bCMS-SPL case study: A proposition based on the Cloud Component Approach

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bCMS-SPL case study:
A proposition based on the Cloud Component Approach.

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Abstract

This paper is a model for the Comparing Modeling Approaches workshop. It presents the cloud component model and a Model for Variability of Refinement Processes used to model the proposed use case [1, 2]. Our targets are high-level and architectural design, and

evolution. Runtime support will be tackled, but is not in the main focus of our paper. We introduce:

- A single system: on the basis of a custom component model, the cloud component model. The latter is dedicated to the modeling of distributed applications [1].
- The whole SPL: on the basis of an MDE refinement process model that has the property of being variable. Its specification is inspired by previous works on refinement and feature models dedicated to provide adaptation capabilities to component-based architectures [2].

1 Introduction

This paper presents an interpretation of the bCMS-SPL use case. Our approach for modeling Software Product Lines (SPL) is based on Component Based Software Engineering (CBSE), Model Driven Architecture (MDA), and model trans.

We provide a development process for adaptive distributed components. From the architectural point of view, we rely on cloud components for modeling the software. A cloud component (CC) is a distributed component where the main idea is that CCs hold the distribution, on the contrary of bindings which are made local to a node. This reversal of the pattern commonly used for components for distribution – distributed bindings and local components – raises some interesting properties. For instance, it hides the distribution-specific properties that are usually delegated to bindings inside the component (QoS, deployment, security, protocols). Thereby, those properties become non-functional properties of the component [1].

From the development process point of view, we combine SPL and MDA using a Model of Variable Refinement Processes (MVRP), that is inspired by Feature Models. The feature modeling method is used for the separation of functional concerns. Each concern is a variation point and alternative solutions to this concern are variations. In MVRP, concerns are implemented using model transformations. Therefore, to build a system variant corresponding to a feature configuration, the base model of the system is step by step transformed from a high abstraction level to the implementation level. Each transformation is compliant with the MDA pattern, i.e. a concern-independent model is transformed into a concern-specific model.

The Section 2 presents the CC metamodel. Section 3 discusses the Model for Variable Refinement Processes we used to model the bCMS-SPL. Finally, sections 4 and 5 respectively present the modeling of the bCMS-SPL using CCs and MVRP, and conclude the proposition. The complete models for bCMS-SPL are available in the appendices.

2 Cloud Component Metamodel

This section provides details about the three most fundamental notions involved in CCs: border, sectors, and connectors.

2.1 Basic concepts

A CC model is a component model for distributed systems [1]. In *fig.1*, we present the central concept behind CC models. Traditionally, components are localized and bindings hold the distribution. The left part of *fig.1* represents this case, component A is a client of component B. Components A and B are both deployed in specific locations and the binding is the glue between those components, implemented for instance using web services or any other binding protocol. Two CCs are depicted in the right part of *fig.1*. Unlike the common scheme, CCs are distributed

and bindings are local. To distinguish cloud components with "common" ones, we represent them with an ellipse shape in the graphical model instead of the common rectangle shape.

Szyperski gives a well recognized definition of a component as *"a unit of composition with contractually specified interfaces and explicit context dependancies only. A software component can be deployed independently and is subject to composition by third parties"* [3, p.41]. Despite an original view of the distribution side, components modeled as CC are fully compliant with this definition, and are therefore components.

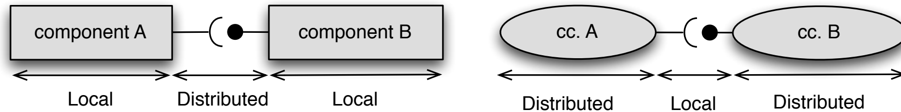

Figure 1: Distribution of components and bindings in common components (left) versus in CCs (right).

The *border* of a CC is the part of the architectural specification that is accessible to the final user of the component, on the contrary to the internal architecture which is hidden by the border. From an internal architecture point of view, CCs are composite components. They are build on top of other components, being cloud or common components, that are deployed on some of its *sectors*. These components are linked with each others on the basis of *connectors* that follow specific rules.

The reader may refer to *fig.2* throughout the reading of this section, as it presents a sample complete architecture for a cloud component that is part of our implementation of the bCMS System. Its purpose is to implement an inter-sector communication service. It transmits messages from one point of the architecture to another: from `send<dataType>` interfaces to `get<dataType>` ones. Inner components of this CC will be detailed in section 2.6.

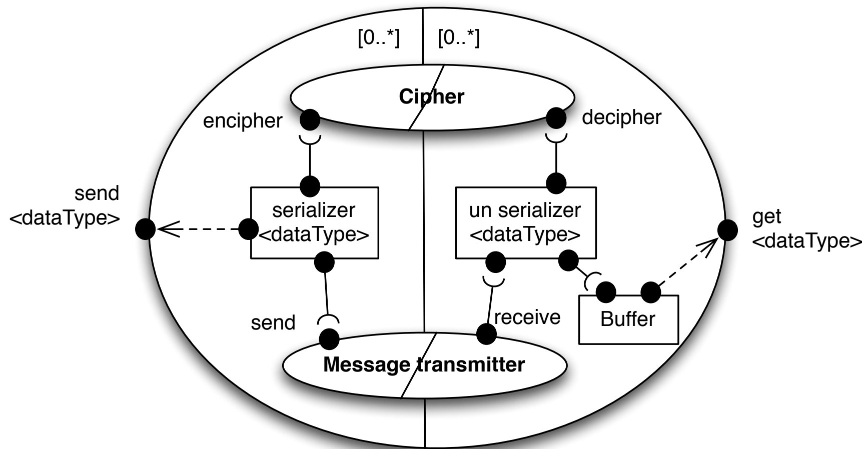

Figure 2: An architectural specification of the generic Data Transmitter CC

2.2 Sectors on cloud components

CCs can be divided in sectors. Sectors are part of the specification of the border of CCs, as well as interfaces. A sector denotes a location in a CC. It is similar to the UML concept of node, and roughly corresponds to physical devices.

