Designing a Meta Object Protocol to Wrap a Standard Graphical Toolkit

Erick Gallesio

Université de Nice - Sophia Antipolis
I3S/CNRS - ESSI
Route des Colles - B.P. 145
06903 Sophia-Antipolis Cedex - FRANCE
Email: eg@unice.fr

Abstract. This paper presents a graphical package which relies on the Tk toolkit and the Scheme programming language. The Tk package is a widely used graphical toolkit built upon the Tcl scripting language. Tcl was not designed as a general purpose programming language and its usage for large-scale software development is generally not suitable. To improve the programming level of the Tk toolkit, we have defined STklos, a Scheme language with a CLOS-like object system. This alternative language has been used to embody the standard Tk widgets in a clean hierarchy of classes, which is presented here. The STklos object system implementation is based on a Meta Object Protocol; this protocol and its usage for accessing the Tk toolkit in an efficient way are also presented here.

1 Motivations

The Tk package [13] is a widely used graphical toolkit which provides a large set of widgets such as buttons, scrollbars, menus or text editors. With these high level widgets, one can build rather complex interfaces with little effort and without coping with the usual intricacies needed when programming under the X window system [14]. The Tk toolkit relies on a small interpretative scripting language named Tcl (Tool Command Language) [11], a string based language with a shell-like syntax.

Tcl is a small scripting language. To easily embed the Tcl interpreter in application programs, some usual programming languages capabilities have been set aside by its author. In particular, Tcl has a poor set of data structures reduced to character strings and associative arrays. It provides numbers, which are simulated with strings and which are, consequently, slow. In fact, a proper usage of Tcl consists in writing small scripts to *glue* large application components written in C or C++. However, experience shows that people are reluctant to use it in this way, and that they often prefer to write applications with a single programming language.

Tk is indeed an application with an embedded Tcl interpreter [12]. The interpretative nature of Tcl provides Tk a simple and attractive interface to develop simple graphical programs. However, the easiness afforded by Tcl for the design of small interfaces is misleading and it often encourages people to start heavy developments with this language. But, writing large applications with a language which lacks ways of structuring data tends to be more and more painful as the program grows. We think that this kind of usage is beyond the scope of a language such as Tcl, and we have tried to propose a solution for a better using of the Tk toolkit.

In order to improve the Tk toolkit for large applications, we decided to replace Tcl by a conventional programming language. Furthermore, the *substitute* language must fulfill some important requirements; it must be

- **high level** and provides useful data types such as structures, arrays, lists or strings
- **small** enough for allowing to embed it in applications (as Tcl)
- **efficient** so that most applications can be written entirely in this language without having to resort to C or C++ programming.
- easily **extensible** so that user can investigate several interesting programming paradigms (*e.g.* objects, prototypes, actors, ...)
- already **defined**. This point is, of course, not mandatory, but we think that it is preferable to use an existing programming language, if possible, rather than defining a new one.

Scheme [1] is a Lisp dialect which satisfies quite well the previous points. It is a statically scoped language with a clear and simple semantic. Moreover, Scheme procedures are first class objects able to capture their creation environment. This language feature is important since it allows us to envision the coding of interfaces *callbacks* in a clean way. In this framework, we have defined STk [3], a graphical package based on Tk toolkit where the Tcl language as been replaced by a Scheme interpreter.

STk is a small and efficient Scheme interpreter. As Tcl, it is small enough to be used simply as a *glue language* which can be embedded in an existing application. Furthermore, the solid basis provided by the Scheme language affords the tools necessary for writing, and maintaining medium size Graphical User Interfaces (GUI). Nevertheless, we think the expressive power of Scheme is not sufficient to envisage its use for large-scale software development. In particular, the lack of an object mechanism increases the programming complexity of large applications. STklos, the object extension of STk, has been defined to alleviate this problem. This extension provides meta classes, multiple inheritance and generic functions *à la* CLOS [7, 15] or Dylan [2]. STklos has also been used to embody the predefined Tk widgets in a hierarchy of classes. Usage of these classes simplifies the core Tk usage by providing an homogeneous access to widget options and by hiding the Tk widgets low level idiosyncrasies. Moreover, as expected, usage of objects facilitates code reuse and definition of new widgets classes. Finally, we think that the object orientation of STklos, as well as the solid basis of the Scheme programming language, afford therefore the tools necessary to envision writing, and maintaining, complex GUI.

The rest of this paper is divided in three sections. The next section presents the STk package and its object system. Wrapping the standard Tk widgets in

STklos classes and the influence of this integration in interfaces programming are described in section 3. STklos implementation relies on a MOP (Meta Object Protocol), in the spirit of the one defined for CLOS [6]. Section 4 presents this protocol and how it has been used to integrate the Tk standard widgets in the Scheme world.

2 Presentation of STklos

Programming with STk can be done at two distinct levels. The first level uses only the standard Scheme constructs and is quite classical. The second level gives access to STklos, the object oriented extension of STk. Of course, both levels can be used at the same time in a single program. However, most of the time, one will use the higher level, resorting to the lower one for specific purposes only.

2.1 STk: the Basic Layer

Starting a session with STk brings the user in the basic layer which gives access to an extended Scheme interpreter able to handle the Tk toolkit. With a little set of rewriting rules from the original Tcl/Tk library, and the Tk manual pages close at hand, one can easily build a STk program using the Tk toolkit.

