A Framework for Designing and Implementing the Ada Standard Container Library

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ABSTRACT

An open issue of the Ada language is the definition of a standard container library. Containers in this library (e.g., sets, maps and lists) shall offer some core functionalities that characterise their behaviour (i.e., different strategies for managing the elements stored therein) as well as other general functionalities. Among these general functionalities, we are interested in alternative ways for accessing the containers, namely direct access by position and traversals using iterators. In this paper, we present the Shortcut-Based Framework (SBF), a framework aimed at providing suitable, uniform, accurate and secure access by position and iterators, while keeping other nice properties such as comprehensibility and changeability. The SBF should be considered as a baseline upon which the Ada standard container library can be built. We assess the feasibility of our proposal defining a quality model for container libraries and evaluating the SBF using some metrics defined with the Goal-Question-Metric approach.

Categories and Subject Descriptors

D.2.2 [**Software Engineering**]: Design Tools and Techniques—*Software libraries, Object-oriented design methods*; D.2.13 [**Software Engineering**]: Reusable Software—*Reusable libraries*; D.3.3 [**Programming Languages**]: Language Constructs and Features—*Frameworks, Data types and structures*; D.2.8 [**Software Engineering**]: Metrics—*Product metrics*

General Terms

Design, Measurement.

Keywords

Container libraries, Iterators, Access by position, Quality models.

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1. INTRODUCTION

Most important object-oriented (OO) programming languages include some standard libraries of reusable components as part of their definition. One kind of such libraries are container libraries. A *container* (also known as *collection*) may be defined as an object that contains (i.e., stores) other objects; examples of containers are sets, maps and sequences. Some of the most well-known container libraries in the OO world are: the Java Collections Framework (JCF) [1] for Java; the Standard Template Library (STL) [18] for C++; and the Eiffel Base Library [13] for Eiffel.

Unfortunately, the Ada language does not provide such a standard container library, in spite of various attempts and claims in this direction, among which we mention:

- Some existing widespread container libraries, as the Charles Container Library [5], Booch Components [4], etc.
- Some events, for instance the *Standard Container Library for Ada* workshop held during the Ada Europe 2002 conference.
- Some wide initiatives, e.g. the Application Standard Components Library [2] or some action items issued by the Ada Conformity Assessment Authority (remarkably the action item AI-302).
- Some opinions and claims, like those in the discussion list at `comp.lang.ada` or the *ACM SIGAda* Chair Message for March 2002 *Ada Letters*: "Such a [Container] Library could be an excellent addition to the Ada International Standard".

Needless to say, the existence of a standard container library for Ada would clearly contribute to the quality of the final Ada artefacts and the effectiveness of the software development process itself. For this reason, having a comprehensive, structured and precise framework for designing and implementing this library becomes utterly important, and this is the objective of the present paper.

We propose in this article a framework [6, 12] (see Sect. 3) named Shortcut-Based Framework (SBF) to drive the design and implementation of the prospective Ada Standard Container library. The SBF is not intented to be a closed proposal of the contents of the library; instead, it has been defined as a baseline upon which a high-quality Ada Standard Container library can be developed. Software quality is always important, but it is even more crucial in standard packages, intended to be used without changes once deployed for a long period of time. In order to measure the quality of the resulting library, we have already defined elsewhere [8] a quality model for this kind of libraries built upon the ISO/IEC 9126-1 Quality Standard [11], summarized in Sect. 2. The SBF-based Ada Standard Container library we are proposing is evaluated with respect to this quality model in Sect. 4.

2. A QUALITY MODEL FOR THE ADA STANDARD CONTAINER LIBRARY

In this section we summarise an ISO-based quality model for the domain of container libraries. First we present the ISO/IEC Quality Standard 9126-1 [11] on which this quality model is based and then a brief description of some relevant quality attributes that are of interest in our proposal. A more exhaustive description of the model has been presented at Ada-Europe 2003 [8].

2.1 The ISO/IEC 9126-1 Quality Standard

The ISO/IEC Quality Standard 9126-1 [11] provides an appropriate and widespread framework for determining a quality model for a given domain of software components. An ISO/IEC-9126-1-based *quality model* is defined by means of general *characteristics* of software, which are further refined into *subcharacteristics*, which in turn are decomposed into measurable *attributes*. Attributes collect the properties that software components exhibit. Intermediate hierarchies of subcharacteristics and attributes may appear making thus the model highly structured.

The ISO/IEC 9126-1 standard fixes six top level characteristics: functionality, reliability, usability, efficiency, maintainability and portability (see Table 1). It also fixes their further refinement into subcharacteristics but does not elaborate the quality model below this level, making thus the model flexible. The model is to be completed based on the exploration of the particular software domain and its application context; because of this, we may say that the standard is very versatile and may be tailored to domains of different nature, such as the one of container libraries.

2.2 An ISO/IEC-based Quality Model for Container Libraries

Functionality is probably the most relevant quality characteristic in the domain of container libraries. Success of the prospective Ada Standard Container Library requires exhibiting the appropriate functionality once considered its design requirements. It should be noted that "appropriate" does not necessarily mean "exhaustive", because an excess of functionality would impact negatively in other criteria such as usability or operability.

Table 2 shows the attributes (name, definition and examples) that play a part on some functionality subcharacteristics. It is worth to remark that the *Suitability* subcharacteristic has been decomposed into two groups of attributes, i.e., two new subcharacteristics:

- *Core Suitability.* Addresses the types of containers offered and their implementations. These types are mainly characterised by the operations for adding, removing, modifying and searching elements.

Table 1: ISO/IEC 9126-1 quality standard

Functionality	
suitability	presence and appropriateness of a set of functions for specified tasks
accuracy	provision of right or agreed results or effects
interoperability	capability of the software product to interact with specified systems
security	prevention to (accidental or deliberate) unauthorized access to data
compliance	adherence to functionality-related standards or conventions
Reliability	
maturity	capacity to avoid failure as a result of faults in the software
fault tolerance	ability to maintain a specified level of performance in case of faults
recoverability	capability of reestablish level of performance after faults
compliance	adherence to reliability related standards or conventions
Usability	
understandability	effort for recognizing the logical concept and its applicability
learnability	effort for learning software application
operability	effort for operation and operation control
attractiveness	capability of the product to be attractive to the user
compliance	adherence to usability related standards or conventions
Efficiency	
time behavior	response and processing times; throughput rates
resource utilization	amount of resources used and the duration of such use
compliance	adherence to efficiency related standards or conventions
Maintainability	
analysability	identification of deficiencies, failure causes, parts to be modified, etc.
changeability	capability to enable a specified modification to be implemented
stability	capability to avoid unexpected effects from modifications
testability	capability to enable for validating the modified software
compliance	adherence to maintainability related standards or conventions
Portability	
adaptability	opportunity for adaptation to different environments
installability	effort needed to install the software in a specified environment
co-existence	capability to co-exist with other independent software in a common environment sharing common resources
replaceability	opportunity and effort of using software in the place of other software
compliance	adherence to portability related standards or conventions

- *General Suitability.* Keeps track of additional functionalities offered by (most of) the containers of the library, such as support for concurrent access or iterators.

