SmartResource: Utilizing Semantic Web Services to Monitor Industrial Resources

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Abstract. Currently the new management technologies for the Web content and Web services are in focus of Semantic Web research community and most of applications and correspondent ontologies are developing most rapidly there. However for industrial adoption of Semantic Web technology these efforts seem to be not enough. Initial orientation of semantic technology development to the Web digital resources results to omitting from consideration other industrial domain resources such as industrial devices, processes and even humans. In this paper some of SmartResource project results are presented, in which the meaning of the term "Semantic Web resource" is expanded and considers industrial objects (devices, machines, systems, etc) and humans (experts, maintenance workers, etc.) as resources and thus as a subject of semantic technology. Elaboration of a specific adaptation mechanism for these types of resources from their natural environment to a Semantic Web environment has been performed and now is a basis for further research and development. Heterogeneous industrial resources (files, documents, services, devices, processes, systems, human experts, etc.) are considered as web-accessible, proactive and cooperative in a sense that they are able to analyze their own state or to order such analysis from remote experts or Web-services to be aware of own condition and to plan behavior towards effective and predictive maintenance.

1 Introduction

Modern industry is looking for fast and global solutions related to Knowledge Management, Enterprise Application Integration, Electronic Commerce, Asset Management, etc. Various industrial standards, which have been created and implemented by different industrial consortiums, appear to be not sufficient for growing interoperability demands. Semantic Web is relatively new initiative within W3C standardization effort to enable machine interpretable metadata in the Web. It provides standards and tools to enable explicit semantics of various Web resources based on semantic annotations and ontologies. Integration in general is considered nowadays as a "killer application" of Semantic Web technology, which particularly can be interpreted as heterogeneous data integration, Enterprise Application Integration and Web-service integration among other interpretations. In contrast to ICT, the semantic technologies represent meanings separately from data, content, or program code, using the open standards for the Semantic

Web. They are language neutral, machine interpretable, sharable, and adaptive, allow ontology based integration of heterogeneous resources.

Trend within worldwide activities related to Semantic Web definitely shows that the technology has emerging grows of interest both academic and business during quite small time interval. The stage of the technology (according to highly qualified expert evaluations [1]) is called now "From skepticism and curiosity to enthusiasm: People are now asking "How" questions as opposed to "Why" and "What"". Moreover prognoses [1] show that "semantic solutions, services and software markets will grow rapidly topping $60B by 2010". Semantic technologies are building blocks of the next mega-wave of economic development, "distributed intelligence" and now is the time for semantic technology investments to strengthen portfolios.

However we cannot say yet that Semantic Web technology as such is mature enough to be accepted by industry in a large scale. The reasons for that we have analyzed in [2-6]. Some of standards still need modifications as well as appropriate tool support. For example, Semantic Web technology offers a Resource Description Framework (RDF) as a standard for semantic annotation of Web resources. It is expected that Web content with RDF-based metadata layer and ontological basis for it will be enough to enable interoperable and automated processing of Web data by various applications. However emerging industrial applications consider e.g. machines, processes, personnel, services for condition monitoring, remote diagnostics and maintenance, etc. to be specific classes of Web resources and thus a subject for semantic annotation. Such resources are naturally dynamic, not only from the point of view of changing values for some attributes (state of resource) but also from the point of view of changing "status-labels" (condition of the resource). Current RDF still needs temporal and contextual extensions.

Also the Semantic Web standards are not yet supporting semantic descriptions of resources with proactive behavior. However as our research shows [4], to enable effective and predictive maintenance of an industrial device in distributed and open environment, it will be necessary to have autonomous agent based monitoring over device state and condition and also support from remote diagnostics Web-Services. This means that the description of a device as a resource will require also the description of proactive behavior of autonomous condition monitoring applications (agents, services) towards effective and predictive maintenance of the device.

Another obstacle for the Semantic Web standardization effort related to the fact that many industrial companies and consortiums has realized that explicit description of semantics of data and domain modeling is necessary for application integration, however used for that their company/consortia specific standards or insufficient for global integration XML language. Even realizing that Semantic Web is providing really global standards for that, it was too late, labor and resource consuming to transform manually huge amount of metadata modeled already from a local to the global standard. One possible solution can be designing semantic adapters, which enable semiautomatic transformation from company specific standards to Semantic Web standards.

Another challenge for Semantic Web is the contradiction between the concepts of centralized and distributed ontology due to a global interoperability demand and a reality of decentralized nature of today’s global businesses. Actually the heterogeneity of ontologies is already the fact, which prevents inter-consortia interoperability. Discovering necessary resource or service in the network, which is heterogeneous on ontology level, requires specific solutions, among which semantic peer-to-peer resource discovery and context-sensitive ontologies can be an option.

