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Applications = Components + GLoo

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Abstract

We are advocating a component-oriented software development approach that provides support for a clear separation between the computational and the compositional entities of an application. This principle is best captured by the application building paradigm “Applications = Components + Scripts.” However, the biggest obstacle for a successful use of this maxim originates from the choice of the scripting mechanisms being used to define applications as compositions of reusable software components. In this paper, we analyze GLoo, a novel component-oriented programming framework, which derives its expressive power from an extensible and *open-ended* scripting language. The design of GLoo aims at a higher-level, scalable, and *problem-oriented* software development approach, which enables simultaneously both *small-scale* and *large-scale* software development through the definition of *specially-designed domain sublanguages*.

*Keywords:* Component Composition, Language Design, Semantics

# Introduction

The component-oriented software technology has emerged as a veritable incarna- tion of a general engineering principle in which the development of new products is based on accumulated, generally available system knowledge and experience. By factoring out certain *stable* entities as reusable components, whose quality is ex- pected to improve with every reuse, the component-based software development approach offers a feasible solution for developing and evolving modern, high-quality software systems [[5](#_bookmark20),[24](#_bookmark39),[29](#_bookmark44)]. However, while our understanding of this technology has grown significantly over the last decade resulting, for example, in the definition of industrial-strength component models like Java Enterprise Beans [[19](#_bookmark32)] and the

.NET framework [[23](#_bookmark38)], most existing component frameworks offer only limited sup- port for the definition of higher-level, scalable, and domain-specific *compositional mechanisms* that reflect the characteristics and constraints of the components be- ing composed [[1](#_bookmark16),[27](#_bookmark42)]. The mismatch between the mechanisms offered by present-day

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component-oriented techniques and the methodology they are supposed to support is due to an unsuitable use of *general-purpose* programming languages, which are not tailored to software composition [[16](#_bookmark31),[20](#_bookmark33),[21](#_bookmark34)].

Furthermore, Aßmann [[5](#_bookmark20)] argues that a comprehensive component-oriented soft- ware development approach not only needs to provide abstractions to represent different component models and composition techniques, but it must also pro- vide a systematic method for constructing large software systems. In particular, a specially-designed *composition language* is required [[5](#_bookmark20),[16](#_bookmark31),[20](#_bookmark33),[21](#_bookmark34)] that (i) allows for an efficient integration of heterogeneous software artifacts, (ii) provides support for a problem-oriented software development approach, and (iii) enables software engineers to incrementally construct component-oriented domain abstractions on demand.

A language that satisfies these design criteria is GLoo, a novel component- oriented programming framework that is based on an *open-ended* scripting language, which allows for the specification of extensible *domain sublanguages* to capture a well-defined subset of a component-oriented software application. In earlier work [[16](#_bookmark31)], we have already demonstrated, how GLoo can be used to specify readily avail- able language abstractions that serve as *syntactic* and *semantic* extensions to the GLoo framework. In this work, we present an approach for the integration of existing software artifacts. In particular, we discuss the refined GLoo programming model and illustrate an approach to define a *Language-of-Java-Services* to incorporate Java software artifacts into the GLoo framework. The *Language-of-Java-Services* not only provides the required language mechanisms to import, configure, and compose Java artifacts, but also represents these Java artifacts as native *ﬁrst-class* entities within the GLoo framework. As a result, we obtain immediate interoperability be- tween the Java and other, already present, heterogenous software artifacts in the GLoo composition framework.

The rest of this paper is organized as follows: in Section [2](#_bookmark1), we briefly describe the main features and design rationale of the GLoo framework and present the design and implementation of the *Language-of-Java-Services* in Section [3](#_bookmark5). In Section [4](#_bookmark13), we discuss both related work and its impact on the design of the GLoo framework. We conclude this paper in Section [5](#_bookmark15) with a summary of our main observations and outline future activities in the area of the specification and implementation of narrow-focused domain sublanguages.

# The GLoo Approach

* 1. *The Design Principles*

One of the major challenges in designing a new programming language is to find the right balance between the features the new language must support and the features that would make the new language more versatile. General-purpose programming languages provide a good example for this dilemma. Rather than providing very high-level and readily available plug-and-play abstractions, general-purpose pro- gramming languages offer, in general, only medium-level language constructs to

build reusable domain abstractions in form of libraries or API’s.

