Reconfiguration using Model-based Diagnosis*

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Abstract

Knowledge-based configuration is a successful application domain for AI techniques. An open issue in many practical domains is that of reconfiguration, typically exhibited by legacy systems that are to be extended, upgraded or simply altered. We discuss the use of a diagnosis approach to reconfiguration. We present the differing application and representation requirements, develop a representation that is suitable for expressing the information about the required and configurable functionalities from the diagnosis point of view, present an example and discuss our experiences.

Introduction

The automated configuration of technical systems is a successful application area for knowledge-based techniques. These representations typically include a component hierarchy and a declarative formalism to describe more complex behavior. The latter can be based on description logics (WWB+93), extensions of constraint satisfaction problems (CSP) (GW96; SFH98), or others. Most of these systems use problem-independent search methods combined with domain-dependent heuristics. However, most of these approaches deal primarily with the notion of configurating systems from scratch (i.e., given a set of requirements). In practice, the use of configuration tools inevitably leads to the problem of being able to alter existing configurations to accommodate alterations to the knowledge base, and extend or adapt legacy systems. The goal of this *reconfiguration* process is to arrive at a new system that corrects the problem (provides the desired new properties) while diverging as little as possible from the originally configured system.

The purpose of this paper is twofold. First, we show how model-based diagnosis can be used to identify desired modifications in an existing system that is confronted with changes in the knowledge base or requirements. We also present a representation for incorporating reconfiguration knowledge (expressed as transmitted functionality) in the standard model-based diagnosis approach, give a simple example problem and discuss the results produced by our implementation.

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Reconfiguration

We use the term reconfiguration to refer to the situation where a configuration problem solver (whose knowledge base is assumed correct) is confronted with an incorrect configuration outside its ordinary search (configuration) process. There are two basic variations how this can happen:

Altered requirements. The customer notices that the system does not provide a particular desired function. This might be either be due to the requirements of the original configuration being incorrect or incomplete (e.g., through operator error or a misunderstanding between customer and vendor), or because the configuration was altered by the customer.

Legacy systems. Some time after purchase, the customer wishes to alter the system's functionality (e.g., simply extend it because the small version he bought is no longer up to handling the increased workload), but while the requirements are sensible, the old system is now inconsistent with the new requirements, either because the knowledge base has changed (e.g., new regulations declare the old configuration unsafe) or because new components are not compatible with the components of the old system.

Given such a setting, the goal is to arrive at a new configuration that will satisfy the altered conditions. From a practical point of view, the issue arises how such solutions can be found. For proposing desired alterations, we use model-based diagnosis. As usual, given a particular system (in this case the existing configuration) and a description of its behavior, we are looking for a set of components in the system whose misbehavior will explain why the system does not work as expected. Note that several of these terms take on a different meaning in the context of reconfiguration.

First, the goal of diagnosis (identifying the "misbehavior") : in the ideal case we are looking for a set of aspects of the configuration whose alteration will yield a consistent configuration. In the general case, where such a diagnosis might refer to incorrectly chosen components, finding such a solution and guaranteeing its correctness would imply solving the whole configuration problem! Clearly, this is not realistic; all we can expect is for the diagnosis process to provide an indication of where to start. In a simple subcase, as shown in our example below where the behavior of the

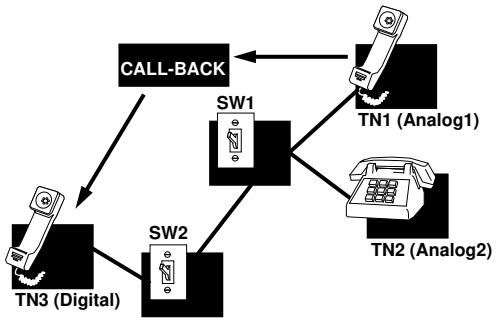

Figure 1: Example Telephone Network

configuration is exclusively in terms of unsuitable parameter choices, providing a full diagnosis is actually possible.

Second, the notion of *misbehavior*. Unlike a malfunctioning hardware system (or a buggy program[1]), where the intended output is distorted by the fault, a configurator does not deal with incorrect behavior. The configuration knowledge merely specifies what conditions need to be satisfied, and it is the purpose of the configurator to provide the correct components and connections to satisfy these conditions for a given set of requirements. Thus, there is no a priori definition of correct and incorrect states, although we will continue to use these terms to distinguish between the choices reasoned about by the diagnosis system.

