Course: Introduction to XQuery and Static Type-Checking

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(Some examples are inspired from the XQuery tutorial by Peter Fankhauser and Philip Wadler, the slides by Rajshekhar Sunderraman, and the slides by John Rushby)

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XQuery - XML Query Language

- XQuery is a SQL-like functional language...
- ... for transforming XML documents into other XML documents
- Allows transforming documents of a given type into another
- A W3C recommendation (www.w3.org/TR/xquery)
- Built around the XPath language
- Turing-complete
- Strongly typed
- Implementations available!

  open-source and commercial (many startups)

Outline

1. XQuery

2. Static Type-Checking

XQuery by Example

- Titles of all books published before 2000:

```
/books/book[@year<2000]/title
```

- Year and title of all books published before 2000:

```
FOR $book in /books/book
WHERE $book/@year < 2000
RETURN <book>{ $book/@year, $book/title }</book>
```

- Books grouped by author:

```
FOR $author in distinct(/books/book/author)
RETURN <author name="{ $author }">
          { /books/book[author = $author]/title }
       </author>
```

XQuery Basics

- General structure (FLWOR expressions):

```
For $var in expr
Let  $var := expr
Where condition
Order By expr
Return expr
```

- All except Return are optional
- Compared to XPath 1.0 node sets, XQuery introduces a notion of order: node sequences
- For (iteration) vs. Let (value is assigned to variable)
- expr can be an XPath expression or another FLWOR expression
- XQuery can be used for a complete document restructuring

More XQuery Examples

Sample XML


```xml
<Transcripts>
  <Transcript>
      <Student StudId="111111111" Name="John Doe"/>
      <CrsTaken CrsCode="CS308" Semester="F1997" Grade="B"/>
      <CrsTaken CrsCode="MAT123" Semester="F1997" Grade="B"/>
      <CrsTaken CrsCode="EE101" Semester="F1997" Grade="A"/>
      <CrsTaken CrsCode="CS305" Semester="F1995" Grade="A"/>
  </Transcript>
  <Transcript>
      <Student StudId="987654321" Name="Bart Simpson"/>
      <CrsTaken CrsCode="CS305" Semester="F1995" Grade="C"/>
      <CrsTaken CrsCode="CS308" Semester="F1994" Grade="B"/>
  </Transcript>
  <Transcript>
      <Student StudId="123454321" Name="Joe Blow"/>
      <CrsTaken CrsCode="CS315" Semester="S1997" Grade="A"/>
      <CrsTaken CrsCode="CS305" Semester="S1996" Grade="A"/>
      <CrsTaken CrsCode="MAT123" Semester="S1996" Grade="C"/>
  </Transcript>
...
</Transcripts>
```

XQuery Example

```
(:  students who took  MAT123  :)
For  $t  In  doc("http://xyz.edu/transcript.xml")//Transcript
Where    $t/CrsTaken/@CrsCode = "MAT123"
Return  $t/Student
```

- Result:

```
<Student  StudId="111111111"  Name="John Doe" />
<Student  StudId="123454321"  Name="Joe Blow" />
```

XQuery and Well-Formedness

- Previous query does not produce a well-formed XML document; the following does:

```
<StudentList>
  {
    For  $t in  doc("transcript.xml")//Transcript
    Where  $t/CrsTaken/@CrsCode = "MAT123"
    Return  $t/Student
  }
</StudentList>
```

- For binds $t to Transcript elements one by one, filters using Where, then places Student-children as children of StudentList using Return

Sample Document Restructuring with XQuery

- Reconstruct lists of students taking each class from transcript.xml
- classes.xml lists course offerings (course code/semester)

```
For  $c  in doc("classes.xml")//Class
Where doc("transcripts.xml")//CrsTaken[@CrsCode = $c/@CrsCode
                                     and @Semester = $c/@Semester]
Return
<ClassRoster CrsCode=$c/@CrsCode Semester=$c/@Semester>
  {
    For  $t  IN  doc("transcript.xml")//Transcript
    Where $t/CrsTaken[@CrsCode = $c/@CrsCode  and
                      @Semester = $c/@Semester]
    Return $t/Student
    Order By $t/Student/@StudId
  }
</ClassRoster>
Order By  $c/@CrsCode
```

Aggregation Example

- Produce a list of students along with the number of courses each student took:

```
For  $t  in  fn:doc("transcripts.xml")//Transcript,
     $s  IN  $t/Student
Let   $c :=  $t/CrsTaken
RETURN
  <StudentSummary
       StudId = $s/@StudId
       Name = $s/@Name
       TotalCourses = fn:count(fn:distinct-values($c)) />
Order By  StudentSummary/@TotalCourses
```

