BoPi - a distributed machine for experimenting Web Services technologies

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Outline

- Introduction to Web Services composition
- Language
  - types
  - primitives
- Loading
- Runtime
- Conclusions
Complex applications are built composing small components. In strictly coupled systems we usually assume:

- a common data model
- the common description of the components
- a status of the components
In loosely coupled distributed systems like Web services we have:

- a standard data model XML
- a standard description of the components WSDL

\[
\text{WSDL}
\]

<table>
<thead>
<tr>
<th>Abstract Information:</th>
<th>schema</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Information:</td>
<td>location</td>
</tr>
</tbody>
</table>

- stateless components interacting by exchanging messages
Standard Languages and Composition

C#, Java, ... can be used for composing Web services but:

- the type system cannot express XML documents natively
- they do not provide for the right level of abstraction
- they are designed for strictly coupled applications
BPEL4WS

BPEL4WS is the proposed standard language for composition:

- XML as data language
- WSDL as service interface language
- XQuery/XPath as interrogation language

BPEL4WS has: variables, parallel execution of activities, send and receive commands, faults and exception handling, name passing (of untyped endpoint references).

BPEL4WS does not have a clear formal description.
The goals of the BoPi project

- a distributed implementation of the asynchronous $\pi$-calculus
- a formalized core language for composing Web Services
- a platform for studying Web Services technologies

...(statically) typed language + runtime
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- a distributed implementation of the asynchronous $\pi$-calculus
- a formalized core language for *composing* Web Services
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...(statically) typed language + runtime
The BoPi language

**Primitives:** asynchronous $\pi$-calculus

**Data and Types:** XML-documents with typed channels (endpoint references)

**Expressions:** labelling, sequencing, constants (for building complex documents)

**Patterns** XML pattern matching (for deconstructing documents)
Type systems: Regular Expression Types + Channels

\[
S ::= \text{schema} | T \text{ base schema} | \text{void void schema} | L[S] \text{ labelled schema} | L[S], S \text{ sequence schema} | S + S \text{ union schema} | <S> \text{ channel schema} | U \text{ constant schema}
\]

\[
L ::= a \text{ (label)} | L + L \text{ (union)} | L \setminus L \text{ (difference)} | \sim \text{ (any label)}
\]

\[
F ::= \text{pattern} | \text{void empty pattern} | S \times \text{ binder pattern} | L[F] \text{ labelled pattern} | F, F \text{ sequence pattern}
\]

where we assume \( \text{def } U_1 = S_1 \ldots \text{def } U_n = S_n \)

(1) in order to keep subtyping decidable only tail recursion is allowed
(2) in order to keep subtyping polynomial unions start with different labels

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Type systems: Regular Expression Types + Channels

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S ::= \begin{align*}
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& T & \text{base schema} \\
& \text{void} & \text{void schema} \\
& L[S] & \text{labelled schema} \\
& L[S], S & \text{sequence schema} \\
& S + S & \text{union schema} \\
& \langle S \rangle & \text{channel schema} \\
& U & \text{constant schema}
\end{align*}
\]

\[
L ::= \begin{align*}
& a \quad \text{(label)} \\
& L + L \quad \text{(union)} \\
& L \setminus L \quad \text{(difference)} \\
& \sim \quad \text{(any label)}
\end{align*}
\]

\[
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Type systems: Regular Expression Types + Channels

\[ S ::= \]

- `schema`
- `T` base schema
- `void` void schema
- `L[S]` labelled schema
- `L[S], S` sequence schema
- `S + S` union schema
- `<S>` channel schema
- `U` constant schema

\[ L ::= \]

- `(label)`
- `a`
- `L + L` (union)
- `L \ L` (difference)
- `~` (any label)

\[ F ::= \]

- `void` empty pattern
- `S x` binder pattern
- `L[F]` labelled pattern
- `F, F` sequence pattern

where we assume \( \text{def } U_1 = S_1 \ldots \text{def } U_n = S_n \)

1) in order to keep subtyping decidable only tail recursion is allowed

(\( \text{def } U = a[], U, b[] + \text{ void is forbidden} \))