Finally, the notion of component changes when we pass the border between the configurator and the diagnostic system. From the point of view of diagnosis, a *component* is any part of the system that provide a certain functionality. If a value choice for a parameter can influence the validity of a configuration, then this parameter needs to be explicitly considered by the diagnosis system as a potential source of the misbehavior; from the point of view of the diagnosis system, it becomes a component.

An Example

Figure 1 shows a telephone network consisting of three phones and two switches. Two phones $tn1$ and $tn2$ are said to be internal phones since they are connected with the same switch $sw1$. $tn3$ is an external phone for $tn1$ and $tn2$. Several types of telephones exist. We distinguish between one digital and two analog types (analog1 and analog2). For brevity we assume that the basic functionality for every kind of phone is equally implemented.

Features of a telephone includes performing a call to an external phone set and the callback function among others. They are determined by the current parameter setting. For every potentially available function, there exists a required parameter setting. The parameters are usually usually set after installation of the telephone network, but some parameters can be changed by the user, especially those affecting their own telephone set. To reset the phone to the initial state required by the desired features, a reconfiguration of the parameter setting must be performed, depending on the structure of the network, the desired functionality, and the system model. The model is (verbally) described in handbooks and technical documentation. For example, a verbal model of the callback function would be the following:

[1]The issue of debugging does arise in configuration problems as well, namely, when debugging a configurator's knowledge base. Despite the superficially similar domain, this is a completely different problem, which will be dealt with elsewhere.

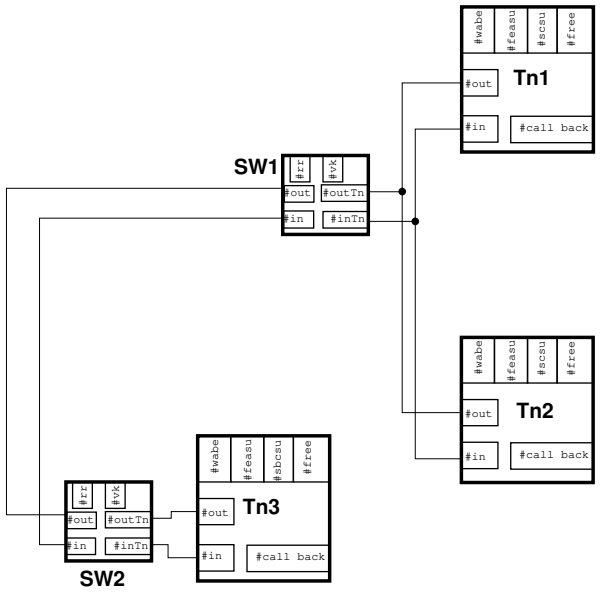

Figure 2: Configuration view of an example telephone network

A phone can establish a callback if the parameter `feasu` and `wabe` are set and if there exists a connection from this phone to the called phone where all involved switches have the `rr` parameter set. For internal calls, the `vk` parameter of the internal switch must be set as well. The called telephone set answers `free` if it is not in involved in another call, and `notfree` otherwise.

Figure 2 depicts a typical view of a small partial configuration as a component-port model, such as used in the constraint-based COCOS configurator (SFH98). Connections between components are expressed via named ports, and parameters of components are named attributes. An object-oriented representation language is used to describe the port and attribute structure of components. The behavior of the components is expressed in terms of constraints which specify valid value assignments for attributes and ports. The callback function would be described as a set of constraints that restricts the involved parameters to valid settings if a setting for the callback parameter is made part of the requirements.

Defining the Model

Model-based diagnosis (Rei87; dKW87) provides a basic framework for diagnosis. The existence of a description for a system (the model) and observations are assumed. The system itself must be composed out of components with a

given behavior. The basic reasoning task in model-based diagnosis is, given a system and observations of that system's behavior, to find a set of components whose incorrect runtime behavior will explain the observations (a more formal definition follows later). A common extension is to explicitly model faulty behavior as well, such as the use of fault models in (SD89), or knowledge about physical impossibilities in (FGN90).

Note: As will become visible later, the configuration and diagnosis view of components are somewhat different. The diagnosis literature refers as a component to any entity in a system that possesses a separate behavior. In our case, this will extend to such things as parameters, which in the configuration view only exist as properties of the component objects. To make the context clear, we will explicitly use the term *diagnosis component* from here on, even though it is somewhat cumbersome.

