An Ontology-based i* Goal-Oriented Referential Integrity Model in Systems of Systems Context

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Abstract: *System of Systems (SoS) results from the integration of a set of independent Constituent Systems (CS) that could be socio or technical, in order to offer unique functionalities. SoS is largely driven by stakeholders' needs and goals taking into consideration SoS-level global goals and CS-level individual goals. It's challenging to manage the satisfaction of these goals in such complex SoS arrangements, where links between these goals may not be clearly known or specified, and competing goals establish a complex stakeholder environment. In this research the i* goal-oriented framework has been utilised in SoS context to identify, model and manage goals of the overall SoS and its constituent systems. This paper discusses a novel Goals Referential Integrity (GRI) model that is intended to maintain the integrity and consistency of both the SoS-level and the CS-level goals, in an attempt to address the current challenges of managing goals in an SoS arrangement. Furthermore, an ontology-based model has been developed to support the GRI model and semantically annotate goals' levels in SoS context, specify the relationships and linkages between the SoS organisation, its constituent systems, global and local goals, and strategic and policy documents. Together the GRI model and its associated ontology model form the Semantic Goals Referential Integrity (SGRI) applied in SoS context, where conflicts between goals at the SoS and the CS-levels can be discovered in an attempt to maintain the semantic integrity of the SoS and CS goals.*

Keywords: *SoS, goal-oriented modelling, i* framework, GRI, ontology, semantic i* enrichment, cancer care informatics.*

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1. Introduction

In recent years, monolithic systems are being composed into more complex bigger systems as Systems of Systems (SoS) that can deliver unique functionalities which span more complex operating environments. An SoS is "a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities [20]".

Several software engineering challenges have emerged due to the evolution of SoSs. One significant challenge is concerned with the management of inconsistent goals and emerging requirements [28]. The various participating Constituent Systems (CS) in an SoS arrangement may present conflicting individual goals among themselves, as well as emerging conflicting goals between the entire SoS and its constituent systems.

It is essential to the success of a system development process, to precisely reflect users' concerns and goals while capturing requirements [29]. Engineering of systems of systems involves more stakeholders than traditional systems engineering, i.e. stakeholders at the CS-level and at the SoS-level, each having their own goals. A complex stakeholder environment is established by competing stakeholders' goals and interests, for which various limitations have occurred when applying traditional Requirements Engineering (RE) methods [20].

However, Goal-Oriented Requirements Engineering (GORE) approaches have recently become very popular as they can be used to drive the requirements engineering process in complex and large-scale systems. Goal-driven approaches are used to explore the objectives of different stakeholders and the activities performed by them to achieve these objectives [24], in order to derive purposeful system requirements at both the SoS-level and the CS-level.

Applying goal management in SoS context is considered challenging as it requires this to be done at multiple levels: the SoS-level and the CS-level. Goals in SoS organisations are owned by a large number of competing stakeholders and independent constituent systems, and linkages amongst them and their goal levels are not usually clearly identified.

The *i** framework [29], a well-known goal-oriented approach, has not been engaged so far in the derivation of goals specifications and goal-oriented modelling in SoS context. Thus, this research work aims at utilising the i* framework together with semantic ontologies in an attempt to address the current challenges of managing inconsistent emerging goals and requirements in complex SoS arrangements. Using this approach, we aim to model and manage goals of different stakeholders at two levels: The SoS high-level goals and the CS-level individual goals.

Furthermore, conflicts occurring between goals at any level of the SoS are intended to be detected and resolved, in order to be well-aligned with users' goals, needs and concerns, and maintain the semantic integrity of both the SoS and the CS goals.

In earlier work, the authors have initiated a Goal-Oriented Requirements Engineering framework for Systems of Systems (SoSGORE) [1] and applied this framework to Cancer Care domain. In addition, they proposed a new "process to extract i* elements and concepts from existing user documentation" and presented a "Reference i* Cancer Care Goal-Oriented Model in Systems of Systems context" in [2].

The aim of this paper is to present a Semantic Goals Referential Integrity (SGRI) model that is aimed at maintaining the integrity and consistency of both the SoS-level goals and the CS-level goals, when any goal at any of the two levels has been changed, deleted or a new goal has been identified. The concepts of this model are linked to semantic ontologies in order to:

1. Represent the SoS-of-interest, its constituent systems and the i* goal models in the global and local levels.
2. Discover relations existing among different goal models and constituent systems.
3. Pave the way to reveal inconsistencies and conflicts that might occur amongst global and local goals at different levels.

The rest of the paper is structured as follows; a review of the state-of-the-art related work is provided in section 2. In section 3, the OntoSoS.GORE framework and its main components are introduced. A Goals Referential Integrity (GRI) model in SoS context is presented in section 4 paving the way in section 5 for an ontology-based model that semantically enriches the GRI model and represents the SoS strategic goal modelling. In section 6, the proposed GRI model and the developed ontology-based model in which together form the SGRI, are applied to a cancer care organisation as the example case study. Finally, section 7 summarises and concludes the SGRI model outcomes and proposes directions for further research.

2. Related Work

This section provides a brief review of the current state-of-the-art on SoS, GORE, the i* framework, and research work that combine ontologies and the i* goal-modelling language.

