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Abstract—In this paper, an open and hierarchical cooperative Unified Requirement Framework (URF) which is composed of four layers: R (role), G (goal), P (process), and S (service resource), is proposed. The meta-model of R, G, P, S and the relationship definition meta-model and rules among R-G-P-S model layers are presented. The meta-model framework based on RGPS is analyzed. URF provides an effective way for the research of dynamic requirement acquisition and analysis for the user-dominant, domain-oriented networked software, self-controlled evolutionary modeling, requirement cooperation and optimization, and requirement management. At last, the usability of RGPS meta-model framework is demonstrated by a case study of requirement analysis in networked logistics software applications.

I. INTRODUCTION (HEADING 1)

With the substantial increase in scale and complexity of network-based information system, the personalized user requirements for these systems have some new characteristics such as uncertainty, multi-role, multi-goal, multi-process, and multi-service, and the intensive interaction between network resources which is not self-possessed by certain network-based information system result in the complexity of software systems. Meanwhile, the interaction, coupling, and cooperation between network-based software system and its elements are more frequent than before, which increases the complexity of software systems. Consequently, we argue that the software of complex systems is evolved into “Networked Software” which has the new feature of change-on-demand, and cooperative change in emergency. The software “Programming”, “Compiling” and “Running” in common sense are extended from “Desktop” to “Network”, and the core issue of software engineering is moving towards the requirement engineering, which becomes the research focus of complex system software engineering.

SEI in CMU submitted the research report of “Ultra-Large-Scale Systems: The Software Challenge of the Future” in 2006 [1]. A series of challenging questions in requirement engineering are brought forward in this report, such as loose-coupled design and evolutionary optimization, interoperability cooperation and control, “computing” software engineering, complexity metrics, monitoring and evaluating, adjustable and predictable system quality, and adaptive system infrastructure. All these challenges are also the research focus on requirement engineering.

The famous journalist of “New York Times” Thomas L. Friedman believe that the globalization is the irresistible trend of modern society in his book “The World is Flat” [2] published in 2005. This book makes clear the relationship between the orthogonal worlds, and makes deep impact to the horizontal organization of society structure: “the pattern of value creation in world is changing from vertical (command and control) to horizontal (relationship and cooperation)”. The world is becoming flatter and transforming from the “small scale” to “mini scale” with the globalization started from 2000, and the software innovation and widespread of network are the driven power in the transformation. This is a globalization of individuals. In this circumstance, the substantial increase in scale and complexity of network-based information system challenge greatly to the software engineering research.

Long tail theory [3] is an experiential conclusion drawn by the data of Amazon.com and online music download websites. The over half sales market of Amazon.com is from the books outside of 130,000 places in the popular list. This data suggests that the future of business and culture dose not rely on the hottest products which are the head of traditional sales curve, but the long tail of the sales requirement curve. Personalized products, creation and consumption become the main stream. With the rising of Internet, the prediction is becoming the reality. The new long tail theory is challenging the traditional Eighty-Twenty rule. People have to think about the characteristics of complex network seriously, such as for the feature of scale-free [4], and it is believed that the feature
of scale-free improves the stability of network, and the feature of non scale-free creates the value of network. With the boom of network business pattern, popular culture is not always dominant in any place; on the contrary, the non-mainstream culture is more energetic. The fast development of many internet enterprises has demonstrated it, such as eBay, yahoo, Amazon, Google, Alibaba, P2P technology, etc. The non-mainstream culture with scientific organization will be more energetic in their lifecycle.

Open software system is flat as the comparison between the constructions of “city” (the interaction and connection between software sub-systems) and “power supply system” (single software system) of city. The interaction and cooperation between software systems create the value. The open software is changing from the individual software system possessed by user to the systems cooperation of “city-like” service used by user, and from the centralized single software system into discrete, interactive, and loose-coupled software complex system, which is the most important issue in the research.

The age of software “personalized requirement” is coming, and the “personalized” requirements by users make service oriented open software be flat. All the individuals stand in the same position in a flat world, and the requirements by individuals in different roles will participate in the integrated internet business environment. Actually, the “personalized” requirement by users of complex information systems on network has the feature of multiplicity (multi-role, multi-goal, multi- business process, multi- service resource). The feature of complex system results from the interaction and integration of “personalized” requirements.