We face a similar problem when designing a composition language. A general- purpose composition language [[17](#_bookmark35),[20](#_bookmark33),[27](#_bookmark42)] should combine aspects of: (i) architectural description languages, allowing us to specify and reason about system architec- tures, (ii) scripting languages, allowing us to specify applications as configurations of components according to a given architectural style, (iii) glue languages, allow- ing us to specify component adaptation, and (iv) coordination languages, allowing us to specify coordination mechanisms and policies for concurrent and distributed components. However, combining these rather orthogonal aspects all in one single language is not a viable option, as the resulting language would become rather large and hard to master. As a consequence, such a language would miss one of its major design goals, that is, to provide a flexible, reliable, and verifiable component-based software development approach.

The design of GLoo builds upon a different strategy that has already been sucess- fully tested in CDL [[12](#_bookmark27)], a language especially designed for the construction of com- pilers. CDL is an *open-ended* programming language with an *empty kernel*. The most unique feature of CDL is that it is a language that does not possess any prede- fined language constructs, except an extension mechanism to *borrow* new language abstractions defined in *macro libraries*, which serve, therefore, as *semantic exten- sions* to the core of CDL. Unlike CDL, however, GLoo already provides some basic support for defining applications as compositions of reusable software components. The core of GLoo is based on the λF -calculus [[15](#_bookmark30)], a variant of the λ-calculus that hosts *dynamic binding*, *explicit namesspaces* [[2](#_bookmark17)], *incremental reﬁnement*, and a *foreign code gateway* as the primary tenants in a single formal framework. GLoo targets a *problem-oriented* software development approach that provides a *formal testbed* for modeling, reasoning, and verifying open-ended language mechanisms in the context of component-oriented software development. The design of GLoo aims at a *scalable* support for the definition of *ﬁrst-class subject-oriented development ar- tifacts* [[22](#_bookmark37)] that constitute narrow-focused *domain-speciﬁc sublanguages*, which are designed, for example, for subsets of a larger component-oriented software architec- ture.

GLoo is a *pure functional* scripting language. Due to its functional nature, GLoo provides a declarative programming paradigm favoring an exogenous control style

[[3](#_bookmark18)] in which computation is encapsulated in components and control flow is encoded in connectors that serve as explicit composition operators [[13](#_bookmark28)]. In addition, GLoo, by means of its built-in gateway mechanism, allows for a simultaneous specification of Java code within the scope of a GLoo specification unit. The Java gateway code serves as *glue code* for both the specification of new data types and the configuration of components to adapt them to actual compositional requirements [[27](#_bookmark42)]. Thus, the GLoo gateway mechanism provides a crucial building block for the definition of new domain abstractions.

GLoo does not offer any support for concurrent composition by default. As a result, it seems that GLoo exhibits a serious deficiency in this area with respect to the requirements for a composition language [[20](#_bookmark33)]. Moreover, Benton et al. [[6](#_bookmark21)] argue

that concurrency is a language feature and should therefore be made an integral part of the underlying language specification. However, the identification and definition of the right set of abstractions for concurrency within a given language is not an easy task. Consider, for example, the industrial-strength languages Java and C#. Both languages offer a rich set of primitives to cope with concurrent activities within a software system. Nevertheless, these abstractions are not powerful enough to separate coordination from computation concerns, as, for example, synchronization has to be specified at the method level or the lifetime of object instances may change due to application-specific settings controlled by the lifetime management of the .NET Remoting infrastructure [[31](#_bookmark46)].

We notice a similar problem in Piccola [[1](#_bookmark16),[17](#_bookmark35)], which can be seen the predecessor of GLoo. Piccola is a small composition language in which support for concurrency is a primary tenant of the language model, as the semantics of Piccola is based on a variant of the π-calculus [[18](#_bookmark36)]. However, the linguistic elements of Piccola related to its support for expressing concurrent activities are very low-level, which gives Piccola the flavor of a “concurrent assembler”. Moreover, Piccola does not offer any kind of support for the encapsulation of a component’s cooperation pat- terns and the computation it is performing. As a consequence, communication and computation concerns occur mixed and interspersed in a typical Piccola specifica- tion impeding both a clear identification of underlying cooperation patterns and a meaningful reuse in a context other than the one the specification has been designed for.