We use a standard consistency-based definition, combined with fault models, for diagnosis.

Definition 1 (System) *A system is a tuple* $(SD, COMP)$ *consisting of a system description* SD *and a set of diagnosis components* $COMP$.

Definition 2 (Diagnosis) *Let* $(SD, COMP)$ *be a system and* OBS *a set of observations for this system. A diagnosis is a function* Δ *that assigns a mode to every diagnosis component such that* $SD \cup OBS \cup \{\Delta(c)|c \in COMP\}$ *is not contradictory.*

Usually, correctly behaving diagnosis components are excluded when writing down a diagnosis, e.g., a diagnosis $\{\neg ab(c1) \wedge stuck_at_1(c2)\}$ is written as $\{stuck_at_1(c2)\}$. In the case where several modes for correct behavior exist, we assume that one mode is the default. Default modes are excluded when writing down a diagnosis. The function Γ answers a diagnosis ignoring default mode assignments ($\Gamma(\Delta) = \{\Delta(c)|\Delta(c) \neq DEFAULT_MODE(c)\}$).

Diagnoses are usually ordered by their cardinality (default mode assignments are ignored). Therefore we define:

Definition 3 (Subsumption) *A diagnosis* Δ_1 *subsumes a diagnosis* Δ_2 *iff* $\forall x \in \Gamma(\Delta_1) \rightarrow x \in \Gamma(\Delta_2)$ *and they are not equal. We write* $\Delta_1 < \Delta_2$.

Definition 4 (Minimal Diagnosis) *A diagnosis* Δ *is a minimal diagnosis for* $(SD, COMP, OBS)$ *iff no other diagnosis subsumes* Δ.

Almost every diagnosis algorithm computes minimal diagnoses,. Note that in general not all supersets of minimal diagnoses are diagnoses (dKMR90). In the rest of this section we show how a model can be formulated (and used) for our example.

The model for the telephone network example consists of models for three different kinds of diagnosis components.

- **Parameters** are treated as separate diagnosis components, which allows us to talk about their state. Every parameter has one output and distinguishes between three modes `undef`, `on` and `off`. No fault behavior is given. The `undef` mode is the default mode meaning that the setting is not known or not important. The behavior of parameters is simple. In the `undef` mode the value `undef`, in the `on` the value `on`, and finally in the `off` mode the value `off` is given to the output.
- **Phones** provide specific functionality to the user depending on their parameter value settings. Since parameters are introduced as diagnosis components, a port exists for every parameter. In addition, one port exists for expressing user requests (and the answer returned by the network) and two ports for the input and output of values related to the invoked functionality. Since we are only interested in setting parameters, phones are assumed to always behave correctly. Therefore, only the mode expressing correctness (`nab`) is used for phones. The behavior of the phone component uses requests (inputs) and parameter settings and associates outputs (answers) with them. A typical function of a phone is establishing a call. This can be described as follows.

  Assume a user `a` wants to call user `b`. The call request `call(a,b)` is placed on the user port. The phone component checks its parameters. If they are set correctly, `call(a,b)` is propagated to the output port which is connected to switches or other internal phones. A phone `b` receiving `call(a,b)` checks whether it is free or not. In the free case a `free(b,a)` is sent back as output, otherwise a `notfree(b,a)` is sent back. If `a` receives a `free(b,a)` or `notfree(b,a)` value, it is propagated to the user port.
- **Switches** behave similarly to phones and, just as phones, are also assumed to always behave correctly. Switches have two ports connected to the input and outputs of internal phones and two ports connected to other switches. Again, for every parameter there is a port. Requests such as `call(a,b)` are propagated from the input to both outputs (the internal and the external) only if the parameters are set appropriately. Answers from other phones (or switches) are received also via one of the inputs and propagated to the output.

The example system from Figure 1 can be transformed into a component connection model, as shown in Figure 3. Note again that any part of the configuration that might require alteration is represented as a diagnosis component; in particular, the parameters subject to constraints are represented explicitly since the diagnosis system will reason about their state. The `request` port has been added to the phone components. This property was not present in the configuration model, it is used to introduce external observations (e.g., the assertion that a callback request was deposited, but no returning call was observed).

The verbal description of the call-back behavior of the telephone network can be directly transformed into a model.