For the other subcharacteristics of functionality, we focus on accuracy and security of access by position and access by

Table 2: Quality Attributes for some Functionality Subcharacteristics

Core Suitability		
Attribute	Definition	Examples
Category variety	Range of different categories of containers offered by the library	Sequences, maps, sets, trees, graphs
Container variety	Range of different containers provided by every category	For sequences: stacks, queues, lists
Implementation variety	Range of different implementations provided by every category	For maps: closed hashing, red-black trees
Operation variety	Range of different operations provided by every container	For stacks: empty, push, pop, top, isEmpty

General Suitability		
Attribute	Definition	Examples
Direct access by position	Types and operations for supporting direct access to elements in containers	Type *position*; operation for deletion by position
Iterators	Types and operations for supporting traversal of containers	Bidirectional, unidirectional; read, read/write
Algorithmic variety	Range of generic algorithms present in the library or in particular containers	Sorting, merging. For arrays: binary search

Accuracy		
Attribute	Definition	Examples
Accurate access by position	Policies and artifacts that ensure right results when accessing by position	A position bound to an element remains the same while it is in the container
Accurate access by iterator	Policies and artifacts that ensure right results when accessing by iterator	Operation for knowing if the current element during traversal has changed

Security		
Attribute	Definition	Examples
Secure access by position	Policies and artifacts that ensure safe use of positions when accessing the container	Operation for knowing if a position is bound to the right element
Secure access by iterator	Policies and artifacts that ensure safe use of iterators when accessing the container	Read-only iterators may not be used in an odd manner

iterators. The study of these two attributes is crucial, since these types of access provoke some particular situations that need to be addressed (e.g., modifications during iterations, access by out-of-date positions, etc.).

From the other ISO/IEC-9126-1 subcharacteristics, we address here understandability, changeability and time and space efficiency (see Table 3).

- Understandability becomes a fundamental property for the Ada community effectively using the library; attributes in this subcharacteristic embrace design issues, documentation and the complexity of the library.

- In our context, changeability means customization to particular needs. A good degree of changeability will allow extending the library with new types of containers and new implementations, and also extending or restricting the behaviour of existing types.

- Efficiency is a classical requirement on container libraries, both time (with complexity measures and real benchmarks) and space (amount of memory required by each container implementation).

3. THE SHORTCUT-BASED FRAMEWORK

As mentioned in the introduction our main objective is not to propose a concrete collection of containers to be included in the Standard Container Library for Ada. Rather we propose the use of a concrete framework for the design of this library: the Shortcut-Based Framework [16]. This framework allows solving the majority of drawbacks (with respect to the quality criteria presented in Sect. 2) that are present in the most widespread container libraries [15]. This is achieved by means of the *Shortcut* concept that we propose at the core of our framework.

3.1 The Shortcut Concept

Shortcuts encapsulate the feature of location or position of an object in a container. Shortcuts provide an abstract, reliable and efficient (all the operations have $O(1)$ as order of complexity) alternative access path to the elements stored in the container. Most of the existing container libraries recognise the need for such a kind of alternative access method and thus they have similar mechanisms but they are *ad-hoc* implementation-dependent and not totally reliable proposals (e.g., iterator in STL [18], references in JCF [1], item in LEDA [17], location in JDSL [9], etc.). Instead, we provide an implementation-independent approach based on the use of shortcuts to implement a generic container which acts as a base class of the rest of concrete containers. Shortcuts allow implementing only once, in the base class, the most common capabilities (e.g., iterators) in a highly efficient and reliable way. The implementation of both the shortcuts and the common capabilities are decoupled from the details of the implementation of its inheritors.

3.2 The Shortcut-Based Framework

In this section we outline the main features of the *Shortcut-Based Framework* (SBF) together with some implementation details. The key point consists on storing the objets of any concrete container in a `Container` class, while keeping in the concrete container only the shortcuts bound to them. We show throughout this section the complete development of this idea.

First, we define the SBF hierarchy for container libraries. This hierarchy has been built borrowing the main ideas from the different hierarchies of some widespread container libraries [4, 18, 17]. Since, we are not interested in fixing all the details of the hierarchy (i.e., which concrete containers, and which concrete operations in them, do exist) the

Table 3: Other Important Quality Attributes

Understandability		
Attribute	Definition	Examples
Separation between type of container - implementation	Degree of separation among the semantics of a type of container and its available implementations	No assumptions on the available implementations
Uniformity	Same strategies and level of detail when dealing with the same concept in different parts of the library	Access by position available to all types of containers
Name appropriateness	Behaviour of library features accordingly to their name	The *getCurrent* operation of an iterator does not change the current element
Quality of documentation	Appropriateness and comprehension of the documentation to make easy the use of the library	UML diagrams for describing the packages; browsing capabilities
Quality of design	Quality of the design of the library	Use of design patterns
Complexity	Size of the library and conceptual difficulty of the offered features	Use of advanced implementation techniques

Changeability		
Attribute	Definition	Examples
Modularity	Extent of the decomposition of the library into modules	One package for container type
Internal reusability	Degree of reusability of the code inside the library	Use of abstract classes
Programming practices	Adoption of best programming practices in-the-small	Avoid global variables; adopt name conventions
Decoupling	Independence of the different packages that are in the library	Use the *Template Method* pattern
Quality of design	Quality of the design of the library	Use of design patterns
Complexity	Difficulty of analysing the internal structure of the library	Intensive use of object-oriented features

Time behavior		
Attribute	Definition	Examples
Order of magnitude	Worst-case execution time of the operations of an implementation as the size of their input grow	Constant time on insertion, $O(1)$; linear time on removal, $O(n)$
Real time efficiency	Execution ellapsed time of (a pattern of) the operations of an implementation with selected benchmarks	Number of ms. for list traversal with 20.000 elements in a given platform

Resource utilization		
Attribute	Definition	Examples
Data structure order of magnitude	Worst-case amount of storage required by the data structure of an implementation as the number of its elements grows	Linear space for a hashing strategy, $O(n)$
Data structure real space efficiency	Number of bytes required by the data structure of an implementation given the space required to represent the elemental data types	$n\times$ the space of a pointer
Order of magnitude of the operations	Worst-case amount of auxiliary storage required by the operations of an implementation as the number of elements in its data structure grows	Linear space for a sorting algorithm

framework should include just its general layout. A complete hierarchy of a container library shall provide: a container base class (where common capabilities are offered); a hierarchy of iterators; locations for accessing and modifying containers; concrete containers classes; and different implementation strategies for each concrete container. Our objective is to reuse in the concrete containers classes the common capabilities of the (fully-implemented) container base class. Figure 1 shows the hierarchy we have chosen for the SBF.

