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Self-Coordination through Dynamic Group Management

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Abstract - In un sistema distribuito il numero di entità che collaborano per raggiungere un obiettivo comune può crescere in maniera notevole. In queste situazioni, il turnover degli elementi può essere elevato, e i requisiti di coordinamento possono diventare complicati anche da attuare. In questi scenari le soluzioni centralizzate non garantiscono la scalabilità.

A-3 è uno stile architetturale per l'implementazione di sistemi in cui ci sono grandi volumi di componenti e molta dinamicità tra le entità.

A3JG è un'implementazione Java dello stile A-3 che mira a fornire agli sviluppatori un tool che permette la creazione di sistemi self-adaptive in cui i nodi sono suddividi in gruppi in grado di coordinarsi da soli. Ho testato A3JG in un ambiente simulato di un ospedale, in cui il numero delle entità che necessitano di coordinamento è elevato e la sicurezza e l'efficienza sono requisiti stringenti.

Abstract - In a distributed system, the number of entities that work together to achieve a common goal, can grow considerably. In these situations, element churn can be high, and the coordination requirements can become too complicated to design. In these scenarios, centralized solutions can not guarantee scalability.

A-3 is an architectural style for the implementation of systems with high volume and high dynamism.

A3JG is a Java implementation of the style A-3, which aims to provide developers with a tool for creating self-adaptive systems in which the nodes are divided into coordinated groups. I tested A3JG in a simulated hospital environment, in which the number of entities that need coordination is high, and safety and efficiency requirements are stringent.

Estratto

Negli ultimi vent'anni si è svolto molto lavoro di ricerca per quanto riguarda i sistemi distribuiti, in particolare ci si è concentrati sul rendere questi sistemi in grado di rispondere ai cambiamenti, che avvengono nell'ambiente in cui operano, in modo automatico. Si vogliono quindi sistemi in grado di adattarsi autonomamente, rispettando comunque i requisiti con cui sono stati implementati.

Si possono identificare 3 fasi in questa lunga ricerca: la prima dal 1991 al 2000, l'architettura software è usato come uno strumento nella fase di progettazione per i sistemi che hanno bisogno di essere adattabili; la seconda dal 2001 al 2008, ha visto l'utilizzo di un'architettura software per sistemi auto-adattivi; l'ultima a partire dal 2009 fino ad oggi, vi è una continua ricerca sull'architettura software.

I contributi collaborativi di questa tesi si collocano in quest'ultima fase, in particola si è concetrata sullo studio di A-3, uno stile architetturale innovativo per la realizzazione di sistemi distribuiti di elevato volume e altamente volatili. A-3 permette di gestire sistemi in cui le entità in gioco sono molteplici e in cui anche il dinamismo di questi partecipanti è molto elevato.

Il concetto principale di questa soluzione è il gruppo, un'astrazione per organizzare un'applicazione in sezioni semi indipendenti, offrendo una visione unica e coerente di tali aggregati, e coordinare le diverse entità. In ogni gruppo, è presente sempre un nodo (supervisor) che coordina le attività degli altri nodi (follower). La suddivisione in gruppi è definita liberamente dello sviluppatore che può anche decidere di aggiungere, rimuovere e modificare i gruppi anche mentre il sistema è già al lavoro. In questo modo, le singole entità possono entrare e uscire liberamente dal sistema, e il problema si riduce alla più semplice gestione di un gruppo.

I diversi nodi all'interno del gruppo possono comunicare tramite

messaggi asincroni, in particolare il supervisore può inviare messaggi in broadcast, multicast e unicast ai sui follower, mentre ogni follower è in grado solo di mandare messaggi al supervisore, e la comunicazione tra follower non è consentita (o deve essere fuori banda). La comunicazione tra i gruppi è resa possibile dal fatto che un singolo nodo può collaborare con più gruppi, si creano così degli intrecci tra i vari team (di qualsiasi tipo, sia gerarchici che annidati), in particolare un nodo può avere il ruolo di supervisor in un gruppo e di follower in un altro. Altra caratteristica di A-3 è quella di permettere un ribilanciamento automatico dei gruppi quando questi sono troppo grandi o piccoli, tramite operazioni di split e merge, in modo tale che la suddivisione sia solo a livello del middleware ma non a livello applicativo.

Data l'importanza del ruolo del supervisore, ogni gruppo è sempre in grado di sostituirlo non appena questo dovesse lasciare il sistema, infatti un'elezione viene gestita da tutti i partecipanti in modo tale da individuare il miglior candidato possibile per succedere al supervisore. Ogni coordinatore ha la possibilità di fare un backup del suo stato così quando lascia il gruppo, il suo sostituto è in grado di recuperare il suo stato interno e ripartire senza una grossa perdita di tempo.

A3JG è l'implementazione in Java dello stile A-3, ed ne include tutte le caratteristiche principali, come il concetto di gruppo, di diversi ruoli e il tipo di comunicazione. A3JG fornisce allo sviluppatore alcuni semplici metodi da implementare per sfruttare pienamente lo stile di A-3, senza spendere più tempo nella progettazione di middleware.

Utilizzando il middleware JGroups per gestire i gruppi e le comunicazioni, il framework A3JG ha tra i sui metodi anche la funzione di elezione, che è gia implementata e che consente di superare le criticità dovute al falure di un supervisore. Inoltre, permette a ogni supervisore di salvare il suo stato in modo conddiviso nel gruppo, in modo tale che quando viene sostituito per effetto dell'elezione, il nuovo eletto è in grado di recuperare lo stato del lavoro senza perdite di tempo.

Una delle caratteristiche di A3JG è quella di fornire al designer del sistema, un metodo di elezione già definito, che viene attivato automaticamente non appena il supervisore lascia il gruppo.

Le performance di A3JG, sono state verificate in un ambiente simulato di un ospedale, dove i requisiti di efficienza e sicurezza sono molto stringenti, e in cui i nodi (che corrispondono ognuno a una persona che entra nell'edificio) sono molto dinamici e presentano un ampio turnover.

Grazie all'uso di A3JG è stato possibile guidare le diverse persone all'interno dell'ospedale in modo efficiente evitando congestioni all'interno dei singoli corridoi, e intervenendo in modo tempestivo anche nel caso in cui ostacoli improvvisi hanno bloccato dei passaggi.

Per avere dati più precisi sulle capacità di A3JG si è passati da un analisi dello scenario nella sua interezza, a quello del singolo caso pessimo, ovvero quando tanti utenti raggiungono lo stesso schermo con la stessa destinazione.

Dall'analisi delle performance si è notato che può rivelarsi molto utile nei lavori futuri realizzare un sistema di comunicazione apposito, che migliori lo scambio delle informazioni tra i nodi sostituendo la mappa condivisa con più elementi divisi in base alla funzionalità dei dati inseriti. Porterebbe benefici anche l'inserimento all'interno del supervisore di un ciclo di controllo MAPE (Monitor, Analyze, Plan, Execute), ossia un ciclo di controllo composto di quattro fasi che dal monitoraggio dell'ambiente esterno permette di eseguire decisioni prese dall'analisi dei valori ricavati dall'ambiente. Questo infatti può contribuire nel migliorare il coordinamento dei singoli gruppi, fornendo al designer nuovi metodi già implementati e solo da estendere, con l'avvertenza di non rendere tra loro dipendenti i vari cicli, evitndo così che il rallentamento del lavoro di un gruppo non causi un rallentamento genereale del sistema.

1 Introduction

The use of distributed systems to achieve goals that are common between the entity of the network is now a common use practice, and this system are often required to be self-adaptive, so also the research is now focused on this field.

These applications can have different complexities, and their entities must be properly coordinated to reach the goal. Coordination can be difficult to reach when the distributed systems are high volume and highly volatile, and when they need to adapt to frequent changes in the execution. In particular their participants must be able to enter or leave the application freely. In centralized solutions, the increasing number of entities, with the consequent increase of difficulty in handling their coordination, may create bottlenecks.

There has been a lot of research in the field of self-adaptive systems. It is possible to identify three different phases in literature. In the first phase the software architecture is seen as a tool for the design of applications in which there is the need of adaptation (for these phase are described Weaves, C2 [6], Darwin and Regis [7], and a research about the need of self-adaptation [8]). In the second phase, software architecture is used to develop self-adaptive systems (here are proposed the studies of Gomaa and Hussein [9], Garlan et al. [10], Hawthorne and Perry [11], and Kramer and Magee [12]), and finally in the third phase, that is still in progress, the focus is on the ideation of software architecture styles (the works presented are by Weynes and Holvoet [13], Georgas et al. [14], and Cheng et al. [15]).

Obviously, what we want, is the possibility to build systems that can be coordinated and managed efficiently, without introducing downtime. It's also necessary to guarantee an efficient and effective exchange of information between participants. Therefore, the system must have reliable delivery that doesn't cause congestion. Often, is also required that some messages be read by entities that have temporarily left the systems. They need to be able to recover these messages once that they return active.

An approach is to manage these difficulties at the software architecture level, and the A-3 middleware helps in this [1][2]. In fact, A-3 is a model for self-organizing distributed systems that have high volume and are highly volatile distributed, system that can easily tolerate the continuous turnover of elements and scale to accommodate increasing numbers of participants. In particular, in this work presents A3JG, that is an implementation of A-3.

The main concept of this solution is the group, an abstraction for organizing an application into semi independent slices, providing a single and coherent view of these aggregates, and coordinating the different entities. In each group, there is a supervisor node that coordinates all the other supervised entities. New components can be added, removed and reorganized dynamically, and all the communication is asynchronous. This subdivision of elements in groups allows the designer to concentrate on coordinating a lower number of elements that are also less dynamic in their behavior. Each group is able to manage a shared state that, in particular, helps its components to recover the internal coordination without downtime. The overall coordination is achieved by allowing nodes to participate in more than one group at a time, with different roles, so they can pass information from one group to another.

A3JG is a Java-based middleware that I've implemented to support A-3. It includes all the major characteristics of A-3, including concepts such as groups, different roles and different types of communication.

This work also shows how A3JG uses JGroups [17], a toolkit for communication, in order to reach the requirement of a reliable communication, and to provide several possibilities of messaging between nodes. In fact, the requirements for message exchanges include the possibility to send messages in unicast, multicast and broadcast. Moreover, A3JG also allows us to communicate with nodes that are temporarily disconnected, saving messages loss of time by the parties concerned.

The developer is free to implement the system as he/she prefers, in fact he/she can decide how to group nodes, what information they have to exchange inside and outside their group. A group can be created as soon as the system starts to work or can be created (destroyed) when they are necessary (not more necessary). Nodes are free to enter or leave the group without restriction (with the exception of those imposed by the developer of the system), making it possible to manage a high turnover of entities.

Another feature that A3JG provides ready to use for developers is the administration of supervisor elections for when supervisors suddenly leave them group.

In this thesis I present various test in a simulated hospital's scenario. A first simulation was done using the Siafu tool [18]. With this context-simulator I recreated a floor of a hospital where people move to reach their destinations through a system of signs managed by A3JG.

However, other tests were also designed to measure A3JG's performance. These tests analyze in worst case scenario. In particular, one studies how and how much communication is affected in this situation. The results show that the main problem due is to the size of messages which may require more network capacity, but some solutions are proposed. I also performed a test to understand the importance of choosing the correct supervisor election strategy. This is the only time when a group remains without coordination, and it is therefore good to try to reduce the number of times that is activated and its total duration.

This thesis is structured in the following way. First, in section 1, I describe the relevant works and the research done in this area of self-adaptive system. In section 2 I present the A-3 style, with all its features. In section 3 there is the description of my project, A3JG, and in section 4 there are the results of the test done with it.

2 Related Work

2.1 Self-adaptive software

When a software system is used in a distributed context where changes are the norm, it expects a continuous help by a human in order to be able to operate in the new condition.

[3] A Self-adaptive software aims to adjust various artifacts and attributes in response to

- internal changes, in the software system's self, that is, the whole body of the software, usually implemented in several layers;
- external changes, in the context, that is, everything in the operating environment that affects the system's properties and its behavior.

The response to these changes must be run-time in order to keep an high level of performance, then the software must have certain characteristics, grouped under the name of self-* properties.

The self-* properties, introduced by IBM, can be divided into three hierarchical levels:

1. General level: in this level there is the self-adaptiveness, that is a global properties that can be divided in some different subset

(self-managing, self-governing, self-maintenance, self-control, and self-evaluating).

2. Major level: here are identified four properties which are a standard de facto, and that are the desired properties for a system:

    - Self-configuration: when there is a change, such as modification of components, the system must reconfigure and adapt itself.
    - Self-optimization: the system has to do with resources and requirements by different users, and the goal is manage them in order to always have the best performance.
    - Self-healing: the system must be able to find and correct errors in order to avoid, and prevent, failure.
    - Self-protection: is the capability of managing the security system.

3. Primitive level: the properties of this layer are the awareness, by the system, of itself (self-awareness) and of the environment in which it operates (context-awareness).

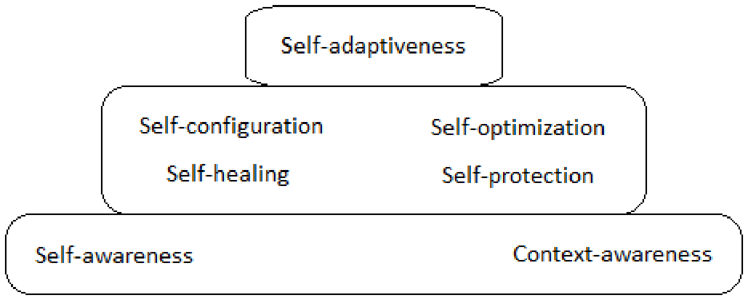


Figure 1: Self-* properties

When you go to create a self-adaptive software, there are several issues to consider, which are requirements that have to be considered in the development.

The first decision to make is whether to create a open or closed system. In a closed system, there is the consideration that there isn't influence from the external environment, so we work with a finite number of elements, and the adaptation has to deal only with this feature in order to implement the adaptation. Instead, in a open system, the system doesn't know what elements there are, because they can enter or leave the work environment, so the system has to find all the features that should influence its performance.

Another consideration is how to implement adaptation: it can be anticipated or un-anticipated. In the first, the system knows all the situations in which has to implement the adaptation, and there isn't the possibility to add new behaviors (closed adaptive). Instead, in the other solution, the situations are measured runtime, so the system can perform new behaviors that are computed by using self-awareness and environmental context information (open adaptive). It's also possible manage the adaptation externally: the system is monitored from outside by an application, and some of its model are maintained at runtime by the observer, which uses this models when there is a conflict in order to resolve problems. Changes are described as operations on the model and imply changes onto the underlying system.

Other characteristics that the developer must analyze concern, for example, the level of autonomy that must have the system, if fully automatically or with human support. Also costs have to be evaluated when the system implements the adaptation, because can be significantly to the performance. Must also be selected the information that the system will use to make the decision to do or not the adaptation, and what needs to be changed in each situation.

2.2 Software architecture

In the embodiment of a self adaptive system, the architecture is a key part of the software design and has to satisfy different needs from different point of view:

- Topology: there can be different interactions among the same elements, and there is the possibility that new elements enter the system.
- Behavior: same elements start behaving differently, new elements are injected in the system.
- Control: MAPE elements must be added, and reliability and robustness must be enforced.

The architecture focuses on the topology of the system and also on quality attributes (e.g., performance) and on non-functional requirements (e.g., cost). It provides an abstract view of a system and its components are clearly identified. When we define an architecture, we have to specify also something about components:

- interface (actions that can perform)
- communications and dependencies (how communicate)
- responsibilities (how reacts when it is questioned)

The architecture is not only the structure of the system, but is any elements of it, and includes the way with which its components are integrated and how interact.

The main parts of an architecture are the components and the connectors. A component is an element that is on the system, and can have different levels of detail and granularity. Each component has a role in the architecture in which it is, and encapsulate related functions and related data.

A connector is always between components, and model the interactions among them. It separate computation from interaction, and minimize component interdependencies, and finally it support the evolution of the software.

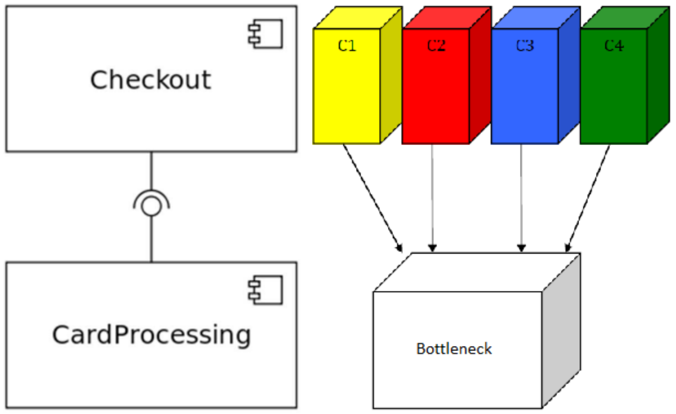


Figure 2: Components and connector

Combining components and connector we create the structure of our architecture, but, in order to avoid bottleneck, is better avoid too many dependencies, in particular, the components that change frequently, must have less dependencies.

The structure built by software architecture is complex and needs more views, and a possibility is the "4+1" view model [4]:

- Logical view: describes architecturally significant elements of the architecture and the relationships between them
- Process view: describes the concurrency and communications elements of an architecture

- Physical view: depicts how the major processes and components are mapped on to the applications hardware
- Development view: captures the internal organization of the software components as held in e.g. a configuration management tool
- Architecture use cases: capture the requirements for the architecture

There are different architectural styles, for example:

- Object-Oriented: objects, that know each other, are related through messages and method invocations
- Client-Server: some clients share the server, and connect through their interfaces. The roles are well-defined
- Pipe and Filter: components are independent and connected through pipes, and act like filters that transform input data streams into output data streams
- Blackboard: there is a central data structure that is used by the components for their work
- Rule-based: is composed by a list of rules and an inference engine that parses input. It searches the knowledge base for applicable rules and attempts to resolve the input.
- Mobile-code: components outsource the execution of code, that is represented as a data.
- Publish-Subscribe: the subscriber is put waiting to receive a certain message or content, and the publisher produces messages. The information has a one-way flow

- Event-based: independent components produce and receive events asynchronously, that pass through event buses, so the communication isn't direct
- Peer-to-Peer: peers are independent entities, each component in the architecture can act as a client or server for the others, so the topology can vary arbitrarily and dynamically
- Service-oriented: business functionality is grouped into self contained and reusable units called services, which are autonomous and discrete units of functionality that are usually accessed remotely

2.3 Research

Is possible to identify three different eras in the development of self-adaptive systems. In the first phase, from 1991 to 2000, the software architecture is used like a design-time tool for systems that need to be adaptive. The second phase, from 2001 to 2008, has seen the use of software architecture for self-adaptive systems. Finally, in the last phase, from 2009 until today, there is an ongoing research on software architecture.

