Designing Service-Oriented Applications in the Presence of Non-Functional Properties: A Mapping Study

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Abstract

This paper discusses the results of a Systematic Mapping carried out to analyze the way in which Non-Functional Requirements (NFR) have been supported in the development of service-oriented applications. We searched scientific production on this subject. We classified the results according to five facets that represent the methods used to assist on the development of NFR for service oriented applications: *(i)* programming paradigm (object/service oriented); *(ii)* contribution (methodology, system, middleware); *(iii)* software process phase; *(iv)* technique or mathematical model used for expressing NFR; and *(v)* the types of NFR addressed by the papers, based on the classification proposed by ISO/IEC 9126. Based on the analysis of the systematic mapping results, we observed the trends and open issues related to NFR and service oriented applications.

Keywords: Non-Functional Requirements, Service-based Software Proces, Systematic Mapping.

1. Introduction

This paper presents a Systematic Mapping (SM) [120] about the design of service-oriented applications in the presence of non-functional requirements. SM is a method

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for analyzing a field of interest (e.g., service oriented applications and NFR). The analysis focuses on periodicity of publications organized by categories called facets combined to answer specific research questions [20] that a scientist wishes to answer with quantitative data generated through the SM steps.

In systems engineering, a non-functional requirement (NFR), also called qualities of a system, refer to the behavior of a system. These criteria are not necessarily related to the output of the system or its application logic, but to the conditions of its execution, its performance, and other properties (e.g., security, fault tolerance). Associating non-functional requirements to services based applications can help to ensure that the resulting application is compliant to the user requirements and also with the characteristics of the services it uses.

NFR are also referred as "constraints", "quality attributes", "quality goals", "quality of service requirements" or "non-behavioral requirements". In the case of service-based applications, non-functional requirements concern the conditions in which the application is executed and also constraints imposed by the services. The variability of terms about NFR comes from vocabularies of different domains, like software engineering, distributed systems, service oriented programming, etc. Therefore, the systematic mapping presented in this paper aims to identify the evolution of the area between 1998-2014 and the relationship between concepts used for defining NFR and associating them to service oriented applications.

The remainder of this paper is organized as follows. Section 2 gives the background about NFR and service oriented applications. Section 3 describes the systematic mapping process and our research protocol, including the search strategy and selection of papers. Section 4 presents and interprets the analytics results. Section 5 concludes the paper and discusses research perspectives.

2. Background

This section introduces the vocabulary and concepts related to non-functional requirement (NFR) for service-based applications.

Non-functional requirements, often called qualities of a system, specify criteria that characterize the conditions in which the system operates. According to [33] there is no formal definition or a complete list of non-functional requirements. However, [106] classifies NFRs into consumer-oriented and technically-oriented attributes.

In the area of Software Engineering, the term non-functional requirement refers to concerns that are not directly related to the functionality of the software. According to [32], NFR are "*requirements which are not specifically concerned with the functionality of a system. They place restrictions on the product being developed and*

the development process, and they specify external constraints that the product must meet".

Expressing and enforcing non-functional requirements for service-based applications is a well-known problem with several associated existing solutions that have modeled thoroughly them for providing middleware services.

2.1. Adding NFR to service compositions

In Service-Oriented Computing [114], pre-existing services are combined to build an application business logic. The selection of services is usually guided by the *functional* requirements of the application being developed [18, 39, 115][2]. An important challenge of service-oriented development is to ensure the alignment between the functional requirements imposed by the business logic and the functions actually being developed.

Functional properties are not the only aspect in the software development process. Non-functional requirements, such as data privacy, exception handling, atomicity and, data persistence, need to be addressed to fit in the application. Adding non-functional requirements and respecting services constraints while composing services is a complex task that implies programming protocols for instance authentication protocols to call a service, and atomicity (exception handling and recovery) for ensuring a true synchronization of the results produced by the service methods calls.

Even if service-oriented computing benefits from reuse, this is usually guided only by functional requirements. Ideally, non-functional requirements should be considered in every phase of the software development. Yet, they are partially or rarely methodologically derived from the specification, being usually added once the code has been implemented. In consequence, the development process does not fully preserve the compliance and reuse expectations provided by the service oriented computing methods.

The literature stresses the need for methodologies and techniques for service oriented analysis and design [114]. Existing approaches argue that the convergence of model-driven software development, service orientation, and business processes improvement are key for developing accurate software [167]. Model Driven Development (MDD) for software systems is mainly characterized by the use of models as a product [138]. These models are successively refined from abstract specifications into actual computer programs.

[2]Functional properties of a computer system are characterized by the effect produced by the system when given a defined input.

2.2. Models, methodologies and environments

General purpose methodologies do not fully consider NFR from the early phases of the (service) software process. Most methods integrate them only after the application has been implemented. This leads to service based applications that are partially specified and, thereby, partially compliant with the requirements of the application.

The modeling of non-functional requirements from the early phases of the development can help the developer to produce applications that can deal with the application context.

2.3. Related work

In [147], we propose a classification of NFR as a result of a study concerning software methodologies for the construction of service-oriented systems. The classification is organized in three layers: *application modeling*, *service composition* and *services*. The service composition layer serves as an integration tier between the service layer (that exports methods and has associated constraints and characteristics) and the application layer that expresses requirements.

