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Formalization of Component Substitutability

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Abstract

Component-Based Software Engineering (CBSE) is increasingly used to develop large scale software. In this context, a complex software is composed of many software components which are developed independently and which are considered as black boxes. Furthermore, they are assembled and often dependent from each other. In this setting, component upgrading is a key issue, since it enables software components to evolve. To support component upgrading, we have to deal with component dependencies which need to be expressed precisely. In this paper, we consider that component upgrade requires managing substitutability between the new and the old components. The substitutability check is based on dependency and context descriptions. It involves maintaining the availability of previously used services, while making sure that the effect of the new provided services do not disrupt the system and the context invariants are still preserved. We present here a formal definition and a verification algorithm for safe component substitutability.

*Keywords:* Component software, Safety, Substitutability, Upgrading.

# Introduction

Component based software has gained recognition as the key technology for building high quality and large software. In this setting, sharing collections of components has become common practice for component oriented appli- cations. These components are independently produced and developed by different providers and reused as black boxes making it necessary to identify component dependencies to guarantee interoperability.

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According to Szyperski’s definition [[11](#_bookmark30)], a component is a unit of compo- sition with contractually specified interfaces and explicit dependencies. An interface describes the provided and the required services of a component. Software consists of the assembly of components in an architecture, by bind- ing a required interface of one component to an offered interface of another component.

In this context, upgrading a component is difficult because this component may be used by several software applications. More generally, replacing a component *Cold* with a component *Cnew* in a system S requires that it does not disrupt S. This property is often described as substitutability [[5](#_bookmark24)].

Several techniques exist to ensure substitutability between components, see for example [[12](#_bookmark31),[13](#_bookmark32)]. All these approaches are built upon the substitution principle of Liskov introduced in [[1](#_bookmark20)] in the context of object oriented pro- gramming. They use the interface type to define a subtyping relation between components and then authorize *Cnew* to replace *Cold* only if *Cnew* is a subtype of *Cold*. Various forms of those types exist, starting with the classical interface type [[10](#_bookmark29)] and enhancing them with behavioral description such as automata for example [[6](#_bookmark25)]. Some related research [[12](#_bookmark31),[13](#_bookmark32)] show that the resulting condi- tion of pure subtyping ensures *safety* of the replacement but is too restrictive. Recent work [[5](#_bookmark24)] has shown the limits of this approach and proposes a less restrictive notion of substitutability depending on the context. In this setting, *Cnew* may safely replace *Cold* in certain systems. In fact, all interfaces not used in the context are ignored when ensuring the subtyping.

To extend our previous work on the formalization of safe component instal- lation and deinstallation [[2](#_bookmark21)], we tried to define contextual substitutability to build a safe replacement operation following the previously cited approaches. But it appeared that the resulting rule needs to be enhanced to reach *safety*. While in other work the new services provided by *Cnew* do not have to meet any requirement, in our setting they may conflict with the context requirements. Generally, replacing a component *Cold* by a new one *Cnew* has an effect on the context and to maintain *safety*, we have to check that effect will not break system invariants. In previously mentioned work, the only effect taken into ac- count is the services that *Cnew* provides. Therefore, ensuring substitutability consist in ensuring compatibility of *Cnew* provided services with the compo- nent requirements that were previously using *Cold* services. This compatibility can have different contract levels (syntactical, behavioral, synchronisation and quality of service) as described in [[4](#_bookmark22)]. This paper advocate adding the ver- ification of component upgrading effects (upgrade) on the target system. In the deployment, it appears that upgrade effect must not disturb the target system. For this, we propose a substitution principle ensuring that (1) the

new component still provides all the services used in the context (as usual) and that (2) new provided services do not conflict with this context (effect verification). The formalization of this substitutability enables us to provide a safe and flexible replacement operation for our deployment system.

The paper is organized as follows. Section [2](#_bookmark1) introduces our dependencies description and illustrates it with the example of a mail server in Linux GNU. In Section [3](#_bookmark5), we present our substitutability approach with a progressive re- finement of substitutability definitions. Section [5](#_bookmark14) describes the substitutability checking algorithm. Section [4](#_bookmark12) illustrates some substitutability examples. Sec- tion [6](#_bookmark18) discusses related work. Finally, Section [7](#_bookmark19) concludes and discusses future work.

