Typechecking XML Updates

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Fun in the Afternoon IV
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Some words of wisdom

When any new language design project is nearing completion, there is always a mad rush to get new features added before standardization. The rush is mad indeed, because it leads into a trap from which there is no escape. A feature which is omitted can always be added later, when its design and its implications are well understood. A feature which is included before it is fully understood can never be removed later.

—C. A. R. Hoare, 1980

Why study (XML) updates?

- XML query languages and transformation languages are good at:
  - Selecting part of the document (XPath, XQuery)
  - Restructuring documents (XDuce, CDuce, XSLT)
- But bad at:
  - Changing part of a document while leaving the rest unchanged
- You can do it...
- but it's painful.
- And probably not very efficient compared to in-place updates.

Current proposals

- Current W3C draft XQuery Update Facility takes a direct approach: add imperative, side-effecting update operations
- It allows aliasing and side-effecting updates to aliased values.
- This can get messy fast, e.g.:

```
for $x in $doc//*
for $y in $doc//*
return (do (insert $x into $y;
               delete $x))
```

- What does this do? What type(s) does it have?

Current proposals

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for $x in $doc//*
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```

- What does this do? What type(s) does it have?
  - Depends strongly on traversal order...
  - Unlike in XQuery, loop cannot necessarily be reordered.

Wait a second...

- Adding updates to XQuery naively seems to negate the benefits of XQuery's purely-functional design
  - Clear semantics
  - Unspecified evaluation order
  - Static typechecking
  - Optimizability based on equational laws
- Does the world need another imperative language?
- After all, SQL manages to support "in-place" updates without aliasing, traversal order dependence, etc...
- (Not that SQL is a paragon of language design either).

Introducing FLUX

- or, Functional Lightweight Updates for XML
- I thought about calling it "Simple Updates for XML" but that doesn't yield as nice an acronym.

An example

- Adding an author

```
UPDATE books/book BY
  INSERT AFTER author
  VALUE <author>Charles Dickens</author>
WHERE name = "Through the Looking-Glass"
```

- Type:

$$books[book[author[string], title[string], year[string]]^*]$$
$$\rightarrow books[book[author[string]^*, title[string], year[string]]^*]$$

Core language

- Core FLUX consists of the following constructs:

$$
\begin{array}{llll}
\text{Expressions} & e & ::= & \cdots \\
\text{Tests} & \phi & ::= & n \mid * \mid \texttt{bool} \mid \texttt{string} \\
\text{Directions} & d & ::= & \texttt{left} \mid \texttt{right} \mid \texttt{children} \mid \texttt{iter} \\
\text{Statements} & s & ::= & \texttt{skip} \mid s; s' \mid \texttt{if } e \texttt{ then } s \texttt{ else } s' \\
 & & \mid & \texttt{let } x = e \texttt{ in } s \mid \phi?s \mid d[s] \\
 & & \mid & \texttt{insert } e \mid \texttt{delete} \mid \texttt{snapshot } x \texttt{ in } s
\end{array}
$$

- *Expressions* are (core) XQuery expressions (we used μXQ)
- *Tests* allow us to examine the structure of the tree
- *Directions* allow us to move somewhere else in the tree
- *Statements* perform tests, moves, basic updates, or combinations of updates

Core language: Expressions

- *Expressions* are (core) XQuery expressions

$$\begin{array}{rcl} e & ::= & () \mid e, e' \mid n[e] \mid w \mid x \mid \texttt{let}\ x = e\ \texttt{in}\ e' \\ & \mid & \texttt{true} \mid \texttt{false} \mid \texttt{if}\ c\ \texttt{then}\ e\ \texttt{else}\ e' \mid e = e' \\ & \mid & x \mid x/\texttt{child} \mid e :: n \mid \texttt{for}\ x \in e\ \texttt{return}\ e' \end{array}$$

- We treat queries as a "black box", reusing the μXQ core language of Colazzo, Ghelli, Manghi and Sartiani (ICFP 2004)

Core language: Tests

- *Tests* allow us to examine the structure of the tree

$$\phi \quad ::= \quad n \mid * \mid \texttt{bool} \mid \texttt{string}$$

- n succeeds when we are at a tree labeled with n
- $*$ succeeds when we are at *any* tree node
- $\texttt{bool}, \texttt{string}$ succeed when we are at a (boolean, string) data node
- Corresponding statement $\phi?s$ means: "If test ϕ succeeds, do s, otherwise do nothing."