The classes involved in this hierarchy are:

- *Bidirectional_iterator*. An abstract class that provides the interface of this kind of iterator, i.e. iterators that support forward and backward traversal of a container.
- Container_iterator. An efficient implementation of Bidirectional_iterator enlarged with a new method that returns the shortcut bound to the current item of the iterator. This class is implemented over the base class Container; as a consequence, it is fully independent of the specific kind of container. All operations of this class shall be $O(1)$ to guarantee highly-efficient access by iterator.
- *Shortcut*. Defines the interface of the the concept of shortcut which encapsulates the feature of location or position of objects.
- Container_shortcut. An efficient (i.e., $O(1)$ time) and secure implementation of the Shortcut interface. Container_shortcut is implemented over the base class Container; as a consequence, it is fully independent of the specific kind of container but can be used for access to items them store.
- Container. This base class acts as a common parent class for all kinds of containers. It provides the interface and implementation of the most common capabilities of container libraries.
- Concrete containers. Children classes of Container that are not leaves, which represent different types of containers (list, map, etc.). Each of them adds the interface and implementation of its specific functionalities to the ones inherited from the Container class.

  The strategy chosen to implement these classes consists on storing the items in the base class Container and the shortcuts bound to them in a concrete implementation (an array, dynamic storage, ...). In order to do this, specific operations of concrete containers are implemented using (if it is necessary) an operation implemented by their subclasses (i.e., using the Template Method design pattern [10]). Concrete containers also define as protected the interface of the de-

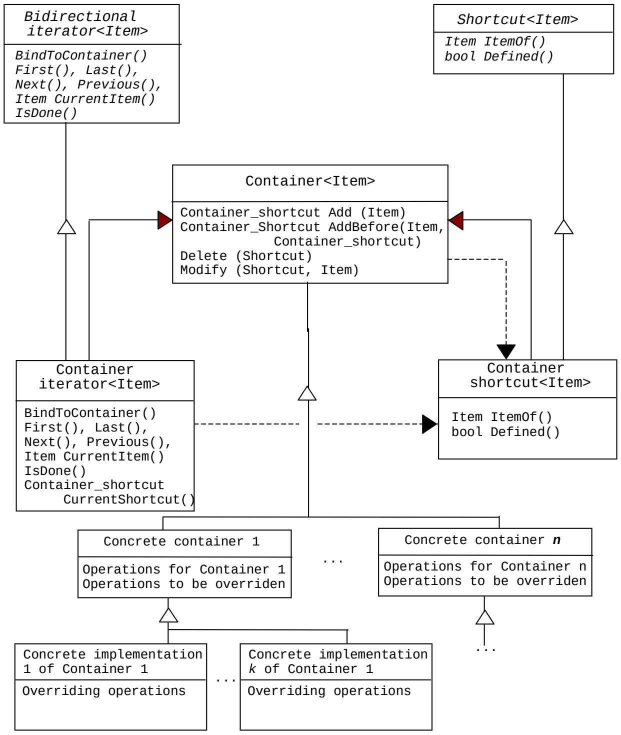


Figure 1: The Shortcut-Based Framework

ferred operations that appear as a result of applying the Template Method design pattern (that we call *concrete interface*) and implement a (in some cases non-efficient) version of them using the Container interface and shortcuts. We want to remark that this implementation strategy uses the base class Container as a black box and, at the same time, makes the concrete container a black box for its children classes. Moreover, all the operations of the container class are $O(1)$. Last but not least, each concrete container is an implementation (non-abstract) class.

- Concrete implementations. Children classes of concrete containers that are leaves. These classes implement the concrete interface by means of data structures. They inherit all the functionalities of the concrete container and as a consequence their implementation can be made avoiding iterators and locations. On the other hand, inherited implementations may remain if they already fulfil efficiency requirements.

3.3 Implementation Details

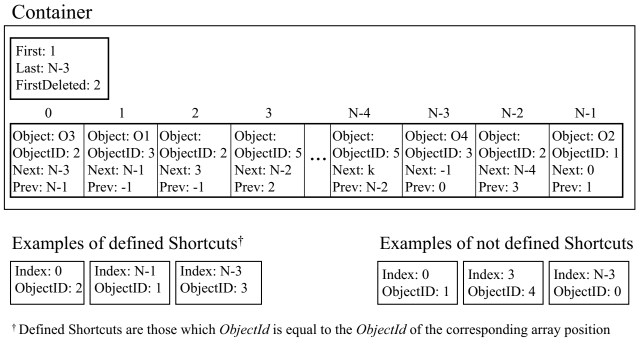
The essential point consists in maintaining an efficient mapping from shortcuts to items in the *Container* base class. There are three possibilities to implement this mapping depending on the underlying memory management scheme:

1. *Using dynamic storage without garbage collection.* In this case the *Shortcut* class shall be implemented with a *smart pointer* [7]. Smart pointers are characterized by the fact that deletion of allocated objects does not take place until there are no shortcuts bound to them. The smart pointer shall point to a tuple containing the object and a *deleted* flag, i.e., an attribute to record if the object is deleted or not. On the other hand, the *Container* base class shall be implemented with a double linked list of these tuples in order to have efficient bidirectional iterators. In the sample code given in this section we use this scheme.

2. *Using dynamic storage with garbage collection.* The smart pointer shall be substituted by a regular pointer. There are no more changes with respect the previous approach.

3. *Using an array.* In this case shortcuts shall be implemented as tuples of an index to the array position and an object identifier which allows check if the object corresponding to the index position of the array has changed. Then the *Container* base class shall be implemented as an array of tuples which contain the object, a item identifier (counts the updates of the array position) and two indexes to the next and previous tuples linking the elements in the iterator ordering. As released shortcuts (the deleted array positions) shall be available somehow to allow further reassignment, we shall link them too. Additional index members corresponding to the position of the first object, the position of the last object and the first free position shall be maintained in the *Container* base class.

As a sample of these three schemes, Figure 2 shows the array-based one.


Container

First: 1
Last: N-3
FirstDeleted: 2

0	1	2	3		N-4	N-3	N-2	N-1
Object: O3 ObjectID: 2 Next: N-3 Prev: N-1	Object: O1 ObjectID: 3 Next: N-1 Prev: -1	Object: ObjectID: 2 Next: 3 Prev: -1	Object: ObjectID: 5 Next: N-2 Prev: 2	...	Object: ObjectID: 5 Next: k Prev: N-2	Object: O4 ObjectID: 3 Next: -1 Prev: 0	Object: ObjectID: 2 Next: N-4 Prev: 3	Object: O2 ObjectID: 1 Next: 0 Prev: 1

Examples of defined Shortcuts†

Index: 0 ObjectID: 2 | Index: N-1 ObjectID: 1 | Index: N-3 ObjectID: 3

Examples of not defined Shortcuts

Index: 0 ObjectID: 1 | Index: 3 ObjectID: 4 | Index: N-3 ObjectID: 0

† Defined Shortcuts are those which *ObjectId* is equal to the *ObjectId* of the corresponding array position

Figure 2: Array-based implementation scheme

It must be remarked that shortcut assignment is properly managed in both schemes. Using dynamic storage, the class defining smart pointers redefines the assignment to detect that a new shortcut has come up. Using an array, normal behaviour of assignment is sufficient.

It can be observed that shortcuts require some extra time and space in order to get all its benefits. We will assess efficiency of the approach in Sect. 4.

