

# Contribution Structures

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## Abstract

*The invisibility of the individuals and groups that gave rise to requirements artifacts has been identified as a primary reason for the persistence of requirements traceability problems. This paper presents an approach, based on modelling the dynamic contribution structures underlying requirements artifacts, which addresses this issue. It shows how these structures can be defined, using information about the agents who have contributed to artifact production, in conjunction with details of the numerous traceability relations that hold within and between artifacts themselves. It further outlines how the approach can be implemented, demonstrates the potential it provides for "personnel-based" requirements traceability, and discusses issues pertinent to its uptake.*

## 1: Introduction

Requirements traceability (RT) has been defined as: *"the ability to describe and follow information about the life of a requirement in both a forwards and backwards direction"* [10]. RT is fundamental for the management of change and evolving requirements when developing and maintaining systems and software. With the introduction and enhancement of tools that provide RT, such as DOORS [29], RDD-100 [1], and RTM [25], the mechanics are in place to establish lifecycle-wide RT. Despite the many advances, RT remains cited as a key problem confronting industry, and as a concern amongst the requirements engineering (RE) community.

Findings from recent work, which investigated the actual problems practitioners experience when they claim to have RT problems, indicated that the majority of these are *informational* in character [9; 10]. This work found problems mainly occur when the above tools are not used to control information about requirements that practitioners want to trace. In particular, inadequate *pre-requirements traceability*, caused by the paucity and unreliability of information about requirements production, was uncovered as a likely reason for RT problems in the longer-term. These informational issues are beginning to be addressed by RT models which delineate the information to record and link types to establish (see [13; 21; 28; 30]).

However, significant findings from this problem analysis were: (a) the lack of agreement regarding the quantity and type of information practitioners wanted to trace about requirements; and (b) the extreme importance they attached to personal contact and informal communication. The latter was not simply found to be a consequence of the first, to cope with information absence, but considered essential to account for the situated character of information needs. This enables any available information to be consolidated, supplemented, or questioned. It

reflects the fact that people are often the final authority about requirements and, as such, are frequently able to prevent potential RT problems. Nevertheless, the ability to find appropriate people was reported to be problematic in practice. We suggest this is because contemporary RT-related work, in its strive to supplant the need for human contact with extensive and traceable information records, does not prepare suitable foundations for this most basic of working practices.

In [10], the inability to locate and access the human sources of requirements, requirements-related information, and requirements-related work, was concluded to be the crux of the multifaceted RT problem. There, we recommended addressing this problem by making details about the social setting that gave rise to the artifacts produced in RE explicit, and so traceable. In [11], we proposed an approach to do this, based on modelling the *contribution structures* underlying requirements artifact, and discussed its applicability to RE in general and to quality improvements in particular.

In this paper, we provide more details of the approach, and show how concepts from the social sciences can provide insights which help to address the problem. In Section 2, we outline both the problem and approach we are taking. Fuller details are given in Sections 3 through to 5. In Section 6, we describe how the approach has been made operational, and illustrate how modelling contribution structures helps extend conventional notions of artifact-based RT with the selective traceability of associated personnel. We discuss the approach and mention our research agenda in Section 7.

## 2: Social infrastructure

In this section, we explain why there is a need to model the *social infrastructure* underlying RE, by which we mean the overall system of agents involved in the requirements production process and relationships they are involved in. We describe deficiencies with prevailing practice which make informed traces of participation untenable, summarise the requirements which arise from these, and outline the approach and its assumptions.

### 2.1: Scope & rationale

We restrict our concern to the issues of pre-requirements traceability and so to the traceability of information relating to the tangible artifacts produced and exchanged in requirements production. Traceability needs to be maintained between such artifacts to prevent what eventually ends up as a requirement being "black-boxed" in a formal requirements document. It provides the ability for such requirements to be re-examined from their source(s) and through their chain(s) of production. In this way, requirements are able to emerge in a more informed

and controlled manner than is possible with *post-requirements traceability* alone. We further limit our scope to that specific information which illuminates the social infrastructure underlying requirements production.