2) in order to keep subtyping polynomial unions start with different labels
Language primitives

\[ P ::= 
\begin{align*}
& 0 \\
& \text{new } x : \langle S \rangle \text{ in } P \\
& x!(E) \\
& x?(F).P \\
& \text{spawn}\{P\} P \\
& \text{match } x \text{ with}\{F_1 \rightarrow P_1 \ldots | F_n \rightarrow P_n\} \\
& \text{select}\{|x_1?F_1\rightarrow P_1 \ldots | x_n?F_n\rightarrow P_n\} 
\end{align*} \]

process
nil
new
send
receive
parallel
match
select

A BoPi program is a list of process definitions: let \( A(F;F) = P; \)

- \( x!(-) \equiv \text{ service invocation } \)
- \( x?(-).P \equiv \text{ service definition } \)
- \( \text{spawn} \equiv \text{ flow (parallel) activity } \)
- \( \text{match} \equiv \text{ XQuery/XPath } \)
- \( \text{select} \equiv \text{ pick activity } \)

\( \text{new} \equiv \text{ service creation } (\notin \text{ BPEL4WS}) \)
Language primitives

\[ P ::= \]

| 0 |
| new \( x : \langle S \rangle \) in \( P \) |
| \( x!(E) \) |
| \( x?(F).P \) |
| \( \text{spawn}\{ P \} \ P \) |
| \( \text{match } x \text{ with}\{ |F_1 \rightarrow P_1 \ldots |F_n \rightarrow P_n \} \) |
| \( \text{select}\{ |x_1?(F_1) \rightarrow P_1 \ldots |x_n?(F_n) \rightarrow P_n \} \) |

A BoPi program is a list of process definitions: let \( A(F; F) = P; \)

- \( x!(-) \equiv \text{service invocation} \)
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new \( \equiv \text{service creation (} \notin \text{ BPEL4WS}) \)
Services as first class entities

- Services can be dynamically created
- Services can be safely sent to other services
  - Services do not need to know each other before the execution
  - Received services can be used only for sending values
    \[ s?(<a[]> + <b[]> x). \ldots \]
- Services can be pattern matched:
  \[
  \text{match } x \text{ with } \{
  \mid <a[]> \rightarrow P
  \mid <b[]> \rightarrow Q
  \}
  \]
An example

def OrderT=order[photo[_, (color[] + bw[])])

let PrintPhoto(<OrderT> print ; void) =
  print?(order[photo[_ p], (color[] + bw[]) ] how)
  spawn{ PrintPhoto(print ; void) } 
  match how with { 
    | color[] -> cPrinter!(p)
    | bw[] -> bwPrinter!(p)
  }

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Running programs

1. the compiler generates typesafe bytecodes represented as XML documents
2. the loader loads bytecode fragments into one or more BoPi machines waiting for code to be uploaded
The loading phase

location MACHINE1 = www.machine1.com:2047/
location MACHINE2 = www.machine2.com:2047/
location MACHINE3 = www.machine3.com:2047/
cPrinter = import www.printers.com/cp.wsdl
bwPrinter = import www.printers.com/bw.wsdl
print = new <OrderT>@MACHINE3
load PrintPhoto.PrintPhoto(print; void)@MACHINE1
load PrintPhoto.PrintPhoto(print; void)@MACHINE2

print is located at MACHINE3 and is used for receiving values by processes running at different locations.

Here we use linear forwarders (CONCUR03) for solving the input capability problem.
location MACHINE1 = www.machine1.com:2047/
location MACHINE2 = www.machine2.com:2047/
location MACHINE3 = www.machine3.com:2047/
cPrinter = import www.printers.com/cp.wsdl
bwPrinter = import www.printers.com/bw.wsdl
print = new <OrderT>@MACHINE3
load PrintPhoto.PrintPhoto(print; void)@MACHINE1
load PrintPhoto.PrintPhoto(print; void)@MACHINE2

print is located at MACHINE3 and is used for receiving values by processes running at different locations.
Here we use linear forwarders (CONCUR03) for solving the input capability problem.
The runtime