Complex information system software based on network is an artificial complex system. One reason for its complexity is due to the network resource based complex user requirement whose characteristics are different from the traditional software requirement in nature, such as the networked diffuse representation of user requirement, human dominant, heterogeneous, different context, combination of personalization and multiplicity; and the requirement also has the feature of uncertainty, high changeability, conflict, fuzzability, uncompleted, real-time interaction, mobile, clustering, high performance (QoS), etc. From the time perspective, the requirements can be proposed by users continuously, and the time sequence of the requirement been proposed can be uncertain (random time sequence, fuzzy time sequence, etc). The research to the new characteristics of requirement engineering breaks through the initial condition and boundary of traditional requirement engineering. This research trend in requirement engineering has been approved in the IEEE Requirement Engineering Conference 05, 06 [5] [6]. In such situation, an open & cooperative unified requirement modeling framework is needed urgently.

The second reason for the complexity is that this kind of software system is based on the network resource with the frequent interaction and dynamic composition between the network resources. The network resource is different from the data resource in which the traditional requirements are based in nature, such as non self-possessed, heterogeneous, different context, frequent dynamic modification, etc. The requirement resource fusion mechanism should be studied in the open requirement modeling, and cooperative modeling, management and service will align with the requirement.

The meta-modeling of this kind of requirement modeling for the complex and open requirement modeling should be investigated, and an open & cooperative unified requirement modeling framework should be provided. This framework is the basic for the requirement engineering of networked software.

II. NETWORKED SOFTWARE AND NETWORKED REQUIREMENT

We present a general description to the “Networked Software” [7] drawn from our previous research: Networked Software is a software complex system whose topology and behavior can evolve dynamically. Networked Software has the feature of complex systems: (1) networked structure character: composite unit is more independent, loose coupling, scalable, dynamic evolution; (2) networked behavior pattern: from the desktop to network, the interaction and cooperative service of large scale and multi-granularity non self-possessed network resource, the system behavior emergence, dynamic composition, continuous running, change on demand, cooperative change in emergency; (3) networked production way: the software possessed by user is changed into software used by user with integrated solutions, distributed production, system dynamic interaction, combinatorial production, and cooperative management.

The “personalized” requirements by large numbers of network users should be integrated dynamically (interaction and cooperation) into the network business environment, and then the networked software system can meet user requirement. Consequently, the requirement specification of networked software is an open & cooperative system solution with dynamic composition and self-adaptation of structure and behavior.

III. REQUIREMENT EMERGENCE COMPUTATION

The requirement specification in different scale and the regularity and predictability in the emergence patterns of model structure & behavior should be discussed for the new feature in “personalized” requirement.

It is the basic features of networked software to have user-dominant and domain-oriented requirement. The online acquisition of user requirement and domain knowledge based requirement analysis should be investigated in order to adapt to the complex network environment, realize the interoperability cooperative composition and optimization of network resource, and meet the personalized requirement specification emergence by users in real-time.

An open requirement modeling framework, requirement clustering, stable requirement domain, and emerging requirement specification by users is studied. The evolutionary growth modeling and timing emergence of the structure and behavior in the integrated system requirement models is investigated. The change on demand and cooperative changes of requirement specifications on networked software system
are implemented. The cooperative work, stepwise optimization, complexity metrics and the modulation mechanism between requirement models and network resource are discussed. All this will be fundamentals in theory and method for scientific requirement management.

IV. HIERARCHICAL & COOPERATIVE UNIFIED REQUIREMENT FRAMEWORK URF

The fundamental concept of URF is MIM (Meet-In-Middle). We suppose that the user requirement is in the top layer, and the network resource is in the bottom layer. For the investigation of mechanism of hierarchical cooperation and management in service-oriented computing open software architecture and requirement service, we propose open requirement model framework (in the middle layer) as shown in Fig. 1. The URF is composed of the Role Model, Goal-model, Process- model, Service resource- model, and the context and semantic relationship among them.

This framework can describe the personalized requirements of multi-role & view, multi-goal, multi-business process, and multi-service in different levels, and this framework can be regarded as a meta-model framework to guide the description of user requirement and system requirement models. The reflective mechanism between open hierarchical & cooperative meta-model (meta level) of requirement framework and user requirement (basic level) is investigated.

Role model describes different types of users, such as the “supplier”, “manufacturer”, “client” in the logistics system.

Goal model: Goal is the specifications to the system requirement (software service plus system environment) expected by users, and goal model describes the functional goal and non-functional goal. Normally the goal model is constructed initially from high-level and abstract expectation specifications, and then the model is decomposed step by step into operational goals, such as the mobile warehouse management, mobile asset management, etc.

Process model describes the business requirement of end users, and they are represented in the business process, such as the mobile warehouse management, mobile asset management, etc.

Service resource model describes the resource which web services can use, such as the text and multimedia material, etc. The system can provide the nearest network configuration of resource for the user by networked URF navigation. One business process can be implemented by several web services, and the web services provide the concrete implementation of a business process.

