Applying Multidimensional Scaling for Responsibility Distribution between Objects
——Linking Conceptual Activity Model and Class Diagram

AKIO IDA1,a) SHIGEO KANEDA2

Received: August 16, 2014, Accepted: February 4, 2015

Abstract: In the field of systems development, linking models are expected for each process to improve understandability and productivity. For example, when Soft Systems Methodology is applied to the uppermost process in a stream and an Object-Oriented Approach is applied to the upstream and midstream processes, if the conceptual activity model of the former and the class diagram of the latter can be linked, then we can build systems that are intuitively simple to understand, easily maintained, and reusable. This paper considers a system’s root definition and proposes an approach for spatial arrangement through multidimensional scaling of responsibilities extracted from a conceptual activity model. We tested our proposed approach on several samples and obtained a spatial responsibility arrangement that is quite reasonable. We believe this approach has the potential to bridge artifacts from the uppermost stream, including conceptual activity models and midstream artifacts represented by class diagrams.

Keywords: Soft Systems Methodology, conceptual model, Object-Oriented Approach, responsibility for knowledge, responsibility for behavior, Multidimensional Scaling

1. Introduction

There is a growing consensus among those in the field of systems development about the requirements for increasing diversification and complexity, and therefore, model- and component-based development processes are employed to facilitate prompt and flexible implementation. For instance, since a prototype can be a process where Soft Systems Methodology (SSM) is employed in the uppermost process to achieve a consensus among the parties involved on objectives, an Object-Oriented Approach (OOA) is applied in the analysis and design stage to achieve them. By linking the obtained models using SSM in the uppermost stream, the OOA models are expected to significantly contribute to achieving those objectives.

However, currently no method links artifacts from such uppermost processes as SSM conceptual activity models and those from such upper- to midstream processes as OOA class diagrams.

Conversely, multidimensional scaling (MDS), which was developed in the field of psychology, is proving to be extremely useful for obtaining the geometrical representation of potential data structures. It has been recently used in many areas, such as marketing and behavioral science, and has also attracted significant attention in the big data boom. A previous study proposed MDS to evaluate OOA structural patterns [1]; however, no examples have demonstrated its use for linking SSM and OOA models.

In this paper, we extract both knowledge and behavioral responsibilities from the root definition of SSM relevant systems, and propose a draft standard for easy quantification of the dependency levels between them. We propose an approach that links SSM and OOA models by analysis using a non-metric MDS, which is a responsibility relationship matrix, and the spatial arrangement for the responsibility distribution of objects.

The remainder of this paper is organized as follows. Related works are discussed in Section 2. In Section 3, our proposed approach is explained by an example. In Section 4, we add consideration on reading and using our proposed approach’s output. Section 5 reports the application results of our proposed approach with a different example. Finally, we state our conclusions in Section 6.

2. Overview of Related Research

2.1 Soft Systems Methodology

In situations where a problem is not clearly defined, the SSM process obtains modifications of the opinions of stakeholders’ (i.e., people with different viewpoints or value systems allow each other’s viewpoints or value systems to coexist during extensive debate) leading to problem resolution [2], [3].

The following are the outlines of SSM’s 7 stages: The 1st stage identifies the problem situation. The 2nd expresses it. The 3rd defines the relevant systems. The 4th is a conceptual modeling of the defined systems. The 5th compares the models and the real...
world. The 6th identifies desirable and feasible changes. The 7th stage takes action to improve the problem situation.

In the 4th stage, a conceptual activity model*1 (conceptual model: elemental activities required to achieve a purpose) is developed from the root definition of a relevant system (purposeful human activity system) that is selected from multiple candidates. In this paper, the authors assume that the system development process (such as the Rational Unified Process) is applied to implement the 5th and subsequent stages. The obtained conceptual activity models are linked to subsequent models of the 5th stage.

2.2 Object-Oriented Approach and Responsibility Distribution Problem

In OOA, responsibility is encapsulated for the knowledge necessary to satisfy the responsibility for the behavior required from a certain object. In this manner, it contributes to building systems that are easy to maintain, reuse, and scale by reducing the dependency (coupling) on other objects while increasing the objects’ strength as modules.