We limit our scope because our empirical studies found that practitioners predominantly claim to have experienced RT problems when, being unable to retrieve requirements information they want from a project repository, they have further been unable to identify those agents in a position to supply it. This was found to be caused by the way details of agent participation are currently recorded and maintained; a reflection of the absence of guidelines to achieve this in RE standards. So, although there have been advances in techniques and tools used to collect, structure, and retrieve as much information as possible about RE activities, there has been little focus on the participants.

## 2.2: Problems

In practice, we found information about RE participants, where not absent, was inadequately described and maintained. Typical records usually consisted of a list of names in an "author/owner" field of a document. Those documents which had been changed were generally characterised by the addition of further names, appended notes, or by official change request forms. This practice was found to compound RT problems, especially as the size and longevity of a project increased, as such records soon become unstructured, unwieldy, and inaccessible for analysis. We found it was not unusual for the end products of RE to lose details about who originally generated a requirement and who was involved in its refinement. This meant that important questions were often unanswerable, like: "Who is responsible for this piece of information?"; "To whom should I refer for more information?"; "Within the remit of which group do decisions about this piece of information lie?"; and "Who was responsible for copying this information into this document?" These shortcomings lead to questions that are answered by agents not best placed to do so. A repercussion is that agent commitment to developing artifacts, as well as to each other, becomes fragmented and lost over time. This suggests that details about RE participants is crucial pre-requirements information to collect for later retrieval.

Simply appending an "author" label to a document results in relatively coarse and static notions of ownership. These tend to refer to those who wrote the document as opposed to those who inspired or formulated the content therein. They neither account for situations in which many agents may have participated, nor for the nature and scope of their participation. In addition, they do not provide a suitable structure in which to represent changing patterns of participation as the document contents evolve. This suggests that any participation details collected need to be evolvable and need to indicate the status of those agents who are party to the production of artifacts, along with additional details like the mode of their participation.

## 2.3: Requirements

The above issues point to a need to maintain a detailed and dynamic model of those agents who have participated in the production of requirements artifacts. In addition, they imply that a dedicated approach is needed to guide the definition, redefinition, and use of this model. The basic requirements for

such an approach are:

- A means to differentiate the ways in which agents contribute to artifacts, which supplies the building blocks with which to model contribution structures.
- A way to account for the various relations between artifacts, to allow agents and artifacts to co-evolve.
- An underlying model which provides a suitable basis for reasoning with and about the information modelled by contribution structures.
- To be practical, the approach must address those issues likely to cause organisational resistance, such as the burden it is to place on the development team.

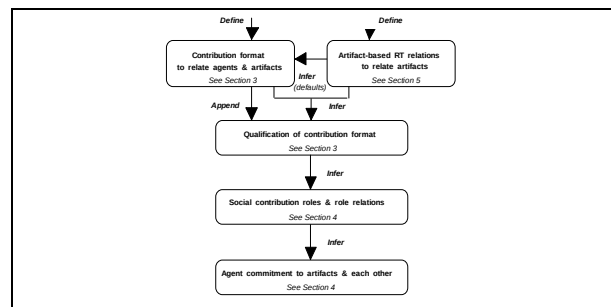


Figure 1: Steps of the approach.

## 2.4: Approach & assumptions

The steps of the approach are shown in Figure 1 and are described in the following sections. Basically, the approach involves linking tangible RE artifacts (*contributions*) to details of agents who have contributed to their production (*contributors*) using *contribution relations*. The term "contribution structure" refers to all the contribution relations defined for an artifact. The potential richness with which this can be described depends upon how the link between agents and artifacts is defined. As artifacts often depend on the existence of other artifacts, or are decomposed into component artifacts, this description also depends upon how well these artifact-based relationships are defined and taken into account. The social infrastructure underlying RE is described by the contribution structures of the artifacts it produces and their interrelationships.

We assume the artifacts are held in an on-line artifact repository which handles conventional artifact-based RT, since tools exist which deal with product interrelations and their traceability. We also assume that various agent details are held in an organisational repository, such as names and positions, and these could be configured to carry out any required forms of organisational modelling.

## 2.5: Related work

Although we are unaware of other research explicitly directed at the above issues, our work has been influenced by work in: (a) software process modelling, notably that exploring the nature of the relationships between agents, their activities, and their products [16; 17; 18; 31]; (b) information systems, like the issues involved in interpreting development from a social action perspective [14]; and (c) the sociology of science and technology, which examines how scientific facts and artifacts

are related to, and influenced by, the social structures from which they arose [2, 4; 20].