Now we will see some projects example for each eras.

2.4 Phase 1

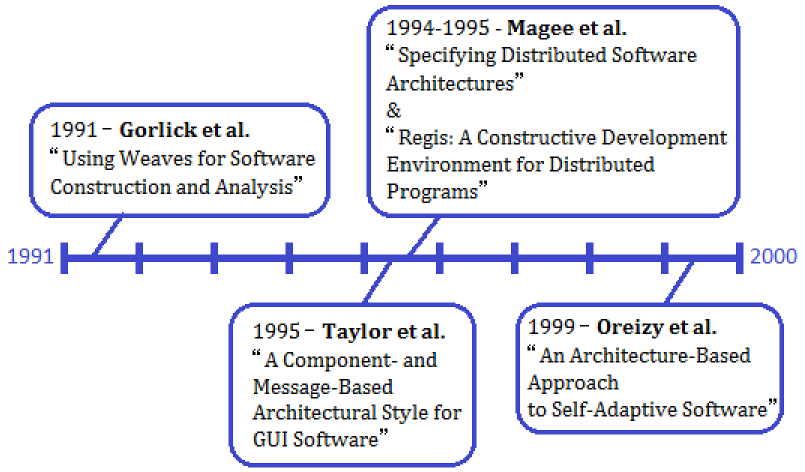

1991 – Gorlick et al. "Using Weaves for Software Construction and Analysis"
1994-1995 - Magee et al. "Specifying Distributed Software Architectures" & "Regis: A Constructive Development Environment for Distributed Programs"
1991
2000
1995 – Taylor et al. "A Component- and Message-Based Architectural Style for GUI Software"
1999 – Oreizy et al. "An Architecture-Based Approach to Self-Adaptive Software"

Figure 3: Phase 1 timeline

2.4.1 Weaves

Weaves, solution proposed by Gorlick and Razouk, are network in which the components (tool fragments) communicate using objects in a low-overhead transmission. In this interconnected network, the data objects are the heart of the information exchange. Each tool fragment is able to perform a single and well-defined action, and is a thread that receives object as input and produces object as output. The information in the form of objects can be exchanged thanks to ports that are attached to queues. Each port is used in order to connect a tool fragment to queues, which in turn buffer and synchronize communication among tool fragments. The queues use a FIFO role for the stream.

The structure of this architectural style is a pipe and filter, but with some differences.

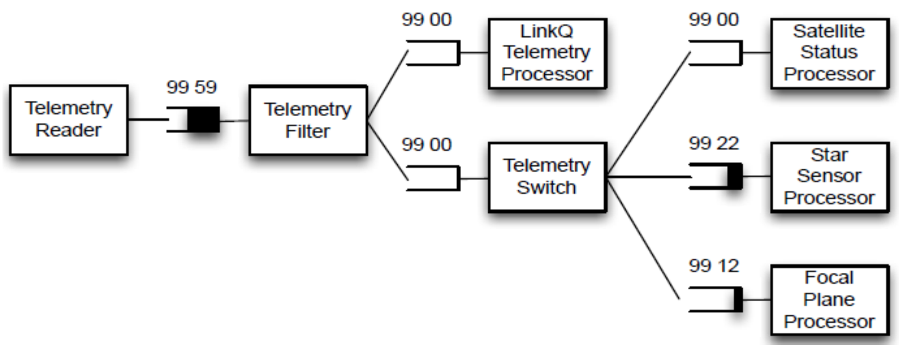


Figure 4: Weave's snapshot

- A component in weave can be made by more routine that cannot be separated
- Weave allows the construction of multigraph in which a tool fragment can implements a many-to-many communications, so it can have multiple inputs and outputs
- Tool fragments process object streams (no byte streams), and each object can encapsulate a large amount of data
- Weave allows the use of different languages for the components implementation
- Each component execute from hundreds to thousands of instruction for each data object
- The same information may be processed simultaneously by more components
- Connectors are explicitly sized queues

Ports and queues are blind, type indifferent, two-layer transport service. Each object is encapsulated in an envelop when it is in a queue, so all datum have the same form. Moreover, a components isn't able to define the source/destination of the objects it receives/sends.

The fact to be blind, increases the flexibility of interconnectivity. Since the transport mechanism is indifferent to the type, it is easy to ensure greater compatibility between components. Weave, also allows for location transparency. Specialized ports help solve output/input incompatibilities, so when a data is sent through a port, its delivery is guaranteed (an object can be or inside a component or in a queue at the same time). When a queue is full, sends an error to the sender, which waits and tries again.

Tool fragment is the active agent in weaves, and its lifecycle management include: start, suspend, resume, sleep and abort. There are two families of tool fragments: one for the inclusion of foreign routine, and the other for the one that are implemented as weave components.

The method that can be used in order to analyze weave are three:

1. Self-metric tool fragments
2. Instruments (specialized tool fragments) inserted in the weaving
3. Observers (separation between data capture and analysis)

2.4.2 C2

The new architectural style proposed by Taylor, Medvidovic and Anderson, is intended for applications that have special requirements for the graphical user interface. The main goal is to allow a more simple reuse of UI's components, but it also achieves other goals, for example the possibility to write the components in different languages, a dynamic change of the architecture, and some other. C2 obtains the benefits of MVC in a distributed and heterogeneous setting.

This style is a layered network of concurrent components hooked together by explicit message-based connectors. The basic concept is to limit the visibility of components, in fact each component in the hierarchy has only knowledge about what is above it, instead is unaware of components beneath it. Each component has a thread of control, but there isn't a shared address space.

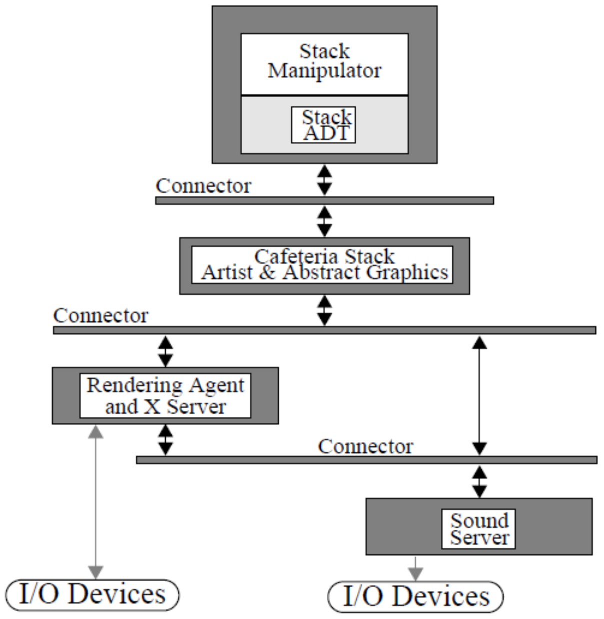


Figure 5: A C2 architecture example for an audio-visual stack manipulation system

A component has a top domain, that contains the notification to which it must respond, and a bottom domain in which there are the notification that it send down. In each component there is a wrapped object, that can have different complexity, and that have an interface used for the notification.

Components are bound thanks to connector: the top of a component may be connected to the bottom of a single connector, instead the bottom may be connected to the top of a single connector. For a connector there isn't a limit of numbers of elements that can be attached to it.

The communication is asynchronously, and use notifications and requests as messages. Notifications flow from up to down, and are sent when there is a mutation in the component. Instead, requests are sent upward in order to require the perform of an action on the above components.

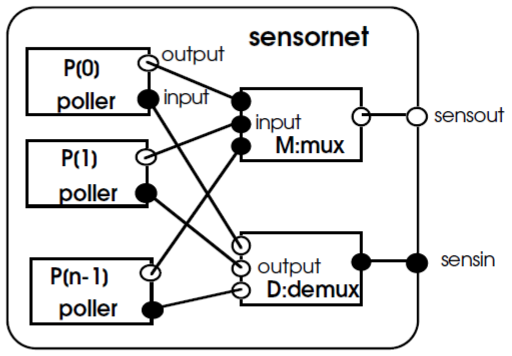
C2 brings some benefits, like the substrate independence, moreover C2 can easily support for component substitution, support for concurrent components and for network-distributed systems, and finally, smart connectors can support filtering policies.

2.4.3 Darwin and Regis

Regis is a programming environment designed by Magee, Dulay and Kramer, to support the work on distributed programs, especially with programs consisting of multiple parallel computational components that cooperate for a common goal. Regis separates the description of the program structure from the programming of the functional components, and gives a support in dynamic program structures managing the increasing complexity.

The computational components in Regis interact via communication objects, that are executed in a framework programmed in Darwin. Darwin is a notation that specifies the high-level organization of computational elements and the interactions between those elements. Components, in Darwin, are composed by services that they provide and services that they require.

Regis is able to manage the complexity of components interconnection thanks to Darwin that allows construction from hierarchically structured configuration descriptions of the set of component instances. The component interface is based on the notion of provided and required interfaces.



```
component sensornet(int n) {
   provide sensin   <port smsg>;
   require  sensout <port smsg>;

   array P[n]:poller;
   inst
      M:mux;
      D:demux;
   forall i:0..n-1 {
      inst P[i] @ i+1;
      bind
           P[i].output -- M.input[i];
           D.output[i] -- P[i].input;
   }
   bind
     M.output -- sensout;
     sensin     -- D.input;
}
```

Figure 6: Composite component type

The goal of Darwin is to allow developers to work both with basic computational components and with other composite components. The obtained program has a hierarchy of composite components, which at run-time, is a set of concurrently instances of computational component. Moreover, hierarchical configuration allows for a scalable solution.

Regis provides C++ automatically generated templates for implementing communication and processing components, and this components incorporate a thread of control. Regis also allows for dynamic configuration, and this means that the system's structure can change over time through dynamic instantiation (allows dynamic structures maintaining information in configuration of the structure being created) and lazy instantiation (components are not instantiated until another component demand them).

2.4.4 The Need for Self-Adaptation

Oreizy et al. have done a reasoning on self-adaptive software. Their work starts with a simple example: imagine a fleet of UAVs (unmanned air vehicles) that is used to disable an enemy field. In the briefing the mission is planned for an airfield without defense. In the midway, intelligence finds that SAMs are defending the airspace, so the fleet has to replanning autonomously the mission, and this lead to two groups of UAVs (a SAM-suppression unit and a airfield suppression unit). So, during the flight, there must be an automatic deploy of new SAM recognition algorithms. In this scenario components are added to fielded and heterogeneous systems with no downtime, and from this example is defined what a self-adaptive system is and what it needs. The replanning can be autonomous, with more distributed planners and can require the human presence in some case, but always required, as assurances, consistency, correctness and distributed change coordination.

Reasoning on self-adaptive software, the questions to made, are different:

- what conditions require the adaptation?
- the adaptation should be open or closed?
- what type of autonomy from human is necessary?
- what are the frequencies of adaptation?
- when the adaptation is cost-effectiveness?
- what type of information should be used and with what accuracy?

The proposed methodology extends from a small adaptation to one in large, and develops the technology needed in the entire range of adaptation.

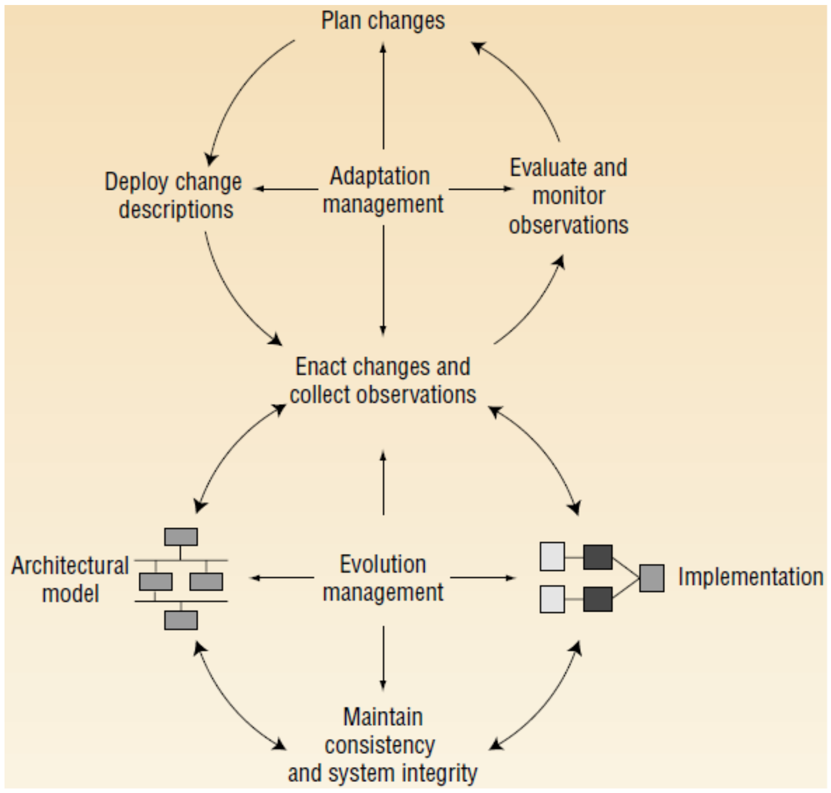

Plan changes
Deploy change descriptions
Adaptation management
Evaluate and monitor observations
Enact changes and collect observations
Architectural model
Evolution management
Implementation
Maintain consistency and system integrity

Figure 7: Adaptation methodology

The upper half represents the life-cycle of adaptive software systems, and in this loop there can be the human presence. The lower half focuses on the mechanism employed to change the application software, and the approach is architecture-based.

2.5 Phase 2

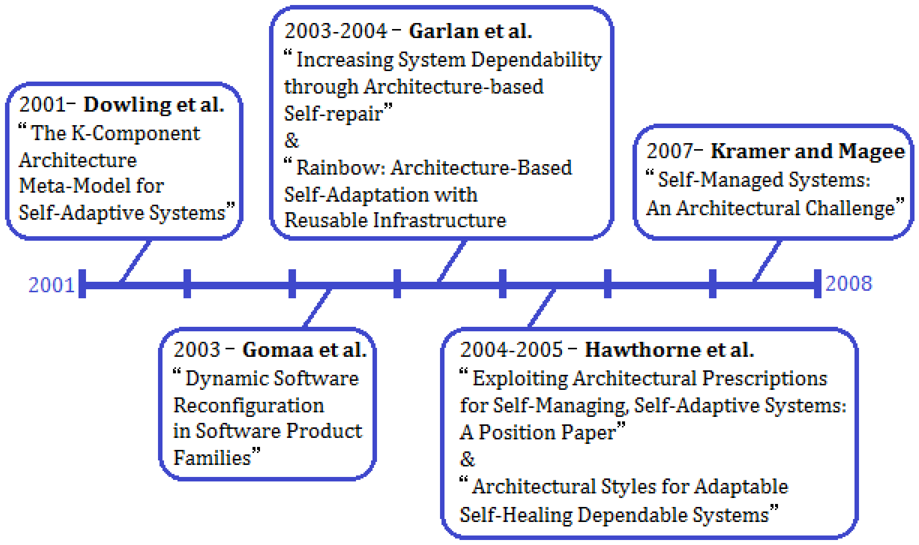

2001– Dowling et al.
"The K-Component Architecture Meta-Model for Self-Adaptive Systems"
2003-2004 – Garlan et al.
"Increasing System Dependability through Architecture-based Self-repair"
&
"Rainbow: Architecture-Based Self-Adaptation with Reusable Infrastructure
2007– Kramer and Magee
"Self-Managed Systems: An Architectural Challenge"
2001
2008
2003 – Gomaa et al.
"Dynamic Software Reconfiguration in Software Product Families"
2004-2005 – Hawthorne et al.
"Exploiting Architectural Prescriptions for Self-Managing, Self-Adaptive Systems: A Position Paper"
&
"Architectural Styles for Adaptable Self-Healing Dependable Systems"

Figure 8: Phase 2 timeline

2.5.1 Software Product Families

The work of Gomaa and Hussein envolves software product family, that is a software architecture that characterizes the similarities and variations that are allowed among the members of a product "family". Their work is part of dynamic reconfiguration of software of the same family. The software configuration is the process of adapting the architecture of the product family to create the architecture of a specific product member, and is a solution when there is an update of the configuration with the system still working.

The main requirements of the dynamic software reconfiguration are the non interference with the parts that are not affected, components should complete their activities prior to reconfiguration, and finally the separation of reconfiguration and application concerns.

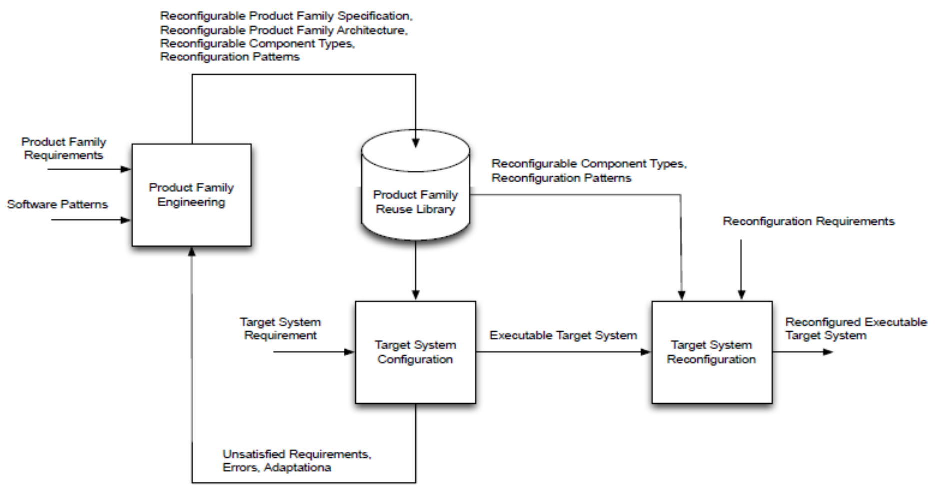

Reconfigurable Product Family Specification,
Reconfigurable Product Family Architecture,
Reconfigurable Component Types,
Reconfiguration Patterns
Product Family Requirements
Software Patterns
Product Family Engineering
Product Family Reuse Library
Reconfigurable Component Types,
Reconfiguration Patterns
Reconfiguration Requirements
Target System Requirement
Target System Configuration
Executable Target System
Target System Reconfiguration
Reconfigured Executable Target System
Unsatisfied Requirements,
Errors, Adaptationa

Figure 9: Reconfigurable evolutionary product family life cycle

Each component has an operating statechart (operational transactions), a main reconfiguration statechart (explains how the component passes through active, passivating, passive, and quiescent states during reconfiguration), one or more operating with reconfiguration statecharts (for handling reconfiguration events in the operating statechart), and finally one or more neighbor component state tracking statecharts. Everything is brought together by a change management model.