We outline here a sample code[1] of the SBF implementation of five participants in the proposed structure, *Container_shortcut*, *Container_iterator*, *Container*, the concrete container *Map* and an implementation of the concrete container *Map*: *MapArray*. This naive implementation has been chosen for illustrating that existing shortcuts and iterators

[1] The complete code can be found at www.lsi.upc.es/∼jmarco/SBFAdaImplementation.zip

remain valid even in data structures that make rearrangements of elements. The specifications and implementations of the *Container_shortcut* and the *Container_iterator* are in the containers specification and body packages. The implementation of shortcuts is made using dynamic memory.

Package specification of the Container class (in file containers.ads). This package contains the specification of shortcuts, iterators and containers. We use a `Pointer` class from the SmartPointer package, which encapsulates the definition of smart pointers. The implementation of the *Shortcut* and *Iterator* classes is the same, it stores a smart pointer `Ptr` to the container node where the item bound to the shortcut or to the iterator is, along with an access to the `Container`. Notice that in the `Delete` operation of the *Container* class, the `Shortcut` parameter is `in out` in order to set its smart pointer to `NULL` for decrementing the number of references to the element removed.

```
with Ada.Finalization;
with SmartPointer;
with SmartPointer.To;
with Bidirectional_Iterators; generic
  type Item is private;
package Containers is
  type Container is tagged private;
---------------------------------------------------
--                    Container Shortcut
---------------------------------------------------
  type Shortcut is tagged private;
  function "=" (ShL,ShR: Shortcut) return Boolean;
  pragma Inline ("=");
  function Item_Of (Sh: Shortcut) return Item;
  pragma Inline (Item_Of);
  function Defined (Sh: Shortcut) return Boolean;
  pragma Inline (Defined);
---------------------------------------------------
--                    Container Iterator
---------------------------------------------------
  package Container_Iterators is new
                 Bidirectional_Iterators(Item);
  type Iterator is new
       Container_Iterators.Bidirectional_Iterator
       with private;
  Procedure Bind_To_Container(It:out Iterator;
                              C: Container'Class);
  pragma Inline (Bind_To_Container);
  Procedure First (It : in out Iterator);
  pragma Inline (First);
  ... -- other iterator's operations
  function "=" (ItL,ItR:Iterator)return Boolean;
  pragma Inline ("=");
  procedure Swap(It1, It2 : in out Iterator);
  pragma Inline(Swap);
---------------------------------------------------
--                    Container
---------------------------------------------------
  procedure Add(In_The_Container:in out Container;
              Elem: Item);
  procedure Add_Before
       (In_The_Container:in out Container;
        The_Shortcut:Shortcut'Class;Elem: Item);
  function Shortcut_To_The_Last_Item_Added
       (In_The_Container:Container'Class)
        return Shortcut;
  procedure Delete(In_The_Container:in out
    Container;The_Shortcut:in out Shortcut'Class);
  procedure Modify (In_The_Container:in out
    Container;The_Shortcut:Shortcut'Class;Elem:Item);
  function Cardinality (C:Container)return Natural;
  pragma Inline(Cardinality);
  Undefined_Shortcut : exception;
  Iterator_Is_Not_Bound : exception;
  Iterator_Out_Of_Range : exception;
private
  type AccessContainer is access all
                 Container'Class;
  type Node is
  record
    Elem: Item;
    Next: SmartPointer.Pointer;
    Previous: SmartPointer.Pointer;
    Deleted_Flag: Boolean := FALSE;
  end record;
  type Shortcut is new Ada.Finalization.Controlled
  with record
    Container: AccessContainer;
    Ptr : SmartPointer.Pointer;
  end record;
  type Iterator is new
  Container_Iterators.Bidirectional_Iterator with
  record
    Container: AccessContainer;
    Ptr: SmartPointer.Pointer;
  end record;
  type Container is new  Ada.Finalization.Controlled
  with record
    AccessC: AccessContainer;
    Cardinality: Natural := 0;
    Dummy: SmartPointer.Pointer;
    Last_Item_Added: SmartPointer.Pointer;
  end record;
  procedure Initialize(C : in out Container);
  procedure Finalize(C : in out Container);
  procedure Adjust(C : in out Container);
  package SP is new SmartPointer.To(Node);
end Containers;
```

Operations of the Container_shortcut class. This code is in the *Containers* package body. We do not present here the `"="` function which implementation is straightforward. Notice that both operations below have constant time cost.

```
function Item_Of (Sh : Shortcut) return Item is
begin
   if not Defined(Sh) then
      raise Undefined_Shortcut;
   end if;
   return Value(Sh.Ptr).Elem;
end Item_Of;

function Defined (Sh : Shortcut) return Boolean is
begin
  if IsNull(Sh.Ptr) then return false;
  elsif Sh.Container = null then return false;
  else return not SP.Value(Sh.Ptr).Deleted_Flag;
  end if;
end Defined;
```

Operations of the Container_iterator class. This code is in the *Containers* package body too. We only show the `Swap` procedure which interchange the iterator order of the items associated to the two iterators, and the `CurrentShortcut` function which returns the Shortcut associated to the *current item*. Smart pointer assignment inside this method keeps track of the existence of a new shortcut to the involved element (this also happens in iterator assignment); also, the container bound to the shortcut is the container bound to the iterator through `BindToContainer`. The rest of operations are the usual ones for iterators and are implemented straightforwardly. As in the case of the `Shortcut` class, all the operations need O(1) time in the worst case.

```
function CurrentShortcut (It : Iterator'Class)
                          return Shortcut is
begin
   if IsDone(It) then
      raise Iterator_Out_Of_Range;
   end if;
   return Shortcut'(Ada.Finalization.Controlled
      with Container => It.Container, Ptr => It.Ptr);
end CurrentShortcut;

procedure Swap(It1, It2 : in out Iterator) is
 PtrAux : SmartPointer.Pointer;
begin
 if not IsDone(It1) and not IsDone(It2)
                     and It1 /= It2 then
  if Value(It1.Ptr).Next /= It2.Ptr and
     Value(It2.Ptr).Next /= It1.Ptr then
   AccessValue(Value(It1.Ptr).Next).Previous:=It2.Ptr;
   AccessValue(Value(It1.Ptr).Previous).Next:=It2.Ptr;
   AccessValue(Value(It2.Ptr).Next).Previous:=It1.Ptr;
   AccessValue(Value(It2.Ptr).Previous).Next:=It1.Ptr;
   PtrAux := Value(It1.Ptr).Next;
   AccessValue(It1.Ptr).Next := Value(It2.Ptr).Next;
   AccessValue(It2.Ptr).Next := PtrAux;
   PtrAux := Value(It1.Ptr).Previous;
   AccessValue(It1.Ptr).Previous:=
                           Value(It2.Ptr).Previous;
   AccessValue(It2.Ptr).Previous := PtrAux;
  elsif Value(It1.Ptr).Next = It2.Ptr then
   AccessValue(It2.Ptr).Previous:=
                           Value(It1.Ptr).Previous;
   AccessValue(Value(It1.Ptr).Previous).Next:=It2.Ptr;
   AccessValue(Value(It2.Ptr).Next).Previous:=It1.Ptr;
   AccessValue(It1.Ptr).Next := Value(It2.Ptr).Next;
   AccessValue(It2.Ptr).Next := It1.Ptr;
   AccessValue(It1.Ptr).Previous := It2.Ptr;
  else
   AccessValue(It1.Ptr).Previous:=
                             Value(It2.Ptr).Previous;
   AccessValue(Value(It2.Ptr).Previous).Next:=It1.Ptr;
   AccessValue(Value(It1.Ptr).Next).Previous:=It2.Ptr;
   AccessValue(It2.Ptr).Next := Value(It1.Ptr).Next;
   AccessValue(It1.Ptr).Next := It2.Ptr;
   AccessValue(It2.Ptr).Previous := It1.Ptr;
  end if;
  PtrAux := It1.Ptr;
  It1.Ptr := It2.Ptr;
  It2.Ptr := PtrAux;
 end if;
end Swap;
```

