Towards a Formally Grounded Software Development Method

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Abstract

One of the goals of software engineering is to provide what is necessary to write relevant, legible, useful descriptions of the systems to be developed, which will be the basis of successful developments. This goal was addressed both from informal approaches (providing in particular visual languages) and formal ones (providing a formal sound semantic basis). Informal approaches are often driven by a software development method, and while formal approaches sometimes provide a user method, it is usually aimed at helping to use the proposed formalism/language when writing a specification. Our goal here is to provide a companion method that helps the user to understand the system to be developed, and to write the corresponding formal specifications. We also aim at supporting visual presentations of formal specifications, so as to "make the best of both formal and informal worlds". We developed this method for the (logical-algebraic) specification languages CASL (Common Algebraic Specification Language, developed within the joint initiative CoFI) and for an extension for dynamic systems CASL-LTL, and we believe it is general enough to be adapted to other paradigms.

Another challenge is that a method that is too general does not encompass the different kinds of systems to be studied, while too many different specialized methods and paradigms result in partial views that may be difficult to integrate in a single global one. We deal with this issue by providing a limited number of instances of our method, fitted for three different kinds of software items and two specification approaches, while keeping a common "meta"-structure and way of thinking. More precisely, we consider here that a software item may be a simple dynamic system, a structured dynamic system, or a data structure. We also support both property-oriented (axiomatic) and model-oriented (constructive) specifications. We are thus providing support for the "building-bricks" tasks of specifying/modelling software artifacts that in our experience are needed for the development process.

Our approach is illustrated with a lift case study, it was also used with other large case studies, and when used on projects by students yielded homogeneous results.

Let us note that it may be used either as itself, e.g., for requirements specification, or in combination with structuring concepts such as the Jackson's problem frames.

Key words: Specification method, formal specification, algebraic-logical specification, visual notation, CASL, CASL-LTL development method ...

1 Introduction

1.1 Aims and Scope

One of the goals of software engineering is to provide paradigms, languages, notations, formalisms (together with a companion user method) to write relevant, legible, useful descriptions of the systems to be developed, which will be the basis of successful developments. This goal has been explored both from informal and formal approaches, while informal notations may put emphasis on varieties of attractive graphics, formal approaches offer the serious basis of a formally described semantics. In both cases, one problem may be that the companion user method is not available to start with, and when it is available another problem is that, while it helps to use the formalism proposed, it does not always help to understand the system to be developed. Another difficulty when struggling with these issues is that systems under study may be quite different in nature (or may include parts that are so), thus different notations/languages and methods may be needed. To define a homogeneous approach, general enough to encompass different issues, but still carrying meaningful and precise guidelines and concepts, is also a goal.

On the one hand, many formalisms and some formal specification methods were developed (see [4] for the distinction between formalism and method), e.g., algebraic specifications and associated methods [2]. On the other hand, we can witness the success of development methods without or with a very limited grounding in sound formal theories, as those based on UML [33], e.g., RUP [24] and COMET [18]. Clearly, there is a need to accommodate both worlds, for instance some recent works try to give a precise semantics to UML ([27, 28]), and the need for UML based rigorous methods has emerged. There are obvious differences between the two kinds of approaches (formal/informal):

- not very friendly notation, sometimes based on exotic mathematical symbols/very friendly visual notation;
- rather rigid with a lot of overhead notation/flexible adaptable notation;
- need time and background to learn the used technique/short time to learn the method;

[1] Work partly supported by the Italian National Project SAHARA (Architetture Software per infrastrutture di rete ad accesso eterogeneo).

- mainly simple toy case studies considered/developed having in mind the real common applications;
- user manuals explaining how to use the various constructs are available/ software development methods based on them are available.

Our attempt is to make the *best* of both worlds by trying to propose a development method which has all the good properties of those commonly used (friendly notation based on simple intuitive visual metaphors, easy to understand and to learn, considering real applications, ...), and that is also *formally grounded*, i.e., its specifications artifacts have a direct counterpart in a formal specification language, and thus a formal semantics, based on well defined underlying formal models. Here, we present a first proposal towards such a method formally grounded on the algebraic specification language CASL-LTL [1, 26, 23]. It covers the requirements and the design phases of the development, offering some techniques to specify requirements and designs for very general software systems. Such techniques result in producing specifications having a precise structure at the conceptual level, which can, then, be presented either in a visual way or as formal CASL-LTL specifications.

In our opinion, a relevant result of this work is that the paradigms and the techniques of our method, being originated from the underlying theory are quite different from those supported by the most practical common methods [2]. For example, we do not make use of "use cases", nor of diagrams showing scenarios, as UML sequence and collaboration, and we are not object-oriented [3]. On the other hand, we are much more systematic and inherently more rigorous, we use diagrams to visually present the behaviour of an active element (not just its reactions to external stimuli), we explicitly define how the various elements in a system cooperate, we explicitly state which are the elements composing a system, etc.

Our previous experiences suggested that the various activities in a development process are based on the "building-bricks" tasks of specifying [4] software items of different nature at different levels of abstractions. So we propose some methods for developing the basic specification blocks using as underlying foundation CASL-LTL, but giving for all of them a corresponding visual presentation. We assume that a "*software item*" may be either

- a *simple dynamic system* (just a dynamic interacting entity in isolation,

[2] However, we would like to benefit from both worlds, e.g., we use a UML-like notation to illustrate our method, and to establish links to UML is a subject of planned further work.

[3] We do not use the concept of objects.

[4] Notice that "to specify/specifications" are the terms used in the formal community, whereas in the practical world the corresponding ones are "to model/models". For example, we have CASL specifications and UML models.

e.g., a sequential process) or

- a *structured dynamic system* (a community of mutually interacting entities, simple or in turn structured), or
- a *data structure* (or data type).

For each case, we give two specification techniques (*property-oriented*, and *constructive* or model-oriented), by giving the abstract structure of the corresponding specifications with the related visual presentation and corresponding formal CASL-LTL specification.

To introduce a specification method we follow the conceptual schema of [4] that we briefly present in Sect. 2.1; furthermore all property-oriented specification methods presented here are all specializations for particular varieties of items of a general method that we present in Sect. 2.2. The sections 3, 4 and 5, devoted respectively to simple dynamic systems, structured dynamic systems, and data structures, have the same structure. First, the considered items are described, then, their property-oriented specification is developed (the specification of the parts and constituent features, the properties specification using the cell filling technique, an illustration on the lift example, and the CASL/CASL-LTL view), and last their constructive specification is described (the characteristics, an illustration on the lift example, and the CASL-LTL or CASL view). Sect. 6 and 7 are devoted to the applications of our specification methods, respectively to some of the most relevant problem frames of M. Jackson [19, 20], and to present the requirements for an Internet-based lottery system. The remaining of our introduction is devoted to a brief presentation of the CASL and CASL-LTL specification languages in Sect. 1.2 , and to the description of our running example with pointers to its specifications in the paper in Sect. 1.3.

1.2 CASL*, the Common Algebraic Specification Language, and* CASL-LTL

"CASL is an expressive language for the formal specification of functional requirements and modular design of software. It has been designed by CoFI[5] , the international *Common Framework Initiative for algebraic specification and development*. It is based on a critical selection of features that have already been explored in various contexts, including subsorts, partial functions, first-order logic, and structured and architectural specifications." [1] The CoFI project is presented in [22], and various documents are available on CASL, in particular the CASL Reference [23] including a complete formal semantics, and the CASL User Manual is being written [11]. Thus, only the features of the language that are used in our examples will be shortly presented.

[5] `http://www.brics.dk/Projects/CoFI`

As shown in the example below, a CASL specification may include the declarations of sorts, operations and predicates (together with their arity), and axioms that are first-order formulae[6], respectively introduced by relevant keywords. Some operations play the role of constructors, thus, "datatype declarations may be used to abbreviate declarations of sorts and constructors."[11]

spec SPECNAME =
  type *type_name* ::= *con_name*($argTypes_{con}$) | ...
  ops *op_name* : $argTypes_{op} \rightarrow resType_{op}$
    ...
  preds *pr_name* : $argTypes_{pr}$
    ...
  axioms *formulae*

As shown below, "large and complex specifications are easily built out of simpler ones by means of (a small number of) specification building primitives ... Union (keyword '**and**') and extension can be used to structure specifications ... Extensions, introduced by the keyword '**then**', may specify new symbols, possibly constrained by some axioms, or merely require further properties of old ones ..."[11]

spec SPECNAME =
  SP_1 **and** ... **and** SP_j **then**
  type *type_name* ::= *con_name*($argTypes_{con}$) | ...
    ...

"In practice, a realistic software specification involves *partial* as well as total functions."[11] Partial operations or constructors are declared with a '?' symbol, and the definedness of a term can be asserted in the axioms.

spec SPECNAME =
  type *type_name* ::= *con_name*($argTypes_{con}$)? | ...
  ops *op_name* : $argTypes_{op} \rightarrow ?\ resType_{op}$
    ...
  axioms
    def(*con_name*(...)) $\Leftrightarrow$ ...

Let use note that special care is needed in specifications involving partial functions [11]. Functions, even total ones, propagate undefinedness, and predicates do not hold on undefined arguments. Terms containing partial functions may be undefined, i.e., they may not denote any value.

Another helpful feature of CASL is the **free** construct. "Free specifications provide initial semantics and avoid the need for explicit negation ... In models of free specifications, it is required that values of terms are distinct except when

[6] with *strong* equality (Sect. 5.2.1) and a 2-valued logics

their equality follows from the specified axioms: the possibility of unintended coincidence between them is prohibited."[11]

spec SPECNAME =
  SP_1 **and** ... **and** SP_j **then**
  free { **type** *type_name* ::= *con_name*($argTypes_{con}$) | ...
    ops *op_name* : $argTypes_{op} \rightarrow ?\ resType_{op}$
    ...
    axioms ... **}**

Generic specifications (also known as parametrized specifications in other specification languages) are very useful for reuse. Their parameter specification is usually very simple, and an instance of a generic specification is obtained by providing an argument specification for each parameter. The following specification is an extension of an instance of the generic specification FINITESET[ELEM] by INT (both are in the basic specifications library [31]).

spec SPECNAME = FINITESET[INT] ... **then** ...

"CASL is the heart of a *family* of languages. Some tools will make use of well-delineated *sub-languages* of CASL ... while *extensions* of CASL are being defined to support various paradigms and applications."[1] One of these extensions is CASL-LTL [26], which was designed for the dynamic systems specification by giving a CASL view to LTL, the Labelled Transition Logic ([5, 17]).

LTL, and thus CASL-LTL, is based on the idea that a dynamic system is considered as a *labelled transition system* (shortly *lts*), and that to specify it one has to specify the labels, the states and the transitions of such system. Recall that an lts is a triple $(State, Label, \rightarrow)$, where $\rightarrow \subseteq State \times Label \times State$. CASL-LTL offers a special construct to declare an lts, by stating that two given sorts correspond respectively to its states and labels, and that a standard arrow predicate corresponds to its transition relation $\rightarrow$.

dsort *st* **label** *lab* stands for **sorts** *st*, *lab*
pred $__ \xrightarrow{__} __ : st \times lab \times st$

The sort *st* is said *dynamic*, because any of its elements, say d represents a dynamic system, whose behaviour is modelled by transition tree associated with d. The root of such tree is decorated with d, and if the tree has a node decorated with d and $d \xrightarrow{l} d'$, then it has a node decorated with d', and an arc from d to d' decorated with l. Moreover, in such tree the order of the branches is not considered, and two identical decorated subtrees with the same root are considered as a unique subtree.

The CASL formulae built by using the transition predicates allow to express some properties on the behaviour of the dynamic elements, but they are not sufficient. For example, by using them we cannot state liveness properties;

whereas they, and other kinds of quite relevant properties, may be expressed by using some temporal logic. Thus, CASL-LTL (as LTL) includes the temporal combinators of the temporal logic of [17], which is many-sorted, first-order, branching-time, CTL-style, and with edge formulae.

The temporal formulae of CASL-LTL are anchored to terms of dynamic sort and express some property about the elements represented by them. Such formulae have the form $in_any_case(dt, \pi)$ or $in_one_case(dt, \pi)$ stating that any path (at least one path) starting from dt satisfies the condition expressed by the path formula π. A *path* starting form a dynamic element is a sequence of concatenated transitions from such element, and represents one of its possible behaviours. A path formula may require that

- the first state/label of the path satisfies some condition $[\ x \bullet cond\ ]$ and $< y \bullet cond >$;
- from some point on the path satisfies a condition expressed by another path formula $\quad eventually\ \pi_1$
- the path satisfies a condition expressed by another path formula until some point where it satisfies a second condition $\quad \pi_1\ until\ \pi_2$
- the path satisfies a condition expressed by another path formula in any point $\quad always\ \pi_1$
- the path satisfies a complex condition, by combining other path formulae by means of the CASL logical combinators, e.g., $\neg$, $\wedge$, $\vee$, $\Rightarrow$ and $\forall$.

1.3 Running Example: the Lift System

To illustrate the use of our specification methods we specify at different levels a lift system and some of its subparts.

A lift system consists of a *lift plant* (that is the cabin, the motor moving it and the doors at the various floors), some software automatically controlling the lift functioning (the *controller*), and the people using it (the *users*). The controller monitors the lift plant by means of *sensors*, which communicate the status of its various components (e.g., there is a sensor detecting the position of the cabin), and directs its behaviour by means of *orders* (e.g., it can order to open/close the doors).

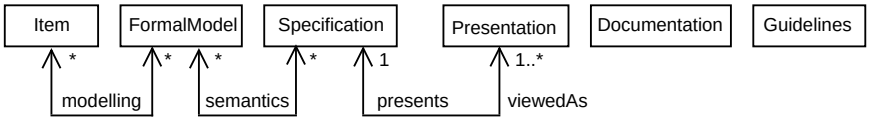
In Sect. 3.2.3 a property-oriented specification of the lift plant considered as a simple system is developed. The lift plant may communicate the status of some of its components by means of sensors (the position of cabin, of the doors at the floors and the working status of the motor), and can influence its components by means of orders (open/close a door at a given floor, stop/to move up/to move down the motor). Moreover, the lift plant interacts with the external world also when some users enter or leave the cabin. Sect. 3.3.2 gives

a constructive specification of a controller for the lift, considered as a simple system. This specification may be considered as an abstract presentation of a design for such a controller. The controller may send orders to the motor and to the doors, and may receive information on the status of the plant by means of its sensors (status of the motor, and positions of the doors and of the cabin). The users interact with the controller by calling for some floor (i.e., requiring that the cabin goes to a given floor). In Sect. 4.2.3 we develop a property-oriented specification of the lift system considered as a structured system with the lift plant, the controller and the users as subparts, and in Sect. 4.3.2 we give a constructive specification of the lift controller where two parts are distinguished. The floor data structure is specified in a property-oriented way in Sect. 5.2.2, and in a constructive way in Sect. 5.3.2 having an explicit number of floors.

2 A specification methods framework

2.1 Specification Methods

To easily present the various specification methods introduced in this paper, we follow the conceptual schema proposed in [4]. In the picture below we report all the ingredients of a generic method using an object-oriented visual notation[7], and briefly comment them below.



Items In our opinion a specification method to be effective should consider a quite precise set of *items* to be specified. Such items should be introduced using the natural language, since clearly they cannot be formally defined.

Formal models of the items Formal models, intended as mathematical structures, are the formal counterparts of the items, introduced before. Each specification method uses a particular set of formal models.

Modelling A precise and rigorous, but not formal, description of how the formal models are associated with the items.

Specifications In a very general way a *specification* is a description of an item at some level of abstraction, intended at a given step of the development process. A *specification* is a way to define a class of formal models: all those modelling the item at a given step of the development process.

[7] Precisely, it is a simple subset of UML 1.3 [33]. Recall that boxes represent classes, and arrows oriented associations.

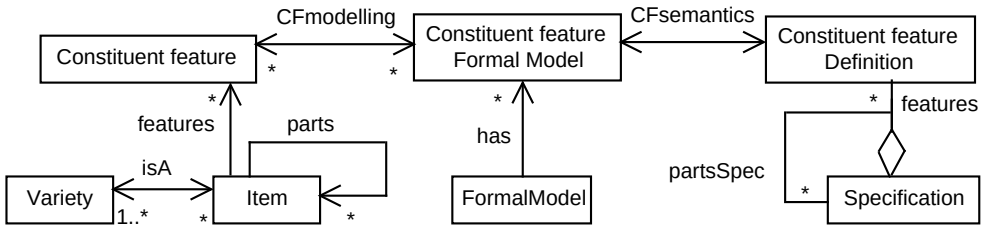
Semantics The semantics links a specification with its formal models.

Presentations We mean by *presentation* a way to display a specification artifact for some particular purpose; for example, we can have a presentation for the human users, or using a special notation to be handled by a tool. A specification method may be equipped with different kinds of presentations. Each presentation should be associated with a unique specification.

Guidelines This part consists of the *guidelines* for steering and helping the task of producing in the best possible way the specifications of the items. The guidelines are understandably driven by the preceding parts of the method, but note the fundamental role played by modelling, if we want seriously to provide professional guidelines.

Documentation We refer to documenting the specification task for use in evolution and maintenance.

We make the following assumptions on the *items*, visually summarized below.



- Items are classified in some *variety* (e.g., functional modules/data types, reactive systems, real-time systems, distributed systems, ...), and the items considered by a method should be all of the same variety [8].
- Items are *structured*, and their subparts are items. Such structure is represented by the association parts [9]. Items associated by parts may be of the same variety (homogeneous structure) or of different varieties (e.g., imperative programs made out from procedures).
- Items are characterized by their *constituent features*. We assume that an item is made by various *constituent features*/ingredients that are orthogonal/nonoverlapping, and that may be classified in different *kinds*.

The above assumptions on the items require that

- the "modelling" (that is how the items are associated with the formal models) should be extended to describe how the constituent features of the various kinds correspond to elements/features of the formal models;

[8] The association isA from Item to Variety does not associate a unique variety with an item, because the same item may be seen as belonging to different varieties; functional modules/data types, e.g., a reactive system is also a particular case of a distributed system.

[9] The white diamond represents the UML aggregation (subobjects containment).

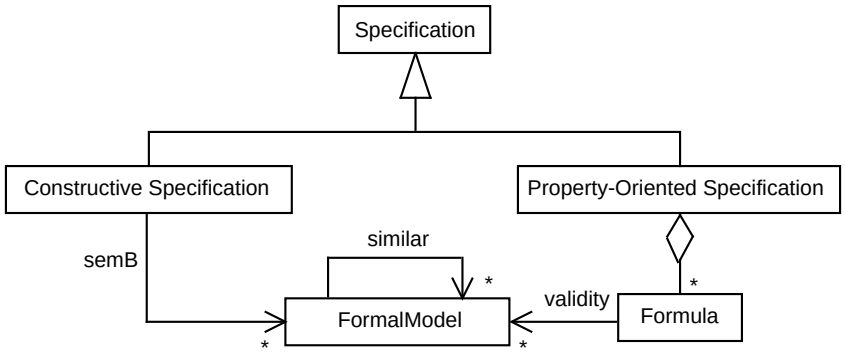


Fig. 1. Property-Oriented and Constructive Specifications

- the models of a specification have (as described by the association has) all the constituent features;
- the specification language should support the separate specifications of the subparts and should offer means to define the constituent features (Constituent Feature Definition);
- the guidelines should take care for finding the parts and the constituent features of an item.

There are various specification styles. The most quoted distinction is between *property-oriented* (or *axiomatic*) and *constructive* (or *model-oriented*). We report the peculiar ingredients of a method using property-oriented or a constructive specifications in Fig. 1 [10].

Property-oriented (axiomatic) We prefer the term *property-oriented*, as more suggestive than axiomatic. For what concerns the semantics, the basic way to define it is as follows: "a model belongs to the semantics of a property-oriented specification if and only if all formulae of the specification are valid on it". The methodological ideas supporting this specification style are:
we describe the item at a certain moment in its development by expressing all its "relevant" properties by sentences provided by the formalism (formulae).

Constructive (model-oriented) In this case the semantics is defined as follows: "a model M belongs to the semantics of a specification if and only if there exists another model belonging to the basic semantics (association semB) of the same specification that is similar to M". The methodological ideas supporting this specification style are:
we describe the item at a certain moment in its development by giving a prototype/archetype of it using the specification language; then we say which are the irrelevant features of this archetype by the relation similar. *If two models*

[10] The arrow with large head stands for the UML specialization.

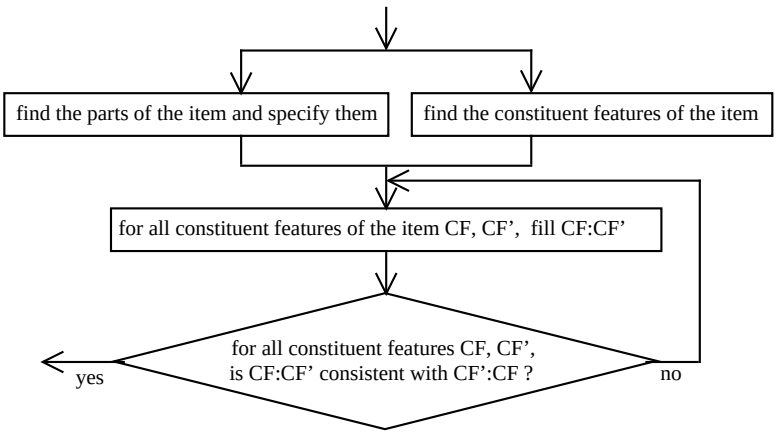


Fig. 2. Exhaustive search guidelines of GPSm

are similar, then they differ from each other for irrelevant details, which can thus be freely fixed later in the development.

The name constructive or construction-oriented means that we specify an item by construction (at the abstraction level supported by the method, that is depending on the formal models and on the specification language); afterwards we would say when another construction may be equivalent.

2.2 A General Property-oriented Specification Method (GPSm)

Now we introduce a General Property-oriented Specification method (GPSm) following the conceptual schema introduced in the Sect. 2.1, by specializing and enriching three ingredients (Guidelines, Presentation and Documentation) of a generic method using property-oriented specifications; these modifications are reported and commented below.

Exhaustive Search Guidelines Fig. 2 shows the guidelines of GPSm. The first steps are to find the parts and to specify them, and to find the constituent features, followed by the search of the properties. GPSm is based on an exhaustive technique for finding all possible relevant properties of an item by examining it from all possible points of view, that is from the viewpoint of all its constituent features. The general idea is to find the properties of a given item by filling the spreadsheet in Fig. 3, whose columns and rows are indexed with the constituent features of this item ($\mathrm{KIND}_1, \ldots, \mathrm{KIND}_k$ are the kinds of the constituent features, and for $i = 1, \ldots, k$ the constituent features of kind KIND_i are $\mathrm{CF}^i_1, \ldots, \mathrm{CF}^i_{n_i}$).