At the application layer, NFR can refer to business rules (e.g., only the user can publish data on their wall) and values (e.g., an email address is a string containing an "@" and a "."). A value NFR expresses constraints about the way data and functions can be accessed and executed. For example, to define which security protocols have to be used to communicate with a service.

Business NFR at the service layer concerns properties that are associated to services and also defines how to call operations (business properties). Examples of this properties are response time and storage capacity.

Finally, the service composition layer gives an abstract view of the kind of properties exported by services that can be combined for providing NFR for a composition. For example, confidentiality, authentication, privacy and access control can provide security at the service composition layer.

In [137], the authors propose a taxonomy of concepts and requirements for existing approaches addressing NFR for service coordination. In their analysis they propose:

- A meta-model for characterizing NFR according to the entity to which they are associated: attribute, concern, action, and activity.
- Six specifications for the definition of NFR: NFR specifications, NFR actions specification, Web service subjects specification, non functional attributes execution order specification, composite Web service subjects specification, stateful non functional constraint specification.

- Seven dimensions for NFR enforcement: separation of concerns, transparent integration of functional and non-functional requirements, quantification, superimposition, integration of NFR with distributed Web service, programming language independence, Web service composition support.

The NFR concepts discussed in [137] are close to those defined in [147]. Although the concepts in [137] are not organized into layers, they correspond to the service and service composition layers in [147]. The enforcement dimensions describe the way NFR are weaved to service coordinations.

We can observe that the papers in our systematic mapping respect, at least partly, these requirements.

3. Mapping process

For performing our systematic mapping we adopt the method proposed in [121] consisting of five steps:

1. **Definition of research questions**, to determine the research scope;
2. **Search of primary papers**, to select candidate papers expressing a query for retrieving references from scientific databases;
3. **Screening of papers**, to identify relevant papers using inclusion and exclusion criteria to narrow the number of papers of interest;
4. **Keywording of abstracts**, to identify terms that are used for producing classification schemes (mapping categories);
5. **Data extraction and mapping process**, to produce the systematic mapping by clustering the papers into the mapping categories.

The results of our systematic mapping are presented as bubble plots in the next section.

3.1. Research questions

The goal of our systematic mapping is to pinpoint evolutions on the terminology of service based applications with NFR, discovering trends and the main results produced by the community. In order to achieve this goal we formulated three research questions:

- *RQ1: Which stages of the service-based software development process have addressed NFR?* This question is devoted to measure the evolution of publication on NFR in service-based software development and to see which phases address NFR the most.

- *RQ2: What type of solutions have been proposed over the years to deal with NFR for service-based software?* This question will help us to identify how NFR are integrated within methodologies, methods, and also environments used for specifying and implementing NFR for service based applications. This question will help us to cover the publications that address particular NFR for web service based applications. It will let us identify the properties recognized by researchers as NFR according to their discipline.

- *RQ3: Which is the scope of existing solutions for addressing NFR?* NFR is a vast domain addressing different aspects according to the level of abstraction. For example, they can refer to the characteristics of the services involved in a composition (availability, reliability, economic cost), it can refer to authentication for calling services, and also to atomicity associated to the whole service composition.

3.2. Search and Screening of Papers

Considering the research questions, we defined a set of keywords to be used for searching relevant works. As stated in the background, NFR are properties that represent the business rules of an application. In the early phases of the development of a Web service based application, they are stated in natural language and then they become constraints of different types in the other phases. Throughout these phases they are referred to as non-functional requirement, concern, attribute, aspect. Based on these keywords and their correlated words the query used was:

(non-functional ***OR*** *non functional* ***OR*** *quality* ***OR*** *NF* ***OR*** *QoS)*

AND

(property ***OR*** *requirement* ***OR*** *aspect* ***OR*** *attribute* ***OR*** *parameter* ***OR*** *concern* ***OR*** *constraint* ***OR*** *approach* ***OR*** *policy* ***OR*** *contract)*

AND

(web service ***OR*** *service composition* ***OR*** *service based application* ***OR*** *service-based application)*

We searched and filtered relevant works in four steps. In the first step we searched in four databases: *Science Direct*[3], *IEEE*[4], *ACM Digital Library*[5] and *CiteSeerX*[6]

[3] `http://www.sciencedirect.com/`
[4] `http://ieeexplore.ieee.org/`
[5] `http://dl.acm.org/`
[6] `http://citeseerx.ist.psu.edu/`

Source/Action	Included	Excluded	Total
ACM-DL	33	56	89
IEEE	71	70	141
Science Direct	56	117	173
CiteSeerX	10	20	30
Total	**170**	**263**	**433**

Table 1: Sources and number of papers.

Inclusion criteria
- Text in English
- Peer reviewed journals, conferences or workshops
- PhD and master thesis
- Focus on NFR for service compositions
Exclusion criteria
- Abstracts, tutorials, short papers, PhD workshops, demonstrations, technical reports
- Papers dealing with service service lookup
- Papers dealing with service matching

Table 2: Inclusion and exclusion criteria.

(see table 1). We retrieved 433 works. The search was done for relevant publications from 1998 to 2014. We stored in several spreadsheets (one per database) the title, year, and abstract of each reference we found.