Operations of the class Container. To get the flavor, we present just the `Add` and the `Delete` (by shortcut) operations. `Add` implements the insertion in a double linked list while `Delete` implements the deletion marking as deleted the item associated to the shortcut, if any, setting to `NULL` the shortcut members `Ptr` and `Container`, and the `Node` smart pointer members `next` and `previous`. We remark that the time efficiency is optimal, O(1), as it was required.

```
procedure Add (In_The_Container : in out Container;
               Elem: Item) is
 Ptr : Pointer := Create;
begin
 AccessValue(Ptr).Elem := Elem;
 AccessValue(Value(In_The_Container.Dummy).Previous).
             Next:=Ptr;
 AccessValue(Ptr).Previous:=
             Value(In_The_Container.Dummy).Previous;
 AccessValue(Ptr).Next:=In_The_Container.Dummy;
 AccessValue(In_The_Container.Dummy).Previous:=Ptr;
 In_The_Container.Cardinality:=
             In_The_Container.Cardinality+1;
 In_The_Container.Last_Item_Added := Ptr;
end Add;
```

```
procedure Delete(In_The_Container: in out Container;
                 The_Shortcut:in out Shortcut'Class) is
begin
 if Defined(The_Shortcut) then
  if The_Shortcut.Container
                =In_The_Container.AccessC then
   AccessValue(The_Shortcut.Ptr).Deleted_Flag := true;
   AccessValue(Value(The_Shortcut.Ptr).Previous).Next:=
               Value(The_Shortcut.Ptr).Next;
   AccessValue(Value(The_Shortcut.Ptr).Next).Previous:=
               Value(The_Shortcut.Ptr).Previous;
   SetNull(AccessValue(The_Shortcut.Ptr).Previous);
   SetNull(AccessValue(The_Shortcut.Ptr).Next);
   if The_Shortcut.Ptr =
            In_The_Container.Last_Item_Added then
    SetNull(In_The_Container.Last_Item_Added);
   end if;
   SetNull(The_Shortcut.Ptr);
   The_Shortcut.Container := null;
   In_The_Container.Cardinality :=
            In_The_Container.Cardinality-1;
  else
   raise Undefined_Shortcut;
  end if;
 end if;
end Delete;
```

Concrete Container `Map` class. This class is in the second level of the SBF class hierarchy. The concrete container `Map` bounds values to keys. We show here the package specification of this class and the implementation of the map operation `Delete` (by key) which illustrates the use of the Template Method design pattern. The identifiers of the deferred operations that appear, as well as the type representations, have the string `Con` as prefix. The `ConDelete` operation deletes the shortcut stored in a concrete implementation of the container abstraction; this shortcut is returned as result and used then to delete the item. Actually this implementation of `Delete` does not depend on the concrete implementation of the map container. We want to remark that its execution time is the same as the execution time of the concrete deferred operation (shortcut operations take $O(1)$ time).

```
generic
  type Key is private;
  type Value is private;
  with function "=" (L, R : Key) return Boolean is <>;
  with function Key_Of (I : Item) return Key is <>;
  with function Value_Of (I : Item) return Value is <>;
package Containers.Maps is
  type Map is new  Container with private;
  procedure Add (In_The_Container : in out Map;
            Elem: Item);
  procedure Add_Before (In_The_Container : in out Map;
            The_Shortcut: Shortcut'Class; Elem: Item);
  procedure Delete (In_The_Container : in out Map;
            The_Shortcut: in out Shortcut'Class);
  procedure Modify (In_The_Container : in out Map;
            The_Shortcut: Shortcut'Class; Elem: Item);
  procedure Delete (In_The_Container : in out Map;
            The_Key: Key);
  function Get (In_The_Container : Map;
            The_Key: Key) return Value;
  function Exist (In_The_Container : Map;
            The_Key: Key) return Boolean;
  Con_Error : exception;
  Not_Existing_Key : exception;
private
  type Map is new  Container with
  record
    Sh : Shortcut;
  end record;
  subtype Con_Item is Shortcut;
  subtype Con_Key is Key;
  subtype Con_Value is Shortcut;
  function Con_Key_Of(CI:Con_Item)return Con_Key;
  pragma Inline(Con_Key_Of);
  function Con_Value_Of(CI:Con_Item)return Con_Value;
  pragma Inline(Con_Value_Of);
  procedure Con_Add (In_The_Container:in out Map;
            Elem: Con_Item);
  procedure Con_Delete (In_The_Container:in out Map;
            The_Key: Con_Key);
  function Con_Get (In_The_Container:Map;
            The_Key: Con_Key) return Con_Item;
  function Con_Exist (In_The_Container : Map;
            The_Key: Con_Key) return Boolean;
end Containers.Maps;
```

The *Delete* map operation uses *Dispatching* operations in order to call the concrete operations of the implementation class that has called *Delete*.

```
procedure Dispatching_Delete (In_The_Container :in out
                    Map'Class; The_Key: Con_Key) is
begin
    Con_Delete(In_The_Container,The_Key);
end Dispatching_Delete;
```

```
procedure Delete (In_The_Container : in out Map;
                  The_Key: Key) is
 Sh : Shortcut;
begin
 Sh := Dispatching_Get(In_The_Container,The_Key);
 Dispatching_Delete(In_The_Container,The_Key);
 Containers.Delete(Container(In_The_Container),Sh);
end Delete;
```

Now, we consider a possible concrete implementation, named `MapArray` for the concrete container *Map*. We have chosen this example because it shows the main points of the SBF:

- The application of the Template Method design pattern.
- The use of parent and children classes as black boxes.
- The persistence of iterators and shortcuts, even when the concrete implementation makes rearrangements of items inside the underlying data structure (as it is the case of `MapArray`).
- The possibility of defining generic algorithms that work over any kind of containers.