As outlined above, the GLoo approach builds upon an extensible language model. Concurrency can be viewed as a *domain aspect*, which should be captured by a specific domain sublanguage that provides support for the denotation of con- current activities and their coordination. This view offers a subtle, but intriguing variation of Benton et al. argument, as it adheres to the requirement that concur- rency has to be made an integral part of the language. However, by capturing the required language abstractions in an extensible domain sublanguage, we achieve a better versatility of the resulting language support. A suitable model for the defini- tion of such a sublanguage is, for example, the *Idealized Worker Idealized Manager* model (IWIM) [[3](#_bookmark18)]. A concrete realization of the IWIM model in GLoo could, for example, mimic Reo [[4](#_bookmark19)], a channel-based exogenous coordination language with first-class connectors that arrange component cooperation in a component-based application.

* 1. *The GLoo Programming Model*

Any methodology for a comprehensive component-oriented software development approach needs to inforce a clear separation between the computational and com- positional entities constituting an application [[27](#_bookmark42)]. For this reason, Schneider has coined

“Applications = Components + Scripts”,

GLoo Input Unit

GLoo Intermediate Code

Output

GLoo Frontend GLoo Backend

GLoo Extensions & Components

Java Compiler

Java Support Classes (\*.class)

Java Support Classes (\*.java)

Fig. 1. The GLoo execution model.

a maxim that not only captures the essence of component-based software en- gineering, but also stresses the fact that a component-based software development approach, in order to truly achieve its goals, must yield software systems that are *extensible*, so that new features can be added without breaking the existing func- tionality, and they must be *composible*, so that features can be recombined to reflect changing requirements on their architecture and design.

The GLoo approach follows this maxim. In GLoo, applications are defined in *speciﬁcation units* that define values or *components*, which can be composed with other values or components already present within the system. By using the GLoo framework, Schneider’s paradigm evolves to

“Applications = Components + GLoo.”

The GLoo framework builds upon an interpreter-based execution model as shown in Figure [1](#_bookmark2). The GLoo frontend analyzes a given input unit, imports required additional units from the GLoo extension library, and generates a *Java support class* for each GLoo unit being used. The support classes serve as *semantic extensions* to the GLoo runtime system, which are generated by the GLoo frontend that distills any specified gateway code into a corresponding Java abstraction within a given support class. The GLoo system uses com.sun.tools.javac to compile the support classes. When the compilation of the support classes finishes without errors, the backend loads the resulting Java classes into memory and starts evaluating the *intermediate code* derived from the input unit.

As a first example, consider the specification shown in Listing [1](#_bookmark3). This unit illustrates, how the Java class java.util.Hashtable can be used in GLoo. The load statement in line 2 adds the *Language-of-Java-Services* to the local scope of the current GLoo unit. The unit LanguageOfJavaServices.lf uses an additional third unit, called JavaClass.lf, which implements a set of abstractions to represent *Java classes* and *Java objects* as first-class values in GLoo. The declaration in line 4 imports the class java.util.Hashtable, which is being used in line 5 to create a new Hashtable object. In its current version, the *Language-of-Java-Services* does not provides any facilities to use generics. However, we will explore the possibility of

* + 1. let
    2. load " Extensions / LanguageOfJavaServices . lf "

3

1. Hashtable = JavaClass (| className = " java . util . Hashtable " |)
2. obj = new Hashtable (||)
3. put = service obj " put " (| key :0 = " java . lang . Object ",
4. value :1 = " java . lang . Object " |)
5. size = service obj " size " (||)
6. in
7. invoke put (| key = " uid ", value = " Markus " |);
8. invoke put (| key = " home ", value = "/ Users / Markus " |);
9. invoke size (||)
10. end

Listing 1: Using java.util.Hashtable in GLoo.

specifying type parameters through the extension of the *Language-of-Java-Services*

in future work.

In lines 6 and 7, we define two services: put and size. Services behave like *method pointers* or delegates [[23](#_bookmark38)] that define an executable record structure con- sisting of a *target object* and a *method descriptor*. The specification of a service requires three elements: (i) a target object, (ii) a string denoting the method name, and (iii) the signature of the method. A signature defines a keyword-based ar- gument list, where each argument is assigned a position and a type. GLoo uses dynamic binding to pass arguments to functions, that is, the position of an argu- ment is irrelevant. Java, on the other hand, uses a position-dependent parameter passing mechanism. GLoo uses the position specification of a binding as a sorting criteria only. More precisely, if the arguments to a function possess explicitly spec- ified positions, GLoo creates an argument list in which position-carrying bindings are placed in front of any position-independent bindings in the specified order. The reader should note, however, that position-independent arguments are ignored when calling Java methods. Thus, the method associated with service put requires two arguments: key at position 0 and value at position 1, both arguments being of type java.lang.Object, whereas service size has no arguments at all.

