How Best to Identify An Elephant
or
Combining Viewpoints in Software Engineering Specification

David Lowe, John Leaney
Computer Systems Engineering,
School of Electrical Engineering,
University of Technology, Sydney

Abstract

Many large projects are ill-defined as a result of the high level of complexity inherent in such systems. It becomes difficult not only to fully specify such systems but even to understand all aspects of the system. From any given viewpoint of the system many of the aspects will be hidden. Therefore multiple viewpoints of the system need to be considered in order to fully understand and specify the system under consideration. This paper discusses the issues relating to the use of multiple system viewpoints; Which viewpoints are required to specify the system? At what depth? How are they to be integrated? How are they to be reconciled? The various issues are raised and discussed and possible directions are considered for developing solutions.

1 Introduction

How many blind men must observe an elephant from different perspectives in order to identify it, with sufficient confidence, as an elephant. If it looks like an elephant, smells like an elephant, feels like an elephant, weighs the same as an elephant, and sounds like and elephant can we conclude that it is an elephant. What is the minimum number of views that we need of the elephant to be able to state that it is an elephant. Which views are irrelevant or redundant. Are there any aspects of the elephant (its weight, for example) which are unimportant to us.

This example, though whimsical, illustrates a number of important issues. Many, if not most, large systems are invariably ill-defined. This is a result of the high level of complexity inherent in such systems. From any given perspective it is impossible to perceive the entire system. Figure 1 graphically illustrates the principal behind this (it may look like an elephant, but is it simply a paper maché replica?). It becomes difficult not only to fully specify such systems but even to understand all aspects of the system. This is particularly true when the system is being considered from a single viewpoint. From any given viewpoint of the system many of the system aspects will be hidden. However every aspect of the system can theoretically be defined given a suitable viewpoint. If this is not true then the system becomes indeterminate.

There is at present no formal methodology to ensure that all aspects of a system are identifiable from a given set of views, to identify which views may be required, or even to determine when the system is fully specified. The problem discussed in this paper is that of the use of multiple viewpoints in system specification. This covers a broad range of questions: Which viewpoints are required? At what depth? How are they to be integrated? How are they to be reconciled?

This article discusses the specification of systems using multiple viewpoints of the system. This technique is common practice (for example CORE [11]) but at present does not achieve its potential through a lack of formalism. Our research is aimed at rectifying this situation, by identifying the issues which need to be addressed and then to formalise these and determine, where possible solutions. This is an area of ongoing research and at present is only in the initial stages. This paper does not attempt to present solutions to these problems, rather it defines and then discusses them, as well as providing indications of the methods that may be appropriate in
solving them.

The following section discusses the specification of systems, and how facets can be hidden when the system is only considered from a subset of the necessary viewpoints. The next section then discusses viewpoint analysis, and its use in specifying a system. This is then followed by a discussion of the issues relating to the combining of viewpoints to obtain a system specification. Finally, directions of research which may be fruitful in solving the issues raised are considered.

2 System Specification

Any software system, however small, can be viewed from different perspectives. The requirements will vary depending upon the perspective being used. For very small systems a single perspective is likely to provide a sufficient understanding of the system. For larger systems however aspects of the system either become hidden for certain perspectives or are interpreted differently. It therefore becomes necessary to consider multiple views of the system, and then to combine and reconcile the aspects of the system identified from each view. At present there is no formal methodology for identifying all aspects of a system, and possibly worse, no method of determining if all aspects have been identified; i.e. there is no method of determining either the necessary or sufficient viewpoints that are required to specify a system.

As systems become progressively larger it becomes more difficult for a single individual (with a restricted set of viewpoints) to understand all aspects of a system. Each individual will carry their own view of the system. For these views certain aspects of the system will be hidden or interpreted in a certain way. This concept is encapsulated neatly in the "elephant system" shown in figure 1), where different men each have a separate view of the elephant. Only when all views are combined we can confidently provide a complete description (or specification?) of the elephant.