Creation of new widgets (button, label, canvas, ...) is done by special STk primitives procedures. For instance, creating a new button can be done as followed

```
(button '.b)
```

Tk uses a very special way to name widgets: a widget name is a kind of pathname which reflects its position in the graphical hierarchy of widgets. In this example, the name of the newly created button is "`.b`". This pathname states that "`b`" is a son of "`.`", the root window. Note that the name of the widget must be *quoted* due to the Scheme evaluation mechanism.

Calling a widget creation primitive, such as `button`, builds a new Scheme object which is called a *Tk-command*. This object, which is considered as a new basic type by the STk interpreter, is automatically stored in a variable whose name is the symbol given to the creation function (`.b` in this case). A Tk-command is a special kind of function which is generally used, as in Tcl/Tk, to customize its associated widget. For instance, the expression

```
(.b 'configure :text "Hello, world" :border 3)
```

allows us to set the text and background options of the `.b` button. Of course, as in Tcl/Tk, parameters can be passed at widget creation time, and the previous button creation and initialization could have been done in a single expression, such as

```
(button '.b :text "Hello, world" :border 3)
```

Tk proposes a general purpose binding mechanism to associate a handlers to an external event (*e.g.* a key press or a mouse action). An event handler is automatically triggered by the library when the given event occurs. In Tcl, an event handler is a string which is evaluated at the global level, whereas in STk it is a Scheme closure. The following expression adds a new event handler to the `.b` button when the third mouse button is depressed over it:

```
(bind .b "<ButtonPress-3>"
      (let ((count 0))
        (lambda ()
          (set! count (+ count 1))
          (format #t "# of button press: ~A~%" count))))
```

This simple example shows that STk handlers are cleaner than Tcl ones: the standard Scheme lexical scoping allows a handler to have its own private global variables (as `count` here); on the other hand, a Tcl handler is a flat string unable to carry an environment.

Even if closures afford a better expressive power for writing event handlers than Tcl strings, programming an interface resorting only to the constructions of the basic layer becomes rapidly tedious. In fact, the STk basic layer can be considered as a kind of *assembly language* for interfaces programming and we will see in section 3 how it can be used for the *reification* of the Tk widgets in STklos classes.

2.2 STk: the Object Layer

STklos, the object extension of STk, is close to the CLOS system [7]; it is briefly introduced in this section. Note that we consider only the language aspects of STklos here and we forget its use for integrating the Tk toolkit for a while.

Definition of a new class is done with the `define-class` macro. For instance,

```
(define-class Point ()
   ((x :init-keyword :x :accessor x-of)
    (y :init-keyword :y :accessor y-of)))
```

defines the characteristics of a point. Two slots are declared here: `x` and `y`. Creation of new instances is done with the `make` constructor:

```
(define p (make Point :x 10 :y 20))
```

The evaluation of the preceding form builds a new point and initializes its slots `x` and `y` with the values 10 and 20. Slot content can be accessed by the two basic primitives `slot-ref` and `slot-set!`. These primitives are low level primitives and users often prefer to use accessors, since they generally lead to a clearer code. For instance, getting the value of the `y` slot of `p` could be done in the following way:

```
(y-of p)                    ; or (slot-ref p 'y)
```

since the `y-of` accessor has been defined for slot `y`. This slot can be set by the generalized `set!` form, as illustrated by the following example:

```
(set! (y-of p) 1)          ; or (slot-set! p 'y 1)
```

Now, we can define the `Rectangle` class which inherits from the `Point` class:

```
(define-class Rectangle (Point)
  ((width  :init-keyword :width  :accessor width-of)
   (height :init-keyword :height :accessor height-of)))
```

The instances of this class have four slots (`x`, `y`, `width` and `height`). Methods[1] defined for instances of the `Point` class can also be used for instances of the `Rectangle` class. For example, the `x` coordinate of a `Rectangle` can be accessed with the accessor method `x-of` defined before.

Previous class definition represents rectangles with a reference point, a width and a height. This representation for rectangles is, most of the time, convenient but we sometimes need a representation using the coordinates of two opposite corners. In that case, *virtual slots* can be used. A virtual slot is a slot which is defined as a normal slot but whose allocation is declared as `:virtual`. Such a slot has a null allocation and its reading (resp. writing) provokes the execution of a getter (resp. setter) function which must be provided by the user within the class definition. The getter and setter functions are defined with the `:slot-ref` and `:slot-set!` options. Here is another writing of the `Rectangle` class using virtual slots:

```
(define-class Rectangle (Point)
  ((width  :init-keyword :width  :accessor width-of)
   (height :init-keyword :height :accessor height-of)

   (x2     :init-keyword :x2     :accessor x2-of
           :allocation   :virtual
           :slot-ref  (lambda (obj) (+ (x-of obj) (width-of obj)))
           :slot-set! (lambda (obj val)
                        (set! (width-of obj) (- val (x-of obj)))))

   (y2     :init-keyword :y2 :accessor y2-of
           :allocation   :virtual
           :slot-ref  (lambda (obj) (+ (y-of obj) (height-of obj)))
           :slot-set! (lambda (obj val)
                        (set! (height-of obj) (- val (y-of obj)))))))
```

In this new definition of `Rectangle`, `x2` and `y2` are virtual slots. The getter and setter associated functions are lambda expressions which compute or set their value depending on other slots value. Note that a virtual slot accessor closure can change the value of standard slots in order to keep the system coherent.