These services are then used in lines 10–12 in which we define a sequence of service invocations that yields the value of the last service invocation, that is, the integer value 2. The abstraction invoke takes a service and a set of arguments, which are encoded as a position-independent extensible record (i.e., a *form* [[15](#_bookmark30)]). Internally, the abstraction invoke uses the signature of the service to assign posi- tions to the corresponding arguments and applies the resulting argument list to the associated Java method.

* 1. *Building Domain Abstractions*

GLoo does not offer any predefined abstractions to denote algorithms, except se- quencing. However, GLoo allows for both *syntatic* and *semantic* extensions. More- over, even though GLoo recognizes most Java operators, their actual semantics is undefined, that is, the user has to supply the GLoo system with an appropriate implementation.

The GLoo extension mechanism allows for the definition of arbitrary domain abstractions ranging from new data types to complex domain sublanguages that

package JavaSupport ; import LambdaF .\*;

public class JavaClassValue extends LiteralValue

{

private Class fClass ;

public Class getClassValue () { return fClass ; }

public JavaClassValue ( Class aClass ) { fClass = aClass ; } public String toString () { return fClass . toString (); }

}

Listing 2: Representing Java classes as first-class values.

provide a user-centric view to a specific problem domain (e.g., a service-oriented interface to the Java API). However, common to all domain abstractions is that they require both a *meta level* and a *programming level*. The purpose of the meta level is to incorporate the new domain abstractions into the GLoo runtime system, whereas the programming level has to provide a set of higher-level programming abstractions that encapsulate the meta level to shield the application programmer from the underlying, potentially very complex, infrastructure of the defined domain abstraction.

The ability to define and integrate new domain abstractions in the GLoo frame- work is of great importance in a comprehensive component-oriented software devel- opment approach. For example, even though GLoo does not offer any predefined concurrency and coordination abstractions, appropriate support for these concepts can be defined as a syntactic and semantic extensions to the GLoo system, which mature over time to provide system architects with an ever-improving support for building reliable, verifiable, and robust component-based software systems.

# The Language-of-Java-Services

* 1. *Classes and Objects as First-Class Values*

In order to define the *Language-of-Java-Services*, we need to integrate Java classes and Java objects in the GLoo framework as first-class values. More presicely, we need to define two *container value types* that encapsulate classes and objects, re- spectively, and a JavaClass meta level that defines the core abstractions to load classes, create objects, call methods, and map GLoo values to Java values and vice versa. Container value types are specified directly in Java as part of the package JavaSupport that is automatically loaded into the GLoo system when processing a specification unit.

The definition of the container value type for Java classes is shown in Listing [2](#_bookmark4). The type JavaClassValue defines a *read-only* value denoting a runtime instance of a Java class. Besides the getter method getClassValue(), we also have to redefine the toString() method to obtain a standard textual representation for the newly defined data type. In addition, by deriving JavaClassValue from the class LiteralValue we guarantee a sound integration of the new container value type in the GLoo framework and promote Java classes to first-class values in the GLoo system.

%{ /\* *auxiliary glue code* \*/ }% let

JavaClass = %{ /\* *load Java class* \*/ }%

newInstance = %{ /\* *reflection-based object instantiation* \*/ }% invoke = %{ /\* *reflection-based method invocation* \*/ }%

in

(| JavaClass = JavaClass , newInstance = newInstance , invoke = invoke |)

end

Listing 3: A schematic view of the GLoo unit JavaClass.lf.

* 1. *The Meta Level*

Listing [3](#_bookmark6) provides an overview of JavaClass.lf [2](#_bookmark7) that implements the meta level of the *Language-of-Java-Services*. The unit JavaClass.lf consists of three parts:

(i) auxiliary glue code, (ii) the meta level gateway methods, and (iii) an export declaration. The auxiliary glue code defines additional behavior required by the gateway methods (e.g., the translation of GLoo values to Java values). The auxiliary code is copied verbatim to the underlying support class of JavaClass.lf. Both, auxiliary code and gateway methods are enclosed in the delimiters %{ and }%. The enclosed program text is treated as a single token by the GLoo frontend.

The gateway methods locally define the meta level for the *Language-of-Java- Services*, which is composed from the method JavaClass to load Java classes, the method newInstance to create a new Java object for a given Java class, and invoke to call a Java method. The reader should note that invoke allows for both class- based and object-based method calls though analyzing the receiver argument of invoke. To publish the meta level, we create a new extensible record in which the gateway methods are bound to externally visible identifiers. Though not required by default, by convention we publish the gateway functions under the same names to retain to the connection between the local and external identifiers.