2.1. Systems of Systems (SoS) and Systems of Systems Engineering (SoSE)

There are substantial differences between monolithic systems which are considered complex, such as an aircraft, and SoS such as an airport. An airport is considered an SoS as it consists of several constituent systems that can operate and be managed independently such as a baggage handling system. SoS are complex systems that result from the integration of a set of independent constituent systems in order to achieve new functionalities, capabilities and goals [18].

SoS have become more complex and difficult to manage, besides, many challenges have been facing SoS requirements engineering due to the unique characteristics of its constituent systems:

1. Operational independence.
2. Managerial independence.
3. Emergent behaviour.
4. Evolutionary nature.
5. The geographical distribution of SoS constituent systems [15].

In addition, inter-disciplinary study, heterogeneity and networks of the constituent systems are other SoS features which were presented in [6].

Systems of Systems Engineering (SoSE) involves more stakeholders than traditional systems engineering, i.e., stakeholders at the CS-level and at the SoS-level, each having their own goals. A complex stakeholder environment is established by competing stakeholders' goals and interests, for which various limitations have occurred when applying traditional requirements engineering methods [20].

A framework on modelling and simulation for SoS was presented based on the Department of Defense Architecture Framework (DoDAF) in [22]. The model was applied on a case of the civil aviation airline transportation SoS, where operational views of the model can be translated into Business Process Modeling Notation (BPMN) using Systems Modeling Language (SysML).

2.2. Goal-Oriented Requirements Engineering (GORE)

GORE is an RE approach that is concerned with the identification of goals to be achieved by the system, the use of goals for eliciting, specifying, analysing, negotiating, documenting, modifying and validating requirements. This is further extended into operational sing goals into functional and non-functional and assigning these goals to specific actors [25, 26].

GORE approaches are widely used to set high-level goals and decompose them until measurable requirements are derived. High-level goals represent the overall organisational key constraints and objectives; thus, capturing stable requirements that are less sensitive to change [8]. Goal-oriented modelling is considered a promising approach applied to systems of systems, as modelling goals can be the key starting point for the requirements engineering of SoS [14].

It is common that goal models are developed during the early stages of the requirements engineering process, by means of the driving role played by goals in that process [25, 29].

The sooner a goal is identified and validated, the more efficient is the RE process. Hence, goal-oriented

RE drives goals in elaborating the requirements that support them [25].

Various GORE approaches that were revealed in the literature such as Goal-oriented Requirement Language (GRL), KAOS (Knowledge Acquisition in autOmated Specification), Tropos and i* [3, 5, 9, 29], share common concepts in goal-modelling:

- Goals which represent the functional objectives of actors.
- Soft-goals which represent the qualities or non-functional objectives.
- Agents or actors which are the stakeholders or systems whose goals need to be achieved.
- Links which represent the interactions and dependencies between actors and goals [4].

2.3. The i* Framework

The i* framework is a goal-oriented approach that is targeted at socio-technical systems modelling and reasoning [30]. The i* framework recognises the domination of social actors and concentrates on the identification and modelling of the intentions and dependencies among actors in an organisation, leading to an early understanding of business organisations.

Currently, the i* framework is one of the most well-known goal-oriented and reasoning frameworks. The ability to evaluate the properties of the model which can help compare different alternative solutions and detect some faults in the modelling system, is one of the i* necessary applications as a modelling framework.

The i* framework proposes two types of strategic models to represent various organisational goals; the Strategic Dependency (SD) model and the Strategic Rationale (SR) model [29].

External relationships among actors are the main focus of the SD model through a network of actor-directed dependency relationships showing what actors demand or need from each other, whether it's a goal, soft-goal, task or resource. Goals refer to services or functional requirements (e.g., diagnosis), whereas soft-goals typically signify qualities and non-functional requirements (e.g., accurate and timely reporting).

Activities performed to achieve goals are represented by tasks (e.g., order test), whilst logical or physical elements that should be delivered among actors to satisfy goals are represented by resources (e.g., medical report or payment). The SR model, however, concentrates on the internal structure of the deliberate relationships among actors, their scope and possible alternatives and the rationale behind them.

2.4. Ontologies and the i* Language

The use of ontologies-explicit formal specifications of the terms in a certain domain and relations among them has increased in a wide range of areas including information systems in recent years [19]. Several research work have been tackling the formalisation of the i* language using ontologies, but not yet from systems of systems point of view.

In [16, 17] the development of meta-ontologies used to describe i* models and aimed at integrating different i* variants, named OntoiStar and OntoiStar+ is presented. Some related work has been performed based on these ontologies, in particular the development of a Tool for the Automatic Generation of Organisational Ontologies (TAGOON+) [16] which automatically transform an i* model both the SD and the SR to instances of OntoiStar and generate organisational ontologies providing the ability of querying and reasoning; and a method for integrating the constructs of i* variants through the use of ontologies [27].

Moreover, in [12, 13] some ontological guidelines for i* modelling, were proposed based on the Unified Foundational Ontology (UFO) [11]. This involved defining a common ontology for the main concepts of the i* language, to assist in clarifying the semantics of the language concepts and interpreting the meaning behind the i* intentional element links. Thus, enhancing the i* language usability through creating a number of common modelling guidelines.