### 3: Relating agents & artifacts

The relation between agents and artifacts could be defined using terms like "contributed to" and "contributed by". However, these would not distinguish different types and degrees of participation, would lead to flat and coarse models of the contribution structure, and so not meet the basic requirements listed above. The crux of the approach is to define this relation in a way which differentiates the nature of each of the contributions and provides a basis for modelling granular and layered contribution structures. In this section, we present a scheme for doing this.

#### 3.1: Foundations

The scheme is derived from work in the area of *sociolinguistics* and, in particular, descriptive models of the interaction between language and social life. Such models aim to provide finer-grained schemes with which to describe and analyse the components of communicative situations than those provided by traditional dyadic models, like in [33]. Specifically, the scheme is based on Goffman's work on the nature of participation in social encounters [7; 8], and motivated by work on *framing* and *involvement strategies* [34].

Goffman's work is concerned with placing the production and reception of *talk* within an interactional framework, so it can be studied as a component of the full physical, social, and cultural environment in which it occurred. To enable such an analysis he decomposes the crude concepts of "hearer" and "speaker" into their underlying constituents, referred to as *participant roles*, which provide smaller elements for identifying and referring to participants. He refers to the set of categories obtained from the decomposition of "hearer" and "speaker" as the *participation framework* and *production format*.

As we are primarily interested in modelling those agents directly involved in requirements production, Goffman's notion of "production format" provides some insight. Here, he suggests 3 analytical capacities in which participants can "speak", which together clarify the notion of "speaker". He refers to these as:

- *Animator* - the transmitter or talking machine.
- *Author* - the composer of the lines.
- *Principal* - the motivator of the words or whose position they establish.

By layering and embedding these capacities he describes how information dependency can also be accommodated.

#### 3.2: Contribution format

We apply Goffman's frame analytic method to study the social organisation of RE, as requirements artifacts are produced and used within a social environment. This partitions the RE space according to participants and non-participants involved in either artifact production or reception. Although we only focus on those participants involved in production in this paper, we anticipate examining the other aspects at a later date. So, and in the spirit of Goffman, we use the concept of a *contribution format* to define the nature of the contribution relations. This delineates 3 fundamental capacities in which agents can contribute to artifacts, which together clarify the notion of

"contribution". These are as:

- *Principal* - those who motivated artifact production and whose position and/or belief is established by it, so responsible for its effect and consequences.
- *Author* - those who chose the artifact's structure and content, so responsible for its form and semantics.
- *Documentor* - those who recorded or transcribed the artifact's content, so responsible for its appearance.

#### 3.3: Further qualification

The approach recommends using attributes to specify further details about the above capacities. As we are presently examining ways in which this can be done as a by-product of the approach, we only mention some preliminary attributes below.

Since signatures are all-pervasive in the development process, signifying the authorisation of artifacts and a transfer of commitments, the principal capacity can be qualified to reflect such sign-off procedures, whether:

- *Approved* by principal.
- *Pending approval* by principal.
- *Not approved* by principal.

The author capacity can be qualified according to the relations the artifact in question has to other artifacts:

- If no relations exist, the authorial status is *Creator*.
- If relations exist, the authorial status is determined relative to the broad communicative function of each relation, and further by their communicative purpose.

More details about this are provided in Section 5.3.

Those who record information have various types and degrees of commitment towards it. This can be reflected in the end result and its reliability. The documentor capacity can be qualified to reflect the mood of transcription, adapting the mood types of [24], so indicating whether the record maker or record keeper is:

- *Certain* the content is true (i.e., *emphatic* mood).
- *Believe* the content is true (i.e., *period* mood).
- *Indifferent* to the content's truth value (i.e., *quotative* and *report* moods).
- *Uninformed* about the content's truth value (i.e., *indefinite* and *question* moods).

### 4: Developing contribution structures

In this section, we describe how the information captured using the above scheme can be manipulated to model richer details about contribution structures. We show how it provides a picture of how agents are related to both artifacts and to each other. We also explain how this imparts details about the *individual* and *collective commitment* of agents to artifacts, and about their *social commitments* to each other, as differentiated by [5].