Each of mentioned tasks is quite challenging itself and requires deep research with much resource before being utilized. However, taking into account the emergent industry needs for such solutions we consider reasonable to investigate the mentioned problems as a system where separate components will be considered as deep as possible with the available resources, but where the main benefit will be achieved in integration of all the components together and prototype environment implementation for such integration. In this paper we are giving the summary of research concepts and research results of the ongoing SmartResource Tekes project (2004-2006) [11], in which we try to address the above challenges. The main objective of this project is to create a global Semantic Web–based cooperative environment for automated industrial maintenance: automated condition monitoring, remote diagnostics and maintenance, sharing services between companies, automatic discovery of needed services initiated by industrial devices, interconnection of diverse systems into a next-generation interoperable industrial environment. The expected contribution of the SmartResource project together with strong research effort includes prototype implementation of distributed Semantic Web enabled maintenance management environment with complex interactions of components, which are devices, humans (experts, operators) and remote diagnostic web-services. The environment will provide automatic discovery, integration, condition monitoring, remote diagnostics, cooperation and learning capabilities of the heterogeneous resources to deal with maintenance problems. Maintenance (software) agents will be added to industrial devices, which assumed to be interconnected in decentralized P2P network and can integrate diagnostic services in order to increase the maintenance performance for each individual device. In the project, the maintenance case is expected to demonstrate the benefits and possibilities of new resource management framework and Semantic Web technology in general for Finnish industry.

Our intention is to provide tools and solutions to make heterogeneous industrial resources (files, documents, services, devices, processes, systems, human experts, etc.) web-accessible, proactive and cooperative in a sense that they will be able to analyze their state independently from other systems or to order such analysis from remote experts or Web-services to be aware of own condition and to plan behavior towards effective and predictive maintenance.

The rest of the paper is organized as follows. In Section 2 we briefly introduce the concept of a Global Understanding Environment (GUN) as an enable environment for implementing the above challenges. In Section 3 we briefly discuss two extensions of RDF, which are necessary for implementation of GUN platforms. In Section 4 we provide the description of the generalized maintenance cycle for heterogeneous resources in the GUN environment. In Section 5 we show our view concerning semantic adaptation of heterogeneous resources to GUN environment. We conclude in Section 6.

2 A Global Understanding Environment

Global Understanding Environment (GUN) [10] is a concept we use to name a Web-based resource "welfare" environment, which provides a global system for automated "care" over (industrial) Web-resources with the help of heterogeneous, proactive, intelligent and interoperable Web-services. The main players in GUN are the following resources: service consumers (or components of service consumers), service providers (or components of service providers), decision-makers (or components of decision makers). All these resources can be artificial (tangible or intangible) or natural (human or other). It is supposed that the "service consumers" will be able: (a) to proactively monitor own state over time and changing context; (b) to discover appropriate "decision makers" and order from them remote diagnostics of the own condition, and then the "decision makers" will automatically decide, which maintenance ("treatment") services are applied to that condition; (c) to discover appropriate "service providers" and order from them the required maintenance. Main layers of the GUN architecture are shown in Fig.1.

