

Memoization Aspects: a Case Study

Santiago Vidal

ISISTAN Research Institute, Faculty
of Sciences, UNICEN University,
Campus Universitario, Tandil, Buenos
Aires, Argentina, Also CONICET
svidal@exa.unicen.edu.ar

Claudia Marcos

ISISTAN Research Institute, Faculty
of Sciences, UNICEN University,
Campus Universitario, Tandil, Buenos
Aires, Argentina, Also CIC
cmarcos@exa.unicen.edu.ar

Alexandre Bergel

PLEIAD Lab, Department of
Computer Science (DCC), University
of Chile, Santiago, Chile
abergel@dcc.uchile.cl

Gabriela Arévalo

Abstract

an abstract

1. Introduction

Coping with emerging requirements is probably one of the most difficult challenges in software engineering [12].

This paper presents a solution to a maintenance problem we recently faced while developing the Mondrian application. Mondrian is an agile visualization engine. It is used in more than a dozen projects. As in many software developments, new requirements set by the increasing set of clients have an impact on assumptions that were hold for years.

Mondrian uses simple two-dimensions rendering to graphically visualize an arbitrary domain. Mondrian is almost exclusively used to visualize software metrics. It allows for a wide range of visual representations¹. One of the strong assumptions that Mondrian holds is the structure of its multiple cache mechanisms.

Mondrian has 9 caches spread over the graphical element hierarchy. The caches aim to quickly render two dimensional widgets, graphically composed of rectangle and line shapes. Mondrian's caches are instance of the memoization technique². Sending twice the same message returns the same value if no side effect impact the computation.

¹<http://www.moosetechnology.org/docs/visualhall>

²<http://www.tfef.org/lisp/hax.html#MEMOIZE>

Unfortunately, the new requirements of Mondrian defeats the purpose of some of the caches it defines. One example is the bounds computation to obtain the circumscribed rectangle of a two-dimensional graphical element. This cache is senseless in a 3D setting. Bypassing the cache result in a complex extension of Mondrian.

We have first identified where the caches are implemented and how they interact with the rest of the application. For each cache, we marked methods that initialize the cache and reset it. We have subsequently undertaken a major refactoring of Mondrian's core: we have produced a prototyping version of Mondrian in which caches are externalized from the base code. Our refactoring was realized via a custom aspect mechanism.

We were able to modularize the cache while preserving the overall architecture and Mondrian performances did not suffer from the refactoring.

The paper makes the following contributions:

- identification of memoizing cross-cutting concern
- refactorization of these cross-cutting concerns into modular and pluggable aspects
- lesson learnt

2. Making Mondrian Evolve

This section details a maintenance problem we have faced when developing Mondrian.

2.1 Turning Mondrian into a framework

Mondrian³ [11] is an agile visualization library. A domain specific language is provided to easily define interactive visualizations. Visualizations are structured along a graph structured, made of possibly nested nodes and edges. Mondrian is a crucial component, used in more than a dozen independent

projects. To meet clients performance requirements, Mondrian authors are paying a great attention to provide fast and scalable rendering. To that purpose, Mondrian contains a number of caches to avoid redundant code executions.

Mondrian is now on the verge to become a visualization engine framework versus a library as it is currently. Mondrian is now used in situations that were not originally planned. For example, Mondrian has been used to visualize the real-time behavior of animated robots⁴, 3D visualizations⁵, whereas Mondrian has been originally designed to visualize software source code using plain 2D drawing [8]. The caches that are intensively used when visualizing software are not useful and may even be a source of slowdown and complexity when visualizing animated robots.

2.2 Memoization

Memoization is an optimization technique used to speed up an application by making calls avoid repeating the similar previous computation. Consider the method `absoluteBounds` that any Mondrian element can answer to. This method determines the circumscribed rectangle of the graphical element:

```
MOGraphElement>>absoluteBounds
  absoluteBoundsCache
  ifNotNil: [ ^ absoluteBoundsCache ].
  ^ absoluteBoundsCache :=
    self shape absoluteBoundsFor: self
```

The method `absoluteBoundsFor:` realizes a heavy computation to determine the smallest rectangle that contains all the nested elements. Since this method does not perform any global side effect, the class `MOGraphElement` defines an instance variable called `absoluteBoundsCache` which is initialized at the first invocation of `absoluteBounds`. Subsequent invocation will therefore use the result previously computed.

Obviously, the variable `absoluteBoundsCache` needs to be set to `nil` when the bounds of the element are modified (e.g., adding a new nested node, drag and dropping).