The proposed change management model, used to define region in which the reconfiguration scenario may be executed, is composed by two elements:

- Extended Change Rules: a component can only be removed if quiescent, and the interconnections can be unlinked if the component is quiescent with respect to those links
- Change Transaction Model: defines the actions to do in order to reconfigure application. Is composed by:

1. Impacted Sets: sets of components that must be brought to quiescence
2. Reconfiguration Commands: actions used for the required changes, are: passivate, checkpoint, unlink, remove, create, link, activate, restore, reactivate

2.5.2 Architecture-based Self-Repair

With their work, Garlan, Cheng and Schmerl want to realize a mechanism that allows a run-time adaptation of the system, in order to increase the dependability of the system. The real problem found is the determination of the moment in which start the adaptation. They provides a generalization of architecture-based self-adaptation by making the choice of architectural style an explicit design parameter in the framework.

The architectural style becomes a first-class run-time entity, and his formalization provides a number of important capabilities for run time adaptation. This kind of use of the style allows to tailor the framework to the application domain. The style determines:

- what needs to be monitored
- what constraints need to be evaluated
- what to do when there is a violation
- how to perform the repair

In order to make the style useful at run time, it is augmented with a set of architectural operators for the style, and with a collection of repair strategies written in terms of these operators.

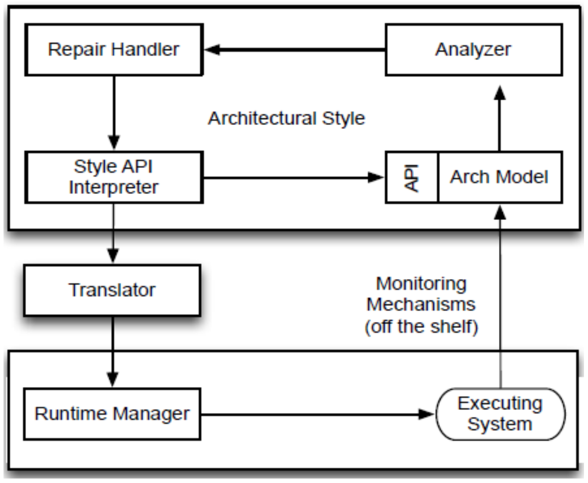


Figure 10: Adaptation Framework

The generic model comprises Components and Connectors with explicit interfaces: ports (component interfaces) and roles (connector interfaces). Components can be further refined through representations, that are more detailed description of the architecture. Semantic properties are described through graph annotation, that have the advantage of being general.

Are also defined repair strategies that correspond to selected constraints of the style. The function of a repair strategy is to determine a problem's cause and how to fix it, and its form is a transactional sequence of tactics. Each tactic has a pre-condition and a repair script.

2.5.3 Operations and Strategies

Hawthorne and Perry focused their research on prescriptive architecture, which derives the implementation architecture from the requirements. The goal of this work is to bridge the gap between requirements engineering and software architecture. The system requirements are modeled as a set of goals, which are divided in functional goals (describe functionality of the system) and constraints (are the quantitative or qualitative properties).

Once defined the goals and constraints, the system is modeled as a set of activities to be performed in order to satisfy the functional goals. Activities are decomposed in a lower-level until they are "atomic" enough to be fulfilled by few roles, that are the abstractions of the roles the objects play to reach a goal. Context-specific behavior is specified by the role and the constraints associated with that role.

An intent framework is used in order to classify and model implementation object functionality. So, the intents capture the essence of an object's purpose and functionality. Activities, roles and intents express formally the kind of information about how to use a component.

Intents specify an object type's behavior using a state change model to describe functions the object can perform, so any two objects with the same intent can be used interchangeably to accomplish the same implementation domain purpose.

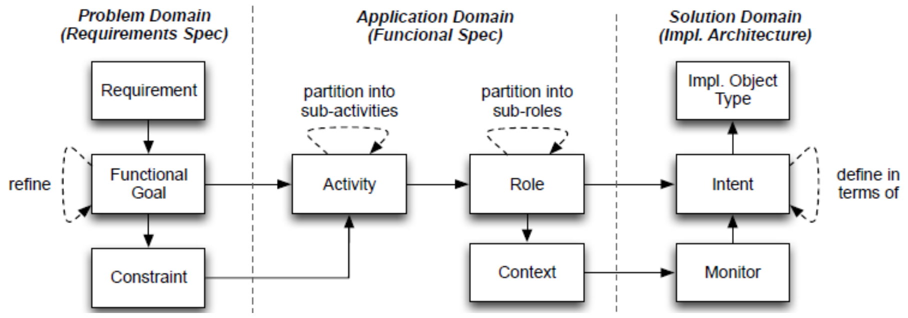

Problem Domain (Requirements Spec)
Application Domain (Funcional Spec)
Solution Domain (Impl. Architecture)
Requirement
refine
Functional Goal
Constraint
partition into sub-activities
Activity
partition into sub-roles
Role
Context
Impl. Object Type
Intent
Monitor
define in terms of

Figure 11: Implementation reification process

2.5.4 An Architectural Challenge

The goal, of an architecture-based self-managed system, is to minimize the degree of explicit management necessary for construction and subsequent evolution whilst preserving the architectural properties implied by its specification. Architecture provides the required level abstraction and generality to deal with self-management, and also can help with the scalability, can be combined with existing work, and has a potential for an integrated approach. The solution proposed by Kramer and Magee is a three-layer architecture, based on Gat's three layer architecture.

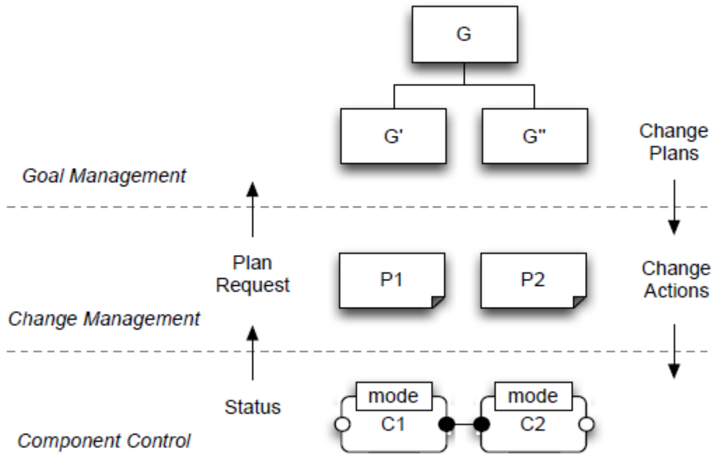


Figure 12: Three-layer architecture

Component Control Layer: this is the bottom layer and concerns with preserving safe application operation during change. It must ensure that the change doesn't generate undesirable transient behavior, so the goal is to preserve safe application operation during the change. Also, during that change, must be ensured that the safety properties aren't violated.

Change Management Layer: is responsible for executing changes in response either to changes in state reported from the lower layer are in response to goal changes. A challenge is to deal with distribution and decentralization, and also to preserve global consistency and guarantee local autonomy.

Goal Management Layer: the problem is to have a precise specification of the goals required of a system, and the challenge is to achieve goal specification such that it is both comprehensible by human and machine. There are also challenges in the decomposition of goals and in the generation of operationalized plans.

2.6 Phase 3

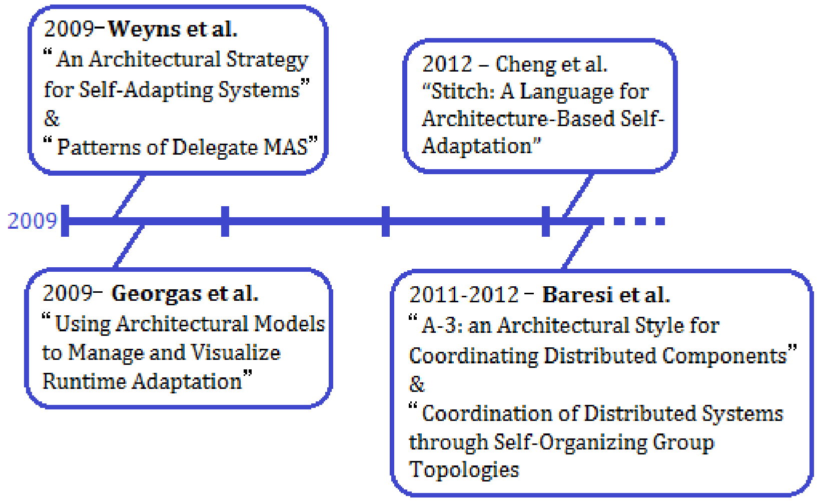

2009–**Weyns et al.**
"An Architectural Strategy for Self-Adapting Systems" & "Patterns of Delegate MAS"
2012 – Cheng et al.
"Stitch: A Language for Architecture-Based Self-Adaptation"
2009
2009– **Georgas et al.**
"Using Architectural Models to Manage and Visualize Runtime Adaptation"
2011-2012 – **Baresi et al.**
"A-3: an Architectural Style for Coordinating Distributed Components" & "Coordination of Distributed Systems through Self-Organizing Group Topologies

Figure 13: Phase 3 timeline

2.6.1 Situated Multi-Agent Systems

Weynes and Holvoet, proposed a solution in which the software is structurated in autonomous entities (agents) situated in an environment, (situated MAS) and is valuated the ability of the agents to adapt themselves during the change. The agents employ the environment to share information and coordinate their behavior. The control, in this solution, is decentralized, because is divided among the agents. Instead, the self-management is the system's capability to manage dynamism and change autonomously, that are the variables that affect the system during operation.

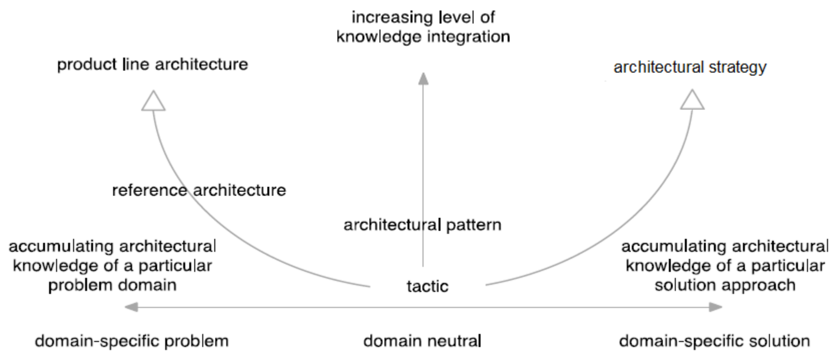

increasing level of knowledge integration
product line architecture
architectural strategy
reference architecture
architectural pattern
accumulating architectural knowledge of a particular problem domain
tactic
accumulating architectural knowledge of a particular solution approach
domain-specific problem
domain neutral
domain-specific solution

Figure 14: Types of architectural approaches

Each agent is composed by three subcomponent:

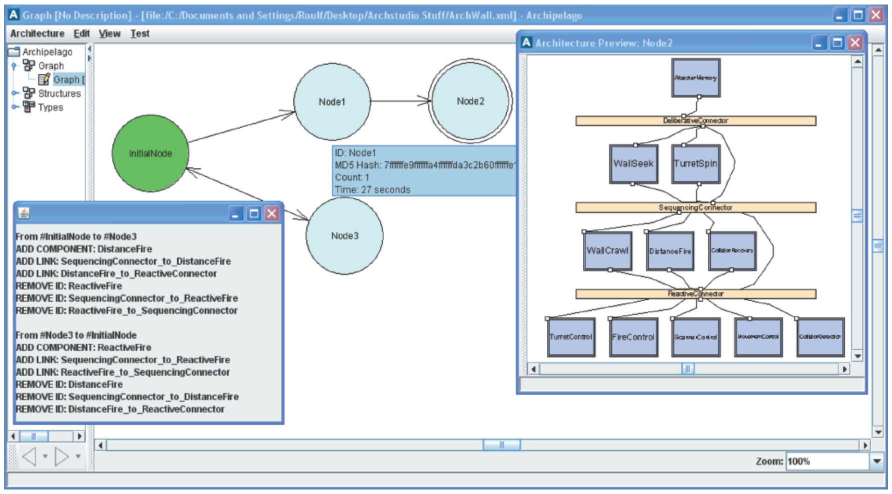
- Perception: is a filtered sensing of the environment, collects runtime information
- Decision Making: is responsible for action selection through the influence-reaction model
- Communication: is responsible for communicative interaction with other agents

Communication and decision making are kept separate because in this way there is a clear separation of concerns, and both functions can act in parallel and proceed at different paces.

The decomposition of the application can be considered in two dimension: horizontal (based on the distinct ways agents can access the environment) and vertical (based on the distinction between the high-level and the low-level interactions).

2.6.2 Management and Visualization

A continuous control of a runtime adaptive software system is nearly impossible, so the work of Georgas, van der Hoek and Taylor, wants to realize the vision of an operations control center through which human users can understand and manage runtime adaptive software systems. This operations control center can contextualize current and past behavior with respect to the system configurations that resulted in these behaviors, support retroactive analysis of historical information about a system's composition and behavior, and, finally, connect to operator-driven proactive management of the system.



```
ID: Node1
MD5 Hash: 7ffffffe9ffffffa4ffffffda3c2b60ffffffe
Count: 1
Time: 27 seconds
```

```
From #InitialNode to #Node3
ADD COMPONENT: DistanceFire
ADD LINK: SequencingConnector_to_DistanceFire
ADD LINK: DistanceFire_to_ReactiveConnector
REMOVE ID: ReactiveFire
REMOVE ID: SequencingConnector_to_ReactiveFire
REMOVE ID: ReactiveFire_to_SequencingConnector

From #Node3 to #InitialNode
ADD COMPONENT: ReactiveFire
ADD LINK: SequencingConnector_to_ReactiveFire
ADD LINK: ReactiveFire_to_SequencingConnector
REMOVE ID: DistanceFire
REMOVE ID: SequencingConnector_to_DistanceFire
REMOVE ID: DistanceFire_to_ReactiveConnector
```

Figure 15: ARCM visualization tool

The main result is a historical graph of architectural configurations organized along three dimension:

- visibility: to see what happened
- understandability: to improve adaptation
- management: to rollback or push the system into an existing configuration

ARCM graph is a directed cyclic graph G=(N,E) with N the set of nodes and E the set of unidirectional edges between nodes. Each n in N defines a specific architectural configuration, and each e in E is defined by a head and a tail node, capturing an adaptation that modified the tail configuration in the one of the head.

2.6.3 Stitch

Is a language for defining and automating the execution of adaptation strategies in an architecture-based self-adaptation framework made by Cheng, Garlan and Schmerl.

The requirements for Stitch are:

- adaptation decision processes should be able to choose the next action depending on the outcome of previous ones
- when evaluating the result of an adaptation action the language should take into account that effects could be susceptible to delay
- strategies should be "guarded" by activation conditions
- should be possible to determine the best strategy to execute if there is more than one
- past successes or failures to adapt should contribute to the overall process

Stitch defines adaptation strategies as decision trees built up from adaptation tactics, which are in turn defined in terms of more primitive operators. The most primitive unit of execution for an adaptation process is the operator, that is determined by the architectural style. A tactic is an abstraction that packages operators into larger units of change. A tactic contains a sequence of operator calls, activation preconditions, a definition of effects that it is attempting to achieve, and an impact vector that specifies how it will impact the system's quality dimensions. In a strategy, each step is the condition execution of a tactic, and it's characterized as a tree of condition-action-delay decision nodes. Each strategy has a context-based activation condition, and allows for the calculation of an aggregate utility function.

The strategy selection is made choosing the strategy with the highest utility. This is achieved through the definition of quality dimensions, utility preferences, impact vectors and branch probabilities.

2.7 Open issues

How we have just seen, the years of work in self-adaptive systems are many but, despite this, the work in this area is still a challenging task.

For example the development of patterns that give guarantees of efficiency in some areas [16]. A system often needs to perform a trade-off analysis between several potentially conflicting goals, so there is the need of practical techniques to define utility functions. There is also a need for more research in the definition of lightweight monitoring techniques, in order to avoid that the effort in monitoring exceeds the benefits of improvements in QoS after an adaptation. Control-loops are essential for self-adaptive systems and the application of the centralized control-loop pattern to a large-scale software system may suffer from scalability problems, so is necessary an approach that integrates both control-loop and decentralized agent. The research has to focus also on more advanced and predictive models of adaptation in order to avoid a system to fail after a change to satisfy his requirements. The characteristics of self-adaptive systems create new challenges for developing high-assurance systems, and novel verification and validation methods are required to provide assurance in this system.

A-3 focuses on high-volume and highly volatile distributed systems, that have very strong coordination requirements, and are hard to design. This kind of system has the need to be flexible to adapt to frequent changes in the execution environment or in the system's available resources. A-3, and so also A3JG, is able to coordinate the behaviors of multiple elements, so that they can reach a common goal.

3 Dynamic Group Management

The idea is to create a middleware that allows the realization of distributed high-volume and highly volatile systems. These systems need to be able to self-adapt and to disseminate new configuration tasks, depending on the needs and availability of its components.

A simple environment that allows to define an example to better understand the characteristics of A-3, is a supermarket. Imagine a system in which the nodes are the shopping carts, the checkouts, and a "controller". Our goal is to coordinate these entities in order to optimize checkouts, and to reduce the amount of waiting time that customers pays in the queue.

3.1 Group view

The main idea of A-3 is to reason on groups of node, instead of on single entities. More clearly, the individual entities are grouped on (eg) similar characteristics and behaviors (the policy is left open and decided by the system designer). Then a developer needs to coordinate the groups, which are seen as entities that are easier to coordinate. This allows for an easier definition of the interactions between entities. In fact a group allows multiple elements to be treated as a single less dynamic block. In this way, each entity may enter or leave the system freely, and the problem is reduced to the smaller one of managing groups.

