A Flexible QoS Measurement Platform for Service-based Systems

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***Abstract*—The transfer of historically grown monolithic software architectures into modern service-oriented architectures creates a lot of loose coupling points. This can lead to an unforeseen system behavior and can significantly impede those continuous modernization processes, since it is not clear where bottlenecks in a system arise. It is therefore necessary to monitor such modernization processes with an adaptive monitoring concept to be able to correctly record and interpret unpredictable system dynamics. This contribution presents a generic QoS measurement framework for service-based systems. The framework consists of an XML-based specification for the measurement to be performed – the Information Model (IM) – and the QoS System, which provides an execution platform for the IM. The framework will be applied to a standard business process of the German insurance industry, and the concepts of the IM and their mapping to artifacts of the QoS System will be presented. Furthermore, design and implementation of the QoS System's parser and generator module and the generated artifacts are explained in detail, e.g., event model, agents, measurement module and analyzer module.**

Keywords–Quality of Service (QoS); Indicator Measurement; XML-Model; Service-orientation; SOA; Complex Event Processing (CEP)

I. Introduction

The background of this work is a cooperation with a partner from the German insurance industry and its IT-Architecture department. Many IT-driven and data-driven companies face the challenge of continually modernizing their infrastructure, technologies, systems and processes. The insurance industry in particular is characterized by the fact that extensive digitization of processes took place very early. This was done well before researching modern service-based approaches, such as 'traditional' service-oriented architectures (SOA) or even microservices (MS) and without the use of distributed infrastructures such as cloud computing. Historically grown software monoliths were state of the art. The modernization of such monoliths in the direction of service-based architectures is a major challenge. This conversion process is the main motivation of this work and will be explained in more detail below.

A. Motivation

Systems cannot be abruptly switched off and replaced by new architectures but must be continuously transformed into modern architectural forms. In this continuous modernization process, monolithic structures are broken down and distributed into services. This gives companies more agility and adaptability to changing business requirements. However, a decentralized and service-oriented system architecture is usually quite fine-granular and loosely coupled. Generally, this provokes an unpredictable dynamic system behavior. This also applies to our partner in the insurance industry. In order to remain competitive, the insurance industry has to respond quickly to customer information portals, such as check24.de, where different insurance companies competitively can offer, e.g., car insurances. This scenario motivates the need for a holistic measurement concept and defines the general application scenario of this work.

So, there is a fundamental need for information about the system behavior. Relevant information is collected in the 'Information Product', which represents the output of the 'Core Measurement Process' (cf. Fig. 1). The 'Information Need' provides the input for the subprocess 'Plan the Measurement Process', the subprocess 'Perform the Measurement Process' generates the Information Product'. The process goal is to satisfy the 'Information Need'.

Nowadays it is normal that customers are demanding online services unpredictably and with high volatility. These volatile demands may lead to bottlenecks in distributed service-oriented architectures. Therefore, a reliable measurement of the whole system behavior is necessary in order to eliminate any bottlenecks. Such a measurement concept and its prototypical implementation are the core contributions of our work.

B. Contribution

In order to monitor individual system components with respect to time behavior, fixed time limits have so far been used. These fixed time limits are often used in historically grown software systems of the German insurance industry. If a system component (service) could not respond within these time limits, this was interpreted as a bad quality feature. However, with these static limits, a dynamic system behavior can be poorly monitored and interpreted. The challenge is to determine, when dynamic systems are overloaded. In this respect, a partner company of the insurance industry demands to integrate a metric, which could replace their static time limits in the future with a more dynamic metric. The general requirements lead to the following questions:

- How could static rules and timeouts be supplemented by a dynamic measurement metric?
- How could the measuring system be built on existing XML-Standards?

In previous work [1] [2] [3], we have already developed a framework for dynamically measuring the service response time as a Quality of Service (QoS) Parameter within service-oriented architectures. Especially in [1] we provided initial implementation details of the dynamic measuring system. Our measuring system considers existing XML standards and can flexibly record the load behavior of a software system. This measuring system should measure the response time as a particular QoS parameter as an example. The measuring system should be able to consider both dynamic limits as well as static limits (optional). Normally, only the dynamic limits should be considered. But, if a service exceeds a fixed limit of, e.g., 5 seconds, then this should also be recognized. Another requirement is that the measuring system should 'inject' measurement agents into a software system as flexible and automated as possible.

As a significant extension to our previous articles, here we contribute in more details in important areas of our work, namely in Section IV and in Section V we show:

- a detailed design model of our QoS generator including an in depth look at its general parser classes as well as its derived measure parser classes,
- our in-memory model for our base XML model,
- much more implementation details on the measurement module and our event model (EventModel),
- and a comprehensive summary of the overall QoS platform based on our previous articles.

In total, our additional contributions provide a much deeper look at our work with respect to design and implementation of our overall system.

The remainder of this article is organized as follows: In Section II, related work concerning the topic of measurement models of service-based systems is explained. The measurement process with its core concepts and the information model are described in Section III and more implementation details in Section IV. Some mathematical equation explains the general measurement concept. After clarifying the general measurement plan, Section VI shows how the planned measurement concept can be applied for detecting the so called 'Spikes', situations of high system-loads. The final Section VII will summarize this work. The different advantages and disadvantages of the described measurement model will be discussed. Also, an outlook to future work will show how the results of this work will be used in upcoming work in Section VII.

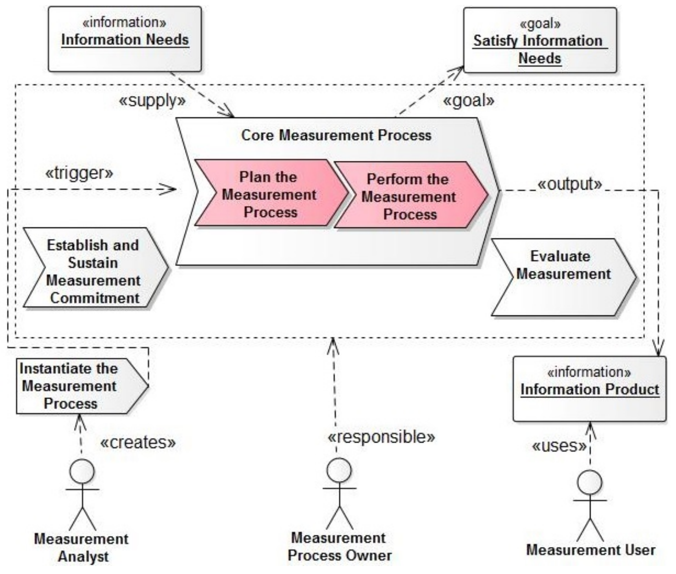

«information» Information Needs
«goal» Satisfy Information Needs
«supply»
«goal»
Core Measurement Process
«trigger»
Plan the Measurement Process
Perform the Measurement Process
«output»
Establish and Sustain Measurement Commitment
Evaluate Measurement
Instantiate the Measurement Process
«information» Information Product
«creates»
«responsible»
«uses»
Measurement Analyst
Measurement Process Owner
Measurement User

Figure 1. The Core Measurement Process

II. Prior and Related Work

In prior work, we already discussed several aspects of the combination of SOA, Business Process Management (BPM), Workflow Management Systems (WfMS), Business Rules Management (BRM), and Business Activity Monitoring (BAM) [4][5][6] as well as Distributed Event Monitoring and Distributed Event-Condition-Action (ECA) rule processing [7][8]. Building on this experience, we now address the area of QoS measurement for combined BRM, BPM, and SOA environments, mainly but not limited to, within the (German) insurance domain.

Work related to our research falls into several categories. We will discuss these categories in sequence.

General work on (event) monitoring has a long history (cf. [9][10] or the ACM DEBS conference series for overviews). Monitoring techniques in such (distributed) event-based systems are well understood, thus such work can well contribute general monitoring principles to the work presented here. This also includes commercial solutions, such as the Dynatrace [11] system or open source monitoring software like, for example, the NAGIOS [12] solution. In these systems there is generally no focus on QoS measurement within SOAs. Also, they usually do not take application domain specific requirements into account (as we do with the insurance domain).