#### 4.1: Foundations

Levinson points out that, when an agent "speaks" in one of the previous capacities, they are also active in a *social role* from which the words take their authority [23]. He maintains that these roles need to be distinguished because, whereas an agent's capacity is likely to remain relatively constant, the social role in which they are active is rather more fluid. This means the same

agents often relate to each other in different ways as their roles change throughout a project, even with respect to a single artifact. Levinson's extensions we are concerned with are his distinctions between *basic* and *derived* production roles. Regarding Goffman's capacities as basic roles, he suggests how these could be re-assembled to derive more complex roles which reflect those attended to in actual language use.

## 4.2: Contribution roles & commitments

Following Levinson, we distinguish between the 3 capacities of the contribution format and the derived social contribution roles that can be inferred from these. These extensions are important because: (a) the notion of "social role" is central to the study of social structures [26]; (b) they provide a handle to explore relations that exist between participants using social network analysis [32]; and (c) they can reveal information that assists with issues of *communicative competence* [15], *social accountability* [3], and *person and social deixis* [22]. Figure 2 shows a simple and example role derivation.

The relationships between agents themselves, and how they vary with respect to different artifacts, provides information about role relations that have been dynamically formed and reinforced in practice. They can help explain actions and manage expectations about inter-agent behaviour. They also tell us about their ensuing social commitments, information rarely captured by formal organisational structures and fixed role models of organisation theory, which enables analysis of informal organisational structures and roles. These relationships can also impart information about: direct and indirect contributors; local power, solidarity, and emerging group alignments; recurrent or occasional collaborators; possible substitute agents; and so forth.

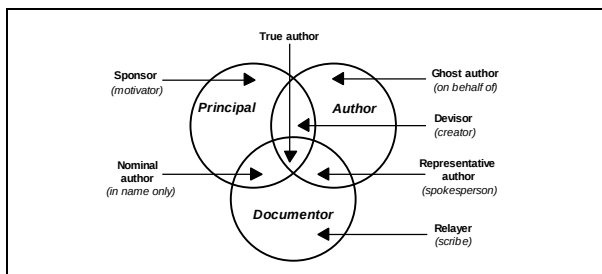


Figure 2: Contribution capacities & roles.

Knowledge of an agent's contribution role with respect to an artifact also provides rudimentary information about individual or group commitments to it, by which we mean about those aspects they can be called to account for. Such information is useful in filtering the retrieval of agent sources to reflect the nature of queries or change proposals.

## 4.3: Example

To illustrate these extensions, consider the case where Olly has decided "*the sensor needs to be polled once every twenty microseconds*", and Dave has written this down as a requirement. Here, Olly is both the principal and author of the written requirement, whereas Dave is its documentor. From this, we can infer that Olly and Dave stand in a devvisor/relayer role relationship with respect to the requirement. As the relayer

of the requirement, all Dave is committed to is its physical appearance, so he can deal with any typographical queries or change requests. Queries like "Why twenty microseconds?", or change proposals like "Why not make it once every ten?", need recourse to Olly, as committed to the actual content and the one whose position would be challenged by any change. Now, if Olly and Dave stand in a devvisor/relayer relationship for all the artifacts they jointly contribute to, the information that can be inferred about the social relationship and commitments between these 2 agents will contrast with that inferred if this were only a once-off. In pursuing such an approach further, a variety of social details can be disclosed that would otherwise remain hidden.

## 5: Relations between artifacts

If one artifact is a subsequent specialisation of another, it seems reasonable to assume that some responsibility for the resulting artifact is retained by the original contributor(s). Our approach therefore deals with the relations that exist within and between artifacts to account for the linked and embedded nature of contributions. In this section, we outline a categorisation for artifact-based traceability relations, and indicate how these both effect and clarify the relationships that exist amongst agents.

### 5.1: Categories

The relations an artifact has to other artifacts defines its *artifact space*. They make it possible to distinguish "original" artifacts from copies and so forth. We suggest there are 3 broad categories of relation, which describe alternative structures, and enable different types of RT:

- *Temporal* relations - which describe the historical structure of development and provide the means to trace requirements history.
- *Developmental* relations - which describe the logical structure of development and provide the means to trace requirements flow-down.
- *Auxiliary* relations - which describe the additional ways development information is related and provide supplementary structures and forms of traceability.

