

Standard for the Subject-oriented Specification of Systems

Albert Fleischmann *Editor*

Standard for the Subject-oriented Specification of Systems

Working Document

Egon Börger
xyz
Stephan Borgert
xyz
Matthes Elstermann
xyz
Albert Fleischmann
xyz
Reinhard Gniza
xyz
Herbert Kindermann
xyz
Florian Krenn
xyz
Thomas Schaller
xyz
Werner Schmidt
xyz
Robert Singer
FH JOANNEUM–University of Applied Sciences
Christian Stary
xyz
Florian Strecker
xyz
André Wolski
TU Darmstadt

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version. Violations are liable to prosecution under the German Copyright Law.

© 2020 Institute of Innovative Process Management, Ingolstadt

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Typeset by the authors

Production and publishing: XYZ

ISBN: 978-3-123-45678-9 (dummy)

Short contents

Short contents · v
Preface · vii
Contents · ix
1 Foundation · 1
2 Structure of a PASS Description · 9
3 Execution of a PASS Model · 19
4 Implementation of Subject Oriented Models · 53
5 Aspects for further standardisation activities · 55
A Classes and Properties of the PASS Ontology · 67
B Mapping Ontology to Abstract State Machine · 89
C PASS CoreASM Reference Implementation · 105
Bibliography · 149

Preface

Contents

Short contents	v
Preface	vii
Contents	ix
1 Foundation	1
1.1 Subject Orientation and PASS	1
1.1.1 <i>Subject-driven Business Processes</i> 1 , 1.1.2 <i>Subject Interaction and Behavior</i> 2 , 1.1.3 <i>Subjects and Objects</i> 4	
1.2 Introduction to Ontologies and OWL	4
1.3 Introduction to Abstract State Machines	6
2 Structure of a PASS Description	9
2.1 Informal Description	9
2.1.1 <i>Subject</i> 9 , 2.1.2 <i>Subject-to-Subject Communication</i> 11 , 2.1.3 <i>Message Exchange</i> 12	
2.2 OWL Description	14
2.2.1 <i>PASS Process Model</i> 14 , 2.2.2 <i>Data Describing Component</i> 15 , 2.2.3 <i>Interaction Describing Component</i> 16	
2.3 ASM Description	17
3 Execution of a PASS Model	19
3.1 Informal Description of Subject Behavior and its Execution . .	19
3.1.1 <i>Sending Messages</i> 19 , 3.1.2 <i>Receiving Messages</i> 20 , 3.1.3 <i>Standard Subject Behavior</i> 21 , 3.1.4 <i>Extended Behavior</i> 24	
3.2 Ontology of Subject Behavior Description	30
3.2.1 <i>Behavior Describing Component</i> 31	
3.3 ASM Definition of Subject Execution	33
3.3.1 <i>Architecture</i> 34 , 3.3.2 <i>Foundation</i> 35 , 3.3.3 <i>Interaction Definitions</i> 36 , 3.3.4 <i>Subject Behavior</i> 37 , 3.3.5 <i>Internal Action</i> 38 , 3.3.6 <i>Send Function</i> 39 , 3.3.7 <i>Receive Function</i> 46 , 3.3.8 <i>Modal Split and Modal Join Functions</i> 48 , 3.3.9 <i>CallMacro Function</i> 49 , 3.3.10 <i>End Function</i> 49	
4 Implementation of Subject Oriented Models	53
4.1 People and organizations	54
4.2 Physical infrastructure	54
4.3 IT-Systems and Software	54

5	Aspects for further standardisation activities	55
5.1	Subjects and Shared Input Pools	55
5.2	Structuring Complex Systems	55
5.3	Business Activity Monitoring for S-BPM	55
	<i>5.3.1 Architecture 55 , 5.3.2 Modeling BAM Parameters at Build Time 55</i>	
5.4	Subject Oriented Project Management	62
5.5	Subject Oriented Project Management	62
A	Classes and Properties of the PASS Ontology	67
A.1	All Classes (95)	67
A.2	Object Properties (42)	76
A.3	Data Properties (27)	81
B	Mapping Ontology to Abstract State Machine	89
B.1	Mapping of ASM Places to OWL Entities	89
B.2	Main Execution/Interpreting Rules	92
B.3	Functions	94
B.4	Extended Concepts – Refinements for the Semantics of Core Actions	96
B.5	Input Pool Handling	98
B.6	Other Functions	100
B.7	Elements Not Covered not by B��rger (directly)	102
C	PASS CoreASM Reference Implementation	105
C.1	Conceptual Differences ASM Semantic / OWL Model	105
C.2	editorial note	105
C.3	Basic Definitions	108
C.4	Interaction Definitions	111
C.5	Subject Rules	111
C.6	State Rules	119
C.7	Internal Action	124
C.8	Send Function	125
C.9	Receive Function	132
C.10	End Function	134
C.11	Tau Function	135
C.12	VarMan Function	135
C.13	Modal Split & Modal Join Functions	141
C.14	CallMacro Function	142
C.15	Cancel Function	144
C.16	IP Functions	145
C.17	SelectAgents Function	147
	Bibliography	149

CHAPTER 1

Foundation

To facilitate the understanding of the following sections we will introduce the philosophy of subject-orienting modeling which is based on the Parallel Activity Specification Scheme (PASS). Additional, we will give a short introduction to ontologies—especially the Web Ontology Language (OWL)—, and to Abstract State Machines (ASM) as underlying concepts of this standard document.

1.1 SUBJECT ORIENTATION AND PASS

In this section, we lay the ground for PASS as a language for describing processes in a subject-oriented way. This section is not a complete description of all PASS features, but it gives the first impression about subject-orientation and the specification language PASS. The detailed concepts are defined in the upcoming chapters.

The term subject has manifold meanings depending on the discipline. In philosophy, a subject is an observer and an object is a thing observed. In the grammar of many languages, the term subject has a slightly different meaning. "According to the traditional view, the subject is the doer of the action (actor) or the element that expresses what the sentence is about (topic)." [Kee76]. In PASS the term subject corresponds to the doer of an action whereas in ontology description languages, like RDF (see section 1.2), the term subject means the topic what the "sentence" is about.

1.1.1 Subject-driven Business Processes

Subjects represent the behavior of an active entity. A specification of a subject does not say anything about the technology used to execute the described behavior. This is different to other encapsulation approaches, such as multi-agent systems.

Subjects communicate with each other by exchanging messages. Messages have a name and a payload. The name should express the meaning of a message informally and the payloads are the data (business objects) transported. Internally, subjects execute local activities such as calculating a price, storing an address, etc.

A subject sends messages to other subjects, expects messages from other subjects, and executes internal actions. All these activities are done in sequences

which are defined in a subject's behavior specification. Subject-oriented process specifications are always embedded in a context. A context is defined by the business organization and the technology by which a business process is executed.

Subject-oriented system development integrates established theories and concepts. It has been inspired by various process algebras (see e.g. [2], [3], [4]), by the basic structure of nearly all natural languages (Subject, Predicate, Object) and the systemic sociology developed by Niklas Luhmann (an introduction can be found in [5]). According to the organizational theory developed by Luhmann, the smallest organization consists of communication executed between at least two information processing entities [5]. The integrated concepts have been enhanced and adapted to organizational stakeholder requirements, such as providing a simple graphical notation, as detailed in the following sections.

1.1.2 Subject Interaction and Behavior

We introduce the basic concepts of process modeling in S-BPM using a simple order process. A customer sends an order to the order handling department of a supplier. He is going to receive an order confirmation and the ordered product by the shipment company. Figure 1.3 shows the communication structure of that process. The involved subjects and the messages they exchange can easily be grasped.



Figure 1.1: The Communication Structure in the Order Process

Each subject has a so-called input pool which is its mailbox for receiving messages. This input pool can be structured according to the business requirements at hand. The modeler can define how many messages of which type and/or from which sender can be deposited and what the reaction is if these restrictions are violated. This means the synchronization through message exchange can be specified for each subject individually.

Messages have an intuitive meaning expressed by their name. A formal semantics is given by their use and the data which are transported with a message. Figure 1.2 depicts the behavior of the subjects "customer" and "order handling".

In the first state of its behavior, the subject "customer" executes the internal function "Prepare order". When this function is finished the transition "order prepared" follows. In the succeeding state "send order" the message "order" is sent to the subject "order handling". After this message is sent (deposited in the input pool of subject "order handling"), the subject "Customer" goes into the state "wait for confirmation". If this message is not in the input pool the subject stops its execution until the corresponding message arrives in the input pool. On arrival, the subject removes the message from the input pool and follows the transition into state "Wait for product" and so on.

The subject "Order Handling" waits for the message "order" from the subject "customer". If this message is in the input pool it is removed and the succeeding



Figure 1.2: The Behavior of Subjects

function "check order" is executed and so on.

The behavior of each subject describes in which order it sends messages, expects (receives) and performs internal functions. Messages transport data from the sending to the receiving subject and internal functions operate on internal data of a subject. These data aspects of a subject are described in section 1.1.3. In a dynamic and fast-changing world, processes need to be able to capture known but unpredictable events. In our example let us assume that a customer can change an order. This means the subject "customer" may send the message "Change order" at any time. Figure 1.3 shows the corresponding communication structure, which now contains the message "change order".

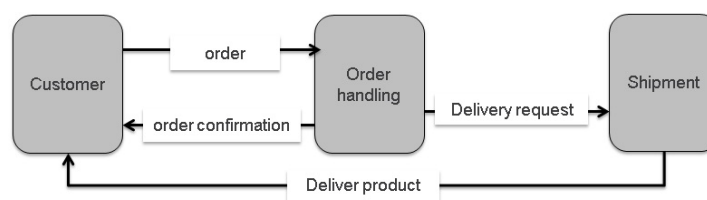


Figure 1.3: The Communication Structure with Change Message

Due to this unpredictable event, the behavior of the involved subjects needs also to be adapted. Figure 1.4 illustrates the respective behavior of the customer.

The subject "customer" may have the idea to change its order in the state "wait for confirmation" or in the state "wait for product". The flags in these states indicate that there is a so-called behavior extension described by a so-called non-deterministic event guard [12, 22]. The non-deterministic event created in the subject is the idea "change order". If this idea comes up, the current states, either "wait for confirmation" or "wait for product", are left, and the subject "customer" jumps into state "change order" in the guard behavior. In this state, the message "change order" is sent and the subject waits in the state "wait for reaction". In this state, the answer can either be "order change accepted" or "order change rejected". Independently of the received message the subject "customer" moves



Figure 1.4: Customer is allowed to Change Orders

to the state "wait for product". The message "order change accepted" is considered as confirmation, if a confirmation has not arrived yet (state "wait for confirmation"). If the change is rejected the customer has to wait for the product(s) he/she has ordered originally. Similar to the behavior of the subject "customer" the behavior of the subject "order handling" has to be adapted.

1.1.3 Subjects and Objects

Up to now, we did not mention data or the objects with their predicates, to get complete sentences comprising subject, predicate, and object. Figure ?? displays how subjects and objects are connected. The internal function "prepare order" uses internal data to prepare the data for the order message. This order data is sent as the payload of the message "order".

The internal functions in a subject can be realized as methods of an object or functions implemented in a service if a service-oriented architecture is available. These objects have an additional method for each message. If a message is sent, the method allows receiving data values sent with the message, and if a message is received the corresponding method is used to store the received data in the object [22]. This means either subject are the entities which use synchronous services as an implementation of functions or asynchronous services are implemented through subjects or even through complex processes consisting of several subjects. Consequently, the concept Service Oriented Architecture (SOA) is complementary to S-BPM: Subjects are the entities which use the services offered by SOAs (cf. [25]).

1.2 INTRODUCTION TO ONTOLOGIES AND OWL

This short introduction to ontology, the Resource Description Framework and Web Ontology Language (OWL), should help to get an understanding of the PASS ontology outlined in section 2 and 3.



Figure 1.5: Subjects and Objects

Ontologies are a formal way to describe taxonomies and classification networks, essentially defining the structure of knowledge for various domains: the nouns representing classes of objects and the verbs representing relations between the objects of classes.

In computer science and information science, an ontology encompasses a representation, formal naming, and definition of the classes, properties, and relations between the data, and entities that substantiate considered domains.

The Resource Description Framework (RDF) provides a graph-based data model or framework for structuring data as statements about resources. A "resource" may be any "thing" that exists in the world: a person, place, event, book, museum object, but also an abstract concept like data objects. Figure 1.6 shows an RDF graph.



Figure 1.6: RDF graphic

RDF is based on the idea of making statements about resources (in particular web resources) in expressions of the form *subject* *predicate* *object*, known as triples. The subject denotes the resource, and the predicate denotes traits or aspects of the resource and expresses a relationship between the subject and the object. In the context of ontology, the term subject expresses what the sentence is about (topic) (see 1.1).

For describing ontologies several languages have been developed. One widely used language is OWL (worldwide web ontology language) which is based on

the Resource Description Framework (RDF).

OWL has classes, properties, and instances. Classes represent terms also called concepts. Classes have properties and instances are individuals of one or more classes.

A class is a type of thing. A type of "resource" in the RDF sense can be person, place, object, concept, event, etc.. Classes and subclasses form a hierarchical taxonomy and members of a subclass inherit the characteristics of their parent class (superclass). Everything true for the parent class is also true for the subclass.

A member of a subclass "is a", or "is a kind of" its parent class. Ontologies define a set of properties used in a specific knowledge domain. In an ontology context, properties relate members of one class to members of another class or a literal.

Domains and ranges define restrictions on properties. A domain restricts what kinds of resources or members of a class can be the subject of a given property in an RDF triple. A range restricts what kinds of resources/members of a class or data types (literals) can be the object of a given property in an RDF triple.

Entities belonging to a certain class are instances of this class or individuals. A simple ontology with various classes, properties and individual is shown below:

Ontology statement examples:

- **Class definition statements:**

- Parent isA Class
- Mother isA Class
- Mother subClassOf Parent
- Child isA Class

- **Property definition statement:**

- isMotherOf is a relation between the classes Mother and Child

- **Individual/instance statements:**

- MariaSchmidt isA Mother
- MaxSchmidt isA Child
- MariaSchmidt isMotherOf MaxSchmidt

1.3 INTRODUCTION TO ABSTRACT STATE MACHINES

An abstract state machine (ASM) is a state machine operating on states that are arbitrary data structures (structure in the sense of mathematical logic, that is a nonempty set together with several functions (operations) and relations over the set).

The language of the so-called Abstract State Machine uses only elementary If-Then-Else-rules which are typical also for rule systems formulated in natural language, i.e., rules of the (symbolic) form

if Condition then ACTION

with arbitrary *Condition* and *ACTION*. The latter is usually a finite set of assignments of the form $f(t_1, \dots, t_n) := t$. The meaning of such a rule is to perform in any given state the indicated action if the indicated condition holds in this state.

The unrestricted generality of the used notion of *Condition* and *ACTION* is guaranteed by using as ASM-states the so-called Tarski structures, i.e., arbitrary sets of arbitrary elements with arbitrary functions and relations defined on them. These structures are updatable by rules of the form above. In the case of business processes, the elements are placeholders for values of arbitrary type and the operations are typically the creation, duplication, deletion, or manipulation (value change) of objects. The so-called views are conceptually nothing else than projections (read: substructures) of such Tarski structures.

An (asynchronous, also called distributed) ASM consists of a set of agents each of which is equipped with a set of rules of the above form, called its program. Every agent can execute in an arbitrary state in one step all its executable rules, i.e., whose condition is true in the indicated state. For this reason, such an ASM, if it has only one agent, is also called sequential ASM. In general, each agent has its own "time" to execute a step, in particular, if its step is independent of the steps of other agents; in special cases, multiple agents can also execute their steps simultaneously (in a synchronous manner).

Without further explanations, we adopt usual notations, abbreviations, etc., for example:

if Cond then M1 else M2

instead of the equivalent ASM with two rules:

if Cond then M1

if not Cond then M2

Another notation used below is

let $x=t$ in M

for $M(x/a)$, where a denotes the value of t in the given state and $M(x/a)$ is obtained from M by substitution of each (free) occurrence of x in M by a .

For details of a mathematical definition of the semantics of ASMs which justifies their intuitive (rule-based or pseudo-code) understanding, we refer the reader to the AsmBook BÄrger, E., StÄrk R. Abstract State Machines. A Method for High-Level System Design and Analysis. Springer, 2003.

Structure of a PASS Description

In this chapter, we describe the structure of a PASS specification. The structure of a PASS description consists of the subjects and the messages they exchange.

2.1 INFORMAL DESCRIPTION

2.1.1 Subject

Subjects represent the behavior of an active entity. A specification of a subject does not say anything about the technology used to execute the described behavior. Subjects communicate with each other by exchanging messages. Messages have a name and a payload. The name should express the meaning of a message informally and the payloads are the data (business objects) transported. Internal subjects execute local activities such as calculating a price, storing an address, etc. External subjects represent interfaces for other business processes.

A subject sends messages to other subjects, receives messages from other subjects, and executes internal actions. All these activities are done in logical order which is defined in a subject's behavior specification.

In the following, we use an example of the informal definition of subjects. In the simple scenario of the business trip application, we can identify three subjects, namely the employee as the applicant, the manager as the approver, and the travel office as the travel arranger.

In general, there are the following types of subjects:

- Fully specified subjects
- Multi-subjects
- Single subjects
- Interface subjects

Fully specified Subjects

This is the standard subject type. A subject communicates with other subjects by exchanging messages. Fully specified subjects consist of the following components:

- **Business Objects**—Each subject has some business objects. A basic structure of business objects consists of an identifier, data structures, and data elements. The identifier of a business object is derived from the business environment in which it is used. Examples are business trip requests, purchase orders, packing lists, invoices, etc. Business objects are composed of data structures. Their components can be simple data elements of a certain type (e.g., string or number) or even data structures themselves.
- **Sent messages**—Messages which a subject sends to other subjects. Each message has a name and may transport some data objects as a payload. The values of these payload data objects are copied from internal business objects of a subject.
- **Received messages**—Messages received by a subject. The values of the payload objects are copied to business objects of the receiving subject.
- **Input Pool**—Messages sent to subjects are deposited in the input pool of the receiving subject. The input pool is a very important organizational and technical concept in this case.
- **Behavior**—The behavior of each subject describes in which logical order it sends messages, expects (receives) messages, and performs internal functions. Messages transport data from the sending to the receiving subject and internal functions operate on internal data of a subject.

Multisubjects and Multiprocesses

Multi-subjects are similar to fully specified subjects. If in a process model several identical subjects are required, e.g. to increase the throughput, this requirement can be modeled by a multi-subject. If several communicating subjects in a process model are multi-subjects they can be combined to a multi-process.

In a business process, there may be several identical sub-processes that perform certain similar tasks in parallel and independently. This is often the case in a procurement process when bids from multiple suppliers are solicited. A process or sub-process is therefore executed simultaneously or sequentially multiple times during overall process execution. A set of type-identical, independently running processes or sub-processes are termed multi-process. The actual number of these independent sub-processes is determined at runtime.

Multi-processes simplify process execution since a specific sequence of actions can be used by different processes. They are recommended for recurring structures and similar process flows.

An example of a multi-process can be illustrated as a variation of the current booking process. The travel agent should simultaneously solicit up to five bids before making a reservation. Once three offers have been received, one is selected and a room is booked. The process of obtaining offers from the hotels is identical for each hotel and is therefore modeled as a multi-process.

Single subjects

Single subjects can be instantiated only once. They are used if for the execution of a subject a resource is required which is only available once.

Interface Subjects

Interface subjects are used as interfaces to other process systems. If a subject of a process system sends or receives messages from a subject which belongs to another workflow system. These so-called interface subjects represent fully described subjects which belong to that other process system. Interface subjects specifications contain the sent messages, received messages and the reference to the fully described subject which they represent.

2.1.2 Subject-to-Subject Communication

After the identification of subjects involved in the process (as process-specific roles), their interaction relationships need to be represented. These are the messages exchanged between the subjects. Such messages might contain structured information—so-called business objects.

The result is a model of the communication relationships between two or more subjects, which is referred to as a **Subject Interaction Diagram** (SID) or, synonymously, as a Communication Structure Diagram (CSD) (see figure 2.1).

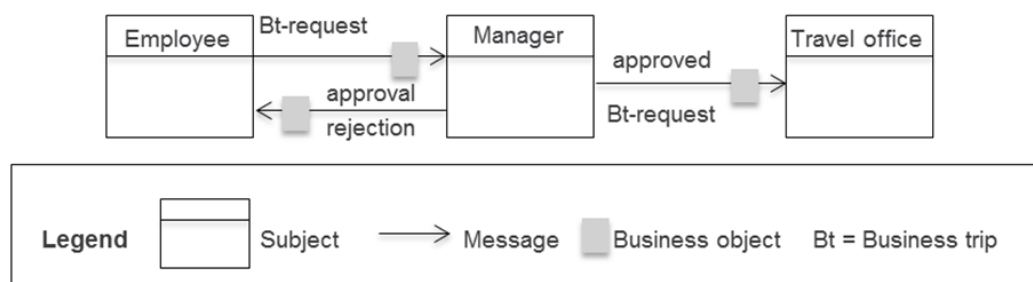


Figure 2.1: Subject interaction diagram for the process 'business trip application'

Messages represent the interactions of the subjects during the execution of the process. We recommend naming these messages in such a way that they can be immediately understood and also reflect the meaning of each particular message for the process. In the sample 'business trip application', therefore, the messages are referred to as 'business trip request', 'rejection', and 'approval'.

Messages serve as a container for the information transmitted from a sending to a receiving subject. There are two options for the message content:

- **Simple data types**—Simple data types are string, integer, character, etc. In the business trip application example, the message 'business trip request' can contain several data elements of type string (e.g., destination, the reason for traveling, etc.), and of type number (e.g., duration of the trip in days).
- **Business Objects**—Business Objects in their general form are physical and logical 'things' that are required to process business transactions. We consider data structures composed of elementary data types, or even other data structures, as logical business objects in business processes. For instance, the business object 'business trip request' could consist of the data structures 'data on applicants', 'travel data', and 'approval data' with each of these in turn containing multiple data elements.

2.1.3 Message Exchange

In the previous subsection, we have stated that messages are transferred between subjects and have described the nature of these messages. What is still missing is a detailed description of how messages can be exchanged, how the information they carry can be transmitted, and how subjects can be synchronized. These issues are addressed in the following sub-sections.

Synchronous and Asynchronous Exchange of Messages

In the case of an asynchronous exchange of messages, sender and receiver wait for each other until a message can be passed on. If a subject wants to send a message and the receiver (subject) is not yet in a corresponding receive state, the sender waits until the receiver can accept this message. Conversely, a recipient has to wait for the desired message until it is made available by the sender.

The disadvantage of the synchronous method is a close temporal coupling between sender and receiver. This raises problems in the implementation of business processes in the form of workflows, especially across organizational borders. As a rule, these also represent system boundaries across which a tight coupling between sender and receiver is usually very costly. For long-running processes, sender and receiver may wait for days, or even weeks, for each other.

Using asynchronous messaging, a sender can send anytime. The subject puts a message into a message buffer from which it is picked up by the receiver. However, the recipient sees, for example, only the oldest message in the buffer (in case the buffer is implemented as FIFO or LIFO storage) and can only accept this particular one. If it is not the desired message, the receiver is blocked, even though the message may already be in the buffer, but in a buffer space that is not visible to the receiver. To avoid this, the recipient has the alternative to take all of the messages from the buffer and manage them by himself. In this way, the receiver can identify the appropriate message and process it as soon as he or she needs it. In asynchronous messaging, sender and receiver are only loosely coupled. Practical problems can arise due to the in reality limited physical size of the receive buffer, which does not allow an unlimited number of messages to be recorded. Once the physical boundary of the buffer has been reached due to high occupancy, this may lead to unpredictable behavior of workflows derived from a business process specification. To avoid this, the input-pool concept has been introduced in PASS. Nevertheless, the number of messages must always be limited, as a business process must have the capacity to handle all messages to maintain some sort of service level.

Exchange of Messages via the Input Pool

To solve the problems outlined in the asynchronous message exchange, the input pool concept has been developed. Communication via the input pool is considerably more complex than previously shown; however, it allows transmitting an unlimited number of messages simultaneously. Due to its high practical importance, it is considered as a basic construct of PASS.

Consider the input pool as a mailbox of work performers, the operation of which is specified in detail. Each subject has its input pool. It serves as a message buffer to temporarily store messages received by the subject, independent of the sending communication partner. The input pools are therefore inboxes for flexible configuration of the message exchange between the subjects. In contrast

to the buffer in which only the front message can be seen and accepted, the pool solution enables picking up (i.e. removing from the buffer) any message. For a subject, all messages in its input pool are visible.

The input pool has the following configuration parameters (see figure 2.2):

- **Input-pool size**—The input-pool size specifies how many messages can be stored in an input pool, regardless of the number and complexity of the message parameters transmitted with a message. If the input pool size is set to zero, messages can only be exchanged synchronously.
- **Maximum number of messages from specific subjects**—For an input pool, it can be determined how many messages received from a particular subject may be stored simultaneously in the input pool. Again, a value of zero means that messages can only be accepted synchronously.
- **Maximum number of messages with specific identifiers**—For an input pool, it can be determined how many messages of a specifically identified message type (e.g., invoice) may be stored simultaneously in the input pool, regardless of what subject they originate from. A specified size of zero allows only for synchronous message reception.
- **Maximum number of messages with specific identifiers of certain subjects**—For an input pool, it can be determined how many messages of a specific identifier of a particular subject may be stored simultaneously in the input pool. The meaning of the zero value is analogous to the other cases.

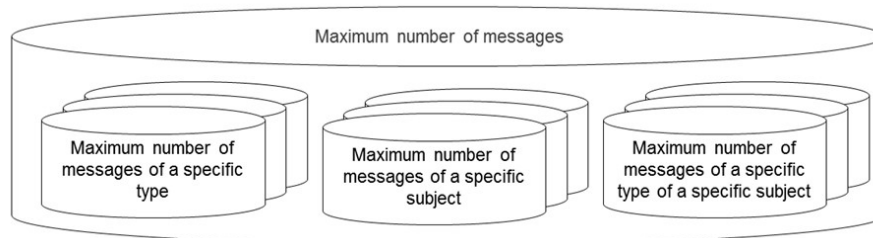


Figure 2.2: Configuration of Input Pool Parameters

By limiting the size of the input pool, its ability to store messages may be blocked at a certain point in time during process runtime. Hence, messaging synchronization mechanisms need to control the assignment of messages to the input pool. Essentially, there are three strategies to handle access to input pools:

- **Blocking the sender until the input pool's ability to store messages has been reinstated**—Once all slots are occupied in an input pool, the sender is blocked until the receiving subject picks up a message (i.e. a message is removed from the input pool). This creates space for a new message. In case several subjects want to put a message into a fully occupied input pool, the subject that has been waiting longest for an empty slot is allowed to send. The procedure is analogous if corresponding input pool parameters do not allow storing the message in the input pool, i.e., if the corresponding number of messages of the same name or from the same subject has been put into the input pool.

- Delete and release of the oldest message—In case all the slots are already occupied in the input pool of the subject addressed, the oldest message is overwritten with the new message.
- Delete and release of the latest message—The latest message is deleted from the input pool to allow depositing of the new incoming message. If all the positions in the input pool of the addressed subject are taken, the latest message in the input pool is overwritten with the new message. This strategy applies analogously when the maximum number of messages in the input pool has been reached, either concerning sender or message type.

2.2 OWL DESCRIPTION

The various building blocks of a PASS description and their relations are defined in an ontology. The following figure 2.3 gives an overview of the structure of the PASS specifications.



Figure 2.3: Elements of PASS Process Models

The class `PASSProcessModelElement` has five subclasses (subclass relations 084, 055, 069, 001 and 085 in figure 2.3). Only the classes `PASSProcessModel`, `DataDescriptionComponent`, `InteractionDescribingComponent` are used for defining the structural aspects of a process specification in PASS. The classes `BehaviorDescribingComponent` and `SubjectBehavior` define the dynamic aspects. In which sequences messages are sent and received or internal actions are executed. These dynamic aspects are considered in detail in the next chapter.

2.2.1 PASS Process Model

The central entities of a PASS process model are subjects which represent the active elements of a process and the messages they exchange. Messages transport data from one subject to others (payload). Figure 2.4 shows the corresponding ontology for the PASS process models.

`PASSProcessModelElements` and `PASSProcessModels` have a name. This is described with the property `hasAdditionalAttribute` (property 208 in 2.3). The class `subject` and the class `MessageExchange` have the relation `hasRelation toModelComponent` to the class `PASSProcessModel` (property 226 in 2.3). The properties `hasReceiver` and `hasSender` express that a message has a sending and receiving subject (properties 225 and 227 in 2.3) whereas the properties `hasOutgoingMessageExchange` and `hasIncomingMessageExchange`

straints which are related to certain messages have references to the class `MessageSpecification`.

There are four subclasses of the class `subject` (in figure 2.6 number 079, 080, 081 and 082). The specialties of these subclasses are described in section 2.1.1. A class `StartSubject` (in figure 2.6 number 83) which is a subclass of class `subject` denotes the subject in which a process instance is started.

All other relations are subclass relations. The class `PASSProcessModelElement` is the central PASS class. From this class, all the other classes are derived (see next sections). From class `InteractionDescribingComponent` all the classes required for describing the structure of a process system are derived.

2.3 ASM DESCRIPTION

In this chapter, only the structure of a PASS model is considered. Execution has not been considered. Because ASM only considers execution aspects in this chapter an ASM specification of the structural aspects does not make sense. The execution semantics is part of chapter 4.

Execution of a PASS Model

3.1 INFORMAL DESCRIPTION OF SUBJECT BEHAVIOR AND ITS EXECUTION

The execution of the subject means sending and receiving messages and executing internal activities in the defined order. In the following sections, it is described what sending and receiving messages and executing internal functions means.

3.1.1 Sending Messages

Before sending a message, the values of the parameters to be transmitted need to be determined. In case the message parameters are simple data types, the required values are taken from local variables or business objects of the sending subject, respectively. In the case of business objects, a current instance of a business object is transferred as a message parameter.