Each sector is associated with a multiplicity within $[n..m]$ with $n \leq m$, $n \in \mathbb{N}$ and $m \in \mathbb{N}*$. When deployed, each sector from a CC has a cardinality property that describes how many times it was deployed to specific locations. The multiplicity is a range in terms of valid cardinalities, and sectors cardinalities must observe this range. If a single cardinality does not fulfill its multiplicity, then the whole CC is said to be in an inconsistent or unstable state, and may fail to render the services for some of its interfaces. Despite being close concepts, the cardinality property is not directly linked to the notion of "instantiating objects": it rather corresponds to the capability of having multiple copies of a sector at the same time in a single CC. We consider that this "duplication" is a deployment issue as it simply brings a sector to a specific location, which is somehow different of object's instanciations. That said, for the seek of simplicity and clarity, we will refer to this duplication property as "instanciations".

Each interface is assigned to a sector, and each sector may hold zero, one, or more interfaces. During deployment, sectors duplicate each interface so that each one is accessible from multiple locations.

On the Data Transmitter CC (*fig.3*), two sectors are defined. Their multiplicity of $[0..*]$ suggests that their respective interfaces, `send<dataType>` and `get<dataType>`, may be accessible from an unconstrained number of locations.

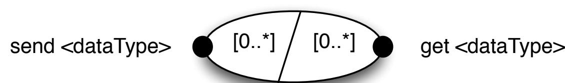

Figure 3: Border of the generic Data Transmitter CC.

2.3 Composite cloud components

The composite term refers to a strong aggregation relation, where parts are owned by a single composite, and their life cycle depends on the composite one. CCs are always composite: they encompass sub-components that can be either CCs (also composite) or common components (either primitive or composite). On the contrary, a common component may embed another component but cannot embed a CC. Composition of CCs must observe several rules. Composite CCs behave differently from composite common components. We will not dwell on the composite common components case as it behaves like in any other hierarchical component model. When being embedded in a composite CC, CCs and common components are not equivalent. Common components are assigned to a single sector, but this constraint does not apply for CCs: it can be in between sectors of the composite. In both cases, the border of the composite hides them completely, and their life cycle depends on that of the composite. Embedded CCs are not part of the border specification of the composite, and are then considered as implementation-related issues. Embedded CCs must observe the multiplicities of the sectors of the composite. In other words, the whole set of interfaces of a sector must be assigned to strictly one sector of the composite. These sectors matching rules are based on the fact that a sector from an embedded CC is instantiated exactly as many times as the composite one: its multiplicity should support the multiplicity of the composite's sector. *fig.4* presents valid and invalid sector matchings. This

rule can be formalized as follows:

General rule: A sector A with a multiplicity of $[n_A..m_A]$ can be embedded in a sector B with a multiplicity of $[n_B..m_B]$ iff $n_A \leq n_B$ and $m_A \geq m_B$.

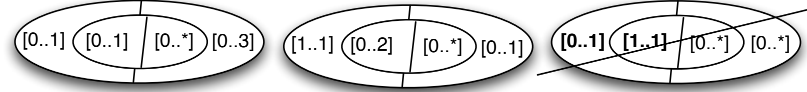

Figure 4: Valid and invalid embedded sector matchings.

When an embedded CC does not match the sectors of the composite, some of its sectors can be *duplicated*. The set of interfaces are duplicated along with the sector. A duplication does not affect the border, and a CC with duplicated sectors is strictly equivalent to the original one although its representation is different. The *fig.5* presents a sector duplication. A cloud component B is to be embedded in a cloud component A. Sectors of B do not match A ones: The [0..1] from B matches [0..1] from A, but $[1..*]$ from B must be duplicated to match with both [1..1] and $[0..*]$ from A. The result of the duplication is two sectors with the same multiplicity than A. The reader should notice that *i)* the δ interface has been duplicated along with the sector and is then available in two sectors of A, *ii)* the duplication do not affect B's border which is equivalent to the unduplicated one from a conceptual point of view, and *iii)* other solutions may exist to embed B in A. The general rule for duplicating $[n..m]$ sectors is as follows:

General rule: A sector with a multiplicity of $[n..m]$ can be duplicated in two sectors with cardinalities of $[n'..m']$ and $[n''..m'']$, iff $n' + n'' \leq n$ and $m' + m'' \leq m$.

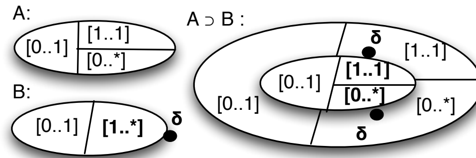

Figure 5: Sector duplication.

2.4 Types of bindings

Composite CCs are built on top of two types of bindings: the promote interface binding, and the functional interface binding. The **interface promotion binding** is the promotion of either the interface of a component or of a CC to the border of the composite. The graphical representation for this type of binding is a dashed arrow (see *fig.2*). The **functional interface binding** is the connection of two compatible interfaces including a required one and a provided one. The graphical representation is a line with a semicircle on the 'provided' side (see *fig.2*). By definition, both those bindings cannot cross any border. All promote interface bindings and functional interface bindings must have their both ends in a single sector.

2.5 The CC metamodel

The *fig.6* presents the CC metamodel. Greyed elements correspond to meta elements involved in the modeling of the border of the CC.

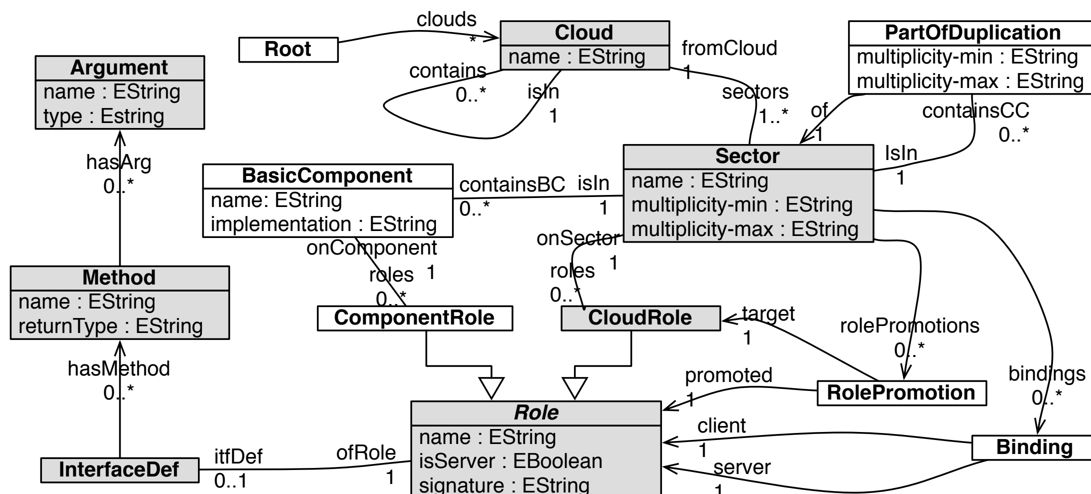

Figure 6: The CC metamodel.