[1] In STklos[5], the execution of a method rely on a subset of the CLOS *generic functions* mechanism (only primary methods are supported and the methods combination cannot be changed).

Since virtual slots do not imply memory allocation, they could easily be simulated with classical accessor methods. But, declaring a slot as virtual allows introspecting functions to "see" it as a standard slot. On the contrary, using a couple of methods to simulate such a slot would hide it to these functions.

3 Integration of Tk widgets

3.1 The Class Hierarchy

This section presents how the standard Tk widgets have been embodied in STKLOS classes. Each graphical object defined in the Tk toolkit such as menu, label or button is represented by a STKLOS class. The corresponding classes constitute a hierarchy which is briefly described here. First, all the classes share a unique ancestor: the `<Tk-object>` class[2]. This class defines a set of slots necessary to establish a communication between the Scheme and Tk worlds. In particular, two slots are defined in this class[3]:

- The `parent` slot contains a reference to the object which (graphically) includes the current object.
- The `Id` slot contains a reference to the low level STK *Tk-command* which implements the STKLOS widget. This *Tk-command*, which is different for each class, is created during STKLOS instance initialization. This slot establishes the link between the STK and the STKLOS layers and guarantees, by keeping a reference to the low level widget, a protection against GC recovery.

The next level of the class hierarchy defines a fork with two branches: the `<Tk-widget>` class and `<Tk-canvas-item>` class. Instances of the former class are classical widgets such as buttons or menus whereas instances of the later are objects contained in a canvas[4] such as lines, ovals or rectangles. Both kind of Tk objects are directly implemented as STKLOS classes in a one-to-one relationship. A partial view of the STKLOS hierarchy is shown in Fig. 1. Here are some important points:

- In Tk, interface widgets (*e.g.* buttons) are first class objects, but canvas items (*e.g.* rectangles) can be accessed only through their containing canvas. Thus, actions on widgets or canvas items must be done in different ways. Accessing a canvas item option requires two references: one to the canvas which contains it and one to its identification (a number) in this canvas. In order to make canvas items first class objects, the class `<Tk-canvas-item>` defines the extra slot `Cid` which contains the Tk identification number associated to the item.

[2] End users will not have to use direct instances of the `<Tk-object>` class (all classes whose name begins with the "Tk-" prefix are abstract classes which should not be instanced; they correspond to the *implementation specific* classes of [9]).

[3] The actual implementation is more complex, but to make easier the reading of this paper, we have simplified the definition of classes, and hence the class hierarchy.

[4] The canvas widget afforded by the Tk library allows 2D structured drawing.

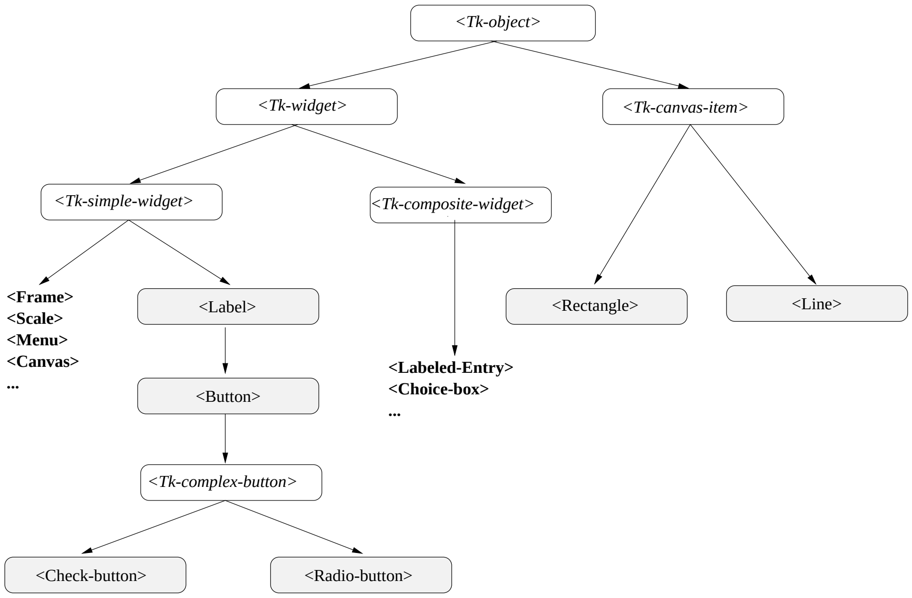

Fig. 1. *A partial view of the* STKLOS *hierarchy*

- The hierarchical view of Tk widgets permits a better apprehension of the Tk toolkit, even if there is no notion of inheritance in standard Tk. According to Fig. 1, a *button* can be seen as a reactive *label*. As a consequence, the methods in charge of the look of a label or button text (font, foreground color, ...) can be gathered in the `<Label>` class. Thus, the `<Button>` class has only to manage the operations which are specific to a reactive text, such as the associated command to invoke when the mouse button is depressed over it.
- Simple and composite widgets share a common ancestor (`<Tk-widget>`). Consequently, composites widgets, which are written in Scheme, are controlled exactly in the same way as C built-in Tk widgets. This kind of widgets is discussed in [4].