The sending subject attempts to send the message to the target subject and store it in its input pool. Depending on the described configuration and status of the input pool, the message is either immediately stored or the sending subject is blocked until delivery of the message is possible.

In the sample business trip application, employees send completed requests using the message 'send business trip request' to the manager's input pool. From a send state, several messages can be sent as an alternative. The following example shows a send state in which the message M1 is sent to the subject S1, or the message M2 is sent to S2, therefore referred to as alternative sending (see Figure 3.1). It does not matter which message is attempted to be sent first. If the send mechanism is successful, the corresponding state transition is executed. In case the message cannot be stored in the input pool of the target subject, sending is interrupted automatically, and another designated message is attempted to be sent. A sending subject will thus only be blocked if it cannot send any of the provided messages.

By specifying priorities, the order of sending can be influenced. For example, it can be determined that the message M1 to S1 has a higher priority than the message M2 to S2. Using this specification, the sending subject starts with sending message M1 to S1 and then tries only in case of failure to send message M2 to S2. In case of message M2 can also not be sent to the subject S2, the attempts to send start from the beginning.



Figure 3.1: Example of alternative sending

The blocking of subjects when attempting to send can be monitored over time with the so-called timeout. The example in Figure 3.2 shows with 'Timeout: 24 h' an additional state transition which occurs when within 24 hours one of the two messages cannot be sent. If a value of zero is specified for the timeout, the process immediately follows the timeout path when the alternative message delivery fails.

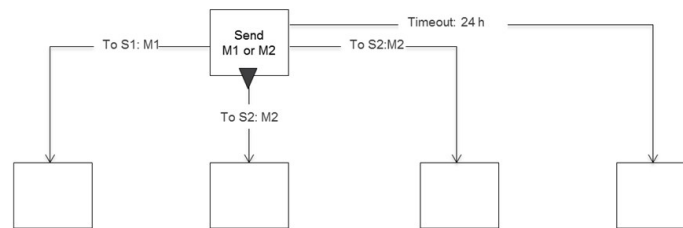


Figure 3.2: Send using time monitoring

3.1.2 Receiving Messages

Analogously to sending, the receiving procedure is divided into two phases, which run inversely to send.

The first step is to verify whether the expected message is ready for being picked up. In the case of synchronous messaging, it is checked whether the sending subject offers the message. In the asynchronous version, it is checked whether the message has already been stored in the input pool. If the expected message is accessible in either form, it is accepted, and in a second step, the corresponding state transition is performed. This leads to a takeover of the message parameters of the accepted message to local variables or business objects of the receiving subject. In case the expected message is not ready, the receiving subject is blocked until the message arrives and can be accepted.

In a certain state, a subject can expect alternatively multiple messages. In this case, it is checked whether any of these messages are available and can be accepted. The test sequence is arbitrary unless message priorities are defined. In this case, an available message with the highest priority is accepted. However, all other messages remain available (e.g., in the input pool) and can be accepted in other receive states.

Figure 3.3 shows a receive state of the subject 'employee' which is waiting for the answer regarding a business trip request. The answer may be an approval or a rejection.

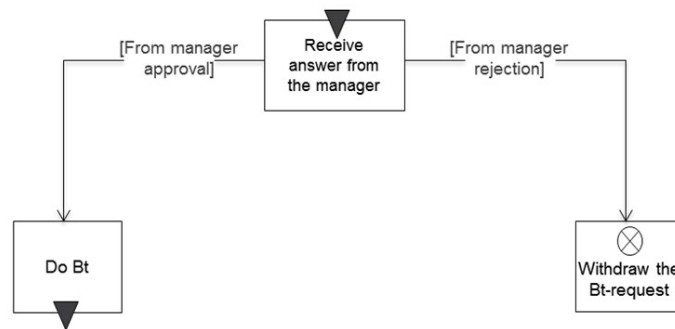


Figure 3.3: Example of alternative receiving

Just as with sending messages, also receiving messages can be monitored over time. If none of the expected messages are available and the receiving subject is therefore blocked, a time limit can be specified for blocking. After the specified time has elapsed, the subject will execute the transition as it is defined for the timeout period. The duration of the time limit may also be dynamic, in the sense that at the end of a process instance the process stakeholders assigned to the subject decide that the appropriate transition should be performed. We then speak of a manual timeout.



Figure 3.4: Time monitoring for message reception

Figure 3.4 shows that, after waiting three days for the manager's answer, the employee sends a corresponding request.

Instead of waiting for a message for a certain predetermined period of time, the waiting can be interrupted by a subject at all times. In this case, a reason for abortion can be appended to the keyword 'breakup'. In the example shown in Figure 3.5, the receiving state is left due to the impatience of the subject.

3.1.3 Standard Subject Behavior

The possible sequences of a subject's actions in a process are termed subject behavior. States and state transitions describe what actions a subject performs and how they are interdependent. In addition to the communication for sending and receiving, a subject also performs so-called internal actions or functions.

States of a subject are therefore distinct: There are actions on the one hand, and communication states to interact with other subjects (receive and send) on the other. This results in three different types of states of a subject. Figure 3.6 shows the different types of states with the corresponding symbols.



Figure 3.5: Message reception with manual interrupt



Figure 3.6: State types and corresponding symbols

In S-BPM, work performers are equipped with elementary tasks to model their work procedures: sending and receiving messages and immediate accomplishment of a task (function state).

In case an action associated with a state (send, receive, do) is possible, it will be executed, and a state transition to the next state occurs. The transition is characterized through the result of the action of the state under consideration: For a send state, it is determined by the state transition to which subject what information is sent. For a receive state, it becomes evident in this way from what subject it receives which information. For a function state, the state transition describes the result of the action, e.g., that the change of a business object was successful or could not be executed.

The behavior of subjects is represented by modelers using Subject Behavior Diagrams (SBD). Figure 3.7 shows the subject behavior diagram depicting the behavior of the subjects 'employee', 'manager', and 'travel office', including the associated states and state transitions.

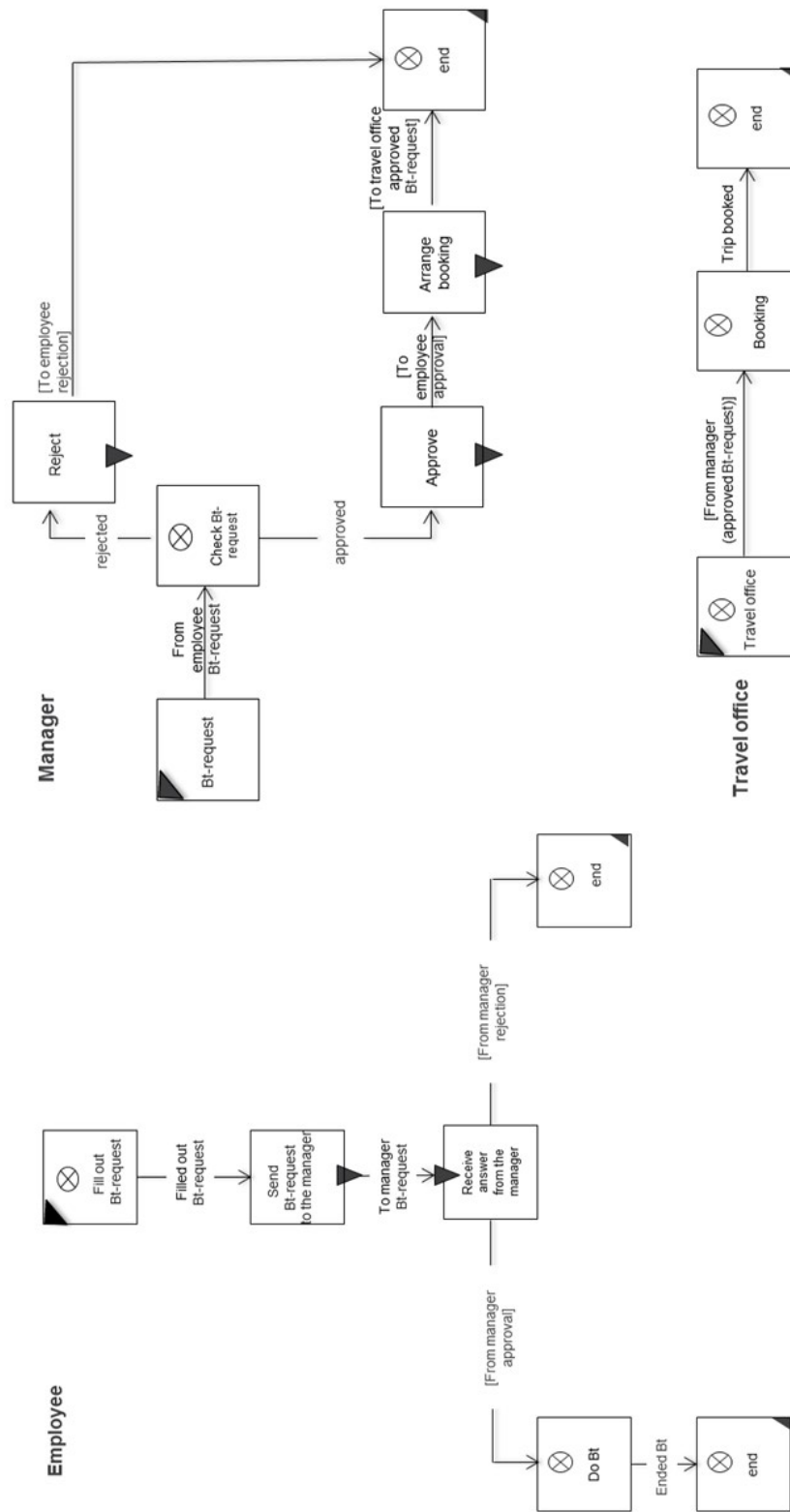


Figure 3.7: Subject behavior diagram for the subjects 'employee', 'manager', and 'travel office'

3.1.4 Extended Behavior

To reduce description efforts some additional specification constructs have been added to PASS. These constructs are informally explained in the following sections.

Macros

Quite often, a certain behavior pattern occurs repeatedly within a subject. This happens in particular when in various parts of the process identical actions need to be performed. If only the basic constructs are available to this respect, the same subject behavior needs to be described many times.

Instead, this behavior can be defined as a so-called behavior macro. Such a macro can be embedded at different positions of a subject behavior specification as often as required. Thus, variations in behavior can be consolidated, and the overall behavior can be significantly simplified.

The brief example of the business trip application is not an appropriate scenario to illustrate here the benefit of the use of macros. Instead, we use an example of order processing. Figure 3.8 contains a macro for the behavior to process customer orders. After placing the 'order', the customer receives an order confirmation; once the 'delivery' occurs, the delivery status is updated.

As with the subject, the start and end states of a macro also need to be identified. For the start states, this is done similarly to the subjects by putting black triangles in the top left corner of the respective state box. In our example, 'order' and 'delivery' are the two correspondingly labeled states. In general, this means that a behavior can initiate a jump to different starting points within a macro.

The end of a macro is depicted by gray bars, which represent the successor states of the parent behavior. These are not known during the macro definition.

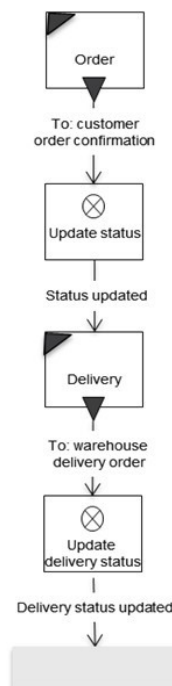


Figure 3.8: Behavior macro class 'request for approval'

Figure 3.9 shows a subject behavior in which the modeler uses the macro 'order processing' to model both a regular order (with purchase order), as well as a call order.

The icon for a macro is a small table, which can contain multiple columns in the first line for different start states of the macro. The valid start state for a specific case is indicated by the incoming edge of the state transition from the calling behavior. The middle row contains the macro name, while the third row again may contain several columns with possible output transitions, which end in states of the surrounding behavior.

The left branch of the behavioral description refers to regular customer orders. The embedded macro is labeled correspondingly and started with the status 'order', namely through linking the edge of the transition 'order accepted' with this start state. Accordingly, the macro is closed via the transition 'delivery status updated'.

The right embedding deals with call orders according to organizational frameworks and frame contracts. The macro starts therefore in the state 'delivery'. In this case, it also ends with the transition 'delivery status updated'.



Figure 3.9: Subject behavior for order processing with macro integration

Similar subject behavior can be combined into macros. When being specified, the environment is initially hidden, since it is not known at the time of modeling.

Guards: Exception Handling and Extensions

Exception Handling— Handling of an exception (also termed message guard, message control, message monitoring, message observer) is a behavioral description of a subject that becomes relevant when a specific, exceptional situation occurs while executing a subject behavior specification. It is activated when a corresponding message is received, and the subject is in a state in which it can respond to the exception handling. In such a case, the transition to exception handling has the highest priority and will be enforced.

Exception handling is characterized by the fact that it can occur in a process in many behavior states of subjects. The receipt of certain messages, e.g., to abort the process, always results in the same processing pattern. This pattern would

have to be modeled for each state in which it is relevant. Exception handling causes high modeling effort and leads to complex process models since from each affected state a corresponding transition has to be specified. To prevent this situation, we introduce a concept similar to exception handling in programming languages or interrupt handling in operating systems.

To illustrate the compact description of exception handling, we use again the service management process with the subject 'service desk' introduced in section 5.6.5. This subject identifies a need for a business trip in the context of processing a customer order – an employee needs to visit the customer to provide a service locally. The subject 'service desk' passes on a service order to an employee. Hence, the employee issues a business trip request. In principle, the service order may be canceled at any stage during processing up to its completion. Consequently, this also applies to the business trip application and its subsequent activities.

Below, it is first shown how the behavior modeling looks without the concept of exception handling. The cancellation message must be passed on to all affected subjects to bring the process to a defined end. Figure 3.10 shows the communication structure diagram with the added cancellation messages to the involved subjects.



Figure 3.10: Communication structure diagram (CSD) of the business trip application

A cancellation message can be received by the employee either while filling out the application or while waiting for the approval or rejection message from the manager. Concerning the behavior of the subject 'employee', the state 'response received from manager' must also be enriched with the possible input message containing the cancellation and the associated consequences (see Figure 3.11). The verification of whether filing the request is followed by a cancellation is modeled through a receive state with a timeout. In case the timeout is zero, there is no cancellation message in the input pool and the business trip request is sent to the manager. Otherwise, the manager is informed of the cancellation and the process terminates for the subject 'employee'.

A corresponding adjustment of the behavior must be made for each subject which can receive a cancellation message, including the manager, the travel office, and the interface subject 'travel agent'.

This relatively simple example already shows that taking such exception messages into account can quickly make behavior descriptions confusing to understand. The concept of exception handling, therefore, should enable supplementing exceptions to the default behavior of subjects in a structured and compact form.

Instead of, as shown in Figure 3.11, modeling receive states with a timeout zero and corresponding state transitions, the behavioral description is enriched with the exception handling 'service cancellation'. Its initial state is labeled with the states from which it is branched to, once the message 'service cancellation' is received. In the example, these are the states 'fill out Bt-request' and 'receive

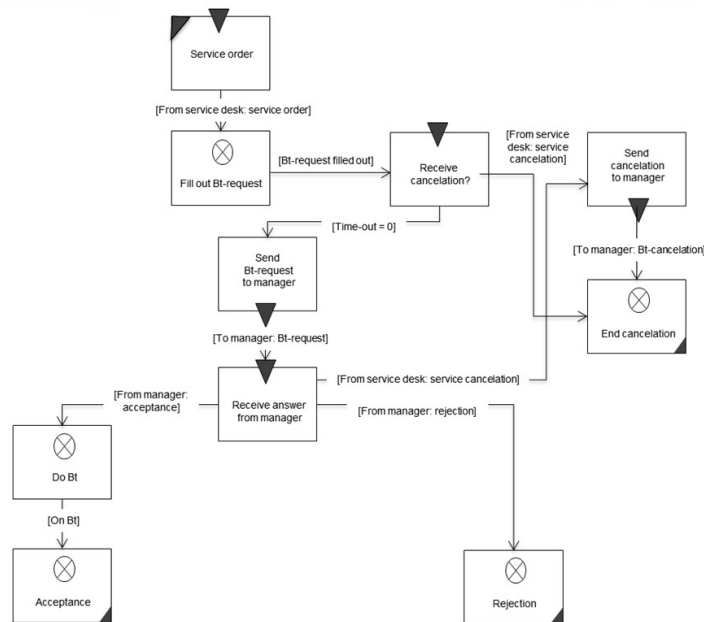


Figure 3.11: Handling the cancellation message using existing constructs

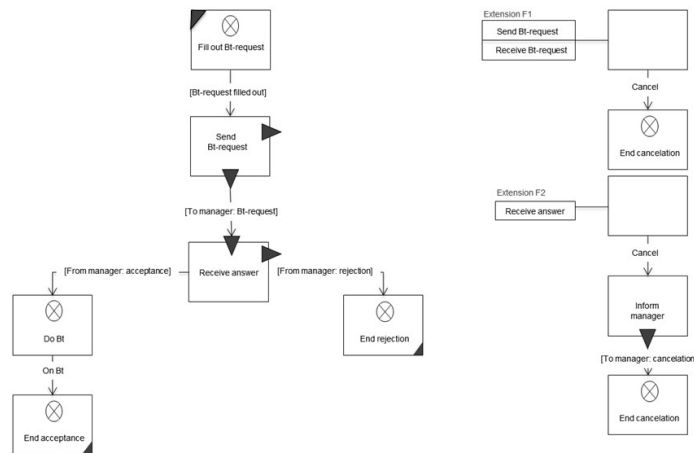


Figure 3.12: Behavior of subject 'employee' with exception handling

answer from manager'. Each of them is marked by a triangle on the right edge of the state symbol. The exception behavior leads to an exit of the subject after the message 'service cancellation' has been sent to the subject 'manager'.

A subject behavior does not necessarily have to be brought to an end by an exception handling; it can also return from there to the specified default behavior. Exception handling behavior in a subject may vary, depending on from which state or what type of message (cancellation, temporary stopping of the process, etc.) it is called. The initial state of exception handling can be a receive state or a function state.

Messages, like 'service cancellation', that lead to exception handling always have higher priority than other messages. This is how modelers express that specific messages are read in a preferred way. For instance, when the approval message from the manager is received in the input pool of the employee, and

shortly thereafter the cancellation message, the latter is read first. This leads to the corresponding abort consequences.

Since now additional messages can be exchanged between subjects, it may be necessary to adjust the corresponding conditions for the input-pool structure. In particular, the input-pool conditions should allow storing an interrupt message in the input pool. To meet organizational dynamics, exception handling and extensions are required. They allow taking not only discrepancies but also new patterns of behavior, into account.

Behavior Extensions— When exceptions occur, currently running operations are interrupted. This can lead to inconsistencies in the processing of business objects. For example, the completion of the business trip form is interrupted once a cancellation message is received, and the business trip application is only partially completed. Such consequences are considered acceptable, due to the urgency of cancellation messages. In less urgent cases, the modeler would like to extend the behavior of subjects in a similar way, however, without causing inconsistencies. This can be achieved by using a notation analogous to exception handling. Instead of denoting the corresponding diagram with 'exception', it is labeled with 'extension'.

Behavior extensions enrich a subject's behavior with behavior sequences that can be reached from several states equivocally.

For example, the employee may be able to decide on his own that the business trip is no longer required and withdraw his trip request. Figure 3.13 shows that the employee can cancel a business trip request in the states 'send business trip request to manager' and 'receive answer from manager'. If the transition 'withdraw business trip request' is executed in the state 'send business trip request to manager', then the extension 'F1' is activated. It leads merely to canceling of the application. Since the manager has not yet received a request, he does not need to be informed.

In case the employee decides to withdraw the business trip request in the state 'receive answer from manager', then extension 'F2' is activated. Here, first the supervisor is informed, and then the business trip is canceled.

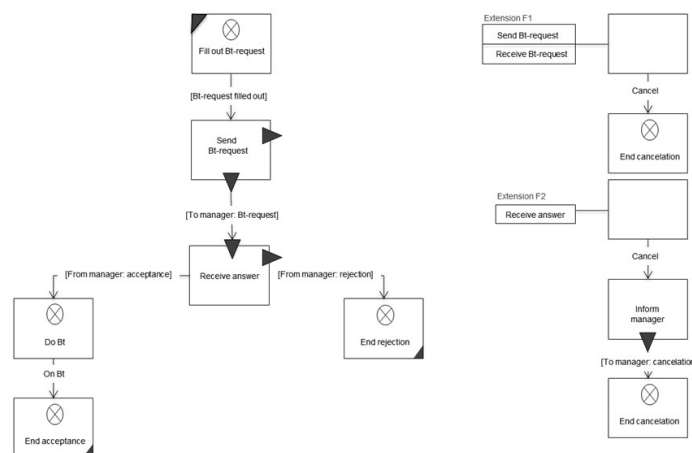


Figure 3.13: Subject behavior of employee with behavior extensions

Alternative Actions (Freedom of Choice)

So far, the behavior of subjects has been regarded as a distinct sequence of internal functions, send and receive activities. In many cases, however, the sequence of internal execution is not important.

Certain sequences of actions can be executed overlapping. We are talking about freedom of choice when accomplishing tasks. In this case, the modeler does not specify a strict sequence of activities. Rather, a subject (or concrete entity assigned to a subject) will organize to a particular extent its own behavior at runtime.

The freedom of choice with respect to behavior is described as a set of alternative clauses which outline several parallel paths. At the beginning and end of each alternative, switches are used: A switch set at the beginning means that this alternative path is mandatory to get started, a switch set at the end means that this alternative path must be completely traversed. This leads to the following constellations:

- Beginning is set/end is set: Alternative needs to be processed to the end.
- Beginning is set/end is open: Alternative must be started but does not need to be finished.
- Beginning is open/end is set: Alternative may be processed, but if so must be completed.
- Beginning is open/end is open: Alternative may be processed but does not have to be completed.

The execution of an alternative clause is considered complete when all alternative sequences, which were begun and had to be completed, have been entirely processed and have reached the end operator of the alternative clause.

Transitions between the alternative paths of an alternative clause are not allowed. An alternate sequence starts in its start point and ends entirely within its endpoint.

Figure 3.14 shows an example for modeling alternative clauses. After receiving an order from the customer, three alternative behavioral sequences can be started, whereby the leftmost sequence, with the internal function 'update order' and sending the message 'deliver order' to the subject 'warehouse', must be started in any case. This is determined by the 'X' in the symbol for the start of the alternative sequences (the gray bar is the starting point for alternatives). This sequence must be processed through to the end of the alternative because it is also marked in the end symbol of this alternative with an 'X' (gray bar as the endpoint of the alternative).

The other two sequences may, but do not have to be, started. However, in case the middle sequence is started, i.e., the message 'order arrived' is sent to the sales department, it must be processed to the end. This is defined by an appropriate marking in the end symbol of the alternatives ('X' in the lower gray bar as the endpoint of the alternatives). The rightmost path can be started but does not need to be completed.

The individual actions in the alternative paths of an alternative clause may be arbitrarily executed in parallel and overlapping, or in other words: A step can be executed in an alternative sequence, and then be followed by an action in any

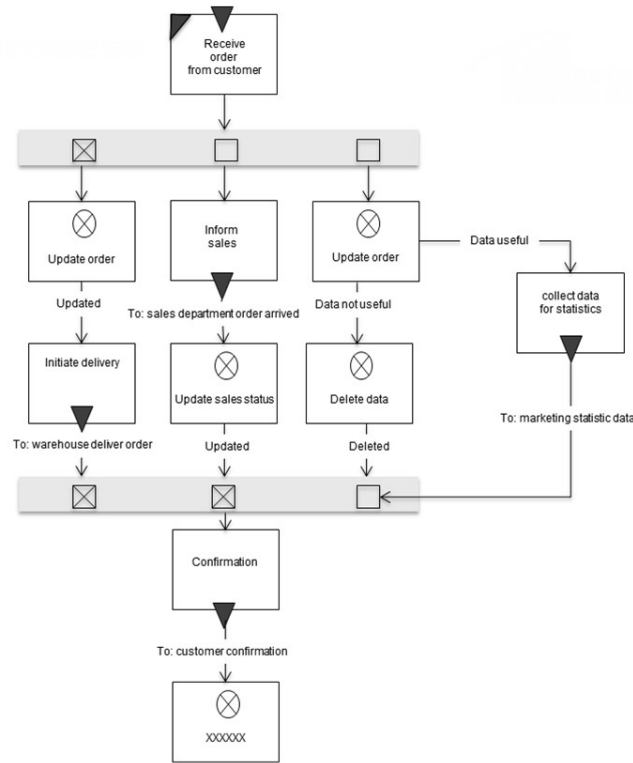


Figure 3.14: Example of Process Alternatives

other sequence. This gives the performer of a subject the appropriate freedom of choice while executing his actions.

In the example, the order can thus first be updated, and then the message 'order arrived' sent to sales. Now, either the message 'deliver order' can be sent to the warehouse or one of the internal functions, 'update sales status' or 'collect data for statistics', can be executed.

The left alternative must be executed completely, and the middle alternative must also have been completed, if the first action ('inform sales' in the example) is executed. Only the left alternative can be processed because the middle one was never started. Alternatively, the sequence in the middle may have already reached its endpoint, while the left is not yet complete. In this case, the process waits until the left one has reached its endpoint. Only then will the state 'confirmation' be reached in the alternative clause. The right branch neither needs to be started, nor to be completed. It is therefore irrelevant for the completion of the alternative construct.

The leeway for freedom of choice with regards to actions and decisions associated with work activities can be represented through modeling the various alternatives—situations can thus be modeled according to actual regularities and preferences.

3.2 ONTOLOGY OF SUBJECT BEHAVIOR DESCRIPTION

Each subject has a base behavior (see property 202 in 3.15) and may have additional subject behaviors (see class *SubjectBehavior* in 3.15) for macros and guards. All these behaviors are subclasses of the class *SubjectBehavior*. The

The following figure shows the details of

States can be starting and/or endpoints of transitions (see properties 228 and 230 in figure 3.16). This means a state may have outgoing and/or incoming transitions (see properties 224 and 217 in figure 3.16). Each transition is controlled by a transition condition which must be true before a behavior follows a transition from the source state to the target state.

States

Appendix

More complex states are choice segments (subclass relation 014). A choice segment contains choice segment paths (subclass 015 and property 200). Each choice segment path can be of one of four types. If a segment path is started



Figure 3.16: Subject Behavior describingComponent



Figure 3.17: Details of States

Transitions

[illegible]

Figure 3.18: Details of transitions

3.3 ASM DEFINITION OF SUBJECT EXECUTION

The goal of this section is to provide a minimal set of reduced rules to establish a foundation to understand the ASM semantics, leaving out certain features and implementation details. It is therefore just an informal introduction to the topic.

simplifications for this chapter:

- no Observer support => no execution state, no state priorities => Cancel not required

- limited scope to InternalAction, Send, Receive, CallMacro, ModalSplit/-ModalJoin, End => no VarMan, Cancel, SelectAgents, Tau
- discuss: proper-termination and CloseIP/OpenIP are motivated from interaction soundness. include? mention? hard-exclude (remove references from code)?
- no KillBehavior (although recursive macros and reservation messages). therefore this will not be sound - but a bit less complicated

3.3.1 Architecture

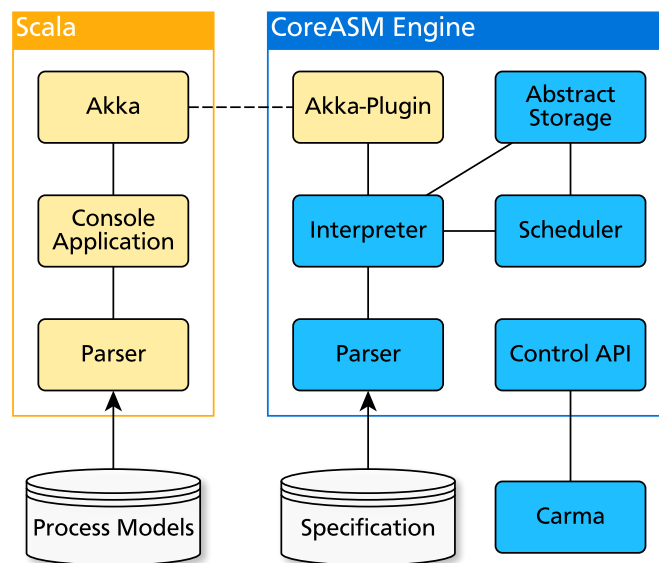


Figure 3.19: Architecture of the reference implementation

The overall architecture is shown in figure 3.19 and consists on the top level of a console application as user interface and the CoreASM engine as execution environment for the PASS-interpreter specification. Both high level components are running in parallel in separate Java Virtual Machine processes. The PASS-interpreter specification file includes an ASM specification of asynchronous multi-agent ASMs, executing each Subject by one ASM-agent each.

The CoreASM engine parses the specification file and executes the rules in the interpreter in cooperation with the abstract storage and the scheduler. The abstract storage stores the state of the ASM and is also used to support TurboASMs and their submachine states.

The scheduler is used to support asynchronous multi-agent ASMs; with the *default* scheduling policy it selects a random subset of the running ASM agents and calls the interpreter for the parallel evaluation of their main rules. If the resultant update sets are consistent they are applied in the abstract storage, otherwise the scheduler selects a different subset of the running ASM agents for a re-evaluation. Supplementary the *onebyone* scheduling policy can be used to evaluate only a single agent per step and the *allfirst* policy can be used to attempt to evaluate all agents at once before falling back to the default scheduling policy in case of inconsistencies. We use the *allfirst* scheduling policy in our work for performance reasons but could use the *default* policy as well.

The Carma application is a simple Java application provided by the CoreASM framework to allow the usage of the CoreASM engine as standalone application in a command line.

The console application is developed in Scala. A user can load, start and execute locally stored S-BPM Process Models with it. The interaction between the console application and the CoreASM engine is realized by Akka actors. The Akka actor of the engine has full read and write access to all CoreASM functions by using a Plug-In interface.

