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Using Resources as Synchronizers to Manage Mobile Process Adaptation

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Abstract: Process management in Mobile Ad-hoc NETworks (MANETs) has to deal with different types of tasks and resources. Teams can be formed with specific goals, such as recognition of a damaged area for disaster assessment, where each member of a team is assigned some task to be performed according to some policy. However, in real situations, it is possible that task assignments and policies have to be revised due to different causes. In addition to typical causes for dynamic changes in adaptive workflows, mobility introduces some specific problems, e.g. the need for new connectivity-maintaining tasks, or reassignment of tasks originally for members who have become unreachable, or who have no sufficient resources to complete the original plan. As these modifications occur dynamically, it is difficult to manage them through hard-coded programs. Rather, we propose the use of a rule-based formalism, expressed in terms of multi-set rewriting. This supports a resource-centered view, in which both data-dependencies between tasks and plan-dependent ordering of tasks are expressed as production and consumption of resources of different types. In turn, rules are themselves seen as resources, so that they are prone to the same rewriting process, in order to redefine process schemas. The paper illustrates these notions and formalisms, and shows some cases of their application.

Keywords: Mobile ad hoc networks, adaptive workflows, multiset rewriting.

1 Introduction

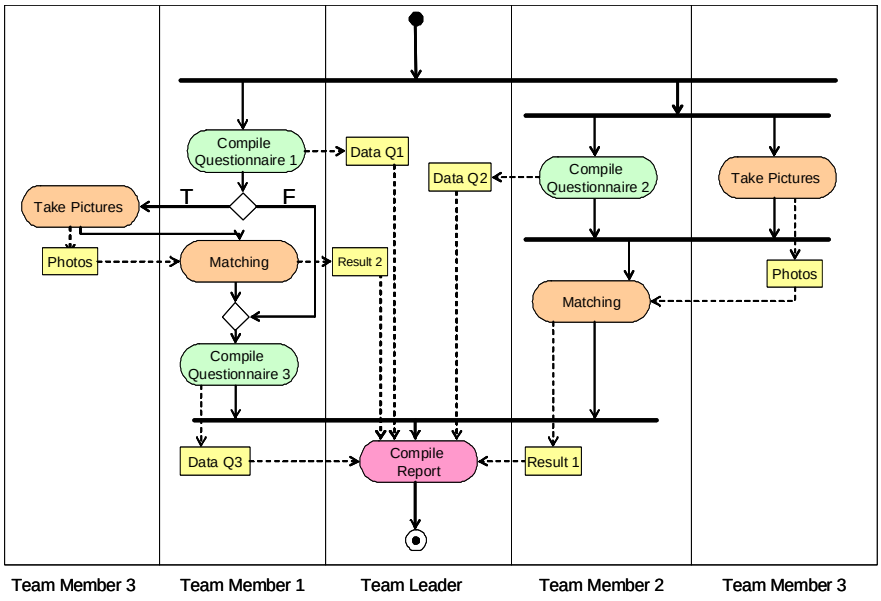
Process management in Mobile Ad-hoc NETworks (MANETs [AZ03]) has to deal with different types of tasks as well as of resources involved. MANETsare networks of mobile devices communicating via wireless links. They are an alternative to infrastructure-based networks whenever an infrastructure has never been available, is no longer available, or cannot be used, as in emergency/disaster situations. In such scenarios, generally, teams are formed with specific goals where each member of a team is assigned some task. When a team is working, it is possible that tasks not related to the original plan must be performed or that the execution order of some tasks has to be modified, so that some alternative assignment of tasks is required.

As an example, Figure 1(a) shows a process schema for a team (e.g., of the Homeland Security Department), equipped with mobile devices (laptops and PDAs), to carry out after an earthquake or a hurricane. The process comprises several tasks: swimlanes represent the assignment of tasks to team members[1]. In detail, the process requires that, after a visual analysis of a building, supported by some map-based application, team member 1 (using his/her device) fills out a report and enters attributes and graphic data related to the damage. The team leader analyzes these reports and spatial data with the help of specific software to schedule the next activities. Team member 3 takes pictures of the precarious buildings, whereas team member 2 is in charge of processing old and recent photos of the site (e.g. to identify architectural anomalies). In this situation, matching new pictures with previous ones might be useful. Suppose that, in the team, there is only one PDA equipped with a photo-camera (e.g., that of team member 3). Therefore, during process enactment, when the condition of the OR-split (the diamond construct) managed by team member 1 is `true`, the member requires the execution of another instance of the task "Take Pictures". In general, the two task instances might be carried out in parallel but, since there is only one member equipped with the needed device, one of the two instances has to be postponed. Figure 1(b) shows a possible restructuring of the process.

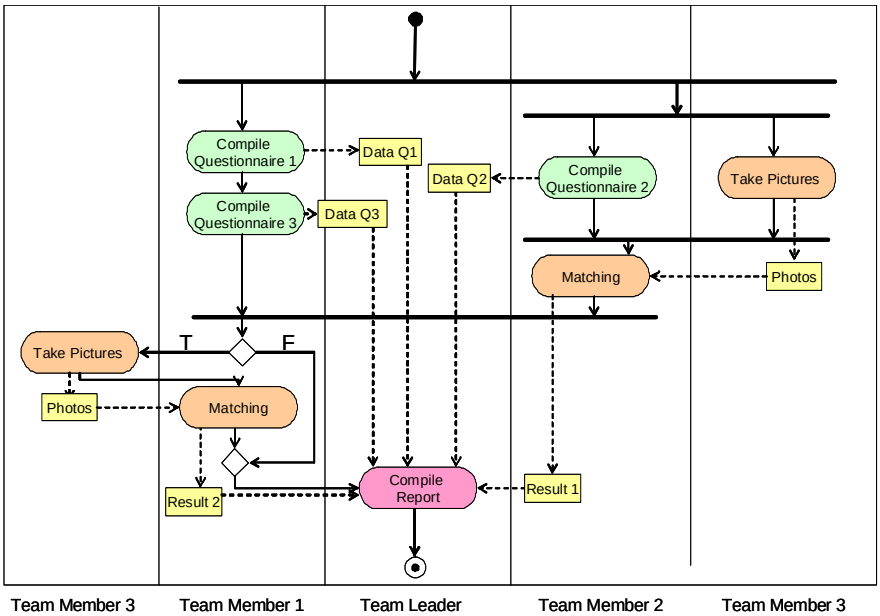
A process management system (PMS) supporting such processes has therefore to deal with modifications of plans through insertion of new tasks, removal of originally planned tasks, or redefinition of task ordering, as well as reassignment of tasks from one member to another. As these modifications occur in a dynamical manner, it is difficult to manage them through hard-coded programs. Therefore, we propose an ECA (Event/Condition/Action [Pat99]) approach for adaptation in process management, by specifying which events (e.g. resource unavailability) can produce possible process restructuring and the set of transformation rules stating the control actions to be performed for adaptation. Such a rule-based approach is highly flexible, as rules are able to react to events at any time during process execution without making assumptions about when these events occur. This is in contrast to the addition of conditional branches to process definitions [SSO01], which does not fit with frequently changing environments such as MANETs. Specifically, in this paper we propose the use of a rule-based formalism, expressed in terms of multi-set rewriting, which supports a resource-centered view, in which both data-dependencies between tasks and plan-dependent ordering of tasks are modeled through resources of different types. Rules are themselves seen as resources, so that they are prone to the same rewriting process, in order to redefine plan management or different ways to achieve the same results.

