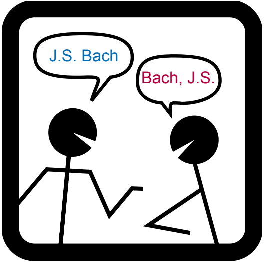
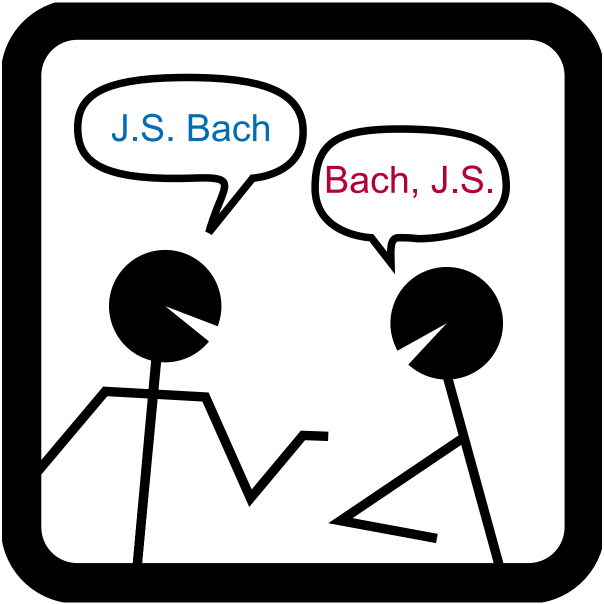
Edit Lenses



Martin Hofmann   Benjamin Pierce   Daniel Wagner

January 27, 2012
POPL Philadelphia

A brief history of lenses



Isomorphisms [Braun et al, 2003; Brabrand et al, 2007]

(Johann, Bach)

Isomorphisms [Braun et al, 2003; Brabrand et al, 2007]

$$(\text{Johann}, \text{Bach}) \xrightarrow{\lambda(x, y).\ (y, x)} (\text{Bach}, \text{Johann})$$

Isomorphisms [Braun et al, 2003; Brabrand et al, 2007]

$$\begin{tikzcd}
(\text{Johann}, \text{Bach}) \arrow[r, "\lambda(x, y).\,(y, x)"] & (\text{Bach}, \text{Johann}) \arrow[d, dashed, "\text{user action}"] \\
& (\text{Bach}, \text{J. S.})
\end{tikzcd}$$

Isomorphisms [Braun et al, 2003; Brabrand et al, 2007]

$$\begin{tikzcd}
(\text{Johann}, \text{Bach}) \arrow[r, "\lambda(x,y).\,(y,x)"] & (\text{Bach}, \text{Johann}) \arrow[d, dashed, "\text{user action}"] \\
(\text{J. S.}, \text{Bach}) & (\text{Bach}, \text{J. S.}) \arrow[l, "\lambda(y,x).\,(x,y)"]
\end{tikzcd}$$

Asymmetric lenses [Foster et al, 2007; Bohannon et al, 2008]

(Johann, Bach, 1685)

Asymmetric lenses [Foster et al, 2007; Bohannon et al, 2008]

$$\lambda(x, y, z).\ (y, x)$$

$$(\text{Johann}, \text{Bach}, 1685) \longrightarrow (\text{Bach}, \text{Johann})$$

Asymmetric lenses [Foster et al, 2007; Bohannon et al, 2008]

$$\begin{tikzcd}
(\text{Johann}, \text{Bach}, 1685) \arrow[r, "\lambda(x,y,z).\,(y,x)"] & (\text{Bach}, \text{Johann}) \arrow[d, dashed] \\
 & (\text{Bach}, \text{J. S.})
\end{tikzcd}$$

Asymmetric lenses [Foster et al, 2007; Bohannon et al, 2008]

$$\begin{tikzcd}
(\text{Johann}, \text{Bach}, 1685) \arrow[r, "\lambda(x, y, z).\ (y, x)"] & (\text{Bach}, \text{Johann}) \arrow[d, dashed] \\
(\text{J. S.}, \text{Bach}, 1685) & (\text{Bach}, \text{J. S.}) \arrow[l, "\lambda(y, x)\ (_, _, z).\ (x, y, z)"']
\end{tikzcd}$$

Symmetric lenses [Hofmann et al, 2011]

(Johann, Bach, 1685)