In the second step, we perform a data cleaning by excluding repeated works.

We performed another filtering procedure by screening the title and the abstract of the papers, looking for those papers that are relevant to our study. In this process, we excluded 263 works. The columns **Included** and **Excluded** in Table 1 show the number of papers that were considered (resp. excluded) on our study.

Finally, in the last step we built the final data collection using exclusion and inclusion criteria shown in table 2. The final data collection contained 170 papers.

3.3. Keywording of Abstracts

According to our research questions and to our interests, the papers were classified into five analysis facets. Analysis facets are classification schemes that define mapping categories to cluster and analyze the papers. The abstracts of the 170 papers included in our mapping were analyzed to discover their contribution to each of the facets defined for our study. The result of this process is a classification of papers

Dimension	References
Specification	[47], [38], [93], [41], [28], [111], [169], [73], [60], [183], [161], [97], [50], [35], [67], [45], [96], [134], [170], [157], [63], [152], [92], [48], [145], [52], [77], [74], [68], [101], [158], [12], [95], [44], [153], [3], [105], [21], [37], [49], [51], [69], [70], [84], [85], [91], [139], [140], [98], [99], [100], [118], [42], [176].
Design	[166], [171], [88], [181], [47], [61], [59], [93], [89], [182], [41], [54], [179], [111], [169], [73], [183], [97], [50], [80], [35], [7], [72], [83], [31], [67], [45], [96], [157], [152], [56], [122], [141], [164], [6], [94], [142], [188], [11], [162], [159], [52], [82], [29], [64], [68], [62], [2], [133], [136], [4], [109], [186], [158], [127], [165], [66], [168], [86], [95], [44], [153], [112], [55], [87], [174], [3], [105], [15], [49], [51], [163], [58], [65], [70], [71], [75], [79], [81], [84], [85], [100], [155], [187], [131], [1], [113], [42], [177], [176], [76], [175], [107], [173], [108], [172], [126], [160], [129], [154], [151], [149], [150].
Implementation	[166], [59], [183], [161], [10], [72], [22], [31], [132], [110], [30], [152], [56], [143], [23], [141], [164], [57], [142], [123], [27], [148], [188], [11], [180], [53], [78], [29], [43], [62], [2], [8], [109], [13], [168], [3], [5], [9], [19], [25], [26], [34], [37], [46], [51], [58], [65], [70], [71], [75], [24], [155], [184], [135], [90], [131], [176], [116], [117], [119], [124], [146],[149].
Tests	[3], [14], [70].
Validation	[161], [16], [77], [3], [21], [26][70], [185].
Manteinance	[156], [22], [132], [125], [2], [8], [130], [109], [13], [186], [9], [105], [25], [65], [70], [178], [119].

Table 3: Facet: Software Process Phase.

for the dimensions of each facet. The results are summarized in Tables 3 to 7. The six facets with the associated classified references of our SM are described next.

Software process phase. Refers to papers that address NFR during a given software process phase: *specification*, *design*, *implementation*, *tests*, *validation* and *maintenance*.

Contribution. Refers to the concrete result described in a reference: *language*, *method*, *tool*, *composition algorithm*, *model*, and *process*.

Paradigm. Refers to the modeling paradigm used to design NFR for service based applications: *model-driven*, *middleware*, *aspect oriented*, *service process language*, *semantic*, *traditional*, *other*.

Technique. Refers to the formal or empirical tool used to develop a solution to deal with NFR within service based applications: *heuristics / optimization*, *graphs*

Dimension	References
Language	[38], [60], [132], [152], [143], [57], [159], [52], [133], [13], [101], [95], [44], [153], [105], [42], [176].
Method	[59], [89], [41], [179], [111], [169], [97], [80], [16], [45], [96], [170], [157], [63], [48], [11], [74], [68], [62], [130], [136], [4], [109], [186], [127], [66], [55], [14], [21], [34], [49], [51], [98], [99], [155], [185], [135], [118], [1], [113], [42], [176], [107], [154].
Tool	[61], [93], [183], [161], [22], [31], [125], [110], [94], [142], [148], [188], [162], [53], [29], [43], [77], [2], [8], [158], [165], [3], [5], [9], [19], [25], [26], [37], [58], [65], [70], [71], [75], [84], [85], [176], [108], [116], [117], [119], [129], [146], [149].
Composition Algorithm	[166], [171], [88], [181], [61], [59], [73], [35], [7], [23], [123], [27], [180], [12], [86], [87], [174], [37], [46], [49], [163], [65], [69], [71], [79], [91], [139], [140], [24], [90], [131], [175], [173], [172], [129].
Model	[47], [28], [73], [10], [50], [67], [145], [6], [82], [78], [15], [26], [177], [160], [151].
Process	[93], [182], [54], [97], [156], [72], [83], [30], [92], [56], [141], [36], [64], [168], [70], [81], [100], [187], [178], [184], [76], [124], [126], [150].

Table 4: Facet: Contribution.