# Dependency description

In this section, we present the precise definition of the relation between a re- quired and a provided service, either of the same component or of two different components. Such a relation is called a *dependency*.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| FETCHMAIL THUNDERBIRD  FDS ≥ 852 FDS ≥ 1508  lib2 lib4  popclient MUA  MDA  MTA spell-Dict corrector  POSTFIX PROCMAIL ORGANIZER  FDS ≥ 1380 popclient MUA manager  ¬*Sendmail* MTA lib3 MDA  libOrg  lib1 FDS ≥ 248  amais AntiVirus spam AntiSpam | | | | | | | |
|  |  |  |  |  |  |  |  |

MTA MDA MUA AntiVirus AntiSpam corrector manager

Fig. 1. A mail server assembly

Fig . [1](#_bookmark2) illustrates a simplified architecture of a mail server on a Linux system. It is composed of five components: POSTFIX, an SMTP server playing the role of a Mail Transport Agent (MTA), FETCHMAIL that recovers mails from a distant server like Pop or IMAP using a mail transport protocol, PROCMAIL,a Mail Deliver Agent (MDA) that manages received mail and enables, for example, mail to be filtered. THUNDERBIRD, a mail manager for reading and composing mail called a Mail User Agent (MUA). Finally, ORGANIZER is an inbox organizer, which allows mailing lists, web pages and users e-mails to be managed. Each

component is represented in Fig. [1](#_bookmark2) by a rectangle with the required interfaces (half circles and square brackets on the left side) and the provided interfaces (black circles on the right side). Requirements in the left hand side of a component, may be of two kinds: (1) software requirements (i.e., services provided by other components), for example libraries (half-circles: *lib*1) or

(2) system requirements expressed by comparison of variables with values represented by square brackets, for example requiring a certain amount of free disk space (*FDS* ≥ 1380*Ko*).

In this example [3](#_bookmark3) , the two forms of dependencies, respectively *intra- dependencies* and *inter-dependencies*, are represented respectively by lines inside components and links between components (like PROCMAIL and THUNDERBIRD, PROCMAIL provides MDA and THUNDERBIRD requires it). There are three main kinds of dependencies, either *mandatory*, *optional* or *negative*:

* a mandatory dependency (represented by a solid line) is a firm requirement. If it is not fulfilled, installation is not possible. For example, POSTFIX needs a terminal with a specific libraries (*lib*1), an amount of free disk space (*FDS* ≥ 1380*ko*).
* an optional dependency (represented by a dashed line) specifies that the component may provide optional services. Such services may not be pro- vided (if their requirements are not fulfilled) without preventing the instal- lation. For example, POSTFIX may provide a service for scanning messages against viruses if the service *amavis* is available. Otherwise POSTFIX can be installed and provides the MTA service, but the service *AntiV irus* is not provided.
* a negative dependency (expressed by a negation) specifies a conflict forbid- ding installation. The conflict may be due to a service or a component. For example, as presented in Fig. [1](#_bookmark2), POSTFIX cannot be installed if the compo- nent SENDMAIL (another component providing MTA) is already installed in the target system.

Intra-dependencies are defined by the producer of the component and used to perform installation. Inter-dependencies result from installation and are used to perform deinstallation and replacement. The two notions are briefly presented below, more details on these concepts are given in [[2](#_bookmark21)].

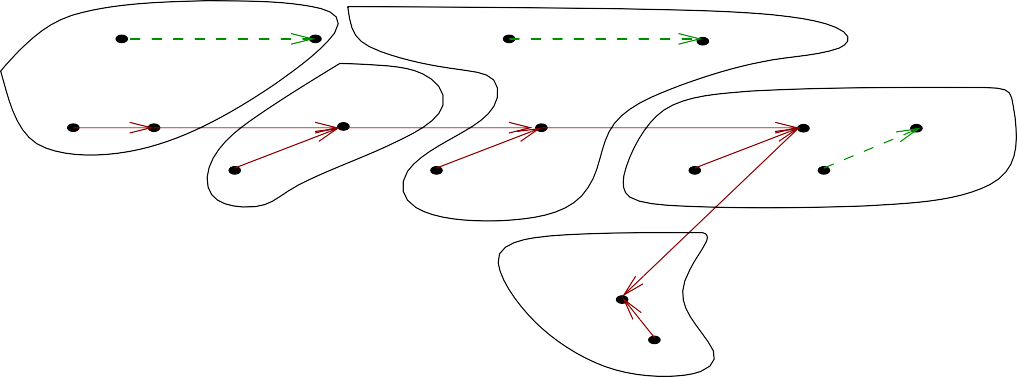
* 1. *Intra-dependencies*

The intra-dependency description language uses the concepts of *dependency*

and *predicate* defined by the following grammar where *s* represents the name

3 To simplify the figure, only some interesting dependencies are represented.

POSTFIX PROCMAIL



AMAVIS.amavis POSTFIX.AntiVirus

SPAM.spam

PROCMAIL.AntiSpam

THUNDERBIRD

C1.lib1 POSTFIX.MTA

FETCHMAIL.popclient

PROCMAIL.MDA

THUNDERBIRD.MUA THUNDERBIRD.corrector

SPELL.spell−Dict

C2.lib2

C3.lib3

C4.lib4

FETCHMAIL

ORGANIZER.manager

Mandatory dependency (M)

Optional dependency (O)

C5.libOrg

ORGANIZER

Fig. 2. Dependency graph of the mail server of Fig. [1](#_bookmark2)

of a service and *c* the name of a component:

*D* ::= *P* ⇒ *s* | *D* • *D* | *D* # *D* | ? *D P* ::= *true* | *P* ∧ *P* | *P* ∨ *P* | *R R* ::= [*v O val* ] | ¬ *s* | ¬ *c* | *c.s* | *s O* ::=*>* | ≥ | *<* |≤| = | /=

The precise semantics of these operators is described in detail in [[2](#_bookmark21)]. In- tuitively, a dependency may be the conjunction • or the disjunctionof two dependencies, an optional dependency ? or a simple dependency *P* ⇒ *s* spec- ifying the requirements *P* of the service *s*. If these requirements are fulfilled the service *s* is available. The requirements are expressed in a first order predicate language with five conditions (*R*) expressing a comparison of an environment variable with a value ([*v O val* ]), a conflict with a service (¬ *s*), with a component (¬ *c*), the requirement of a service provided by a precise component (*c.s*) or any component (*s*). Examples of such predicates appear in Fig. [1](#_bookmark2) on the required interfaces represented in the left-hand side of a com- ponent. For exemple the dependency description of the component POSTFIX is : ([*FDS* ≥ 1380] ∧ (*sendmail*) ∧ *lib* ⇒ *MTA*)•?(*Amavis* ⇒ *AV* )

* 1. *Inter-dependencies*

When a component is installed in a system S, each of its requirements is fulfilled by binding it to any existing component of S satisfying the require- ment. This binding is what we call an *inter-dependency*. It is the result of installation and is required to ensure safe deinstallation and replacement. We have chosen to represent inter-dependencies by a *dependency graph* (see [[2](#_bookmark21)] for more details). A node of a dependency graph is an available service *s* with its

provider (*c.s*) and an edge is a pair of nodes *n*1 −→ *n*2 meaning that *n*2 requires *n*1. Each edge is labeled (above the arrow) by the kind of dependency, either mandatory M or optional O. Fig. [2](#_bookmark4) presents the dependency graph of the mail server of Fig. [1](#_bookmark2). We can see that some solid (resp. dashed) lines inside compo- nents in the Fig. [1](#_bookmark2) (intra-dependencies) are reflected in Fig. [2](#_bookmark4) by solid (resp. dashed) edges. For example, POSTFIX depends on *lib*1 which is provided by a component C1, so the used service is C1.*lib*1. This dependency is a manda- tory one (solid edge in Fig. [2](#_bookmark4) *C*1*.lib* '−→*P OST FIX.MT A*). POSTFIX has also an optional dependency, it can provide an Anti virus (POSTFIX.*AntiV irus*) if a service *amavis* provided by a component (for example AMAVIS) is available. This dependency is represented in the graph by a dashed edge. The sys- tem requirements (like *FDS* ≥ 1380) and negative dependencies (SENDMAIL) are not represented in the graph. The inter-dependencies between compo- nents in Fig. [1](#_bookmark2) are represented in the graph as mandatory edges between services, for example the service *popclient* provided by FETCHMAIL is linked with service *popclient* required by PROCMAIL, the corresponding edge in Fig. [2](#_bookmark4) is *FET CHMAIL.popclient* '−→*P ROCMAIL.MDA*.

# What is substitutability?

In this section, we present and analyze progressively the substitutability prob- lem, we propose definitions and rules to check the correctness and safety of substitutability. In general, two forms of compatibility between components can be defined: vertical compatibility and horizontal compatibility. The verti- cal compatibility is called substitutability, it expresses the requirements that allow the replacement of one component by another (*Cold* by *Cnew* in Fig. [3](#_bookmark6)). The horizontal compatibility expresses connexion between a provided service of a component and a required service of another component (*Cold* used by *Cclient* in Fig. [3](#_bookmark6)). When substituting the component *Cold* for the component *Cnew*, we have to ensure that the component *Cclient* can use the services pro- vided by *Cnew* as it used previously those provided by *Cold* and the new pro- vided services do not conflict with *Cclient* and all other client components.

* 1. *Substitutability deﬁnitions*

Following the current trend, we define two kinds of substitutability, one ad- dressing substitutability in a particular context and the other independent of the context. The definitions of strict and contextual substitutability are given below and are inspired by those of Brada in [[5](#_bookmark24)].

is *Cold compatible* with *Cclient*?

*Cold Cclient*

*P*1 *S*3



*S*2

*P*1

*P*2

*S*1

is *Cnew substitutable* for *Cold*?

*S*'

2

*S*4 *S*'

1

*P*2 *P*3

*P* '

1

*P* '

2

*P* '

3

*Cnew*

Fig. 3. Vertical and horizontal compatibility

Definition 3.1 (Strict substitutability)

A component *Cold* is *strictly substitutable* for a component *Cnew*, if the latter can replace *Cold* in all contexts.