Symmetric lenses [Hofmann et al, 2011]

(Johann, Bach, 1685)

(1685, Air on G)

Symmetric lenses [Hofmann et al, 2011]

$$\lambda(x, y, z)\ (\_, w).\ ((y, x, w), (z, w))$$

$$(\text{Johann}, \text{Bach}, 1685) \longrightarrow$$

$$(1685, \text{Air on G})$$

Symmetric lenses [Hofmann et al, 2011]

$$\lambda(x, y, z)\ (\_, w).\ ((y, x, w), (z, w))$$

$$(\mathsf{Johann}, \mathsf{Bach}, 1685) \longrightarrow (\mathsf{Bach}, \mathsf{Johann}, \mathsf{Air\ on\ G})$$

$$(1685, \mathsf{Air\ on\ G})$$

Symmetric lenses [Hofmann et al, 2011]

$$\lambda(x, y, z)\ (\_, w).\ ((y, x, w), (z, w))$$

$$\begin{array}{ccc} (\text{Johann}, \text{Bach}, 1685) & \longrightarrow & (\text{Bach}, \text{Johann}, \text{Air on G}) \\ & (1685, \text{Air on G}) & \big\downarrow \\ & & (\text{Bach}, \text{J. S.}, \text{Goldberg Variations}) \end{array}$$

Symmetric lenses [Hofmann et al, 2011]

$$\lambda(x, y, z)\ (\_, w).\ ((y, x, w), (z, w))$$

$$(\text{Johann}, \text{Bach}, 1685) \longrightarrow (\text{Bach}, \text{Johann}, \text{Air on G})$$

$$(1685, \text{Air on G})$$

$$\longleftarrow (\text{Bach}, \text{J. S.}, \text{Goldberg Variations})$$

$$\lambda(y, x, w)(z, \_).\ ((x, y, z), (z, w))$$

Symmetric lenses [Hofmann et al, 2011]

$$
\begin{tikzcd}
(\text{Johann}, \text{Bach}, 1685) \arrow[r, "{\lambda(x, y, z)\ (\_, w).\ ((y, x, w), (z, w))}", "{(1685, \text{Air on G})}"'] & (\text{Bach}, \text{Johann}, \text{Air on G}) \arrow[d, dashed] \\
(\text{J. S.}, \text{Bach}, 1685) & (\text{Bach}, \text{J. S.}, \text{Goldberg Variations}) \arrow[l, "{\lambda(y, x, w)(z, \_).\ ((x, y, z), (z, w))}"']
\end{tikzcd}
$$

Symmetric lenses [Hofmann et al, 2011]

$$\begin{tikzcd}
(\text{Johann}, \text{Bach}, 1685) \arrow[r, "\lambda(x,y,z)\,(_,w).\,((y,x,w),(z,w))", "(1685, \text{Air on G})"'] & (\text{Bach}, \text{Johann}, \text{Air on G}) \arrow[d, dashed] \\
(\text{J. S.}, \text{Bach}, 1685) & (\text{Bach}, \text{J. S.}, \text{Goldberg Variations}) \arrow[l, "(1685, \text{Goldberg Variations})"', "\lambda(y,x,w)(z,_).\,((x,y,z),(z,w))"]
\end{tikzcd}$$

Alignment

$$\begin{matrix} (\text{Johann}, \text{Bach}, 1685) \\ (\text{Franz}, \text{Liszt}, 1811) \end{matrix} \longrightarrow \begin{matrix} (\text{Bach}, \text{Johann}, \text{Air on G}) \\ (\text{Liszt}, \text{Franz}, \text{Liebesträume}) \end{matrix}$$

Alignment

(Johann, Bach, 1685) ⟶ (Bach, Johann, Air on G)

(Franz, Liszt, 1811) ⟶ (Liszt, Franz, Liebesträume)

(1685,Air on G)

(1811,Liebesträume)

Alignment

(Johann, Bach, 1685) $\longrightarrow$ (Bach, Johann, Air on G)

(Franz, Liszt, 1811) (Liszt, Franz, Liebesträume)

(1685,Air on G)

(1811,Liebesträume)

(Liszt, Franz, Liebesträume)

(Bach, J. S., Goldberg Variations)

Alignment

(Johann, Bach, 1685)
(Franz, Liszt, 1811)

(Bach, Johann, Air on G)
(Liszt, Franz, Liebesträume)