The first 2 categories capture the *macrostructure* of the RE process. The relations used here are fairly well established and used to provide traditional forms of RT. The third category captures the *microstructure* of the RE process. We are mainly concerned with developing a suitable set of relations here because: (a) there is no well established set in use; and (b) it is these that have subtle, though crucial, effects on contribution structures. The 2 types of auxiliary relation we are most concerned with in this paper are those of *containment* and *connectivity*.

### 5.2: Containment relations

By recording the relation between a composite artifact and those other artifacts which are its components, we can make the task of assigning the contribution format much easier. Though clearly a composite artifact may have different agents acting in identical capacities with respect to its components, it is a default assumption they are the same, until declared otherwise. As a containment relation is purely structural, no further leverage is to be gained from clarifying the reason for containment. These

relations lead to a layering effect and enable multiple contribution formats to be defined, interrelated, and managed.

### 5.3: Connectivity relations

To inform a useful set of connectivity relations, one which highlights the different ways in which these relations impinge on the determination of contribution structures, we look to work in *text linguistics* [6]. This area examines the ways in which textual occurrences are related, but we only focus on the purely text-centred relations of *cohesion* and *coherence* for our purposes.

Cohesion relations are those which deal with how the components of a surface text are mutually dependent and "stick together", so deal with *connectivity at the surface* (see [12]). Coherence relations are those which deal with how the components of a text are mutually accessible and relevant, so deal with *connectivity of the underlying content*. According to [19], work on coherence includes theories of discourse relations, theories of discourse structure, and theories which combine both of these.

Our set of connectivity relations draws upon all the above work, which deals with connectivity at the sentential level of text, and extends the underlying concepts to the level of artifacts. For this reason, we do not claim to have a conclusive set, but a working set to examine the impact of such relations on modelling contribution structures. Our set of relations is divided into 2 groups, which reflect the broad *communicative function* a connectivity relation can serve, either to:

- *Reference* - where the physical content of the source and target artifacts is linked but does not overlap.
- *Adopt* - where the physical content of the source and target artifacts is linked and overlaps in some way, either directly copied or manipulated.

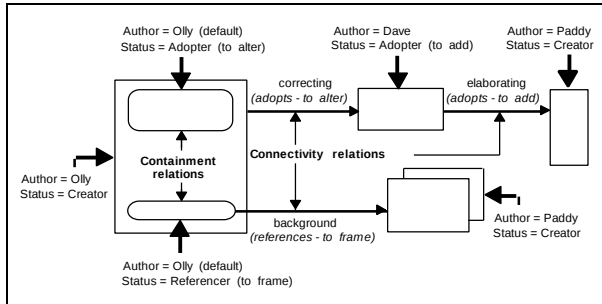


Figure 3: Connectivity & containment relations.

In this paper, we do not describe how these groups are further decomposed to enable more granular forms of analysis, based on the identification of cohesion and coherence relations. However, we point to this in Figures 3 and 6. Also, in Figure 3 we do indicate how these relations can reveal the agent chains of dependency that emanate from common artifacts. This illustrates how the authorial status of an artifact depends on the connectivity relations it has to other artifacts.

## 6: Implementation of the approach

In this section, we describe the tool we have prototyped to experiment with and refine the approach, and we further

illustrate its operation using a scenario.

### 6.1: Tool support

We have developed a prototype in which conventional artifact-based RT can be extended with associated contribution structures. A schematic is given in Figure 4. We suggest it could be supported by minimal extensions to existing tools, notably to those used for document preparation. It assumes that requirements artifacts are held in an on-line repository which manages the artifact-based traceability relations of Section 5. The connectivity and containment relations are defined in the artifacts themselves, using extensions to descriptive markup, and their end points are hypertextually linked. For instance, this could be done using the *Hypertext Markup Language* (HTML) instantiation of the *Standard Generalized Markup Language*, by introducing high level link semantics of "references", "adopts", and "contains".