3.2 Accessing Tk Widgets Options

Each Tk toolkit widget accepts a specific set of options which enables its aspect customization such as its color, font, text or relief. Options may be specified either on the command line when the widget is created or with the `configure` operation which is applicable to all Tk widgets. In STKLOS, each option of a Tk widget is seen as an object slot, and getting or setting the configuration of a Tk option is equivalent to read or write an object slot. The following example shows a possible STKLOS definition of a Tk button.

```
(define-class <Button> (<Label>)
   ((command :accessor command :init-keyword :command
             :allocation :tk-virtual))
   :metaclass <Tk-metaclass>)
```

This new class inherits from `<Label>` and owns an extra slot called `command`. The allocation of this slot is qualified with `:tk-virtual`. Tk-virtual slots are special purpose slots: they can be used as normal slots but they are not allocated in the Scheme world (*i.e.* their value is stored in one of the structures manipulated by the Tk library instead of in a Scheme object). Consequently, reading or writing such a slot is done in a particular way: access to Tk-virtual slot uses in turn the standard Tk `configure` operation as in 2.1. Tk-virtual widgets slots are a special kind of virtual slots which are managed by the meta class `<Tk-metaclass>`. Defining a class using this meta class allows the modification of a slot accessors at the lowest level. Therefore, the value of a virtual slot always reflect the actual value of the associated Tk option (remember that no space is reserved for this slot in the Scheme core and that accesses are directly done within the Tk data structures). The specification of the meta class of the `<Button>` class in given with the `:metaclass` option[5]. It is important to note that the construction of the slot accessors is made at class creation so that no particular computation is necessary when accessing such a slot. Thus, customizing a widget by using a slot access at the STklos level is **as efficient as** using a standard Tk option configuration at the STk base level.

The previous definition of `<Button>` is not sufficient for a complete integration of the Tk button widget in a STklos class. Indeed, the MOP ensures that `Tk-constructor` is called when creating a new `<Tk-widget>` (and `<Button>` is an indirect instance of `<Tk-widget>` as shown in Fig. 1). This function must determine the Tk library function (a *Tk-command*) which has to be called to create the new widget. The following method for `Tk-constructor` suffices to do this job:

```
(define-method Tk-constructor ((b <Button>))
   button)
```

The previous `<Button>` class and `Tk-constructor` method definitions are the two only things necessary for defining a new STklos widget. This point is particularly important since it permits to minimize the integration cost of new Tk widgets and, consequently, to *follow* future Tk releases with minimal coding.

The following variable definition shows how we can use the above `<Button>` class:

```
(define b (make <Button> :font "fixed"
                         :command (lambda () (display "Hello\n"))))
```

This expression assigns to the symbol `b` a new instance of `<Button>`. Changing the font or the command associated to this object could be done by using either the `slot-set!` or the generalized `set!` primitives as shown in 2.2.

[5] In fact, this meta class citation can be omitted since `<Label>` (or one of its ancestor) has probably already specified it. In this case the system will automatically choose the most specific meta class.

3.3 Comparison of STklos and Standard Tk

Some of the advantages of STklos, approach over standard Tk have already been discussed before. In this section, we go on further this discussion.

Low Level Detail Hiding One of the most important benefits when embodying Tk widgets in STklos is that most of the Tk idiosyncrasies are hidden to the user. As a positive consequence, this improves greatly the level we can program GUI. A major improvement concerning this point is that we do not need anymore to take care of the Tk widget naming conventions. The fact that Tk imposes that the name of a widget must reflect the hierarchy to which it belongs, and the lack of relative naming conventions are very severe constraints when designing a GUI. These points make difficult, in standard Tk, the definition of reusable interface components and usage of long pathnames (which are current in non toy applications) is very awkward to manage. Furthermore, these conventions lead to change large pieces of code as soon as a modification is done in the widget hierarchy. In this sense, Tk naming conventions do not fit well with GUI programming since the design of an interface brings aesthetic problems which often conduct to develop it on a trial and error basis.

In STklos, Tk naming convention are completely hidden and the only thing the user needs to know when creating a new object is the widget which contains it. This object is called its parent. An example of nested widgets creation is shown below:

```
(define f  (make <Frame>))
(define b1 (make <Button> :text "B1" :parent f))
(define b2 (make <Button> :text "B2" :parent f))
```

The buttons `b1` and `b2` created here specify that their parent is the frame `f`. Since this frame does not specify a particular parent, it is supposed to be a direct descendant of the root window. Note that only the definition of `f` should be changed if we decide that `f` should no more be a top-level frame. A modification in the hierarchy of this widget is automatically propagated to all the widgets belonging to this hierarchy. STklos also extends this parent notion to take into account canvas items (rectangles, lines, ovals, ...): a canvas item is considered to be a descendant of the canvas which contains it. This vision of the canvas items allows the STklos user to manipulate canvas items as first class objects. For instance,

```
(define c (make <Canvas>))
(define r (make <Rectangle> :parent c :coords '(0 0 50 50)))
```

defines a rectangle called `r` in the `c` canvas. As said before, accessing this rectangle implies the use of two references in standard Tk: the canvas which contains it, and its identification number in this canvas. In STklos, both informations are contained in the object which represent the rectangle. For instance, after executing the expression,

```
(bind r "<Enter>" (lambda (x y)
                     (format #t "Mouse enters in ~A ~A~%" x y)))
```

a message is displayed, each times the mouse enters the `r` rectangle. It is important to note here that we would use *exactly* the same expression to associate such a binding to a simple widget such as a button or a label, whereas it needs two different syntactic forms in Tcl/Tk, since the procedures which access a canvas item or an interface widget are different.