The paper is structured as follows: in Section 2, the general framework supporting process adaptation in MANET is presented. In Section 3, we give an overview of the WIPPOG language and its computation model, which is used as the language for rule definition. Section 4 details on the proposed rule-based formalism, while Section 5 applies the rewriting machinery to the scenario above. Finally, in Sections 6 and 7 we discuss related work and conclude the paper.

[1] Tasks belonging to swimlanes with the same name are intended to be assigned to the same team member (e.g., swimlanes of team member 3). We have used this notation only for clarity of presentation.



(a) Process



(b) Modified process

Figure 1: Dynamic changes in process coordination due to resource management.

2 General Framework

A *process schema* is a description of a business process in sufficient detail that it can be directly executed by a *process management system* [WMC06]. It consists of a set of *tasks* to be performed according to a specified *scheduling* (*control flow*), and undertaken by *roles*, defining organizational entities, such as humans or devices (actors). An executing instance of a process schema is called a *case* or *process instance*. A *task* is an atomic unit of work which is run to completion once initiated. We assume that each process has a unique *start task* and a unique *end task*.

Since tasks may be executed in different orders, it is useful to identify conditions enabling their execution. These can be related to both data and control flows. Therefore, each task has pre-conditions holding before the task is carried out and post-conditions which should hold after task execution. As an example, in the sub-process P of Figure 2(c), task t_k has *(i)* a pre-condition on control flow: t_i has to be carried out in order that the execution of t_k can start; and *(ii)* a pre-condition on data c and b that holds after the execution of both t_i and t_j.

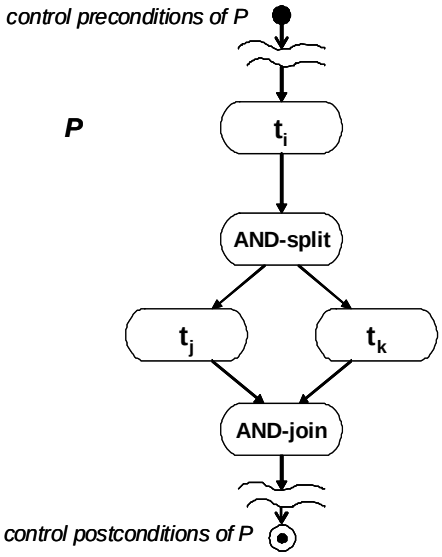
Control flow occurs via the *control channel*, which is usually indicated by a solid arrow between tasks. Control channels represent the business policies of the process; they describe *temporal relations* among process tasks, i.e. when a task can be carried out with respect to the execution of other process tasks. As an example, Figure 2(a) describes the business policy of the process P depicted in Figure 2(c). In this case, both tasks t_j and t_k must be carried out after the execution of t_i; t_j and t_k can be carried out concurrently.

There may also be a distinct *data channel* between process tasks for communicating *data elements* between two tasks. Where a distinct data channel is intended, it may be illustrated with a dotted line. The data channel represents *causal relations* among process tasks. It describes data dependencies between two tasks and establishes when data pre-conditions of a task are satisfied with respect to data obtained from the execution of other tasks. As an example, in Figure 2(b) data dependencies between tasks are reported. In this case, task t_j can be carried out after the execution of t_i (it consumes the data a), but before the execution of t_k; moreover, t_k can be carried out only after the execution of t_i and t_j (it needs both data b and c).

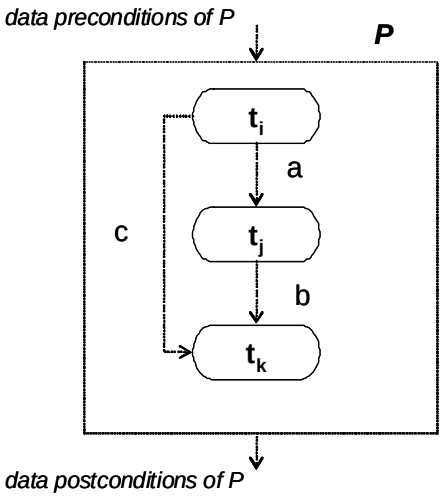
In the model proposed in this paper, the exchange of data between tasks is modelled through the exchange of *data resources*: a process schema is associated with a finite multi-set G of data resources. Each resource $d \in G$ has a specific type, and there may be several instances of d in G at the same time. We usually call G the *data resource pool* (drp) of the process.

Under this perspective, each task t may be considered as a producer/consumer of data resources. It takes some data resources as input (data pre-conditions) and produces other data resources as output (data post-conditions), i.e. $t : D_I \multimap D_O$. In general, the data pre-conditions and post-conditions of a task can be considered as finite multi-sets over a specific data alphabet Π, so that a task t can be modeled as a multi-set rewriter[2]. Its execution consumes from drp a multi-set of data resources satisfying its data pre-conditions, and produces a new data resource pool (drp') according to its data post-conditions. We also say that drp' derives from drp through t, and denote it with $drp \stackrel{t}{\Longrightarrow} drp'$. As regards the input parameters of the process schema, they constitute the data pre-conditions of the start task, whereas the output parameters are the post-conditions of the end task.