(1685,Air on G)
(1811,Liebesträume)

(Franz, Liszt, 1685)
(J. S., Bach, 1811)

(Liszt, Franz, Liebesträume)
(Bach, J. S., Goldberg Variations)

Alignment

(Johann, Bach, 1685)
(Franz, Liszt, 1811)

(Bach, Johann, Air on G)
(Liszt, Franz, Liebesträume)

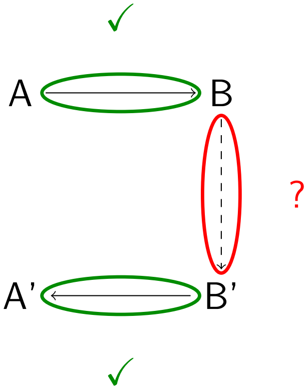
(1685,Air on G)
(1811,Liebesträume)

(Liszt, Franz, Liebesträume)
(Bach, J. S., Goldberg Variations)

(Franz, Liszt, 1811)
(J. S., Bach, 1685)

(Franz, Liszt, 1811)
(J. S., Bach, 0000)

How to improve?



Contributions

- Theoretical framework
  - Model for first-class edits
  - Formulation of lenses on edits
  - Adaptation of behavioral laws
- Lens syntax
  - Composition, products, sums
  - Filtering, mapping, reshaping
- Embedding of state-based lenses
- Haskell library

First-class edits

Edits are a monoid M:

$$\mathbf{1}_M \cdot m = m \cdot \mathbf{1}_M = m$$

$$m_1 \cdot (m_2 \cdot m_3) = (m_1 \cdot m_2) \cdot m_3$$

With a partial monoid action $\odot \in M \times X \to X$:

$$\mathbf{1}_M \odot x = x$$

$$(m_1 \cdot m_2) \odot x = m_1 \odot (m_2 \odot x)$$

Editing lists

Set ∂X are edits for X.
Define atomic edits E for X^*:

- modify(p,$\mathrm{d}x$) where $p \in \mathbb{N}, \mathrm{d}x \in \partial X$
- resize(i,j,x) where $i, j \in \mathbb{N}, x \in X$
- reorder(i,f) where f permutes $\{0, \ldots, i\}$

Take E^* (words of atomic edits) for list edits $\partial(X^*)$.

Edit sequence example

$$\begin{array}{ccc} & & \mathsf{A} \\ \mathsf{A} & & \mathsf{B} \\ & \dashrightarrow & \\ \mathsf{B} & & \mathsf{C} \\ & & \mathsf{D} \end{array}$$

$$[\mathsf{resize}(2, 4, \mathsf{C}), \mathsf{modify}(3, \mathrm{d}x)]$$

Another example

$$\begin{tikzcd} A & A' \\ B \arrow[r, dashed] & B' \\ C & C' \end{tikzcd}$$

$$[\mathrm{modify}(0, \mathrm{d}x), \mathrm{modify}(1, \mathrm{d}x'), \mathrm{modify}(2, \mathrm{d}x'')]$$

But. . .

What about this?

$$[\text{resize}(1, 2, A), \text{resize}(2, 1, A), \text{resize}(1, 2, A), \ldots]$$

Make it a monoid

Introduce an operation

$$\cdot \in E^* \times E^* \to E^*$$

that concatenates, then optimizes.

Respect optimization!