- The grouping effect is achieved because $c is bound to a new set of nodes for each binding of $t

XQuery and Validation

Validating the output

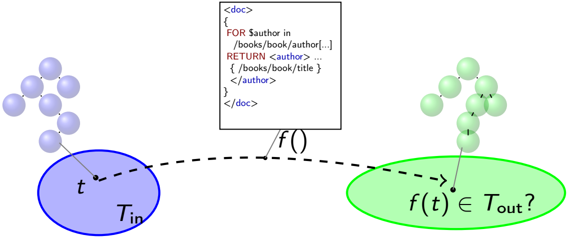
- We can validate the output dynamically for runtime error detection
- Too late for some applications
- Can we detect errors at compile-time?

XQuery is strongly typed

- XQuery is equipped with a sound static type system
- Static type checking is possible to some extent

The Static Type-Checking Problem For XML

- Given:
  - Source code of some program f (in e.g. XQuery)
  - A type T_{in} for input documents
  - A type T_{out} for expected output documents
- Problem: Does $f(t) \in T_{\text{out}}$ for all $t \in T_{\text{in}}$?



- Crucial problem for avoiding runtime errors, verifying systems of producers/consumers
- Static detection of runtime errors

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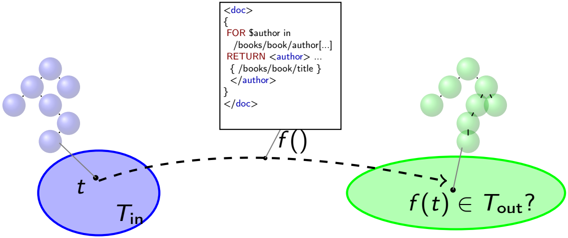


- Crucial problem for avoiding runtime errors, verifying systems of producers/consumers
- Static detection of runtime errors $\rightarrow$ impossible in general!

Fundamental Limits: Recall Computability Theory

Rice's Theorem, 1953

Any property which is non-trivial[1] concerning the semantics of a turing-complete programming language is undecidable[2].

(1) non-trivial: neither always true nor always false

(2) Paraphrasing: there is no algorithm that decides a non-trivial property on the program source code, as this would amount to solving Turing's halting problem.

What are the consequences?

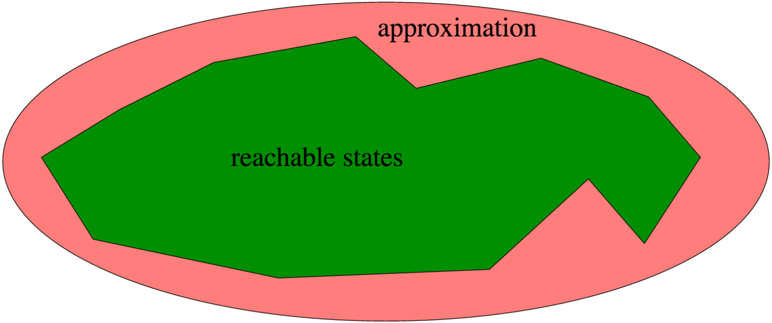
We have to approximate, but there's a price

Rice's Theorem says there are inherent limits on what can be accomplished by automated analysis of programs

- Sound (miss no errors)
- Complete (no false alarms)
- Automatic
- Allow arbitrary (unbounded) memory structures
- Termination (final results)