Dimension	References
Model-Driven	[38], [110], [188], [11], [4], [109], [13], [168], [15], [51], [71], [42].
Middleware	[171], [47], [182], [28], [54], [111], [73], [60], [183], [10], [72], [22], [31], [132], [125], [141], [27], [77], [130], [66], [168], [3], [19], [25], [26], [37], [75], [79], [175], [108], [126], [146], [149].
Aspect-Oriented	[10], [125], [110], [144], [152], [2], [109], [44], [153], [163], [176].
Software Product Line	[70], [131].
Semantic	[54], [179], [111], [97], [157], [152], [56], [164], [52], [29], [2], [12], [3], [5], [105], [37], [46], [58], [69], [187], [108], [129], [151].
Traditional	[35], [7], [96], [48], [122], [133], [95], [79], [84], [155].
Other	[166], [88], [181], [61], [59], [93], [89], [41], [169], [161], [50], [80], [156], [83], [67], [16], [45], [30], [92], [143], [23], [145], [6], [94], [57], [142], [123], [36], [148], [162], [159], [180], [82], [53], [78], [64], [43], [74], [68], [62], [136], [158], [86], [21], [49], [140], [24], [178], [184], [135], [90], [118], [1], [113], [176].

Table 5: Facet: Paradigm.

Dimension	References
Heuristics/Optimization	[166], [88], [181], [61], [59], [182], [179], [111], [80], [35], [132], [45], [96], [48], [6], [123], [74], [62], [8], [130], [136], [4], [66], [55], [87], [174], [5], [49], [65], [69], [71], [79], [81], [84], [85], [91], [139], [140], [99], [187], [131], [113], [107], [173], [116], [124], [154], [146], [150].
Graphs/Planning	[89], [78], [37], [184], [135], [76], [146].
Evolutionary Techniques	[59], [93], [183], [22], [83], [31], [45], [23], [180], [25], [46], [71], [24], [1].
Formal Methods	[7], [134], [145], [82], [101], [12], [86], [174], [21], [100], [129].
Automata/Petri Nets	[28], [156], [158], [174], [185], [119].
Agents	[54], [68], [178].
Ad-hoc/Other	[171], [181], [47], [38], [93], [41], [179], [73], [60], [161], [97], [50], [72], [67], [16], [30], [157], [92], [56], [143], [122], [141], [94], [57], [142], [36], [27], [148], [188], [11], [162], [159], [52], [53], [29], [64], [43], [77], [2], [133], [165], [168], [95], [153], [51], [65], [81], [98], [155], [118], [1], [42], [177], [176], [175], [108], [172], [117], [160], [151].

Table 6: Facet: Main Technique/Mathematical Model.

/ planning, *genetic algorithm / genetic programming* , *Petri nets*, *formal method*, *automata*, *agents*, and *ad-hoc / other*.

NFR type. Refers to the types identified by the ISO/IEC 9126 (*functionality, reliability, usability, efficiency, maintainability, portability*) and it also includes *local/-global* and *QoS as general parameter*. Each ISO NFR type has associated dimensions that defines it. The *functionality* refers to suitability, accuracy, interoperability, security, and functionality compliance. The *reliability* of a system is defined by its maturity, fault tolerance, recoverability, reliability compliance. The *usability* of a system is defined by its understandability, learnability, operability, attractiveness, and usability compliance. The *efficiency* of a system is defined by its time behavior, resource utilization, and efficiency compliance. The *maintainability* of a system is defined by its analyzability, changeability, stability, testability and maintainability compliance. The *portability* of a system is defined by its adaptability, installability, co-existence, replaceability, and portability compliance.

We analyzed data quantitatively by reading the papers and by clustering them according to the facets. The following section shows the analysis results and answers our research questions.

Dimension	References
Functionality	[10], [35], [143], [27], [148], [49], [51], [163], [155], [185], [1], [42], [151].
Reliability	[41], [169], [35], [27], [148], [37], [49], [65], [140], [1], [42], [177], [76], [154].
Usability	[7], [155], [1], [42], [76].
Efficiency	[169], [35], [7], [143], [27], [188], [34], [49], [163], [70], [155], [1], [42], [177], [76], [119], [154], [151].
Maintainability	[1], [42], [76].
Portability	[65], [1], [42], [76].
Local/Global QoS	[28], [179], [157], [48], [6], [77], [8], [158], [12], [127], [66], [15], [26], [84], [85], [139], [98], [99], [187], [178], [184], [124], [160], [154].
QoS treated as a general parameter	[166], [171], [88], [181], [47], [38], [61], [59], [93], [89], [182], [54], [111], [73], [60], [161], [97], [50], [80], [156], [72], [22], [83], [31], [132], [67], [16], [45], [125], [110], [30], [144], [152], [92], [48], [56], [23], [122], [141], [164], [145], [94], [57], [142], [123], [36], [11], [162], [159], [180], [52], [82], [53], [29], [64], [43], [77], [74], [68], [62], [2], [130], [133], [136], [4], [109], [13], [17], [186], [101], [165], [168], [86], [95], [44], [153], [112], [55], [87], [174], [3], [5], [9], [14], [105], [19], [21], [25], [46], [58], [69], [70], [71], [75], [79], [81], [91], [98], [24], [185], [135], [90], [131], [118], [113], [176], [175], [107], [173], [108], [172], [116], [117], [126], [160], [128], [129], [146], [149], [150].

