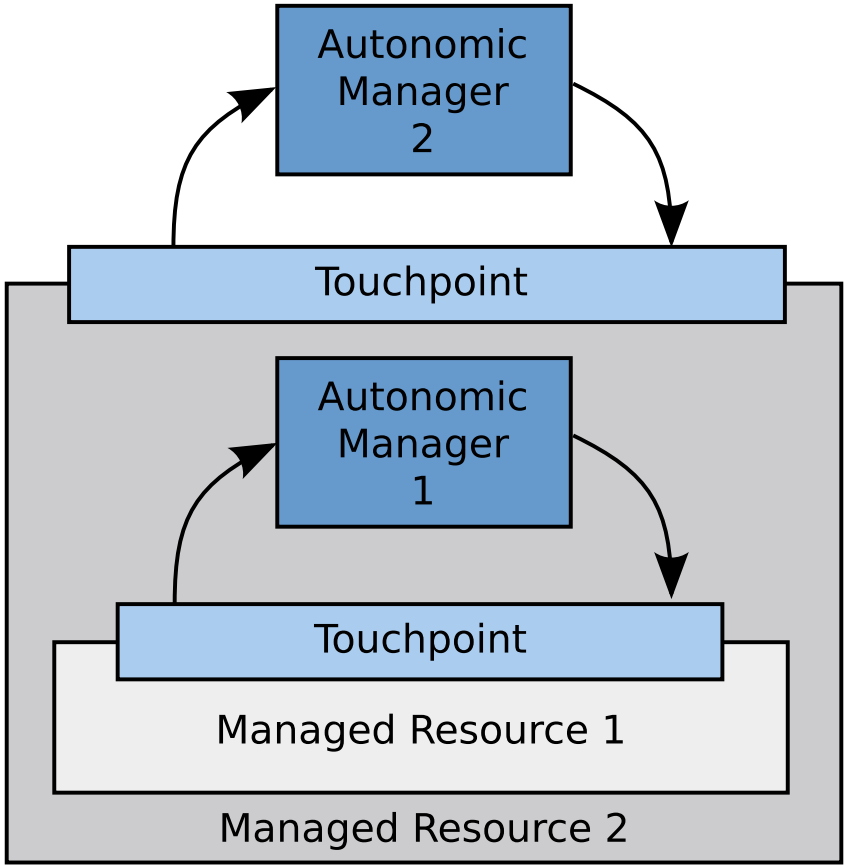

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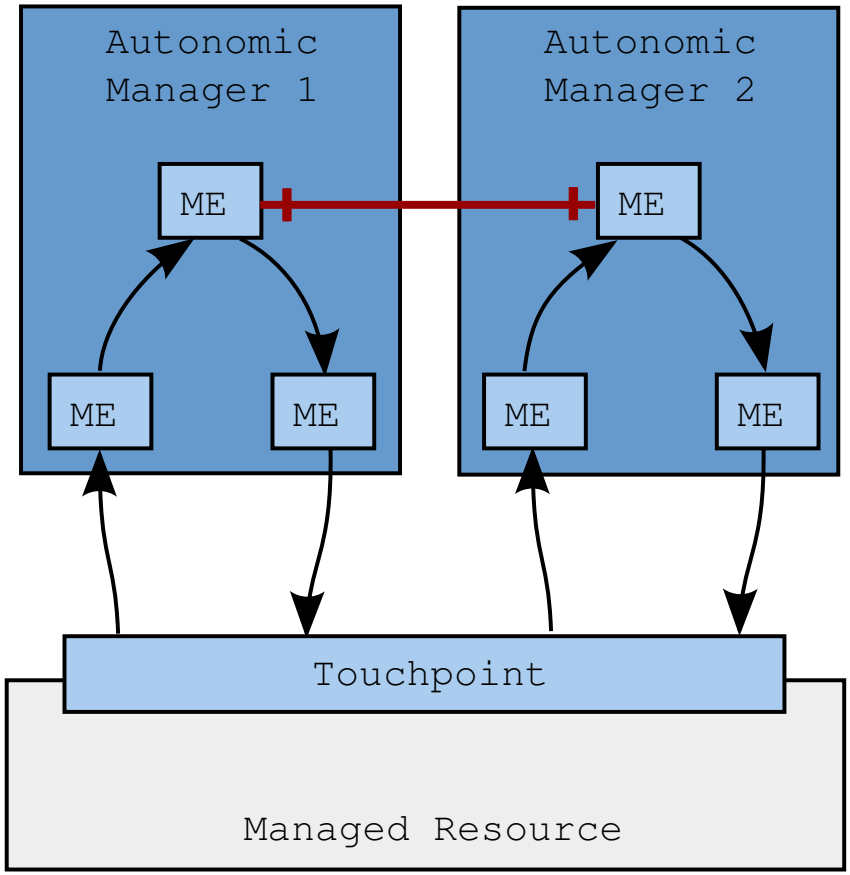

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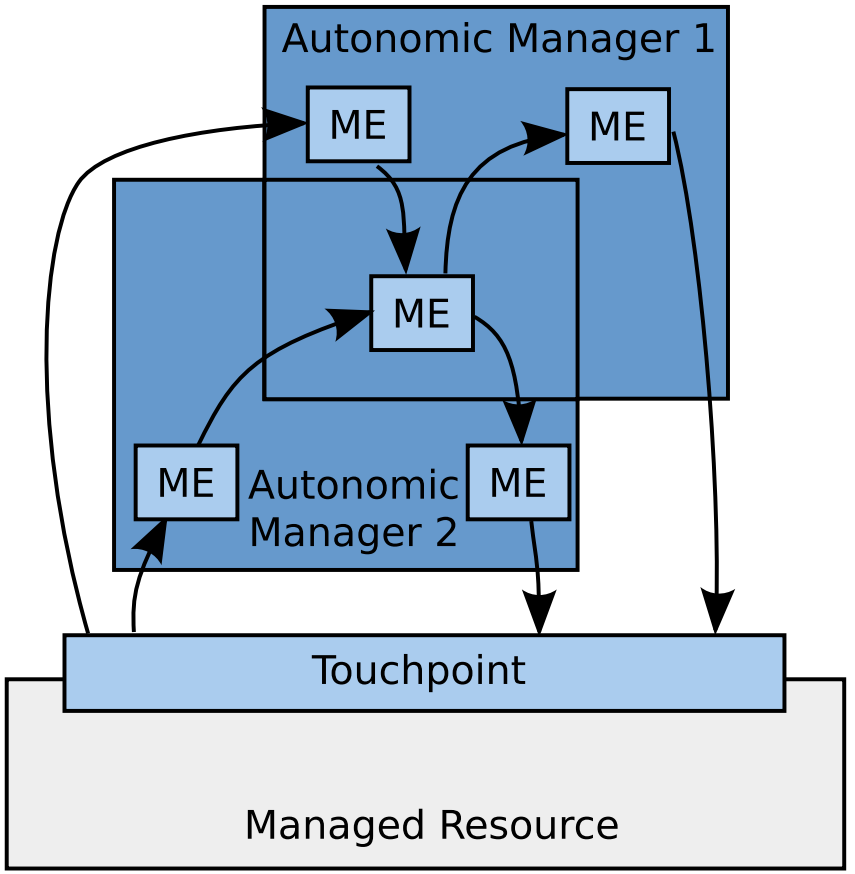
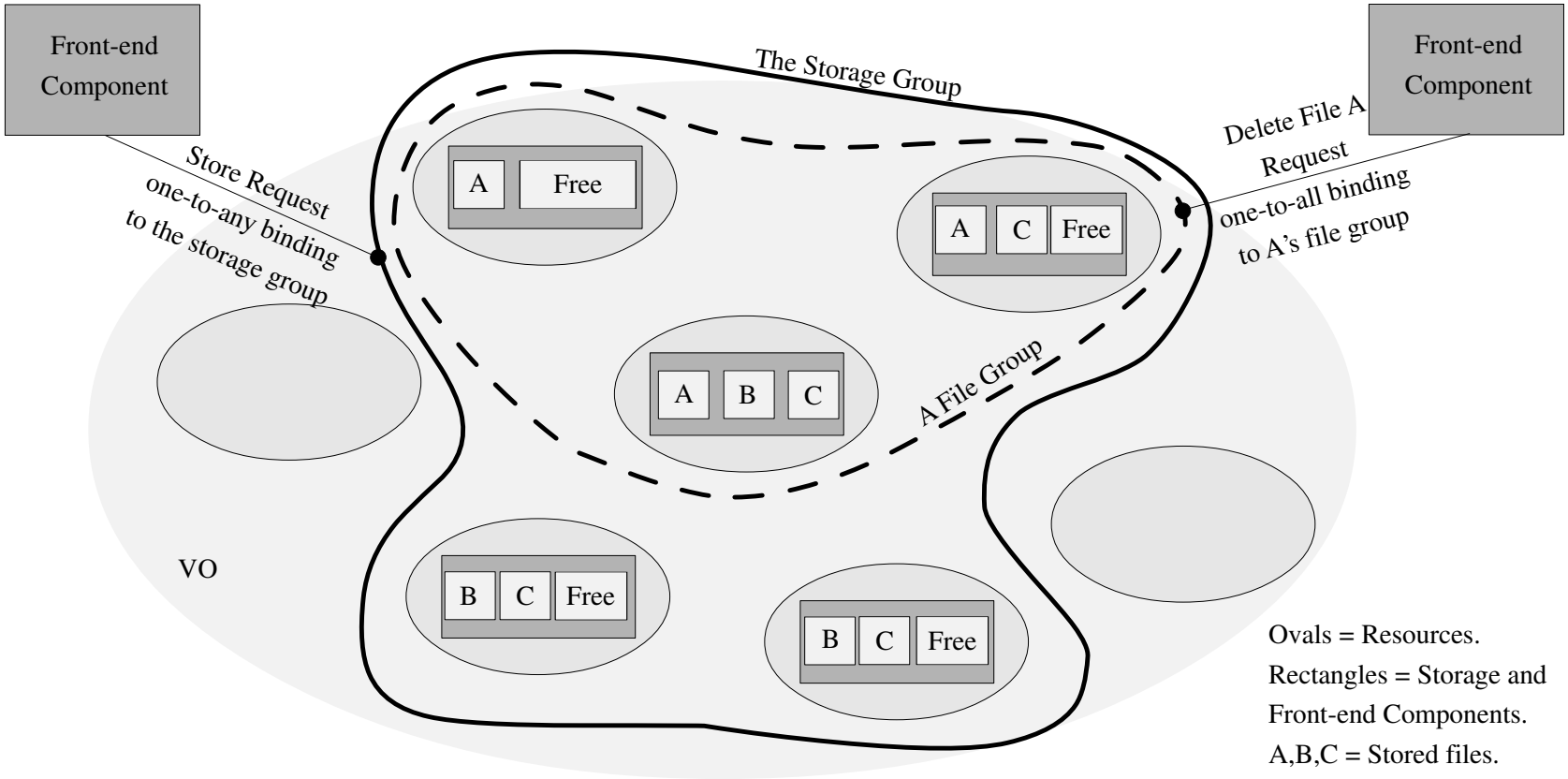


Use Case: YASS

- YASS: Yet Another Storage Service
- Users can store, read and delete files on a set of distributed resources.
- Transparently replicates files for robustness and scalability.
- Deployed in a dynamic distributed environment

YASS functional part



YASS Management Objective

- **MO1:** Maintain file replication degree
- **MO2:** Maintain total storage space and total free space
- **MO3:** Release unused storage
- **MO4:** Increasing availability of popular files
- **MO5:** Balance stored files among allocated resources

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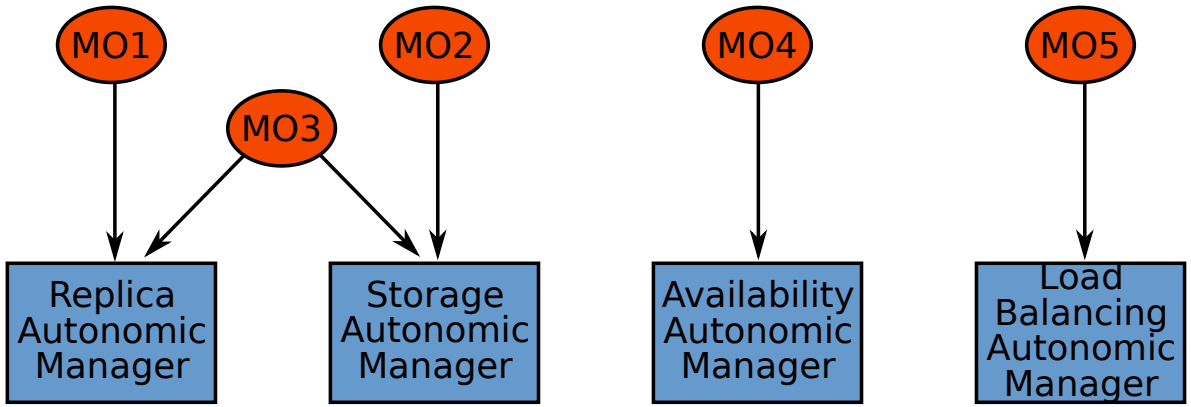
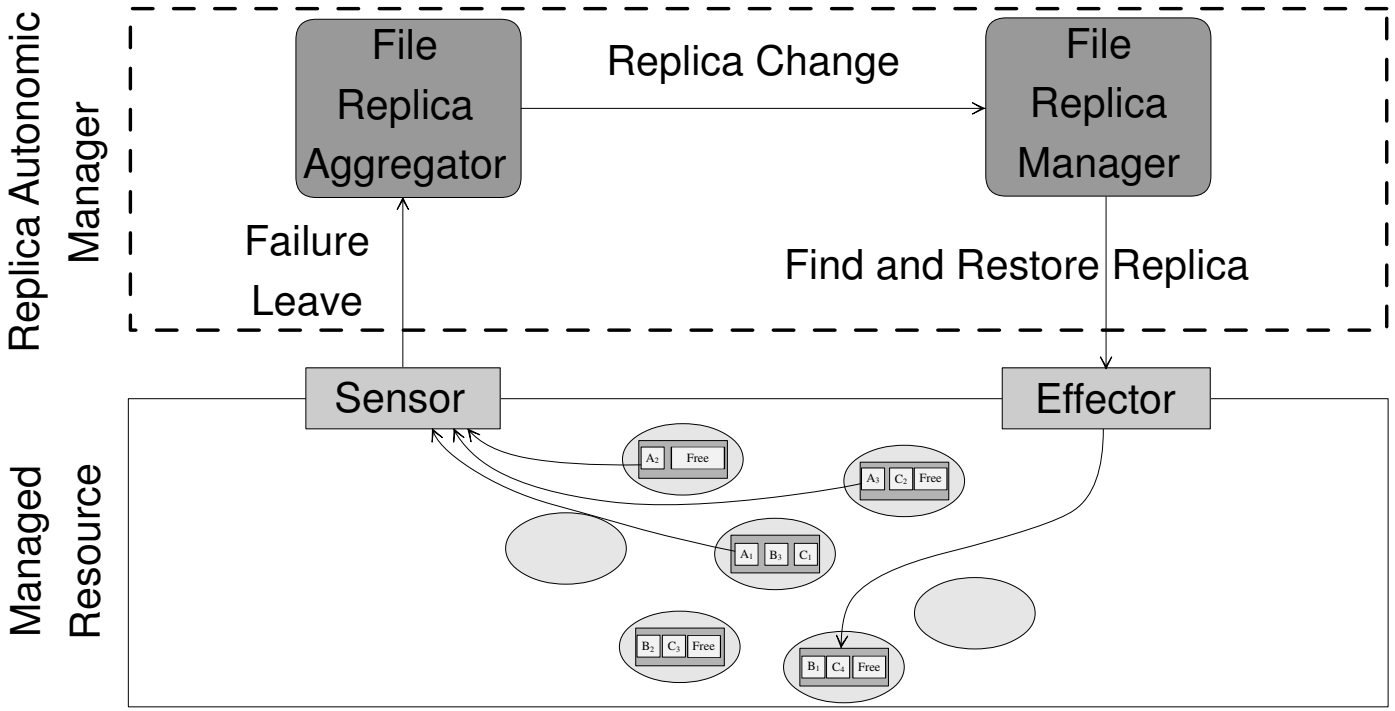