3.3.2 Foundation

The interpreter uses asynchronous multi-agent Turbo ASMs. It supports the concurrent execution of multiple process models and multiple instances of each process model. Each instance has a unique *ProcessInstanceID* (short: PI) assigned. Within a process instance multiple instances of a subject can occur (MultiSubject concept). Each subject instance has an agent assigned, to distinguish the subject instances. This agent is identified by its name. We therefore identify a subject instance by the tuple (Process Model ID, Process Instance ID, Subject ID, Agent Name). This tuple is called *Channel* (short: ch), as it is used in the mobility of channels concept in order to support distributed communication patterns.

In the interpreter, each subject instance has an ASM Agent assigned, that keeps track of its current state, where we mean state in the sense of which subject data is present, the content of the inputpool queues and also the active SBD states. This state is stored in ASM functions and assigned to the *Channel*.

```
// ASM Agent -> Channel
function channelFor : Agents -> LIST

derived processIDFor(a)      = processIDOf(channelFor(a))
derived processInstanceFor(a) = processInstanceOf(channelFor(a))
derived subjectIDFor(a)      = subjectIDOf(channelFor(a))
derived agentFor(a)          = agentOf(channelFor(a))

derived processIDOf(ch)      = nth(ch, 1)
derived processInstanceOf(ch) = nth(ch, 2)
derived subjectIDOf(ch)      = nth(ch, 3)
derived agentOf(ch)          = nth(ch, 4)
```

Listing 1: Channel definitions

In the function `channelFor` the assignment from the ASM Agents to their *Channels* is stored. The derived functions are used to lookup certain tuple elements of the channel.

Analogous to programming languages we call Subject Data *Variables*. Their scope is either bound to a Subject or a Macro Instance and can only be accessed by the Subject. Variables are identified by their name and have an explicit data type and a value.

Variables are stored in the `variable` function which maps from the Subject's Channel, the scoped Macro Instance ID and the Variable's name to a pair of the data type and value. For Variables that are not scoped to a Macro Instance, and

are therefore accessible for any state in any Macro Instance of the Subject, the unused Macro Instance ID 0 is used.

The function `variableDefined` is used to keep track of Variables that are in use, so that their content can be reset upon the termination of a Macro Instance or the Subject, respectively.

```
// Channel * macroInstanceNumber * varname -> [vartype, content]
function variable : LIST * NUMBER * STRING -> LIST

// Channel -> Set[(macroInstanceNumber, varname)]
function variableDefined : LIST -> SET
```

Listing 2: variable

3.3.3 Interaction Definitions

We implement the interaction between Subjects as asynchronous Message exchange. Messages are placed into the Inputpool of the receiver where they are then retrieved from when the receiver is in a Receive state.

Messages

The message content consists of the actual payload and its data type. As this reference implementation is intended only for an abstract process execution we abstract the payload / business objects to be just a text given as string.

For the communication with MultiSubjects, i.e. sending the same Message to multiple Agents of one Subject, we use an *all-or-none* strategy. This is accomplished by separating the sending of a Message into two phases: first a reservation Message is placed at each receiver into the Inputpool. Only after all reservations could be placed they are then replaced with the actual Message.

Inputpool

The Inputpool is structured into multiple FIFO queues per Subject ID of the sender, the Messagetype and the CorrelationID.

The Inputpool can be limited to allow a maximum number of Messages and reservations per sender Subject ID and Messagetype; in case the Inputpool Limit is reached no additional reservation can be placed. To support the proper termination of a Subject a specific queue (and also the complete Inputpool) can be closed, in which case no additional reservation can be placed into it, too.

The queues of the Inputpool are stored in the `inputPool` function. The function `inputPoolDefined` is used to keep track of the locations of the queues that are in use, so that their content can be checked upon termination. The function `inputPoolClosed` is used to store whether a queue is closed. The special location `inputPoolClosed(ch, undef, undef, undef)` is used to store whether the complete Inputpool is closed.

We define the function `derived availableMessages(receiverChannel, senderSubjectID, msgType, ipCorrelationID)` to return the Messages from the location `inputPool(receiverChannel, senderSubjectID, msgType, ipCorrelationID)` that can be received, i.e. that it filters out reservations and reduces Messages from the same sender to only the oldest one.


```

// Channel * senderSubjID * msgType * correlationID
// -> [msg1, msg2, ...]
function inputPool : LIST * STRING * STRING * NUMBER -> LIST

/* stores all locations where an inputPool was defined */
// Channel -> {[senderSubjID, msgType, correlationID], ...}
function inputPoolDefined : LIST -> SET

// Channel * senderSubjID * msgType * correlationID
function inputPoolClosed : LIST * STRING * STRING * NUMBER
-> BOOLEAN

```

Listing 3: inputPool

3.3.4 Subject Behavior

As depicted in figure ??, a Subject Behavior consists at least of one *Main Macro* and might have an arbitrary number of minor Macros, called *Additional Macros*.

```

rule SubjectBehavior =
  MacroBehavior(1)

```

Listing 4: SubjectBehavior

The MacroBehavior rule controls the evaluation of all active states for the given Macro Instance ID MI.

```

rule MacroBehavior(MI) =
  let ch = channelFor(self) in
  choose stateNumber in activeStates(ch, MI) do
    Behavior(MI, stateNumber)

```

Listing 5: MacroBehavior

From that list a state `stateNumber` is chosen to be evaluated with the Behavior rule.

The evaluation of a state is structured into three main phases: initialization, the state function and an optional transition behavior.

The state function is responsible for the selection of an outgoing transition and has to supervise the Timeout. It also has to enable and disable its outgoing transitions, meaning that transitions can be available depending on some dynamic state, for example whether a certain Message is present in the Inputpool. Usually the outgoing transition will be selected by the environment, however with auto-transitions it is possible that such an transition is automatically selected as soon as it becomes enabled and as long as there are no other transitions to select from.

In the beginning the Behavior rule initializes the state with the StartState rule, which will set `initializedState` to `true`. If the function should not be aborted the Perform rule calls the state behavior of the underlying function until it is completed. In the next phase the selected transition will be initialized by the StartSelectedTransition rule and the transition behavior will be performed with the PerformTransition rule until it is completed as well.

```

rule Behavior(MI, currentStateNumber) =
  let s = currentStateNumber,
      ch = channelFor(self) in
    if (initializedState(ch, MI, s) != true) then
      StartState(MI, s)
    else if (abortState(MI, s) = true) then
      AbortState(MI, s)
    else if (completed(ch, MI, s) != true) then
      Perform(MI, s)
    else if (initializedSelectedTransition(ch, MI, s) != true) then
      StartSelectedTransition(MI, s)
    else
      let t = selectedTransition(ch, MI, s) in
        if (transitionCompleted(ch, MI, t) != true) then
          PerformTransition(MI, s, t)
        else
          Proceed(MI, s, targetStateNumber(processIDFor(self), t))

```

Listing 6: Behavior

As last step the Proceed rule removes the current state and adds the selected transition's target state.

The environment has full read access to all functions of this semantics and knows therefore each running Subject, their Macro Instances and their active states.

To define a homogeneous interface between the Function semantics and the environment we define the function wantInput to be written by an Function when it requires an external input, for example if an outgoing transition has to be chosen.

```

// Channel * MacroInstanceNumber * StateNumber -> Set[String]
function wantInput : LIST * NUMBER * NUMBER -> SET

```

Listing 7: wantInput

This function is read by our console application for all active states to present the user a list of possible decisions that can be made.

The environment then writes its external input in a corresponding function, for example for a transition decision into the selectedTransition function, and clears the wantInput function of that state.

The SelectTransition rule adds the "TransitionDecision" requirement into the wantInput function.

If the wantInput function already contains the "TransitionDecision" requirement nothing needs to be done and another state can be evaluated by the MacroBehavior rule. The same applies if there are no outgoing transitions enabled. Otherwise the requirement is added to the wantInput function.

3.3.5 Internal Action

The *Internal Action* is used to model DoStates, Subject-internal activities and decisions. It is labeled with a textual description of the activity that the Agent should perform. The outgoing transitions are labeled with a textual description


```

rule SelectTransition(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  if (|outgoingEnabledTransitions(ch, MI, s)| = 0) then
    skip // BLOCKED: none to select
  else if (not(contains(wantInput(ch, MI, s),
                        "TransitionDecision")) then
    add "TransitionDecision" to wantInput(ch, MI, s)
  else
    skip // waiting for selectedTransition

```

Listing 8: SelectTransition

of the possible execution results. Since the activity is performed outside of the interpreter all outgoing transitions are enabled from the beginning on and no transition rule has to be defined. Therefore the state function only consists of the timeout check and transition selection.

```

rule StartInternalAction(MI, currentStateNumber) = {
  StartTimeout(MI, currentStateNumber)

  EnableAllTransitions(MI, currentStateNumber)
}

```

Listing 9: StartInternalAction

The initialization of the InternalAction starts the Timeout and enables all outgoing transitions.

```

rule PerformInternalAction(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  if (shouldTimeout(ch, MI, s) = true) then {
    SetCompleted(MI, s)
    ActivateTimeout(MI, s)
  }
  else if (selectedTransition(ch, MI, s) != undef) then
    SetCompleted(MI, s)
  else
    SelectTransition(MI, s)

```

Listing 10: PerformInternalAction

The state function checks if a Timeout should be activated; otherwise the SelectTransition rule is called until the selectedTransition function has been set.

3.3.6 Send Function

The Send Function sends a Message. Disregarding the optional Timeout and Cancel transitions it must have exactly one outgoing transition which has to have parameters that define at least the Messagetype and the receiver's Subject ID.

We use an *all-or-none* strategy to send Messages to MultiSubjects, which means that the actual Message is only send when all receivers are able to store it in their Inputpool. Therefore the Send Function is structured into two phases: in the first phase, realized as state function, reservation Messages are placed and in the second phase, realized as transition function, these reservations are replaced with the actual Message.

To place a reservation in a receiver's Inputpool there must be space available in the corresponding queue and the receiver must not be *non-proper* terminated.

```
// Channel * MacroInstanceNumber * StateNumber -> Set[Messages]
function receivedMessages : LIST * NUMBER * NUMBER -> SET

// Channel * MacroInstanceNumber * StateNumber -> Set[Channel]
function receivers : LIST * NUMBER * NUMBER -> SET

// Channel * MacroInstanceNumber * StateNumber
function messageContent      : LIST * NUMBER * NUMBER -> LIST
function messageCorrelationID : LIST * NUMBER * NUMBER -> NUMBER
function messageReceiverCorrelationID : LIST * NUMBER * NUMBER
    -> NUMBER

// Channel * MacroInstanceNumber * StateNumber -> Set[Channel]
function reservationsDone : LIST * NUMBER * NUMBER -> SET

function nextCorrelationID : -> NUMBER
function nextCorrelationIDUsedBy : NUMBER -> Agents
```

Listing 11: receivedMessages

The Send Function stores the message content it has to send in the `messageContent` function. The `receivers` function is used to store the required receivers. When a reservation message has been placed at a receiver its Channel is added to the `reservationsDone` function.

The global function `nextCorrelationID` is used to increment CorrelationIDs. To ensure the uniqueness of a CorrelationID the `nextCorrelationIDUsedBy` function is used to store the ASM agent that used the given CorrelationIDs.

The initialization of the Send Function resets / initializes the `receivers` and `reservationsDone` functions. If the communication transition has a `messageContentVar` parameter given the content of that Variable is loaded and stored in the `messageContent` function. If it has a `messageNewCorrelationVar` parameter given a new CorrelationID is created and stored in the `messageCorrelationID` function. It will be stored in the Variable after the messages have been send. If the message that will be send correlates to a previous message from the receiver the CorrelationID from the Variable in `messageWithCorrelationVar` will be loaded so that the message is stored in the corresponding inputpool queue of the receiver.

In the state function the `SelectReceivers` rule is called until the receivers have been selected. The `SelectReceivers` rule interacts with the environment through the `Selection` and `SelectAgent` Functions in order to either select existing Channels from a Variable, given as parameter on the communication edge, or to select new assignments of Agents for the receiver Subject.

```

rule StartSend(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  // there must be exactly one transition
  let t = first_outgoingNormalTransition(pID, s) in {
    receivers(ch, MI, s) := undef
    reservationsDone(ch, MI, s) := {}
    let mcVName = messageContentVar(pID, t) in
      messageContent(ch, MI, s) := loadVar(MI, mcVName)

    // generate new CorrelationID now, it will be stored
    // in a Variable once the message(s) are send
    let cIDVName = messageNewCorrelationVar(pID, t) in
      if (cIDVName != undef and cIDVName != "") then {
        messageCorrelationID(ch, MI, s) := nextCorrelationID
        nextCorrelationID := nextCorrelationID + 1
        // ensure no other agent uses this same correlationID
        nextCorrelationIDUsedBy(nextCorrelationID) := self
      }
      else
        messageCorrelationID(ch, MI, s) := 0

    // load receiver IP CorrelationID now, to avoid
    // influences of any changes of that variable
    let cIDVName = messageWithCorrelationVar(pID, t) in
    let cID = loadCorrelationID(MI, cIDVName) in
      messageReceiverCorrelationID(ch, MI, s) := cID
  }

```

Listing 12: StartSend

```

rule PerformSend(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  if (receivers(ch, MI, s) = undef) then
    SelectReceivers(MI, s)
  else if (messageContent(ch, MI, s) = undef) then
    SetMessageContent(MI, s)
  else if (startTime(ch, MI, s) = undef) then
    StartTimeout(MI, s)
  else if (|receivers(ch, MI, s)| =
    |reservationsDone(ch, MI, s)|) then
    TryCompletePerformSend(MI, s)
  else if (shouldTimeout(ch, MI, s) = true) then {
    SetCompleted(MI, s)
    ActivateTimeout(MI, s)
  }
  else
    DoReservations(MI, s)

```

Listing 13: PerformSend

The Timeout is started only when the receivers and the messageContent functions are defined. Until all reservations are placed, and if no Timeout occurs, the DoReservations rule attempts to place further reservation messages. If all reservations are placed the TryCompletePerformSend rule completes the state function, depending on whether no receiver is *non-proper* terminated.

```
rule SetMessageContent(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  if not(contains(wantInput(ch, MI, ch),
                  "MessageContentDecision")) then
    add "MessageContentDecision" to wantInput(ch, MI, ch)
  else
    skip // waiting for messageContent
```

Listing 14: SetMessageContent

The SetMessageContent rule is called if no message content is given as parameter on the communication transition until the messageContent function is written by the environment.

```
// handle all receivers
rule DoReservations(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  let receiversTodo = (receivers(ch, MI, s) diff
                      reservationsDone(ch, MI, s)) in
  foreach receiver in receiversTodo do
    DoReservation(MI, s, receiver)
```

Listing 15: DoReservations

The DoReservations rule iterates over all receivers that did not already receive a reservation message. The DoReservation rule then tries to place a reservation message for such receiver.

The DoReservation rule does not try to place a reservation message if the receiver is *non-proper* terminated. Otherwise it determines the necessary parameters of the queue to use and builds the reservation message. To support sending to an External Subject a translation of the sender's original Subject ID to the Subject ID used in the External Process is performed by the searchSenderSubjectID function.

When the queue at inputPool(rCh, xSID, msgType, dstCorr) was not created yet a new queue is assigned to that location and remembered in the inputPoolDefined function on the receiver's side. If the queue is either closed or full no reservation message can be placed, otherwise it is enqueued at the end.

After all reservations could be placed the TryCompletePerformSend rule has to ensure that no receiver terminated *non-proper* in the meantime. In that case the Send Function blocks and can only be left by a Timeout or Cancel transition. Otherwise the state function is completed and the behavior can continue with the transition function.

The transition function calls the ReplaceReservation rule to replace all reservations with the actual Message. The EnsureRunning rule (re)starts a re-

```

// handle single reservation
// result true if hasPlacedReservation, adds to reservationsDone
rule DoReservation(MI, currentStateNumber, receiverChannel) =
  if (properTerminated(receiverChannel) = true) then
    let ch = channelFor(self),
        pID = processIDFor(self),
        sID = subjectIDFor(self),
        s = currentStateNumber in
    let Rch = receiverChannel,
        RpID = processIDOf(receiverChannel) in
    let sIDX = searchSenderSubjectID(pID, sID, RpID) in
    let msgCID = messageCorrelationID(ch, MI, s),
        RCID = messageReceiverCorrelationID(ch, MI, s) in
    // there must be exactly one transition
    let t = first_outgoingNormalTransition(pID, s) in
    let mT = messageType(pID, t) in
    let resMsg = [ch, mT, {}, msgCID, true] in
    seq
      // prepare receiver IP
      if (inputPool(Rch, sIDX, mT, RCID) = undef) then {
        add [sIDX, mT, RCID] to inputPoolDefined(Rch)
        inputPool(Rch, sIDX, mT, RCID) := []
      }
    next
      if (inputPoolIsClosed(Rch, sIDX, mT, RCID) != true) then
        if (inputPoolGetFreeSpace(Rch, sIDX, mT) > 0) then {
          enqueue resMsg into inputPool(Rch, sIDX, mT, RCID)
          add Rch to reservationsDone(ch, MI, s)
        }
      else
        skip // BLOCKED: no free space!
    else
      skip // BLOCKED: inputPoolIsClosed
  else
    skip // BLOCKED: non-properTerminated

```

Listing 16: DoReservation

ceiver if it is not already running. If the communication transition has the parameter `messageStoreReceiverVar` defined the used receivers of the Message are stored in that Variable. Also, if the communication transition has the parameter `messageNewCorrelationVar` defined the CorrelationID that was created in `StartSend` and used for the send messages will be stored in the given Variable.

Analogous to the `DoReservation` rule the `ReplaceReservation` rule has to determine the queue and build both the reservation message and the actual Message. It then can replace the reservation in the queue with the actual message.

To abort the Send Function all placed reservations have to be removed.

Just like the `ReplaceReservation` rule the `CancelReservation` rule determines the location of the queue and rebuilds the reservation message. It then removes the reservation from the queue.

```

rule TryCompletePerformSend(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  if (anyNonProperTerminated(receivers(ch, MI, s)) = true) then
    if (shouldTimeout(ch, MI, s) = true) then {
      SetCompleted(MI, s)
      ActivateTimeout(MI, s)
    }
  else
    // BLOCKED: a receiver where a reservation was placed has
    // terminated non-proper in the meantime
    skip
  else {
    // there must be exactly one transition
    let t = first_outgoingNormalTransition(pID, s) in
      selectedTransition(ch, MI, s) := t

    SetCompleted(MI, s)
  }

```

Listing 17: TryCompletePerformSend

```

rule PerformTransitionSend(MI, currentStateNumber, t) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in {
    foreach r in reservationsDone(ch, MI, s) do {
      ReplaceReservation(MI, s, r)

      EnsureRunning(r)
    }

    let storeVName = messageStoreReceiverVar(pID, t) in
      if (storeVName != undef and storeVName != "") then
        SetVar(MI, storeVName, "ChannelInformation",
              reservationsDone(ch, MI, s))

    let cIDVName = messageNewCorrelationVar(pID, t) in
      if (cIDVName != undef and cIDVName != "") then
        SetVar(MI, cIDVName, "CorrelationID",
              messageCorrelationID(ch, MI, s))

    SetCompletedTransition(MI, s, t)
  }

```

Listing 18: PerformTransitionSend

```

rule ReplaceReservation(MI, currentStateNumber, receiverChannel) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      sID = subjectIDFor(self),
      s = currentStateNumber in
  let Rch = receiverChannel,
      RpID = processIDOf(receiverChannel) in
  let t = first_outgoingNormalTransition(pID, s) in
  let mT = messageType(pID, t) in
  let sIDX = searchSenderSubjectID(pID, sID, RpID),
      msgCID = messageCorrelationID(ch, MI, s),
      RCID = messageReceiverCorrelationID(ch, MI, s) in
  let resMsg = [ch, mT, {}, msgCID, true],
      msg = [ch, mT, messageContent(ch, MI, s), msgCID, false],
      IPold = inputPool(Rch, sIDX, mT, RCID) in
  let IPnew = setnth(IPold, head(indexes(IPold, resMsg)), msg) in
  inputPool(Rch, sIDX, mT, RCID) := IPnew

```

Listing 19: ReplaceReservation

```

rule AbortSend(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in {
    foreach r in reservationsDone(ch, MI, s) do
      CancelReservation(MI, s, r)

    SetAbortionCompleted(MI, s)
  }

```

Listing 20: AbortSend

```

rule CancelReservation(MI, currentStateNumber, receiverChannel) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      sID = subjectIDFor(self),
      s = currentStateNumber in
  let Rch = receiverChannel,
      RpID = processIDOf(receiverChannel) in
  let t = first_outgoingNormalTransition(pID, s) in
  let mT = messageType(pID, t) in
  let sIDX = searchSenderSubjectID(pID, sID, RpID),
      msgCID = messageCorrelationID(ch, MI, s),
      RCID = messageReceiverCorrelationID(ch, MI, s) in
  let resMsg = [ch, mT, {}, msgCID, true],
      IPold = inputPool(Rch, sIDX, mT, RCID) in
  let IPnew = dropnth(IPold, head(indexes(IPold, resMsg))) in
  inputPool(Rch, sIDX, mT, RCID) := IPnew

```

Listing 21: CancelReservation

3.3.7 Receive Function

The Receive Function retrieves Messages from the Inputpool. The state function updates the enabled outgoing transitions according to the available Messages in the corresponding queue. When an outgoing transition is selected the Messages are removed from the queue by the transition function.

In the beginning of the state function the Timeout is started and then checked each time. If the Timeout doesn't need to be activated each outgoing transition is either set to be enabled or disabled by the CheckIP rule.

```

rule PerformReceive(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  // startTime must be the time of the first attempt to receive
  // in order to support receiving with timeout=0
  if (startTime(ch, MI, s) = undef) then
    StartTimeout(MI, s)
  else if (shouldTimeout(ch, MI, s) = true) then {
    SetCompleted(MI, s)
    ActivateTimeout(MI, s)
  }
  else
    seq
      forall t in outgoingNormalTransitions(pID, s) do
        CheckIP(MI, s, t)
    next
      let enabledT = outgoingEnabledTransitions(ch, MI, s) in
      if (|enabledT| > 0) then
        seq
          if (selectedTransition(ch, MI, s) != undef) then
            skip // there is already an transition selected
          else if (|enabledT| = 1) then
            let t = firstFromSet(enabledT) in
            if (transitionIsAuto(pID, t) = true) then
              // make automatic decision
              selectedTransition(ch, MI, s) := t
            else skip // can not make automatic decision
          else skip // can not make automatic decision
        next
          if (selectedTransition(ch, MI, s) != undef) then
            // the decision was made
            SetCompleted(MI, s)
          else
            // no decision made, waiting for selectedTransition
            SelectTransition(MI, s)
      else
        skip // BLOCKED: no messages

```

Listing 22: PerformReceive

When exactly one auto transition is enabled, and no transition had been selected, an automatic selection for that transition is made. Otherwise a transition decision from the environment is required.


```

rule CheckIP(MI, currentStateNumber, t) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  let sID      = messageSubjectId      (pID, t),
      mT       = messageType           (pID, t),
      cIDVName = messageWithCorrelationVar(pID, t),
      countMin = messageSubjectCountMin (pID, t) in
  let cID = loadCorrelationID(MI, cIDVName) in
  let msgs = availableMessages(ch, sID, mT, cID) in
  if (|msgs| >= countMin) then
    EnableTransition(MI, t)
  else
    DisableTransition(MI, s, t)

```

Listing 23: CheckIP

The CheckIP rule loads the parameters from the communication transition attributes to determine the corresponding queue and the available Messages in it. The messageSubjectCountMin argument defines the minimal required number of different sender Agents of a MultiSubject. If the optional parameter messageWithCorrelationVar is not set the CorrelationID 0 is used.

When there are sufficient Messages, from different Agents of a MultiSubject, available the transition is enabled, otherwise it is set to be disabled.

```

rule PerformTransitionReceive(MI, currentStateNumber, t) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  let sID      = messageSubjectId      (pID, t),
      mT       = messageType           (pID, t),
      cIDVName = messageWithCorrelationVar(pID, t),
      countMax = messageSubjectCountMax (pID, t) in
  let cID = loadCorrelationID(MI, cIDVName) in {
    seq
    // stores the messages in receivedMessages
    InputPool_Pop(MI, s, sID, mT, cID, countMax)
    next
    if (messageStoreMessagesVar(pID, t) != undef and
        messageStoreMessagesVar(pID, t) != "") then
      let msgs = receivedMessages(ch, MI, s),
          vName = messageStoreMessagesVar(pID, t) in
      SetVar(MI, vName, "MessageSet", msgs)

    SetCompletedTransition(MI, s, t)
  }

```

Listing 24: PerformTransitionReceive

The transition function removes the available Messages from the Inputpool and optionally stores them in the Variable given as transition parameter messageStoreMessagesVar.

It first determines the location of the queue and passes them to the Input-

Pool_Pop rule which removes up to countMax of the oldest Messages from the queue at the location inputPool(ch, xSID, msgType, ipCorr) and stores them temporarily in the receivedMessages function.

3.3.8 Modal Split and Modal Join Functions

The ModalSplit Function initiates parallel execution paths that will be joined again in a ModalJoin Function.

```
rule ModalSplit(MI, currentStateNumber, args) =
  let pID = processIDFor(self),
      s = currentStateNumber in {
    // start all following states
    foreach t in outgoingNormalTransitions(pID, s) do
      let sNew = targetStateNumber(pID, t) in
        AddState(MI, s, MI, sNew)

    // remove self
    RemoveState(MI, s, MI, s)
  }
```

Listing 25: ModalSplit

It adds the target states of all outgoing transitions to the active states of its Macro Instance and removes itself.

```
// Channel * MacroInstanceNumber * joinState -> Number
function joinCount : LIST * NUMBER * NUMBER -> NUMBER

// number of execution paths have to be provided as argument
rule ModalJoin(MI, currentStateNumber, args) =
  let ch = channelFor(self),
      s = currentStateNumber,
      numSplits = nth(args, 1) in
  seq // count how often this join has been called
    if (joinCount(ch, MI, s) = undef) then
      joinCount(ch, MI, s) := 1
    else
      joinCount(ch, MI, s) := joinCount(ch, MI, s) + 1
  next
  // can we continue, or remove self and will be called again?
  if (joinCount(ch, MI, s) < numSplits) then {
    // drop this execution path
    RemoveState(MI, s, MI, s)
  }
  else {
    // reset for next iteration
    joinCount(ch, MI, s) := undef
    SetCompletedFunction(MI, s, undef)
  }
```

Listing 26: ModalJoin

The ModalJoin Function takes the number of execution paths to join as parameter, which doesn't need to be modelled explicitly as it could be determined

when the Process Model is parsed. The `joinCount` function is used to count how many times an execution path was already joined and is incremented each time an execution path leads to this state.

Until all but one execution paths are joined the current state is removed from the list of active states of the current Macro Instance. If the last execution path reached this state the `joinCount` function is reset for the next iteration and the state function is set to completed, so that the Macro Behavior proceeds regularly to the next state.

3.3.9 CallMacro Function

The `CallMacro` Function creates a new Macro Instance for the Macro ID given as first parameter. It is responsible for the evaluation of that Macro Instance and therefore calls the `MacroBehavior` rule with the created Macro Instance ID.

```
// Channel * macroInstanceNumber -> result
function macroTerminationResult : LIST * NUMBER -> ELEMENT

// Channel * macroInstanceNumber -> MacroNumber
function macroNumberOfMI : LIST * NUMBER -> NUMBER

// Channel * macroInstanceNumber * StateNumber -> MacroInstance
function callMacroChildInstance : LIST * NUMBER * NUMBER -> NUMBER
```

Listing 27: `macroTerminationResult`

The `callMacroChildInstance` function stores the Macro Instance ID of the created Macro Instance. The `macroTerminationResult` function is written, either with the boolean `true` or a string to indicate which outgoing transition of the `MacroState` should be selected, when the Macro Instance terminates.

The state function has two phases: in the beginning the Macro Instance is created and then in the main phase evaluated.

In the first phase the value of the `nextMacroInstanceNumber` function is stored in the `callMacroChildInstance` function and incremented. The `activeStates` for the new Macro Instance is initialized and the start state will be added later on in the `MacroBehavior` rule of the current Macro Instance.

The `CallMacro` Function can have an optional list of Variable names whose values are passed into Macro Instance-local Variables of the called Macro Instance with the `InitializeMacroArguments` rule.

The second phase evaluates the created Macro Instance.

When the Macro Instance has terminated its result is used to select the outgoing transition of the `CallMacro` state and the `callMacroChildInstance` function is reset for the next iteration. Otherwise the `MacroBehavior` rule is called for the created Macro Instance ID.

The `InitializeMacroArguments` rule iterates over all required macro parameters. For each parameter it loads the value of the Variable in the current Macro Instance and stores it in the new Macro Instance.