Therefore, object identification and appropriate responsibility distribution are critical, and many rules and guidelines have been proposed, e.g., BCE by Jacobson [4], Wirfs-Brock’s role stereotypes [5], Larman’s GRASP [6], and Martin’s SOLID principles [7]. However, these examples only provide general standards or guidelines for responsibility separation, without offering any tips about individual problems.

Some small-scale examples exist. Consider the example of developing a billiards game simulator through OOA. Determining such a simulator with just the above guidelines is difficult because the following questions must be answered. Under what class of responsibility should ball-collision detection be considered? How should the post-collision energy exchange be viewed?

One problem with OOA is that the suitability of the responsibility distribution is only evaluated after the structural and behavioral modeling of a use-case realization. We believe that it is possible to outline the responsibility distribution to objects at an earlier stage.

2.3 Multidimensional Scaling and Spatial Responsibility Distribution

MDS can be broadly divided into two types: metric and non-metric. A metric MDS is a technique for interval scale data that geometrically represents the structure hidden in the data in the space of a few dimensions. A non-metric MDS expands metric MDS by also considering ordinal scale data [8].

To clearly understand MDS, consider a map of the Japanese island of Hokkaido. The distances between its cities can be simply obtained using a ruler. If only the distance relationships are approximately identical to those between the actual cities on the map. In this example, although the directions also match the actual map, that result is merely coincidental.

MDS is not used to visualize structures that are already known; it obtains distance relationship data (both acceptable similarity and dissimilarity data) for pairs of objects and arranges them in a space with a minimum number of dimensions (up to three is preferable for readability).

J.B. Kruskal’s method [8], a type of non-metric MDS, uses the stress values as the goodness of the fit index for spatial arrangements. Stress values broadly correspond to the goodness of the fit evaluation, as outlined in Table 2 [8], [9].

3. Proposed Approach

Based on these situations and outcomes, this paper proposes an approach that uses MDS to link SSM and OOA models. We assume that an object-oriented development process (such as the Rational Unified Process) is applied later to the implementation of SSM’s 5th stage*2.

We propose a draft standard to extract the responsibilities for knowledge (RFKs) and responsibilities for behavior (RFBs) from each node of the conceptual activity model that is required to realize the root definition of a relevant system. We also propose easy quantification of their dependency levels.

In our proposed approach, RFBs are defined as the required behaviors to realize the root definition of the relevant system, and

---

*1 In this paper, we use “conceptual activity model” to distinguish it from the “conceptual model” in the object-oriented approach.

*2 Activities that already exist in the traditional SSM is not included in this proposal.
RFKs are the required knowledge for achieving the RFBs. In each node of the conceptual activity model, a RFB takes the form of an action verb and is a candidate for the operation for an object. A RFK takes the form of a countable noun or a noun phrase, and is a candidate for an object or an attribute.

Using a non-metric MDS, we analyze the responsibility dependency level matrix and attempt the spatial arrangement of responsibilities. Figure 2 shows an overview of our proposed approach. Step 1 extends the activities in SSM’s 3rd stage. Step 2 extends the work in its 4th stage. Steps 3, 4, and 5 are additional steps to the legacy SSM. Step 6 adds viewpoints from the spatial arrangement of the responsibilities.

As shown in Fig. 2, our proposed approach extracts responsibilities from the conceptual activity model that was developed from SSM’s root definition. The dependency levels between the responsibilities are obtained and a spatial responsibility arrangement is acquired. The approach then uses this result as a reference for subsequent SSM stages and OOA class diagram generation. We explain the process of our proposed approach using some examples below.

3.1 STEP 1: Describing a System’s Root Definition

System requirements basically define “when,” “by whom,” and “what for (why),” a system is used. For instance, in a use case model, “when” corresponds to the business event, “who” to the actors, and “what for” to the use case. On the other hand, in SSM a representation in the following format is termed a root definition of a relevant system: “a system to do X, by Y, to achieve Z.” Representing “thought activity” using a root definition is important to guarantee recoverability, which is an academic standard in SSM [2].

Our proposed approach adds information regarding “who” (W) to the SSM root definition as the format to define requirements in SSM. This “who” (W) is the customer defined in the CATWOE analysis of SSM’s 3rd stage and uses the following format: “a system where W does X by Y to achieve Z.” Adding W facilitates the extraction of each node of the conceptual activity model as an action sentence by clarifying the subject as the actor. The following are examples of root definitions used in our proposed approach:

**Example 1:** “A system where parents who are considering enrolling their child in a tutoring academy (W) do a comparative investigation (X) by searching for tutoring academies, subjects, locations, tuition fees, special features, and tutors (Y) to select an academy (Z).”