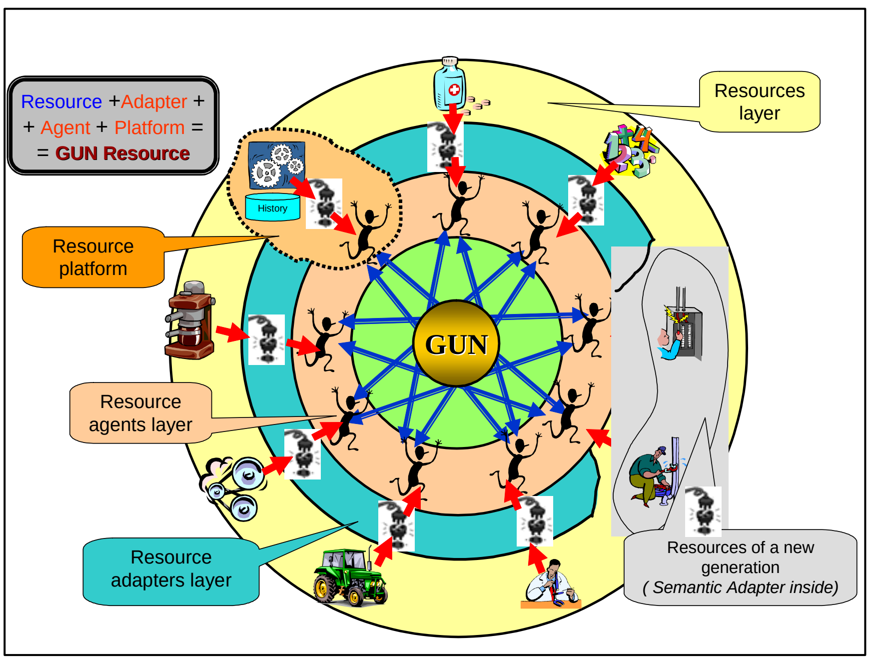


Fig. 1. Layers of the GUN architecture

Industrial resources (e.g. devices, experts, software components, etc.) can be linked to the Semantic Web-based environment via adapters (or interfaces), which include (if necessary) sensors with digital output, data structuring (e.g. XML) and semantic adapter components (XML to Semantic Web). Agents are assumed to be assigned to each resource and are able to monitor semantically reach data coming from the adapter about states of the resource, decide if more deep diagnostics of the state is needed, discover other agents in the environment, which represent "decision makers" and exchange information (agent-to-agent communication with semantically enriched content language) to get diagnoses and decide if a maintenance is needed. It is assumed that "decision making" Web-services will be implemented based on various machine learning algorithms and will be able to learn based on samples of data taken from various "service consumers" and labeled by experts. Implementation of agent technologies within GUN framework allows mobility of service components between various platforms, decentralized service discovery, FIPA communication protocols utilization, and MAS-like integration/composition of services.

3 RDF Evolution

As it was mentioned above, current W3C standard for Resource Description Framework (RDF) still needs temporal and contextual extensions. This motivates one of the objectives of SmartResource project, which is Resource State/Condition Description Framework (RSCDF), as an extension to RDF, which introduces upper-ontology for describing such characteristics of resources as states and correspondent conditions, dynamics of state changes, target conditions and historical data about previous states. These descriptions are supposed to be used by external Web-services (e.g. condition monitoring, remote diagnostics and predictive maintenance of the resources). Pilot version of RSCDF and appropriate schema is presented in [7]. The basic new components of RCSDF are: (1) the quadruple representation of RDF triplet statement (subject-predicate-object-context), where the context is represented with a container of RDF statements; (b) the definition of a property in RSCDF Schema in addition to definition of a domain and a range of the property will also include the definition of a context of the property as the set of possible properties from the context container for this property (see Fig. 2).

Another direction of the RDF development is based on a limitation that RDF is not yet suitable for semantic descriptions of resources with proactive behavior. The description of a device as a resource will require also the description of proactive behavior of autonomous condition monitoring applications (agents, services) towards effective and predictive maintenance of the device. For that we are developing within SmartResource project another extension of RDF, which is Resource Goal/Behavior Description Framework (RGBDF) to enable explicit specification of maintenance goals and possible actions towards faults monitoring, diagnostics and maintenance. Based on RSCDF and RGBDF and appropriate ontological support, we also plan to design RSCDF/RGBDF-enabled GUN platforms for smart resources (devices, Web-services and human experts) equipped by adapters and agents for proactivity, and then to apply several scenarios of communication between the platforms towards learning Web-services based on device data and expert diagnostics to enable automated diagnostics of devices by Web-services.

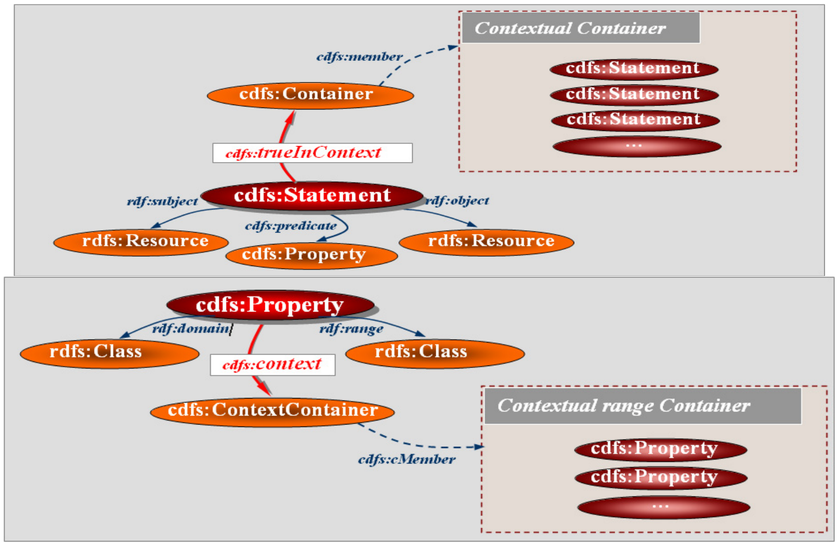


Fig. 2. Basics of the RSCDF extension in comparison to RDF

The above evolution of RDF towards two directions: RSCDF (dynamics and context awareness) and RGBDF (proactivity and self-maintenance) as the result will lead to enable standards for the GUN architecture (see Fig. 3).

