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MODELLING SOFTWARE SYSTEMS IN CONFIGURATION MANAGEMENT

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A model of a software system is presented. It is on the one hand sufficiently rich to represent the architectural and development-induced relations which are decisive in building the configuration, and on the other hand simple enough to allow efficient processing. We distinguish variants and revisions as two kinds of components. Systems are represented by two kinds of nodes in an AND/OR-type graph. The model forms a basis for a method to build a configuration.

1. Introduction

Software systems change more often than it is usually admitted. In fact, the changes are to be considered more a rule than an exception. Reasons for the unstability are not only possible errors which are to be corrected, but first of all the changing nature of the surrounding world to which the software system should be permanently adopted in the process of the so-called maintenance.

Software systems consist of many components which may undergo changes, as they indeed frequently do. These modifications are usually incremental, so it appears to be reasonable to consider results of such modifications to be versions of particular components rather than independent objects. In a traditional model of versions (Estublier, 1988; Reichenberger, 1994; Tichy, 1988), two different kinds of modifications are reflected in two kinds of versions: revisions and variants.

Revisions result from modifications which are caused by error correction, functionality enhancement, and/or adaptation to changes in the environment. They develop in a time sequence, with each next one usually intended to replace the previous one.

Variants of software components can be described as alternative implementations of a particular concept (Mahler and Lampen, 1988). A new variant represents an alternative solution. Variants usually exist concurrently. They result from experimental development or modifications towards ameliorating system properties.

A family of software components comprises a set of such versions of a software component that were formed by gradual modifications of the given component. A software system configuration is a set of software components which is consistent.

A software system consists of many interrelated software components. A model is used to express its structure, respecting in our case the viewpoint of building the

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software system configuration. A frequent and quite natural way of representation is by means of a tree (see e.g. Rochkind, 1975; Tichy, 1985) or, more generally, by means of an oriented graph which is usually constrained to be an acyclic one (Heimbigner, 1988; Luqi, 1990; Mahler and Lampen, 1990; Oquendo *et al.*, 1989; Plaice and Wadge, 1993; Reichenberger, 1989; Vescoukis *et al.*, 1992; Yau and Tsai, 1987). Sometimes, the graphs have a special structure. In (Holt and Mancoridis, 1994), the structure of a software system is expressed by the so-called tube graphs. They support control of changes of relations between the components during the system development with respect to given constraints on its architecture.

A general approach to models based on graphs is to represent the components by nodes and the relations between them by edges. They differ mainly on the ways of expressing the relations between components and in structuring the components.

The relations between the components are very important from the point of view of configuration management. In fact, if the components were independent, most of the problems with software configuration management during software development and maintenance would simply dissapear. Among the important relations influencing configuration building, we list e.g. *depends_on*, *contains*, *refers_to*, *uses*, *is_variant*, *is_revision* etc.

A model of a software system expresses first of all its structure. When referring to each of the parts of the system, it uses names. The form of the model is influenced by the intended application. In software configuration management, the software system is frequently modelled by a graph in various variations. Besides an acyclic graph and a tree, some authors also use an AND/OR graph, whose advantages become apparent especially in connection with supporting the process of building a software system configuration.

In (Tichy, 1986), a model which is essentially an AND/OR graph is presented, and its advantages are stressed in comparison with a more "classical" acyclic graph. In this model, the AND nodes represent configurations, the OR nodes represent families of components (i.e. groups of versions) and the leaves represent atomic components. The AND and OR nodes can be freely combined in the graph. Configurations represent in fact composite components, because the AND nodes take care of integration during configuration building. In the model, the AND/OR graph has been generalized to an attributed graph, i.e. each node can have an associated set of attributes.

A model based on AND/OR graphs has been also presented in (Estublier, 1992). A component of a software system is represented by a three-level scheme: family of components — interface — realization. It is allowed to form versions of both the interface and the realization of a component. Taking into account that the interface of a component changes significantly less frequently than its realization, we can make use of this concept in the software system development. On the other hand, the model becomes more complicated and less transparent. In the AND/OR graph, the AND nodes and the leaves represent realizations whereas the OR nodes represent the interface of software components.

The aim of this paper is to devise a way of modelling software systems that would suit the process of building a software system configuration. We have also developed

a method to support the software engineer in building the configuration. The method uses the presented model.