**Example 2:** “A system where a billiards enthusiast (W) learns how to strike a ball (X) by simulating the game on a computer (Y) to improve her skill (Z).”

3.2 STEP 2: Development into a Conceptual Activity Model

A relevant system’s root definition encapsulates its functional requirements. However, because it contains insufficient information, the responsibilities required by the system components cannot be extracted from such a simple definition. Therefore, we developed a conceptual activity model from the root definition in modeling sessions between these involved persons, e.g., those who request or provide system development.

A conceptual activity model (CM) expresses the activities to achieve the means (Y) which expressed in the root definition. The number of nodes of a CM is recommended approximately 7 ± 2. Each node of the CM expresses a predicate, its subject is W (but not written). The node format is action verb (V) + a countable noun (O) or V + noun phrase (O). In Japanese, the format is “O を V する.” If relations of “owner-possession” are recognized between the countable nouns included in the noun phrase, you must constitute it by connecting those countable nouns with Japanese particle “の”.

Figure 3 is an example output of the conceptual activity model
for example 1, which is developed from the root definition in this step.

3.3 STEP 3: Extracting Responsibilities from the Conceptual Activity Model

We extracted countable nouns and verbs from each node of the CM as RFKs and RFBs, respectively. This is considerably easier than extracting objects from a Japanese language requirement specification. This is because a conceptual activity model follows the format, “V (action verb) O (countable noun),” unlike the unformatted requirement descriptions in Japanese, and because of the nature of Japanese, which contains many existential clauses (not action clauses) [10].

In previous research, we clarified the correlation between English word classes and class diagram elements [11]. Class or attribute names are countable nouns, and operation names are action verbs. Even if it is an action verb, however, the thing that should record the action’s result assumes it a class. It is difficult to judge quickly whether the countable nouns in predicates are class or attribute names. However, below in Section 3.6, we apply MDS and consider the spatial arrangements of responsibilities. Therefore determining whether they are classes or attributes, is not necessary at this step. Here we simply regard countable nouns and action verbs as RFKs and RFBs, respectively.

Table 3 shows the extracted RFKs and RFBs in this step.

3.4 STEP 4: Estimating Dependency Levels among Responsibilities

Since the present approach uses MDS at a later step, the dependency levels among all responsibilities were extracted in Section 3.3 because the object, attribute, and operation candidates collectively need to be quantified.

If the dependency levels are estimated manually, a very convenient method is desired. We chose the following standard for quantification based on a trial and error process. Since the values only have to satisfy an ordinal scale depending on the strength of the dependency, integral values 0–4 (five levels) were used. However, because 4 (strongest) denotes the dependency level between identical responsibilities, it is used as the default value for diagonal elements. 0 signifies an undetermined relationship. Since we do not display diagonal elements and 0, they are not featured in the tables below. The aim of this quantification is to obtain ordinal scale data that is satisfied among all responsibilities for the following quantification standards. In order to achieve this goal, we assume dependency levels, among RFKs and RFBs, which must have an ordinal scale data that is satisfied among all responsibilities for the tables below. The aim of this quantification is to obtain or-

3.4.1 Quantification of Dependency Levels among RFKs

This quantification standard is based on the idea that when a couple of RFKs (countable nouns) have “owner-possession” relation then they are depending on each other. We think such RFKs should be placed closer to each other. Actually, in a class diagram, when RFK A owns RFK B, RFK B is modelled as an attribute of RFK A. Also, when RFK A owns RFK B, the relation between RFK A and RFK B is modelled as a “has_a” association. Therefore we evaluate that there is dependency between RFK A and RFK B.

Now focused on a Japanese case particle ‘∅’ in the quantification to estimate dependency levels between RFKs. ‘∅’ frequently expresses an affiliational or possessional relationship between two countable nouns at the predicate in the nodes of Japanese written in conceptual activity models. In this case the dependency levels between RFKs (i.e., countable nouns) linked with these particles can be considered strong. In other words, the dependency level between two countable nouns connected ‘∅’ can be quantified at a relatively strong-level.

For example, to realize Register lecturer in charge of session a lecturer has to be determined before the session is o-

Register lecturer in charge of session

Table 4 shows the standard that we employed, and Table 5 shows the results obtained for the dependency levels between RFKs based on it.