3.3.10 End Function

The `End` Function is used to terminate the current Macro Instance and has no outgoing transitions. If the current Macro Instance is the Main Macro Instance the `End` Function terminates the Subject.

```

rule CallMacro(MI, currentStateNumber, args) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  let childInstance = callMacroChildInstance(ch, MI, s) in
  if (childInstance = undef) then
    // start new Macro Instance
    let mIDNew = searchMacro(head(args)),
        MINew = nextMacroInstanceNumber(ch) in
    seqblock
      nextMacroInstanceNumber(ch) := MINew + 1
      macroNumberOfMI(ch, MINew) := mIDNew
      callMacroChildInstance(ch, MI, s) := MINew

    if (|macroArguments(ch, mIDNew)| > 0) then
      InitializeMacroArguments(MI, mIDNew, MINew, tail(args))

      StartMacro(MI, s, mIDNew, MINew)
    endseqblock
  else
    let childResult = macroTerminationResult(ch, childInstance) in
    if (childResult != undef) then {
      callMacroChildInstance(ch, MI, s) := undef

      // transport result, if present
      if (childResult = true) then
        SetCompletedFunction(MI, s, undef)
      else
        SetCompletedFunction(MI, s, childResult)
    }
  else
    // Macro Instance is active, call it
    MacroBehavior(childInstance)

```

Listing 28: CallMacro

```

rule InitializeMacroArguments(MI, mIDNew, MINew, givenSrcVNames) =
  local
    dstVNames := macroArguments(processIDFor(self), mIDNew),
    srcVNames := givenSrcVNames in
  while (|dstVNames| > 0) do {
    let dstVName = head(dstVNames),
        srcVName = head(srcVNames) in
    let var = loadVar(MI, srcVName) in
      SetVar(MINew, dstVName, nth(var, 1), nth(var, 2))

    dstVNames := tail(dstVNames)
    srcVNames := tail(srcVNames)
  }

```

Listing 29: InitializeMacroArguments

```

rule PerformEnd(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  if (|activeStates(ch, MI)| > 1) then
    AbortMacroInstance(MI, s)
  else {
    if (MI = 1) then { // terminate subject
      ClearAllVarInMI(ch, 0)
      ClearAllVarInMI(ch, 1)

      FinalizeInteraction()

      program(self) := undef
      remove self from asmAgents
    }
    else { // terminate only Macro Instance
      ClearAllVarInMI(ch, MI)

      let res = head(stateFunctionArguments(pID, s)) in
      if (res != undef) then
        // use parameter as result for CallMacro State
        macroTerminationResult(ch, MI) := res
      else
        // just indicate termination
        macroTerminationResult(ch, MI) := true
    }

    // remove self
    RemoveState(MI, s, MI, s)
  }

```

Listing 30: PerformEnd

The PerformEnd rule calls the AbortMacroInstance rule until no other states are active in the current Macro Instance.

If the current Macro Instance is the Main Macro Instance the Subject terminates. To do so the End Function resets all Variables of the Subject and terminates the ASM agent. Additionally, the FinalizeInteraction rule is called ...

Otherwise the Macro Instance was created by a CallMacro Function and only the Variables of the current Macro Instance are reset. If the End Function has a parameter it is stored in the function macroTerminationResult, so that the CallMacro Function proceeds with the corresponding outgoing transition. If no parameter is given the value is just set to **true** to indicate a termination without any particular result.

Implementation of Subject Oriented Models

Subject oriented models address the internal aspects and structures of a system. They are essentially models of the internal structure of a system and cover organizational and technical aspects. When implementing the models, it is now necessary to establish the relationship between the process model and the available resources. Figure 4.1 shows the individual steps from a process model to the executable process instance.

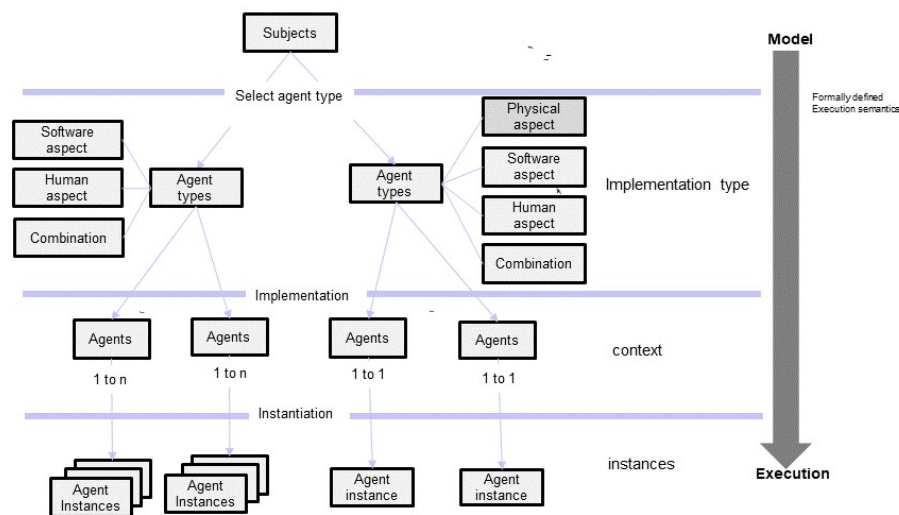


Figure 4.1: Implementation steps

In a system model, the actors, the actions, their sequences and the objects manipulated by the actions are described. Actions (activities) can be performed by humans, software systems, physical systems or a combination of these basic types of actors. We call them the task holders. For example, a software system can automatically perform the "tax rate calculation" action, while a person uses a software program to perform the "order entry" activity. The person enters the order data via a screen mask. The software checks the entered data for plausibility and saves it. However, activities can also be carried out purely manually,

for example when a warehouse worker receives a picking order on paper, executes it, marks it as executed on the order form and returns it to the warehouse manager.

When creating a system model, it is often not yet known which types of actors execute which actions. Therefore, it can be useful to abstract from said model when starting to describe processes by introducing abstract actors. A modeling language should allow the use of such abstractions. This means that when defining the process logic, no assertion should have to be made about what type of actor is realized. In S-BPM, the subjects represent abstract actors.

In the description of the control logic of a process, the individual activities are also described independently of their implementation. For example, for the action "create a picking order" it is not specified whether a human actor fills in a paper form or a screen mask, or whether a software system generates this form automatically. Thus, with activities the means by which something happens is not described, but rather only what happens.

The means are of course related to the implementation type of the actor. As soon as it has been defined which types of actors are assigned to the individual actions, the manner of realization of an activity has also been defined. In addition, the logical or physical object on which an action is executed also needs to be determined. Logical objects are data structures whose data is manipulated by activities. Paper forms represent a mixture between logical and physical objects, while a workpiece on which the "deburring" action takes place is a purely physical object. Therefore, there is a close relationship between the type of task holder, the actions and the associated objects actors manipulate or use when performing actions.

A system model can be used in different areas. The process logic is applied unchanged in the respective areas. However, it may be necessary to implement the individual actors and actions differently. Thus, in one environment certain actions could be performed by humans and in another the same actions could be performed by software systems. In the following, we refer to such different environments of use for a system model as context. Hence, for a process model, varying contexts can exist, in which there are different realization types for actors and actions.

In Subject Oriented Modeling, actors are not assigned to individual activities, but rather the actor type is assigned to an entire subject. This assignment is not part of the process logic, but in the most simple way it is done instead for each process in a separate two-column table. The left column contains the subject name and the right column the implementation type. If there are several contexts for a model, a separate assignment table is created for each of them. The assignment of the implementation type forms the transition between the system logic and its implementation. Subsequently, it has to be defined which persons, software systems and physical systems represent the actors and how the individual actions are concretely realized. These aspects are described in detail in the following subsections.

4.1 PEOPLE AND ORGANIZATIONS

4.2 PHYSICAL INFRASTRUCTURE

4.3 IT-SYSTEMS AND SOFTWARE

Aspects for further standardisation activities

5.1 SUBJECTS AND SHARED INPUT POOLS

5.2 STRUCTURING COMPLEX SYSTEMS

5.3 BUSINESS ACTIVITY MONITORING FOR S-BPM

5.3.1 Architecture

A BAM environment supported by Complex Event Processing consists of several elements necessary at build time and at runtime (see 5.1) [27, 8, 15]. At build time a modeling environment should provide tools for designing processes (e.g. Metasonic Build) and defining process performance indicators (PPIs), BAM events, rules, thresholds etc. as well as parameters for their visualization in report and on dashboards. At runtime there are (1) event producers like a process engine (e.g. Metasonic Flow) or an ERP system (e.g. SAP) which feed events into an event cloud or stream (chronologically ordered). (2) Event Processing Agents (EPA) form the event processing logic. They process events based on metrics, event patterns, rules and other parameters specified at design time. Their basic logical functions include filtering and transforming events and detecting patterns among them. Global state elements allow them accessing data from outside the application (e.g. from an ERP system). EPAs put the results of their processing (also to be understood as events) out to Event Consumers (3) like dashboards or process engines. Input and Output Adapters (IA, OA) transform event data between different formats of system elements as necessary. All system elements involved form an Event Processing Network (EPN), in which events are exchanged by communication mechanisms.

5.3.2 Modeling BAM Parameters at Build Time

As mentioned in the last section it is necessary not only to model the processes, but also numerous pieces of information relevant for a sound process monitoring in the sense of Business Activity Monitoring (BAM model). These can be derived from answers to questions like what, when, how and how often should be measured by whom [25]. The information should also include how single metrics are to be aggregated in order to determine Process Performance Indicators

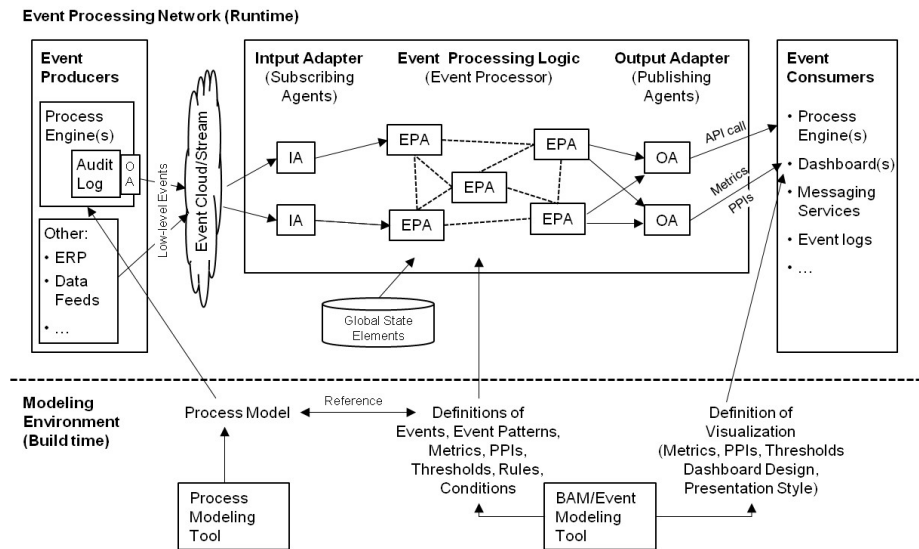


Figure 5.1: Integrated BAM/CEP Architecture [27]

(PPIs). For systematically collecting and documenting the necessary information fact sheets or templates for metrics and performance indicators have been developed [17, 20]. 5.2 shows an extract of a sample fact sheet defined for the average processing time of activities (see also [31, 23]). Definitions like this are in part basis for the reports presented in section 2.2. They can be considered to be a first model for describing BAM parameters.

Replacing the content column by more formal ontology-based linguistic patterns as suggested by Del-Río-Ortega et al. (see table 2) could help relating PPIs to elements of the process model, performing automated analysis [5] and implementing the measurement at runtime.

Table. 2. PPI Template based on Linguistic Patterns [5]

Friedenstab et al. argue that such linguistic patterns do not fit to the usually graphical modeling of processes which makes integration difficult [12]. The authors discuss some more approaches to BAM modeling. With regard to the limitations revealed, they present a BAM-related extension of the graphical Business Process Model Notation (BPMN) [12]. Using an abstract language syntax based on the Unified Modeling Language (UML) they started defining meta models for language constructs needed for BAM as there are Duration, Frequency, Composed Basic Measure, Aggregated Measure, Filter, Target Definition, Actions, Measure-based Expressions and Dashboard. Figure 8 depicts the example for the duration of elements on different levels of detail, where the grey colored parts indicate references to the BPMN specification.

In a second step Friedenstab et al. developed a concrete syntax allowing for modeling the abstract language elements with graphical symbols and text labels. Parts of it are visible in figure 9. The example shows the BAM model for determining the cycle times of a purchase order process modeled in BPMN (lower part). The upmost part for example expresses the fact that the overall cycle time (Duration) for the last 50 instances (Filter) has to be determined and displayed on the dashboard (Dashboard). Monitoring the average of the overall cycle time for completed instances controls the modeled business logic of the process. If it is above 48 hours goods are delivered with an express shipping

Attribute	Content
	Characteristics
Identifier	Average activity time
Description	Average time of a process activity within a certain period
To-be value/unit	tbd specifically (min.)
Tolerance range/unit	tbd specifically (%)
Escalation Rules/ Actions	In case of violation alert the process owner and start escalation process (tbd specifically)
Addressees	Process Owner, Middle Mangement, Accountants (tbd specifically) Responsibility Process Owner (tbd specifically)
	Measuring and Computing
Measuring Object (Single) Metrics	All instances of the process 'Purchase Order' Start time and end time of all activities of the process
Measuring Method	Read time stamps for beginning and end of activities written by Metasonic Flow
Measuring Frequency Algorithms	For every single instance as it occurs For computing period: 1 day.
Data Sources (general)	Tables in the database of Metasonic Suite: RT_PROCDESC, RT_PROCINST, REC_PARADESC, REC_RECTRANS, UM_USER
Data Sources (specific)	Activity processing time (for one instance): SELECT TIMESTAMP1 (SELECT STARTTIME FROM RT_PROCINST WHERE RT_PROCDESC = <i>process (purchase order)</i> AND ID = <i>instance (9)</i> FROM REC_RECTRANS WHERE RT_STDESC = <i>state (fill_in_form)</i> AND RT_PROCINST = <i>instance (9)</i> Completed instances: see separate fact sheet .
Computing Period (time, no. of inst.)	Daily
	Presentation
Presentation Style	As-is value and to-be value in combination with a spark line showing the historical development, deviation from to-be value in %
Presentation Frequency	Weekly and in case of escalation
Archiving	Stored in additional database table, linked with RT_PROCDESC

Table 5.1: Fact Sheet for a PPI (extract)

Attribute	Linguistic Pattern	Example
PPI-<ID> Process	<PPI descriptive name> <process ID the PPI is related to>	PPI-001 Average time of RFC analysis Request for change (RFC)
Goals	<strategic or operational goals the PPI is related to>	BG-002: Improve customer satisfaction BG-014: Reduce RFC time to response
Definition	The PPI is defined as <DurationMeasure> <CountMeasure> <ConditionMeasure> <DataMeasure> <DerivedMeasure> <AggregatedMeasure> [expressed in <unit of measure>]	The PPI is defined as the average of Duration of Analyse RFC activity
Target	The PPI value must be greater lower than [or equal to] <bound> be between <lower bound> and <upper bound> [inclusive] fulfil the following constraint: <target constraint>	The PPI value must be slower than or equal to 1 working day
Scope	The process instances considered for this PPI are the last <n> ones those in the analysis period <AP-x>	The process instances considered for this PPI are the last 100 ones
Source	<source from which the PPI measure can be obtained>	Event logs of BPMS
Responsible	<role> <department> <organization> <person>	Planning and quality manager
Informed	<role> <department> <organization> <person>	CIO
Comments	<additional comments about the PPI>	Most RFCs are created after 12:00

Table 5.2: Fact Sheet for a PPI (extract)

if the average cycle time is more than. Otherwise standard shipping is carried out. A deviation also leads to an alert sent to the process owner, while in any case the average is to be presented on the dashboard. The latter is also valid for the third time-related metric in the example, the partial cycle-time for the company-internal part of the process, which is set into relation with the overall cycle time.

The concept presented by Friedenstab et al. is thoroughly thought-out and clearly and precisely elaborated. The idea now is to adapt it to Subject-oriented Business Process Management and relate the abstract syntax to the S-BPM meta model instead of BPMN. Due to S-BPM being a more precise and comprehensive notation than BPMN [2] the mapping should be possible without problems. Table 3 compares the BPMN specification elements used by [12] with the ones appropriate in S-BPM [9].

BPMN Specification Element	S-BPM Specification Element
Process, Activity, Flow Nodes	Process, Subject Behaviour States (Function, Send, Receive, Start, End)
Frequency (Countable Element)	Process, Activity, Data Objects, Data States
Duration (Time-Consuming Element)	Process, Subject Behaviour States (Function, Send,

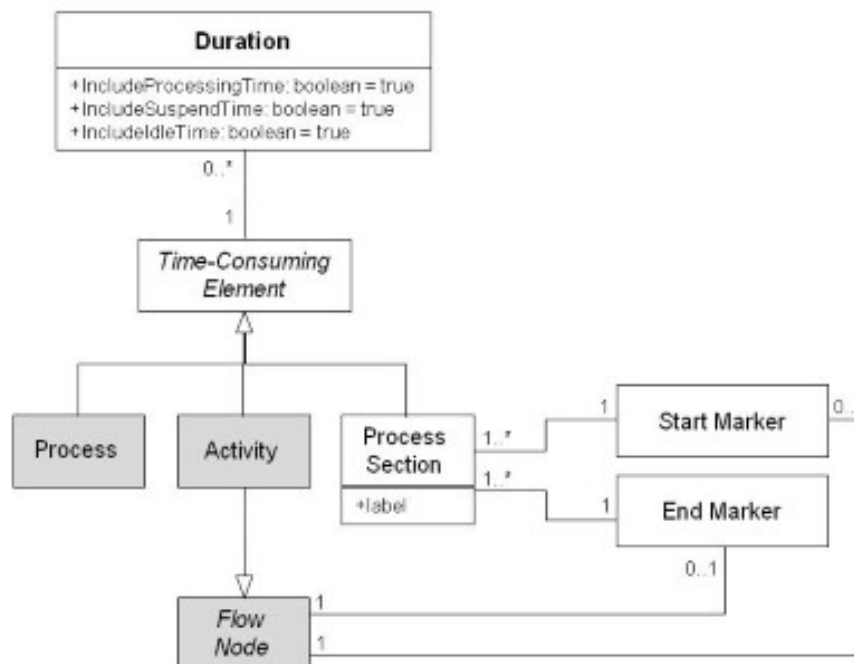


Figure 5.2: Meta Model for Duration (related to BPMN) [12]

Receive), Business Objects and their States Actions Process Process Measure-based Expressions Expression, Sequence Flow Incoming Message

The remaining constructs as well as the extensions do not depend on the process modeling language and thus are not included in the table. On the other hand S-BPM, following its paradigm of regarding subjects, predicates and objects as equally important parts of a process, offers the subject as an additional specification element to add. In figure 10 we modified the picture of figure 8 by replacing the BPMN by S-BPM elements and adding the subject. This allows modeling the determination of the overall time a subject (respectively the allocated resource(s)) spends on working on a process instance. This is of interest for cost-related analysis (see section 2.3).

Fig. 10. Meta Model for Duration (related to S-BPM)

In order to show how the BAM language syntax constructs can be related to subject-oriented models we designed the purchase order process in S-BPM. Due to missing information in the BPM model some assumptions were necessary like who performs the process steps (subjects). We then added the BAM modeling symbols to create a monitoring model similar to that in figure 9. The result is depicted in the following graph. In the lower part it includes the subject interaction diagram (SID) of the process. The SID shows the subjects involved and how they coordinate themselves in the course of action by exchanging messages. In the monitoring model in the upper part a difference can be seen. The partial cycle time for the company-internal activities can be modeled by just relating the clock symbol to the subject 'Sales'. In the example this subject represents all steps carried out within the organization. In the same way we can determine the cycle time for the other subjects.

Fig. 11. BAM Model for Cycle Times of a Purchase Order Process based

on S-BPM Given a special information demand a more granular modeling of BAM parameters is possible on the subject behavior level. Figure 12 for example details the behavior of “Sales” including all receive, send and functional states walked through by the subject. The symbols indicate that the average cycle time between order reception and confirming the order to the customer should be measured. In the same way cycle times between states in behaviours of different subjects can be modelled.

5.6 Fig. 12. BAM Model for Cycle Time of a Process Section based on S-BPM Back on the level of subject interaction diagram we could also model to determine the overall time for receiving (waiting), sending and doing, both by process and by subject. Modeling on the two diagram levels reduces complexity.

4 Conclusion and future Work This contribution systematized Business Process Monitoring and shed some light on the current state of monitoring in the context of S-BPM. Starting there we emphasized Business Activity Monitoring and took a closer look to the modelling of BAM parameters. We showed that the approach for BPMN presented by Friedenstab et al. can be adapted to S-BPM with little effort and that S-BPM shows additional potential to further develop the concept. This is where future work needs to continue. The first step to go should be elaborating, detailing and tailoring the modeling language for the needs of S-BPM in order define a comprehensive basis for the succeeding task of developing easy-to-use software tool support. These could be pursued as parts of the Open S-BPM Initiative, which is underway to develop “ among other artifacts - a process modeling and a process execution software for S-BPM, both based on the Eclipse Ecore meta model (see [11, 14] and <http://www.i2pm.net/open-s-bpm/projects>). The BAM modeling tool should make use of the model data created by the process modeling tool and add its results to a combined model base both for process execution and BAM. The third step would then be to build BAM functionality which at runtime processes events according to the subject-oriented BAM models. There is some evidence that S-BPM provides good premises to support event processing [10], e.g. by integration of a CEP Engine or single Event Processing Agents as subjects into processes. This has to be proven by a thorough investigation of the interrelationship and integration potential of CEP and S-BPM concepts and solutions. Generating code for BAM functionality out of the BAM model is another challenge to tackle [12]. With the clear formal semantic of its underlying process algebra the S-BPM modeling language allows this for process models [9]. Consequently it seems to be worthwhile to investigate the possibilities of code generation out of BAM models too.

In such an environment a S-BPM-based process engine like Metasonic Flow would not only be event producer and event consumer, but also part of the event processing logic, communicating with other elements by message exchange (see figure 7).

References

1. Accorsi, R., Ulrich, M., Van der Aalst, W.: Process Mining, Informatik Spektrum, Band 35, Heft 5, 2012, pp. 354-359.
2. Bärger, E.: Approaches to modeling business processes: a critical analysis of BPMN, workflow patterns and YAWL, Journal of Software and Systems Modeling, Vol. 11 (3) 2012, pp. 305-318.
3. Chandy, K., Schulte, W.: Event Processing: Designing IT Systems for Agile Companies, New York, 2010.
4. DeFee, J., Harmon, P.: Business Activity Monitoring and Simulation, in: Fischer, L. (ed.), Workflow Handbook, Future Strategies Inc., Lighthouse Point, 2005, pp.53-74.
5. Del-Río-Ortega, A., De Reyna, M., Durán Toro, A., Ruiz-Cortés, A.: Defining Process Performance Indicators by Using Templates and Patterns, in: Barros, A.,

Gal, A., Kindler, E. (eds.): BPM 2012, LNCS 7481, Springer, Berlin Heidelberg, 2012, pp. 223-228. 6. Dinter, B., Bucher, T.: Business Performance Management, in: Chamoni, P., Gluchowski, P. (Eds.), *Analytische Informationssysteme*, 3rd Ed., Springer, Berlin Heidelberg, 2006, pp. 23-50. 7. Eckert, M., Bry, F.: Complex Event Processing (CEP), *Informatik Spektrum*, Band 32, Heft 2, 2009, pp. 163-167. 8. Etzion O., Niblett P.: *Event Processing in Action*, Manning Publications, Stamford, 2011. 9. Fleischmann, A., Schmidt, W., Stary, C., Obermeier, S., BÄúrger, E.: *Subject-oriented Business Process Management*, Springer, Berlin Heidelberg, 2012. 10. Fleischmann, A., Schmidt, W., Stary, C., Strecker, F.: Nondeterministic Events in Business Processes, *Proceedings of the 6th International Workshop on Event-driven Business Process Management (edBPM2012)*, co-located with BPM 2012, Tallinn/Estonia, *Lecture Notes in Business Information Processing (LNBIP)*, Springer, Berlin Heidelberg, 2012. 11. Fleischmann, A., Schmidt, W., Stary: Open S-BPM, in: Fischer, H., Schneeberger, J. (Eds.), *Proceedings of the 5th International Conference S-BPM ONE 2013*, *Communications in Computer and Information Sciences (CCIS)* No. xxx, Springer, Berlin Heidelberg 2013. 12. Friedenstab, J.-P., Janiesch, C., Matzner, M., MÄijller, O.: Extending BPMN for Business Activity Monitoring, *45th Hawaii International Conference on System Sciences*, 2012, pp. 4158-4167. 13. HeÄš, H.: Von der Unternehmensstrategie zur Prozess-Performance äÄš Was kommt nach Business Intelligence? in: Scheer, A.-W., Jost, W., HeÄš, H. und Kronz, A., *Corporate Performance Management*, Berlin, 2005, pp. 7-29. 14. Institute of Innovative Process Management (I2PM), www.i2pm.net. 15. Janiesch, C., Matzner, M., MÄijller, O.: A Blueprint for Event-driven Business Activity Management, in: Rinderle, S., Toumani, F., and Wolf, K. (Eds.), *9th International Conference on Business Process Management (BPM)*. LNCS 6896, Springer, Berlin Heidelberg, 2011, pp. 17-28. 16. Kang, J., Kwan, H.: A Business Monitoring System Supporting Real-Time Business Performance Management, *Proceedings of the 2008 Third International Conference on Convergence and Hybrid Information Technology (ICCIT '08)* Vol. 1, Washington DC 2008, pp. 473-478. 17. KÄijtz, M.: *Kennzahlen in der IT: Werkzeuge fÄijr Controlling und Management*. 3. Aufl., dpunkt, Heidelberg, 2009. 18. Luckham, D., Schulte, R. (Eds.): *Event Processing Glossary Version 2.0/2011*, Event Processing Technical Society, <http://www.complexevents.com/2011/08/23/event-processing-glossary-version-2-0/>, last access 2012-07-25. 19. Luckham, D.: *The Power of Events: An Introduction to Complex Event Processing in Distributed Enterprise Systems*, Amsterdam, 2002. 20. Marx GÄšmez, J., Junker, H., Odebrecht, S.: *IT-Controlling*, Erich Schmidt Verlag, Berlin 2009. 21. Metasonic Flow, User Manual V4.4, Metasonic AG, www.metasonic.com, Pfaffenhofen, 2012. 22. Panagos, E., Rabinovich, M.: Predictive Workflow Management, *Proceedings of the 3rd International Workshop on Next Generation Information Technologies and Systems*, 1997, pp. 193-197. 23. Pehlke, A.: *Aufbau eines Business Activity Monitoring fÄijr den subjektorientierten Ansatz des Business Process Managements (S-BPM)*, Bachelor Thesis, University of Applied Sciences Ingolstadt, Ingolstadt 2012. 24. Petzel, E., Czaja, R., *Simulation-based Process Optimization*, in: Fischer, H., Schneeberger, J. (Eds.), *Proceedings of the 5th International Conference S-BPM ONE 2013*, *Communications in Computer and Information Sciences (CCIS)* No. xxx, Springer, Berlin Heidelberg 2013. 25. Schmelzer, H., Sesselmann, W.: *GeschÄdftsprozessmanagement in der Praxis*, 7. Auflage, Hanser, MÄijlnchen, 2010. 26. Schmidt, W., Fleischmann, A. und Gilbert, O.: Subjeksi-

entiertes Geschäftsprozessmanagement, HMD – Praxis der Wirtschaftsinformatik, Heft 266, 2009, pp. 52-62. 27. Schmidt, W.: Business Activity Monitoring, in: Rausch, P., Sheeta, A., Ayesh, A., Business Intelligence and Performance Management - Theory, Systems and Industrial Applications, Springer UK, 2013. 28. Schulte, W., Gassman, B.: Business Activity Monitoring, in: Dixon, J. (ed.): Hype Cycle for Business Process Management 2012. Gartner Inc. 2012, pp. 92-94. 29. Van der Aalst, W.: Process Mining, Springer, Berlin Heidelberg, 2011. 30. Von Ammon, R. Ertlmaier, T., Etzion, O., Kofman, A., Paulus, T.: Integrating Complex Events for Collaborating and Dynamically Changing Business Processes in: Dan, A., Gittler, F. and Toumani, F. (Eds.): ICSOC/ServiceWave 2009, LNCS 6275, Springer, Berlin Heidelberg, 2010, pp. 370-384. 31. Zehbold, C., Schmidt, W., Fleischmann, A.: Activity-Based Costing for S-BPM, in: Fischer, H., Schneeberger, J. (Eds.), Proceedings of the 5th International Conference S-BPM ONE 2013, Communications in Computer and Information Sciences (CCIS) No. xxx, Springer, Berlin Heidelberg 2013. 32. Zehbold, C.: Controllingansatz für S-BPM, Working Papers Series of the University of Applied Sciences Ingolstadt, No. 25, Ingolstadt, 2012.