A cell with index CF^i_j:CF^i_j contains the properties about the constituent feature CF^i_j, and a cell with index CF^i_j:CF^h_m contains the properties expressing

		KIND$_1$				KIND$_k$		
		CF_1^1	.....	CF_{n1}^1	.....	CF_1^k	.....	CF_{nk}^k
KIND$_1$	CF_1^1							
	.....							
	CF_{n1}^1							
	.....							
KIND$_k$	CF_1^k							
	.....							
	CF_{nk}^k							

Fig. 3. Properties Spreadsheet

the relationships between CF_j^i and CF_m^h. We assume that the properties filling the various cells follow particular schemas depending on the kinds of the two indexing elements and on the formulae of the chosen specification language. We need schemas for the cells indexed by:

KIND$_i$ **- KIND**$_i$ for $i = 1, \ldots, k$ the properties about a constituent feature of kind KIND$_i$ considered by itself, and the properties about the relationships between a constituent feature of kind KIND$_i$ and another one of the same kind

KIND$_i$ **- KIND**$_j$ for $i, j = 1, \ldots, k$, $i \neq j$ the properties about the relationships between a constituent feature of kind KIND$_i$ and another one of kind KIND$_j$.

Note that the relationships between two different constituent features, say CF and CF', appear in two different cells (i.e., in CF:CF' and in CF':CF), thus we have computed this relationship twice, but in the first case the emphasis/viewpoint is on CF, and in the second case on CF'. The general method requires then to check that they are consistent. In the case of a negative answer, we found some inconsistency that must be eliminated. Usually, this activity helps detect some problematic or misunderstood aspects of the specified item.

Note also how the spreadsheet filling technique results in producing a quite structured navigable set of properties, which should be suitable to support evolution. For example, if the ideas about the specified item changes, and such changes result in adding/removing constituent features, then the properties may be easily modified, in such case we have just to add/delete some specific rows/columns.

Cell Contents Presentation As regards the presentation of the produced specifications, GPSm should provide:

- a nice way to present the properties filling each relevant type of the cells of the spreadsheet;
- a nice way to arrange the contents of the various cells of the spreadsheet; for example by means of a precise sectioning schema with related titles.

The result of this process then needs some presentation work and rearrangement of the found properties to yield a specification nicer to read.

Cells Filling Documentation The documentation of the specification process should make recoverable the spreadsheet filling, the justifications of the consistency of the symmetric cells, and a justification for any empty cell.

2.3 Introducing a Method

To introduce a method in this paper, following the general conceptual framework of Sect. 2.1, we proceed in the following way. We begin by introducing the specified items, the used formal models, and the rationale linking the latter to the first (section "*X Item*" where X may be simple or structured system, or data structure), and this part is common for both property oriented and model oriented methods introductions that follow. For each kind of specification, we adopt the following:

- we show the form of the specification visual presentation. To avoid the obvious problems of precisely presenting a visual notation we follow the UML style (metamodelling), by giving the structure of these artifacts by means of a class diagram presenting all their components, and then saying how to visually depicting them. We accompany this part by the guidelines to produce such artifacts. (Section "*The ... specifications*")
- This is then illustrated on an example: the lift (section "*Example: ...*").
- Finally we present the corresponding formal specification artifacts (section "CASL-LTL *(or* CASL*) View*").

3 Specification of Simple Systems

3.1 Simple System Item

Following the framework presented in Sect. 2.1 we describe the simple system items structure. Here the word *system* denotes a dynamic system of whatever kind, and so evolving along the time, without any assumption about other

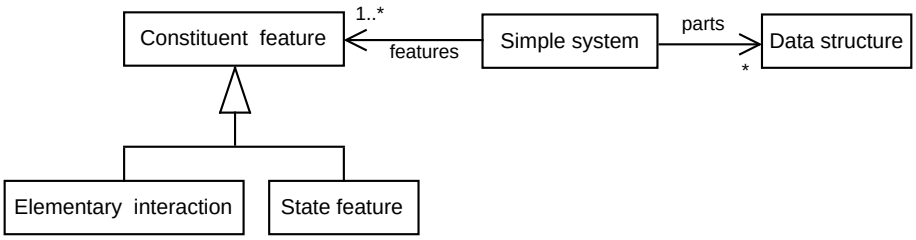


Fig. 4. Simple System Item

aspects of its behaviour; thus it may be a communicating/nondeterministic/ sequential/... process, a reactive/parallel/concurrent/distributed/... system, but also an agent or an agent system. A *simple system* is a system without any internal components cooperating among them.

In our approach we assume that simple systems are seen formally as *labelled transition systems*, see Sect. 1.2. The "modelling" is as follows. The states of an lts modelling a simple system represent the relevant intermediate situations in the life of the system, and each transition $s \xrightarrow{l} s'$ represents the *capability* of the system in the state/situation s of evolving into the state/situation s'; the label l contains information on the conditions on the external environment for the capability to become effective, and on the transformation induced on this environment by the execution of the transition, i.e., it fully describes the interaction of the system with the external environment during this transition.

To design effective and simple specification methods we assume that the labels have the standard form of a set of *elementary interactions*, where each elementary interaction intuitively corresponds to an elementary (that is not further decomposable) exchange with the external environment. We also assume that the elementary interactions are of different types, and that each type is characterized by a name and by some arguments (elements of some data structures). The above considerations lead us to choose the *elementary interaction types* (just *elementary interactions* from now on) as constituent features of the simple systems.

The form of the states (which are the intermediate situations during the system's life) is also a characterizing feature of simple systems, therefore we need *state constituent features*. However, they are technically different for the property-oriented and the constructive case, and so we will describe them later, when presenting the two methods.

Thus, to define the constituent features of a simple system we use values of various *data structures*; they are the "parts" of the simple systems.

We summarize the parts and features of simple systems in Fig. 4.

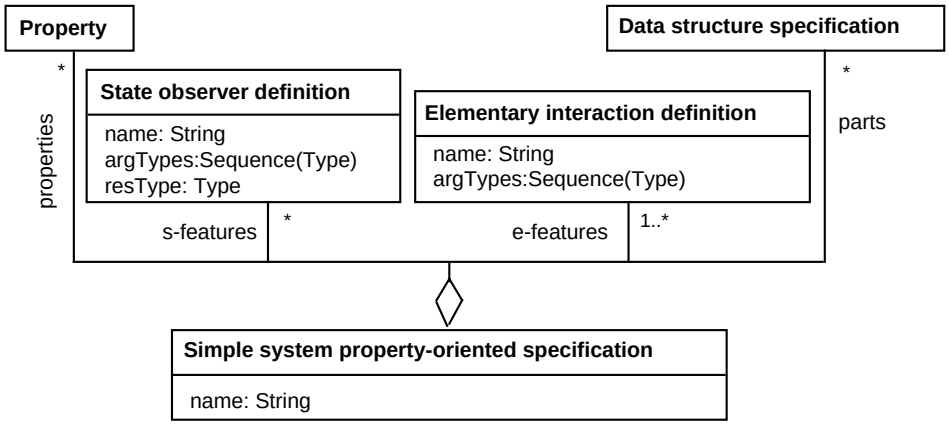


Fig. 5. Simple System Property-Oriented Specification

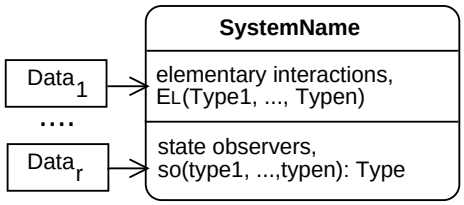


Fig. 6. Visual presentation of a simple system: parts and constituent features

3.2 Property-oriented specifications

The property-oriented specification method for simple systems we propose is a specialization of GPSm introduced in Sect. 2.2. According to Fig. 2, we first have to find the parts and constituent features, and then to fill the cells to express the properties.

3.2.1 The specification of parts and constituent features

To keep the specification level abstract, we do not completely describe the states, but we just list what we should be able to observe on them, and thus the state features will correspond to elementary observations on the states (*state observers*). A state observer is characterized by a name, some arguments (elements of some *data structures*), and by the observed value (element of some data structure)[11].

Fig. 5 shows the structure (by means of a UML class diagram) of a property-oriented specification of a simple system, and Fig. 6 how to visually depict its parts and the constituent features. type in Fig. 6 stands for a type of values defined by one of the subparts data structures ($\mathsf{DATA}_1, \ldots, \mathsf{DATA}_j$).

[11] If the observed value is a boolean, then it may be specified with a predicate. For simplicity sake (and by lack of space), this case will not be considered in this paper.

3.2.2 Cell schemas (properties)

All properties about a simple system correspond to properties on the lts modelling it, and thus on its labels, states and transitions. Recalling our assumptions on the form of the states and labels, these properties may only relate the values observed by the various state observers on a state, express which are the admissible sets of *elementary interactions* building a label, and relate the source state, the label and the target state of a transition. Our method offers appropriate ways to present these properties show below.

Label properties: $ei(arg)$ **incompatible with** $ei'(arg')$ **if** $cond(arg,arg')$
where ei and ei' are two elementary interactions and *cond* is a property of their arguments. It means that under some condition, if the two elementary interactions are different [12], then they are incompatible, i.e., no label may contain both.

State properties: *cond*
where *cond* is a condition in which state observers may appear. It means that for any state the values returned by the state observers must satisfy this condition.

State formulae may include also special atoms, listed below, expressing properties on the *paths* (concatenated sequences of transitions) leaving/reaching the state, that is on the future/past behaviour of the system from this state.

- **in any case eventually** *eIn* **happen**
  It means that any path starting from the state will contain a transition whose label contains the elementary interaction described by *eIn*.
- **in any case sometime** *eIn* **happened**
  Similarly, it means that any path reaching the state will contain a transition whose label contains the elementary interaction described by *eIn*.

These atoms may also be built by **in one case** (instead of **in any case**, with the meaning there exists at least one path such that ...), or **next** (instead of **eventually**, with the meaning "the label of the first transition of the path contains ..."), or **before** (instead of **sometime**, with the meaning "the label of the last transition of the path contains ...").

Transition properties: *cond*
where *cond* is a condition in which state observers on the source and target states (resp. denoted by "non primed" *so* and "primed" *so'* identifiers, and from now on referred to as *source state observers* and *target state observers*), and atoms of the form "*eIn* **happen**" may appear. It means that a transition $tr = x \xrightarrow{l} y$ satisfies *cond*, where source state observers are evaluated on the source state x of tr, target state observers are evaluated on the target state y of tr, and atoms of the form "*eIn* **happen**" hold iff the elementary interaction described by *eIn* belongs to the label l of tr.

[12] Then, it is not necessary to express that they are different.

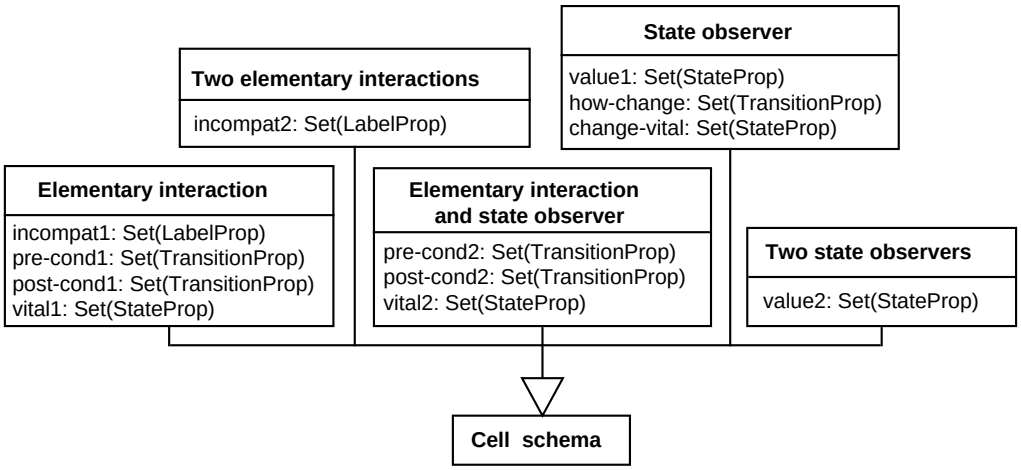
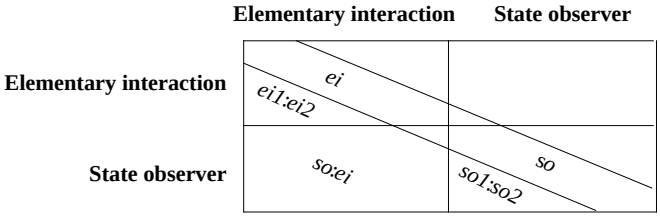


Fig. 7. Simple System Cell schemas

The constituent features of simple systems are of two kinds, elementary interactions and state observers, and so we have to consider five kinds of cells, as shown below.



We present the schemas for two kinds of cells in Fig. 8 and 9 (the others are in the Appendix A). There, *arg* stands for generic expressions of the correct types, possibly with free variables, and *cond*(*exprs*) for a generic condition where the free variables of *exprs* may appear.

3.2.3 Example: a Property-Oriented Specification of a Lift plant

As an example, we give theproperty-oriented specification of a lift plant, considered as a simple system. To specify the lift plant should be the first step for developing the lift system, indeed a precise knowledge of the plant is of fundamental importance for developing a good lift system. The lift plant may communicate the status of some of its components by means of sensors (the position of cabin and of the doors at the floors and the working status of the motor), and its components may be influenced by means of orders (open/close a door at a given floor, stop/move up/move down the motor). Moreover, the users may enter or leave the cabin.

We show the parts and the constituent features of the lift plant in Fig. 10. The elementary interactions (in the upper compartment) model the sensors attached to the plant, the orders that it can receive, and the fact that some

incompat1 (label property) If their arguments satisfy some conditions, then two instantiations of *ei* are incompatible, i.e., no label may contain both.

$ei(arg_1)$ **incompatible with** $ei(arg_2)$ **if** $cond(arg_1, arg_2)$

pre-cond1 (transition property) If the label of a transition contains some instantiation of *ei*, then the source state of the transition must satisfy some condition.

if $ei(arg)$ **happen then** $cond(arg)$
where source state observers must appear in $cond(arg)$ and target state observers cannot appear

post-cond1 (transition property) If the label of a transition contains some instantiation of *ei*, then the target state of the transition must satisfy some condition). The condition on the target state may require also the source state to be expressed.

if $ei(arg)$ **happen then** $cond(arg)$
where target state observers must appear in $cond(arg)$ and source state observers may appear in $cond(arg)$

vital1 (state property) If a state satisfies some condition, then any sequence of transitions starting from it will eventually contain a transition whose label contains *ei*. Note that in these properties **in any case** may be replaced by **in one case** and **eventually** by **next**.

if $cond(arg)$ **then in any case eventually** $ei(arg)$ **happen**

Fig. 8. Elementary interaction (*ei*) cell schema

value1 (state property) The results of the observation made by *so* on a state must satisfy some conditions.

cond, where *so* must appear in *cond*

how-change (transition property) If the observed value changes during a transition, then some condition on source state, target state, old and new value holds, and some elementary interactions must belong to the transition label.

if $so(arg) = v_1$ **and** $so'(arg) = v_2$ **and** $v_1 \neq v_2$ **then**
$cond(v_1, v_2, arg)$ **and** $ei_1, \ldots, ei_n$ **happen**

change-vital (state property) If a state satisfies some condition, then the observed value will change in the future. Note that in these properties **in any case** may be replaced by **in one case** and **eventually** by **next**.

if $cond(v_1, v_2, arg)$ **and** $so(arg) = v_1$ **and** $v_1 \neq v_2$ **then**
in any case eventually $so(arg) = v_2$

Fig. 9. State observer (*so*) cell schema

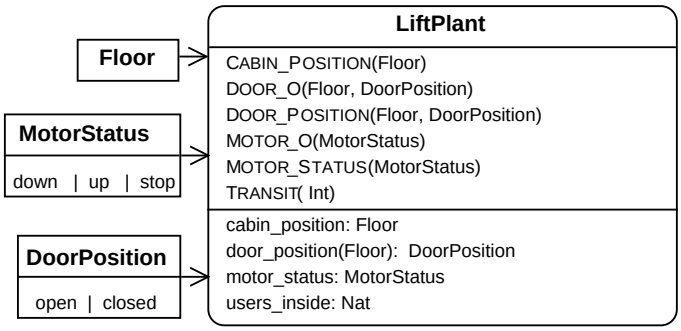


Fig. 10. LiftPlant: Parts and Constituent Features

users enter/leave its cabin, whereas the state observers (in the lower compartment) define the status of its components and how many users are inside its cabin.

To define the above constituent features we need some data:
- Floor: the floors among which the cabin is moving (see 5.2.2 for its specification),
- MotorStatus: the possible statuses of the motor(moving up, moving down or stopped),
- DoorPosition: the possible positions of the doors at the floors (open or closed).
MotorStatus and DoorPosition are two simple enumeration data structures, for which we use an ad hoc notation, writing their constructors separated by |.

We followed the cell filling methods to find all the relevant properties of the lift plant, but here we dropped repeated formulae, after having checked the absence of contradictions, and slightly rearranged the others to improve readability. The properties on the orders are detailed below, while the others (on the sensors, the cabin, and the users entering/leaving the cabin) are given in the Appendix B. The elementary interactions and the state observers used below are declared in Fig. 10.

– Only appropriate groups of orders may be received simultaneously by the lift plant; precisely, at most one order for the motor and one for the doors.
  MOTOR_O(ms_1) **incompatible with** MOTOR_O(ms_2)
  DOOR_O(f_1,dps_1) **incompatible with** DOOR_O(f_2,dps_2)
– An order can be received only when its execution is possible; precisely move up (down) only when the motor is stopped and the cabin is not at the top (ground) floor, and open the door at f only when no door is open, the cabin is at floor f and the motor is stopped.
  if MOTOR_O(up) **happen then** $motor_status = stop$ **and** $cabin_position \neq top$
  if MOTOR_O($down$) **happen then**
    $motor_status = stop$ **and** $cabin_position \neq ground$
  if DOOR_O(f_1,$open$) **happen then**
    (**for all** $f \bullet$ **if** $f \neq f_1$ **then** $door_position(f) \neq open$) **and**
    $cabin_position = f_1$ **and** $motor_status = stop$

– The orders are always correctly executed.
  if MOTOR_O(ms) **happen then** $motor_status' = ms$
  if DOOR_O(f,dps) **happen then** $door_position'(f) = dps$

The complete specification of the lift plant given following our method (see also Appendix B) may seem long, but we think that it is quite complete and it shows all relevant information to build the software for handling it. For example, such specification makes clear that – sensors never break down (the state observers corresponding to sensors are total), – motor and doors may change status by themselves as a result of some failure (no property requires that, if the motor changes its status, an order has been received), and – the plant takes care of some security checks, such as to avoid that the motor goes down when the cabin is at the ground floor.

3.2.4 CASL-LTL *View*

Here we present the CASL-LTL [26] corresponding version of the property-oriented specification of simple systems produced following our method introduced in Sect. 3.2,. Let *poSpec* be a property-oriented specification of simple systems having the form described in Fig. 5, and assume that

- $poSpec.\mathsf{parts} = \{ds_1, \ldots, ds_j\}$ are the parts, and $\mathrm{DS}_1, \ldots, \mathrm{DS}_j$ the corresponding CASL-LTL specifications;
- $poSpec.\mathsf{e\text{-}features} = \{ei_1, \ldots, ei_n\}$ are the elementary interactions;
- $poSpec.\mathsf{s\text{-}features} = \{so_1, \ldots, so_m\}$ are the state observers.

Below we give the CASL-LTL specification corresponding to *poSpec*. Notice that the constructors and the operations may be partial, and this is denoted by a '?', e.g., "$so_i.\mathsf{name} : st \times so_i.\mathsf{argTypes} \rightarrow ?\ so_i.\mathsf{resType}$".

spec ELEMINTER =
  free type *elemInter* ::=
    $ei_1.\mathsf{name}(ei_1.\mathsf{argTypes}) \mid \ldots \mid ei_n.\mathsf{name}(ei_n.\mathsf{argTypes})$
spec $poSpec.\mathsf{name}$ =
  FINITESET[ELEMINTER] **and** DS_1 **and** ... **and** DS_j **then**
  dsort *st* **label** *FinSet*[*elemInter*]
  ops $so_1.\mathsf{name} : st \times so_1.\mathsf{argTypes} \rightarrow so_1.\mathsf{resType}$
    ...
    $so_m.\mathsf{name} : st \times so_m.\mathsf{argTypes} \rightarrow so_m.\mathsf{resType}$
  axioms
    formulae corresponding to the cell fillings, defined below case by case

Label property: eIn_1 **incompatible with** eIn_2 **if** *cond*
  the corresponding formula is
  $$\neg\,(eIn_1 = eIn_2) \ \wedge\ cond \ \wedge\ S \xrightarrow{l} S' \ \Rightarrow\ \neg\,(eIn_1 \in l \ \wedge\ eIn_2 \in l)$$

State property: *cond*

the corresponding formula is obtained by adding S (a variable of sort st) as extra argument to each state observer appearing in *cond*, and by replacing the special temporal combinators as follows:

in any case ...	$in_any_case(S, \ldots)$
in one case ...	$in_one_case(S, \ldots)$
eventually eIn **happen**	$eventually \ < l \bullet eIn \in l >$
next eIn **happen**	$next \ < l \bullet eIn \in l >$
sometime eIn **happened**	$sometimes \ < l \bullet eIn \in l >$
before eIn **happened**	$before \ < l \bullet eIn \in l >$

Transition property: *cond*

the corresponding formula is $S \xrightarrow{l} S' \Rightarrow cond'$, where *cond'* is obtained from *cond* by adding S as an extra argument to each source state observer, by adding S' as an extra argument to each target state observer, and by replacing each atom of the form "eIn **happen**" with "$eIn \in l$".

3.3 Constructive specifications

3.3.1 The specifications characteristics

The constructive specification method for simple system that we present is similar in many respects to the property-oriented one introduced in Sect. 3.2. Indeed, the items (simple systems), their parts and their constituent features of kind elementary interactions, the formal models and the modelling are the same. But, the state features are different, since we have here *state constructors* instead of state observers. In this case we have to build the states of the lts modelling a simple system, and we consider that those states may be classified into different categories, according to the different system behaviour. Technically, the states will be a data structure having a constructor with typed arguments (see Sect. 5), for each state category. The state constructors are the state constituent features.