- **Parameters:** $parameter(P) \rightarrow$

$$on(SW) \rightarrow out(SW) = on$$
$$off(SW) \rightarrow out(SW) = off$$
$$unknown(SW) \rightarrow out(SW) = unknown$$

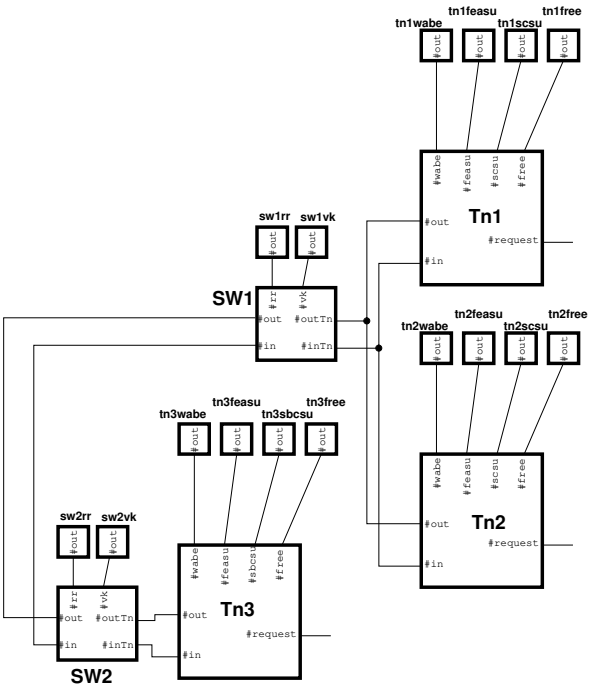

Figure 3: Diagnosis component oriented view of the example network

- **Phones:** $phone(P) \Rightarrow$

$$callback(P, P') \in request(P) \wedge feasu(P) = on \wedge wabe(P) = on \rightarrow callback(P, P') \in out(P)$$

$$callback(P', P) \in in(P) \wedge scsu(P) = on \wedge free(P) = on \rightarrow cb_free(P, P') \in out(P)$$

$$callback(P', P) \in in(P) \wedge scsu(P) = on \wedge free(P) = off \rightarrow cb_notfree(P, P') \in out(P)$$

$$cb_free(P', P) \in in(P) \rightarrow cb_free(P', P) \in request(P)$$

$$cb_notfree(P', P) \in in(P) \rightarrow cb_notfree(P', P) \in request(P)$$

Because we want to use the component model for reconfiguration, we are interested in specifying all relevant parameters. Therefore the following rules are introduced:

$$callback(P, P') \in request(P) \wedge feasu(P) \neq false \wedge wabe(P) \neq false \rightarrow feasu(P) = true \wedge wabe(P) = true$$

- **Switches:** $switch(SW) \Rightarrow$

$$callback(P, P') \in in(SW) \wedge rr(SW) = on \wedge vk(SW) = on \rightarrow callback(P, P') \in out(SW)$$

$$callback(P, P') \in in(SW) \wedge rr(SW) = on \rightarrow callback(P, P') \in outtoswitch(SW)$$

$$callback(P, P') \in infromswitch(SW) \wedge rr(SW) = on \rightarrow callback(P, P') \in out(SW)$$

$$callback(P, P') \in infromswitch(SW) \wedge rr(SW) = on \rightarrow callback(P, P') \in outtoswitch(SW)$$

$$cb_free(P, P') \in in(SW) \rightarrow cb_free(P, P') \in out(SW)$$

$$cb_free(P, P') \in in(SW) \rightarrow cb_free(P, P') \in outtoswitch(SW)$$

$$cb_free(P, P') \in infromswitch(SW) \rightarrow cb_free(P, P') \in out(SW)$$

$$cb_free(P, P') \in infromswitch(SW) \rightarrow cb_free(P, P') \in outtoswitch(SW)$$

$$cb_notfree(P, P') \in in(SW) \rightarrow cb_notfree(P, P') \in out(SW)$$

$$cb_notfree(P, P') \in in(SW) \rightarrow cb_notfree(P, P') \in outtoswitch(SW)$$

$$cb_notfree(P, P') \in infromswitch(SW) \rightarrow cb_notfree(P, P') \in out(SW)$$

$$cb_notfree(P, P') \in infromswitch(SW) \rightarrow cb_notfree(P, P') \in outtoswitch(SW)$$

We explicitly add the following closure axiom:

$$callback(P, P') \in in(SW) \wedge rr(SW) \neq off \rightarrow rr(SW) = on$$

This rule specifies that, if a callback request has been relayed by switch SW, the switch setting required for the relay must have been correct (or the relay action would not have taken place).