5.4 SUBJECT ORIENTED PROJECT MANAGEMENT

5.5 SUBJECT ORIENTED PROJECT MANAGEMENT

Model for Cycle Times.jpg

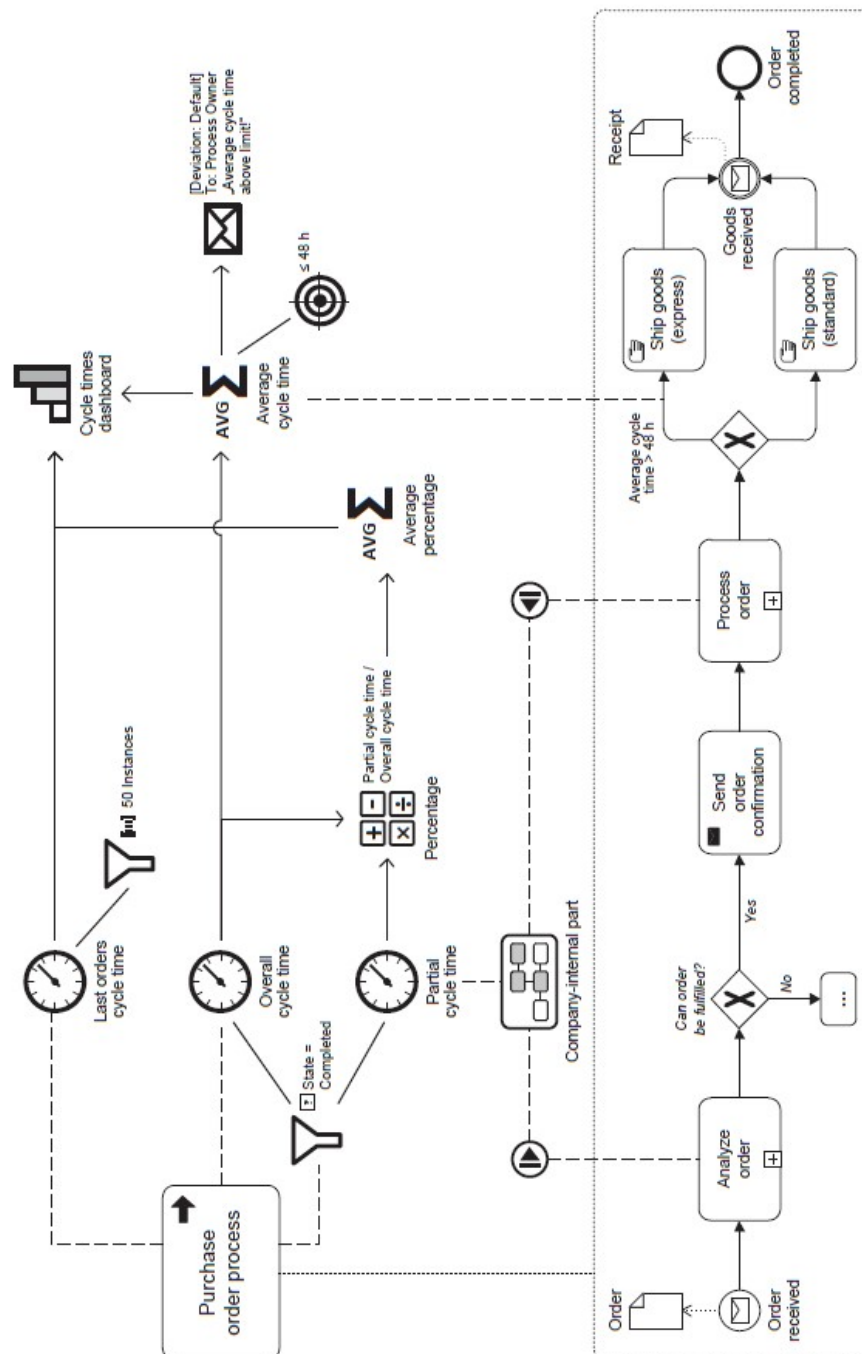


Figure 5.3: BAM Model for Cycle Times of a Purchase Order Process based on BPMN [12]

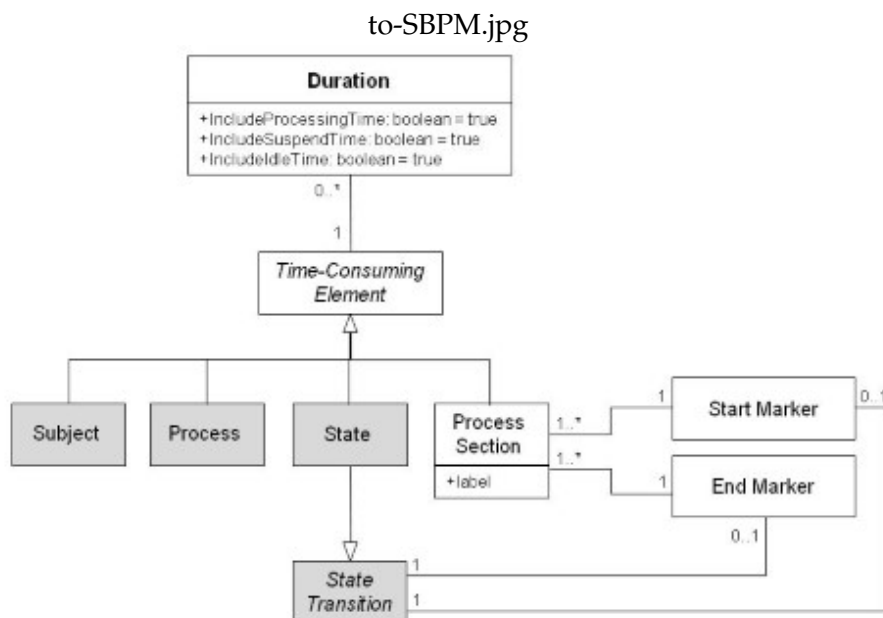


Figure 5.4: Meta Model for Duration (related to S-BPM)

Cycle-Times-of-a-Purchase-Order-Process-based-on-S-BPM.png

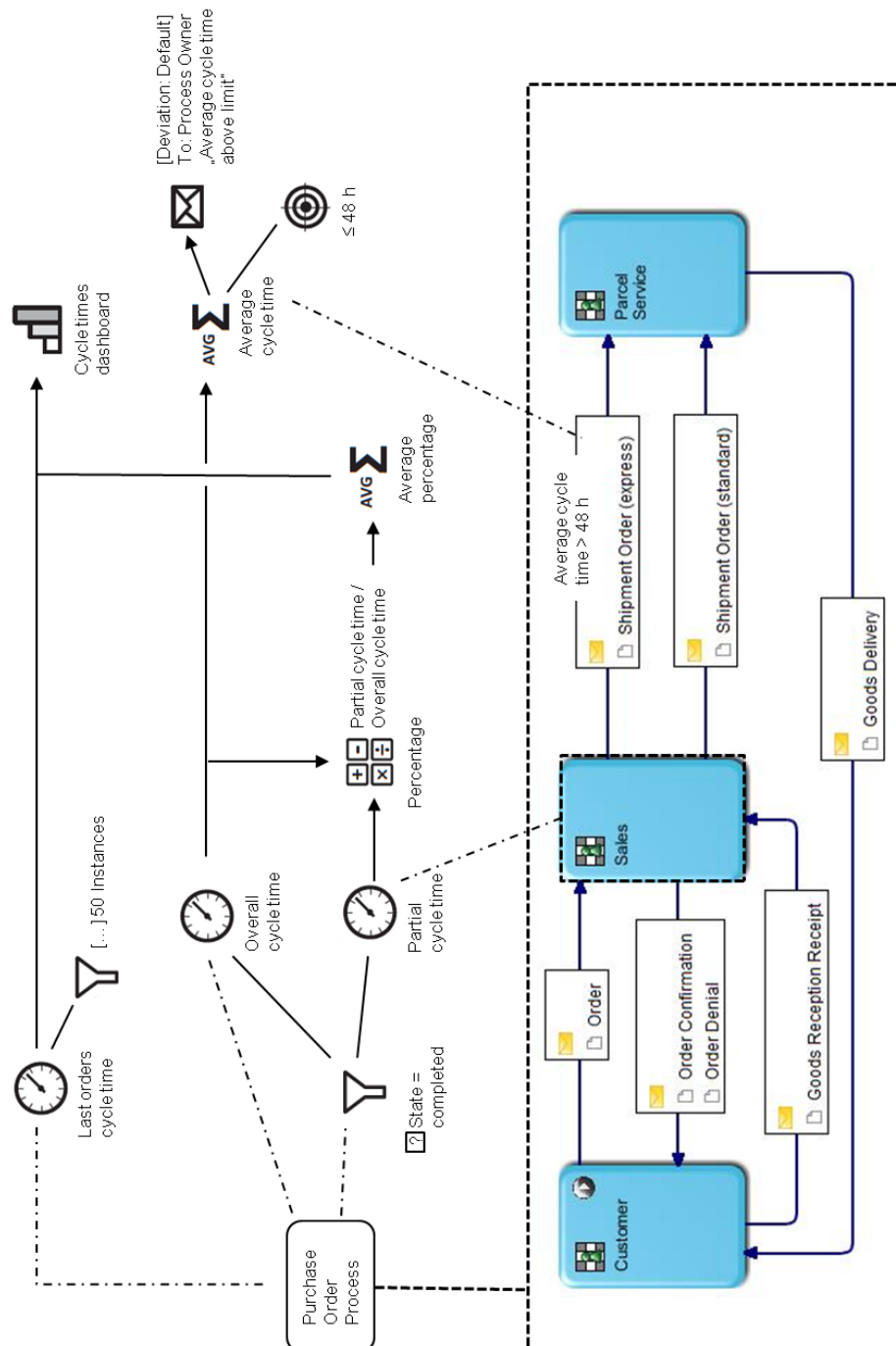


Figure 5.5: BAM Model for Cycle Times of a Purchase Order Process based on S-BPM

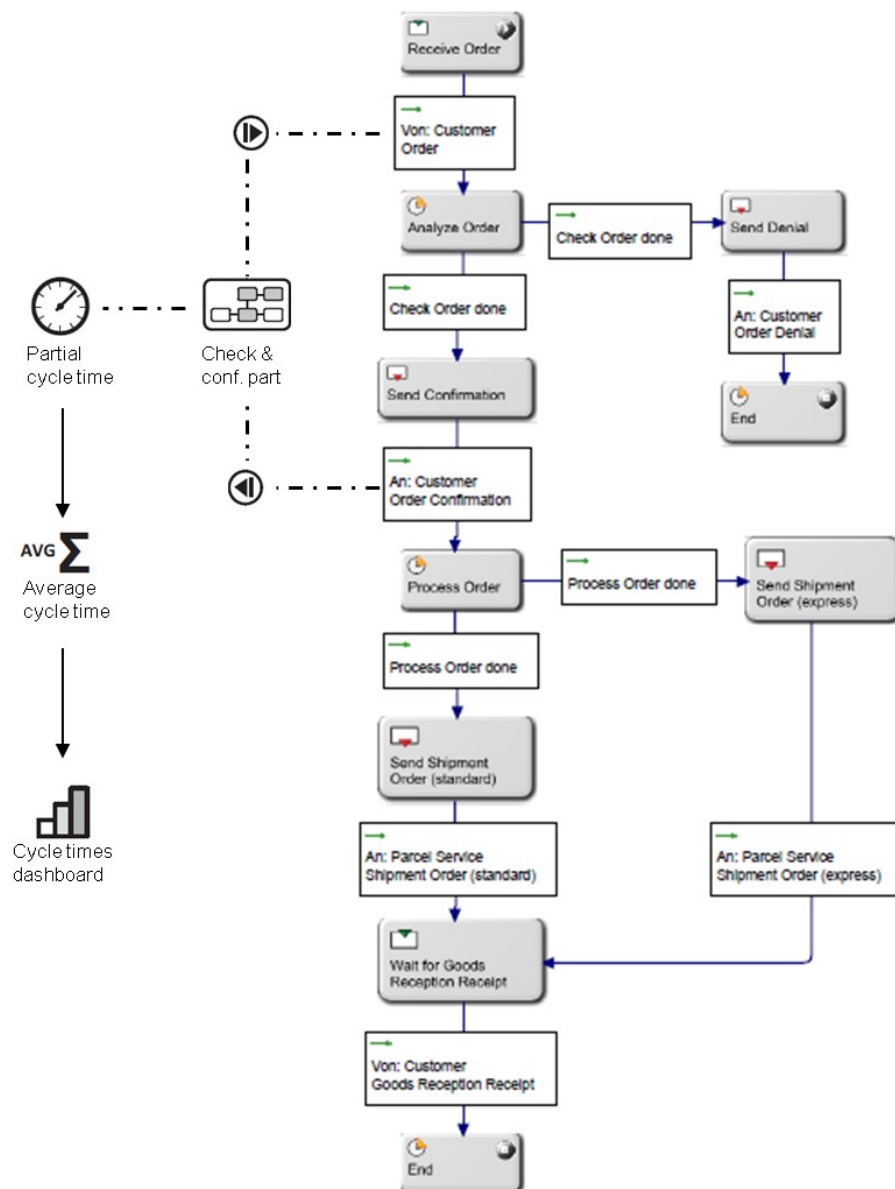


Figure 5.6: BAM Model for Cycle Time of a Process Section based on S-BPM

Classes and Properties of the PASS Ontology

A.1 ALL CLASSES (95)

- SRN = Subclass Reference Number; Is used for marking the coresponding relations in the following figures. The number identifies the subclass relation to the next level of super class.
- PASSProcessModelElement
 - BehaviorDescribingComponent; SRN: 001
Group of PASS-Model components that describe aspects of the behavior of subjects
 - Action; SRN: 002
An Action is a grouping concept that groups a state with all its outgoing valid transitions
 - DataMappingFunction ; SRN: 003
Standard Format for DataMappingFunctions must be define: XML? OWL? JSON? Definitions of the ability/need to write or read data to and from a subject's personal data storage. DataMappingFunctions are behavior describing components since they define what the subject is supposed to do (mapping and translating data) Mapping may be done during reception of message, where data is taken from the message/Business Object (BO) and mapped/put into the local data field. It may be done during sending of a message where data is taken from the local vault and put into a BO. Or it may occur during executing a do function, where it is used to define read(get) and write (set) functions for the local data.
 - DataMappingIncomingToLocal ; SRN: 004
A DataMapping that specifies how data is mapped from an an external source (message, function call etc.) to a subject's private defined data space.
 - DataMappingLocalToOutgoing ; SRN: 005
A DataMapping that specifies how data is mapped from a subject's private data space to an an external destination (message, function call etc.)
 - FunctionSpecification ; SRN: 006
*A function specification for state denotes
Concept: Definitions of calls of (mostly technical) functions (e.g. Web-service, Scripts, Database access,) that are not part of the process model.
Function Specifications are more than "Data Properties"? -> - If special function types (e.g. Defaults) are supposed to be reused, having them as explicit entities is a the better OWL-modeling choice.*
 - CommunicationAct ; SRN: 007
A super class for specialized FunctionSpecification of communication acts (send and receive)

- ReceiveFunction ; SRN: 008
Specifications/descriptions for Receive-Functions describe in detail what the subject carrier is supposed to do in a state.
DefaultFunctionReceive1_EnvironmentChoice : present the surrounding execution environment with the given exit choices/conditions currently available depending on the current state of the subjects in-box. Waiting and not executing the receive action is an option.
DefaultFunctionReceive2_AutoReceiveEarliest: automatically execute the according activity with the highest priority as soon as possible. In contrast to DefaultFunctionReceive1, it is not an option to prolong the reception and wait e.g. for another message.
- SendFunction ; SRN: 009
Comments have to be added
- DoFunction ; SRN: 010
Specifications or descriptions for Do-Functions describe in detail what the subject carrier is supposed to do in an according state. The default DoFunction
1: present the surrounding execution environment with the given exit choices/conditions and receive choice of one exit option → define its Condition to be fulfilled in order to go to the next according state. The default DoFunction
2: execute automatic rule evaluation (see DoTransitionCondition - ToDo) More specialized Do-Function Specifications may contain Data mappings denoting what of a subjects internal local Data can and should be:
a) read: in order to simply see it or in order to send it of to an external function (e.g. a web service)
b) write: in order to write incoming Data from e.g. a web Service or user input, to the local data fault
- ReceiveType ; SRN: 011
Comments have to be added
- SendType ; SRN: 012
Comments have to be added
- State ; SRN: 013
A state in the behavior descriptions of a model
 - ChoiceSegment ; SRN: 014
ChoiceSegments are groups of defined ChoiceSegmentPaths. The paths may contain any amount of states. However, those states may not reach out of the bounds of the ChoiceSegmentPath.
 - ChoiceSegmentPath ; SRN: 015
ChoiceSegments are groups of defined ChoiceSegmentPaths. The paths may contain any amount of states. However, those states may not reach out of the bounds of the ChoiceSegmentPath. The path may contain any amount of states but may those states may not reach out of the bounds of the choice segment path. Similar to an initial state of a behavior a choice segment path must have one determined initial state. A transition within a choice segment path must not have a target state that is not inside the same choice segment path.
 - MandatoryToEndChoiceSegmentPath ; SRN: 016
Comments have to be added
 - MandatoryToStartChoiceSegmentPath ; SRN: 017
Comments have to be added
 - OptionalToEndChoiceSegmentPath ; SRN: 018
Comments have to be added
 - OptionalToStartChoiceSegmentPath ; SRN: 019
ChoiceSegmentPath and (isOptionalToEndChoiceSegmentPath value false)
- EndState ; SRN: 020
An end state a behavior. A subject behavior may have one or more end states. Only Do and Receive states may be end states. Send States cannot be end states. There are no individual end states that are not Do, Send, or Receive States at the same time.
- GenericReturnToOriginReference ; SRN: 021
Comments have to be added

- InitialStateOfBehavior ; SRN: 022
The initial state of a behavior
- InitialStateOfChoiceSegmentPath ; SRN: 023
Similar to an initial state of a behavior a choice segment path must have one determined initial state
- MacroState ; SRN: 024
A state that references a macro behavior that is executed upon entering this state. Only after executing the macro behavior this state is finished also.
- StandardPASSState ; SRN: 025
A super class to the standard PASS states: Do, Receive and Send
 - DoState ; SRN: 026
The standard state in a PASS subject behavior diagram denoting an action or activity of the subject in itself.
 - ReceiveState ; SRN: 027
The standard state in a PASS subject behavior diagram denoting an receive action or rather the waiting for a receive possibility.
 - SendState ; SRN: 028
The standard state in a PASS subject behavior diagram denoting a send action
- StateReference ; SRN: 029
A state reference is a model component that is a reference to a state in another behavior. For most modeling aspects it is a normal state.
- Transition ; SRN: 030
An edge defines the transition between two states. A transition can be traversed if the outcome of the action of the state it originates from satisfies a certain exit condition specified by it's "Alternative"
 - CommunicationTransition ; SRN: 031
A super class for the CommunicationTransitions.
 - ReceiveTransition ; SRN: 032
Comments have to be added
 - SendTransition ; SRN: 033
Comments have to be added
 - DoTransition ; SRN: 034
Comments have to be added
 - SendingFailedTransition ; SRN: 035
Comments have to be added
 - TimeTransition ; SRN: 036
Generic super calls for all TimeTransitions, transitions with conditions based on time events. E.g. passing of a certain time duration or the (reoccurring) calendar event.
 - ReminderTransition ; SRN: 037
Reminder transitions are transitions that can be traverses if a certain time based event or frequency has been reached. E.g. a number of months since the last traversal of this transition or the event of a certain preset calendar date etc.
 - CalendarBasedReminderTransition ; SRN: 038
A reminder transition, for defining exit conditions measured in calendar years or months
Conditions are e.g.: reaching of (in model) preset calendar date (e.g. 1st of July) or the reoccurrence of a long running frequency ("every Month", "2 times a year")
 - TimeBasedReminderTransition ; SRN: 039
Comments have to be added
 - TimerTransition ; SRN: 040
Generic super calls for all TimeTransitions, transitions with conditions based on time events. E.g. passing of a certain time duration or the (reoccurring) calendar event.
 - BusinessDayTimerTransition ; SRN: 041
Timer transitions, denote time outs for the state they originate from. The

condition for a timer transition is that a certain amount of time has passed since the state it originates from has been entered.

The time unit for this timer transition is measured in business days. The definition of a business day depends on a subject's relevant or legal location

- **DayTimeTimerTransition ; SRN: 042**

Timer Transitions, denoting time outs for the state they originate from. The condition for a timer transition is that a certain amount of time has passed since the state it originates from has been entered.

Day or Time Timers are measured in normal 24 hour days. Following the XML standard for time and day duration. They are to be differed from the timers that are timeout in units of years or months.

- **YearMonthTimerTransition ; SRN: 044**

Timer transitions, denote time outs for the state they originate from. The condition for a timer transition is that a certain amount of time has passed since the state it originates from has been entered.

Year or Month timers measure time in calendar years or months. The exact definitions for years and months depends on relevant or legal geographical location of the subject.

- **UserCancelTransition ; SRN: 045**

A user cancel transition denotes the possibility to exit a receive state without the reception of a specific message.

The user cancel allows for an arbitrary decision by a subject carrier/processor to abort a waiting process.

- **TransitionCondition ; SRN: 046**

An exit condition belongs to alternatives which in turn is given for a state. An alternative (to leave the state) is only a real alternative if the exit condition is fulfilled (technically: if that according function returns "true")

Note: Technically and during execution exit conditions belong to states. They define when it is allowed to leave that state. However, in PASS models exit conditions for states are defined and connected to the according transition edges. Therefore transition conditions are individual entities and not DataProperties.

The according matching must be done by the model execution environment.

By its existence, an edge/transition defines one possible follow up "state" for its state of origin. It is coupled with an "Exit Condition" that must be fulfilled in the originating state in order to leave the state.

- **DoTransitionCondition ; SRN: 047**

A TransitionCondition for the according DoTransitions and DoStates.

- **MessageExchangeCondition ; SRN: 048**

MessageExchangeCondition is the super class for Send End Receive Transition Conditions the both require either the sending or receiving (exchange) of a message to be fulfilled.

- **ReceiveTransitionCondition ; SRN: 049**

ReceiveTransitionConditions are conditions that state that a certain message must have been taken out of a subjects in-box to be fulfilled.

These are the typical conditions defined by Receive Transitions.

- **SendTransitionCondition ; SRN: 050**

SendTransitionConditions are conditions that state that a certain message must have been successfully passed to another subjects in-box to be fulfilled.

These are the typical conditions defined by Send transitions.

- **SendingFailedCondition ; SRN: 051**

Comments have to be added

- **TimeTransitionCondition ; SRN: 052**

A condition that is deemed 'true' and thus the according edge is gone, if: a surrounding execution system has deemed the time since entering the state and starting with the execution of the according action as too long (predefined by the outgoing edge)

A condition that is true if a certain time defined has passed since the state this condition belongs to has been entered. (This is the standard Timeout Exit condition)

- **ReminderEventTransitionCondition** ; SRN: 053
Comments have to be added
 - **TimerTransitionCondition** ; SRN: 054
Comments have to be added
- **DataDescribingComponent** ; SRN: 055
Subject-Oriented PASS Process Models are in general about describing the activities and interaction of active entities. Yet these interactions are rarely done without data that is being generated by activities and transported via messages. While not considered by BÄürger's PASS interpreter, the community agreed on adding the ability to integrate the means to describe data objects or data structures to the model and enabling their connection to the process model. It may be defined that messages or subject have their individual DataObjectDefinition in form of a SubjectDataDefinition in the case of FullySpecifiedSubjects and PayloadDataObjectDefinition in the case of MessageSpecifications In general, it expected that these DataObjectDefinition list on or more data fields for the message or subject with an internal data type that is described via a DataTypeDefinition. There is a rudimentary concept for a simple build-in data type definition closely oriented at the concept of ActNConnect. Otherwise, the principle idea of the OWL standard is to allow and employ existing or custom technologies for the serialized definition of data structures (CustomOrExternalDataTypeDefinition) such as XML-Schemata (XSD), according elements with JSON or directly the powerful expressiveness of OWL itself.
 - **DataObjectDefinition** ; SRN: 056
*Data Object Definitions are model elements used to describe that certain other model elements may posses or carrier Data Objects.
E.G. a message may carrier/include a Business Objects. Or the private Data Space of a Subject may contain several Data Objects.
A Data Objects should refer to a DataTypeDefinition denoting its DataType and structure.
DataObject: states that a data item does exist (similar to a variable in programming)DataType: the definition of an Data Object's structure.*
 - **DataObjectListDefinition** ; SRN: 057
Data definition concept for PASS model build in capabilities of data modeling. Defines a simple list structure.
 - **PayloadDataObjectDefinition** ; SRN: 058
*Messages may have a description regarding their payload (what is transported with them).
This can either be a description of a physical (real) object or a description of a (digital) data object*
 - **SubjectDataDefinition** ; SRN: 059
Comments have to be added
 - **DataTypeDefinition** ; SRN: 060
*Data Type Definitions are complex descriptions of the supposed structure of Data Objects.
DataObject: states that a data item does exist (similar to a variable in programming).
DataType: the definition of an Data Object's structure.*
 - **CustomOrExternalDataTypeDefinition** ; SRN: 061
Using this class, tool vendors can include their own custom data definitions in the model.
 - **JSONDataTypeDefinition** ; SRN: 062
Comments have to be added
 - **OWLDataTypeDefinition** ; SRN: 63
Comments have to be added
 - **XSD-DataTypeDefinition** ; SRN: 064
XML Schemata Description (XSD) is an established technology for describing structure of Data Objects (XML documents) with many tools available that can verify a document against the standard definition
 - **ModelBuiltInDataTypes** ; SRN: 065
Comments have to be added

- PayloadDescription ; SRN: 066
Comments have to be added
 - PayloadDataObjectDefinition ; SRN: 067
*Messages may have a description regarding their payload (what is transported with them).
This can either be a description of a physical (real) object or a description of a (digital) data object*
 - PayloadPhysicalObjectDescription ; SRN: 068
*Messages may have a description regarding their payload (what is transported with them).
This can either be a description of a physical (real) object or a description of a (digital) data object*
- InteractionDescribingComponent ; SRN: 069
This class is the super class of all model elements used to define or specify the interaction means within a process model
 - InputPoolConstraint ; SRN: 070
*Subjects do implicitly posses input pools.
During automatic execution of a PASS model in a work-flow engine this message box is filled with messages.
Without any constraints models this message in-box is assumed to be able to store an infinite amount of messages.
For some modeling concepts though it may be of importance to restrict the size of the input pool for certain messages or senders.
This is done using several different Type of InputPoolConstraints that are attached to a fully specified subject.
Should a constraint be applicable, an "InputPoolConstraintHandlingStrategy" will be executed by a work-flow engine to determine what to do with the message that does not fit in the pool.
Limiting the input pool for certain reasons to size 0 together with the InputPoolConstraintStrategy-Blocking is effectively modeling that a communication must happen synchronously instead of the standard asynchronous mode. The sender can send his message only if the receiver is in an according receive state, so the message can be handled directly without being stored in the in-box.*
 - MessageSenderTypeConstraint ; SRN: 071
*An InputPool constraint that limits the number of message of a certain type and from a certain sender in the input pool.
E.g. "Only one order from the same customer" (during happy hour at the bar)*
 - MessageTypeConstraint ; SRN: 072
*An InputPool constraint that limits the number of message of a certain type in the input pool.
E.g. You can accept only "three request at once*
 - SenderTypeConstraint ; SRN: 073
*An InputPool constraint that limits the number of message from a certain Sender subject in the input pool.
E.g. as long as a customer has non non-fulfilled request of any type he may not place messages*
 - InputPoolContstraintHandlingStrategy ; SRN: 074
*Should an InputPoolConstraint be applicable, an "InputPoolConstraintHandlingStrategy" will be executed by a work-flow engine to determine what to do with the message that does not fit in the pool.
There are types of HandlingStrategies.
InputPoolConstraintStrategy-Blocking - No new message will be adding will need to be repeated until successful
InputPoolConstraintStrategy-DeleteLatest - The new message will be added, but the last message to arrive before that applicable to the same constraint will be overwritten with the new one. (LIFO deleting concept)
InputPoolConstraintStrategy-DeleteOldest - The message will be added, but the earliest message in the input pool applicable to the same constraint will be deleted (FIFO deleting concept)*

InputPoolConstraintStrategy-Drop - Sending of the message succeeds. However the new message will not be added to the in-box. Rather it will be deleted directly.

- **MessageExchange** ; SRN: 075
A message exchange is an element in the interaction description section that specifies exactly one possibility of exchanging messages in the given process context of the model. A message exchange is a triple of, a sender, a receiver, and the specification of the message that may be exchanged.
While message exchanges are singular occurrences, they may be grouped in MessageExchangeLists
- **MessageExchangeList** ; SRN: 076
While MessageExchanges are singular occurrences, they may be grouped in MessageExchangeLists.
In graphical PASS modeling that is usually the case when one arrow between two subjects contains more than one message and thereby specifies more than one possible message exchange channel between the two subjects.
- **MessageSpecification** ; SRN: 077
MessageSpecification are model elements that specify the existence of a message. At minimum its name and id.
It may contain additional specification for its payload (contained Data, exact form etc.)
- **Subject** ; SRN: 078
The subject is the core model element of a subject-oriented PASS process model.
 - **FullySpecifiedSubject** ; SRN: 079
Fully specified Subjects in a PASS graph are entities that, in contrast to interface subjects, linked to one or more Behaviors (they possess a behavior).
 - **InterfaceSubject** ; SRN: 080
Interface Subjects are Subjects that are not linked to a behavior. In contrast, they may refer to FullySpecifiedSubjects that are described in other process models.
 - **MultiSubject** ; SRN: 081
The Multi-Subject is term for a subject that "has a maximum subject instantiation restriction" within a process context larger than 1.
 - **SingleSubject** ; SRN: 082
Single Subject are subject with a maximumInstanceRestriction of 1
 - **StartSubject** ; SRN: 083
Subjects that start their behavior with a Do or Send state are active in a process context from the beginning instead of requiring a message from another subject.
Usually there should be only one Start subject in a process context.
- **PASSProcessModel** ; SRN: 084
The main class that contains all relevant process elements
- **SubjectBehavior** ; SRN: 085
Additional to the subject interaction a PASS Model consist of multiple descriptions of subject's behaviors. These are graphs described with the means of BehaviorDescribingComponents
A subject in a model may be linked to more than one behavior.
 - **GuardBehavior** ; SRN: 086
A guard behavior is a special usually additional behavior that guards the Base Behavior of a subject. It starts with a (guard) receive state denoting a special interrupting message. Upon reception of that message the subject will execute the according receive transition and the follow up states until it is either redirected to a state on the base behavior or terminates in an end-state within the guard behavior
 - **MacroBehavior** ; SRN: 087
A macro behavior is a specialized behavior that may be entered and exited from a function state in another behavior.
 - **SubjectBaseBehavior** ; SRN: 088
The standard behavior model type
- **SimplePASSElement** ; SRN: 089
Comments have to be added
- **CommunicationTransition** ; SRN: 090
A super class for the CommunicationTransitions.