The specification technique is similar to that followed in Sect. 3.2 in that we have also to determine the parts and the constituent features, the only difference is that now we do not give properties but instead we define precisely the states, the labels and the transition of the lts modelling the specified simple system. The definition of the labels and of the states is quite trivial (the labels are sets of elementary interactions, and the states are built by the state constructors). For what concerns the transitions, we define them by means of conditional rules of the following form

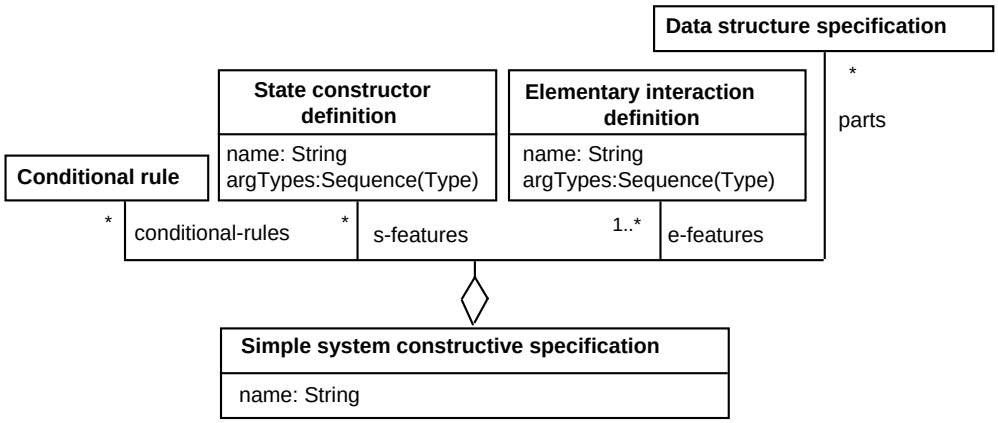


Fig. 11. Simple System Constructive Specification

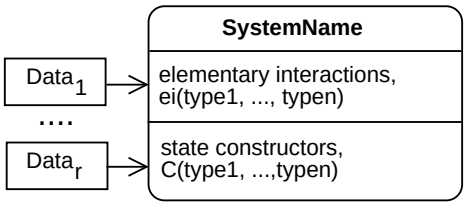


Fig. 12. Simple System Constructive Specification: parts and constituent features

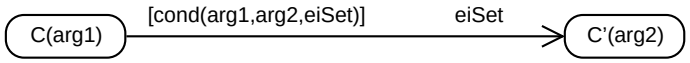
(*) $\quad$ **if** $pos\text{-}cond(arg_1, arg_2, eiSet)$ **then** $C(arg_1) \xrightarrow{eiSet} C'(arg_2)$

where

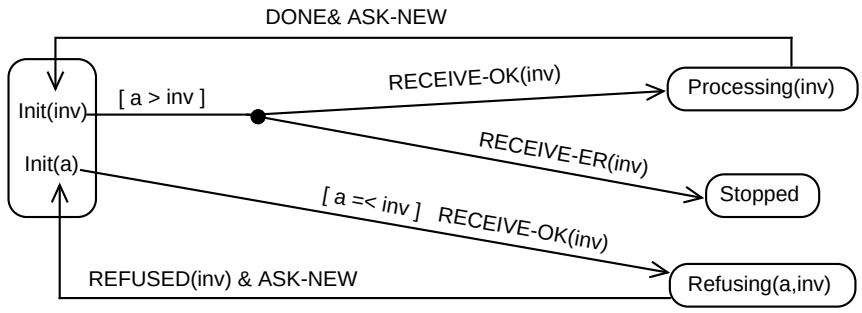
- C and C' are state constructors, resp. of the source and target states
- $eiSet$ is a set of elementary interactions
- and $pos\text{-}cond(arg_1, arg_2, eiSet)$ is a conjunction of positive atoms in which the free variables of arg_1, arg_2 and $eiSet$ may appear.

The form of our constructive specifications of simple system is summarized in Fig. 11.

We present how to visually depict the parts and the constituent features of a simple system constructive specification in Fig. 12. A conditional rule defining the transitions as in (*) above will be visually represented as the following oriented arc



The visual presentations of all the conditional rules may be then put together building an oriented graph, as originally proposed in [30], by collecting all source and target rounded boxes related to states built by the same constructor, and by writing only once repeated constructor instantiations and repeated conditions. For example, the following diagram



shows the combination of the visual presentations of the following five conditional rules.

$$\textbf{if } a > inv \textbf{ then } Init(a) \xrightarrow{RECEIVE-OK(inv)} Processing(inv)$$
$$\textbf{if } a > inv \textbf{ then } Init(a) \xrightarrow{RECEIVE-ER(inv)} Stopped$$
$$\textbf{if } a \leq inv \textbf{ then } Init(a) \xrightarrow{RECEIVE-OK(inv)} Refusing(a, inv)$$
$$Refusing(a, inv) \xrightarrow{\{REFUSED(inv), ASK-NEW\}} Init(a)$$
$$Processing(inv) \xrightarrow{\{DONE, ASK-NEW\}} Init(inv)$$

3.3.2 Example: a Constructive Specification of a Controller for a Lift

As example in this section, we give the constructive specification of a controller for the lift, considered as a simple system. This specification may be considered as an abstract presentation of a design for such a controller. Our controller may send orders to the motor and to the doors, and may receive information on the status of the plant by means of its sensors (status of the motor, and positions of the doors and of the cabin). The users interact with the controller by calling the floors, that it by requiring that the cabin goes to a given floor.

Following our method we first determine the elementary interactions, the used data structures, and finally define the behaviour of the controller. In this case the elementary interactions (see Fig. 13) correspond to sending the orders, and to receiving signals from the sensors and calls from the users. To needed data structures are Floor10 (providing an *ord* operation yielding the floor number), defined in Sect. 5.3.2, MotorStatus and DoorPositions. The latter is defined by using the predefined parametric type List [31]. DoorPositions also has a derived predicate *all_Close_But* defined by the following conditional rules. Recall that *select* given a list and a natural number returns the element in such position, and that we assume that the positions of the various doors are listed one after the other starting from *ground* till to *top*.

if *select*(*ord*(*ground*),*dposs*) = *open* **and**
  select(*ord*(*second*),*dposs*) = *closed* **and** ... **and**
  select(*ord*(*top*),*dposs*) = *closed* **then**
  all_Close_But(*ground*,*dposs*)
...

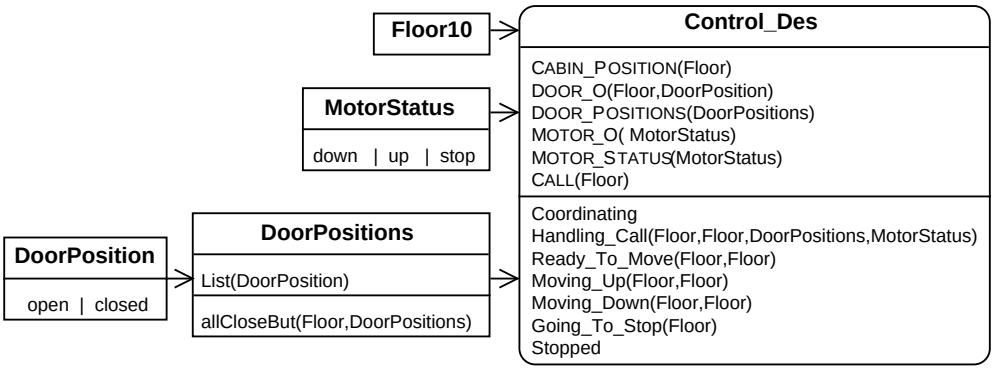
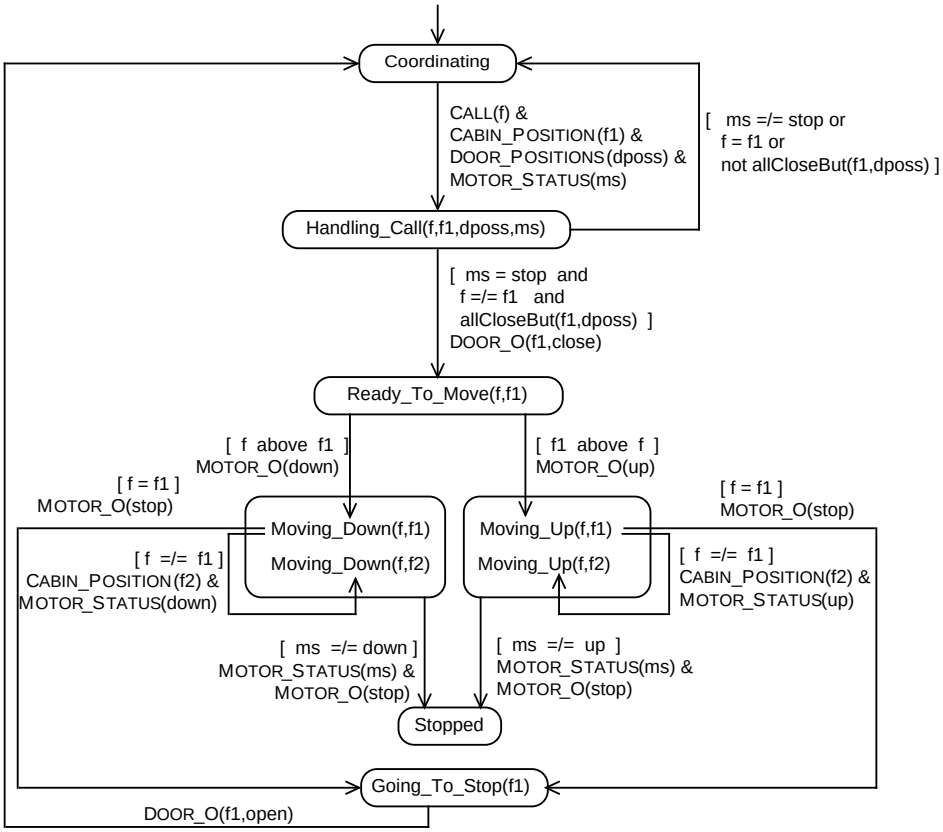


Fig. 13. Lift Controller (design): Parts and Constituent Features

if $select(ord(top),dposs) = open$ **and**
$select(ord(ground),dposs) = closed$ **and** ... **and**
$select(ord(ninth),dposs) = closed$ **then**
$all_Close_But(top,dposs)$

The behaviour of the controller is shown below.



It waits for a call from the users (Coordinating), then if the call may be satisfied, closes the door (DOOR_O(f1, close)) and orders to the motor to move in the correct versus, till the cabin reaches the required floor (Stopping(f1)). Then, it opens the door and waits for the next call. It is also able to detect some failures (an order to the motor has not been executed), and in such cases it

stops to work.

3.3.3 CASL-LTL *View*

Here we present the CASL-LTL [26] corresponding version of our constructive specifications of simple systems introduced before in Sect. 3.3. Let *conSpec* be a constructive specification of simple systems having the form described in Fig. 11, and assume that

- $conSpec.\mathsf{parts} = \{ds_1, \ldots, ds_j\}$ are the parts, and $\mathrm{DS}_1, \ldots, \mathrm{DS}_j$ the corresponding CASL-LTL specifications;
- $conSpec.\mathsf{e\text{-}features} = \{ei_1, \ldots, ei_n\}$ are the elementary interactions;
- $conSpec.\mathsf{s\text{-}features} = \{sCon_1, \ldots, sCon_m\}$ are the state constructors.

Below we give the CASL-LTL specification corresponding to *conSpec*.

spec ELEMINTER =
  free type *elemInter* ::=
    $ei_1.\mathsf{name}(ei_1.\mathsf{argTypes}) \mid \ldots \mid ei_n.\mathsf{name}(ei_n.\mathsf{argTypes})$
spec *conSpec*.NAME =
  FINITESET[ELEMINTER] **and** DS_1 **and** ... **and** DS_j **then**
free {
  dsort *st* **label** *FinSet*[*elemInter*]
  ops $sCon_1.\mathsf{name} : sCon_1.\mathsf{argTypes} \rightarrow st$
    ...
    $sCon_m.\mathsf{name} : sCon_m.\mathsf{argTypes} \rightarrow st$
  axioms
    formulae corresponding to conditional rules
} end

A conditional rule

$$\textbf{if } pos\text{-}cond(arg_1, arg_2, eiSet) \textbf{ then } C(arg_1) \xrightarrow{eiSet} C'(arg_2)$$

is expressed by the CASL-LTL formulae

$$pos\text{-}cond(arg_1, arg_2, eiSet) \Rightarrow C(arg_1) \xrightarrow{eiSet} C'(arg_2).$$

4 Specification of Structured Systems

4.1 Structured System Items

A *structured system* item is a specialization of the simple dynamic system of Sect. 3; indeed it is a simple system made by several other dynamic systems, its *subsystems*, which are either simple or in turn structured. We assume that

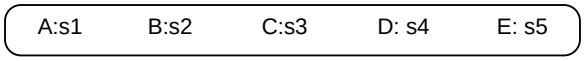
each subsystem is uniquely identified by some identity. A situation during the life of a structured system is fully characterized by the situations of its subsystems, and its (global) moves just consist of the simultaneous executions of (local) moves of some of its subsystems.

The specification methods for structured systems (property-oriented and constructive), which we present here, are specializations of those for simple systems (see Sect. 3). Thus also structured systems will be modelled by labelled transition systems (lts); but in this case their states will be sets of states of those lts's modelling the subsystems, and their transitions will correspond to simultaneous executions of sets of subsystems transitions (the latter are named their *components*). To represent which are their composing subtransitions, we need to enrich the labelled transitions with an extra part containing such *information*. It is not appropriate to only extend the labels of the transitions with the information about the subsystems moves. Indeed, *labels* should model only the system interaction with the outside world, and in many cases the subsystems moves are completely transparent to outside, as, e.g., two subsystems exchanging a message between themselves. Thus, to describe a given global transition we both need its label (that is a set of elementary interactions visible from outside) and its information part (on the subsystem moves that may not all be visible from outside). For simplicity sake we do not consider here the case of subsystems that may be created and destroyed dynamically, but there are no technical problems to handle them.

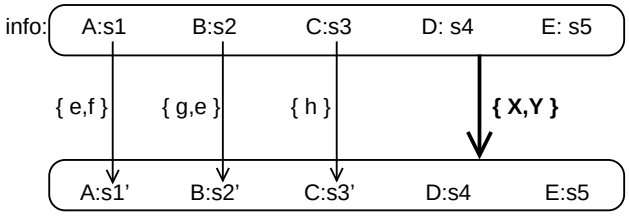
Technically, it means that to model structured systems we use *generalized lts*, that are lts specialized by adding an information part to each transition. Thus a generalized lts is a 4-uple $(State, Label, Info, \rightarrow)$, where $\rightarrow \subseteq Info \times State \times Label \times State$, and *Info* is the set of the additional information attached to the transitions. A generic transition is usually written $inf : x \xrightarrow{l} y$. The additional information for the generalized lts modelling the structured systems, which must represent the composing subtransitions, will be sets of pairs made by a subsystem identity (the subsystem performing the subtransition) and by an elementary interaction (belonging to the label of the subtransition). We name these pairs *local elementary interactions*, shortly *local interactions* from now on. We exemplify the concepts introduced so far in Fig. 14.

To take into account the role played by the subsystems in the moves of the structured systems, we consider also the local interactions as their constituent features. Structured systems have also a new kind of parts, the composing subsytems, which may be either simple or in turn structured. Structured systems have special state observers returning the states of the subsystems, which are denoted by the subsystem identities themselves (we do not need to declare them, since they are implicitly determined by the subsystem declarations.) Notice that, however, we need also other state observers. Indeed, property-oriented specifications are usually at a quite abstract level and we may want

a sample state of SS (s1, ..., s5 are respectively the states of A, ..., E)



a sample transition of SS (global transition/move)



- **its composing local transitions/moves**

  s1 $\xrightarrow{\{e,f\}}$ s1' s2 $\xrightarrow{\{g,e\}}$ s2' s3 $\xrightarrow{\{h\}}$ s3'

- **its local interactions** (the subsystems D and E do not take part in the global move) A.e A.f B.g B.e C.h
- **its (global) elementary interactions** of SS towards the outside resulting from the subsystem moves X Y
- **its (additional) information** info = { (A, e), (A,f), (B,g), (B,e), (C,h) }

Fig. 14. Example of a structured system SS, with five subsystems, A, B, C, D and E

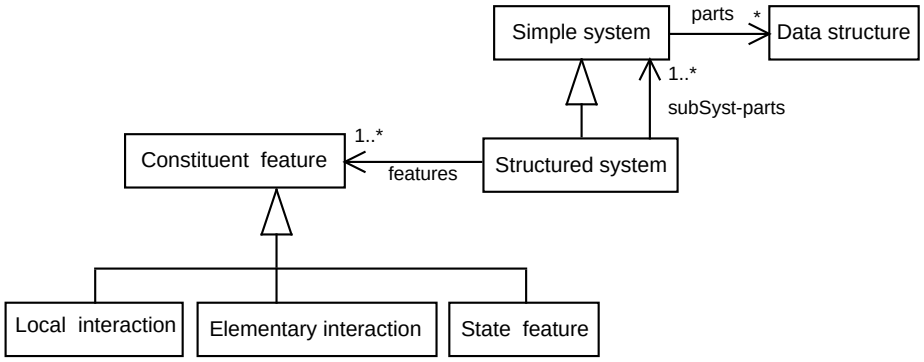


Fig. 15. Structured System Item

to observe something on the structured system states without knowing which subsystems (and in which way) contribute to this observation. An example may be an observer checking if there is an error in the system, when we do not know anything about the error situations of the single subsystems.

We summarize the parts and constituent features of structured systems in Fig. 15.

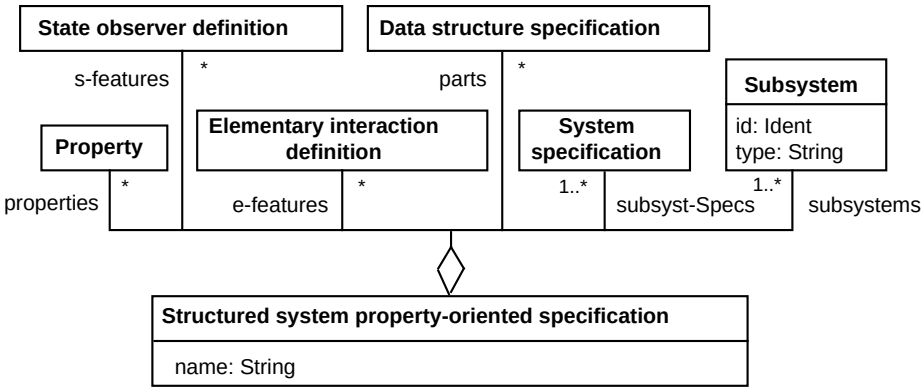


Fig. 16. Structured System Property-Oriented Specification

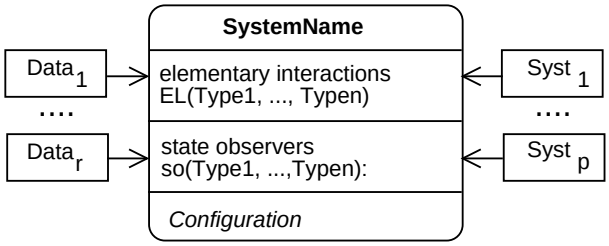
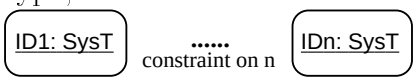


Fig. 17. Visual presentation of a structured system: parts and constituent features

4.2 Property-oriented specifications

The method for property-oriented specifications of structured systems, which we present here, is a specialization of the one for the simple systems of Sect. 3.

4.2.1 Specification of parts and constituent features

We assume that a structured system may have many subsystems of the same type (i.e., whose specification is the same), and that they are identified by elements of a special data structure IDENT (standard identifiers). Thus to specify the subsystem parts it is sufficient to give the subsystem specifications, and for any subsystem its identity and its *type*, i.e., the name of its specification. The local interactions are implicitly determined after we have given the subsystems, and so they do not need to be explicitly specified. The structure of a property-oriented specification of a structured system is then summarized in Fig. 16. Fig. 17 presents how to visually depict the parts and the constituent features of a property-oriented structured system specification. In this picture Syst_1, ..., Syst_p are the names of the subsystem specifications, given apart, and *Configuration* is a visual presentation of which are the subsystems . A subsystem is represented by a rounded box containing its identity and type, that is the name of the corresponding specification. We use the notation 

to represent a set of subsystems of type SysT

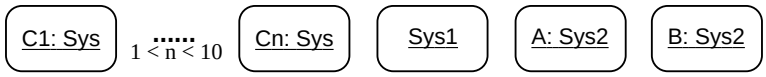


Fig. 18. Configuration example

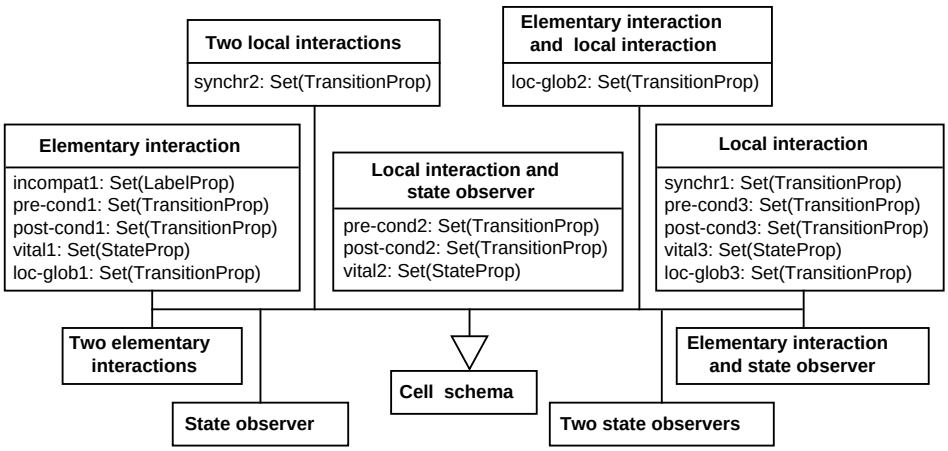


Fig. 19. Structured System Cell schemas

made by n elements with n satisfying some constraint. In the particular case where there is just a unique element of a type we can drop the subsystem identity and write only the (underlined) type name; thus the subsystem will be named as the type. In Fig. 18 we show an example of a configuration; the structured system with that configuration has one subsystem of type Sys1, named Sys1, two subsystems of type Sys2 named respectively A and B, and n, with $1 < n < 10$ subsystems of type Sys named respectively C1, ..., Cn.

4.2.2 Cell schemas (properties)

Structured systems have a new kind of constituent features, the local interactions, so we have new types of cells to be filled; moreover local interactions should be considered also when defining the schemas for the cells already used for simple systems. The state observers corresponding to subsystem states should be considered as the others, with the corresponding cells.

