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WHAT'S IN AN AGREEMENT?
A FORMAL ANALYSIS AND
AN EXTENSION OF WS-AGREEMENT

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What's in an Agreement? An Analysis and an Extension of WS-Agreement

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Abstract. Non-functional properties of services and service compositions are of paramount importance for the success of web services. The negotiation of non-functional properties between web service provider and consumer can be agreed a priori by specifying an agreement. WS-Agreement is a recently proposed and emerging protocol for the specification of agreements in the context of web services. Though, WS-Agreement only specifies the XML syntax and the intended meaning of each tag, which naturally leads to posing the question of "What's in an Agreement?" We answer this question by providing a formal definition of an agreement and analyzing the possible evolution of agreements and their terms. From our analysis we identify ways in which to make an agreement more robust and long lived by proposing two extensions to the specification and supporting environment.

1 Introduction

Web Services (WS) are a set of technologies that allow the construction of massively distributed and loosely coupled applications. The main characteristics of a distributed system based on WS resides in the asynchronicity of the message exchange, the absence of a unique owner of the application, and the openness of the XML based protocols used for the interaction. The present attention to web services is due to the potentials of the technology. WS are proving to enable the creation of virtual enterprises, to create the possibility for inter-company and intracompany interoperation, to allow the creation of open electronic marketplaces. Not only, web services can be used also to allow for spontaneous networking and interoperation between different appliances in the context of ambient intelligence [2].

One of the most thought provoking issues in web services is that of automatically composing individual operations of services in order to build complex added-value services. The research on composition is well under way, but most of the focus is on functional properties of the composition, that is, how does one automatically compose? How does one enrich the services with semantic self-describing information? How does one discover the available services to use for the composition? If, on the one hand, this is crucial, on the other one, it is not enough. Non-functional properties of the composition are also of paramount importance in defining the usability and success of a composed service. Think for instance of desiring a service that performs a biological computation composing the services offered by a number of web service enabled machines. If the user knows that the composition is correct with respect to his goal, he will be satisfied with the answer he receives, but if the answer takes 3 years to be delivered to the user, the correctness is of little use. Therefore, the quality of a composed service is very important when interacting with an asynchronous system built out of independent components.

With the term Quality of Service (QoS) we refer to the non-functional properties of an individual service, or a composition of services. The term is widely used in the field of networking. Usually it refers to the properties of availability and performance. In the field of web services, the term has a wider meaning. Any non-functional property which affects the definition and execution of a web service falls into the category of QoS, most notably, accessibility, integrity, reliability, regulatory, and security [15]. Dealing with QoS requires the study of a number of problems. One, the design of quality aware systems. Two, the provision of quality of service information at the level of the individual service. Three, ensuring that a promised quality of service is actually provided during execution. In [1], we addressed the first issue by using the Tropos design methodology, and the second one by resorting to WS-Policy to describe QoS properties. In this paper, we consider the second and third issues; in particular, we show how to provide a framework to negotiate the provision of a service according to a predefined QoS, and how to handle changes during the interactions of web services, and how to prevent the QoS conditions failure.

WS-Agreement is an XML based language and protocol designed for advertising the capabilities of providers and creating agreements based on initial offers, and for monitoring agreement compliance at run-time. The motivations for the design of WS-Agreement stem out of QoS concerns, especially in the context of load balancing heavy loads on a grid of web service enabled hosts [10]. However, the definition of the protocol is totally general and allows for the negotiation of QoS in any web service enabled distributed system. If, on the one hand, the proposal of WS-Agreement is a step forward for obtaining web service based systems with QoS guarantees, on the other hand, the protocol proposal is preliminary. The current specification [3] defines XML syntax for the language and protocol, and it gives a vague textual overview of the intended semantics, without defining a set of formal mathematical rules. Furthermore, a reference architecture is

proposed to show how WS-Agreement are to be handled, [13]. Nevertheless, a formal analysis of what an agreement is still missing.

In this paper, we address the question *What's in an Agreement?* In particular, we provide a formal analysis of WS-Agreement by resorting to finite state automata, we provide a set of formal rules that tie together agreement terms and the life-cycle of an agreement. From the analysis, some shortcomings of the protocol become evident. Most notably, there is no checking of how close a term to being violated and, even more, breaking one single term of the agreement results in terminating the whole agreement, while a more graceful degradation is desirable. Therefore, we propose an extension of the protocol for which we provide appropriate semantics, that allows for providing warning before the violation of an agreement and eventually the renegotiation of running agreements by tolerating the break of a term.

Web service QoS issues are gaining attention and have been addressed in a number of recent works. Some approaches are based on the extension of the Web Service Description Language (WSDL) to define not only functional, but also non-functional properties of the service, e.g., [11]. The main idea of the approach is simple: provide syntax to define terms which refer to non-functional properties of operations. The problem with this kind of approach is that the QoS definition is tied to the individual operation, rather than with the service as a whole; furthermore, there is no run-time support. Once a quality is defined, it can not be changed at execution time.

In [18], the authors propose to define WS QoS by using XML schemata that both service consumers and service providers apply to define the agreed QoS parameters. The approach allows for the dynamic selection of WS depending on various QoS requirements. On the negative side, the life-cycle of agreements is not taken into account, and it is not possible to define an expiration for a negotiation. The feasibility of using constraint programming to improve the automation of web services procurement is shown in [16]. A semantic web approach, in which services are searched on the basis of the quality of semantically tagged service attributes is presented in [17]. A predictive QoS model for workflows involving QoS properties is proposed in [6]. In [9], the authors propose a model and architecture to let the consumer rate the qualities of a service. In addition, the industry has proposed a number of standards to address the issue of QoS: IBM Web Service Level Agreement (WSLA) and HP's Web Service Management Language (WSML) are examples of languages used to describe quality metrics of services, [12]. A recent proposal is the specification of a new WS protocol, called Web Services Agreement Specification [3]. In [7], it is presented the Agreement-Based Open Grid Service Management (OGSI-A) model. Its aim is to integrate Grid technologies with Web Service mechanisms and to manage dynamically negotiable applications and services, using WS-Agreement. The WS-Agreement protocol proposal is supported by the definition of a managing architecture: CREMONA–An Architecture and Library for Creation and Monitoring of WS-Agreement [13]. The Web Services Agreement Specification defines the interaction between a service provider and a consumer, and a proto-

col for creating an agreement using agreement templates. The above approaches show that frameworks for QoS definition and management are essential to the success of the web service technology, but there are a number of shortcomings that still need to be addressed. First, no one has worked out a formal definition of what the semantics of a QoS negotiation should be. Second, the frameworks should be more flexible at execution time because actual qualities of services may change over time during execution.

The remainder of the paper is organized as follows. In Section 2, we present the WS-Agreement protocol defined in [3]. In Section 3, we propose a formal definition of an agreement and of its life-cycle. Section 4 is devoted to the presentation of an extension of WS-Agreement with the goal of improving the duration and tolerance of an agreement in execution. Preliminary experimental results are in Section 5. Concluding remarks are summarized in Section 6.

2 WS-Agreement

In order to be successful, web service providers have to offer and meet guarantees related to the services they develop. Taking into account that a guarantee depends on actual resource usage, the service consumer must request state-dependent guarantees from the service provider. Additionally, the guarantees on service quality must be monitored and service consumers must be notified in case of failure of meeting the guarantees. An agreement between a service consumer and a service provider specifies the associated guarantees.

The agreement can be formally specified using WS-Agreement Specification [3]. The WS-Agreement specification was developed by the GRAAP Working Group (Grid Resource Allocation and Agreement Protocol WG) of the Scheduling and Resource Management (SRM) Area of the GGF to standardize means for agreements creation processes.

A WS-Agreement is a XML-based document containing descriptions of the functional and non-functional properties of a service oriented application. It consists of two main components that are the agreement Context and the Agreement Terms. Figure 1 illustrates the main structure of WS-Agreement as defined in [3]. The agreement Context includes the description of the parties involved in the agreement process, and various metadata about the agreement. One of the most relevant components is the duration of the agreement, that is, the time at which the agreement is no longer valid.

Functional and non-functional requirements are specified in the Terms section, that is divided into *Service Description Terms* (SDTs) and *Guarantee Terms*. The first provides information to define the services functionalities that will be delivered under the agreement. An agreement may contain any number of SDTs. An agreement can refer to multiple components of functionalities within one service, and can refer to several services. Guarantee Terms define an assurance on service quality associated with the service described by the Service Description Terms. An agreement may contain zero or more Guarantee Terms. The main parts of a Guarantee Term are:

/GuaranteeTerm/ServiceScope is the list of service names a guarantee applies to;

/GuaranteeTerm/QualifyingCondition is an optional condition that expresses a precondition under which a guarantee holds;

/GuaranteeTerm/ServiceLevelObjective is a condition that must be met to satisfy the guarantee; and

/GuaranteeTerm/BusinessValueList is a list of business value elements associated with a service level objective.

Fig. 1. WS-Agreement structure

[8] specifies a definition for guarantee terms in WS-Agreement and provides mechanisms for defining guarantees. An agreement creation process starts when an agreement initiator sends an agreement template to the consumer. The structure of the template is the same as that of an agreement, but an agreement template may also contain a Creation Constraint section, i.e., a section with constraints on possible values of terms for creating an agreement. [4] enables customizations of terms and attributes for the agreement creation. After the consumer fills in the template, he sends it to the initiator as an offer. The initiator decides to accept or reject the offer depending on the availability of resource, the service cost, and other requirements monitored by the service provider. The reply of the initiator is a confirmation or a rejection.