Definition 3.2 (Contextual substitutability)

A component *Cold* is *substitutable* in a context *Ctx* for a component *Cnew* if the latter can replace *Cold* in the context *Ctx*.

Contextual substitutability is related to the context which represents the resources and the architecture of the target system. Ideally, it could be the union of the dependencies of all components (part of the system). The result- ing description of the context would be a huge logical term. Its manipulation when deciding whether to authorize a deployment operation would be difficult and expensive (in calculation). Thus, we have chosen instead a safe approxi- mation of the context description. The context definition is presented in [[2](#_bookmark21)]. It is summarized as follows:

Definition 3.3 (Context)

The *Context* is composed of (1) an environment E storing the values of environ- ment variables (OS, disk space, etc.), (2) a set C of four-tuples (*c,* P*s,* F*s,* F*c*) storing for each installed component *c* its provided services P*s*, forbidden ser- vices F*s* and forbidden components F*c* [4](#_bookmark7) and (3) a dependency graph G storing

4 The required services of a component are stored in the dependency graph not in the component tuple.

the dependencies (the required and the provided services of each component and the relation between them).

* 1. *Component substitutability*

To decide whether a component *Cnew* can substitute a component *Cold*, it is necessary to compare what they provide and what they require. Indeed, the provided (or required) services of *Cnew* can be the same or different from those of *Cold*. We therefore have to study all the possibilities. Fig. [4](#_bookmark8) depicts the different possible relations between the old and the new set of provided (resp. required) services:

* + - case 1: the set of provided (resp. required) services of *Cnew* is included in the set of provided (resp. required) services of *Cold*;
    - case 2: the set of provided (resp. required) services of *Cnew* and *Cold* are equal;
    - case 3: the set of provided (resp. required) services of *Cold* is included in the set of provided (resp. required) services of *Cnew*;
    - case 4: the two sets are different from each other and can have some services in common.

old

old

new

new

new

old

old

new

case 1 case 2 case 3 case 4

Fig. 4. Comparison according to the old and the new service sets

There are four cases for provided services combining with four cases for required services leading to sixteen possibilities. To illustrate these cases, we suppose that the component *Cold* provides the services *PS*1 and *PS*2 and requires the services *RS*1 and *RS*2. Table [1](#_bookmark9) represents the different forms that the component *Cnew* may have, depending on its provided and required services. Each cell of the table corresponds to numerous possible components and is here represented by one possible component for illustrative purposes only.

In fact, the sixteen possible cases can be refined to table [2](#_bookmark10) below, containing eight possibilities combining only three conditions:

* + - ensure new requirements (NR) of *Cnew*. For example, in line 1, is *RS*3

satisfied?

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Provides  Requires | more | same | fewer | different |
| more | *RS*1 *PS*1  *RS*2 *PS*2  *RS*3 *PS*3 | *RS*1 *PS*1  *RS*2 *PS*2  *RS*3 | *RS*1 *PS*1  *RS*2 *RS*3 | *RS*1 *PS*1  *RS*2 *PS*4  *RS*3 |
| same | *RS*1 *PS*1  *RS*2 *PS*2  *PS*3 | *RS*1 *PS*1  *RS*2 *PS*2 | *RS*1 *PS*1  *RS*2 | *RS*1 *PS*1  *RS*2 *PS*4 |
| fewer | *RS*1 *PS*1  *PS*2 *PS*3 | *RS*1 *PS*1  *PS*2 | *RS*1 *PS*1 | *RS*1 *PS*1  *PS*4 |
| different | *RS*1 *PS*1  *RS*4 *PS*2  *PS*3 | *RS*1 *PS*1  *RS*4 *PS*2 | *RS*1 *PS*1  *RS*4 | *RS*1 *PS*1  *RS*4 *PS*4 |

Table 1 Substitutability possibilities

* + - * ensure no conflicts (NC) between the new services of *Cnew* and the system. For example, in column 1, is *P S*3 in conflict with the system?
      * ensure that all previously provided services which are not provided by *Cnew* are not necessary for the system (NON). For example, in column 3, is *P S*2 (previously provided by *Cold* and not provided by *Cnew*) necessarily used?

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| zzzzz Provides  zzzz  Requires zzz | more | same | fewer | different |
| same / fewer | NC |  | NON | NC+NON |
| different / more | NR+NC | NR | NR+NON | NR+NC+NON |

Table 2 Substitutability conditions

This table shows the different substitutability conditions on the context. The only cell corresponding to strict substitutability is the empty one. The condition is then that *Cnew* requires the same thing or less than *Cold* and provides the same services. The seven other cells represent contextual substi- tutability. Necessary and sufficient conditions (NSC) for strict and contextual substitutability are defined as follows:

NSC 1 (Strict substitutability) *A component Cold is strictly substitutable for a component Cnew iff they provide the same services and Cnew has the same or fewer requirements than Cold.*

NSC 2 (Contextual substitutability) *A component Cold is substitutable for a component Cnew in a context Ctx iff:*

* + - *all the new requirements of Cnew are satisﬁed in Ctx (NR).*
    - *none of the new provided services is in conflict with Ctx (NC).*
    - *none of the services provided by Cold not provided by Cnew is used necessarily within Ctx (NON).*

Compared to existing substitutability approaches, the condition (NC) is orig- inal because it enables to take into account various form of component effects on the context (potential conflicts that can occur due to the new compo- nent) and maintaining the safety of the system. In an extension of our system not presented here, we have the specification of non-functional properties. Re- placing a component by another may have an impact on the system properties and therefore may be forbidden. An example of a such substitution is further discussed in Section [6](#_bookmark18).