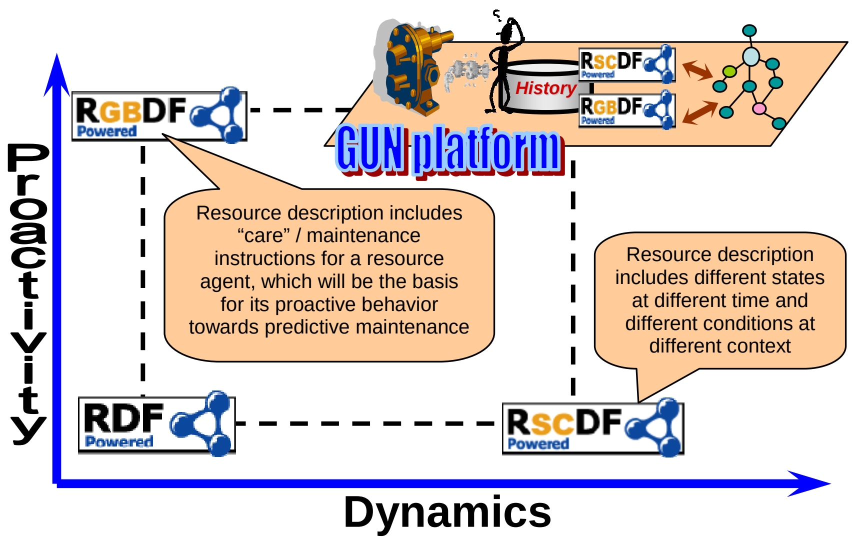


Fig. 3. RDF Evolution through dynamics and proactivity towards GUN platforms

4 SmartResource Maintenance Lifecycle

As it was mentioned above, the GUN environment meant for online condition monitoring and predictive maintenance of various industrial resources. Utilization of RSCDF and RGBDF allows creation agent-driven GUN platforms for each industrial resource where all data related to monitoring, diagnostics and maintenance of the resource will be collected in the resource history ("lifeblog") and managed by the resource agent. The basic and more or less universal maintenance lifecycle of a resource (device, expert, service, etc.) and its contribution to the resource history is shown in Fig. 4.

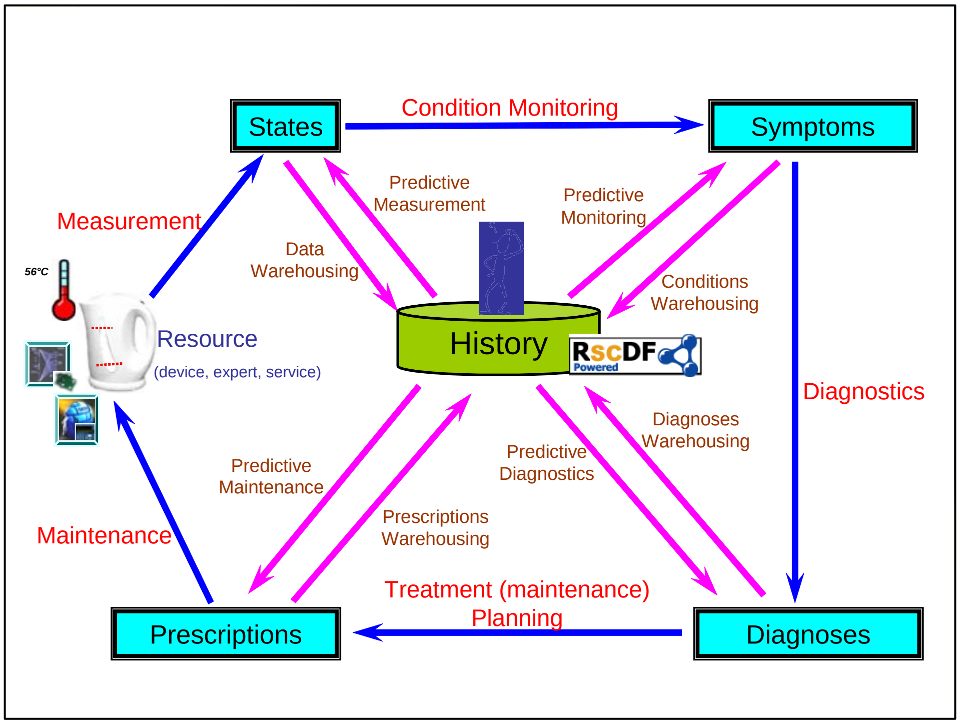
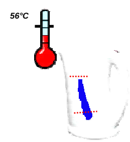
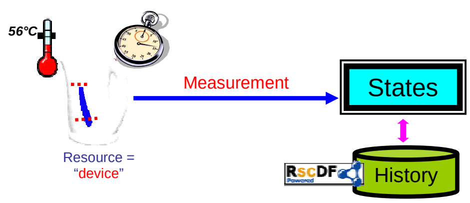
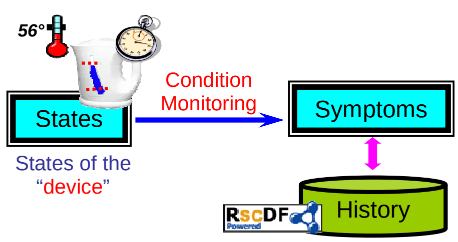
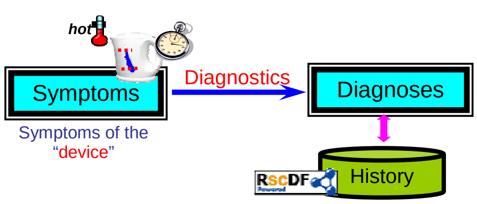