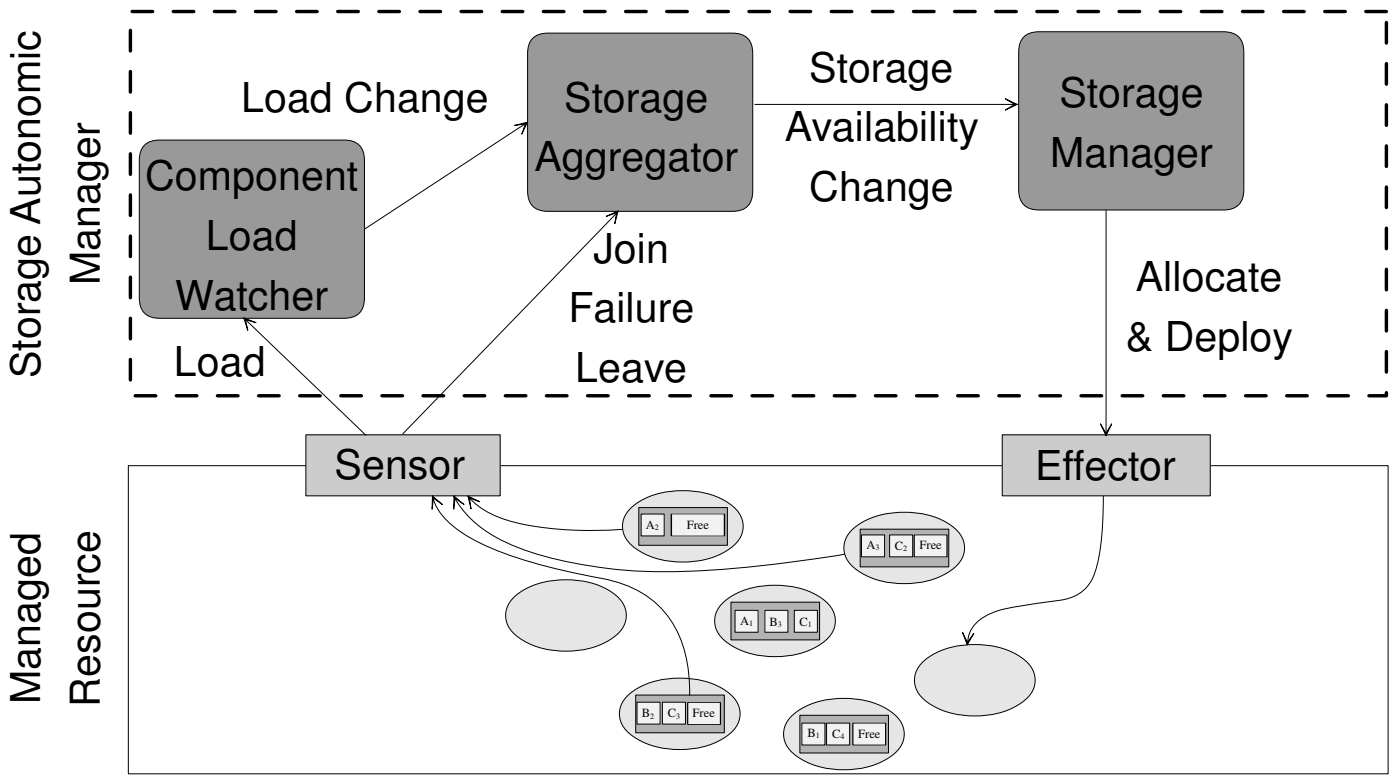
Touchpoints

- Load sensor to measure the current free space
- Access frequency sensor to detect popular files
- Replicate file actuator to add one extra replica of a file
- Move file actuator to move files for load balancing

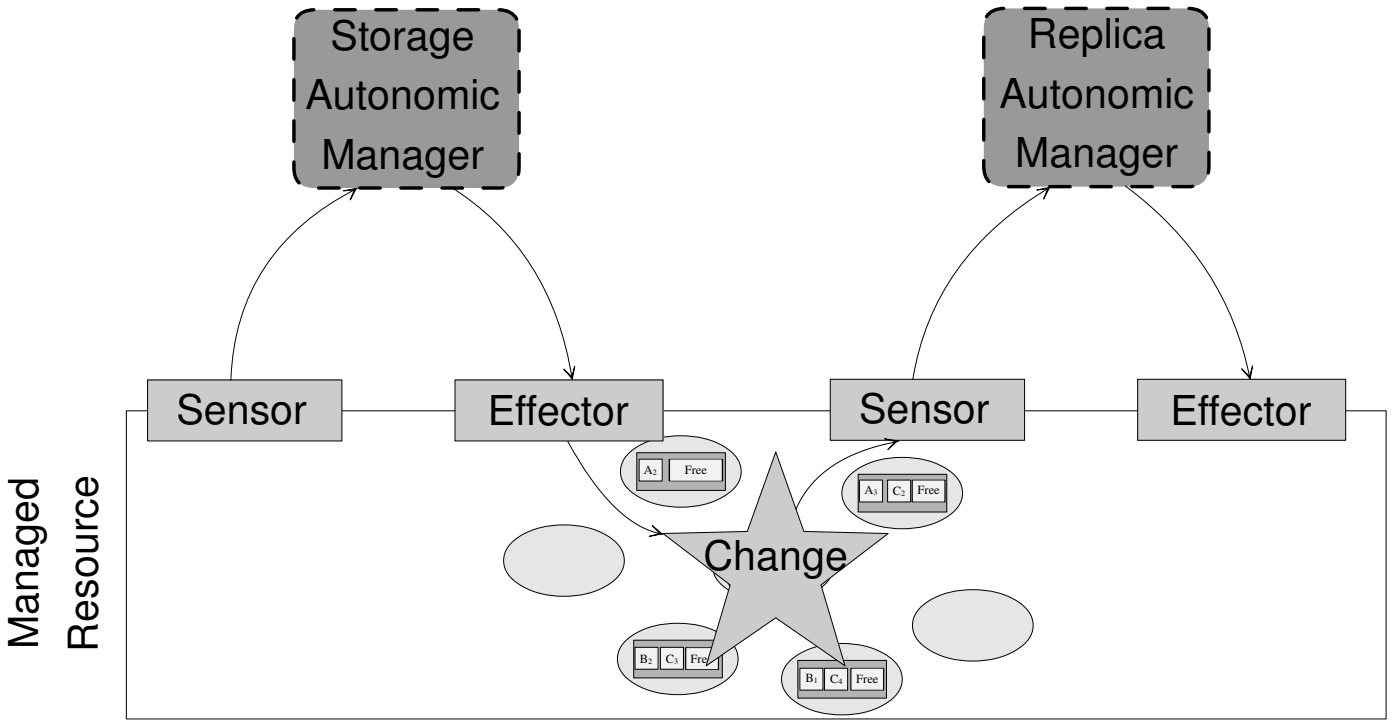
MO1: Maintain the File Replication Degree



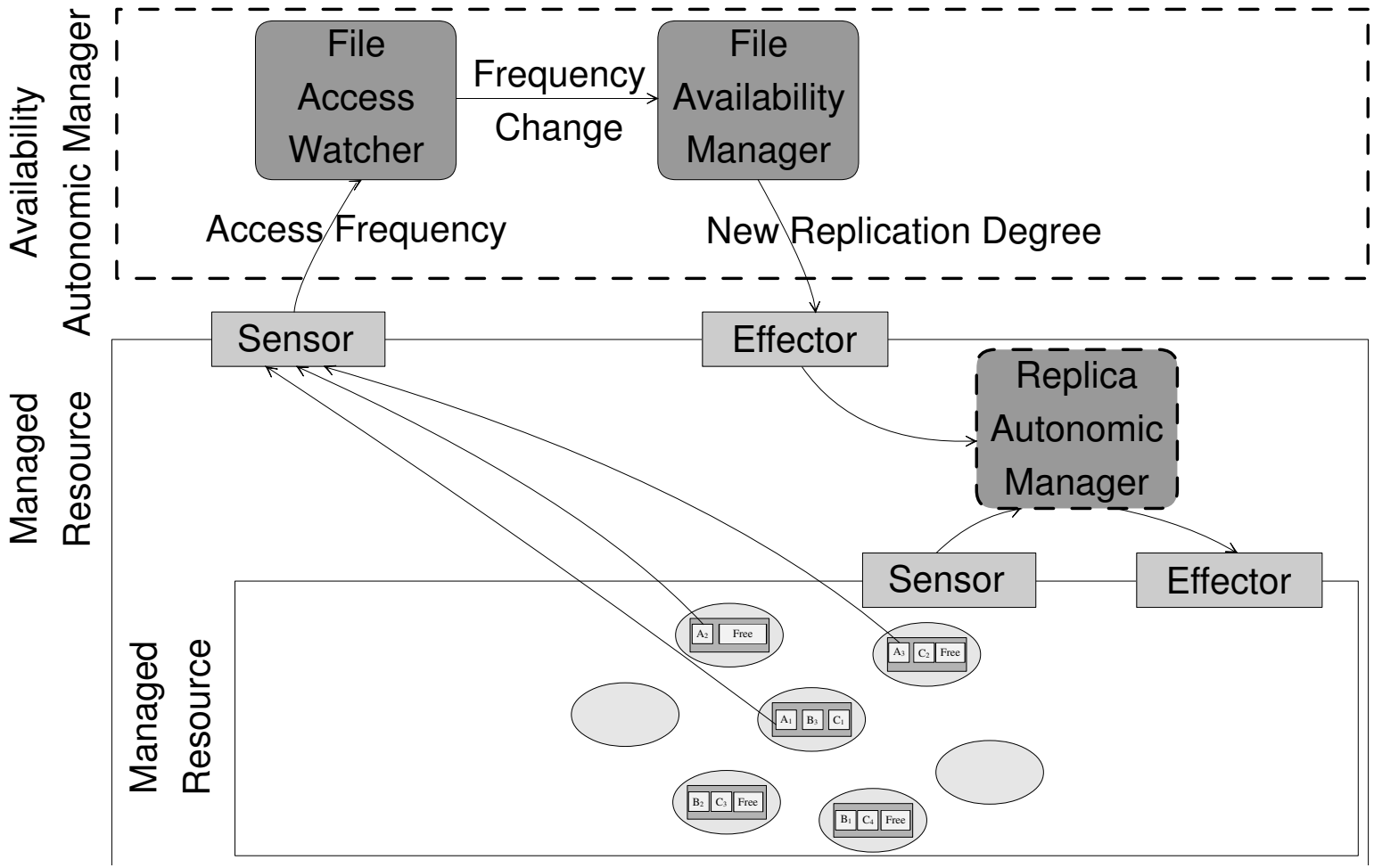
MO2: Maintain the Total Storage Space and Total Free Space



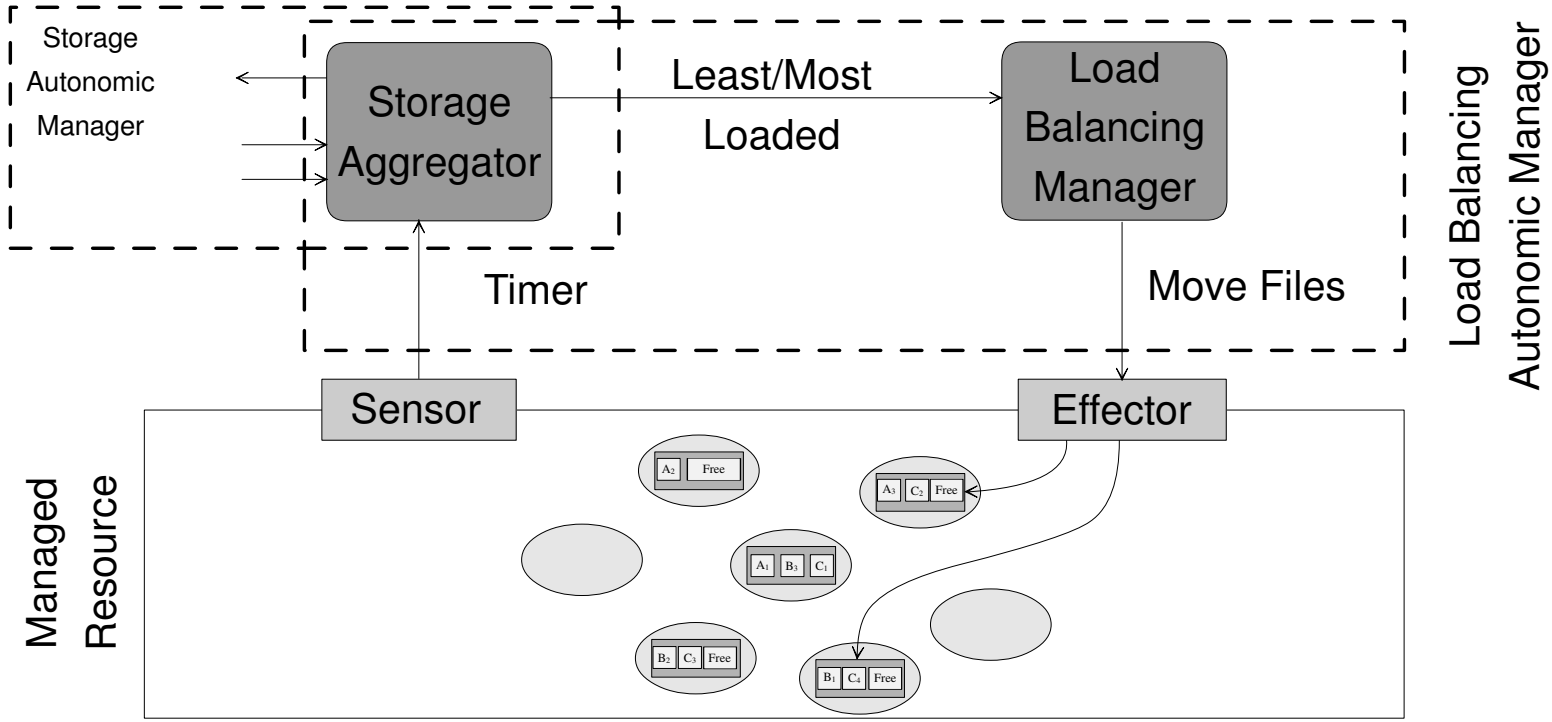
MO3: Release Unused Storage



MO4: Increasing the Availability of Popular Files



MO5: Balance the Stored Files Among the Allocated Resources



Outline

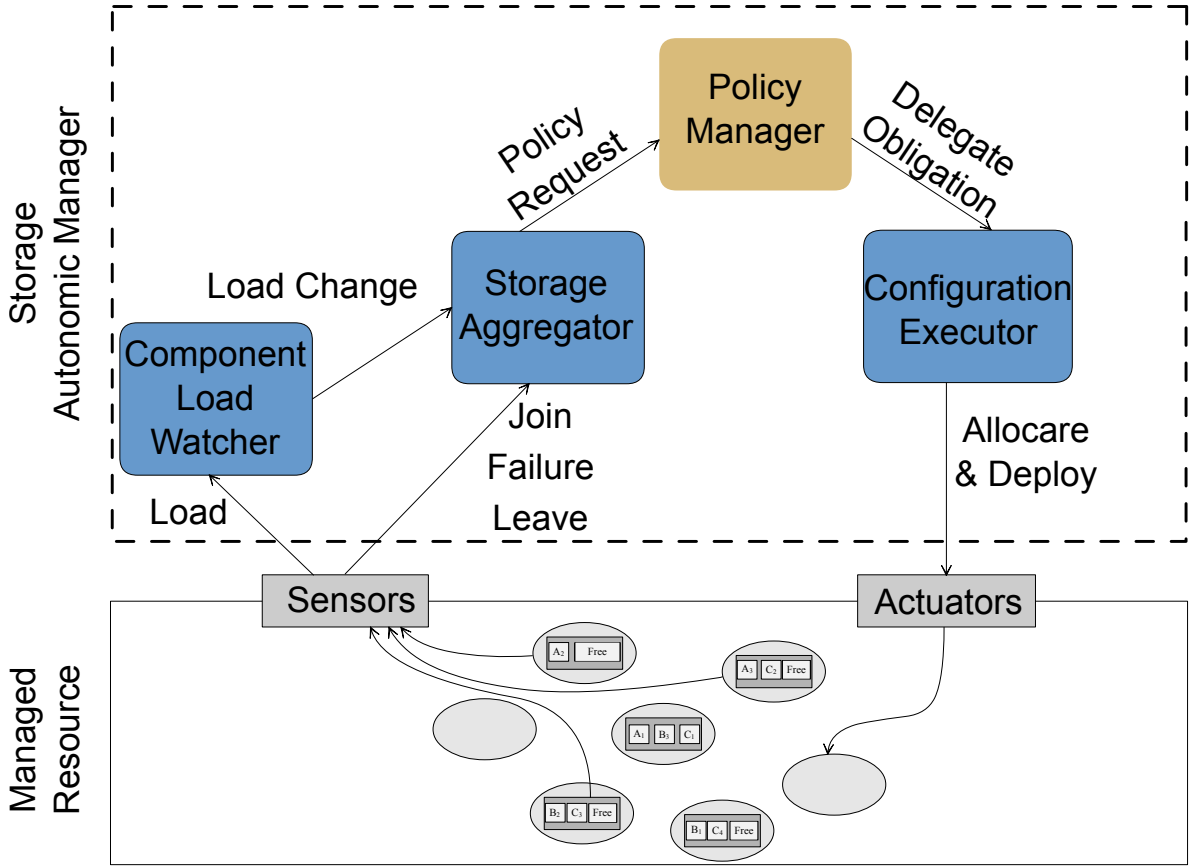
Policy-based Management

- Self-management under guidelines defined by humans in the form of management policies
- Management policy
  - A set of rules that govern the system behaviors
  - Reflects the business goals and/or management objectives

Drawbacks of "Hard-coded" Policy

- Application developer has to be involved in policy implementation
- Hard to trace policies
  - Policies are "hard-coded" (embedded) in the management code of a distributed system
  - Policy logic is scattered in implementation
- Change of policies may requires rebuilding and redeploying of the application (or at least its management part)

Example: YASS Self-Configuration Using Policies



Policy Languages (used in this work)