Table 7: Facet: NFR Type-ISO/IEC 9126 (Extended).

4. Outcomes

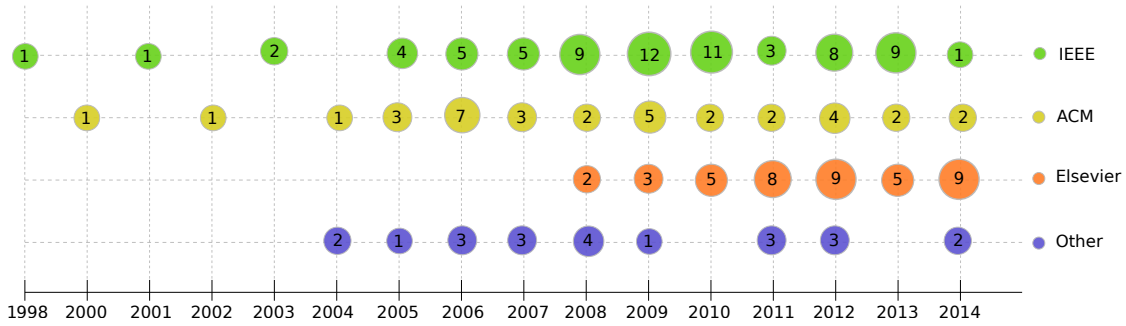
This section is devoted to the analysis and discussion of the results for our systematic mapping. We proceed by *(i)* presenting the collected data in a graphic form and *(ii)* answering the research questions for our study.

4.1. Quantitative analysis

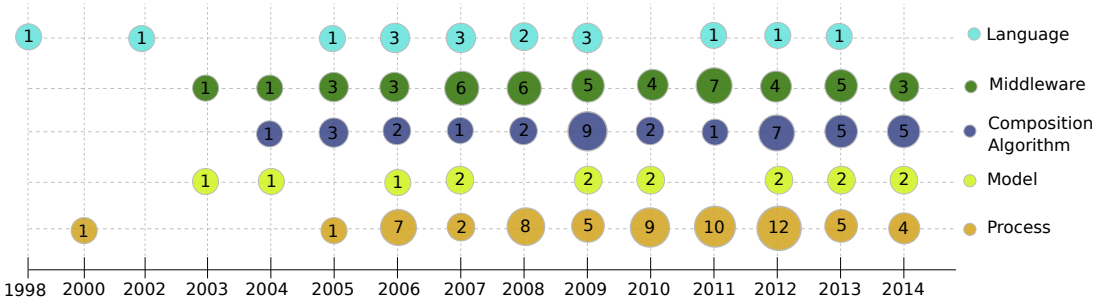
Our quantitative analysis of the results shows the frequencies of publications for each facet. Results have been aggregated in bubble charts (see Figure 1a).

We computed bubble charts that aggregate the number of papers published by year in the area (see Figure 1). The following presents the aggregated view of the number of papers published by year and by facet.

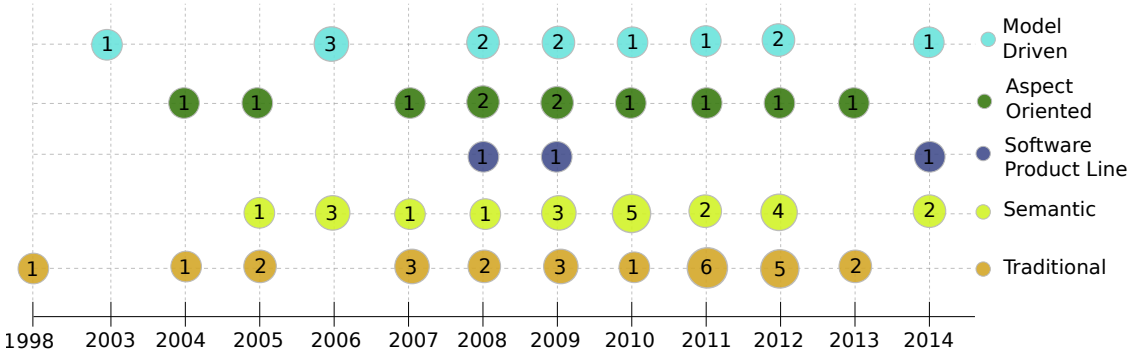
Despite the low number of works tackling *other* publishers, they maintain their presence over the years, mainly between 2008-2014. IEEE and ACM are the publishers that most published papers related to service-oriented applications considering non-functional properties. Considering Elsevier, we can found papers only from 2008. Figure 1a presents the publications for each publisher per year.



(a) Publisher per Year.



(b) Contribution per Year.



(c) Paradigm per Year.

Figure 1: Publications per Year.

Figure 1b presents the distribution of papers per contribution category by year. As shown in the figure, particularly between 2008 and 2012 most papers propose a middleware and a process, while composition algorithms were mainly published in 2008 and 2012. Papers proposing *SPL* are not numerous but the number remains stable along the years, while semantic and traditional proposals are quite popular.