2.3 Problem.

Mondrian intensively uses memoization for most of its computation. A user-performed interaction that leads to an update of the visualization invalidates the visualization. These memoization have been gradually introduced over the development of Mondrian (which started in 2006). Each unpredicted usage led to a performance problem which has been solved using a new memoization. There are about 32 memoizations in the current version of Mondrian.

These caches have been shaped along the common usage of Mondrian. Visualizations produced in Mondrian are *all* static, employ colored geometrical objects.

Extending the range of applications for Mondrian turns some of the caches senseless. For example `absoluteBoundsCache` has no meaning in the three-dimensional version of Mondrian

since the circumscribed rectangle is meaningful only with two dimensions.

Using delegation. We first tried to address this problem by relying only on explicit objects, one for each cache. This object would offer the necessary operations for accessing and resetting a cache.

As exemplified with the `absoluteBounds` method given above, the caches are implemented by means of dedicated instance variables defined in the `Cache` class. That is to say, each cache is associated with an instance variable. In this way, a variable of the `Cache` class, called `generalCache`, is defined in the `MOGraphElement` class. Through this variable the different caches can be accessed by means of the `cacheAt:(key)` method where `key` is a string with the name of the cache.

Figure 1 illustrates this situation where a graph element has one instance of the `Cache` class, itself referencing to many instances of `CacheableItem`, one for each cache.

Below is shown how is written the `absoluteBounds` method following this approach:

```
MOGraphElement>>absoluteBounds
  (generalCache cacheAt: 'absoluteBoundsCache')
  ifCacheNil: [
    (generalCache cacheAt: 'absoluteBoundsCache')
    putElement: (self shape absoluteBoundsFor: self)].
  ^ (generalCache cacheAt: 'absoluteBoundsCache')
    getInternalCache.
```

As can be seen, with this approach the different instance variables related with the caches are replaced by a unique variable called `generalCache`. On the other hand, the legibility of the method is deteriorated as well as the performance.

Significant overhead. This modularization solely based on delegating message has a significant overhead at execution time because of additional indirection. The separation of this concern is not a trivial problem. Specifically, when this solution the caches mechanism was 3 to 10 times slower, being the delay proportional to the number of elements.

2.4 Requirement for refactoring

Refactoring Mondrian is a task that has to be realized with care. In particular, the refactoring has to follow the constraints:

- all cache accesses have to be identified. This is essential to have all the caches equally considered.
- no cost of performance must be incurred, else it defeats the whole purpose of the work
- readability must not be reduced

3. Refactoring

The goal of the refactoring is the separation of the *Cache Concern* from the four essential classes of *Mondrian*: *MOGraphElement* and its subclasses (*MOEdge*, *MONode*, and *MORoot*). These classes total 235 methods and more than 1000 number of lines of codes.

⁴<http://www.squeaksource.com/Calder.html>

⁵<http://www.squeaksource.com/Klotz.html>

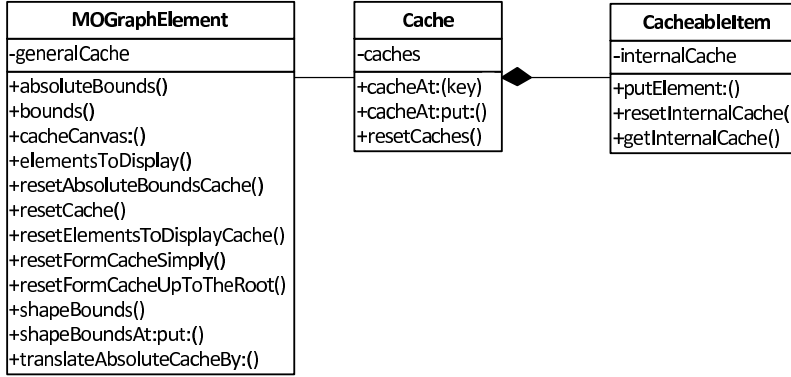


Figure 1. Cache behavior delegation.

3.1 Identifying caches

The first step of the refactoring is the identification of the caches. This initial identification of the caches is done with the information provided by the developers of Mondrian and it lies in to know the variables related to the caches and the places where they are used. The caches are mostly identified by browsing the methods in which the caches variables are referenced and accessed. Nine different caches are found in Mondrian: *cacheShapeBounds*, *cacheForm*, *boundsCache*, *absoluteBoundsCache*, *elementsToDisplayCache*, *lookupNodeCache*, *cacheFromPoint*, *cacheToPoint*, and *cacheBounds*. Each of them has a different internal structure according to what is stored: *boundsCache* will hold an instance of the class *Rectangle* and *cacheForm* an instance of a bitmap *Forms*, for example.