- SPL
  - Simplified Policy Language
  - Designed for management
  - ▸ SPL example
- XACML
  - eXtensible Access Control Markup Language
  - Primarily designed for access control
  - ▸ XACML example

Performance Evaluation

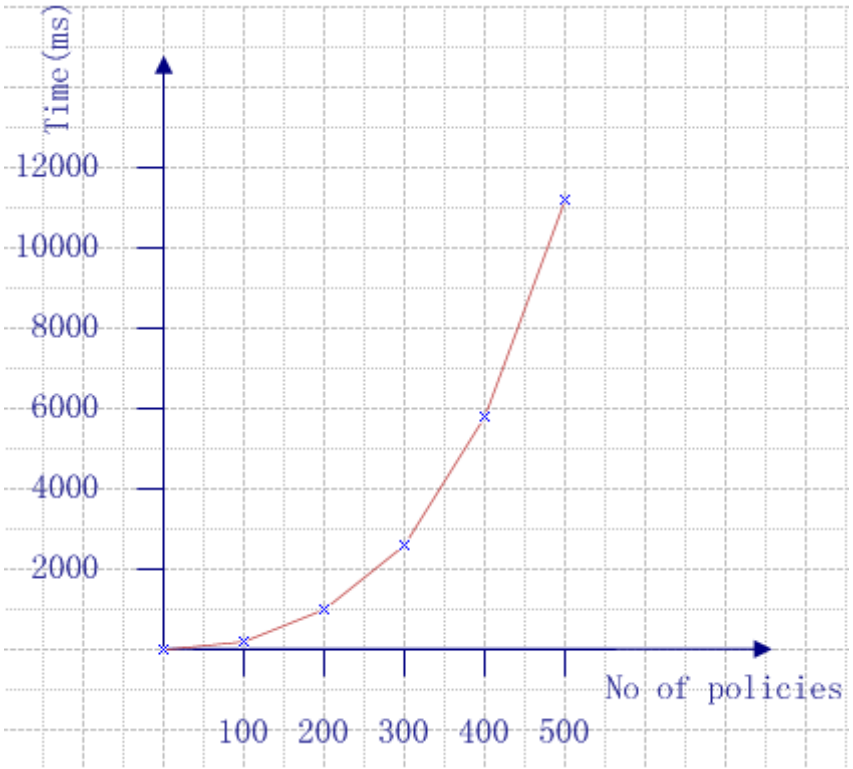


Figure: SPL

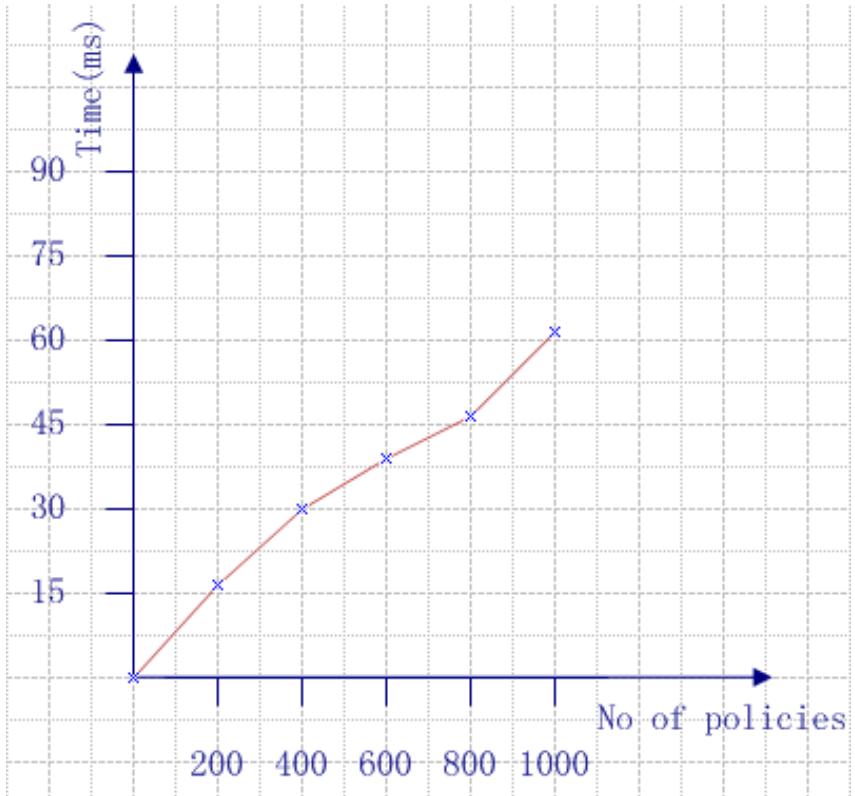
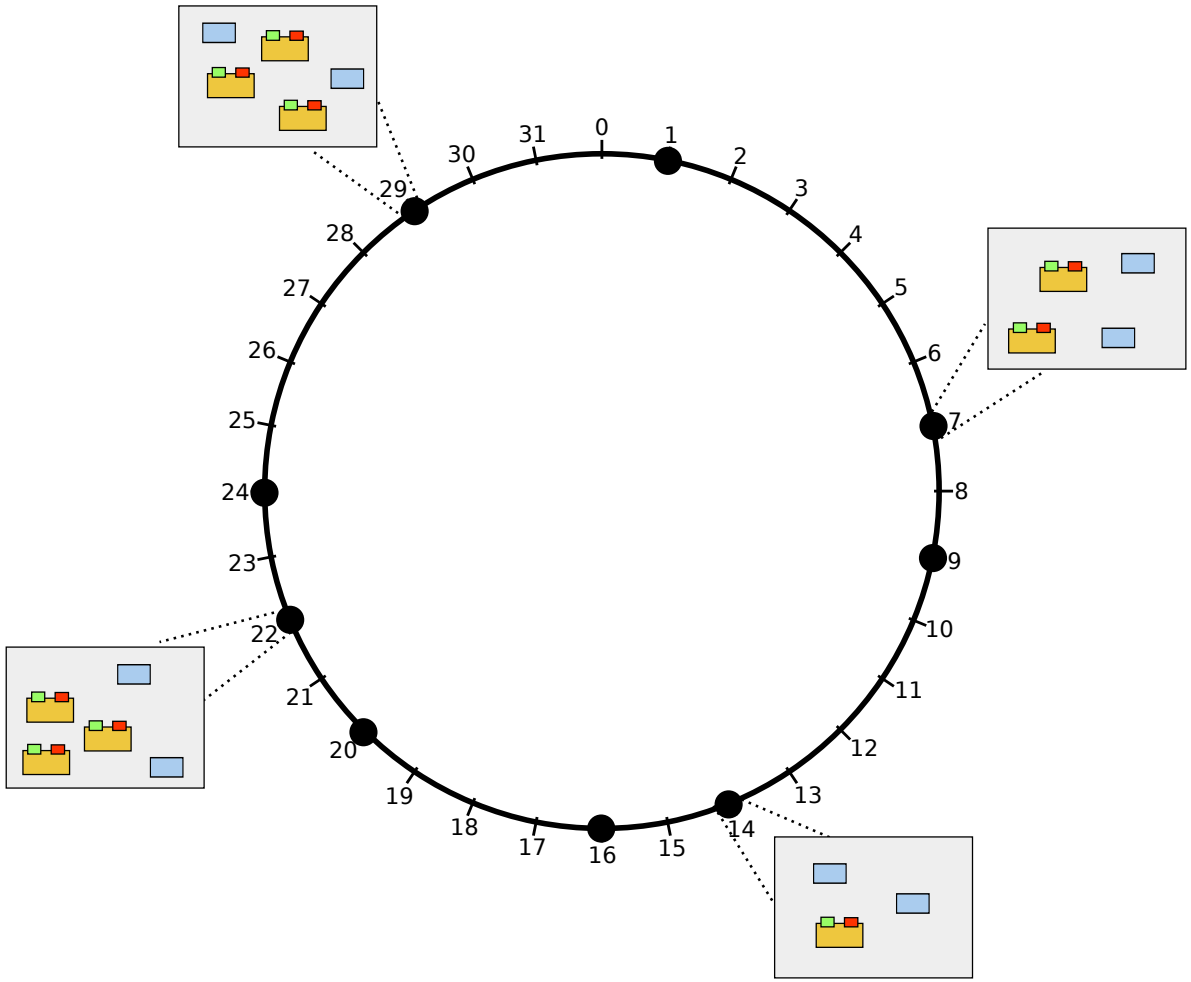


Figure: XACML

Outline

Robust Management Elements



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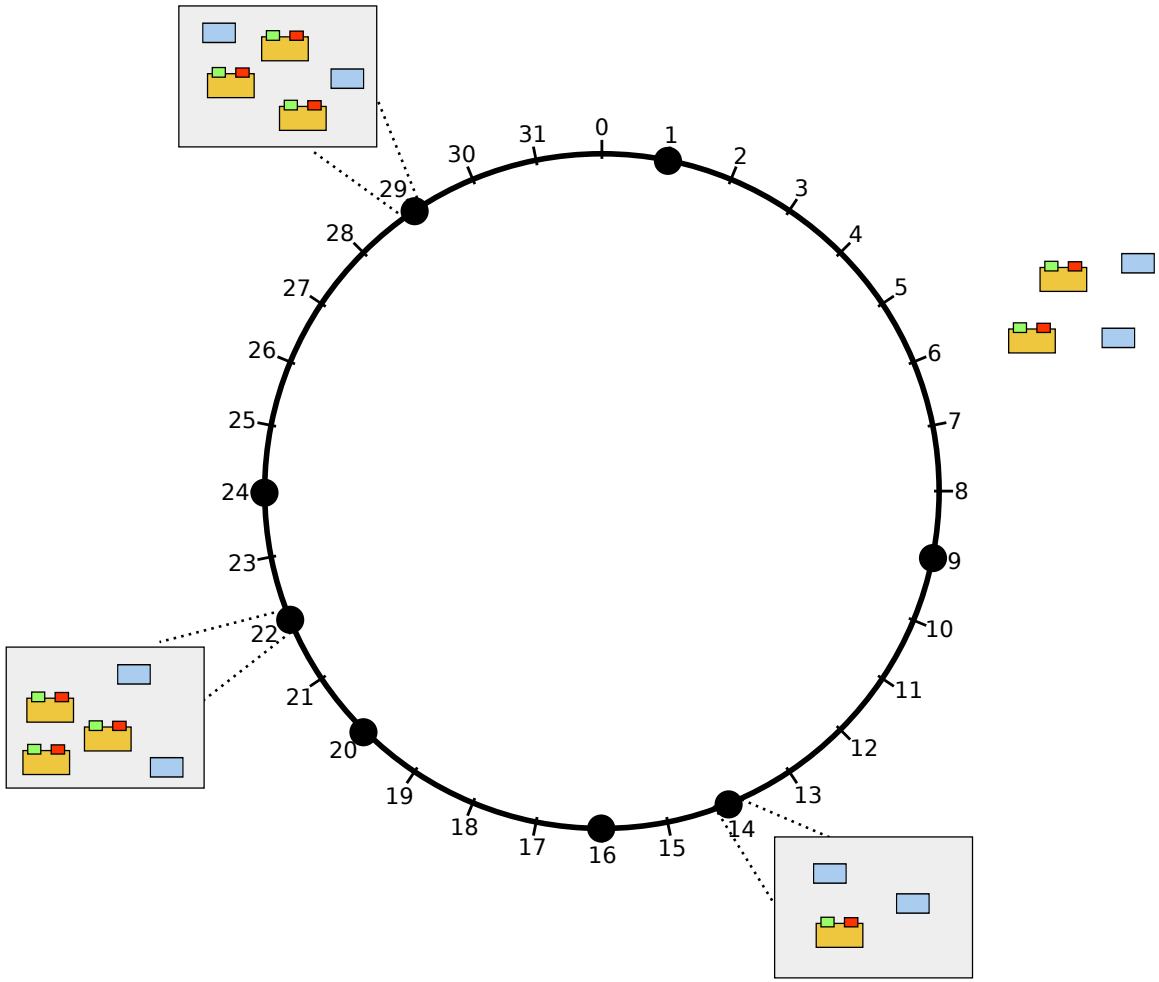

Robust Management Elements

A Robust Management Element (RME) should:

- Be replicated to ensure fault-tolerance
- Survive continuous resource failures by automatically restoring failed replicas on other nodes
- Maintain its state consistent among replicas
- Provide its service with minimal disruption in spite of resource join/leave/fail (high availability)
- Be location transparent (i.e. clients of the RME should be able to communicate with it regardless of its current location)

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- Finite state machine replication
- SMART algorithm for changing replica set (migration)
- Our decentralized algorithm to automate the process

End Result

A Robust Management Element (RME) that can be used to build robust management!

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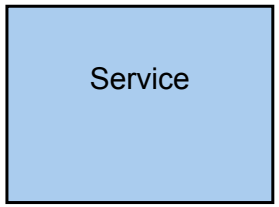

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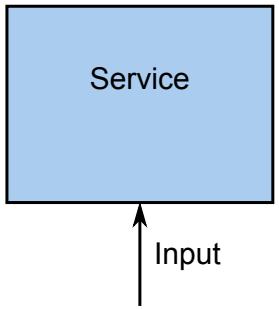

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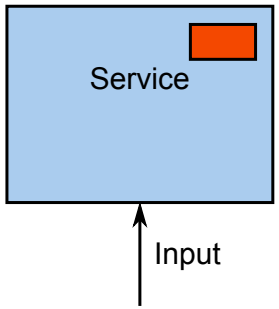

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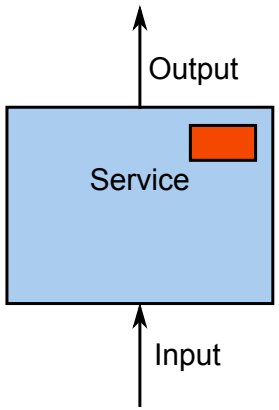

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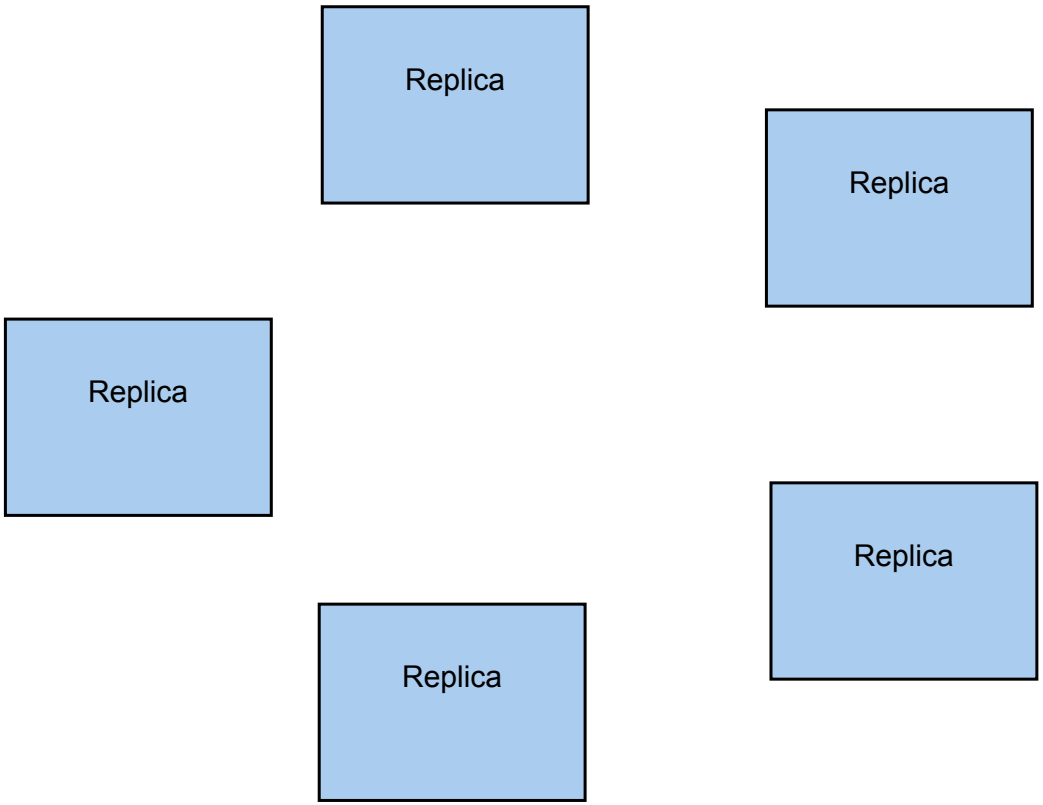