4.2. Analysis by combining facets

For the analysis, we computed the volume of publications by publisher (Figure 1a). We also analyzed the publications considering the facets *contribution* and *paradigm* as pivot references that can be then put in perspectives by combining them with the other three facets (see Figures 1b and 1c). The facet contribution serves to organize papers that propose solutions for modelling, expressing and implementing NFR for service-based applications (Figures 2, 3 and 4). The facet paradigm serves to organize papers that propose methodologies for implementing service based software with NFR (Figure 5).

4.2.1. Contribution - Process - Paradigm facets

We combined the facet *contribution* with the facets *process* and *paradigm* to try to observe the relationship between the contribution associated to software development phase and the type of contribution reported in a paper (see Figure 2). We observed that NFR are rarely considered in the test, validation and maintenance phases of a service-based software development methodology. There are 8 papers that relate middleware (contribution) with the maintenance phase in their proposals. Specification (35.29%), Design (68.24%) and Implementation (38.82%)[7] are the phases most frequently addressed in papers. Papers addressing the design phase of the service-based software development is the that has almost all categories of contributions defined in our facet. Yet, fewer consider middleware and language as adapted contributions for addressing NFR in these phases. Middleware proposals focus on the implementation phase in 30 papers (17.65%), and 26 papers (15.29%) on the design phase. Languages seem to be well adapted for expressing NFR in the specification (11 works – 6.47%), and design phases (10 works – 5.88%). The majority of papers proposing a Process in the Contribution facet (53.46%) are related to the categories of the facet software process phase).

Associating the facets contribution and paradigm we observed that there are few works (1.76%) that use Software Product Line to propose some kind of contribution

[7]There are papers which were classified in more than one category, considering all facets, *e.g.*, one paper may be classified in design and implementation; or middleware and composition algorithm.

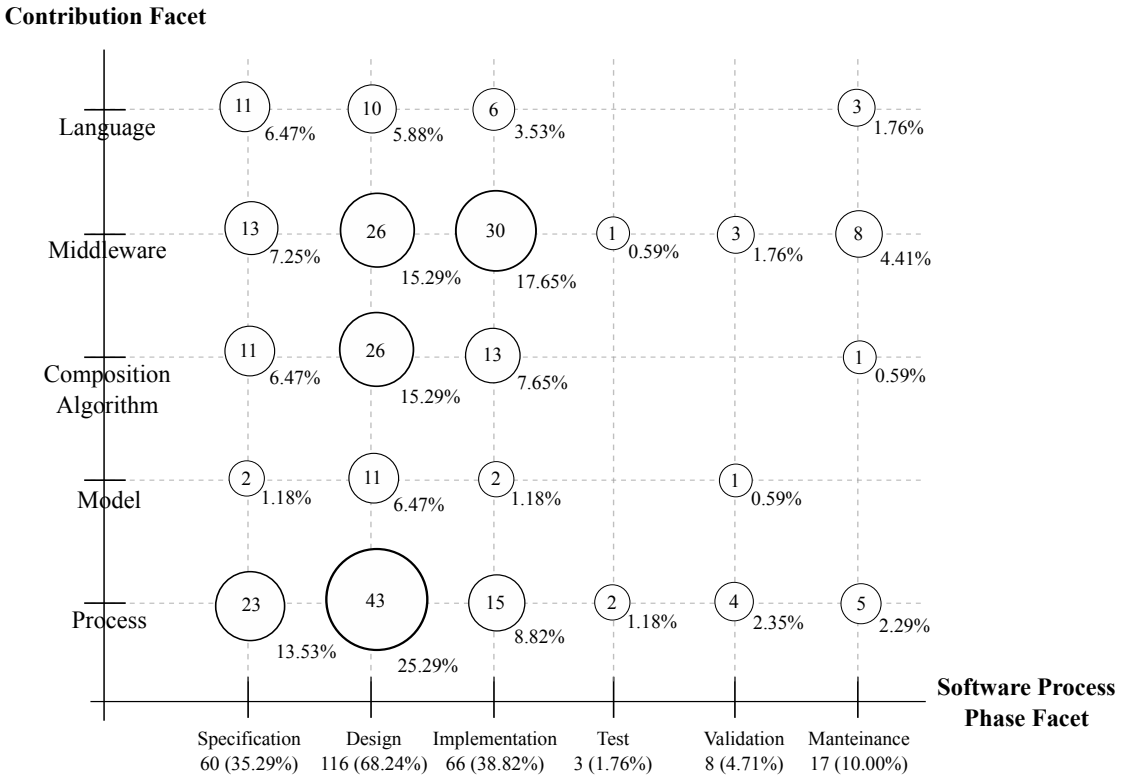


Figure 2: Facet Contribution with facet Software Development Process.

for service-based software with NFR. Semantic and traditional paradigms are almost systematically used when papers propose a Middleware and a Process. Works that propose a composition algorithm are almost always related to at least one of the paradigm categories.