3. The OntoSoS.GORE Framework

This research work aims to utilise the i* goal-oriented framework along with semantic technologies, in developing an "Ontology-based Goal-Oriented Requirements Engineering framework for Systems of Systems", namely the "OntoSoS.GORE" [1, 2].Figure 1 illustrates the two goal levels of the OntoSoS.GORE framework: the SoS-level and the CS-level, and Figure 2 demonstrates the framework's main components and layers.

The OntoSoS.GORE framework consists of three main layers:

1. Global and local goal-oriented i* modelling in SoS context, presented in this section.
2. Maintaining goals referential integrity by developing a GRI model and ontologising the i* strategic goal modelling in SoS context, discussed in sections 4 and 5 respectively.
3. Applying conflict management mechanisms consisting of two phases: conflict detection and conflict resolution, which will be discussed in further research work.

The development of the OntoSoS.GORE framework has adopted a hybrid of top-down and bottom-up approaches for modelling global and local goals for an SoS and its constituent systems as depicted in Figure 1 Applying a top-down approach (from the SoS to constituent systems) in isolation might not be effective in capturing aspects related to the constituent systems.

On the other hand, using a bottom-up approach by itself (from constituent systems to the SoS) may not be able to consider important concerns related to the SoS as a whole [4].

In SoS domain, goals are characterised as either SoS-level goals, which are the global high-level objectives of the SoS-of-interest as a whole, or as CS-level goals, which are local goals assigned to specific constituent system(s). The constituent systems that comprise the SoS must be determined and composed in order to identify possible arrangements of these systems to contribute to the recognition of the global goals established for the SoS, and the satisfaction of these global goals based on their capabilities [4].

The main objective of the first layer of the OntoSoS.GORE framework is to develop using the i* framework, Global Goal-Oriented Models (GGOMs) for the SoS as a whole, and Local Goal-Oriented Models (LGOMs) for its constituent systems. In order to accomplish this, the SoS-level goals and the CS-level goals should be identified as well as the actors and stakeholders who own these local and global goals, and the relationships and dependencies between them. This is done through analysing and studying the strategic documents, policies and procedures of the SoS organisation and its comprised constituent systems. In [2] Cancer Care SoS strategic goal modelling using the i* framework was presented as an example.

Applying the i* framework, SD and SR models are developed representing the LGOMs for the local levels and the constituent systems. The stakeholders' needs and goals of each constituent system and the external relationships between them, are modelled in SD models. On the other hand, the internal description of actors' intentional relationships, the rationale behind them, the space of alternatives for each actor, and how hard goals and tasks contribute to achieving soft-goals (i.e., qualities) are modelled in SR models.

Two approaches could be followed to develop the LGOMs for the local levels:

1. Developing a LGOM for each constituent system in the SoS arrangement.
2. Developing a LGOM for each policy document of the SoS organisation, where each policy document includes one or more constituent system(s).

Determining which approach to follow depends on the SoS arrangement itself, its organisational structure, and the existing or accumulated requirements. Analysing, comprehending and understanding the SoS organisation, its constituent systems, its strategic documents, policies and procedures leads to identifying the most appropriate approach for developing the LGOMs.

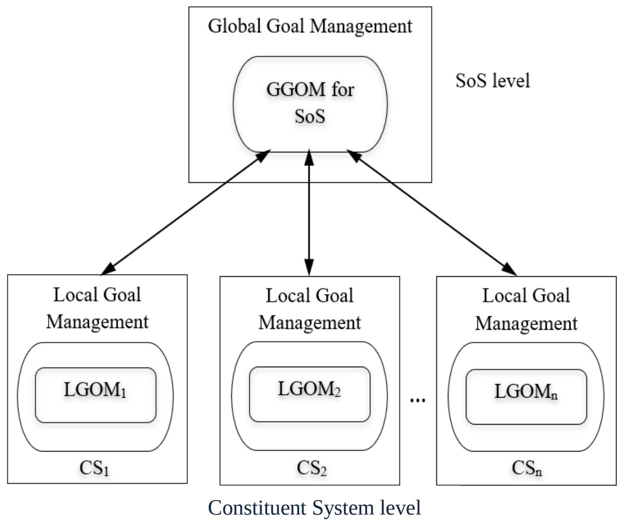

Figure 1. The OntoSoS.GORE Framework Goal Levels.

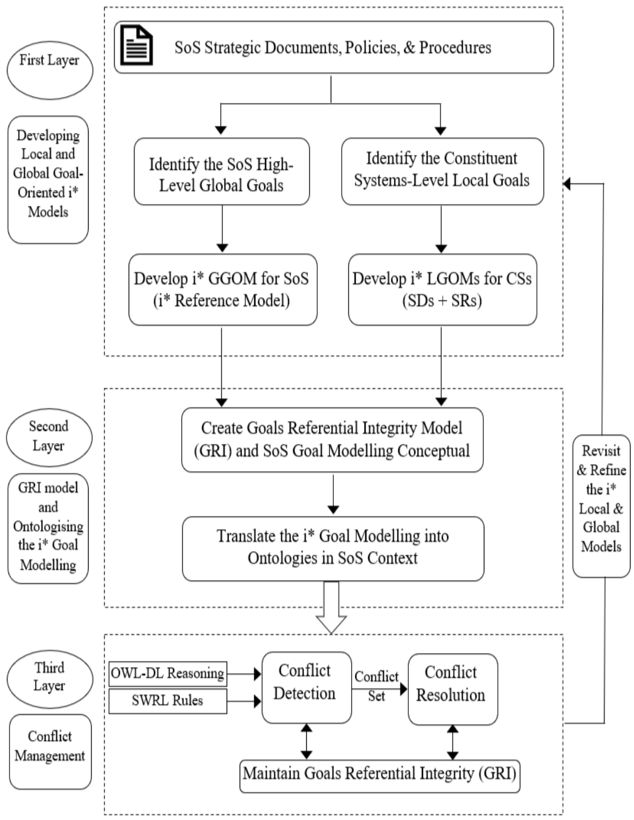

Figure 2. The OntoSoS.GORE Framework Main Components.