2.6 Example: The Generic Data Transmitter CC.

In the sample architectural specification of the generic Data Transmitter CC depicted in *fig.2*, the two types of sub-components are depicted: common components (serializer<dataType>, unserializer<dataType>, Buffer), and cloud components (Cipher and Message Transmitter). The specification of the sub-CCs are depicted in *fig.7*. These two CCs, Cipher and Message Transmitter, are similar because they both do not include any sub-CCs. However, they are very different in their spirit. The Cipher CC does not include any communication. It is a logical aggregation of the cipherer and decipherer, that by definition should not communicate with each other. This logical aggregation expresses that the elements are linked together. For instance, the adaptation of one implies the adaptation of the other. On the other hand, in the Message transmitter CC, the communication between the sectors is based on a broadcast of each message received by message senders to each message receiver. The way messages are routed between these components is not represented, and therefore depends on the implementation of Message Sender and Message Receiver components. Of course, a configuration of the communication is necessary for both those components, but it is not part of the model.

3 Model for Variable Refinement Processes (MVRP)

To model the bCMS product line, we rely on a model of refinement processes, that has the property of being variable: the Model for Variable Refinement Processes (MVRP). Its syntax is based on the syntax of Feature Models (FM) defined by Czarnecki [4]. However, its semantic slightly changes to represent the fact that MVRP features are model refinements. The latter property implies major differences on the semantic of features and configurations.

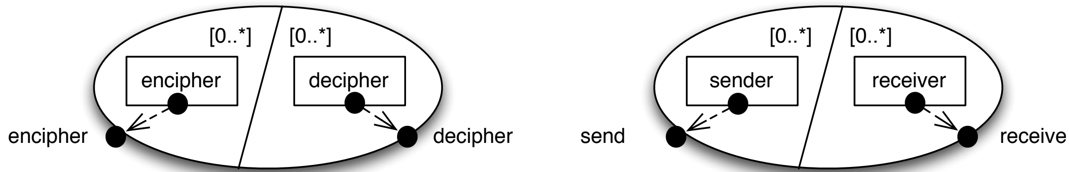

Figure 7: The cipher CC (left) and the message transmitter CC (right)

MVRP models are based on our previous work on a feature model implementation that describes hierarchies of component-based architectures using feature models, in order to provide dynamic adaptation capabilities [2].

3.1 MVRP

MVRPs are dedicated to CC models[1]. Each CC is associated with an MVRP model that defines some architectural variants of it, on the basis of a set of refinement processes. Indeed, each feature of an MVRP is implemented using a model transformation, and thus is a part of the refinement of the architecture. Moreover, an MVRP also includes solutions, which are parameters for features. A solution is equivalent to advices in Aspect-Oriented Modeling approaches. The question of the implementation of each feature with a model transformation will be tackled in section 3.2.

The root feature introduces the border of the CC, including its sectors and its interfaces. Other features introduce architectural elements that are considered as nonfunctional from the final CC user point-of-view. In other words, sub-sequent features do not modify the border of the CC (unless explicitly, as explained bellow). This consideration is important as it implies that all the sub-sequent variants are compliant with the border of the CC.

Configurations of MVRPs can be chosen by a designer, similarly as for FMs. A configuration represents a set of choices in the variation points offered by the MVRP. When a configuration is chosen from an MVRP, the selected set of features represents a sequence of transformations, that, when being executed, produces an architectural variant of the CC. We base our approach on the staggedconfiguration as described by Czarnecki [4]: features can get a multiplicity in MVRP. The MVRP undergoes a first refinement stage when it is added to a composite. This first stage configures all the features that have an influence on the border definition. Those features can be identified by an affect link, which is described thereafter.

A set of refinements is not a simple juxtaposition of features. Indeed, when a feature gets refined by another one, it can naturally loose some of its functional and nonfunctional properties. This is a major difference with FMs as the features of an FM must be independent. Keeping the independency of features when configuring an FM is a major problem, which is known as the *feature interaction* problem [5]. With MVRP, it is natural from the designer point of view that a feature may affect other ones, as the selection of a feature in a configuration naturally leads to a modification of the architecture. Moreover, we also consider that the selection of some configurations is done by the designer at the same time than specification and generation. Indeed, feature interactions can be monitored in each step of the configuration. This particularity limits the number of available variants from an MVRP, but increases the designer control over what is

[1]They may be applicable to other metamodels of architecture, but we have not yet studied how they might apply. This is for us a clear perspective of work.

generated with the processes, and also resolves problems on point-cut specifications (not detailed here).

The *fig.8* presents an example of MVRP for the Message Transmitter CC and its sub-CCs. The `<data>transmitter`, `Message transmitter`, and `Cipher` are the roots of three MVRPs. They are linked with each other using MVRP references, which are similar to FM references [4]. During the configuration of the CC, the MVRP references are unfolded, and are made part of the configuration.