Fig. 4. SmartResource maintenance lifecycle

It is important to mention that such lifecycle has sense for really different types of resources including all GUN players: "service consumers", "service providers" and "decision makers". Table 1 illustrates the different stages of the maintenance lifecycle in relevance to different types of GUN resources: industrial devices, experts and Web-services. It can be seen that the terms "measurement", "condition monitoring", "diagnostics" and "maintenance", etc. have wider meaning than the traditional ones and can be applied to all tangible or intangible resources as the general concept of "care".

Table 1. Stages of the maintenance lifecycle for different types of resources

<table>
<tr><th>Resource</th><th>Stage of the maintenance lifecycle</th></tr>
<tr><td colspan="2">

A device</td></tr>
<tr><td>
</td><td>Measurement: At a certain time point the embedded sensors of the “device” get the set of (physical) parameters, which characterize the current state of the device. This set of parameters should be organized in a structured document “State” in RSCDF language based on “Resource Ontology”.</td></tr>
<tr><td>
</td><td>Condition Monitoring: At a certain time point the embedded “alarm system” of the “device” recognizes symptoms based on automatic monitoring of the device states against formal description of the symptoms. The set of possible symptoms for certain device and their definitions are stored in “Resource Ontology”. The result of condition monitoring should be organized in a structured document “Symptoms” in RSCDF language linked to “States”.</td></tr>
<tr><td>
</td><td>Diagnostics: At a certain time point the temporal track of states and symptoms of the “device” is sent to remote diagnostics. The external Web service or expert assigns the diagnosis to the device. The set of possible diagnoses for certain device and their definitions are stored in “Resource Ontology”. The result of diagnostics should be organized in a structured document “Diagnoses” in RSCDF language linked to “States” - ”Symptoms” description of the device.</td></tr>
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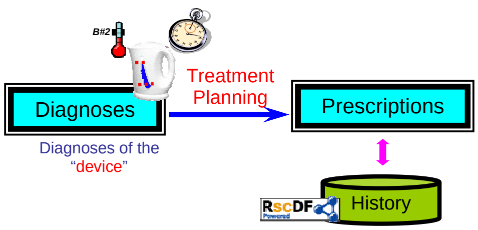
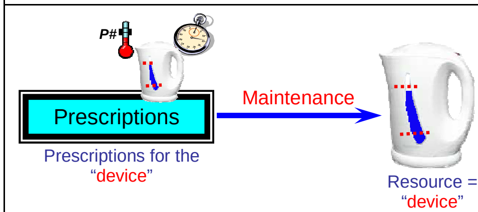


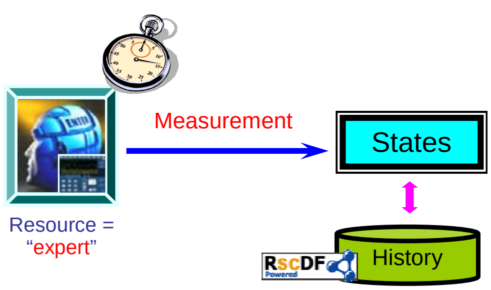
Treatment Planning: At a certain time point the temporal track of states, symptoms and diagnoses of the "device" is sent to remote service or expert for Treatment Planning. The service or expert assigns the prescriptions to the device. The set of possible prescriptions for certain device and their definitions are stored in "Resource Ontology". The result should be organized in a structured document "Prescriptions" in RSCDF language linked to device description.