Concrete Implementation `MapArray`. This class is at the bottom level of the SBF class hierarchy. This array-based implementation of the `Map` includes the code for the deferred concrete operation `ConDelete`. It is worth to remark that this implementation changes positions of elements in the array; in despite of these rearrangements, all the existing shortcuts and iterators keep being valid.

```
procedure Con_Delete(In_The_Container:in out MapArray;
                     The_Key: Con_Key) is
begin
 if not Con_Exist(In_The_Container,The_key) then
    raise Not_Existing_Key;
 end if;
 In_The_Container.FirstFree :=
           In_The_Container.FirstFree-1;
 for i in In_The_Container.Cache ..
           In_The_Container.FirstFree-1 loop
   In_The_Container.MapA(i) :=
           In_The_Container.MapA(i+1);
 end loop;
 SmartPointer.SetNull(
 In_The_Container.MapA(In_The_Container.FirstFree).Ptr);
end Con_Delete;
```

3.4 Use of the SBF

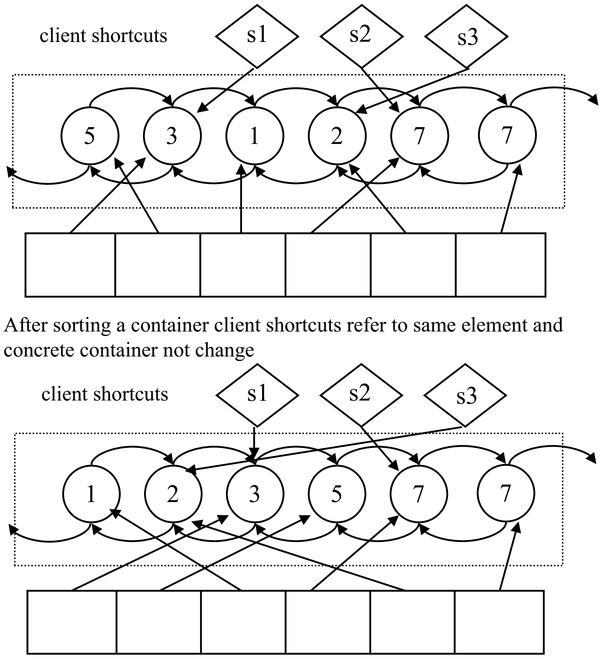
We illustrate here how to use a SBF-based Ada Container Library by presenting two generic algorithms over it: *Min_In_Range* and *Sort*. The *Min_In_Range* algorithm returns the minimun element found between two iterators in a given order. The *Sort* algorithm sorts the elements of a container (with respect to the iteration order). Fig. 3 shows an example of the last one in which can be observed that after sorting the container all the shortcuts refer to the right object. We remark that these generic algorithms work for any kind of container with the same time efficiency (because iterators are independent of the concrete container).

The Min_In_Range *generic algorithm*

```
generic
  type Item is private;
  with function "<" (L,R:Item) return boolean is <>;
  with package BI is new Bidirectional_Iterators(Item);
  use BI;
function Min_In_Range(FirstIt,LastIt:
          BI.Bidirectional_Iterator'Class)
          return BI.Bidirectional_Iterator'Class is
  ItMin,It: BI.Bidirectional_Iterator'Class:= FirstIt;
begin
  while not IsDone(It) and It /= LastIt loop
    if CurrentItem(It) < CurrentItem(ItMin) then
      ItMin := It;
    end if;
    Next(It);
  end loop;
  return ItMin;
end Min_In_Range;
```

The sort *generic algorithm*

```
generic
  type Item is private;
  with function "<" (L,R:Item) return boolean is <>;
  with package C is new Containers(Item);
  use C;
  procedure Sort (C1 : in out C.Container'Class);
procedure Sort (C1: in out C.Container'Class) is
 function Min_In_Range is new
 GenericAlgorithms.Min_In_Range(Item => Item,
         "<" => "<", BI => C.Container_Iterators);
 It1, It2, ItMin : C.Iterator;
begin
 if Cardinality(C1) /= 0 then
   Bind_To_Container(It1,C1);
   Bind_To_Container(It2,C1);
   Last(It2);
   Next(It2);
   while not IsDone(It1) loop
     ItMin:=Iterator(Min_In_Range(It1,It2));
     Swap(It1,ItMin);
     Next(It1);
   end loop;
 end if;
end Sort;
```



After sorting a container client shortcuts refer to same element and concrete container not change

Figure 3: Sorting a container.

4. EVALUATING THE SHORTCUT-BASED FRAMEWORK

In this section we carry out the assessment of the SBF introduced in the last section. We proceed as follows. First we define some metrics for reasoning about the quality of a SBF-based Ada container library, using the ISO/IEC-9126 quality model for container libraries presented in Sect. 2 and then we reason about how the SBF affects the value of these metrics. Remarkably, this study is carried out without making any assumption about the library other than it is built on top of our framework.

There are many proposals for defining metrics. We have adopted one of the most widespread approaches, the Goal-Question-Metric (GQM) [3]. In GQM, goals of the product under measurement are identified, and then some questions are raised to characterize the way the assessment of a specific goal is going to be performed. Last, a set of metrics is associated with every question in order to answer it in a quantitative way; metrics can be objective or subjective. The final result of the GQM approach is a hierarchical structure in graph-like form, since metrics may influence in more than one question, and questions may be related to more than one goal. Goals are composed of four elements: purpose, issue, object and viewpoint. In our framework, these elements take the following form:

- Purpose. Presence or absence of a particular feature or characteristic in the library.
- Issue. The GQM recommends to identify quality goals; then, we define one issue for each attribute of the ISO/IEC-based quality model. As a consequence, we have as many goals as quality attributes.
- Object. Always the SBF-based Ada Standard Container Library.

Table 4: GQM Model for the Suitability Attributes

Goal	Question	Metric	Value
Purpose: Have an appropriate Issue: Category variety Viewpoint: Ada community	Has the library the most frequently used categories of containers?	% of *basic* categories	N.A.
	Has the library a robust proposal of categories of containers?	100 − % of *unnecessary* categories	N.A.
Purpose: Have an appropriate Issue: Container variety Viewpoint: Ada community	Has the library the most frequently used types of containers for each category?	mean(% of *basic* types of containers for each category it has)	N.A.
	Has the library a robust proposal of types of containers?	100 − % of conflicts among two *basic* types of containers	N.A.
		100 − mean(% of *unnecessary* types of containers in each category it has)	N.A.
Purpose: Have an appropriate Issue: Implementation variety Viewpoint: Ada community	Has the library the most frequently used types of implementation strategies for each category?	mean(% of *basic* implementation strategies for each type of container it has)	N.A.
	Has the library a robust proposal of implementation strategies for each container?	100 − mean(% of *unnecessary* implementations of containers in each category it has)	N.A.
Purpose: Have an appropriate Issue: Operation variety Viewpoint: Ada community	Has the library the most frequently used operations for each container?	mean(% of *basic* operations in each type of container it has)	N.A.
	Has the library a robust proposal of operations for each container?	100 − mean(% of *unnecessary* operations in each type of container it has)	N.A.

N.A.: Not Affected

- Viewpoint. There are two viewpoints: the Ada community, as end user of the library; and the library developers themselves, who may have their own interests.

4.1 Assessment of Core Suitability

Table 4 presents a summary of goals, questions and metrics for the suitability attributes[2]. Questions are the same for the four goals bound to the four suitability attributes: expressive power embraced by the library, and quality of its contents.