Uniform Access to the Toolkit Usage of generic functions is also a significant improvement over the Tk basic level programming since it allows an homogeneous access to Tk commands. Suppose that we want to give access to the value of a `scale` or an `entry` widget with the generic function `value`. This can easily be done by the following method in STklos:

```
(define-method value ((obj <Tk-simple-widget>))
   ((Id obj) 'get))
```

In this case, one method is sufficient to implement the getter function since the Tk sub-option for reading the value of a scale or an entry is the same. Writing the setter function for those widgets is a little bit more complicated since the way of changing a scale value is different from the way of changing an entry value in Tk:

```
(define-method (setter value) ((obj <Scale>) v)
  ((Id obj) 'set v))

(define-method (setter value) ((obj <Entry>) v)
  ((Id obj) 'delete 0 'end)
  ((Id obj) 'insert 0 v))
```

Using the same generic function (with two different methods) permits to hide to the user these low level details and gives him/her a coherent access to the toolkit. In the call,

```
(set! (value x) 100)
```

the system chooses the method to apply depending on the class of `x`. Of course, an error[6] will be signaled if `x` is not an entry or a scale. Note that this notion of widget value could also be easily implemented with a virtual slot (see 2.2) even if `:value` does not exist as a Tk option *per se*. This approach, which is the one chosen in the current released library, allows introspecting functions to manage the value of a widget as a standard slot. In particular, this library offers a small interface builder which heavily use introspection to automatically build

[6] more exactly, the system calls the `no-applicable-method` generic function which, by default, signals an error, as in CLOS. User can specialize this function to provide another handler.

specialized widget editors. Defining `value` as a virtual slots for most widgets allows the user to tune it in the same fashion as the font or the background Tk options. Designing an interface builder using only standard Tk constructs would have been a lot more painful.

The previous examples show that programming with STklos brings the power of a full featured object language in the area of GUI construction. However, this fine integration of the Tk toolkit could not have been done without the underlying Meta Object Protocol of STklos. This protocol is discussed in the following section.

4 Implementation

In the previous section, we show through several examples the gain provided by an object language to use the Tk toolkit. The simplicity of these examples could make think that the definition of an *ad-hoc* object system for Tk widgets could suffice to have an OO vision of the toolkit. However, we feel that this approach, which has been widely used for Tcl, is not the good one. Providing a general purpose Scheme object system, which can easily be customized for using Tk, seems a far better approach. Indeed, in the GUI area, applications programmers often need to be able to use introspection on the objects they manipulate, or they need to define new ways to access object slots when composing several widgets. These constraints have led us to define a MOP based object extension for STk, because it is probably the cleanest way to achieve the requirements expressed above.

This section presents how to integrate Tk widgets in a hierarchy such as the one shown in Fig. 1. The discussion is split in two parts. First, we present the services a MOP must offer for this integration and then, we show how we can exploit them to build this hierarchy.

4.1 The STklos Meta Object Protocol

STklos meta object protocol implementation is based on Tiny-Clos [8], a minimal MOP written in Scheme. Current version of STklos MOP is written in C and in Scheme. Code written in C correspond to the generic functions calls, which allows to implement them as efficiently as possible. The rest of the implementation, where time consumption is less important (*e.g.* computation of class precedence lists or printing methods), is written in Scheme. This conducts to an efficient implementation where the overhead of OO programming *vs* "classical" programming is as low as possible.

As said before, STklos is a general purpose OO extension, but a great attention has been carried for the services its MOP must provide in order to integrate easily and efficiently Tk widgets in STklos objects. The STklos protocol must at least offer following capabilities:

- a way to intervene in the initialization of a STklos widget. The first task which must be done at this stage consists to generate a name (using the Tk

conventions) for the widget which will implement the new instance. Then, the instance creation arguments list must be filtered to distinguish the user arguments which concern only STKLOS (*e.g.* the `parent` slot discussed in 3.1) from those which correspond to Tk options. This distinction among parameters is necessary because the Tk library raises an error when it encounters a parameter it does not know how to manage.
– the possibility to define slots with special behaviour and allocation schemes. In effect, beyond virtual slots already discussed in 2.2, the protocol should allow to map the Tk widget options as slots of a STKLOS object. Note that the way to do this mapping will be different for a simple widget and a canvas item, since Tk offers two different methods for accessing their options. Furthermore, the protocol for defining slots must be as simple as possible to allow application programmers to extend the library with new kinds of widgets.

The creation of a STKLOS object is done with the `make` generic function. As in CLOS, this function first allocates a new instance (by calling the generic function `allocate-instance`) and then returns this instance initialized. Initialization of the new instance is performed by the `initialize` generic function.