R, G, P, S meta-model is open, and they can evolve dynamically with the requirement change by user. The meta-relationship among R-G-P-S meta-models can evolve with the requirement change by user. These two kinds of cooperative changes construct the open URF meta-framework.

S models, domain-oriented requirement by user groups and its requirement aggregation, provide the solution model of domain fundamental requirement specification modeling, and S model is the requirement model of usable resource based on URF.

As shown in Fig. 1 and Fig. 2, with the drive of personalized user requirement, the user-satisfied requirement model specifications can be emerged in real-time based on fundamental requirement modeling solutions using domain fusion resources and other available resources.

- Role-model
- Goal-model
- Process-model
- Service resource-model

Figure 2. Unified Requirement Framework URF and its evolutionary growth

Real-time emergence of current user requirements can be integrated into system requirement model dynamically. The domain-oriented requirement can vary in a stable period and range. The adaptive emergence of system requirement can be done in the process of dynamic evolution and integration of system requirement model.

A. Meta-models of RGPS

Meta-model of R, G, P, S (as shown in Fig. 3, 4, 5, 6) are proposed and defined as follows, and these meta-models can be used to guide the domain-oriented R, G, P, S modeling.
The Role meta-model employs the concept from domain-oriented modeling [8][9], and agent-oriented modeling [10]. The concept of Organization, Role, Actor and Goal are also mentioned in many publications [8][10][11]. The Organizational Goal and Personal Goal are introduced in [11]. The requirement modeling by user groups is the emphasis in networked software requirement modeling, and we introduce the concept of Crowd Goal in the Role meta-model, at the same time, the Functional Goal can be implemented by business process, and the NonFunctional Goal can promote or hinder the implementation of Functional Goal.

The Goal model is the research focus in the domain of requirement engineering in recent years. We borrow the basic concept [11] from goal modeling, and define the meta-model according to the characteristics of networked software requirement acquisitions. In the domain modeling, the goals should be classified into obligatory and optional goals in software product family, and we introduce the feature modeling (the representative method in domain modeling) to cope with the variability in requirement modeling. Goal and Process can be both regarded as the features in a certain domain, and can be classified into mandatory, alternative and optional features. Normally the goal refinement can be decomposed using AND/OR graph and we take the variability modeling into account in the decomposition process. The Goal and Softgoal in the traditional goal modeling can be mapped into Functional Goal and NonFunctional Goal respectively in our Goal model. The Functional Goal has three basic attributes: operation (the concept from operation ontology), object (the concept from entity ontology) and manner. Operational Goal is a kind of Functional Goal, and it is the smallest goal unit in the hierarchy of goal decomposition, and it can be implemented by business processes.

For the Process model, we borrow the concept from OWL-S [12] and PSL [13]. We introduce the characteristics of variability according to the domain modeling requirement, and define the goal for each process that the process can achieve.

The service model refers to the specification in semantic web services, WSDL-S [14] and OWL-S [12]. There are two kinds of services in the service model, Atomic Service and Composite Service. Atomic Service is deployed in web and can realize an independent function, and Composite Service is composed of several Atomic Services with certain orchestration while taking the QoS of services into account. From the function point of view, the services can implement the business process, and the QoS of service can be attached to the NonFunctional Goal. Each service has the candidate service which can substitute the original service in real-time when unavailable. The Message parameter of Service has certain Datatype, and the Datatype is the data types defined in XML schema or the concept in entity ontology, and the Operation of Service is the concept in operation ontology.

B. Hierarchical & Cooperative Relationship Meta-model of URF

For the requirement meta-modeling of networked software, the focus is the hierarchical & cooperative meta-model definition among the R-G-P-S meta-models (as shown in Fig.
7), which can be used to guide the domain-oriented modeling mapping and transformation among R, G, P, S. For instance, the cooperative relationship meta-model between R-G models based on application context; the cooperative relationship meta-model between G-P models based on business domain rules and application context; the cooperative relationship meta-model between P-S models based on requirement of user group and application semantics, etc.

![Figure 7. Cooperative relationship meta-model among R-G-P-S models](image)

**C. Relationship Rules**

The design rules of the relationship among R-G-P-S meta-models in URF are presented in Table 1: (1) relationship rules between R and G model based on application context; (2) relationship rules between G and P model based on domain planning and application context; (3) relationship rules between P and S model based on requirement of user group. These rules can be used to guide the model mapping and transformation among R, G, P, S models.