$$(e \cdot e') \odot x = e \odot (e' \odot x)$$

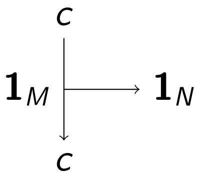
✓ Edits

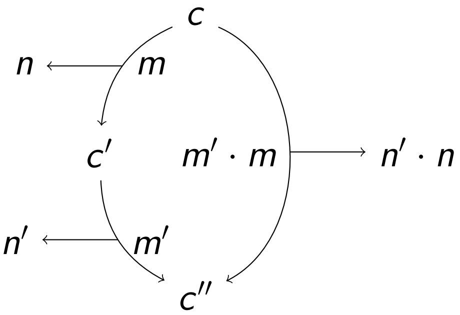
Lenses

Stateful monoid homomorphisms

Definition

A stateful monoid homomorphism
$h : M \times C \to N \times C$ satisfies





Monoid homomorphisms

Definition

A monoid homomorphism $h : M \rightarrow N$ satisfies

$$n \longleftarrow m$$

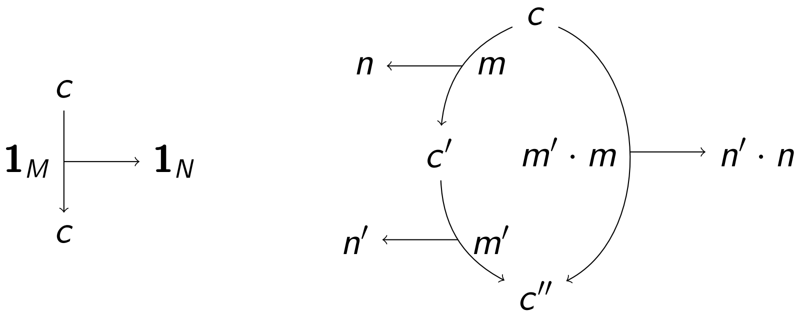
$$\mathbf{1}_M \longrightarrow \mathbf{1}_N \qquad\qquad m' \cdot m \longrightarrow n' \cdot n$$

$$n' \longleftarrow m'$$

Stateful monoid homomorphisms

Definition

A stateful monoid homomorphism
$h : M \times C \to N \times C$ satisfies



Lens definition

Definition

Edit lens $\ell : \langle M, X\rangle \leftrightarrow \langle N, Y\rangle$ has:

- a complement set C of private data
- consistency relation $K \in X \times C \times Y$
- stateful monoid homomorphisms

$$\Rrightarrow : M \times C \to N \times C$$

$$\Lleftarrow : N \times C \to M \times C$$

that preserve consistency

Consistency

$$\begin{array}{c} (\text{Johann}, \text{Bach}, 1685) \\ (\text{Franz}, \text{Liszt}, 1811) \end{array} \longrightarrow \begin{array}{c} (\text{Bach}, \text{Johann}, \text{Air on G}) \\ (\text{Liszt}, \text{Franz}, \text{Liebesträume}) \end{array}$$

$$\begin{array}{c} (1685, \text{Air on G}) \\ (1811, \text{Liebesträume}) \end{array}$$

What do we do with *modify*$(9999, \mathrm{d}x)$?

Consistency vs. round-trip laws

Round-trip laws:
"*There exists an invariant restored by the lens*."

Consistency relations:
"There exists an invariant restored by the lens,
and that invariant is K."

Partition: the code view

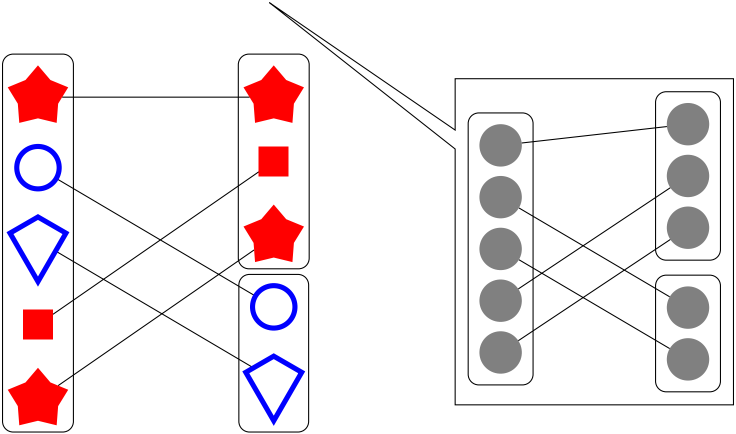
$$\mathit{partition} \in (X \oplus Y)^* \leftrightarrow X^* \otimes Y^*$$

