Advances in Programming Languages

APL15: Bidirectional Programming

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http://www.inf.ed.ac.uk/teaching/courses/apl

Topic: Bidirectional Programming and Text Processing

This block of lectures covers some language techniques and tools for manipulating structured data and text.

- Motivations, simple bidirectional transformations
- Boomerang and complex transformations
- XML processing with CDuce

This lecture introduces some of the motivations and basic concepts behind bidirectional programming.

Outline

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View Update Problem

A classic problem in databases: how can we propagate changes in a *view* on the data back into the database itself?

University Staff Database (Confidential)

Name:	David Aspinall
Email:	`da@inf.ed.ac.uk`
Staff Number:	1230935
Pay grade:	pt 6.II
Home Address:	10 London Road, E7 5QA

. . .

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University Cycle to Work Scheme

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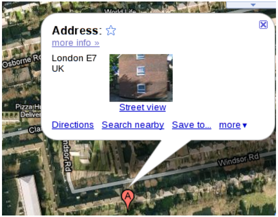
A bit odd!



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University Cycle to Work Scheme

Name:	David Aspinall
Home Address:	10 London Road, **EH**7 5QA
Distance to work:	2.6 miles

Corrected. A more feasible candidate for cycling to work.

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...	

This fix should be updated in the staff database.

View Update: requirements

$$\begin{tikzcd} s \arrow[r, "\mathrm{q}"] & v \end{tikzcd}$$

- A *view* v is generated by an arbitrary query q on the *source* database;

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View Update: requirements

$$\begin{tikzcd}
s \arrow[r, "q"] \arrow[d, "t"'] & v \arrow[d, "u"'] \\
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- A *view* v is generated by an arbitrary query q on the *source* database;
- The view is updated by an update function u to v';
- The source must be updated *correspondingly* to s' by a translation function t, so that the same query q yields v' again.

View Update: Challenges

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- *non-surjective*: an update may have no possible source update
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In database world, present state-of-the-art is to use *triggers* which are custom programmed for particular views. Drawbacks:

- must be re-programmed for each query/allowed update
- duplicates information from the query
- error prone: must check consistency with query, maintain in tandem.

Solution: Bidirectional programming

Idea: write one program get for the query q, and automatically derive another one put which propagates view changes back to the source data, whenever it is possible.

Advantages:

- no need to maintain separate programs
- ideally, consistency is ensured automatically too.

The put function goes in the opposite direction to get. So when both exist, we have a *bidirectional transformation*.

Hence *bidirectional* programming, where we write bidirectional transformations. Ordinary programs, of course, run only in one direction.

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- **user interfaces**: helping to implement the model-view-controller paradigm, by ensuring that view updates consistently change the model and vice-versa.
- **data synchronization**: unifying and mediating between data held in different formats, such as address book data.
- **marshalling**: transferring data across networks, or mediating between different applications, allowing changes in a safe way.

Outline

1. Motivations
2. Language design
3. Semantics
4. Boomerang example
5. Summary

Designing a bidirectional language

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- **meta-programming**: trying to generate put from get, case-by-case.
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Boomerang: A Programming Language Approach

Ideas behind **Boomerang**:

- design a special purpose bidirectional programming language
- every expressible program denotes a bidirectional transformation
- error messages are specific to domain
- can ensure all programs have correct bidirectional behaviour
- take a *functional* approach (ex: why?)

History at University of Pennsylvania, Benjamin Pierce:

- late 1990s, early 2000s: popular *Unison* file synchronization tool built on carefully designed semantic foundations.
- mid 2000s: *Harmony* project, investigating view updates for XML and then bidirectional programming.

See **J. Nathan Foster**'s, PhD thesis *Bidirectional Programming Languages*, University of Pennsylvania, 2009. The diagram on p.35 and some of the following content is adapted from this PhD thesis and earlier papers co-authored with Benjamin Pierce and other collaborators.

Outline

Putting and Getting

Suppose we have a set of *source* values S and view values V.