Maintenance: At a certain time point the embedded effectors of the resource or/and the maintenance workers get the maintenance plan as set of prescriptions and provide the maintenance.

An expert

An expert (as well as a service) is supposed to be a decision-making resource. However due to hidden decision making mechanism an expert is most complicated resource for condition monitoring, remote diagnostics and maintenance. Talking below about the "health status" of a decision-maker we mean the actual quality of decisions it makes comparably to the expected one.



Measurement: The internal state of an expert, which characterizes its decision model, is hidden from the system and cannot be perceived by any sensors. However at any time point the resource agent is able to access the log file of the queries received and decisions made by the expert up to now. This file should be organized in a structured document "State" in RSCDF language based on "Resource Ontology".

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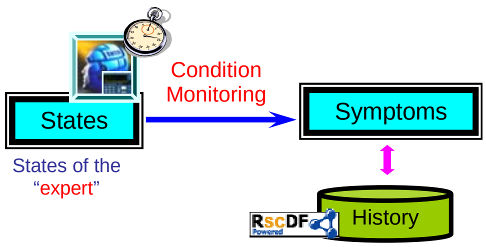

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<td>

Condition Monitoring: Any time an expert can be tested by a testing set of already labeled data from some certification service to check his/her prediction ability. Symptoms can be discovered as trends towards incorrect predictions in comparison to expected ones. The result of condition monitoring should be organized in a structured document "Symptoms" in RSCDF language linked to "States".

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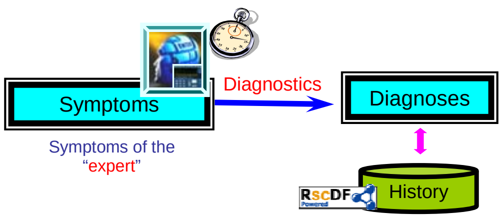

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Diagnostics: At a certain time point the temporal track of states and symptoms of the "expert" is sent to remote diagnostics. The special external Web service for decision-making diagnostics assigns the diagnosis to the expert. The set of possible "diagnoses" for experts and their definitions are stored in "Resource Ontology". The result of diagnostics should be organized in a structured document "Diagnoses" in RSCDF and linked to "States - Symptoms" description of the expert.

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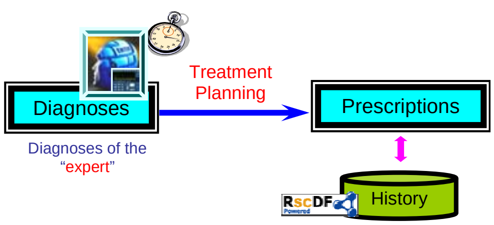

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Treatment Planning: Expert is the most problematic resource for automated maintenance. That is why only self-maintenance is supposed. At a certain time point the temporal track of states, symptoms and diagnoses of the "expert" is sent to some advanced remote service for Treatment Recommendations. The set of possible recommendations for experts and their definitions are stored in "Resource Ontology". The result should be organized in a structured document "Prescriptions" in RSCDF language linked to expert description.