Class slots are computed when the class is initialized. The STKLOS MOP calls the generic function `compute-get-n-set` which, given the definition of a slot, returns a couple of procedures. These procedures correspond to the reader and writer functions for the slot. In case of a virtual slot definition (see 2.2), for instance, `compute-get-n-set` returns a list constituted of the two evaluated lambda expressions given in the `:slot-ref` and `:slot-set!` options.

4.2 Using the MOP to Wrap Tk Widgets

We present here only the salient points which are necessary to the integration of Tk widgets and simple canvas items in an object world. The code exposed here is simpler than the one which is used in the current distribution of STK, but principles are the same. A complete listing of the source code of this simplified implementation is given in annex.

Managing Tk Options as Object Slots. When a new class is created, the generic function `compute-get-n-set` is called for each slot this class defines. This function takes two parameters: the class which is being created and the slot definition (a list). This allows us to define a meta class which takes into account a special kind of slots: *tk-virtual* allocated slots. The meta class in charge of these slots is called `<Tk-metaclass>`. This class is defined as:

```
(define-class <Tk-metaclass> (<class>)
  ((valid-options :accessor Tk-valid-option)))
```

The slot `valid-options` contains the list of options a Tk widget recognizes. This slot is initialized when a new widget class is defined (its value is set to the list of the slots whose allocation is *Tk-virtual*). Usage of `valid-options` will be discussed later.

Tk-virtual slots have been presented in 3.2. Reading and writing this kind of slot implies the use of the `configure` sub-option which is always available for Tk widgets. In standard Tk, reading the value of a widget option, such as `width`, for a given widget `w` must be done with

```
(list-ref (w 'configure :width) 4)
```

Setting the width of this widget to the value `val` is a little bit simpler and can be expressed as:

```
(w 'configure :width val)
```

Consider now a canvas item whose enclosing canvas and identification number are respectively `c` and `id`; reading and writing the value of its `width` option can be done with

```
(list-ref (c 'itemconfigure id :width) 4)
```

and

```
(c 'itemconfigure id :width val)
```

We said in previous subsection that the generic function `compute-get-n-set` has in charge slot allocation. Given the Tk conventions exposed before, it is easy to define a `<Tk-metaclass>` specialized method for this function. This method must return a list whose first element is a closure for reading the slot, and whose second element is a closure for its writing:

```
(define-method compute-get-n-set ((class <Tk-Metaclass>) slot)
  (if (eqv? (get-slot-allocation slot) :tk-virtual)
      ;; this is a Tk-virtual slot
      (let ((opt (make-keyword (car slot))))
        (list (lambda (obj) (list-ref ((Id obj) 'configure opt) 4))
              (lambda (obj val) ((Id obj) 'configure opt val))))
      ;; call super compute-get-n-set
      (next-method)))
```

This method first tests the allocation type of the slot with `get-slot-allocation`. If the slot is a Tk-virtual one, this method returns the reader and writer closures in a list. Otherwise, this method calls `next-method`, that is to say the `compute-get-n-set` method defined over the super class of `<Tk-metaclass>`.

Since Tk accesses canvas items options in a different way than simple widgets ones, `<Tk-metaclass>` cannot be used for reading and writing their slots. A meta class for canvas items can be simply defined as

```
(define-class <Tk-item-metaclass> (<Tk-Metaclass>)
  ())
```

Given this meta class and the Tk conventions shown before, it is simple to define a `compute-get-n-set` method specialized for canvas items:

```
(define-method compute-get-n-set ((class <Tk-item-metaclass>) slot)
  (if (eqv? (get-slot-allocation slot) :tk-virtual)
      (let ((opt (make-keyword (car slot))))
        (list (lambda (obj)
                (list-ref ((Id obj) 'itemconfigure (Cid obj) opt) 4))
              (lambda (obj val)
                ((Id obj) 'itemconfigure (Cid obj) opt val))))
      (next-method)))
```

Two points are important to note here:

- Methods of the generic function `compute-get-n-set` are very dependent of the procedure Tk proposes for accessing widget options. However, it must be noted that only the two returned lambda expressions should be re-written if the author of the Tk toolkit decides to change current conventions. We can even say that the MOP permits to write programs which are less dependent of the Tk toolkit than Tcl/Tk programs, since dependences can be isolated in a few methods instead of being spread all over the code.
- The protocol for accessing the slots of new kind of widgets is easily customizable. The STklos library uses it for the Tk text tags (a tag is an annotation which allows to associate a script to a portion of the string associated to a Tk `text` widget). Defining a meta class for text tags and a specialized `compute-get-n-set` method suffice to see them as first class objects whose state is stored in the slots of a STklos instance. Similarly, the STklos library defines a meta class for managing composite widgets where a slot access for a compound widget can be propagated to some of its composing widgets.