When developing a LGOM for each constituent system; for each CS_i, where $1 \leq i \leq n$ and n is the number of the constituent systems, there is a $LGOM_i$ which is a set of SD_i and SR_i models, as in (1):

$$LGOM_i.CS_i = SD_i.CS_i + SR_i.CS_i \,, 1 \leq i \leq n \tag{1}$$

For each CS_i, there is an SD_i, which consists of a group of actors and different types of dependencies between them as presented mathematically in (2):

$$SD_i.CS_i = \sum_{j=1}^{m} \quad A_{ji} + GD_{ji} + SGD_{ji} + TD_{ji} + RD_{ji} \,, \quad 1 \leq i \leq n \; and \; 1 \leq j \leq m \tag{2}$$

Where: A_{ji}: $Actor_j$ in SD $model_i$

GD_{ji}: Goal $dependency_j$ in SD $model_i$

SGD_{ji}: Softgoaldependency$_j$ in SD model$_i$
TD_{ji}: Task dependency$_j$in SD model$_i$
RD_{ji}: Resource dependency$_j$ in SD model$_i$

Also, for each CS_i, there is an SR_i to be modelled as presented mathematically in (3):

$$SR_i.CS_i = \sum_{j=1}^{m} A_{ji} + AB_{ji} + GD_{ji} + SGD_{ji} + TD_{ji} + RD_{ji} + MEL_{ji} + TDL_{ji} + CL_{ji}\ ,$$
$$1 \le i \le n \; and \; 1 \le j \le m \qquad (3)$$

Where: A_{ji}: Actor$_j$ in SR model$_i$
AB_{ji}: Actor$_j$ Boundary in SR model$_i$
GD_{ji}: Goal dependency$_j$ in SR model$_i$
SGD_{ji}: Softgoaldependency$_j$ in SR model$_i$
TD_{ji}: Task dependency$_j$in SR model$_i$
RD_{ji}:Resource dependency$_j$ in SR model$_i$
MEL_{ji}: Means-end link$_j$ in SR model$_i$
TDL_{ji}: Task decomposition link$_j$ in SR model$_i$
CL_{ji}: Contribution link$_j$ in SR model$_i$

In addition, GGOMs for the entire SoS are developed. One part of developing the global models, is concerned with modelling the global high-level goals of the SoS and the strategic relationships among actors at the SoS-level. Another part following, is modelling the most generic goals, dependencies and concepts extracted from the developed global and local goal models to be expressed in a global generic SD model, towards proposing a Reference i* Goal-Oriented Model for the SoS-of-interest. The development of the integrated GGOM is given in (4):

$$GGOM.SoS = \bigcup_{i=1}^{n} LGOM_i.CS_i\ , 1 \le i \le n \qquad (4)$$

The integration process followed to develop the GGOMs is dependent on the schematic information stored and inferred from the local models to create the global view. This method also focuses on resolving any structural discrepancies amongst the local models. Moreover, the GGOM generated will be refined continuously as the goals of the SoS are evolving and changing over the time.

In the following sections, we present two main components of the OntoSoS.GORE framework that follow the development of the GGOMs and LGOMs:

1. GRI model that maintains the consistency and integrity of both the SoS-level and the CS-level goals.
2. ontologising the SoS strategic goal modelling representing the SoS, its constituent systems, their global and local goals and the links and dependencies between them, in order to apply the GRI model and keep the consistency of goals in SoS context.

This brings the advantages of ontologies such as querying and reasoning to the i* strategic goal modelling and paves the way for applying conflict management mechanisms and strategies.

4. Maintaining Goals Referential Integrity (GRI) in SoS Goal Modelling

The term integrity refers to "the correctness or validity of the data in the database, as defined explicitly by means of integrity rules or constraints, i.e. rules that define properties to be satisfied by the database" [10]. *Referential integrity*, as a concept, in database systems represents the cement that keeps relational database components together. In relational databases, such components are tables and the link between two tables is a foreign key. Referential integrity ensures that relationships between tables remain consistent [21]. Figure 3 shows an example of applying referential integrity constraints in part of a bank database.

Within the OntoSoS.GORE framework a new term is proposed in SoS and GORE context, namely GRI. It is defined as "the capability to maintain the integrity of the SoS goals with the evolving local goals of the constituent monolithic systems". GRI intends to keep the integrity and consistency of both the SoS-level goals and the CS-level goals, if either any goal at any of the two levels has been changed, updated, deleted or a new goal has been identified. The integrity of goals should be kept both ways: top-down (from the SoS to the CS); and bottom-up (from the CS to the SoS).This will also pave the way for the conflict management process to be applied to the multiple levels of the SoS arrangement.