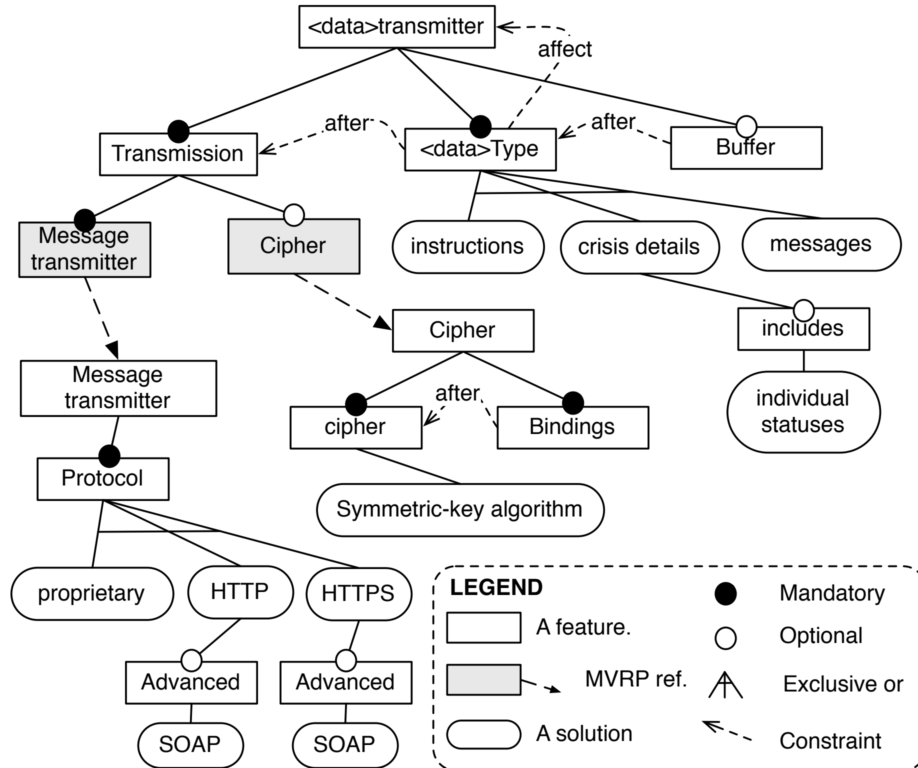

Figure 8: Model of Variable Refinement Process (MVRP) for the generic Message Transmitter CC.

There are some constraints defined on MVRP models that express a sequential ordering on the execution of the features. The `after` constraint is one of them. When an `after` constraint is defined between two features, it indicates that the feature at the source of it must be executed after the feature of its target. It can be because it needs some of its elements at that point for the definition of a point-cut, to reuse or transform them. Another type of constraints is defined in MVRP models: the `affect` constraints. The target of affect constraints is always its direct root feature of the MVRP. An affect constraint expresses that the border of the component is modified by the transformation that implements the feature: multiplicities, sectors, interfaces... Then, when it is encompassed in a CC, its border may be modified to match the needs of the composite one.

3.2 Features implementation

We base our approach for the implementation of features for MVRP and CCs on previous works in our team [7]. As depicted in *fig.9*, the approach of those previous works (on top of the figure) contrasted with AOM approaches (on bottom of the figure). With AOM, all the flexibility is in the advice and in the point-cut definitions, as the weaver is universal. On the other hand, with this approach, the designer first designs the solution metamodel and then creates a model transformation that injects this concern in the base model. Then, the flexibility is both in the solution model and in the transformation: the solution becomes highly reusable [6]. The price for this high flexibility and reusability is that it requires an important engineering time to implement the features.

To implement the features for MVRP and CCs, we choose intermediate approaches. We base the approach on two feature schemes. Each feature may be implemented in the one or the other. First, we dedicate our features to MVRPs and CCs. This way, we simplify features implementation by not requiring any sort of human activity during the specification of the feature implementation. Second, we still separate the solution implementation metamodel and the base metamodel. This implies that the solution of each feature is expressed in a metamodel that is different from the base metamodel, unlike classical AOM approaches, and keeps its reusability.

4 Modeling the bCMS-SPL using CCs and MVRPs

The bCMS-SPL system modeled using CCs and MVRPs is presented in the appendices. It consists in the description of four MVRPs. Each MVRP is associated with a sample CC, that results of a configuration of the MVRP. The four MVRPs are the followings:

- the bCrashCC System CC (*fig.10*, *fig.11*),
- the common Coordinator Process CC (*fig.12*, *fig.13*),
- the Station Coordinator Process CC (*fig.14*, *fig.15*),
- the information aggregator CC (*fig.16*, *fig.17*).

4.1 bCrash System

The bCrash System CC (*fig.10*, *fig.11*) is the main component of our model for the bCMS system. It represents a whole bCMS System architecture. The root feature of the bCrash System introduces the border of the CC: its interfaces (`Station GUI`, `GPS GUI`, `hand held device GUI`) and sectors (with multiplicities of [1..1], [0..∗] and [0..∗]). The sectors describe respectively a station (either a police station or a fire station), a GPS device in a vehicle (either a police car or a fire truck), and a hand held device for an individual (either police man or firemen). The MVRP is composed of two sub-features:

The first one, "design a station", is a composite feature that aims at introducing a station in the MVRP. During the configuration of this MVRP, a partial configuration of this feature is proceeded each time a station has to be introduced in the system [4]. This partial configuration results in a new feature with a [1..1] multiplicity. Each time this feature is executed as a model transformation, it adds three sectors to the CC, resulting in a new station to be introduced in the system. The border is modified by this addition, so `affect` constraint is then specified from the "design a station" feature to the root feature. The "station feature" and its single solution "SCP" introduces a "station coordinator process" in between each sectors of the station, and