- ReceiveTransition ; SRN: 091
Comments have to be added
- SendTransition ; SRN: 092
Comments have to be added
- DataMappingFunction ; SRN: 093
Definitions of the ability/need to write or read data to and from a subject's personal data storage.
DataMappingFunctions are behavior describing components since they define what the subject is supposed to do (mapping and translating data)
Mapping may be done during reception of message, where data is taken from the message/Business Object (BO) and mapped/put into the local data field.
It may be done during sending of a message where data is taken from the local vault and put into a BO.
Or it may occur during executing a do function, where it is used to define read(get) and write (set) functions for the local data.
 - DataMappingIncomingToLocal ; SRN: 094
A DataMapping that specifies how data is mapped from an external source (message, function call etc.) to a subject's private defined data space.
 - DataMappingLocalToOutgoing ; SRN: 095
A DataMapping that specifies how data is mapped from a subject's private data space to an external destination (message, function call etc.)"
- DoTransition ; SRN: 096
Comments have to be added
- DoTransitionCondition ; SRN: 097
A TransitionCondition for the according DoTransitions and DoStates.
- EndState ; SRN: 098
An end state a behavior. A subject behavior may have one or more end states. Only Do and Receive states may be end states. Send States cannot be end states.
There are no individual end states that are not Do, Send, or Receive States at the same time.
- FunctionSpecification ; SRN: 099
A function specification for state denotes
Concept: Definitions of calls of (mostly technical) functions (e.g. Web-service, Scripts, Database access,) that are not part of the process model.
Function Specifications are more than "Data Properties"? -> - If special function types (e.g. Defaults) are supposed to be reused, having them as explicit entities is a the better OWL-modeling choice.
 - CommunicationAct ; SRN: 100
A super class for specialized FunctionSpecification of communication acts (send and receive)
 - ReceiveFunction ; SRN: 101
Specifications/descriptions for Receive-Functions describe in detail what the subject carrier is supposed to do in a state.
DefaultFunctionReceive1_EnvironmentChoice : present the surrounding execution environment with the given exit choices/conditions currently available depending on the current state of the subjects in-box. Waiting and not executing the receive action is an option.
DefaultFunctionReceive2_AutoReceiveEarliest: automatically execute the according activity with the highest priority as soon as possible. In contrast to DefaultFunctionReceive1, it is not an option to prolong the reception and wait e.g. for another message.
 - SendFunction ; SRN: 102
Comments have to be added
 - DoFunction ; SRN: 103
Specifications or descriptions for Do-Functions describe in detail what the subject carrier is supposed to do in an according state.
The default DoFunction 1: present the surrounding execution environment with the given exit choices/conditions and receive choice of one exit option -> define its Condition to be fulfilled in order to go to the next according state.

The default DoFunction 2: execute automatic rule evaluation (see DoTransitionCondition).

More specialized Do-Function Specifications may contain Data mappings denoting what of a subjects internal local Data can and should be:

a) read: in order to simply see it or in order to send it of to an external function (e.g. a web service)

b) write: in order to write incoming Data from e.g. a web Service or user input, to the local data fault

- **InitialStateOfBehavior ; SRN: 104**
The initial state of a behavior
- **MessageExchange ; SRN: 105**
A message exchange is an element in the interaction description section that specifies exactly one possibility of exchanging messages in the given process context of the model.
A message exchange is a triple of, a sender, a receiver, and the specification of the message that may be exchanged.
While message exchanges are singular occurrences, they may be grouped in MessageExchangeLists
- **MessageExchangeCondition ; SRN: 106**
MessageExchangeCondition is the super class for Send End Receive Transition Conditions the both require either the sending or receiving (exchange) of a message to be fulfilled.
 - **ReceiveTransitionCondition ; SRN: 107**
ReceiveTransitionConditions are conditions that state that a certain message must have been taken out of a subjects in-box to be fulfilled.
These are the typical conditions defined by Receive Transitions.
 - **SendTransitionCondition ; SRN: 108**
SendTransitionConditions are conditions that state that a certain message must have been successfully passed to another subjects in-box to be fulfilled.
These are the typical conditions defined by Send transitions.
- **MessageExchangeList ; SRN: 109**
While MessageExchanges are singular occurrences, they may be grouped in MessageExchangeLists.
In graphical PASS modeling that is usually the case when one arrow between two subjects contains more than one message and thereby specifies more than one possible message exchange channel between the two subjects.
- **MessageSpecification ; SRN: 110**
MessageSpecification are model elements that specify the existence of a message. At minimum its name and id.
It may contain additional specification for its payload (contained Data, exact form etc.)
- **ModelBuiltInDataTypes ; SRN: 111**
Comments have to be added
- **PayloadDataObjectDefinition ; SRN: 112**
Messages may have a description regarding their payload (what is transported with them).
This can either be a description of a physical (real) object or a description of a (digital) data object
- **StandardPASSState ; SRN: 113**
A super class to the standard PASS states: Do, Receive and Send
 - **DoState ; SRN: 114**
The standard state in a PASS subject behavior diagram denoting an action or activity of the subject in itself.
 - **ReceiveState ; SRN: 115**
The standard state in a PASS subject behavior diagram denoting an receive action or rather the waiting for a receive possibility.
 - **SendState ; SRN: 116**
The standard state in a PASS subject behavior diagram denoting a send action
- **Subject ; SRN: 117**
The subject is the core model element of a subject-oriented PASS process model.

- FullySpecifiedSubject ; SRN: 118
Fully specified Subjects in a PASS graph are entities that, in contrast to interface subjects, linked to one or more Behaviors (they possess a behavior).
- InterfaceSubject ; SRN: 119
Interface Subjects are Subjects that are not linked to a behavior. In contrast, they may refer to FullySpecifiedSubjects that are described in other process models.
- MultiSubject ; SRN: 120
The Multi-Subject is a term for a subject that "has a maximum subject instantiation restriction" within a process context larger than 1.
- SingleSubject ; SRN: 121
Single Subject are subject with a maximumInstanceRestriction of 1
- StartSubject ; SRN: 122
*Subjects that start their behavior with a Do or Send state are active in a process context from the beginning instead of requiring a message from another subject.
Usually there should be only one Start subject in a process context.*
- SubjectBaseBehavior ; SRN: 123
The standard behavior model type

A.2 OBJECT PROPERTIES (42)

Property name	Domain-Range	Comments	Reference
belongsTo	Domain: PASSProcessModelElement	Generic ObjectProperty that links two process elements, where one is contained in the other (inverse of contains).	200
contains	Range: PASSProcessModelElement Domain: PASSProcessModelElement	Generic ObjectProperty that links two model elements where one contains another (possible multiple)	201
containsBaseBehavior	Range: PASSProcessModelElement		202
containsBehavior	Domain: Range: Subject SubjectBehavior		203
containsPayload-Description	Domain: Range: MessageSpecification PayloadDescription		204
guardedBy	Domain: Range: State, Action GuardBehavior		205
guardsBehavior	Domain: GuardBehavior	Links a GuardBehavior to another SubjectBehavior. Automatically all individual states in the guarded behavior are guarded by the guard behavior. There is an SWRL Rule in the ontology for that purpose.	206
guardsState	Range: SubjectBehavior State, Action guardedBy		207
hasAdditionalAttribute	Domain: Range: PASSProcessModelElement AdditionalAttribute		208
hasCorrespondent	Domain: Range: Subject	Generic super class for the ObjectProperties that link a Subject with a MessageExchange either in the role of Sender or Receiver.	209

Property name	Domain-Range	Comments	Reference
hasDataDefinition	Domain: Range:	DataObjectDefinition	210
hasDataMapping-Function	Domain: Range:	DataObjectDefinition state, SendTransition, ReceiveTransition DataMappingFunction	211
hasDataType	Domain: Range:	PayloadDescription or DataObjectDefinition	212
hasEndState	Domain: Range:	DataTypeDefinition SubjectBehavior or ChoiceSegmentPath State, not SendState	213
hasFunction-Specification	Domain: Range:	State FunctionSpecification	214
hasHandlingStrategy	Domain: Range:	InputPoolConstraint InputPoolConstraint-HandlingStrategy	215
hasIncomingMessage-Exchange	Domain: Range:	Subject MessageExchange	216
hasIncomingTransition	Domain: Range:	State Transition	217
hasInitialState	Domain: Range:	SubjectBehavior or ChoiceSegmentPath State	218
hasInputPoolConstraint	Domain: Range:	Subject InputPoolConstraint	219
hasKeyValuePair	Domain: Range:		220
hasMessageExchange	Domain: Range:	Subject Generic super class for the Object-Properties linking a subject with either incoming or outgoing MessageExchanges.	221

Property name	Domain-Range	Comments	Reference
hasMessageType	Domain: Range:	MessageTypeConstraint or MessageSenderTypeConstraint or MessageExchange MessageSpecification	222
hasOutgoingMessage-Exchange	Domain: Range:	Subject MessageExchange	223
hasOutgoingTransition	Domain: Range:	State Transition	224
hasReceiver	Domain: Range:	MessageExchange Subject	225
hasRelationToModel-Component	Domain:	PASSProcessModelElement	226
hasSender	Range:	PASSProcessModelElement	227
hasSourceState	Domain: Range:	MessageExchange Subject	228
hasStartSubject	Domain: Range:	Transition State	229
hasTargetState	Domain: Range:	PASSProcessModel StartSubject	230
hasTransitionCondition	Domain: Range:	Transition State	231
isBaseBehaviorOf	Domain: Range:	TransitionCondition SubjectBaseBehavior	232

Property name		Domain-Range	Comments	Reference
isEndStateOf	Domain: Range:	State and not SendState SubjectBehavior or ChoiceSegmentPath		233
isInitialStateOf	Domain: Range:	State SubjectBehavior or ChoiceSegmentPath		234
isReferencedBy	Domain: Range:			235
references	Domain: Range:			236
referencesMacroBehavior	Domain: Range:	MacroState MacroBehavior		237
refersTo	Domain:	CommunicationTransition	Communication transitions (send and receive) should refer to a message exchange that is defined on the interaction layer of a model.	238
requiresActiveReception-OfMessage	Range: Domain:	MessageExchange ReceiveTransitionCondition		239
requiresPerformed-MessageExchange	Range: Domain:	MessageSpecification MessageExchangeCondition		240
SimplePASSObject-Propertie	Range: Domain:	MessageExchange	Every element/sub-class of SimplePASSObjectProperties is also a Child of PASSModelObjectProperty. This is simply a surrogate class to group all simple elements together	241

A.3 DATA PROPERTIES (27)

Property name		Domain-Range	Comments	Reference
hasKey	Domain: Range:			
hasLimit	Domain: Range:			
hasMaximumSubjectInstanceRestriction	Domain: Range:			
hasMetaData	Domain: Range:			
hasModelComponentComment	Domain: Range:		equivalent to rdfs:comment	
hasModelComponentID	Domain: Range: Domain:		The unique ID of a PASSProcessModelComponent	
hasModelComponentLabel	Range: Domain: Range:		The human legible label or description of a model element.	

Property name		Domain-Range	Comments	Reference
hasPriorityNumber	Domain:		Transitions or Behaviors have numbers that denote their execution priority in situations where two or more options could be executed. This is important for automated execution. E.g. when two messages are in the in-box and could be followed, the message denoted on the transition with the higher priority (lower priority number) is taken out and processed. Similarly, SubjectBehaviors with higher priority (lower priority number) are to be executed before Behaviors with lower priority.	
	Range:			

Property name		Domain-Range	Comments	Reference
hasReoccurrenceFrequencyOrDate	Domain:		A data field meant for the two classes ReoccurrenceTimeOutTransition and ReoccurrenceTimeOutExit-Condition. ToDo: Define the according data format for describing the iteration frequencies or reoccurring dates. Opinion: rather complex: expressive capabilities should cover expressions like: "every 2nd Monday of Month at 7:30 in Morning." Every 29th of July" or "Every Hour", "ever 25 Minuets" , "once each day", "twice each week" etc	
hasSVGRepresentation	Range: Domain:		The Scalable Vector Graphic (SVG) XML format is a text based standard to describe vector graphics. Adding according image information as XML literals is therefor a suitable, yet not necessarily easily changeable option to include the graphical representation of model elements in the an OWL file.	
hasTimeBasedReoccurrenceFrequencyOrDate	Range: Domain: Range:			

Property name		Domain-Range	Comments	Reference
hasTimeValue	Domain: Range:		Generic super class for all data properties of time based transitions.	
hasToolSpecificDefinition	Domain:		This is a placeholder DataProperty meant as a tie in point for tool vendors to include tool specific data values/properties into models. By denoting their own data properties as sub-classes to this one the according data fields can easily be recognized as such. However, this is only an option and a placeholder to remind that something like this is possible.	
hasValue	Range:			
hasYearMonthDurationTimeOutTime	Domain: Range:			
isOptionalToEndChoiceSegmentPath	Domain: Range:			
isOptionalToStartChoiceSegmentPath	Domain: Range:			
owl:topDataProperty	Domain: Range:			
PASSModelDataProperty	Domain:		Generic super class of all DataProperties that PASS process model elements may have.	
	Range:			

Property name		Domain-Range	Comments	Reference
SimplePASSDataProperties	Domain:		Every element/sub-class of SimplePASSDataProperties is also a Child of PASS-ModelDataProperty. This is simply a surrogate class to group all simple elements together	
	Range:			

Mapping Ontology to Abstract State Machine

The following tables show the relationships between the PASS ontology and the PASS execution semantics described as ASMs. Because of historical reasons in the ASMs names for entities and relations are different from the names used in the ontology. The tables below show the mapping of the entity and relation names in the ontology to the names used in the ASMs.

B.1 MAPPING OF ASM PLACES TO OWL ENTITIES

Places are formally also functions or rules, but are used in principle as passive/static storage places.

OWL Model element	ASM interpreter	Description
X - Execution concept "the state the subject is currently in as defined by a State in the model"	<i>SID_state</i>	Execution concept "no model representation, Not to be confused by a model "State" in an SBD Diagram. State in the SBD diagram define possible <i>SID_States</i> . A Diagram that is a completely connected SBD
SubjectBehavior "under the assumption that it is complete and sound."	<i>D</i>	
State	<i>node</i>	A specific element of diagram D - Every node 1:1 to state
State	<i>state</i>	The current active state of a diagram determined by the nodes of Diagram D
InitialStateOfBehavior, EndState	<i>initial state,</i> <i>end state</i>	The interpreter expects and SBD Graph D to contain exactly one initial (start) state and at least one end state.
Transition	<i>edge / outEdge</i>	"Passive Element" of an edge in an SBD-graph
TransitionCondition	<i>ExitCondition</i>	Static Concept that represents a Data condition
Execution Concept "ID of a Subject Carrier responsible possible multiple Instances of according to specific SubjectBehavior "	<i>subj</i>	Identifier for a specific Subject Carrier that may be responsible for multiple Subjects
Represented in the model with InterfaceSubject	<i>ExternalSubject</i>	A representation of a service execution entity outside of the boundaries of the interpreter (The PASS-OWL Standardization community decided on the new Term of Interface Subject to replace the often-misleading older term of External Subject)
SubjectBehavior or rather SubjectBaseBehavior as MacroBehaviors and GuardBehaviors are not covered by Burger	<i>subject-SBD /</i> <i>SBDsubject_{subject}</i>	Names for completely connected graphs / diagrams representing SBDs
Object Property: <i>hasFunctionSpecification</i> (linking State , and FunctionSpecification -> (State <i>hasFunctionSpecification</i> FunctionSpecification))	<i>service(state) /</i> <i>service(node)</i>	Rule/Function that reads/returns the service of function of a given state/node

OWL Model element	ASM interpreter	Description
DoState SendState ReceiveState	<i>function state,</i> <i>send state,</i> <i>receive state</i>	<p>The ASM spec does not itself contain these terms. The description text, however, uses them to describe states with an according service (e.g. a state in which a (ComAct = Send) service is executed is referred to as a send state) Seen from the other side: a SendState is a state with service(state) = Send)</p> <p>Both send and receive services are a ComAct service. The ComAct service is used to define common rules of these communication services.</p>
CommunicationActs with sub-classes (ReceiveFunction SendFunction) <i>DefaultFunctionReceive1_EnvironmentChoice</i> <i>DefaultFunctionReceive2_AutoReceiveEarliest</i> <i>DefaultFunctionSend</i>	<i>ComAct</i>	<p>Specialized version of Perform-ASM Rule for communication, either send or receive. These rules distinguish internally between send and receive.</p>

B.2 MAIN EXECUTION/INTERPRETING RULES

The interpreter ASM Spec has main-function or rules that are being executed while interpreted.

- BEHAVIOR(subj,state)
- PROCEED(subj,service(state),state)
- PERFORM(subj,service(state),state)
- START (subj,X, node)

These make up the main interpreter algorithm for PASS SBDs and therefore have no corresponding model elements but rather are or contain the instructions of how to interpret a model.

OWL Model element	ASM interpreter	Description
Execution concept	<i>BEHAVIOR(subj;state)</i>	Main interpreter ASM-rule/Method
Execution concept	<i>BEHAVIOR(subj;node)</i>	ASM-Rule to interpret a specific node of Diagram D for a specific subject
Execution concept	Behaviorsubj (D)	Set of all ASM rules to interpret all nodes/states in a SBD(iagram) D for a given subj (set of all <i>BEHAVIOR(subj;node)</i>)
State hasFunctionSpecification FunctionSpecification Specialized in: DoFunction and CommunicationActs with ReceiveFunction SendFunction There exist a few default activities: DefaultFunctionDo1_EnvironmentChoice DefaultFunctionDo2_AutomaticEvaluation	<i>PERFORM(subj ; ser-vice(state); state)</i>	Main interpreter ASM-rule/Method
CommunicationActs with ReceiveFunction SendFunction DefaultFunctionReceive1_EnvironmentChoice DefaultFunctionReceive2_AutoReceiveEarliest DefaultFunctionSend	<i>PERFORM(subj ;ComAct; state)</i>	ASM-Rule specifying the execution of a Communication act in an according state)

Table B.2: Main Execution/Interpreting Rules

B.3 FUNCTIONS

Functions return some element. They are activities that can be performed to determine something. Dynamic functions can be considered as "variables" known from programming languages, they can be read and written. Static functions are initialized before the execution, they can only be read. Derived functions "evaluate" other functions, they can only be read. They may be thought of as a global method with read-only variables

OWL Model element	ASM interpreter	Description
Function that the return state should correspond to/be derived from one of the multiple State in an SBD model	$SID_state(subj)$	Dynamic ASM-Function that stores the current state of a subj
State hasOutgoingTransition Transition (input / worked on link / output (Set of Transition) (linking State with)	$OutEdge(state)$ $OutEdge(state.i)$	Function that returns the set of outgoing edges of a state or a single specific edge i
Object Property: hasTargetState (linking Transition and State \rightarrow Transition hasTargetState State	$target(edge)/$ $target(outEdge) /$	Function that returns the follow up state of an outgoing transition ($outEdge$ is a special denomination for an $edge$ returned by the $outEdge$ -Function)
Object Property: hasSourceState (linking Transition and State \rightarrow Transition hasSourceState State (input / worked on link / output)	$source(edge)$	Function that returns the source state of an edge
Determine Follow up state Mechanic		
Exit conditions in PASS are defined on their corresponding Transitions and therefore are called TransitionCondition Transitions have (hasTransitionCondition) (State \rightarrow hasOutgoing-Transition \rightarrow Transition \rightarrow hasTransitionCondition \rightarrow Transition-Condition)	$ExitCond(e)$ $ExitCond(outEdge)$ $ExitCond.i(e)$ $ExitCond(e)(subj,state)$	Derived Function that evaluates the ExitCondition of a given edge/outgoing edge
Execution Concept	$select_{Edge}$	ASM Function that determines an edged (transition) to follow.
Execution Concept (connected to: State , and FunctionSpecification)	$completed(subj ;$ $service(state); state)$	Function that returns true if the Service of a certain state is complete IF the subject is in that state
Execution Concept		Rule/Function that gives that returns the service of function of a given state

Table B.3: Derived Functions

B.4 EXTENDED CONCEPTS AND REFINEMENTS FOR THE SEMANTICS OF CORE ACTIONS

OWL Model element	ASM interpreter	Description
Function that the return state should correspond to/be derived from one of the multiple State in an SBD model	<i>SID_state(subj)</i>	Dynamic ASM-Function that stores the current state of a subj
State hasOutgoingTransition Transition (input / worked on link / output (Set of Transition) (linking State with)	<i>OutEdge(state)</i> <i>OutEdge(state;i)</i>	Function that returns the set of outgoing edges of a state or a single specific edge <i>i</i>

Table B.4: Refinements places

B.5 INPUT POOL HANDLING

OWL Model element	ASM interpreter	Description
Refers to a set of InputPoolConstraints of Subject that has hasInputPoolConstraints for its Input Pool	<i>constraintTable(inputPool)</i>	Function that Returns the set of all input Pool constraints
Execution Concept with evaluation relevance for: MessageSenderTypeConstraint and SenderTypeConstraint	<i>sender/receiver</i>	Identifiers for possible subject instances trying to access an input pool
Refers to a set of InputPoolConstraints of Subject that has hasInputPoolConstraints for its Input Pool	<i>msgType</i>	Function that Returns the set of all input Pool constraints
Execution Concept	<i>select MsgKind(subj_stateall;i)</i>	ASM Function that determines the message kind (all message type all) to be received in a given receive state.
InputPoolConstraintHandlingStrategy And their individual default instances: InputPoolConstraintStrategy-Blocking InputPoolConstraintStrategy-DeleteLatest InputPoolConstraintStrategy-DeleteOldest InputPoolConstraintStrategy-Drop	<i>/Blocking; DropYoungest; DropOldest; DropIncoming/</i>	Default Input Pool handling strategies for
Execution Concept all can be restricted by InputPoolConstraint for its Input Pool	<i>P / inputPool</i>	The actual Input Pool
synchronous communication		Definition for an input pool constraint set to 0 requiring sender and receiver interpreter to be in the corresponding send and receive states at the same time in order to actually communicate (as messages cannot be passed to an input pool)

Table B.5: Input Pool Handling

B.6 OTHER FUNCTIONS

OWL Model element	ASM interpreter	Description
Exit conditions in PASS are defined on their corresponding Transitions and therefore are called TransitionCondition . Execution Concept: can be set on. Execution Concept: used to determine the correct exit	<i>NormalExitCond</i>	is used internally to $\hat{A}llRemember\hat{A}$ that neither a timeout nor a user cancel have happened, so that the correct exit transition can be taken.
In the model to be interpreted the according aspects are captured by TimerTransitions that have (hasTransitionCondition) a TimerTransitionCondition containing the date. The timeout(state) function should read the information.	Timer/Timeout Mechanic: The evaluation and handling of timeouts is defined (and refined) with several rules and functions. <i>OutEdge(timeout(state), Timeout(subj, state, timeout(state)), SetTimeoutClock(subj, state)</i> is used to evaluate the timeout condition, <i>OutEdge(Interrupt_service(state)(subj, state)</i> is used to define how the corresponding service should be canceled. <i>OutEdge(TimeoutExitCond)</i> is used internally to $\hat{A}llRemember\hat{A}$ that a timeout happened, so that the correct exit transition can be taken.	
In PASS models the possibility to arbitrarily cancel the execution of a (receive) function and the possible course of action afterwards may be discerned via a UserCancelTransitions	User Cancel/Abrupt Mechanic: The evaluation and handling of user cancels is defined (and refined) with several rules and functions. <i>UserAbrupt(subj, state)</i> is used to evaluate the user decision, <i>Abrupt_service(state)(subj, state)</i> is used to define how the corresponding service should be aborted. <i>AbruptExitCond</i> is used internally to $\hat{A}llRemember\hat{A}$ that a user cancel happened, so that the correct exit transition can be taken.	
With the definition of the data properties hasMaximumSubjectInstanceRestriction The MultiSubject are actually the standard and SingleSubject the special case	<i>MultiRound / mult(alt) / InitializeMultiRound / ContinueMultiRoundSuccess (among others)</i>	Definition of Functions and ASM rules for interaction between multiple Subjects at once
Handling of ChoiceSegment & ChoiceSegmentPath hasOutgoingTransition (input / worked on link / output (Set of Transition) (linking State with)	<i>AltAction / altEntry(D) / altExit(D) AltBehDgm(altSplit) altJoin(altSplit)</i>	Rules for the semantics/handling of ChoiceSegments
State hasOutgoingTransition Transition (input / worked on link / output (Set of Transition) (linking State with)	<i>Compulsory(altEntry(D))</i> and <i>textit-Compulsory(altExit(D))</i>	

Table B.6: Other Functions

B.7 ELEMENTS NOT COVERED NOT BY BÄURGER (DIRECTLY)

OWL Model element	Description
ReminderTransition / ReminderEventTransitionCondition	This type time-logic-based transitions did not exist when the original ASM interpreter was conceived. They were added to PASS for the OWL Standard. They can be handled by assuming the existence of an implicit calendar subject that sends an interrupt message (reminder) upon a time condition (e.g. reaching of a calendarial date) has been achieved. (includes the specialized (CalendarBasedReminderTransition , TimeBasedReminderTransition)
DataDescribingComponent / DataMappingFunction	The PASS OWL standard envisions the integration and usage of classic data element (Data Objects) as part of a process model. The BÄŭrger Interpreter does not assume the existence of such data elements as part of the model. However, the refinement concept of ASMs could easily been used to integrate according interpretation aspects. (Includes Elements such as PayloadDescription for Messages or DataMappingFunction)

Table B.7: Other Functions

PASS CoreASM Reference Implementation

C.1 CONCEPTUAL DIFFERENCES ASM SEMANTIC / OWL MODEL

This implementation provides more language elements than covered by the OWL description and also gives some concrete implementations, that are left abstract in the OWL description.

See table C.1, table C.2 and table C.3 for details.

C.2 EDITORIAL NOTE

To fit the code onto the pages it has been compacted. Instead of writing:

```
rule Behavior(macroInstanceNumber, currentStateNumber) =
  if (initializedState(channelFor(self),
                        macroInstanceNumber,
                        currentStateNumber) != true) then
    StartState(macroInstanceNumber, currentStateNumber)
  else // ...
```

Listing 31: Behavior, spread-out snippet

the code blocks are transformed to a more compact notation:

```
rule Behavior(MI, currentStateNumber) =
  let s = currentStateNumber,
      ch = channelFor(self) in
  if (initializedState(ch, MI, s) != true) then
    StartState(MI, s)
  else // ...
```

Listing 32: Behavior, compact snippet

Some elements are intentionally left out in order to preserve space.

For example, the `rule InputPool_Pop` and the `derived availableMessages` function contain lengthy list traversals, and their definitions contain undocumented parameters used in a test environment for debugging.

Other functions like `derived searchMacro` or `derived hasTimeoutTransition` should be self-explanatory.

Concept	Reference Implementation	OWL
End State	Implemented as a DoState that hasFunctionSpecification EndFunction , cannot be a ReceiveState . Forbids any hasOutgoingTransition .	Must either be DoState or ReceiveState . Allows hasOutgoingTransition for Subject Restart.
Subject Restart	Implicit after <i>proper termination</i> when an additional message arrive.	Explicit via EndState on a ReceiveState , not after termination.
Proper Termination	On termination of a Subject it determines if the InputPool is empty and a Subject Restart is allowed. If the InputPool is not empty further messages are blocked and the Subject is not allowed to restart.	<i>Absent</i> .
InputPoolConstraint	Only the MessageSender-TypeConstraint with InputPoolConstraintStrategy-Blocking is supported. Setting the limit to 0 means unlimited. Synchronous send & receive is not supported.	Allows various combinations of limits set per Sender, MessageType or both. The combination InputPoolConstraintStrategy-Blocking with the limit of 0 means synchronous send & receive. Additionally defines the strategies DeleteLatest, DeleteOldest and Drop.
Mobility of Channels	Concept to store and forward at runtime references to other subjects and their agents.	<i>Absent</i> .
CorrelationID	Concept to correlate messages, e.g. responses to requests, so that messages can be send and received reliable in a loop.	<i>Absent</i> .
Choice Segments	Choice Segments are initiated by an explicit Modal Split State and joined with an explicit Modal Join State. The target State of every outgoing Transition from the Modal Split State is an InitialStateOfChoiceSegmentPath . Every Choice Segment Path is therefore mandatory to start. Also, every Choice Segment Path is mandatory to end and must have a Transition to the Modal Join State.	Choice Segment Paths can be optional to start and optional to end. Choice Segment Paths are not connected by Transitions to the Choice-Segment State and its target State.

Table C.1: Conceptual differences between this reference implementation and the OWL description (1).

Concept	Reference Implementation	OWL
Subject Data Scope	A DataObjectDefinition can be scoped to either the Subject or a SubjectBehavior . When it is scoped to a Behavior its value is accessible only within instances of that Behavior, i.e. within a single instance of a Macro Behavior. When it is scoped to the Subject its value is accessible from every SubjectBehavior instance, given there is no locally scoped Data Object Definition with the same ID.	Is always scoped to the Subject.
Macro Data Arguments	A MacroState can copy the value of a DataObjectDefinition into the scope of another DataObjectDefinition , which is scoped to the referenced MacroBehavior .	<i>Absent.</i>
Data Modification Functions	Data Modification Functions perform operations on Subject Data, e.g. concatenation of objects having a set-valued data type.	<i>Absent.</i>
Data Mapping Functions	StoreMessageFunction stores the received messages in a local Data Object. UseMessageContentFunction uses the value of a Data Object as content of the outgoing message. UseCorrelationIDFunction uses the value of a Data Object as CorrelationID of the outgoing message.	<i>Abstract.</i>
InputPool Functions	InputPool Functions perform operations on the Subject's InputPool, e.g. close it for some message types or sender Subjects.	<i>Absent.</i>
Macro Exit Parameter	Attribute on the End State of a Macro Behavior that selects a corresponding Transition on the MacroState .	<i>Absent.</i>
Timer Transition	The Timer Transition Condition has to be defined in seconds.	It is possible to define the timeout in arbitrary time durations, including in business days.
Reminder Transition	<i>Absent.</i>	A ReminderTransition can be traversed if a certain time based event or frequency has been reached.

Table C.2: Conceptual differences between this reference implementation and the OWL description (2).

Concept	Reference Implementation	OWL
Cancel Function	Enables the UserCancel-Transition of a referenced State .	<i>Absent.</i>
State Priorities	A utility to support the Observer Concept. When multiple states are active only the states with the highest priority can perform. The Function of such states can conditionally allow states with a lower priority to perform.	<i>Absent.</i>
Observer	Implicitly supported, requires modelling of a ReceiveState with a high State Priority to interrupt another path. After the exception handling the interrupted behavior can continue, be aborted with the Cancel Function or the Subject can terminate by an EndState.	Explicitly supported. Executes the GuardBehavior , not possible to return to the interrupted state.

Table C.3: Conceptual differences between this reference implementation and the OWL description (3).