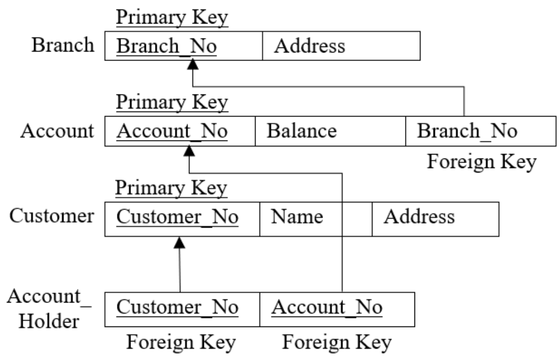

Figure 3. Referential Integrity Constraints in Part of a Bank Database, adapted from [7].

Three types of goals constraints are identified and applied to maintain and enforce goals referential integrity in an SoS arrangement:

1. Insert goals constraints.
2. Update goals constraints.
3. Delete goals constraints [2].

Figure 4 presents a GRI model in the SoS context and shows the relationships and interactions between the SoS and its constituent systems, the SoS global goals in the SoS-level, and the CS local goals in the CS-level, and how the global and local goals are linked together to maintain the goals referential integrity.

In Figure 4, the column “SoS” added to the “Global Goal” and “Constituent System” tables, links each global goal and constituent system with the SoS organisation they belong to. The columns “GG” and “CS” in the “Local Goal” table indicates the SoS global goal in which the corresponding local goal contributes to achieving, and the constituent system where this local goal is identified, respectively.

In order to define the multiple goal-levels in an SoS arrangement, besides the relationships and linkages between these goal levels and corresponding components such as constituent systems; a conceptual metamodel for SoS strategic goal modelling using the i* framework has been developed. As illustrated in Figure 5,the model describes the relationships and links between the SoS, its constituent systems, the global and local goals besides links to the organisation’s policy documents and i* models. The model supports the GRI model and provides the enforcement of goals referential integrity in an SoS arrangement.

Four different levels of goals are adopted in this metamodel:

1. *SoS Global Goals*: which are the highest strategic priorities and missions of the SoS organisation.
2. *Strategic Goals*: which aim at achieving the global goals and are also considered within the SoS-level.
3. *Strategic Sub-Goals*: that are required to satisfy the strategic goals in the upper level.
4. *Constituent Systems Local Goals:* which are the individual goals of each constituent system that collaborate together in order to achieve the higher-level strategic goals.

These levels are able to be redesigned to represent more or less goal levels depending on the SoS-of-interest being modelled, its organisational and goals structure.

In order to enforce the referential integrity and the links between the global and local goals in different levels of the SoS, the aforementioned metamodel is translated into semantic ontologies in the following section.

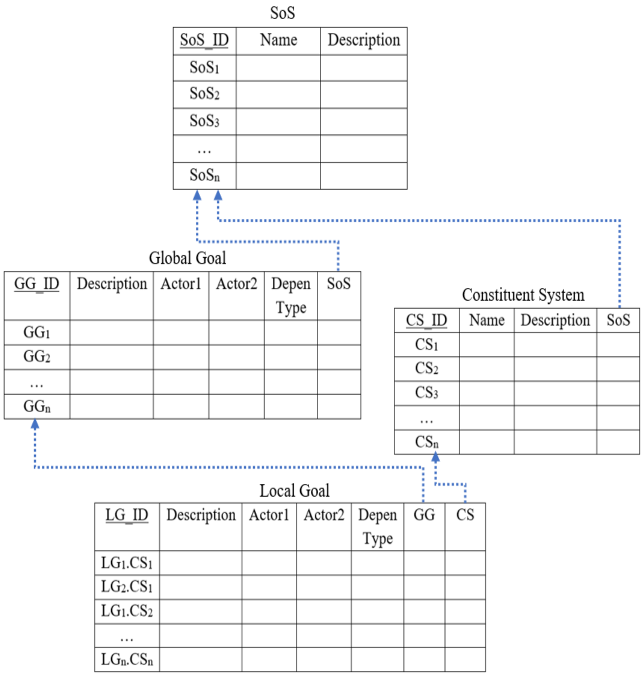

Figure 4. Maintaining Goals Referential Integrity in SoS Goal Modelling.

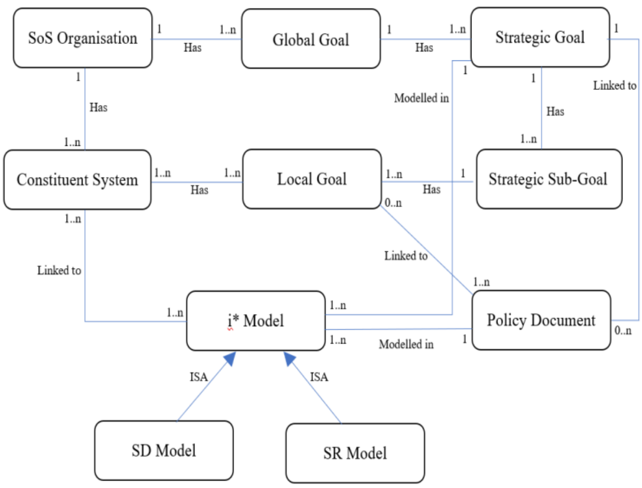

Figure 5. Metamodel for i* Strategic Goal Modelling in SoS Context.