After this initial identification, the fragment of codes in which the caches are used are grouped together based on the purpose of its use (e.g., saving information, obtaining the data stored). Each group is associated with different activities:

- Initialize and reset the cache: the fragments of code in this group initialize or reset a cache variable putting them in nil or creating an instance of an object.
- Retrieve the cache value: this group obtains the information that is saved in a cache.
- Store data in the cache: the code fragments grouped here store information into a cache variable.

The task of group the fragments of code of the different caches is achieved with the goal of identifying possible strategies for refactoring. Alexandre ▶ *I do not understand this sentence. "The task of group" ?* ◀ Santiago ▶ *Mas arriba habia puesto "the fragment of codes in which the caches are used are grouped together based on the purpose of its use". A eso me refiero con "The task of group", la tarea de agrupar el codigo segun lo que hacen* ◀. These groups allows the identification of code patterns that are repeated in the use of the caches. For each pattern found a refactoring strategy is associated. These code patterns are described in the following subsections.

3.2 Pattern Description

We identified 5 code patterns based on Mondrian source code and are described below. Each pattern is described with a relevant typical occurrence, the number of occurrences we found in Mondrian and an illustration.

Reset Cache. A cache has to be invalidated when its content has to be actualized. We refer to this action as reset. The code to express a reset is *cache:=resetValue* where *resetValue* and the initial value the cache has to have. Typically, the *resetValue* depends on the type of the stored value. It could be nil, an empty dictionary, or a particular value (e.g., 000). Eighteen occurrences of this pattern are found in Mondrian. We found that in some occurrences the reset of the caches is performed before the logic of the method, and other methods in which the reset must be done after. For example, the method `MOGraphElement>>shapeBoundsAt:put:` resets the caches *absoluteBoundsCache* and *boundsCache* before modifying the cache *cacheShapeBounds*. In contrast, the method `MONode>>translateBy:bounded:` resets the caches *boundsCache* and *absoluteBoundsCache* after executing most of the sentences of the method.

Consider the method `MOGraphElement>>resetCache`. This method is called whenever the user drag and drop a graphical element. In this method the *Reset Cache* pattern is repeated in four occasions to reset the caches *boundsCache*, *absoluteBoundsCache*, *cacheShapeBounds*, and *elementsToDisplayCache*. In this case, the reset of the caches can be done before or after the execution of the methods *resetElementsToLookup* and *resetMetricCaches*.

```

MOGraphElement>>resetCache
    self resetElementsToLookup.
    boundsCache := nil.
    absoluteBoundsCache := nil.
    cacheShapeBounds := SmallDictionary new.
    elementsToDisplayCache := nil.
    self resetMetricCaches
  
```

Lazy initialization. In some situations it is not relevant to initialize the cache before it is actually needed. This happens when a graphical element is not outside the window:

no cache initialization is required for a graphical element if the element is not displayed. These caches are relevant only when the user actually see the element by scrolling the visualization. Typically, the structure of this pattern is: `^ cache ifNil:[cache:=newValue]`. Mondrian contains five occurrences of a lazy cache initialization. Consider the `bounds` method:

```
MOEdge>>bounds
^ boundsCache ifNil:[boundsCache:= self shape
  computeBoundsFor: self ].
```

The circumscribed rectangle is returned by `computeBoundsFor:` and is performed only when an edge is actually visible (`bounds` is used in `drawOn:`, the rendering method).

Cache Initialization. This pattern represents a situation in which a value is assigned to a cache. The structure of the pattern is only an assignation: `cache := aValue`. This pattern is found in three occasions. Consider the method `cacheCanvas`:

```
MOGraphElement>>cacheCanvas: aCanvas
  cacheForm:= aCanvas form
  copy: ((self bounds origin + aCanvas origin-(101))
    extent: (self bounds extent + (202))).
```

The method `cacheCanvas:` is invoked only during testing in order to verify some characteristics of the caches such as their effectiveness.