With respect to expressive power, we feel necessary to distinguish among basic and advanced categories, types of containers, implementation strategies and operation sets. The concept of basic depends on the viewpoint (this is marked in the table with the italics style). So, the Ada community may classify e.g. graphs as a basic category of containers or as advanced one, depending on their particular requirements. In this paper we focus on basic elements, to simplify metrics definition; a deeper analysis shall consider advanced elements yielding to additional metrics. Therefore, the metrics are defined as a measure of the basic elements of each kind present in the library. We argue that the metrics are not affected at all by the adoption of the SBF; in other words, the containers, implementations and operations chosen to be present in the library would not be altered or restricted anyway by our proposal. Some particular remarks about situations that are problematic in other approaches but not in ours follow:

- The SBF allows types of containers with arbitrary removal and modification operations.
- The SBF allows implementations with any kind of memory management (arrays, dynamic storage with or without garbage collection, resizable memory chunks, etc.).
- The SBF allows implementations with rearrangement of elements in its data structure after modifications (e.g., open addressing hashing).

We characterize content quality by robustness, basically presence of unnecessary or conflicting elements in the library. Again, our proposal does not interfere with the robustness of the library: shortcuts do not improve or damage the robustness of the core suitability of the library.

4.2 Assessment of other Functionality Attributes

Table 5 shows an excerpt of the GQM model for other functionality attributes. Some explanations follow:

- Access by position is characterized by the set of operations that use shortcuts to access the elements in the container: lookup, removal and modification. We measure the percentage of containers that provide each of these operations. The SBF provides 100% coverage.
- For iterators, the questions elucidate which types exist (see for instance [18] for a summary of types of iterators). We show as example the questions for two of those types. We use the same metric as before with the same 100% result.
- Concerning algorithmic variety, we distinguish among the algorithms provided by the library and the possibility of defining new ones[3]. In both cases we focus on algorithms using positions or iterators. The SBF is well-suited for both categories, because it does not restrict the type of algorithms that can be designed (see Sect. 3.4 for examples). Remarkably, generic algorithms that traverse the container using iterators are allowed to modify the container during iteration.

[2] It is not a goal of the paper to give detailed arguments supporting this particular model; in fact, this would require to present a whole metrics plan as defined in [19].

[3] This last question is also relevant for changeability; we remark that the GQM approach allows questions to be bound to more than one goal.

Table 5: GQM Model for other Functionality Attributes

Goal	Question	Metric	Value
Purpose: Have Issue: Access by position Viewpoint: Ada community	Does the library provide an operation for retrieving by position?	% of containers that provide it	100 %
	Does the library provide an operation for removing by position?	% of containers that provide it	100 %
	Does the library provide an operation for modifying by position?	% of containers that provide it	100 %
Purpose: Have Issue: Access by Iterators Viewpoint: Ada community	Does the library allow removing during iteration?	% of containers that provide it	100 %
	Does the library allow modifying during iteration?	% of containers that provide it	100 %
Purpose: Have Issue: Algorithmic variety Viewpoint: Ada community	Has the library the most frequently used algorithms?	% of *basic* generic algorithms	N.A.
	Does the library allow defining new generic algorithms that work with all containers?	% of containers for which is possible	100 %
Purpose: Have Issue: Accurate Access by position Viewpoint: Ada community	Is it impossible to access to an item other than the original one?	100% − % of cases that is possible	100 %
	Is it possible to use implementation strategies that make rearrangements without making positions out-of-date?	% of cases that is possible	100 %
	Do positions remain valid when insertions or deletions take place?	% of cases that remains valid	100 %
Purpose: Have Issue: Accurate Access by iterator Viewpoint: Ada community	Is it impossible to traverse the data structure beyond the last element?	100% − % of cases that is possible	100 %
	Does the iterator remain valid when insertions or deletions take place?	% of cases that remains valid	90 %
Purpose: Have Issue: Secure Access by position Viewpoint: Ada community	Is it impossible to use a position to access to a wrong container?	100% − % of cases that is possible	100 %
	Is an exception raised if a position which does not have associated an object is used?	% of cases that is raised	100 %
	Is it possible to know if a position its bound to an element in a container?	% of cases that it is possible	100 %
Purpose: Have Issue: Secure Access by iterator Viewpoint: Ada community	Is it possible to know if an iterator is still valid or not?	% of cases that is possible	100 %
	Is it impossible to use operations not valid given the type of the iterator?	100% − % of cases that remains valid	100 %

N.A.: Not Affected

- In accuracy and security goals, we have included questions for identifying those situations that can yield to erroneous behaviour. We include some examples in the table addressing to scenarios that typically fail to behave accurately in other proposals. For instance, the SBF ensures accuracy of results even for those strategies that rearrange the elements in the data structure. Metrics just count the percentage of failure cases. We remark that the SBF suffers just a restriction: removal of the current element during an iterator makes the iterator undefined[4].

4.3 Assessment of Understandability and Changeability

Briefly, we summarize in this section the points that show how the SBF supports these attributes. First, the concept of shortcut is in fact a kind of container-oriented design pattern; in fact, we have formulated the SBF in terms of design patterns [16] using the notation of [10]. The use of design patterns has been mentioned in Sect. 2 as a technique supporting quality of design, and also enhances quality of documentation and uniformity, since all the concepts are applied the same way to all kinds of containers.

The internal structure of the SBF exhibits also other properties that have been identified as quality attributes. First, access by position and iterators rely on a clear distinction among specification and implementation of containers; furthermore, shortcuts and iterators follow this distinction, i.e. they are formulated in terms of the specification and do not impose any restriction on the implementations of the containers. Second, complexity is kept up to a minimum level: for instance, the set of operations to manage shortcuts and iterators is small and always the same, shortcuts are obtained as a result of the usual insertion operation without any further action, etc. Next, other design properties such as modularity and loose coupling are fulfilled as a consequence of our proposal. Last, internal reusability is favoured due to the organization of the class hierarchy in the SBF; this property makes library customization and extension easier.

[4] Even this restriction could be avoided with a little extra cost, but we have considered it unnecessary.

4.4 Assessment of Efficiency

The assessment of the SBF concerning efficiency turns out to be a crucial point. It is clear that there must be a price to pay for having access by position and iterators fulfilling suitability, accuracy, security, understandability and changeability as explained above, and this price is efficiency. Nevertheless, we have checked that efficiency is not seriosusly damaged by the SBF. We summarize our study in terms of the efficiency attributes identified in Sect. 2.2.

4.4.1 Assessment of Time Behavior

Order of magnitude. It is worth to remark two fundamental things. First, all the operations that involve shortcuts and iterators are as efficient as they can be, which means that access by shortcut is $O(1)$, and traversals using iterators are $O(n)$, being n the number of elements in the container. Second, the order of magnitude of the core operations of the containers (i.e., those using neither shortcuts nor iterators) remains the same; in other words, shortcut management can be done without penalising the order of magnitude of the operations.

Real time efficiency. We have carried out some experiments for assessing this quality attribute. We have developed a SBF-based version of the Booch Components library (see [14] for details) and then we have compared some execution results on a large set of instances with the original version of the library. As an example, we have measured the results for three representative processes (insertion, lookup and iteration) in a particular type of container, namely a Bag implemented with a hashing table. In order to cover a reasonable sample of representative scenarios we have considered the following three criteria: container's element size, percentage of occupation of the Bag and number of collisions by bucket produced by the hash function. For each scenario, different bag sizes and different number of insertions (depending of the number of occurrences of each item) have been tested.