Core language: Directions

- *Directions* allow us to move somewhere else in the tree

$$d \quad ::= \quad \texttt{left} \mid \texttt{right} \mid \texttt{children} \mid \texttt{iter}$$

- `left`, `right` move to the beginning or end of the current sequence.
- `children` moves to the child sequence of the current tree node
- `iter` moves to *each element* of the current sequence, in parallel.
- $d[u]$ means: "move according to d, then do u"

Core language: Statements

- *Statements* perform tests, moves, basic updates, or combinations of updates

$$\begin{array}{rcl} s & ::= & \mathtt{skip} \mid s; s' \mid \mathtt{if}\ e\ \mathtt{then}\ s\ \mathtt{else}\ s' \\ & \mid & \mathtt{let}\ x = e\ \mathtt{in}\ s \mid \phi?s \mid d[s] \\ & \mid & \mathtt{insert}\ e \mid \mathtt{delete} \mid \mathtt{snapshot}\ x\ \mathtt{in}\ s \end{array}$$

- `skip`, sequence, `if`: standard

Core language: Statements

- *Statements* perform tests, moves, basic updates, or combinations of updates

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\end{array}
$$

- `let`: binds a variable x to the result of an XQuery expression e
- `let`-bound variable values are *immutable*; semantically, this makes a copy of e
- This is important for avoiding aliasing.

Core language: Statements

- *Statements* perform tests, moves, basic updates, or combinations of updates

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- `insert` e: inserts expression e at current position
- `delete`: deletes current selection
- test $\phi?s$, move $d[s]$ already discussed

Core language: Statements

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$$

- `snapshot`: binds x to *current value* of the context.
- Note: Like `let`-bound variables, `snapshot` variables are *immutable*.
- `snapshot` is the *only way* to read from the mutable store

Semantics

- Values are trees/forests:

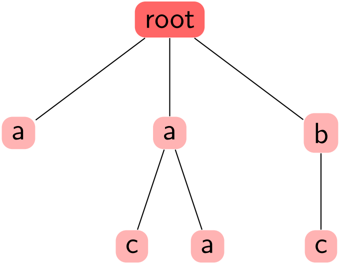
$$\begin{array}{rcl} t & ::= & \mathit{string} \mid \mathit{bool} \mid a[f] \\ f & ::= & () \mid t, f \end{array}$$

- Semantics of values, updates is purely *value-based*
- We do not even mention "node ids"
- Semantics straightforward; rather than bore you with details, here's a graphical example

Example

Example update

children[iter[a?children[left [insert b[]]]]]



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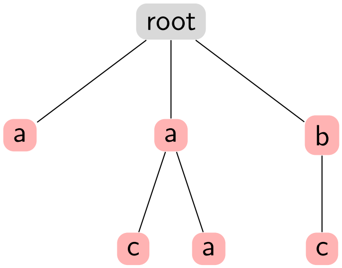
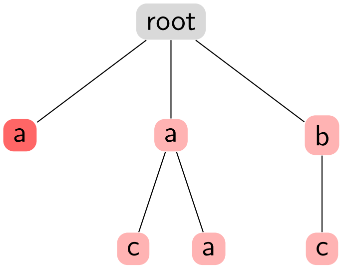


Example

Example update

children[iter[*a*?children[left [insert *b*[]]]]]



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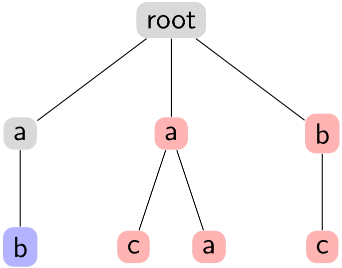

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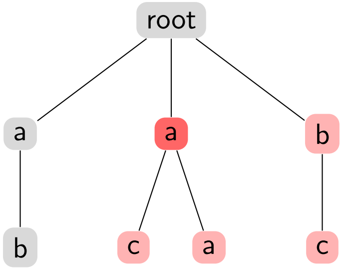

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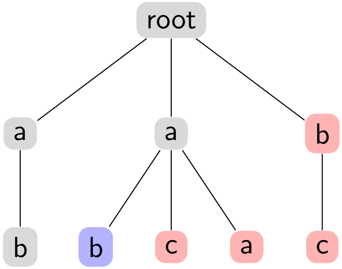
Example update

$$\texttt{children}[\texttt{iter}[a?\texttt{children}[\texttt{left}\ [\texttt{insert}\ b[]]]]]$$



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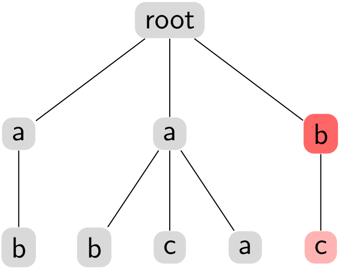
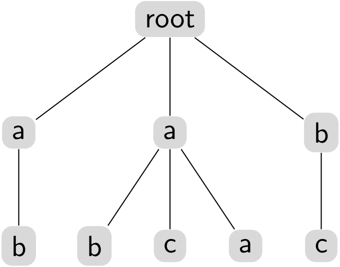


Example

Example update

$$\texttt{children}[\texttt{iter}[a?\texttt{children}[\texttt{left}\ [\texttt{insert}\ b[]]]]]$$