Active Database Management Systems (ADBMS) offer some elements for use in our work (see [13][14] for overviews). Event monitoring techniques in ADBMSs are partially useful, but concentrate mostly on monitoring ADBMS internal events, and tend to neglect external and heterogeneous event sources. A major contribution of ADBMSs is their very well defined and proven semantics for definition and execution of Event-Condition-Action (ECA) rules. This leads to general classifications for parameters and options in ADBMS core functionality [14]. We may capture options that are relevant to event monitoring within parts of our general event model. QoS aspects are handled within ADBMS, for example, within the context of database transactions. Since ADBMSs mostly do not concentrate on heterogeneity (and distribution), let alone SOAs, our research work extends into such directions.

The closest relationship to our research is the work, which directly combines the aspects QoS and SOA. As many as 2002 several articles fall into this category. However, in almost all known articles the SOA part focuses on WS-* technologies. This is in contrast to our work, which takes the operational environment of our insurance industry partners into account.

Examples of Webservice (WS-*) related QoS work include QoS-based dynamic service bind [15][16], related WS-* standards such as WS-Policy [17], and general research questions for QoS in SOA environments [18]. Design aspects and models for QoS and SOA are, for example, addressed in [15][19][20][21][22]. As for WS-* Web services, we also take XML as foundational modelling language for our work. SOA performance including QoS is discussed in articles [23], and monitoring for SOA in articles such as [24][25][26][27].

Uniqueness of our research is that it takes all the above-mentioned aspects into account. We provide a detailed XML based measurement model, as well as a generator-supported, generic SOA monitoring framework. All of it takes especially the operational environment of our insurance industry partners into account, which is a large-scale SOA, but only partially WS-* technology based. This makes our work highly relevant in practice. Even more, since we base our modelling on standards, which are highly relevant for German insurance businesses (cf. VAA [28], ISO/IEC 9126 [29][30]), our work is of a quite general nature and thus can be transferable (at least within the insurance domain).

III. Plan the Measurement Process

The Core Measurement Process can be divided into two parts. First of all, the planning of the measurements takes place, which determines how the Information Need can be answered. In the second part, the planned methods of measurement will be implemented.

A. Core Concepts of the Abstract Information Model

To measure the response time behavior of a dynamic system, the definition of static response time limits is often not sufficient. When a system component (service) is deployed in a different hardware environment or in a different cloud environment, this will affect the response time of this system component. Static limits would have to be adapted manually to the new execution environment of the services. Furthermore, individual services share hardware resources with many other services. This can lead to an unpredictable system behavior, especially in complex business processes. Therefore, static limits are not sufficient, but a more flexible solution is required. The approach of this work is the investigation of a measurement concept, which is more flexible and based on the standard deviation of system load of a specifiable measuring period.

The insurance industry in particular is characterized by strong seasonal fluctuations. Towards the end of the year, many customers switch their insurance contracts and are provoking high system loads. In times of such high system loads, the mentioned static limits would be continuously exceeding. The information would be lost at the time when high loads are peaking in such a strongly demanded period. It is important to know when the current system is heavily loaded. Knowledge about this information represents the so-called Information Need (Fig. 1) of our partner from the insurance industry.

To answer this Information Need, the average response time behavior μ of a system component is firstly computed for a freely definable time period. For example, on the basis of the last $n = 500$ measured response times of the services. On the basis of this, the standard deviation is calculated within this period, shown in (1):

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n-1}} \qquad (1)$$

After this calculation, the current response time r of a service is set in relation to this standard deviation s. If the response time r of a currently requested service exceeds this standard deviation by the factor of 2x then this is considered as an overload situation:

$$\text{Spike detected: } r > \mu + 2 * s \qquad (2)$$

This calculation takes place continuously. As soon as a service is requested again, its response time is recorded and set in relation to the last one (e.g., the last 500 measured values). It is therefore a continuous and rolling measurement. This measuring system can be applied both for very slow system components on a daily base and also to very fine-granular services that interact in the range of milliseconds.

The important fact is that the standard deviation is calculated continuously over a defined time period, and the current response time of a service is set in relation to this. Therefore, the measuring system adapts to seasonal fluctuations, and it is possible to identify, which user requests (service calls) are currently very critical with respect to the general response time behavior, independently of the prevailing current load situation. This allows fast and more precise analysis of systems and less misinterpretation due to incorrectly set static time limits. This dynamic measurement concept can give a more reliable answer to the Information Need of our project partners.

B. Mapping of the Concepts of the Information Model

In this subsection, a QoS Information Model (QoS IM) is presented in a more detailed manner. The QoS IM is a XML document that includes values of the concepts for a given application scenario. The concepts and their relationships with each other are introduced in [3]). Here we focus on the implementation of the concepts.

The QoS IM is created during the planning stage when executing the subprocess 'Plan the Measurement Process', cf. Fig. 1). The XML document is used to automatically generate the QoS Platform's artefacts. The measurements results (i.e., the output of 'Perform the Measurement Process') are produced by the QoS Platform. They are persistently stored for subsequent analysis, typically in a database system.

We opted for XML as universally accepted standard which is highly flexible, platform and vendor independent and supported by a wide variety of tools. Furthermore, XML comes with a standardized schema definition language, namely XML Schema. This is a big advantage against other languages such as JSON for example.

In the QoS IM, we specify the measurement concepts for the check24.com scenario, or the Proposal Service respectively. Due to space limitation, the discussion is restricted to the following concepts (cf. [3]):

- Measurable Concept – outlines in an abstract way, how the Quality Attributes are determined to satisfy the Information Need,
- Base Measure – specifies by its Measurement Method how the value of Quality Attribute is to be determined,
- Derived Measure – uses one or more Base Measures or other Derived Measures, whilst the Measurement Function specifies the calculation method and thus the combination of the Measures used,
- Indicator – is a qualitative evaluation of Quality Attributes, which directly addresses the issue raised in the Information Needs.

The Measurable Concept `Processing_Time` references

```
1  <MeasurableConcept Name="Processing_Time">
2   <SubCharacteristic Name="Performance"/>
3   <BaseMeasure Name="t_inst"/>
4   <BaseMeasure Name="t_term"/>
5   <DerivedMeasure Name="t_proc"/>
6   <DerivedMeasure Name="Count_StdDev_Calls"⤸
       />
7   <DerivedMeasure Name="Count_Calls"/>
8   <DerivedMeasure Name="⤸
       StdDev_Calls_Percentage"/>
9   <DerivedMeasure Name="Failed_Calls"/>
10 </MeasurableConcept>
```

Listing 1. Calculation of the Proposal Service's Processing Time

```
1  <BaseMeasure Name="t_inst">
2   <Scale TypeOfScale="Rational" Type="R"/>
3   <Attribute ServiceID="BAS_001" ⤸
       AttributeName="ServiceCallID"/>
4   <MeasurementMethod Name="⤸
       recordTimeOfServiceCall">
5   <Implementation>
6    <Agent Class="ServiceAgent">
7    <Method>
8    <Attribute Name="ServiceCallID" Type="⤸
        xs:integer"/>
9    <Attribute Name="Time" Type="xs:string" ⤸
        Computed="time"/>
10   <Event Name="ServiceStartEvent"/>
11   </Method>
12   </Agent>
13  </Implementation>
14  </MeasurementMethod>
15 </BaseMeasure>
```

Listing 2. Start Time of a Proposal Service Call

by name all necessary Base and Derived Measures (cf. listing 1).

The definition of the Base Measure `t_inst` is shown in listing 2. Its task is to capture the start time of a Proposal Service call (by a user request). The element `Attribute` specifies the attribute of the Proposal Service to be observed. The element hierarchy of `Implementation` defines all platform specific information to automatically generate all artefacts needed for the measurement, i.e., the agent class with attributes and the measurement method (cf. subsection IV).

The Derived Measure `Count_StdDev_Calls` presented in listing 3 calculates the number of Proposal Service calls that exceeds twice the standard deviation (cf. subsection IV, (2)).