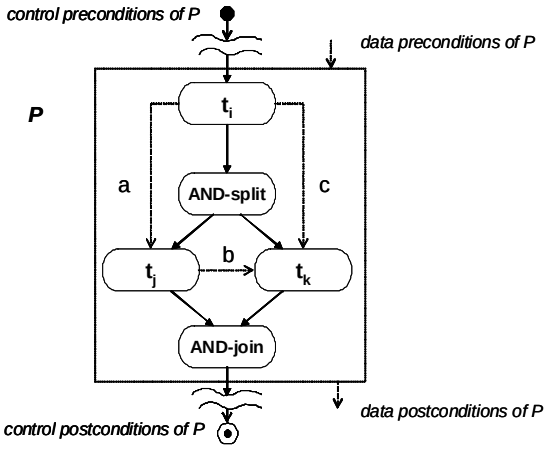
[2] In the remainder of the paper, when we refer to a task t we mean t as a multi-set rewriting rule.



(a) Temporal relation.



(b) Causal relation.



(c) Example of process schema.

Figure 2: Example of business policies and data dependencies in process schema (dotted lines represent data dependencies).

The same idea can be applied for process execution with respect to control flow. The execution of a process P is modelled as producing/consuming special synchronization (*synch*) resources representing its progress state. Consumption and production of synch resources follows the scheduling defined in the process schema. A process task is ready to be carried out (is *enabled*) at a certain time of the process execution if its enabling synch resources are present in the synch resource pool (srp) of the process. According to this vision, a process task $t : S_I \multimap S_O$ can be considered as a *rewriter* of synch resource multi-sets; specifically, it consumes a multi-set of synch resources satisfying its control pre-conditions S_I from a synch resource pool (srp), and produces new resources in the synch pool (srp') according to its control post-conditions S_O. Again, we say that srp' derives from srp through t, and we denote it with $srp \stackrel{t}{\Longrightarrow} srp'$.

The combination of data and control flow specifications defines the order for task execution, by identifying data and synch conditions enabling their execution. Therefore, the enactment of a process is concurrently driven by both specifications, usually given through different notations.

To give a uniform and coherent representation of both data and control flow specifications of a process P, we consider a correspondent set of multi-set rewriting rules P, named *PMR-system* (Process Multi-set Rewriting system), by taking the union of the two multi-set rewriting systems defined by the data and control flows (we assume resources are named differently in the two systems). Moreover, in modelling process adaptation, PMR-system rules are also seen as resources, and a set of high-level rewriting rules consumes/produces them in order to redefine the schema. Specifically, if *PMRS* is a PMR-system associated with a process schema P, and $\mathscr{R}_P$ and $\mathscr{R}_{P'}$ are the sets of rules describing P before and after, respectively, the adaptation a, then the execution of a produces a change from $\mathscr{R}_P$ to $\mathscr{R}_{P'}$. We also denote this with $\mathscr{R}_P \stackrel{a}{\Longrightarrow} \mathscr{R}_{P'}$.

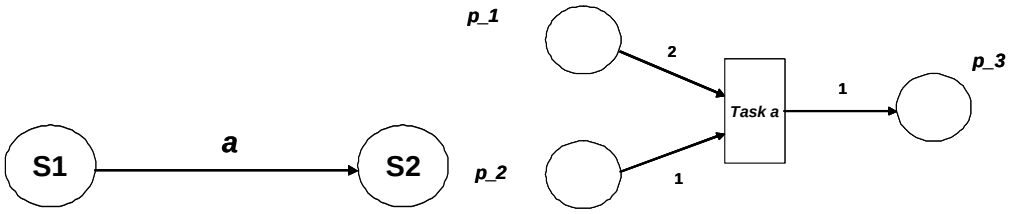
3 WIPPOG Model and Environment

In this section we give an overview of the WIPPOG (WHEN, IF, PROCESSES, PRODUCES, OUTS, and GETS) language and computation model [BDD+04], used here to describe rules representing both process schemas and process adaptations.

WIPPOG provides a common framework for specifying transitions expressed through different visual notations. It is based on the notion of a process *transition* and details out different aspects of its pre- and post- conditions. Processes are assumed to occur within entities taking part in some computational system, called *agents*. An agent is endowed with a set of rules defining its possible behaviours, and a pool of resources describing its state at any given time. A *resource* is an item with a type t in a set T, an *identifier* uniquely defining it, and an optional set of attributes with values on well-established domains. The set of all resources on T is called $\mathscr{W}(T)$.

The effect of a transition is modelled as consumption/production of resources as specified by WIPPOG rules. WIPPOG distinguishes internal resources, which have to be present in the agent, from external resources that an agent has received from its environment. In a similar way, resources may be produced to remain in the pool defining the agent state, or to be spread out in the environment, possibly to be exploited by other agents.

Transition preconditions may include checks on attribute values of internal or external resources to be consumed. New attribute values may be produced by means of a dedicated function component of the transition. Variables may be used in the transition to refer to attribute values,



(a) A transition in a finite state automata. (b) A transition in a Place/Transition net.

Figure 3: Examples of transition systems modelled by WIPPOGrules.

and matching is performed against values of existing resources.

A WIPPOG rule is thus formed by the following six components:

WHEN: internal resources which have to be available to the process. Attributes can appear, with either a constant value or a variable name.

GETS: externally produced resources which have to be available to the process. Attributes can appear, with either a constant value or a variable name.

IF: a predicate in which variables appearing in the WHEN or GETS components can occur.

PROCESSES: computational activities associated with the transition. They are considered to be always successful. Assignments to attribute values for the new resources produced by the transition are specified here.

PRODUCES: resources which have to be internally created as result of the transition execution. If variables appear, their names have to be present either in the WHEN or GETS components, or in the left-hand side of an assignment in the PROCESS component.

OUTS: resources which are externally available as a result of the transition execution. If variables appear, their names have to be present either in the WHEN or GETS components, or in the left-hand side of an assignment in the PROCESS component.

The application of a WIPPOG rule *(i)* matches resources mentioned in the WHEN and GETS components with resources from the (resp., internal and input) resources pools; *(ii)* if a match exists and also satisfies the conditions in the IF component, then: *(a)* removes the matched resources; *(b)* executes the activities specified in the PROCESSES component; and *(c)* produces (either for internal or external use) the resources specified in the PRODUCES and OUTS components, placing them in the internal or output resource pools, respectively. An agent cannot directly add something to its own input pool, nor can it remove anything from its output pool.