* 1. *The Core Language*

A domain sublanguage can be best described as a *many-sorted algebra* in which the component types are the sorts of the algebra and the grammar of the domain sub- language is captured by the algebra’s signature [[1](#_bookmark16)]. This algebraic view of domain sublanguages provides us with a precise means not only to capture specific problem domains, but also to reason about their properties in a concise and elegant way.

When defining a domain sublanguage, we always aim at a solution with a small footprint, that is, an approach in which the discovery of the actual capabilities of a component is deferred until the corresponding information is actually being required. Using this technique, we can, for example, prevent the GLoo runtime system from creating expensive and potentially unnecessary adapter abstractions to bridge between GLoo and Java. Furthermore, we favor the application of the *continuation-passing-style* (CPS) to define the elements of a sublanguage. Using this technique, function names take the role of *keywords* of the defined sublanguage, whose meanings provide a control context to evaluate a given programming abstrac- tion. In other words, each sublanguage defines a *continuation-passing interpreter*

2 We omit the presentation of the embedded Java code due to a lack of space.

let

Java = load " Extensions / JavaClass . lf"

propagate\_positions =

(\ Positions :: (\ Arguments :: (| Positions # Arguments |)))

in

(|

JavaClass = Java . JavaClass ,

new = (\ Class :: (\ Args :: Java . newInstance (| Args , class = Class |)))

|)

end

Listing 4: The core of the *Language of Java Services*.

in which the continuations *mimic* the parsing process of the underlying syntactic categories.

The core of the *Language-of-Java-Services* is shown in Listing [4](#_bookmark8). The core ex- poses two abstractions: the type constructor JavaClass and the function new that takes a class container value and returns a function, which expects an extensible record denoting the constructor arguments to be passed to the meta level function Java.newInstance. The term (|Args, class = Class|) defines a so-called *bind- ing extension* in which the record Args is refined by the binding class = Class. Again, the order of bindings in an extensible record is insignificant. However, in case of the occurrence of bindings with the same label, the right-most binding has precedence.

In addition, the core also defines the function propagate positions, visible to the local scope of the unit only. The purpose of this function is to combine the posi- tion information specified in the signature record with the bindings in the argument record. The term (|Positions # Arguments|), denoting the composition of the bindings of both records giving the bindings of Arguments precedence [[15](#_bookmark30)], yields a record that has the same bindings as Arguments, except that positions have been added if necessary. More precisely, if a binding in Arguments does not possess an explicitly specified position, then the record Positions is consulted to assign that binding a position.

* 1. *A Smalltalk-like Programming Model*

To add a *message* paradigm to the core language, we define the functions send and to, as shown in Listing [5](#_bookmark10). The function send takes a method name and a message descriptor, denoted by @Args [3](#_bookmark9) (an *open context argument*), to return a new function that requires a continuation. This continuation is the function to that *sends* the method encoded in to the receiver object Object. The underlying meta level function invoke does not distinguish between different calling paradigms. It uses the record (|Args, receiver = Object|) to determine and call the desired method.

To illustrate the use of the Smalltalk-like programming model, consider the specification given in Listing [6](#_bookmark11) that illustrates the setup of a Swing *Hello World* application. This example demonstrates not only the use of the abstractions send

3 The formal parameter Args serves as a placeholder for an explicit lookup environment for the free occur- rences of variables in the body of the function send (i.e., signature, arguments, and Args).

send = (\ MethodName ::

(\ @Args :: let

new\_args = propagate\_positions signature arguments NewArgs = (| Args , arguments = new\_args |)

in

(\ Receiver :: Receiver (| NewArgs , method = MethodName |))

end )),

to = (\ Args :: (\ Object :: Java . invoke (| Args , receiver = Object |)))

Listing 5: The Smalltalk-like extension.

let

load " Extensions / LanguageOfJavaServices . lf"

JFrame = JavaClass (| className = " javax . swing . JFrame " |) JLabel = JavaClass (| className = " javax . swing . JLabel " |)

in

send

" setDefaultLookAndFeelDecorated "

(| arguments = (| defaultLookAndFeelDecorated :0 = true |) |) to JFrame ;

let

frame = new JFrame (| arguments = (| title :0 = " HelloWorldSwing " |) |)

in

send

" add "

(| signature = (| comp :0 = " java . awt . Component " |), arguments =

(| comp = new JLabel

(| arguments = (| text :0 = " Hello World " |) |) |) |) to ( send " get ContentPane " (||) to frame );

end end

Listing 6: Using the Smalltalk-like programming model.

and to, but also shows that Java classes are first-class values (e.g., JFrame). The specification is clearly more verbose than its corresponding Java program, as we are required to explicitly specify the signatures of methods. However, the actual code portions are the same. Moreover, due to the small footprint of the underlying meta level, the required runtime overhead for setting up the Swing application in GLoo is negligible.