2. An Outline of the Proposed Approach

Solving various problems related to building software system configurations in the process of software development and maintenance requires describing the actual software system in a simplest possible way which is still sufficiently rich to reflect the principal relations and properties decisive in the building process.

We attempt to describe a software system to be used during development and maintenance, and specifically in building the software system configuration. Therefore our model encompasses those parts of the system and those relations among them which are important for building a configuration. When attempting to identify them, it is instructive to bear in mind that a software system is created in a development process which can be viewed as a sequence of transformations. Because the initial specification of the system does not (and should not) include details of the solution, the overall orientation of the transformations is from abstract towards concrete. However, this does not mean that each particular transformation, especially when applied to a particular subsystem or a component, is concretisation. In fact, abstracting, generalizing, and specializing transformations are involved as well. Let us mention the importance of such kinds of transformations in software reuse, reverse engineering, etc.

Among all the possible kinds of transformations, it is important to distinguish all those which correspond to the notion of the component version. Creating a component version can be done in one of two possible ways. In the first, versions are created to represent alternative solutions of the same specification. They differ in some attributes. Such 'parallel' versions, or variants, are frequently a result of different specializations. In the other, versions are created to represent improvements of previous ones. Such 'serial' versions, or revisions, are frequently a result of concretizations of the same variant.

Versions can by identified by the relation *is_version*. This relation is reflexive, symmetric and transitive. It defines equivalence classes within the set of all the components, each of which is described as a family of software components, i.e. the family is a set of all components which are versions of one another. However, within a family we can recognize a binary relation *is_variant*. This relation is an equivalence. The equivalence classes are called variants.

We introduce a software component as a revision. In our meaning, even the first concretization of a variant is called a revision. A software component consists of two parts: an interface and a realization. In fact, from the point of view of the software configuration management, the realization part is of only secondary importance. The relations between components and the components' properties are more important as defined in the interface. Here, we identify two parts. One part of the component's interface is a description of the variant, which is common for all the revisions of that variant. Any change to it results in forming a new variant. The other part is the revision's own interface. Any change to only a revision part results in forming a new revision.

The relations between software components can be of two kinds:

- relations expressing the system's architecture, concerned especially with the funcionality of the components and the structure of the system, such as *depends_on*, *specifies*, *uses*,
- relations expressing some aspects of the system's development process, with important consequences, especially for the version management, such as *is_variant*, *has_revision*, which we shall commonly refer to as development-induced relations.

The architectural relations are defined only between variants and families. As a result, any change of such relations during forming a new revision must result in a new variant. We assume that all the revisions of a given variant have the same architectural relations.

It can be seen from the above that revisions do not have the 'sovereignty' to maintain their own architectural relations. All their relations are completely determined by the variant they belong to. This observation is very important because it allows us to simplify the situation and to include into a software system model only two kinds of elements: families and variants.

For a family, the model should represent links to all its variants (links are implicitly defined by the *is_variant* relation). When building a configuration, exactly one such variant is to be included for each family found to be included in the configuration.

For a variant, the model should represent links to all those families which are referred to in that variant (links are defined by architectural relations). When building a configuration, precisely all such families are to be included for each variant found to be included in the configuration. It should be noted that when a family or a variant is found to be included in the configuration during the process of its building, ultimately precisely one software component will be included. The selection of a variant and a software component within a variant is a part of the version control subproblem.

3. Families of Software Components

Let us attempt to identify the class of those transformations of states in the software development process which result in forming a new version of some component. According to our analysis, two features are crucial: the language (specification formalism) of the component being transformed, and the '1-to-1' property which means that one component is transformed into exactly one component. We assume that all the specification formalisms used in the software development process are categorized into groups. Each group represents some type of formalism, e.g. the structure diagram, the programming language etc. The assumption allows us to consider as versions two components which are written in two different, but closely related languages. For example, it is often the case that we have two implementations of some algorithm, one in language L_1 (say, C), and the other one in language L_2 (e.g. Pascal). Naturally, we wish to consider them as versions. Therefore we distinguish a special class of transformations. A transformation is said to be *t_version*, if it preserves both the specification formalism and the '1-to-1' property.