To develop a system with A-3 it is therefore necessary to define what groups that will be present, and characterizes them. To do this, we need to define the roles the nodes will play within a group. In particular, A-3 allows two different kinds of roles: supervisor and follower. In each group there is only one supervisor and one or more followers (as many as required and as supported by the network). The supervisor's task is to coordinate the followers, which join a group for advice on how to behave depending on the situation at hand. Each entity can be both supervisor and follower in more than one group, but they can have only one active role for each group in which they participate.

By comparison with the C2 project, the roles of A-3 correspond to the components of the first, while there is a single connector that enables the exchange of messages in each group (see 3.2). Also in Weaves there is the distinction between components and connector, but there aren't specific different roles between components.

In A-3, while the supervisor has knowledge of the group's structure and of its members, the follower node may not know how the group is structured.

In the example of supermarket we can, for example, define a group "CHECKOUTS", in which the supervisor is the controller and the followers are all the active checkouts. Another group could be the "CARTS" that run in the supermarket; once again the controller could be the supervisor. We have N other groups "CHECK_#", in which the checkout number # is the supervisor, and the carts in the queues are the followers.

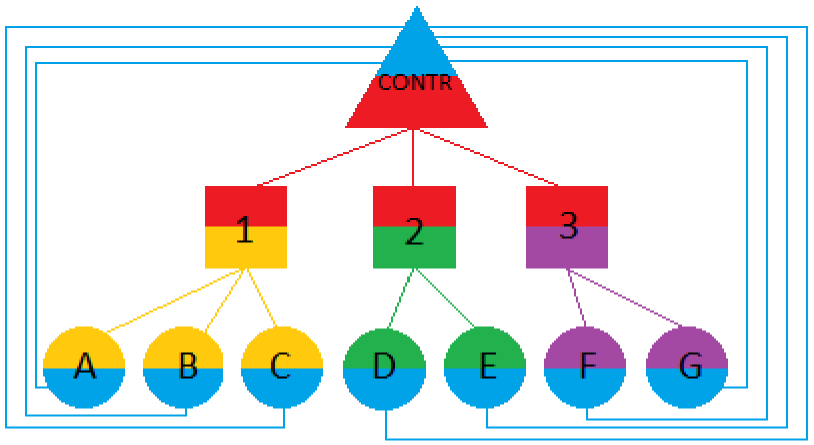


Figure 16: Group view in supermarket's example

Figure 16 shows groups. Triangle indicates controller, squares represent checkouts, and circles represent carts. Each color corresponds to one of the groups we defined before.

3.2 Communication

In order to achieve coordination A-3 allows nodes inside each group to communicate. The kind of communication is different based on role.

The supervisor can send messages:

- in broadcast, to each member of the group
- in multicast, to some members of the group
- in unicast, to only one follower of the group

Instead, a follower can only send message to its supervisor; communication between followers isn't allowed (it must be out of band). All messaging is asynchronous. Moreover, the supervisor can communicate with its followers even when they are offline, because messages can be saved in memory, such that they can be delivered it when followers join the group. The message remain available for a certain amount of time, so after this period the message is deleted. Followers can also send updates to their supervisors. For example, They can send messages to allow to know that the sender joined the group or that its status changed. The kinds of notifications are optional. The developer can use them, for example, to keep trace of each group's population.

In the work of Taylor at al., the communication is more limited, in one direction making requests, the other notifications, and the messages can only move one step at a time, but we can imagine the separation between components of two different level as a separation between groups, but in A-3 components of the same group can communicate. This is, also, different from Weaves, where a message is an object, but no component knows the source (destination) of a received (sent) object. It is more free respect to A-3, where each component knows the sender (receiver) of its messages.

In the case of the supermarket, for example, the controller may send messages to the crates to tell them to stay open/closed based on the amount of waiting customers, while the carts can tell the controller the amount of objects that are carrying, so that the supervisor can better manage also checkouts and send them to the most appropriate queue.

3.3 Group collaboration

So far we have seen how the individual groups are coordinated internally with A3, but in a large-scale system, groups may wish to work together. In order to realize the collaboration, A-3 allows to group composition. This is achieved by allowing single element to work in different groups, with different roles. This allow for different compositions in which each single element that is shared between two or more groups can, therefore, share information between these groups.

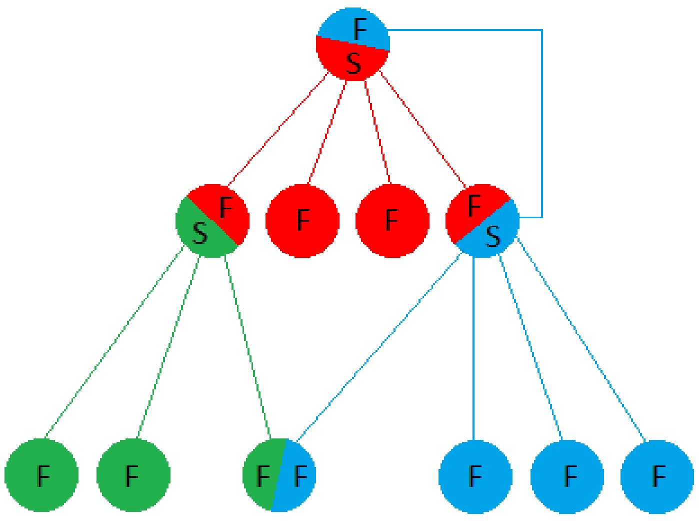


Figure 17: Group composition

Figure 17 shows three groups (red, green and blue). Two follower nodes of the “red” group, are also supervisors in the other groups, this because for a node, you can have different roles in different groups. These two node are also responsible for the coordination between groups “red-green” and “red-blue”, and their work in the beneath clusters influences the working cycle of the “red” group. Instead the “green” and “blue” groups share follower. Moreover, a follower of the “blue” group is also supervisor in the “red” group, and this creates a nested composition.

The possible type of composition are three.

3.3.1 Shared Followers

We can have a supervised component that simultaneously belongs to two groups, and the supervisors of these groups can collaborate using the shared follower as an intermediary for messages. The follower can also receives conflicting coordination directives from the two supervisor, and in this case it is up to the component itself to manage and resolve the conflict, since the configuration doesn't support explicit coordination between the two supervisors. In the supermarket's example, each cart is a follower in both the groups in which it participates, so they are shared follower (figure 16, circles are shared supervised components). Figure 17 shows this composition between groups "green" and "blue" which have a node in common.

3.3.2 Hierarchical composition

Another possible composition is the hierarchical one, in which a supervisor has a follower that is supervisor in another group. This component contributes to the top group with a digest of the knowledge it collects from the bottom group. This allows the top group's supervisor to have a complete view of the system, without having to interact with all the components in the system. In this case, the supervisor in the high level is a centralized coordinator. This case is shown in the example of the supermarket between the controller and all its checkout followers, because each checkout is also supervisor in the group "CHECK_#".

3.3.3 Nested composition

In A-3 is allowed to have a structure in which all the supervisor are also follower in another group, so there isn't only one node able to see the entire system, but all supervisor nodes in a circle structure have a complete view of the system. To avoid infinite nesting coordination directives, each supervisor only sends directives to its own supervised components using multicast messages, and avoids sending them to the other supervisor. The resulting coordination is completely distributed. In figure 17 there is this kind of composition thanks to the two “red” followers that are supervisors in “green” and “blue”, and the “blue” follower that is supervisor in “red”. In this example “red” and “blue” supervisors have a complete view of the system.

3.4 Safe Group Management

A-3 also allows supervisor to store important data, or anything else that needs to be tolerant to fault and easily recoverable when necessary, to distributed memory in a redundancy fashion.

The architecture, supports continuous node exchanges. If a follower enters/exits, no problems arise, because the other nodes are not actually interested in knowing who is in the group, while the supervisor will change the workload of those who are connected. The extreme case is the one in which the entry of a new node makes the size of the group too large, requiring the group to split. In this situation the supervisor must decide which nodes should migrate to the new subgroup, because is the only one that has knowledge about the group’s structure. Vice versa, when the size of the group is too small, the supervisor has to merge multiple groups. All this movement of nodes and changes of the structure aren’t visible at the application layer, because the user of the system can see only one group with all his nodes.

In the supermarket environment, follower traffic is due, for example, to the opening or closing of a checkout, or to the arrival of a new cart in the payzone.

If a supervisor leaves the group we have a delicate situation: since there is only one supervisor in a group, and it must always be present. When it dies the followers must take the responsibility of keep the group alive. How? Simply by starting an election to find the new supervisor, who can use the information saved from previous supervisor in the replicated memory to immediately update its status and continue to manage the group as if nothing had happened. Otherwise, without replacement, the group has no reason to exist because there would be no coordination of internal nodes. The possibility to elect and save data in memory is very important, because it avoids the supervisors from becoming single points of failure. In fact, if it periodically stores important data in the group, when it fails, the new supervisor can retrieve these information and continue the coordination of the followers with minimum delay.

4 The A-3 Framework

A3JG is an open-source implementation of A-3 made by me, that allows the implementation of self-adaptive systems. It is built using JGroups, that is a group communication middleware. In this work, JG is also used for managing groups.

Now we will see how A3JG is implemented, and what a developer needs to do in order to use it for his/her application.

4.1 Architecture

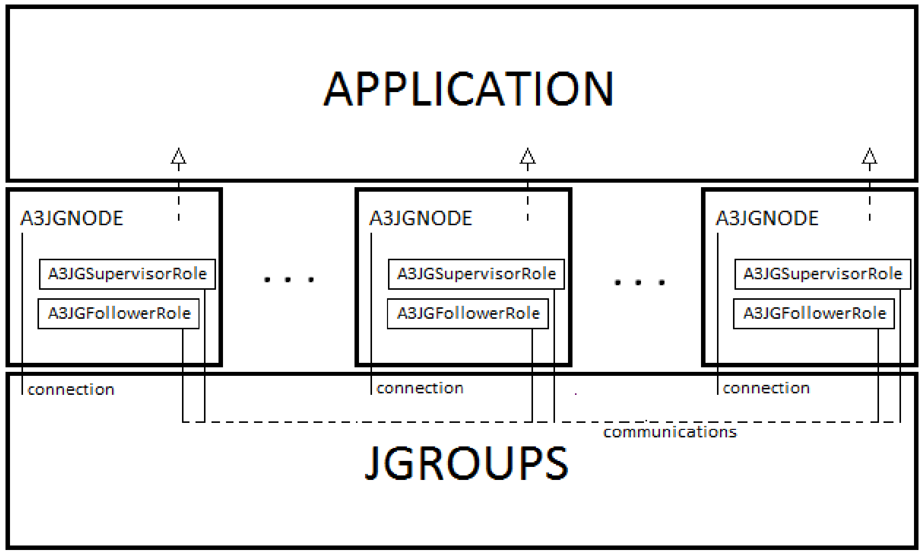


Figure 18: A3JG Architecture

In the lowest level of the architecture, we have JGroups which is an open source project that provides tools for managing groups and, in particular, in this work it is responsible for all the connections and the transfer of messages exchanged. In the middle there are all the nodes that are distributed, also in different locations. Each node is unique and is responsible for managing its roles, that are stored in two distinct map (one for the supervisor and one for the follower). An application needs to implement the nodes (e.g. one for each distributed host) and the roles, and then to connect them to a group.

4.2 JGroups

As already said, A3JG uses different features of JGroups, in particular to manage the groups (which in JG are called clusters) and the communication between groups.

4.2.1 What is JG?

JGroups is a project that aims to build a reliable communication between members of a group. The communication is in multicast and it can use both IP and TCP as transport (the protocol stack is flexible to every need).

JG allows developers to create (automatically when a node joins a group that doesn't exist) and delete clusters. Each group can be populated with members coming from LANs and WANs. It also provides tools to receive notifications about changes that occur within the cluster. Each group is distinguishable thanks to the name.

4.2.2 Main features

The channel allows the nodes to join a group, and then to work with the other members. Through the channel, each member sends and receives its messages, and can be used only by one node. To be able to see the messages and the notifications, it is necessary to pass a receiver (ReceiverAdapter) to the channel.

A channel can be connected only to one group so, if a node has to work in multiple groups, it needs more channels. Each channel is distinct thanks to a unique address, and has a view with the addresses of the other members in the cluster.

You can use an XML file to pass configuration parameters of the channel, and this happens when a channel is created (if you do not pass the file, JG uses the default configuration).

JGroups provides building blocks to make the most of what it offers the channel, without having to rewrite the code base. From an architectural point of view, they are on a layer above the channel, and they are used when the developers need high-level interface. A building block widely used in A3JG is the ReplicatedHashMap.

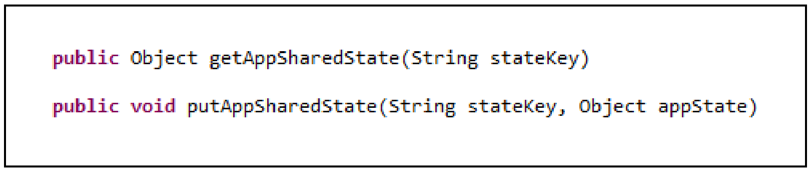
Finally, the protocol stack plays an important asset in JGroups. In fact, it is so flexible that can adapt to any application. It's composed by many levels of protocols, that are passed in a bidirectional way, then any message that is sent or is received, has to cross all the layers. The realization of the stack depends on the XML file that the developer can use to create the channel. This thing shows how you can create different configurations based on need.

4.2.3 JG in A3JG

A3JG uses different features of JGroups. To connect to a group, a node uses a JChannel, and the active channels are saved in a map on the node (the map's key is the name of the group). The channel is used to create a new cluster (group) or to connect to an existing one. Through the channel all the communication between the nodes flows. It's possible to pass a specific configuration of the protocol stack through a XML file, but if no file is passed, the default configuration is used.

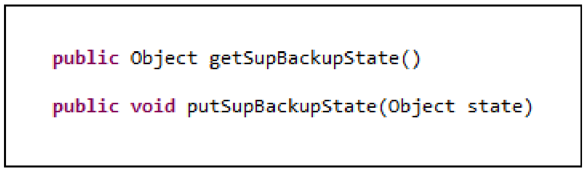
In order to save information about the current state of the group, save messages and manage the election of a new supervisor, A3JG uses the ReplicatedHashMap, that is a concurrent hashmap shared between each member of the cluster. Indeed, A3JG makes use of a modified version of RHM, in fact, to be able to freely manage the function viewAccepted, it was necessary to create a copy (viewAcceptedOriginal) that is invoked whenever there is a change in the group. Keys, which are already used by A3JG on the map, not to be used for a correct work are: “A3Supervisor”, “A3SupBackupState”, “A3SharedState” + int, “A3Message”, “A3MessageInMemory_” + int, and all JChannel address.

It’s possible to share a state, on the map, between supervisor and followers using:



```
public Object getAppSharedState(String stateKey)

public void putAppSharedState(String stateKey, Object appState)
```

and save a supervisor backup state using:



```
public Object getSupBackupState()

public void putSupBackupState(Object state)
```

Both A3JGSupervisorRole and A3JGFollowerRole implement ReceiverAdapter, to allow them to send messages to other members of the group and to receive updates on changes of the structure of the group. The ReceiverAdapter is used in order to receive message sent to the channel, and to see when the View is changed. The View is a list that contains all the active nodes in the cluster at the moment it is called.

A3JGRHMNotification class, instead, implements Notification of ReplicatedHashMap, and can be used to see all the modification of the RHM and how change its entirety.

4.3 A3JGNode.class

This is the first class that the developer needs to extend (it's an abstract class). A3JGNode identifies a single and autonomous device that is connected in the distributed system, and that has its own features and functionality. As already said, in A-3 every node can be inserted in one or more groups, and this property also occurs in A3JGNode, because it is possible to define multiple roles which the node can employ and the groups in which it can work.

4.3.1 How define a node

Therefore every node is an independent unit of work, for this reason each A3JGNode has an unique identifier, and this "ID" is defined at the creation time, through the constructor (is a String). Being a physical unit, it is also characterized by a "resourceThreshold", that cannot be exceeded (is an integer). This last value can be changed using getter and setter. Two other attributes that the developer can modify are "timeout" and "inNodeSharedMemory", but we will see their function later.

After its creation, a node needs to be filled with something else by the developer, in particular he/she has to work with three maps: "supervisorRoles", "followerRoles" and "groupInfo". In order to make the node able to work, the roles of supervisor and follower must be added, which are stored in the two separated maps. Each node must be able to act in different groups with different behaviors depending on the situation, so it's necessary to define the instructions of the behavior that the node must implement in each group which can participate. In these maps there are only the instruction (the keys are names of role's classes) that can be shared between multiple groups.

In order to connect the node to one group is also necessary to pass the information relating to the cluster where you want to join. This is done using A3JGroup, and this information is saved in "groupInfo" with the name of the group as key.

In figure 19 there is an example of a node after the insertion of information of some roles and groups (for simplicity, from now on, the groups will be named with color).

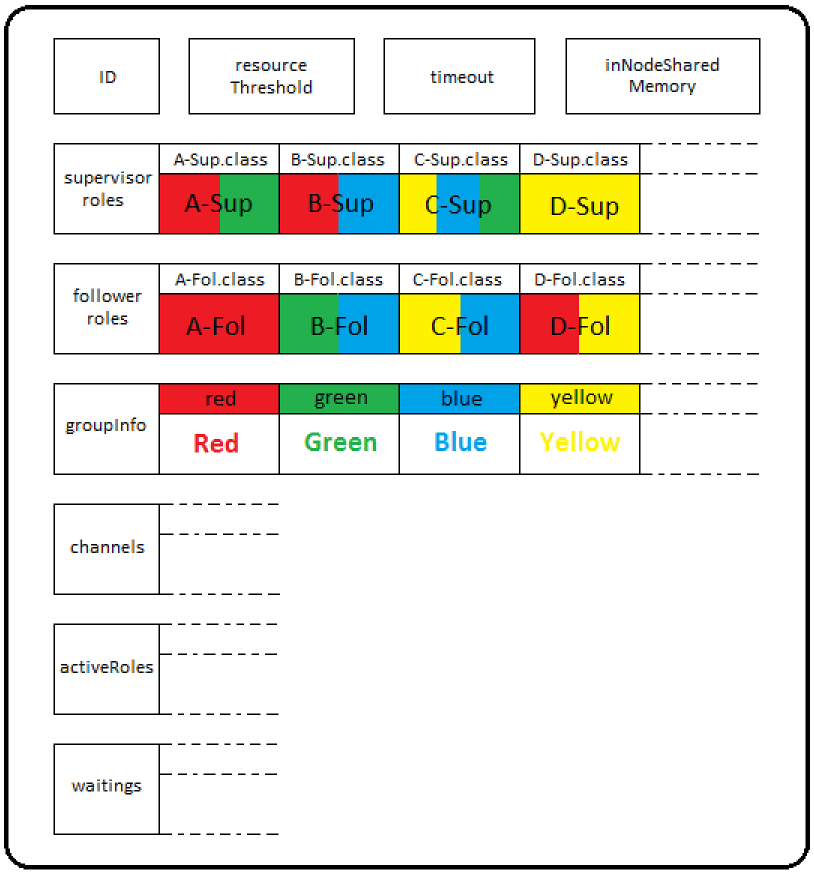


Figure 19: A3JGNode

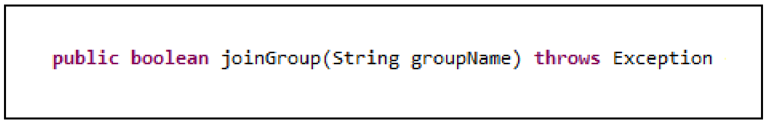
In the node represented i figure 19, in “supervisorRoles”, four different A3JGSupervisorRole (A-Sup, B-Sup, C-Sup and D-Sup are the keys) were added, and, the same happens in “followerRoles” with four A3JGFollowerRole (A-Fol, B-Fol, C-Fol and D-Fol are the keys). The colors in background of these two maps are the groups in which the role content can be used. Instead in “groupInfo” there are information of the four different group in which the node can work.