* 1. *A Service-Oriented Programming Model*

The message-oriented programming model offers a purely object-oriented view to Java software artifacts. Moreover, each method invocation requires an explicit sig- nature, which makes the Smalltalk-like abstractions more suitable for configuration rather than control flow purposes. For this reason, we extend the *Language-of-Java- Services* with a *service-oriented* paradigm. More precisely, we add the functions service and invoke (as shown in Listing [7](#_bookmark12)) that serve as a minimal extension to the core language in order to provide support for a service-oriented programming model. The function service creates a record that denotes a method pointer in the service-oriented programming model. To call the method associated with the method pointer, the function invoke (i) propagates the positions defined in the sig- nature of the service to the actual arguments, (ii) composes the resulting argument list with the method pointer, and (iii) calls the meta level function Java.invoke

to execute the service. With the service-oriented programming model we achieve a component-oriented view in which components encapsulate computations and and control flow is encoded in sequences of service invocations that act as explicit com- position operators.

service = (\ Obj ::

(\ MethodName ::

(\ Sig :: (| receiver = Obj , method = MethodName , signature = Sig |)))) ,

invoke = (\ @Service ::

(\ Args :: let

args = propagate\_positions signature Args

in

Java . invoke (| Service , arguments = args |)

end ))

Listing 7: The service-oriented extension.

# Related Work

The GLoo framework owes many of its design principles to Piccola, an experi- mental programming language that has already demonstrated the feasibility of a high-level composition language that provides a component-oriented view to soft- ware artifacts defined in a different host language [[1](#_bookmark16),[14](#_bookmark29),[27](#_bookmark42)]. Unlike GLoo, however, Piccola is based on the Piccola-calculus [[1](#_bookmark16)], a variant of the π-calculus, in an at- tempt to unite an asynchronous communication paradigm with the notion of *explicit namespaces* [[2](#_bookmark17)].

Piccola uses *composition scripts* as primary programming units, which denote a single component or application. Complied scripts are stored in the Piccola *component library* [4](#_bookmark14) that contains two kinds of information: *binaries* and *component interface deﬁnitions*. The component binaries are a kind of object files that need to be transformed into an executable agent image by a component linker. The interface definitions, on the other hand, are used by the Piccola compiler to perform static checks when a corresponding component is used within a script.

In order to seamlessly integrate external software artifacts, Piccola provides so- called *peer forms*, which define wrapper-like abstractions to mediate between both the Piccola representation and the host representation of services [[1](#_bookmark16)]. Peer forms rely on a built-in *Java-Piccola-Brigde* that uses so-called *peer classes* to instantiate external host objects. Peer classes are an integral part of the Piccola runtime system and are the sole means to incorporate existing software artifacts into the Piccola framework. There is, however, a significant runtime overhead associated with the use of peer classes to perform service discovery. In order to reduce this overhead, Piccola uses so-called *lazy service evaluation*. Unfortunately, Piccola’s lazy service evaluation strategy is not application transparent and is very costly, since it requires term duplication [[1](#_bookmark16)].

4 This feature is only available in Piccola-1

As a consequence, even though Piccola is an expressive language, it is far from providing the ease and flexibility required to build reliable component-based applications. The reason for this is twofold. First, Piccola still exhibits a con- ceptual gap between the mechanisms offered by language abstractions of Piccola and the component-oriented methodology that it is supposed to support. Secondly, the language abstractions provided by Piccola are still very low-level and there is no support for defining *syntactic* and/or *semantic* extensions to the language so that the encoding of higher-level software abstractions becomes unwieldy for real programming tasks.