A transformation is applied to a state which consists of software components. Generally, it may involve several components and it may result in a different number of

components. For example, any refinement step which refines a component (according to the divide and impera principle) into two components transforms one component into two components. Of course, all the remaining components are assumed to stay unchanged during this particular transformation, as they are not involved. Such a transformation can never create a version.

A transformation which changes radically the language will not result in a version. For example, if a process specified by a data flow diagram is implemented by a module written in C, the module will not be considered as a version of the DFD specification.

Only transformations preserving both the described properties lead to versions. In such a way, all the versions are formed solely by *t_version* transformations. Transformations of any other kind lead to forming new sets of components. Sets of software components which have been formed by applying *t_version* transformations within them are understood to be in the *is_version* relation. Such understanding of the notion version conforms to most of the related works in the SCM area. The sets formed in the described way are called families of software components.

Summarizing, the family of software components is such a set of software components that the components included have been formed gradually only by *t_version* transformations. These transformations define a binary relation on the set of software components of a software system S. Let us call this relation $t_version_S$. It is asymmetric and irreflexive.

We get the binary relation $is_version_S$ if we take the reflexive and transitive closure of the relation $(t_version_S \cup t_version_S^{-1})$. This reflects the above informal description of the relation $is_version_S$.

Definition 1. Let $COMPONENT_S$ be a set of components of a software system S. Let a binary relation $t_version_S \subseteq COMPONENT_S \times COMPONENT_S$ be given as follows:

$x \; t_version_S \; y \Leftrightarrow y$ is formed by applying transformation *t_version* to x in the software system S.

Then the binary relation $is_version_S \subseteq COMPONENT_S \times COMPONENT_S$ is given as

$$is_version_S = (t_version_S \cup t_version_S^{-1})^*$$

To simplify notation, the index S will be omitted whenever it is sufficiently clear from the context which software system is being referred to. Thus, we write occasionally $COMPONENT$ instead of $COMPONENT_S$, *is_version* instead of $is_version_S$, etc.

Proposition 1. *The relation is_version is an equivalence.*

Proof. The relation is defined as the reflexive and transitive closure, and therefore it is trivially reflexive and transitive. It is also symmetric, because the relation $(t_version \cup t_version^{-1})$ is symmetric. ■

The relation *is_version* defines classes of equivalence on the set of components of a software system. The classes represent families of software components.

Definition 2. Let $COMPONENTS_S$ be a set of components of the software system S, and $is_versions_S$ be a binary relation $is_versions_S \subseteq COMPONENTS_S \times COMPONENTS_S$. The set of all equivalence classes induced by the $is_versions_S$ relation is denoted by $FAMILY_S$:

$$FAMILY_S = \Big\{F \,|\, F = \{x \,|\, x \in COMPONENTS_S \wedge x \; is_version \; y \text{ for some } y \in COMPONENTS_S\}\Big\}$$

and called the set of families of software components of the software system S. An element of $FAMILY_S$ is called the family of software components.

4. Variants

Next, we focus our attention on the structure of a software component itself. We define which kinds of properties a component has. Based on that, we can define variants as sets of those components which share certain attributes.

Definition 3. Let $COMPONENTS_S$ be a set of software components of a software system S, and $FAMILY_S$ a set of families of S. Let F, $NAME_ATTR, NAME_REL$ be mutually exclusive sets of names. Let DOM be a set of domains of admissible values of attributes such that for each name $a \in NAME_ATTR$ there is only one domain $D_a \in DOM$ of admissible values of an attribute named a. Let $f_name_S : FAMILY_S \to F$ be an injective function which assigns a unique name to each family of a software system S. Moreover, let e be a well-formed constraint expression from a suitable language and r be an expression from a specification language. We define the software component to be a quintuple c_S:

$$c_S = \Big\{ArchRel : REL, FunAttr : ATTR1, CompAttr : ATTR2, Constr : e, Realis : r\Big\}$$

where REL is a set of pairs $(RelationId : n, FamilyId : t)$, $n \in NAME_REL$, $t \in \{x \,|\, x \in F \wedge f_name_S^{-1}(x) \in FAMILY_S\}$, and $\neg(c_S \in f_name_S^{-1}(t))$, $ATTR1$ and $ATTR2$ are finite sets of pairs $(a, d), a \in NAME_ATTR$, $d \in D_a$.