`Count_StdDev_Calls` is based on a different Derived Measure, namely `t_proc`, which computes the processing time of a Proposal Service call (cf. `Uses` element, line 2). The element `Implementation` comprises of all information that is used to generate the analyzer class (cf. subsection IV). The analyzer executes the SQL Select statement (cf. lines 8 to 16), which represents the content of the element `Plain`. This is done by the measurement function `calculateNumberOfCallsAboveSTDDEV`, shown in line 3, whenever an event `ServiceDurationEvent` has been fired (cf. line 6).

```
1  <DerivedMeasure Name="Count_StdDev_Calls">
2   <Uses><DerivedMeasure Name="t_proc"/></⤸
       Uses>
3   <MeasurementFunction Name="⤸
       calculateNumberOfCallsAboveSTDDEV">
4    <Implementation>
5     <Analyzer>
6      <Query Class="ServiceDuration" Type="⤸
         xs:long">
7       <Plain>
8       SELECT COUNT(*) FROM serviceduration
9       WHERE
10      TINTS > TIME_SECS(DATEADD('DAY',
11                -30,NOW()))
12      AND TPROC > (SELECT AVG(TPROC)
13                    + (2 * STDDEV(⤸
                         TPROC))
14      FROM serviceduration
15        WHERE TINTS > TIME_SECS(
16            DATEADD('DAY',-30, NOW())))
17      </Plain>
18     </Query>
19    </Analyzer>
20   </Implementation>
21  </MeasurementFunction>
22  <UnitOfMeasurement>ms</UnitOfMeasurement>
23  <TargetValue>1</TargetValue>
24 </DerivedMeasure>
```

Listing 3. Compute the Number of Proposal Service Calls that Exceed Twice the Standard Deviation

Finally, the Indicator `SLoT_proc`, shown in listing 4, evaluates the adequacy of the processing time of all Proposal Service calls.

`SLoT_proc` is based on two different Derived Measures, namely `StdDev_Calls_Percentage`, and `Failed_Calls` respectively (cf. `Uses` element, lines 4 to 7). The first measure, `StdDev_Calls_Percentage`, takes `Count_StdDev_Calls` and `Count_Calls` and does some basic arithmetic computation.

The element `DecisionCriteria` specifies a decision table, so that a value, computed by the Derived Measures, can be mapped to the entry of the given nominal scale (i.e., high, medium, low). The element `Implementation` comprises all information to generate the analyzer class (cf. subsection IV), which implements the decision table and the mapping.

IV. Design of the QoS Generator

The initial phases of applying an IM (cf. Fig. 2) were shown in Section III-B. This section discusses subsequent phases (especially about generators, artefacts, etc.) in detail. Please note, although its concepts are transferable, our QoS Generator aims not to be of generic nature but is tailored specifically towards our XML based IM and needs of our partner companies. Furthermore, the generated artefacts are specific to our current QoS Platform. Both offer the flexibility to tailor each part to the specific needs of each of our partner companies.

Several different artefacts have to be generated to apply a specific IM. The basic design of the QoS Generator is given in

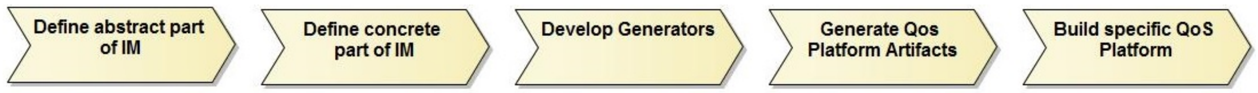

Define abstract part of IM
Define concrete part of IM
Develop Generators
Generate Qos Platform Artifacts
Build specific QoS Platform

Figure 2. Phase from IM to QoS System.

```
<Indicator Name="SLoT_proc">
 <AnalysisModel Name="⤸
     computeAdequacyOfProcessingTime">
 <Scale TypeOfScale="Nominal" Type=.../>
 <Uses>
 <DerivedMeasure Name="⤸
     StdDev_Calls_Percentage"/>
 <DerivedMeasure Name="Failed_Calls"/>
 </Uses>
 <DecisionCriteria>
 <Implementation>
  <Analyzer>
  <IndicatorTable Class="⤸
      IndicatorController" Type="HMN">
  <IndicatorEntry>
   <Input>devPercentageCount < 5 && ⤸
       badCount == 0</Input>
   <Result>low</Result>
  </IndicatorEntry>
  <IndicatorEntry>
   <Input>devPercentageCount >= 5 && ⤸
       badCount == 0</Input>
   <Result>mittel</Result>
  </IndicatorEntry>
  <IndicatorEntry>
   <Input></Input>
   <Result>hoch</Result>
  </IndicatorEntry>
  </IndicatorTable>
  </Analyzer>
 </Implementation>
 </DecisionCriteria>
 </AnalysisModel>
</Indicator>
```

Listing 4. Compute the Adequacy of the Processing Time of all Proposal Service Calls

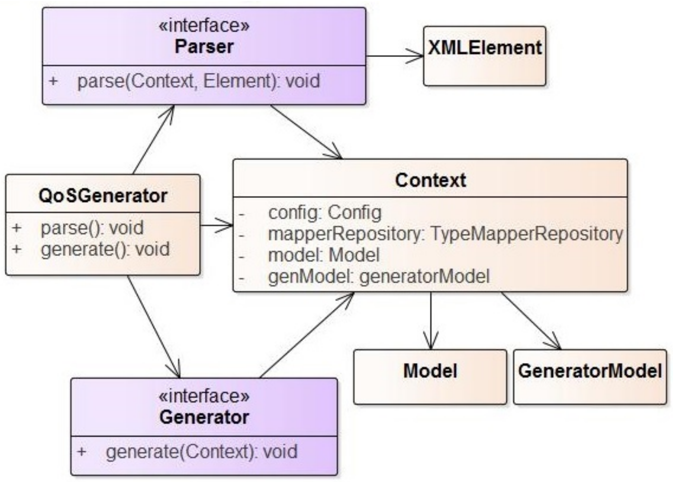


Figure 3. Design of the QoS Generator.

Fig. 3. In general, it consists of a parser step and a generator step. Purpose of the first step (parser) is to build an optimized in-memory model of an given IM. A specific parser gets the XML root element and parses an abstract or concrete part. The second step (generator) consists of different generators reading the in-memory model to generate specific artefacts (e.g., classes, rule files, etc.). This distinction is necessary for the desired flexibility of the QoS Platform itself and follows the single responsibility principle. Further explanations of the in-memory model, the QoS-Generator parsers and generators are given in this section. At the end a brief overview of the execution of these components is described.

a) In-memory model: The optimized model is part of the `Context` class. Furthermore, it contains general configuration information, a `TypeMapperRepository` and a `GeneratorModel`. The TypeMapperRepository contains mappers to translate XML Schema types into implementation specific types (e.g., SQL, Java, etc.). The GeneratorModel contains specific information (package definitions, etc.) for the generators and is shared between them by the Context class.

An overview of the in-memory model is given in Fig. 6. The model contains class representations of all IM concepts like Services or Events. A major part is the representation of Measure concepts which is combined in the MeasurableConcept class. It contains references to BaseMeasure and DerivedMeasure classes. Also it contains helper methods to access these (e.g., based on the name) or `Measurement Methods` and `Measurement Functions` directly. Each IM concept class contains all attributes and elements as shown in the XML. Instead of accessing the XML directly, this approach offers helper methods and direct references to other parts of the IM. Where possible attributes are not represented in simple String values but instead by more specialized types like enums or else. Further optimizations can be implemented upon this basis.

b) QoS-IM parsers: A brief overview of all parsers is given in Fig. 4. As stated before each IM concept has a corresponding parser class. The Context and XML root element is given to each parser. The QoS Generator defines the order in which these parsers have to be executed. Basis for all parsers is the minimal Parser interface which defines only the `parser(...)` method. Thus, all parsers can be implemented completely independent, which allows to implement more complex optimizations or more in-depth evaluations of an IM.