- the virtual machine loads bytecodes and interprets their instructions
- the channel manager interfaces the virtual machine to the network and handles channels;
The BoPi machine logically

\[ M_1 \]

\[
\begin{array}{c|c}
  x & y \\
  V & y?(F).Q \\
  x!(E), y?(F).P \\
\end{array}
\]

- \( M_1 \) is the name of the machine
- \( x, y \) are the channels managed by the local channel manager
- \( x!(E), y?(F).P \) are the ready processes
- \( y?(F).Q \) is a process waiting for a value on \( y \)
The interpreter

- **spawn**: a new thread is added to the ready pool
- **match**: the pattern matching algorithm is executed and the result (a substitution) is used in the continuation
- **process invocation**: the body of the process is executed with the actual parameters
- **new/send/receive/select**: are forwarded to the channel manager
The channel manager

The channel manager is responsible for:

- channels creation (new)
- channels deletion
- outputs (send)
- inputs (receive, select)
- marshalling
- unmarshalling

It keeps a list of queues (one for each managed channel) containing input requests and outputs waiting to be consumed.
A local process creates a new channel \( \text{new } x : <S> \) in \( \mathcal{P} \)

\[
\begin{array}{c}
M_1 \\
\text{new } x : <S> \text{ in } \mathcal{P}
\end{array} \rightarrow \begin{array}{c}
M_1 \\
x' : <S> \\
\mathcal{P}\{x'/x\}
\end{array}
\]

the channel manager creates a new **typed** queue and the WSDL interface of the channel.

- the runtime representation of a channel is the URI the WSDL
- the channel is typed because data coming from untrusted parties need to be validated before processing
Receive

A local process receives on a local channel:

\[
\begin{array}{c}
\text{M}_1 \\
x : \langle S \rangle \\
x?(F).P
\end{array}
\rightarrow
\begin{array}{c}
\text{M}_1 \\
x : \langle S \rangle \\
x?(F).P
\end{array}
\]

\[
\begin{array}{c}
\text{M}_1 \\
x : \langle S \rangle \\
V \\
x?(F).P
\end{array}
\rightarrow
\begin{array}{c}
\text{M}_1 \\
x : \langle S \rangle \\
P_\sigma
\end{array}
\]

\[\sigma = V/F\]

A local process receives on a remote channel:

\[
\begin{array}{c}
\text{M}_1 \\
x?:\langle S \rangle \\
x?(F).P
\end{array}
\]

\[
\begin{array}{c}
\text{M}_2 \\
x : \langle S \rangle \\
x?(F).P
\end{array}
\rightarrow
\begin{array}{c}
\text{M}_1 \\
x' : \langle S \rangle \\
x'??(F).P
\end{array}
\]

\[
\begin{array}{c}
\text{M}_2 \\
x : \langle S \rangle \\
x \rightarrow x'
\end{array}
\]
Local Send

A local process sends a document over a local channel:

$$M_1 \xrightarrow{x:S} x!(V)$$

$$\sigma = V/F$$
A local process performs an input on a list of local channels:

\[
M_1 \quad \begin{array}{|c|c|}
\hline
x : \langle S \rangle & y : \langle T \rangle \\
\hline
x?(F_x).P + y?(F_y).Q & \\
\hline
\end{array}
\quad \rightarrow 
\quad \begin{array}{|c|c|}
\hline
x : \langle S \rangle & y : \langle T \rangle \\
\hline
x?(F_x).P & y?(F_y).Q \\
\hline
\end{array}
\]

when a value is received on either \(x\) or \(y\) inputs linked in the list are deleted.
A local process performs an input on a list of local/remote channels:

- If a value is received on the channel $y'$ the input on $x$ is deleted.
- If a value is received on the local channel $x$ the input of $y'$ is deleted and an undo forwarder $y' \rightarrow y$ is created.
Conclusions and future works

We presented:

- a distributed implementation of the full-asynchronous $\pi$-calculus
- a typed language for Web services composition and its runtime
- a simple architecture for experimenting Web services technologies (transactions, error/exception handling, . . .)

We plan to:

- compile BPEL4WS into BoPi
- extend the language with transactions and timed-transactions
- study contracts