In the definition, we have given names to elements of tuples to be able to refer to them throughout the text. For example, if e is a software component, i.e. a quintuple, we may refer to its first element as $e.ArchRel$, to its second element as $e.FunAttr$, etc. For example, let us consider a software component $c1$, for which there exists an architectural relation *contains* with family of software components INIT, and a relation *has_document* with family DOCUM:

$$\begin{aligned}
c1 = \Big(&\{(contains, INIT), (has_document, DOCUM)\}, && \%architectural\ relations\\
&\{(phase, implementation), (operating_system, UNIX), && \%functional\ attributes\\
&(prog_language, C), (algorithm, simple), (type_of_problem, diagnose)\}, &&\\
&\{(author, peter), (date, 95_01_15), (status, working)\}, && \%other\ attributes\\
&(parameters = ordered) \Rightarrow (system_ver = UNIX_4_3), && \%constraint\\
&\#define... && \%program\ in\ C\ language\\
\Big)&
\end{aligned}$$

In the structure of a software component, besides other elements, we have also included a constraint expression and a specification expression. We shall make use of them in the process of building a configuration.

In order to describe variants, we define a binary relation *is_variant* which determines a set of software components with equally defined architectural relations, functional attributes and constraints within a given family.

Definition 4. Let $COMPONENTS_S$ be a set of software components of a software system S with binary relation $is_version_S$. The binary relation $is_variant_S \subseteq COMPONENTS_S \times COMPONENTS_S$ is defined by

$$x\ is_variant_S\ y \Leftrightarrow x\ is_version_S\ y \wedge x.ArchRel = y.ArchRel \wedge x.FunAttr = y.FunAttr \wedge x.Constr = y.Constr$$

Proposition 2. *Relation is_variant is an equivalence.*

Proof. We use properties of binary relations *is_version* and '=' which are both equivalences, i.e. they are reflexive, symmetric and transitive. We show that these properties hold for *is_variant* as well.

The relation *is_variant* is reflexive because the following holds:

$$\forall x\ (x\ is_version\ x \wedge x.ArchRel = x.ArchRel \wedge x.FunAttr = x.FunAttr \wedge x.Constr = x.Constr) \Rightarrow \forall x\ (x\ is_variant\ x)$$

The relation *is_variant* is symmetric because the following holds:

$$\begin{aligned}\forall x, y\ (x\ is_variant\ y \Leftrightarrow (&x\ is_version\ y \wedge x.ArchRel \\ &= y.ArchRel \wedge x.FunAttr = y.FunAttr \wedge x.Constr \\ &= y.Constr) \Leftrightarrow (y\ is_version\ x \wedge y.ArchRel \\ &= x.ArchRel \wedge y.FunAttr = x.FunAttr \wedge y.Constr \\ &= x.Constr) \Leftrightarrow y\ is_variant\ x)\end{aligned}$$

The relation *is_variant* is transitive because the following holds:

$$\begin{aligned}\forall x, y, z\ (x\ is_variant\ y \wedge y\ is_variant\ z \Leftrightarrow (&x\ is_version\ y \wedge x.ArchRel \\ &= y.ArchRel \wedge x.FunAttr = y.FunAttr \wedge x.Constr \\ &= y.Constr \wedge y\ is_version\ z \wedge y.ArchRel \\ &= z.ArchRel \wedge y.FunAttr = z.FunAttr \wedge y.Constr \\ &= z.Constr) \Leftrightarrow (x\ is_version\ y \wedge y\ is_version\ z \wedge x.ArchRel \\ &= y.ArchRel \wedge y.ArchRel = z.ArchRel \wedge x.FunAttr \\ &= y.FunAttr \wedge y.FunAttr = z.FunAttr \wedge x.Constr \\ &= y.Constr \wedge y.Constr = z.Constr) \Leftrightarrow x\ is_variant\ z)\end{aligned}$$

■

Definition 5. Let $COMPONENTS_S$ be a set of software components of a software system S and $is_variant_S$ be its variant relation. A set of all equivalence classes in the relation $is_variant_S$ is given by

$$VARIANTS_S = \Big\{ V \,|\, V = \{\, x \,|\, x \in COMPONENTS_S \wedge x \; is_variant_S \; y \text{ for some } y \in COMPONENTS_S \Big\}$$

and called the set of variants of S. An element of the set $VARIANTS_S$ is called the variant.