Finally, to complete the system description for the telephone network, we have to specify the diagnosis components that will be used (only shown partially for brevity):

$$switch(sw1) \wedge switch(sw2) \wedge phone(tn1) \wedge phone(tn2) \wedge phone(tn3) \wedge parameter(tn1wabe) \wedge \ldots$$

and their interconnections

$$out(tn1wabe) = wabe(tn1) \wedge out(tn1feasu) = feasu(tn1) \wedge \ldots$$

Now we can apply the system description to the phone example. A call back request is stated as observation

$$callback(tn1, tn3) \in request(tn1)$$

We can easily prove that the mode assignment

$$\Delta = \{on(tn1feasu), on(tn1wabe), off(sw1rr)\}$$

is a (minimal) diagnosis wrt. SD and OBS. From $on(tn1feasu)$ and $on(tn1wabe)$ follows that $call(tn1, tn3, callback) \in out(tn1)$. Because $off(sw1rr)$ holds, $out(sw1rr) = off$ follows and nothing more can be derived. Therefore the assumptions about diagnosis component modes in Δ do not contradict the the conjunction of observations and system description, and Δ is a diagnosis. Minimality can be checked by removing an element and checking consistency.

Applying the Model to Reconfiguration

Continuing the telephone example, we can compute all minimal diagnoses using the system description and the observation introduced in the previous section. This set is given by:

- $\{off(tn1wabe)\}$
- $\{off(tn1feasu)\}$
- $\{on(tn1wabe), on(tn1feasu), off(sw1rr)\}$
- $\{on(tn1wabe), on(tn1feasu), on(sw1rr), off(sw2rr)\}$
- $\{on(tn1wabe), on(tn1feasu), on(sw1rr), on(sw2rr), off(tn3free)\}$
- $\{on(tn1wabe), on(tn1feasu), on(sw1rr), on(sw2rr), on(tn3free), off(tn3scsu)\}$
- $\{on(tn1wabe), on(tn1feasu), on(sw1rr), on(sw2rr), on(tn3free), on(tn3scsu)\}$

All these diagnoses represent possible configurations (i.e., in this restricted example, parameter choices) that do not contradict the observations. But most of the diagnoses do not actually establish the desired function (in our case the callback function). To get the correct configuration which ensures the desired functionality, we have to apply a filter condition. For the example, a filter criterion would be that the diagnosis together with the system description and the given observation should allow to derive $cb_free(tn3, tn1) \in request(tn1)$.

In (WS97), configuration problems are divided into valid, suitable, and optimal configuration. Valid configurations satisfy all constraints, whereas suitable ones are valid and satisfy requirements, too. Optimal constraints satisfy optimality criteria. In our case, minimal diagnoses can be viewed as valid configurations. Those diagnoses which allow us to derive the observations which correspond to the desired function (e.g., a callback arriving at the original phone) are classified as suitable configurations.

Definition 5 (Suitable Configuration) *Let F be a (logical) sentence specifying the desired functionality. A suitable configuration Δ for $(SD, COMP, OBS)$ is a minimal diagnosis with the following property*

$$SD \cup OBS \cup \{\Delta(c) | c \in COMP\} \models F$$

A suitable configuration for the callback function is the minimal diagnosis

$$\{on(tn1wabe), on(tn1feasu), on(sw1rr), on(sw2rr), on(tn3free), on(tn3scsu)\}$$

The definition of suitable configurations works like a filter condition on the set of minimal diagnoses, i.e., potential configurations.

An alternative way of achieving the same effect would be to change the system description by the explicit specification of non-derivable behaviors. An example for such a change would be the following rule. If the rr parameter of switch $sw1$ is off, no callback functionality can be achieved:

$$callback(P, P') \in in(SW) \wedge rr(SW) = off \Rightarrow \neg cb_free(P', P) \in out(SW)$$

The introduction of these rules would allow to derive only suitable configurations. However, explicitly representing impossible behavior increases the size of the system description, and thus increases the total computation time for diagnosis. Since checking suitability is very fast, it should be preferred. This runtime behavior is similar to the advantage of using physical impossibilities (FGN90) compared to the effects caused by introducing fault models (SD89).