GLoo offers a *problem-oriented* software development approach that allows for both *programming in-the-small* and *programming in-the-large* [[10](#_bookmark25)]. The GLoo model for the definition of narrow-focused domain-specific sublanguages is governed by the *subject-oriented programming approach* [[22](#_bookmark37)]. Subject-oriented programming is a generalization of the object-oriented paradigm. A *subject* is roughly equivalent to an entire program in an object-oriented language in which all code within that subject shares the same set of class and type hierarchies, operations, and object state. Moreover, to construct more powerful subject-oriented entities, various com- position rules exist that allow for the combination of subjects. These rules specify mappings between class and type hierarchies in the composed subjects and describe how methods dispatch from within one subject impacts the other subjects in the composition. In other words, a subject can be viewed as a *compositional style* that encapsulates a *ﬁrst-class development artifact* specific to some domain that assists developers to solve problems in that domain in a more efficient manner.

There is a renewed and intense interest in feasible solutions to the *extensibility problem*. In order to retain their usefulness in a real-world environment, software systems must be continually adapted. However, the key to a successful software evolution approach lies in acknowledging the existence of the extensibility problem and designing a system in a way, so that it can evolve on demand. Several ap- proaches have emerged (e.g., Smalltalk [[11](#_bookmark26)], CLOS [[28](#_bookmark43)], Ruby [[30](#_bookmark45)], Tcl [[32](#_bookmark47)], Mixins [[9](#_bookmark24)], Traits [[25](#_bookmark40)], , or Classboxes [[7](#_bookmark22)]) that focus on a particular technique, known as *class extensions*. Class extensions allow for a modular addition of both new classes and new operations to an existing class hierarchy without relying on standard inher- itance mechanisms. Moreover, class extensions provide a controllable mechanism to incorporate new behavior into existing applications and allow, therefore, for a reliable, verifiable, and robust software evolution approach. The extension mecha- nism offered by GLoo facilitates the definition of class extensions. Moreover, due to the ability to define both syntactic and semantics extensions, GLoo is not lim- ited to one specific model for class extensions. New models can be introduced to the GLoo system by defining a corresponding domain sublanguage that offers the required programming abstractions, as if they were native to the GLoo language (e.g., *Language-of-Traits* [[16](#_bookmark31)]).

# Conclusion and Future Work

Crucial to the success or failure of a software project is not only our understand- ing of the problem domain, but also the choice of the programming languages and their support for modeling the problem domain. General-purpose programming languages offer a reasonable support for the encapsulation of domain expertice in prefabricated software entities that can be reused by rearranging them in new com- posites [[29](#_bookmark44)]. However, general-purpose programming languages are less useful when specifying applications as compositions of reusable software components, as they exhibit a mismatch between the the abstraction level of the supported language constructs and the level of abstraction at which software composition takes place.

In this paper, we have analyzed GLoo, a novel component-oriented programming framework that allows for the definition of narrow-focused compositional domain sublanguages that provide a user-centric view of a given problem domain for the application programmer (i.e., the component assembler [[29](#_bookmark44)]). GLoo is a dynamic, open-ended composition language that rests upon dynamic binding, explicit names- paces, incremental refinement, and a foreign code gateway, concepts all crucial for a comprehensive component-oriented software development approach.

The foreign code gateway is the most important innovation of GLoo with respect to its predecessor Piccola and provides us with an effective means to incorporate Java code directly into the scope of GLoo specification unit to construct problem- oriented domain abstractions, as illustrated in the definition of the *Language-of- Java-Services*. The GLoo programming model allows for a light-weigth and scal- able approach to define domain abstractions. Rather than building large, mono- lithic domain models, the GLoo approach fosters the definition of small, first-class subject-oriented development artifacts that can be composed and extended to build larger and more complex and possibly concurrent compositional programming ab- stractions.

However, the gateway mechanism is based on a very fragile technique. At the moment almost no compile-time checks are performed to verify the bridge between GLoo and the embedded Java code. This can result in the occurrences of runtime exceptions due to improper values bound to the expected arguments. Even though the GLoo system is robust enough to properly handle these exceptions, it is more desirable to perform some kind of assertion checking both at compile- and runtime. For this reason, we plan to revise the gateway mechanism by including means to denote *contractual speciﬁcations* [[8](#_bookmark23)]. Contractual specifications ensure that a given feature can be safely combined with other features or deployed in a new context. By adding the notion of *contract* to a getaway function, all conditions for its application are stated explicitly and formally as part of the getaway interface specification, which will enable the GLoo compiler to deduce a set of assertions that have to hold before and after the invocation of a getaway function. This technique in concert with a refined mechanism to pass values to and from a getaway function will provide us with a more robust extension mechanism in the future, while retaining its embodied flexibility.