An agreement life-cycle includes the creation, termination and monitoring of agreement states. Figure 2 shows a representation of the life-cycle. When an agreement is created, it does not imply that it is monitored. It remains in an `not_observed` state until services start their execution. The semantics of the states is as follows:

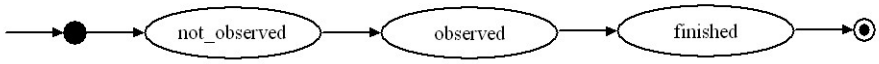

Fig. 2. The life-cycle of a WS-Agreement

- `not_observed`: the agreement is created and is in execution, but no service involved in the agreement is running; and
- `observed`: at least one service of the agreement is running;
- `finished`: the agreement terminates either successfully or not.

We illustrate a simple example in order to explain the WS-Agreement specification and its features. A possible application scenario is the request of executing fidelity-card operations[3]. Two parties act in this scenario: a shopping center

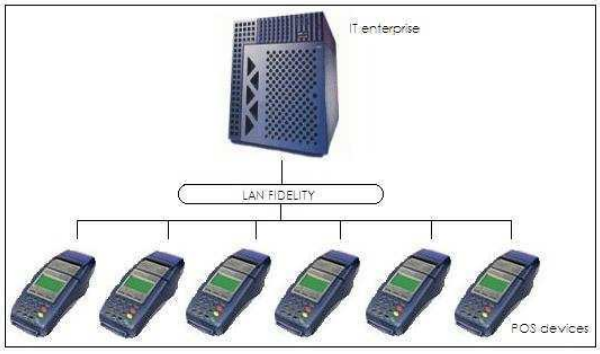

Fig. 3. Fidelity-card scenario

with several Point of Sale (POS) devices, and an IT enterprise with a server farm managing the operations and fidelity database. This scenario is depicted in Figure 3. A store of a shopping center sends a request to the server farm, asking the execution of a typical fidelity-card operation, e.g., fidelity-points, car park payment, etc. The server farm executes the request and sends a reply to the store, eventually interacting with the bank circuit for payments.

In this scenario, the agreement defines a list of operations to be executed, and an optional set of guarantees for providing a quality of service, i.e., number of operation request for a minute, number of processing operation for a minute, service cost, etc. Let us consider, for instance, the QoS related to the speed of execution: it is necessary to process many operations in a short time. Therefore,

[3] Example based on a project of the IT company DeltaDator `http://www.deltadator.it`

provider and consumer assume that the number of requests for minute should be less that 5, the number of processing operations for minute should be more than 12, and the service cost for a single operation should be less that 1 USD.

According to the established agreement between the server farm, the shopping centers, and the stores, fidelity-card operations will be executed taking into account the services required and the guarantees defined in the agreement.

3 What's in an Agreement?

The WS-Agreement specification provides XML syntax and a textual explanation of what the various XML tags mean and how they should be interpreted. Thank to the syntax, it is possible to prepare machine readable agreements, but a formal notion of agreement is missing. In this section, we formalize the notion of agreement by defining its main components.

Definition 1 (Term). *A* term t *is a couple* (s, g) *with* $s \in S$ *and* $g \in G$*, where* S *is a set of* n *services and* G *is a set of* m *guarantees.* $T \subseteq S \times G$ *is the set of the terms* t*.*

In words, a term involves the relationship between a service s and a guarantee g, not simply a specific tag of the agreement structure. If the service s appears in the list of services, which the guarantee g is applied to, it means that the couple (s, g) is a term. The number of terms varies between 0 and $n \cdot m$, where 0 means that there is no association between services and guarantees, and $n \cdot m$ indicates the case where each guarantee is associated with all services.

Definition 2 (Agreement). *An* agreement A *is a tuple* $\langle S, G, T \rangle$*, where* S *is a set of* n *services,* G *is a set of* m *guarantees, and* T *is the set of the terms* t*.*

In the following analysis, it is more convenient to consider the agreement as a set of *Terms* rather than a set of related services and guarantees. From the definition of WS-Agreement, we say that an agreement can be in one and only one of three states: `not_observed`, `observed` and `finished`.

Definition 3 (External state). *The* external state A_{es} *of an agreement* A *is an element of the set* {`not_observed`, `observed` *or* `finished`}*.*

We call the above state external, as it is the observable one. We also define an internal state of an agreement, which captures the state of the individual terms.

Definition 4 (Internal state). *The* internal state A_{is} *of an agreement* A *is a sequence of terms' states* $ts_1, \ldots, ts_p$ *of maximum size* $n \cdot m$*, where* $ts_i = (ss_j, gs_k)$ *represents the state of* g_k *guarantee with respect to the state of the* s_j *service. Service and guarantee states range over the following sets, respectively:*

- $ss_j \in$ {`not_ready`, `ready`, `running`, `finished`}*, and*
- $gs_k \in$ {`not_determined`, `fulfilled`, `violated`}*.*

From the definition of *Term*, we see that services and guarantees are related and we can define the internal state of an agreement, but it is necessary to distinguish between terms that have the same service and terms that have the same guarantee.

Proceeding in our goal of answering the question of what is in an agreement, we define the relationship between the internal and external state of an agreement A. First, we note that not all state combinations make sense. For instance, it has no meaning to say that a guarantee is `violated`, when a service is in a `not_ready` state. The only admissible combinations are the following ones.

(1) (`not_ready`, `not_determined`) (2) (`ready`, `not_determined`)
(3) (`running`, `fulfilled`) (4) (`running`, `violated`)
(5) (`finished`, `fulfilled`) (6) (`finished`, `violated`)

In theory, there are 63 possible combinations of states in which terms can be. That is, $\sum_{i=1}^{6} \binom{6}{i}$ all terms could be in state (1), or in state (2),... or in state (6); there could be terms in states (1) and (2), (1) and (3), and so on. But again, considering the definition of WS-Agreement in [3], one concludes that not all 63 combinations make sense. Furthermore, it is possible to extract the possible evolutions of these aggregated internal states.

	terms are in state	state of the agreement	transitions
(A)	(1)	`not_observed`	(B)
(B)	(1)(2)	`not_observed`	(C) (E)
(C)	(1)(2)(3)	`observed`	(D)(E)(F)(G)
(D)	(1)(2)(3)(5)	`observed`	(F)(G)
(E)	(1)(2)(4)	`observed`	(F)(H)
(F)	(1)(2)(3)(4)(5)	`observed`	(H)
(G)	(5)	`finished`	
(H)	(1)(2)(3)(4)(5)(6)	`finished`	

Fig. 4. Transition table for the relation between internal and external states

When an agreement is created its external state is `not_observed`, while all services are `not_ready` and all guarantees are `not_determined`, i.e., state (1). In the next stage some services will be `ready` while others will still be `not_ready`, i.e., there will be terms in state (1) and (2). In this case, the external state is also `not_observed`. Proceeding in this analysis, one can conclude that there are 8 situations in which terms can be. We summarize these in the table in Figure 4. In the table, we also present the relation between the internal states and the external states, and the set of transitions to go from one set of states to another. The latter transitions are best viewed as an automaton.

Referring to Figure 5, at the beginning all the terms are tied to services which are not running (A). At some point, some services will be ready to start (B).

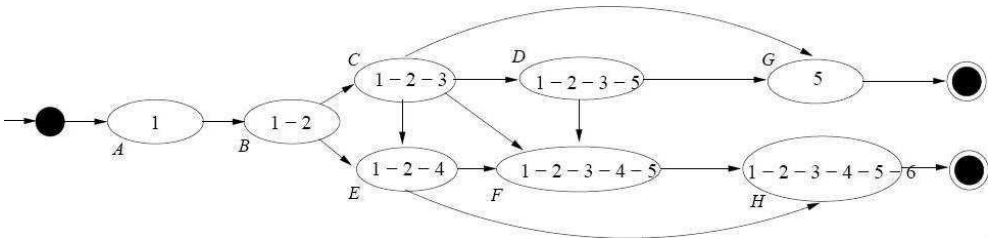

Fig. 5. Automaton representation of the table in Figure 5

Services which are ready will start execution. This may result in an immediate violation of a term (E), or in executions fulfilling the term (C). If the latter is the case, more and more services will execute. This may result in violations, which bring us to states (E) or (F), or in no violation. Some services may successfully terminate execution, case (D). If all services terminate with no violation, we end successfully in state (G). If any service has a violation at any time, we end in state (E) or (F) and from there, unavoidably, in state (H), which is a failure state.

4 Extension of WS-Agreement

From the semantics and formal analysis presented in Section 3, inspecting the automaton provided, we note that if the agreement arrives into the states (E) or (F) there is a non recoverable failure, and consequently an agreement termination. Even if one single term is violated, the whole agreement is terminated. Furthermore, when an agreement is running there is no consideration on *how* the guarantee terms are fulfilled. Our goal is to provide an extension of WS-Agreement and of its semantics in order to make agreements more long-lived, and robust to individual term violations. To reduce the occurrence of these failures, following the initial proposal in [14], we propose an extension of WS-Agreement specification.