C.3 BASIC DEFINITIONS

```

function channelFor : Agents -> LIST

derived processIDFor(a)      = processIDOf(channelFor(a))
derived processInstanceFor(a) = processInstanceOf(channelFor(a))
derived subjectIDFor(a)      = subjectIDOf(channelFor(a))
derived agentFor(a)          = agentOf(channelFor(a))

derived processIDOf(ch)      = nth(ch, 1)
derived processInstanceOf(ch) = nth(ch, 2)
derived subjectIDOf(ch)      = nth(ch, 3)
derived agentOf(ch)          = nth(ch, 4)

```

Listing 33: channelFor

```

// Channel -> List[List[MI, StateNumber]]
function killStates : LIST -> LIST

// Channel * macroInstanceNumber -> List[StateNumber]
function activeStates : LIST * NUMBER -> LIST

```

Listing 34: activeStates

```

// -> PI
function nextPI : -> NUMBER
// PI -> Channel
function nextPIUsedBy : NUMBER -> Agents

// Channel -> Number
function nextMacroInstanceNumber : LIST -> NUMBER

// Channel -> Boolean
function properTerminated : LIST -> BOOLEAN

derived anyNonProperTerminated(chs) =
  exists ch in chs with (properTerminated(ch) = false)

// Channel * MacroInstanceNumber * StateNumber -> Set[String]
function wantInput : LIST * NUMBER * NUMBER -> SET

```

Listing 35: nextPI

```

// Channel * MacroInstanceNumber * StateNumber -> BOOLEAN
function initializedState : LIST * NUMBER * NUMBER -> BOOLEAN

// Channel * MacroInstanceNumber * StateNumber -> BOOLEAN
function completed : LIST * NUMBER * NUMBER -> BOOLEAN

// Channel * MacroInstanceNumber * StateNumber
function timeoutActive : LIST * NUMBER * NUMBER -> BOOLEAN
function cancelDecision : LIST * NUMBER * NUMBER -> BOOLEAN

// Channel * MacroInstanceNumber * StateNumber -> BOOLEAN
function abortionCompleted : LIST * NUMBER * NUMBER -> BOOLEAN

// Channel * MacroInstanceNumber * StateNumber
function selectedTransition : LIST * NUMBER * NUMBER -> NUMBER
function initializedSelectedTransition : LIST * NUMBER * NUMBER
  -> BOOLEAN
function startTime : LIST * NUMBER * NUMBER -> NUMBER

// Channel * MacroInstanceNumber * TransitionNumber -> BOOLEAN
function exitCondition : LIST * NUMBER * NUMBER -> BOOLEAN

// Channel * MacroInstanceNumber * TransitionNumber -> BOOLEAN
function transitionCompleted : LIST * NUMBER * NUMBER -> BOOLEAN

```

Listing 36: initializedState

```

derived shouldTimeout(ch, MI, stateNumber) = return boolres in
  let pID = processIDof(ch) in
    if (hasTimeoutTransition(pID, stateNumber) = true
        and startTime(ch, MI, stateNumber) != undef) then
      let t = outgoingTimeoutTransition(pID, stateNumber) in
        let timeout = (transitionTimeout(pID, t)
                       * 1000 * 1000 * 1000) in
          let runningTime = (nanoTime()
                             - startTime(ch, MI, stateNumber)) in
            boolres := (runningTime > timeout)
    else
      boolres := false

```

Listing 37: shouldTimeout

```

// Channel * macroInstanceNumber * varname -> [vartype, content]
function variable : LIST * NUMBER * STRING -> LIST

// Channel -> Set[(macroInstanceNumber, varname)]
function variableDefined : LIST -> SET

```

Listing 38: variable

```

// Channel * macroInstanceNumber -> result
function macroTerminationResult : LIST * NUMBER -> ELEMENT

// Channel * macroInstanceNumber -> MacroNumber
function macroNumberOfMI : LIST * NUMBER -> NUMBER

// Channel * macroInstanceNumber * StateNumber -> MacroInstance
function callMacroChildInstance : LIST * NUMBER * NUMBER -> NUMBER

```

Listing 39: macroTerminationResult

C.4 INTERACTION DEFINITIONS

```

// Channel * senderSubjID * msgType * correlationID
// -> [msg1, msg2, ...]
function inputPool : LIST * STRING * STRING * NUMBER -> LIST

/* stores all locations where an inputPool was defined */
// Channel -> {[senderSubjID, msgType, correlationID], ...}
function inputPoolDefined : LIST -> SET

// Channel * senderSubjID * msgType * correlationID
function inputPoolClosed : LIST * STRING * STRING * NUMBER
  -> BOOLEAN

derived inputPoolIsClosed(ch, senderSubjID, msgType, cID) =
return boolres in
let isClosed = inputPoolClosed(ch, senderSubjID, msgType, cID) in
  if (isClosed = undef) then // default: global state
    boolres := inputPoolClosed(ch, undef, undef, undef)
  else
    boolres := isClosed

```

Listing 40: inputPool

```

// Channel * MacroInstanceNumber * StateNumber -> Set[Messages]
function receivedMessages : LIST * NUMBER * NUMBER -> SET

// Channel * MacroInstanceNumber * StateNumber -> Set[Channel]
function receivers : LIST * NUMBER * NUMBER -> SET

// Channel * MacroInstanceNumber * StateNumber
function messageContent      : LIST * NUMBER * NUMBER -> LIST
function messageCorrelationID : LIST * NUMBER * NUMBER -> NUMBER
function messageReceiverCorrelationID : LIST * NUMBER * NUMBER
  -> NUMBER

// Channel * MacroInstanceNumber * StateNumber -> Set[Channel]
function reservationsDone : LIST * NUMBER * NUMBER -> SET

function nextCorrelationID : -> NUMBER
function nextCorrelationIDUsedBy : NUMBER -> Agents

```

Listing 41: receivedMessages

C.5 SUBJECT RULES

```

rule GenerateUniqueProcessInstanceID = {
  nextPI := nextPI + 1
  result := nextPI
  // ensure that `nextPI` is not used by multiple agents in the
  // same ASM step. A collision would occur when multiple agents
  // try to call this rule in the same asm step
  nextPIUsedBy(nextPI) := self
}

```

Listing 42: GenerateUniqueProcessInstanceID

```

rule StartProcess(processID, additionalInitializationSubject,
                  additionalInitializationAgent) =
  let pID = processID in
  local PI in
    seq
      PI <- GenerateUniqueProcessInstanceID()
    next {
      result := PI

      foreach sID in keySet(processSubjects(pID)) do
        if (sID = additionalInitializationSubject) then
          let ch = [pID, PI,
                    sID, additionalInitializationAgent] in
            InitializeSubject(ch)
        else if (isStartSubject(pID, sID) = true) then
          let agentSet = safeSet(predefinedAgents(pID, sID)) in
            if (|agentSet| = 1) then
              // shortcut: avoid user interaction
              let agentName = firstFromSet(agentSet) in
                let ch = [pID, PI, sID, agentName] in
                  seq
                    InitializeSubject(ch)
                  next
                    StartASMAgent(ch)
            else
              SelectAgentAndStartASMAgent(pID, PI, sID)
    }

```

Listing 43: StartProcess

```
// -> SET[ASMAgent]
function asmAgents : -> SET

derived running(ch) = exists a in asmAgents
                      with channelFor(a) = ch

rule EnsureRunning(ch) =
  if (running(ch) != true) then
    StartASMAgent(ch)

rule StartASMAgent(ch) =
  extend Agents with a do {
    add a to asmAgents
    channelFor(a) := ch
    program(a)    := @StartMainMacro
  }

rule PrepareReceptionOfMessages(ch) =
  // might be called multiple times, esp. via SelectAgents
  if (properTerminated(ch) = undef) then {
    properTerminated(ch) := true

    inputPoolDefined(ch) := {}
    inputPoolClosed(ch, undef, undef, undef) := false
  }

rule FinalizeInteraction =
  let ch = channelFor(self) in
  let proper = inputPoolIsEmpty(ch, undef, undef, undef) in
  properTerminated(ch) := proper

rule InitializeSubject(ch) = PrepareReceptionOfMessages(ch)
```

Listing 44: StartASMAgent

```

rule StartMainMacro =
  let ch = channelFor(self),
      pID = processIDFor(self) in {
    killStates(ch) := []

    let MI = 0 in { // 0 => global / predefined variables
      variableDefined(ch) := {[MI, "$self"], [MI, "$empty"]}
      variable(ch, MI, "$self") := ["ChannelInformation", {ch}]
      variable(ch, MI, "$empty") := ["Text", ""]
    }

    let MI = 1, // 1 => MainMacro Instance
        mID = subjectMainMacro(pID, subjectIDFor(self)) in
    let startState = macroStartState(pID, mID) in {
      macroNumberOfMI(ch, MI) := mID

      nextMacroInstanceNumber(ch) := MI + 1

      activeStates(ch, MI) := [startState]
    }

    program(self) := @SubjectBehavior
  }

```

Listing 45: StartMainMacro

```

rule StartMacro(MI, currentStateNumber, mIDNew, MINew) = {
  let pID = processIDFor(self) in
  let startState = macroStartState(pID, mIDNew) in {
    activeStates(channelFor(self), MINew) := []
    AddState(MI, currentStateNumber, MINew, startState)
  }
}

```

Listing 46: StartMacro

```

// called from PerformEnd and AbortCallMacro
rule AbortMacroInstance(MIAbort, ignoreState) =
  let ch = channelFor(self) in {
    foreach currentState in activeStates(ch, MIAbort) do {
      add [MIAbort, currentState] to killStates(ch)
    }

    ClearAllVarInMI(ch, MIAbort)
  }

```

Listing 47: AbortMacroInstance

```

/*
- REPEAT
  - Behavior should be executed again for this state
  - updates from this execution step will be merged with the
    following execution step in one global ASM update
  - no other states are allowed to be executed
- DONE
  - no other active states are allowed to be executed
  - new states are started
  - global ASM / LTS step will be done
- NEXT
  - nothing changed / waiting for input
  - other active states with the same priority can be executed
  - active states with lower priority can not be executed
- LOWER
  - nothing changed / waiting for input
  - other active states, even with lower priority, can be executed
*/

// Channel * MacroInstanceNumber * stateNumber
function executionState : LIST * NUMBER * NUMBER -> NUMBER

// Channel * MacroInstanceNumber
function macroExecutionState : LIST * NUMBER -> NUMBER

// Channel * MacroInstanceNumber * stateNumber -> List[(MI, s)]
function addStates : LIST * NUMBER * NUMBER -> LIST

// Channel * MacroInstanceNumber * stateNumber -> List[(MI, s)]
function removeStates : LIST * NUMBER * NUMBER -> LIST

```

Listing 48: SetExecutionState

```

rule AddState(MI, currentStateNumber, MINew, sNew) =
  add [MINew, sNew]
  to addStates(channelFor(self), MI, currentStateNumber)

rule RemoveState(MI, currentStateNumber, MIOld, sOld) =
  add [MIOld, sOld]
  to removeStates(channelFor(self), MI, currentStateNumber)

```

Listing 49: AddState

```

rule SubjectBehavior =
  choose x in killStates(channelFor(self)) do
    KillBehavior(nth(x, 1), nth(x, 2))
  ifnone
    seqblock
      MacroBehavior(1)
    next // reset
      macroExecutionState(channelFor(self), 1) := undef

```

Listing 50: SubjectBehavior

```

rule KillBehavior(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  if (initializedState(ch, MI, s) != true) then {
    // state is not initialized,
    // remove without further abortion

    remove [MI, s] from killStates(ch)
    remove s from activeStates(ch, MI)
  }
  else if (abortionCompleted(ch, MI, s) = true) then {
    ResetState(MI, s)
    remove [MI, s] from killStates(ch)
    remove s from activeStates(ch, MI)
  }
  else seqblock
    executionState(ch, MI, s) := undef
    addStates(ch, MI, s)      := []
    removeStates(ch, MI, s)   := []

    // NOTE: no new state must be added.
    // Also, removeStates should be empty,
    // as those states should be added to killStates
    Abort(MI, s)
  endseqblock

```

Listing 51: KillBehavior

```

rule MacroBehavior(MI) =
  let ch = channelFor(self),
      pID = processIDFor(self) in
  local remainingStates := activeStates(ch, MI) in
  seq
    macroExecutionState(ch, MI) := undef
  next
  // NOTE: can not be done with foreach,
  // as remainingStates is modified
  while (|remainingStates| > 0) do
    let stateNumber
      = getAnyStateWithHighestPrio(pID, remainingStates) in
    seqblock
      executionState(ch, MI, stateNumber) := undef
      addStates(ch, MI, stateNumber)      := []
      removeStates(ch, MI, stateNumber)   := []

      Behavior(MI, stateNumber)

      // NOTE: mutates remainingStates!
      let state = executionState(ch, MI, stateNumber) in
      UpdateRemainingStates(MI, stateNumber, state, remainingStates)

      UpdateActiveStates(MI, stateNumber)
    endseqblock

```

Listing 52: MacroBehavior

```

rule UpdateRemainingStates(MI, stateNumber,
                           exState, remainingStates) =
  let ch = channelFor(self),
      pID = processIDFor(self) in
  if (exState = REPEAT) then {
    remainingStates := [stateNumber]

    macroExecutionState(ch, MI) := DONE

    // reset
    executionState(ch, MI, stateNumber) := undef
  }
  else if (exState = DONE) then {
    seq // end loop ...
    remainingStates := []
    next
    // ... but add new states of this MI to initialize them,
    // so that all states have the same start time
    foreach x in addStates(ch, MI, stateNumber)
      with nth(x, 1) = MI do {
        add nth(x, 2) to remainingStates
      }

    macroExecutionState(ch, MI) := DONE

    // quasi-reset
    executionState(ch, MI, stateNumber) := NEXT
  }
  else if (exState = NEXT) then {
    seq
    remove stateNumber from remainingStates // remove self
    next
    // reduce to states with same priority
    let prio = statePriority(pID, stateNumber) in
    remainingStates
      := filterStatesWithSamePrio(pID, remainingStates, prio)

    if (macroExecutionState(ch, MI) != DONE) then
      macroExecutionState(ch, MI) := NEXT
  }
  else if (exState = LOWER) then {
    remove stateNumber from remainingStates // remove self

    if (macroExecutionState(ch, MI) != DONE
        and macroExecutionState(ch, MI) != NEXT) then
      macroExecutionState(ch, MI) := LOWER
  }

```

Listing 53: UpdateRemainingStates

```

rule UpdateActiveStates(MI, stateNumber) =
  // NOTE: everything needs to be sequential,
  // as activeStates is a list and not a set
  let ch = channelFor(self) in seqblock
    foreach x in addStates(ch, MI, stateNumber) do
      let xMI = nth(x, 1),
          xN = nth(x, 2) in {
        add xN to activeStates(ch, xMI)
      }

    addStates(ch, MI, stateNumber) := undef

    foreach x in removeStates(ch, MI, stateNumber) do
      let xMI = nth(x, 1),
          xN = nth(x, 2) in {
        // remove one instance of xN, if any
        remove xN from activeStates(ch, xMI)

        ResetState(xMI, xN)
      }

    removeStates(ch, MI, stateNumber) := undef
  endseqblock

```

Listing 54: UpdateActiveStates

```

// whether the state should be aborted or not
derived abortState(MI, stateNumber) =
  ((timeoutActive(channelFor(self), MI, stateNumber) = true) or
   (cancelDecision(channelFor(self), MI, stateNumber) = true))

```

Listing 55: abortState

```

rule Behavior(MI, currentStateNumber) =
  let s = currentStateNumber,
      ch = channelFor(self) in
    if (initializedState(ch, MI, s) != true) then
      StartState(MI, s)
    else if (abortState(MI, s) = true) then
      AbortState(MI, s)
    else if (completed(ch, MI, s) != true) then
      Perform(MI, s)
    else if (initializedSelectedTransition(ch, MI, s) != true) then
      StartSelectedTransition(MI, s)
    else
      let t = selectedTransition(ch, MI, s) in
        if (transitionCompleted(ch, MI, t) != true) then
          PerformTransition(MI, s, t)
        else {
          Proceed(MI, s, targetStateNumber(processIDFor(self), t))
          SetExecutionState(MI, s, DONE)
        }
  }

```

Listing 56: Behavior


```

rule AbortState(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  if (abortionCompleted(ch, MI, s) != true) then
    Abort(MI, s)
  else {
    if (cancelDecision(ch, MI, s) = true) then {
      let t = outgoingCancelTransition(pID, s) in
      let target = targetStateNumber(pID, t) in {
        Proceed(MI, s, target)
      }
    }
    else if (timeoutActive(ch, MI, s) = true) then {
      let t = outgoingTimeoutTransition(pID, s) in
      let target = targetStateNumber(pID, t) in {
        Proceed(MI, s, target)
      }
    }
  }

  SetExecutionState(MI, s, DONE)
}

```

Listing 57: AbortState

C.6 STATE RULES

```

rule StartState(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in seqblock
  InitializeCompletion(MI, s)
  abortionCompleted(ch, MI, s) := false

  ResetTimeout(MI, s)
  cancelDecision(ch, MI, s) := false

  DisableAllTransitions(MI, s)
  initializedSelectedTransition(ch, MI, s) := false

  wantInput(ch, MI, s) := {}

  case stateType(pID, s) of
    "function"      : StartFunction(MI, s)
    "internalAction" : StartInternalAction(MI, s)
    "send"          : StartSend(MI, s)
    "receive"       : SetExecutionState(MI, s, LOWER)

    // shortcut: directly to PerformEnd w/o ASM step
    "end"           : SetExecutionState(MI, s, REPEAT)
  endcase

  initializedState(ch, MI, s) := true
endseqblock

```

Listing 58: StartState

```

rule ResetState(MI, stateNumber) =
  let ch = channelFor(self),
      s = stateNumber in {
    executionState(ch, MI, s) := undef

    initializedState(ch, MI, s) := undef

    completed(ch, MI, s) := undef
    abortionCompleted(ch, MI, s) := undef

    startTime(ch, MI, s) := undef
    timeoutActive(ch, MI, s) := undef

    cancelDecision(ch, MI, s) := undef

    selectedTransition(ch, MI, s) := undef

    let pID = processIDFor(self) in
    forall t in outgoingNormalTransitions(pID, s) do {
      exitCondition(ch, MI, t) := undef
      transitionCompleted(ch, MI, t) := undef
    }

    initializedSelectedTransition(ch, MI, s) := undef

    wantInput(ch, MI, s) := undef

    // from StartSend
    receivers                (ch, MI, s) := undef
    reservationsDone         (ch, MI, s) := undef
    messageContent           (ch, MI, s) := undef
    messageCorrelationID     (ch, MI, s) := undef
    messageReceiverCorrelationID(ch, MI, s) := undef
  }

```

Listing 59: ResetState

```

rule Perform(MI, currentStateNumber) =
  let pID = processIDFor(self)
      s = currentStateNumber in
  case stateType(pID, s) of
    "function"      : PerformFunction(MI, s)
    "internalAction" : PerformInternalAction(MI, s)
    "send"          : PerformSend(MI, s)
    "receive"       : PerformReceive(MI, s)
    "end"           : PerformEnd(MI, s)
  endcase

```

Listing 60: Perform

```

rule SelectTransition(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  if (|outgoingEnabledTransitions(ch, MI, s)| = 0) then
    // BLOCKED: none to select
    SetExecutionState(MI, s, NEXT)
  else if (not(contains(wantInput(ch, MI, s),
                        "TransitionDecision")))) then {
    add "TransitionDecision" to wantInput(ch, MI, s)
    SetExecutionState(MI, s, DONE)
  }
  else
    // waiting for selectedTransition
    SetExecutionState(MI, s, NEXT)

```

Listing 61: SelectTransition

```

rule StartSelectedTransition(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in {
    let t = selectedTransition(ch, MI, s) in {
      InitializeCompletionTransition(MI, t)
      initializedSelectedTransition(ch, MI, s) := true
    }

    SetExecutionState(MI, s, REPEAT)
  }

```

Listing 62: StartSelectedTransition

```

rule PerformTransition(MI, currentStateNumber, t) =
  let pID = processIDFor(self),
      s = currentStateNumber in
  case stateType(pID, s) of
    "function"      : PerformTransitionFunction(MI, s, t)
    "internalAction" : SetCompletedTransition(MI, s, t)
    "send"          : PerformTransitionSend(MI, s, t)
    "receive"       : PerformTransitionReceive(MI, s, t)
  endcase

```

Listing 63: PerformTransition

```

rule StartFunction(MI, currentStateNumber) =
  let pID = processIDFor(self) in
  let functionName = stateFunction(pID, currentStateNumber) in {
    StartTimeout(MI, currentStateNumber)

    if (startFunction(functionName) = undef) then
      skip
    else
      call startFunction(functionName) (MI, currentStateNumber)

    SetExecutionState(MI, currentStateNumber, LOWER)
  }

```

Listing 64: StartFunction

```

rule PerformFunction(MI, currentStateNumber) =
  let s = currentStateNumber in
    if (shouldTimeout(channelFor(self), MI, s) = true) then {
      SetCompleted(MI, s)
      ActivateTimeout(MI, s)
    }
  else
    let pID = processIDFor(self) in
    let functionName = stateFunction(pID, s),
        args = stateFunctionArguments(pID, s) in
    call performFunction(functionName) (MI, s, args)

```

Listing 65: PerformFunction

```

rule AbortFunction(MI, currentStateNumber) =
  let pID = processIDFor(self) in
  let functionName = stateFunction(pID, currentStateNumber) in
  if (abortFunction(functionName) = undef) then
    SetAbortionCompleted(MI, currentStateNumber)
  else
    // must set abortionCompleted eventually
    call abortFunction(functionName) (MI, currentStateNumber)

```

Listing 66: AbortFunction

```

rule PerformTransitionFunction(MI, currentStateNumber, t) =
  let pID = processIDFor(self),
      s = currentStateNumber in
  let functionName = stateFunction(pID, s) in
  if (performTransitionFunction(functionName) = undef) then
    SetCompletedTransition(MI, s, t)
  else
    call performTransitionFunction(functionName) (MI, s, t)

```

Listing 67: PerformTransitionFunction

```

rule SetCompletedFunction(MI, currentStateNumber, res) =
  let ch = channelFor(self),
      s = currentStateNumber in {
    if (res = undef) then
      choose t in outgoingNormalTransitions(pID, s) do
        selectedTransition(ch, MI, s) := t
    else
      let t = getTransitionByLabel(pID, s, res) in
        selectedTransition(ch, MI, s) := t
  }
  SetCompleted(MI, s)
}

```

Listing 68: SetCompletedFunction

```

rule Proceed(MI, s_from, s_to) = {
  AddState(MI, s_from, MI, s_to)
  RemoveState(MI, s_from, MI, s_from)
}

```

Listing 69: Proceed

```

rule StartTimeout(MI, currentStateNumber) =
  let ch = channelFor(self) in {
    startTime(ch, MI, currentStateNumber) := nanoTime()
    timeoutActive(ch, MI, currentStateNumber) := false
  }

rule ResetTimeout(MI, currentStateNumber) =
  let ch = channelFor(self) in {
    startTime(ch, MI, currentStateNumber) := undef
    timeoutActive(ch, MI, currentStateNumber) := undef
  }

rule ActivateTimeout(MI, currentStateNumber) =
  let ch = channelFor(self) in
    timeoutActive(ch, MI, currentStateNumber) := true

```

Listing 70: StartTimeout

```

rule InitializeCompletion(MI, currentStateNumber) =
  let ch = channelFor(self) in
    completed(ch, MI, currentStateNumber) := false

rule SetCompleted(MI, currentStateNumber) =
  let ch = channelFor(self) in {
    SetExecutionState(MI, currentStateNumber, REPEAT)
    completed(ch, MI, currentStateNumber) := true
  }

rule SetAbortionCompleted(MI, currentStateNumber) =
  let ch = channelFor(self) in {
    SetExecutionState(MI, currentStateNumber, DONE)
    abortionCompleted(ch, MI, currentStateNumber) := true
  }

```

Listing 71: InitializeCompletion

```

rule EnableTransition(MI, t) =
  exitCondition(channelFor(self), MI, t) := true

rule EnableAllTransitions(MI, currentStateNumber) =
  let pID = processIDFor(self),
      s = currentStateNumber in
  forall t in outgoingNormalTransitions(pID, s) do
    EnableTransition(MI, t)

rule DisableTransition(MI, currentStateNumber, t) =
  exitCondition(channelFor(self), MI, t) := false

rule DisableAllTransitions(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in {
    forall t in outgoingNormalTransitions(ppID, s) do
      DisableTransition(MI, s, t)

    selectedTransition(ch, MI, s) := undef
  }

```

Listing 72: EnableTransition

```

rule InitializeCompletionTransition(MI, t) =
  transitionCompleted(channelFor(self), MI, t) := false

rule SetCompletedTransition(MI, currentStateNumber, t) = {
  SetExecutionState(MI, currentStateNumber, REPEAT)

  transitionCompleted(channelFor(self), MI, t) := true
}

```

Listing 73: InitializeCompletionTransition

C.7 INTERNAL ACTION

```

rule StartInternalAction(MI, currentStateNumber) = {
  StartTimeout(MI, currentStateNumber)

  EnableAllTransitions(MI, currentStateNumber)

  SetExecutionState(MI, currentStateNumber, LOWER)
}

```

Listing 74: StartInternalAction

```

rule PerformInternalAction(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  if (shouldTimeout(ch, MI, s) = true) then {
    SetCompleted(MI, s)
    ActivateTimeout(MI, s)
  }
  else if (selectedTransition(ch, MI, s) != undef) then
    SetCompleted(MI, s)
  else
    SelectTransition(MI, s)

```

Listing 75: PerformInternalAction

C.8 SEND FUNCTION

```

rule StartSend(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  // there must be exactly one transition
  let t = first_outgoingNormalTransition(pID, s) in {
    receivers(ch, MI, s) := undef
    reservationsDone(ch, MI, s) := {}
    let mcVName = messageContentVar(pID, t) in
      messageContent(ch, MI, s) := loadVar(MI, mcVName)

    // generate new CorrelationID now, it will be stored
    // in a Variable once the message(s) are send
    let cIDVName = messageNewCorrelationVar(pID, t) in
      if (cIDVName != undef and cIDVName != "") then {
        messageCorrelationID(ch, MI, s) := nextCorrelationID
        nextCorrelationID := nextCorrelationID + 1
        // ensure no other agent uses this same correlationID
        nextCorrelationIDUsedBy(nextCorrelationID) := self
      }
      else
        messageCorrelationID(ch, MI, s) := 0

    // load receiver IP CorrelationID now, to avoid
    // influences of any changes of that variable
    let cIDVName = messageWithCorrelationVar(pID, t) in
      let cID = loadCorrelationID(MI, cIDVName) in
        messageReceiverCorrelationID(ch, MI, s) := cID

    SetExecutionState(MI, s, LOWER)
  }

```

Listing 76: StartSend

```

rule PerformSend(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  if (receivers(ch, MI, s) = undef) then
    SelectReceivers(MI, s)
  else if (messageContent(ch, MI, s) = undef) then
    SetMessageContent(MI, s)
  else if (startTime(ch, MI, s) = undef) then {
    StartTimeout(MI, s)
    SetExecutionState(MI, s, REPEAT)
  }
  else if (|receivers(ch, MI, s)| =
           |reservationsDone(ch, MI, s)|) then
    TryCompletePerformSend(MI, s)
  else if (shouldTimeout(ch, MI, s) = true) then {
    SetCompleted(MI, s)
    ActivateTimeout(MI, s)
  }
  else
    DoReservations(MI, s)

```

Listing 77: PerformSend

```

rule TryCompletePerformSend(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  if (anyNonProperTerminated(receivers(ch, MI, s)) = true) then
    // BLOCKED: a receiver where a reservation was placed has
    // terminated non-proper in the meantime
    if (shouldTimeout(ch, MI, s) = true) then {
      SetCompleted(MI, s)
      ActivateTimeout(MI, s)
    }
  else
    SetExecutionState(MI, s, NEXT)
  else {
    // there must be exactly one transition
    let t = first_outgoingNormalTransition(pID, s) in
      selectedTransition(ch, MI, s) := t

    SetCompleted(MI, s)
  }

```

Listing 78: TryCompletePerformSend


```

rule SelectReceivers(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  // there must be exactly one transition
  let t = first_outgoingNormalTransition(pID, s) in
  let min = messageSubjectCountMin(pID, t), // 0 => ALL
      max = messageSubjectCountMax(pID, t) in // 0 => no limit
  let recVName = messageSubjectVar(pID, t),
      recSID = messageSubjectId(pID, t) in
  if (recVName != undef and recVName != "") then
    let rChs = loadChannelsFromVariable(MI, recVName, recSID) in
    if (|rChs| = 0 or (min != 0 and |rChs| < min)) then
      // BLOCKED: not enough receivers given
      SetExecutionState(MI, s, NEXT)
    else if (max != 0 and |rChs| > max) then
      // too many receivers given -> call VarMan-Selection
      SelectReceivers_Selection(MI, s, rChs, min, max)
    else {
      // receivers fit min/max -> use them
      receivers(ch, MI, s) := rChs
      SetExecutionState(MI, s, REPEAT)
    }
  else // no variable with receivers -> call SelectAgents
    if (selectAgentsResult(ch, MI, s) != undef) then
      let y = selectAgentsResult(ch, MI, s) in {
        receivers(ch, MI, s) := y
        selectAgentsResult(ch, MI, s) := undef // reset

        SetExecutionState(MI, s, REPEAT)
      }
    else
      SelectAgents(MI, s, recSID, min, max)

```

Listing 79: SelectReceivers

```

rule SelectReceivers_Selection(MI, currentStateNumber,
                               rChs, min, max) =
  let ch = channelFor(self),
      s = currentStateNumber in
  let res = selectionResult(ch, MI, s) in
  if (res = undef) then
    let src = ["ChannelInformation", rChs] in
    Selection(MI, s, src, min, max)
  else {
    selectionResult(ch, MI, s) := undef
    receivers(ch, MI, s) := res

    SetExecutionState(MI, s, REPEAT)
  }