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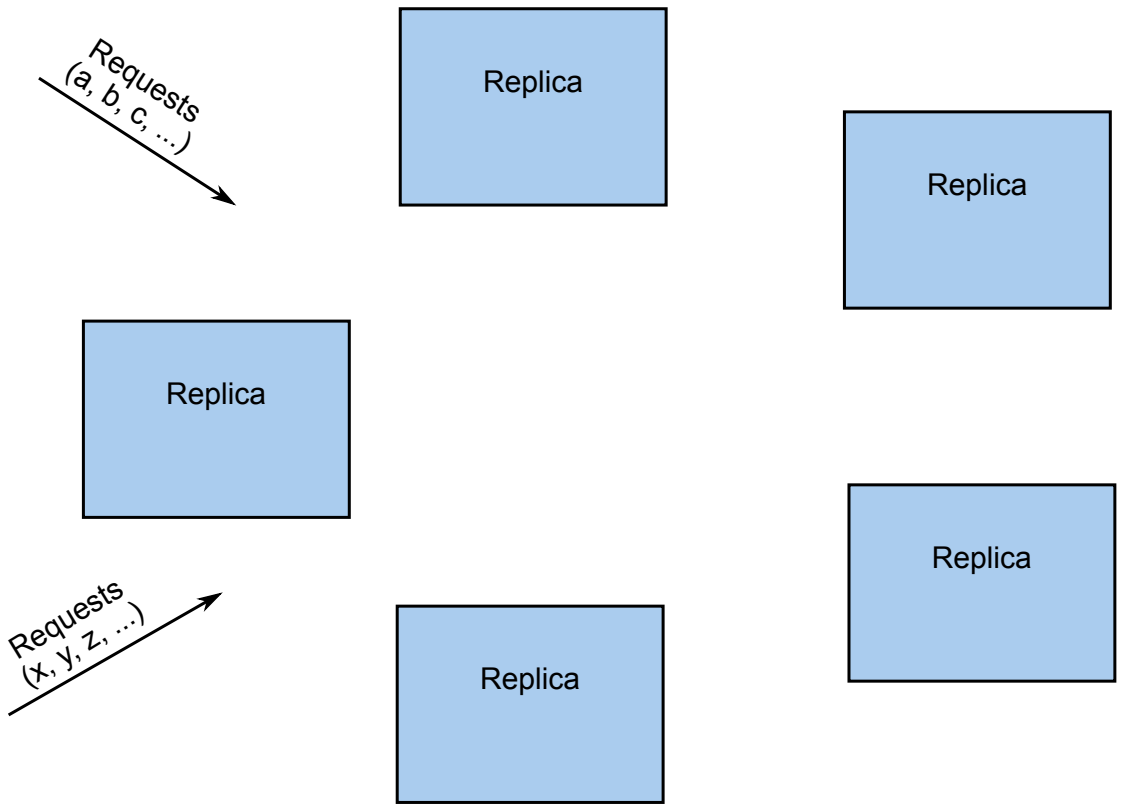

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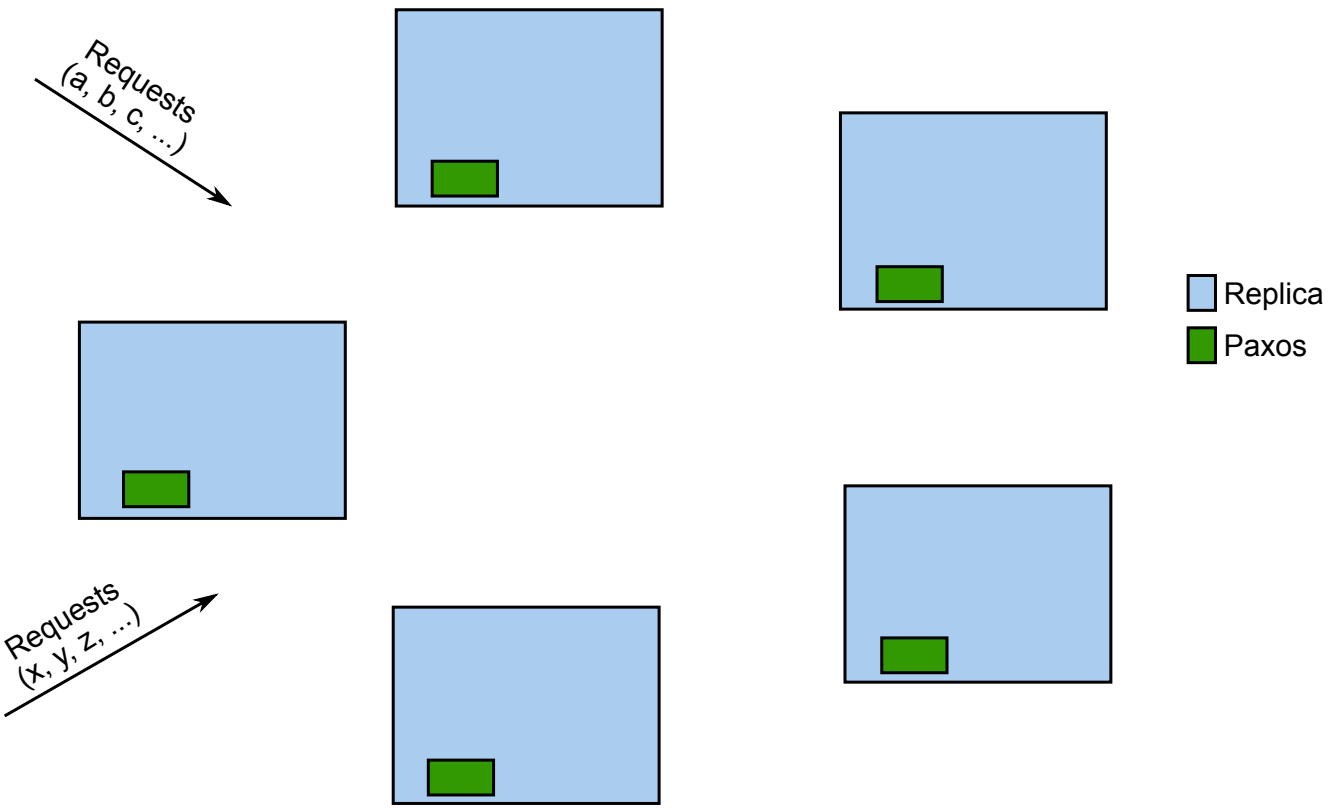

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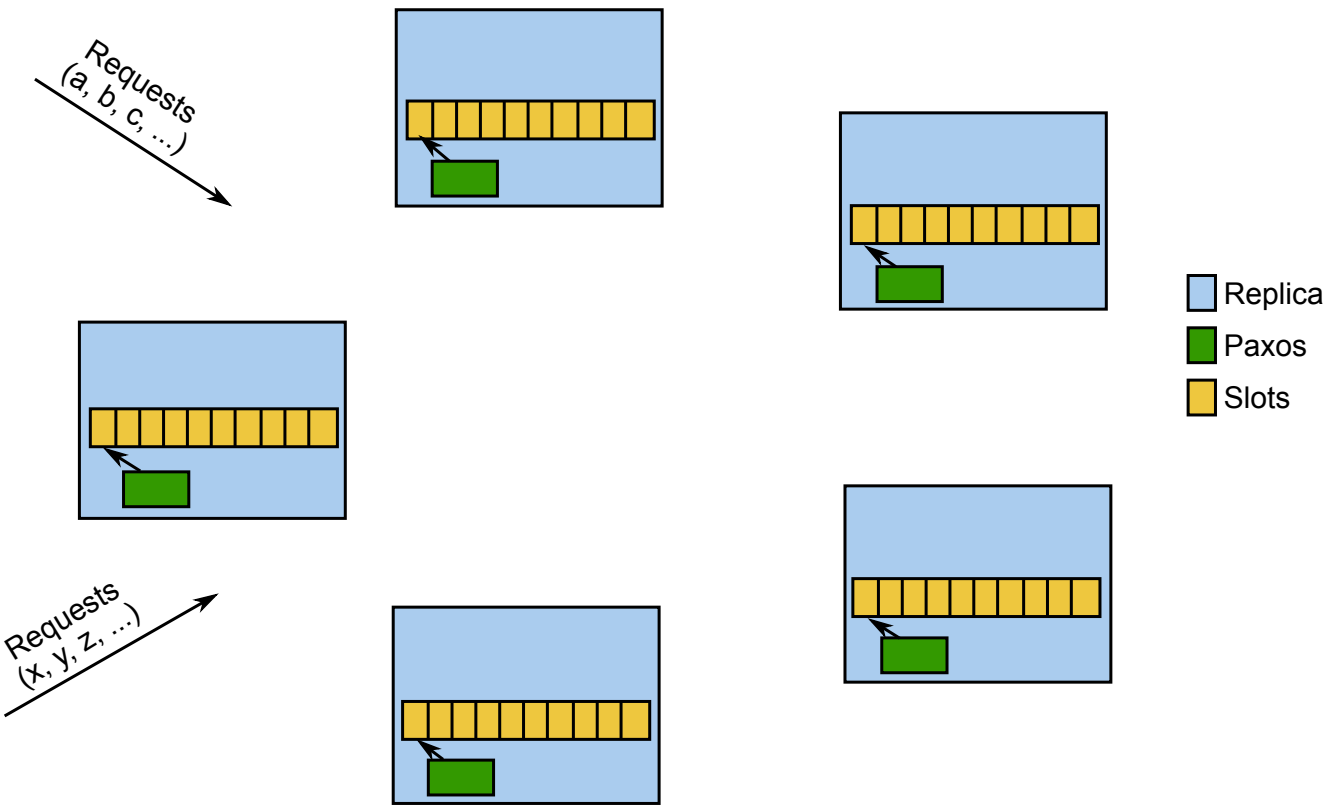

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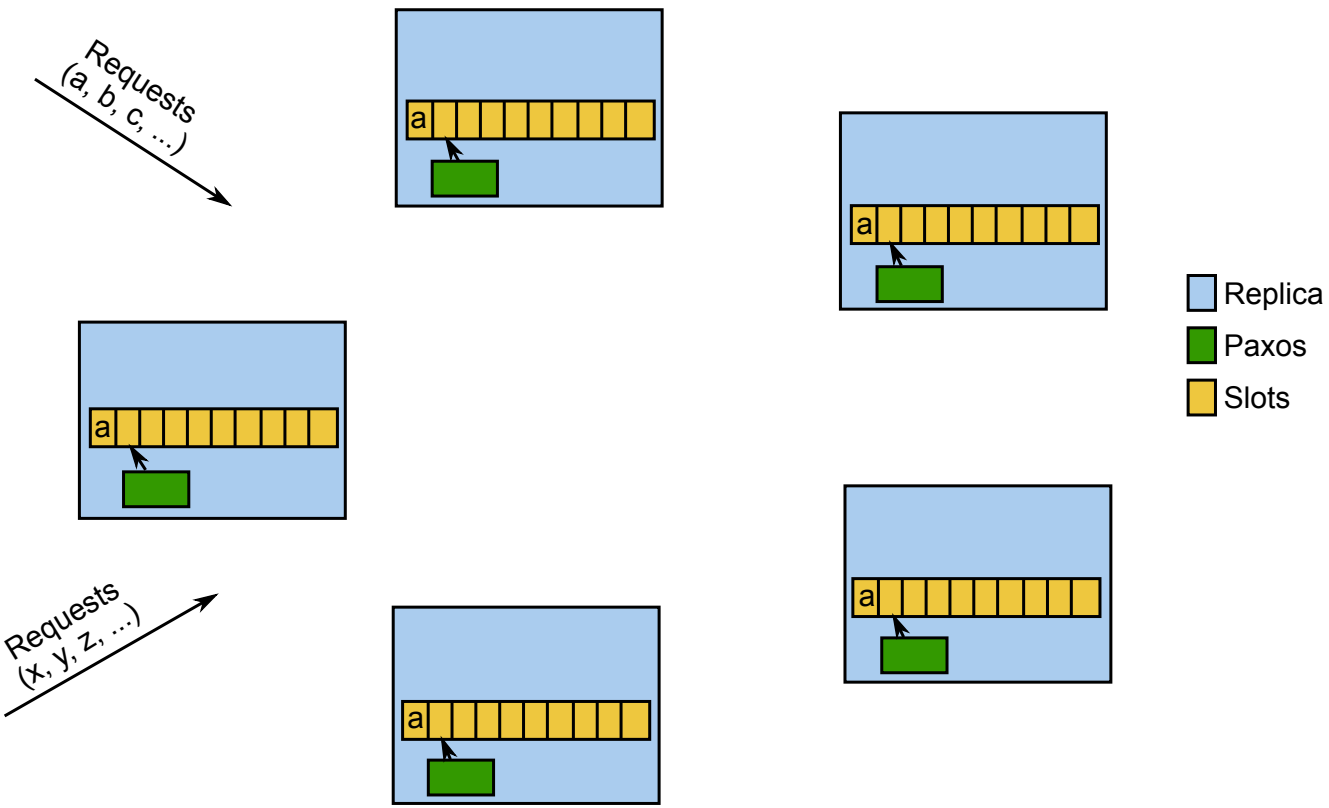

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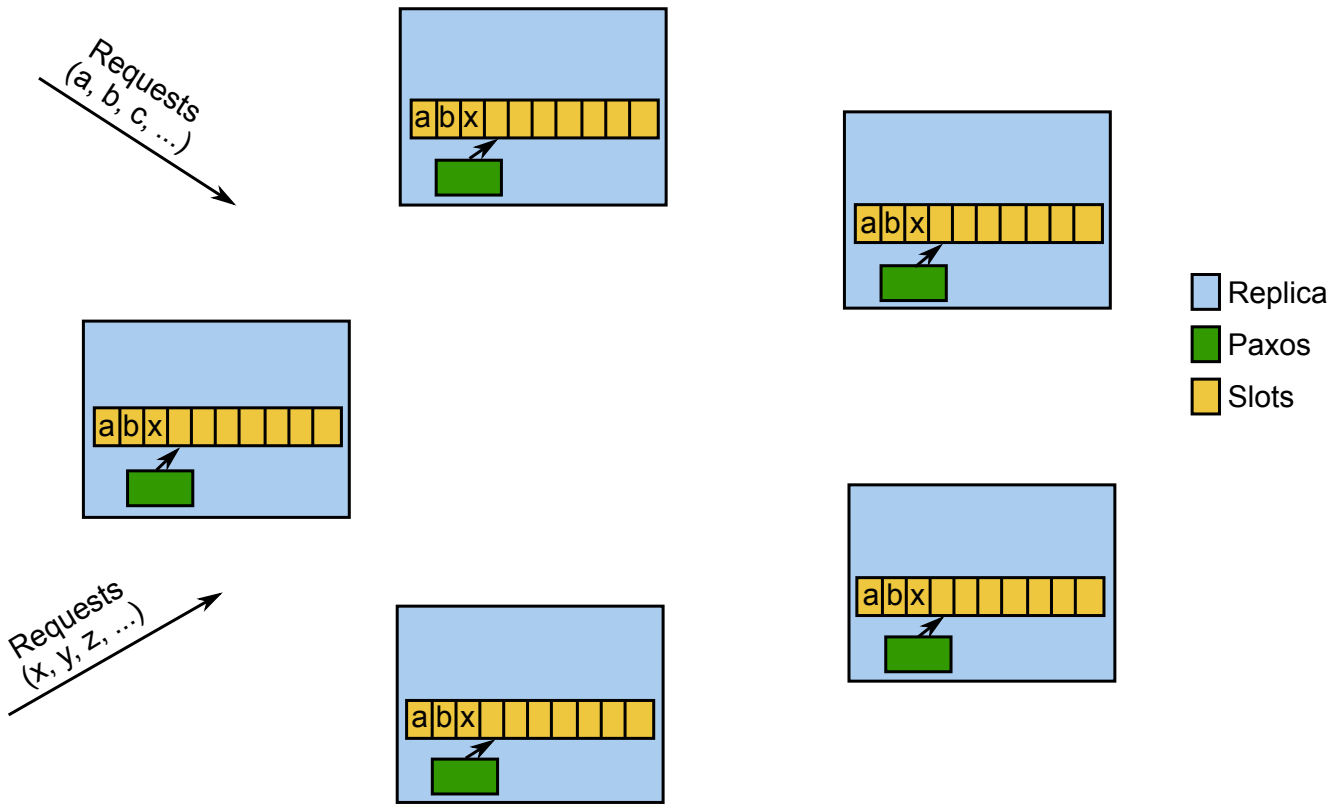