As an example, Figure 3(a) shows a transition from state $S1$ to state $S2$ on input a in a finite state automata. By using a resource *current* to indicate the current state and a resource *input* to wrap symbols from the automata alphabet, we have the following WIPPOG rule:

```
WHEN: current(name = ''S1'')
```

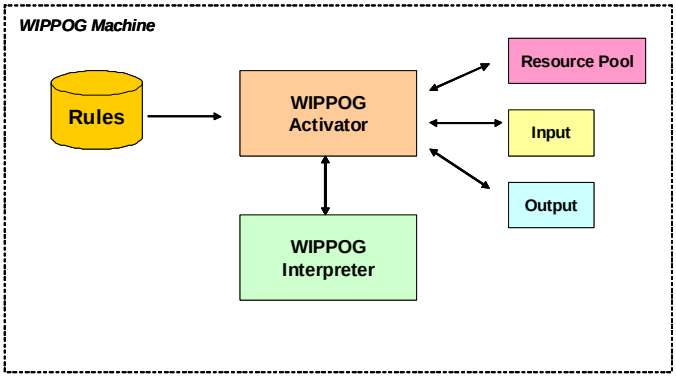


Figure 4: The architecture of a WIPPOGmachine.

```
GETS: input(value = ``a'')
PRODUCES: current(name = ``S2'')
```

Figure 3(b) specifies a Place/Transition Petri net, in which a transition consumes two tokens from place *p_1*, one token from place *p_2*, and produces one token in place *p_3*. Using an integer-valued attribute `tokens` to denote the number of tokens in a place, and a resource *place* to indicate the places involved in the transition, the following WIPPOG rule results:

```
WHEN: place(id = p_1; tokens as X),
  place(id = p_2; tokens as Y),
  place(id = p_3; tokens as Z)
IF: X ≥ 2, Y ≥ 1
PROCESSES: X1 := X − 2, Y1 := Y − 1, Z1 := Z + 1
PRODUCES: place(id = p_1; tokens as X1),
  place(id = p_2; tokens as Y1),
  place(id = p_3; tokens as Z1)
```

The modification of a given resource is modelled in WIPPOG by presenting the resource with the same identifier in both the WHEN and the PRODUCES components. Attributes in such resources maintain their values, if not specified otherwise.

A WIPPOG *machine* (*WM*) provides a computational environment to execute WIPPOG rules. It consists of (see Figure 4): a WIPPOG *Interpreter*, applying one WIPPOG rule at a time, from those present in the *Rules* base, coherently with the role of the different components and according to an activation policy managed by the WIPPOG *Activator*. The WIPPOG execution process acts on both the *Resource Pool* which contains the resources describing the state of the agent, and the *Input* and *Output* compartments of the *WM*, which allow its communication with other processes. An interpreter tries the activation of a rule every time it is requested by an activator; the WIPPOG *Activator* is therefore responsible for implementing policies and managing the resources pool, thus realizing a transition *step*.

In order to manage both process execution and adaptation, we use a hierarchical set of WIPPOG

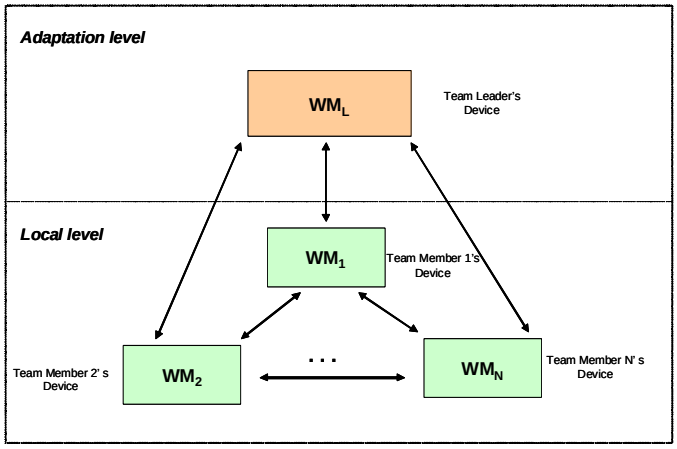


Figure 5: The hierarchical set of WIPPOGmachines modelling the proposed framework.

machines (WMs) (see Figure 5): a WM at the *adaptation* level and WMs at the *local* level. The high-level WM manages dynamic changes which can occur during process enactment, by executing specific WIPPOG rules needed to adapt the process. With respect to our scenario, such a machine should be running on the team leaders' device. On the other hand, local WMs are concerned with the actual execution of tasks, and should be running on devices belonging to other team members. Therefore, in our system we have multi-set rewriting rules which act at two levels i.e., at the adaptation level and at the execution (local) level.

WIPPOG is relatively small (∼250Kb), so that it can be loaded on a powerful PDA running a Java Virtual Machine. However, if some member has not sufficient power, an image of its policy pool can be kept at the team's leader device and managed from there.

4 The Rule-based Formalism

Before describing local and adaptation rules, we give concepts and terms about multi-sets and rules, matches and direct derivations. We set this work in the context of High-Level Replacement Systems, of which multisets are an instance [GPS98] .

A multi-set G over an alphabet Π is a function from Π into the natural numbers $\mathcal{N}$ such that only a finite number of elements from Π is assigned a non-zero function values, i.e.: $G : \Pi \to \mathcal{N}$, and $a \in G$ if and only if $G(a) > 0$. Here, elements in multi-sets are terms [BN98], i.e., $\Pi = T(\Sigma, X)$, where $T(\Sigma, X)$ denotes the set of all Σ-terms over the set of variables X, such that $\Sigma \cap X = \emptyset$. With $T(\Sigma, \emptyset) \subset T(\Sigma, X)$ we denote the set of all *ground terms* over Σ (the constant terms), and with $\mathcal{M}(\Pi)$ the set of all finite multi-sets of terms over Π. In addition, if σ is a substitution function, then G_σ is the multi-set obtained by applying σ to each term belonging to G.

A *rewriting rule* p has three components: an antecedent L, a consequent R, and an interface K which describes what is to be preserved through the application of a rule. Formally, a rule $p = (L \xleftarrow{l} K \xrightarrow{r} R)$ is defined by a span of morphisms l and r. Applying a rule means finding a match $m : L \to G$ for L in a source object G and replacing the matched occurrence of L with

an occurrence of R, thus producing a target object H. This process is denoted as the *direct transformation* $G \overset{t,m}{\Longrightarrow} H$ via a rule t and match m. Moreover, rules have no side effects, i.e., H differs from G only for the removal of elements present in L but not mentioned in K, and the insertion of elements mentioned in R, but not present in L. Here, the involved category CAT has multisets of terms in $T(\Sigma, X)$ as objects and injective maps as morphisms. A rule $t : L \multimap R$, is now modeled as $t : L \overset{l}{\longleftarrow} K \overset{r}{\longrightarrow} R$ with K, L and R collections of WIPPOG resources in $\mathscr{M}(\Pi)$. In particular, resources which are preserved (i.e. their identifiers appear both in WHEN and in PRODUCES), appear in K, L, and R; those to be consumed only in L; and the produced ones only in R. Resources in GETS and OUTS appear only in L and R respectively, and the IF and PROCESSES components are expressed through application conditions.