Return Cache. This pattern shows the situation in which a cache is accessed. The structure of the pattern is the return of the cache: `return cache`. This pattern is found in four occasions. Next, the method `shapeBounds` is presented as an example in which `cacheShapeBounds` is accessed.

```
MOGraphElement>>shapeBounds
^ cacheShapeBounds
```

Cache Loaded. This pattern checks whether one cache or more are initialized or conversely, if they are not nil. So, the structure of the pattern for a single cache is `cache != nil`. This pattern is found in two occasions. Next the method `isCacheLoaded` is presented as an example of this pattern.

```
MOGraphElement>>isCacheLoaded
^cacheForm notNil.
```

Additionally, Table 1 gives the occurrences of each pattern in the `MOGraphElement` hierarchy, the methods involved in each pattern, and the caches related with a pattern.

Figure 2 shows the distribution of the caches over the main Mondrian classes. In this figure, the methods in which the caches are used are shown. Also, Figure 2 shows in which class each cache is defined. As can be seen, the caches are used and defined across the whole class hierarchy.

3.3 Refactoring Strategy

Alexandre ▶ *I was wondering. Why not to rename this section as "Memoization as an aspect"? After some discussion with Eric, we*

are still doing aop, even without AspectJ or an explicit aspect language. We could then use "weaving" instead of "injection" ◀

Once the code patterns are identified, strategies to refactor them are established. The goal of the refactorization is the extraction of these patterns from the main code without changing the behavior of the system.

Several alternatives were explored to encapsulate the *Cache Concern*. After exploring a variety of options such as the separation of the concern by means of the definition of an exclusive class for managing caches or the use of proxies to intercept messages, an approach based on code injection was chosen. This solution has the advantage of encapsulating the concern in a new unit while the code that it is finally executed after the injection is similar to the original code of *Mondrian*. So, the performance is not affected. In order to encapsulate the source code related with the code patterns the *pragma* mechanism is used. *Pragmas* are the method annotation syntax implemented by Pharo.

The refactoring strategy used is: for each method that contains code related to the *Cache Concern*, the code related to the concern is extracted using a pragma that is defined in the method. The decision to define the pragma inside the method is in order to allow a better visibility of the code that is injected. The pragmas used have a structure according to each code pattern. In general, the pragmas structure is `<patternCodeName: cacheName>` where `cacheName` indicates the name of the cache that will be injected and `patternCodeName` indicates the pattern code to be generated. For example, the pragma `<LazyInitializationPattern: #absoluteBoundsCache>` indicates that the *Lazy Initialization* pattern will be injected for the cache `absoluteBoundsCache` in the method in which the pragma is defined.

Alexandre ▶ *it also creates a variable in the class doesn't it? ◀*

Santiago ▶ *No, the only addition into the original method is the pragma ◀*

Alexandre ▶ *Ok, but what happens with the instance variable? ◀*

Santiago ▶ *Sorry, I don't understand. What instance variable? ◀*

Alexandre ▶ *We are here describing the weaving approach ◀*

Santiago ▶ *But the weaving approach is the injection approach (just with another name). Isn't it? ◀*

Once that the cache code is extracted into the pragmas, the code to be injected is automatically generated before the execution of the system. Specifically, the automatic injection of a pragma in a method is achieved following the next steps:

1. A new method is created with the same name that the method that contains the pragma but with the prefix "compute" plus the name of the class in which is defined. For example, given the next method

```
MOGraphElement>>absoluteBounds
<LazyInitializationPattern: #absoluteBoundsCache>
^ self shape absoluteBoundsFor: self
```

a new method called `computeMOGraphElementAbsoluteBounds` is created.

Cache	Occurrences	Methods involved	Caches involved
<i>Reset Cache</i>	18	10	boundsCache, absoluteBoundsCache, cacheShapeBounds, elementsToDisplayCache, cacheForm, cacheFromPoint, cacheToPoint
<i>Lazy Initialization</i>	5	5	elementsToDisplayCache, absoluteBoundsCache, boundsCache, cacheBounds
<i>Cache Initialization</i>	3	3	cacheForm, cacheFromPoint, cacheToPoint
<i>Return Cache</i>	4	4	cacheShapeBounds, cacheForm, cacheFromPoint, cacheToPoint
<i>Cache Loaded</i>	2	2	cacheForm, cacheFromPoint, cacheToPoint
Total	32	24	

Table 1. Cache Concern scattering summary.