To model structured systems, we upgraded lts's to generalized lts, which differ for the additional information part of the transitions (the set of the local interactions). Now, we consequently upgrade the properties on the transitions (see Sect. 3.2.2) with new atoms "*lIn* **happen**" (where *lIn* is a local interaction) which express that *lIn* belongs to the set of the transition local interactions. More precisely, *lIn* **happen** holds on a transition of a generalized lts "$inf : x \xrightarrow{l} y$" iff $lIn \in inf$. The new properties will allow us to take into account the local interactions when expressing the properties the various cells.

In Fig. 19 we present the schemas for the new cells and the updates of those already used for simple systems, where undetailed "boxes" refer to Fig. 7 as well

synchr1 (transition property) Under some condition, an instantiation of *sid.ei* is/is not synchronized (i.e., executed simultaneously) with another instantiation of the same *sid.ei*, i.e., one is a component of a global transition iff the other also is/is not so; clearly the two instantiations are performed by different subsystems.

if $cond(arg,arg_1)$ **and** $sid.ei(arg)$ **happen then** $sid_1.ei(arg_1)$ **happen**
or
if $cond(arg,arg_1)$ **and** $sid.ei(arg)$ **happen then not** $sid_1.ei(arg_1)$ **happen**

loc-glob3 (transition property) If an instantiation of *sid.ei* is a component of a global transition, then, under some condition, the label of this global transition must contain some elementary interaction, or vice versa.

if $sid.ei(arg)$ **happen and** $cond(arg,eIn)$ **then** eIn **happen**
or
if eIn **happen and** $cond(arg,eIn)$ **then** eIn **happen**

pre-cond3,post-cond3,vital3 defined as the homonymous slots for simple system but where the elementary interaction is replaced by the local interaction.

Fig. 20. Local interaction (*sid.ei*) cell schema

synchr2 (transition property) Under some condition, an instantiation of $sid_1.ei_1$ is/is not synchronized with an instantiation of $sid_2.ei_2$, i.e., one is a component of a global transition iff the other also is/is not so; clearly the two instantiations are performed by different subsystems.

if $cond(arg_1,arg_2)$ **and** $sid_1.ei_1(arg_1)$ **happen then** $sid_2.ei_2(arg_2)$ **happen**
or
if $cond(arg_1,arg_2)$ **and** $sid_1.ei_1(arg_1)$ **happen then**
not $sid_2.ei_2(arg_2)$ **happen**

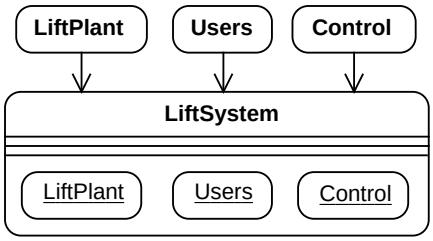
Fig. 21. Two local interactions ($sid_1.ei_1$:$sid_2.ei_2$) cell schema

as the slots that are not redefined here. Clearly, for the parts already defined in Sect. 3.2.2, here we must consider also the local interactions together with elementary interactions in the state and transition properties. The schemas for the various cells are reported in Fig. 20 and 21, and in Appendix C.

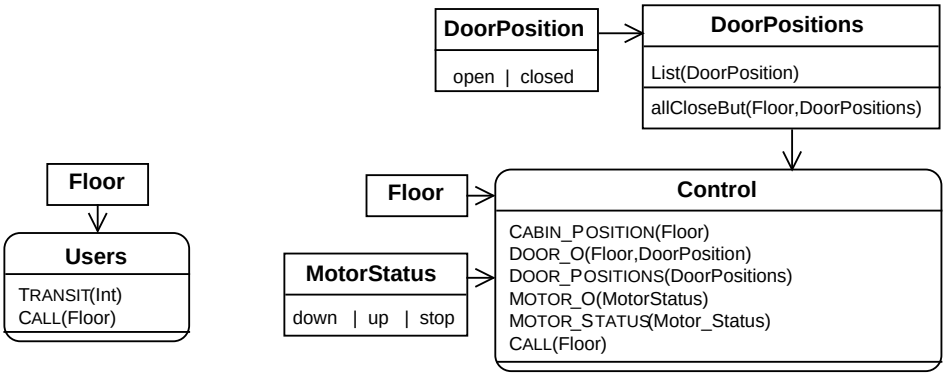
4.2.3 Example: a Property-Oriented Specification of a Lift System

The lift system consists of the lift plant, see Sect. 3.2.3, the automated software controller and the users; and, it is a structured system. Here we use our method to express its relevant properties, which are mainly about how its subparts influence each other. The produced specification may be considered as a precise

definition of the requirements on the controller, stating precisely how it will affect and interact with its context.



The above picture shows the parts and the constituent features of the lift system. The subsystems are the plant, the controller, and the users (a unique system modelling all the lift users), and all of them are simple systems; whereas the used data structures are those of the subsystems and so we do not repeat them. We specify in a property-oriented way the three subsystems. The specification of the lift plant, LiftPlant, has been given in Sect. 3.2.3 and those of the users and of the controller are here.



Notice that these specifications have no properties, because in this case we do not know anything on the behaviour of the users (for instance we do not assume that a user that enters the lift will eventually leave it), and the requirements concern only the effects of the controller on the context, and not its precise behaviour. The lift system is closed, in the sense that it does not interact with its outside world, or better possibly interactions do not concern the requirement that we have to describe; thus the elementary interaction compartment is empty. No state observer different from those observing the states of the subsystems is needed, and so also the other compartment is empty. Thus, the only constituent features of the lift systems are of kind local interactions, and to give its properties we have just to fill cells of the form "Local interaction" and "Two local interactions", whose ***loc-glob*** parts will be always empty.

All the local interactions with the same name of different subsystems are synchronized. We give just an example of such properties, the one concerning calling the cabin.

Users.CALL(f) **synchronized with** Control.CALL(f)

Instead the local interaction "Control.DOOR_POSITIONS" is synchronized with many of the kind "LiftPlant.DOOR_POSITION".

Control.DOOR_POSITIONS(dps_1::...::dps_{10}) **synchronized with**
LiftPlant.DOOR_POSITION($ground$,dps_1), ..., LiftPlant.DOOR_POSITION(top,dps_{10})

The last property is a post condition concerning the users' calls.

if Users.CALL(f) **happen then in any case eventually**
LiftPlant.$cabin_position(f)$ **and** LiftPlant.$motor_status(stop)$ **and**
LiftPlant.$door_position(f)$ $= open$

4.2.4 CASL-LTL *View*

Here we present the CASL-LTL corresponding version of our property-oriented specification of structured systems introduced before in Sect. 4.2.1. The only difference with the case of the simple system of Sect. 3.2.4 is that now we use generalized lts, however CASL-LTL offers a special construct to declare that three sorts correspond to the states, the labels and the additional information of a generalized lts together with a standard arrow predicate corresponding to the transition relation.

dsort st **label** lab **info** inf stands for
sorts st, lab, inf
pred $__ : __ \xrightarrow{__} __ : inf \times st \times lab \times st$

Let *poSpec* be a property-oriented specification of structured systems having the form described in Fig. 16, and assume that

- $poSpec$.parts $= \{ds_1, \ldots, ds_j\}$ are the parts, and $\mathrm{DS}_1, \ldots, \mathrm{DS}_j$ the corresponding CASL-LTL specifications;
- $poSpec$.subsyst-Specs $= \{ssp_1, \ldots, ssp_k\}$ are the subsystem specifications, $\mathrm{SSP}_1, \ldots, \mathrm{SSP}_k$ are the corresponding CASL-LTL specifications, and $\mathrm{ELEMINTER}_1, \ldots, \mathrm{ELEMINTER}_k$ are the specifications of their elementary interactions;
- $poSpec$.e-features $= \{ei_1, \ldots, ei_n\}$ are the (global) elementary interactions;
- $poSpec$.s-features $= \{so_1, \ldots, so_m\}$ are the state observers;
- $poSpec$.subsystems $= \{ss_1, \ldots, ss_r\}$ are the subsystems.

Below we give the CASL-LTL specification corresponding to *poSpec*.

spec LOCALINTER =
ELEMINTER$_1$ **and** ... **and** ELEMINTER$_k$ **and** IDENT **then**
free type $subElemInter$ ::= $_(elemInter_1) \mid \ldots \mid _(elemInter_k)$
%% disjoint union of the elementary interaction types of the subsystems
free type $localInter$ ::= $< _, _ > (ident, subElemInter)$

spec *poSpec*.name =
FiniteSet[ElemInter] **and** FiniteSet[LocalInter] **and**
DS_1 **and** ... **and** DS_j **and** SSP_1 **and** ... **and** SSP_k **then**
dsort *st* **label** *FinSet*[*elemInter*] **info** *FinSet*[*localInter*]
ops so_1.name : $st \times so_1$.argTypes $\rightarrow so_1$.resType %% state observers
...
so_m.name : $st \times so_m$.argTypes $\rightarrow so_m$.resType
ss_1.id : $st \rightarrow ss_1$.type %% observers of the subsystem states
...
ss_r.id : $st \rightarrow ss_r$.type
axioms
formulae corresponding to the cell fillings, see below

For the properties on structured systems we have used a new kind of transition properties, and so here we give how to transform them in Casl-Ltl. Similarly to what was done in Sect. 3.2.4, a transition property *cond* is transformed into $inf : S \xrightarrow{l} S' \Rightarrow cond'$, where *cond'* is obtained from *cond* by adding S as an extra argument to each source state observer, by adding S' as an extra argument to each target state observer, and by replacing each atom of the form "*eIn* **happen**" with $eIn \in l$, and each atom of the form "*lIn* **happen**" with $lIn \in inf$.

4.3 Constructive specifications

4.3.1 The specifications characteristics

The constructive specification method for structured system that we present is similar in many respects to the property-oriented one introduced in Sect. 4.2. We first determine the parts and the constituent features, and that can be done as before, the only difference is that in this case we do not define any state features, because the states are fully determined by the subsystems (they are just sets of subsystem states). Then, we do not give properties but instead we define precisely the additional information, the states, the labels and the transition of the generalized lts modelling the specified structured system.

The definition of the additional information, the labels and the states is as for the property-oriented case (the additional information are sets of local interactions, the labels are set of elementary interactions, and the states are sets of subsystem states together with their identities). For what concerns the transitions, similarly to the case of simple systems, we define them by means of conditional rules stating which groups of local transitions (of the subsystems) may be executed together resulting in a global (of the structured system) transition. The general form of such rules, visually depicted in Fig. 22, is

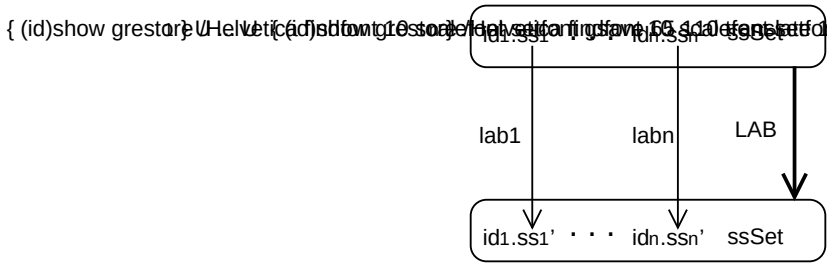


Fig. 22. Visual presentation of a generic rule defining global transitions

$$
\begin{array}{l}
(\#)\ \textbf{if}\quad ss_1 \xrightarrow{lab_1} ss_1'\ \textbf{and}\ \ldots\ \textbf{and}\ ss_n \xrightarrow{lab_n} ss_n'\ \textbf{and} \\
\qquad \textit{pos-cond}(lab_1, \ldots, lab_n, LAB, ssSet)\ \textbf{then} \\
\{(id_1.x) \mid x \in lab_1\} \cup \ldots \cup \{(id_n.x) \mid x \in lab_n\} : \\
\qquad \{id_1.ss_1, \ldots, id_n.ss_n\} \cup ssSet \xrightarrow{LAB} \{id_1.ss_1', \ldots, id_n.ss_n'\} \cup ssSet
\end{array}
$$

stating that if $ss_1 \xrightarrow{lab_1} ss_1'$, ..., $ss_n \xrightarrow{lab_n} ss_n'$ are local transitions (i.e., of the subsystems id_1, ..., id_n), and their labels satisfy some condition, then we have a global transition (of the structured system), in whose source state we distinguish the subsystems subjected to a local transition (with source states ss_1, ..., ss_n) and those staying idle (with source states in $ssSet$), that is labelled by LAB, and that whose additional information is the set of the involved local interactions ($\{(id_1, x) \mid x \in lab_1\} \cup \ldots \cup \{(id_n, x) \mid x \in lab_n\}$). The condition may concern also the possible transitions of the subsystems staying idle ($ssSet$) and the label of the resulting global transition LAB.

To help the specifier write such complex rules our method, inspired by the SMoLCS approach [3], proposes to proceed in the following way.

Recalling that the labels of the systems consists of sets of elementary interaction, we first determine which groups of local interactions must be executed together (*synchronized sets*). Then, we assume that a set of local transitions can build a global transition if and only if their corresponding local interactions can all be combined into disjoint synchronized sets. Furthermore, we add to each synchronized set a global elementary interaction (of the structured system), expressing the interaction with the external environment resulting from the execution of the set of local interactions. The transition shown in Fig. 14 may be, for example, motivated by the following synchronized sets (*null* stands for no global elementary interaction)

$$(\{\mathsf{A.e}, \mathsf{B.e}\}, \mathit{null}), (\{\mathsf{A.f}\}, \mathsf{X}), (\{\mathsf{B.g}, \mathsf{C.h}\}, \mathsf{Y})$$

Notice that A.f is not synchronized with other local interactions.

Thus the rule (#) can be specialized in the following way (we present it in four parts followed by the corresponding comments):

(1) **if** $ss_1 \xrightarrow{lab_1} ss'_1$ **and** ... **and** $ss_n \xrightarrow{lab_n} ss'_n$ **and**
(2) $\{(id_1.x) \mid x \in lab_1\} \cup \ldots \cup \{(id_n.x) \mid x \in lab_n\} =$
$linSet_1 \cup \ldots \cup linSet_k$ **and**
(3) $(linSet_1, EI_1), \ldots, (linSet_k, EI_k)$ are synchronized sets **then**
(4) $linSet_1 \cup \ldots \cup linSet_k$:
$\{id_1.ss_1, \ldots, id_n.ss_n\} \cup ssSet \xrightarrow{\{EI_1,\ldots,EI_k\}} \{id_1.ss'_1, \ldots, id_n.ss'_n\} \cup ssSet$

If
(1) $ss_1 \xrightarrow{lab_1} ss'_1, \ldots, ss_n \xrightarrow{lab_n} ss'_n$ are local transitions (i.e., of subsystems)
(2) each local transition determines a set of local interactions
$\{(id_i.x) \mid x \in lab_i\}$ $i = 1, \ldots, n$
(2)&(3) local interactions may be combined to form synchronization sets $linSet_1, \ldots, linSet_k$
(3) accompanied by the global elementary interactions $EI_1, \ldots, EI_k$
then
(4) we have a global transition (of the structured system), in whose source state we distinguish the subsystems subject to a local transition (with source states $ss_1, \ldots, ss_n$) and those staying idle (with source states in $ssSet$), that is labelled by the global elementary interactions $EI_1, \ldots, EI_k$, and that whose additional information is the set of the involved local interactions ($linSet_1 \cup \ldots \cup linSet_k$).

This rule states that any group of local transitions (of the subsystems) whose elementary interactions build a group of synchronized sets may result in a global transition (of the structured system) [free mode]. If we need to express that at most one of such set is selected at each step [inter mode], the above rules may be changed by setting $k = 1$. If instead, we need that only maximal groups of subsystem transitions are selected (i.e., the subsystems in $ssSet$ cannot perform some other synchronized set of local moves) [max mode], then we add in the premise the condition that $ssSet$ cannot move. Thus, to define the above rules, we only need to define which are the synchronized sets of local interactions and the mode in which the subsystem transitions are picked up (for the case of maximal parallelism we need also to define also an additional predicate $noMove$, again by conditional rules).

The set of synchronized local interactions may be in turn defined by conditional rules (synchronization rules) having the form

(+) **if** $pos\text{-}cond(\{sid_1.ei_1,\ldots,sid_k.ei_k\},EI)$ **then**
$(\{sid_1.ei_1,\ldots,sid_k.ei_k\},EI)$ is a synchronized set

The form of the constructive specifications of structured systems is summarized in Fig. 23.

The parts and the constituent features of a constructive specification of a structured system are visually presented as for the property-oriented specifi-

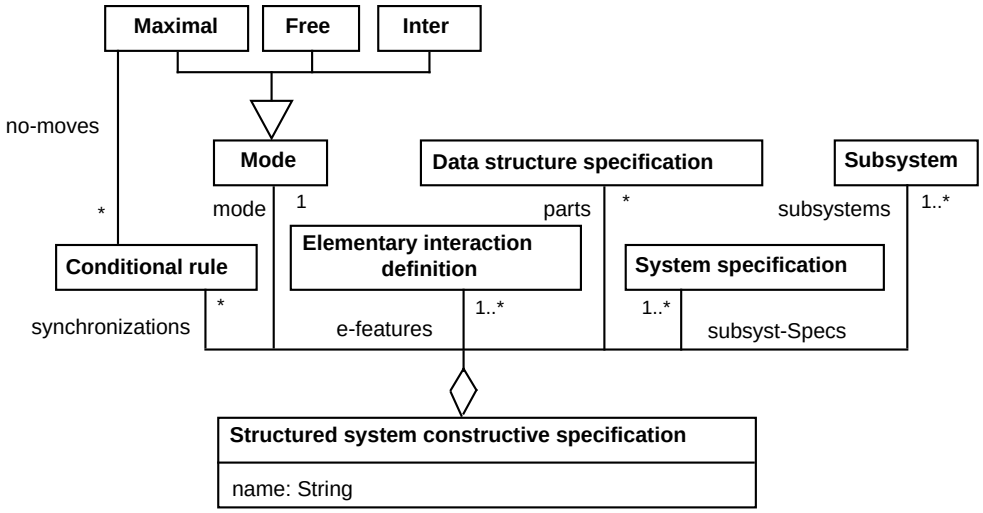


Fig. 23. Structured System Constructive Specification

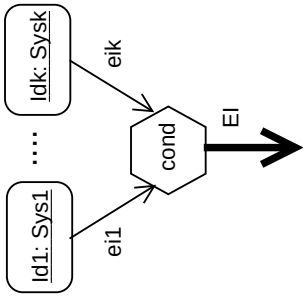


Fig. 24. Visual presentation of a synchronization rule

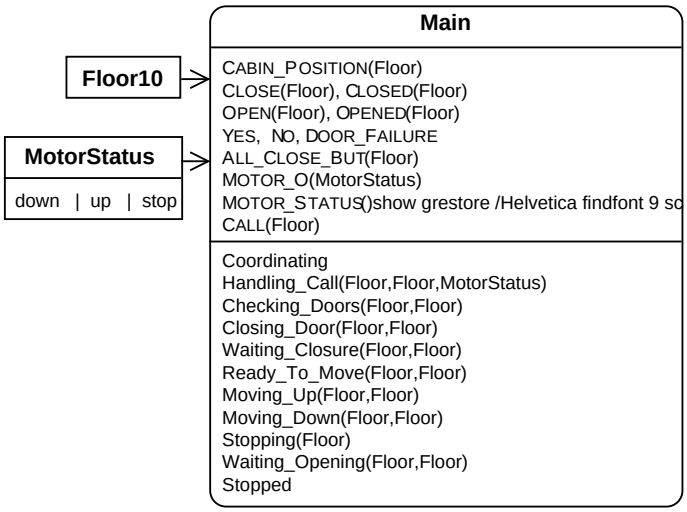
cations, see Fig. 17, but now in the name compartment we put an indication of the mode of the system (inter, max, or free). A rule defining the synchronized sets as in (+) above will be visually represented as in Fig. 24, where Id1: Sys1 .... Idk: Sysk is a fragment of the configuration of the system. The visual presentations of all the synchronization rules may be then put together building an oriented graph by collecting all rounded boxes depicting the same subsystems. The rules defining the *noMove* predicate, if any, are visually depicted as a standard predicate, see Sect. 5.3.

4.3.2 Example: a Constructive Specification of a distributed lift controller

As example we specify the design of another controller of the lift system that differently from that of Sect. 3.3.2 consists of two processes, one taking care of the doors (detecting failures and making sure that each order sent to them is correctly executed) and a main part taking care of interacting with the users, the motor and the cabin.