We propose two extensions to WS-Agreement. The first is used to **(i) anticipate violations**, while the second is devoted to the **(ii) run-time renegotiation**. (i) WS-Agreement considers guarantees of a running service as fulfilled or violated. Nothing is said about how the guarantee is fulfilled. Is the guarantee close or far to being violated? Is there a trend bringing the guarantee close to its violation? We propose to introduce a new state for the agreement in which a warning has been issued due to the fact that one or more guarantees are likely to be violated in the near future. By detecting possible violations, one may intervene by modifying the run-time conditions or might renegotiate the guarantees which are close to being violated. (ii) The WS-Agreement specification does not contemplate the possibility of changing an agreement at run-time. If a guarantee is not fulfilled because of resource overload or faults in assigning availability

to consumers, the agreement must terminate. For maintaining the service and related supplied guarantees, it is necessary to create another agreement and negotiate the QoS again. This approach wastes resources and computational time, and increases network traffic.

To allow a renegotiation at runtime, it is necessary to add a structure to the agreement protocol syntax for defining renegotiation possibilities, i.e. negotiation terms. The goal of negotiation terms is to have the chance to modify the agreement applying the negotiation terms rather than respecting the original agreement. Applying the negotiation terms means that the services included in the agreement will be performed according to the new guarantees.

4.1 Life-cycle and semantics for the extended agreement

To obtain the desired extensions, we expand the set of states in which an agreement and a guarantee term can be and thus update the transition system. More precisely, the definition of an agreement does not change with respect to Definition 2, the difference lies in the fact that the set of terms T is now extended with special *negotiation terms*. These terms are defined as in Definition 1, but have a different role, i.e., they specify new conditions that enable modification of guarantees at run-time.

To account for the new type of terms, we need to extend the definition of external and internal state of an agreement. The external states of an extended agreement are enriched by the `warned` state, `checked` state, the `revisited` state, and the `denied` state. We say that an agreement can be in one of seven states. `not_observed`, `observed` and `finished` have the same meaning as in WS-Agreement, Figure 2. An Agreement is in state `checked` when the monitoring system is checking its services and guarantees. From the `checked` state the agreement can go to five different states: to `finished` if the agreement finishes its life-cycle; to `denied` if the agreement is violated and no *negotiation terms* can be applied, the agreement must terminate; to `warned` if the monitoring system has issued at least one warning for at least one term; back to `observed` if the agreement is fulfilled; to `revisited` if the agreement is fulfilled or violated and a *negotiation term* can be applied.

Definition 5 (Extended External state). *The* extended agreement external state A_{xes} *of an agreement* A *is an element of the set* {`not_observed`, `observed`, `warned`, `checked`, `revisited`, `denied` *or* `finished`}.

The transitions between states are illustrated by the automaton in Figure 6, which is an extension of the one presented in Figure 2. The automaton represents the new evolution of an agreement where a guarantee can be modified during the processing of a service or a warning can be raised. When a guarantee is violated we have two situations: the first presents a recoverable violation which implies the chance to apply a negotiation term and so the agreement is in a revisited state, the second presents a non recoverable violation which implies that there is no suitable negotiation term for the current violated guarantee and so the

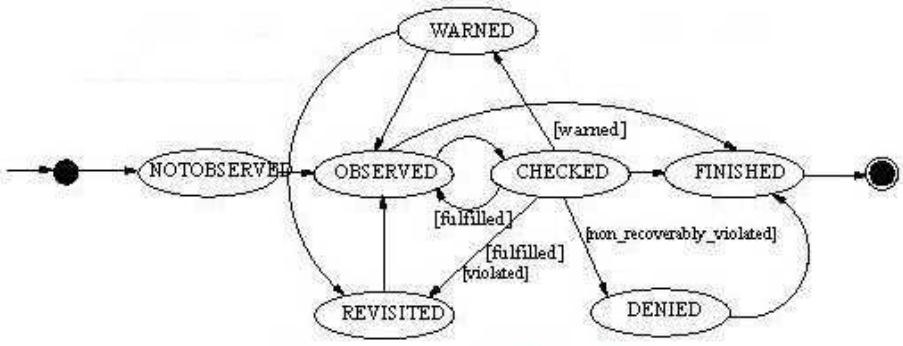

Fig. 6. The life-cylce of the WS-Agreement extension

agreement must terminate. Otherwise, if a warning is raised, this can be ignored or the agreement can go in a renegotiation state by ending in the revisited state. Also, when a guarantee is fulfilled, it is possible to change the current agreement configuration, applying a negotiation term that changes the QoS.

The internal state definition for the extended agreement is similar to the internal state definition stated before, but a new state for the services is added and two for the guarantees. A new state is `stopped` and is needed to define a state of a service where its associated guarantee is unrecoverable violated and the service must terminate or the guarantee can be revisited. It is an intermediate state. A guarantee can also be `warned` if it is close to being violated in a given time instant. Other state for a guarantee is the `non_recoverable_violated` state in which a guarantee is violated and it has no related negotiation terms for the current violation.

Definition 6 (Extended Internal state). *The* extended internal state A_{xis} *of an agreement* A *is a sequence of terms' states* $ts_1, \ldots, ts_p$ *of maximum size* $n \cdot m$*, where* $ts_i = (ss_j, gs_k)$ *represents the state of* g_k *guarantee with respect to the* s_j *service. Service and guarantee states range over the following sets, respectively:*

- $ss_j \in$ {`not_ready`, `ready`, `running`, `stopped`, `finished`}, *and*
- $gs_k \in$ {`not_determined`, `fulfilled`, `warned`, `violated`, `non_recoverably_violated`}.

As for Definition 4, one notes that not all the state combinations make sense. The only possible ones are the combinations itemized in Section 3 plus the following four:

(7) (`stopped`, `fulfilled`)
(8) (`stopped`, `violated`)
(9) (`stopped`, `non_recoverably_violated`)
(10) (`running`, `warned`)

The state combinations (7), (8) and (9) determine the states when a service is stopped because a guarantee is violated or is being modified. In state (7) a guarantee is fulfilled and we try to improve it applying a positive negotiation term. In (8) and (9) a guarantee is currently violated. In (8) the service is stopped and the guarantee is violated but it is possible to apply a negotiation term and to preserve the agreement again. In (9), instead, the guarantee is irrecoverably violated and the agreement must terminate, there are not any suitable negotiation terms. State (10) represents the fact that a warning has been raised for a running service guarantee.

	terms are in state	state of the agreement	transitions
(A)	(1)	`not_observed`	(B)
(B)	(1)(2)	`not_observed`	(C)
(C)	(1)(2)(3)	`observed`	(D)(E)(F)(G)
(D)	(1)(2)(3)(5)	`observed`	(F)(G)(I)
(E)	(1)(2)(4)	`checked`	(F)(H)(I))
(F)	(1)(2)(3)(4)(5)	`checked`	(H)(I))(J)(K)(L)
(G)	(5)	`finished`	
(H)	(1)(2)(3)(4)(5)(6)	`finished`	
(I)	(1)(2)(3)(4)(5)(7)	`observed`	(D)(E)(F)(G)
(J)	(1)(2)(3)(4)(5)(8)	`revisited`	(D)
(K)	(1)(2)(3)(4)(5)(9)	`denied`	(F)(H)
(L)	(1)(2)(3)(5)(7)(10)	`warned`	(C)(D)(H)(I)(J))

Fig. 7. Extension of the transition table for the relation between internal and external states

The relation between internal and external states of an extended agreement is an extension of the one presented in the table in Figure 4, and it is presented in Figure 7. The table respects the original agreement evolution and presents some new transitions.

4.2 Extended Agreement structure

The proposed extension is reflected in a new component of a WS-Agreement, as shown in Figure 8, and in an appropriate XML syntax.

The section *Terms* is extended with a new subsection called *Negotiation Terms* that makes references to the services defined in *Service Description Terms* and to the guarantees of *Guarantee Terms*.

The following XML code illustrates the *Negotiation Terms* structure.

```
1   <NegotiationTerm wsag:Name="xs:NCName"
2           Counter="xsd:integer"
3           Monitored="xs:boolean">
```

```
        <GuaranteeScope>
            ...
        </GuaranteeScope> *
        <NegotiationRange>
            <GuaranteeName>...</GuaranteeName>
            <Minimum>...</Minimum>
            <Maximum>...</Maximum>
        </NegotiationRange> *
        <ServiceLevelObjective>
            ...
        </ServiceLevelObjective>*
        <BusinessValueNegList>
            ...
        </BusinessValueNegList>
    </NegotiationTerm>
```

Fig. 8. Extended WS-Agreement structure

/NegotiationTerm encloses a description of a negotiation term that can be applied under specific circumstances;

/NegotiationTerm/@wsag:Name represents the name given to a term;

/NegotiationTerm/@Counter represents the maximum number of renegotiations that are allowed with the current term. The attribute is necessary to avoid circumstances where an agreement is fulfilled for too long because it

respects the negotiation term instead of the original guarantee. The default value is 1;

/NegotiationTerm/@Monitored is a boolean variable, that identifies across multiple negotiation terms and guarantee terms which one is currently monitored and checked. In other words, the attribute Monitored defines if the guarantee g_i is checked under the values of the Guarantee Term or the values of the Negotiation Term;

/NegotiationTerm/GuaranteeScope is a list of guarantee names referring to the respective wsag:GuaranteeName attributes of one or more of the guarantee terms in the agreement. The negotiation terms can apply to every guarantee in the list and refer to the parameters defined in the respective guarantee terms;

/NegotiationTerms/NegotiationRange represents the range of variable values. It presents a minimum and a maximum value of the corresponding variable that the negotiation term is applied to. If the current value is included in the range, it is possible to negotiate it applying the term;

/NegotiationTerm/ServiceLevelObjective is a list of conditions that must be met to satisfy the negotiation term. The ServiceLevelObjetive is very similar to the homonym term of the guarantees section: it identifies the new conditions that must apply to the renegotiated agreement. They refer to the variables defined in the ServiceDescriptionTerm and used in the GuaranteeTerm defined in the scope; and

/NegotiationTerm/BusinessValueList contains a list of business value parameters associated with a service level objective, each expressing a different feature of the objective.