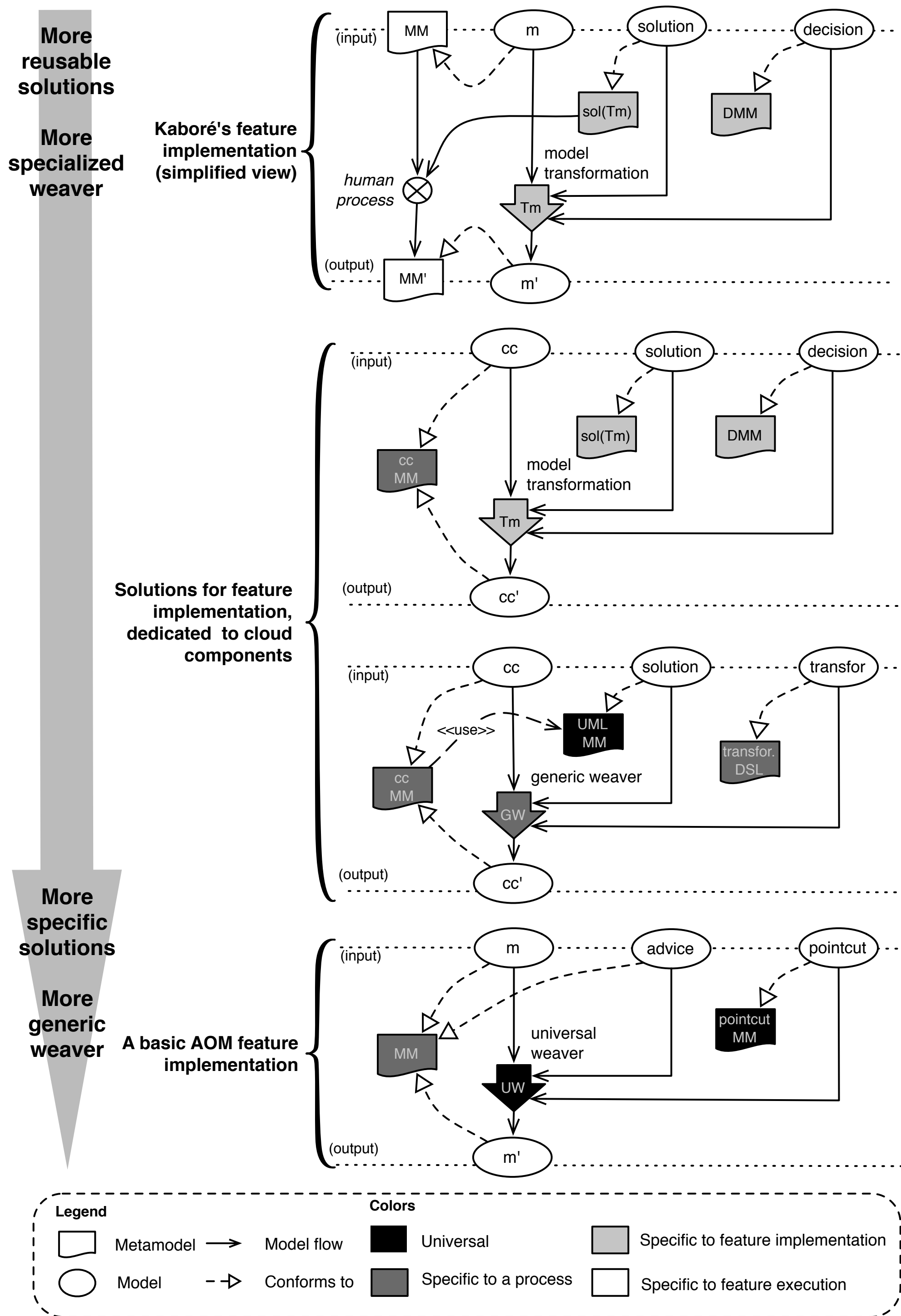

Figure 9: Sample schemes for features implementation.

the “promote bindings” promotes the interfaces of this component to the global one (see *fig.11*). The introduction of the Station Coordinator Process may also affect the bCrash system's border, when it has to add an interface to communicate with vehicles that are not in his scope (e.g., citizen vehicles).

The second sub-feature of the root feature, “coordinator”, introduces a “common coordinator process CC” in between each station sector of the architecture. This component is composed of a single sector, but the latter is duplicated to match the number of station sectors of the bCrash System. This CC, its functionalities and its MVRP are described in details thereafter.

4.2 Common Coordinator Process

The Common Coordinator Process CC (*fig.12*, *fig.13*) is a component that enables an inter-station communication. The data it transmits are “crisis details”, this is why it is based on a “message transmitter CC” with the “crisis details” feature selected (see *fig.8*), as this selection determines the data type held by the “Message Transmitter component”. The reader may note that this “Common Coordinator Process CC” does not hold any variation, and there is only one refinement process that corresponds to its MVRP. However, as it embeds a “message transmitter CC”, it inherits its variations and thus there are still some variants for it.

4.3 Station Coordinator Process

The Station Coordinator Process CC (*fig.14*, *fig.15*) describes the architecture for a single station, that can be either a police station or a fire station. Thus the CC includes several components such as :

- A route planner CC, in charge of computing and transmitting routes to vehicle GPS devices.
- An information aggregator CC, that collects information for each station and manages a coordination with other stations. This CC is described in details bellow. One of its sectors was duplicated to match both the individuals and the vehicles sectors.
- A data transmitter CC, that is another variant for the “generic Message Transmitter CC”.
- An authentication system CC, that provides authentication capabilities to identify the station users and individuals (either police officers or firemen) of the system.
- An instructions manager is a common component that is in charge of preparing and sending instructions to individuals as well as GPS coordinates to vehicles to go to the crash place. It is under control of the station coordinator agent (via the “GUI” element).
- Other components includes: GUI, Auth Screen, GPS, and device.

On the MVRP side, there are not many variations in it, except on the authentication which is optional, and on the types of communications that are allowed (with station vehicles and/or citizen vehicles). The latter may affect the border of this CC by adding interfaces to communicate with other stations vehicles, or with citizen vehicles, that both are not actors in the scope of the Station Coordinator Process CC. This case is not represented in the figure.

4.4 Information aggregator

The information aggregator CC (*fig.16*, *fig.17*) is the CC where details on the crisis are stored. It includes a database component (“DB”) to store crisis details, two components to update and

access the database ("DB updater" and "DB access"), a message transmitter to collect database update transactions from either individuals or vehicles, and a coordinator which is a daemon that forwards every update in the DB to any other stations. It is interesting to note that, from the border point of view, the localization of the data managed by the information aggregator is not important, and for instance could have been replicated on each client sector.

4.5 Others

We previously presented the following CCs and their MVRP, so we will not elaborate any more on them:

- the generic message transmitter CC (*fig.8*, *fig.2*),
- the cipher CC (*fig.8*, *fig.7*),
- the Message Transmitter CC (*fig.8*, *fig.7*).

Moreover, for a seek of conciseness, the two following CCs will not be detailed further:

- the authentication system CC (*fig.18*),
- the route planner CC (*fig.18*).

However their architecture follows a similar scheme as the ones previously presented

4.6 Variations

In this section, we will comment on how each variation is handled using the model.

(7.1) Police and Fire Stations multiplicity. The multiplicity of the "design a station" feature of the bCrash System CC can handle this variation during the configuration of the MVRP (see *fig.10*).

(7.2) Vehicles Management. The management of the possibility of sending to and receiving messages from vehicles is handled in the Station Coordinator Process (*fig.14*, *fig.15*), during the configuration of the "vehicle management" feature. Moreover, as a Station Coordinator Process manages a single station, the inter-station vehicles communication and the communication with citizen vehicles is also reified in the bCrash System CC (*fig.10*, *fig.11*).

(7.3) Vehicles Management Communication Protocol. The management of this variability is done when configuring each "generic Message Transmitter CC", by selecting the right features "HTTP"/"HTTPS"/"SOAP" features (see *fig.8*).

(7.4) Crisis Multiplicity. We are not able to model this variation using our approach because we are modeling architectures. Modeling this variation implies updating primitive components implementations, which case we cannot handle (e.g., in the DB component, or in the coordinator in *fig.17*).