A rule t is *enabled* in G if and only if there exists a substitution $\sigma : X \to \Pi$, such that $L_\sigma \sqsubseteq G_\sigma$, where $\sqsubseteq$, $\sqcup$, $\sqcap$, $\setminus$ denote inclusion, union, intersection and difference between two multi-sets, respectively. In this case we say that there is a *match-inclusion* m: $L \to G$ through σ that fixes an occurrence of L in G, and $G \overset{t,m,\sigma}{\Longrightarrow} H$ denotes the *direct derivation* from G to H by rule t, match m and substitution σ, where the *derived multi-set* H_σ is obtained by replacing the occurrence of L_σ in G_σ by R_σ, i.e.: $H_\sigma = (G_\sigma \setminus (L_\sigma \setminus K_\sigma)) \sqcup (R_\sigma \setminus K_\sigma)$. Here, K_σ is given by the intersection of L_σ and R_σ (i.e., $(L_\sigma \sqcap R_\sigma) = K_\sigma$), and l and r are two injective match-inclusion functions from K_σ into L_σ and R_σ, respectively. This guarantees the *gluing condition* in multi-set rewriting; specifically the *identification condition* is always satisfied [TFKV99].

4.1 Local Rules

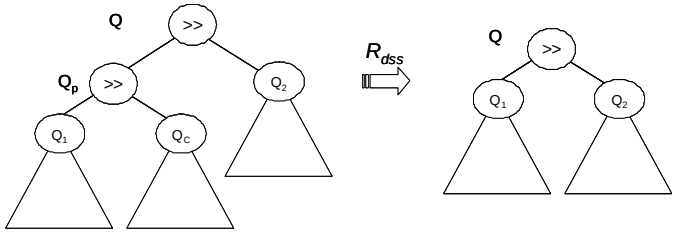
We give now the definition of a PMR-system $\mathscr{R}_P$ (the local rules) representing a process schema P[3]. Here, the admitted set of synch resources is composed of: the `start(name = ''t'')` synch resource enabling the execution of task t which indicates that task t is ready to be carried out (its control flow pre-conditions are satisfied); the `completed(name = ''t'')` synch resource indicating the termination of task t; finally, the special synch resources INIT and STOP are required to be produced/consumed by the unique *start* and *end* tasks of a process P.

A *Process Multi-set Rewriting system (PMR-system) PMRS* for a process schema P is a pair $PMRS = \langle \mathscr{R}_P, \{\text{INIT}, \texttt{start(name = ''P'')}\}\rangle$, where $\mathscr{R}_P$ is the set of WIPPOG rules representing P, and $\{\text{INIT}, \texttt{start(name = ''P'')}\}$ is the *start multi-set* for $\mathscr{R}_P$.

A sequence of direct derivations $\Delta = \{\text{INIT}, \texttt{start(name = ''P'')}\} \overset{r_1}{\Longrightarrow} rp_1 \overset{r_2}{\Longrightarrow} \cdots \overset{r_n}{\Longrightarrow} rp$, with $rp_i = drp_i \sqcup srp_i$, for $i \geq 0$, is a *derivation* of *PMRS*, also denoted by $\{\text{INIT}, \texttt{start(name = ''P'')}\} \Longrightarrow^* rp$[4]. The language $\mathscr{L}(PMRS)$ generated by the PMR-system *PMRS* is the set of all multi-sets rp such that $\{\text{INIT}, \texttt{start(name = ''P'')}\} \Longrightarrow^* rp$. An execution of *PMRS* is a derivation $\{\text{INIT}, \texttt{start(name = ''P'')}\} \Longrightarrow^* \{\text{STOP}\}$.

[3] A detailed procedure used to define a set of WIPPOG rewriting rules starting from both data and control flow specifications can be found in [De 07].

[4] drp_i and srp_i are the data and synch resource pools of the process schema P at the step i of the derivation.



(a) CTT diagrammatic notation of the rule

```
GETS: change(type = “RDSS”; name as Q)

WHEN: rule(id = SQ; prod as PDSQ),
      rule(id = EQ11; prod as PDEQ1),
      rule(id = SQ1)
      rule(id = EQ1)

IF: SQ==“START_”+Q.label() AND EQ11==“END_”+Q.1().1().label()
    AND SQ1==‘‘START_’’+Q.1().label() AND EQ1==‘‘END_’’+Q.1().label()

PROCESSES: PDSQc := (PDSQ ⊕ {start(name = Q.1().1().label())})
                          - {start(name = Q.1().label())},
           PDEQ1c := (PDEQ1 ⊕ {start(name = Q.2().label())})
                             - {start(name = Q.1().2().label())}

PRODUCES: rule(id = SQ; prod as PDSQc),
          rule(id = EQ11; prod as PDEQ1c)
```

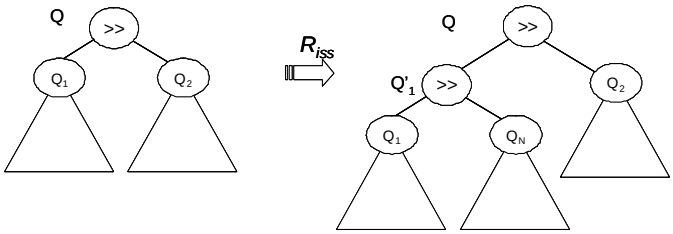
(b) Rule in WIPPOG language

Figure 6: A WIPPOG rule for downsizing adaptation: sequence delete in sequence construct.

4.2 Adaptation Rules

High-level rewriting rules are used to adapt processes during their enactments. They modify the process flow on the basis of the causal relations between tasks and the policy established within the process management system, e.g., maximizing the number of tasks executed in parallel, or reducing the number of tasks performed in parallel (for example, by saving resources), or other policies. In [De 07], a complete set of rewriting rules for adaptation has been defined. By following the categorization proposed in [EM97], rules are classified in: *(i) downsizing*, reducing the set of traces (i.e. possible executions of tasks according to the process control flow) in the new adapted process; and *(ii) upsizing*, extending the set of traces with respect to the old process.