The basic bidirectional property we want is that given some get function (database query),

$$get \quad : \quad S \to V$$

we should have a way to compute updates on S from altered views, i.e., find a corresponding put function with type:

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An alternative type for put is possible: we might instead try to record and characterise the update operations and make put take as its argument a *delta*. This might allow more accurate source changes, can you think of an example?

Put and Get laws

$$\begin{tikzcd}
s \arrow[r, "get(s)"] \arrow[d, "put(v',s)"'] & v \arrow[d] \\
s' \arrow[r, "get(s')"'] & v'
\end{tikzcd}$$

To make this commute we want this equation to be satisfied: for all view elements v' and source elements s,

$$get(put(v', s)) = v'$$

A put followed by a get must give us back the thing we put in: the **PutGet** law.

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A put followed by a get must give us back the thing we put in: the **PutGet** law.

On the other hand, if we put back the same thing that we got out, we don't expect any change to the source:

$$put(get(s), s) = s$$

This is the **GetPut** law.

PutGet and GetPut together are a rather loose specification. . .

Creating from a view

It's useful to also be able to synthesise a source element from a view element, perhaps giving *default* values to parts of the source that are not manifest in the view.

This motivates a third type of function:

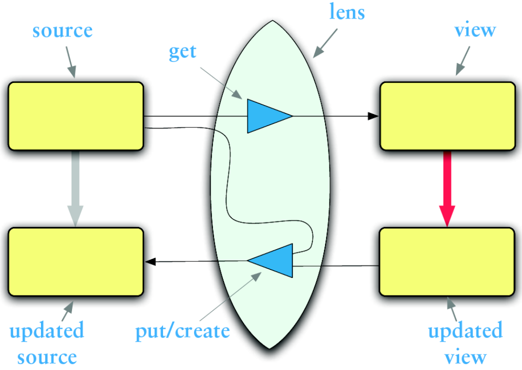
$$create \quad : \quad V \longrightarrow S$$

Create must satisfy the obvious **CreateGet** law:

$$get(create(v)) = v$$

Lenses

A *lens* is an abstraction which captures all these pieces.



A lens l is written $l \in S \Leftrightarrow V$ to show its set of source values S and set of view values V.

Programming with Lenses

Boomerang is a programming language for constructing lenses.

- simple lenses are easy to express
- lenses can be combined using *combinators*
- larger lenses can be expressed more easily using *grammars*
- a library of useful pre-defined lenses is supplied

A fundamental design decision is to make the functions that comprise lenses always *total*. If a program compiles, then put can never go wrong at run time due to a forbidden update.

The abstraction is always maintained: combinations of lenses construct new lenses which again satisfy the required laws.

The language has a strong type system which helps ensure these things statically. In particular, every lens has a fixed source domain S and view domain V, described by types. These are often built from *regular expressions* denoting sets of strings.

Regular Expressions

Let Σ be an alphabet of characters $c \in \Sigma$. Strings over the alphabet Σ are ranged over by $s \in \Sigma*$. The empty string is denoted ϵ. Given two strings s_1 and s_2, their concatenation is $s_1 \cdot s_2$.

Recall the language of *regular expressions* R used to describe sets of strings:

$$R \quad ::= \quad s \quad | \quad R \cdot R \quad | \quad R|R \quad | \quad R*$$

with familiar meanings.
($R_1|R_2$ stands for the union of the sets denoted by R_1 and R_2).

Simple Lenses: Copy

Given a regular expression R, then

$$\text{copy } \mathrm{R} \qquad \in \qquad \mathrm{R} \Leftrightarrow \mathrm{R}$$

defines a lens with source domain R and target (view) domain R, such that for $s, v \in \mathrm{R}$

$$\begin{array}{lcl} get(s) & = & s \\ put(v, s) & = & v \\ create(v) & = & v \end{array}$$

This lens is an identity, it simply copies from source to the view. Since the source and view domains are the same, no information is hidden.

Simple Lenses: Constant

Given a regular expression R, and any string k, then the constant lens

$$\texttt{const}\ \mathrm{R}\ \mathrm{k} \qquad \in \qquad \mathrm{R} \Leftrightarrow \{\mathrm{k}\}$$

such that for $s, v \in \mathrm{R}$

$$\begin{array}{lcl} get(s) & = & \mathrm{k} \\ put(v, s) & = & s \\ create(v) & = & default(\mathrm{R}) \end{array}$$

Going forwards, this lens ignores its source and always produces the view k. Going backwards, it ignores any (necessarily vacuous) updates and leaves the source unchanged.