(7.5) Confidentiality of Data Communication. This variability is handled by selecting the "Cipher" feature in the "generic Message Transmitter CC" (see *fig.8*). This adds the "Cipher CC", and creates interfaces on the "serializer" components, and adds the bindings.

(7.6) Authentication of System's Users. This variability is handled by selecting the optional authentication feature in the "Station Coordinator process CC" (see *fig.14*). This adds the "Authentication System CC", the two "Auth screen" components, adds the interfaces on the "Gui" and "device" components, and creates the bindings. Here, the variations on the MVRP of the "Authentication System CC" are not depicted in the model, however it would create variants of the "Authentication System CC".

(7.7) Communication Layer. This variability is handled by selecting the right "Protocol" feature in the "message Transmitter CC" (see *fig.8*). This modifies the reference to the implementation of the "sender" and "receiver" components in the "message transmitter CC", so that it can handle each protocol.

5 Conclusion

This approach has several benefits. The CC model offers the possibility of making logical aggregations of distributed component, giving the opportunity to model distributed architectures in a convenient manner. Those logical aggregations ease the specification of nonfunctional properties on communication. The MVRP model offers to the designer the possibility to take advantage of the properties of the underlying component architecture (e.g., a border hides its internals) during the specification of the refinements of the architecture. This properties limits the impact of feature interactions. Moreover, the MVRP model makes feature interactions more explicit by modeling the refinements instead of independent features. The implementation of the features using original model transformations schemes offers the possibility to reuse features solutions (models and metamodels) in numerous situations, and offers more expressivity in to those models as they are not expressed in the base metamodel.

The original goal of our work is to reach runtime reconfiguration of distributed components architectures [2]. At runtime, a variant can be replaced by another one by a reconfiguration platform. This platform, which is also a cloud component, uses information from the variable refinement process to achieve the planning and the execution of the reconfiguration actions.

As our approach is essentially oriented on the architecture level, we were not able to model fine grained situations such as the one described in sections 4 and five of the Requirement Definition Document. However, we plan to study in the near future how feature implementations could be extended by integrating other informations, such as feature models artifacts, adaptation specific information, or the generation of code for primitive components. We believe that our future implementation will be able to handle such fine grained situations.

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Appendices

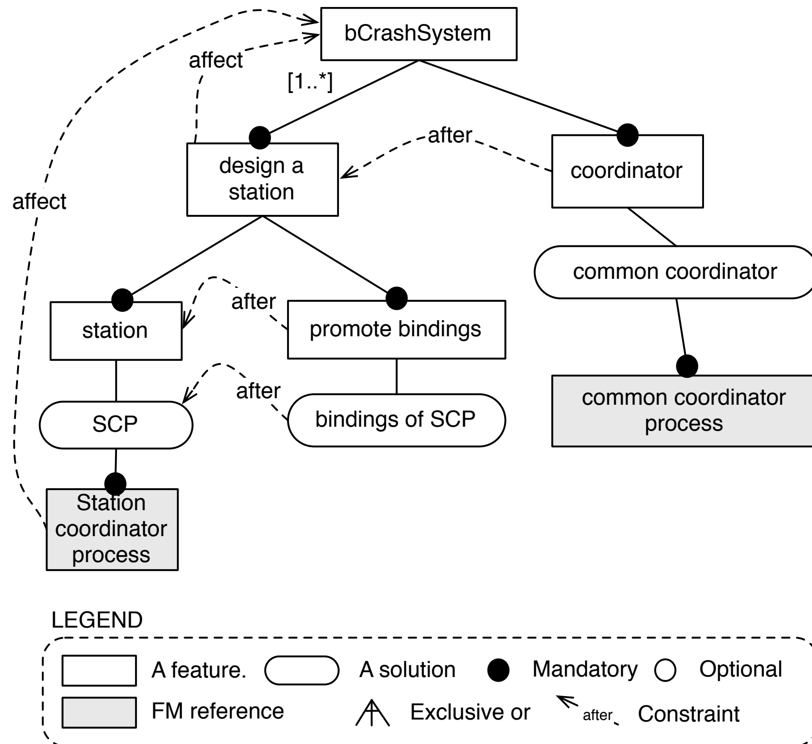

Figure 10: MVRP for the bCrash System CC.