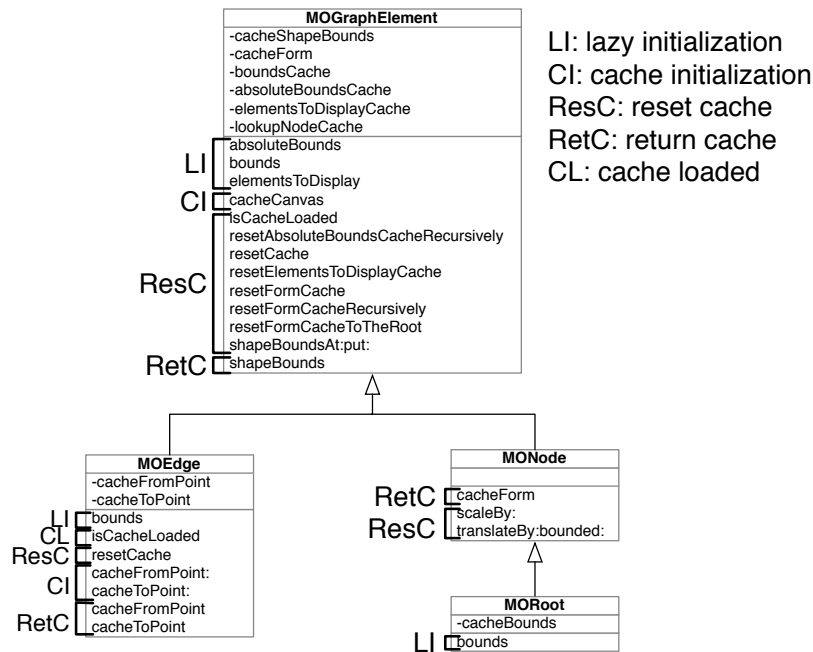


Figure 2. Pattern locations in the MOGraphElement hierarchy

2. The code of the original method is copied into the new method.

```
MOGraphElement>>computeMOGraphElementAbsoluteBounds
  ^ self shape absoluteBoundsFor: self
```

3. The code inside the original method is replaced by the code automatically generated according to the pattern defined in the pragma. This generated method contains a call to the new method of the Step 1.

```
MOGraphElement>>absoluteBounds
  absoluteBoundsCache
  ifNotNil: [ ^ absoluteBoundsCache ].
  ^ absoluteBoundsCache:=
    (self computeMOGraphElementabsoluteBounds)
```

In this way, the refactored cache code is executed with Mondrian.

In order to automatically generate the code to be injected, the injector code mechanism provides a *CachePattern* interface. In this way, each cache pattern has to implements this interface which allow the generation of the methods mentioned above. Basically each subclass is responsible of the definition of the pragma to be used and the generation of the code sentences to be injected related with the cache whereas the interface *CachePattern* creates the methods to be added to the system. This class hierarchy is shown in Fig. 3.

Next, the refactorings applied to each code pattern are presented.

Reset Cache. In order to refactor this pattern each statement that resets a cache was extracted using a pragma. The pragma contains the cache to be resetted. Owing to in some cases the resets are done at the beginning of a method and others at the end, a hierarchy of Reset Cache pattern is created. As is shown in Fig. 3, this hierarchy is composed of the classes *AbstractResetCachePattern*, *BeforeResetCachePattern*, and *AfterResetCachePattern*. The pragmas are defined in the classes at the bottom of the hierarchy as *<BeforeResetCachePattern: cacheName>* and *<AfterResetCachePattern: cacheName>* respectively. For example, in the case presented in Section 3.2 of the method *resetCache*, a pragma is defined for each reset of a cache leaving a cleaner code in the method. In this case all the resets are done before the method call, so the pragmas used are the defined by *BeforeResetCachePattern*. Even though the order of calls is changed (in comparison with the original method), the method behavior is not modified. The code to be generated will reset the cache defined in the pragma. Following, the refactored code is presented:

```
MOGraphElement>>resetCache
  <BeforeResetCachePattern: #absoluteBoundsCache>
  <BeforeResetCachePattern: #elementsToDisplayCache>
  <BeforeResetCachePattern: #boundsCache>
  <BeforeResetCachePattern: #cacheShapeBounds>
  self resetElementsToLookup.
  self resetMetricCaches
```

The methods *resetElementsToLookup* and *resetMetricCaches* performs additional activities that do not involve the cache variables. For this reason they remain in the *resetCache* method.

After the code injection the *resetCache* method is transformed into:

```
MOGraphElement>>resetCache
  absoluteBoundsCache:=nil.
  elementsToDisplayCache:=nil.
  boundsCache:=nil.
  cacheShapeBounds:=SmallDictionary new.
  self computeMOGraphElementresetCache
```

where the method *computeMOGraphElementresetCache* is:

```
MOGraphElement>>computeMOGraphElementresetCache
  self resetElementsToLookup.
  self resetMetricCaches
```

This mechanism of injection of the generated code is the same for the rest of the patterns.