4.2.2. Combining facets Contribution and Mathematical Model

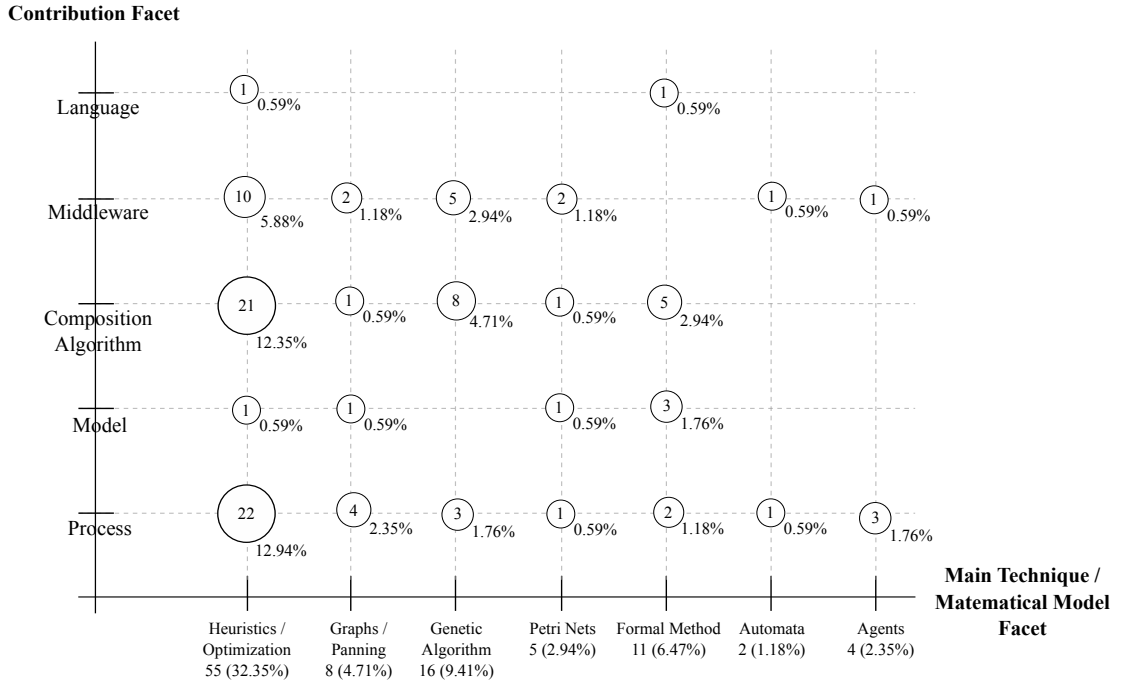


Figure 3: Contribution and Mathematical Model Facets.

We combined the facets *Contribution* and *Mathematical model* to determine which formal tool has been used the most to define different types of contributions (i.e., languages, models, methods), or whether there is a generic formal tool used for all types of contributions (Figure 3). We observed that contributions proposing algorithms or processes for automatizing service composition use in general heuristics or optimization category (55 papers – 32.35%). The majority of the contributions proposed composition algorithms (21 papers – 12.35%) and processes (22 papers – 12.9%). The majority of contributions proposing Middleware and Process use Petri Nets, Automata and Agents. Only 2 papers (1.18%) propose new languages for service-based software with NFR.

Figure 4: Facets Contribution and NFR Type.

4.2.3. Combining the facets Contribution and NFR type

We combined the facets *Contribution* and *NFR type* to observe the papers that (i) report solutions concerning all NFR types o just particular ones for service-based software; and (ii) the contributions that are used the most for specific NFR types (see Figure 4). First, with respect to the type of NFR, the proposals concerning general solutions that address NFR as a type of QoS are very popular (129/170 papers – 75.88%). Quality properties are expressed and associated to service compositions. There are few proposals that address other NFR types (e.g., Usability, Maintainability, Portability, Functionality, Reliability and Efficiency). Only 15 works (8.82%) address one of these NFR types.

4.2.4. Combining the facet Paradigm with the facets Contribution and Software process development

Combining the facet Paradigm with the facets Contribution and Software process development (Figure 5) it is possible to observe the phases in which software methodologies contribute to address NFR for service-based software. We also observed whether there is a connexion between the paradigm used by methodologies with respect to the way the address NFR. First of all, the most popular

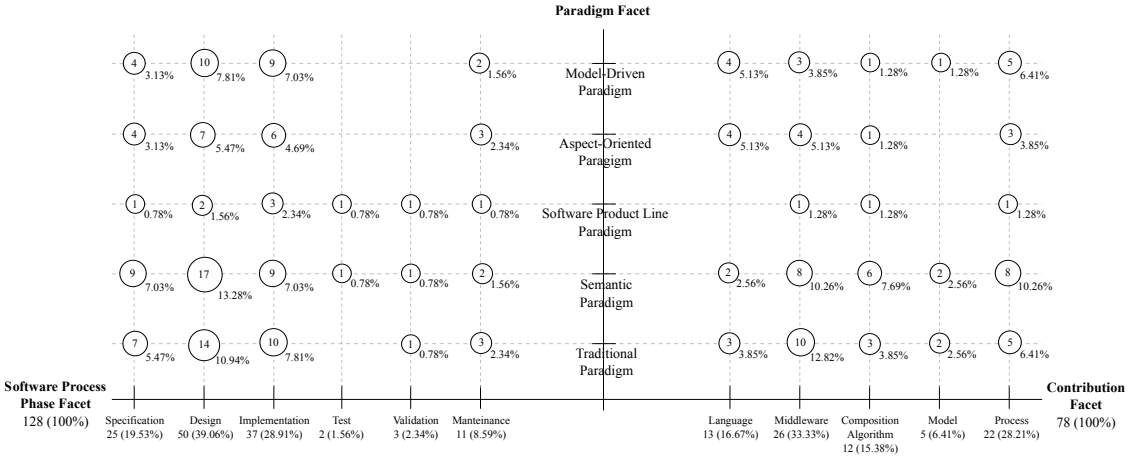


Figure 5: Paradigm and Contribution/Process Facets.