3.4.2 Quantification of Dependency Levels among RFBs and RFKs

This quantification standard is based on the idea that verbs that manage the lifecycles of certain nouns should be placed closer together than other verbs that do not manage their lifecycles. These responsibility dependency levels are obtained through CRUD, which is an acronym for Create, Read, Update, and Delete, the four basic functions in persistent object software handling. A Create or Delete controls the lifecycle of its target; therefore it is assigned the second highest score (i.e., 3). A Read refers only to

Table 3

<table>
<thead>
<tr>
<th>Extracted RFKs</th>
<th>Extracted RFBs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training session</td>
<td>Regular training academy</td>
</tr>
<tr>
<td>Subject</td>
<td>Regular subject</td>
</tr>
<tr>
<td>Preparation for students</td>
<td>Regular preparation</td>
</tr>
<tr>
<td>Tuition fee for preparation</td>
<td>Regular tuition fees</td>
</tr>
<tr>
<td>Special features of preparation</td>
<td>Regular special features</td>
</tr>
<tr>
<td>Session of preparation</td>
<td>Regular session</td>
</tr>
<tr>
<td>Register in charge of session</td>
<td>Regular session location</td>
</tr>
<tr>
<td>Location of session</td>
<td>Regular tuition academy information</td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th>Dependency Level</th>
<th>Minimum</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Knowledge</th>
<th>Subject</th>
<th>Property of subjects</th>
<th>Tuition fee for preparation</th>
<th>Specialty features of preparation</th>
<th>Session of preparation</th>
<th>Location of charge</th>
<th>Location of session</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Knowledge</td>
<td>Subject</td>
<td>Property of subjects</td>
<td>Tuition fee for preparation</td>
<td>Specialty features of preparation</td>
<td>Session of preparation</td>
<td>Location of charge</td>
<td>Location of session</td>
</tr>
<tr>
<td>Register lecturer in charge of session</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Knowledge</th>
<th>Subject</th>
<th>Property of subjects</th>
<th>Tuition fee for preparation</th>
<th>Specialty features of preparation</th>
<th>Session of preparation</th>
<th>Location of charge</th>
<th>Location of session</th>
</tr>
</thead>
<tbody>
<tr>
<td>Register lecturer in charge of session</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6 Quantification standard for dependency levels among RFBs and RFKs.

<table>
<thead>
<tr>
<th>Dependency level</th>
<th>Meaning</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 or D-3</td>
<td>Held responsibility for behavior creator or change and responsibility for knowledge</td>
<td>Between Register subject and Subject in Subject is created when the Subject is registered.</td>
</tr>
<tr>
<td>L-2</td>
<td>Held responsibility for behavior updates and responsibility for knowledge</td>
<td>Between Register session location and Session when a session location is created, the Session is updated.</td>
</tr>
<tr>
<td>H=1</td>
<td>Held responsibility for behavior needs and responsibility for knowledge</td>
<td>Between Register provision and Tutoring provision, Register provision and Subject, the Tutoring academy and the Subject are needed when a Provision is created.</td>
</tr>
<tr>
<td>2</td>
<td>None of the above</td>
<td></td>
</tr>
</tbody>
</table>

Table 7 Obtained relationship levels between RFBs and RFKs for Example 1.

3.4.3 Quantification of Dependency Levels among RFBs

This quantification standard is based on the idea that verbs that directly use it for certain verbs should be placed closer than verbs that do not use it or use it indirectly.

We obtained the quantification of the dependency levels between RFBs from the connection statuses between activities in the conceptual activity model. For example, in Fig. 2, the node, Register subject provided by tutoring academies directly uses Register tutoring academies and Register subject.

The dependency levels between the RFBs obtained by this quantification standard do not contribute to a better spatial arrangement, but at least they are not detrimental. This quantification standard gives a value that exceeds 0 for the pair of action verbs that are directly linked with an arrow. Of course, as we delve further, we might find a dependency level that exceeds 1, even between action verbs noted in the nodes of the conceptual activity model that are linked indirectly by arrows. Furthermore, we believe that a dependency is needed from the caller node to the called node but not in the reverse direction. This quantification standard includes the above consideration. This explains why the scored value is not 3, even though two nodes are linked directly in the conceptual activity model.