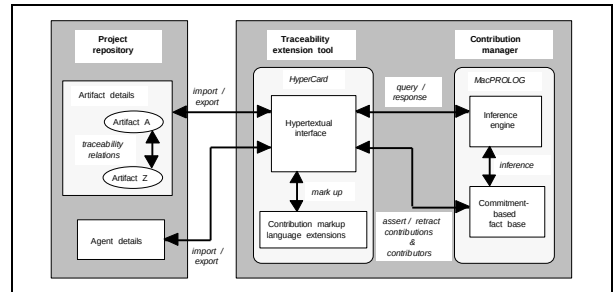


Figure 4: Tool architecture.

The *traceability extension tool* provides a hypertextual interface to the project repository. It enables interactive definition of additional artifact-based traceability relations, agent details, and contribution formats, which are reflected in the underlying markup of the artifact. The primitive elements we use to do this could easily be implemented as extensions to the HTML Document Type Definition.

The *contribution manager* is responsible for modelling and maintaining contribution structures. It contains rules that use the information captured by the markup to build models, determine default capacities, social roles and commitments, and to enable more complex deduction. So, by querying artifacts or agents, related artifacts, agents, and any derived information can be accessed. Each item is a hypertextual trace anchor providing a navigational springboard from which to instigate forms of traceability.

### 6.2: Example scenario

We use the scenario in Figure 5 to illustrate some of the information obtained from modelling contribution structures and to indicate how this can inform practice. We mention the details that can be uncovered about the social dimension of the requirement produced in the scenario and explain how this can be used to provide an overall picture in which to understand the problem with it, locate those involved, and address the problem with suitable agents. It may be helpful to refer to Figure 1.

Firstly, the artifact-based RT relations are defined. Note that the temporal and developmental relations are the ones specified

and maintained by conventional repositories providing artifact-based RT. Figure 6 shows the additional containment and connectivity relations between the artifacts produced, as represented by the tool. On querying paragraph y, these relations locate the email message as the reason for the change from paragraph x, whilst the other relations retrieve the various derivation paths to its origin as the requirement in the wish list.

A project began with a wish list, reporting needs from users, which was written up by a scribe and authorised by a project leader. The project leader held a meeting, of which an audio record was made, to discuss the list with stakeholders. A transcript of the meeting was made by secretaries. From these documents an initial requirements specification (RS) was written by some requirements engineers. After circulation, a revised version of the RS was written, where an alteration had been made to the requirement specified in paragraph x as a result of an email message from the Managing Director's Assistant to the project leader. In this message, the M.D. passed on a verbal change request she received from user 1. This corrected version of the requirement is in paragraph y of the revised RS. Unfortunately, member 2 of the requirements engineers introduced an error when carrying out this change, because he did not acknowledge the subtlety of the wording in the fragment of the email message concerned.

Figure 5: Scenario text.

Secondly, Figure 6 illustrates how the contribution formats have been defined. The underscores signify those capacities which have been determined from containment relations. This means that the artifacts retrieved following the query can be augmented with associated contributors, further indicating the capacities in which they have contributed. This information points out: (a) although member 2 is the author of paragraph y, he is altering member 1's authored contribution of paragraph x due to the M.D.'s email message, thus revealing authorial dependencies; (b) when member 2 first became involved, as both an individual and group member, and in what capacity; (c) who was involved in the same capacities as member 2 with the previous version of the requirement, member 1; (d) member 2's relation to and collaboration record with member 1; etc.

As explained in Section 4, the tool can determine social contribution roles, role relations, and commitments. This means we are alerted to: (a) the fact that the M.D. was acting on behalf of user 1 when requesting change, so is only superficially the change instigator, as their respective social roles of ghost author and motivator for the email fragment delineate where their commitments lie; (b) the basis for this role relation being their joint collaboration in the meeting, to which member 2 was not party; (c) the authority for the change, as user 1 is the original deviser of the requirement in the wish list, so ultimately committed to its realisation and effect; etc. We do not pursue the scenario here. What is obtained from modelling contribution structures is the subject of a further paper.