4.3 Example

Referring to the POS scenario introduced in Section 2, we can see how the extended version of WS-Agreement behaves. We assume that the shopping center and the IT enterprise establish an agreement in order to define interactions and the qualities of the service provided. In the agreement they specify some service terms and guarantee terms for fidelity-card operations. Following the operation and the interaction's model stated in the WS-Agreement specification, consumer and provider negotiate resources and qualities of the services.

For instance, besides the agreement about services and guarantees, with the extension it is possible to add some negotiation terms that give the freedom to change the agreement at runtime.

The main and exclusive service defined in the agreement is the execution of fidelity-card operation. Associated with this service we specify two variables that are bandwidth and memory, which can be checked on the service provider side by a monitoring system. Depending on this variable, it is simple to identify some service's properties like the number of operation's execution per minute, the number of request per minute and the service cost. We specify the metric of the variable and in the section dedicated to the guarantee statement we assign ranges of values that should be met to fulfill the current agreement.

Let us consider an agreement example adapting the WS-Agreement structure to our example.

```
<wsrp:GetResourcePropertyResponse>
    <wsag:Name>AgreementExample</wsag:Name>
    <wsag:Context/>
    <wsag:Terms>
    <wsag:All>
        ....
        <wsag:All>
            <wsag:ServiceDescriptionTerm wsag:Name="bandWidth"
                    wsag:ServiceName="Operation">
            </wsag:ServiceDescriptionTerm>
            <wsag:ServiceDescriptionTerm wsag:Name="memorySize"
                    wsag:ServiceName="Operation">
            </wsag:ServiceDescriptionTerm>
        </wsag:All>

        <wsag:ServiceProperties wsag:ServiceName="Operation">
            <wsag:VariableSet>
                <wsag:Variable wsag:Name="requestMinute"
                        wsag:Metric="time:duration">
                    <wsag:Location>
                        ...
                    </wsag:Location>
                </wsag:Variable>
                <wsag:Variable wsag:Name="numberOfOperationMin"
                        wsag:Metric="time:duration">
                    <wsag:Location>
                        ...
                    </wsag:Location>
                </wsag:Variable>
                <wsag:Variable wsag:Name="serviceCost"
                        wsag:Metric="float">
                    <wsag:Location>
                        ...
                    </wsag:Location>
                </wsag:Variable>
            </wsag:VariableSet>
        </wsag:ServiceProperties>

        <wsag:GuaranteeTerm wsag:Name="operationRequestMinute"
                Monitored="True" Negotiability="True">
            ...
            <wsag:ServiceLevelObjective>
                requestMinute IS_LESS_INCLUSIVE 5
```

```
            </wsag:ServiceLevelObjective>
            ...
        </wsag:GuaranteeTerm>

        <wsag:GuaranteeTerm wsag:Name="operationMinuteCount"
                Monitored="True" Negotiability="True">
            ...
            <wsag:ServiceLevelObjective>
                numberOfOperationMinute IS_MORE_INCLUSIVE 12
            </wsag:ServiceLevelObjective>
            ...
        </wsag:GuaranteeTerm>

        <wsag:GuaranteeTerm wsag:Name="operationCost"
                Monitored="True" Negotiability="True">
            ...
            <wsag:ServiceLevelObjective>
                serviceCost IS_LESS_INCLUSIVE 1
            </wsag:ServiceLevelObjective>
            ...
        </wsag:GuaranteeTerm>

        <wsag:NegotiationTerm wsag:Name="Neg1"
                Counter="2" Monitored="False">
            <wsag:GuaranteeScope>
                <wsag:GuaranteeName>
                    operationMinuteCount
                </wsag:GuaranteeName>
                <wsag:GuaranteeName>
                    operationCost
                </wsag:GuaranteeName>
                <wsag:GuaranteeName>
                    operationRequestMinute
                </wsag:GuaranteeName>
            </wsag:GuaranteeScope>
            <NegotiationRange>
                <wsag:GuaranteeName>
                    operationRequestMinute
                </wsag:GuaranteeName>
                <--! requestMinute values-->
                <Minimum>4</Minimum>
                <Maximun>6</Maximun>
            </NegotiationRange>
            <wsag:ServiceLevelObjective>
                <ServiceLevelObjectiveAssertion>
```

```
107                     numberOfOperationMin IS_MORE_INCLUSIVE 24
108                 </ServiceLevelObjectiveAssertion>
109                 <ServiceLevelObjectiveAssertion>
110                     serviceCost IS_LESS_INCLUSIVE 2
111                 </ServiceLevelObjectiveAssertion>
112             </wsag:ServiceLevelObjective>
113             <wsag:BusinessValueList>
114                 ....
115             </wsag:BusinessValueList>
116         </wsag:NegotiationTerm>
117     </wsag:All>
118     </wsag:Terms>
119 <wsrp:GetResourcePropertyResponse>
```

Service consumer and service provider start their interactions taking into account the established agreement described above. In this scenario it is possible that the monitoring system at provider side notices that the consumer sends more requests per minute than the number stated in the agreement, exceeding the maximum value, 4 (defined in the guarantee at line 43). For instance, the provider can not fulfill all the requests from the consumer as previously agreed. Thanks to the proposed extension, it is possible to renegotiate the current guarantee. In the *NegotiationTerms* (lines 84 to 107), there is a term referring to the current guarantee that gives the freedom to increase the number of requests per minute up to 24, if service cost is increased of 2 USD. Applying this negotiation term, defined and agreed on by both service consumer and provider at agreement creation's time, the consumer will pay more, but can ask more executions per minute: in this case an increase of performance means an increase of service cost. Furthermore, if a monitoring system that interacts with the agreement and service architecture anticipates violation, consumer and provider renegotiate the agreement in advance.

In this simple execution on the running example, we see that using the extension it is possible to maintain the current agreement, mediating guarantees that are likely to be violated, currently violated, and guarantee that are widely fulfilled. Instead, using the original version the agreement must terminate as soon as a guarantee is violated.

4.4 Framework

The proposed extension to WS-Agreement must be handled by an appropriate framework that allows for monitoring and provides run-time renegotiation.

On the one hand, there must be rules specifying when and how to raise a warning for any given guarantee. These rules should be easy to compute to avoid overloading of the monitoring system and be fast to provide warnings. In addition they should provide good performance in detecting as many violations as possible generating the minimum number of false positives. A forecasting method which enjoys this characteristics is the linear least squares method [5].

The method of linear least squares requires a straight line to be fitted to a set of data points such that the sum of the squares of the vertical deviations from the points to the line is minimized. By analyzing such a parameter of the line as a slope ratio, it is possible to predict a change over time.

On the other hand, to allow for renegotiation of guarantee terms at runtime the parties involved in the agreement need to be able to decide whether a renegotation has been agreed upon. Before execution it must be possible to specify negotiation terms. This can be done by using appropriate templates in the spirit of the original work in [13].

5 Preliminary experimental results

We have conducted preliminary experimentation to show the feasibility of the warning strategy. We used synthetic data. We generated a sequence of 1100 elements considered as a service guarantee for a single operation over a continuous time interval (for instance the cost of a service which should be below the value 10). The points were generated by a function that returns a random number greater or equal to 6.00 and less or equal to 14.00, evenly distributed. We split the data set into two subsets. The first part of the data set was used to decide the size of the time window and of the threshold values to be used for prediction. The rest of the data was used for evaluating the system. The data set and the results of the experiments for 100 points for three time windows, i.e. 5, 10, and 20, are presented in the Appendixes. Where `SUM` and `MEAN` are calculated for each time window and `a` is a tangent of slope angel.

To evaluate the method we consider the following performance measures: *Precision* is the ratio of the number of true warnings (i.e., warnings thrown to notify violation points) to the number of total warnings (i.e., true warnings and false warnings). *Recall* is the ratio of the number of warned violations (i.e., violation points for which a warning is issued) to the number of total violation points. Total violation points include warned violations and missed violations.

The following table summarizes the results of the experimentation for time window equal 5:

	Warnings		**Violations**	
	True	***False***	***Warned***	***Missed***
	303	11	156	13
Total	314		169	
Precision	**96.50%**			
Recall			**92.31%**	

The number of true and false warnings is shown in the first column. The difference in the number of total warnings and violations is due to the fact that more than one warning in the same time window may refer to the same violation. The number of warned and missed violations is reported in the second column of the table. The total sum of warnings and violations is in the "Total" row. The last two rows present the precision and recall of the method.