$$
\begin{array}{lllr}
C & = & \{L, R\}^* & \\
\mathit{init} & = & \varepsilon & \\
K & = & \{(z, \mathsf{map}_{\mathsf{tagof}}(z), (\mathsf{lefts}(z), \mathsf{rights}(z))) \mid z \in (|X| + |Y|)^*\} & \\
\Rrightarrow_g(\mathsf{mod}(p, \mathrm{d}v), c) & = & (\mathsf{fail}, c) \text{ when } p > |c| & (1) \\
\Rrightarrow_g(\mathsf{mod}(p, \varepsilon), c) & = & (\varepsilon, c) \text{ when } 1 \le p \le |c| & (2) \\
\Rrightarrow_g(\mathsf{mod}(p, \mathrm{d}v\mathrm{d}vs), c) & = & (d'\,d, c'') \text{ where } 1 < n \quad (d, c') = \Rrightarrow_g(\mathsf{mod}(p, \mathrm{d}vs), c) & (3) \\
 & & \qquad 1 \le p \le |c| \quad (d', c'') = \Rrightarrow_g(\mathsf{mod}(p, \mathrm{d}v), c') & \\
\Rrightarrow_g(\mathsf{mod}(p, \mathsf{switch}_{jk}(\mathrm{d}v)), c) & = & (d_2 d_1 d_0, c[p \mapsto k]), \text{ where } (p_L, p_R) = \mathsf{count}(p, c) \quad d_0 = \mathsf{map}_{\lambda d.\,\mathsf{tag}(j,d)}(\mathsf{del}'(p_j)) & (4) \\
 & & \qquad d_2 = \mathsf{tag}(k, \mathsf{mod}(p_k, \mathrm{d}v)) \quad d_1 = \mathsf{map}_{\lambda d.\,\mathsf{tag}(k,d)}(\mathsf{ins}'(p_k)) & \\
\Rrightarrow_g(\mathsf{mod}(p, \mathsf{stay}_j(\mathrm{d}v)), c) & = & (\mathsf{tag}(j, \mathsf{mod}(p_j, \mathrm{d}v)), c), \text{ where } (p_L, p_R) = \mathsf{count}(p, c) & (5) \\
\Rrightarrow_g(\mathsf{mod}(p, \mathsf{fail}), c) & = & (\mathsf{fail}, c) & (6) \\
\Rrightarrow_g(\mathsf{ins}(i), c) & = & (\mathsf{left}(\mathsf{ins}(i)), \mathsf{ins}(i)\ c) & (7) \\
\Rrightarrow_g(\mathsf{del}(i), c) & = & (d_1 d_0, \mathsf{del}(i)\ c), \text{ where } \quad c' = \mathsf{reverse}(c) \quad d_0 = \mathsf{left}(\mathsf{del}(n_L - 1)) & (8) \\
 & & \qquad (n_L, n_R) = \mathsf{count}(i+1, c') \quad d_1 = \mathsf{right}(\mathsf{del}(n_R - 1)) & \\
\Rrightarrow_g(\mathsf{reorder}(f), c) & = & (d_L d_R, c'), \text{ where } \quad h = \mathsf{iso}(c) \quad c' = \mathsf{reorder}(f)\ c & (9) \\
 & & \qquad h' = \mathsf{iso}(c') \quad (n_L, n_R) = \mathsf{count}(|c|, c) & \\
 & & \qquad h'' = h'^{-1}; f(|c|); h \quad f_k(n \ne n_k) = \lambda p.\, p & \\
 & & \qquad d_L = \mathsf{left}(\mathsf{reorder}(f_L)) \quad f_L(n_L) = \mathsf{inl}; h''; \mathsf{out} & \\
 & & \qquad d_R = \mathsf{right}(\mathsf{reorder}(f_R)) \quad f_R(n_R) = \mathsf{inr}; h''; \mathsf{out} & \\
\Rrightarrow_g(\mathsf{fail}, c) & = & (\mathsf{fail}, c) & (10) \\
\Lleftarrow_g(\varepsilon, c) & = & (\varepsilon, c) & (11) \\
\Lleftarrow_g(\mathrm{d}v\mathrm{d}vs, c) & = & (d'd, c'') \text{ when } n > 1, \text{ where } (d, c') = \Lleftarrow_g(\mathrm{d}vs, c) \quad (d', c'') = \Lleftarrow_g(\mathrm{d}v, c') & (12) \\
\Lleftarrow_g(\mathsf{left}(\mathsf{mod}(p, \mathrm{d}x)), c) & = & (\mathsf{stay}_L(\mathsf{mod}(p', \mathrm{d}x)), c), \text{ where } p' = \mathsf{iso}(c)^{-1}(\mathsf{inl}(p)) & (13) \\
\Lleftarrow_g(\mathsf{left}(\mathsf{reorder}(f)), c) & = & (\mathsf{reorder}(f'), c), \text{ where } g(\mathsf{inr}(p)) = \mathsf{inr}(p) \quad f'(n \ne |c|) = \lambda p.\, p & (14) \\
 & & \qquad g(\mathsf{inl}(p)) = \mathsf{inl}(f(n_L)(p)) \quad f'(|c|) = h; g; h^{-1} & \\
 & & \qquad (n_L, n_R) = \mathsf{count}(|c|, c) \quad h = \mathsf{iso}(c) & \\
\Lleftarrow_g(\mathsf{left}(\mathsf{ins}(i)), c) & = & (\mathsf{ins}(i), \mathsf{ins}(i)\ c) & (15) \\
\Lleftarrow_g(\mathsf{left}(\mathsf{del}(0)), c) & = & (\varepsilon, c) & (16) \\
\Lleftarrow_g(\mathsf{left}(\mathsf{del}(i)), c) & = & (d''\ \mathsf{del}'(p), c''), \text{ where } h = \mathsf{iso}(c) \quad (n_L, n_R) = \mathsf{count}(|c|, c) & (17) \\
 & & \qquad p = h^{-1}(\mathsf{inl}(n_L)) \quad (d'', c'') = \Lleftarrow_g(d', c') & \\
 & & \qquad c' = \mathsf{del}'(p)\ c \quad d' = \mathsf{left}(\mathsf{del}(i - 1)) & \\
 & & \text{when } 0 < i \le n_L + 1 & \\
\Lleftarrow_g(\mathsf{left}(\mathsf{del}(i)), c) & = & (\mathsf{fail}, c) \text{ otherwise} & (18) \\
\Lleftarrow_g(\mathsf{left}(\mathsf{fail}), c) & = & (\mathsf{fail}, c) & (19) \\
\Lleftarrow_g(\mathsf{right}(\mathrm{d}y), c) & & \text{similar} &
\end{array}
$$