Attributes “channels”, “activeRoles” and “waitings” must not be changed manually, otherwise A3JG won’t behave properly.

4.3.2 Join a group

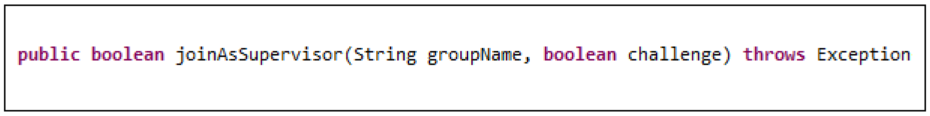
After these steps, it is possible to connect the node to a group using the join function. Now, depending on the type of the application to be implemented, the value to assign to "timeout" must be evaluated, which is by default 10000. This attribute indicates the milliseconds in which JGroups try to fetch the state of the ReplicatedHashMap used in the group. In order to modify the value, you can use the setter.

To call the "joinGroup" function, it is only necessary pass the name of the group that you want to join.



```
public boolean joinGroup(String groupName) throws Exception
```

Another possibility is the joinAsSupervisor function (compared to regular join it has also a boolean as input), that force the election of the node as the supervisor of the group.



```
public boolean joinAsSupervisor(String groupName, boolean challenge) throws Exception
```

With this function it is possible for the node to be directly elected as a supervisor (passing it the parameter "challenge" equal to False) or take a challenge with the supervisor in charge, if any (passing it the parameter equal True). In the first case, the old supervisor tries to become a follower of the group if it has the role, otherwise it terminates. In the second case, the winner of the challenge will be the supervisor of the group, instead the loser tries to become a follower of the group if it can.

Both the functions work in the same way. At the beginning there is a control on the list of existing active channels, that are saved in the “channels” map (the key is the name of the group). If already exists a channel with key equal to “groupName”, the function end. Then there is a control on groupInfo, if the node doesn’t have information about the group to join, the function ends.

Now we know that we can join the group, so the channel must be created and, before the creation, there is a control on “groupInfo” in order to recover the XML configuration file of the channel (if it exists). After the creation, the channel is put on “channels” map, and the key is “groupName”. Before connecting the channel, the ReplicatedHashMap is created, then the function tries to connect the channel to the group referred, finally, after the connection, the RHM is updated.

After these steps the role that the node will use to work in the group in which it’s connected is activated (“true” if the node has joined the group, false otherwise).

The return of both functions is the success of the join operation.

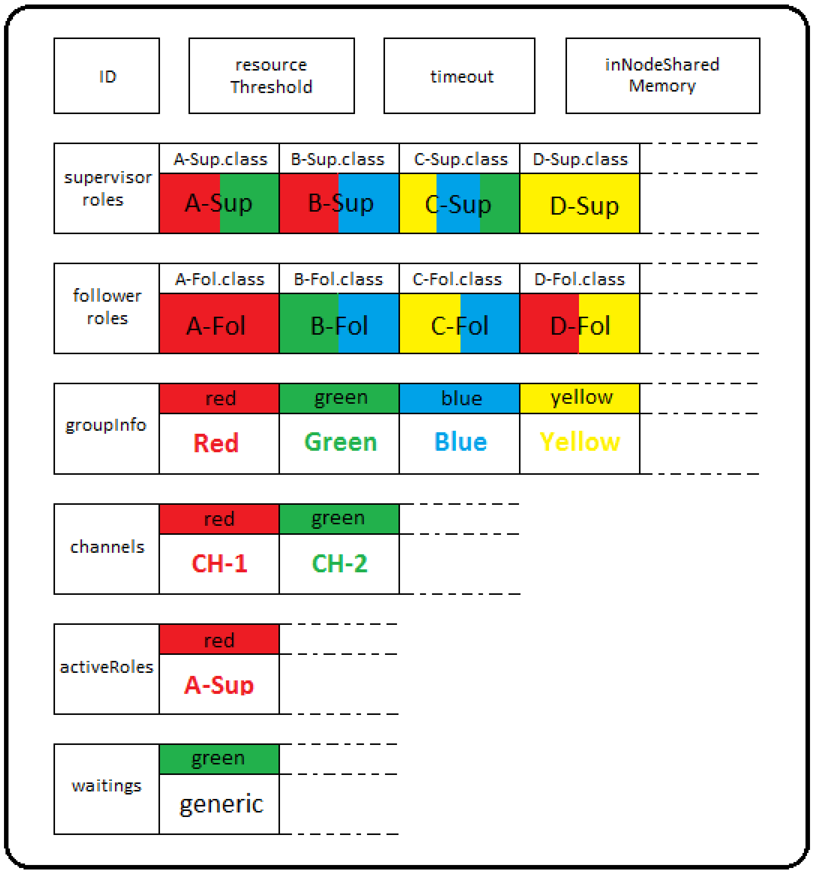


Figure 20: A3JGNode after two call to joinGroup

Figure 20 shows the previous node after the call of joinGroup("red") and joinGroup("green"). In the "red" cluster this node has the supervisor role, instead "green" doesn't have an active role because there is an election in the "green" group, so the node is waiting the end of the election before activating a role. In both cases, the respective channel is put on "channels" map, but, in the "red" case, the role is active and for this reason, it is in "activeRoles", instead in the "green" case there is a genericRole in the "waitings" map.

4.3.3 Activation of the role

When a node joins a group, there is an automatic activation of a role for the new node in the cluster. The role that is activated (with a regular join) depends on the situation of the group, and there are 3 cases:

1. The group doesn't yet exist: in this case, only a node that can be able to be a supervisor can create the group. The node that creates the cluster is the first supervisor of the group, so if a node tries to join a group that doesn't yet exist, and it isn't able to be a supervisor for that group, the cluster isn't created and the join of the node doesn't succeed.

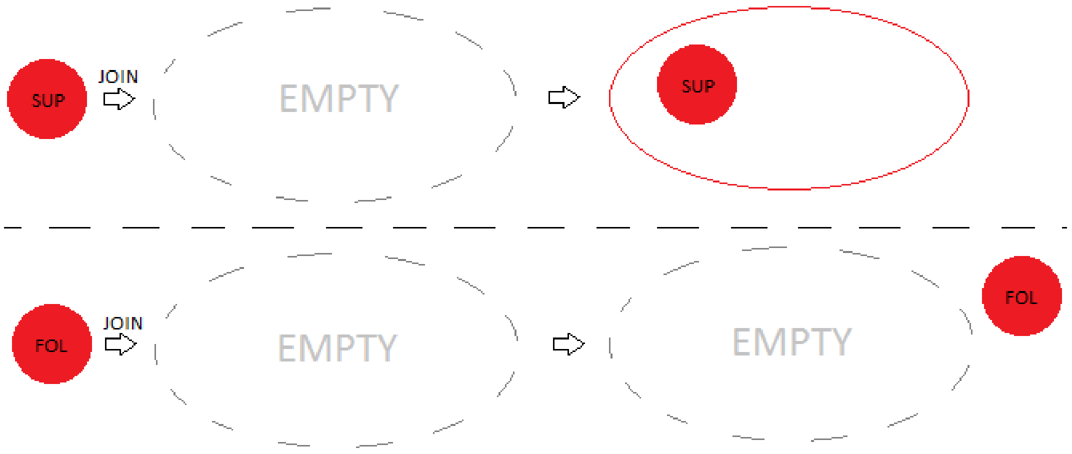


Figure 21: Group doesn't exist

2. The group exists and it works correctly: in this case, if the node, that wants to join the group, can be a follower of it, the join succeed, otherwise the node doesn't join the cluster.

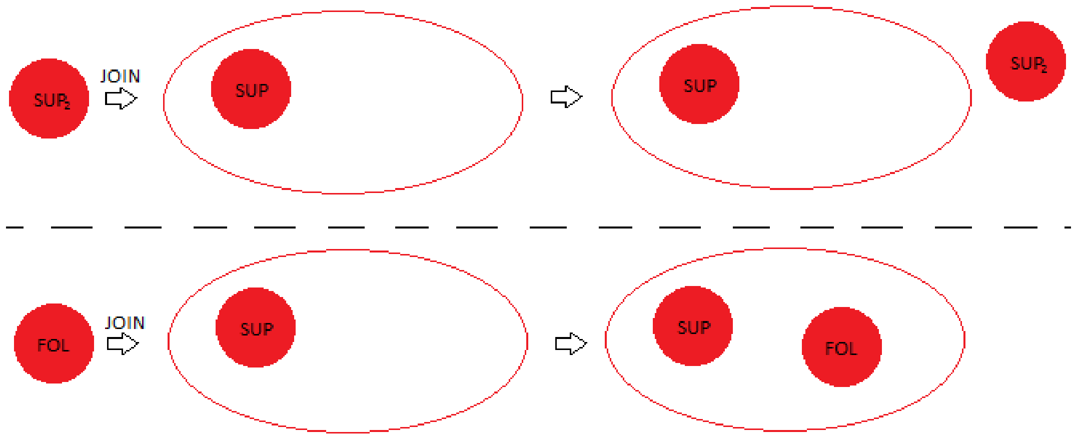


Figure 22: Group exists

3. The group is already existing, but there is the supervisor election: in this case a new comer has to wait until the end of the election to receive the assignment. The role of this node during the election is the GenericRole (it can receive messages and participate to the election). At the end of the election, if the node won the election, it becomes the new supervisor otherwise, if it is capable, becomes a follower. If no one is able to become a supervisor, the group is destroyed, because there must always be a supervisor.

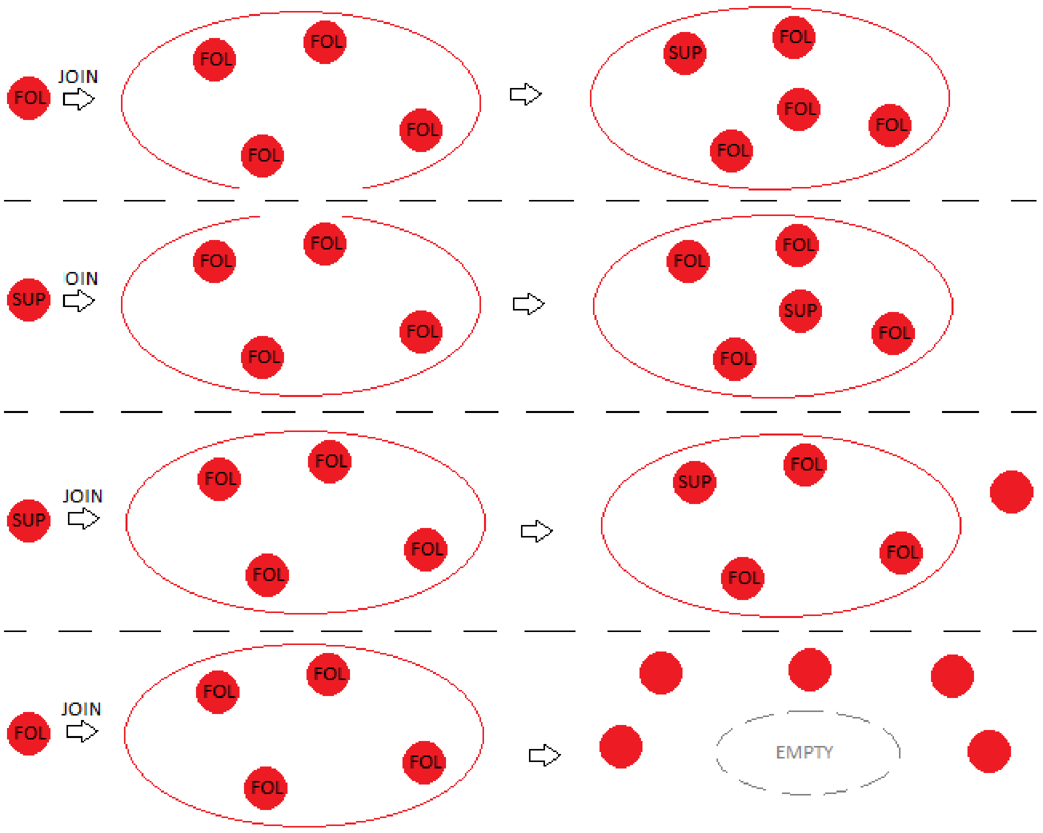


Figure 23: Join during election

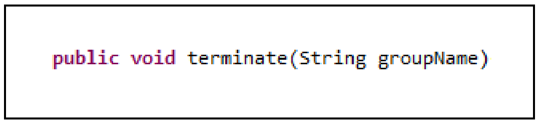
4.3.4 Communication between groups

Previously, we have seen how the communication between groups is via roles that are implemented in the same node. This thing is realized here through a shared memory space saved in the node, it can be used by any active role of the group, and can be seen, obviously, by all the active followers and supervisors of the same node.

This space is "inNodeSharedMemory", an it is where an object, that will be defined by the developer depending on the application that wants to realize, can be saved. Roles access it using getter and setter.

4.3.5 Leave the group

When a node no longer wants to be part of a group, it can call the terminate function, that terminates the role's thread and closes the JChannel.



```
public void terminate(String groupName)
```

From "channels" and from "activeRole" the values that have key equal to "groupName" are removed.

Now, if the node wants to participate to the work of that group, it needs to recall the joinGroup.

4.4 A3JGSupervisorRole.class

The developer must extend beyond the node, other two classes, which are used to define the behavior of the supervisor and of the follower. These two (abstract) classes are A3JGSupervisorRole and A3JGFollowerRole, which extend ReceiverAdapter and implement Runnable.

4.4.1 The supervisor role

This class must be extended every time you want to define a new kind of supervisor.

As already seen, the supervisor is the leader of the group, and the one that controls the work of the followers giving them information through messages. It is the core of the cluster, and everything revolves around it, so it is necessary to have always an active supervisor in each group, and when it dies, it must be replaced otherwise the cluster is closed.

The supervisor is also the one that can create a new group when this doesn't exist yet, while the follower, as we have seen, doesn't have this capacity.

So the idea in A-3 is that it is the supervisor the node with capacities for managing the fate of the group through its decision, for this reason it's the one that can implement the MAPE control loop. An automatic manager uses this loop, that is composed by four parts (Monitoring, Analysis, Planning and Execution), in this way: first information are captured from the external environment and the agent analyzes them in order to identify the best behavior to be taken to achieve its goal in this situation, then it performs the chosen actions. In fact, only the supervisor has the tool to receive information by all the members of the group, and to send the directives to all other participants. The MAPE control loop isn't yet deployed in A3JG, but is a future work.

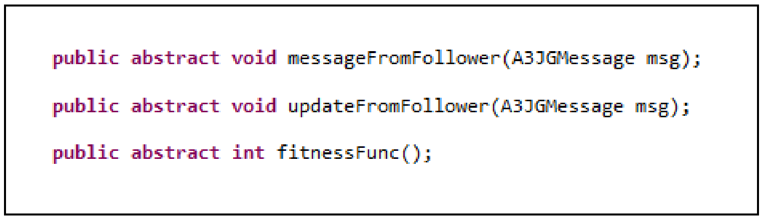
4.4.2 Structure

The supervisor has different attributes. There is a boolean ("active") that is used in order to define the status of the role, an integer that represent the cost of the role ("resourceCost"), a long that is used to indicate the time to split the group and by default it is equal to 1000 milliseconds ("splitTime"), the channel used to connect to the cluster ("chan"), the A3JGNode membership of the role ("node"), the ReplicatedHashMap used to exchange some information with the other members ("map"), an instance of MessageDelete ("deleter") and an integer ("index") used by the message "deleter" and we will see later its function, an A3JGRHMNotification to get notify from RHM ("notifier"), and the last is a boolean used when the group is splitted.

Of all these attributes, the only two that must be set by the programmer are those related to the costs (it's passed with the constructor, and it can be changed with the setter) and to the split time, the others are managed by A3JG.

4.4.3 Functions to extend

This class implements Runnable, so the run function of the thread and must be extended, in addition to it, also other three functions.



```
public abstract void messageFromFollower(A3JGMessage msg);

public abstract void updateFromFollower(A3JGMessage msg);

public abstract int fitnessFunc();
```

The run function is the one where the developer will put the behavior of the supervisor, and here the MAPE control loop (or the control can substitute the run function) can be put.

The first and the second function in the picture, are used in order to implement the communication between members of the same group.

The first is called whenever a follower sends a message to the supervisor, so in it there must be the code necessary to enable the supervisor to manage the received message ("msg"). For example, the supervisor can react to every received message, or can save the messages in memory and read them in a different moment, both the behaviors can be implemented in "messageFromFollower".

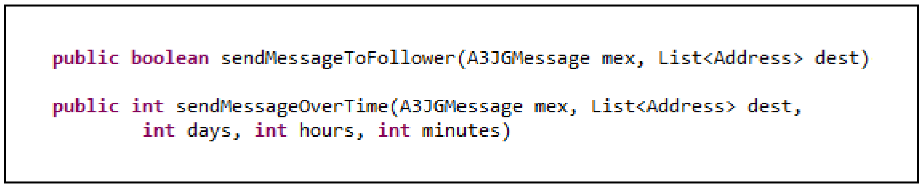
Instead, the second function is called whenever an update from a follower arrives to the supervisor. Also here the content of the update is "msg", and the kind of the update depends on how the application is implemented by the programmer. The developer can manage the update as preferred according to the type of system that he/she wants to realize.