From the results obtained, we have observed that the execution time of iteration and the execution time of lookup (with respect to the number of items) are independent of the scenario in the case of the shortcut version, while in the case of the original version the execution time increases proportionally to the size of the items and in some cases (instances are generated randomly) inversely proportional to the percentage of occupation of the bag, and the execution time of lookup grows proportionally to the size of the item. In all the cases, the execution time of the shortcuts version is less than the execution time of the original version and oscillates between 1.5 and 3 times faster in the case of iteration, and between 3 and 15 times faster in the case of lookup. The insertion overhead in the shortcuts version, which oscillates between a bit more than 1 and 3 times slower than in the original version.

Figure 4 shows the number of iterations required to amortise the insertion overhead in the best case (B.C. curves) and the worst case (W.C. curves) for some representative scenarios. The overhead of insertions is amortised with 2 and 8 iterations respectively. In general, time efficiency of insertion with shortcut gets closer to the one of the original version as size of elements increases; we remark that with strings of 300 characters, there are cases where one single iteration makes our proposal better than the original one.

All the test programs and the Ada-95 packages needed to generate these programs together with the shortcut version can be found at www.lsi.upc.es/∼jmarco/testing.html and the original library at www.pogner.demon.co.uk/components/bc.

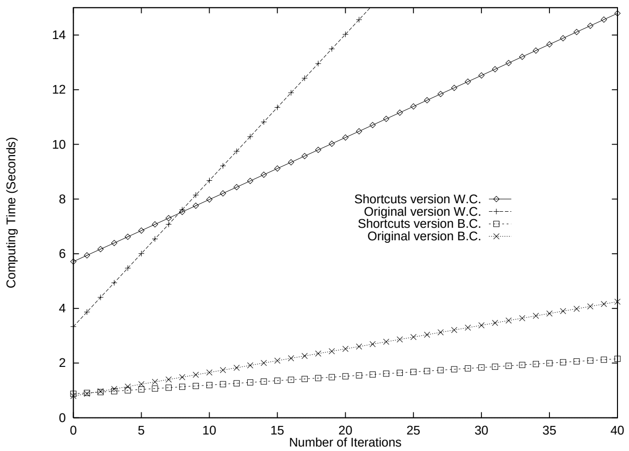


Figure 4: Comparing the original version of Booch Components with the shortcuts version.

4.4.2 Assessment of Resource Utilization

Data structure real space efficiency. Being N the number of elements in the container and assuming a pointer-based implementation of shortcuts without garbage collection, which is the worst case concerning space efficiency, the total amount of extra space required for shortcut management is:

$$2 \cdot N \cdot \mathit{space}(\text{pointer}) + N \cdot \mathit{space}(\text{shortcut}) + \\ N \cdot \mathit{space}(\text{bool}) + N \cdot \mathit{space}(\text{integer})$$

The first operand comes from the double linked list[5], the second one from the shortcuts stored in the implementation of a concrete abstraction and the last two operands from the deleted flag and the reference counter. We would like to remark that this waste of space will usually generate a later saving, when shortcuts substitute identifiers (generally strings, which require more space than shortcuts) in references from other containers. Identifiers would be requiered if the Ada Standard Container Library would not provide access by position, or if this access by position were unaccurate or unsecure and so rejected in critical systems. The relationship between these two factors may be formally established.

Let N be the total number of objects in the container and R the total number of external references to objects in the container. Since generally,

$$\mathit{space}(\text{identifier}) \geq \mathit{space}(\text{pointer}) \qquad (1)$$

then $\exists k \geq 1$ s.t. $(k{+}1)\cdot\mathit{space}(\text{pointer}) > \mathit{space}(\text{identifier}) \geq k\cdot\mathit{space}(\text{pointer})$ and since $\mathit{space}(\text{shortcut}) = 2\cdot\mathit{space}(\text{pointer})$ (because we use two pointers for assuring that a particular shortcut is bound to a particular container) and assuming the worst case $\mathit{space}(\text{bool}) = \mathit{space}(\text{integer}) = \mathit{space}(\text{pointer})$, space is really saved when the relationship

$$R \cdot \mathit{space}(\text{identifier}) \geq (6 \cdot N + 2 \cdot R) \cdot \mathit{space}(\text{pointer}) \qquad (2)$$

[5] The space of a smart pointer is the same as a regular one.

holds, which is satisfied when the following condition holds:

$$R \cdot k \geq 6 \cdot N + 2 \cdot R \tag{3}$$

For example, if identifiers were strings of average size 40 (i.e., $k = 10$ with pointers requiring 4 bytes) and there is an external reference to each of them ($N = R$), then by substituting from (3) we obtain:

$$10 \cdot R \geq 8 \cdot R$$

that obviously holds.

Order of magnitude of the data structure. From the result above, we can verify that the addition of shortcut management does not increase the order of magnitude of the data structure used in the container implementation.

Order of magnitude of the auxiliary space in operations. Any operation, either related to core or general suitability, suffers from more than an $O(1)$ increment of auxiliary space.

5. CONCLUSIONS

In this paper we have presented the Shortcut-Based Framework (SBF) as the basis for designing and implementing a prospective Ada Standard Container Library. The SBF aims at supporting access by position and iterators suitable for containers in the library. The proposal is built around the concept of shortcut. We have arranged a class hierarchy that includes base classes for containers, shortcuts and iterators, and specializations for types of containers and implementations. We have assessed the quality of the SBF-based container library using an ISO/IEC-based quality model, together with some metrics defined with the Goal-Question-Metric approach.

We think that the main contributions of our work are:

- The SBF provides high-quality access by position and iterators. Unlike other approaches for handling this kind of access, the SBF provides rich suitability and ensures accuracy and security of their use. Also, our approach provides uniformity and supports understandability and changeability of the library, among other advantages. We have quantified the cost of the approach regarding efficiency, which turns out to be not severe; in fact, both time and space overhead may disappear under some circumstances.

- The SBF provides absolute freedom for the core suitability of the library, i.e., types of containers, implementation strategies and operations offered. For this reason, our approach does not interfere with the discussion about whether an existing Ada library (Charles, Booch Components, etc.) can be used as the basis for the standard library, or else if this library shall be design and implemented from the scratch.

- Our proposal has been assessed thoroughly using an exhaustive quality model and a set of metrics. It should remain clear that in this paper we have not presented neither the whole quality model nor the whole set of metrics, for the sake of brevity; we have focused on those parts of the model and those metrics that are more relevant for our proposal.

To be more precise, the SBF avoids the following problems, which are very usual in other proposals for dealing with access by position and iterators:

- Out-of-date positions or iterators. Shortcuts are decoupled from physical positions (either memory addresses or array indexes).

- Restrictions on the use of iterators. Remarkably it is allowed to update the container during a traversal.

- Restrictions on the implementation strategy. Remarkably, implementations in which the elements may change their position are allowed. Also, the SBF may be tailored to any kind of memory management scheme.

- Lack of uniformity. All the containers offer the same operations for iterating and accessing by position.

- Lack of internal reuse. The cost of extending the library with new types of containers or new implementation strategies is diminished due to the reuse of code for shortcut management.

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