Partition: the consistency view

$$K \subset (A+B)^* \times C \times (A^* \times B^*)$$

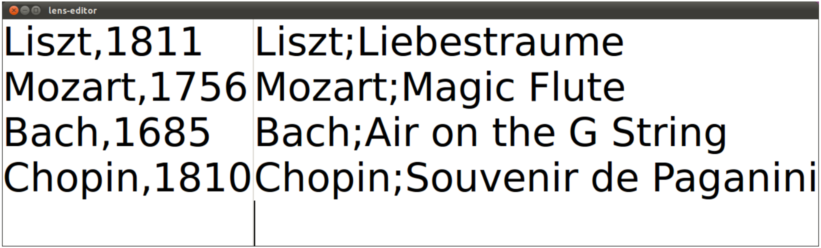
$$K = \{(z, \cdots, (\mathrm{lefts}(z), \mathrm{rights}(z)))\}$$



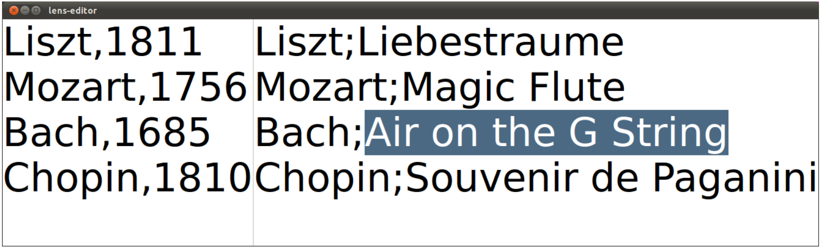
Contributions

- Theoretical framework
  - Model for first-class edits
  - Formulation of lenses on edits
  - Adaptation of behavioral laws
- Lens syntax
  - Composition, products, sums
  - Filtering, mapping, reshaping
- Embedding of state-based lenses
- Haskell library

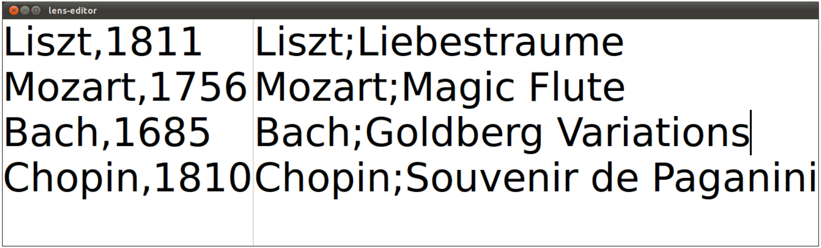
Demo


lens-editor
Liszt,1811
Mozart,1756
Bach,1685
Chopin,1810
Liszt;Liebestraume
Mozart;Magic Flute
Bach;Air on the G String
Chopin;Souvenir de Paganini