First we specify the two composing subsystems DoorHandler and Main, respectively in Fig. 26 and Fig. 25, and after the structured system Distr_Control in

Parts and constituent features



Behaviour

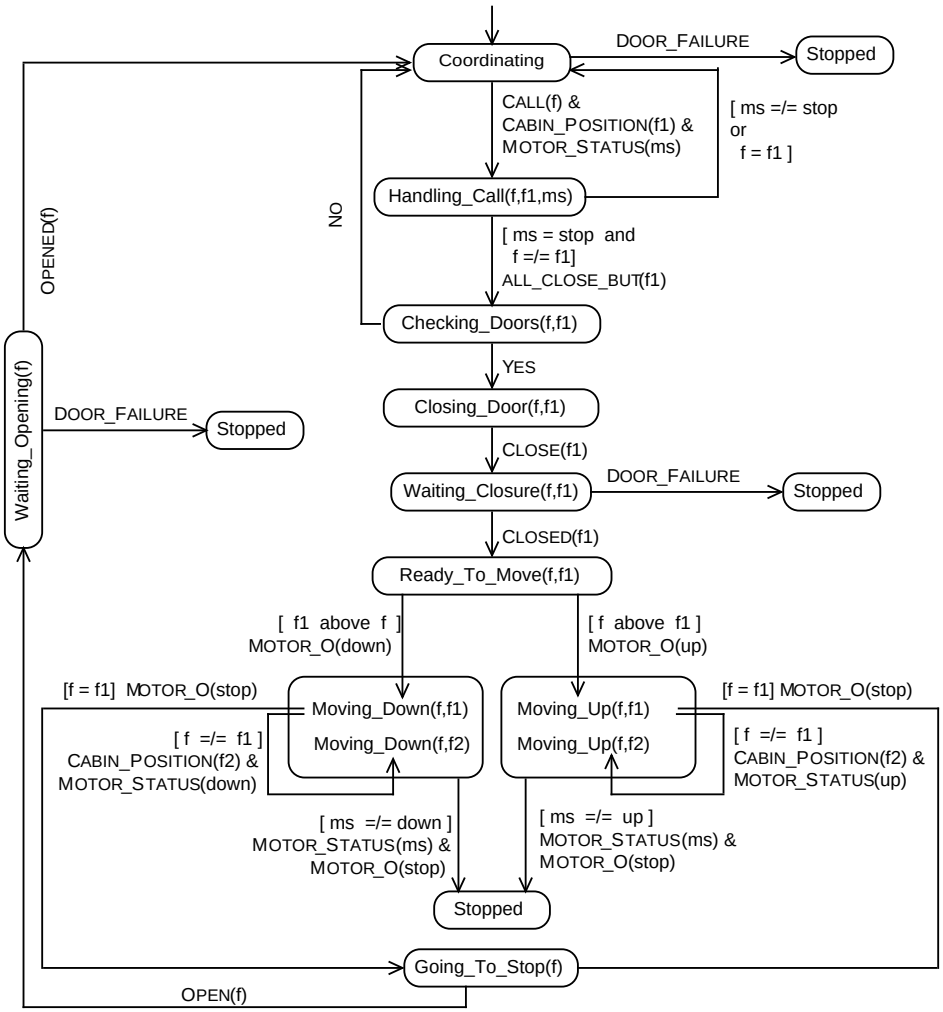
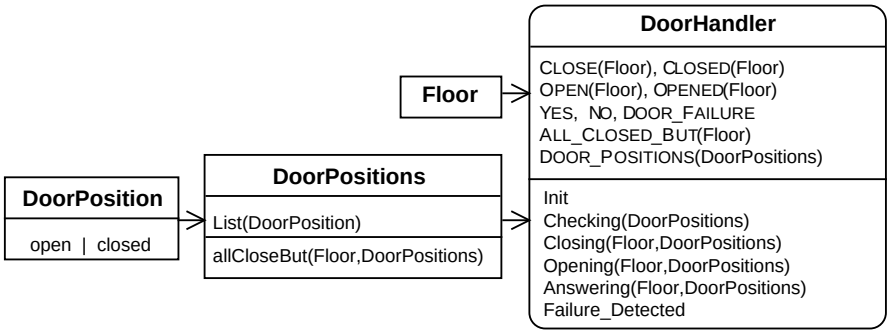


Fig. 25. Main: Specification

Parts and constituent features



Behaviour

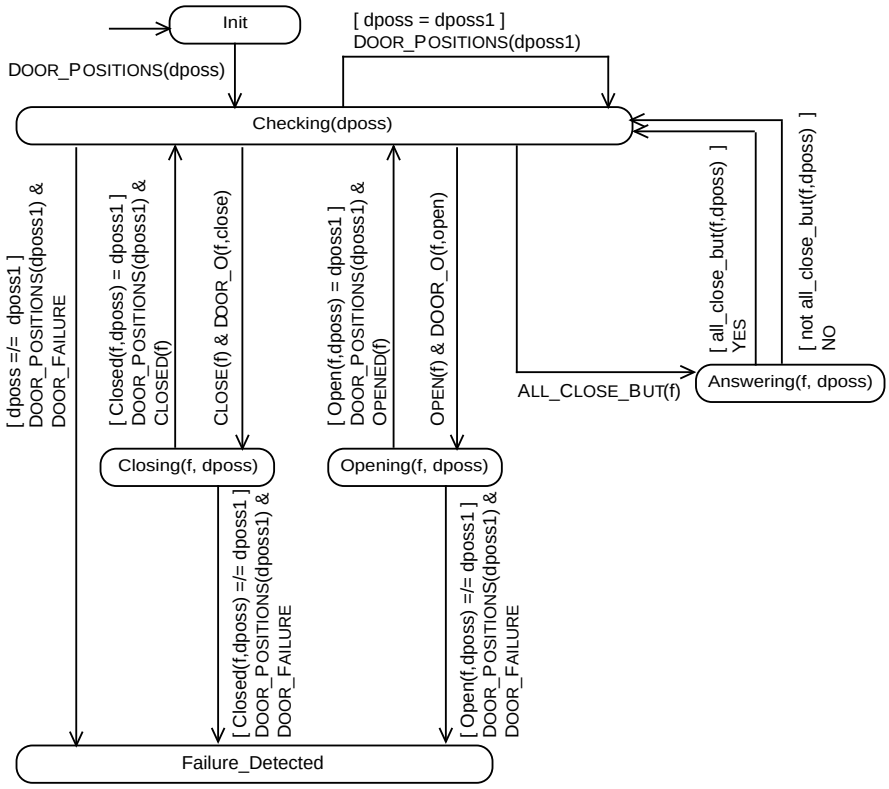
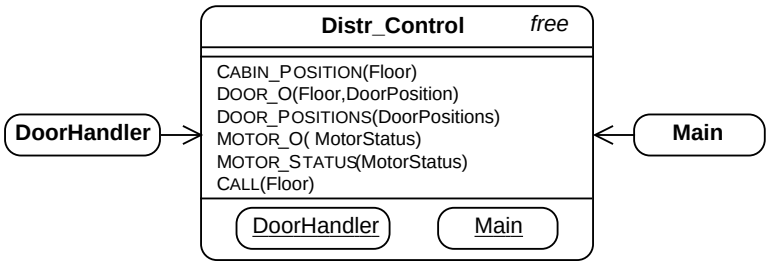


Fig. 26. DoorHandler: Specification

Fig. 27. Since, in Distr_Control only elementary interactions with the same name and the same arguments of different subsystems are synchronized, to present the synchronization rules it is sufficient to decorate any cooperation icon by a list of elementary interaction names.

Parts and constituent features



Synchronization rules

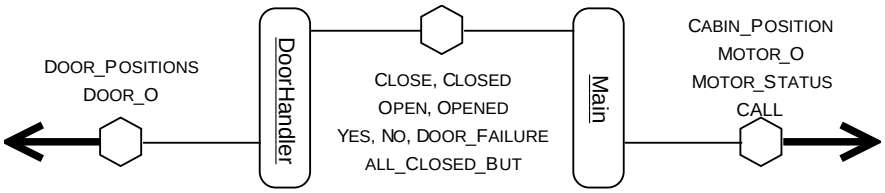


Fig. 27. Distr_Control: Specification

4.3.3 CASL-LTL *View*

Here we present the CASL-LTL [26] corresponding version of our constructive specifications of structured systems introduced before in Sect. 4.3.1.

Let *conSpec* be a constructive specification of structured systems having the form described in Fig. 23, and assume that

- $conSpec.\mathsf{parts} = \{ds_1, \ldots, ds_j\}$ are the parts, and $\mathrm{DS}_1, \ldots, \mathrm{DS}_j$ the corresponding CASL-LTL specifications;
- $conSpec.\mathsf{subsyst\text{-}Specs} = \{ssp_1, \ldots, ssp_k\}$ are the subsystem specifications, and $\mathrm{SSP}_1, \ldots, \mathrm{SSP}_k$ are the corresponding CASL-LTL specifications;
- $conSpec.\mathsf{e\text{-}features} = \{ei_1, \ldots, ei_n\}$ are the elementary interactions;
- $conSpec.\mathsf{s\text{-}features} = \{so_1, \ldots, so_m\}$ are the state observers;
- $conSpec.\mathsf{subsystems} = \{ss_1, \ldots, ss_r\}$ are the subsystems.

Below we give the CASL-LTL specification corresponding to *conSpec*.

ELEMINTER and LOCALINTER have been defined in Sect. 4.2.4.

spec STRUCTSTATE =
  SSP_1 **and** ... **and** SSP_k **then**
free {
  generated type *structState* ::=
    $ss_1.\mathsf{name} : _(ss_1.\mathsf{type}) \mid \ldots \mid ss_r.\mathsf{name} : _(ss_r.\mathsf{type}) \mid$
    $_ \,||\, _ : structState \times structState$
  axioms

$ss_1 \mid\mid ss_2 = ss_2 \mid\mid ss_1$
$ss_1 \mid\mid (ss_2 \mid\mid ss_3) = (ss_1 \mid\mid ss_2) \mid\mid ss_3$
$ss \mid\mid ss = ss'$

} end

spec *conSpec*.name =
FINITESET[ELEMINTER] **and** FINITESET[LOCALINTER] **and**
STRUCTSTATE **and** DS_1 **and** ... **and** DS_j **then**

free {
dsort *structState* **label** *FinSet*[*elemInter*] **info** *FinSet*[*localInter*]
preds *isSynchronizedSet* : *FinSet*[*localInter*] × *FinSet*[*elemInter*]
noMove : *structState*
axioms
formulae corresponding to the synchronization rules, see below
%% a formula of the form below for all n, $1 \leq n \leq r$ and all k, $1 \leq k \leq n$

$$ss_1 \xrightarrow{lab_1} ss'_1 \ \wedge \ \ldots \ \wedge \ ss_n \xrightarrow{lab_n} ss'_n \ \wedge$$
$$\{(ss_1.\mathsf{Id}, ei) \mid ei \in lab_1\} \cup \ldots \cup \{(ss_n.\mathsf{Id}, ei) \mid ei \in lab_n\} =$$
$$linSet_1 \cup \ldots \cup linSet_k \ \wedge$$
$$isSynchronizedSet(linSet_1, EI_1) \ \wedge \ \ldots \ \wedge$$
$$isSynchronizedSet(linSet_k, EI_k) \ \Rightarrow$$
$$ss_1 \mid\mid \ldots \mid\mid ss_n \mid\mid ssSet \xrightarrow{\{EI_1,\ldots,EI_k\}} ss'_1 \mid\mid \ldots \mid\mid ss'_n \mid\mid ssSet$$

%% axioms corresponding to the conditional rules defining *noMove*,
%% if any, following Sect. 5.3.3
.....

} end

A synchronization rule as (+) in Sect. 4.3 corresponds to the following CASL-LTL formula

$$pos\text{-}cond(\{(Id1, ei1), \ldots, (Idk, eik)\}, EI) \ \Rightarrow$$
$$isSynchronizedSet(\{(Id1, ei1), \ldots, (Idk, eik)\}, EI)$$

The above specification correspond to the mode Free. If the mode is Inter, then the rules defining the transition are changed by setting $k = 1$. If it is instead Max you add in the premise the condition $noMove(ssSet)$.

5 Specification of Data Structures

5.1 Data Structure Items

A *data structure* consists of a set of values, some constructors for denoting them, some operations and predicates. The constructors, the operations and the predicates may also have arguments of other types, thus a data structure may have other data structures as subparts. Constructors and operations may be total (always defined), or partial (denoted by a '?' symbol). Constructors and operations may be constants (considered as 0-ary operations), and

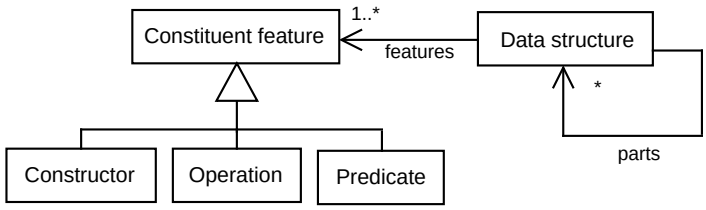


Fig. 28. Data Structure Item

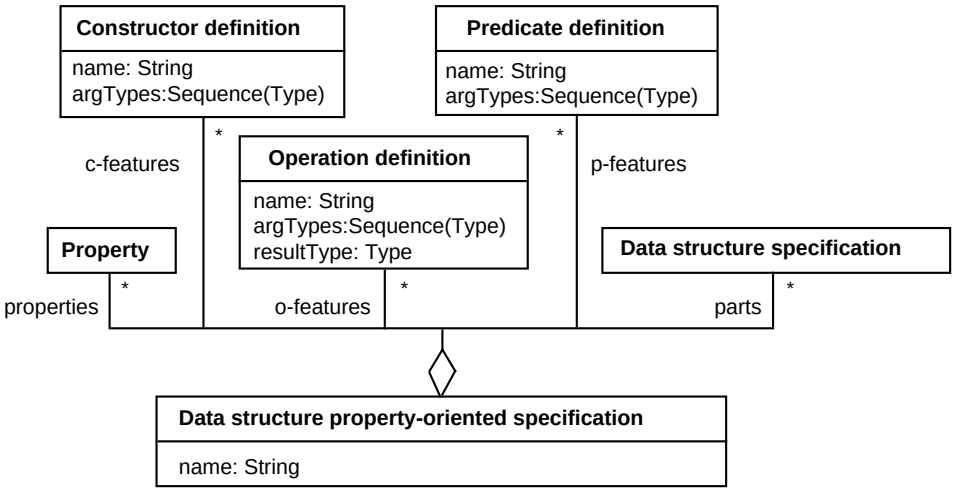


Fig. 29. Data Structure Property-Oriented Specification

constants are always defined (or total).

In our setting the data structures are seen formally as *many sorted algebras*, or *structures*, and the modelling is quite trivial: the carriers model the set of values, and functions (of course of different kinds) model constructors, operations and predicates. Thus, data structures may be characterized by their constructors, operations and predicates, and so they will have three corresponding kinds of constituent features. In Fig. 28 we summarize the constituent features and parts of the data structures. Let us recall that in the property-oriented case, the listed constituent features are necessary (but not restrictive), while in the constructive case they are fully described (and thus restrictive).

5.2 Property-oriented specifications

5.2.1 Specification of parts and constituent Features and cell schemas

The property-oriented specification method for data structures we propose is a specialization of GPSm introduced in Sect. 2.2. After having identified the parts and constituent features (Fig. 29 with the visual presentation in Fig. 30), the properties are expressed using the cell filling approach.

The constituents of data structures are of three kinds, constructors, predicates

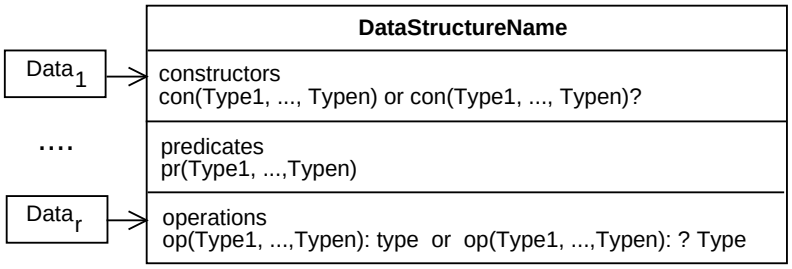


Fig. 30. Visual presentation of a Data Structure: parts and constituent features

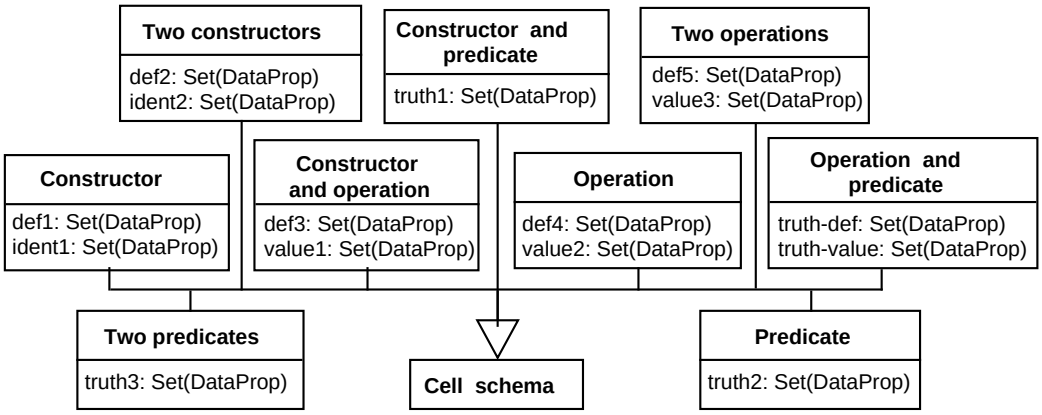


Fig. 31. Data Structure: Cell schemas

---

def2 Conditions on the relationships between the definedness of con_1 with that of con_2 (required only for partial constructors)

cond

where *cond* includes atoms of the form $\mathbf{def}(con_1(arg_1))$ and of the form $\mathbf{def}(con_2(arg_2))$

ident2 The values represented by con_1 are/are not identified with values represented by con_2:

when all defined *cond*

where *cond* includes atoms of the form $con_1(arg_1) = con_2(arg_2)$

Fig. 32. Two constructors (con_1:con_2) cell schema

and operations, and so we have to consider nine kinds of cells; and we present their schemas in Fig. 31, and the details in Fig. 32 and 33, and in Appendix D. Let us note that, as regards constructors and operations, the properties to be described should in particular address both definedness and the values denoted/returned. In CASL, "=" is the *strong equality*, characterized by the fact that $t = t'$ iff either both terms are defined and denote the same value or both are undefined. Thus a property $t = t'$ in the case t is defined implicitly requires also that t' must be defined. In order to avoid the undefined case, the premises of many properties used in the cell schemas require the definedness of all the elements involved in the property, thus their form is

truth-def Conditions on the relationships between the truth of *pr* and the definedness of *op* (required only for partial operations)

when all defined *cond*

where *cond* includes atoms of the form $pr(arg_1)$ and of the form $\mathbf{def}(op(arg_2))$

truth-value Conditions on the relationships between the truth of *pr* and the values returned by *op*:

when all defined *cond*

where *cond* includes atoms of the form $pr(arg_1)$ and of the form $op(arg_2)$

Fig. 33. Operation and predicate (*op*:*pr*) cell schema

if (**and** t is a term appearing in $_{cond}$ $\mathbf{def}(t)$) **then** *cond*.

Because properties having the above form may be quite long, they are usually written in a more compact way as:

when all defined *cond*

5.2.2 Example: a Property-Oriented Specification of Floor

We specify the Floor data structure used in the lift related examples.

Floor
ground, top
_ above _(Floor,Floor)
next(Floor): ? Floor previous(Floor): ? Floor

shows that the constructors are *ground* and *top*, the predicate is *above*, and the (partial) operations are *next* and *previous*. Moreover, Floor does not use any other data structure. The properties given below were worked out using our cell filling approach, then redundant properties were removed and the result was reorganized.

- There exists a ground and a top floor, and they are different.
  $ground \neq top$
- *above* is total order over the floors with *top* as maximum and *ground* as minimum.
  if $f \neq ground$ **then** f *above ground*
  if $f \neq top$ **then** *top above* f
  $f_1 = f_2$ **or** f_1 *above* f_2 **or** f_2 *above* f_1
  not f *above* f
  if f_1 *above* f_2 **then not** f_2 *above* f_1
  if f_1 *above* f_2 **and** f_2 *above* f_3 **then** f_1 *above* f_3

– *next* returns the floor immediately above a given one, if it exists, i.e., there is no floor between f and $next(f)$.[13]
  def($next(ground)$) **and not def**($next(top)$)
  def($next(f)$) **iff** top *above* f
  when all defined $next(f)$ *above* f **and**
  not exists $f_1 \bullet (next(f)$ *above* f_1 **and** f_1 *above* $f)$
  when all defined $next(previous(f)) = previous(next(f)) = f$
– Properties on *previous* are similar to those of *next*, and are given in Appendix E.

5.2.3 CASL *View*

Here we present the CASL[14] corresponding version of our property-oriented specification of data structures introduced in Sect. 5.2.

Let *poSpec* be a property-oriented specifications of data structures having the form described in Fig. 29, and assume that

- $poSpec$.parts $= \{ds_1, \ldots, ds_j\}$ are the parts, and $\mathrm{DS}_1, \ldots, \mathrm{DS}_j$ the corresponding CASL specifications;
- $poSpec$.c-features $= \{con_1, \ldots, con_n\}$ are the constructors;
- $poSpec$.o-features $= \{op_1, \ldots, op_m\}$ are the operations;
- $poSpec$.p-features $= \{pr_1, \ldots, pr_p\}$ are the predicates.

Below we give the CASL specification corresponding to *poSpec* (some constructors and operations may be partial, which is denoted by '?', cf. Sect. 1.2).

spec $poSpec$.name =
  DS_1 **and** ... **and** DS_j **then**
  type $poSpec$.name ::= con_1.name(con_1.argTypes) | ... | con_n.name(con_n.argTypes)
  ops op_1.name : op_1.argTypes → op_1.resType
    ...
    op_m.name : op_m.argTypes → op_m.resType
  preds pr_1.name : pr_1.argTypes
    ...
    pr_p.name : pr_p.argTypes
  axioms
    formulae corresponding to the cell fillings

The CASL formulae corresponding to the cell fillings for data structures are quite obvious, since their abstract structure is the same, the only difference is in the concrete syntax.

[13] The first two axioms are redundant with the third, we kept them just to show the processing with the method.
[14] Here we do not need to use the CASL-LTL extension.

5.3 Constructive specifications

5.3.1 The specifications characteristics

The constructive specification method for data structure is similar in many respects to the property-oriented one introduced in Sect. 5.2. First, we determine the used data structures (the parts), the constructors, the predicates and the operations (the constituent features). Then, we state when the constructors and operations are defined, which constructors represent the same values, which are the values returned by the operations and when the predicates hold. That is done by means of groups of conditional rules defined in the following.

Recall (cf. Sect. 1.2, the spirit of the CASL free construct) that our constructive specifications by conditional rules follow the basic principle that "something is true in the specified item if and only if it can be deduced by the rules". Thus a partial constructor/operation is undefined except if there is a rule explicitly stating that it is defined. In the same way, a predicate does not hold except if there is a rule explicitly stating that it holds.[15] Let us also remind that constructors, operations and predicates are strict.

con-def For each constructor *con*, a set of conditional rules expressing when *con* is defined:

if *pos-cond*(*pats*) (**and** $_{t \text{ is a term appearing in } pats}$ **def**(t)) **then def**(*con*(*pats*))

where *pos-cond* is a conjunction of positive atoms in which the operations of the data structure do not appear[16], and *pats* (for patterns) are expresssions built only by constructors and variables

The above restrictions on the form of the rules should help avoid to implicitly introduce the definedness of other combinations of constructors and should help the specifiers have a clear idea of when the constructor is defined.

con-ident For each constructor *con*, a set of conditional rules expressing in which cases it represents values that may be represented also by using other constructors:

when all defined if *pos-cond*($pats_1$,$pats_2$) **then** *con*($pats_1$) = $pats_2$

where *pos-cond* is a conjunction of positive atoms where the operations of the data structure do not appear[17], and $pats_1$, $pats_2$ are expresssions built only by constructors and variables.

Note that all constructors represent different values except if there is a rule explicitly stating that they are the same. If this part is empty all

[15] In a 2-valued logics, we do not address the issue of undefinedness of a predicate since it means it does not hold.

[16] To our knowledge, this "constructors only" constraint needs to be relaxed in some exceptional cases, as our example in Sect. 5.3.2.

[17] Ibid.