Both the functions are called by the implementation of the "receive" function of JGroups, that is present in A3JGSupervisorRole class.

The last function in the picture is the fitness function that is used when there is a supervisor election or someone outside the group calls a "joinAsSupervisor". The function must return an integer that indicates how much is convenient to choose a node to be the new supervisor with respect to the others (for nodes which cannot be a supervisor in the group of the election, this value is set to 0 by default). This value is very important because it let the node to be the supervisor of the group, and the goal is to have as the leader a node that doesn't slow down the work of other members. You should consider in this function, for example, how much free space there is in the node.

4.4.4 Send message to followers

In order to send message to the other members, there are two functions available for the supervisor.



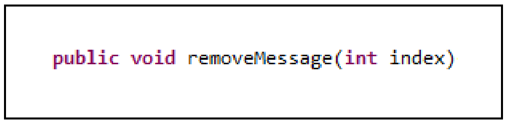
```
public boolean sendMessageToFollower(A3JGMessage mex, List<Address> dest)

public int sendMessageOverTime(A3JGMessage mex, List<Address> dest,
        int days, int hours, int minutes)
```

These two methods are very similar. The A3JGMessage (see 4.6) is set as content of a message defined by JGroups, and it is sent with the send method of the channel. The first is used when you want to send a message (“mex”) in broadcast or multicast or unicast. The three types of communication are achieved thanks to the parameter “dest”, that is a list of address. If it is equal to null or contains the addresses of all members, we have a broadcast communication, if there is only one address we have a unicast case, otherwise it is a multicast.

The second function works in the same way, the difference is that the message “mex” will be saved in memory on the ReplicatedHashMap for a time defined by the three integers that are passed (how many days, hours and minutes the message will be saved before its deletion). The message is sent only to the addresses in he list, but from the ReplicatedHashMap it can be read by anyone.

When a new message must be saved on the map, first recovers from RHM the object saved with the key “A3Message”, which is a HashMap which uses as keys the “index” of the message, while the other field is the Date of end validity of that message, then the A3JGMessage is saved in the RHM with the key equal to “A3MessageInMemory_” + the variable “index” of this class. You can save a message with an infinite time by passing 0 as value of “days”, “hours” and “minutes”.

In order to delete a message saved in memory, A3JG uses an automatic deleter, that is an instance of MessageDelete (see 4.8.3). This tool checks the message every tot milliseconds, and deletes each message found with an expired life time. There is also the opportunity to delete a message manually, using:



```
public void removeMessage(int index)
```

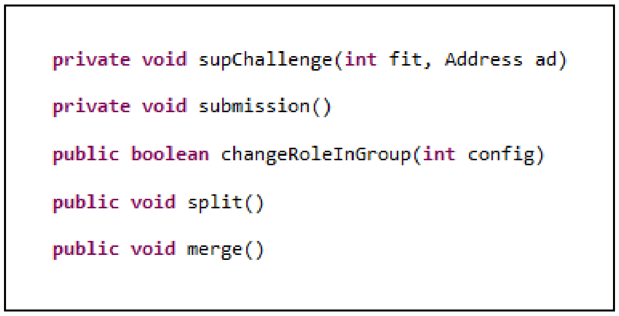
This function forces the “deleter” to eliminate the message with index equal to the integer passed. Messages with an infinite lifetime can be deleted only using this function. The attribute “index” is always equal to the integer following the highest number currently used in RHM.

4.4.5 Other supervisor methods

The functions “supChallenge” and “submission” are used automatically by A3JG after a “joinAsSupervisor”. The first, activated when the parameter of the join is “true”, checks if the current supervisor has the highest fitness value, and so it has to remain the supervisor, otherwise tries to change the current behavior with a follower role. The second instead tries to activate a follower role, and if it fails, it terminates the participation of the node in the group.

The function “changeRoleInGroup” is used by the supervisor when it wants to switch its current behavior with another supervisor role allowed for the group in which it participates. Here must be passed the number equal to the key of the chosen role as it is set in the group information. The function deactivates the current role and activates the new behavior.

The last two functions available are “split” and “merge” and they are obviously used in order to split a group that is too big, or merge two groups that were previously divided.



```
private void supChallenge(int fit, Address ad)

private void submission()

public boolean changeRoleInGroup(int config)

public void split()

public void merge()
```

4.5 A3JGFollowerRole.class

4.5.1 The follower role

This class is used to define the behavior of followers. In a group there may be more than one follower, but all of them talk only with the supervisor. We can see the follower as units of work coordinated by the decisions of the supervisor. The goal is to make sure that the followers are able to send the information that the supervisor needs to define the strategy of work. Followers must also understand and implement what they are told by the supervisor of the group.

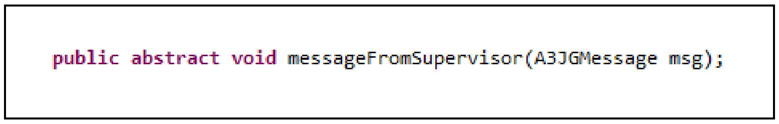
4.5.2 Structure

The structure of the class is similar to that of the supervisor. The attributes, that a follower has, are: a boolean for the activation status ("activate"), an integer for the cost ("resourceCost"), the channel used to connect the role to a cluster ("chan"), the A3JGNode membership ("node"), the ReplicatedHashMap shared between the other members ("map"), an ElectionManager (see 4.8.1) used when the supervisor dies ("em"), an A3JGRHMNotification to get notifications from RHM ("notifier"), an integer to take into account the number of attempts to carry out the election ("attempt"), an integer that defines the maximum number of attempts ("maxAttempt") that by default is set to 3, and finally a long variable that indicates the milliseconds within conduct the election ("electionTime") that by default is equal to 1000.

The developer has to manage the cost variable (assigned with the constructor), and has the possibility to modify the number of allow attempts and the value of the election time, which need to be well calibrated with respect to the type of application and the system to be realized, because these two values indicate the time in which the group will be without supervisor, so without a coordination of the followers. The importance of these values can be seen on section 5.3.2.

4.5.3 Functions to extend

Compared to the previous class, here, in addition to the run function of the thread, you should extend only another method.



```
public abstract void messageFromSupervisor(A3JGMessage msg);
```

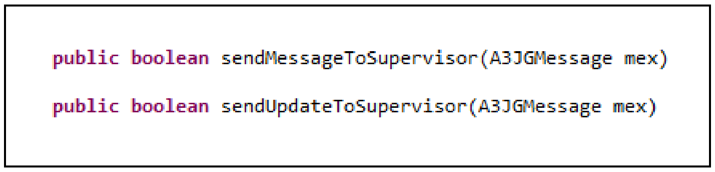
In the run function should be put the conduct which the follower must have within the working group but, unlike the supervisor, here there is no need to insert a MAPE control, because this type of membership is ideally less clever, and it just needs to do what it is asked by the group leader.

Instead, in the above method, there must be the code necessary to understand what it's asked to do by the supervisor, and any countermeasures to implement the actions required. With this function, the follower receives the messages sent by the supervisor when it's online. In order to get the messages that leader saves on the RHM, the follower can use the method "getMessageOverTime" that returns a list of all A3JGMessage stored at the moment.

As in the supervisor's case, also "messageFromSupervisor" is called by the implementation of the "receive" function of JGroups, that is present in A3JGFollowerRole class.

4.5.4 Send messages to supervisor

In order to send information to the supervisor, each follower can use two different ways:



```
public boolean sendMessageToSupervisor(A3JGMessage mex)

public boolean sendUpdateToSupervisor(A3JGMessage mex)
```

In both functions, the A3JGMessage is set as content of a message defined by JGroups, and it is sent with the send method of the channel. A follower can send messages only in unicast, and the recipient is, obviously, the supervisor (the exchange of messages between followers is not allowed in the A3JG's network).

As you can guess, the messages sent by the first method are received by the supervisor with "messageFromFollower", while those sent by the second reach their destination through "updateFromFollower".

With "sendMessageToSupervisor", you can send, for example, information to respond to requests made by the supervisor, and in most of the cases this will be used more than the "sendUpdateToSupervisor", which is more suited for example to notify the entry and the exit from the group, or the end of an important task. Of course it is up to the developer to decide how to use them to obtain the best possible results compared to the system that he/she intends to achieve.

4.5.5 Other follower methods

As in the supervisor's case, also the follower can change its active role in a group, for example, in order to better meet the needs of the moment, and the function that allows this is "changeRoleInGroup". This allows the follower to switch its current behavior with another that is allowed for the group it participates in. The follower must pass the number equal to the key of the chosen role as it is set in the group's information. The function deactivates the current role and activates the new behavior, so it works as the one that uses the supervisor.

An interesting method used by the follower is the “viewAccepted”, which is a function made available by JGroups and that is activated every time there is a change between the members of the cluster. In A3JG it’s used in order to get the moment when a supervisor election should be taken. The election is initiated by the first follower present in the list of members of the group (the list is the same for all nodes). The election begins by starting the ElectionManager thread (see 4.8.1).

4.6 A3JGMessage.class

When you want to send a message to another node, you must use the functions implemented by the supervisor and followers, which are prepared to achieve the communication between members of the same cluster. The body of the sent message is defined by the A3JGMessage class.

A3JGMessage is the object used to achieve the communication between nodes of the same group, but the developers may decide to use it also for the communication between active roles of the same A3JGNode, that, as already seen, occurs through a shared space of memory.

In fact, we can see A3JGMessage as a container, inside which we will put the information that the supervisor and the followers have to be exchanged, and it is, therefore, thought and realized in such a way as to support any type of content, leaving the designer free to decide its shape.

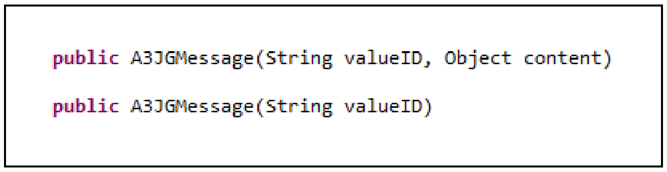
4.6.1 Structure

A3JGMessage implements Serializable because it’s a JGroups requirement in order to perform the exchange of object on the network. The are three variables: a boolean to indicate the type of the message making a distinction between normal message and update ("type"), but if the send functions available in A3JG are used you don't have to worry about the assignment of this value; an Object, that is the space where we put all the information to exchange ("content") and this must be a Serializable object, otherwise the message won't arrive to destination; and the last is a String used to recognize the message ("valueID"), you can use it as a unique ID (but if the message are so many may be not comfortable) or as a category ID (can act as a filter when it is received by the role).

The content of "valueID" is also checked by the reception function present in the roles, and depending on its value it is handled differently (application message and user message). For this reason, the developer must avoid using as identifier the following strings that are yet in use by A3JG in order to perform its work:

"A3FitnessFunction", "A3NewSupervisor", "A3Deactivate", "A3SplitNewSupervisor", "A3SplitChange", "A3MergeGroup", "A3StayFollower", "A3SupervisorChallenge" and "A3SupervisorChange".

In order to create a new message, two constructors are available:



```
public A3JGMessage(String valueID, Object content)

public A3JGMessage(String valueID)
```

As you can see, you have in both cases the string identifier, that must be present because, as already said, it's always checked when it comes in the recipient's function. Instead the Object to be put in "content" is optional.

Getter and setter allow to manage and change the value of these attributes.

4.7 A3JGroup.class

A3JGroup is used to define the information relating to a group of A-3. For each group, you must create an instance of A3JGroup, with the respective information. A node, in order to be able to connect itself to a group, must have the information about it.

Therefore, before a node tries to join, it must have received the information concerning the group, and the developer has to give the same data to all the nodes that will participate in the work of the cluster. If the information are different, two nodes of the same group may conflict because they use roles that are not compatible, so the developer has to be careful when he/she gives the information to the node and must ensure the consistency of these, otherwise he/she won't get the desired results.

4.7.1 Structure

As already mentioned several times, there can be more behaviors available for each role, then in this class must be stored all these possibilities, and this let us say that A3JG is used in the implementation of open-adaptive system, because it is always possible to add new behaviors. In order to save this information, there are two maps that store the canonical name of the classes that extend A3JGSupervisorRole and A3JGFollowerRole with the behavioral code. The key of both maps is an integer, and, for the default role, the key is 0, instead all values are defined by the developer. The name of these two attributes are "supervisor" and "follower".

Another variable is a String used to save the path to the XML file with the configuration of the channel ("groupConnection"). Obviously, all nodes must have the same configuration to be able to recover them in the same group. The last attribute ("groupDescriptor") can be used to save information and a description about the group identified by A3JGroup.

For each group of the system, the developer has to create an instance of A3JGroup using the constructor.

```
public A3JGroup(String supervisorDef, String followerDef)
```

The constructor requires the canonical name of the two behavioral classes that will be used as default role for the group. This two roles will be used when the node joins the group, so if the node has all the (eg follower) role available in a group, but it doesn't have the default (follower) role it can't join the group (as follower, but it can as supervisor if it has the default supervisor role).

All the others behavior are added to the group information through add function, in which you have to pass an integer, that will be the key, and the canonical class name of the role as String.

```
public void addSupervisor(int index, String className)

public void addFollower(int index, String className)
```

4.8 Other features

So far we have seen the part of application of A3JG that is visible by the developers, but there is another part that is hidden, or better, that doesn't require code's changes, because it concerns some automatic mechanisms that are used to implement some features of A-3 announced in section 3.

4.8.1 ElectionManager.class

The ElectionManager is called into action whenever a supervisor leaves the group, and it is therefore necessary to find a substitute for it. This mechanism is one of the strengths of A3JG, because it is able to find the best possible replacement for the role of supervisor without the developer has to write a single line of code. In fact, once the fitness functions have been defined, it will be the same A3JG to deal with the automatically retrieve of these values and to decide which is the best.

Then, using A3JG, there is no more need to worry about having to manage the replacement of a supervisor that leaves the group, and this leads to a greater ease of use.

The ElectionManager is a Thread, so the class implements a Runnable. In order to achieve the election, four variables are used. There is a boolean ("decide") that by default is set to true, and changes its value to false if during the election a new member joins the group from the outside, and so a new election process must be activated; a long attribute ("electionTime") that represent the milliseconds that the EM has to wait in order to obtain fitness value, and can be changed depending on the type of the application and of the system that the developer wants to realize, through the same attribute that there is in A3JGFollowerRole; the ReplicatedHashMap ("map") shared between nodes and that will be used to get the value of fitness; and the last is an instance of the channel ("chan") of the node that creates the Thread, which is necessary to let the EM to send messages to nodes of the group.

As we have seen, each group has an instance of View, which contains a list of the members of that cluster, and this view can be retrieved through the channels of the roles, so all nodes can have the same list with the same items and, because the members are added in the order they join the group, in the exact same order.

The election process takes advantage of this common list.

As seen in 4.5.5, each follower implements“viewAccepted” that is activated every time there is a change in the member list, and when this happens, every follower controls in the list of members of the group if the supervisor is still present. When the leader leaves the group, its address disappears from the list, and the first follower on it is the one that takes the job of starting the election of the new supervisor.

Each time a new node tries to join the group that is unsupervised, the chief election relaunched the process to include the new comer, as it could be the best candidate to become a supervisor, but to prevent this to be repeated indefinitely, the number of attempts is defined, and can be changed by the follower. Since in the list the order of group membership is maintained, the follower in charge of starting the election will be the same.

When the thread ElectionManager starts, it begins its work by sending a A3JGMessage to all nodes, with “valueID” equal to “A3FitnessFunction”. When a follower receives this message, an automatic behavior already set starts, which loads in the shared RHM the fitness value of that node using as key the address of its channel. If a node can act only like a follower in this group, his fitness value is equal to 0, otherwise it depends on the developer’s implementation of the supervisor’s “fitnessFunction”.

After sending, EM waits for a time in milliseconds equal to the value of the variable “electionTime”, and if, in this amount of time, a new node has joined the group, this instance of ElectionManager ends and it is replaced by another thread that started with the entry of the new member, as seen before, otherwise it starts the actual search of the new supervisor. From this moment, if a new member come, it can’t participate to the election. With a simple “for” loop, the manager controls all the fitness values stored in RHM, and saves the address (which is the key values) of the node with the highest fitness. When there is equality of values is chosen the node that has been in the group longer (the for loop uses the order of the list of members of the View).

If the fitness value of the node chosen to be the new supervisor is equal to 0 (that is the lowest possible value), this means that there isn't a node able to take the burden of being the new coordinator of the group, so the ElectionManager sends a A3JGMessage with "valueID" equal to "A3Deactivate" that gives the order to the followers to terminate themselves and, consequently, the group is deleted. Instead, if the fitness value is greater than 0, the manager, before cleans the map by the fitness value added for the election, then sends a message to the node chosen as new supervisor, with "valueID" equal to "A3NewSupervisor", that starts the process of deactivation of the role of follower and activates the supervisor role in that group, instead to all other nodes is made know, with another A3JGMessage, with "valueID" equal to "A3StayFollower", that the election is over and that they should continue to behave as they did up to that moment.

Figure 24 shows the election process with the supervisor that left the group, the follower that starts the ElectionManager which sends messages to nodes, the writing and reading from RHM, and finally the selection of the new supervisor with the last sending of A3JGMessage.