Demo

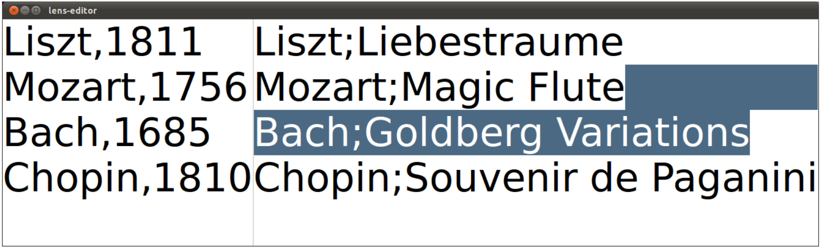

lens-editor
Liszt,1811
Mozart,1756
Bach,1685
Chopin,1810
Liszt;Liebestraume
Mozart;Magic Flute
Bach;Air on the G String
Chopin;Souvenir de Paganini

Demo

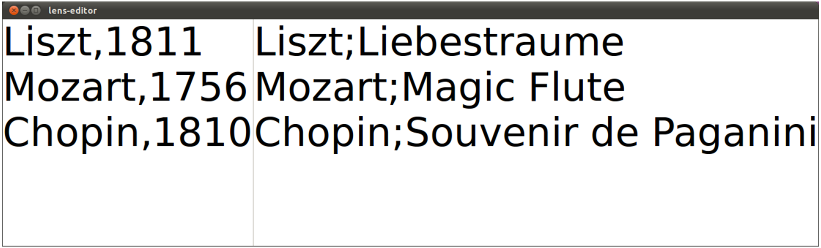


[Modify 2 ([], [Delete 0 8, Insert 0 “Goldberg Variations”])]

Demo

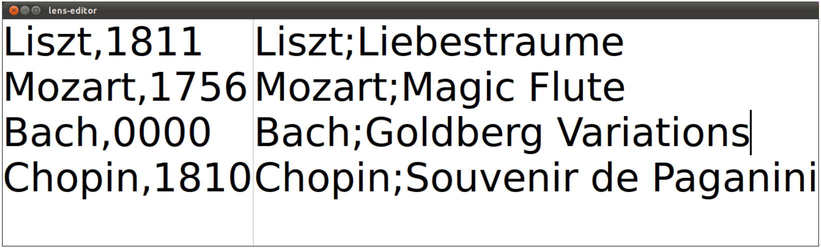

lens-editor
Liszt,1811
Mozart,1756
Bach,1685
Chopin,1810
Liszt;Liebestraume
Mozart;Magic Flute
Bach;Goldberg Variations
Chopin;Souvenir de Paganini

Demo



[Rearrange [0,1,3,2], Delete 1]

Demo



[Insert 1,
Modify 3 ([Insert 0 “Bach”], [Insert 0 “Goldberg Variations”]),
Rearrange [0,1,3,2]]

Other approaches to edits

as congruence classes of functions

- monoids subsume functions
- can have more intensional representation
- "Towards an algebraic theory of bidirectional transformations", Stevens, ICGT 2008

as skeleton structures

- not specific to containers
- fundamental objects are less complex
- "Matching lenses: alignment and view update", Barbosa, et al., 2010

as a category

- see paper for partial actions vs. arrows
- smaller edits: need not store entire source/target structures in edit
- more syntax and combinators available
- "From state- to delta-based bidirectional model transformations: The (a)symmetric case", Diskin, et al., 2011

Questions

```
cabal install edit-lenses-demo
```

Whoa, hold up... partial?

Can't we just do nothing?

Consider the following optimization:

$$[\text{resize}(j, k, x)] \cdot [\text{resize}(i, j, x)] = [\text{resize}(i, k, x)]$$

Bad optimization

$$
\begin{tikzcd}
 & {[a]} \arrow[dl, dashed, "\text{resize}(0, 1, a)"'] \arrow[ddr, dashed, "\text{resize}(0, 2, a)"] & \\
{[a]} \arrow[d, dashed, "\text{resize}(1, 2, a)"'] & & \\
{[a, a]} & & {[a]}
\end{tikzcd}
$$