5. Ontologising the i* Strategic Goal Modelling in SoS Context

The use of formal ontologies has increased in a wide range of areas as a way of specifying content-specific agreements for the sharing and reuse of knowledge among software entities, besides the use of reasoning and logic inference offered by ontologies.

Developing an ontology consists of:

1. Defining the ontology classes.
2. Classifying them in a taxonomic hierarchy (subclass-superclass).
3. Defining properties and restrictions on them and identifying allowed values for these properties.
4. Filling in the values for properties for individual instances.

An ontology together with a set of individual instances of classes constitute a knowledge base [19].

In this paper, an ontology-based model is developed using the Ontology Web Language (OWL) [23], that semantically enriches the GRI model and represents the SoS strategic goal modelling, towards maintaining the consistency and referential integrity of goals, and form together with the proposed GRI model; the SGRI.

The metamodel demonstrated in Figure 5 was translated into a formal ontology representation. The ontology classes represent the main elements of the SoS i* goal modelling, e.g. SoS, constituent system, global goal, strategic goal, strategic sub-goal, local goal, i* model, policy document, dependency type, depender actor, dependee actor, etc. Table 1 shows part of the ontology main classes with their associated properties, and Figure 6 depicts a snapshot of the developed ontology for i* strategic goal modelling in SoS context.

The set of objects created and the describable relationships between them define the links between the global and local goals and provide traceability to these goals. Therefore, satisfying the local goals at the CS-level contributes at satisfying the global goals at the SoS-level.

The significance of applying an ontology-based approach is the use of detecting and resolving semantic heterogeneities and maintaining the consistency of goals at both local and global levels. The developed ontologies pave the way for the conflict detection phase to be put into action by means of reasoning and rules that can be added to the ontology classes. The formal ontological representation of the SoS goal levels along with the links and relationships between the global and local goals provides the mean to check for any inconsistencies or conflicts that may occur amongst goals in the local and global levels for the SoS-of-interest.

In an SoS arrangement goal conflicts may occur in three levels:

1. Conflicts occurring in the CS-level amongst individual local goals of constituent systems.
2. Conflicts occurring in the SoS-level amongst high-level global goals of the entire SoS.
3. Conflicts occurring between the local and global levels amongst CS local goals and SoS global goals.

Following the development of the SoS strategic goal modelling ontology, another software tool is being developed with reference to the conceptual metamodel presented in Figure 5, in order to create a strategic dashboard for SoS organisations with access to their main SoS high-level strategic goals and the CS-level local goals linked to Key Performance Indicators (KPIs) that adhere to satisfying these goals.

Table 1. The Main Ontology Classes and Properties for SoS i* Strategic Goal Modelling.

Class	Properties
SoS_Organisation	- SoS_ID - SoS_Name - SoSOrg_Has_ConstSystem - SoSOrg_Has_GG
Constituent_System	- ConstSystem_ID - ConstSystem_Name - ConstSystem _Has_LG - ConstSystem_IsLinkedTo_iStarModel - ConstSystem_ParticipatesIn_SoSOrg
Global_Goal	- GG_ID - GG_Description - GG_Has_StrGoal - GG_BelongsTo_SoSOrg - GG_Has_Depender_Actor - GG_Has_Dependee_Actor - GG_Has_Dependency_Type
Strategic_Goal	- StrGoal_ID - StrGoal_Description - StrGoal_BelongsTo_GG - StrGoal_Has_StrSubG - StrGoal_IsLinkedTo_PolDocument - StrGoal_IsModelledIn_iStarModel - StrGoal_Has_Depender_Actor - StrGoal_Has_Dependee_Actor - StrGoal_Has_Dependency_Type
Startegic_Sub_Goal	- StrSubG_ID - StrSubG_Description - StrSubG_BelongsTo_StrGoal - StrSubG_Has_LG - StrSubG_IsLinkedTo_KPI - StrSubG_Has_Depender_Actor - StrSubG_Has_Dependee_Actor - StrSubG_Has_Dependency_Type
Local_Goal	- LG_ID - LG_Description - LG_IsAssignedTo_ConstSystem - LG_BelongsTo_StrSubGoal - LG_IsLinkedTo_PolDocument - LG_Has_Depender_Actor - LG_Has_Dependee_Actor - LG_Has_Dependency_Type
iStar_Model (SD or SR model)	- Model_ID - Model_Title - iStarModel_EncapsulatesModelFor_ StrGoal - iStarModel_IsLinkedTo_ConstSystem
Policy_Document	- Policy_No - Policy_Title - PolDoc_IsLinkedTo_StrGoal - PolDoc_IsLinkedTo_LocalGoal - PolDoc_IsModelledIn_iStarModel
KPI	- KPI_Description - KPI_IsLinkedTo_StrSubGoal