Ordering diagnoses based on fault probabilities of individual diagnosis components as is common in hardware diagnosis of course makes no sense in this domain. Instead, one could examine the influence of such factors as

- obsolescence (e.g., how old is a component, or how many revisions behind current technology). This would obviously be relevant in case of a legacy system situation.
- how strongly is the component involved in the configuration (e.g., in terms of influenced constraints, connected components etc.). This is a notion that bears a strong similarity to concepts used in domain-independent CSP optimization.
- how easy was it for the customer (or the configured system's administrator, or any of the system's users, etc.) to alter that parameter, or change that particular diagnosis component? (A terminator plug would be easier to remove than a 5kg switching module.)

These considerations are topics for future research.

Background and Implementation

The model presented here was implemented using the Smalltalk-based DTalk framework, developed in the Dike project to provide a diagnosis kernel for diagnosis applications in conjunction with the COCOS configurator (SFH98). The example presented in this paper, while somewhat simplified for presentation, corresponds closely to one of the real-world problems that prompted interest in the Dike project. The reconfiguration model, while requiring certain special features such as set-valued connections, is mainly an extension at the modelling level, not at the level of the underlying diagnosis implementation.

The main requirement for a direct re-use of the modelling approach without extensions is that the behavior of the systems involved must be representable in discrete terms, so that it is possible to map the system's behavior to propagated functionality expressions the way it is done in this paper, e.g., for the `callback` or `cb_notfree` properties. The use of the approach in more general design domains is a topic for future research.

Using Visualworks 2.5 on a Sun Ultra Sparc under Solaris, the valid configurations for the example are computed in about 0.9 seconds. Checking whether a configuration is suitable or not takes 12 ms. Therefore, searching for a suitable configuration for the desired functionality can be done in less than 1 second. Given this particular example feature (callback), the system is reasonably well-behaved in that feature propagation time will increase linearly with the system size. If, however, diagnoses indicate that a particular

component (as opposed to a parameter) is at fault, then the system will naturally not be able to "finish" the configuration – it can only provide a pointer which parts of the configuration should be removed, so that the configurator can attempt to continue with the new, consistent, partial configuration.

Discussion

The goal of this paper is to examine the use of diagnosis for the reconfiguration of an existing technical system. The assumptions typically made for a configuration domain include the existence of a fixed set of component types that can be connected via a well-defined set of ports and parameterized over various switches to provide certain functional requirements. It is these assumptions which allow a fairly direct mapping from a configuration representation to the system description used in model-based diagnosis and the use of standard model-based diagnosis algorithms. (Interestingly enough, the debugging of a configuration knowledge base also provides a possibility to employ model-based diagnosis, although the requirements and mode of application differ as much from the scenario depicted here as they differ from conventional hardware diagnosis, again requiring an entirely different set of assumptions and methods. This topic will be dealt with elsewhere.)

The example model included in this paper demonstrates the above requirements. It is a typical diagnosis system description insofar as ports in the system are explicit, and the functionality provided by components is exclusively propagated through the ports to other components connected along these ports. The effects caused by the propagation therefore depend entirely on the behavior of the receiving component and a system model can be composed from individual component models.

At the same time, there are two major differences. Reasoning about parameters of the configuration problem requires elevating the parameters themselves to the status of diagnosis components. Furthermore, the complex behavior of the individual parts of the phone example is expressed not by propagating low-level signal values along the connections, but instead high-level predicates that also carry global information (e.g., a `cb_notfree` message, even if it is not ultimately propagated correctly, implies that the connection from caller to called is available). The introduction of set-valued signals allows the use of one port to carry information about multiple propagated functionalities.

The model avoids explicit reasoning about topological properties of the system, since for example the reachability of a component (or the availability of alternate paths through the phone network) is handled by the propagation mechanism. The disadvantage is that if only a small part of the system is actually involved in the problem, propagating to remote parts of the system is both needless and computationally expensive. Earlier versions of the model required explicit information about topological properties and reachability, but might be more efficient for large networks. This is balanced by the fact that for large networks, explicitly describing and writing down all required properties will be a fairly onerous task.