Variants are important to simplify management of software component versions in selecting a revision of some component, or in building a configuration. We can treat an entire group of components in a uniform way due to the fact that all of them have the relevant properties defined as equal.

Let us present an example of a software system which includes versions of (some of) its components. The example is taken from the software system KEX, (Bieliková *et al.*, 1992; Návrat *et al.*, 1989). The system elements are shown in Fig. 1 along with architectural relations between them.

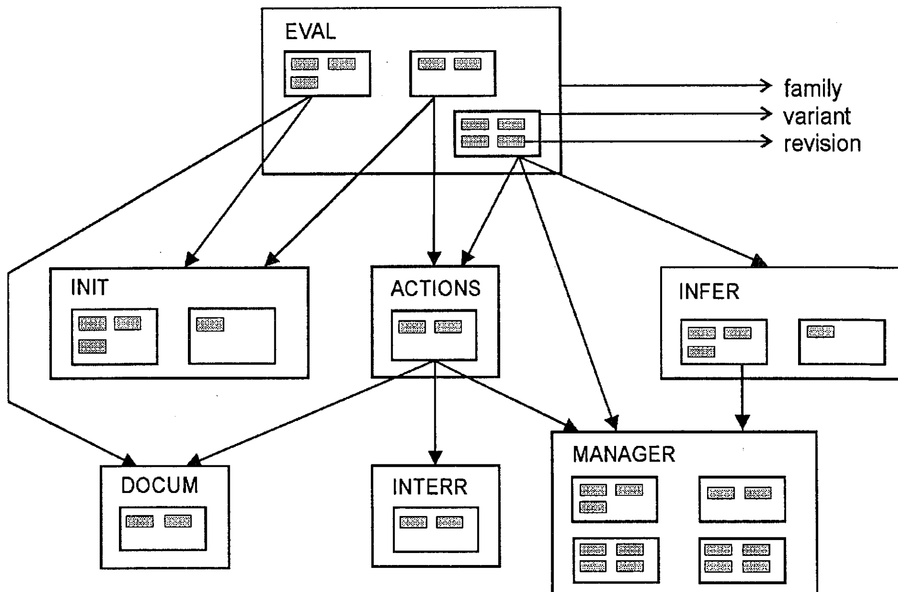

Fig. 1. An example of a software system: partial hierarchy of elements.

In Fig. 1, the elements are organized in a hierarchy. Families of software components comprise variants and the variants comprise revisions. Architectural relations

are defined on the level of variants (they are the same for all revisions within a variant) between a variant and a family of software components. The software system in Fig. 1 consists of seven families of software components. They are identified by the names: EVAL, INIT, ACTIONS, INFER, DOCUM, INTERR, MANAGER. Each family includes several software components, e.g. the family EVAL includes three sets of components (i.e. variants) which include in turn nine revisions. Thus, the family EVAL includes nine software components.

5. A Model of a Software System

The concepts introduced above allow us to formulate a model of a software system. When proposing the model, we attempt to find one which would support the process of building a configuration. That is why, in our model, those parts and relations of the software system are represented explicitly, which is crucial in the process of building a configuration.

Our approach is based on the assumption that families of software components, variants and revisions are the basic entities involved in version management. All the relations between these entities can be grouped into architectural relations and development-induced relations. The development-induced relations determine a membership of a variant in the family of components, and a membership of a revision in a variant. Architectural relations must be defined explicitly on the level of variants and must be the same for all the revisions included in a given variant. This assumption is very important, because it allows us to formulate a model of a software system which comprises only two kinds of elements: families and variants.

From the point of view of a family, the model should represent families and variants included in them. We shall call this relation *has_variant*. From the point of view of a variant, the model should represent architectural relations which are defined for each variant. When building a configuration, for each family already included in the configuration there must be exactly one variant selected. For each variant already included in the configuration, all the families related to that variant by architectural relations must be included. Taking into account that a software component is determined completely only after selection of a revision, a resulting configuration is built by selecting exactly one revision for each selected variant.

We propose to represent elements and relations incorporated into a model of a software system by an oriented graph.