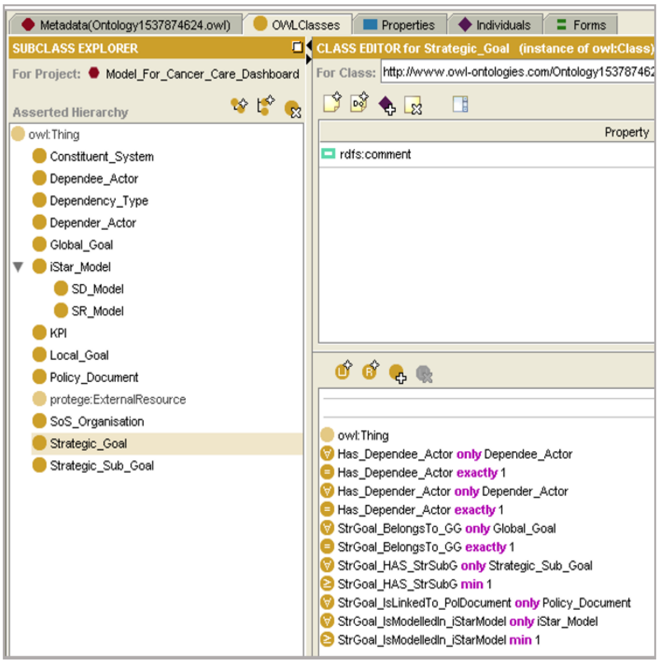

Figure 6. A Snapshot of the SoS i* Strategic Goal Modelling Ontology.

The dashboard is linked to a database that allows data to be constantly updated, and is aimed at providing at-a-glance views of KPIs relevant to a particular objective or strategic goal, which enable the SoS organisation to accomplish the following: align strategies with organisational goals and KPIs; check the progress and achievement of strategic priorities and goals; capture specific data points and get constantly updated reports of KPIs; monitor the contribution of the various departments in the organisation; save time compared to running multiple reports; obtain total visibility of all constituent systems instantly; and attain the ability to identify and resolve any inconsistencies and conflicts. This part of the research will be published in further future work.

6. Example: Cancer Care Case Study

The i* goal-oriented modelling has not been applied to the area of Cancer Care earlier. However, the OntoSoS.GORE framework is applied in this research to the Cancer Care case study at King Hussein Cancer Centre (KHCC) in Jordan from an original SoS perspective, where the cancer patient is the focus in the cancer care journey involving all the concerned Cancer Care providers, stakeholders and departments.

Two categories of user documentation have been collected from KHCC for the purposes of applying the research framework to the Cancer Care case study; KHCC's strategic plans, and KHCC's policies and procedures. KHCC's strategic plan consists of three main strategic global goals (priorities). Further down, there are 11 strategic goals, 59 sub-strategic objectives, 109 initiative actions (local goals) performed to satisfy the upper-level goals. Global and Local goal modelling of KHCC's strategic documents, plans, policies and procedures; and a Reference i* Cancer Care Goal-Oriented Model for Systems of Systems were presented earlier in [2].

In this section, we present applying the SoS GRI model and its associated ontology to KHCC Cancer Care. An instantiation of the ontology is created to describe the Cancer Care global and local goals linked to corresponding constituent systems, policy documents and i* models. Figure 7 illustrates an example of maintaining goals referential integrity in a Cancer Care SoS arrangement by linking the constituent systems local goals with their corresponding global goals while applying i* goal modelling.

Cancer Care SoS at KHCC comprises more than 40 constituent systems under different categories: clinical systems and care providers (e.g., physicians, chemotherapy, pharmacy and laboratory systems); monitoring systems (e.g., infection control system and ministry of health); legislation systems (e.g., Admission Discharge and Transfer (ADT) committee, governmental laws, and accrediting bodies); and supporting systems (e.g., IT, finance, food and beverage system). The Local Goals (LG) of these constituent systems were identified and linked back to their corresponding Global Goals (GG) in the SoS-level. Therefore, any modification, addition, or deletion of goals applied on any of the levels will be restricted by enforcing the goals referential integrity through the identified links between the tables shown in Figure 7.

Figure 8 demonstrates the instantiation of the developed ontology to the Cancer Care case study, showing an example of the OWL class "Strategic Goal". In the instantiation, individuals were created and added to the ontology classes. These individuals were extracted from KHCC's strategic documents, policies and procedures and from the developed i* goal models during the research study.

In Figure 8 for example, 11 strategic goals in KHCC were added to the class "Strategic Goal", each has a unique ID and a description. The strategic goals were linked to other classes by identifying the following: the corresponding global goal (priority) in the upper level, their strategic sub-goals identified in the lower level, the policy documents they relate to, the i* models they were modelled in, the depender and dependee actors, and the type of dependency (i.e., goal, soft-goal, task or resource).

The standardisation of knowledge offered by the ontology-based model for SoS strategic goal modelling, defines clearly the links between classes, and in particular the global and local goals, provides traceability of these goals to their policy documents and i* models, and facilities monitoring the satisfaction of the local goals in the CS-level which contributes at satisfying the global goals in the SoS-level.

SoS

SoS ID	Name	Description
SoS1	Cancer Care	
SoS2		
…		
SoSn		

Global Goal

GG ID	Description	Actor1 (Depender)	Actor2 (Dependee)	Depen Type	SoS
GG1	Improve patient's experience	Patient	KHCC Care Providers	Hard goal	SoS1
GG2	Foster patient's safety	Patient	KHCC Care Providers	Soft goal (Quality)	SoS1
GG3	Provide optimal portfolio of cancer care services	Patient	KHCC Care Providers	Hard goal	SoS1

Constituent System

CS ID	Name	Description	SoS
CS1	Lab System		SoS1
CS2	Pharmacy System		SoS1
CS3	IT System		SoS1
…			
CSn			

Local Goal

LG ID	Description	Actor1 (Depender)	Actor2 (Dependee)	Depen Type	GG	CS
$LG_1.CS_1$	Minimise lab waiting times	Patient	Lab	Soft goal (Quality)	GG1	CS1
$LG_1.CS_2$	Minimise pharmacy waiting times	Patient	Pharmacy	Soft goal (Quality)	GG1	CS2
$LG_1.CS_3$	Improve the process of following KPIs	QMO	IT Head	Task	GG2	CS3
…						
$LG_n.CS_n$						

Figure 7. Example of Maintaining Goals Referential Integrity in a Cancer Care SoS.