The GLoo framework also provides support for *Model-Driven Engineering* [[26](#_bookmark41)]. Model-Driven Engineering (MDE) technologies combine domain-specific modeling languages with program synthesis tools for creating domain-specific models of large- scale systems. Models are considered first class entities. The GLoo programming paradigm does not impose any restrictions on definable development artifacts. In future work we plan, therefore, to use the GLoo as a *model-integrated computing* *platform* and perform feasibility studies to ascertain the effectiveness of representing domain models in the GLoo framework.

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# Appendix: GLoo Syntax

*Script* ::= [ *Code* ] ‘let’ *Declarations* ‘in’ *SingleValue* ‘end’

*Declarations* ::= { *Declaration* }\*

*Declaration* ::= [ ‘@’ ] *Binder Binding* | ‘load’ *String Binding* ::= ‘load’ *String* | *SingleValue*

*Form* ::= ‘(||)’ | *Identifier* | ‘(|’ *FormContexts* ‘|)’ *FormContexts* ::= *FormDereferences* { ‘[’ *Form* ‘]’ }\* *FormDereferences* ::= *FormRestrictions* { ‘−>’ *Label* }\* *FormRestrictions* ::= *FormExtensions* { ‘\’ *Form* }\* *FormExtensions* ::= *PrimaryForm* { ‘#’ *Form* }\* *PrimaryForm* ::= *FormBindings* | *Form* [ ‘,’ *FormBindings* ] *FormBindings* ::= *FormBinding* { ‘,’ *FormBinding* }\* *FormBinding* ::= *Binder SingleValue*

*SingleValue* ::= [ ‘$’ ] *SeqValue* { ‘[’ *Form* ‘]’ }\*

*SeqValue* ::= *OrValue* { ‘;’ *OrValue* }\*

*OrValue* ::= *AndValue* { ‘||’ *AndValue* }\* *AndValue* ::= *BitOrValue* { ‘&&’ *BitOrValue* }\* *BitOrValue* ::= *XorValue* { ‘|’ *XorValue* }\* *XorValue* ::= *BitAndValue* { ‘∧’ *BitAndValue* }\*

*BitAndValue* ::= *EquivalenceValue* { ‘&’ *EquivalenceValue* }\* *EquivalenceValue* ::= *RelationalValue* { (‘==’ | ‘!=’) *RelationValue* }\* *RelationalValue* ::= *ShiftValue* { (‘<’ | ‘<=’ | ‘>’ | ‘>=’) *ShiftValue* }\* *ShiftValue* ::= *AddValue* { (‘<<’ | ‘>>’ | ‘>>>’) *AddValue* }\* *AddValue* ::= *TimesValue* { (‘+’ | ‘−’) *TimesValue* }\* *TimesValue* ::= *UnaryValue* { (‘∗’ | ‘/’ | ‘%’) *UnaryValue* }\*

*UnaryValue* ::= [ ‘++’ | ‘−−’ | ‘+’ | ‘−’ | ‘∼’ | ‘!’ ] *PrimaryValue* [ ‘++’ | ‘−−’ ] *PrimaryValue* ::= *LiteralValue* | *PrimaryPrefix* { ‘− >’ *Label* }\* [ ‘.’ *Label* ] { *PrimaryValue* }\* *PrimaryPrefix* ::= *Code* [ ‘:’ *QualifiedId* ] | *Form* | ‘(’ ‘\’ *Formal* ‘::’ *SingleValue* ‘)’ |

‘(’ *SingleValue* ‘)’ | ‘let’ *Declarations* ‘in’ *SingleValue* ‘end’

*LiteralValue* ::= ‘epsilon’ | *Integer* | *Float* | *String* | *Character Formal* ::= [ ‘@’ ] *Identifier* | ‘(’ ‘)’

*Binder* ::= *Label* ‘=’

*Label* ::= *Identifier* [ ‘:’ *Integer* ] | ‘{’ *SingleValue* ‘}’

*Code* ::= ‘%{’ *Java program text* ‘}%’

*Identifier* ::= (‘a’-‘z’,‘A’-‘Z’){‘a’-‘z’,‘A’-‘Z’,‘0’-‘9’,‘ ’}\*

*QualifiedId* ::= *Identifier* { ‘.’ *Identifier* }\*

*Integer* ::= (‘0’-‘9’){‘0’-‘9’}\*

*Float* ::= [ *Integer* ] ‘.’ *Integer* | *Integer* ‘.’ [ *Integer* ]

*String* ::= ‘”’ { *all characters except* ‘”’ }\* ‘”’

*Character* ::= ‘’’ { *all characters except* ‘’’ }\* ‘’’