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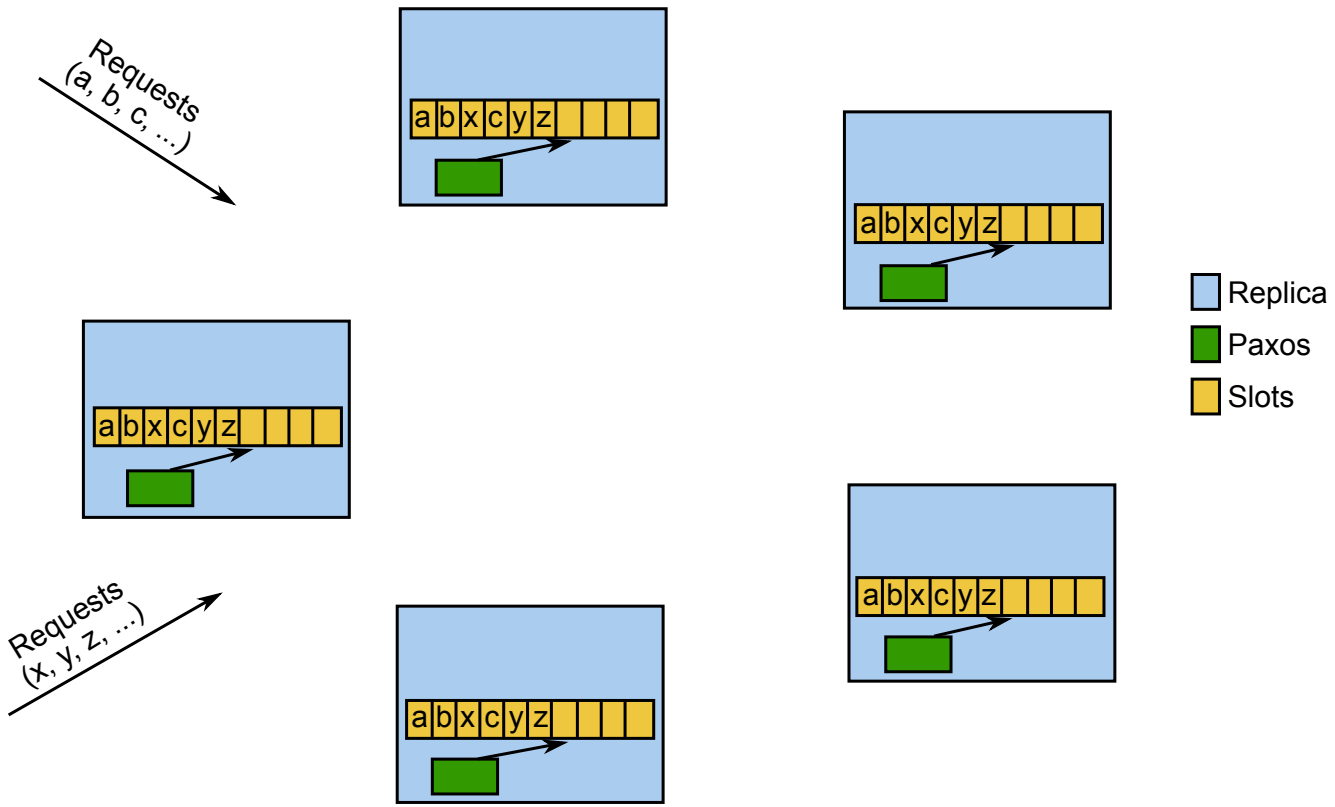

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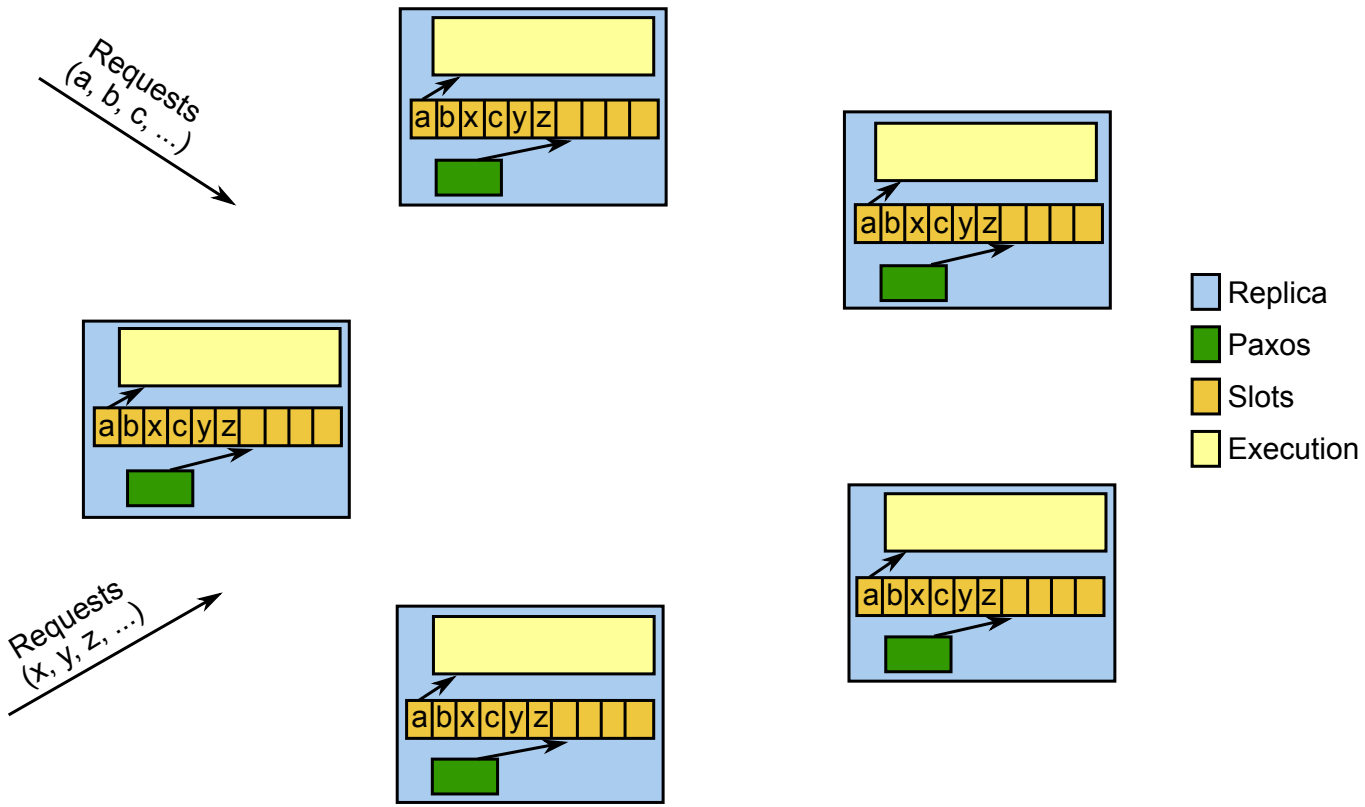

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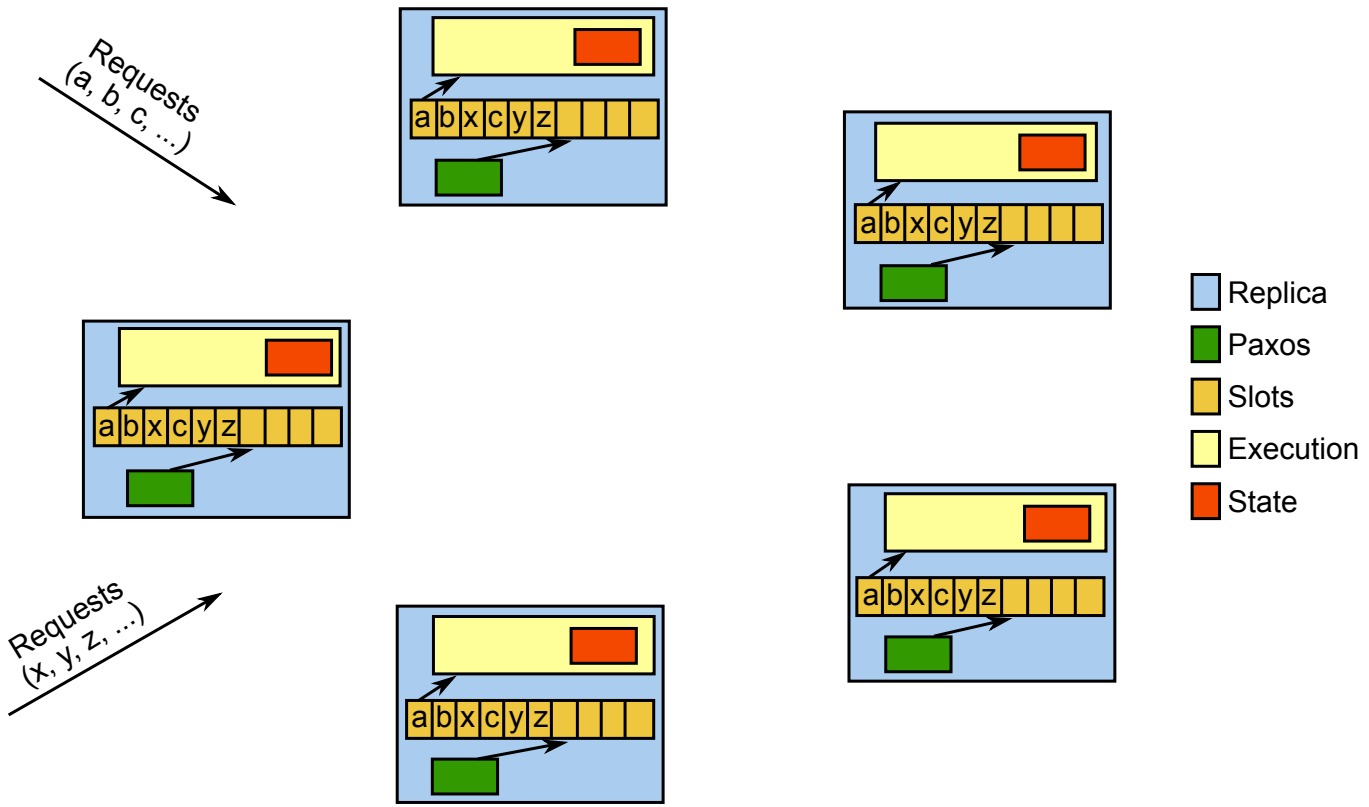

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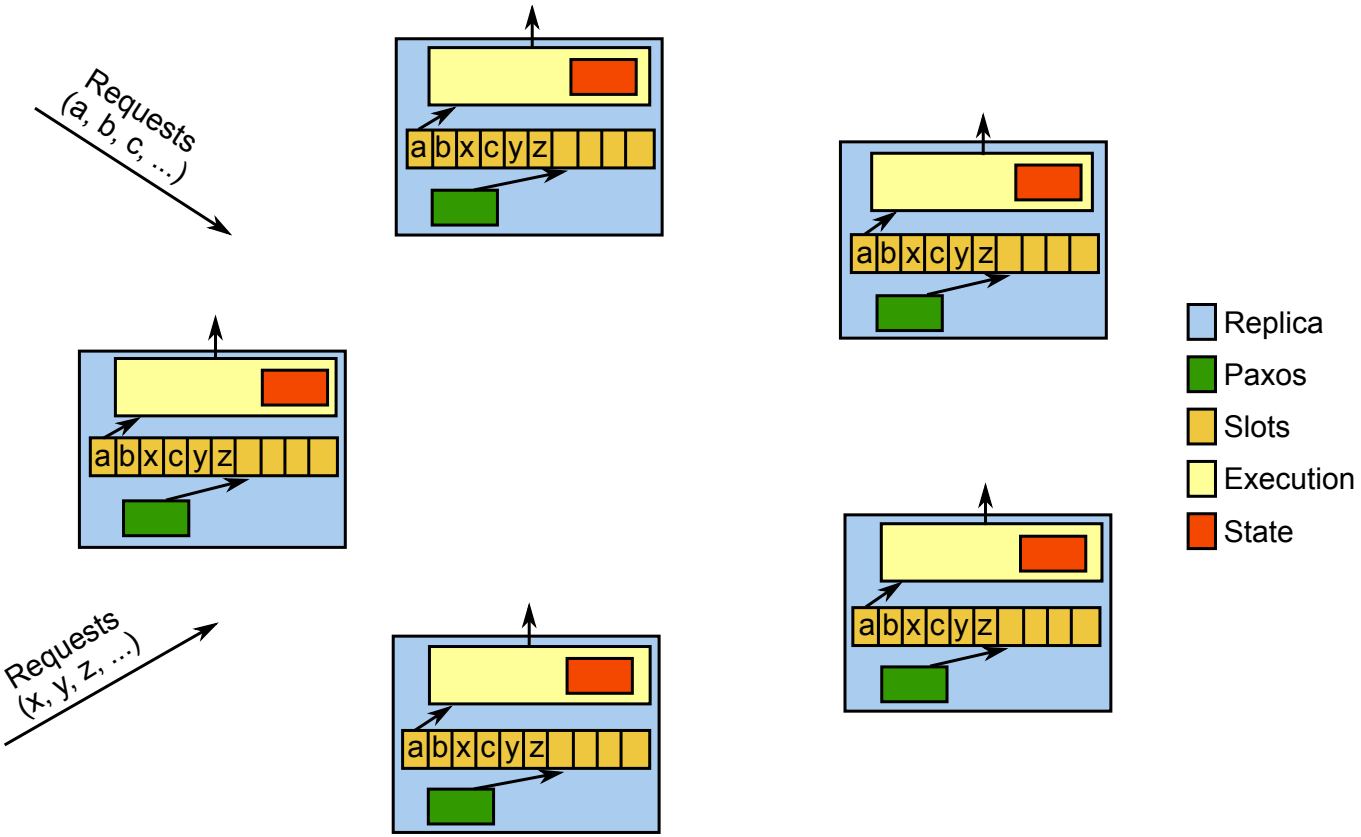

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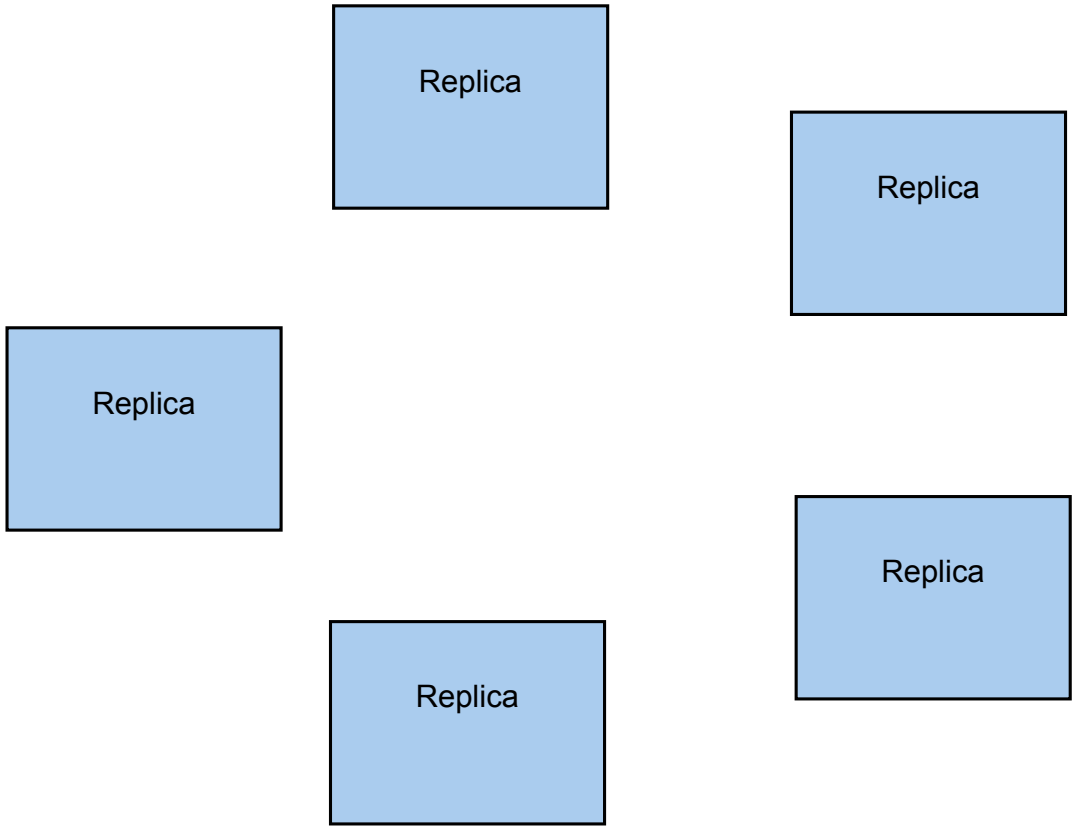

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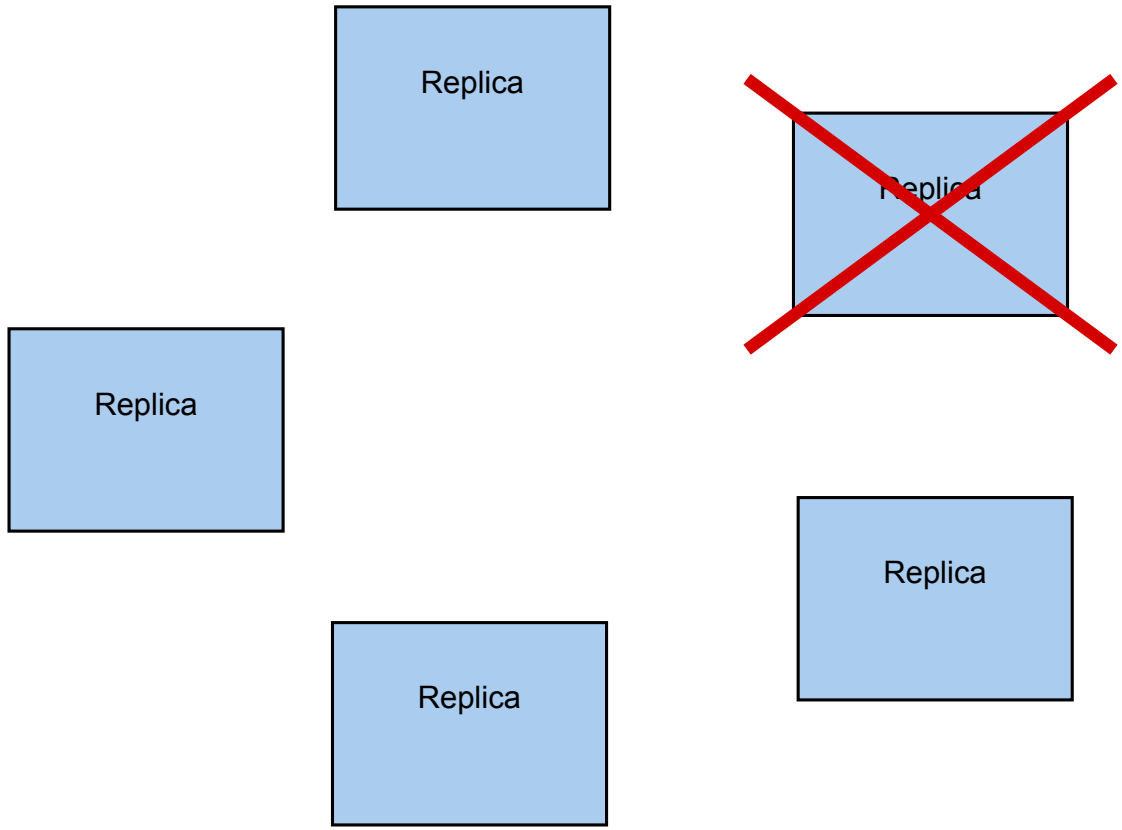