Lazy Initialization. To refactor this pattern the precondition checking is encapsulated into a pragma defined as *<LazyInitializationPattern: cacheName>*. Given that the cache is initialized with a value when the precondition fails, the original method is modified to return this value. For example, in the case of the *bounds* method presented in the previous section, the code related to the cache is extracted using the pragma and only the value to initialize the cache remains in the method as shown the code below:

```
MOEdge>>bounds
  <LazyInitializationPattern: #boundsCache>
  self shape computeBoundsFor: self.
```

In this way, the code to be generated for this example will be *boundsCache ifNotNil: [^ boundsCache]. ^ boundsCache:= computeMOEdgeBounds*.

Cache Initialization. The refactorization of this cache is similar to the last one. Given that the structure of the pattern is an assignation, the first section of the assignation (*cacheName:=*) will be generated automatically by the code injection mechanism using a pragma defined as *<CacheInitializationPattern: cacheName>*. So, only the value at which is initialized remains in the method. In the case of the example presented in Section 3.2, the refactored code is shown below:

```
MOGraphElement>>cacheCanvas: aCanvas
  <CacheInitializationPattern: #cacheForm>
  (aCanvas form copy: ((self bounds origin + aCanvas
    origin
    - (1@1)) extent: (self bounds extent + (2@2)))).
```

Return Cache. In this refactorization the entire return clause is encapsulated by the pragma. The pragma is defined as *<ReturnCachePattern: cacheName>*. Following, the refactored code for the example shown in the last section is presented:

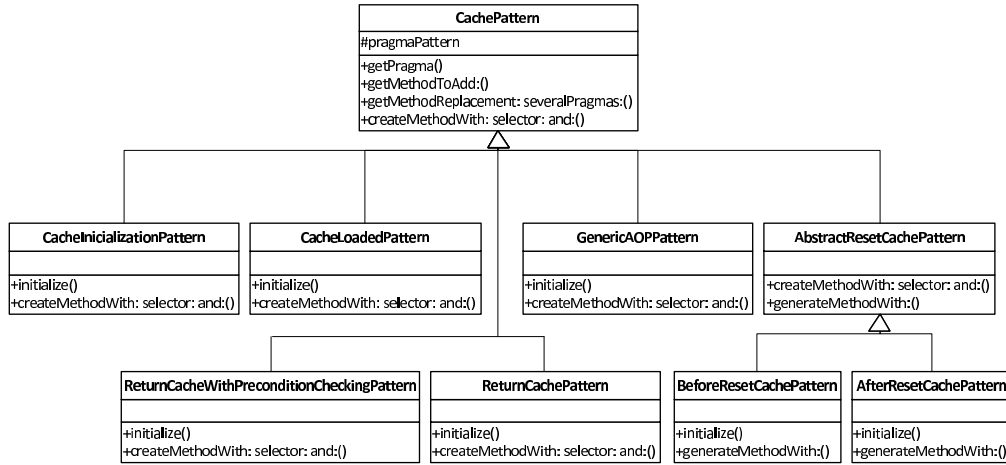


Figure 3. Pattern hierarchy.

```
MOGraphElement>>shapeBounds
<ReturnCachePattern: #cacheShapeBounds>
```

Cache Loaded. In order to refactor this pattern the cache checking is encapsulated by a pragma defined as `<CacheLoadedPattern: cacheName>`. The code generated contains a sentence in which the checking is done for all the caches defined in the pragmas of this pattern contained in a method. In the case of the example presented in Section 3.2, the refactored code is shown below:

```
MOGraphElement>>isCacheLoaded
<CacheLoadedPattern: #cacheForm>
```

With the use of these patterns the *Cache Concern* is refactorized properly in more than 85% of the methods of the *MOGraphElement* hierarchy that uses one or more caches.

Alexandre ▶ *Does it mean that 85% of Mondrian methods use a cache?* ◀ **Santiago** ▶ *No, I mean that from all the methods that uses a cache 85% could be refactorized with the pattern structure* ◀ The main reason because some of the uses of the caches are not encapsulated by means of cache patterns are (1) the code belongs to a cache pattern but the code related with the cache is too mixed with the main concern, or (2) the code does not match with any of the patterns described. For example the method

```
MOGraphElement>>nodeWith: anObject ifAbsent: aBlock
| nodeLookedUp |
lookupNodeCache ifNil: [ lookupNodeCache :=
  IdentityDictionary new ].
lookupNodeCache at: anObject ifPresent: [ :v | ^ v ].
nodeLookedUp := self nodes detect: [:each | each
  model = anObject ] ifNone: aBlock.
lookupNodeCache at: anObject put: nodeLookedUp.
^ nodeLookedUp
```

could not been refactorized because the cache *lookupNodeCache* is used to make different computations across the whole method by which is closely tied to the main concern.