The above illustrates that any given system (apart from trivial cases) will be multifaceted and will contain multiple requirements that need to be satisfied. If the system is to be accurately and sufficiently specified (i.e. a software system is to be developed which solves the given problem completely and accurately) then it needs to be thoroughly understood; all the system requirements need to be explicitly identified. If aspects of the system are either not identified, or misinterpreted, then they cannot be taken into account in the problem solution, leading to an incomplete or possibly incorrect solution. The first stage in a problem solution is generally to specify accurately and completely the problem or system. Formal methods and tools for achieving the specification are therefore important. Viewpoint analysis is one such tool, and as such it should be ensured that it is developed to a stage where it achieves its potential.
3 Viewpoint Analysis

3.1 Description of Viewpoint Analysis

In order to identify all aspects of a system, the system will need to be considered from multiple viewpoints. This is shown (using a graphical analogy) in figure 2. Viewpoint analysis [5] recognises that at every decomposition step in analysing a system, the system can be viewed from different viewpoints. Typical viewpoints for a computer system might be the users of the system, other computer systems interfacing to the system, constraints placed on the system, the designers of the system etc. Typically there will exist two main types of viewpoint; user viewpoints and methodological viewpoints.

The first step in traditional viewpoint analysis is to identify the possible viewpoint of the system. This is often represented using a viewpoint bubble diagram or viewpoint hierarchy [5, 4]. This is essentially simply a collection of viewpoint names. No structure is imposed on the analysis or representation of the viewpoints at this stage. It is important however to recognise all possible viewpoints, as their may be aspects of the system which are only identifiable from a single or small subset of viewpoints. Typical sources of knowledge to assist in the identification of viewpoints will be user requirements specifications, system knowledge, etc.

A number of guides can be used in the selection of viewpoints [11]. The first of these is that the viewpoints should not overlap (ideally they should be orthogonal). This ensures that later stages of the viewpoint analysis can perform the viewpoint clustering in such a way as to ensure orthogonal clustering. This requirements however places severe restrictions on the identification and selection of appropriate viewpoints. Other guides are that the data sources and sinks should be viewpoints, non-functional system characteristics can be used as viewpoints and each functional viewpoint should perform information processing.

Once all appropriate viewpoints have been selected (it is recognised that there is no definitively correct set of viewpoints for a given system) they are then clustered. Typical clusters will be function, data, user, and service (all functional viewpoints) and non-functional viewpoints. Once the clusters have been created a structure must then be imposed upon them. This is usually represented diagramatically. During this stages the viewpoints and clusters should also be rationalised. Once this has been achieved the resultant viewpoint diagram can be used in the system modelling.

An assessment of viewpoint analysis reveals it be rather ad hoc. Admittedly it is a very powerful tool and can provide valuable insights into requirements analysis. It should however be capable of much more than it currently achieves. The major problem is the lack of formalism in the technique.

3.2 Problems with Viewpoint Analysis

There are an number of problems and limitations with the current state of viewpoint analysis. Primarily this relates to the lack of formal, mathematically precise, methodologies. There is no assurance that the techniques outlined above will result in a sufficient description of the problem (unless every single possible viewpoint has been identified; something which in turn, we have no way of knowing). A number of explicit issues will be identified and discussed.

Sufficient and necessary views: At present there is no formal method for determining whether a given set of views are sufficient to completely describe a given system. A system is defined by utilising as many viewpoints as possible. Whether these are sufficient to fully define a system is not determined. Similarly, no method exists for analysing whether a given view, or set of views, is necessary for the system definition. This can lead to the unnecessary determination and analysis of many viewpoints.

Optimum views: Related to the above is the issue of selecting the optimum set of views to be used in the suf-
icient definition of a system. There may exist many sets of views which can provide the sufficient definition, however there exist no guidelines for selecting the optimum set. The problem is worse still, insofar as there is no metric to use in determining the usefulness of a view; i.e. one set of views cannot be considered better than another unless some metric exists for comparing the sets of views and/or viewpoints.

**View reconciliation:** In many cases, different views may lead to different interpretations of the system (or aspects of the system). Some method of reconciling such differences needs to be developed (this is discussed further in the section on data fusion).

**Sufficient specification:** We may know that we require a sufficient specification of a system, but we need some method of determining when this condition has been met. Given a set of viewpoints of a system, we can derive a specification, but we then need to be able to assess the completeness of this specification. At present this is achieved by simple exhaustive analysis of all viewpoints.

The above issues can become even more confusing when it is realised that a “sufficient specification” of a system is in itself a complex issue. Many aspects of a system may be irrelevant to a given problem/solution in light of other aspects, i.e. not all aspects of the system are orthogonal (for example, if we know the elephants age and weight, then we can calculate its gender, rather than explicitly obtaining a relevant view !)

4 Fusion of Multiple Sources of Data

The issues outlined above are a specific example of problems that exist in many fields; that of the fusion of multiple sources of data. This problem arises in fields as disparate as sensor fusion, object recognition, management etc.