Rules consume/produce special resources taken/put from/into a *rule resource pool* (*rrp*) by the process management system when change events take place. These resources represent rules belonging to the PMR-system representing a process schema; when a *change request* resource



(a) CTT diagrammatic notation of the rule

```
GETS: change(type = “RISS”; name as Q; new as N)

WHEN: rule(id = SQ; prod as PDSQ),
      rule(id = EQ1; prod as PDEQ1)

IF: SQ == “START_”+Q.label() AND EQ1 == “END_””+Q.1().label()

PROCESSES: PDSQc := (PDSQ - {start(name = Q.1().label())}) ⊕ {start(name = N.label())},
           WSQ’1 := {start(name = N.label())},
           PDSQ’1 := {start(name = Q.1().label())},
           PDEQ’1 := {start(name = Q.2().label())},
           WEQ’1 := {completed(name = N.2().label())},
           PDEQ1c := (PDEQ1 - {start(name = Q.2().label())}) ⊕ {start(name = N.2().label())}
           SQ’1 := “START_” + N.label(), EQ’1 := “END_”+N.label()

PRODUCES: rule(id = SQ; prod as PDSQc),
          rule(id = SQ’1; when as WSQ’1; prod as PDSQ’1),
          rule(id = EQ1; prod as PDEQ1c),
          rule(id = EQ’1; when as WEQ’1; prod as PDEQ’1)
```

(b) Rule in WIPPOG language

Figure 7: A WIPPOG rule for upsizing adaptation: sequence insertion in sequence construct.

is produced (i.e., the change event takes place), some rules are removed from rrp and new ones are added into it, yielding a new rule resource pool rrp' representing the adapted process. Specifically, the high-level rewriting system manages (rewrites) multi-sets which are composed by the following elements (resources) expressed in WIPPOG. As these are resources, they have identifier attributes, which we will omit when not needed.

- `rule(id, when, gets, if, proc, prod, outs)` is a resource for a WIPPOG rule in the PMR-system realizing the process schema P. The attribute `id` refers to the identifier associated with the rule, whereas the other attributes specify each component of the corresponding rule;
- `change(id, type, name, new)` is a resource for a change event (described by its `type`) involving the rule (the part of the process) named by `name`. It represents the event which starts process adaptation. The attribute `new` describes the possibly empty set of rules (the new sub-process) to be added.

Hence, a *High-level Process Multi-set Rewriting system (HPMR-system) HPMRS* for a PMR-

system $PMRS = \langle \mathscr{R}_P, \{\text{INIT}, \texttt{start(name = ``P'')}\}\rangle$ and a set $ADAPT$ of rules for adaptation, is the pair $HPMRS = \langle ADAPT, \mathscr{R}_P\rangle$. A sequence of direct derivations $High_\Delta = \mathscr{R}_P \stackrel{a_1}{\Longrightarrow} \mathscr{R}_{P_1} \stackrel{a_2}{\Longrightarrow} \cdots \stackrel{a_n}{\Longrightarrow} \mathscr{R}_{P_n}$, is a *derivation* of the HPMR-system $HPMRS$, also denoted by $\mathscr{R}_P \Longrightarrow^* \mathscr{R}_{P_n}$. The language $\mathscr{L}(HPMRS)$ generated by the HPMR-system $HPMRS$ is the set of all multi-sets $\mathscr{R}_{P_n}$ such that $\mathscr{R}_P \Longrightarrow^* \mathscr{R}_{P_n}$.

Figures 6 and 7 show examples of high-level downsizing and upsizing rules, respectively. In the upper side of the Figures, a simplified version of the CTT diagrammatic notation [MPS02], is used to indicate the synchronization constraint imposed on the process. The operator ">>" denotes sequentiality and indicates that the tasks in the right subtree can be executed only after those in the left subtree have been completed. Leaves represent elementary tasks. Specifically, the rule with type R_{dss} in Figure 6 (Sequence Delete in Sequence Construct) deletes a sequential sub-process (identified by the label obtained through the method `label()` of the object contained in the variable Q) from a sequence construct. In detail: the `GETS` component contains the *change request* resource needed to enable the rule, whereas the `WHEN` component identifies the local rules to be changed / removed from *rrp*. The rules are identified by concatenation of the strings "START_" or "END_" with unique labels associated to each node belonging to process tree. The methods `1()` and `2()` return the left and right child, resp., of a subtree Q. On the other hand, the `PROCESSES` component contains the computational activities to be executed with the transition: in particular, some synch resources[5] are removed and added from the `PRODUCES` components of the rules involved during the adaptation. Finally, the `PRODUCES` component produces the new rule resources representing the adapted process, which is the result of applying the high-level rule.

5 Applying the Model

In this section we apply the rewriting machinery to the scenario described in Section 1. We recall that restructuring is needed when the condition of the OR-split construct present in the process schema becomes `true`. In fact, in this case, the process instance requires the execution of another instance of the task "Take Pictures", and, since there is only one PDA (resource) equipped with photo-camera in the team (i.e., the PDA of the team member 3), one of the two instances has to be postponed with respect to the other.

The left-hand side of Figure 8 shows the process of Figure 1 (a) as a binary tree in the simplified CTT notation. A tree node with value "–" represents the null operation in the false branch of the OR-split construct. When the process management system produces a *resource unavailability event* for team member 3 (a change resource is produced), the inference engine module changes the PMR-system $\langle \mathscr{R}_P, S\rangle$ into the new one $< \mathscr{R}_{P''}, S >$, by *(i)* removing tasks "Take Pictures" and "Matching" within the OR-Split construct in sequence the tasks "Compile Questionnaire 1" and "Compile Questionnaire 3", and *(ii)* adds these tasks before "Compile Report".

This mechanism can exploit a layered organization analogous to that proposed in [PHE+07], so that a *mobility layer* can signal disconnection events for the *workflow layer* to rearrange the attribution of tasks in the *work layer*. Specifically, the process engine consumes two *change*

[5] With the notation `start(name = Q)` we denote the synch resource start associated with the sub-process `Q`.