These uses of the caches that are not encapsulated by patterns are also refactorized by means of pragmas. For these cases a *Generic AOP* pattern is used. The pragmas used have the structure `<cache: cacheName before: " after: ">` where *cache* indicates the name of the cache that will be injected. The clauses before and after indicate the source code that will be injected and when it will be injected in regard to the execution of the method. That is to say, the code inside the original method will be replaced by the code pointed out in the before clause of the pragma, a call to the new method will be added, and the code contained in the after clause of the pragma will be added at the end. For example, the refactorization of the method presented previously is

```
MOGraphElement>>nodeWith: anObject ifAbsent: aBlock
<cache: #lookupNodeCache before: ' lookupNodeCache
  ifNil: [lookupNodeCache := IdentityDictionary new ].

  lookupNodeCache at: anObject ifPresent: [ :v | ^ v ].
  ^lookupNodeCache at: anObject put: (' after: ' )'>
| nodeLookedUp |
nodeLookedUp := self nodes detect: [:each | each
  model = anObject ] ifNone: aBlock.
^ nodeLookedUp
```

As can be seen, all the sentences with references to the cache *lookupNodeCache* are encapsulated into the before clause of the pragma.

4. Results

The use of the presented patterns could be used to compose the caches behavior improving the maintenance of the system. In this line, the contribution of the approach is twofold. First, the mechanism of encapsulation and injection could be used to refactor the currently Mondrian caches (and also those that may be introduced in future) improving the code reuse. Second, the code legibility is increased because the *Cache Concern* is extracted from the main concern leaving a cleaner code.

The cache composition is achieved during the injection phase. As the different pieces of code that are related to the cache are encapsulated by means of the patterns, an implicit process of division of the complexity of the caches behavior is achieved. That is to say, this kind of approach helps the developer by splitting the caches behavior in small fragments of code. These fragments of code are encapsulated by the patterns and they are finally composed during the injection phase. For example, the functionality related to the cache *absoluteBoundsCache* is refactored by the patterns *Reset Cache*, *Lazy Initialization*, and *Cache Initialization*.

One of the main priorities during the refactoring process was not to affect the performance of the system. For this reason a group of benchmarks were measured in order to evaluate the cache performance when a set of nodes and edges are displayed. The variations observed between the system before and after applying refactorings are not significant. That is because, in general, the code after the injection of the caches is the same that the original code before the Mondrian refactoring. There were only minor changes such as the reorder of statements in some methods (without changes in the behavior) and the deletion of methods with repeated code. The details of the benchmarks results are shown in Figure 4 in which the time execution to the nodes and edges visualization were calculated. The results of both benchmarks were average over a total of 10 samples. As can be seen, as was expected, there are not remarkable variations during these displaying.

Using cache in the main logic This experience has been the opportunity to rethink on the implementation of Mondrian. We found one occurrence where a cache variable is not solely used as a cache, but as part of main logic of Mondrian. The method *bounds* contains an access to *boundsCache*:

```
MOGraphElement >>bounds
...
self shapeBoundsAt: self shape ifPresent: [ :b | ^
  boundsCache := b ].
...

MOGraphElement >>translateAbsoluteCacheBy: aPoint
absoluteBoundsCache ifNil: [ ^ self ].
absoluteBoundsCache := absoluteBoundsCache
  translateBy: aPoint
```

The core of Mondrian is not independent of the cache implementation. The logic of Mondrian rely on the cache to implement its semantics. This is obviously wrong and this situation is marked as a defect⁶.

Singularity of #displayOn: Displaying a node uses all the defined caches to have a fast rendering. We were not able to define `#displayOn:` as the result of an automatic composition. The main problem is that this method uses intensively the cache to load and save data during its execution. For this reason, the code related to the cache is very scattered across

the method making the restructuration of it by mean of cache patterns almost unviable. So, this method was restructured using the Generic AOP pattern.