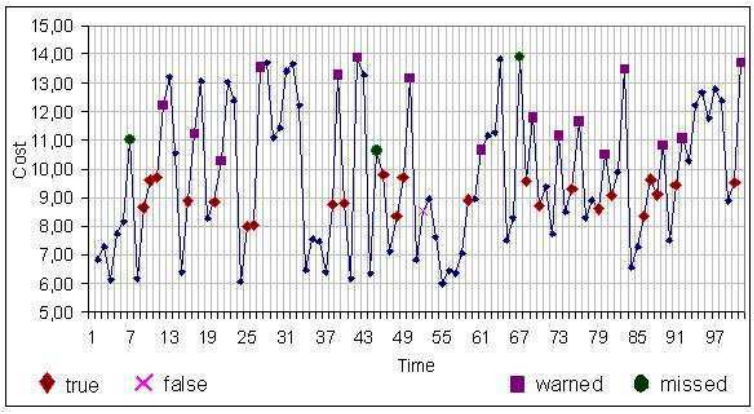

Fig. 9. Experimental results for 100 points

The results of experimentation on the first 100 points of the data set for time window equal 5 is shown in Figure 9. In the figure, two types of warnings, true and false, are marked by diamonds and crosses, respectively. A warning is thrown if the cost and tangent of the cost curve are higher then the threshold (8 for cost and 0.1 for the tangent differences). Squares represent warned violation points, while circles indicate missed violation points.

The method shows good performance when the increase in cost is smooth (points 8, 9, and 10), a case that normally takes place during web services execution. If the change in values is abrupt then the method fails to generate warnings, e.g., points 43 (cost is 6.36) and 44 (cost is 10.63). It is difficult to find a violation point if the point is in the very beginning of the process, within or just after the first time window (point 7). The latter cases should be considered exceptional, in fact those occur only 13 times in the whole experiment.

In the experimentation using the method, more than 92% of violation points are warned in advance, and 96.5% of thrown warnings are true warnings. Using bigger time windows does not improve performances:

Time window is 10

	Warnings		**Violations**	
	True	***False***	***Warned***	***Missed***
	300	21	135	34
Total	321		169	
Precision	**93.46%**			
Recall			**79.88%**	

Time window is 20

	Warnings		**Violations**	
	True	***False***	***Warned***	***Missed***
	299	21	103	66
Total	320		169	
Precision	**93.44%**			
Recall			**60.95%**	

6 Concluding Remarks

Describing and invoking an individual functionality of a web service is becoming more and more common practice. One of the next steps is moving from functional properties of basic services to non-functional properties of composed services. The non-functional properties need to be specified by the services, but also to be negotiated among services.

WS-Agreement is a protocol that defines a syntax to specify a number of guarantee terms within an agreement. We looked into the protocol specification with the goal of providing a formalization of the notion of an agreement and proposing a formal representation for the internal and external states in which an agreement can be. From this analysis we discovered that an agreement can be made more long-lived and robust with respect to forecoming violations. We presented the details of the proposed extension in formal terms and provided some preliminary experimentation on synthetic data.

This work prods for more investigation of agreements and of their management. In the next future, we plan to dive into the details of a framework implementing the extended agreement version and then to experiment on real data coming from an actual case study.

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APPENDIX A-1

Table 1: Experimental results for time window equal to 5

Time=x	**Cost=y**	**MEAN(y)**	**SUM(x)**	**SUM(x^2)**	**SUM(y)**	**SUM(xy)**	**a=tg(L)**	**DELTA(a)**
1	6,82	7,23	15,00	55,00	40,17	123,7425	0,323903077	0,04340576
2	7,29	8,06	20,00	90,00	41,97	170,6752	0,280497315	0,07618884
3	6,15	7,84	25,00	135,00	43,18	219,4595	0,356686156	**0,16961689**
4	7,72	8,33	30,00	190,00	46,03	281,4232	0,526303046	**0,11012745**
5	8,14	8,71	35,00	255,00	48,76	347,6657	0,636430491	**0,1779651**
6	**11,00**	9,03	40,00	330,00	50,47	408,3451	0,458465387	0,28833747
7	6,17	9,27	45,00	415,00	51,70	466,9735	0,170127912	0,03686006
8	**8,64**	10,68	50,00	510,00	52,48	522,7161	-0,20698797	0,03864497
9	**9,61**	11,06	55,00	615,00	51,82	567,5097	-0,24563294	0,05098635
10	**9,72**	10,42	60,00	730,00	50,32	601,8648	-0,19464658	**0,10597148**
11	12,23	10,25	65,00	855,00	49,95	648,4417	-0,0886751	0,0294245
12	13,22	10,05	70,00	990,00	50,03	700,9917	0,059250601	0,15249956
13	10,54	10,02	75,00	1135,00	50,67	762,1655	0,21175016	0,05093909
14	6,41	9,57	80,00	1290,00	51,21	821,9658	0,262689247	**0,22697761**
15	**8,88**	10,05	85,00	1455,00	51,76	880,3093	0,035711636	0,09757375
16	11,23	10,33	90,00	1630,00	51,66	928,6026	-0,13328539	0,16421178
17	13,05	10,70	95,00	1815,00	50,84	962,9757	-0,29749716	0,0469352
18	8,27	10,56	100,00	2010,00	49,76	992,5975	-0,25056196	0,16810671
19	**8,84**	10,12	105,00	2215,00	49,08	1029,7591	-0,08245525	**0,13957299**
20	10,27	9,96	110,00	2430,00	49,84	1098,6183	0,222028241	**0,31517007**
21	13,04	9,51	115,00	2655,00	51,44	1188,5498	0,537198314	0,23494008
22	12,37	9,61	120,00	2890,00	54,56	1317,2417	0,77213839	0,04150659
23	6,07	9,88	125,00	3135,00	57,61	1447,5459	0,730631797	0,32532431
24	**8,02**	10,88	130,00	3390,00	60,09	1566,3738	0,405307489	0,35444298
25	**8,05**	11,56	135,00	3655,00	60,65	1637,0849	-0,05086451	0,46314621
26	13,55	12,63	140,00	3930,00	59,76	1668,0935	-0,51401071	0,28963355
27	13,71	12,66	145,00	4215,00	56,61	1633,7156	-0,80364426	0,25853814
28	11,08	12,36	150,00	4510,00	51,98	1548,8388	-1,0621824	0,02394135
29	11,42	11,44	155,00	4815,00	46,96	1444,7638	-1,08612375	0,47621326
30	13,40	10,67	160,00	5130,00	44,21	1408,5323	-0,60991049	0,56858831
31	13,68	9,48	165,00	5455,00	42,48	1401,5462	-0,04132218	0,25110599
32	12,22	8,03	170,00	5790,00	41,68	1420,1287	0,292428172	**0,27734993**
33	6,50	7,33	175,00	6135,00	43,84	1540,1772	0,569778099	0,03453584
34	7,55	8,69	180,00	6490,00	47,60	1719,7995	0,604313942	**0,21074257**
35	7,48	8,94	185,00	6855,00	48,62	1802,7475	0,393571369	0,1636685
36	6,39	8,68	190,00	7230,00	49,75	1892,6213	0,229902871	0,21029158
37	**8,75**	10,19	195,00	7615,00	51,86	2022,6452	0,019611292	0,2028422
38	13,30	11,09	200,00	8010,00	51,11	2042,1158	-0,2224535	0,09314686
39	**8,80**	9,71	205,00	8415,00	48,46	1983,7082	-0,31560035	0,1105877
40	6,18	10,07	210,00	8830,00	47,87	2006,2977	-0,42618806	**0,15992153**
41	13,91	10,80	215,00	9255,00	47,42	2036,4921	-0,26626653	0,22894715
42	13,29	9,44	220,00	9690,00	45,66	2009,4797	0,037319382	**0,12888284**