Aloumous [2] has performed work on the general problem of fusing data from various sources for use in computer vision:

Most of the basic problems in computer vision, as formulated, admit infinitely many solutions. But vision is full of redundancy and there are several sources of information that if combined can provide unique solutions for a problem. Furthermore, even if a problem as formulated has a unique solution, in most cases it is unstable. Combining information sources leads to robust solutions. . . . Another approach to the solution of ill-posed problems would be to look for information sources in order to augment the number of physical constraints and achieve uniqueness of the parameters to be computed.

This quote is as equally applicable to combining viewpoints as it is to combining sources of information when identifying objects. The comment about instability is especially salient. Many systems are dynamic and therefore the viewpoints which are required are not just those to specify the system, but also its dynamics.

Ikononomoulos et al [6] have considered the general problem of image processing and analysis in a multisensory environment. The problem of sensor fusion or integration is considered and a number of applications discussed. Abidi et al [1] also consider the fusion of data, though specifically for an autonomous robot. Perhaps the richest source of ideas relating to the fusion of various forms of image data (or any types of data) is connectionist theory [3]. This allows parallel ‘computations’ to take place with the results of each computation combining in some fashion to derive an overall conclusion. One of the earliest examples of this technique being applied to recognition was Selfridge’s pandemonium model [10] which was used for character recognition.

One technique which has being developed [8, 9] to combine information sources is to use each source of information to instantiate all possible solutions that agree with the given view. The instantiated hypotheses are then either combined or assessed depending upon the application. This does not have immediate application to this particular problem, as it relies on having a finite set of solutions which are known a priori. It may however be adapted if the system being analysed is one of a finite set of system classes which can then be identified.

Another possibility is to use a reverse approach, where a single viewpoint is initially used. The bounds of the system that are consistent with this view are quantified, and then another view is selected which provides the maximum information about the aspects of the system which are still hidden. This can be repeated until all aspects of the system have been identified.

The most immediately relevant techniques to software engineering relate to inversion of Data Flow Diagrams (DFD’s) to Entity/State Diagrams (ESD’s) and vice versa. The DFD will tend to identify functions, the ESD will identify entities. Each of these techniques can be used to independently obtain a (particular methodological) viewpoint of the system. They can then be inverted to cross-check the capture of requirements and subsequently to identify the deficiencies. This is one method of converting an imprecise specification into a precise specification; an area that is covered in detail by Lehman [7]. This illustrates one further point insofar as it is important to be able to convert the data obtained from the various views into compatible forms.

In general, when the information obtained from two
sources (or viewpoints) is combined, the resultant information is the union of of the two sources. Thus in order to maximise the total information obtained the two sources should be as close to orthogonal (in the information space) as possible. How desirable this will be is dependent upon the reliability of particular views. If there is low reliability then intersection between the views will provide cross-checking, and hence increase the confidence in the resultant specification.

5 Possible Solutions

This paper is not intended to solve the issues that have been raised. Nevertheless a number of directions can be outlined.

The first step in this process is to determine and fully specify a metric which can be used in the comparison of the 'quality' or 'usefulness' of one viewpoint as compared to another. The logical starting place for this type of analysis would be to use information theory to measure and subsequently maximise the information that can be obtained from any given viewpoint. A method for expressing a metric may be based on a formal specification language such as Z [12] or based on probability or fuzzy logic.

Once a metric for assessing viewpoints has been identified the problem of selecting the optimum set of views for any given system can be considered. Again information theory is likely to provide the best approach. Part of this may well involve an analysis of methods to determine the degree of system specification that is considered sufficient.

One possible technique may be categorise general classes of systems, and then outline the views (or provide guidelines to be used in determining the views) for each class. Identification techniques can then be used to determine the class that a given system belongs to, whereupon the views required for that class can be used. This reduces the problem from an infinite set of systems to a finite set. Whether a suitable set of general systems can be identified or not is unknown at this stage.

6 Conclusions

This paper has attempted to identify some of the viewpoint analysis issues that have yet be properly addressed. Viewpoint analysis is an important tool in system specification. We propose however that it should be capable of much more than is currently the case. The major criticisms revolve around the lack of formalism relating to the selection and fusion of viewpoints. There is at present no method of determining whether a given set of viewpoints is either necessary, sufficient or optimum in order to specify a system. Possible methods of modifying the current techniques are described, with the major focus being initially providing a metric to determine the usefulness of a given viewpoint. This should then be followed by the development of techniques to select the optimum set of sufficient viewpoints. It is admitted that there is considerable work to be done in this field before the described aims are achieved.

References