5. Discussion

The injection mechanism may reorder statements in the instrumented method. This is the case of the *reset* method (which was presented in the previous section). As was shown, in this case the caches are reset at the beginning of the method and after that the method *resetElementsToLookup* and *resetMetricCaches* are invoked in contrast with the original method in which the former was invoked at the beginning and the former at the end. Even though the order of calls is changed the behavior of the method is not modified. The consistent behavior was checked in a manual way and by mean of automatic test.

Alexandre ▶ *How many occurrences of statement reordering?* ◀

Importance of the tests However, in practice, this has not caused any noticeable problem. The extensive test set of Mondrian remained green after the instrumentation.

6. Related Work

Most of the work in AOP has been focused in Java and AspectJ. An approach called AspectS has been proposed for Smalltalk-Squeak [7]. This is a general purpose AOP language with dynamic weaving. **Santiago** ▶ *No estoy seguro de como justificar que no utilizamos AspectS para los caches. Si funciona en squeak funciona en pharo? Una posibilidad es el overhead que implica la definicion de los pointcuts y aspectos y que no se garantizaba la misma performance en la ejecucion* ◀ Several approaches have been presented in order to refactor and migrate OO systems to AO ones. Some of these approaches use a low level of granularity focusing in the refactorization of simple languages elements such as methods or fields [1, 3, 5, 13, 15]. On the other hand, other approaches are focused in a high level of granularity. This kind of approach tries to encapsulate into an aspect an architectural pattern that represents a CCC. That is, these approaches are focused on the refactorization of a specific type of concern. Our work is under this category. Others works that deals with the refactorization in a high level of granularity are discussed next. Da Silva et al. [4] present an approach of metaphor-driven heuristics and associated refactorings. The refactorization of the code proposed is applicable on two concerns metaphors. A heuristic represents a pattern of code that is repeated for an specific concern and it is encapsulated into an aspect by means of a set of fixed refactorings. Van der Rijst et al.. [10, 14] propose a migration strategy based on crosscutting concern sorts. With this approach the CCCs are described by means of concern sorts. In order to refactor the code, each specific CCC sort indicates what refactorings should be applied to encapsulate it into an aspect. Hannemman et al. [6] present a

⁶<http://code.google.com/p/moose-technology/issues/detail?id=501>

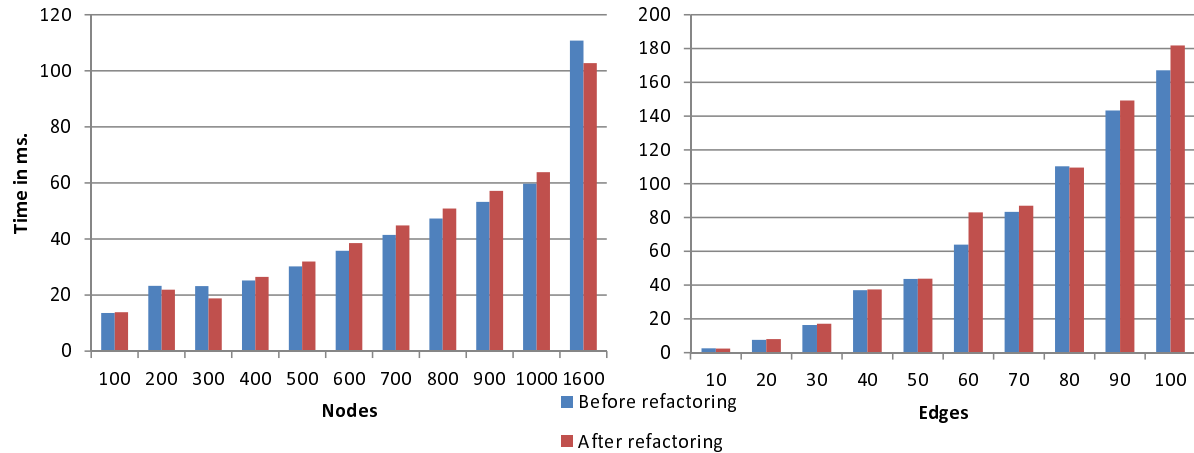


Figure 4. Benchmark of performance.

role-based refactoring approach. Toward this goal the CCCs are described using abstract roles. In this case the refactorings that are going to be used to encapsulate a role are chosen by the developer in each case. Finally, AOP has been used for some mechanisms of cache in the past. Bouchenak et al. [2] present a dynamic web caching content approach based on AOP. In order to achieve this goal, a set of weaving rules are specified using AspectJ as aspect-oriented language. In this same line, Loughran and Rashid [9] propose a web cache to evaluate an aspect-oriented approach based on XML annotations.

7. Conclusion

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