An overview of the `DerivedMeasureParser` class and its basic dependencies is given in Fig. 5. While the Context contains the Model (and thus all previously parsed elements), the XML Element class usually contains the Information Need concept of the given QoS IM. Parsers are divided into classes for abstract and concrete parts. As shown before the abstract part is parsed first and thus this parser calls their concrete part parsers. In this case the concrete parts are parsed by the `DerivedMeasureParser` and `MeasurementFunctionParser`. The latter one handles all needed subsequent parsers calls. A Derived Measure can

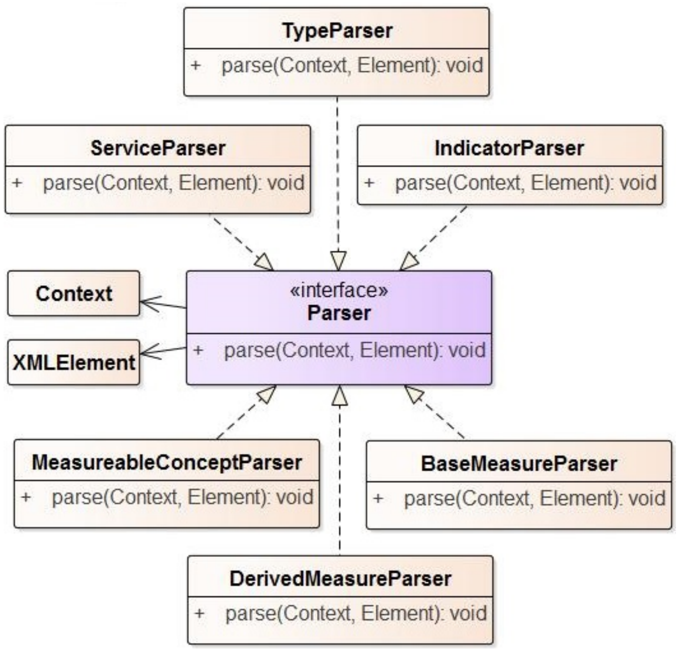

TypeParser
+ parse(Context, Element): void
ServiceParser
+ parse(Context, Element): void
IndicatorParser
+ parse(Context, Element): void
Context
«interface»
Parser
+ parse(Context, Element): void
XMLElement
MeasureableConceptParser
+ parse(Context, Element): void
BaseMeasureParser
+ parse(Context, Element): void
DerivedMeasureParser
+ parse(Context, Element): void

Figure 4. Overview of the parser classes.

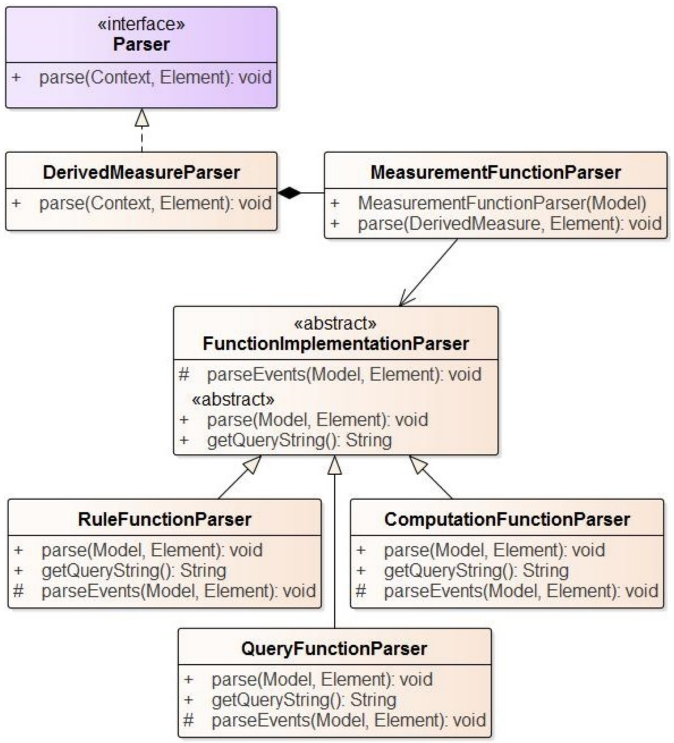

«interface»
Parser
+ parse(Context, Element): void
DerivedMeasureParser
+ parse(Context, Element): void
MeasurementFunctionParser
+ MeasurementFunctionParser(Model)
+ parse(DerivedMeasure, Element): void
«abstract»
FunctionImplementationParser
# parseEvents(Model, Element): void
«abstract»
+ parse(Model, Element): void
+ getQueryString(): String
RuleFunctionParser
+ parse(Model, Element): void
+ getQueryString(): String
# parseEvents(Model, Element): void
ComputationFunctionParser
+ parse(Model, Element): void
+ getQueryString(): String
# parseEvents(Model, Element): void
QueryFunctionParser
+ parse(Model, Element): void
+ getQueryString(): String
# parseEvents(Model, Element): void

Figure 5. Overview of the Derived Measure parser class.

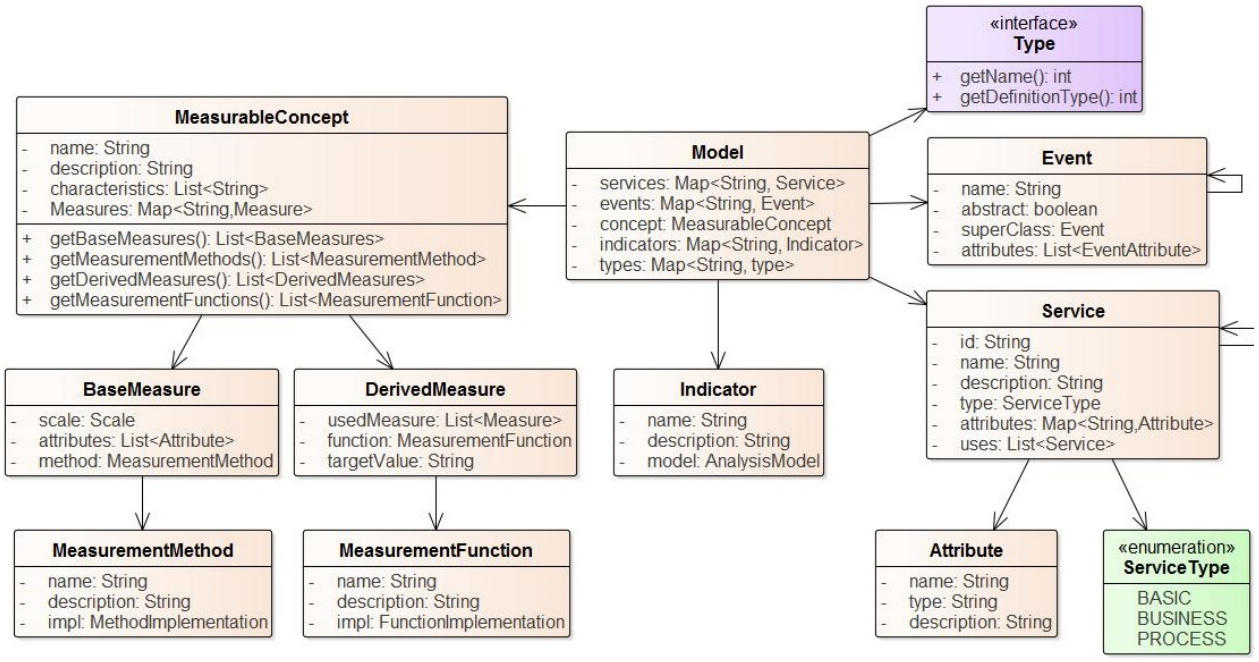
contain a concrete part for rule-, query- or computation-functions. To determine these each parser defines a unique XML query string based on XPath.

c) QoS-Platform generators: While the parsers are tailored towards the IM model, the generators are tailored towards implementation artefacts or QoS Platform concepts. There are generators for the QoS Agent, Indicator implementation or complex event processing (CEP) rules. An overview of the different generators is given in Fig. 7. Each generator has a specific task concluding in the generation of certain artefacts. This further supports the flexibility of the QoS Platform itself. All generators implement the `Generator` interface and thus get the Context and GeneratorModel objects. Purpose of the latter is to share certain information between different generator in a defined and consistent way. In this case only three Java package definitions are shared. The Velocity template engine (cf. [31]) was chosen because of its ease of use and simplicity. It offers access to Java objects through a template language which can be used to generate HTML or Java code. To further simplify the generator implementation several abstract base classes were developed. While the `VelocityShellGenerator` only offers basic initializations, the `VelocityGenerator` prepares nearly everything to generate artefacts. Only the file name and the specific arguments for the template have to be provided. This differentiation was needed because the QueryGenerator creates several different artefact types (e.g., SQL files, Java classes) and thus uses several different templates. The other generators only have to use one template in the moment.