* 1. *Ensuring substitutability in our context*

To ensure substitutability in our system, it is necessary to :

* + - determine which case is examined,
    - evaluate the corresponding conditions among NR, NC and NON.

Using our dependency descriptions presented in section [2](#_bookmark1) it is easier to calculate and compare provided services than required ones. In our approach, we do not consider requirements because the conditions are described in pred- icate logic and it is rather complex to compare requirements for each provided service. Therefore, we check substitutability according to provided services only as follows:

1. NR and NC: to check the new requirements (NR) and prevent new con- flicts (NC), we reassess the installability condition of the new component *Cnew*. This condition ensures, on the one hand, that all the component requirements are fulfilled (NR) and, on the other hand, that the pro- vided services are not in conflict with context (NC). Therefore, the NR and NC conditions correspond to ensuring installability as presented in

[[2](#_bookmark21)]: (*Ctx* ▶ *Cnew* : *Dnew*).

1. NON: this condition is based on the calculation of provided services from the right-hand member of the dependencies. So, for each provided service of *Cold* which is not provided by *Cnew* we have to check that it has no mandatory dependency (i.e., it is a leaf in the dependency graph) or it is only used (directly or indirectly) by optional services (in the graph,

all paths coming from it must be optional, see definition [3.4](#_bookmark11)). In fact, it corresponds to the deinstallation requirements of [[2](#_bookmark21)].

Definition 3.4 (Mandatory dependencies (*MD* )) The set of mandatory dependencies (*MD* ) of a service *s* provided by a component *c* (*c.s*) in a de- pendency graph (G) is the set of nodes which use necessarily this service. It

is defined as :

*MD* (G*, c.s*)= {{*c*'*.s*'}∪ *MD* (G*, c*'*.s*') M ' '

| *c.s* −→ *c .s*

∈ G}

The condition NON can be expressed as follows:

{(*MD* (G*, Cold.s*) | *s* ∈ (*Cold.*P*s* \ *Cnew.*P*s*)} = ∅

We summarize the different substitution conditions for the four cases il- lustrated in Fig. [4](#_bookmark8) and table [2](#_bookmark10) as follows:

* + - * providing more (case 3): *Cnew* is installable (NR+NC);
      * providing the same (case 2): *Cnew* is installable (NR);
      * providing less (case 1): *Cnew* is installable (NR) and services from *Cold.*P*s* \

*Cnew.*P*s* are not used necessarily (NON);

* + - * different (case 4): *Cnew* is installable (NR+NC) and services from *Cold.*P*s* \

*Cnew.*P*s* not used necessarily (NON).

# How substitutability is checked?

The substitutability handled in our system is only a contextual one. We have to calculate the context denoted *Ctx* without *Cold* (*Ctx* \ *Cold*), i.e., simulate the effect of removing from the context the component *Cold* with its four-tuple (*Cold,* P*s,* F*s,* F*c*). Then, we have to check the installability of *Cnew* in the resulting context (*Ctx* \ *Cold*). The formal definition of contextual substitutability is presented below:

Theorem 4.1 *Contextual substitutability*

*A component Cold is substitutable for a component Cnew in a context Ctx if:*

* + - * *Cnew is installable in Ctx* \ *Cold;*
      * *all provided services of Cold which are not provided by Cnew (Cold.*P*s* \ *Cnew.*P*s) must not be used necessarily in the context (NON condition):*

{(*MD* (G*, Cold.s*) | *s* ∈ (*Cold.*P*s* \ *Cnew.*P*s*)} = ∅

Substitutability is checked as depicted in the diagram of Fig. [5](#_bookmark13). First, the new context *Ctx*' is calculated without the old component *Cold*. So, *Ctx*' is

Calculation of *Ctx*′ = *Ctx* \ *cold*

yes

*C* installable in *Ctx*′?