Table 8 shows the employed standard, and Tables 9 and 10 show the dependency levels between the RFBs obtained from Example 1.

3.5 STEP 5: Applying Non-metric MDS

Once the dependency levels between the responsibilities have been quantified, and the lower triangular matrix has been obtained from the square matrix, MDS is applied. Since the values for the responsibility dependency levels used in this approach are on an ordinal scale, a non-metric MDS must be selected. The Dependency levels are regarded as approximations between responsibilities.

Various methods exist for the application of MDS, such as the use of statistical packages including SPSS or open source products including the R language for statistical analysis. However, we decided to use a manually written program based on the implementation of Kruskal’s method in Ref. [12]. As the contents are well known in the case of a manually written program, this will be useful for the incorporation of MDS into a conceptual activity model editor in future studies.

Processing the data of Table 9 with MDS obtains the spatial responsibilities arrangement in Fig. 4.

3.6 STEP 6: Evaluating Spatial Responsibility Arrangement

Figure 4 clearly shows that Tutoring academy and Subject are separated and that responsibilities Tuition fees for provision and Special features of provision are exactly in the middle of the imaginary line that connects the two classes. In Fig. 4 RFKs are displayed with upper or under lines.

The distance between the responsibilities in the spatial arrangement obtained by our proposed method is not a difference in kilometers, like the spatial arrangement of cities; rather, it is the difference in the dependency level between responsibilities. Closely arranged responsibilities have a strong relationship with each other and should be placed in the same class when they are encapsulated. If they are not placed in the same class, perhaps the degree of coupling to each other shows very high multiple classes. On the other hand, separately arranged responsibilities have a weak dependency relationship, suggesting that they need not be placed in the same class when they are encapsulated.

Information of the spatial arrangement is effective as a clue for the distribution of the responsibilities to the objects, which is an important matter in the Object-Oriented Approach.
Table 10  Obtained dependency levels between responsibilities for Example 1 (Overall view for Tables 5, 7, and 9).

<table>
<thead>
<tr>
<th>Responsibilities</th>
<th>Tutoring academy</th>
<th>Subject</th>
<th>Provision by academy of subjects</th>
<th>Tuition fee for provision</th>
<th>Special features of provision</th>
<th>Session of provision</th>
<th>Lecturer in charge of session</th>
<th>Location of session</th>
<th>Register tutoring academy</th>
<th>Register subject</th>
<th>Register provision</th>
<th>Register tuition fees</th>
<th>Register special features</th>
<th>Register location</th>
<th>Register session lecturer in charge</th>
<th>Register session location</th>
<th>Search tutoring academy information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tutoring academy</td>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Provision by academy of subjects</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuition fee for provision</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special features of provision</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Session of provision</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lecturer in charge of session</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location of session</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Register tutoring academy</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Register subject</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Register provision</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Register tuition fees</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Register special features</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Register location</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Session of provision</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4  Spatial responsibilities arrangement for Example 1, obtained by MDS (after 44 iterations, converged stress value = 0.188).

Fig. 5  Manually created class diagram for Example 1 (Inclined notation shows contrast with Fig. 4).

academy of subjects has nearly equal dependence between Tutoring academy and Subject. The dependence between Session of provision and Tutoring academy, and Session of provision and Subject. Tuition fee for provision and Special features of provision have a strong dependence to Provision by academy of subjects. Therefore, these three RFKs can be encapsulated into the same class. Strong dependence is also recognized between Lecturer in charge of session and Location of session. Therefore, these two RFKs can be encapsulated into the same class, which also has a strong dependence to Session of provision.

Although the stress value is high at 0.188 and the spatial arrangement of the RFBs is not so good, we successfully obtained a RFK structure that closely resembles a manually created class diagram (Fig. 5). The spatial arrangement of the RFBs is not very good because the quantification standard of the dependence level among RFBs is not substantial.

4. Discussion

4.1 Instructions for Reading Obtained Spatial Arrangement

We outline some considerations regarding the interpretation of the spatial arrangement of responsibilities. Because no relations are shown in the spatial arrangement, reading requires the support of connecting lines between the responsibilities. These connections are determined from the system’s root definitions. A conceptual activity model is an “objective → means” graph developed for determining the root definition (objective) of the relevant system, and therefore, the RFKs (objects or attributes) entered on each node are essential to achieve the objective.