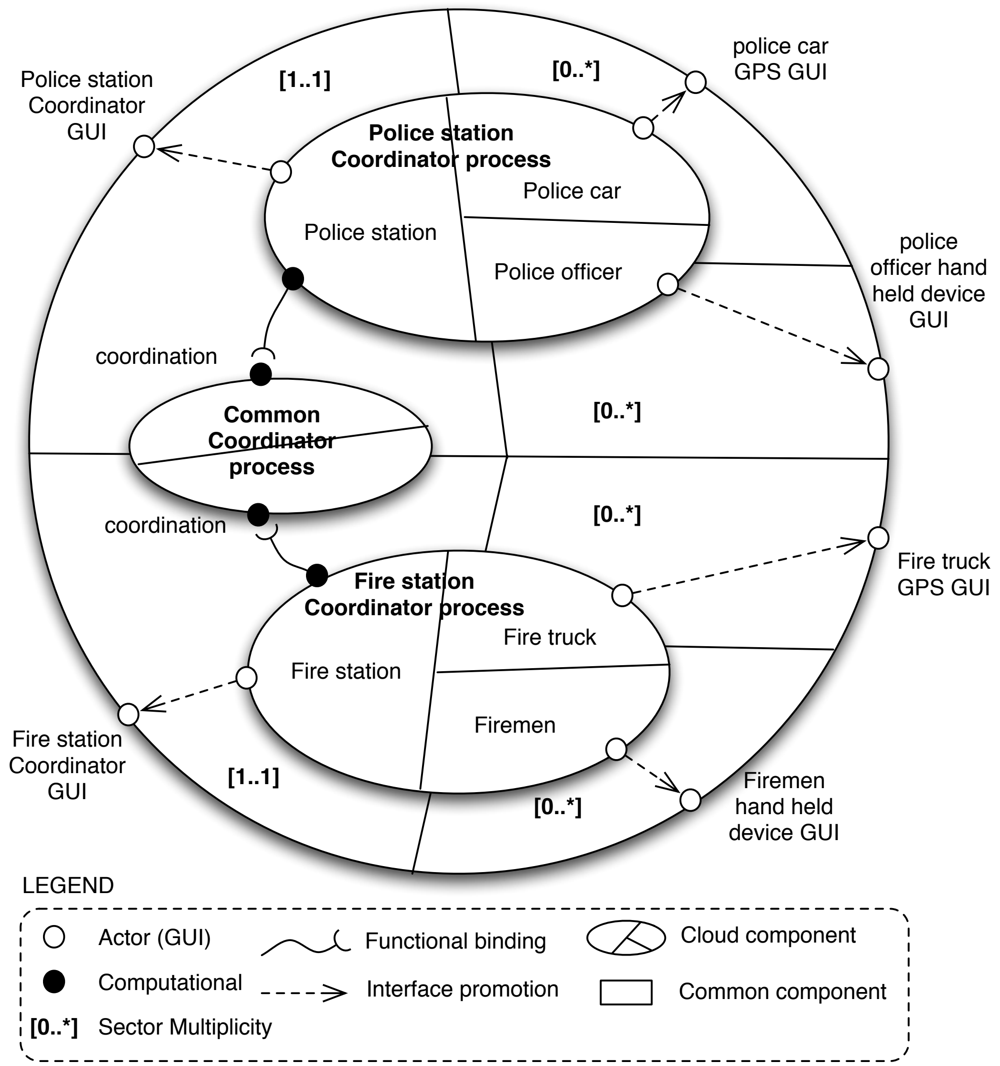

Figure 11: A sample bCrash System CC with two stations.

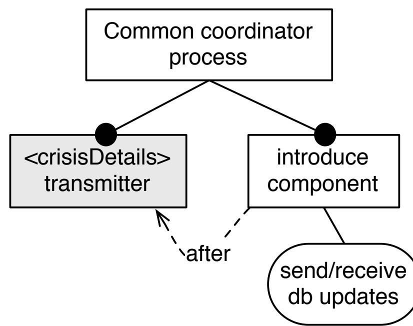

Figure 12: MVRP for the common Coordinator Process CC.

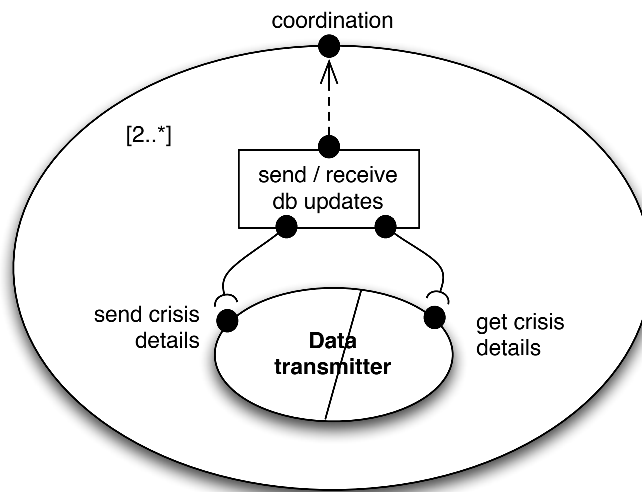

Figure 13: A sample common Coordinator Process CC.

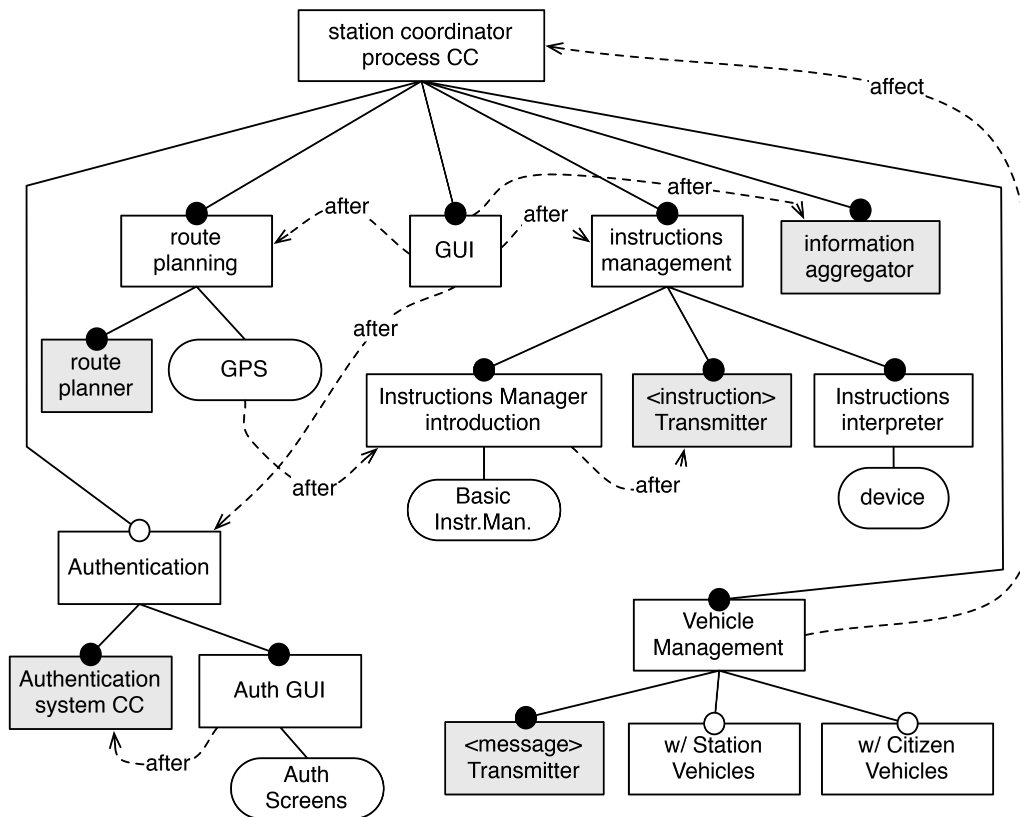

Figure 14: MVRP for the Station Coordinator Process CC.