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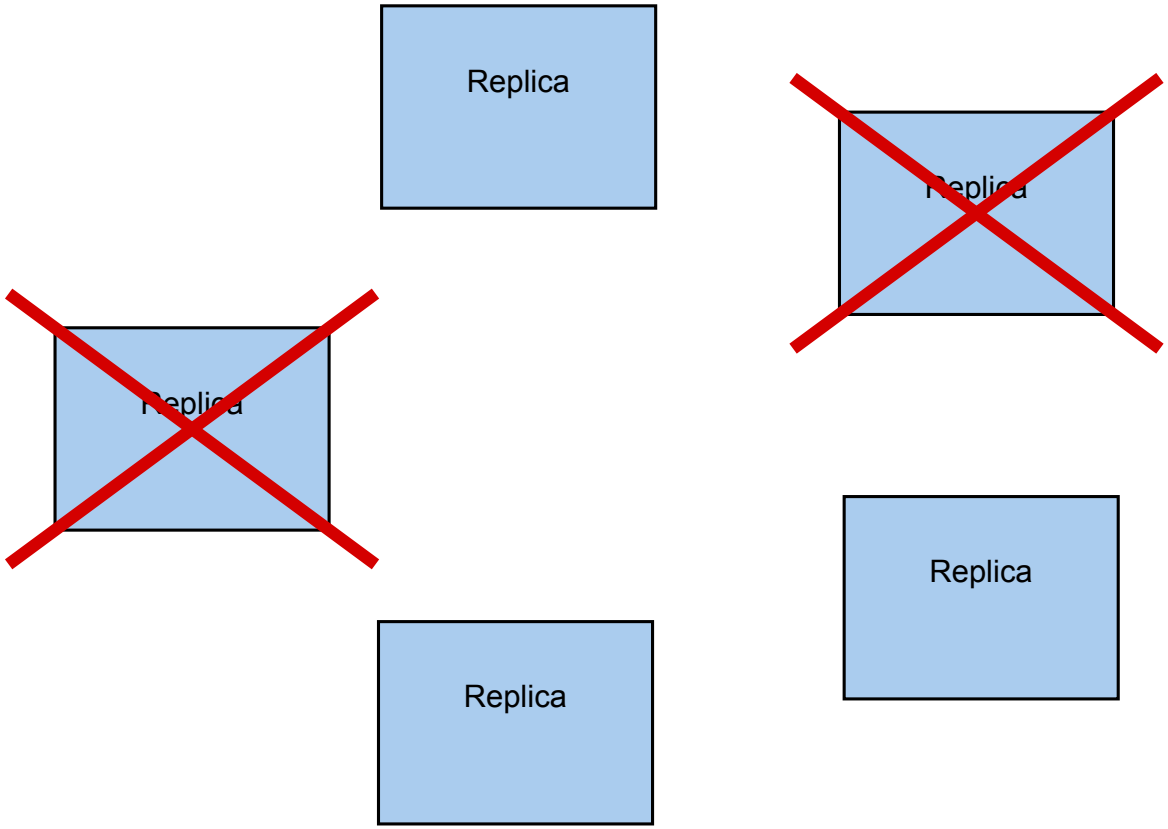

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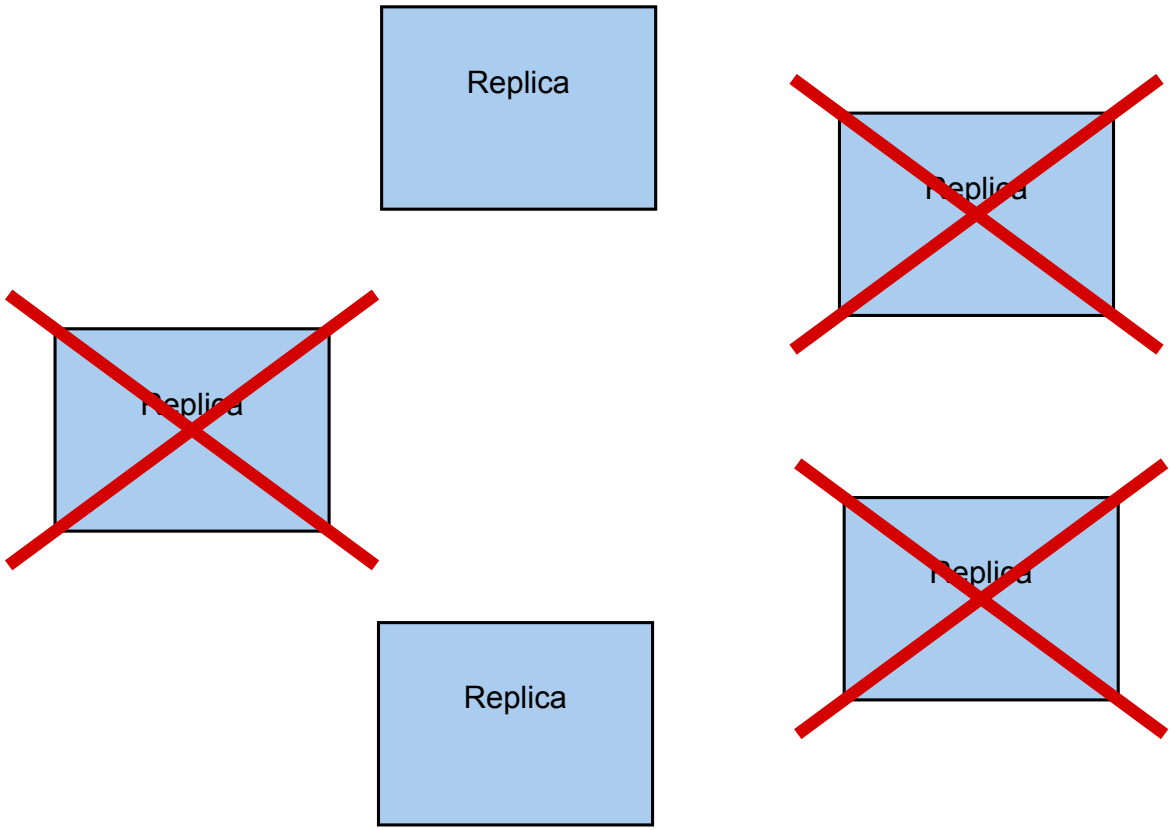

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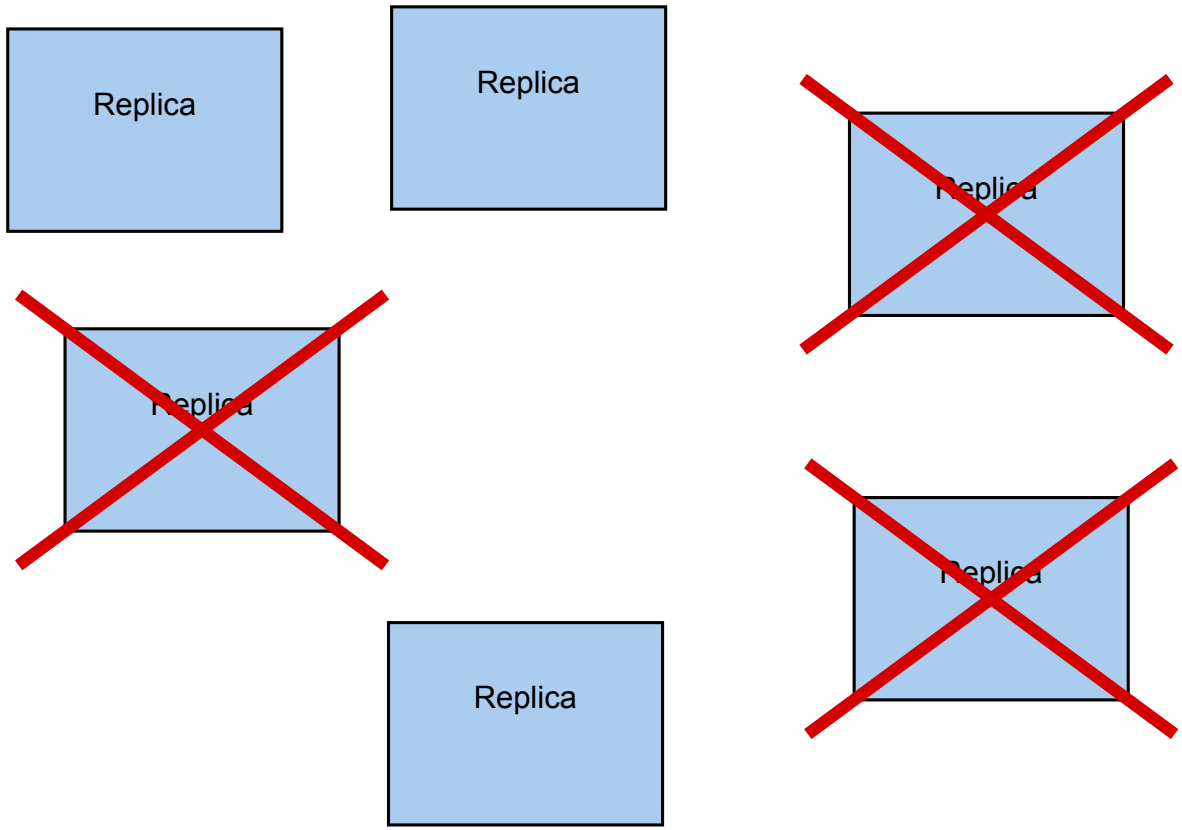

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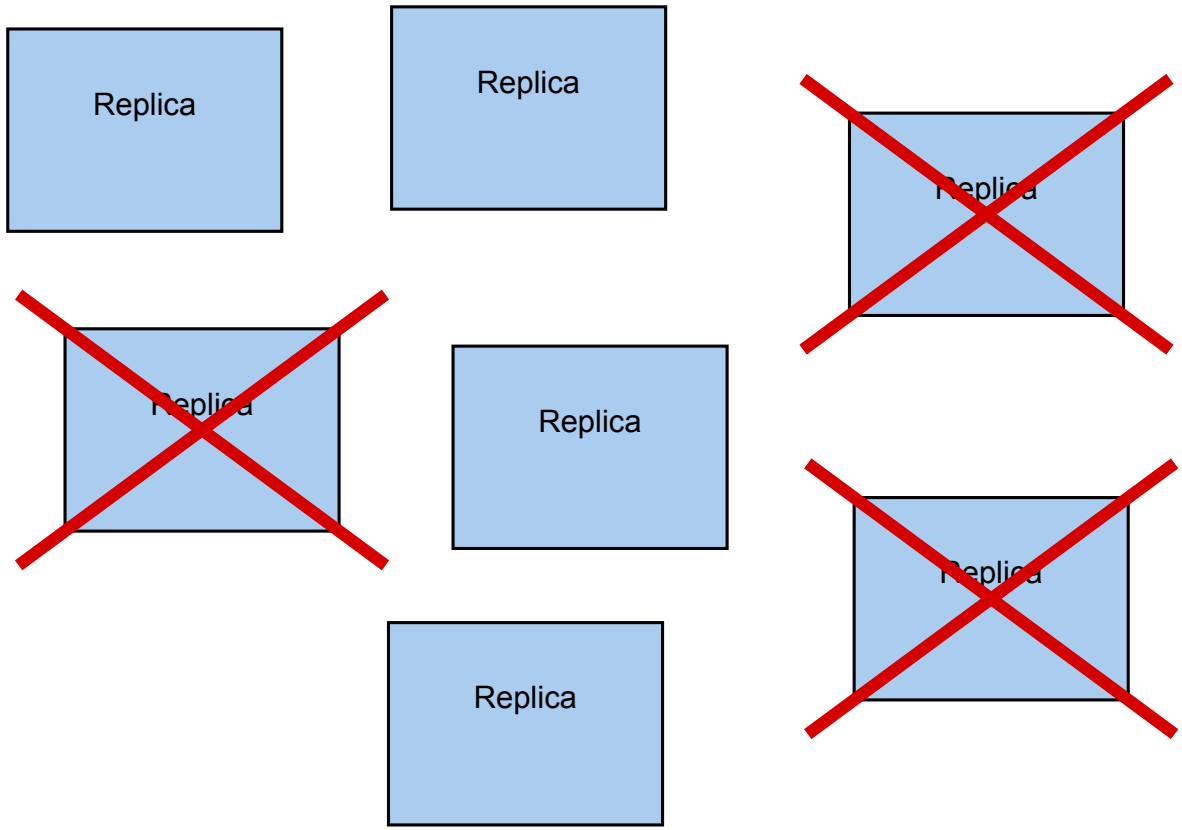

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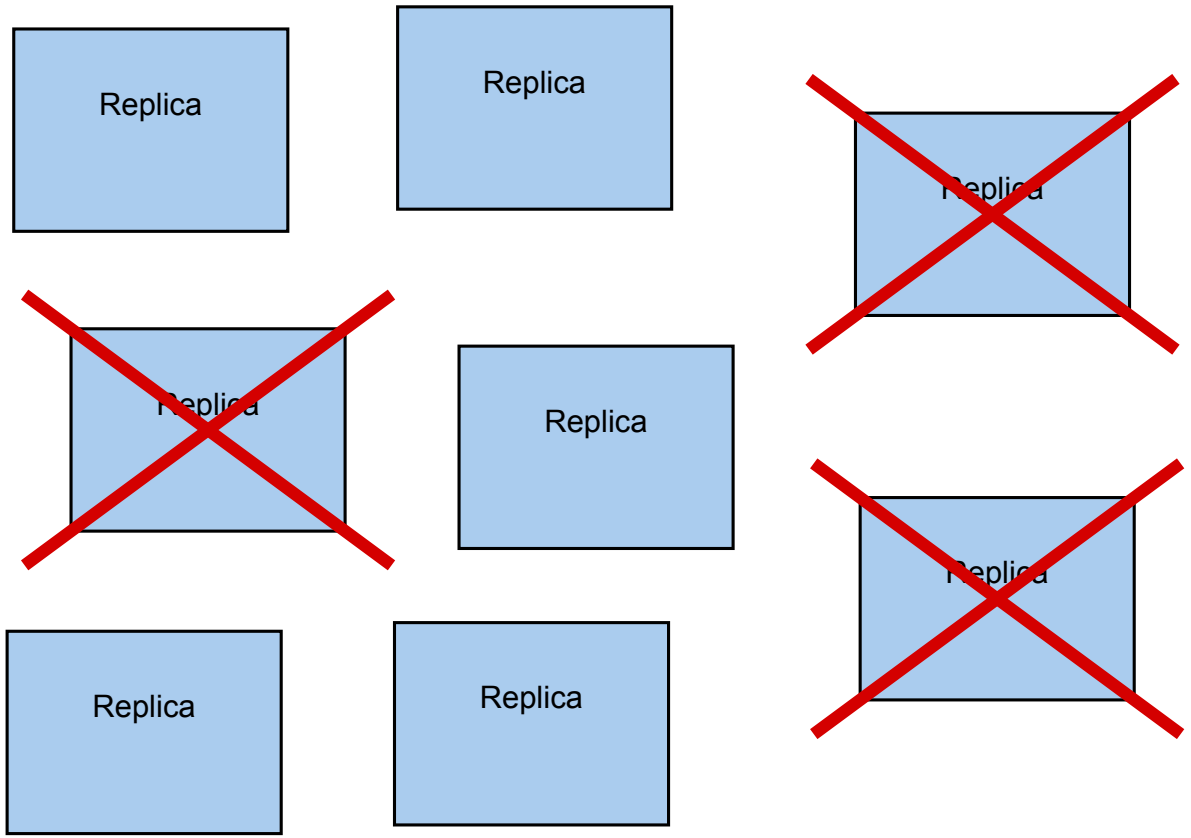

Migration: Basic Idea

- A configuration is the set of replicas
- Replicas include the configuration as part of the state
- A special request that changes the configuration
- Handled like normal requests (assigned a slot then executed)
- The change take effect after α slots
- We used the SMART algorithm Details

Our Algorithm

Goals

- Automatically maintain configuration in a decentralized way
- Select resources, detect failures, and decide to migrate
- Users find service without central repository

Approach

- We use Structure Overlay Networks(SONs)
- We use replica placement schemes (such as symmetric replication) to select nodes that will host replicas
- We use lookups and DHT ideas
- We use failure detection provided by SONs