A detailed view of the `QueryGenerator` is given in Fig. 8. Different SQL files and Java query classes are generated by this generator. To initialize several Velocity Template classes, direct access to the VelocityEngine is needed. Several `TypeMapper` classes are retrieved from the TypeMapperRepository. Actual generation is delegated to several `generate...` methods. Each one builds the corresponding `VelocityContext` and calls the `writeToFile(...)` method to render the template. The VelocityContext is basically a key value map which can be accessed inside of a template.

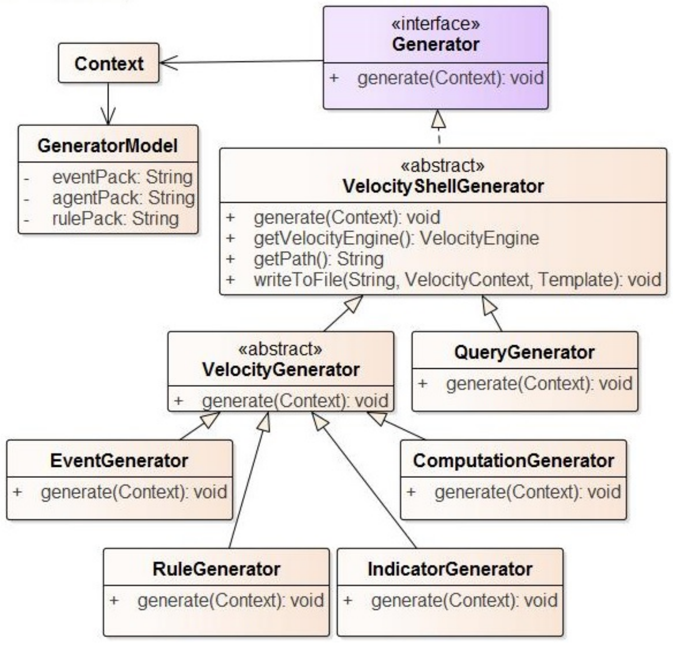
d) QoS-Generator execution: An example of a QoS Generator parser execution is given in Fig. 9. After the IM is parsed by a SAX compatible parser, the XMLElements are given to each one separately. Every IM concept is parsed from the abstract part to the concrete part. In this case, the `Uses`, `UnitOfMeasurement` and `TargetValue` elements are parsed by the `DerivedMeasureParser`. After the `MeasurementFunctionParser` parses the relevant attributes (e.g., the Name attribute) and creates the corresponding Model class, it determines which type of implementation it contains. This is done by a query string that each `FunctionImplementationParser` offers. In this specific case, the `MeasurementFunction` contains a query and thus the `QueryFunctionParser` is executed. Each query implementation uses certain events to execute a query. To parse these, the inherited method `parseEvents` is given the Event elements.

A brief overview of the a query generator execution is given in Fig. 10. The initialization step of each generator consists of initializing the needed Velocity Templates. Each template represents a certain type of file that



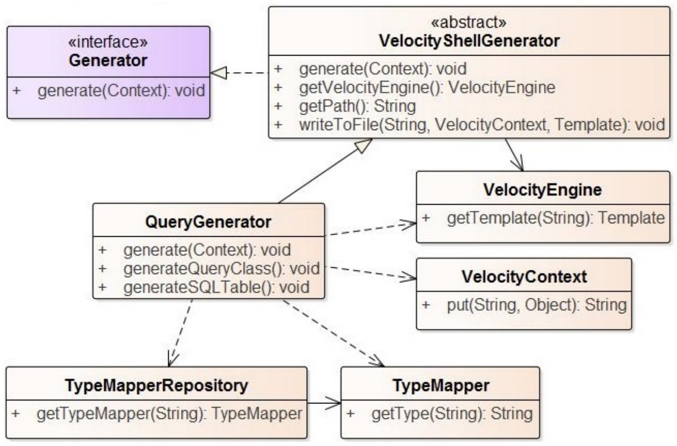
«interface» Type
+ getName(): int
+ getDefinitionType(): int
MeasurableConcept
- name: String
- description: String
- characteristics: List<String>
- Measures: Map<String,Measure>
+ getBaseMeasures(): List<BaseMeasures>
+ getMeasurementMethods(): List<MeasurementMethod>
+ getDerivedMeasures(): List<DerivedMeasures>
+ getMeasurementFunctions(): List<MeasurementFunction>
Model
- services: Map<String, Service>
- events: Map<String, Event>
- concept: MeasurableConcept
- indicators: Map<String, Indicator>
- types: Map<String, type>
Event
- name: String
- abstract: boolean
- superClass: Event
- attributes: List<EventAttribute>
Service
- id: String
- name: String
- description: String
- type: ServiceType
- attributes: Map<String,Attribute>
- uses: List<Service>
BaseMeasure
- scale: Scale
- attributes: List<Attribute>
- method: MeasurementMethod
DerivedMeasure
- usedMeasure: List<Measure>
- function: MeasurementFunction
- targetValue: String
Indicator
- name: String
- description: String
- model: AnalysisModel
MeasurementMethod
- name: String
- description: String
- impl: MethodImplementation
MeasurementFunction
- name: String
- description: String
- impl: FunctionImplementation
Attribute
- name: String
- type: String
- description: String
«enumeration» ServiceType
BASIC
BUSINESS
PROCESS

Figure 6. Overview of the in-memory model.



Context
«interface» Generator
+ generate(Context): void
GeneratorModel
- eventPack: String
- agentPack: String
- rulePack: String
«abstract» VelocityShellGenerator
+ generate(Context): void
+ getVelocityEngine(): VelocityEngine
+ getPath(): String
+ writeToFile(String, VelocityContext, Template): void
«abstract» VelocityGenerator
+ generate(Context): void
QueryGenerator
+ generate(Context): void
EventGenerator
+ generate(Context): void
ComputationGenerator
+ generate(Context): void
RuleGenerator
+ generate(Context): void
IndicatorGenerator
+ generate(Context): void

Figure 7. Overview of different generators.



«interface» Generator
+ generate(Context): void
«abstract» VelocityShellGenerator
+ generate(Context): void
+ getVelocityEngine(): VelocityEngine
+ getPath(): String
+ writeToFile(String, VelocityContext, Template): void
VelocityEngine
+ getTemplate(String): Template
QueryGenerator
+ generate(Context): void
+ generateQueryClass(): void
+ generateSQLTable(): void
VelocityContext
+ put(String, Object): String
TypeMapperRepository
+ getTypeMapper(String): TypeMapper
TypeMapper
+ getType(String): String

Figure 8. QueryGenerator and certain dependencies.

can be generated. The `QueryGenerator` is derived from `VelocityShellGenerator` and thus the initialization step is very complex to offer more flexibility. A query consists of Java and SQL files, thus several templates are needed. The generation is started through the `generate(Context)` method call. The first step is to determine the needed TypeMappers. As stated before mappers for Java and SQL types are needed, which can be loaded by their names (e.g., 'java', 'sql'). The second step is to generate the files and artefacts by building the needed `VelocityContext` classes and calling the derived method `writeToFile`. Each `VelocityContext` object contains all data (e.g., variable names, data types, etc.) in a simple Map like data structure. Inside each template certain special codes can be used to access Context data, execute loops or use conditional statements to determine what will be rendered.