The topic of reconfiguration in a diagnostic context was originally brought up in (CR91), but for a different purpose. The intent was not to alter the result of a configuration task, but to provide limited repair capability in the context of hardware diagnosis. The process is envisioned as follows: Given a system that exhibits fault symptoms, diagnosis is performed to find out which components are faulty. After these components are known, diagnosis is again performed, but this time targeted at a different set of literals. Instead of ab assumptions that refer to the abnormality of components, the second diagnosis step searches for a set R_Δ of components such that assuming $\{rcfg(c)|c \in R_\Delta\} \wedge \{\neg rcfg(c)|c \in COMPS - R_\Delta\}$ is consistent with the observations, system description, and diagnosis from the initial step. The $rcfg$ (reconfiguration) literals take the place of the ab literals in the first step. Basically, the system description explicitly specifies (in terms of the $rcfg$ predicate) which reconfiguration operations are possible in the system. Reconfiguration following diagnosis also plays a major role in (WN96).

Closer to what we are attempting in the work presented here, the concept of using diagnosis for controlling redesign has been previously studied, e.g., in (GS96; ABBW93). The redesign approach of the KRITIK system family (GS96) is based on a functional representation (called *Structure-Behavior-Function* (SBF) approach). A device is described in terms of its internal and observable behavior. The internal behavior describes the causal processes that determine the output behaviors of the device. Those output behaviors which are intended by the designers (as opposed to potential side effects, desirable or not) are referred to as the *function* of the device. The system allows to represent the behavior of components over time by way of state transition information.

Unlike (GS96), we do not distinguish between diagnosis for missing functions or unexpected behaviors. The notion of misbehavior simply corresponds to the existence of an observation that is not consistent with the system description, and the diagnosis is not dependent upon whether the problem is due to missing functionality or spurious outputs. This distinction lies exclusively in the observations provided. The KRITIK systems are also applicable to generic, non-discrete design problems in a wider range of areas such as mechanical engineering which we have not studied yet due to our focus on configuration problems.

Unlike generic flow-based representations for diagnosis (CGTT93), there is no generic categorization of components in our approach, as the behavior of different components towards a particular functionality depends on the individual role of the components. It must be explicitly modelled as part of the system description, since a generic and exhaustive classification of the purpose of parameters, switches, and components in the types of systems we deal with is not forthcoming, as opposed to mechanical or physical domains.

An algorithm for model-based redesign was also introduced in (ABBW93). The paper focuses on parametric and component redesign of technical systems. It is assumed that the specification and model of the old system (which should

be redesigned) and the specification of the intended system are available. The proposed diagnostic reasoning method uses a variant of focused Sherlock (dK91). Searching for a redesign is done by diagnosing the old system. Instead of a value propagation mechanism for searching for conflicts under specific assumptions, expression propagation is used. Expressions are computed according to the given component behavior. Since (ABBW93) does only use a subset of all (minimal) conflicts, computed diagnosis candidates can turn out not to be diagnoses. Therefore, the proposed algorithm iterates over the testing of diagnosis candidates and computing of new diagnoses using the obtained test result until a satisfying solution has been found.

The paper distinguishes between *parametric redesign, component redesign*, and *innovative redesign*, but explicitly limit themselves (as we do) to the first two classes. The approach suffers from a number of restrictions. First, it assumes the existence of a separate specification for both the old and new versions of the system, so that more information is available compared to a situation where only the existing system and the required specification of the new system are given. In particular, the old specification is necessary to generate useful test cases (useful in the sense that they improve diagnosis performance). Second, the approach and algorithm are variants of their standard diagnosis counterparts without providing clear reasons for the variations. Furthermore, the algorithm is based on propagation of symbolic expressions, which leads to problems not only in terms of performance, but also in terms of decidability. It also requires the use of an external equation solver (e.g., MAPLE). The illustration of the approach was limited to the D74 circuit.

Conclusion

In this paper we have presented the use of a model-based approach to reconfiguration, i.e., the configuration of a new system based on an inconsistent old one. Our goal was not to provide an internal control mechanism for the configurator, as is the case with, e.g., (BGP94), but rather an adjunct that will provide an indication of the necessary alterations for a configuration that is presented to the configurator by an "outside" event.

The approach we have presented is quite flexible and can be extended to cover additional functional features of the system without altering the representation of the callback function. Finally, like the configuration specification, the system description is modular, i.e., the functionality of the system as a whole is derived from the composition of the individual components. This is achieved by using a system description that uses ports to transmit symbolic, structured values.

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