Our Algorithm

Goals

- Automatically maintain configuration in a decentralized way
- Select resources, detect failures, and decide to migrate
- Users find service without central repository

Approach

- We use Structure Overlay Networks(SONs)
- We use replica placement schemes (such as symmetric replication) to select nodes that will host replicas
- We use lookups and DHT ideas
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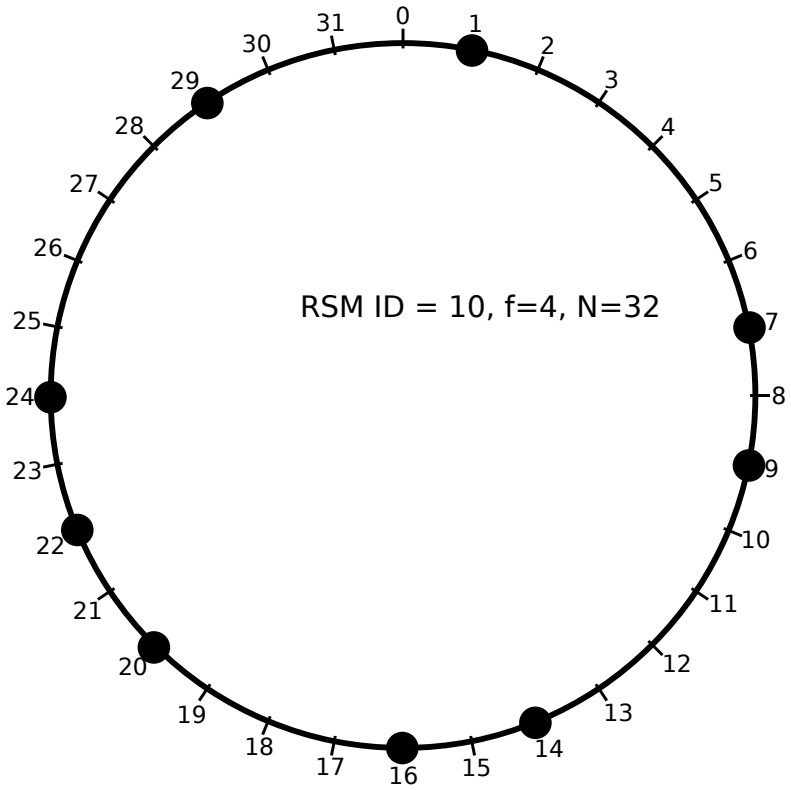
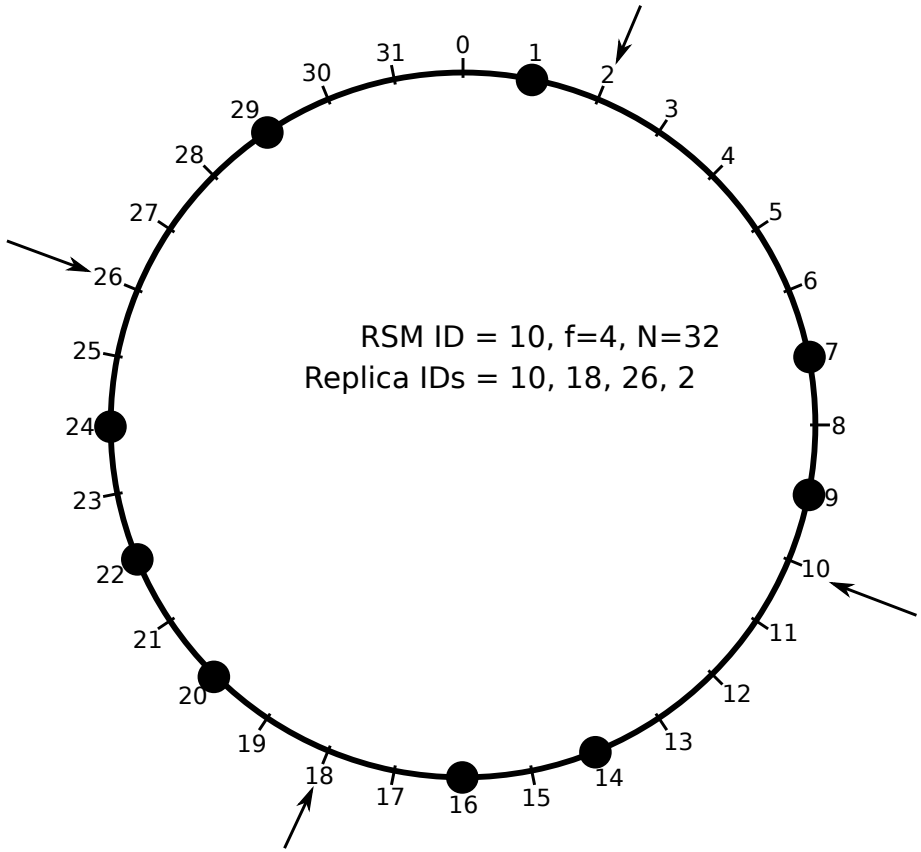
Creating a Replicated State Machine (RSM)

Any node can create a RSM. Select ID and replication degree



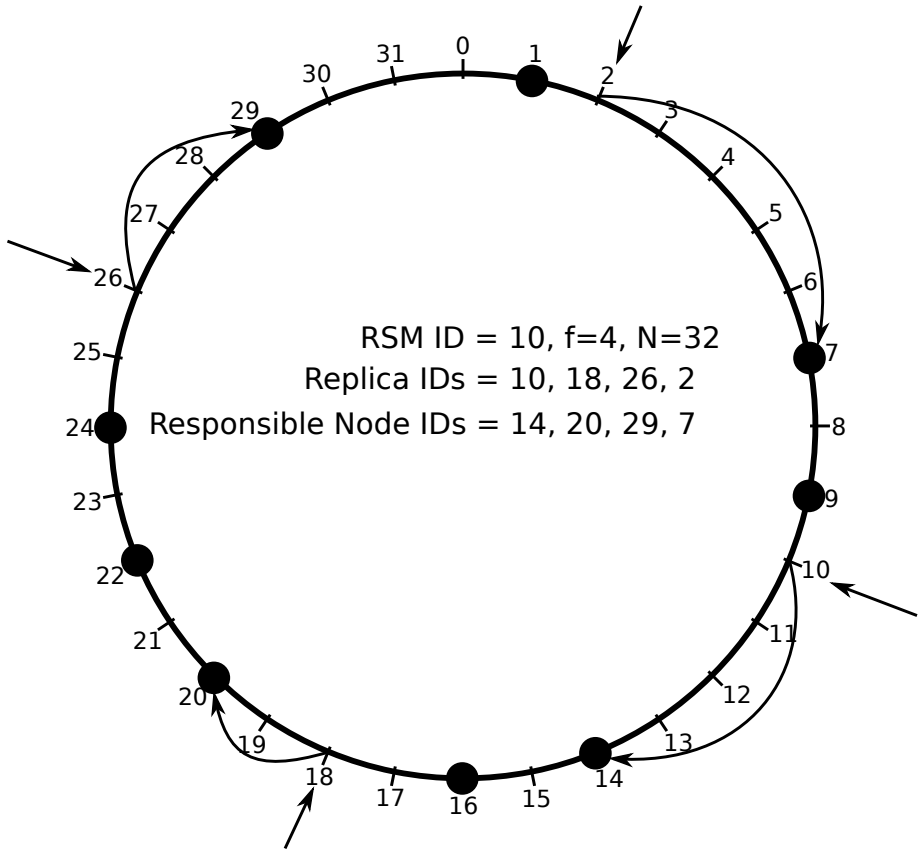
Creating a Replicated State Machine (RSM)

The node uses symmetric replication to calculate replica IDs



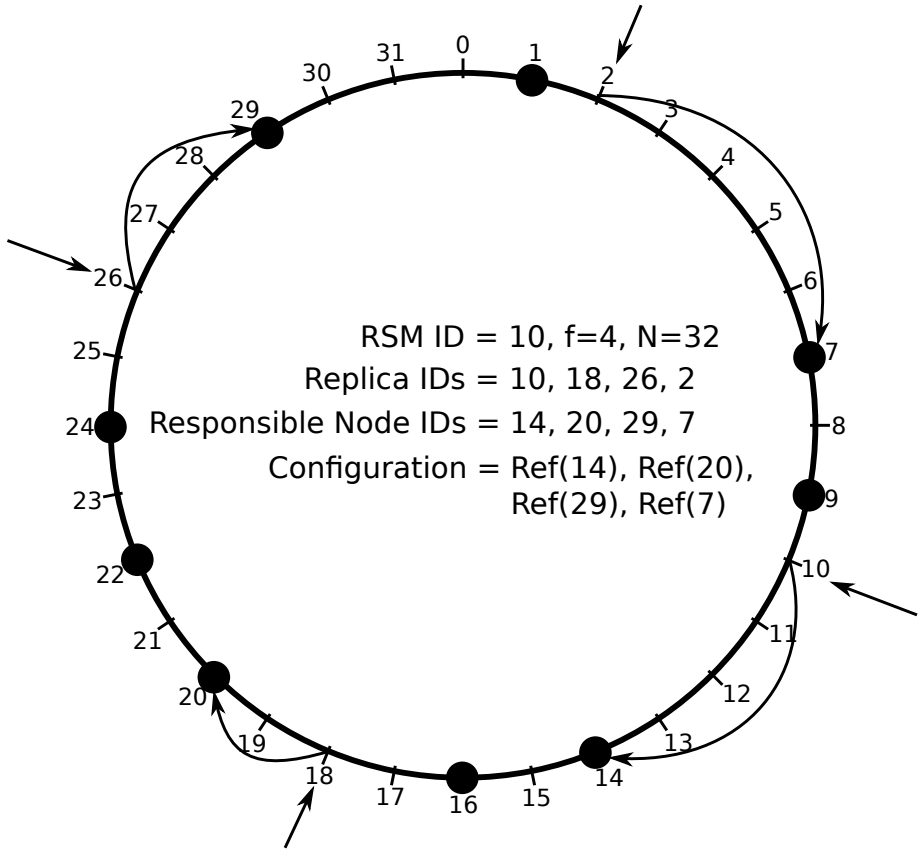
Creating a Replicated State Machine (RSM)

The node use lookups to find responsible nodes . . .



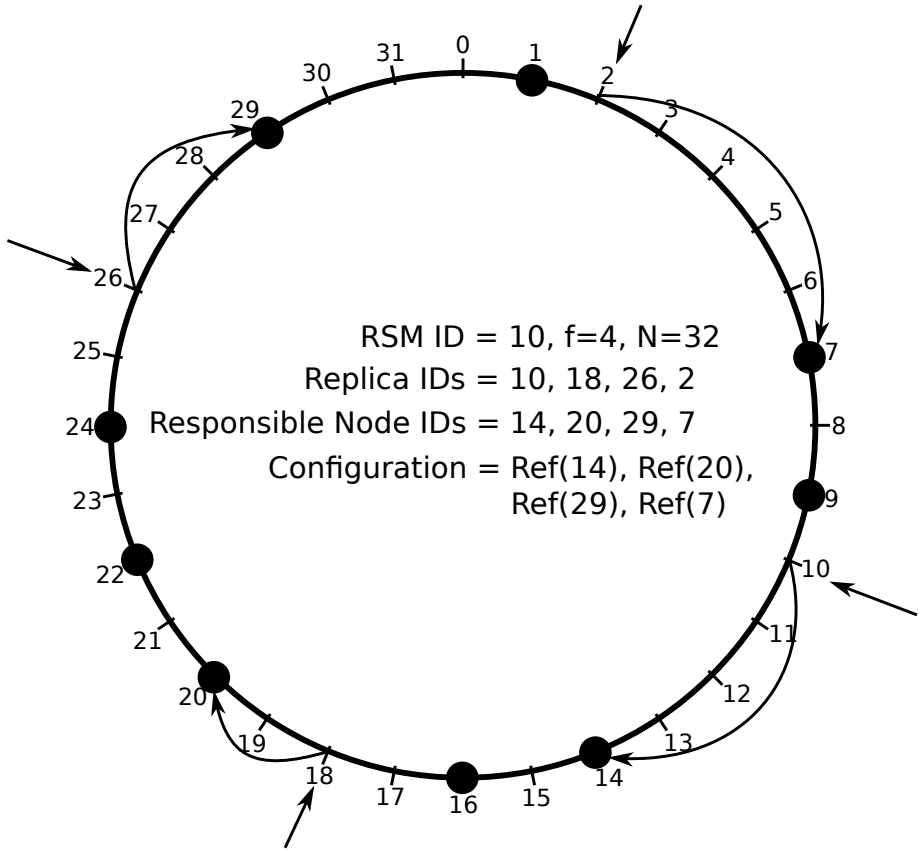
Creating a Replicated State Machine (RSM)

. . . and gets direct references to them



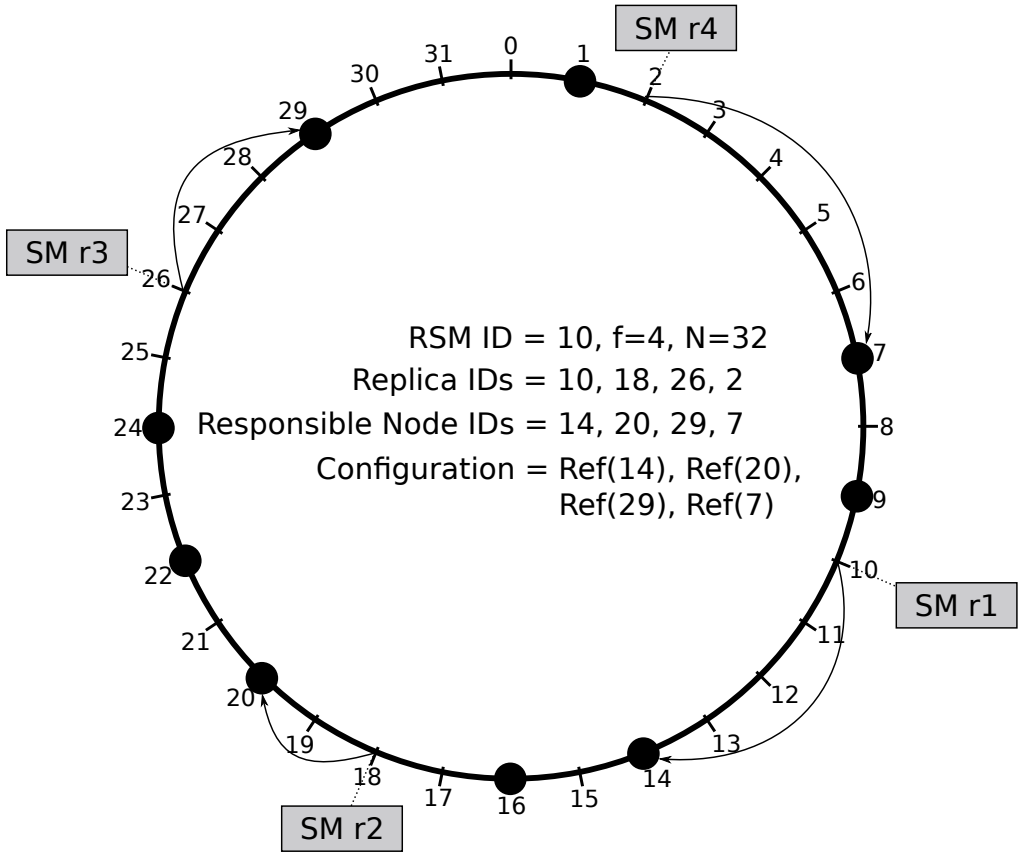
Creating a Replicated State Machine (RSM)

The set of direct references forms the configuration



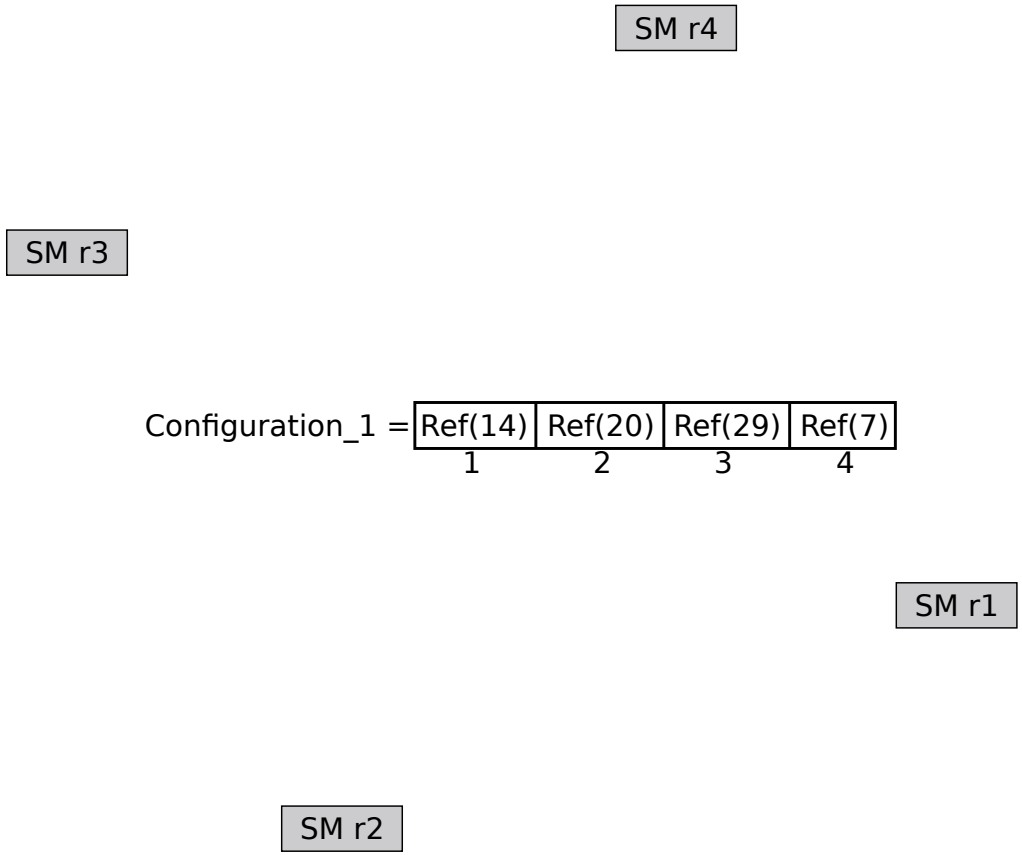
Creating a Replicated State Machine (RSM)