Definition 6. Let $FAMILY_S$ be a set of families of software components, $VARIANT_S$ be a set of variants of a software system S. Let F be a set of names and $f_name_S : FAMILY_S \rightarrow F$ be an injective function which assigns a unique name to each family of the software system S. Let $A \subseteq VARIANT_S \times F$ be a binary relation defined as follows

$$e_1 \; A \; e_2 \Leftrightarrow \exists x \exists r (x \in e_1 \wedge r \in x.FunRel \wedge r.FamilyId = e_2)$$

Let $O \subseteq F \times VARIANT_S$ be a binary relation defined as

$$e_1 \; O \; e_2 \Leftrightarrow e_2 \subseteq f_name_S^{-1}(e_1)$$

We define the model of the software system S to be an oriented graph $M_S = (N, E)$, where $N = F_S \cup VARIANTS_S$ is a set of nodes with

$$F_S = \left\{ x \,|\, x \in F \wedge f_name_S^{-1}(x) \in FAMILYS_S \right\}$$

and $E = A \cup O$ is a set of edges, such that every maximal connected subgraph has at least one root.

We remark that the binary relation A represents architectural relations and the relation O reflects the relation *has_variant*.

Any element of $E, (v_1, v_2) \in E$, which is called an edge, belongs to one from among two mutually exclusive kinds. We have either $e_1 \in VARIANTS_S$ and $e_2 \in F_S$, i.e. the edge is from A, or $e_1 \in F_S, e_2 \in VARIANTS_S$, i.e. the edge is from O. In the former case, the node e_1 is called the A-node. In the latter case, the node e_1 is called the O-node. Such graphs are called A/O graphs.

An A/O graph which models a software system has several properties following directly from the definitions of the family of software components, the variant, and the model itself:

P1) Every O-node has at least one successor.

P2) Every A-node has exactly one predecessor.

P3) On every path, A-nodes and O-nodes alternate.

The requirement that the model of a software system should have at least one root is motivated by the fact that the model should be adequate to the purpose of building the software system configuration. When there is no root in a model, it is not possible to determine which components are to be selected for the configuration. Actually, the requirement is not a restriction in the case of software systems. This follows from the very nature of the development of software systems and its description by transformations of solution states. Let us mention that the known approaches to modelling a software system by a graph assume that there is at least one root, cf. (Estublier, 1992; Miller and Stockton, 1989; Narayanaswamy and Sacchi, 1987; Ploedereder and Fergany, 1989).

The model of the software system depicted in Fig. 1 can be expressed by an A/O graph in Fig. 2. To simplify referencing the variants, we invented names for them. They are derived from the name of the corresponding family of software components combined with a natural number.

Let us stress once again that in our model only families of software components and their variants are represented explicitly. We have been led to this choice by the fact that revisions neither represent different concepts or solutions nor introduce them. Whenever a revision attempted to do so, according to our model it would become a variant. On the other hand, revisions are mere improvements, repairs or enhancements. Creating a revision does not assume any change in architectural relations between the components in a software system. That is why they need not be represented in the system's model.

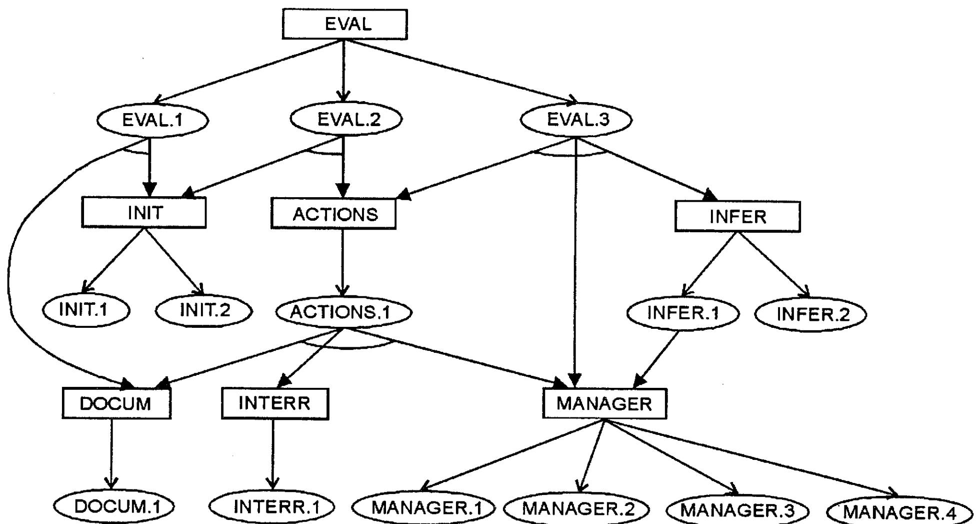

Fig. 2. Software system of Fig. 1 modelled by an A/O graph.