**TABLE I. DESIGN RULES OF THE RELATIONSHIP AMONG R-G-P-S META-MODELS**

<table>
<thead>
<tr>
<th>Role model</th>
<th>Goal model</th>
<th>Process model</th>
<th>Service resource model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role model</td>
<td>Meta model</td>
<td>Reverse R-G</td>
<td>Reverse P-R</td>
</tr>
<tr>
<td>Goal model</td>
<td>Context-based</td>
<td>Meta model</td>
<td>Reverse S-G</td>
</tr>
<tr>
<td>Process model</td>
<td>Pass the R-G</td>
<td>Domain and Context-based</td>
<td>Meta model</td>
</tr>
</tbody>
</table>

**D. Core model of Requirement Engineering for Networked Software - URF**

URF plays a central role in the process of requirement engineering, and is regarded as the core model of Requirement Engineering for Networked Software. URF can support effectively the requirement engineering activities as described below by practical investigation and experiment:

1) **Support of personalized and multiplicity requirement description**

Personalized and preferential requirement by user, and user can select any level or the composition from R, G, P, S in URF, and submit personalized requirement.

2) **Domain modeling based on URF**

The domain model and requirement model can be isomorphic based on URF, and URF can also support the requirement engineering in the perspective of syntax, structure, semantics and context, which guarantee the interoperability between domain model and requirement model.

3) **Domain-oriented candidate solution of requirement modeling**

The domain model based on URF can provide the guideline for the domain-oriented candidate solution of requirement modeling, and the candidate solution can be the initial model for the evolutionary modeling of system requirement specification.

4) **Acquisition and analysis of personalized and multiplicity user requirement by URF heuristic approach**

URF and domain knowledge can support the online acquisition and analysis of the user requirement, including the investigation of requirement description language SORL (Service-Oriented Requirement Language) based on ontology, domain model description language OWL-S+ (+ for QoS), and the mapping and transformation between SORL and OWL-S+.

5) **Support of real-time composition of personalized and multiplicity user requirements**

The initial model for model evolution is composed of the solution model for the domain fundamental requirement, and the engine for model evolution is the requirement acquired online by current users. The user satisfied requirement specification can emerge in real-time by networked mining and dynamic composition of resources.

6) **Support of the combination and evolutionary modeling of system requirement specification**

The requirement specification model of current user should be integrated into the domain business requirement modeling. The stable period of domain-oriented requirement can be analyzed by the time occurring sequence of requirement by the requirement management and monitor based on URF. The system satisfied requirement specification can emerge in real-time by optimized resource combination and evolutionary modeling of requirement modeling.

7) **Satisfactory verification and validation of requirement specification based on URF**
URF and its meta-models, relationship rules can provide a feasible way for the satisfactory verification and validation of requirement specification. E.g. the S-P-G relationship provides a way for the verification and validation about whether service resource can satisfy the business process of users, and also the user goals.

8) Requirement and Domain model management based on URF

URF provide the consistency and interoperability between requirement specification management and domain model management, and also provide the mechanism for the cooperative growth of requirement specification, requirement lifecycle management, service and traceability management, and stable period adjustment of domain requirement.

V. CASE STUDY OF RGPS – HIERARCHICAL & COOPERATIVE REQUIREMENT MODELS OF NETWORKED LOGISTICS SOFTWARE

The example shown below is a partial requirement models for networked logistics software based on RGPS meta-model. There are many roles in logistics domain, such as Customer, Administrator etc. and in the perspective of an Administrator of logistics domain, there are many goals for this role, such as Transportation vehicle management solution, and Mobile storehouse management solution. The goal of Transportation vehicle management solution can be achieved by several processes, such as Mobile vehicle scheduler, Mobile vehicle loading, and finally the process of Mobile vehicle scheduler can be realized by the dynamic composition of service resource, including Starting scan, Stopping scan, and Scheduler service, etc.

Figure 8. A case study of RGPS in the domain of networked logistics software

VI. CONCLUSION

With the substantial increase in scale and complexity of network-based information system, an open hierarchical & cooperative unified framework for requirement modeling of networked software URF is proposed in this paper, with the appearance of personalized and multiplicity user requirement, and the non self-possessed resource in Internet. In essence, URF provides a framework for the requirement meta-modeling, and its related meta-models, which can guide the requirement modeling and domain modeling of complex information systems based on network, and provide the fundamentals of solution. URF has the features of open, scalable, hierarchical cooperation, evolutionary growth, and verification and validation of requirement specifications.

The future work includes: RGPS meta-model framework based on URF with the investigation of large numbers of domain requirement models, and combination with classical applications; the real-time composition of personalized and multiplicity requirement by user and real-time emergence of user satisfied requirement; the combination, evolutionary modeling and massive emergence of system requirement models; requirement management and domain model management based on RGPS meta-models in URF.

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