paradigms adopted by software development methodologies are Semantic with 17 papers (13:28%), Model-Driven Development with 10 papers (7.81%) and Traditional paradigm with 14 works (10.94%). Second, the analysis shows that the phases Test and Validation are rarely addressed by methodologies independently of the adopted paradigm (2 papers for Test and 3 for Validation). In contrast, the Design, Specification and Implementation phases are addressed by a lot of methodologies independently of the adapted paradigm.

In the following sections we provide answers to the reaserch questions presented in section 3.1.

4.3. RQ1: Which stages of the service-based software development process have addressed NFR?

Analyzing the data presented in Figures 2 and 5, we observe that NFRs are considered at all stages of the software process for web applications. However, most of the research efforts have focus on the design phase. Other popular contributions are related to the organization of the software process, as well as to the proposal of middleware solutions.

Post-implementation phases (tests, validation and maintenance) are still to be better explored. Contrarily to our expectations, the testing activity is addressed by a very small number of papers. This may indicate that either *(i)* testing NFR compliance do not require specific techniques or *(ii)* there is a research opportunity/challenge in this area.

Semantic tools (such as ontologies) are the preferred method for supporting NFRs in web applications. Although the usage of model-driven techniques is significant, we have not identified papers reporting on testing and validation using this approach. We believe that this is an area that deserves further investigation.

Our study shows that only a few initiatives deal with testing NFRs using traditional software engineering methods for web applications. This is not surprising since traditional testing techniques are most commonly applied to functional requirements.

Figure 2 also shows a lack of language support for the testing and validation phases of software development. Some initiatives, such as [147, 40], try to bridge this gap with the help of *Design-by-Contract* techniques [102, 104, 103].

4.4. RQ2: What type of solutions have been proposed over the years to deal with NFR for service-based software?

As we can observe from Figure 1b, a significant number of papers are devoted to the definition of steps to structure the software development process. These efforts are concentrated on the specification and design phases. (Figure 2.)

From Figure 1c, we can see that traditional software process techniques have dominated the scene over the years. Semantic tools are the second most important approach, followed by model-driven techniques. Along the years, we cannot identify any prevailing software process paradigm, since their distribution is regular. (Figure 5.)

In contrast to the regularity of distribution among paradigms, about 40% of the papers use heuristics/optimization/evolutionary techniques. These mathematical models are mainly applied to define steps of the development process as well as composition algorithms. (Figure 3.)

4.5. RQ3 : Which is the scope of existing solutions for addressing NFR?

From Figure 4, we can observe that only a small portion of the papers deal with specific types of NFR, when considering the ISO/IEC 9126 classification. The distribution of NFR among this minority of papers is somehow regular and does not reflect the tendency among the papers, which is to model NFR/QoS in a more general way. Most of the papers in our mapping represent NFR/QoS as a set of variables/parameters. In these papers, NFR are represented as values, associated to conditions. There is no semantics associated to these variables. For instance, both *Efficiency* and *Reliability* may be represented just numerically (and, perhaps, associated to conditions defining upper and lower bounds).

Some papers (about 15%) make a distinction between the *service* and the *composition* levels, by considering QoS/NFR as local and global parameters. Although

a service composition is conceptually a service, NFR at the composition level may have to integrate and aggregate restrictions over their components. Each service that makes part of a composition may also have local restrictions.

5. Concluding remarks

The mapping results presented can be the starting point to motivate new studies, support the investigation of specific problems not sufficiently explored yet. The quantitative analysis provides an idea of the trends in service-based software development with NFR, including methodologies, languages and tools. The distribution of the papers that deal with NFR shows that they are addressed in different domains but the vocabulary changes a lot and that there is a need of consensus, despite the existence of specifications like ISO/IEC 9126. When NFR are addressed at the level of the services they are related to QoS measures like economy or economic cost, availability, authentication requirements for contacting a service. NFR as defined by ISO/IEC 9126 are vast and papers address one or two at a time, particularly those related to the software engineering domain. Middleware solutions provide frameworks that consider different types of NFR but this concerns only the implementation stage of the software development process. This implies that the compliance between the design and the implementation might not be ensured.

With respect to the procedure to build systematic mappings, we think that it may be enriched by the addition of a qualitative perspective. That could be done by explicitly adding filtering and clustering criteria related to the provenance of the papers, the impact factor of the conference/journal where they appear, the reputation of the authors (given for example by their H factor), the institution and country of the authors. Without discarding the quantitative analysis, adding these criteria could increase the quality and value of the analysis. Similarly, we feel that choosing key words in the second phase of the methodology can be empirical, using vocabularies of the knowledge domain, could help to have a more representative choice. We are currently working in providing tools that can help to add quality to the systematic mapping method.

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