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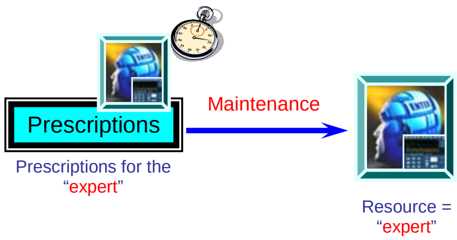
<td>
</td>
<td>Maintenance: At a certain time point the “expert” gets the recommendations and provides self-maintenance (e.g. more learning).</td>
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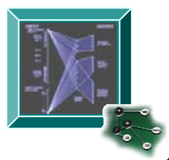
<td colspan="2">
A service</td>
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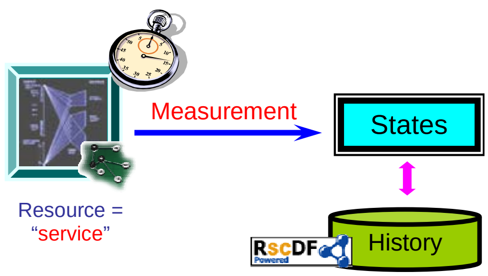
<td>
</td>
<td>Measurement: The internal state of a service, which is set of active decision-making models built based on training sets, any time can be accessed by a resource agent. This file should be organized in a structured document “State” in RSCDF language based on “Resource Ontology”.</td>
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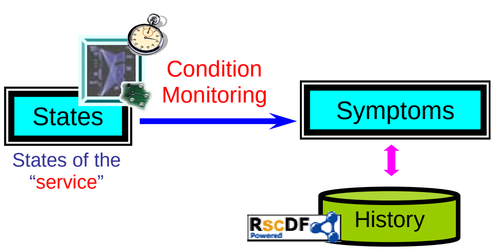
<tr>
<td>
</td>
<td>Condition Monitoring: Any time a service can be tested by a testing set of already labeled data from any device or some certification service to check his/her prediction ability. Symptoms can be discovered as trends towards incorrect predictions in comparison to expected ones. The result of condition monitoring should be organized in a structured document “Symptoms” in RSCDF language linked to “States”.</td>
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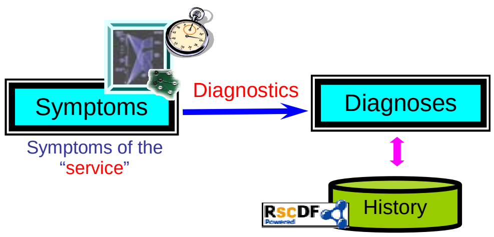
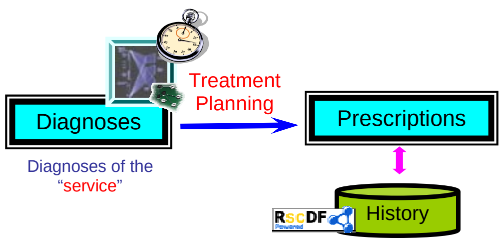
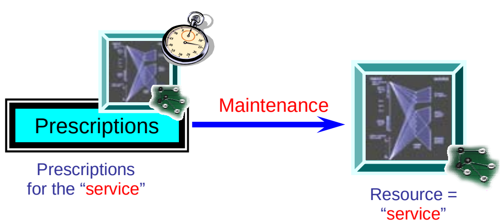
	*Diagnostics:* At a certain time point the temporal track of states and symptoms of the “service” is sent to remote diagnostics. The special external Web service for decision-making diagnostics assigns the diagnosis to the service. The set of possible “diagnoses” for services and their definitions are stored in “Resource Ontology”. The result of diagnostics should be organized in a structured document “Diagnoses” in RSCDF and linked to “States - Symptoms” description of the service.
	*Treatment Planning:* At a certain time point the temporal track of states, symptoms and diagnoses of the “service” is sent to local or remote adaptation subsystem of the service for calculating model parameters adjustments. The set of possible adjustments for different models and their definitions are stored in “Resource Ontology”. The result should be organized in a structured document “Prescriptions” in RSCDF language linked to service description.
	*Maintenance:* At a certain time point the maintenance prescriptions are processed by local adaptation subsystem of the service and appropriate parameters of the models will be updated.

5 General Adaptation Framework

One of obstacles for the Semantic Web standardization effort related to the fact that many industrial companies and consortiums has realized that explicit description of semantics of data and domain modeling is necessary for application integration, however are using for that their company/consortia specific standards or inappropriate for global integration XML language. Even realizing that Semantic Web is providing really global standards for integration, it was too late, labor and resource consuming to transform manually huge amount of metadata modeled already from a local to the global standard. One possible solution can be designing semantic adapters, which enable semiautomatic transformation from company specific standards to Semantic Web standards. This motivates another objective of SmartResource project described in this paper, which was designing General Adaptation Framework (GAF), which enables designing GUN adapters from various data formats to RSCDF and back. The pilot version of the task is presented in [8] and moreover the samples of adapters for three different samples of heterogeneous resources (device data, expert interface, Web-Service) have been developed [9].

There is a variety of resources intended for integration into a common GUN environment. For more efficient analysis, all the resources were divided into three basic classes: devices, services and humans. These resources represent real world objects, which should interact in some way. The adaptation of such heterogeneous resources in common sense lies in providing an environment, which would allow them to communicate in a unified way via standard protocol. Semantic transformation assumes also an existence of appropriate tools for specification of mapping rules. Ontology engineer plays key role in the scenario of establishment mapping rules.