Continued on next page

Table 1 – continued from previous page

Time=x	**Cost=y**	**MEAN(y)**	**SUM(x)**	**SUM(x^2)**	**SUM(y)**	**SUM(xy)**	**a=tg(L)**	**DELTA(a)**
43	6,36	8,45	225,00	10135,00	45,54	2051,0481	0,166202219	**0,13137866**
44	**10,63**	9,12	230,00	10590,00	46,54	2141,1912	0,03482356	0,04461928
45	**9,79**	9,62	235,00	11055,00	46,45	2182,1725	-0,07944284	0,23933213
46	7,12	9,04	240,00	11530,00	44,41	2128,4947	-0,31877497	**0,22776182**
47	**8,33**	9,32	245,00	12015,00	42,89	2096,0601	-0,54653679	0,07779394
48	**9,72**	9,44	250,00	12510,00	40,65	2026,1403	-0,62433074	0,10768977
49	13,17	9,02	255,00	13015,00	37,90	1927,6654	-0,51664097	0,30853998
50	6,84	7,59	260,00	13530,00	35,83	1861,2316	-0,20810099	0,20259363
51	**8,53**	7,51	265,00	14055,00	35,79	1896,8181	-0,00550735	0,3420924
52	8,96	7,08	270,00	14590,00	36,67	1983,4979	0,347599753	0,32741413
53	7,61	6,70	275,00	15135,00	38,94	2148,6381	0,675013888	**0,15477028**
54	6,00	6,96	280,00	15690,00	42,45	2385,5092	0,829784172	0,07800286
55	6,46	7,55	285,00	16255,00	46,67	2669,3751	0,907787034	0,22460476
56	6,36	8,39	290,00	16830,00	50,02	2907,9730	0,683182276	0,40130334
57	7,05	9,35	295,00	17415,00	52,05	3073,5866	0,281878935	0,20561997
58	**8,92**	10,20	300,00	18010,00	53,66	3220,1913	0,076258963	0,02834418
59	8,94	11,18	305,00	18615,00	54,08	3297,5696	-0,10460314	0,00934486
60	10,68	10,89	310,00	19230,00	53,12	3292,2474	-0,113948	0,04968174
61	11,17	10,42	315,00	19855,00	52,69	3318,9858	-0,06426626	0,0076328
62	11,29	10,96	320,00	20490,00	52,96	3388,4927	-0,07189906	**0,11697243**
63	13,80	10,62	325,00	21135,00	51,44	3341,6516	-0,18887149	0,00507635
64	7,52	10,22	330,00	21790,00	50,58	3336,4195	-0,19394784	**0,17084077**
65	8,30	10,47	335,00	22455,00	49,46	3310,2570	-0,36478861	0,0370389
66	**13,91**	10,68	340,00	23130,00	48,21	3274,9384	-0,32774971	0,31757193
67	**9,57**	9,45	345,00	23815,00	47,20	3256,5240	-0,01017778	0,05113006
68	11,81	9,76	350,00	24510,00	47,54	3328,1549	0,061307834	0,04304458
69	**8,74**	9,10	355,00	25215,00	47,11	3346,0211	0,104352412	**0,10055596**
70	9,38	9,22	360,00	25930,00	47,37	3410,6953	-0,00379646	0,05174562
71	7,73	9,67	365,00	26655,00	47,76	3485,9759	-0,05554207	0,0576182
72	11,15	9,79	370,00	27390,00	47,18	3490,0366	-0,11316028	0,09883578
73	8,51	9,34	375,00	28135,00	46,80	3509,6077	-0,0143245	**0,15681279**
74	**9,30**	9,36	380,00	28890,00	47,77	3632,6021	0,171137288	0,01140987
75	11,65	9,60	385,00	29655,00	48,32	3722,1210	0,182547159	**0,09935687**
76	8,31	9,09	390,00	30430,00	47,97	3742,1389	0,083190293	0,08129748
77	8,92	9,40	395,00	31215,00	47,99	3789,6989	-0,16448778	0,16601903
78	**8,62**	10,32	400,00	32010,00	47,65	3808,3905	-0,33050681	0,03310181
79	10,52	9,90	405,00	32815,00	45,51	3682,7417	-0,36360862	0,22625017
80	**9,06**	9,25	410,00	33630,00	44,64	3659,2742	-0,13735844	**0,12857864**
81	9,90	9,11	415,00	34455,00	44,47	3690,9272	-0,0087798	**0,12926787**
82	13,48	9,06	420,00	35290,00	44,66	3752,4469	0,138047675	**0,17012539**
83	6,55	8,18	425,00	36135,00	45,19	3843,9302	0,308173061	0,09855835
84	7,28	9,03	430,00	36990,00	46,83	4029,6770	0,209614715	0,04924684
85	**8,36**	9,08	435,00	37855,00	47,91	4170,8678	0,258861556	**0,16197068**
86	**9,63**	9,30	440,00	38730,00	49,97	4401,6386	0,420832234	0,11407072
87	**9,10**	9,59	445,00	39615,00	52,28	4658,1929	0,534902956	0,03953986

Continued on next page

Table 1 – continued from previous page

Time=x	**Cost=y**	**MEAN(y)**	**SUM(x)**	**SUM(x^2)**	**SUM(y)**	**SUM(xy)**	**a=tg(L)**	**DELTA(a)**
88	10,81	9,83	450,00	40510,00	54,64	4923,4940	0,574442814	0,04177206
89	7,52	10,11	455,00	41415,00	57,18	5209,1048	0,53267075	0,34464896
90	**9,44**	11,14	460,00	42330,00	58,77	5408,9535	0,188021787	0,0552442
91	11,08	11,61	465,00	43255,00	58,70	5457,7733	-0,13277758	0,0965707
92	10,29	11,95	470,00	44190,00	58,55	5501,3023	-0,22934828	0,04545857
93	12,23	12,37	475,00	45135,00	57,71	5480,1765	-0,27480685	0,07953285
94	12,67	11,70	480,00	46090,00	56,04	5378,2826	-0,195274	**0,16287234**
95	11,77	11,07	485,00	47055,00	55,95	5427,8012	0,032401661	0,46625649
96	12,81	11,46	490,00	48030,00	58,59	5746,5965	0,498658147	0,37855373
97	12,38	11,12	394,00	38814,00	47,13	4646,8024	0,120104416	0,00138675
98	8,88	10,70	297,00	29405,00	36,01	3568,3056	0,121491162	0,00579566
99	**9,52**	11,61	199,00	19801,00	25,31	2519,7508	0,127286825	0,00975195
100	13,70	13,70	100,00	10000,00	13,70	1370,3878	0,137038779	0,13703878

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Table 2: Experimental results for time window equal to 10

Time=x	**Cost=y**	**MEAN(y)**	**SUM(x)**	**SUM(x^2)**	**SUM(y)**	**SUM(xy)**	**a=tg(L)**	**DELTA(a)**
1	6,82	8,13	55,00	385,00	95,53	543,3912	0,218017622	0,05466949
2	7,29	8,67	65,00	505,00	97,69	648,4934	0,163348129	0,04048192
3	6,15	9,26	75,00	645,00	99,40	755,6575	0,122866209	0,02630716
4	7,72	9,70	85,00	805,00	100,43	861,6447	0,096559046	**0,03389327**
5	8,14	9,57	95,00	985,00	100,58	960,6535	0,062665778	**0,0356303**
6	**11,00**	9,64	105,00	1185,00	101,01	1062,8870	0,027035476	0,01350696
7	6,17	9,66	115,00	1405,00	101,30	1163,7963	-0,013528514	0,0297994
8	8,64	10,35	125,00	1645,00	101,79	1268,7597	-0,043327909	0,01377464
9	9,61	10,32	135,00	1905,00	101,65	1369,8900	-0,029553265	**0,02824855**
10	9,72	10,24	145,00	2185,00	101,84	1476,5554	-0,001304715	0,03236162
11	**12,23**	10,29	155,00	2485,00	102,36	1589,3344	0,033666333	0,0493702
12	13,22	10,37	165,00	2805,00	103,14	1708,5852	0,083036533	0,04885362
13	10,54	10,29	175,00	3145,00	103,89	1829,0414	0,131890158	**0,03315406**
14	**6,41**	9,84	185,00	3505,00	104,72	1951,0172	0,16504422	0,0043573
15	**8,88**	10,00	195,00	3885,00	106,04	2081,0956	0,160686922	0,01214657
16	11,23	9,92	205,00	4285,00	107,15	2208,8957	0,148540357	0,03421956
17	13,05	10,15	215,00	4705,00	108,29	2337,6486	0,114320793	0,07157924
18	8,27	10,22	225,00	5145,00	108,48	2444,2851	0,042741552	0,01107092
19	**8,84**	10,50	235,00	5605,00	108,10	2536,0230	-0,053812473	0,06114942
20	10,27	10,76	245,00	6085,00	107,67	2628,5131	-0,114961895	0,05303013
21	13,04	11,07	255,00	6585,00	106,72	2707,5366	-0,167992028	0,06006481
22	12,37	11,13	265,00	7105,00	104,74	2756,6642	-0,228056841	0,03047548

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Table 2 – continued from previous page