The create an element in the source, we have to pick one. The function $default(\mathrm{R})$ stands for the choice of an arbitrary value from the set R (in practice this may be defined by the programmer).

Deletion and Insertion

Lenses to insert and delete are defined using the constant lens.

$$\begin{aligned} \mathit{del}\,\mathsf{R} &\in \mathsf{R} \Leftrightarrow \{\epsilon\} \\ \mathit{del}\,\mathsf{R} &= \texttt{const}\,\mathsf{R}\,\epsilon \end{aligned}$$

$$\begin{aligned} \mathit{ins}\,v &\in \{\epsilon\} \Leftrightarrow \{v\} \\ \mathit{ins}\,v &= \texttt{const}\,\{\epsilon\}\,v \end{aligned}$$

Simple Lenses: Concatenation

Given two lenses $l_1 \in S_1 \Leftrightarrow V_1$ and $l_2 \in S_2 \Leftrightarrow V_2$, their concatenation

$$l_1 \;.\; l_2 \qquad \in \qquad S_1 \cdot S_2 \Leftrightarrow V_1 \cdot V_2$$

is defined, provided both $S_1 \cdot S_2$ and $V_1 \cdot V_2$ are *splittable*.

i.e., given $s \in S_1 \cdot S_2$ we can find unique $s_1 \in S_1, s_2 \in S_2$ such that $s_1 \cdot s_2 = s$.

The underlying functions of $l_1 \;.\; l_2$ each split their inputs and pass to the underlying functions from l_1 and l_2 respectively, and then concatenate the results.

For example:

$$get(s_1 \cdot s_2) \quad = \quad (get(s_1)) \cdot (get(s_2))$$

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First Boomerang Example

```
module Staffdb =
let NAME = [a-zA-Z ]+  let EMAIL = [a-zA-Z@.]+
let STAFFNUM = [0-9]{7} let SALARY = [5-9] . "." . [l]+
let ADDRESS = [a-zA-Z0-9 ]+
let POSTCODE = [A-Z0-9]+ . " " . [A-Z0-9]+

let cycleinfo : lens =
          (copy NAME) . ", "
        . del EMAIL . del ", "
        . del STAFFNUM . del ", " . del SALARY . del ", "
        . del ADDRESS . del ", "
        . (ins "Map-distance-from: ")
        . (copy POSTCODE)

let cycleinfos : lens =
    "" | cycleinfo . (newline . cycleinfo)*
```

Testing get

```
let staffdb : string =
<<
David Aspinall, da@inf.ed.ac.uk, 1230935, 6.II, 10 London Road, E7 5QA
Ian Stark, stark@inf.ed.ac.uk, 0579035, 7.II, 14A Queen Anne Street, EH1 FZM
>>

test cycleinfos.get staffdb = ?
```

Produces:

```
Test result:
"David Aspinall, Map-distance-from: E7 5QA
Ian Stark, Map-distance-from: EH1 FZM"
```

Testing put

test cycleinfos.put
<<
David Aspinall, Map−distance−from: EH7 5QA
Ian Stark, Map−distance−from: EH1 FZM
>>
into staffdb = ?

Produces:

```
Test result:
"David Aspinall, da@inf.ed.ac.uk, 1230935, 6.II,
  10 London Road, EH7 5QA
Ian Stark, stark@inf.ed.ac.uk, 0579035, 7.II,
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```

(newlines added to fit on slide)

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Summary

Bidirectional Programming

- Bidirectional transformations map view updates back to source
- Applications: database views, MDD, UIs, sync, . . .
- Foundations: get, put, create, and laws.

Next Lecture

- Boomerang: positions and normalization
- A magic way to get bidirectional transformations

Homework

- Check that the simple lenses shown define functions satisfying the GetPut, PutGet, and CreateGet laws.
- Download Boomerang and try it out.