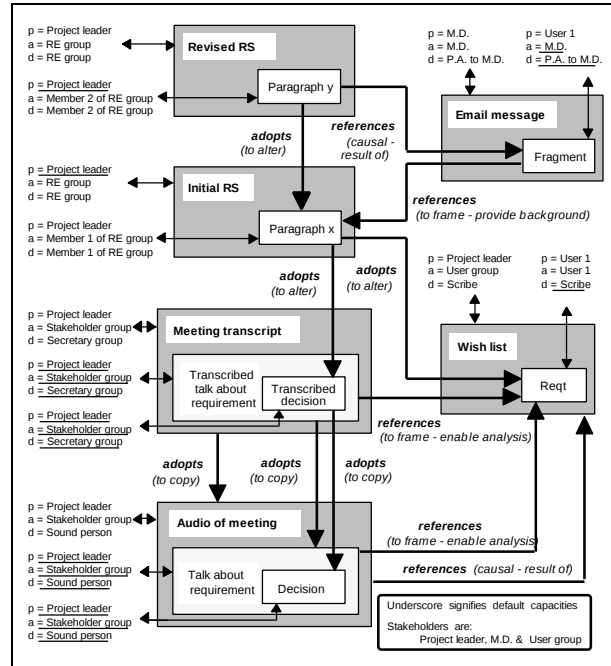


Figure 6: Connectivity relations, containment relations, & contribution formats of the scenario.

## 7: Discussion

In this section, we discuss the benefits and issues with the approach, and refer to our research agenda.

### 7.1: Strengths

The approach provides a practical way to deal with the absence of required information, supplement documented information, and deal with the human side of requirements change and management. This is because it makes it possible to selectively identify the most appropriate agents to provide information or involve in the change process. This helps ensure requirements stay modifiable and maintainable. In addition, priority access structures can be constructed to guide these activities, since the complex nature of the underlying contributions has been handled in a disciplined way. Also, we believe the approach provides a better basis for the many speech-act-based forms of analysis that are often carried out to examine the communication that has taken place in development. This is because knowledge of the underlying social network is a prerequisite for such analyses; agents communicate as the incumbents of social roles, which impacts illocutionary force. The ability to identify implicit and derived group contributions also means that more suitable forms of group-based analyses can be invoked where appropriate.

### 7.2: Limitations

A potential issue, and one we are looking into, is that of organisational resistance to the approach. This is because clearer patterns of accountability has both positive and negative

aspects (see [27]). The costs and benefits to RE participants is another issue, though we believe the extra effort the approach requires is minimal and practical. In addition, we have yet to properly examine the issues involved in scaling the approach to problems of industrial size. Other problems may arise not only from reliance on people to instantiate the contribution format, but from their ability to characterise it according to our scheme. However, this scheme is only an initial one designed to evaluate the basic ideas, so the actual terms and number of terms we have chosen are not too critical. An alternative approach would be to uncover the contribution capacities the participants themselves orient to whilst in the process of producing requirements artifacts. Similarly, to appeal to any institutional roles, role-relations, and commitments that are found to be prevalent in the domain of RE. In-depth field studies of working practices would be essential.

### 7.3: On-going & future work

The approach requires more refinement and critical evaluation. To do this, we are enhancing the tool to carry out case studies with practitioners. Future work will involve examining issues such as: (a) how the contribution format could be automatically captured; (b) how tools could be integrated to automatically instigate communication with the agents retrieved as a result of trace queries, according to preferred protocols; (c) how the approach could be coupled with schemes supporting requirements discussion and negotiation; and (d) the possibilities that arise for project management, as by linking contribution structures to organisational models, predefined and actual organisational structures could be compared, strategies could be found to integrate new personnel and deal with ramifications of any who leave, etc.

### 7.4: Summary

RT is a key technology for managing development in the face of evolving requirements. In this paper, we have explained the value that can be gained by tying people into the RT equation, particularly since this provides the firmest foundation for dealing with the many issues relating to pre-requirements traceability. We have outlined an approach to model and keep track of the contribution structures underlying evolving requirements artifacts. We have further indicated how the approach provides the ability to extend conventional forms of artifact-based RT with accompanying contribution structures, which thereby offers a way to accommodate the diverse forms of personnel-based RT practitioners were found to need in our empirical studies. Finally, we have described how this approach is being implemented, refined, and evaluated.

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