If maintainability, understandability, and reusability are ignored, a functional system can be designed even if they are united in one class. Thus, direct or indirect connections originally exist between all RFKs. According to the MDS output results, if the responsibility groups that are assembled in the vicinity are extracted as classes, then one must assume the existence of connections between them.

In software engineering, the distribution of responsibilities is always designed based on the perspective that “if elements with intrinsically strong connections are massed together, they are stable against future remodeling.” The MDS output supports this...
4.2 Discussion On Using Spatial Arrangement

SSM’s conceptual activity model is a verb-oriented model. On the other hand, our proposed spatial arrangement is a noun oriented model. They are relations that supplement each other.

We can use SSM’s 5th stage, as a basis for the discussion of potential changes to real world problem situations expressed in the 2nd stage. The comparison allows the examination of differences between the current real world situation and the models of relevant systems and facilitates debate about why these differences exist [3]. The comparison focuses on possible better ways of carrying out activities or identifying new knowledge.

In this paper, we assume that a system development process (such as the Rational Unified Process) is applied to the implementation of the 5th and subsequent stages, to implement actions that are designed to fulfil changes identified as both desirable and feasible. This is itself a new problem situation that requires the design or redesign of relevant systems. Having identified what must be done, the above models are now a hard system problem, and can be tackled using a traditional engineering-based approach.

5. Application to a Different Example

We applied our proposed approach to the second example given in Section 3.1 and confirmed a change in the stress value when the number of responsibilities was increased slightly. Figure 6 shows the development of the conceptual activity model from the root definition results.

Table 10 was obtained by extracting the responsibilities from the conceptual activity model and estimating and arranging the various responsibility dependency levels. Figure 7 was obtained by applying MDS to the data in Table 11. In Fig. 7 the RFKs are displayed with upper or underlined. The stress value improved to 0.092, which probably reflects the increased number of responsibilities and a greater volume of information.

Note that in Fig. 7, the Rolling friction of ball is closer to Table than Balls on Table, the Detect ball-ball contact responsibility is closer to Table, and the Reproduce ball-ball collision respon
ity is closer to Balls on Table. The class diagram in Fig. 8 was created based on the spatial positions in Fig. 7. Although this is somewhat subjective, the information was very useful when creating Fig. 8.

Furthermore, we considered the classes shown in Fig. 8 as a Model part in the Model-View-Controller architecture pattern [13] and made a class diagram as a design model by adding View and Controller classes to them (Fig. 9).

The subsequent implementation trial using Java produced a favorable outcome. In particular, the separation of the contact detection and the collision recurrence in the model of the analysis stage, made possible by the arrangement of the MDS, reduced the responsibility of the ball class and made the subsequent detailed design and implementation work easier.

It is not clear from the experimental results whether object placement based on the standard outlined in the present proposal is truly appropriate in the context of the functional requirements, but we believe that it is at least consistent with the Object Oriented paradigm, which encapsulates responsibilities with the objective of achieving high cohesion and low coupling.

Therefore, we consider this approach to be a potential method to bridge artifacts from the uppermost stream such as conceptual activity models and midstream artifacts represented by class diagrams. Furthermore, our proposed method to connect SSM...
artifacts with the OOA responsibility distribution design exhibits originality.

6. Conclusion

This paper employs Soft Systems Methodology (SSM) as an uppermost stream methodology and Object-Oriented Approach (OOA) as a mid- to upstream methodology to extract a conceptual activity model from a system root definition to quantify the dependency levels between extracted responsibilities and to use the spatial arrangement obtained through Multi-dimensional Scaling (MDS) as a reference to create a class diagram.

Although we generally locate objects in an object-oriented manner, it is also rational to identify their responsibilities, arrange them in a space, create responsibility groups based on their dependency levels, and consider them from this perspective. Our proposed method also exhibits originality by connecting SSM artifacts with the OOA responsibility distribution design.

However, because manual implementation of our proposed approach is extremely complex, future work will implement a conceptual activity model editor with an embedded MDS and automate its process from responsibility extraction to spatial arrangement. Automation can generate more detailed responsibility dependency levels. For instance, the number of arrows making their way through a specific node to another node in a conceptual activity model could color the responsibility dependency levels.

If our approach is implemented, it may be possible to realize an intelligent modeling tool that proposes class diagrams. Our future work will continue along these lines.

References