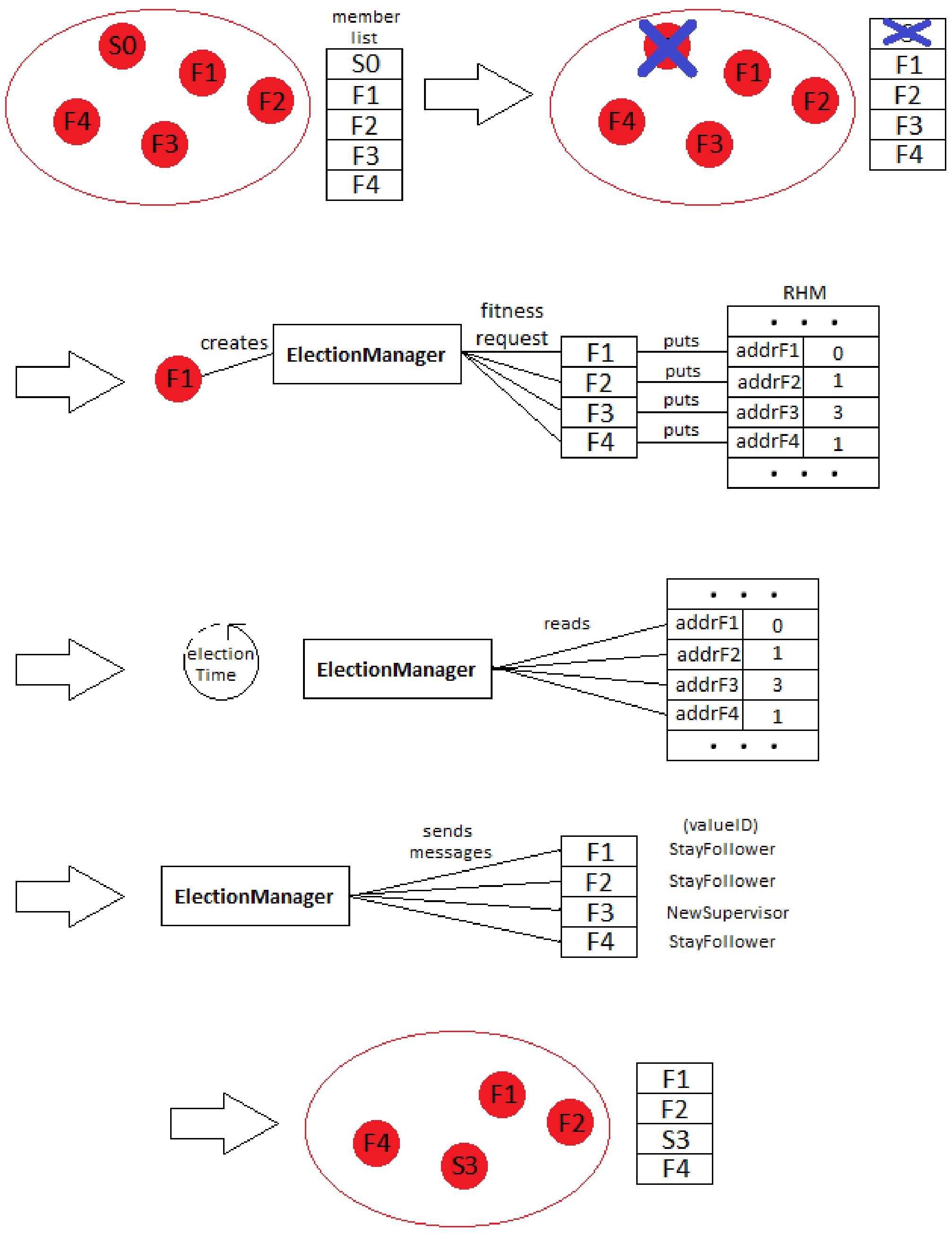


Figure 24: Election process

4.8.2 GenericRole.class

This class has been made to have a dummy role in order to not block a node when it can not start up a behavior for the group to which it wants to combine, typically when there is an ongoing election in the group or the node called a “joinAsSupervisor” with challenge.

When a node has activated the GenericRole, it has limited capacity for action in the group: it is able to receive messages, but includes only those related to the A3JG application, and can use a method needed to perform the challenge with the supervisor to contend the role of coordinator.

If we look at the class in detail, we see that it is an extension of a ReceiverAdapter, and that there are the variables needed to be connected to the group and receive information. These variables are the A3JGNode (“node”), the channel (“chan”), the ReplicatedHashMap (“map”) and the A3JGRHMNotification (“notifier”), namely those that serve to the role, that will be activated, in order to work in the group, and their values are set automatically during the join.

The situations in which the genericRole is created are two, and as can be seen, one is with the “joinGroup” and the other with the “joinAsSupervisor”.

In the first case, this role is activated when the node tries to join a group that has an election in place. This happens to make sure that new members can participate in the elections. To do this, when the GenericRole is created, the method “waitElection” is activated. This function, first of all, try to determine if the election is still in progress, and if so, it contributes sending its fitness value, but there is no guarantee that its value will be considered, but if a message arrives that requires the value of fitness, then it will be compared with other followers. Instead, if it finds the value “A3Deactivate” on the RHM, it means that the election is already over without finding a new supervisor, and in this case the node terminates its role and exits from the group which must be closed. This class has implemented the receive function in the same way as a follower, this is because the generic must be able to understand the messages that the application A3JG sends, then, if it enters the group when the election has not yet been completed, it will be able to receive the message with the role to be activated at the end of the poll.

In the second case, the GenericRole is activated in order to perform the challenge. When the “joinAsSupervisor” creates the role, it calls the “supervisorChallenge” function, that implements the first part of the duel. First, this method retrieves the fitness value of the node, and then it sends to the supervisor a A3JGMessage with the fitness value as the content and valueID equal to "A3SupervisorChallenge". At this point, the supervisor, after having received the message, it evaluates the winner of the challenge, and sends the result to the generic using a message. If the identifier is equal to "A3NewSupervisor", then the new member has won the challenge and becomes the supervisor, if it is equal to "A3StayFollower", it means that it lost the challenge and tries to activate the role of follower, in the negative case it exits from the group.

Thus, the GenericRole is thought of as a temporary state for a node, and after a short time, it will be replaced by one of the two main roles of A3.

4.8.3 MessageDelete.class

As seen, the skills of a supervisor include the ability to save A3JGMessage on the ReplicatedHashMap, in such a way that even nodes which aren’t online at the time of transmission, can read its contents. These messages can remain in memory for a long time, but after this period can be no longer valid and should be removed so that new members can not read them, and then take actions that are no longer needed.

As already said, the supervisor can manually delete these messages, via the function “removeMessage”, but A3JG provides also an automatic deleter that is able to delete messages from the RHM when they are no longer valid.

In detail, the deleter available to supervisors is a thread that is activated only when there are A3JGMessage on the map then, when the supervisor sends messages to be saved in memory, and it remains active as long as there are messages on the RHM, or when the supervisor role is taken by another node and there are messages stored by its predecessor. In the class there is a boolean variable (“active”) in order to keep alive the thread until there are messages on the RHM; the ReplicatedHashMap (“map”) that is the same used by the supervisor; an integer (“waitTime”) that is the period of time with which it repeats the search of the messages to be deleted; an HashMap<Integer, Date> (“chiavi”) whose value is taken by the RHM; and the last variable is an arraylist of integer (“deleteKey”) which is filled in each cycle with the message keys to be deleted from the map.

With each cycle, MessageDelete takes the value of the A3Message and saves it in the variable “chiavi”, then flows across this map and controls which objects have the expiration date earlier than the current time, they are marked by inserting the value of their key in “deleteKey”. At this point, the deleter research on RHM objects with key “A3MessageInMemory_” + each value that is in “deleteKey”, deleting them from the ReplicatedHashMap (they are also removed from “A3Message”). Now, if the size of the map saved in “A3Message”is equal to 0, this means that there are no more message saved in the RHM, so the MD ends automatically, otherwise it waits “waitTime” milliseconds before re-cycle.

The MessageDelete class also contains a method to remove a single message, and it is called by the supervisor to delete A3JGMessage manually ("toDelete").

4.8.4 SplitManager.class

This is the last feature of A3JG, and serves to rebalance a group when it is too large and, for example, the internal coordination between nodes becomes difficult. This procedure is initiated by the supervisor of the group, then the developer can define the maximum size of the cluster based on the application that he wants to make. The effect of this action is to split the group into two, balanced in such a way to have the same number of members, and with a follower of the first group that is the supervisor in the second. Of course is also available the inverse function (merge) that combines two groups previously separated.

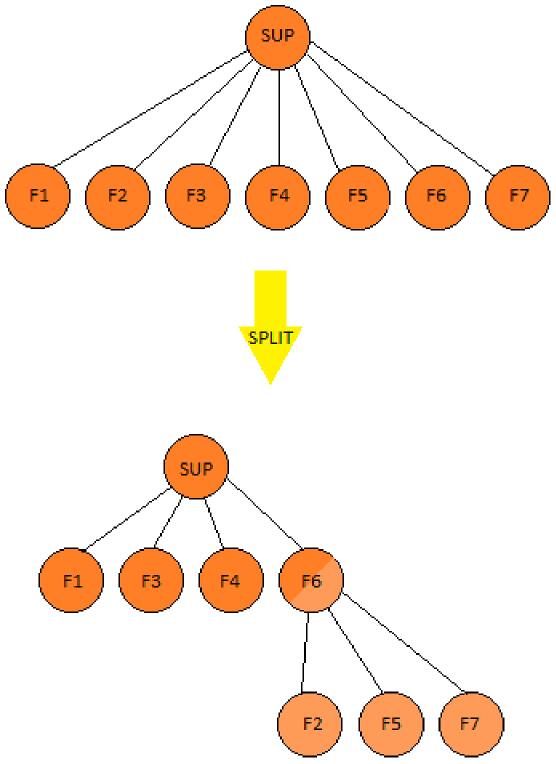


Figure 25: Split function

In order to achieve the separation, the SplitManager is used. This class (that implements Runnable) has only three variables: a long ("splitTime") number that takes its value from the variables with the same name in A3JGSupervisorRole; the RHM ("map"); and the last is a channel ("chan") for the communication between the members of the group.

When the SplitManager is activated, first of all sends a message to all those present to take their fitness value to locate the node that will make a bridge between the two future groups. Then, after a time defined by "splitTime", if there isn't a node able to do both follower and supervisor, the split fails, otherwise the member with the highest fitness value receives a A3JGMessage with "valueID" equal to “A3SplitNewSupervisor” and becomes the supervisor of the new group (that will be created by it). To some other member is sent the message saying “A3SplitChange”, and those will be the followers of the new group. In the received message, as content there is the new configuration to be adopted.

in order to join groups, it must be the supervisor of the second group to call the merge function.

In figure 11 we can see an example of how the split function works. Initially, the group “orange” has a supervisor (“SUP”) and seven followers (“F1”, “F2”, an so on up to “F7”). Then, “SUP” call the “split” and A3JG identifies “F6” as a node shared between the two groups, so it remains follower of “SUP” as well as “F1”, “F3” and “F4”, but becomes supervisor of the new group and has as followers “F2”, “F5” and “F7”

4.9 Support material

The source code of the A3JG project is hosted by GoogleCode and is available at http://code.google.com/p/a3-jgroups/. There is also the support material for people wishing to develop a system using A3JG. There is the javadoc of the code, and a manual with guidelines for understanding what A3JG is and how to make a project with it. The manual also contains two guided examples to learn how to use this implementation of A-3.

In the source code, there are also other examples ranging from the creation of a simple group with 3 nodes, to the use of all the features of A3JG. These examples have been also used as a first test of the functionality of the project.

5 Performance Evaluation

5.1 Hospital's scenario

The scenario used to evaluate A3JG's performance takes place in a hospital. In this context, we need to manage a high number of people (staff, patients and visitors), to reach a good level of efficiency and safety in the environment. All these people have different needs and different departments to visit, so even getting everyone to their desired destination can be a complex problem. Therefore we use A3JG to guide people as they travel through the hospital. Moreover this guidance is self-adaptive.

The experiment simulates the hospital's environment. Each person is give a wristband is given to each person when they enter the hospital. It has information about the person's destination and can be used to show the person the path to follow (in this work, each destination is identified by a color). Through the hospital there are screens placed at each corridor intersection. They are used to communicate directions to the wristband. These screens can adapt what they show based on the people who are close to them, so they have to monitor all the movement near them.

We created the following A-3 groups:

- Screen: in this group there are all the screens (as followers), plus the hospital's server (as the supervisor)
- Color(i): for each screen(i), there is a group for each possible

color (destination). The screen(i) is the supervisor and one person is a follower

- SubColor(i): for each color(i) group, there is a cluster in which people that are near the screen(i) are connected, that have "color" as their destination (the supervisor is the one that is also follower in Color(i), all the other are followers)

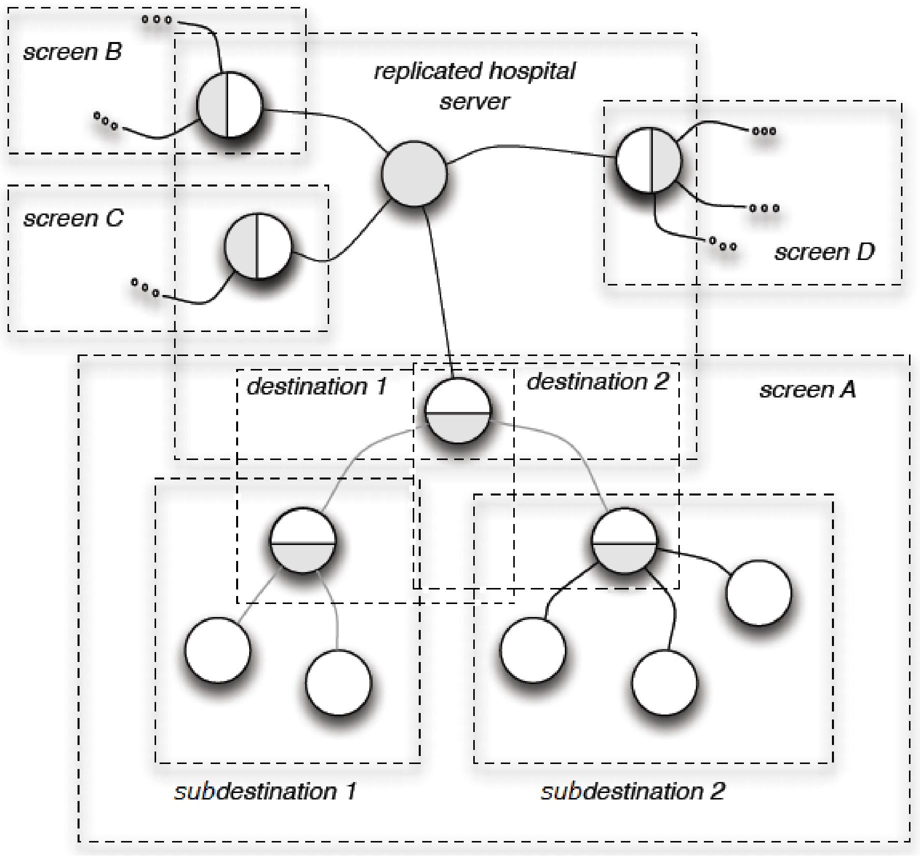


Figure 26: Group composition

The scenario also has the following types of nodes:

- the Hospital's server: that is the supervisor of the Screen's group; it is replicated for fault-tolerance
- Screen: is a screen, and it has the follower role for the Screen's group, and the supervisor roles for all groups Color(i) that are activated by the screen
- Human: is a person, without distinction between staff, visitor and patients, because this distinction is made by the destination. Human can be a follower in group Color(i), and both a supervisor and a follower in group SubColor(i)

5.2 Siafu

The first simulation was made using Siafu, an open-source context-simulator written in Java. Siafu provides models for agents, places and the context, and by altering these values we can influence the scenario.

For the simulation of the hospital scenario, I mapped a hypothetical floor plan, in which the significant places, those used as destinations for the test, are two access point (that are identified by the GREEN color), a laboratory for blood's analysis (this destination has the RED color), a room for radiology (BLUE color) and, finally, the physiotherapy room (which destination's color is YELLOW). There are also six screens placed at six crossing corridors. For this simulation I used a single PC (Intel core i7 with 8 GB of RAM), so all the connections are on the local network, and communication is performed using the UDP protocol.

I created the screens group ("SCREEN"), in which the hospital's server acts as a supervisor and the six screens act as followers. Each screen is also the supervisor of four local groups, one for each possible destination ("RED0", "BLUE0", "GREEN0", "YELLOW0", ..., "RED5", "BLUE5", "GREEN5", "YELLOW5"). Each of these groups has only one person as its follower. This person creates the corresponding subgroup in which he is the supervisor and all the other people, with the same direction and near the same screen, are followers (“SUBRED0”, “SUBBLUE0”, “SUBGREEN0”, “SUBYELLOW0”, ..., “SUBRED5”, “SUBBLUE5”, “SUBGREEN5”, “SUBYELLOW5”). The groups are therefore 1 for the screens, 4 for each screen, and a subgroup for each group created by the screen, in total: 1 + 4*6 + 4*6 = 49. however the subgroups, are created only when there is a person near a screen that has to go to that destination. So, there were 25 groups always active, and other 24 that were created and destroyed according to the position of the people in the map.

The nodes are:

- 1 hospital's server (with one connection)
- 6 screen (with 5 connection for each screen, for a total of 30)
- 50 human (with one active connection for each, except for those that are also in the color's group created by the screen, and that can be, maximum, 24).

The total number of nodes that there are in this experiment is 57, with a maximum of 1 + 30 + 74 = 105 active connections at the same time.

In this simulation, the number of people entering the hospital depends on the time of day, like in a real case. They enter using one of the two access point, with a destination that is assigned in a random way. Once that a person reaches his destination, a new destination is assigned, until he leaves the hospital.

During the setup of the environment, the screen's group is created, and as soon as a screen joins it, it gets information about the general route from the hospital's server. At the same time, each screen creates its color groups, and waits for people to arrive. When a person is near a screen, he/she tries to connect to the color subgroup of his destination. If he/she is connected as a follower, he/she asks his/her supervisor for information about the path. Otherwise, if he is connected as a supervisor (and so he is the creator of the subgroup), he/she tries to connect to the color group of his/her destination, and then asks the screen that is the supervisor in the group about the path. When a person leaves the area near the screen, he disconnects from the screen's network. If it was the supervisor of the subgroup, an election between the other people in the group takes place. As a consequence, each screen only needs to supervise a small group of representatives to be able to manage high-volumes of people.

I have also added an obstacle in one corridor, that it is activated manually. This way is possible to see if the system can promptly react to guarantee the safety of the people. The screens have the task of monitoring the corridors in search of obstacles, and of notifies central server, so that it can send the new path for each destination to all screens.

The simulation shows that people that enter with no knowledge about the route and disposition of the rooms, are able to reach their destination following only the instructions given by the screen, minimizing their waiting time, even when an obstacle appears.

A video clip of this simulation is available on GoogleCode, together with the source code.

This test shows that A3JG can be used in this kind of scenario, but, in order to understand its performance, I have other worst case scenario test. In these scenarios all the people arrive at the same screen, and with the same needs.