In the SmartResource project, two-stage transformation (syntactic + semantic) from XML to RSCDF was performed within a complex prototype system [8]. This approach was tested on the adaptation of condition monitoring data for a paper machine, generated by software simulator. The initial device data was generated in XML format and the task was to transform it into the RSCDF format. The prototype system is based on J2EE platform and utilizes JBoss application server for the implementation. The pilot implementation involves JSP, Servlets and EJB techniques and uses MVC pattern. Resource adapters are deployed as enterprise JavaBeans on the application server. The control servlet gets requests from the clients and redirects them to appropriate adapters. Then different java server pages are generated as response for the client. According to the approach of two-stage transformation, canonical XML schema was designed and several different XML schemata were used for testing the phase of syntactic (XML to XML) transformation. To perform syntactic transformation to the common XML canonical form, for each of the three XML schemata corresponding XSLT files were generated using MapForce trial version. All classes, which constitute the semantic adapter, are packaged into one template package. Logically the classes could be divided into four parts. The first part of classes corresponds to the logic, which reflects the structure of the RSCDF document, the second reflects the structure of the original XML document and encapsulates the logic of processing this structure, the third represents the engine which plays the role of RSCDF document builder, and fourth is the set of reusable utilities for DOM processing. For implementation of the second phase – canonical-to-canonical semantic transformation (XML^0-RSCDF), method based on ontology of templates was applied. During the analysis of RSCDF document, reusable templates can be extracted. For instance, from the RSCDF document two types of templates were distinguished – structural templates (or pattern) and tag templates. Structural templates reflect the structure of the RSCDF graph according to its schema. Depending on the canonical XML document, some branches of the RSCDF graph have the same structure and could be cloned while processing. On the other hand, the tag templates correspond to the RSCDF classes. In fact, tag template represents some classes from RSCDF schema. Tag template has a body and a changing part, which can have different types:

- link to other tag template;
- link to XML data;
- link to ontology data;
- generated value.

Fig. 5 represents an example of a tag template. The variable X_n is obtained during a run-time either from ontology or from the XML file, or generated by the generator. The variable Y_n is obtained from the identifier of from other template, thus the RSCDF tag, depends on the other RSCDF tags will be generated after them. In this way the adapter recursively calls methods of template creation until it will reach the leaf nodes.

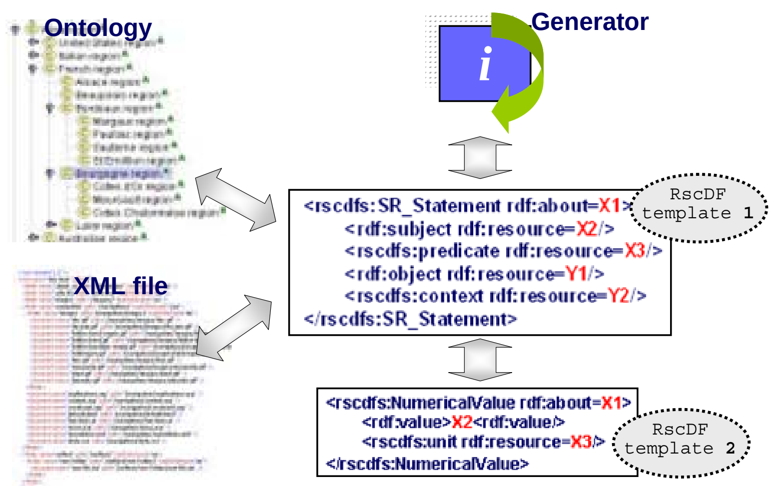


Fig. 5. Illustration of a semantic adaptation/transformation stage within GAF

6 Conclusion

The designed GUN, GAF, RSCDF, and RGBDF concepts and their implementation due to their original universality are supposed to find many applications in various domains, in which distributed heterogeneous resources exist and problems of interoperability and integration into dynamic open environments are emerging. Besides its main application area – integration of industrial assets – more than once the project results were analyzed in a context of such application areas as Wellness (integration of human patients with embedded medical sensors, doctors-experts and medical web services), Ecology (natural environment with sensors, human experts in an environmental monitoring and Web

Services for environmental diagnostics and prediction), Organizational management (staff/students with corresponding monitored organizational data, managers and automated systems for organizational diagnostics and management), Video Security Systems (objects under observation, monitoring experts and video/image automated processing tools), and many other.

Acknowledgement

We appreciate support from TEKES for the SmartResource project as well as contributions from the partner companies: TeliaSonera, Metso Automation, TietoEnator and Jyvaskyla Science Park.

References

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