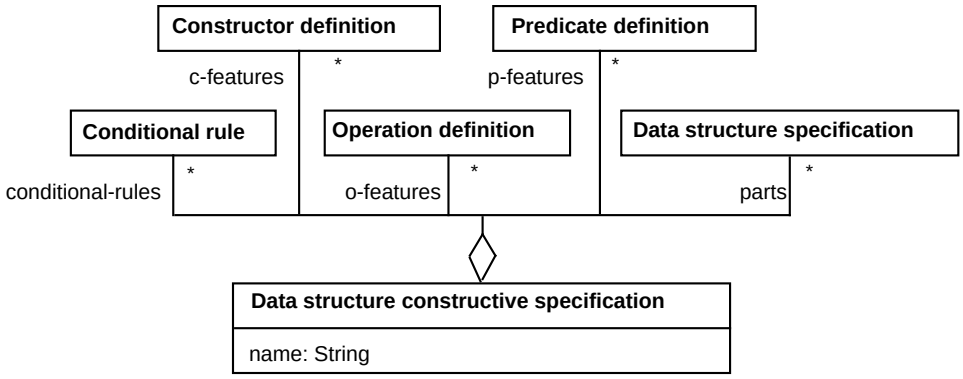


Fig. 34. Data Structure Constructive Specification

constructors denote different values.

op-def For each operation *op*, a set of conditional rules expressing when *op* is defined:

if *pos-cond*(*pats*) (**and** $_{t \text{ is a term appearing in} pats}$ **def**(t)) **then def**(*op*(*pats*))

where *pos-cond* is a conjunction of positive atoms, and *pats* are expresssions built only by constructors and variables.

op-val For each operation *op*, conditional rules stating which are the values returned by *op*:

when all defined if *pos-cond*(*pats*,*expr*) **then** *op*(*pats*) = *expr*

where *pos-cond* is a conjunction of positive atoms, and *pats* are expresssions built only by constructors and variables.

pr-truth For each predicate *pr*, a set of conditional rules stating when *pr* holds:

when all defined if *pos-cond*(*pats*) **then** *pr*(*pats*)

where *pos-cond* is a conjunction of positive atoms, and *pats* are expresssions built only by constructors and variables.

The form of the constructive specifications of data structure is summarized in Fig. 34 (details of the constructor, predicate and operation definitions are as in Fig. 29).

The visual presentation of the parts and the constituent features of a data structure constructive specification is the same as for the property-oriented ones, see Fig. 30. The conditional rules belonging to a ***con-def*** slot are visually presented as follows. First we group together all rules whose consequences have the same form; then each group, say, e.g., **if** $cond_1$ **then def**(*con*(*pats*)), ..., **if** $cond_K$ **then def**(*con*(*pats*)), will be visually presented by **def**(*con(pat)*) **if** [*cond*1 / ····· / *cond*K] .

Similarly, we represent the rules belonging to a slot ***op-def***; whereas each group of rules belonging to a slot ***pr-truth*** having the same consequence will

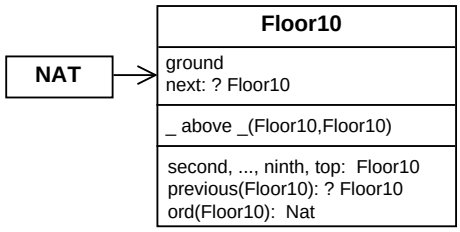
be presented by *pr(pat)* **holds if** $\boxed{\begin{array}{l} cond1 \\ \cdots\cdots \\ condK \end{array}}$.

For what concerns the rules belonging to a ***op-val*** slot, we first group together all rules whose consequences (they are equations) have the same left side; then each group, say, e.g.,
if $cond_1$ **then** $op(pats) = expr_1$, ..., **if** $cond_K$ **then** $op(pats) = expr_K$,
will be then visually presented by *op(pat)* = $\boxed{\begin{array}{l} exp1 \ \textbf{if} \ cond1 \\ \cdots\cdots \\ expK \ \textbf{if} \ condK \end{array}}$.
Similarly, we represent the conditional rules in a ***con-ident*** slot.

The visual ordering of the rules should help detect lacking or overlapping cases, which may lead, e.g., to define two different values of an operation for the same argument. As usual, we then drop repeated formulae, after having checked the absence of contradictions, and slightly rearrange the others to improve readability.

5.3.2 Example: a Constructive Specification of Floor10

Here we consider the floor data structure with a maximum of ten floors (used in Sect. 3.3.2 and Sect. 4.3.2).



shows the constructors, *ground* and *next*, the predicate *above*, and the operations *second*, ..., *ninth*, *top*, *previous* and *ord*. The conditional rules defining the various constituents of Floor10 are given below, since there are quite simple, we do not give a visual presentation.

– Definedness of constructors (only *next* is partial)
  def$(next(f))$ **if** $ord(f) < 10$ [18]
– Operations *second*, ..., *ninth* are just shortcuts.
  $second = next(ground)$
  ...
  $top = next(ninth)$

[18] Here, the "constructors only" constraint (cf. footnote 16) is relaxed for legibility sake, and we allow the use of *ord*.

– Definition of the partial operation *previous*

$\mathbf{def}(previous(f))$ **if** $ord(f) > 1$

$previous(next(f)) \ = f$ **if** $\mathbf{def}(next(f))$

– Definition of the total operation *ord*

$\mathbf{def}(ord(f))$

$ord(ground) \ = 1$

$ord(next(f)) \ = ord(f) + 1$ **if** $\mathbf{def}(next(f))$

– Definition of the predicate *above*

$next(f)$ *above* f

if f_1 *above* f_2 **and** f_2 *above* f_3 **then** f_1 *above* f_3

It is interesting to compare this with the Floor example given in Sect. 5.2.2. Note that the constructors are not the same to start with, and that we do not need to express the same properties.

5.3.3 CASL *View*

The CASL corresponding version of our constructive specifications of data structure is quite similar to that for the property-oriented case; the only difference is that in this case the resulting algebraic specification has an initial semantics (this results from using the **free** construct) instead of a loose one.

spec *conSpec*.name =
  DS_1 **and** ... **and** DS_j **then**
free {
  type *conSpec*.name ::= con_1.name(con_1.argTypes)? | ... | con_n.name(con_n.argTypes)
  ops op_1.name : op_1.argTypes →? op_1.resType
    ...
    op_m.name : op_m.argTypes → op_m.resType
  preds pr_1.name : pr_1.argTypes
    ...
      pr_p.name : pr_p.argTypes
  axioms
    formulae corresponding to the conditional rules
} end

6 Applying our Formally Grounded Specification Methods to Classes of Systems ("Problem Frames")

In Fig. 35 we show by means of a simple UML class diagram how the basic formally grounded specification methods introduced before can be used to support the specification of the most relevant problem frames of M. Jackson (see [19, 20]).

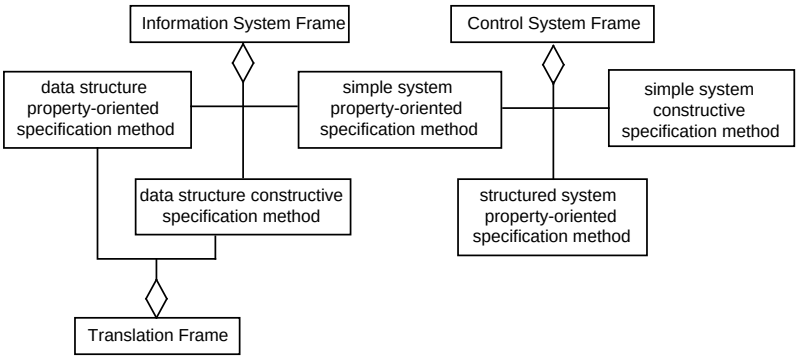
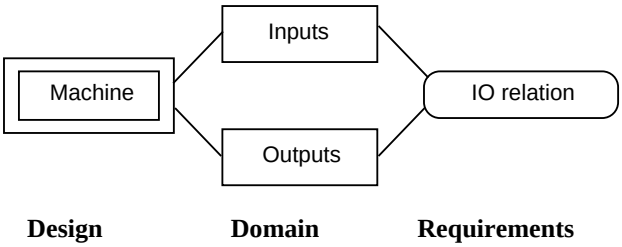


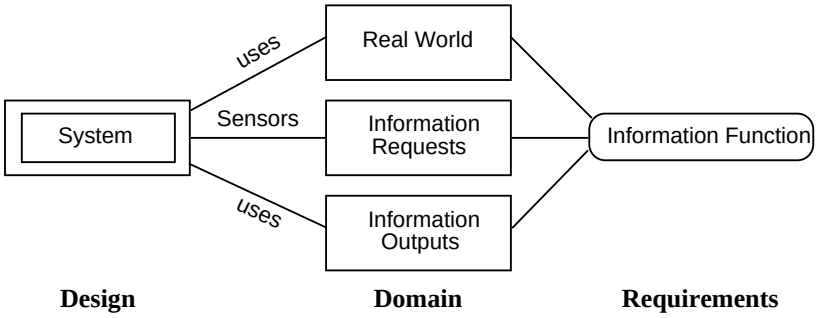
Fig. 35. How our specification methods are used for problem frames

6.1 Translation Frame



The translation frame domain is given by the Inputs and the Outputs, the requirements are described by the input/output relationship, IO Relation, and the design is the Machine. An example of a translation frame problem is a compiler, where the Inputs are the source programs, the Outputs are the executable programs, the IO Relation is given by the language and computer semantics, and the Machine is the compiler.

To develop a software system matching the frame "Translation" using our method means to specify the various components of the frame as presented above. Technically, the domain is a pair of data structures, Inputs and Outputs, which should be specified by constructive specifications following Sect. 5.3; the IO Relation may be seen as a data structure having Inputs and Outputs as parts and a predicate representing IO Relation, and can be specified by a property-oriented specification following Sect. 5.2. Finally the design is seen as a partial function (or a sequential program or an algorithm) *Tran* that associates an element of Outputs with an element of Inputs, and so it is again a data structure having Inputs and Outputs as subparts and an operation *Tran*, that will be specified by a constructive specification following Sect. 5.3.



To quote [19], "In its simplest form, an information system provides information, in response to requests, about some relevant real-world domain of interest." The information system frame domain is given by the RealWorld, the InformationRequests and the InformationOutputs, the requirements are described by the InformationFunction, and the design is the System. The RealWorld may be a *static* domain (e.g., if the system provides information on Shakespeare's plays), or a *dynamic* domain (e.g., "the activities of a currently operating business" [19]). Here we consider information system frames with a dynamic domain, so "The RealWorld is *dynamic* and also *active*." [19].

To develop a software system matching the frame "Information System" using our method means to specify the various components of the frame as presented above.

The RealWorld is a dynamic system, thus it is specified following Sect. 3.2 but with some peculiarity corresponding to its particular nature. All its elementary interactions correspond to signal, throughout some sensors, something happening inside it that is relevant for the information system. The InformationRequests and the InformationOutputs are two data structures that are specified by simply giving their constructive specifications, following Sect. 5.3.

Clearly, InformationFunction to produce the correct information output, given an information request, should take into account the real world, more precisely its current state and also its past history as known by the values communicated by the sensors. Technically, these information may be abstractly represented by a sequence of sets of elementary interactions (recall that each elementary interaction corresponds to some value communicated by a sensor). So we can define it by a standard data structure, HISTORY, whose definition is given once. Thus to specify InformationFunction means to give a constructive specification of a particular data structure following Sect. 5.3; such data structure must have as subparts InformationRequests, InformationOutputs and HISTORY, and an operation
InformationFunction : $History \times InformationRequets \rightarrow InformationOutputs$.

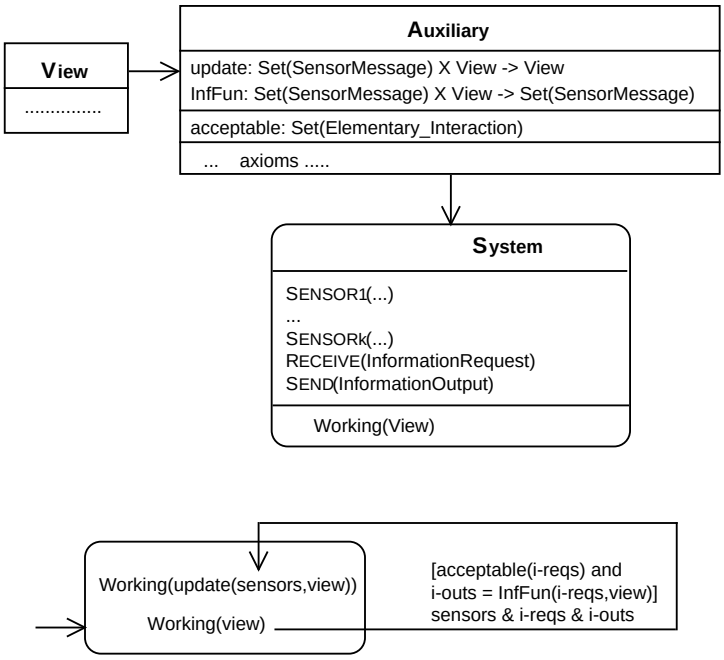


Fig. 36. System Specification: elementary constituents, parts and behaviour

To design an "Information System" means to design the System, a dynamic system interacting with the RealWorld (by receiving the values sensed by the sensors), and with the users (by receiving the information requests and sending back the information outputs). We assume that the System:

- keeps a view of the actual situation and of the past history of the RealWorld,
- updates it depending on the info received by the sensors,
- decides which information requests from the users to accept in each instant,
- answers to such requests with the appropriate information outputs using its view of RealWorld,
- immediately receives in a correct way any message sent by the sensors of the RealWorld,
- immediately handles the received informationrequests.

The design of the System will be specified by a constructive specification of a simple system following Sect. 3.3. The elementary interactions are those corresponding to receive some info on some sensors, to receive information requests and the send out information outputs. The unique state constructor is *Working* parameterized by a real world view. This specification is visually reported in Fig. 36, where VIEW is a data structure describing in an appropriate way (i.e., apt to permit to answer to all information requests) the System's views of the possible situations of the RealWorld. Thus, to specify the System it is sufficient to give:

- the specification VIEW;
- the axioms defining the operation *update* describing how the System updates

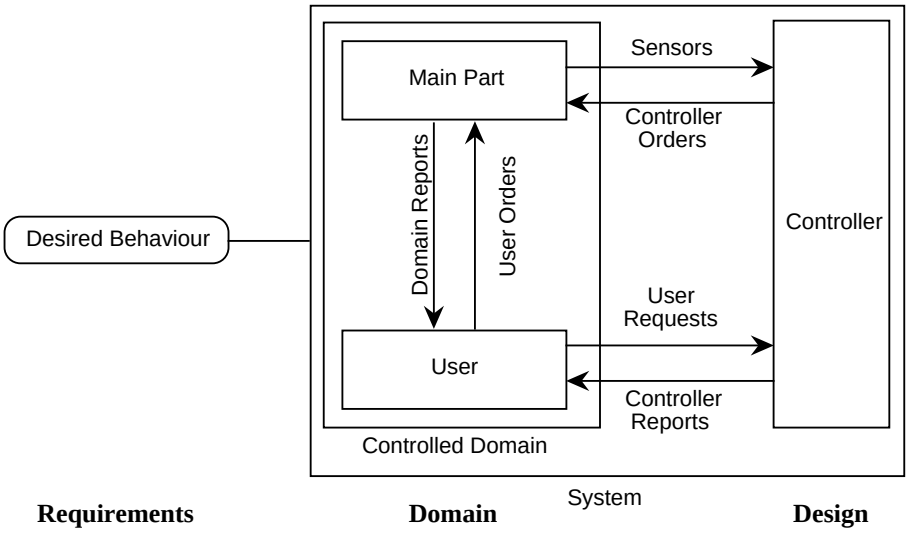


Fig. 37. Control System Frame Schema

its view of the RealWorld when it detects some events;

- the axioms defining the predicate *acceptable* describing which sets of requests may be accepted simultaneously by the System;
- the axioms defining the operation *Inf_Fun* describing what is the result of each information request depending on the System's view of the the RealWorld situation.

That means to give a constructive specification of a data structure, AUXILIARY in Fig. 36, having as parts InformationOutputs, InformationRequests, VIEW and the predicate *acceptable* and the operations *update* and *Inf_Fun*.

6.3 Control System Frame

We report the general schema of the control system frame following Jackson's book [19] in Fig. 37. The controlled domain may include the users of the thing controlled by the software that we are going to develop, thus we call the "controlled thing" the *main part* (shortly indicated as MainPart in the following). Thus the first step is to see precisely how the considered problem matches the "control system frame".

To use our specification methods to support the whole development of a software system matching the frame "Control System with User" means to specify System and Desired Behaviour in Fig. 37; clearly some parts of this specification correspond to the requirements, some other to the domain, and the remaining to the design.

Technically, System is a structured system and Desired Behaviour is a set of additional properties over it. We specify System following Sect. 4.2, clearly

taking into account its peculiarity, and splitting its properties in those desired (Desired Behaviour) and in those corresponding to its intrinsic nature (the others). Now, we list the peculiar features of System.

- System has three subsystems, whose types are respectively User, MainPart and Controller.
- System is closed (i.e., no interactions with the external world, and thus the label of its transitions will be always the empty set of elementary interactions), for this reason we drop the elementary interaction part in its specification.
- The only state observers ofSystem are the selectors of the states of the MainPart and of the User. We do not consider the observer corresponding to the state of Controller, because we will never express properties about it, but we will just fully specify when specifying the Controller.

The elementary interactions of the three subsystems are classified into six categories listed below, and the interactions of any particular category belong to the two subsystems to whom they are connected in Fig. 37; e.g., Sensors are interactions of both the MainPart and of the Controller.

Sensors or better the elementary interactions corresponding to sending/receiving the data collected by the sensors present on the MainPart (precisely MainPart sends and Controller receives).

Controller Orders or better the elementary interactions corresponding to sending/receiving orders to modify MainPart (precisely Controller sends and MainPart receives).

User Requests or better the elementary interactions corresponding to sending/receiving the requests of the User to for Controller about the wanted behaviour of the MainPart (precisely User sends and Controller receives).

Controller Reports or better the elementary interactions corresponding to sending/receiving the reports on what is going on in the MainPart sent (precisely Controller sends and User receives).

User Orders or better the elementary interactions corresponding to sending/receiving orders from the User to modify MainPart (precisely User sends and MainPart receives).

Domain Reports or better the elementary interactions corresponding to sending/receiving the reports on what is going on in the MainPart (precisely User sends and MainPart receives).

The three subsystems behave in a truly parallel way and cooperate only by performing simultaneously the shared interactions of the above six categories. Thus the ***synchr1*** and the ***loc-glob1*** properties of System are standard and do not depend on the particular case.

The used data structures, the elementary interactions of the subsystems and

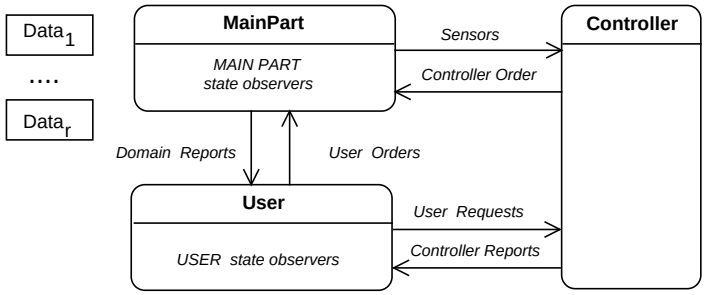


Fig. 38. Visual presentation of the structure of a control frame

the architecture diagram of System are collected in a unique visual presentation, sketched in Fig. 38, where D1, ..., Dr are the used data structures.

The specification of the MainPart is obtained by specializing the method for property-oriented [19] specifications of simple systems of Sect. 3.2. Some parts of the specification of MainPart have been already determined (e.g., the elementary interactions, already determined together those of the other subsystems), many are standards (e.g., the incompatibility between elementary interactions whose kind is different, as a user order and a controller order), and other have a particular form (e.g., the properties about a Controller order, where only the ***post-cond1*** slot is not empty).

Similarly, also the specification of the User is obtained by specializing the method for simple system of Sect. 3. Let us note that, while concentrating on properties that are relevant to the system, often this specification will be very short (especially in the case of a human user). However, it may reflect some rules of the directions for use. Indeed, the system to be developed may be guaranteed under the condition that the directions for use are followed by the user.

The Desired Behaviour, that is the final aim of the system that we have to develop, i.e., the system requirements, consists technically of a set of particular properties on System of Fig. 37.

- ***post-cond1*** properties for all local moves User: *UR* with *UR* user request
- ***pre-cond1*** and ***vital1*** properties for all local moves User: *CR* with *CR* controller report
- properties on the state observers corresponding to the states of the MainPart and of User
- properties on the relationships between the state observer corresponding to the states of the MainPart and the one to the states of User

The Controller (i.e., the design part of the frame) should be specified by a

[19] In the case that we fully know how MainPart, for example, when it is a mechanical/electromechanical appliance, we may instead give a constructive specification.

constructive specification following the method proposed in Sect. 3.3 if it is a simple system or the one proposed in Sect. 4.3 otherwise; but with the particularity that the elementary interactions have been already determined.

7 Requirement Specification of an Internet Based Lottery Application

7.1 The problem

We have to develop an application ALL (ALgebraic Lottery) to handle algebraic lotteries. The lotteries are said "algebraic" because the tickets are numbered by integer numbers, the winners are determined by means of an *order* over such numbers, and a client buys a ticket by selecting its number. Whenever a client buys a ticket, he gets the right to another free ticket, which will be given at some future time, fully depending on the lottery manager decision. The number of a free ticket is generated by the set of the numbers of the already assigned tickets following some *law*. Thus a lottery is characterized by an *order* over the integers determining the winners and a *law* for generating the numbers of the free tickets. To guarantee the clients of the fairness of the lottery, the order and the law, expressed rigorously with algebraic techniques, are registered by a lawyer before the start of any lottery.

The application will be Internet based, thus the tickets will be bought and paid on-line using credit cards with the help of an external service handling them. Possible clients must register with the lottery system to play; and clients access the system in a session-like way. An external service takes care of the authentication of the clients. The winners are informed by email messages, and email is used also to inform the registered clients of the start and of the end of the various lotteries.

Requirement Specification: The technique

We use our method for property oriented specifications of structured systems (see Sect. 4.2) to specify the requirements for ALL. Indeed, ALL together with the external entities interacting with it, named in the following *context entities* (e.g., the manager and the email system) is a structured system, which we name SYSTEM.

ALL and all the context entities will be modelled by simple systems, because there is no need to investigate the internal structure of the context entities and of ALL. Indeed, for the former, only how they interact with ALL is relevant,

and for what concerns ALL, to give it a structure in terms of cooperating subsystems means to fix already in the requirement phase an architecture for it, mixing the early design phases with the requirement one.