V. Implemented concepts and their artefacts

In the following paragraphs, different concrete parts and their corresponding artefacts are presented. Note, only excerpts are shown and currently not all elements of the abstract part are used. In Fig. 11 an overview of the QoS System and it's different components is given. The Measurement Agents (or QoS Agent) are only design-wise part of the QoS-System. In general they are placed inside the measured system (e.g., an

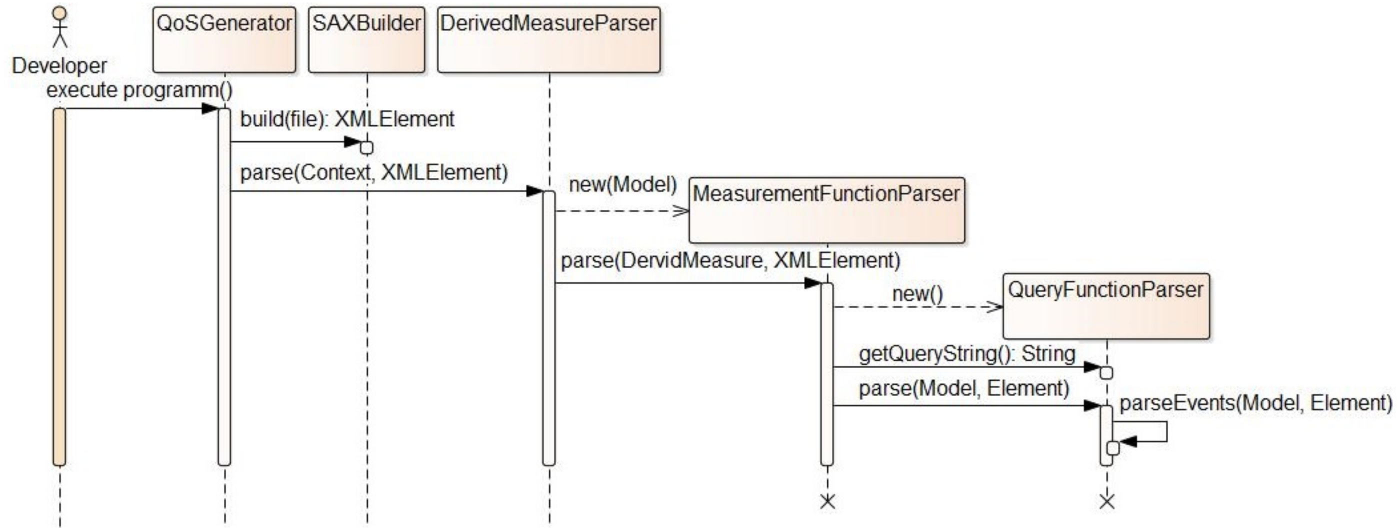


Figure 9. Overview of a parser execution.

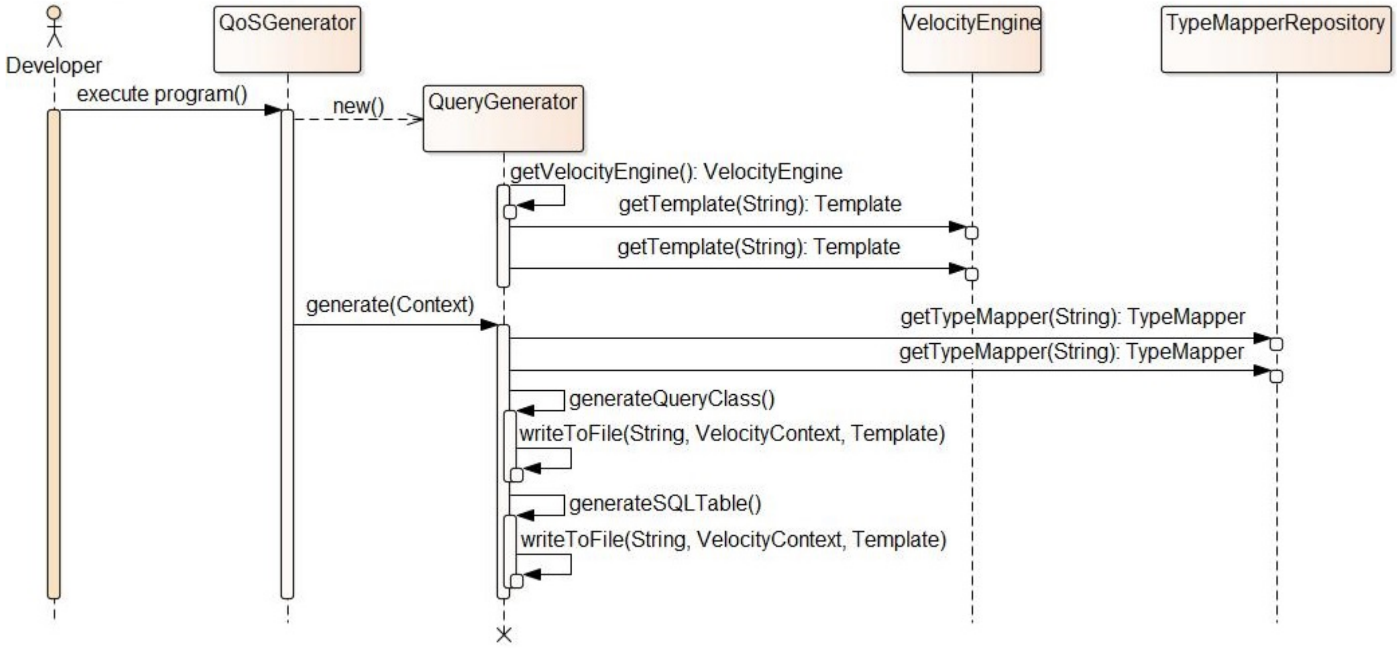

Developer
QoSGenerator
VelocityEngine
TypeMapperRepository
execute program()
new()
QueryGenerator
getVelocityEngine(): VelocityEngine
getTemplate(String): Template
getTemplate(String): Template
generate(Context)
getTypeMapper(String): TypeMapper
getTypeMapper(String): TypeMapper
generateQueryClass()
writeToFile(String, VelocityContext, Template)
generateSQLTable()
writeToFile(String, VelocityContext, Template)

Figure 10. Overview of a generator execution.

ESB, process engine, etc.) and send its results to the QoS Platform. In our current case, this is done via REST but other technologies (e.g., Sockets, CORBA, SOAP, JMS) can be implemented too. The QoS Platform consists of two distinct components.

QoS Measurement is the 'first stage' and contains logic to format or filter incoming events. Furthermore, it contains a CEP engine (JBoss Drools) to further compute and analyze the event stream. QoS Analyzer module is the 'second stage' and contains the main computation of Derived Measures and Indicators. Interfaces to offer these data to downstream systems (e.g., alerting) are also implemented in this module. While the QoS Measurement handles incoming events as fast as possible, the Analyzer module is heavily based on SQL queries and computations which are only executed when needed.

a) Event Model: The `EventModel` is a concrete part inside an IM but part of a specific IM Measure. It is defined aside of these concepts and defines the different events used inside QoS Platform, especially by the QoS Agent and the Measure components. It offers concepts to define events, their `Attributes` and dependencies (inheritance) between them. Currently used is the model shown in Listing 5.

From this model several Java POJOs are generated, which are shown in Fig. 12. An overview of the generated code is shown in Listing 6 and Listing 7. Each Attribute is generated with their mapped type, their name and the needed getters and setters. Furthermore, `abstract` keyword is generated if set

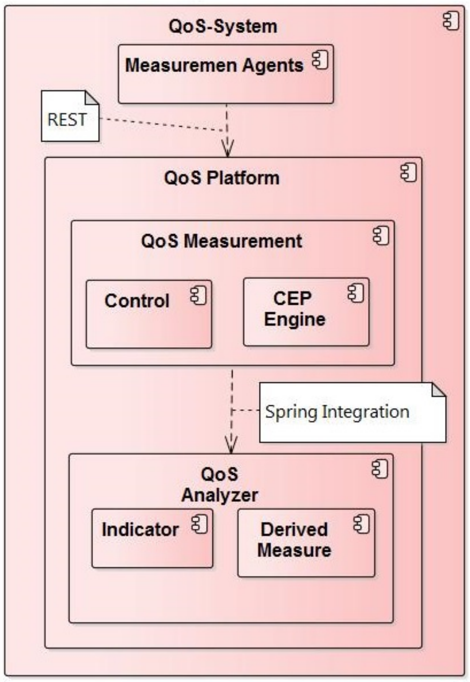


Figure 11. Overview of the QoS System.

```
<EventModel>
 <EventType Name="ServiceBaseEvent" Abstract=↩
     "true">
  <Attribute Name="id"
     Type="xs:positiveInteger"/>
  <Attribute Name="t_term"
     Type="xs:positiveInteger"/>
 </EventType>
 <EventType Name="ServiceStartEvent"
     Super="ServiceBaseEvent"/>
 <EventType Name="ServiceEndEvent"
     Super="ServiceBaseEvent"/>
 <EventType Name="ServiceDurationEvent">
  <Attribute Name="id"
      Type="xs:positiveInteger"/>
  <Attribute Name="t_inst" Type="xs:long"/>
  <Attribute Name="t_proc" Type="xs:long"/>
 </EventType>
</EventModel>
```

Listing 5. EventModel concrete part of an IM.

to true. If a super class is set, the Java extends clauses are generated too. The `ServiceBaseEvent` is mainly used by the QoS Agent and Measurement component. The ServiceDurationEvent is a complex event created through the CEP rule. While the id attributes are simply integers as defined by the insurance system, the other attributes are of data type long. This is necessary to hold timestamps with the needed precision.

b) Measurement Agent: The concrete part of the Base Measure `t_inst` is given in Listing 2. It defines `Attribute` elements and references the computed QoS Event. The ServiceCallID is parsed from Service Call data. The Time attribute will be computed by the Agent itself. Furthermore, a class attribute is given in the Agent element. It is used to structure the generated code and the corresponding artefacts. The specific method name is derived from the `MeasurementMethod` element. While the QoS Agent is designed as part of the QoS System, it is actually placed directly into the SOA as part of the ESB component. The used ESB is a partner specific implementation.