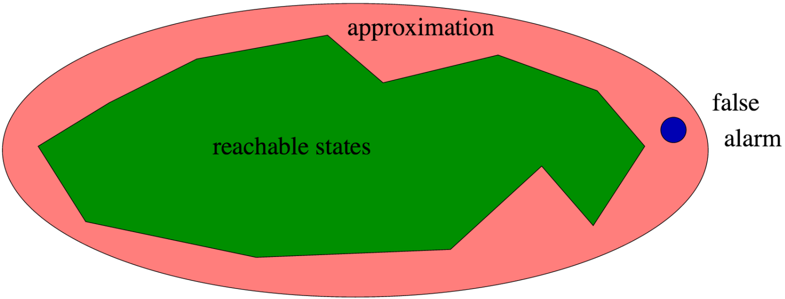
Choose at most 4 of the 5

Approximations



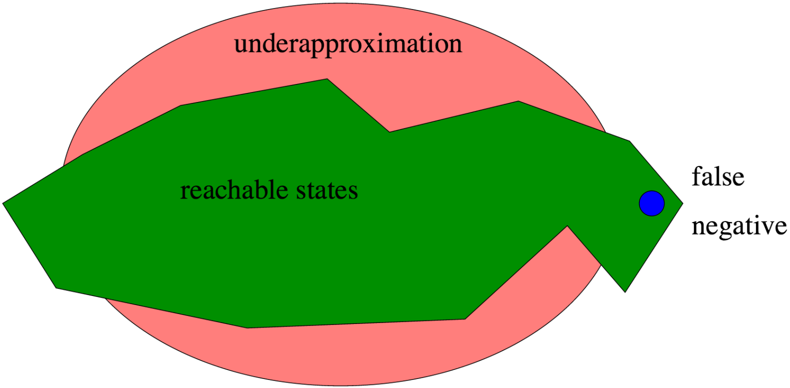
Sound approximations include all the behaviors and reachable states of the real program, but are easier to compute

But Sound Approximations Come with a Price



May flag an error that is unreachable in the real program: a false positive, or false alarm

Unsound Approximations Come with a Price, Too



Can miss real errors: a false negative

Required Choice for XQuery

- We drop one of the following:
  - Sound (miss no errors)
  - Complete (no false alarms)
  - Automatic
  - Allow arbitrary (unbounded) memory structures
  - Termination (final results)

Required Choice for XQuery

- We drop one of the following:
  - Sound (miss no errors)
  - ~~Complete (no false alarms)~~
  - Automatic
  - Allow arbitrary (unbounded) memory structures
  - Termination (final results)
- This means we can theoretically look for method satisfying all other requirements!

Choice Recap

Soundness

- For a given class of errors, a *sound* static analysis method detects errors in a exhaustive manner. (never wrongly considers that a program is safe when actually it is not)
- Soundness provides a "payoff": by soundly checking a web app written in XQuery, one can be **certain** that **certain** errors will **certainly** not happen.
- Short of this, we just have a bug-finder (might be useful, but does not constitute a sufficient basis for establishing guarantees)

Incompleteness

- False alarms

Scientific Challenge

- Reducing the number of false alarms by increasing the precision of the analysis while keeping time and memory costs low

Zoom on Static Type-Checking For XQuery

- Given:
  - Source code of some program f (in e.g. XQuery)
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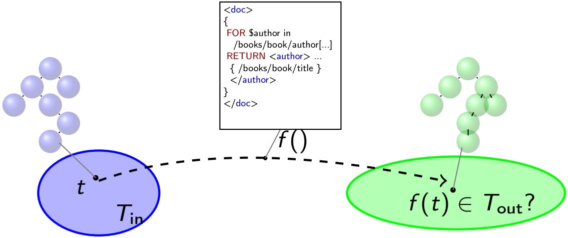

- XQuery comes with a sound static type system for a core fragment (optionally implemented)
- There's plenty of promising research technology around

→ So far, we must know more about types for XML...

References

XQuery

- Many tutorials online
- Books
- Standard specifications available from the W3C:
  - XQuery 1.0: An XML Query Language, W3C Recommendation 14 December 2010 (revised 7 September 2015). `http://www.w3.org/TR/xquery/`
  - XQuery 1.0 and XPath 2.0 Formal Semantics, W3C Recommendation 14 December 2010 (revised 7 September 2015). `http://www.w3.org/TR/xquery-semantics/`

XQuery and Static Typing

[1] XQuery and Static Typing: Tackling the Problem of Backward Axes.
Pierre Genevès and Nils Gesbert.
In ICFP'15: Proceedings of the ACM SIGPLAN International Conference on Functional Programming (ICFP), Sept. 2015.
http://tyrex.inria.fr/publications/icfp15.pdf

Analyses: [2,3], Semantics: [4], Transformation and Core XQuery: [5]

[2] Eliminating dead-code from XQuery programs. Pierre Genevès and Nabil Layaïda. Proceedings of the 32nd ACM/IEEE International Conference on Software Engineering (ICSE) - Volume 2, pages 305-306, 2010.

[3] Impact of XML schema evolution. Pierre Genevès, Nabil Layaïda and Vincent Quint. ACM Transactions on Internet Technology (TOIT), volume 11, number 1.

[4] XPath Formal Semantics and Beyond: a Coq based approach. Pierre Genevès and Jean-Yves Vion-Dury. Emerging Trends Proceedings of the 17th International Conference on Theorem Proving in Higher Order Logic: TPHOLs 2004, pages 181-198.

[5] Compiling XPath for streaming access policy. Pierre Genevès and Kristoffer Rose. Proceedings of the 2005 ACM Symposium on Document Engineering, pages 52-54, 2005.