The node sends a *Create* message to the configuration

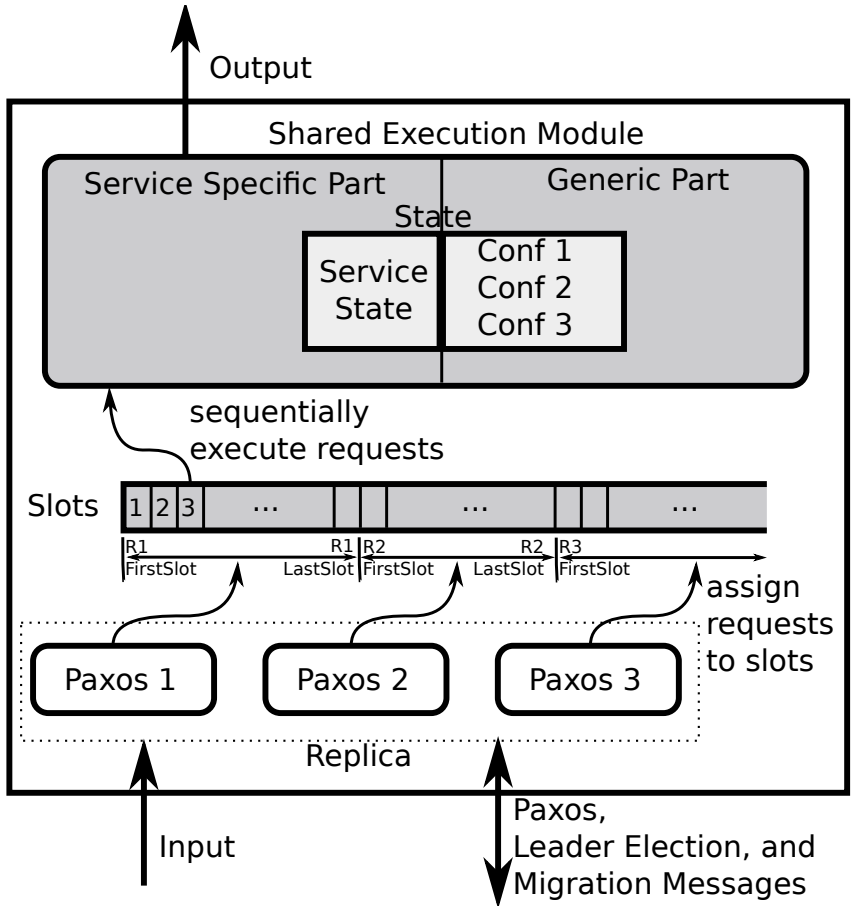


Creating a Replicated State Machine (RSM)

Now replicas communicate directly using the configuration



Replica Architecture



When to Migrate?

- To fix Lookup inconsistencies
- To handle resource churn

Handling Lookup Inconsistency

- Because of lookup inconsistency the configuration may contain incorrect nodes
- The inconsistency is detected when a node receives a request targeted at a replica that the node does not have but should be responsible for
- In this case the node issues a configuration change request asking the current configuration to replace the incorrect node with itself

Handling Churn

- Similar to handling churn in a DHT
  - When a node joins it gets a list of replicas (RSM_ID and rank) it is responsible for form its successor
  - When a node leaves it hand over replicas to its successor
  - When a node fails the successor uses symmetric replication and interval cast to find replicas it should be responsible for
- After getting the list of replicas the node issue a configuration request to each RSM to replace incorrect node with itself

Changing the Configuration (Migration)

- In SMART the admin sends a configuration change request that contains all nodes in the new configuration
- We can not do the same in a decentralized fashion to avoid conflicts

Example

- Assume current configuration is {A, B, C, D}
- Node X detects that C is dead and requests change to {A, B, X, D}
- Node Y detects that D is dead and requests change to {A, B, C, Y}
- Y overrides the change made by X!

Changing the Configuration (Migration)

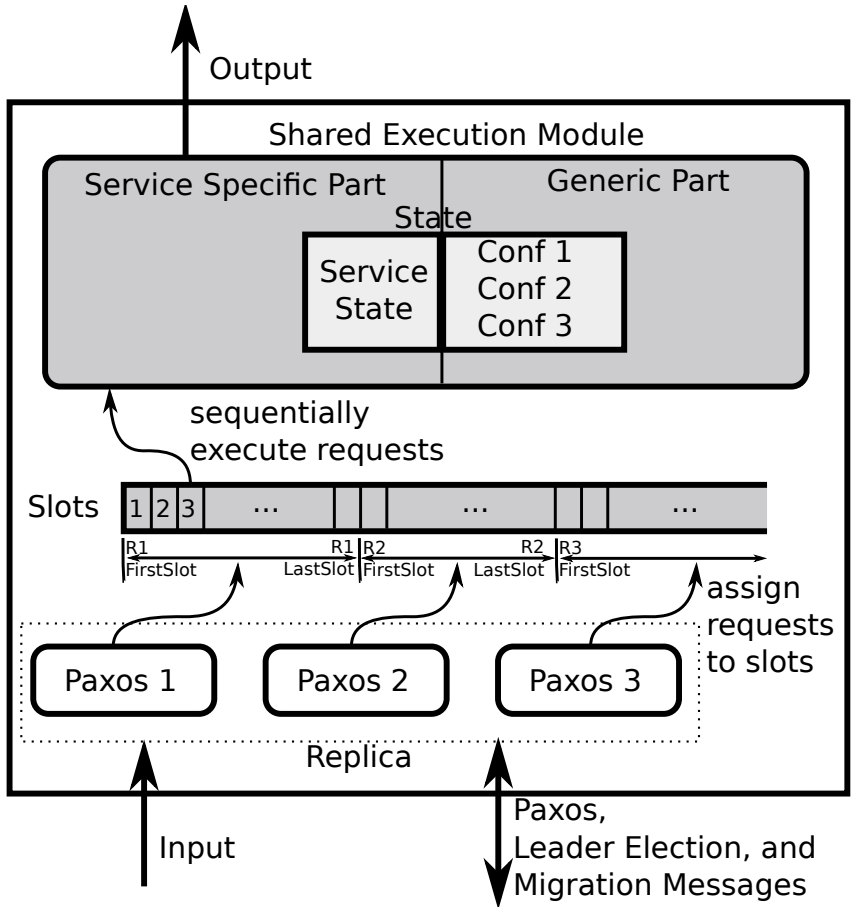
- In our approach the request does not contain the entire configuration. It contain only a request to replace a particular node

Example

- Assume current configuration is {A, B, C, D}
- Node X detects that C is dead and requests replacing replica 3 with itself
- Node Y detects that D is dead and requests replacing replica 4 with itself
- The end result is {A, B, X, Y}

Robust Management Elements

- Our approach is generic and can be useful for many services
- We use it in Niche to implement Robust Management Elements
- Replace the service specific part of the execution module with a management element



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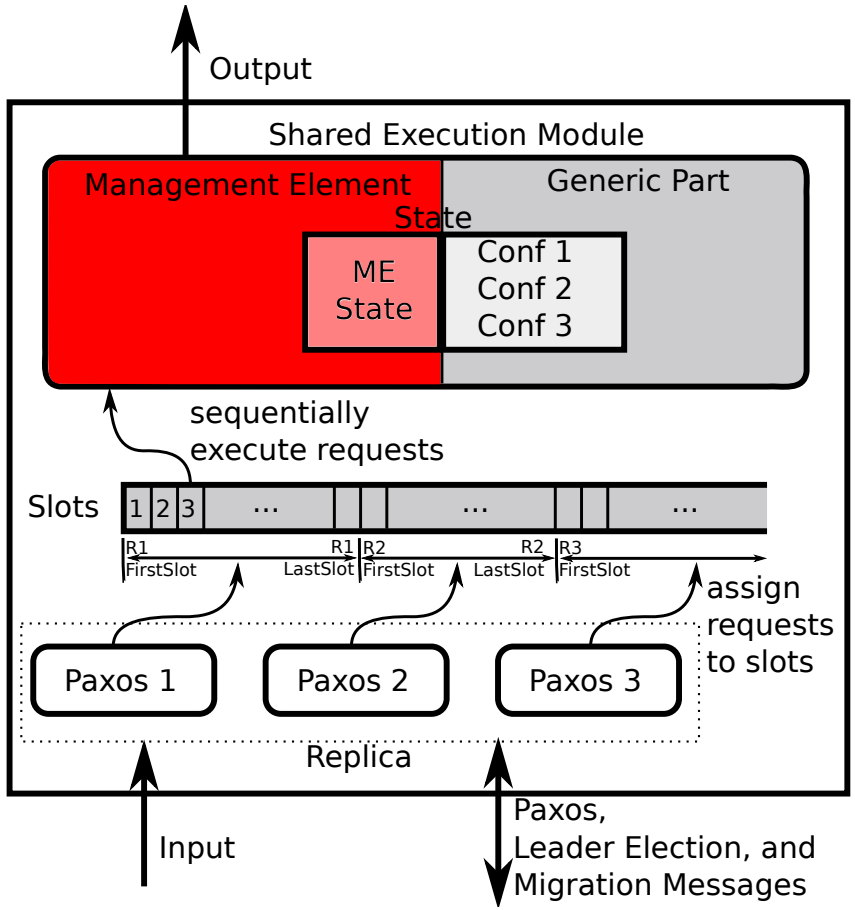


Outline

Conclusions

- Niche Platform
  - Enable self-management
  - Programming and runtime execution
  - Large-scale and/or dynamic systems
- Methodology
  - Design space and guidelines
  - Interaction patterns
- YASS use case
- Policy based management
- Robust Management Elements

Future Work

- Refine design methodology including steps and interaction patterns
- Consider more use cases focusing on real applications
- Study and investigate management patterns and techniques
  - Distributed control, distributed optimization
  - Model Predictive Control (MPC)
  - Reinforcement learning in (feedback) control
  - Networked Control System (NCS)
- Focus more on self-tuning
- Complete work on Robust Management Elements
- Port Niche to Kompics component model

Thank you for careful listening :-)

Questions?

SPL Policy Example

```
Policy {
  Declaration {
    lowloadthreshold = 500;
  }
  Condition {
    storageInfo.totalLoad <= lowloadthreshold
  }
  Decision {
    manager.setTriggeredHighLoad(false) &&
    manager.delegateObligation("release storage")
  }
}:1;
```

Return

XACML Policy Example

```
<Policy PolicyId="lowLoadPolicy"
        RuleCombiningAlgId="urn:oasis:names:tc:xacml:1.0:rule-combining-algorithm:permit-overrides">
  <Target>
    <Subjects>       <AnySubject />     </Subjects>
    <Resources>       <AnyResource />     </Resources>
    <Actions>
      <Action>
        <ActionMatch MatchId="urn:oasis:names:tc:xacml:1.0:function:string-equal">
          <AttributeValue DataType="http://www.w3.org/2001/XMLSchema#string">
            load
          </AttributeValue>
          <ActionAttributeDesignator AttributeId="urn:oasis:names:tc:xacml:1.0:action:action-id"
                                     DataType="http://www.w3.org/2001/XMLSchema#string" />
        </ActionMatch>
      </Action>
    </Actions>
  </Target>
  <Rule Effect="Permit" RuleId="lowLoad">
    <Condition FunctionId="urn:oasis:names:tc:xacml:1.0:function:double-less-than-or-equal">
        <Apply FunctionId="urn:oasis:names:tc:xacml:1.0:function:double-one-and-only">
         <EnvironmentAttributeDesignator DataType="http://www.w3.org/2001/XMLSchema#double"
                                    AttributeId="totalLoad"/>
       </Apply>
      <AttributeValue> 500 </AttributeValue>
    </Condition>
  </Rule>
  <Obligations>
    <Obligation FulfillOn="Permit" ObligationId="2">
      <AttributeAssignment AttributeId="lowLoad_obligation" DataType="http://www.w3.org/2001/XMLSchema#integer">
        "release storage"
      </AttributeAssignment>
    </Obligation>
  </Obligations>
</Policy>
```

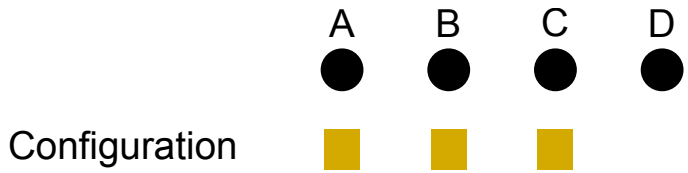
Return

Migration: The SMART Algorithm

- SMART is a new technique for changing the set of nodes (configuration) where a replicated service runs (i.e. migrating the service)
- Advantages over other approaches (as described by SMART authors):
  - Allows migrations that replace non-failed nodes (suitable for automated service)
  - Can pipeline concurrent requests (performance optimization)
  - Provides complete description

Configuration-Specific Replicas

- Each replica is associated with one and only one configuration
- Migration creates a new set of replicas (configuration)
- Simplifies the migration process
- Each configuration uses its own instance of the Paxos algorithm
- Inefficient implementation (use shared execution module to improve it)



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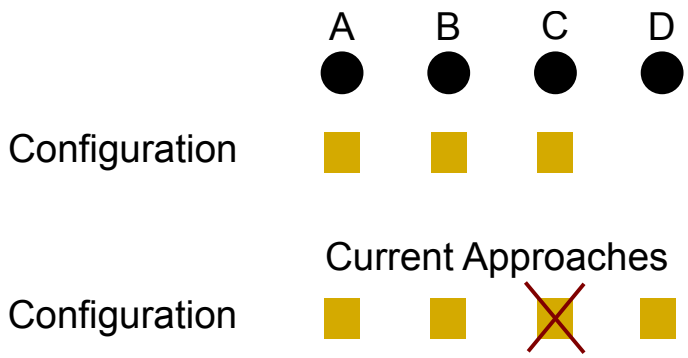

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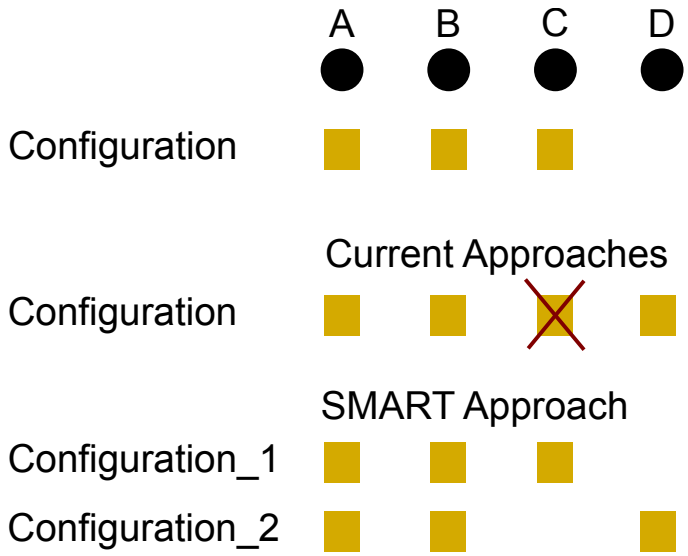

SMART

- Avoids inter-configuration conflicts by assigning none overlapping range of slots [*FirstSlot*, *LastSlot*] to each configuration
- The old configuration sends a Join message to the new configuration
- A replica in a new configuration need to copy state from another replica (up till at least $FirstSlot - 1$)
- Destroying old configurations (Finished and Ready messages)
- Clients use a configuration repository to find the current configuration
- SMART does not deal with how to select a configuration and when to migrate

Challenges Implementing Lamport's Idea

- **Unaware-leader challenge:** A new leader may not know the latest configuration
- **Window-of-vulnerability challenge:** Migrations that remove or replace a machine can create a period of reduced fault tolerance
- **Extended-disconnection challenge:** After a long disconnection, a client may be unable to find the service
- **Consecutive-migration challenge:** If request n changes the configuration, requests $n + 1$ through $n + \alpha - 1$ cannot change the configuration
- **Multiple-poll challenge:** A new leader may have to poll several configurations

Return