*new*

no

*Cold.*P*s*

yes

*C .*P \ *C*

*old s new s*

*.*P = ∅

no

NON

no

yes

*Cold* not substitutable

*Cold* is substitutable

Calculation of *Cnew.*P*s*

Fig. 5. Substitutability phases

*Ctx* without the set of all provided services of *Cold* and without its forbid- den services and forbidden components. Then, we check whether the new component can be installed using installability rules in the new context, i.e., all *Cnew* requirements are fulfilled in *Ctx*' and its provided services does not conflict with *Ctx*' (the rules are described in [[2](#_bookmark21)]). Once the installation of the new component is possible in the new context, we calculate the effect of its installation in the context from its dependency description using installation rules described in [[2](#_bookmark21)], i.e., its provided services, forbidden services, forbidden component and the new dependency graph (it is illustrated in the diagram of the Fig. [5](#_bookmark13) by the calculation of *Cnew*.P*s*).

Since the set of provided services depends on the availability of services in the context, we need to use installation rules to calculate it. The two main phases of substitutability are the installability and the calculation of provided services (installation) which depend on the context description and the component dependency description (*D*1 • *D*2*, D*1 *D*2, or ?*D*). The calcu- lation of provided services is not obvious without evaluating the dependency description in the context. Even if the component is installable the provided services depend on fulfilled dependency conditions in the context. Therefore, we present the calculation of provided services depending on the dependency descriptions (*D*1 • *D*2*, D*1 *D*2, or ?*D*):

* + - For *D*1 • *D*2, *D*1 and *D*2 must be verified in *Ctx*', and the set of provided services is the union of the provided services of *D*1 and those of *D*2. For ex- ample, considering the following description: ((*C*1*.S*1 ⇒ *S*2)•(*S*3 ∧[*FDS* ≥ 10]) ⇒ *S*4), the installability conditions are :
* *S*1 belongs to the set of provided services of *C*1 and *S*2 is not forbidden in the context and
* *S*3 belongs to the set of available services of the context, the condition [*FDS* ≥ 10] is verified and *S*4 is not forbidden in the context.

Thus, the provided services are *C.*P*s* = {*S*2*, S*4} or ∅

* + - * *D*1 *D*2 is verified if *D*1 is verified in *Ctx* or *D*2 is verified in *Ctx*. For exam- ple, for: ((*C*1*.S*1 ⇒ *Stext*)(*S*3 ∧ [*FDS* ≥ 10]) ⇒ *Sgraph*), the installability conditions are :
* *S*1 belongs to the set of provided services of *C*1 and *Stext* is not forbidden in the context else
* *S*3 belongs to the set of available services of the context, the condition [*FDS* ≥ 10] is verified and *Sgraph* is not forbidden in the context.

The set of provided services is *C.*P*s* = {*Stext*} else {*Sgraph*} else ∅

* + - * ?*D* is always installable, for example: ?(*C*1*.S*1 ⇒ *S*2), the set of provided services is *C.*P*s* = {*S*2} if *S*1 ∈ *C*1*.*P*s* and *S*2 is not forbidden else ∅

Next, we compare the provided services of *Cold* with those of *Cnew*. *Cold* is substitutable in two cases: either the set of previously provided services which are no longer provided by *Cnew* is empty or each of these services are not necessarily used by other components in the context.

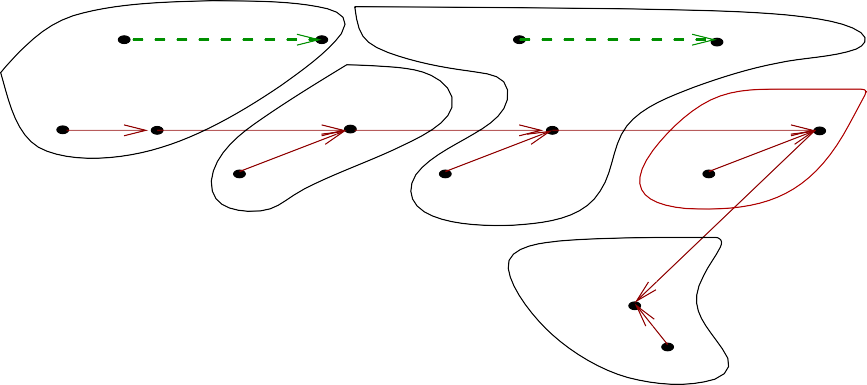
# Example

Let us illustrate component substitutability by examining two substitutabil- ity scenarios. First, the new component provides fewer services. Second, the new component provides more services. The first case may happen for opti- mizing purposes by replacing one component by another which requires fewer resources and provides fewer services. For example, we replace THUNDERBIRD by SYLPHEED. We suppose that the service THUNDERBIRD.*corrector* (a spell checker) is the only service which is not provided by SYLPHEED. The system must ensure the condition NON i.e., this service is not used by another com- ponent. According to the dependency graph of the mail server represented in Fig. [2](#_bookmark4) of section [2](#_bookmark1), the service THUNDERBIRD.*corrector* is a leaf in the graph. Thus, THUNDERBIRD.*corrector* is not used by another component and NON condition is ensured. The component THUNDERBIRD can be substituted by SYLPHEED which provides fewer services if SYLPHEED is installable, i.e., its re- quired services are available in the context. The required services here are the libraries (C6.*lib*6) which means the libraries *lib*6 provided by any component, for example C6 (see Fig. [6](#_bookmark15)).