Widget Initialization. When a new object is initialized, the MOP ensures that the `initialize` generic function is called. This method must filter the arguments given to `make` in order to pass only valid options to Tk, and to take into account slots which deal only with STklos (such as `parent`, for example). This method is given below:

```
(define-method initialize ((self <Tk-simple-widget>) initargs)
   ;; Use split-options on initargs to separate STklos slots from Tk
   ;; ones. Set parent to the root window if not specified in initargs
  (let* ((options (split-options (Tk-valid-options (class-of self))
                                 initargs))
         (parent  (get-keyword :parent (cdr options) *root*)))
     ;; Call the Tk command which creates the widget
    (set! (Id self) (apply (tk-constructor self)
                           (make-tk-name parent)
                           (car options)))
     ;; Initialize other slots (i.e. non Tk-virtual ones)
    (next-method self (cdr options))))
```

The list of valid Tk options is found in the slot `valid-options` of the class of the widget which must be initialized. Given this list, options are separated in two lists with the `split-options` helper function (this function returns a list whose first element is the set of Tk options and whose rest contains the other arguments). Given for instance the call

```
(define b (make <Button> :parent p :text "Hi" :counter 12))
```

this method will call the generic function `Tk-constructor` to find the *Tk-command* which implements the widget at the STk basic level. Then, it calls this command with a generated name and the list `(:text "Hi")`. As said before, the value returned by the Tk widget constructor must be stored in the `Id` slot of the new instance. From this point, all *tk-virtual* slots are initialized and the call to `next-method` at the end of this method ensures the initializations of other slots with the list `(:parent p :counter 12)`. So, slots of user defined classes which inherit from standard STKLOS classes are properly initialized. The `initialize` method for canvas items follows the same principles and is not developed here. Interested readers can find it in the annex.

Performances In order to compare the performances of STk against Tcl ones, we will compare the STK basic layer with Tcl/Tk first and then we will compare STK and STKLOS.

Tcl is by nature an interpreted language and some of its aspects make difficult the writing of a compiler for this language. Furthermore, the fact that Tcl is a string language implies that the values manipulated by a program must always be converted to strings, which is time consuming. This explains the poor performances of the current Tcl interpreter. Some compilers for this language have been announced but, to our knowledge, none has been achieved at this date.

STK current implementation also relies on an interpreter. However, the semantic of the Scheme programming language has been designed to allow simple and efficient interpreters or compilers implementations. STK interpreter is hence small an offers good performances. In particular, it runs 4 to 7 times faster than Tcl interpreter on general purpose computations. When using the Tk toolkit, Tcl takes advantage of the way arguments are passed to the functions of the library. In effect, the Tk toolkit uses the C language `argc/argv` classical convention for arguments passing. Given these conventions, the STK interpreter must convert to strings the parameters given to *Tk commands*, whereas this conversion is unnecessary in Tcl since everything is kept as strings in the interpreter. However, the penalty induced by these conversions is generally negligible facing the overall computation time of a program, and interfaces written with STK tend to be faster than Tcl ones.

Let us consider now the performances of STKLOS comparing to STK. In STKLOS, as in CLOS, the generic function call mechanism costs a lot. Because this mechanism can be the bottleneck of a MOP based architecture, it has been implemented in C to be as fast as possible. However, the current implementation is relatively direct and don't use yet the optimizations which can generally be applied on generic function calls. This explains the relative poor performances of generic function calls compared to closure invocation. Actually, a generic function call is 6 times slower than a simple Scheme function call. Consequently, an interface written in STKLOS is far much slower than an application resorting only on simple STK constructs. The generic function overhead can even makes STKLOS programs, under certain circumstances, a little bit slower than Tcl programs. However, applying *memoization* optimization techniques such as the one presented in [10] will decrease the ratio between generic and non generic functions to provide performances close to the basic layer.

5 Conclusion

We have shown in this paper the STKLOS object system and how it can be tailored to provide an easy access to a standard graphical toolkit. One of the major benefits of this system is that it allows a neat *reification* of a class-less toolkit. This point is important since it is generally admitted that an object vision of widgets greatly improves the level of GUI programming.

STKLOS provides a real programming language for the Tk toolkit. Furthermore, the underlying meta object protocol of STKLOS provides a pleasant way to access the toolkit options for each widget and it allows us to hide most of the idiosyncrasies of this toolkit in a clean way. It makes easier the developement of large Graphical User Interfaces with Tk, and extend hence the interest of this toolkit.

Availability

STKLOS is distributed with the STK package and runs on a wide variety of architectures and systems. The last version of this package is available at the following address: `ftp://kaolin.unice.fr/pub/STk.tar.gz`.

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Annex: A Minimal Meta Object Protocol for Tk