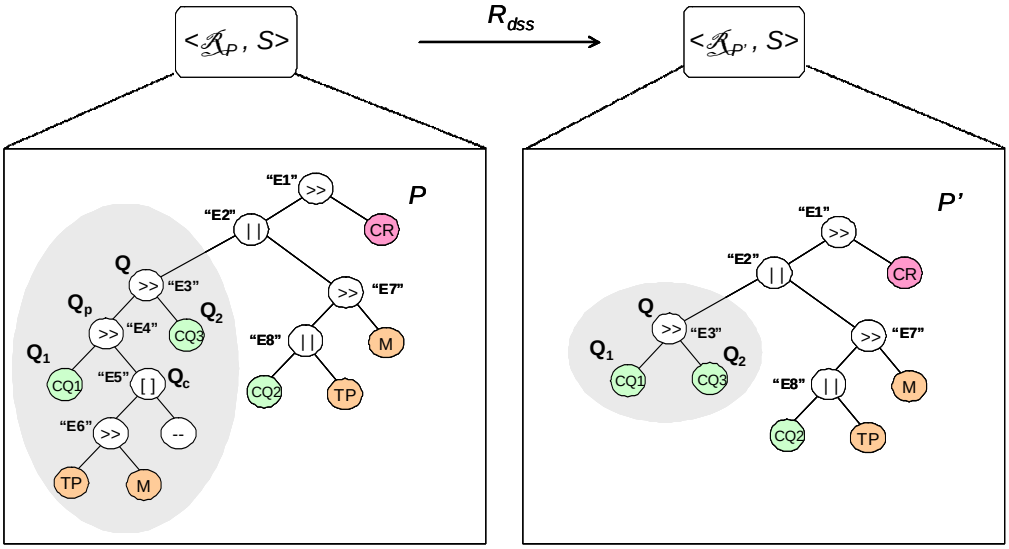


Figure 8: Process Transformation 1: Sequence Delete in Sequence Construct.

request resources produced by a specific predictive module which alerts about resource unavailability (these resources are put in the `GETS` component of the WM running on the device of the team leader): firstly, a *change request* resource *change(id = "ce1", type = "RDSS"; name = "E4";)* is consumed, where "RDSS"is the rule type to be applied, and "E4" denotes the name of the rule which is going to be changed in the PMR-system; secondly, a *change request* resource *change(id = "ce2", type = "RISS"; name = "E1"; new = "E4")* is taken from the change resource pool. "E1" is the name of the rule to be changed, and "E4" is the name of rule to be added in the PMR-system together with all rules representing the sub-tree with root node "E4".

In consuming the two change resources, the adaptive process engine applies the relative rewriting rules belonging to the high-level rewriting system. The matches to the local rules are constrained by the values of the attributes in the *change request* events. Specifically, in the first case, it applies rule R_{dss} (Sequence Delete in Sequence Construct), and in the second case rule R_{iss} (Sequence Insertion in Sequence Construct). In particular, in both cases the high-level rules consume rule resources associated to specific branches of the process schema and produce new ones according to the adopted rewriting rule.

The rule resource pool after the application of the two adaptation rules R_{dss} and R_{iss} is as follows [6]:

$\mathscr{R}_P = \mathscr{R}_{P_0} \sqcup$

```
{ rule(id = ''START_E3''; ...),
  rule(id = ''START_CQ1''; ...),
  rule(id = ''START_E4''; ...),
  rule(id = ''END_E4''; ...)
```

[6] In describing the resources associated to rules, we have reported in bold or omitted part of them (`gets`, `if`, `proc`, `outs` components) not relevant for understanding the rewriting process.

```
}
```

$\mathscr{R}_{P'} = \mathscr{R}_{P_0} \sqcup$

```
{ rule(id = ``START_E3'';
    when = start(name = ``E3'');
    gets = msgs_for_E3;
    if = conds_for_E3;
    proc = procs_for_E3;
    prod = start(name = ``CQ1'');
    outs = msgs_from_E3),
  rule(id = ``START_CQ1''; ...  ;
    prod = start(name = ``CQ3''); ...)
}
```

$\mathscr{R}_{P'} = \mathscr{R}_{P_1} \sqcup$

```
{ rule(id = ``START_E1''; ...),
  rule(id = ``END_E4''; ...)
  rule(id = ``END_E2''; ...)
  rule(id = ``START_E4''; ...)
}
```

$\mathscr{R}_{P''} = \mathscr{R}_{P_1} \sqcup$

```
{ rule(id = ``START_E1'';
    when = start(name = ``E1'');
    gets = msgs_for_E1;
    if = conds_for_E1;
    proc = procs_for_E1;
    prod = start(name = ``E4'');
    outs = msgs_from_E1),
  rule(id =``END_E4''; ...;
    prod = start(name = ``CR''); ...)
  rule(id =``START_E4''; ...;
    prod = start(name = ``E2''); ...)
  rule(id =``END_E2''; ...;
    prod = start(name = ``E5''); ...)
}
```

The application of both rules yields the new processes depicted in the right-hand side of Figure 8 (note the new subtree with root node "$>>$" and children "$CQ1$" and "$CQ2$") and Figure 9. The PMR-system $(< \mathscr{R}_P, S >)$ defining the process before the translations is changed into $(< \mathscr{R}_{P''}, S >)$ in which some WIPPOG rules are altered as required by R_{dss} and R_{iss}. Note that, in this case, the process does not add or remove rules, but only changes activation conditions.

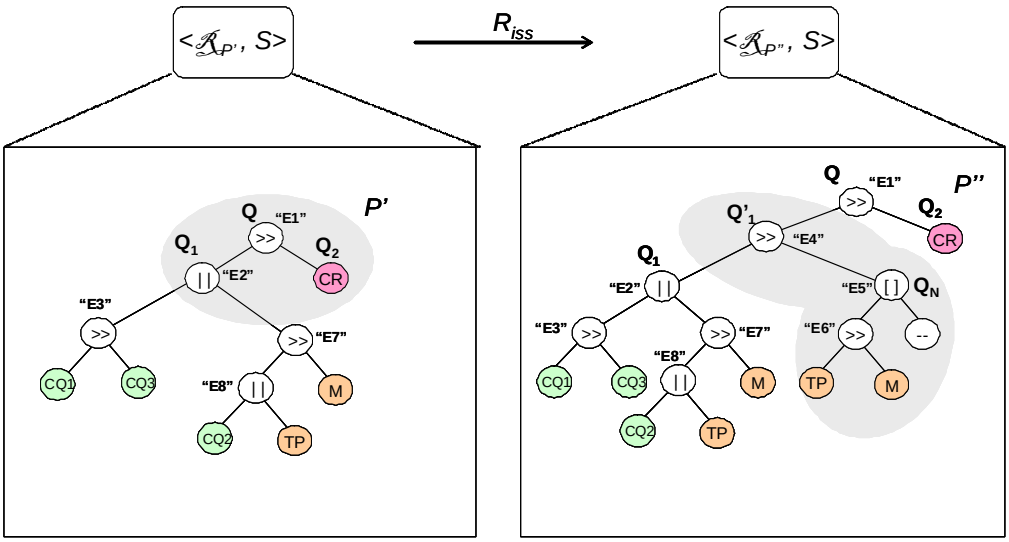


Figure 9: Process Transformation 2: Sequence Insertion in Sequence Construct.