Time=x	**Cost=y**	**MEAN(y)**	**SUM(x)**	**SUM(x^2)**	**SUM(y)**	**SUM(xy)**	**a=tg(L)**	**DELTA(a)**
23	**6,07**	11,12	275,00	7645,00	102,71	2803,1397	-0,258532321	0,00109521
24	8,02	11,16	285,00	8205,00	100,80	2851,4505	-0,259627535	**0,02411943**
25	8,05	11,11	295,00	8785,00	98,84	2896,3891	-0,235508104	**0,06156826**
26	13,55	11,06	305,00	9385,00	97,24	2951,3312	-0,173939849	**0,08983111**
27	13,71	10,34	315,00	10005,00	95,92	3014,4587	-0,084108743	**0,06208096**
28	11,08	9,85	325,00	10645,00	95,39	3098,2776	-0,022027786	0,01093581
29	11,42	10,07	335,00	11305,00	95,31	3193,8744	0,011091974	**0,02932336**
30	13,40	9,81	345,00	11985,00	94,66	3268,9450	0,040415335	**0,04363697**
31	13,68	9,08	355,00	12685,00	94,70	3368,7216	0,084052305	0,00140217
32	12,22	9,11	365,00	13405,00	95,53	3493,6514	0,082650138	0,03925717
33	6,50	9,21	375,00	14145,00	95,80	3596,1024	0,043392969	**0,02774855**
34	**7,55**	9,20	385,00	14905,00	95,53	3676,7031	-0,015644418	0,04986196
35	**7,48**	9,51	395,00	15685,00	95,40	3762,9663	-0,065506374	**0,05299198**
36	**6,39**	9,74	405,00	16485,00	94,50	3817,4694	-0,11849835	**0,04481287**
37	**8,75**	9,81	415,00	17305,00	93,03	3847,4579	-0,163311219	**0,02636083**
38	13,30	9,77	425,00	18145,00	91,42	3869,7021	-0,189672048	0,01656756
39	**8,80**	9,41	435,00	19005,00	89,72	3885,7812	-0,206239611	0,02421843
40	**6,18**	9,85	445,00	19885,00	88,30	3910,2396	-0,230458044	0,0008971
41	13,91	9,92	455,00	20785,00	86,02	3894,6495	-0,231355141	**0,05215731**
42	13,29	9,38	465,00	21705,00	84,05	3893,6605	-0,17919783	**0,05452696**
43	**6,36**	8,95	475,00	22645,00	82,89	3927,0056	-0,124670866	**0,05248059**
44	10,63	9,07	485,00	23605,00	82,39	3990,1435	-0,07219028	**0,04379112**
45	**9,79**	8,61	495,00	24585,00	82,39	4080,7434	0,028399163	**0,07801288**
46	**7,12**	8,27	505,00	25585,00	83,00	4200,5276	0,106412038	**0,05844862**
47	**8,33**	8,20	515,00	26605,00	84,13	4346,5363	0,164860661	**0,08085597**
48	9,72	8,07	525,00	27645,00	86,10	4540,3024	0,245716629	**0,06231822**
49	13,17	7,99	535,00	28705,00	88,44	4756,8121	0,308034848	**0,04439407**
50	6,84	7,57	545,00	29785,00	91,15	4996,6370	0,352428922	0,01774983
51	**8,53**	7,95	555,00	30885,00	94,26	5259,0945	0,33467909	0,03699432
52	**8,96**	8,22	565,00	32005,00	96,86	5497,0736	0,297684774	0,06964982
53	**7,61**	8,45	575,00	33145,00	98,85	5702,5956	0,228034949	0,07898171
54	**6,00**	9,07	585,00	34305,00	100,59	5896,8919	0,149053235	**0,08769269**
55	**6,46**	9,22	595,00	35485,00	101,19	6025,6124	0,061360543	**0,04767844**
56	**6,36**	9,40	605,00	36685,00	101,81	6158,1876	-0,013682099	0,05204252
57	**7,05**	10,16	615,00	37905,00	102,58	6303,1633	-0,065724624	**0,04157139**
58	**8,92**	10,41	625,00	39145,00	102,04	6368,3863	-0,107296017	0,02173265
59	**8,94**	10,70	635,00	40405,00	101,18	6413,9810	-0,12902867	0,00941276
60	10,68	10,68	645,00	41685,00	99,71	6419,6470	-0,138441431	0,01672865
61	11,17	10,55	655,00	42985,00	98,44	6437,4948	-0,121712779	**0,02171059**
62	11,29	10,21	665,00	44305,00	97,26	6459,8501	-0,100002187	0,0247791
63	13,80	10,19	675,00	45645,00	96,65	6517,9521	-0,075223091	**0,04396942**
64	**7,52**	9,66	685,00	47005,00	96,29	6593,3138	-0,03125367	0,00238885
65	**8,30**	9,84	695,00	48385,00	96,26	6687,6673	-0,028864822	0,00362003
66	13,91	10,18	705,00	49785,00	95,85	6755,1991	-0,025244797	0,01297622
67	**9,57**	9,62	715,00	51205,00	94,77	6775,2239	-0,012268578	0,00411793

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Table 2 – continued from previous page

Time=x	**Cost=y**	**MEAN(y)**	**SUM(x)**	**SUM(x^2)**	**SUM(y)**	**SUM(xy)**	**a=tg(L)**	**DELTA(a)**
68	11,81	9,55	725,00	52645,00	94,39	6841,7733	-0,016386507	0,00284757
69	8,74	9,23	735,00	54105,00	94,09	6913,7692	-0,019234079	0,00854611
70	9,38	9,41	745,00	55585,00	94,32	7024,7118	-0,027780189	0,01589265
71	**7,73**	9,38	755,00	57085,00	94,08	7099,5016	-0,043672842	0,01297485
72	11,15	9,60	765,00	58605,00	93,91	7179,3225	-0,05664769	0,00999789
73	**8,51**	9,83	775,00	60145,00	93,64	7253,0779	-0,046649799	0,01137097
74	9,30	9,63	785,00	61705,00	92,81	7283,0233	-0,035278833	**0,03130161**
75	11,65	9,43	795,00	63285,00	92,76	7374,3853	0,003977219	**0,05588907**
76	8,31	9,10	805,00	64885,00	93,44	7526,7138	0,059866293	**0,04427754**
77	8,92	9,23	815,00	66505,00	94,79	7734,0561	0,104143835	**0,05398641**
78	8,62	9,25	825,00	68145,00	96,33	7960,3022	0,158130246	0,05439557
79	**10,52**	9,47	835,00	69805,00	98,18	8215,5585	0,212525814	**0,03602018**
80	9,06	9,17	845,00	71485,00	99,62	8438,2722	0,248545995	0,00949005
81	9,90	9,21	855,00	73185,00	101,56	8704,3118	0,258036047	0,01177243
82	**13,48**	9,32	865,00	74905,00	103,88	9007,9974	0,26980848	0,00580349
83	6,55	9,00	875,00	76645,00	106,14	9308,9179	0,26400499	0,04563948
84	**7,28**	9,57	885,00	78405,00	108,88	9653,6995	0,218365513	0,04474717
85	**8,36**	10,11	895,00	80185,00	110,98	9946,9872	0,17361834	0,04332776
86	**9,63**	10,45	905,00	81985,00	112,38	10180,7598	0,130290585	0,04037229
87	**9,10**	10,77	915,00	83805,00	113,38	10381,5843	0,089918298	0,04974696
88	10,81	11,10	925,00	85645,00	113,73	10522,9901	0,040171338	**0,02539145**
89	**7,52**	10,91	935,00	87505,00	113,33	10594,8277	-0,014779885	0,0133063
90	9,44	11,11	945,00	89385,00	114,03	10773,5217	-0,028086188	0,04950663
91	11,08	11,53	955,00	91285,00	116,63	11144,4004	0,077592818	0,04386085
92	10,29	11,58	864,00	83004,00	105,10	10095,0113	0,121453671	0,00030534
93	12,23	11,74	772,00	74540,00	93,51	9029,4858	0,121148327	0,00061068
94	12,67	11,67	679,00	65891,00	81,77	7937,3089	0,120537648	0,0005654
95	11,77	11,51	585,00	57055,00	70,10	6839,9016	0,119972243	0,00024737
96	12,81	11,46	490,00	48030,00	58,59	5746,5965	0,119724877	5,9011E-05
97	12,38	11,12	394,00	38814,00	47,13	4646,8024	0,119783889	0,00160666
98	**8,88**	10,70	297,00	29405,00	36,01	3568,3056	0,121390549	0,00587558
99	9,52	11,61	199,00	19801,00	25,31	2519,7508	0,127266131	0,00977265
100	13,70	13,70	100,00	10000,00	13,70	1370,3878	0,137038779	0,13703878

APPENDIX A-3

Table 3: Experimental results for time window equal to 20

Time=x	**Cost=y**	**MEAN(y)**	**SUM(x)**	**SUM(x^2)**	**SUM(y)**	**SUM(xy)**	**a=tg(L)**	**DELTA(a)**
1	6,82	9,21	210,00	2870,00	203,48	2263,5197	1,304954048	0,17634434
2	7,29	9,52	230,00	3310,00	204,35	2465,4129	1,128609711	0,13118704

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Table 3 – continued from previous page