The second example addresses the substitution of a component providing

POSTFIX PROCMAIL

AMAVIS.amavis



POSTFIX.AntiVirus

SPAM.spam

PROCMAIL.AntiSpam

C1.lib1

POSTFIX.MTA

C2.lib2

FETCHMAIL.popclient

C3.lib3

PROCMAIL.MDA

SYLPHEED.MUA

C6.lib6

SYLPHEED

FETCHMAIL

ORGANIZER.manager

Mandatory dependency (M)

Optional dependency (O)

C5.libOrg

ORGANIZER

Fig. 6. Substitution of THUNDERBIRD by SYLPHEED

more services. For instance, replacing THUNDERBIRD with the mail user agent of SEAMONKEY which has numerous enhancements, for example: a Chat service. (see Fig. [7](#_bookmark16)).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| FETCHMAIL SEAMONKEY  FDS ≥ 852 FDS ≥ 2508  MUA  lib2 MDA ∧ lib7  popclient  ircclient Chat  MTA spell-Dict corrector  POSTFIX PROCMAIL ORGANIZER  FDS ≥ 1380 popclient MUA manager  ¬*Sendmail* MTA lib3 MDA  libOrg  lib1 FDS ≥ 248  amais AntiVirus spam AntiSpam | | | | | | | |
|  |  |  |  |  |  |  |  |

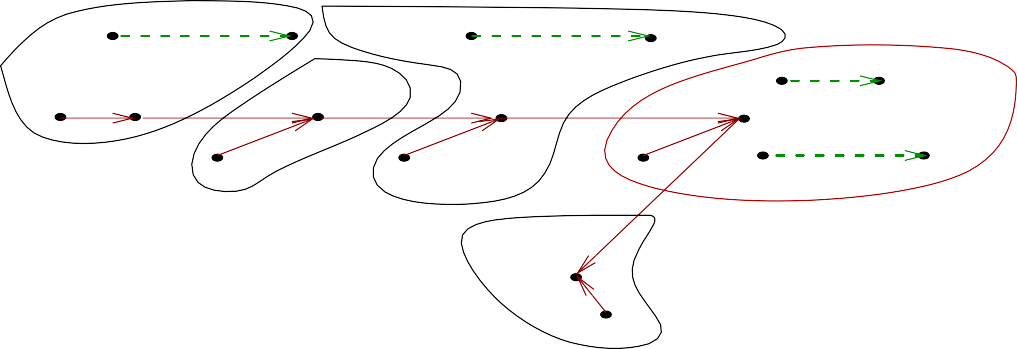
MTA MDA MUA AntiVirus AntiSpam corrector manager

Fig. 7. The mail server with SEAMONKEY

Checking substitutability corresponds to ensuring the requirements of SEAMONKEY (C7.*lib*7, IRC.*ircclient*, SPELL.*spell* − *Dict*, etc.) which are dif- ferent from those of THUNDERBIRD and ensuring that the additional provided services do not disrupt the context. The related dependency graph is presented in Fig. [8](#_bookmark17).

Now, let’s illustrate our main contribution, the two substitution examples of THUNDERBIRD presented above may not be possible even if conditions on provided services are fulfilled (*Cold.*P*s* \ *Cnew.*P*s* = ∅ and NON). Indeed,

POSTFIX PROCMAIL



AMAVIS.amavis POSTFIX.AntiVirus

SPAM.spam

PROCMAIL.AntiSpam

SEAMONKEY

IRC.ircclient SEAMONKEY.chat

C1.lib1 POSTFIX.MTA

FETCHMAIL.popclient

PROCMAIL.MDA

SEAMONKEY.MUA

SPELL.spell−Dict SEAMONKEY.corrector

C2.lib2 C3.lib3 C7.lib7

FETCHMAIL

ORGANIZER.manager

Mandatory dependency (M)

Optional dependency (O)

C5.libOrg

ORGANIZER

Fig. 8. Substitution of THUNDERBIRD by SEAMONKEY

according to the diagram of Fig. [5](#_bookmark13), we have to verify firstly the installability conditions of SEAMONKEY and SYLPHEED. One of the most important part in the installability condition is the verification of the effect of the component in the context. If we suppose that the service *chat* is forbidden in the context, then the condition of the installability of SEAMONKEY is not verified. Therefore the substitution is not possible before comparing provided services of each component.

Finally, we can have invariants in the context that we need to preserve. For example, we may have to preserve the security level of a system by forbidding the installation of any service that can decrease the security level of the system (like the service ftp for example). Let’s suppose a component *Cnew* which provides the service ftp and someone want to replace component *Cold* by *Cnew*. The fact that the service ftp decreases the security level will forbid the replacement of *Cold* by *Cnew* even if it provides all necessary services and does not require too much.