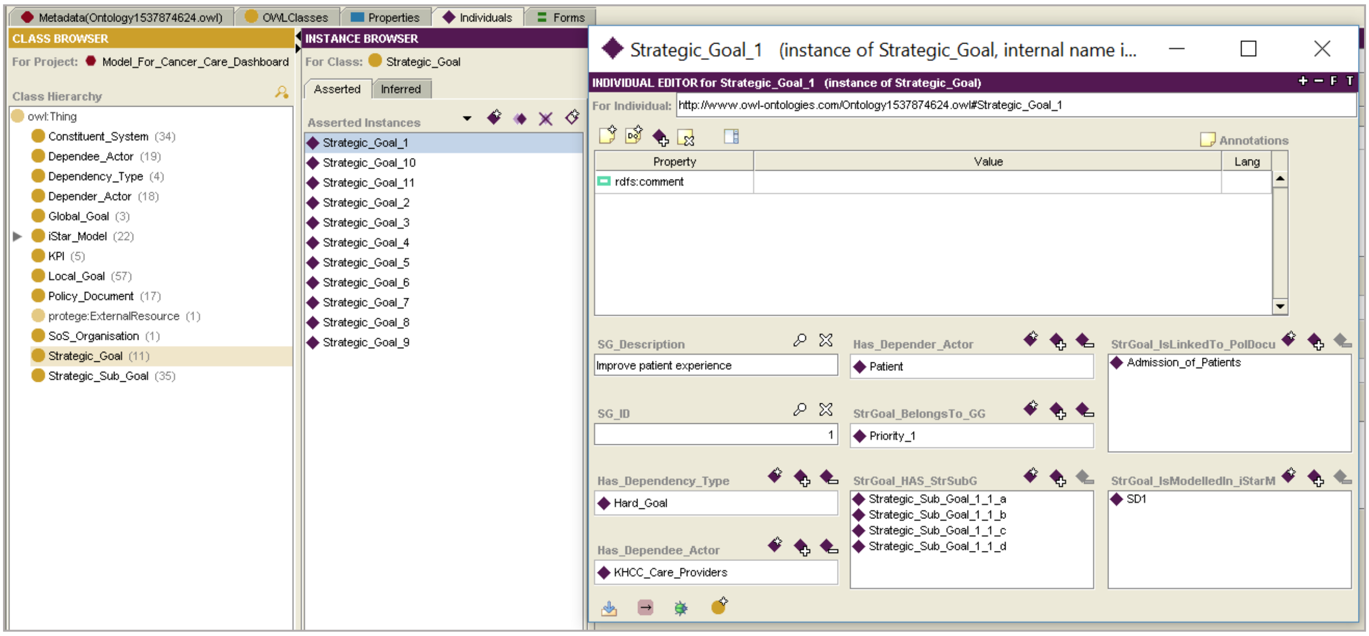

Figure 8. A Snapshot of the Ontology Instantiation of a Cancer Care SoS.

7. Conclusions and Future Directions

The OntoSoS.GORE framework utilises the i* goal-oriented framework along with ontology semantic representations in developing an Ontology-based Goal-Oriented Requirements Engineering framework for Systems of Systems, which aims at modelling and managing SoS goals at different levels: the SoS high-level goals and the CS-level individual goals. The research framework is applied to the Cancer Care domain from a systems of systems perspective.

This paper has presented a Semantic SGRI model in SoS context. The first part includes developing a GRI model that links the SoS global goals with the evolving local goals of the constituent monolithic systems and maintains the integrity and consistency of both the SoS-level goals and the CS-level goals, in an attempt to address the problem of managing goals in complex SoS arrangements.

The second part of the SGRI model represents an ontology-based system in SoS context to support the GRI model and semantically represent the relationships of the multiple levels of goals in an SoS arrangement linked also to corresponding policy documents and i* goal models. Building the ontology contributes to knowledge sharing and standardisation in SoS strategic goal modelling domain, informs the satisfaction and achievement of the global and local goals and paves the way for goals conflict detection and resolution.

Furthermore, a conceptual metamodel for SoS i* strategic goal modelling is presented to define the multiple goal-levels in an SoS arrangement, besides the relationships and linkages between these goal levels and corresponding components such as constituent systems, the organisation's policy documents and i* models.

In future work, a software tool that extends the ontology representation of SoS strategic goal modelling is being developed, and the use of reasoning offered by the ontological approach will be combined with conflict management mechanisms and strategies aiming at managing the process of modelling the SoS global goals and the individual local goals of its constituent systems, as well as detecting and resolving any inconsistencies or conflicts that may occur amongst goals in the different levels of the SoS arrangement.

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