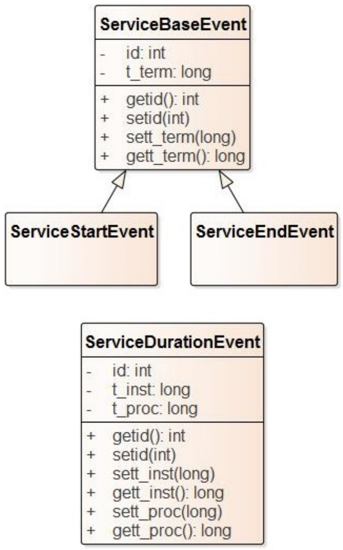


Figure 12. Detailed view of the generated Event classes.

```
public abstract class ServiceBaseEvent  {
 private int id;
 public int getid() {
  return id;
 }
 public void setid(int id) {
  this.id = id;
 }

 private long t_term;
 public long getT_term() {
  return t_term;
 }
 public void setT_term(long t_term) {
  this.t_term = t_term;
 }
}
```

Listing 6. Generated Java POJO ServiceBaseEvent.

c) Measurement Module: A brief overview of the Measurement module is given in Fig. 13. The QoS Agent send several events to this module. Each event is currently handled and formatted by `EventController` and `EventFormatter` classes. The formatters are needed because Agents only sent raw string-based data. After the formatter constructs actual Event classes, these are given to the Drools CEP Engine. This is done through the `DroolsEndpoint` class. These classes are considered to be part of the QoS Platform core. Thus, they are not generated and only adjusted if needed. EventFormatter are written for each Event that a BaseMeasure uses. In the `postConstruct` method, the CEP engine is

```
public class ServiceDurationEvent  {
 private int id;
 public int getid() {
  return id;
 }
 public void setid(int id) {
  this.id = id;
 }

 private long t_inst;
 public long gett_inst() {
  return t_inst;
 }
 public void sett_inst(long t_inst) {
  this.t_inst = t_inst;
 }

 private long t_proc;
 public long gett_proc() {
  return t_proc;
 }
 public void sett_proc(long t_proc) {
  this.t_proc = t_proc;
 }
}
```

Listing 7. Generated Java POJO ServiceDurationEvent.

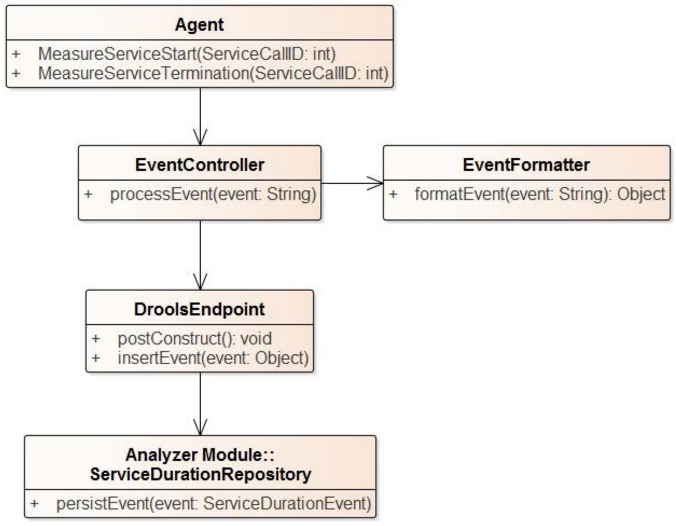

Agent
+ MeasureServiceStart(ServiceCallID: int)
+ MeasureServiceTermination(ServiceCallID: int)
EventController
+ processEvent(event: String)
EventFormatter
+ formatEvent(event: String): Object
DroolsEndpoint
+ postConstruct(): void
+ insertEvent(event: Object)
Analyzer Module::
ServiceDurationRepository
+ persistEvent(event: ServiceDurationEvent)

Figure 13. Overview of the measurement module.

further initialized with logging capabilities and a Spring Integration Channel. The `ServiceDurationRepository` of the Analyzer module is listening on this channel and persists every incoming complex event.

The concrete part of the Derived Measure `t_proc` is given in Listing 8. It contains the definition of the CEP rule, which computes the complex event ServiceDurationEvent. Plain element indicates that this code fragment will be placed 'as is' into a rule file. Only certain definitions (e.g., for event classes) will be added. The rule file is loaded on start up by the CEP engine (JBoss Drools) of the QoS Measurement module. The generated rule file is shown in Listing 9. Besides the import definitions, also the package definition is added. This

```
<Rule>
 <Event Name="ServiceDurationEvent"
  Handle="output"/>
 <Plain>
  rule "Service Duration Rule"
  when
   $start : ServiceStartEvent()
   $end : ServiceEndEvent(
    this after[ 0s , 2s ] $start &&
    this.id == $start.id
   )
  then
   channels["analyzer"].send(
    new ServiceDurationEvent(...)
   );
  end
 </Plain>
</Rule>
```

Listing 8. Concrete Part of a Rule.

```
package de.hshannover.ccitm.qos.measurement;

import de.hshannover.ccitm.qos.events.*;

declare ServiceEndEvent
 @role( event )
end
declare ServiceDurationEvent
 @role( event )
end
declare ServiceStartEvent
 @role( event )
end

rule "Service Duration Rule"
when
 $start : ServiceStartEvent()
 $end : ServiceEndEvent( this after[ 0s , 2s ⤸
     ] $start && this.id == $start.id )
then
 logger.info("Duration rule fired");
 ServiceDurationEvent duration = new ⤸
     ServiceDurationEvent();
 duration.setid($start.getid());
 duration.sett_inst($start.getT_term());
 duration.sett_proc($end.getT_term() - $start⤸
     .getT_term());
 channels["analyzer"].send(duration);
end
```

Listing 9. Generated rule file.

definition is based upon the information of the GeneratorModel described earlier. Another important and generated part are the `declare` statements. These define the Event POJOs as CEP events in the JBoss Drools sense. As shown, only the actual needed events of the included rule have declare statements.

d) Analyzer Module: The generated class and rule files for the DerivedMeasures are part of the QoS Platform (and part of the QoS Platform.war). For example, the generated classes

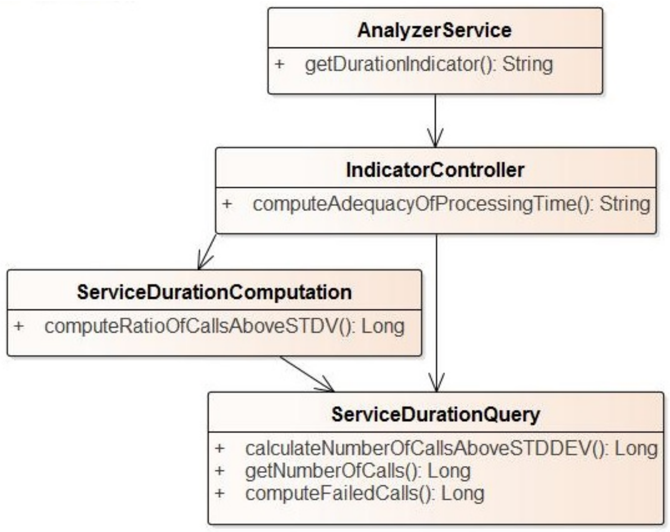

AnalyzerService
+ getDurationIndicator(): String
IndicatorController
+ computeAdequacyOfProcessingTime(): String
ServiceDurationComputation
+ computeRatioOfCallsAboveSTDV(): Long
ServiceDurationQuery
+ calculateNumberOfCallsAboveSTDDEV(): Long
+ getNumberOfCalls(): Long
+ computeFailedCalls(): Long

Figure 14. Detailed view into the Analyzer Module.

of the Analyzer module are shown in Fig. 14. Indicator and *-Duration classes are integrated, if needed manually, into the QoS Platform. The AnalyzerService class is considered part of the QoS Platform core and implements the REST interface for downstream systems (e.g., alerting).