SYSTEM is a closed system, i.e., it cannot interact with its external world, and thus it has no elementary interactions. Moreover, all possible cooperations among its subsystems are binary ones between ALL and one context entity, and do not result in an elementary interaction of SYSTEM.

ALL is the most relevant of the subsystems of SYSTEM, and its specification is more complex of those of the other ones. Its properties are exactly the requirements for the application that we have to develop. Notice that using our specification method we express all the requirements for the application to be developed (ALL), but also what we either assume or know about the context entities, thus making clear which is the context of the application.

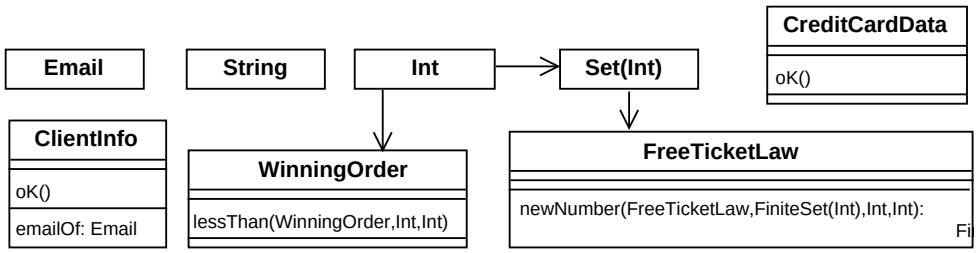
Because the specification of SYSTEM is quite complex, to make it more readable we decided:

- to collect all the specifications of data structures appearing in the specification of SYSTEM (parts of it and of its subsystems) together in a unique diagram Data View, and assume that they are implicitly added as parts whenever needed;
- to collect together in a Context View the diagram showing the parts and constituents features of SYSTEM and the one showing the cooperations among its subsystems; indeed such diagrams show the entities appearing in the context of the application and how it interacts with them. The specifications of the context entities are given separately.
- to allow to define auxiliary/additional state observers;
- to use in properties a derived if-then-else logical combinator:
  if *cond* **then** $cond_1$ **else** $cond_2$ stands for
  (**if** *cond* **then** $cond_1$) **and** (**if not** *cond* **then** $cond_2$);
- to use in properties a derived " **is impossible**" combinator:
  cond **is impossible** stands for
  if *cond* **then** *False*;
- to simply write "*all incompatible*" in the elementary interaction compartment, whenever all the elementary interactions of a system are mutually pairwise incompatible.
- to synchronize only elementary interactions with the same name and the same arguments; and thus it is sufficient to decorate any cooperation icon by a list of elementary interaction names. To further improve the readability, an elementary interaction XX owned by both two subsystems, say S1 and S2, which will be synchronized will be named either S1_XX or S2_XX depending on which of the two subsystems is the responsible of the resulting cooperation.

Requirement Specification: The Artifact

Here we report only the Data View, the Context View, the specification of one of the context entities (the authorization service) and the group of requirements about the registration of a client, the remaining parts of the requirement specification are in the Appendix F.

Data View



For each winning order *wo*, $lessThan(wo,_,_)$ is a total order over the integer.

$lessThan(wo,i,i)$

if $lessThan(wo,n_1,n_2)$ **and** $n_1 \neq n_2$ **then not** $lessThan(wo,n_2,n_1)$

if $lessThan(wo,n_1,n_2)$ **and** $lessThan(wo,n_2,n_3)$ **then** $lessThan(wo,n_1,n_3)$

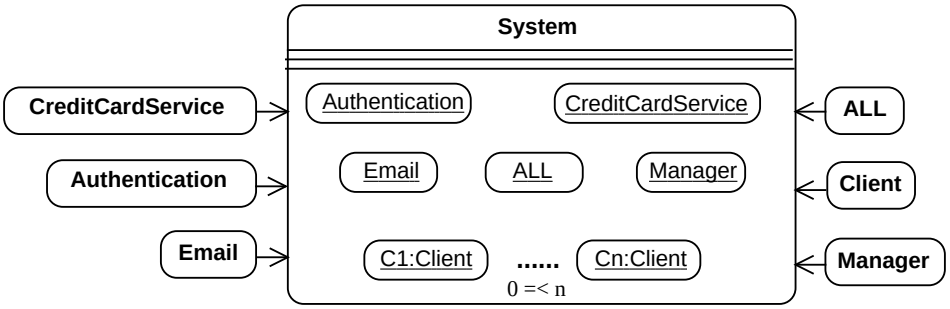
For each free ticket law *ftl*, $newNumber(ftl,ns,d,m)$ returns a set containing m integer numbers, between $-d$ and d, and not belonging to ns.

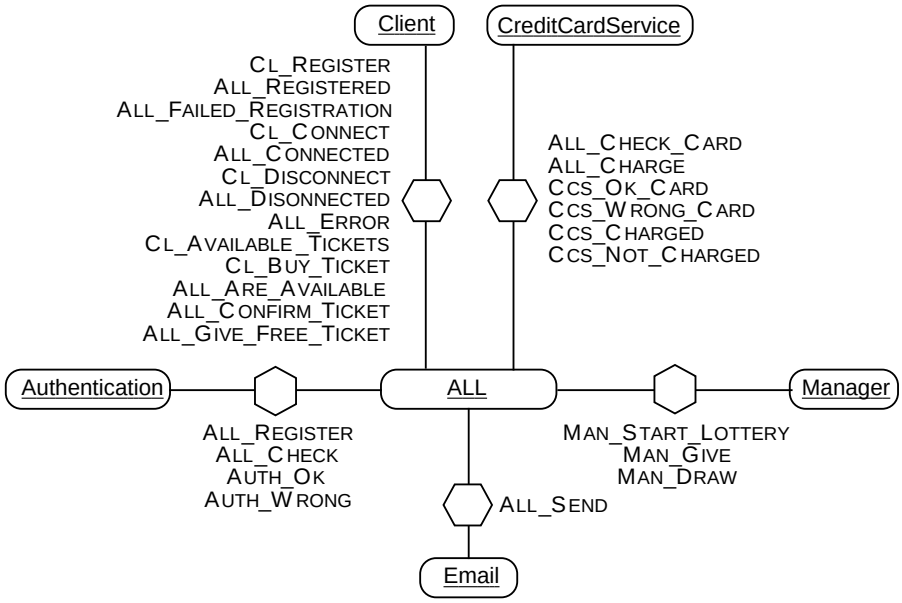
if $newNumber(ftl,ns,d,m) = ns'$ **then**

$size(ns) = m$ **and** $ns \cap ns = \{\}$ **and**

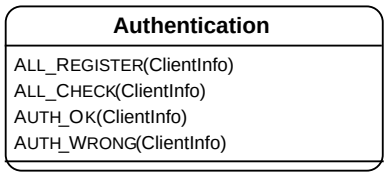
for all x • **if** $x \in ns$ **then** $x \leq d$ **and** $-d \leq x$

Context View





Authentication Service Specification



The authentication service is always ready to accept a request to register a client.
in one case next ALL_REGISTER(ci) **happen**

The authentication service never confirms a registration of a client. This comments is motivated by the fact that during the cell filling activity, we found that a slot of a cell (precisely the postconditon of the elementary interaction ALL_REGISTER) was empty.

The authentication service cannot send out simultaneously a positive and a negative answer to a request to check a client.
AUTH_OK(ci) **incompatible with** AUTH_WRONG(ci)

The authentication service is always ready to accept a request to check a client.
in one case next ALL_CHECK(ci) **happen**

The authentication service after receiving a request to check a client will inform that either is ok or not.
if ALL_CHECK(ci) **happen then in any case eventually**
AUTH_OK(ci) **happen or** AUTH_WRONG(ci) **happen**

The Requirements for the Application **ALL**

ALL

CL_REGISTER(ClientInfo,CreditCardData)	ALL_REGISTER(ClientInfo)
ALL_REGISTERED(ClientInfo,CreditCardData)	ALL_CHECK(ClientInfo)
ALL_FAILED_REGISTRATION(ClientInfo,CreditCardData)	AUTH_OK(ClientInfo)
CL_CONNECT(ClientInfo)	AUTH_WRONG(ClientInfo)
ALL_CONNECTED(ClientInfo)	
CL_DISCONNECT(ClientInfo)	
ALL_DISONNECTED(ClientInfo)	
ALL_ERROR(ClientInfo)	
CL_AVAILABLE_TICKETS(ClientInfo)	ALL_SEND(Email,String)
ALL_ARE_AVAILABLE(ClientInfo,FiniteSet(Int))	
CL_BUY_TICKET(ClientInfo,Int)	
ALL_CONFIRM_TICKET(ClientInfo,Int)	
ALL_GIVE_FREE_TICKET(ClientInfo)	
ALL_CHECK_CARD(CreditCardData)	MAN_START_LOTTERY(WinningOrder,FreeTicketLaw,Int)
ALL_CHARGE(CreditCardData,Int)	MAN_GIVE(Int)
CCS_OK_CARD(CreditCardData)	MAN_DRAW
CCS_WRONG_CARD(CreditCardData)	
CCS_HARGED(CreditCardData,Int)	
CCS_NOT_CHARGED(CreditCardData,Int)	

lotteryRunning	registered(ClientInfo)
dimension: Int	connected(ClientInfo)
winningOrder: WinningOrder	creditCard(ClientInfo): ?CreditCardData
freeTicketLaw: FreeTicketlaw	freeTickets(ClientInfo): ?Int
owner(Int): ? ClientInfo	

Auxiliary/derived state observers

assignedTickets: FINITESET(INT)

returns the set of the numbers of the tickets already assigned to some client (i.e., bought or given away by the manager).

$i \in$ *assignedTickets* **iff def**(*owner*(i))

availableTickets: FINITESET(INT)

returns the set of the numbers of the still available tickets.

$i \in$ *availableTickets* **iff**

$i \leq$ *dimension* **and** $i \geq$ -*dimension* **and** $i \notin$ *assignedTickets*

winners: FINITESET(*Int*)

returns the set of the numbers of the winning tickets, which are the first K numbers w.r.t. the current winning order, where K is the dimension of the lottery module 5000.

size(*winners*) = *dimension mod* 5000 **and**

for all n_1, n_2 •

if $n_1 \in$ *winners* **and** *lessThan*(*winningOrder*,n_1,n_2) **then** $n_2 \in$ *winners*

A client registers with **ALL**

ALL cannot handle two different registration requests simultaneously.

CL_REGISTER(*ci*,*ccd*) **incompatible with** CL_REGISTER(*ci'*,*ccd'*)

If ALL receives a registration request from a client, then
    if the presented personal information or credit card data are wrong, or
        the client is already registered, or
        there is another registered client with the same email,
    then
        ALL informs the client that his registration has failed
    otherwise,
        ALL checks the credit card with the credit card service.
        If the answer from the credit card service is positive, then
            ALL registers the client with the authentication service,
            and informs him that has been registered;
        otherwise ALL informs him that his registration has failed.

if CL_REGISTER(ci,ccd) **happen then**
    if (**not** $ok(ci)$ **or not** $ok(ccd)$ **or** $registered(ci)$ **or**
        exists ci' **s.t.** $registered(ci')$ **and** $emailOf(ci) = emailOf(ci')$) **then**
        in any case next ALL_FAILED_REGISTRATION(ci,ccd) **happen**
    else
        in any case next ALL_CHECK_CARD(ccd) **happen and**
            (**eventually** CCS_OK_CARD(ccd) **happen and**
                next ALL_REGISTER(ci) **happen and**
                next ALL_REGISTERED(ci,ccd) **happen**
            or
            eventually CCS_WRONG_CARD(ccd) **happen and**
                next ALL_FAILED_REGISTRATION(ci,ccd) **happen**)

ALL is always ready to accept registration requests by the clients.
in one case next CL_REGISTER(ci,ccd) **happen**

If the credit card of a client is recorded, then the client is registered, and the data about such card are correct.
if def($creditCard(ci)$) **then** $registered(ci)$ **and** $ok(creditCard(ci))$

The credit card of a client can never be changed.
$creditCard(ci) \neq creditCard'(ci)$ **is impossible**

If ALL receives a message about the validity of a card from the credit card service, then it has asked to check such card.
if (CCS_OK_CARD(ccd) **happen or** CCS_WRONG_CARD(ccd) **happen**) **then**
    in any case sometime ALL_CHECK_CARD(ccd) **happened**

There are no properties concerning ALL_REGISTER; this means that ALL assumes that the authentication service always accept its requests, and that it never sends back a confirmation of the registration.

If ALL asks the authentication service to check a client, then it must be able to

receive its answer (positive or negative).
if ALL_CHECK(ci) **happen then in any case eventually**
ALL_OK(ci) **happen or** AUTH_WRONG(ci) **happen**

If ALL receives a message about the identity of a client from the authentication service, then
it has asked to check such client.
if (AUTH_OK(ci) **happen or** AUTH_WRONG(ci) **happen**) **then**
in any case sometime ALL_CHECK(ci) **happened**

If a client is informed that he has been registered, then
he made a registration request, and
now is registered together with his credit card data, and
has no right to receive any free ticket.
if ALL_REGISTERED(ci,ccd) **happen then**
in any case sometime CL_REGISTER(ci,ccd) **happened and**
$registered'(ci)$ **and** $creditCard'(ci) = ccd$ **and** $freeTickets'(ci) = 0$

If ALL asks the credit card service to check a card, then
it will be able to receive its answer (positive or negative).
if ALL_CHECK_CARD(ccd) **happen then in any case eventually**
CCS_OK_CARD(ccd) **happen or** CCS_WRONG_CARD(ccd) **happen**

If a client is informed that his registration request is failed, then
he made a registration request.
if ALL_FAILED_REGISTRATION(ci,ccd) **happen then**
in any case sometime CL_REGISTER(ci,ccd) **happened**

If a client is registered, then a credit card data and the number of free tickets which it may receive are available.
if $registered(ci)$ **then def**($creditCard(ci)$) **and def**($freeTickets(ci)$)

Only ALL, as a consequence of a request of the client, may register a client.
if not $registered(ci)$ **and** $registered'(ci)$ **then** ALL_REGISTERED(ci,ccd) **happen**

Once a client is registered he cannot be cancelled.
$registered(ci)$ **and not** $registered'(ci)$ **is impossible**

8 Conclusions, Related and Further Work

In this paper we have presented an attempt to design a basis for software development methods that are formally grounded, shortly FG. By *formally grounded* we mean methods

– which have all the good properties of those commonly used (friendly nota-

tion based on simple intuitive visual metaphors, easy to understand and to learn, relevant for real applications, providing precise and helpful guidelines, ...),
- but where any used specification has a direct formal semantics (not to be shown to the users) based on well defined underlying formal models,
- and also where the pragmatic characteristics of the first point have been determined by the underlying formal foundations.

Notice that by formally-grounded we intend more than just to have a formal semantics.[20] We mean that the underlying concepts are reflected in the method and used as such (although they are distilled to the potential user through methodological guidelines and nice visual notations).

As a formal basis for grounding our methods we have chosen the algebraic specification language CASL [23] and its extension for behavioural/dynamic specifications CASL-LTL [26]. Reasons for this choice are that from works on algebraic specifications, "foundations have been laid down for a neat formal treatment of requirement and design specifications, including neat semantics" [8]. Then, the CASL language, resulting from a common effort of the scientific community in this area, "encompasses all previously designed algebraic specification languages, has a clean, perfectly designed semantics" [8]. Finally, its goal is a family of related extension and restriction languages.

Our intention was to investigate if this idea is feasible, and so we proceeded in a quite systematic way, so as to handle any possible case and to exhibit how to produce the specifications (we do not just to give some sample FG specifications). Our previous experiences suggested that the various activities in a development process are based on the "building-bricks" tasks of specifying/modelling software artifacts of different nature at different levels of abstractions. So we have proposed some methods for developing the basic specification/modelling blocks for data structures, simple systems (just dynamic interacting entities in isolation, e.g., sequential processes), and structured systems (communities of mutually interacting entities, simple or in turn structured). We also address two kinds of specifications, the more abstract property-oriented ones, and the more concrete constructive ones. To present our specification method for these different cases, we have followed the conceptual schema of [4], where the distinction between the chosen specification formalism and all the other ingredients are explicitly presented.

To try to evaluate the strength and the applicability of our proposal we have used three of the M. Jackson problem frames [19, 20] as a kind of benchmark

[20] For example, a classical imperative programming language that has a formal semantics based on rewriting rules is not formally grounded on rewriting in our terms; indeed, users develop programs thinking in terms of assignments and not of rewrites.

(see [14, 15] and Sect. 6 for a summary). The result of this experiment is that all the specifications required to cope with these problem frames (i.e., specifications concerning the problem domain, the requirements and the design) can be given using our method. For each case, all relevant aspects of the frame may be satisfactorily expressed, through user friendly presentations, while the corresponding underlying formal specifications, suitable for possible formal analysis, are available. We have made another experiment concerning the specification of the requirements for an application for running Internet based lotteries see Sect. 7. The same case study has been used by one of the authors to present a UML-based *precise* method [6], quite different from the RUP [24]. Interesting enough, the development of the formally-grounded specification helped finding some small errors in the UML based one and highlighted some peculiar aspects of the specified requirements that were less obvious in the UML one. On the other side, the FG specification could express all the relevant properties of the considered application, in a different style, not scenarios based and not object-oriented, but in a property oriented fashion. Another difference between the two approaches is that in the FG one any data used in the application is naturally picked up and explicitly specified (in FG, email addresses , Sect. 7, are a data structure, whereas in the UML one [6, 7] they are just strings) and so less type mismatches should be possible.[21] We have used the same case study and the two approaches in student projects, and the results were that the levels of the UML were quite different, including some very bad ones, whereas the FG specifications were quite homogeneous as regards the quality level, and quite similar. We think this is probably due to the fact that our method provides precise detailed guidelines.

Another point we would like to recall is how this work on FG methods may also result in the development of new specification/modelling techniques, perhaps based on new paradigms, to be integrated in practical common methods. For example, our method is not object-oriented but *active-entities oriented* (or also agent-oriented), and offers a new kind of visual diagrams to present the behaviour of active entities (e.g., processes or agents), the behaviour diagrams (see Sect. 3.3). These new diagrams can be the basis for an extension of the UML statecharts (see [25]) overcoming their limitation to model only reactive behaviour. Also the new cell-filling technique for finding the properties, used here to find the axioms for the underlying logical-algebraic specification, may be at the basis of rigorous techniques for generating precise UML models, or for their inspection, to help to check whether all aspects of the modelled system have been considered.

In this paper we propose some methods grounded in a formal notation, with the aim of having some of the benefits of using formal methods available

[21] We would like to recall that an undetected type mismatch was one of the many concatenated facts causing the disaster of the Ariane 5.

within practical usual development methods, trying to reduce the impact of all the well-know disadvantages of their use (as exotic notation, and hard underlying formal concepts based on complex mathematics). This approach is quite new and so there are not, for what we know, similar approaches, except for works by the authors, as the JTN (a formally grounded visual notation for the design of Java targeted applications see [16]); see also [8] for further considerations on our view of the relationships between formal and practical used methods. However, we would like to mention works that address issues complementary to ours, e.g., how to write readable specifications in CASL [32], avoiding semantic pitfalls (also addressed in the CASL reference manual [11]), how to use/combine observability concepts for writing specifications [10], guidelines for the iterative and incremental development of specification [12].

Most of the work in the literature concerning the combination of formal methods with practical ones follows different approaches. A lot of approaches match the following pattern "take some practical more or less precise notation, e.g., UML, select a subset (usually small) of it, give this subset a formal semantics either directly or by translation into some formal notation". In many cases the final aim is to allow to use the good verification/validation tools associated with the chosen formalism. For example, for what concerns UML this pattern may be found instantiated with a large variety of formalism (we just cite one nice paradigmatic example [21], for more references look at [29]). A more recent pattern is the following "select a subset of the specifications given using some formalism and show that they correspond/can be presented as particular UML diagrams" (e.g., see [9]). The main differences of these approaches with ours is that they usually handle a particular kind of specifications applicable to particular problems to be able to use tools to automatically do some checks on the specifications.

On another side, many aspects of our FG specifications methods are quite general and not strictly related to CASL, CASL-LTL and in general to the algebraic specifications, as, for instance, the general GPSm method for property oriented specifications. So we would like to investigate whether it is possible to build other FG specification methods starting from different formal basis. We think that this can be done if we choose some formalism based on other formal models as stream processing functions (instead of labelled transition systems) as the one in [13].

For what concerns the general GPSm method for property oriented specifications, we are working to see if it can be to adapted also to produce UML models, or models on a (quite substantial) UML subset to which a formal semantics may be given.

Clearly, to be able to promote the use our proposed FG methods we need to develop supporting software tools. Such tools should consist of a graphical

editor helping to prepare the visual specifications, of a type checker signalling all static errors, and of wizards implementing the proposed guidelines, this will be really important for the GPSm method, and obviously of a part offering the possibility to generate the underlying corresponding formal specifications. Such tools do not pose any particular problem, and can be developed using the current technology, only given the necessary material resources. Instead, we do not plan the development of any specific tool for verification and or validation, the existing tools for the underlying specifications may be used.

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A Simple system, cell schemas

In what follows *arg* stands for generic expressions of the correct types, possibly with free variables, and *cond*(*exprs*) for a generic condition where the free variables of *exprs* may appear.

---

incompat2 (label property) If their arguments satisfy some conditions, then an instantiation of ei_1 and one of ei_2 are incompatible, i.e., no label of a transition may contain both.

$ei_1(arg_1)$ **incompatible with** $ei_2(arg_2)$ **if** $cond(arg_1, arg_2)$

Two elementary interactions (ei_1:ei_2) cell schema

---

value2 (state property) The results of the observation made by so_1 and so_2 on a state must satisfy some conditions

cond, where both so_1 and so_2 must appear in *cond*

Two state observers (so_1:so_2) cell schema

---

pre-cond2 (transition property) If the label of a transition contains some instantiation of *ei*, then the result of the observation made by *so* on the source state of the transition must satisfy some condition.

if *ei*(*arg*) **happen then** *cond*(*arg*)
where only source state observers may appear in *cond*(*arg*) and *so* must appear in *cond*(*arg*)

post-cond2 (transition property) If the label of a transition contains some instantiation of *ei*, then the result of the observation made by *so* on the target state of the transition must satisfy some condition.

if *ei*(*arg*) **happen then** *cond*(*arg*)
where source and target state observers may appear in *cond*(*arg*) and *so'* must appear in *cond*(*arg*)

vital2 (state property) If the result of the observation made by *so* on a state satisfies some condition, then any path starting from it will eventually contain a transition whose label contains *ei*. Note that in these properties **in any case** may be replaced by **in one case** and **eventually** by **next**.

if *cond*(*arg*) **then in any case eventually** *ei*(*arg*) **happen**
where *so* must appear in *cond*(*arg*)

Elementary interaction and state observer (*ei*:*so*) cell schema

B Example: Fragment of a Property-Oriented Specification of a Lift plant

The lift example is introduced in Sect. 1.3, and its property-oriented specification is presented in Sect. 3.2.3 where only properties on the orders are given; here, we present the other properties.