```

Listing 80: SelectReceivers_Selection

```

rule AbortSend(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in {
    foreach r in reservationsDone(ch, MI, s) do {
      CancelReservation(MI, s, r)
    }

    SetAbortionCompleted(MI, s)
  }

```

Listing 81: AbortSend

```

rule PerformTransitionSend(MI, currentStateNumber, t) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in {
    foreach r in reservationsDone(ch, MI, s) do {
      ReplaceReservation(MI, s, r)

      EnsureRunning(r)
    }

    let storeVName = messageStoreReceiverVar(pID, t) in
      if (storeVName != undef and storeVName != "") then
        SetVar(MI, storeVName, "ChannelInformation",
              reservationsDone(ch, MI, s))

    let cIDVName = messageNewCorrelationVar(pID, t) in
      if (cIDVName != undef and cIDVName != "") then
        SetVar(MI, cIDVName, "CorrelationID",
              messageCorrelationID(ch, MI, s))

    SetCompletedTransition(MI, s, t)
  }

```

Listing 82: PerformTransitionSend

```

rule SetMessageContent(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
    if not (contains(wantInput(ch, MI, ch),
                    "MessageContentDecision")) then {
      add "MessageContentDecision" to wantInput(ch, MI, ch)
      SetExecutionState(MI, ch, DONE)
    }
    else
      // waiting for messageContent
      SetExecutionState(MI, ch, NEXT)

```

Listing 83: SetMessageContent

```
// handle all receivers
rule DoReservations(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  local hasPlacedReservation := false in
  seq
    let receiversTodo = (receivers(ch, MI, s) diff
                        reservationsDone(ch, MI, s)) in
  foreach receiver in receiversTodo do
    local tmp := false in
    seq
      // result is true if a reservation was made
      tmp <- DoReservation(MI, s, receiver)
    next if (tmp = true) then
      hasPlacedReservation := true
  next
  if (hasPlacedReservation = true) then
    // reservation(s) placed, make update
    SetExecutionState(MI, s, DONE)
  else
    // no reservations made, allow other states
    SetExecutionState(MI, s, NEXT)
```

Listing 84: DoReservations

```

// handle single reservation
// result true if hasPlacedReservation, adds to reservationsDone
rule DoReservation(MI, currentStateNumber, receiverChannel) =
  if (properTerminated(receiverChannel) = true) then
    let ch = channelFor(self),
        pID = processIDFor(self),
        sID = subjectIDFor(self),
        s = currentStateNumber in
    let Rch = receiverChannel,
        RpID = processIDOf(receiverChannel) in
    let sIDX = searchSenderSubjectID(pID, sID, RpID) in
    let msgCID = messageCorrelationID(ch, MI, s),
        RCID = messageReceiverCorrelationID(ch, MI, s) in
    // there must be exactly one transition
    let t = first_outgoingNormalTransition(pID, s) in
    let mT = messageType(pID, t) in
    let resMsg = [ch, mT, {}, msgCID, true] in
    seq
      // prepare receiver IP
      if (inputPool(Rch, sIDX, mT, RCID) = undef) then {
        add [sIDX, mT, RCID] to inputPoolDefined(Rch)
        inputPool(Rch, sIDX, mT, RCID) := []
      }
    next
      if (inputPoolIsClosed(Rch, sIDX, mT, RCID) != true) then
        if (inputPoolGetFreeSpace(Rch, sIDX, mT) > 0) then {
          enqueue resMsg into inputPool(Rch, sIDX, mT, RCID)
          add Rch to reservationsDone(ch, MI, s)
          result := true
        }
      else
        result := false // BLOCKED: no free space!
    else
      result := false // BLOCKED: inputPoolIsClosed
  else
    result := false // BLOCKED: non-properTerminated

```

Listing 85: DoReservation

```

rule CancelReservation(MI, currentStateNumber, receiverChannel) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      sID = subjectIDFor(self),
      s = currentStateNumber in
  let Rch = receiverChannel,
      RpID = processIDOf(receiverChannel) in
  let t = first_outgoingNormalTransition(pID, s) in
  let mT = messageType(pID, t) in
  let sIDX = searchSenderSubjectID(pID, sID, RpID),
      msgCID = messageCorrelationID(ch, MI, s),
      RCID = messageReceiverCorrelationID(ch, MI, s) in
  let resMsg = [ch, mT, {}, msgCID, true],
      IPold = inputPool(Rch, sIDX, mT, RCID) in
  let IPnew = dropnth(IPold, head(indexes(IPold, resMsg))) in
  inputPool(Rch, sIDX, mT, RCID) := IPnew

```

Listing 86: CancelReservation

```

rule ReplaceReservation(MI, currentStateNumber, receiverChannel) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      sID = subjectIDFor(self),
      s = currentStateNumber in
  let Rch = receiverChannel,
      RpID = processIDOf(receiverChannel) in
  let t = first_outgoingNormalTransition(pID, s) in
  let mT = messageType(pID, t) in
  let sIDX = searchSenderSubjectID(pID, sID, RpID),
      msgCID = messageCorrelationID(ch, MI, s),
      RCID = messageReceiverCorrelationID(ch, MI, s) in
  let resMsg = [ch, mT, {}, msgCID, true],
      msg = [ch, mT, messageContent(ch, MI, s), msgCID, false],
      IPold = inputPool(Rch, sIDX, mT, RCID) in
  let IPnew = setnth(IPold, head(indexes(IPold, resMsg)), msg) in
  inputPool(Rch, sIDX, mT, RCID) := IPnew

```

Listing 87: ReplaceReservation

C.9 RECEIVE FUNCTION

```

rule PerformReceive(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
    // startTime must be the time of the first attempt to receive
    // in order to support receiving with timeout=0
    if (startTime(ch, MI, s) = undef) then {
      StartTimeout(MI, s)
      SetExecutionState(MI, s, REPEAT)
    }
    else if (shouldTimeout(ch, MI, s) = true) then {
      SetCompleted(MI, s)
      ActivateTimeout(MI, s)
    }
    else
      seq
        forall t in outgoingNormalTransitions(pID, s) do
          CheckIP(MI, s, t)
        next
        let enabledT = outgoingEnabledTransitions(ch, MI, s) in
        if (|enabledT| > 0) then
          seq
            if (selectedTransition(ch, MI, s) != undef) then
              skip // there is already an transition selected
            else if (|enabledT| = 1) then
              let t = firstFromSet(enabledT) in
              if (transitionIsAuto(pID, t) = true) then
                // make automatic decision
                selectedTransition(ch, MI, s) := t
              else skip // can not make automatic decision
            else skip // can not make automatic decision
          next
          if (selectedTransition(ch, MI, s) != undef) then
            // the decision was made
            SetCompleted(MI, s)
          else
            // no decision made, waiting for selectedTransition
            SelectTransition(MI, s)
        else
          SetExecutionState(MI, s, LOWER) // BLOCKED: no messages

```

Listing 88: PerformReceive

```

rule PerformTransitionReceive(MI, currentStateNumber, t) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  let sID      = messageSubjectId      (pID, t),
      mT       = messageType           (pID, t),
      cIDVName = messageWithCorrelationVar(pID, t),
      countMax = messageSubjectCountMax (pID, t) in
  let cID = loadCorrelationID(MI, cIDVName) in {
    seq
      // stores the messages in receivedMessages
      InputPool_Pop(MI, s, sID, mT, cID, countMax)
    next
      if (messageStoreMessagesVar(pID, t) != undef and
          messageStoreMessagesVar(pID, t) != "") then
        let msgs = receivedMessages(ch, MI, s),
            vName = messageStoreMessagesVar(pID, t) in
          SetVar(MI, vName, "MessageSet", msgs)

    SetCompletedTransition(MI, s, t)
  }

```

Listing 89: PerformTransitionReceive

```

rule CheckIP(MI, currentStateNumber, t) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  let sID      = messageSubjectId      (pID, t),
      mT       = messageType           (pID, t),
      cIDVName = messageWithCorrelationVar(pID, t),
      countMin = messageSubjectCountMin (pID, t) in
  let cID = loadCorrelationID(MI, cIDVName) in
  let msgs = availableMessages(ch, sID, mT, cID) in
    if (|msgs| >= countMin) then
      EnableTransition(MI, t)
    else
      DisableTransition(MI, s, t)

```

Listing 90: CheckIP

C.10 END FUNCTION

```

rule PerformEnd(MI, currentStateNumber) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  if (|activeStates(ch, MI)| > 1) then {
    // does not remove currentStateNumber
    AbortMacroInstance(MI, s)
    SetExecutionState(MI, s, DONE)
  }
  else {
    if (MI = 1) then { // terminate subject
      ClearAllVarInMI(ch, 0)
      ClearAllVarInMI(ch, 1)

      FinalizeInteraction()

      program(self) := undef
      remove self from asmAgents
    }
    else { // terminate only Macro Instance
      ClearAllVarInMI(ch, MI)

      let res = head(stateFunctionArguments(pID, s)) in
      if (res != undef) then
        // use parameter as result for CallMacro State
        macroTerminationResult(ch, MI) := res
      else
        // just indicate termination
        macroTerminationResult(ch, MI) := true
    }

    // remove self
    RemoveState(MI, s, MI, s)
    SetExecutionState(MI, s, DONE)
  }

```

Listing 91: PerformEnd

C.11 TAU FUNCTION

```

rule StartTau(MI, currentStateNumber) =
  EnableAllTransitions(MI, currentStateNumber)

rule Tau(MI, currentStateNumber, args) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  choose t in outgoingEnabledTransitions(t, MI, s)
    with (transitionIsAuto(pID, t) = true) do {
    selectedTransition(t, MI, s) := t
    SetCompleted(MI, s)
  }
  ifnone // WARN: unable to choose auto transition!
    if (selectedTransition(t, MI, s) != undef) then
      SetCompleted(MI, s)
    else
      SelectTransition(MI, s)

```

Listing 92: Tau

C.12 VARMAN FUNCTION

```

rule AbortVarMan(MI, currentStateNumber) = {
  ResetSelection(MI, currentStateNumber)
  SetAbortionCompleted(MI, currentStateNumber)
}

rule VarMan(MI, currentStateNumber, args) =
  let s = currentStateNumber,
      method = nth(args, 1),
      A = nth(args, 2),
      B = nth(args, 3),
      C = nth(args, 4),
      D = nth(args, 5) in
  case method of
    "assign"           : VarMan_Assign    (MI, s, A, B)
    "storeData"       : VarMan_StoreData(MI, s, A, B)
    "clear"           : VarMan_Clear     (MI, s, A)

    "concatenation"   : VarMan_Concatenation(MI, s, A, B, C)
    "intersection"    : VarMan_Intersection (MI, s, A, B, C)
    "difference"      : VarMan_Difference  (MI, s, A, B, C)

    "extractContent"  : VarMan_ExtractContent      (MI, s, A, B)
    "extractChannel"  : VarMan_ExtractChannel      (MI, s, A, B)
    "extractCorrelationID": VarMan_ExtractCorrelationID(MI, s, A, B)

    "selection"       : VarMan_Selection(MI, s, A, B, C, D)
  endcase

```

Listing 93: VarMan

```
rule VarMan_Assign(MI, currentStateNumber, A, X) =  
  let a = loadVar(MI, A) in {  
    SetVar(MI, X, head(a), last(a))  
  
    SetCompletedFunction(MI, currentStateNumber, undef)  
  }  
  
rule VarMan_StoreData(MI, currentStateNumber, X, A) = {  
  SetVar(MI, X, "Data", A)  
  
  SetCompletedFunction(MI, currentStateNumber, undef)  
}  
  
rule VarMan_Clear(MI, currentStateNumber, X) = {  
  ClearVar(MI, X)  
  
  SetCompletedFunction(MI, currentStateNumber, undef)  
}
```

Listing 94: VarMan_Assign

```

rule VarMan_Concatenation(MI, currentStateNumber, A, B, X) =
  let a = loadVar(MI, A),
      b = loadVar(MI, B) in {
    if (a = undef and b = undef) then
      ClearVar(MI, X)
    else if (a = undef) then
      SetVar(MI, X, head(b), last(b))
    else if (b = undef) then
      SetVar(MI, X, head(a), last(a))
    else
      let x = (last(a) union last(b)) in
        SetVar(MI, X, head(a), x)

    SetCompletedFunction(MI, currentStateNumber, undef)
  }

rule VarMan_Intersection(MI, currentStateNumber, A, B, X) =
  let a = loadVar(MI, A),
      b = loadVar(MI, B) in {
    if (a = undef or b = undef) then
      ClearVar(MI, X)
    else
      let x = (last(a) intersect last(b)) in
        SetVar(MI, X, head(a), x)

    SetCompletedFunction(MI, currentStateNumber, undef)
  }

rule VarMan_Difference(MI, currentStateNumber, A, B, X) =
  let a = loadVar(MI, A),
      b = loadVar(MI, B) in {
    if (a = undef) then
      ClearVar(MI, X)
    else if (b = undef) then
      SetVar(MI, X, head(a), last(a))
    else
      let x = (last(a) diff last(b)) in
        SetVar(MI, X, head(a), x)

    SetCompletedFunction(MI, currentStateNumber, undef)
  }

```

Listing 95: VarMan_Concatenation

```

rule VarMan_ExtractContent(MI, currentStateNumber, A, X) =
  let a = loadVar(MI, A) in
  let msgs = last(a) in
  let msgsContent = map(msgs, @msgContent) in
  let varType = head(firstFromSet(msgsContent)) in {
    SetVar(MI, X, varType, flattenSet(map(msgsContent, @last)))

    SetCompletedFunction(MI, currentStateNumber, undef)
  }

rule VarMan_ExtractChannel(MI, currentStateNumber, A, X) =
  let a = loadVar(MI, A) in
  let msgs = last(a) in
  let msgsChannel = map(msgs, @msgChannel) in {
    SetVar(MI, X, "ChannelInformation", msgsChannel)

    SetCompletedFunction(MI, currentStateNumber, undef)
  }

rule VarMan_ExtractCorrelationID(MI, currentStateNumber, A, X) =
  let a = loadVar(MI, A) in
  let msgs = last(a) in
  let msgsCorrelationID = map(msgs, @msgCorrelation) in {
    SetVar(MI, X, "CorrelationID",
      firstFromSet(msgsCorrelationID))

    SetCompletedFunction(MI, currentStateNumber, undef)
  }

```

Listing 96: VarMan_ExtractContent

```

// Channel * MI * n
function selectionVartype : LIST * NUMBER * NUMBER -> STRING
function selectionData    : LIST * NUMBER * NUMBER -> LIST
function selectionOptions : LIST * NUMBER * NUMBER -> LIST
function selectionMin     : LIST * NUMBER * NUMBER -> NUMBER
function selectionMax     : LIST * NUMBER * NUMBER -> NUMBER
function selectionDecision : LIST * NUMBER * NUMBER -> SET

function selectionResult : LIST * NUMBER * NUMBER -> SET

rule VarMan_Selection(MI, currentStateNumber, srcVName, dstVName,
                      minimum, maximum) =
  let ch = channelFor(self) in
  let src = loadVar(MI, srcVName),
      res = selectionResult(ch, MI, currentStateNumber) in
  if (res = undef) then
    Selection(MI, currentStateNumber, src, minimum, maximum)
  else {
    selectionResult(ch, MI, currentStateNumber) := undef

    SetVar(MI, dstVName, head(src), res)

    SetCompletedFunction(MI, currentStateNumber, undef)
  }

rule ResetSelection(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in {
    selectionVartype (ch, MI, s) := undef
    selectionData    (ch, MI, s) := undef
    selectionOptions (ch, MI, s) := undef
    selectionMin     (ch, MI, s) := undef
    selectionMax     (ch, MI, s) := undef
    selectionDecision(ch, MI, s) := undef
  }

```

Listing 97: VarMan_Selection

```

rule Selection(MI, currentStateNumber, src, minimum, maximum) =
  let ch = channelFor(self),
      s = currentStateNumber in
  if (selectionData(ch, MI, s) = undef) then {
    let l = toList(last(src)) in
    if (head(src) = "MessageSet") then {
      selectionData (ch, MI, s) := l
      selectionOptions(ch, MI, s) := map(l, @msgToString)
    }
    else if (head(src) = "ChannelInformation") then {
      selectionData (ch, MI, s) := l
      selectionOptions(ch, MI, s) := map(l, @chToString)
    }

    selectionVartype (ch, MI, s) := head(src)
    selectionMin (ch, MI, s) := minimum
    selectionMax (ch, MI, s) := maximum
    selectionDecision(ch, MI, s) := undef

    SetExecutionState(MI, s, REPEAT)
  }
  else if (selectionDecision(ch, MI, s) = undef) then {
    if not(contains(wantInput(ch, MI, s),
                    "SelectionDecision")) then {
      add "SelectionDecision" to wantInput(ch, MI, s)

      SetExecutionState(MI, s, DONE)
    }
    else
      // waiting for selectionDecision
      SetExecutionState(MI, s, NEXT)
  }
  else {
    let res = pickItems(selectionData(ch, MI, s),
                        selectionDecision(ch, MI, s)) in
    selectionResult(ch, MI, s) := res

    ResetSelection(MI, s)
    SetExecutionState(MI, s, REPEAT)
  }

```

Listing 98: Selection

C.13 MODAL SPLIT & MODAL JOIN FUNCTIONS

```

rule ModalSplit(MI, currentStateNumber, args) =
  let pID = processIDFor(self),
      s = currentStateNumber in {
    // start all following states
    foreach t in outgoingNormalTransitions(pID, s) do
      let sNew = targetStateNumber(pID, t) in
        AddState(MI, s, MI, sNew)

    // remove self
    RemoveState(MI, s, MI, s)

    SetExecutionState(MI, s, DONE)
  }

```

Listing 99: ModalSplit

```

// Channel * MacroInstanceNumber * joinState -> Number
function joinCount : LIST * NUMBER * NUMBER -> NUMBER

// number of execution paths have to be provided as argument
rule ModalJoin(MI, currentStateNumber, args) =
  let ch = channelFor(self),
      s = currentStateNumber,
      numSplits = nth(args, 1) in
  seq // count how often this join has been called
    if (joinCount(ch, MI, s) = undef) then
      joinCount(ch, MI, s) := 1
    else
      joinCount(ch, MI, s) := joinCount(ch, MI, s) + 1
  next
  // can we continue, or remove self and will be called again?
  if (joinCount(ch, MI, s) < numSplits) then {
    // drop this execution path
    RemoveState(MI, s, MI, s)
    SetExecutionState(MI, s, DONE)
  }
  else {
    // reset for next iteration
    joinCount(ch, MI, s) := undef
    SetCompletedFunction(MI, s, undef)
  }

```

Listing 100: ModalJoin

C.14 CALLMACRO FUNCTION

```

rule AbortCallMacro(MI, currentStateNumber) =
  let ch = channelFor(self),
      s = currentStateNumber in
  let childInstance = callMacroChildInstance(ch, MI, s) in
  if (|activeStates(ch, childInstance)| > 0) then {
    AbortMacroInstance(childInstance, undef)
    SetExecutionState(MI, s, DONE)
  }
  else {
    callMacroChildInstance(ch, MI, s) := undef
    SetAbortionCompleted(MI, s)
  }

```

Listing 101: AbortCallMacro

```

rule InitializeMacroArguments(MI, mIDNew, MINew, givenSrcVNames) =
  local
    dstVNames := macroArguments(processIDFor(self), mIDNew),
    srcVNames := givenSrcVNames in
  while (|dstVNames| > 0) do {
    let dstVName = head(dstVNames),
        srcVName = head(srcVNames) in
    let var = loadVar(MI, srcVName) in
      SetVar(MINew, dstVName, nth(var, 1), nth(var, 2))

    dstVNames := tail(dstVNames)
    srcVNames := tail(srcVNames)
  }

```

Listing 102: InitializeMacroArguments


```

rule CallMacro(MI, currentStateNumber, args) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  let childInstance = callMacroChildInstance(ch, MI, s) in
  if (childInstance = undef) then
    // start new Macro Instance
    let mIDNew = searchMacro(head(args)),
        MINew = nextMacroInstanceNumber(ch) in
    seqblock
      nextMacroInstanceNumber(ch) := MINew + 1
      macroNumberOfMI(ch, MINew) := mIDNew
      callMacroChildInstance(ch, MI, s) := MINew

      if (|macroArguments(ch, mIDNew)| > 0) then
        InitializeMacroArguments(MI, mIDNew, MINew, tail(args))

      SetExecutionState(MI, s, DONE)

      StartMacro(MI, s, mIDNew, MINew)
    endseqblock
  else
    // perform existing Macro Instance
    let childResult = macroTerminationResult(ch, childInstance) in
    if (childResult != undef) then {
      callMacroChildInstance(ch, MI, s) := undef

      // transport result, if present
      if (childResult = true) then
        SetCompletedFunction(MI, s, undef)
      else
        SetCompletedFunction(MI, s, childResult)
    }
  else seqblock
    // Macro Instance is active, call it ...
    MacroBehavior(childInstance)

    // ... and transport its execution state
    let mState = macroExecutionState(ch, childInstance) in
      SetExecutionState(MI, s, mState)

    // reset
    macroExecutionState(ch, childInstance) := undef
  endseqblock

```

Listing 103: CallMacro

C.15 CANCEL FUNCTION

```

rule CheckCancel(MI, currentStateNumber, t) =
  let ch = channelFor(self),
      pID = processIDFor(self) in
  let tName = transitionLabel(pID, t) in
  let nCancel = stateNumberFromID(pID, tName) in
  if (contains(activeStates(ch, MI), nCancel) = true) then
    // referenced state is active in this Macro Instance
    EnableTransition(MI, t)
  else
    DisableTransition(MI, currentStateNumber, t)

```

Listing 104: CheckCancel

```

rule Cancel(MI, currentStateNumber, args) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  seq
  forall t in outgoingNormalTransitions(pID, s) do
    CheckCancel(MI, s, t)
  next
  let enabledT = outgoingEnabledTransitions(ch, MI, s) in
  if (|enabledT| > 0) then
    seq
    if (|enabledT| = 1) then
      let t = firstFromSet(enabledT) in
      if (transitionIsAuto(pID, t) = true) then
        selectedTransition(ch, MI, s) := t
    next
    if (selectedTransition(ch, MI, s) != undef) then
      let t = selectedTransition(ch, MI, s) in
      SetCompletedFunction(MI, s, transitionLabel(pID, t))
    else
      SelectTransition(MI, s)
  else // BLOCKED: no corresponding active states
    SetExecutionState(MI, s, LOWER)

```

Listing 105: Cancel

```

rule Abort(MI, currentStateNumber) =
  let pID = processIDFor(self),
      s = currentStateNumber in
  case stateType(pID, s) of
    "function" : AbortFunction(MI, s)
    "internalAction" : SetAbortionCompleted(MI, s)
    "send" : AbortSend(MI, s)
    "receive" : SetAbortionCompleted(MI, s)
  endcase

```

Listing 106: Abort

```

rule PerformTransitionCancel(MI, currentStateNumber, t) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber in
  let tLabel = transitionLabel(pID, t) in
  let nCancel = stateNumberFromID(pID, tLabel) in {
    cancelDecision(ch, MI, nCancel) := true
    SetCompletedTransition(MI, s, t)
  }

```

Listing 107: PerformTransitionCancel

C.16 IP FUNCTIONS

```

rule CloseIP(MI, currentStateNumber, args) =
  let ch = channelFor(self),
      senderSubjID = nth(args, 1),
      msgType = nth(args, 2),
      cIDVName = nth(args, 3) in
  let cID = loadCorrelationID(MI, cIDVName) in {
    inputPoolClosed(ch, senderSubjID, msgType, cID) := true

    if (inputPool(ch, senderSubjID, msgType, cID) = undef) then {
      add [senderSubjID, msgType, cID] to inputPoolDefined(ch)
      inputPool(ch, senderSubjID, msgType, cID) := []
    }

    SetCompletedFunction(MI, currentStateNumber, undef)
  }

```

Listing 108: CloseIP

```

rule OpenIP(MI, currentStateNumber, args) =
  let ch = channelFor(self),
      senderSubjID = nth(args, 1),
      msgType = nth(args, 2),
      cIDVName = nth(args, 3) in
  let cID = loadCorrelationID(MI, cIDVName) in {
    inputPoolClosed(ch, senderSubjID, msgType, cID) := false

    if (inputPool(ch, senderSubjID, msgType, cID) = undef) then {
      add [senderSubjID, msgType, cID] to inputPoolDefined(ch)
      inputPool(ch, senderSubjID, msgType, cID) := []
    }

    SetCompletedFunction(MI, currentStateNumber, undef)
  }

```

Listing 109: OpenIP

```

rule CloseAllIPs(MI, currentStateNumber, args) =
  let ch = channelFor(self),
    s = currentStateNumber in {
    inputPoolClosed(ch, undef, undef, undef) := true

    forall key in inputPoolDefined(ch) do
      let sID = nth(key, 1),
        mT = nth(key, 2),
        cID = nth(key, 3) in {
        inputPoolClosed(ch, sID, mT, cID) := true
      }

    SetCompletedFunction(MI, s, undef)
  }

```

Listing 110: CloseAllIPs

```

rule OpenAllIPs(MI, currentStateNumber, args) =
  let ch = channelFor(self),
    s = currentStateNumber in {
    inputPoolClosed(ch, undef, undef, undef) := false

    forall key in inputPoolDefined(ch) do
      let sID = nth(key, 1),
        mT = nth(key, 2),
        cID = nth(key, 3) in {
        inputPoolClosed(ch, sID, mT, cID) := false
      }

    SetCompletedFunction(MI, s, undef)
  }

```

Listing 111: OpenAllIPs

```

// correlation can be wildcard (*)
rule IsIPEmpty(MI, currentStateNumber, args) =
  let ch = channelFor(self),
      s = currentStateNumber,
      senderSubjID = nth(args, 1),
      msgType = nth(args, 2),
      correlationIDVName = nth(args, 3) in
  local cID in
  seq
    if (correlationIDVName = undef or
        correlationIDVName = 0 or
        correlationIDVName = "") then {
      cID := 0
    }
    else if (correlationIDVName = "*") then {
      cID := undef
    }
    else {
      cID := loadCorrelationID(MI, correlationIDVName)
    }
  next
  if inputPoolIsEmpty(ch, senderSubjID, msgType, cID) then
    SetCompletedFunction(MI, s, "true")
  else
    SetCompletedFunction(MI, s, "false")

```

Listing 112: IsIPEmpty

C.17 SELECTAGENTS FUNCTION

```

// Channel * MacroInstanceNumber * StateNumber -> BOOLEAN
function selectAgentsDecision : LIST * NUMBER * NUMBER -> SET

function selectAgentsProcessID : LIST * NUMBER * NUMBER -> STRING
function selectAgentsSubjectID : LIST * NUMBER * NUMBER -> STRING
function selectAgentsCountMin : LIST * NUMBER * NUMBER -> NUMBER
function selectAgentsCountMax : LIST * NUMBER * NUMBER -> NUMBER

function selectAgentsResult : LIST * NUMBER * NUMBER -> SET

rule SelectAgentsAction(MI, currentStateNumber, args) =
  let ch = channelFor(self),
      s = currentStateNumber,
      vName = nth(args, 1),
      sIDLocal = nth(args, 2),
      countMin = nth(args, 3),
      countMax = nth(args, 4) in
  if (selectAgentsResult(ch, MI, s) != undef) then {
    SetVar(MI, vName, "ChannelInformation",
            selectAgentsResult(ch, MI, s))
    selectAgentsResult(ch, MI, s) := undef

    SetCompletedFunction(MI, s, undef)
  }
  else
    SelectAgents(MI, s, sIDLocal, countMin, countMax)

```

Listing 113: SelectAgentsAction

```

rule SelectAgents(MI, currentStateNumber, sIDLocal, min, max) =
  let ch = channelFor(self),
      pID = processIDFor(self),
      s = currentStateNumber,
      PI = processInstanceFor(self) in
  let predefAgents = predefinedAgents(pID, sIDLocal),
      resolvedInterface = resolveInterfaceSubject(sIDLocal) in
  let resolvedProcessID = nth(resolvedInterface, 1),
      resolvedSubjectID = nth(resolvedInterface, 2) in
  if (selectAgentsDecision(ch, MI, s) != undef) then {
    local createdChannels := {} in
    seq
      foreach agent in selectAgentsDecision(ch, MI, s) do
        if (resolvedProcessID = pID) then
          // local process, use own PI
          let ch = [pID, PI, sIDLocal, agent] in {
            InitializeSubject(ch)
            add ch to createdChannels
          }
        else // external process, create new PI
          local newPI in
          seq
            newPI <- StartProcess(resolvedProcessID,
                                  resolvedSubjectID, agent)
          next
            add [resolvedProcessID, newPI,
                resolvedSubjectID, agent] to createdChannels
        next
      selectAgentsResult(ch, MI, s) := createdChannels

    // reset for next iteration
    selectAgentsDecision (ch, MI, s) := undef
    selectAgentsCountMin (ch, MI, s) := undef
    selectAgentsCountMax (ch, MI, s) := undef
    selectAgentsProcessID(ch, MI, s) := undef
    selectAgentsSubjectID(ch, MI, s) := undef

    SetExecutionState(MI, s, REPEAT)
  }
  else if (hasSizeWithin(predefAgents, min, max) = true) then {
    selectAgentsDecision(ch, MI, s) := predefAgents
    SetExecutionState(MI, s, REPEAT)
  }
  else if not(contains(wantInput(ch, MI, s),
                      "SelectAgentsDecision")) then {
    add "SelectAgentsDecision" to wantInput(ch, MI, s)

    selectAgentsProcessID(ch, MI, s) := resolvedProcessID
    selectAgentsSubjectID(ch, MI, s) := resolvedSubjectID
    selectAgentsCountMin (ch, MI, s) := min
    selectAgentsCountMax (ch, MI, s) := max
    selectAgentsResult (ch, MI, s) := undef

    SetExecutionState(MI, s, DONE)
  }
  else // waiting for selectAgentsDecision
    SetExecutionState(MI, s, NEXT)

```

Listing 114: SelectAgents

Bibliography

[Kee76] E. L. Keenan. 1976.