Hereafter is a minimal implementation of the Meta Object Protocol described in section 3. Three widgets classes (`<Canvas>`, `<Label>` and `<Button>`) and two canvas items (`<Line>` and `<Rectangle>`) are defined using this MOP. The protocol exposed here has been simplified to fit in the limited size of this paper and defined widgets recognize only a small subset of the Tk options. However, in spite of this size, this MOP is completely operational.

```
;;;;
;;;; Utilities
;;;;
(define make-tk-name
  (lambda (parent)
    (gensym (format #f "~A.v" (if (eq? parent *root*) "" (Id parent))))))

(define split-options
  (lambda (valid-slots initargs)
    (letrec
        ((separate
          (lambda (valids args tk-opt other)
            (if (null? args)
                (cons tk-opt other)
                (if (member (car args) valids)
                    (separate valids (cddr args)
                              (list* (car args) (cadr args) tk-opt)
                              other)
                    (separate valids (cddr args)
                              tk-opt
                              (list* (car args) (cadr args) other)))))))
```

```
      (separate valid-slots initargs '() '()))))

;;;;
;;;; Simple widgets
;;;;
;;
;; <Tk-metaclass> class definition and associated methods
;;
(define-class <Tk-Metaclass> (<class>)
  ((valid-options :accessor Tk-valid-options)))


(define-method initialize ((class <Tk-Metaclass>) initargs)
  (next-method)
  ;; Build a list of allowed keywords. These keywords will be passed to
  ;; the Tk-command at build time
  (let ((slots        (slot-ref class 'slots))
        (res          '())
        (tk-virtual?  (lambda(s)
                        (eqv? (get-slot-allocation s) :tk-virtual))))
    (for-each (lambda (s)
                (when (tk-virtual? s)
                  (let ((key (make-keyword (car s))))
                    (set! res (cons key res)))))
              slots)
    ;; Store this list in the new allocated class
    (set! (Tk-valid-options class) res)))


(define-method compute-get-n-set ((class <Tk-Metaclass>) slot)
  (if (eqv? (get-slot-allocation slot) :tk-virtual)
      ;; this is a Tk-virtual slot
      (let ((opt (make-keyword (car slot))))
        (list (lambda (o)   (list-ref ((Id o) 'configure opt) 4))
              (lambda (o v) ((Id o) 'configure opt v))))
      ;; call super compute-get-n-set
      (next-method)))

;;
;; Basic virtual classes for widgets: <Tk-object>, <Tk-widget> and
;; <Tk-simple-widget>
;;
(define-class <Tk-object> ()
  ((Id      :accessor Id)                                ;; Widget Id
   (parent  :accessor parent :init-keyword :parent)))   ;; Parent widget

(define-class <Tk-widget> (<Tk-object>)
  ())
```

```
(define-class <Tk-simple-widget> (<Tk-widget>)
  ;; Each widget has at least the slot bg for its background colour
  ((bg :accessor bg :init-keyword :bg :allocation :tk-virtual))
  :metaclass <Tk-Metaclass>)


(define-method initialize ((self <Tk-simple-widget>) initargs)
  ;; Use split-options on initargs to separate STklos slots
  ;; from Tk ones. Set parent to the root window if not specified
  ;; in initargs
  (let* ((options (split-options (Tk-valid-options (class-of self))
                                 initargs))
         (parent  (get-keyword :parent (cdr options) *root*)))
    ;; Call the Tk command which creates the widget
    (set! (Id self) (apply (tk-constructor self)
                           (make-tk-name parent)
                           (car options)))
    ;; Initialize other slots (i.e. non Tk-virtual ones)
    (next-method self (cdr options))))


;;
;; We can now define three widget classes: <Label>, <Button> and <Canvas>
;; as well as their associated Tk-command
;;
(define-class <Label> (<Tk-simple-widget>)
  ((font :accessor font :init-keyword :font :allocation :tk-virtual)
   (text :accessor text :init-keyword :text :allocation :tk-virtual)))

(define-class <Button> (<Label>)
  ((command :accessor command :init-keyword :command
            :allocation :tk-virtual)))

(define-class <Canvas> (<Tk-simple-widget>)
  ())

(define-method tk-constructor ((self <Label>))  label)
(define-method tk-constructor ((self <Button>)) button)
(define-method tk-constructor ((self <Canvas>)) canvas)


;;;;
;;;; Canvas items widgets
;;;;
;;
;; <Tk-item-metaclass> class definition and associated methods
;;

(define-class <Tk-item-metaclass> (<Tk-Metaclass>)
```

```
  ())

(define-method compute-get-n-set ((class <Tk-item-metaclass>) slot)
  (if (eqv? (get-slot-allocation slot) :tk-virtual)
      ;; this is a Tk-virtual slot
      (let ((opt (make-keyword (car slot))))
        (list (lambda (obj)
                (list-ref ((Id obj) 'itemconfigure (Cid obj) opt) 4))
              (lambda (obj val)
                ((Id obj) 'itemconfigure (Cid obj) opt val))))
      ;; call super compute-get-n-set
      (next-method)))

;;
;; Basic virtual class: <Tk-canvas-item>
;;
(define-class <Tk-canvas-item> (<Tk-object>)
  ((Cid :accessor  Cid)
   (width :accessor width :allocation :tk-virtual))
  :metaclass <Tk-item-metaclass>)


(define-method initialize ((self <Tk-canvas-item>) initargs)
  (let* ((options (split-options (Tk-valid-options (class-of self))
                                 initargs))
         (parent  (get-keyword :parent (cdr options) #f))
         (coords  (get-keyword :coords (cdr options) #f)))
    (if (not (and parent coords))
        (error "Parent widget and coordinates must be given!!"))
    (set! (Id  self) (Id parent))
    (set! (CId self) (apply (Id parent)
                            'create
                            (canvas-item-initializer self)
                            (append coords (car options))))
    ;; Initialize other slots (i.e. non Tk-virtual ones)
    (next-method self (cdr options))))

;;
;; We can now define two canvas item classes: <Line> and <Rectangle>
;; as well as their associated initializer
;;
(define-class <Line>      (<Tk-canvas-item>)
  ())

(define-class <Rectangle> (<Tk-canvas-item>)
  ((fill  :accessor fill :init-keyword :fill :allocation :tk-virtual)))

(define-method canvas-item-initializer ((self <Rectangle>)) "rectangle")
(define-method canvas-item-initializer ((self <Line>))      "line")
```