Static typing

- FLUX core operations can all be statically typed
- We use XDuce-style regular expression types

$$\tau ::= \texttt{string} \mid \texttt{bool} \mid a[\tau] \mid \tau, \tau' \mid \tau|\tau' \mid \tau^* \mid \epsilon$$

  with inclusion-based subtyping
- Key idea: To typecheck an $\texttt{iter}[u]$ operation at τ, typecheck u at each *singleton tree component* of τ, and combine the results
- Examples:

$$\texttt{iter}[a?\texttt{left}\ [\texttt{insert}\ b]] : (a[c])^* \mid (a, b)^* \Rightarrow (b, a[c])^* \mid (b, a, b)^*$$

$$\texttt{iter}[a?\texttt{children}[\texttt{delete}]] : (a[c])^* \mid (a, b)^* \Rightarrow (a[])^* \mid (a, b)^*$$

Static typing

- Judgment $\Gamma \vdash^1 \{\tau\}\ u\ \{\tau'\}$: u updates singular input τ to output τ' given variables typed by Γ
- Judgment $\Gamma \vdash^* \{\tau\}\ u\ \{\tau'\}$ similar, but expects a *sequence* of type τ

Children

$$\frac{\Gamma \vdash^* \{\tau\}\ s\ \{\tau'\}}{\Gamma \vdash^1 \{n[\tau]\}\ \texttt{children}[s]\ \{n[\tau']\}}$$

Snapshot

$$\frac{\Gamma, x{:}\tau \vdash^a \{\tau\}\ s\ \{\tau'\}}{\Gamma \vdash^a \{\tau\}\ \texttt{snapshot}\ x\ \texttt{in}\ s\ \{\tau'\}}\ a \in \{1, *\}$$

Static typing

- $\Gamma \vdash_{\texttt{iter}} \{\tau\}\ s\ \{\tau'\}$ an auxiliary judgment, meaning "iterating s changes τ to τ'"
- Here, α is "atomic" $(n[\tau], \texttt{bool}, \texttt{string})$

Iteration

$$\frac{\Gamma \vdash_{\texttt{iter}} \{\tau\}\ s\ \{\tau'\}}{\Gamma \vdash^{*} \{\tau\}\ \texttt{iter}[s]\ \{\tau'\}} \qquad \frac{\Gamma \vdash^{1} \{\alpha\}\ s\ \{\tau\}}{\Gamma \vdash_{\texttt{iter}} \{\alpha\}\ s\ \{\tau\}}$$

$$\frac{}{\Gamma \vdash_{\texttt{iter}} \{()\}\ s\ \{()\}} \qquad \frac{\Gamma \vdash_{\texttt{iter}} \{\tau_1\}\ s\ \{\tau_1'\} \quad \Gamma \vdash_{\texttt{iter}} \{\tau_2\}\ s\ \{\tau_2'\}}{\Gamma \vdash_{\texttt{iter}} \{\tau_1, \tau_2\}\ s\ \{\tau_1', \tau_2'\}}$$

$$\vdots$$

Static typing

- For test typechecking, $\alpha <: \phi$ means that some value of type α matches test ϕ

Test

$$\frac{\alpha <: \phi \quad \Gamma \vdash^1 \{\alpha\}\ s\ \{\tau\}}{\Gamma \vdash^1 \{\alpha\}\ \phi?s\ \{\tau\}} \qquad \frac{\alpha \not<: \phi}{\Gamma \vdash^1 \{\alpha\}\ \phi?s\ \{\alpha\}}$$

- Atomic updates

Insert/delete

$$\frac{\Gamma \vdash e : \tau}{\Gamma \vdash^* \{()\}\ \texttt{insert}\ e\ \{\tau\}} \qquad \frac{}{\Gamma \vdash^* \{\tau\}\ \texttt{delete}\ \{()\}}$$

Static typing

- Subtyping is by regular (tree) language inclusion.
- Can re-use Hosoya, Vouillon and Pierce's subtyping algorithm.
- Type soundness holds (proof not hard).
- Currently, consider type checking with respect to *fixed input type*
- This is reasonable for DB applications because schema usually given in advance
- Type inference/principal typing would be nice to have though.

Deciding typechecking

- In the presence of subtyping/subsumption, typechecking is no longer syntax-directed, and an expression may have many types.
- Usual solution: Define an algorithmic system that is syntax directed and restricts the use of subsumption
- Show that arbitrary derivations can be normalized to algorithmic ones by "permuting subsumption downwards"
- For FLUX, this mostly works.
- But straightforward induction fails for $\Gamma \vdash_{\mathtt{iter}} \{\tau\}\ s\ \{\tau'\}$ judgment
- Requires a trickier "semantic" argument (considering structure of regular expression types)

Related Work

- Liefke, Davidson [SSDBM 1999] — introduced an update language for complex object databases that heavily influenced FLUX
- Collazzo, Ghelli, Manghi, Sartiani [ICFP 2004] — defined μXQ and type system which we have re-used
- Many "imperative XQuery" approaches to updates (XQuery!, XQueryP, XQueryU, XQuery Update Facility).
- Zarfaty/Gardner/Calcagno - Logics for reasoning about low-level (DOM-like) operations on XML-like trees.
- My update type system is reminiscent of "arrows" (and also Hoare Type THeory); maybe some formal relationship

Conclusions

- FLUX is work in progress
- Presented a high-level update language
- Discussed core language with sound type system and decidable typechecking
- Hope I've convinced you that we can have updates without the full complications of imperative programming.