The usual interpretation is that the A-nodes are origins of edges leading to nodes, all of which must be considered provided the A-node is under consideration (logical AND). Similarly, the O-nodes are origins of edges leading to nodes, from among which exactly one must be considered provided the O-node is under consideration (logical OR).

The model of a software system describes all the possible configurations. The space of configurations is extremely large even for modest systems. For example, assuming a rather small system with 100 families, and with 2 versions within each family, we have 2^{100} different versions of the system. The problem is that practically only very few of them are useful, either for maintenance or for further development. To solve the problem how to find a desired version of the software system (i.e. a configuration) without having to search the space of all possible versions is therefore very practical.

The model of the software system we presented above simplifies greatly the problem of building a configuration. The problem can be formulated in terms of searching a graph. Besides simplifying the problem, the model also simplifies representation of the large set of possible configurations. Without such a model, large tables of configurations would have to be kept, which would be a source of difficulties during maintenance.

Taking into account the fact that the nodes in our model are component families and variants, but not revisions (i.e. the actual components), it follows that any configuration we build by searching the model can only be a generic one. It can identify several configurations of the software system. A configuration of a software system

built solely from software components, i.e. revisions, is called a bound one. A generic configuration consists of variants and it determines a set of bound configurations. To build a usable (bound) configuration from a generic one, one revision for each variant in the generic configuration must be selected.

Now we can review the main points of our method for building a configuration. First, a model of a given software system must be available. The model is a suitable way of representing all the possible configurations. Several different configurations can be built from it, usually based on different required purposes of the desired configuration, as e.g. a configuration for the end user, a configuration for further development, etc. Such configurations can be specified by different configuration requirements. This second phase results in a generic configuration. In the third phase, a revision for each variant must be selected, resulting in a bound configuration. A detailed description of the method shall be presented elsewhere.

The space of software system configurations is hierarchical, with two levels. One level comprises all the possible generic configurations. For each generic configuration, the second level comprises all the corresponding bound configurations. Such organization provides for a high degree of reuse. When building a new configuration, we can reuse the current generic configuration as long as all the changes are revisions within the desired generic configuration. Only when a change results in modifying the set of variants, a new generic configuration must be built.

6. Experiments

The proposed method for modelling software configurations has been implemented as a part of a larger project aiming at the development of a method of building a configuration. We have performed experiments to analyse its properties. We have developed an experimental implementation of the method in Prolog. The implementation endeavour has become an interesting research question by itself. While devising an algorithm implementing our method, we essentially faced the problem of searching an A/O graph with constraints. This led us to techniques similar to those used in truth maintenance systems, and finally to devising a programming technique for implementing such algorithms which use markings to maintain consistency. A more detailed description of these results is reported in (Bieliková, 1995; Bieliková and Návrat, 1995).

7. Conclusion

One of the reasons behind our approach to software configuration management is to allow software engineers to write down information which is effectively interpretable by a supporting tool. We have identified a possible 'portfolio' for such information. It is based on a model of a software system represented by an A/O graph. In our model, we assume that there are two kinds of versions, viz. variants and revisions. In the model, only variants, along with component families are represented. A variety of architectural relations can be defined between variants and families.

Our approach makes not only the process of building a configuration easier, but it provides for a high degree of reuse. One can reuse a software system model, a built

generic configuration and configuration requirements. The fact that architectural relations can be defined between variants and families allows our model to be "more generic" as e.g. those of (Bernard *et al.*, 1987; Leblang and Chase, 1987; Mahler and Lampen, 1988; Tichy, 1985). At the same time, our model is more informative than those cited above in the sense that several models are usually needed to describe the information contained in our model. In particular, they allow architectural relations to be defined only between component families.

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