On the sensors

A sensor cannot signal two different values simultaneously.
MOTOR_STATUS(ms_1) **incompatible with** MOTOR_STATUS(ms_2) **if** $ms_1 \neq ms_2$
CABIN_POSITION(f_1) **incompatible with** CABIN_POSITION(f_2) **if** $f_1 \neq f_2$

A sensor always signals the correct data.
if MOTOR_STATUS(ms) **happen then** $motor_status = ms$
if CABIN_POSITION(f) **happen then** $cabin_position = f$

A sensor cannot break down, thus it may always be able to signal the correct value.
in one case next MOTOR_STATUS($motor_status$) **happen**
in one case next CABIN_POSITION($cabin_position$) **happen**

On the cabin and motor

If the motor is moving up (down), then the cabin position will change.
if $motor_status = up$ **then** $cabin_position' = next(cabin_position)$
if $motor_status = down$ **then** $cabin_position' = previous(cabin_position)$

The cabin position changes only if the motor is working in the corresponding versus and the change corresponds to one floor.
if $cabin_position \neq cabin_position'$ **then**
$(cabin_position' = next(cabin_position)$ **and** $motor_status = up)$ **or**
$(cabin_position' = previous(cabin_position)$ **and** $motor_status = down)$

On the users entering/leaving the cabin

At most one elementary interaction of kind TRANSIT may happen each time.
TRANSIT(i) **incompatible with** TRANSIT(i') **if** $i \neq i'$

The users may enter/leave the cabin only if they are not too numerous, the cabin is at a floor with the door open and the motor is stopped.
if TRANSIT(i) **happen then**
$users_inside + \mathrm{i} \leq 15$ **and** $users_inside + \mathrm{i} \geq 0$ **and**
$motor_status = stop$ **and** $door_position(cabin_position) = open$

The number of people inside the cabin changes only iff someone enters/leaves it.
if TRANSIT(i) **happen then** $users_inside' = users_inside + \mathrm{i}$
if $users_inside' = users_inside + \mathrm{i}$ **and** $\mathrm{i} \neq 0$ **then** TRANSIT(i) **happen**

At most 15 people may be inside the cabin simultaneously.
users_inside ≤ 15

If the door at a floor of the cabin is open and the motor is stopped, then
any appropriate number of people may enter/leave the cabin.
if *motor_status* = *stop* **and** *door_position*(*cabin_position*) = *open* **and**
users_inside+ i ≤ 15 **and** *users_inside*+ i ≥ 0 **then**
in one case next TRANSIT(i) **happen**

C Structured system, cell schemas

---

loc-glob1 (transition property) If a global transition is composed of some local interactions, then, under some condition, an instantiation of *ei* belongs to the label of this global transition; or vice versa, i.e., if an instantiation of *ei* belongs to the label of a global transition, then, under some condition, this global transition is composed of some local interactions.

if $lIn_1, \ldots, lIn_n$ **happen and** $cond(arg, lIn_1, \ldots, lIn_n)$ **then** $ei(arg)$ **happen**
or
if $ei(arg)$ **happen and** $cond(arg, lIn_1, \ldots, lIn_n)$ **then** $lIn_1, \ldots, lIn_n$ **happen**

Elementary interaction (*ei*) cell schema

---

loc-glob2 (transition property) If an instantiation of *sid.ei* is a component of a global transition, then, under some condition, the label of this global transition must contain an instantiation of ei_1, or vice versa.

if $cond(arg, arg_1)$ **and** $sid.ei(arg)$ **happen then** $ei_1(arg_1)$ **happen**
or
if $cond(arg, arg_1)$ **and** $ei_1(arg_1)$ **happen then** $sid.ei(arg)$ **happen**

Elementary interaction and local interaction (ei_1:*sid.ei*) cell schema

---

pre-cond2*,*post-cond2*,*vital2 defined as the homonymous slots for simple system but where the elementary interaction is replaced by the local interaction.

Local interaction and state observer (*sid.ei*:*so*) cell schema

D Data structures, cell schemas

---

def1 Conditions on the definedness of *con* (required only for partial constructors) [22] :

cond, where *cond* includes atoms of the form **def**(*con*(*arg*))

ident1 The values represented by *con* are/are not identified with those represented by other constructors.

when all defined *cond*, where *cond* includes atoms of the form *con*(*arg*) $= \ldots$

Constructor (*con*) cell schema

---

def3 Conditions on the definedness of the application of *op* to values represented by *con* (required only for partial operations):

cond, where *cond* includes atoms of the form **def**(*op*(*con*(*arg*)))

value1 Conditions on the values returned by the application of *op* to values represented by *con*:

when all defined *cond*, where *cond* includes terms of the form *op*(*con*(*arg*))

Constructor and operation (*con*:*op*) cell schema

---

truth1 Conditions on the truth of *pr* over the values represented by *con*:

when all defined *cond*, where *cond* includes atoms of the form *pr*(*con*(*arg*))

Constructor and predicate (*con*:*pr*) cell schema

---

def4 Conditions on the definedness of *op* (required only for partial operations):

cond, where *cond* includes atoms of the form **def**(*op*(*arg*))

value2 Conditions on the values returned by *op*:

when all defined *cond*, where *cond* includes terms of the form *op*(*arg*)

Operation (*op*) cell schema

[22] Note that constants are always total.

def5 Conditions on the relationships between the definedness of op_1 with that of op_2 (required only for partial operations):

cond

where *cond* includes atoms of the form **def**($op_1(arg_1)$) and of the form **def**($op_2(arg_2)$)

value3 Conditions on the values returned by op_1 with that returned by op_2:

when all defined *cond*

where *cond* includes terms of the form $op_1(arg_1)$ and of the form $op_2(arg_2)$

Two operations (op_1:op_2) cell schema

---

truth2 Conditions on the truth of *pr*:

when all defined *cond*, where *cond* includes atoms of the form *pr*(*arg*)

Predicate (*pr*) cell schema

---

truth3 Conditions on the relationships between the truth of pr_1 and that of pr_2:

when all defined *cond*

where *cond* includes atoms of the form $pr_1(arg_1)$ and $pr_2(arg_2)$

Two predicates (pr_1:pr_2) cell schema

E Example: Fragment of a Property-Oriented Specification of Floor

This example is given in Sect. 5.2.2 where the properties of *previous* given below were skipped.

previous returns the floor immediately below a given one, if it exists.
There is no floor between *previous*(*f*) and *f*.

def(*previous*(*top*))
not def(*previous*(*ground*))
def(*previous*(*f*)) **iff** *f above ground*
when all defined
  f above previous(*f*) **and**
  not exists f_1 • (*f above* f_1) **and** f_1 *above previous*(*f*))

F Fragment of the Requirement Specification of an Internet Based Lottery Application

Context Entity Specifications

Manager
MAN_START_LOTTERY(WinningOrder,FreeTicketLaw,Int) MAN_GIVE(Int) MAN_DRAW *all incompatible*

When the manager starts a new lottery/gives away free tickets/draws the winners, he cannot do anything else.

Email
ALL_SEND(Email,String)

The email service is always able to receive a request to send an email message.
in one case next ALL_SEND(em,s) **happen**

CreditCardService
ALL_CHECK_CARD(CreditCardData) ALL_CHARGE(CreditCardData,Int) CCS_OK_CARD(CreditCardData) CCS_WRONG_CARD(CreditCardData) CCS_CHARGED(CreditCardData,Int) CCS_NOT_CHARGED(CreditCardData,Int) *all incompatible*

When the credit card service receives a request/sends out an answer, it cannot do anything else.

If the credit card service receives a request of controlling a card, then
it will answer with either an ok or a wrong card message.
if ALL_CHECK_CARD(ccd) **happen then in any case eventually**
CCS_OK_CARD(ccd) **happen or** CCS_WRONG_CARD(ccd) **happen**

The credit card service is always ready to accept a request to check a card.
in one case ALL_CHECK(ccd) **happen**

If the credit card service receives a request to charge some money on a card, then
it will inform that the same has been either charged or not.
if ALL_CHARGE(ccd,m) **happen then in any case eventually**
CCS_CHARGED(ccd,m) **happen or** CCS_NOT_CHARGED(ccd,m) **happen**

The credit card service is always ready to accept a request to charge some amount on a card.
in one case ALL_CHARGE(ccd,m) **happen**

Client
CL_REGISTER(ClientInfo,CreditCardData)
ALL_REGISTERED(ClientInfo,CreditCardData)
ALL_FAILED_REGISTRATION(ClientInfo,CreditCardData)
CL_CONNECT(ClientInfo)
ALL_CONNECTED(ClientInfo)
CL_DISCONNECT(ClientInfo)
ALL_DISONNECTED(ClientInfo)
ALL_ERROR(ClientInfo)
CL_AVAILABLE_TICKETS(ClientInfo)
CL_BUY_TICKET(ClientInfo,Int)
ALL_ARE_AVAILABLE(ClientInfo,FiniteSet(Set))
ALL_CONFIRM_TICKET(ClientInfo,Int)
ALL_GIVE_FREE_TICKET(ClientInfo) *all incompatible*

All the possible activities of a client are mutually incompatible.

If the client sends a request to ALL, then
it will accept its answer, whatever it may be.
if CL_REGISTER(ci,ccd) **happen then in any case eventually**
ALL_REGISTERED(ci,ccd) **happen or**
ALL_FAILED_REGISTRATION(ci,ccd) **happen**
if CL_CONNECT(ci) **happen then in any case eventually**
ALL_CONNECTED(ci) **happen or** ALL_ERROR(ci) **happen**
if CL_AVAILABLE_TICKETS(ci) **happen then in any case eventually**
exists ns **s.t.** ALL_ARE_AVAILABLE(ci,ns) **happen**
if CL_BUY_TICKET(ci,i) **happen then in any case eventually**
ALL_CONFIRM_TICKET(ci,i) **happen or** ALL_ERROR(ci) **happen**

The Requirements for the Application ALL

The manager starts a new lottery

If ALL receives a request of starting a new lottery, then
the proposed dimension is greater than 1 and a multiple of 5000,
no lottery is running;
and after, a lottery will be running, characterized by the proposed parameters
(winning order, free ticket law and dimension),
and where no client owns a ticket.
Finally, all registered clients will be informed by an email message of the fact.
if MAN_START_LOTTERY(wo,ftl,d) **happen then**
$d \geq 1$ **and** $d \ mod\ 5000 = 0$ **and**
not $lotteryRunning$ **and**
$lotteryRunning'$ **and**
$dimension' = d$ **and** $winningOrder' = wo$ **and** $freeTicketLaw' = ftl$ **and**
for all $i\bullet$ **not def**($owner'(i)$) **and**
for all $ci\bullet$ **if** $ci \in registered$ **then**
in any case next ALL_SEND($emailOf(ci)$,"Started New Lottery")

When ALL receives a request from the manager of starting a new lottery, it cannot do anything else.
MAN_START_LOTTERY(*wo*,*ftl*,*d*) **incompatible with** *eIn*

If no lottery is running, then ALL must be able to accept a request from the manager, with appropriate parameters, of starting a new one.
if not *lotteryRunning* **and** $d \geq 1$ **and** $d \ mod\ 5000 = 0$ **then**
    in one case next MAN_START_LOTTERY(*wo*,*ftl*,*d*) **happen**

The dimension of the lottery must be a multiple of 5000 and greater than 1.
$dimension\ mod\ 5000 = 0$ **and** $dimension \geq 1$

The dimension, the winning order and the free tickets law of the lottery change only when a new lottery is started.
if $dimension \neq dimension'$ **then**
    exists *wo*, *ftl* **s.t.** MAN_START_LOTTERY(*wo*,*ftl*,*dimension'*) **happen**
if $winningOrder \neq winningOrder'$ **then**
    exists *d*, *ftl* **s.t.** MAN_START_LOTTERY(*winningOrder'*,*ftl*,*d*) **happen**
if $freeTicketLaw \neq freeTicketLaw'$ **then**
    exists *d*, *wo* **s.t.** MAN_START_LOTTERY(*wo*,*freeTicketLaw'*,*d*) **happen**

A lottery becomes running only after the manager started it.
if not *lotteryRunning* **and** *lotteryRunning'* **then**
    exists *d*, *wo*, *ftl* **s.t.** MAN_START_LOTTERY(*wo*,*ftl*,*d*) **happen**

The manager gives away some free tickets

When ALL receives a request from the manager of giving away some free tickets, it cannot do anything else.
MAN_GIVE(*nbil*) **incompatible with** *eIn*

If ALL receives a request to give away *nbil* free tickets, then
    a lottery is running, there are still available at least *nbil* tickets, and
    at least half of the tickets have been already assigned;
    and after, ALL selects *nbil* clients having the right to receive a free ticket, and
    each of them will get a ticket, whose number is determined by the current
    free ticket law.
if MAN_GIVE(*nbil*) **happen then**
    lotteryRunning **and** $size(availableTickets) \geq nbil$ **and**
    $size(assignedTickets) \geq dimension$ **and**
    exists *luckies* **s.t.** $size(luckies) = nbil$ **and**
        for all $ci \bullet$ **if** $ci \in luckies$ **then**
        $freeTickets(ci) > 0$ **and**
        exists unique $i \in freeTicketLaw(dimension, assignedTickets, nbil)$ **s.t.**
            in any case next ALL_GIVE_FREE_TICKET(*ci*,*i*) **happen**

If a lottery is running, there are still available at least *nbil*, and at least half of the tickets have been already assigned, then
ALL may receive a request to give away *nbil* free tickets.
if *lotteryRunning* **and** *size*(*assignedTickets*) $\geq$ *dimension* **and**
size(*availableTickets*) $\geq$ *nbil* **then**
in one case next MAN_GIVE(*nbil*) **happen**

If a client receives a free ticket, then
the number of free tickets which he has the right to get decrease by 1, and
after he is the owner of such ticket.
if ALL_GIVE_FREE_TICKET(*ci*,*i*) **happen then**
freeTickets′(*ci*) = *freeTickets*(*ci*) -1 **and** *owner*′(*i*) = *ci*

If the number of free tickets which a client has the right to get decrease by 1, then
he received a free ticket.
if *freeTickets*′(*ci*) = *freeTickets*(*ci*) -1 **then**
exists *i* **s.t.** ALL_GIVE_FREE_TICKET(*ci*,*i*) **happen**

The manager draws the winners

When ALL receives a request from the manager of drawing the winners,
it cannot do anything else.
MAN_DRAW **incompatible with** *eIn*

If ALL receives from the manager a requests to draw the winners, then
a lottery is running and there are no more available tickets;
and after, ALL informs by an email message the owners of the winning tickets
(as many as the dimension of the lottery module 5000,
whose numbers are the first w.r.t. the current winning order).
Finally, the lottery is terminated, and
ALL informs all the registered clients, always by an email message,
of the end of the lottery.
if MAN_DRAW **happen then**
lotteryRunning **and** *availableTickets* = {} **and**
(**for all** *i* • **if** *i*∈ *winners* **then**
in any case next ALL_SEND(*emailOf*(*owner*(*i*)),"Won Prize") **happen**)
and not *lotteryRunning*′ **and**
(**for all** *ci* • **if** *ci*∈ *registered* **then**
in any case eventually
ALL_SEND(*emailOf*(*ci*),"Lottery terminated") **happen**)

If a lottery is running and there are no more available tickets, then
ALL must be able to receive from the manager a requests to draw the winners.
if *lotteryRunning* **and** *availableTickets* = {} **then**
in one case next MAN_DRAW **happen**

If a lottery ends, then the manager has drawn the winners.
if *lotteryRunning* **and not** *lotteryRunning'* **then** MAN_DRAW **happen**

A client connects to ALL

If ALL receives a connection request by a client, if
    if the client is registered and not already connected, then
        ALL checks his identity with the authentication service. Thus,
        if the answer of the authentication service is positive, then
            ALL informs the client that he is connected,
        otherwise
            ALL informs the client that his request is an error;
    otherwise
        ALL informs the client that his request is an error.

if CL_CONNECT(ci) **happen then**
    if *registered*(ci) **and not** *connected*(ci) **then in any case**
        next ALL_CHECK(ci) **happen and eventually**
            (AUTH_OK(ci) **happen and next** ALL_CONNECTED(ci) **happen**
            or
            AUTH_WRONG(ci) **happen and next** ALL_ERROR(ci) **happen**)
    else
        in any case ALL_ERROR(ci) **happen**

ALL is always ready to accept connection requests by the clients.
in one case next CL_CONNECT(ci) **happen**

If a client is informed that he is connected, then
    he made a connection request and now his connection is registered.
if ALL_CONNECTED(ci) **happen then**
    in any case sometime CL_CONNECT(ci) **happened and** *connected'*(ci)

If a client is informed that his request was an error, then
    he made either a connection or a disconnection request or
    a request to show the available tickets or to buy a ticket.
if ALL_ERROR(ci) **happen then in any case sometime**
    CL_CONNECT(ci) **happened or** CL_DISCONNECT(ci) **happened or**
    CL_AVAILABLE_TICKETS(ci) **happened or**
    CL_BUY_TICKET(ci,i) **happened**

Notice that the fact that the same error message is used by ALL to answer to two different requests is made explicit by our method, while it is more hard to be spotted by use-case driven approaches, because the problematic error message appears in two different use cases.

A client disconnects from ALL

If ALL receives a disconnection requests from a client, then
    if the client is connected, then
        ALL informs him that he has been disconnected
    otherwise
        ALL informs him that his request was an error.
if CL_DISCONNECT(ci) **happen then**
    if *connected*(ci) **then**
        in any case next ALL_DISCONNECTED(ci) **happen**
    else
        in any case next ALL_ERROR(ci) **happen**

ALL is always ready to accept disconnection requests by the clients.
in one case next CL_DISCONNECT(ci) **happen**

If a client is informed that his request was an error, then he made either a disconnection request or some other request.

A connected client must be also registered.
if *connected*(ci) **then** *registered*(ci)

If a client becomes connected, then ALL has connected him.
if not *connected*(ci) **and** *connected'*(ci) **then** ALL_CONNECTED(ci) **happen**

If a client becomes disconnected, then ALL has disconnected him.
if *connected*(ci) **and not** *connected'*(ci) **then** ALL_DISCONNECTED(ci) **happen**

If a client is informed that he has been disconnected, then
    he made a disconnection request and now is disconnected.
if ALL_DISCONNECTED(ci) **happen then**
    in any case sometime CL_DISCONNECT(ci) **happened and**
    not *connected'*(ci)

Notice, how this property precisely states that ALL cannot realize any mechanism of automatic disconnection (e.g., after some time). Similar requirements, concerning what the system cannot do, are usually neglected in classical use case based approaches.

A client checks which are the tickets still available

If ALL receives a request of showing the available tickets, then
    a lottery is running and
    if the client is connected, then
        ALL will inform him of which are the available tickets
    otherwise
        ALL will inform him that his request was an error.
if CL_AVAILABLE_TICKETS(ci) **happen then**
    lotteryRunning **and**
    if *connected*(ci) **then**
        in any case next ALL_ARE_AVAILABLE(ci,*availableTickets*) **happen**
    else
        in any case next ALL_ERROR(ci) **happen**

If a lottery is running, then
    ALL may accept requests to show the available tickets.
if *lotteryRunning* **then**
    in one case next CL_AVAILABLE_TICKETS(ci) **happen**

If a client is informed that his request was an error, then he made either
a request to show the available tickets or some other request.

If ALL says to a client that *tckts* are the available tickets, then
    a lottery is running, *tckts* are the available tickets, and
    the client has requested such information
if ALL_ARE_AVAILABLE(ci,*tkcs*) **happen then**
    lotteryRunning **and** *tkcs* = *availableTickets* **and**
    in any case sometime CL_AVAILABLE_TICKETS(ci) **happened**

A client buys a ticket

If a client tries to buy the ticket with number i, then
    a lottery is running and
    if the client is connected and i is available, then
        ALL asks the credit card service to charge the sum of 1000 and
            if the credit card service confirms the chargement, then
                ALL confirms to the client that he has got the ticket i
            otherwise
                ALL informs the client that his request was an error;
    otherwise
        ALL informs the client that his request was an error.

if CL_BUY_TICKET(ci,i) **happen then**
    lotteryRunning **and**
    if *connected*(ci) **and** $i \in$ *availableTickets* **then**
        in any case next ALL_CHARGE(*creditCard*(ci), 1000) **happen and**
            eventually
                CCS_CHARGED(*creditCard*(ci), 1000) **happen and**
                next ALL_CONFIRM_TICKET(ci,i) **happen**
                or
                CCS_NOT_CHARGED(*creditCard*(ci), 1000) **happen and**
                next ALL_ERROR(ci) **happen**
    else
        in any case next ALL_ERROR(ci) **happen**

If a lottery is running, then ALL may accept requests to buy tickets.
if *lotteryRunning* **then**
    in one case next CL_BUY_TICKET(ci,i) **happen**

If a client is informed that his request was an error, then he made either
a request to buy a ticket or some other request.

If ALL confirms to a client that him bought a ticket i, then
    the client has asked for i, i was available, and after
    the client is the owner of i, and has gained the right to another free ticket.
if ALL_CONFIRM_TICKET(ci,i) **happen then**
    in any case next CL_BUY_TICKET(ci,i) **happen and**
    $i \in$ *availableTickets* **and**
    $owner'(i) = ci$ **and** $freeTickets'(ci) = freeTickets(ci) + 1$

Only registered clients may own tickets.
if def($owner(i)$) **then** $registered(owner(i))$

The number of free tickets to which a client has the right to get increases by 1,
    then he bought a ticket.
if $freeTickets'(ci) = freeTickets(ci) + 1$ **then**
    exists i **s.t.** ALL_CONFIRM_TICKET(ci,m) **happen**

If ALL asks the credit card service to charge a sum on a card, then
it will be able to receive a message confirming or negating the operation.
if ALL_CHARGE(*ccd*,*m*) **happen then in any case eventually**
    CCS_CHARGED(*ccd*,*m*) **happen or** CCS_NOT_CHARGED(*ccd*,*m*) **happen**

If ALL receives a message about the result of a request to charge a card
from the credit card service, then
    it asked such chargement.
if (CCS_CHARGED(*ccd*,*m*) **happen or** CCS_NOT_CHARGED(*ccd*,*m*) **happen**) **then**
    in any case sometime ALL_CHARGE(*ccd*,*m*) **happened**