Parametric lenses: change notification for bidirectional lenses

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Abstract
In most complex applications it is inevitable to maintain dependen-
cies between the different subsystems based on some shared data.
The subsystems must be able to inform the dependent parties that
the shared information is changed. As every actual notification has
some communication cost, and every triggered task has associated
computation cost, it is crucial for the overall performance of the
application to reduce the number of notifications as much as pos-
sible. To achieve this, one must be able to define, with arbitrary
precision, which party is depending on which data. In this paper
we offer a general solution to this general problem. The solution
is based on an extension to bidirectional lenses, called parametric
lenses. With the help of parametric lenses one can define composi-
tional parametric views in a declarative way to access some shared
data. Parametric views, besides providing read/write access to the
shared data, also enable to observe changes of some parts, given by
an explicit parameter, the focus domain. The focus domain can be
specified as a type-based query language defined over one or more
resources using predefined combinators of parametric views.

1. Introduction
Complex applications commonly have to deal with shared data. It
is often confined to the use of a relational database coupled with
a simple concurrency control method, e.g., optimistic concurrency
control [2]. In other cases, when a more proactive behavior is re-
quired, polling or some ad hoc notification mechanism can be in-
voked. At the farther end of the range there are some very involved
applications (multi-user applications, workflow management sys-
tems, etc.), which are based on interdependent tasks connected by
shared data. In the most general case, one has to deal with com-
plex task dependencies defined by shared data coming from diverse
sources, e.g. different databases, shared memory, shared files, sen-
sors, etc.

As an example, consider the following case which is based on
a prototype we have developed for the Dutch Coastguard [3]; it
will be used throughout the paper to introduce the problem, and
the concepts of the proposed solution. We have a small database which
acts as a source of data of ships: name, cargo capacity, last known
position, etc. The positions of the ships are updated regularly as
the ships move; ships have a transponder on board which send their
latest position on a regular basis. As a basic task, we simply want
to show the positions of the ships on a map, of which users are
allowed to select an area to view, the focus of their interest, the
focus domain. In this setting we can think of map instances and
update processes as interdependent tasks that are connected by the
data of ships they share. When the position of a ship is updated in
the database, the map instances, of which focus domain covers the
old or the new coordinates, must be refreshed.

From a theoretical perspective, it would be correct behavior to
notify every map instance on ship movement. However, this leads
to huge efficiency issues in practice. There are many thousands of
ships in the North Sea constantly moving around. Only those map
instances need to be refreshed on which area the position of a ship
is changed. As every actual notification has some communication
cost, and every triggered task has associated computation cost, it
is crucial for the overall performance of the application to reduce
the number of notifications as much as possible. Thus, we need a
notification system which, for efficiency reasons, is as accurate as
possible.

As the problem described above is a very common computa-
tional pattern, we would like to offer a general, reusable solution.
In addition, we would like to solve it efficiently enough to be com-
parable with the ad-hoc solutions.

From the computational perspective, focusing on a specific do-
main of the underlying data can be achieved by creating and work-
ing with one of its abstract views. Lenses [1] are commonly used
for creating abstract views. They can be used to support partial
reading and writing, for access restriction or to provide a specific
view of the data. Lenses enable to define bi-directional transforma-
tions. In a nutshell, a lens describes a function that maps the input
to an output (called get) and backwards (called put). The get func-
tion maps the input to some output, while the put function maps the
modified output, together with the original input, to a modified
input:

\[ \text{get } \in X \rightarrow Y \]
\[ \text{put } \in Y \times X \rightarrow X \]

In our example two kind of abstract views are needed for serving
different processes: one to show the ships located in a given area
of the map, and another one for the update process, which periodically
updates the coordinates of a ship in the database.

The general notification problem is as follows. Given is a set of
shared data sources of any type (A and B in the picture) holding a
set of data \((D_A, D_B)\). There are also given some lenses defined
on top of the data sources and on each other. These are \(L_1, L_2, L_3\) and
\(L_4\) in the picture. One typical question can be, e.g., whether a given
update through \(L_4\) affects the \(L_1\) view or not? What about the other
way around?

Unfortunately, lens theory does not say anything about how to
discover when an update get issued through some lens may effect
the data seen through some other. In this paper we present a general extension to lenses as a solution for this general problem. In this extension, called parametric lenses, lenses are partially defunctionalized to extract a first-order parameter (the focus domain: $\phi, \psi$) that groups a set of similar lenses into a single parametric lens in which the parameter essentially encodes which part of the source domain is mapped to the view domain by the lens. Parametric lenses also return a predicate in the put direction. This predicate, called the invalidation function, encodes some semantic information associated with the actual focus domain, and enables the engine to decide which domains are affected by a change of data. It tells whether the particular update of focus $p \in \phi$ affects a get operation of a given focus $q \in \phi$. With other words, it says whether the value of a previous read of some focus $q$ is still valid or not. It returns true to indicate that the given focus must be re-read to be up to date.

$$\text{get}_p \in \phi \times X \rightarrow Y_{\phi}$$

$$\text{put}_p \in \phi \times Y_{\phi} \times X \rightarrow X \times (\phi \times \text{Bool})$$

In our example, the focus domain is a type which enables to specify the area of the map one wants to focus on; the invalidation function then would predicate whether two values of the focus domain, two areas, overlap or not.

Pure parametric lenses cannot be applied to some shared data directly, therefore they attached to the shared data through a non-pure abstract interface called parametric view. The parametric views are allowed to be composed using predefined combinators. Using these combinators, one is able to specify the focus domain as a type-based query language defined over one or more resources. With the query language, one can focus on a specific part of the underlying shared data during reading, writing, or it can be used for notification purposes.

We offer the following contributions in the paper:

1. We introduce parametric lenses as a general extension to lenses which enables to develop efficient notification libraries for them;
2. Parametric lenses are embedded into compositional parametric views which are defined over shared data;
3. The executable semantics, using Haskell [4], of the combinators and an underlying notification engine is provided and explained. The complete Haskell implementation along with the example developed in the paper can be found at https://wiki.clean.cs.ru.nl/File:Pview.zip;
4. Parametric lenses have been introduced in the iTask coastguard case study described above.

References