Time=x	**Cost=y**	**MEAN(y)**	**SUM(x)**	**SUM(x^2)**	**SUM(y)**	**SUM(xy)**	**a=tg(L)**	**DELTA(a)**
3	6,15	9,77	250,00	3790,00	204,95	2670,0966	0,997422675	**0,10245994**
4	7,72	9,77	270,00	4310,00	205,34	2877,2449	0,89496274	**0,0807761**
5	8,14	9,79	290,00	4870,00	205,75	3084,5957	0,814186636	**0,06586812**
6	**11,00**	9,78	310,00	5470,00	206,28	3296,5920	0,748318519	0,05293039
7	6,17	9,91	330,00	6110,00	206,90	3503,6202	0,695388126	0,04616344
8	8,64	10,29	350,00	6790,00	207,07	3702,5191	0,64922469	0,04147934
9	9,61	10,41	370,00	7510,00	206,59	3887,8847	0,607745349	0,03827949
10	9,72	10,50	390,00	8270,00	205,92	4078,8053	0,569465863	0,03291508
11	**12,23**	10,68	410,00	9070,00	205,25	4262,3379	0,536550782	0,03010095
12	13,22	10,75	430,00	9910,00	204,07	4429,5675	0,50644983	0,02801009
13	10,54	10,70	450,00	10790,00	202,56	4588,9660	0,478439743	**0,02623774**
14	6,41	10,50	470,00	11710,00	200,93	4749,8904	0,452202003	**0,02255605**
15	8,88	10,56	490,00	12670,00	199,56	4906,4367	0,429645958	**0,02110136**
16	**11,23**	10,49	510,00	13670,00	198,06	5059,7221	0,408544602	**0,02025299**
17	13,05	10,25	530,00	14710,00	196,58	5223,3566	0,388291608	**0,01775634**
18	8,27	10,03	550,00	15790,00	195,34	5385,5742	0,37053527	0,01531728
19	8,84	10,28	570,00	16910,00	194,22	5536,4909	0,355217986	**0,01538761**
20	**10,27**	10,28	590,00	18070,00	192,64	5677,0568	0,339830375	**0,01557967**
21	13,04	10,08	610,00	19270,00	191,07	5838,0311	0,324250708	0,01295941
22	12,37	10,12	630,00	20510,00	189,92	5994,6118	0,311291302	0,01232205
23	**6,07**	10,17	650,00	21790,00	188,60	6142,0724	0,298969248	**0,0124023**
24	**8,02**	10,18	670,00	23110,00	187,13	6296,3105	0,286566953	0,01048107
25	**8,05**	10,31	690,00	24470,00	186,02	6446,6427	0,276085879	**0,01040532**
26	13,55	10,40	710,00	25870,00	184,62	6588,2246	0,265680556	**0,01074953**
27	13,71	10,08	730,00	27310,00	183,06	6740,3090	0,25493103	**0,00889583**
28	11,08	9,81	750,00	28790,00	182,16	6905,9997	0,246035195	**0,00815296**
29	11,42	9,74	770,00	30310,00	181,59	7088,9293	0,237882239	0,00667442
30	13,40	9,83	790,00	31870,00	181,20	7253,6705	0,231207819	**0,00695518**
31	13,68	9,50	810,00	33470,00	180,50	7412,6784	0,224252641	**0,00617902**
32	12,22	9,24	830,00	35110,00	180,25	7593,9518	0,218073623	**0,00570482**
33	**6,50**	9,08	850,00	36790,00	180,21	7787,6632	0,212368799	**0,00443613**
34	**7,55**	9,14	870,00	38510,00	180,46	7968,7036	0,207932667	**0,00503572**
35	**7,48**	9,06	890,00	40270,00	180,69	8180,2184	0,202896949	**0,00457894**
36	**6,39**	9,01	910,00	42070,00	181,16	8405,9305	0,198318006	**0,00338976**
37	**8,75**	9,01	930,00	43910,00	181,94	8620,4890	0,194928241	**0,00342552**
38	13,30	8,92	950,00	45790,00	182,82	8854,0437	0,191502717	**0,00288486**
39	**8,80**	8,70	970,00	47710,00	183,88	9088,7194	0,188617859	**0,00293227**
40	**6,18**	8,71	990,00	49670,00	185,15	9353,8150	0,185685593	0,002184
41	13,91	8,93	1010,00	51670,00	186,49	9597,7057	0,183501588	0,00258896
42	13,29	8,80	1030,00	53710,00	187,52	9838,0766	0,180912626	0,00241538
43	**6,36**	8,70	1050,00	55790,00	188,62	10084,2095	0,178497241	0,00163301
44	10,63	9,07	1070,00	57910,00	189,93	10315,9023	0,176864236	**0,00251875**
45	**9,79**	8,91	1090,00	60070,00	190,51	10524,7028	0,174345484	**0,00218852**
46	**7,12**	8,84	1110,00	62270,00	191,23	10735,6541	0,172156962	0,00193625
47	**8,33**	9,18	1130,00	64510,00	192,03	10945,0967	0,170220715	**0,00257137**

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Table 3 – continued from previous page

Time=x	**Cost=y**	**MEAN(y)**	**SUM(x)**	**SUM(x^2)**	**SUM(y)**	**SUM(xy)**	**a=tg(L)**	**DELTA(a)**
48	**9,72**	9,24	1150,00	66790,00	192,28	11137,6080	0,167649348	0,00262935
49	13,17	9,35	1170,00	69110,00	192,44	11330,0889	0,16502	**0,00259**
50	**6,84**	9,12	1190,00	71470,00	192,44	11507,7035	0,162430003	**0,00252877**
51	**8,53**	9,25	1210,00	73870,00	192,61	11706,1604	0,159901231	**0,00270909**
52	**8,96**	9,21	1230,00	76310,00	192,65	11909,4647	0,157192136	0,00213069
53	**7,61**	9,32	1250,00	78790,00	192,90	12101,0992	0,155061446	**0,00278276**
54	**6,00**	9,37	1270,00	81310,00	192,99	12330,9000	0,152278688	**0,00231991**
55	**6,46**	9,53	1290,00	83870,00	193,23	12549,1069	0,149958783	0,00212583
56	**6,36**	9,79	1310,00	86470,00	193,47	12758,1386	0,147832957	**0,0026392**
57	**7,05**	9,89	1330,00	89110,00	193,46	12984,7168	0,145193761	**0,00231089**
58	**8,92**	9,98	1350,00	91790,00	193,57	13206,9042	0,142882873	**0,00209265**
59	**8,94**	9,97	1370,00	94510,00	193,76	13426,8420	0,140790225	0,00196201
60	10,68	10,05	1390,00	97270,00	193,98	13644,6960	0,138828218	**0,00218193**
61	11,17	9,96	1410,00	100070,00	194,08	13872,3471	0,136646287	**0,00162589**
62	11,29	9,90	1430,00	102910,00	194,48	14095,4773	0,135020393	0,0014999
63	13,80	10,01	1450,00	105790,00	194,97	14323,7974	0,133520488	**0,00178574**
64	**7,52**	9,65	1470,00	108710,00	195,19	14546,8066	0,131734744	**0,00132392**
65	**8,30**	9,64	1490,00	111670,00	195,98	14811,1924	0,130410826	**0,00122997**
66	13,91	9,64	1510,00	114670,00	196,98	15102,3997	0,129180853	0,00090588
67	**9,57**	9,42	1530,00	117710,00	198,13	15384,9327	0,128274973	0,00073963
68	11,81	9,40	1550,00	120790,00	199,57	15698,6435	0,12753534	0,00062996
69	**8,74**	9,35	1570,00	123910,00	201,18	16029,3434	0,126905385	0,00081107
70	**9,38**	9,29	1590,00	127070,00	202,85	16398,7848	0,126094312	0,00029098
71	**7,73**	9,29	1610,00	130270,00	204,91	16769,0146	0,125803336	0,00019779
72	11,15	9,46	1630,00	133510,00	207,15	17162,3806	0,125605547	0,00046126
73	**8,51**	9,42	1650,00	136790,00	209,27	17577,3008	0,12514429	0,00007281
74	**9,30**	9,60	1670,00	140110,00	211,60	17958,9326	0,125217105	0,00001999
75	11,65	9,77	1690,00	143470,00	213,67	18314,4364	0,125197119	0,00030568
76	**8,31**	9,78	1710,00	146870,00	215,41	18657,7396	0,124891439	0,00017273
77	**8,92**	10,00	1730,00	150310,00	217,09	18975,2020	0,124718708	0,00039307
78	**8,62**	10,17	1750,00	153790,00	218,20	19230,7662	0,124325638	**0,00161252**
79	10,52	10,19	1770,00	157310,00	218,73	19574,0375	0,122713114	**0,00169671**
80	**9,06**	10,14	1790,00	160870,00	220,15	20099,9797	0,121016403	0,0091322
81	**9,90**	10,37	1810,00	164470,00	223,72	19260,3968	0,130148606	0,00090785
82	13,48	10,39	1729,00	157909,00	213,35	18404,3728	0,131056453	0,00136974
83	**6,55**	10,22	1647,00	151185,00	202,95	17525,4364	0,132426189	0,00186863
84	**7,28**	10,44	1564,00	144296,00	192,73	16671,7692	0,134294817	0,00238602
85	**8,36**	10,64	1480,00	137240,00	182,29	15799,0579	0,136680841	0,0035604
86	9,63	10,79	1395,00	130015,00	171,66	14888,5285	0,140241241	0,00496794
87	9,10	10,87	1309,00	122619,00	160,87	13982,1019	0,14520918	0,00834975
88	10,81	11,01	1222,00	115050,00	150,00	13066,3186	0,153558933	0,02328719
89	7,52	11,02	1134,00	107306,00	138,99	11996,9064	0,176846122	0,08575614
90	9,44	11,34	1045,00	99385,00	127,97	10794,7799	0,262602259	0,18500944
91	**11,08**	11,53	955,00	91285,00	116,63	11144,4004	0,077592818	0,04386085
92	10,29	11,58	864,00	83004,00	105,10	10095,0113	0,121453671	0,00030534

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Table 3 – continued from previous page

Time=x	**Cost=y**	**MEAN(y)**	**SUM(x)**	**SUM(x^2)**	**SUM(y)**	**SUM(xy)**	**a=tg(L)**	**DELTA(a)**
93	12,23	11,74	772,00	74540,00	93,51	9029,4858	0,121148327	0,00061068
94	12,67	11,67	679,00	65891,00	81,77	7937,3089	0,120537648	0,0005654
95	11,77	11,51	585,00	57055,00	70,10	6839,9016	0,119972243	0,00024737
96	12,81	11,46	490,00	48030,00	58,59	5746,5965	0,119724877	5,9011E-05
97	12,38	11,12	394,00	38814,00	47,13	4646,8024	0,119783889	0,00160666
98	**8,88**	10,70	297,00	29405,00	36,01	3568,3056	0,121390549	0,00587558
99	**9,52**	11,61	199,00	19801,00	25,31	2519,7508	0,127266131	0,00977265
100	13,70	13,70	100,00	10000,00	13,70	1370,3878	0,137038779	0,13703878