The concrete part of the Derived Measure `COUNT_STDEV_CALLS` is given in Listing 3. It contains the SQL query to get the count of all events with a runtime above the doubled standard deviation. The generated class is shown in Listing 10. The `QUERY_STDDEV_EVENTQuery` attribute contains the SQL query given in a Plain element. Again, the class attribute is used to structure the code and artefacts, but the Type attribute is specific for a query and specifies the return type (in this case Long) of the query. The name of method is given in the `MeasurementFunction` element. Also, this class contains the SQL queries for other derived measures. Furthermore, needed imports and Spring code to integrate the jdbcOperations object are generated.

The concrete part of the Indicator `SLoT_proc` is given in Listing 4. Each `IndicatorEntry` element consists of an `Input` where the Indicator condition is defined and a `Result` element, which contains the actual Indicator response. Each of these results has to be a valid HMN type. The generated IndicatorController class is given in Listing 11. The dependencies to other Measure results are given by the `Uses` element. This information is also used for generation and manual modifications. In this case, the ratio of service calls above the standard deviation is computed by the `ServiceDurationComputation` class. The `ServiceDurationQuery` class provides the number of failed service calls.

VI. Measurements

For the evaluation of the described measurement concept, it is stressed with an initial load test. The general 'Information Need' (Fig. 1) is the information about how volatile a software

```
public class ServiceDurationQuery {
 private String QUERY_STDDEV_EVENTQuery =
  "SELECT COUNT(*) FROM serviceduration
 WHERE
  TINTS > TIME_SECS(DATEADD('DAY',-30,NOW()))
 AND TPROC > (SELECT AVG(TPROC)
  + (2 * STDDEV(TPROC))
 FROM serviceduration
 WHERE TINTS >
  TIME_SECS(DATEADD('DAY',-30, NOW())))";
 ...

 private JdbcOperations jdbcOperations;

 public ServiceDurationQuery(DataSource ⤸
     dataSource) {
  jdbcOperations =
    new JdbcTemplate(dataSource);
 }

 public Long ⤸
     calculateNumberOfCallsAboveSTDDEV() {
  return jdbcOperations.queryForObject(
    QUERY_STDDEV_EVENTQuery, Long.class );
 }

 public Long getNumberOfCals() {
  return jdbcOperations.queryForObject(
   QUERY_EVENT_COUNTQuery, Long.class );
 }

 public Long computeFailedCalls() {
  return jdbcOperations.queryForObject(
   QUERY_FAILED_EVENTQuery, Long.class );
 }
}
```

Listing 10. Generated query class.

system is currently being stressed. Static thresholds cannot fulfill the desired 'Information Need' of the partner companies in the insurance industry. The dynamic approach of measuring the spikes, which exceed the standard-deviation of a measuring period, can provide better answers here. For the evaluation, such spikes are directly provoked. When generating the spikes, two parameters are randomly influenced:

- Intensity: The intensity of the spikes.
- Frequency: The frequency at which the spikes occur.

In the stress test, the two parameters 'Intensity' and 'Frequency' are set. A high intensity means that a spike is generated with a high level of volatility. The intensity describes, how long the response time of a service request is and how 'intensive' the standard deviation is exceeded according to (1). The frequency determines, how often such a spike should occur in the stress test. The stress test therefore generates very volatile measurement events, which must be recorded dynamically by the measuring system. So, a random variation of these two parameters will provoke volatile stress situations with unpredictable intensity and frequency. This allows the measuring system to be tested as strongly and dynamically as possible. Some of the preliminary results measured with the QoS System are shown in Fig. 15. The yellow line shows the standard deviation barrier. In this case, 3 % of all measured

```
public class IndicatorController {
 @Autowired
 ServiceDurationQuery durationQuery;
 @Autowired
 ServiceDurationComputation ⤸
     durationComputation;

 public String ⤸
     computeAdequacyOfProcessingTime() {
  long devPercentageCount = ⤸
      durationComputation.⤸
      computeRatioOfCallsAboveSTDV();
  long badCount = durationQuery.⤸
      computeFailedCalls();

  if(devPercentageCount < 5 &&
   badCount == 0) {
    return "low";
  }
  if(devPercentageCount >= 5 &&
   badCount == 0) {
    return "middle";
  } else {
   return "high";
  }
}}
```

Listing 11. Generated indicator class.

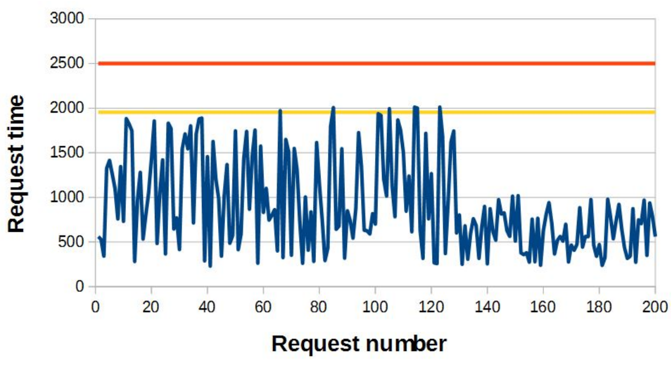


Figure 15. Preliminary Measurement Results.

requests (6 service calls) are violating the barrier, thus the computed indicator would be low. Above 5 %, the indicator would be middle. The red line shows the SLA barrier introduced by service consumers like check24.de. If one request exceeds this barrier, the indicator switches to high. A more thorough test and evaluation based on these loads will be given in our future work. But based on these results, the measurement concept can be used to even measure very volatile stress situations.

VII. Conclusion and Future Work

In this article, we presented an approach for monitoring a distributed SOA environment, which we see as a promising path to take. Our SOA Quality Model is aimed to follow the ISO/IEC-Standard 15939 (cf. [32]), which enables a wide range of use cases. Our Measurement Concept outlines an execution platform for the specific QoS Information Model, which should cause minimal impact on the SOA environment.

The separation of Measurement Agents and QoS-Analyzer on one hand allows lightweight agents and on the other hand a very capable analyzer component. Furthermore, certain parts of our QoS Platform can be replaced or complemented with common tools, e.g., from the microservices eco system. For example, Netflix's Hystrix could be used to implement a BaseMeasure or Prometheus to implement DerivedMeasures. This flexibility in our architecture with the general concept given by our SOA Quality Model offers new opportunities for our partner companies.

Already in previous work [2] [3], we presented our general measurement concept, an initial business process (the 'check 24' Proposal Service insurance use case, a basic business relevant scenario), and our information model and concept. The core contributions of the present article are implementation details of our approach.

Therefore, in Section IV, we dive deeply into design and operation of the QoS Generator. In Section V, implementation details of the generated artifacts – e.g., event model, agent, measurement module, and analyzer module – are described in depth.

Our ongoing work of applying the QoS System to an application scenario relevant to our partner in the insurance industry (the so called 'Check 24 process'), will provide evidence of the practical usability of the created framework. Furthermore, a more thorough evaluation will be the main part of our future work.

To this end, we designed and implemented a simulation environment based on the QoS System and applied to the partner's system architecture. The simulation environment will be feed with real data, i.e., the number of requests per unit of time over the day, to perform measurement and analysis.

It is expected that our monitoring system will help to discover potential bottlenecks in the current system design of our partner's distributed services. Therefore, it will create value in the process of solving these issues.

In future work, we have planned to apply our existing work to the more complex insurance process 'Angebot erstellen' ('create individual proposal') of the VAA [28]. Thus, we will implement a more complex insurance scenario. Moreover, the actual measurement and analysis of the results are an ongoing process, which is yet to be finalized.

We also have plans to apply these results onto cloud-based environments. Furthermore, a deeper subdivision or extraction, from the current coarse granular SOA services into fine-grained microservices, will be investigated by us in future work 'where it makes sense', for e.g., to allow for a better scalability of individual microservices.

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