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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  ```
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                               delete $x))
  ```

- 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:

  \[
  \text{books[book[author[string], title[string], year[string]]*]}
  \rightarrow \text{books[book[author[string]*, title[string], year[string]]*]}
  \]
Core language

- **Core Flux** consists of the following constructs:

  - **Expressions** \( e ::= \ldots \)
  - **Tests** \( \phi ::= n | * | bool | string \)
  - **Directions** \( d ::= left | right | children | iter \)
  - **Statements** \( s ::= skip | s; s' | if e then s else s' \)
    - \( | let x = e in s | \phi s | d[s] \)
    - \( | insert e | delete | snapshot x in s \)

- *Expressions* are (core) XQuery expressions (we used \( \muXQ \))
- *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

\[ e ::= () \mid e, e' \mid n[e] \mid w \mid x \mid \text{let } x = e \text{ in } e' \]
\[ \mid \text{true} \mid \text{false} \mid \text{if } c \text{ then } e \text{ else } e' \mid e = e' \]
\[ \mid x \mid x/\text{child} \mid e :: n \mid \text{for } x \in e \text{ return } e' \]

- We treat queries as a “black box”, reusing the $\mu$XQ core language of Colazzo, Ghelli, Manghi and Sartiani (ICFP 2004)
Core language: Tests

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

  \[ \phi ::= n \mid \ast \mid \text{bool} \mid \text{string} \]

- \(n\) succeeds when we are at a tree labeled with \(n\)
- \(\ast\) succeeds when we are at *any* tree node
- `bool, string` succeed when we are at a (boolean, string) data node
- Corresponding statement \(\phi?\)'s means: “If test \(\phi\) succeeds, do \(s\), otherwise do nothing.”
Core language: Directions

- *Directions* allow us to move somewhere else in the tree
  \[ d ::= \text{left} \mid \text{right} \mid \text{children} \mid \text{iter} \]

- 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

\[
s ::= \text{skip} \mid s; s' \mid \text{if } e \text{ then } s \text{ else } s'
\]

\[
\mid \text{let } x = e \text{ in } s \mid \phi ? s \mid d[s]
\]

\[
\mid \text{insert } e \mid \text{delete} \mid \text{snapshot } x \text{ in } s
\]

- skip, sequence, if: standard
Core language: Statements

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

\[
s ::= \text{skip} \mid s; s' \mid \text{if } e \text{ then } s \text{ else } s'
\]
\[
| \hspace{1cm} \text{let } x = e \text{ in } s \mid \phi?s \mid d[s]
\]
\[
| \hspace{1cm} \text{insert } e \mid \text{delete} \mid \text{snapshot } x \text{ in } s
\]

- `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

\[
s ::= \text{skip} \mid s; s' \mid \text{if } e \text{ then } s \text{ else } s'
\mid \text{let } x = e \text{ in } s \mid \phi? s \mid d[s]
\mid \text{insert } e \mid \text{delete} \mid \text{snapshot } x \text{ in } s
\]

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

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

\[
s ::= \text{skip} | s; s' | \text{if } e \text{ then } s \text{ else } s' \\
| \text{let } x = e \text{ in } s | \phi? s | d[s] \\
| \text{insert } e | \text{delete} | \text{snapshot } x \text{ in } s
\]

- **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:

  \[
  t ::= \text{string} \mid \text{bool} \mid a[f] \\
  f ::= () \mid t, f
  \]

- 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 update

```latex
children[iter[a?children[left [insert b[]]]]]
```
Example update

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

Example update

\[
\text{children[iter[a?children[children[insert b][]]]]]}
\]

The diagram represents a tree structure:
- **Root** node
  - **Left** child: `a`
  - **Right** child: `b`
    - **Left** child: `a`
    - **Right** child: `c`
Example update

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

Example update

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

```plaintext
children[iter[a?children[left [insert b[]]]]]
```
Example update

```plaintext
children[iter[a?children[left [insert b[]]]]]
```
Example

Example update

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

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

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

with **inclusion-based subtyping**

- Key idea: To typecheck an \texttt{iter[u]} operation at \( \tau \), typecheck \( u \) at each **singleton tree component** of \( \tau \), and combine the results

- Examples:

\begin{align*}
\text{iter}[a?\text{left}[\text{insert } b]] &: (a[c])^* \mid (a, b)^* \Rightarrow (b, a[c])^* \mid (b, a, b)^* \\
\text{iter}[a?\text{children}[\text{delete}]] &: (a[c])^* \mid (a, b)^* \Rightarrow (a[])^* \mid (a, b)^*
\end{align*}
Static typing

- Judgment $\Gamma \vdash^1 \{\tau\} u \{\tau'\}$: $u$ updates singular input $\tau$ to output $\tau'$ given variables typed by $\Gamma$

- Judgment $\Gamma \vdash^\ast \{\tau\} u \{\tau'\}$ similar, but expects a sequence of type $\tau$

**Children**

$$\Gamma \vdash^\ast \{\tau\} s \{\tau'\} \quad \frac{}{\Gamma \vdash^1 \{n[\tau]\} \text{children}[s] \{n[\tau']\}}$$

**Snapshot**

$$\Gamma, x:\tau \vdash^a \{\tau\} s \{\tau'\} \quad \frac{}{\Gamma \vdash^a \{\tau\} \text{snapshot}\ x \ \text{in}\ s \{\tau'\}} \quad a \in \{1, \ast\}$$
Static typing

- $\Gamma \vdash_{\text{iter}} \{\tau\} \ s \ \{\tau'\}$ is an auxiliary judgment, meaning “iterating $s$ changes $\tau$ to $\tau'$”

- Here, $\alpha$ is “atomic” ($\text{var}[$, bool, string)

### Iteration

- $\Gamma \vdash_{\text{iter}} \{\tau\} \ s \ \{\tau'\}$
- $\Gamma \vdash_{\text{iter}} \{\alpha\} \ s \ \{\tau\}$
- $\Gamma \vdash_{\text{iter}} \{()\} \ s \ \{()\}$
- $\Gamma \vdash_{\text{iter}} \{\tau_1\} \ s \ \{\tau'_1\}$
- $\Gamma \vdash_{\text{iter}} \{\tau_2\} \ s \ \{\tau'_2\}$
- $\Gamma \vdash_{\text{iter}} \{\tau_1, \tau_2\} \ s \ \{\tau'_1, \tau'_2\}$
- $\vdots$

- $\Gamma \vdash \ \{\tau\}$
- $\Gamma \vdash \ \{\alpha\}$
- $\Gamma \vdash \ \{()\}$
- $\Gamma \vdash \ \{\tau_1\}$
- $\Gamma \vdash \ \{\tau_2\}$
- $\Gamma \vdash \ \{\tau_1, \tau_2\}$
- $\vdots$
**Static typing**

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

\[
\begin{align*}
\alpha &: \phi & \Gamma &\vdash \{\alpha\} \ s \ \{\tau\} & \alpha &\not:<: \phi \quad & \Gamma &\vdash \{\alpha\} \ \phi?\ s \ \{\alpha\}
\end{align*}
\]

- Atomic updates

\[
\begin{align*}
\Gamma &\vdash e : \tau & \Gamma &\vdash^* \{()\} \ insert \ e \ \{\tau\} & \Gamma &\vdash^* \{\tau\} \ delete \ \{()\}
\end{align*}
\]
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 \textit{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 $\Gamma \vdash_{\text{iter}} \{\tau\} s \{\tau'\}$ 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 $\mu$XQ and type system which we have re-used
- 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.