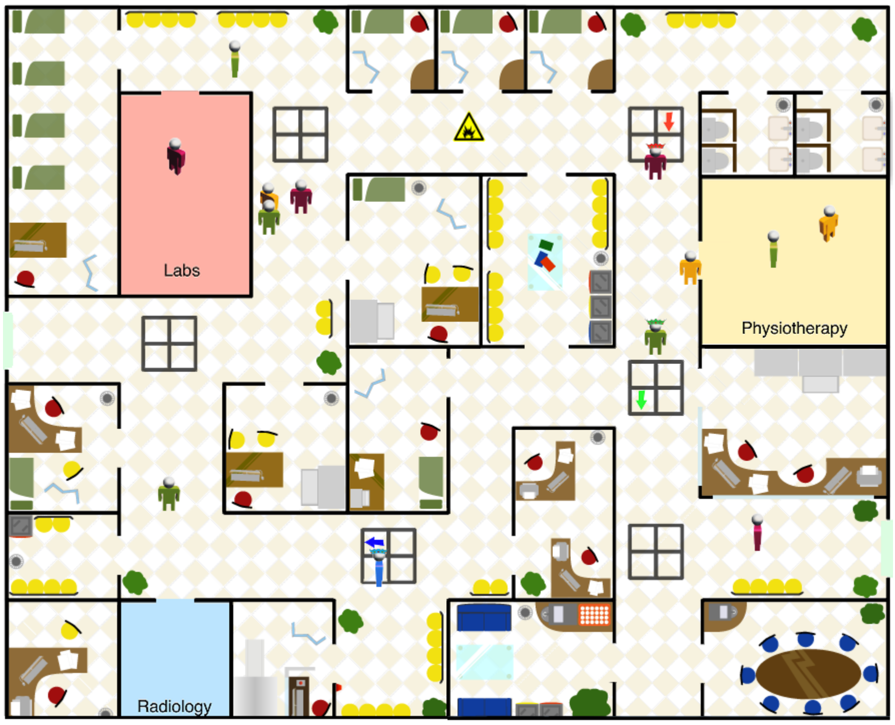


Figure 27: Siafu screenshot

5.3 Worst case scenario

In this test we only consider one screen, and all the people that enter the system have the same destination. Like in the Siafu simulation, the system must ensure efficiency and safety, so efficient message exchanges must be guaranteed.

The groups created in this test are:

- Color: the groups created by the screen, also behaves as their supervisor. Since this is a worst case scenario, here there are four different color/destination ("RED", "BLUE", "GREEN", "YELLOW")
- SubColor: these are the groups that are created when a person

is near a screen. Since all the people have the same direction, we have only one group ("SUBRED")

The number of groups is 5; three of them will be practically empty since all the people will have the same direction. The "SCREEN" group isn't created because, in this test, We assume that the screen already knows the path for each destination, and that no obstacle will appear in the environment.

For this test I used 5 PCs: one with an Intel Core i7 and 8 GB of RAM, three with Intel Core 2s and 4 GB of RAM and one with an Intel Core i5 and 4 GB of RAM. The first PC hosted the screen. The PCs were connected in LAN through a wifi router, and the messaging is achieved using the UDP protocol.

The test is made up of two phases.

5.3.1 Phase 1

Phase 1 evaluated how A3JG performed in evaluating the nodes fitness functions. To obtain the best result from the election process, and to reach all the safety goals, we need to be able to finish the election chores. This would allow more nodes to participate in the election process, ensuring the best possible choice was made.

The ElectionManager class was modified so that when a supervisor leaves its group, the election manager collects a timestamp when the first message is sent to the followers (START), a timestamp for when the last write into the ReplicatedHashMap (LAST_MSG) occurs, and a timestamp for when the last election request message is sent to the followers (END).

The number of messages sent depends, obviously, on the number of nodes in the system. So, if N is the number of nodes, the messages sent for the election are:

- 1 message from the election manager for each follower request their fitness function (N messages)
- 1 update of the ReplicatedHashMap for each node after each update (N^2 messages)
- 1 notification message after the electionTime has elapsed for each node (N messages)

If the election starts at time $t = 0$, and the electionTime ends at time $t = t_e$, between 0 and t_e we sent $N + N^2$ messages; while after t_e we send N more messages. In total, in the entire process, the number of messages that are sent is:

$$N + N^2 + N = 2N + N^2$$

To save time during each update on the map to determine how many fitness function are considered by the election manager, it was necessary to send this timestamp from each node to the manager in order to have synchronized information of the entire process, so between 0 and t_e, other N messages are sent, but this allow us to not underestimate the time necessary for the entire process. However, the binding value is given by the N^2.

I used the 5 PCs described previously, to simulate the scenario with increasingly high numbers of people near the screen. I started with 1 person per each screen at the first step, and went up to 40 people per screen in the fourteenth test.

The election policy was to use only 1 attempt to find the new supervisor (so all the new nodes that enter the group during the election are not taken into account), and 1 second was the allowed election time.

This simulation was done in two different situations:

1. Stable: in this case, during the election, no node tried to join or leave the group.
2. Unstable: this is the more realist case. The people are moving around the screen without a defined pattern, so during an election nodes can join or leave the group freely.

Once I captured all the data, I calculated the time between the beginning of the election and the last save to the RHM (S - LM) and the time between the beginning and the end of the election (S - E). Table 1 illustrates the result for the stable case.

In the unstable case, each person can stay in the group from 19 to 48 seconds (the value is assigned randomly) and when one leaves the group, after two seconds it rejoins it. Table 2 shows the results in this case.

The two diagrams in figures 28 and 29 show a comparison between the results obtained in the two different cases.

From the diagram in figure 28, it is possible to notice that, in the stable situation, until the number of people is under 100, the time (in milliseconds) to complete the data sending is in the same order of magnitude. Beyond 100 people, the value increases exponentially. Moreover in the unstable version, the values for cases in which there are less than 100 nodes have the same order of magnitude. In particular, the value obtained with 5 people is the same in the two cases. For all the other steps, the values obtained in the unstable case are much bigger. In particular there are nodes that, in situations with more than 100 nodes, are not able to return their fitness value in less than 1 seconds (7 nodes out of 125 for the 5.6%, 9 out of 150 for the 6%, and 14 out of 200 for the 7%).

In the step with 200 nodes, 40200 messages are sent in the first phase of the election (before t = electionTime). Considering the stable case, in which only messages regarding the election itself are

STEP	# PEOPLE	START (ms)	LAST_MSG (ms)	END (ms)	S - LM	S - E
1	5	34263	34295	35265	32	1002
2	10	16650	16684	17654	34	1004
3	20	45425	45472	46471	47	1046
4	30	40251	40298	41265	47	1014
5	40	21364	21411	22378	47	1014
6	50	199518	199565	200533	47	1015
7	60	24804	24851	25849	47	1045
8	70	19257	19335	20309	78	1052
9	80	51000	51078	52029	78	1029
10	90	43250	43328	44296	78	1046
11	100	30347	30440	31402	93	1055
12	125	36763	36904	37949	141	1186
13	150	96379	96706	97620	327	1241
14	200	31062	31779	32278	717	1216

Table 1: Stable case

STEP	# PEOPLE	START (ms)	LAST_MSG (ms)	END (ms)	S - LM	S - E
1	5	68415	68448	69425	33	1010
2	10	78278	78484	79323	206	1045
3	20	90312	90484	91451	172	1139
4	30	51431	51681	52461	250	1030
5	40	58187	58483	59232	296	1045
6	50	39867	40272	40912	405	1045
7	60	92049	92376	93187	327	1138
8	70	11489	11972	12527	483	1038
9	80	25097	25970	26173	873	1076
10	90	18235	19077	19343	842	1108
11	100	36089	36884	37243	795	1154
12	125	60832	62373	62086	1541	1254
13	150	54363	55970	55736	1607	1373
14	200	99568	104500	100785	4932	1217

Table 2: Unstable case

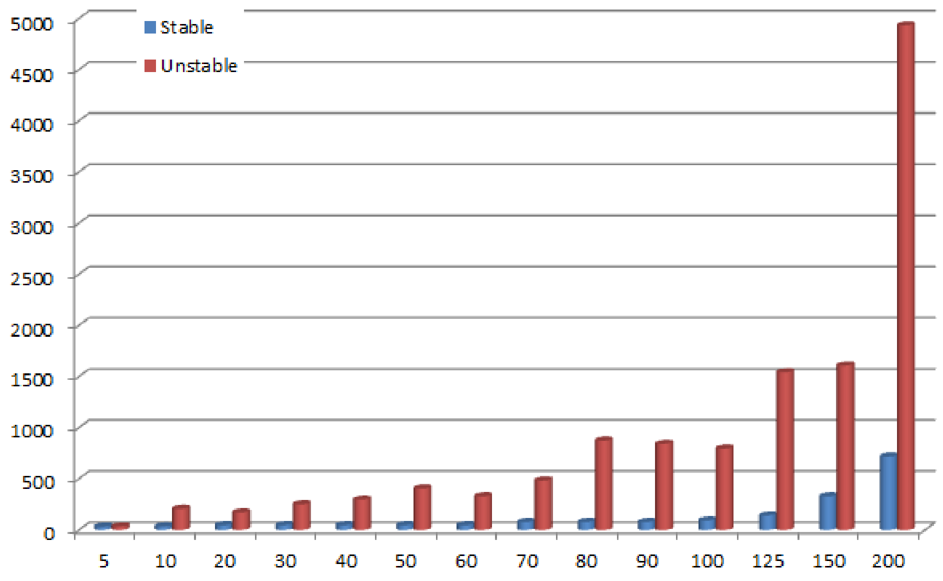


Figure 28: S - LM diagram

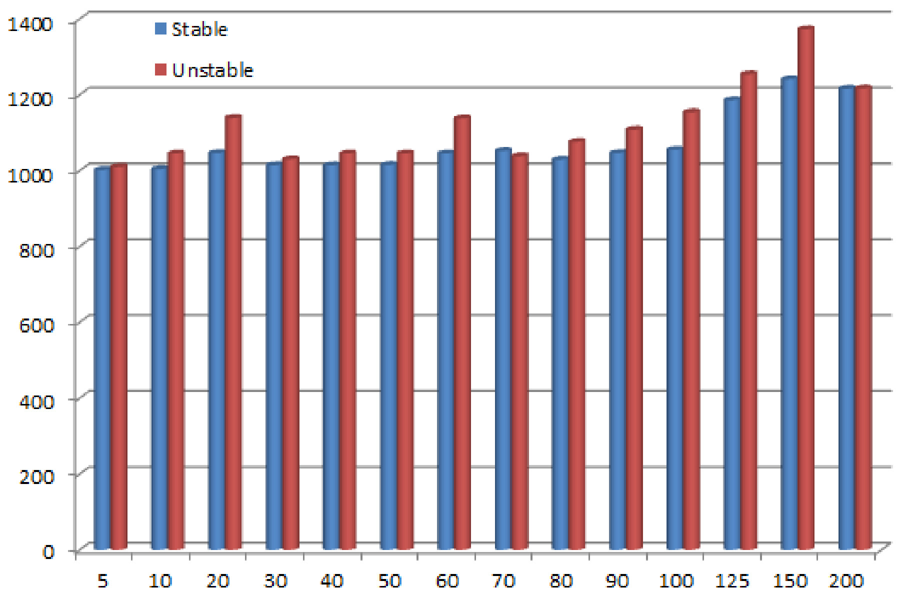


Figure 29: S - E diagram

sent, and where the maximum message size is 4KB (due to the size of the RHM), we need a network capable of sending 157 MB/sec.

The diagram in figure 29 shows the total time necessary for the entire election at each step. One second of this time is due to the election time. Also it is possible to notice that the best results are obtained with less than 100 nodes, and that the high values in the unstable case, for steps over 100 node, are caused by the increasing message traffic due to that are not able to send their fitness value in time.

5.3.2 Phase 2

Phase 2 evaluated A3JG's performance using different strategies for the election process. In fact, A3JG allows developers to implement different policies; they are not forced to use the election manager with its preset default values.

Once again the groups that are created are 4(the four possible direction), and there is 1 subgroup for the red direction, for a total of 5 groups. The number of active nodes is 41 (1 is the screen, and 40 people that cross the area).

The values that can be modified manually are the number of attempts that take place and the election time, that is the time that the election manager waits before choosing the new supervisor. In particular, the developer must also implement the fitness function, which is the core of the election policy.

For the test, I've compared four different strategies:

- Case A: maxAttempt = 1, electionTime = 1 sec, fitness function that chooses the person that will stay in the group for the most time.

- Case B: maxAttempt = 3, electionTime = 1 sec, fitness function that chooses the person that will stay in the group for the most time.

- Case C: maxAttempt = 1, electionTime = 1 sec, fitness function that chooses the new supervisor randomly.
- Case D: maxAttempt = 3, electionTime = 1 sec, fitness function that chooses the new supervisor randomly.

With these configurations, it is possible to compare how different choices affect the result. For all four cases I set 1 second as the election time because, in the environment, I need the election process to finish as quickly as possible.

I tried each case three times. In particular, each simulation had a duration of five minutes and each person could be connected to the screen for a time between 19 to 48 seconds, and after that one leaves the group, he must wait 2 seconds before rejoining the group.

The results of my tests are shown in Table 3. The first column is the case, the second is the total number of supervisors that were activated (one is the first that arrives to the screen and he is activated as supervisor without election), then there is the medium time spent in the election process. The fourth column is the total time spent without an active supervisor, and the last column is the average life time.

Comparing the values between cases A and B, and cases C and D, couples that have the same fitness function but different number of attempts, we can see that cases B and D spend more time without coordination. However, the number of elected supervisor is smaller. Therefore, in situations in which the recovery process is critical, it is preferable to have a greater number of attempts.

LABEL	# SUP	Tm election (ms)	T no sup (ms)	Tm sup life (ms)
A	8	1043	7301	36587
A	8	1021	7147	36607
A	8	1014	7098	36613
B	8	1433	10031	36246
B	7	1485	8910	41584
B	7	1461	8766	41605
C	13	1017	12204	22138
C	12	1015	11165	24070
C	12	1014	11154	24071
D	11	1510	15100	25900
D	16	1437	21555	17403
D	11	1403	14030	25997

Table 3: Comparison of strategies

Instead, comparing cases A and C, and cases B and D, which use different fitness functions, the results show that a good fitness strategy greatly reduces the number of performed elections. It is an important feature that must be implemented in the best way possible to improve the general performance.

5.4 How can we improve?

From these tests, it is clear that the main limiting factor is the network. It's necessary, first of all, to have a network that can support the system and its workload. Unfortunately it's not always possible to have a good network. Some tricks can be used, however, when the situation is critical. For example, if we consider the hospital, in which people join the group to set the information about their destination, we can improve the performance by disconnecting a follower as soon as he gets the information he/she needs. This way, if there are 200 people near the screen, the number of active connections remains lower, since we only need to connect the supervisor and the few people that just arrived near the screen.

Another possibility is to use more groups, so that when there is an election, a lower number of followers will participate in the process, and thus the traffic on the network will be reduced.

There is also some work that can be done on A3JG to improve its performance. For example, future work could develop a dedicated communication network that replaces JGroups. This substitution can improve the A3JG's capacity because now it is using the ReplicatedHashMap of JGroups, but this feature is not guaranteed to operate well, and it also increases the size of the messages during the election. In fact, for the moment, the RHM is used to achieve different characteristics of A3JG, but all this can lead to excessive slow down in the election process. So, in the new connection and communication substrate, it should be possible to distinguish the different areas in which the map is currently being used, so that different elements of the network.

Future work should also consider the development of a MAPE control loop that will complement (or replace) the current coordination process, and which may provide better tools for managing the supervisor, and consequently the followers. In fact, for the moment the control cycle does not have distinct phases, and this may require the developer to create a control part, with probable lower performance. However, inserting the MAPE control loop within individual supervisors (who seem to be the most suitable entity), we should also be careful to not tie the overall coordination of the system to the individual groups. If this should happen a single group could cause delays to the whole system.

6 Conclusion

Research on self-adaptive systems started about twenty years ago, and in these years many solutions and ideas have been proposed. A-3 is an innovative solution for the realization of distributed systems with a high number of components that can freely join and leave the system, and where the coordination and management requirements are very strong. A-3 proposes the use of groups to de-centralize the management of the nodes, so that the designer can concentrate on the coordination of elements that are less dynamic. This also allows nodes to move freely; in fact, individual entries and exits do not cause problems for the general management of the system.

This work presented A3JG, a Java-based implementation of A-3, that allows distributed nodes to collaborate to reach a common goal using the A-3 style. It allows the creation of groups, and the policy of grouping can be freely decided by the developer of the application. Each node can assume a role in each group in which it can work, and for each group an entity can be a supervisor (only one for each group) or a follower. These two roles are obtained in the middleware extending the A3JGSupervisorRole and A3JGFollowerRole classes. Thanks to these two, the developer is able to use all the features of A-3, such as different types of message exchange on the election process.

This thesis presented several tests to verify the actual usefulness of A3JG as a middleware. In particular, these tests focused on the realization of a self-adaptive hospital environment, in which people are guided inside the building to reach their destinations efficiently and safely. In an environment such as a hospital, each day thousands of people between staff, patients and visitors that move inside it, and if each of these represents a node in our network, a centralized management is not able to ensure crucial requirements such as security.

The first test, showed how systems that use A3JG are able to easily manage the task of providing the directions and guiding people through the corridors without problems. Even in the case in which an accident occurs in a corridor, entities predisposed to monitor the environment for possible dangers are able to notice the problem immediately and report it to the server so that the hospital can adapt its paths to ensure the safety of persons.

The second test was designed to measure the performance of the system, and it concerned on the worst case scenario, given that the requirements can be very stringent as when human lives are at stake. From this simulation, it was clear that a first limit, which is not easily surmountable, is given by the capacity of the network. However I have proposed possible solutions to be able to operate also in these conditions. The tests also emphasized the need to work on A3JG's connection-level and node communication capabilities, in such a way to have a network designed specifically for its characteristics. This, in turn, should allow us to reduce the traffic generated by message exchanges, and to improve its performance.

Finally, it was shown that the designer's choices can greatly affect the overall performance of the system. In fact, the developer is required to provide some details on how to evaluate the nodes during election, enable the system to recover a supervisor when it leaves the network. From the tests I noticed that when the developer uses an optimal strategy for assigning the fitness value, and he fits correctly the parameters of the election manager, this can significantly reduce the periods in which a group remains without a guide.

As for future work, there is the need to correctly insert MAPE control loops inside the supervisor, providing even simple methods to the developer, so that through these he/she can organize the coordination within the group. A problem can be given by the possibility of a node to join more than a group, and then to create an information exchange between these groups. In fact, must be avoid that the slowing down of the MAPE loop of a shared node can be propagated within the other groups, and then that the overall coordination of the system is slowed down.

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