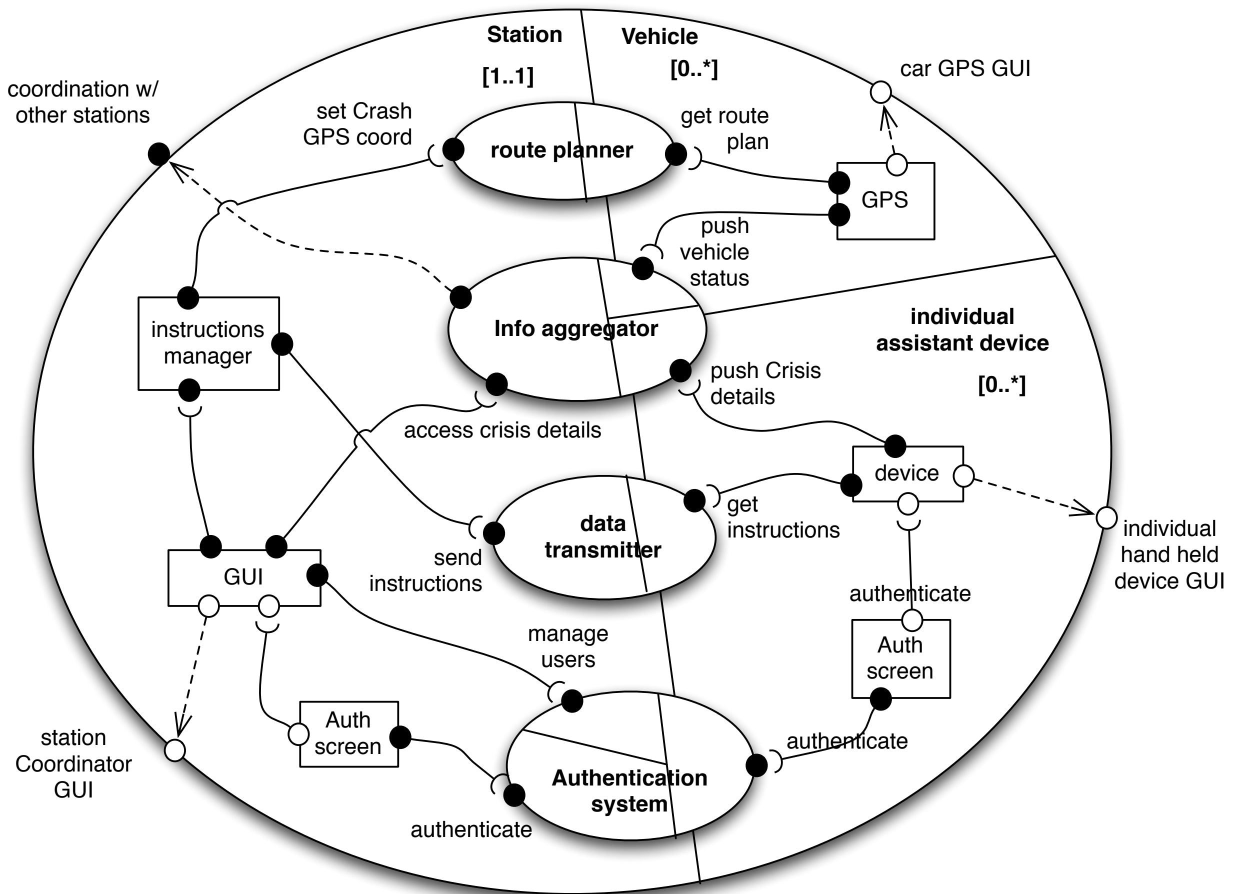

Figure 15: A sample Station Coordinator Process CC.

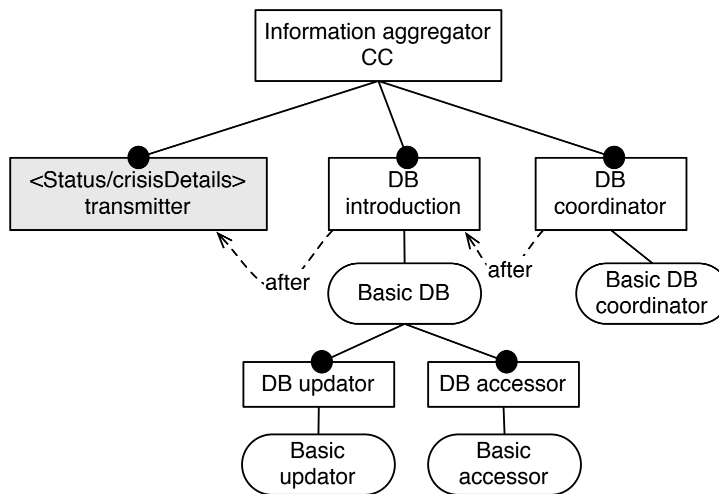

Figure 16: MVRP for the information aggregator CC.

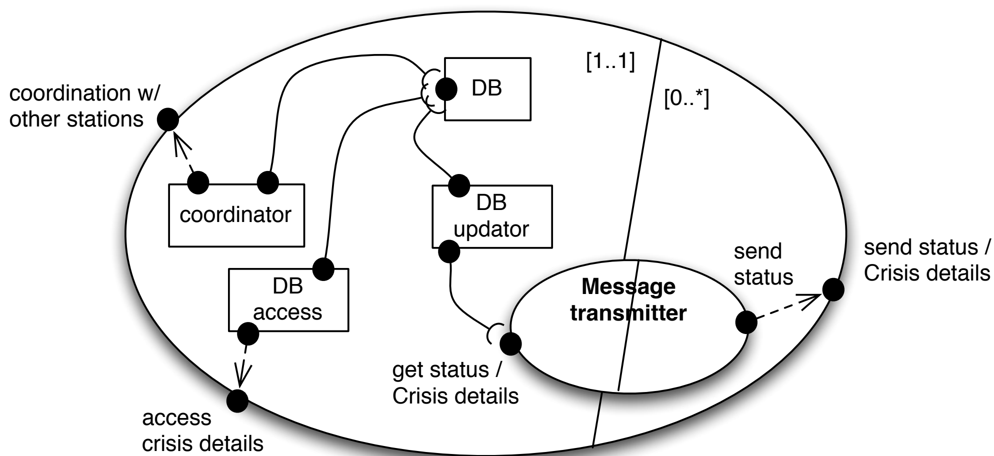

Figure 17: A sample information aggregator CC.

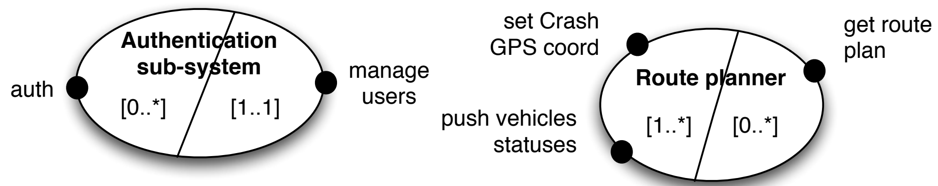

Figure 18: The borders of the authentication system CC and of the route planner CC.