# Related work

The issue of component substitutability has already been addressed in liter- ature. We mention here only those which are the closest to our work and summarize the most common approaches dealing with the substitutability problem.

In oriented object programming, the substitution principle of Liskov is a particular definition of subtype which was introduced in [[1](#_bookmark20)]. This concept of subtype is founded on the concept of substitutability, i.e., if S is a subtype of T then we can substitute objects of the type S for objects of the type T without deteriorating the desirable properties of a program. However, although the

concept of subtype is approved in [[10](#_bookmark29)], the rules based on typing are rather restrictive. We therefore choose a more flexible approach that allows us to make choices according to the system and user requirements.

Substitutability is presented in [[9](#_bookmark28)] as a relation between the types of the old and the new components. This approach is based on a contract defini- tion which is a consequence of the definition of the component type [[8](#_bookmark27),[7](#_bookmark26)]. Substitutability is based on the definition of the compatibility between the component and all the elements with which it interacts. Compatibility is de- fined in terms of syntactic, semantic, and pragmatic contracts for operations, interfaces, ports and components. Thus, a component A is substitutable for another component B if its compatibility with other components is preserved after the substitution and the new required properties are checked. Our work follows the same principle but it is done on the interface signature only.

The concept of substitutability in [[5](#_bookmark24)] is defined for black box components. The principle is to check that the substitution of the component preserves the consistency of the preliminary configuration. The concepts of context of deployment, strict substitutability and contextual substitutability are defined. The representations of component specifications and the deployment context are based on the ENT model (*Export*, *Needs*, *Ties*). The definition of strict substitution is different from ours because it considers that the new compo- nent must provide at least the same thing and requires at most the same thing as the old component (generalization of the needs and specialization of the re- quirements). In the case of “strict” substitutability there is no check for new required interfaces since those are not supposed to exist and they are ”for- bidden” by the strict subtyping case. Nevertheless, new provided interfaces are allowed and therefore checked. However, in our work, the verification is done for the new requirements as well as for the new provided services without using subtyping rules. We think that the strict substitutability is not really interesting because the component needed functionalities depend on the envi- ronment in which it is used and it does not verify the effects on the context and its invariants.

Despite enhancements in substitutability specification at signature, seman- tics and protocol levels, we believe that these works do not take into account the effect of the component. Indeed, they do not verify potential conflicts that can occur after substitution, due to new services. Therefore, in our ap- proach we impose more constraints on the new provided services and ensure that they do not conflict with the existing context and its *invariants* are pre- served. For example, when we want to substitute a component which provides http with another providing http and ftp services and the system forbid non-secure services like ftp, such a substitution cannot occur. Furthermore,

taking into account the potential effect of the new component on the system can be generalized. It is applied not only to conflicts but also to other kinds of effect. For example, the substitutability verification of non-functional prop- erties needs such a mechanisms as the new component may conflicts with the system invariants. Another example of use is the resource consumption. The new component despite being functionally equivalent may not work because it consumes too much resources for the system. For this reason, we have to control the effect of the new component on the context.

# Conclusion and Future work

In this work, we have presented a formalization of component substitutability. Our formalization is based on dependencies and context descriptions which are also used for installation and deinstallation phases in [[2](#_bookmark21)]. It aims at providing a safe and flexible component upgrade. The key concept is the comparison between dependency descriptions of the new and the old component. The comparison concerns provided services and does not take into account required services. We have defined the *strict* and the *contextual* substitutability and we have concentrated only on *contextual* one. We have presented an analysis of different substitutability cases and summarized them into three key conditions. These conditions involve checking the installability rule of the new component (verifying requirement and ensuring that provided services will not conflict with the context of the system) and checking the effect of deinstallation of the old component using the dependency graph. A prototype implementing our proposal has been developed in Ocaml. Our objective is to ensure the safety of substitutability without being restrictive by authorizing all cases of substitutability. For example, replacing a component which has a lot of unused services with another which has fewer provided services (only those which are useful) is possible. This substitutability can also depends on a system policy or property models as described in [[3](#_bookmark23)]. We focus on ensuring the safety of the system, i.e., verifying the *requirements*, the *effect* of the substitution and preserving context *invariants*, component and service *properties*.

Now, we aim to parametrize the substitutability check by policies and properties (for example, if the policy tries to optimize resources we cannot replace a component by another one which requires a lot of resources). Fur- thermore, we are working on a dependency description extension to express properties on services and components. As future work we aim at extending our system to overcome its two main limitations, which are:

* to substitute a component assembly, we have to calculate the dependency of a composite component using the dependencies of its sub-component.
* in our current approach, components and services are identified by their names. This identity must be extended to include interface type and prop- erty information. This means changing from name equivalence to a form of subtyping when determining dependencies between services. In such an approach, we could reuse behavioral substitutability such as [[6](#_bookmark25)] for example.

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