6 Related Work

The adaptation of processes to possible exceptional cases or to changes in management policies has been soon recognised as a necessity for practical uses of process management systems [EKR95, VA97, BCC+99]. Solutions to the related problem of dynamic change i.e., how to transform the process without suspending all its instances or waiting for all instances to have come to conclusion, with the possibility of creating inconsistent states of process instances have been studied in formal frameworks, typically defined by Petri nets, such as: WF-nets [AWW03], Flow Nets [EK95], and MILANO nets [AM00] (i.e. marked, acyclic Free-Choice Petri Nets).

Moreover, adaptation of single process instances becomes necessary when exceptional situations occur or the structure of a process dynamically evolves. When the needed changes and their scope for process evolution are known at design time, adaptations can be pre-planned and automated [HJKW96, LC93, MGR04]. In contrast ad-hoc changes have to be applied as response to unforeseen exceptions [RD98].

Ad-hoc change in process management is handled in the ADEPT, Breeze, $WASA_2$, e-Flow systems [RD98, SMO00, Wes01, CS01], in which the issue of manually modifying process schemas and then automatically migrating active process instances to the new schema is addressed, and the AGENTWORK one [MGR04], which is one of the few examples of process management system in which adaption is not manual, but automatic and pre-planned, on the basis of a rule-base approach based on ECA (Event/Condition/Action) model to automatically detect logical failures and to determine necessary process changes. The previous approaches are targeted to infrastructure-based workflows, in which modifications of the schemas are less frequent, but the number of running instances is very high, so that they are less suited to MANETcontext, in which adaptation concerns a single instance of workflow, under constant possible need for change. For a detailed discussion of these approaches, see [RRD04, RR06].

Several algebraic approaches to rewriting supporting flexibility and adaptability for Petri net classes can be found in the literature (see [Hof06] for a survey). The recent proposal of Algebraic Higher-Order (AHO) Nets [Hof06] is a novel modeling technique combining the advantages of the well-researched classes of Coloured Petri Nets [Jen92] and Algebraic High-Level Nets [EHP+02]. AHO-Nets can be seen as a formal approach for Higher-Order Object Nets [Han97], which are well-established for modeling process schemas. Specifically, high-level net classes are obtained by combining Petri nets with an appropriate data type part. While the net structure of AHO-Nets is graphically modeled by Petri nets, the concept of higher-order partial algebras turned out to be well-suited data type part for AHO-Nets. The combination of these techniques is achieved by the inscription of net elements with terms over the given data type part. All these algebraic approaches are very suitable when used at the design-time (they are useful during a design-time reasoning phase on probable deadlock situations of the system), but they are not adequate for modeling run-time aspects, such as unforeseen events during the process execution.

The approach proposed in this work is situated in the framework of the algebraic approach to rewriting, which has been widely used for term rewriting, graph transformations, higher-order structures, and put to work in several contexts (for surveys, see [CMR+97, EEKR99]). In particular, the DPO approach has been applied to the description of several types of process, to describe both the behaviour of systems and changes in their structures. For example, Distributed Graph Transformations exploit a hierarchical view of distributed systems, where high-level "network" graphs define the overall architecture of a distributed system, while low-level "specification" ones refer to the specific implementation of local systems [TFKV99]. The approach is similar to that presented in this work; there, rules act at two levels, i.e., a modification of the network graph must be accompanied by a consequent transformation in the associated specification graphs. Moreover, low-level graphs must agree on transformations of interface nodes i.e., nodes which represent common objects or relations. This approach has been applied to manage dynamic change in distributed databases in [TGM98].

7 Conclusion and Future Work

We have presented a rule-based formalism for modelling the complex processes involved in the activity of a team cooperating over a MANETand their adaptations. The formalism, expressed in terms of multi-set rewriting, supports a resource-centered view in which both data-dependencies between tasks and plan-dependent ordering of tasks are expressed as production and consumption of resources of different types. Moreover, rules themselves are seen as resources, so that they are prone to the same rewriting process, in order to redefine process schemas.

Generally, process schemas are modeled through Petri nets with an initial marking, called place/transition (P/T) systems, which lend themselves to simple visualizations of processes and their executions. With respect to the formalism proposed in this work, it is possible to associate a non-hierarchical coloured Petri-net (CP-net) for each PMR-system representing a process schema. Thus, by the P/T-net theory (Theorem 2.16 in [Jen92]), for each non-hierarchical CP-net, it is possible to construct an equivalent P/T-net, i.e., a P/T net which has exactly the same behaviour as the non-hierarchical CP-net. In [De 07] a procedure to construct a non-hierarchical CP-net starting from a PMR-system is given.

Furthermore, we will consider organizational issues such as assignment of tasks to team members within the proposed framework, and a thorough study will be done to relate this formalism to the general framework of [BRMH06], based on Algebraic Higher-Order Nets (AHO-Nets) [Hof06], which is an high-level net class combining Petri nets and a suitable higher-order data type part. Differently from the multi-set rewriting model presented in this work, the AHO-Nets framework provides an implicit distinction between the four phases of the system for process adaptation – i.e., process execution, process suspending, process changing, and process re-execution – throughout the machinery of the Petri net, while our approach explicitly distinguishes between these activities.

An adaptive process management system for MANETs is being implemented, specifically targeted to emergency teams equipped with PDAs and laptops (i.e., teams with not too powerful devices). Such a system, referred to as MOBIDIS, is partly realized[7], and will be completed and then validated in the context of the research project IST FP6 *WORKPAD*[8]. This prototype will be used also for validating the algebraic approach presented in this work.

Finally, transformations between *workflow patterns*[9] can be studied, in which high-level rules will represent possible changes between them.

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